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HEARINGS

BEFORE THE

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SUBCOMMITTEE ON

TRANSPORTATION, AVIATION AND
COMMUNICATIONS

OF THE

COMMITTEE ON

SCIENCE AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

NINETY-SIXTH CONGRESS

SECOND SESSION

FEBRUARY 6 AND 7, 1980

[No. 95]

VOLUME III

Printed for the use of the
Committee on Science and Technology

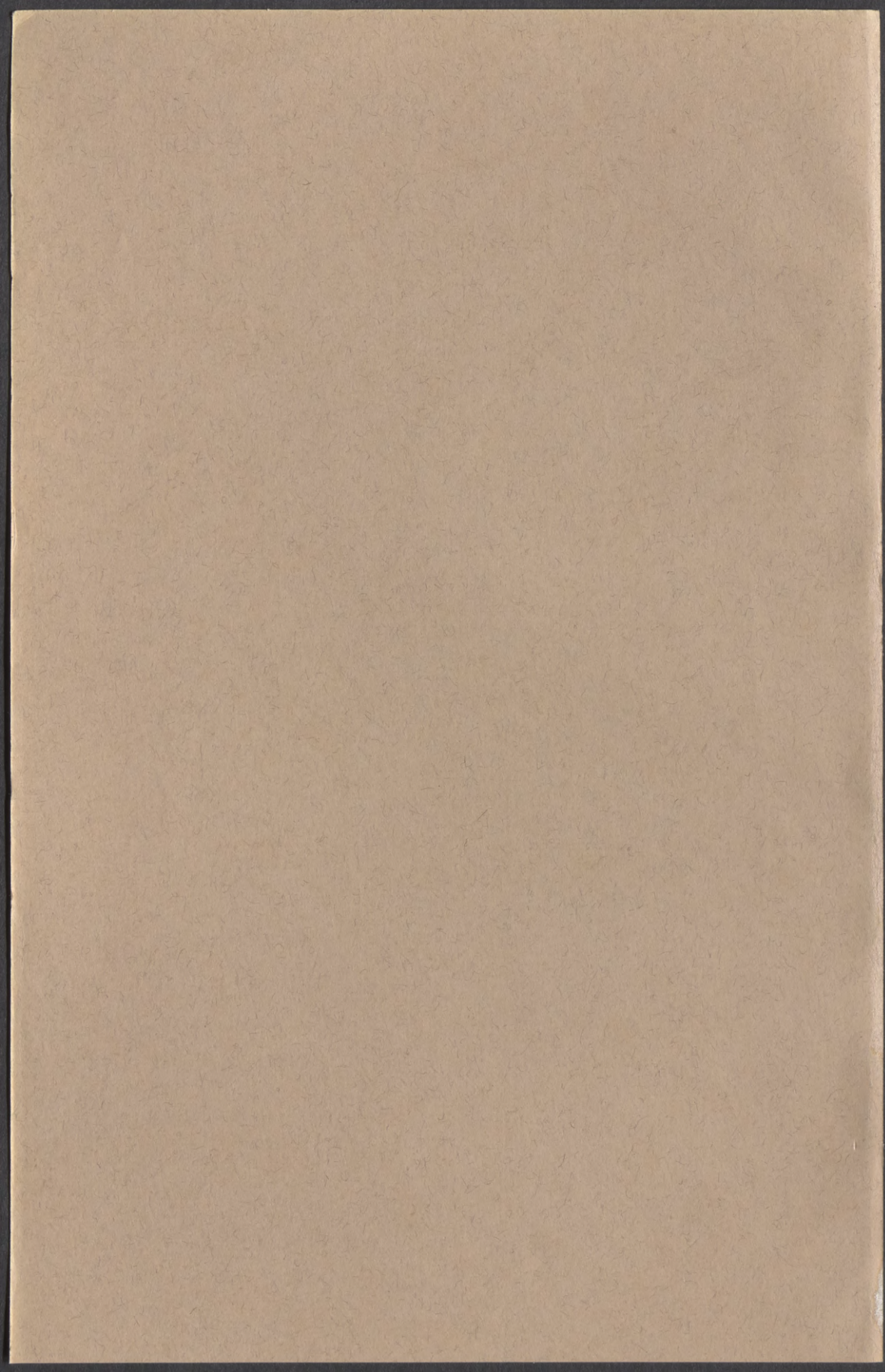


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WASHINGTON : 1980

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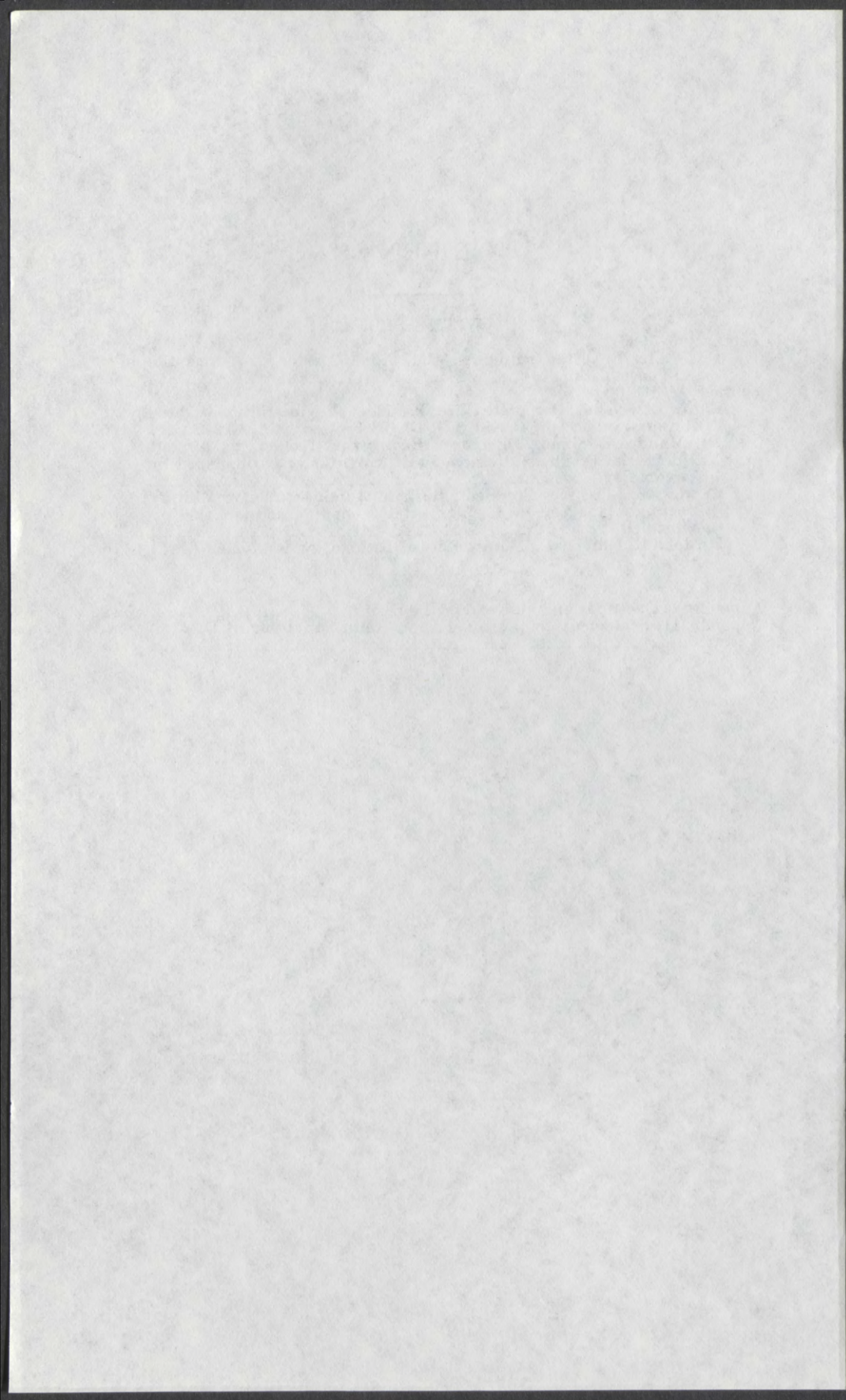
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1981 NASA AUTHORIZATION

WEDNESDAY, FEBRUARY 6, 1980

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND COMMUNICATIONS,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2 p.m., in room 2325, Rayburn House Office Building, the Honorable Tom Harkin (chairman) presiding.

Mr. HARKIN. The Subcommittee on Transportation, Aviation, and Communications will come to order.

Today, the subcommittee will open the budget season with the second phase of our annual review and authorization of the fiscal year 1981 NASA aeronautics program.

The first phase, which was completed last fall consisted of program review hearings here in Washington, along with visits to several NASA field installations and some of our major industrial facilities.

The information gathered at these meetings provided a useful background for the budget hearings that we are starting today, leading to markup of the fiscal year 1981 authorization, which will begin, if I am not mistaken, on March 6.

Specifically, we will hear only from NASA during today's hearing. Tomorrow, selected outside witnesses will testify concerning particular aeronautical issues.

Today, we have, as our sole witness, Dr. Walter B. Olstad, Acting Associate Administrator for Aeronautics and Space Technology, NASA. I understand that he is accompanied by Mr. Bill Aiken, Chief Engineer, Office of Aeronautics and Space Technology.

Dr. Olstad, welcome to the subcommittee. We have your prepared statement which I am certain you do not wish to read in full. Without objection, it is included in the record.

The remarks of Mr. Goldwater will also be inserted in the record without objection.

[The prepared statement of Hon. Barry M. Goldwater follows:]

OPENING STATEMENT OF HON. BARRY M. GOLDWATER, JR., RANKING MINORITY MEMBER, SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND COMMUNICATION, FEBRUARY 6, 1980

Thank you, Mr. Chairman I join you in welcoming Dr. Olstad and Mr. Aiken from NASA today.

Last week Dr. Frosch was here to give us a posture statement on NASA's fiscal year 1981 budget. I heard some good things and some bad things. I'll talk about the good things first, because there are fewer of them.

I am glad to see NASA's four new starts and augmentations. The advanced turboprop, or "propfan," is certainly timely because it holds the promise of significantly reducing both fuel consumption and aircraft noise. Variable cycle engine research and rotorcraft research have also been pushed by this Subcommittee. I also support your jet engine "hot-section" research program.

Turning to the bad side, there were eleven new starts or augmentations which OMB shot down. Some of these are quite important, and I hope to hear about them during the questioning. Of course, from where I sit, I never know how hard NASA fought OMB to save these programs.

The worst part of the fiscal year 1981 aeronautics budget is the decline from \$308 million to 290 million. It seems to me that you've picked the wrong time to start downhill after several years of progress. Today we find ever-increasing threats to the U.S. aeronautics industry from foreign technology, which is heavily government subsidized. We also find an increasing threat to national security from foreign powers. Our military has always relied on NASA for support in many fields of aeronautical R&D. But now you're cutting back. This certainly appears to be the wrong time for a cutback.

Last week Dr. Frosch said that the decline in NASA's aeronautics budget was due to the phasing down of the ACEE program. He said that it was still an "open question" regarding NASA's future role on programs like ACEE. Apparently this open question prevented you from coming up with enough new programs to fill in as ACEE tapered off.

I don't understand Dr. Frosch's hesitation. Everyone I talk to in the industry is pleased with the ACEE program. We feel that NASA was farsighted in 1975 to launch a major initiative to save fuel in aviation. You farsightedness has paid off and will continue to pay off as newer transports save millions of gallons of fuel, thanks to ACEE R&D. Now Dr. Frosch seems to be trying to snatch defeat out of the jaws of victory.

In closing I'd like to mention two more things:

First, I'd like to thank you again for the Noise Briefing which NASA and FAA gave us last December 18.

Second, I'm glad to see that NASA isn't completely dropping out of wake vortex alleviation, although I'd like to see you do more. I certainly hope you will fully support the L-1011 flight tests with FAA this Spring.

Thank you.

Mr. HARKIN. You may proceed in any manner that you so desire.
Dr. OLSTAD. Thank you.

STATEMENT OF DR. WALTER B. OLSTAD

Dr. OLSTAD. Thank you, Mr. Chairman.

Mr. HARKIN. Please proceed.

Dr. OLSTAD. I am pleased to be here and present to you the NASA aeronautics budget for fiscal year 1981.

As you indicated, a formal statement, which I will not read, has been submitted. It is not my intention to read through all of that.

In September, during the preauthorization hearings, we discussed the accomplishments of the fiscal year 1979 program. I hope that as a result of that discussion plus other insights into the activities, such as the visits you mentioned, you share my optimism in our ability to continue to make significant advances in the field of aeronautics. In this hearing, I will present an overview of our proposed budget, followed by a description of the fundamental R. & T. portion. Now, Mr. Bill Aiken will then follow and discuss the proposed vehicle technology program. Before getting into it, I would like to make a couple of introductions to the committee, Mr. Chairman.

As you are aware, we have an executive development program where we bring in promising executives from the field centers to headquarters

for a year to give them exposure to the headquarters environment. We have two with us this year, Dr. David Pofert from the Lewis Research Center, who is serving as manager of the Advanced Propulsion Systems Officer in the Aeronautical Systems Division, and Dr. James Albers, from the Dryden Flight Research Center, currently serving as the Program Manager in the Propulsion Office of the Research and Technology Division.

Mr. HARKIN. Welcome to the subcommittee.

Dr. OLSTAD. As I am sure that you are aware, there are a number of factors that go into devising a budget request [fig. R-5]. One of the principal factors is the content of the ongoing programs and we have commitments to complete those activities already authorized, such as the ACEE program.

We also look to opportunities resulting from advances in technology and opportunities to focus newly developed technology on specific applications, such as taking generic airfoil research and focusing it on helicopter blade problems and utilizing new tools developed from technology, such as the computer, to advance aeronautics. We have to look at the aviation needs and respond to the concerns of the military and the civilian market. We arrive at that through advisory committees, in coordination with other agencies, especially the DOD and FAA; and special studies, such as the one that produced the white paper. This was prepared at your request. All of that goes through a filter, if you will, to arrive at a program where we have to balance between the near and the far term, the applied and fundamental kinds of research, and among the vehicle classes and maintain a consistency with our own in-house capabilities.

Our aeronautics budget request for total fiscal year 1981 is \$290.3 million [fig. R-1]. This represents an overall reduction of about 6 percent from the previous fiscal year. That is mainly the result of having passed the peak funding requirements of the aircraft energy efficiency (ACEE) program. The R. & T. base request, on the second line, is up from \$119 million in fiscal year 1980 to \$131 million in 1981, an increase of some 10 percent.

Another thing that I will bring to your attention is that we no longer carry the systems studies or the experimental programs as separate line items. We have included them all together in the systems technology category. That is consistent with the OAST reorganization that took place this past year.

There are a number of enhancements in this budget request. One is in the rotorcraft area and another in cycle engine technology. The enhancements were stimulated by the additions that the Congress made to the fiscal year 1980 budget.

There are two other enhancements in the advanced turboprop and turbine engine areas. We will discuss these in more detail later in the presentation, Mr. Chairman.

Mr. HARKIN. Yes.

Dr. OLSTAD. We look here at the split of the budget [fig. R-2]. I will show it in two ways on this chart. On the left we show the R. & T. base, about 45 percent of the total, and systems technology. On the right is the vertical cut of our budget which pretty much follows our

OAST organization in terms of applications categories. The fundamental research and technology which represents about 37 percent of the budget has a strong correlation with, but not a direct correspondence to, the R. & T. base on the left side. Working our way around the wheel, you see advanced propulsion technology, which is about 19 percent. Transport aircraft technology is 17 percent. General aviation is a little over 3 percent. The low-speed technology area is 12 percent and the high-speed area about 11 percent.

Figure R-3 illustrates more graphically the earlier discussion about passing the peak in the ACEE funding. The ACEE funding is that part of the curve shown by the two dashed lines. You can see that 1980 was the peak year for this program. All the other areas, particularly the fundamental R. & T., show an increase or essentially stay even. The fall off in the budget is mainly in the ACEE program. This program is a large share of our budget and will continue to be for several years.

Now, before talking about the specifics of what we plan to do, Mr. Chairman, in fiscal year 1981, I wanted to take a little time to review some of the accomplishments that have already come out of the ACEE program. We are into the program about 3 years or so. Already we are seeing some very significant accomplishments [fig. R-4].

At the upper left is an artist's conception of the Boeing-767 aircraft. The yellow areas there indicate where they will use composite structures. That is a direct result of our ACEE program. We estimate that the use of composites in that airplane will lead to about a 72,000-gallon saving in aircraft fuel per aircraft per year.

Looking at the lower left, there are four improved engine components, resulting from our engine component improvement program, that have been committed to production of the new General Electric CF-6 and Pratt & Whitney JT90 engines. We estimate here an average total fuel savings of 52,000 gallons per engine per year. The engine diagnostics activity which provides a better understanding of performance degradation in aircraft engines is illustrated in the upper right. Concepts resulting from this understanding have been adopted by eight domestic and three foreign airlines. These will modify their maintenance and refurbishment procedures. We estimate this will lead to a net savings of fuel of about 30,000 gallons per aircraft per year.

In the lower right, flight test of the KC-135 with the winglets is illustrated. This activity is jointly funded with the Air Force. The Air Force is giving serious consideration to installing winglets as a fleet retrofit on all of their KC-135's. We estimate a 6- to 8-percent reduction in cruise drag. This translates into the 68,000 gallons per aircraft per year in fuel savings.

In the center is a picture of the L-1011-500, which incorporates a 10-foot wing extension made possible by the use of active controlled gust load alleviation systems. The higher aspect ratio, due to the longer wings, leads to an increase in cruise efficiency of about 3 percent and a fuel savings of about 200,000 gallons per aircraft per year. Even at this early stage in the ACEE program, it looks like the return as far as fuel savings on the ACEE investment will be very large indeed.

Figure R-6 represents a table of contents for discussing the specifics of the proposed fiscal year 1981 aeronautics program.

The fundamental R. & T. applies to all classes or, at least, to several vehicle classes. We break up the fundamental R. & T. into several categories (fig. 7). There are the disciplines of aerodynamics, materials and structures, propulsion, avionics, and human factors. About 23 percent of the fundamental R. & T. budget is in aerodynamics.

Also, 26 percent is in materials and structures, 35 percent in propulsion, and about 12 percent in avionics and human factors. The rest is multidisciplinary activities.

Turning to aerodynamics, I am sure that you are aware that the computer has already proven to be a very powerful tool. We have only begun to realize its full potential. We are working very hard and very aggressively to extend our capability in this area. We are shooting for a goal in the mid-1980's of computational methods that will allow us to compute the full flow about a three-dimensional real aircraft configuration. This will be a real milestone.

What we will do in fiscal year 1981 is to improve the computational efficiency of a number of advanced methods in order to reduce computer time (fig. R-9). We will also be developing new methods particularly suited to the current class of supercomputers like the ILLIAC and the STAR which are capable of performing many calculations simultaneously.

One of the new techniques to reduce computational time is called vector processing.

One of our major activities is to write computer codes that are almost completely vectorized which permit many calculations to be performed simultaneously. This technique is opposed to the conventional and slower sequential operations called scalar. Vector processing is not the easiest thing to do. We are working our way to the right on the curve and will be greatly reducing the relative computation cost.

Illustrated is a rather simple wing body combination which we are able to model with such a calculation. We are currently able to move pretty far to the right or to the righthand side of the curve for this simple case to achieve a savings in computation cost and time by roughly a factor of 10. We will be applying this vector technique to other more difficult calculations during fiscal year 1981.

In the area of wake vortex research (fig. R-13) we have been working with the FAA to alleviate this turbulence problem encountered by aircraft in the approach pattern. We have completed flight tests with the B-747 and verified the effectiveness of wing spoilers. In April of this year, we will be conducting, again with the FAA, tests on the L-1011. During the B-747 tests we got some unexpected results. Quite frankly, we found out we were not as smart as we thought we were. As a result, in fiscal year 1981, we are going back to some of the fundamentals and will attempt to obtain an understanding of why these techniques really work. From that base, we hope to develop reliable techniques that will allow us to devise operational strategies or design modifications to alleviate the wake vortex problem with minimum fuel and noise penalties.

The area of advanced composites is illustrated in figure R-15. As is very apparent to us from our ACEE program experience, composites are certainly going to play a very important and growing role in increasing the efficiency of future aircraft.

A major focus of our program is to achieve a thorough understanding of material behavior and ability to analyze and to ultimately predict that behavior.

On the left are listed the major areas of activity in our advanced composites technology program. We are working to develop failure prediction analyses as illustrated on the upper right side. Shown is a schematic of a finite element, computer analysis of impact damage. This could be a model of the impact of runway debris on a composite panel, for example; we also will be working to develop reliable non-destructive test methods.

On the lower right there is a computer-generated image of an ultrasonic scan of a damaged composite panel. We will be attempting to correlate the analysis with the nondestructive testing techniques thereby greatly enhancing our understanding of the behavior. That, in techniques for inspection of new components and improved damage turn will lead to better quality control and use of the nondestructive tolerance. Also, we will be working to improve durability and obtain tougher, more processible resins.

One of the major problems in aircraft engines is the rapidly rising costs of maintenance due to the limited lifetime of engine materials. This is shown on the curve in the upper left (figure R-18), and is the result of increased complexity of engine components and their operation at higher temperatures and pressures. In an attempt to keep this curve from continuing to rise, we are working in a number of areas. One is advanced alloys for use in the turbine blades. There are two alloys that look particularly promising to us. One is an oxide dispersion strengthened superalloy, which is a superalloy containing very minute bits of yttria and aluminum oxide. We also are looking at the tungsten fiber reinforced metallic composite. It looks very promising for use in the turbine blades.

At the same time, we have a great interest in the more conventional alloys. We are faced with the problem of the availability of elements that now go into making up these alloys. These are principally cobalt and chromium, which are not readily available in the United States, but are obtained from sources that can best be described as unstable. So, we think it is extremely important to develop substitute alloys using more readily available materials. We will be working to a limited degree in that area.

Coating technology is used to control oxidation, corrosion and erosion. We will exploit new coating and plasma spray technology. We will develop coating methodologies and try to develop increased strain tolerance. In the area of the sealing concepts, we are looking at advanced turbine blade tip seal systems. One of the promising sealing concepts there appears to be a single crystal alloy with about 10 times the fatigue strength and 2 times the oxidation resistance compared to currently used seal materials. It would be bonded to the tip of the blade. We will do some full-scale engine ground tests with that particular concept.

Mr. HARKIN. Are you talking here about bonding the blade, Dr. Olstad?

Dr. OLSTAD. No, just the tip. The single crystal alloy is bonded to the tip of the blade to improve fatigue and oxidation resistance, to an abrasive material is added to the tip of it reduce the gap between the tip of the blade and the liner or the case.

Mr. HARKIN. I see. You are talking about the single crystal blade, putting something on the tip?

Dr. OLSTAD. That is another activity. We are talking in this case about an add-on to the tip of the blade. The tip is a single crystal. It is a different thing than the total single crystal type blade.

Mr. HARKIN. That is another activity.

Dr. OLSTAD. Yes.

Mr. HARKIN. Thank you.

Mr. GOLDWATER. I have a question.

Mr. HARKIN. Mr. Goldwater.

Mr. GOLDWATER. What do you gain by adding something onto the tip?

Dr. OLSTAD. You reduce tip erosion by putting the right kind of material there. You greatly reduce the gas leakage and increase the efficiency of the turbine stage.

Mr. GOLDWATER. Thank you.

Mr. HARKIN. You may continue as you wish.

Dr. OLSTAD. It cuts down the leakage there, Mr. Goldwater.

Mr. GOLDWATER. Leakage?

Dr. OLSTAD. Yes, leakage of the hot gas past the blade tip.

The next figure addresses the first of the fiscal year 1981 enhancements (figure R-19). We are looking at the engine hot section technology. This is not a materials development program as such. We will be starting out to understand better the environment that the hot section components must withstand and the behavior of the components in that environment. The first goal is to develop an analytical life-prediction method and to characterize the environment. We are able to do this because of improvements in both measurement techniques and our analytical capability. This activity should serve as a technology base for future hot section designs with increased durability and reduced maintenance cost.

The hot section represents about 20 percent of the engine weight and is responsible for about 60 percent of the engine maintenance cost. We will be involving disciplines such as heat transfer, material behavior and failure modes. We will use structural modeling and analysis as indicated on the lower right-hand side of the picture.

The computational fluid dynamics (figure R-21), as I indicated, has lead already to some significant advances in external aerodynamics. We are now seeking to achieve similar advantages or advances in the area of internal flow within engines. We look to the same advantages of lower cost, time and risk in our propulsion research and development activities. In particular, during fiscal year 1981, we will be developing two-dimensional and three-dimensional viscous flow models throughout the engine (figure R-21). Detailed flow solutions between blades of the fan compressor, and turbines stages are indicated in the upper left. Also, we will be developing flow models for complex inlet

geometries, as indicated in the lower left, and solutions for the mixed flow in the exhaust stream, where, there are both cold and hot gasses, illustrated in the lower right.

The computational fluid dynamics in propulsion is not as well developed as in external aircraft flows. One of the reasons for this is the complexity of the internal flow. The greater computer power that is becoming available to us and our improvements in computational methods will help us to analyze these complex flow situations.

Small engine components tend to be less efficient than large commercial aircraft engine components, illustrated in the upper left of figure R-22. There are a number of reasons why this is true. They are less efficient because the surface areas are larger than the flow areas, meaning that the viscous influence is greater. The clearance-to-passage height is greater, tending to lead to more leakage. They are more difficult to cool because of their smaller size, so you have to be content with lower temperature cycles. This means lower thermodynamic efficiency and higher rotational speeds. There is a gear box loss the rotational speed is reduced to the lower speed that is required. What we propose to do in this area is to make measurements with better tools now available to better understand the flow in the engines and develop computational methods to improve our analysis techniques. We will develop advanced cooling methods and ceramic materials which will enable us to increase the operating temperature. We will be looking for unique design concepts applicable to small machinery and looking at the gear box problem. We need speed reduction systems that can be applied here simply and more cheaply.

Mr. GOLDWATER. Let me ask a question.

Dr. OLSTAD. Yes.

Mr. HARKIN. Mr. Goldwater..

Mr. GOLDWATER. What is the last picture that you had up there?

Dr. OLSTAD. In the lower left is a schematic of a radial turbine in a small engine which shows some of the problem areas and some of the technology areas, such as the high temperature and pressure flow between the blades of the turbine. As the flow enters the turbine, there are closer clearances which the flow must traverse than in a large turbine. We are talking about the ratio of the clearance to the engine size. It is more difficult to achieve this in the smaller machine. The flow is then directed inward and exits nearer the center line of the turbine. We are using advanced cooling and ceramic materials in the turbine; also improved shapes.

Mr. GOLDWATER. Thank you.

Dr. OLSTAD. We are very concerned about the availability of high grade jet fuels. We may not be able to count on their availability very much longer. We already see some degradation in the fuels that are available. We will be conducting a research activity to look at the consequences of using lower-grade fuel, such as lower-grade petroleum coming from the Alaskan oil fields, and from coal and oil shale. What we will try to do is to characterize these probable future aviation fuels. Figure R-24 depicts some of the problems associated with use of these fuels. They tend to have a higher freezing point and also a higher boiling point. They have a reduced thermal stability which leads to carbon deposits and gum deposits. They have a higher aromatic con-

tent that leads to soot formations and the overheating of the liner walls.

Our research will first focus on characterizing these fuels, starting with the characterization of the typical broad property fuels, as we call them. We will then look at the emissions resulting from their use, their combustion, and what is required in the way of advanced combustors, nozzles, and other component concepts to cope with the use of such fuels.

Some aspects of our fiscal year 1981 activities in simulation technology and avionics and human factors are illustrated in figure R-280. One area will be to provide full fidelity in terminal areas simulation. This will be a multi-aircraft full mission simulation with simulated aircraft and control in which we will study future terminal area concepts. This area supports our joint NASA-FAA programs such as the cockpit display of the traffic information and heads-up display.

We will also look at the reduced visibility effects to identify the visual cues used by pilots in low visibility flight conditions and evaluate alternative methods of generating the simulation more realistically. An important part of the simulation programs is insuring its validity as indicated on the right side of the figure. A typical landing approach experiment with the results of the simulation are displayed. The limits are shown in the area that is marked by an "X" on the screen.

Concerning the problem of community response to aircraft noise, there are two sides to this problem. The sender and the receiver. We work on both aspects (fig. R-29). We have made significant gains to reduce engine noise at the source. We are also learning how the noise annoys people. We know, for example, that lower noise levels repeated frequently can be of equal or greater annoyance than a loud noise repeated less frequently, as illustrated by the chart on the left. Now, we show the equal annoyance contours are shown as a function of the noise level and frequency of operators or flyover rate. Now, along any of the diagonal lines, the annoyance is potentially equal. We have also learned what influence the time of day has on the level of annoyance and how to predict the noise footprint of the various aircraft in the terminal area. That is indicated here on the right where we show such footprints of aircraft activity. Beginning in fiscal year 1981, we will put our knowledge of annoyance and footprints together with a population distribution for specific airports in a computerized community responsive noise model. With that model we will be able to assess with much greater accuracy the impact of further advances in noise reduction technology, changes in operational procedures, changes in the fleet mix and other possible noise reduction strategies. This will be a tool with which we can attempt to codify the impact of the various noise reduction options. We recognize that we won't achieve total quantification because human response will always be subjective. We are trying to get closer to it.

Mr. GOLDWATER. Excuse me.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. Where are you now doing this particular work?

Dr. OLSTAD. At Langley Research Center.

Mr. GOLDWATER. Are you using a specific standard noise measurement for this work?

Dr. OLSTAD. There are a number of specific standard noise measurements used in our analysis and predictions. While aircraft noise levels are quite accurately known, the standard noise measurements, which involve human response, are subject to some uncertainty. We will be using the prediction procedures in the computer model in an attempt to reduce the uncertainty associated with all aspects of community response to noise.

Mr. GOLDWATER. Thank you. Could we go back to the heads-up display?

You went over it very quickly. It is also mentioned on page 41 of your written testimony.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. It looks like you are reinventing the wheel, based upon what you have written on page 41. Your statement, in essence, says that we don't know anything about heads-up display and that we have very little experience with it. Some of the things that you are trying to find out have already been examined. For example, you are saying it puts too great a workload on the pilot. The French have done extensive work on heads-up display. So have the British. As a matter of fact, the U.S. military has used it extensively, as mentioned.

I think that this is a good place for you to be working, but not to reinvent something that has been in use in passenger service for a long time. If you are looking at advanced activities in this area or an advanced state-of-the-art, that is another thing. But when you are talking about whether or not it places too great a workload on the pilot and other basic things, then it seems to me that those are the things that we have plenty of experience with already.

Dr. OLSTAD. Hopefully, we are not reinventing the wheel. That certainly is not our intent.

Mr. GOLDWATER. Instead of taking the time here, maybe you could provide us with a more in-depth report as to exactly what it is that you're trying to do in this particular area, as well as the amount of money and people involved.

Dr. OLSTAD. Yes, sir. But I would like to take just a minute here because last week I was at Ames and saw a video tape of a simulation of the heads-up display. I was quite struck by it. What they did is that they ran some pilots in a simulator. On several of the runs, an aircraft incursion onto the runway from a taxiway was simulated. That was on the visual display. Some of the pilots were using the heads-up display. The pilots using the heads-up display identified or recognized that there was, indeed, an aircraft sitting on the runway on which they were trying to land but much later than did those without heads-up display. On a couple of occasions the pilots using the heads-up display even saw the aircraft.

I guess that our feeling about this is that we don't know all that there is to know about it. We would like to work on the human factors. We have worked with the French and with the Canadians. We have exchanged pilots and simulators. Hopefully, we are not doing what you imply. We certainly don't want to.

Mr. GOLDWATER. I was interpreting the words of your written testimony. That was all.

Dr. OLSTAD. We'll provide that for the record.

[The above-referred information to be furnished to committee follows:]

NASA's head-up display (HUD) research is one very important element of our human factors program in which we seek to understand the basic principles of information transfer to a pilot. Our overall goal is to develop human factors guidelines for future crew stations which would use advanced avionics and operate in an advanced Air Traffic Control (ATC) system. Although some forms of HUD have been used operationally for several years, the full potential of presenting information in a head-up form has not yet been realized. We have been investigating basic human factor parameters involved in presenting head-up information as well as advanced HUD concepts which present more and/or higher levels of information. We have also been working with FAA to develop a knowledge base which had not existed for them to use in the certification of HUDs being proposed for U.S. commercial aircraft. The joint NASA/FAA program is virtually complete and will be finished in fiscal year 1981. The NASA resources associated with this activity are as follows:

R. & D. funds (in thousands):

Fiscal year:	
1976	\$ 5
1977	168
1978	542
1979	515
1980	183
1981	215

Man-years:

Fiscal year:	
1976	0.5
1977	2.5
1978	4.0
1979	7.0
1980	5.0
1981	4.0

We expect to continue exploring head-up presentations as one important display option as the technology moves towards highly integrated cockpits of the future.

A more in-depth report on this topic will be forwarded to the Subcommittee later as requested.

Mr. GOLDWATER. Thank you.

Dr. OLSTAD. I will now turn this over to Bill Aiken who will discuss the aeronautical systems activities, Mr. Chairman.

Mr. AIKEN. This is the more applied research area in the fiscal year 1981 aeronautics program (figure R-30). As you see from the chart, it is organized by vehicle classes. There is the high speed aircraft program which includes the work that we do relative to the high performance military aircraft as well as our supersonic cruise programs. The general aviation program includes our agricultural aircraft activities and the low speed aircraft section includes the V/STOL.

Mr. GOLDWATER. Could you use the microphone, please.

Mr. HARKIN. Move closer to the mike.

Mr. AIKEN. The transport program area includes the elements, some elements, of the ACEE program such as the energy efficient transport, the large composite structure program, and the aviation safety part of our program. It includes the terminal configured vehicle activities. There is also the advanced propulsion systems program, which I'll

cover in more depth later, and which includes the energy efficient engine, the advanced turboprops and the variable cycle engine technology.

First, I'm going to talk a little bit about the high speed aircraft area. With the limited time available, I can only give a few key examples of some of the activities planned for 1981, Mr. Chairman.

Mr. HARKIN. Yes.

Mr. AIKEN. This chart indicates the types of activities that will be continuing—wind tunnel tests of advanced configurations more appropriate for the advanced military aircraft than for civil transport or aviation aircraft (fig. R-31).

Pictured here are the forward swept wing model and the advanced two-dimensional nozzle for fighter configurations. This type of activity is carried out mostly at our Langley Research Center. From some of these programs come our potential flight programs for future implementation.

Now, the figure R-3 shows one of the elements of our 1981 program in the supersonic cruise research area. We have continuing programs in aerodynamics, system studies, and structures which are coming along quite well.

I have chosen to illustrate one of the key technology areas where we have a very limited data base right now. We are trying to get the type of information for supersonic and subsonic speeds needed for the integration of the propulsion system in a supersonic transport or a high-speed bomber airplane.

In the supersonic area we need to look at the characteristics shown here to verify our aerodynamic design codes. They will be run in the 10- by 10-foot tunnel at the Lewis Research Center. The lower part of the diagram shows a subsonic version. We will run a test of the same configuration in the 9- by 15-foot section of the same tunnel at Lewis for noise suppression and off design performance.

A major activity at our Dryden Flight Research Center will continue in 1981 with the HiMAT research vehicle—figure R-35—which first flew in July 1979. We have had two other flights since then, all of which have been successful. We are gradually expanding the operating envelope and have cleared the aircraft in the ranges shown roughly by the shaded area.

In 1981, we will continue to expand this envelope while obtaining the stability and control loads and the data that is necessary to correlate the wind tunnel and analysis data.

Mr. GOLDWATER. What is the altitude and mach number for that?

Mr. AIKEN. I believe about 45,000 feet.

Mr. GOLDWATER. And the mach number?

Mr. AIKEN. It is about 1.8 mach.

Mr. GOLDWATER. Thank you.

Mr. AIKEN. We are trying to work on the transonic characteristics. Most testings will be in the transonic speed range to increase the load factor that the aircraft could operate at. The key characteristics that don't show up too well in the figure include the fact that the vehicle has a fully digital control system and the wings are made out of composite materials and fiber reinforced plastics. As the airplane is load-

ed, in maneuvering flight, the wing maintains the proper angle of attack for maximum lift and efficiency.

Now, Mr. Chairman, here I will shift to some highlights on the low speed aircraft area.

First, we have the Rotor System Research Aircraft—figure R-36. I would like to point out at this time that the rotorcraft program in 1980 was augmented by an additional \$5 million by the Congress. That augmentation has held through the 1981 budget cycle. We have about a \$26 million per year rotorcraft program. In 1981 we will continue the flight research on the test vehicle that is shown on the left. We will use our full scale tunnel at Ames Research Center for the large scale rotor research to develop new rotor systems. They can then be flight tested with the workhorse vehicle shown on the left. The leg of the tunnel shown on the right will be completed by late 1981 and we will be back in the tunnel testing at that time.

Mr. HARKIN. Mr. Goldwater.

Mr. GOLDWATER. What, specifically, are you doing there? How much money was that?

Mr. AIKEN. The whole rotor craft program is \$26 million, Mr. Goldwater.

Mr. GOLDWATER. What are you trying to find out with this program?

Mr. AIKEN. Everything that one needs to know about the rotorcraft—figure R-38. We are covering the basic aerodynamics, using the small-scale rotors in the analysis of the structural vibration characteristics and the transmission for the propulsion system as well as operating systems and the avionics systems that are unique to the rotorcraft operations. It's an across-the-board thing. Every discipline which is unique to rotorcraft.

Mr. HARKIN. Mr. Goldwater.

Mr. GOLDWATER. How much industry participation is involved?

Mr. AIKEN. A great deal of this work, particularly in the structural vibration area and the large rotors that you saw on the previous charts would be done by industry. Industry participation is particularly strong.

Mr. GOLDWATER. All right.

Mr. HARKIN. Proceed.

Mr. AIKEN. As you'll see in the next chart, we are planning to go on to the vibration problems.

Mr. GOLDWATER. These are areas of need?

Mr. AIKEN. Yes, the advanced rotorcraft technology program, for which we have a \$5 million augmentation for this year, is phase 1—A of a NASA total program that came out, I believe, in 1977 in the rotorcraft task force report which was done 95 percent by industry with NASA as a catalyst.

Mr. GOLDWATER. Thank you.

Mr. AIKEN. That rotorcraft package is in our planning cycle and we're trying to work on the elements of it. This is step No. 1.

Mr. GOLDWATER. Yes.

Mr. AIKEN. Figure R-39 indicates what we are doing in response to Mr. Goldwater's question. There was a state-of-the art review in fiscal year 1979 to establish what had to be done in the way of modeling

and structural vibration analysis so that it would be possible to carry the design process through with less effort than the approach used today. The rotorcraft design is a bit more black magic than standard aircraft design—industry recognizes this. In the 1981 to 1982 time frame, a NASA and industry team will develop the methods for analysis and, eventually, the large-scale vibration tests to develop a general data base so that everybody can work with the same set of ground rules to cut down some of the cut and try aspects. Some of the money made available in 1980 is directed at this problem of analysis and is shown in yellow. The shake tests that will begin in 1981 will be a result of the additional funds available.

Another aspect of the low-speed program area is our continual activity in V/STOL (fig. R-4). Shown is a small scale model test to simulation and computer modeling. The tools that are shown on the left are used with the analysis techniques which may be followed by large-scale tests. This activity provides an advanced data base for future aircraft. These advanced designs seem to look like military aircraft. We are trying to provide a data base for the Navy in case they make the decision to go to an advanced V/STOL aircraft. Work in this area includes some propulsion systems research at Lewis Research Center. We have a V/STOL program of \$7 to \$8 million which isn't a lot because the models—the ones in the upper right—have jet engines in them and are quite expensive to build.

Mr. GOLDWATER. Excuse me.

Mr. AIKEN. Yes, sir.

Mr. GOLDWATER. Mr. Aiken, are you working closely with the Navy on this?

Mr. AIKEN. Yes. They have the Harrier.

Mr. GOLDWATER. They have a XFV-12 also, don't they?

Mr. AIKEN. But that's only been flown captive at Langley. It has a slight problem in developing enough thrust to overcome its weight. It has not flown yet otherwise.

Mr. GOLDWATER. They've flown portions of the wings on a test stand. That was at Columbus.

Mr. AIKEN. They are trying to increase the efficiency of the system. There's a good chance that will be a successful vehicle.

Mr. GOLDWATER. It's an interesting concept.

Mr. AIKEN. Yes.

Mr. GOLDWATER. Thank you.

Mr. HARKIN. Go ahead.

Mr. AIKEN. As to cooperation with the Navy, this program is fully coordinated with them. Until this fiscal year they have been providing money to NASA through transfer of funds to help support our efforts.

In the general aviation area, there is continued emphasis on the stall/spin research (fig. R-43). Stall/spin has been one of the major problems of flight safety with this type of aircraft. Our goal is to come up with a stall/spin-proof aircraft and design a handbook that will keep the designers from making the more obvious mistakes. The tools that we use are wind tunnel testing in our tunnels at Langley and simulators. In such a safe simulator environment there is the possibility to check out the peculiar characteristics that might be indicated by the wind tunnel tests, but dangerous to fly.

More recently, there has been the development in flight and through wind tunnel tests of a specific airplane modification shown here. This aircraft uses a large edge on the outer 40 percent of the wing to solve a stall problem—that is, the airplane is essentially now stall- or spin-proof. However, I doubt if this is a general solution to the problem.

There is a great deal more in the general aviation program. There are other aerodynamics programs as well as considerable propulsion activity, some of which is covered in this material.

Mr. GOLDWATER. What about the propeller work?

Mr. AIKEN. We will try to keep up with that so that we can do this next year, hopefully to increase it.

Mr. GOLDWATER. What happened?

Mr. AIKEN. It did not make the grade in our budget submission. We did have a planned program.

Mr. GOLDWATER. Was it zeroed out by OMB?

Mr. AIKEN. \$1½ million for the first year. The whole program was \$10 or \$12 million over several years. We are going to try to get started on it, but it won't be at the same pace. The idea is to improve the efficiency of the lighter weight propellers, and pick up the 2 or 3 percent that seems available at lower speeds.

Mr. GOLDWATER. Will it have noise implications?

Mr. AIKEN. Yes. You have a constraint. If you increase the propeller speed, you increase the noise. It is not a particularly serious problem.

Figure R-47 represents the advanced agricultural aircraft concept. It is to be tested in our vortex facility and wind tunnels. It is the most far out approach we have come up with to date. Relative to improving the distribution of the chemicals and controls, it would have a higher volume for carrying chemicals and the resulting system would have a lower application cost. We are not proposing this as a new design, but to explore what can be done with new concepts.

Our standard program includes wind tunnel tests of a specific agricultural aircraft with minor modifications of the system and devices so that you can control the distribution path and increase the accuracy.

Mr. GOLDWATER. Are you doing work on dispersal patterns at this time, and dispersal techniques with conventional means, Mr. Aiken?

Mr. AIKEN. Yes.

Mr. GOLDWATER. Go ahead.

Mr. AIKEN. We have a standard agricultural aircraft that has been tested in our tunnel at Langley and has been flown at Wallops. We are trying to measure the effects of wind as well as what can be done to the flaps or wing tips to modify the downwash distribution to control the dispersal of the chemicals. We are doing the actual flight tests and will continue those.

Mr. GOLDWATER. Thank you.

Mr. AIKEN. In the transport area, as I mentioned earlier, one of—

Mr. GOLDWATER. Excuse me.

Mr. AIKEN. Yes, sir.

Mr. GOLDWATER. On the agricultural aircraft problem, do you have any preliminary reports or results which are available?

Mr. AIKEN. Yes. We will be sure you get those, Mr. Chairman.

Mr. GOLDWATER. I would like to see an analysis of what has actually occurred and the results, or anything else that is pertinent at this time to agriculture.

Mr. AIKEN. Yes.

Mr. GOLDWATER. Thank you.

Mr. AIKEN. We will provide that.

Mr. HARKIN. Proceed.

[The above-referred information to be furnished the committee follows:]

Since 1976 NASA has been conducting research to improve agricultural aerial applications technology and to increase the usefulness of general aviation aircraft for aerial applications. Primary efforts are to improve the aerial application dispersal and distribution systems by providing suitable disposition patterns (single-swath, uniform concentration of material on the ground) and controlling the drift of dispersants from the target area. Research is currently underway to determine aircraft wake interactions with a variety of dispersal materials and to determine how to modify aircraft wake characteristics to improve dispersal swath control.

Aircraft model and full-scale tests have been conducted in Langley Research Center's wind tunnels and Vortex Research Facility to investigate aerodynamic modifications which show promise of increasing the effectiveness of the aircraft wake in aiding dispersal distribution, while simultaneously improving aircraft efficiency and performance.

Results of NASA research are continually being published and presented at meetings of members of the agricultural aerial applications community. Some recent publications and presentations are listed below:

1. Jordan, F. L., Jr., "NASA Agricultural Aircraft Wake Modification Research," Presented at the 1979 Southeastern Farm Show, Raleigh, North Carolina, February 1979.

2. Holmes, B. J., "Status of Research on Aerial Applications Technology." Presented at the 1979 Spring Meeting of the Association of American Pesticide Control Officials, March 1979.

3. Johnson, Joseph L., Jr., McLemore, H. Clyde, White, Richard, and Jordan, Frank L., Jr., "Full-Scale Wind-Tunnel Investigation of an Ayres S2F-800 Thrush Agricultural Airplane," Presented at SAE Meeting, SAE Paper 790618, April 1979.

4. Holmes, B. J., Razak, K., and Morris, D. J., "Data and Analysis Procedures for Improved Aerial Applications Mission Performance," Presented at 1979 National Agricultural Engineers Joint Meeting—Annual Update on Agricultural Aviation Research, Las Vegas, Nevada, December 10-13, 1979.

5. Ogburn, M. E., "Results of Aerodynamic, Stability and Control, and Handling Qualities Studies of a Representative Agricultural Aircraft," Presented at 1979 National Agricultural Aviation Association/American Society of Agricultural Engineers Joint Meeting—Annual Update on Agricultural Aviation Research, Las Vegas, Nevada, December 10-13, 1979.

6. Jordan, F. L., Jr., "Update of AG Aircraft Model Research in Langley's Vortex Facility," Presented at 1979 National Agricultural Aviation Association/American Society of Agricultural Engineers Joint Meeting—Annual Update on Agricultural Aviation Research, Las Vegas, Nevada, December 10-13, 1979.

7. Jordan, Frank L., Jr., "Development of Test Methods for Scale Model Simulation of Aerial Applications in the NASA Langley Vortex Facility," to be presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colorado, March 18-20, 1980.

The last publication above (item 7) presents the results of research tests in the Langley Vortex Facility using agricultural aircraft scaled models and dynamically scaled test particles to study interactions between the aircraft wake and the dispersed particles. This paper will be presented at the AIAA 11th Aerodynamic Testing Conference, March 18-20, 1980, and it describes the particle scaling analysis, test methods for visualization of particle trajectories, and measurement and computer analysis of test deposition patterns.

Tests using winglets on a representative agricultural airplane have demon-

strated that wake properties can be tailored aerodynamically to produce desirable effects on dispersal disposition and drift characteristics. As a result of these tests, Cessna Aircraft Co. is considering wing changes in their 1982 agricultural aircraft to incorporate winglets. In addition, the Ayres Corp., which builds the Thrush agricultural airplane, has developed as a result of NASA research, into a 1979 production airplane; and various agricultural aircraft manufacturers are using NASA computer programs to study methods to improve wake interactions.

Mr. GOLDWATER. Thank you, Mr. Chairman.

Mr. AIKEN. The transport aircraft program includes a safety program. Figure R-48 demonstrates some of the types of testing we have conducted at the Langley Research Center.

Tires and landing gears can be tested to improve braking and improve the control characteristics of the systems at the landing dynamics facility. There is a request in the fiscal year 1981 budget for an expansion and updating of this facility at an estimated cost of about \$15 million. What is needed is to increase the velocity from its present 110-knot capability to 220-knots.

When this facility was built in 1956, it was one that represented the undercarriage weights, tire sizes, and the velocity of aircraft that were being built in that particular time frame. We are now up to aircraft which land at 150- to 160-knots. The Shuttle lands at over 200-knots. The plan is to be able to conduct tests for the higher speed aircraft. The modifications require a new carriage and an increase in power in the drive system as well as a lengthening of the track in order to continue conducting this type of research for the more modern aircraft.

Mr. GOLDWATER. Where is the track?

Mr. AIKEN. Langley Research Center, Hampton, Va., Mr. Goldwater.

Mr. GOLDWATER. Thank you.

Mr. AIKEN. Another major element of our transport aircraft program is the continuing activity in the terminal configured vehicle program (fig. R-40). It is a modified B-737. The objectives are to develop an on-board system on the aircraft for better air traffic control compatibility with future air traffic control systems and for more efficient flight management. It puts together all of the technology that is developed for the on-board systems from the R. & T. activities to provide the test bed for such concepts. It covers a broad range of digital controls and displays.

In 1981 work will be continuing on devices for precision touchdown and turnoff in a semiautomatic mode. We will include in the test vehicle for the cockpit display of traffic information. This program is conducted almost completely with, and coordinated with the FAA.

Next we will discuss about some of the elements of the ACEE program. I have selected the energy efficient transport for a starter (fig. R-50).

Mr. HARKIN. Yes.

Mr. AIKEN. The upper lefthand chart is a picture of the tail section of a Lockheed L-1011. The plan is to design and fabricate a small horizontal tail.

Mr. GOLDWATER. Could you repeat that?

Mr. AIKEN. This will improve the lift or the drag characteristics. The righthand side in the chart reflects a 3 to 5 percent drag reduc-

tion. This is a particularly important way of potentially saving fuel for this aircraft. We will be actually in a design phase and will start flight tests in 1982.

The upper righthand part of the chart refers to a test program that is underway right now. It is on a B-747. This will be used in conjunction with other programs to determine the impact of the exterior loads transmitted to the engine through the nacelle which covers the pylon. Now, even for such a massive system, the engine can be distorted and the whole shaft could bend a bit causing rubbing or deterioration. This would establish the model for engine design and case design. This is the first chance that we've had, or that anybody has had, to actually measure the input loads. We will have pressure distributions and accelerations as roughly shown on that diagram.

Another 1981 program is the DC-10 winglets. There are potential large drag reductions possible. There is about a 3- to 4-percent minimum drag reduction possibility, and probably up to 5 or 6 percent. The program would include fabrication and flight tests in 1981.

Another major ACEE program element is our composite primary structures program, figure R-51. The DC-10 aircraft, shown in the upper left, will be test flown in 1981. The red-colored part is the fin. At present, the plan is to manufacture eight of these components. For the B-737, the horizontal stabilizer will be produced in a number of sets and one nonflying set and will be flying in 1980. On the Lockheed 1011, we are building three fins, but they will not be flight tested under the present planning.

Another part of our advanced propulsion systems program is the energy efficient engines. Figure R-53 simply shows one of the components of the high pressure compressor. The lower right chart shows the increase in the efficiency of the compressor. The engine will have a 10-stage compressor with about a 3- to 4-point increase in efficiency for the compressor. This happens to be a General Electric component.

In 1981, the fabricated compressors will be run in a compressor to establish their performance.

The advanced turboprop program is shown in three phases in figure F-56. It is another augmentation to the 1981 technology program. Phase 1 was completed, or will be completed, in 1980, and we are ready to start with phase 2. That will move us up to 8- to 10-foot diameter propellers. There will be supporting analysis and design work. The big problem is establishing the technology for the design and fabrication of the blades made out of composite materials. Eventually we would test this system in an appropriate wind tunnel.

The figures R-58 and R-59 are both on the variable cycle engine program. Figure R-58 shows the engine program which was scheduled to have been phased out in 1980, but which has been augmented in the 1981 program plan. This figure shows the kinds of elements that we have worked on and that GE worked on in 1976 to 1980. We are working on the noise reduction aspects and acoustics and what can be done acoustically; also the acoustics lining of and acoustics shield approaches. There is a hot jet of air at a higher velocity that is used to shield the main flow and a flow shield separation between the engine and the ground.

In the bottom, the major elements of the 1981 program show a front block fan being developed and a low pressure turbine modification. There is also more work on the mechanical part of this duct at the back end.

The final chart (figure R-59) would be similar activities for Pratt and Whitney but different because the engine cycle is different. This shows 1976 to 1980 when we concentrated on the duct burner and checked out the ejector and the nozzle. In 1980, with the augmentation, we will move to a better duct burner and mechanical suppressor work. We will do more work on the acoustics on the whole system in fiscal year 1981.

Mr. Chairman, that concludes my presentation today.

Mr. HARKIN. Thank you.

Mr. AIKEN. I will turn it back at this time to Dr. Olstad to conclude.

Dr. OLSTAD. We believe our program proposal contains a strong effort in fundamental research. We will continue to pursue planned objectives and ongoing programs, such as the ACEE program, with significant enhancements in the variable cycle engines, rotorcraft technology and advanced turboprops and turbojet engine technology.

Recent planning activities that we have undertaken have indicated these to be areas in need of early emphasis. Clearly, a strong aeronautical program is required to meet the urgent needs, the national needs, for a healthy aviation industry and continued pre-eminence in the world market place for effective military weapons systems, greater energy efficiency and reduced environmental impact.

I want to assure you that NASA fully intends to play a major role in meeting these objectives.

Thank you, Mr. Chairman.

Mr. HARKIN. Thank you for your statement. We certainly hope so, too. We will do what we can to make sure that they do. Thank you very much, Doctor and Mr. Aiken for that very comprehensive overview.

I just have a couple of questions. The first would be in looking at the aeronautics budget, we have the recommendations that were made to OMB.

Dr. OLSTAD. Yes.

Mr. HARKIN. OMB dropped every proposed initiative except four. Those were the hot section technology, rotorcraft, the variable cycle engine and the advanced turboprop. Do the items that were dropped reflect in any broad way your priorities?

Dr. OLSTAD. Yes. I think that is true. Rotocraft and the variable cycle engine technology, were our first two priority enhancements. We did get a substantial portion of what we had asked for. The advanced turboprop and the hot section technology were a little farther down the list. They are not out of line with the priorities.

Mr. HARKIN. There are two here that I'm concerned about, Doctor.

Dr. OLSTAD. Yes, sir.

Mr. HARKIN. It seems that we, in aviation, have got to start looking ahead at the available fuels that we will have and the restrictions that may be placed upon us in the battle for limited supplies of petro-

leum-based fuels that we have. I am wondering if this is one area that perhaps we should place a little higher priority on. Could you address yourself to that?

Dr. OLSTAD. Yes, sir. However, I would like to provide some additional material for the record.

Mr. HARKIN. Please go ahead.

[Material referred to follows:]

Aviation fuels are currently produced to adhere to very stringent specifications which evolved during periods of high petroleum supplies and low prices. These fuels make up only a small portion of the overall product mix of petroleum production—currently about 6 percent. Future disruptions in the supply of petroleum feedstocks and increasing demand for other middle distillate fuels (e.g., diesel fuels) are expected to result in continued and more frequent availability problems with specialty jet fuels. There is also an increasing scarcity of high-quality crude feedstocks available to the United States. Severe economic and energy consumption penalties will result if lower-grade crudes must continue to be refined to current jet-fuel specifications. These factors will ultimately lead to changes or relaxation in the properties of future aviation fuels. The need exists for a major effort devoted to the development of aircraft and engine technologies to utilize future aviation fuels with relaxed or broadened properties.

The proposed Aircraft Technology for Future Fuels (ATFF) program goes beyond the ongoing fuels research that was described in the testimony by involving the major refiners in comprehensive system analyses and working more closely with the major commercial engine manufacturers as well as those of general aviation engines. Specifically, the principal thrusts of the ATFF program include: fuel characterization; definition and evaluation of advanced component concepts; definition of the range of potential fuel property variations; tradeoff studies of fuel property variations as compared to aircraft and engine technologies; evaluation of the effects of fuel property variations on current systems; and research on advanced engine and aircraft fuel systems.

The ongoing research activities in fiscal year 1981 will address some of these thrusts with varying limitations on the scope of effort. The proposed Aircraft Technology for Future Fuels (ATFF) program would build on the ongoing Fuels R&T Base and Broad Specification Fuels System Technology programs to provide a comprehensive approach to the problems associated with future aviation fuels. The ATFF program would focus on generating the technologies needed to safely and efficiently utilize broadened property aviation fuels derived from petroleum, shale oil or coal in current and future aircraft engines and fuel systems.

The proposed fiscal year 1981 funding for the ATFF program was \$4 million. This funding would include systems analysis and tradeoff studies to determine the effects of changing fuel properties on refinery operations and fuel availability as compared to the costs of engine and aircraft fuel system technologies needed to utilize these fuels. Efforts would be initiated to evaluate the effects of fuel property variations on current engines and aircraft fuel systems and determine the degree of property variation allowable in these systems. Research efforts on advanced engine and aircraft fuel system components would be expanded considerably to develop the necessary technology to utilize potential future hydrocarbon fuels in current and advanced commercial and general aviation aircraft.

Dr. OLSTAD. Yes. As I indicated, Mr. Chairman, during the testimony, we will be doing some work in that area. Our request was to substantially accelerate this and to do more in fiscal year 1981. We share the concern about the availability of high quality fuel. We already see some degradation in the fuel available and certainly the outlook at the present time is for a rapidly worsening situation. The priority that is placed on this activity is a function of the world situation and

every day it seems to be getting a little worse. So, that is one reason why we consider the alternate fuels program a high priority. We would like to do more work in that area if we could.

Mr. HARKIN. I really don't want to ask this question, but I guess I have to. Since the tail off of the ACEE program in fiscal year 1981 from \$116 million to \$85 million, and as it will continue to drop in fiscal year 1982, OMB seems to be bent on preventing any new starts to fill this wedge where we had tapered off. This leads to my question. Do you see another drop in the overall aeronautics funding this year?

Dr. OLSTAD. No; I don't think that we will see a drop. OMB has treated the ACEE program as one-of-a-kind program, which it was. It was designed to meet a particular need and to accelerate the R. & T. activities and to do some things very near term and others on the longer term. This is toward solving the fuel problem and increasing the efficiency. I think, as I indicated earlier, it is already showing that it was very effective in doing this. I feel that if we see other similar kinds of critical needs in this alternate fuels area, it may be one of those, say, the increasing requirement for military support. It could be one of those. There may be others. I think that they would be considered on a case-by-case basis. With proper justification, we would have a good chance of augmenting our budget to solve this.

Mr. HARKIN. I have one final question.

Dr. OLSTAD. Yes.

Mr. HARKIN. This is on the supersonic transport, I was at Pratt and Whitney on Monday. Someone there, and I don't attribute this necessarily to any one individual, but they said that the present level of funding in advanced supersonics is too low to ever get to a viable environmentally acceptable supersonic transport.

Could you please comment on that?

Dr. OLSTAD. I don't disagree. What we are trying to do is develop a base technology from which you can make a decision that now is the time, if that is the proper decision. Then we can work with more developmental kinds of activities. We are working with key technologies and the variable cycle engine is one of those. We feel that is the real key at this point to make this supersonic aircraft an attractive possibility. Our program is not designed to get the technology in hand so the manufacturer can say: "I'm ready to build." There is a good bit of development technology and demonstration that would also be required.

Mr. HARKIN. It seems to me that if we don't fund it enough to bring the technology forward to the point where we can make a go or no-go decision, based upon factors other than it can't be done, and that type of thing, that we are never going to get to that point.

Dr. OLSTAD. Mr. Chairman, I hope that I didn't give you a wrong impression. I didn't mean to imply here that we could not bring it to the point of decision. There are different kinds of decision points. One is that I am ready to build right now. That is not what we are aiming toward. The other is the technology is available with proper engineering and using that technology then we are ready to build. That is where we are trying to bring it. We think that we are doing this successfully. We are building this research and technology base. We certainly are not doing the demonstration technology. That comes

after the initial decision. That is when we start talking about when we would do it.

Mr. HARKIN. Thank you. Mr. Volkmer.

Mr. VOLKMER. Thank you, Mr. Chairman.

What increase would be necessary in the budget to bring this to where, say, within a year, that you could begin work on demonstration?

Dr. OLSTAD. Mr. Aiken will respond.

Mr. AIKEN. I don't think that any amount of money made available in that short a time period could bring us to that point. We think it is a minimum 5-year program, sir.

Mr. VOLKMER. Five years?

Mr. AIKEN. Yes.

Mr. VOLKMER. On technology development?

Mr. AIKEN. Yes. We need more work on the engines. We did have, and I wouldn't call it a plan, but an outline, in the white paper that was prepared for your subcommittee where it showed what we would hope to be able to do to get the program going downstream. In a year or two, we could move into a new core for an engine and expand our structures program, which is the biggest problem in terms of requiring funds for the high speed structures.

We could probably get a decision if you followed a program outline similar to the one in the white paper.

Mr. VOLKMER. Thank you.

Mr. HARKIN. Mr. Goldwater.

Mr. GOLDWATER. Thank you, Mr. Chairman.

I have a comment on the presentation. I think that the four new starts that were presented are good ones. The efforts in variable cycle engine; propfans, rotor craft, and hot section technology are all good programs that need the support of the committee.

Dr. OLSTAD. Thank you.

Mr. GOLDWATER. The committee has supported these programs over the years. Looking at the budget presentation, I am disturbed by the penciling out by OMB of some 11 programs, or augmentations, as you call them. I think this is somewhat disturbing in light of the fact that today we are finding increasing threats by foreign competition. Certainly, there is also the implication of national security and national defense. The military has always relied on NASA to supplement some of their work and to help advance the state of the art in aeronautical R. & D.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. If there ever was a time not to cut out some of these programs, I think that time is now. I am not sure what the Congress will wind up doing with this budget, but I think that the mood is to try to strengthen the budget to allow for further work on programs that have already been started and to fund some of the new programs that were proposed to OMB.

I would like to thank you for the briefing on noise that was provided December 18. I want to thank NASA and you for this.

In addition, I am pleased that NASA is not dropping out of the wake vortex activity, that NASA will work with the FAA—and

hopefully with more interest from industry—on the L-1011 test flights this coming spring.

There were a couple of things that I wanted to raise at this time.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. I am somewhat concerned about the meager level of funding for the supersonic flight area. You do have increased funding on the variable cycle engine thanks to congressional action. But about aerodynamics, materials, structures, flight testing? What is the level of the funding in these areas of supersonic flight? What is the total budget for that program, as such?

Mr. AIKEN. The non-variable cycle engine part of it is \$10.5 million. That is the part that is directed toward the supersonic cruise with an SST implication. In addition, there is approximately \$20 million which could be categorized as being high performance military oriented with supersonic connotations. These are things such as wind tunnel tests, advanced configurations and flight tests of the F-14. It is a whole series of flight tests and wind tunnel tests. They are not directly SST-related, but high performance military applications. I don't know whether that answers the question.

Mr. GOLDWATER. You have \$10.5 million and additional moneys that I guess you derive from the military.

Mr. AIKEN. Not from the military, but our budget in the high speed aircraft area is about \$32 million, of which about \$10.5 million is SST-oriented. The rest of that could almost be considered as direct support of the military type programs.

Dr. OLSTAD. The aerodynamics work would be primarily in the low-speed and the high-lift range—the off-cruise operation. This presents the largest aerodynamic problem when you are trying to wed this into an efficient supersonic cruise configuration.

Mr. GOLDWATER. There was a recent statement by industry on NASA's SST research program. They were asked to comment on NASA's effort in this particular area with the assumption that we continue this program at current spending levels. They were asked when they would expect that this technology would lead to an eventual application in some form of aircraft. The answer was "never." Their explanation was that at these funding levels NASA is not getting into the large component testing which is necessary.

Could you please comment on that? Also what kinds of things should we be doing which we are not doing, in order to arrive at some point in the future with an airplane, either military or civilian, with that application?

Dr. OLSTAD. I think that is a correct assessment. We are working trying to improve the technology. I think what is needed is some sort of a policy decision that says the United States should proceed with the supersonic transport. That is not NASA's decision to make. If such a decision is made, I think that industry correctly assesses the situation that they can't individually do or support all of the development required. The outlook for the aircraft sales is for something on the order of 300 supersonic aircraft. There really is a question about the paycheck. Industry itself, if it has to provide all of the up front R. & D. expenses, they may be very reluctant to make such a decision.

Some support may be required. It is not a NASA decision. It is a larger policy decision.

Our activity is geared toward providing the technology base so that, when such a decision is made, we can use the best technology. We are not really gearing toward a target date. We are trying to continually update the technology, Mr. Goldwater.

Mr. GOLDWATER. Wasn't there a recent meeting at Langley on this issue?

Dr. OLSTAD. Yes.

Mr. GOLDWATER. What was the result of this?

Mr. AIKEN. It was a technical conference, reporting, again, as we do every couple of years on the state of the technology of the design of transports. It depends on where you're sitting as to whether the results were spectacular or the same. But each time that we've had these meetings there have been more and more indications that the technology has been moving along to a point where a supersonic transport which will meet the environmental constraints and is economically feasible is a good possibility. It is always with the caveat that more dollars are needed in the technology area and the structures and engine sides, to have a big enough data bank so you can say, "Yes, we are here."

Mr. GOLDWATER. It seems to me that we are never going to arrive at a point in the future where a decision to go can be made unless industry has some kind of consensus as to the direction. That is, at least on the larger questions. I am talking about how we build something like this, and what kind of dollars will it take, and whether this should be Federal, public, private, a combination of both, or with foreign involvement? Do you feel that industry is fairly unanimous in their thinking on supersonic flight as this applies to commercial aviation?

Mr. AIKEN. As far as I can tell from Pratt & Whitney and Boeing and GE, and from the other people working with us on the program, I would say it is unanimous there is a good possibility and that this should be pursued.

Mr. GOLDWATER. Have you been able to outline a program or has industry—that would lead to such an eventuality? And what should Federal Government be doing to supplement it? I am talking about what the Government could do in the form of research and development that would lead to a point where industry could take over and then build it.

Mr. AIKEN. Yes. Last year and the year before—in response to requests from the Committee for Program Plans for SST R. & D. development, we did submit reports showing development plans. We are still on the lower part of the funding curve. In the white paper, there is a reiteration of the program elements required to get to that decision point. We are talking about a minimum of half a billion dollars on a 5-year period to get to that point.

Now, as Dr. Olstad said, the kinds of funding that you are seeing in the NASA budget are only the beginning of the curve to build up to do it. We do have plans which industry helped us design that could be implemented. They are in the white paper that we submitted to your subcommittee in September.

Mr. GOLDWATER. I would like to recess this committee for a few minutes. I have to vote. I will be back in 5 minutes. We stand in recess until then.

[A short recess was taken.]

Mr. GOLDWATER. The committee will be in order.

I have several other questions that I would like to ask, Doctor.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. I have always been concerned about the relationship that NASA has with the military and what portion of your budget would be supplemented by the military. Specifically, I wonder if you could comment on which programs in NASA's aeronautical R. & D. have military involvement?

Dr. OLSTAD. Let me run down some of the numbers first. Then I will ask Bill for some help in terms of specific programs.

Mr. GOLDWATER. Go ahead.

Dr. OLSTAD. To give you a feel at this time for the level of support in terms of direct requests from the military, we supply about \$5 million worth of support. In terms of joint cooperative programs, which is where we reach agreements and have memoranda of understandings; that's about \$28 million. That part of our activities, which are directly applicable, would be things like much of the high speed work that Bill has talked about other than the supersonic transport or the focused work; also the V/STOL activity. That amounts to about \$63 million. That totals about \$97 million which we think is pretty applicable to the military.

We estimate, and it is a rough estimate because this is kind of a subjective judgment, about \$71 million of the other work is broadly applicable to the military. This makes a total of about \$168 million. In terms of the specific programs, Bill can comment on this matter.

Mr. GOLDWATER. Yes.

Mr. AIKEN. Within those numbers there are major programs with the Army at three of our laboratories concerning rotorcraft. These are at Langley, Lewis, and Ames. The Army has its own installations that are colocated with ours. Sometimes it is a bit difficult to sort out whether it is military oriented or civil oriented. Many of the activities are joint funded. There is a major interface.

I spoke already about the V/STOL area. I might have overstated it in terms of direct support. We still should have a V/STOL technology base even if the Navy should not be currently interested. They would be potential users of the technology. The work is designed to provide a base where they can go ahead with the new V/STOL aircraft if they choose to.

Almost all of the flight research activities conducted are either joint or cooperative programs with the military, or they have a very major military outlook. These are not weapons systems, but research in configurations, operating envelopes, stability and control characteristics, and even fixes for some of the aircraft where they encounter problems even after they have been in production. That activity runs about \$13 million a year, if you add up the cost of operating the Center where the F-15, F-14, and the F-111 aircraft are operated. These are joint programs with a great deal of military interest.

At the Langley Research Center, as I also mentioned, there is a great deal of advanced configuration development. If the future can be measured by the past, then the future fighter and bomber aircraft of the military will probably come pretty much out of the designs being worked on in the wind tunnel analysis and the theoretical development of aircraft that are done at Langley. The F-14 and F-15 aircraft and the F-111 were all essentially based on basic work done at Langley. The wind tunnel models, those out of the past, look almost like the final product. I would say that we have a big, active interface with the military in terms of these programs.

We also have coordination activities that go on daily at the Centers and Headquarters level; also at the administrative level. We have bi-monthly meetings with our counterparts at DOD and the Aeronautics Panel of the AACB. We have six working groups working on a range of problems of mutual interest. We have semiannual meetings with the Air Force Systems Command Laboratories and our laboratory personnel, which help to avoid any duplication and to run on the joint programs whenever possible.

Mr. GOLDWATER. It is disturbing that your budget has gone down to \$290 million. That prompts me to ask this. How much of this activity which benefits the military is being supplemented with military dollars? Are you getting reimbursed for the work that is benefiting the military, or is it being done gratis?

Mr. AIKEN. I wouldn't call it gratis. We feel it is part of our job to develop a technology base in aeronautics regardless of whether it is civil or military application. In some cases, the funds come into the program from the military appropriated directly. Some of the joint programs that I mentioned have been generally carried out because neither agency had sufficient resources to do the whole job by themselves. The military aeronautics R. & T. people in the past have been fairly well strapped for new programs. That is why there are many joint flight programs between NASA and the military. Reimbursement itself, I don't think is a particularly great idea. The major wind tunnel facilities in the tunnel plan that we operate are national facilities and we, by law, are not to be reimbursed for them. They have the first call on the use of those facilities.

Dr. OLSTAD. I would point out many vehicles that we used for flight tests are supplied by the military, such as engines that we test at the Lewis Laboratory. Many of them are supplied by the military. There are other ways of reimbursing us. There is a good relationship in terms of acquiring the kinds of facilities and equipment that we need in our program, Mr. Goldwater.

Mr. GOLDWATER. I guess I ask the same questions every year. It seems to me that the military has a huge budget. Your budget is relatively small.

Dr. OLSTAD. There are some things that I think that we do well that have military application. I think it is important that we use our capability there. It is really a lot less important as to what organizational badge we are wearing at the time. If we have the capability in a certain area, I think it is appropriate that we do the work.

Mr. GOLDWATER. Which of the programs that were cancelled by OMB would have had the most benefit to the military, Dr. Olstad?

Dr. OLSTAD. There are two. One is the V/STOL propulsion system activity, which would have almost direct application to the military. At least that is the first application that we see. The other is the high performance advanced flight experiments. The activity that would have been conducted would be very much directed toward the military type of aircraft. That would have been a total of \$5.5 million for fiscal year 1981.

Mr. GOLDWATER. At NASA's last hearing, I made a statement about the need for NASA to look into research on the question of pilot fatigue and jet lag. I wonder if you could review NASA's response to this expression of interest.

Dr. OLSTAD. Yes. What we have done is set up a study team at Ames Research Center to review the state-of-the-art with regard to the understanding of this problem. Upon completion of that review we will convene a workshop. We will bring in experts from outside of NASA. We will determine in the workshop what R. & T. activities, if any, should be undertaken and what resources at the time would be required. The major output of the workshop will be a report. If we conclude that an activity is required, we intend to adjust some of our fiscal year 1981 funds to support some effort in his area.

Mr. GOLDWATER. I noted that \$5 million for human factors was denied by OMB. How much money are you putting into human factors?

Mr. AIKEN. It is \$6.5 million in 1981.

Mr. GOLDWATER. They denied \$5 million additional.

Mr. AIKEN. The \$5 million addition included both avionics and human factors. The basic avionics and flight control program is about \$6.9 million. The total program in avionics, flight controls, and human factors is about \$13.4 million. The request was for an additional \$5 million.

Mr. GOLDWATER. What kind of things would you look at with the additional \$5 million?

Dr. OLSTAD. First of all, as I am sure you are well aware, 80 percent of the accidents that occur in civil aviation can be traced to pilot error. So, clearly, there is a tremendous potential there for improving what is already a good, but not perfect, safety record. This would be accomplished through human factors activities. We would look at design and validation methods through human factors research. This is an area where we don't have a long history and where we are building up and obtaining more information. We are learning more about it. It had been more of a subjective kind of thing in the past. We are now trying very hard to make an engineering science out of it. I think that we have made some very excellent strides. There are a number of problem areas that have been prioritized by the people at Ames Research Center. They are not able to handle the whole list. There are manpower limitations. That's one of the major difficulties. There was also a proposed enhancement in the avionics and controls areas. Here we intended to look at advances in control theory and application through the use of the rapidly improving microelectronics in an attempt to try to factor these improvements and that state-of-the-art into the avionics and control area. Finally, the proposed enhancement would have per-

mitted us to look at the total system and to integrate it into developing systems concepts.

Mr. GOLDWATER. OMB cut out a new start on conservation of scarce aerospace materials, such as cobalt and chromium. Apparently, we import these materials from unstable sources like Russia. What is the extent of this problem and what do you propose to do about it?

Dr. OLSTAD. It is rather serious. For example, Zaire supplies about 70 percent of the cobalt used in the United States. None of it comes from the United States. This element is pretty vital to jet engines. Just a couple of years ago, as a result of the civil war in Zaire, the supply was drastically cut and the price increased seven times. Also, Russia and Africa represent really the only sources for chromium. As you point out, it is an unstable kind of situation. What we would like to do most is to find replacement alloys or superalloys that depend heavily on elements for which there is a stable supply. So, it's a pretty fundamental kind of program. We want a better feel for what is happening in the alloying process when you make an alloy and how to go about making a replacement for some of these scarce, or potentially scarce, elements.

Mr. GOLDWATER. Is there any work being done in the private sector in this area? I suspect that there probably is.

Dr. OLSTAD. I suspect that there is. We will have a limited activity addressing the problem of scarce materials requested.

Mr. GOLDWATER. I wonder if you could give us more detail on that problem, as well as the proposed plan?

Dr. OLSTAD. We would be happy to.

[The above-referred information follows:]

As you are aware, NASA Lewis Research Center has had a continuing program on high temperature alloy research for gas turbine engines. Part of this research has been directed at determining the strengthening and oxidation mechanisms of these alloys so as to improve material properties and achieve greater performance. We have recently shifted some of the emphasis of the ongoing program to explore the role of strategic elements in these alloys. Although quite a bit of information exists, this more detailed examination is necessary if we are to substitute for the scarce elements. We must be able to achieve equivalent properties without using cobalt, for example. This is not an easy task, since the current alloys have previously been tailored to meet operating component needs.

The broad objectives of our approach to conservation of strategic aerospace metals is to reduce the dependency of the U.S. aerospace industry on strategic metals such as cobalt, tantalum, columbium, and chromium by providing the technology needed to minimize the strategic metal content of critical components in gas turbine engines. An expanded program would involve developing a greater understanding of the roles of these metals in critical gas turbine alloys; identifying modified alloy composition and processing techniques so as to reduce the use of these metals; and evaluating the potential new classes of structural alloys and coating as direct substitutes. It is likely that new coatings will be required because both tantalum and chromium add oxidation resistance to the alloy. Coating technology has the potential of maintaining this resistance at lower strategic metal content.

The thrust would be to provide the technology to reduce at least 25 percent of the strategic material content for a modified engine alloy and to eliminate the metal entirely where possible in some engine components.

Mr. GOLDWATER. You talked about composite materials. Are you doing anything with kevlar?

Dr. OLSTAD. Yes, one example is in the B-767, where kevlar is one of the materials used in the composites. This is a direct result of our ACEE and preceeding programs on composites.

Mr. GOLDWATER. If I may, I have a question for one of the executive development people who accompanied you today.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. I would like to know more about the propfan program, such as when a commercial propfan would appear on the market and how much fuel it could save compared to a jet?

Dr. OLSTAD. Dr. Poferl.

Dr. POFERL. The program as it is now structured brings the technology readiness along to the point where we would anticipate application in the 1990's.

Now, the benefits that we would expect from the advanced propfan technology would vary from about 15 to 30 percent over this for an advanced turbo fan to up to 20 to 30 percent, depending on the average stage; also it is a function—

Mr. GOLDWATER. Could you come forward?

Dr. POFERL. The propfan shows its advantage on the longer flights.

Mr. GOLDWATER. Such as?

Dr. POFERL. Flights that require extensive time at mach 0.7 to 0.8. That's also where the high-speed propfan shows dramatic improvement over the technology in the Electra type propellers. If you are not at those speeds for an extended period of time, the advantage in going to the advanced propeller design becomes negligible. If the stage length is small, you spend your time getting to altitude and back down. The high speed propfan is not designed to be that efficient at the low velocity because of the thin airfoil. The thicker airfoil of the Electra-type prop would have better lift-to-drag characteristics at low speeds. We see the major benefits at the mach 0.7 to 0.8 range. The advantages of the propfan over the Electra-type propeller becomes less dramatic at shorter stage lengths.

Mr. GOLDWATER. Are we at the point of fixing the design of the blade configuration?

Dr. POFERL. We are still working on what we anticipate to be a near optimum configuration. We are working on the 2-foot models. We are now working at that scale. We have investigated the 8-blade propellers with various sweeps. We are moving to the 19-blade propellers because we think that there is even a further advantage to be gained as far as the propeller efficiency and the noise reduction in a 10-blade propeller. We have not sorted it out completely but we are getting close.

Mr. GOLDWATER. Could this program be accelerated if there were more dollars put into it?

Dr. POFERL. If that question means could the technology be done earlier by accelerating downstream portions of the programs, I would say that the answer is yes. For instance, if the flight demonstration portion that we plan downstream was moved up, we might be able to save a year or two in the time in which that technology is done. However, you must realize if you do that, you have to go on a more risky path. In other words, you have to assume that the large-scale structural part of the program is going to be a success because you have to determine what the flight test bed would be and move ahead with the other items at the time.

Mr. GOLDWATER. Could you give us an expedited program in dollars that would match that kind of effort?

Dr. POFERL. Yes.

Mr. GOLDWATER. I think it is an important program. It is becoming increasingly apparent that we are going to have problems with oil and available fuels for aviation. I was reading in the Aviation Week and Space Technology magazine of December 17 about a 15-cent-per-gallon hike in the price of fuel in the first quarter of 1980. Accompanied with that announcement were hints from the oil companies that the fuel allocations for next year may be as low as 76 percent of the 1978 levels. So, obviously, the fuel efficiency effort is very important. If propfan technology is going to make a contribution, then we may accelerate that program. It may become apparent that we have to. That information would be helpful.

Mr. POFERL. Yes.

Mr. GOLDWATER. Is there any relationship between the propfan development and the work that you are doing with general aviation propellers? Is the technology similar?

Mr. AIKEN. Backing off from the high speed point that Dr. Poberl was talking about, I think there are applications of modifications of the advanced turboprop to the commuter field, but probably not to general aviation. However if you are talking about a general aviation aircraft that flies at mach 0.8, the answer is yes.

Mr. GOLDWATER. We would like to understand more about this work.

Mr. AIKEN. Yes. It is not a limited technology application.

Mr. GOLDWATER. If you could provide for the committee a more detailed explanation of the general aviation propeller program and the proposed program that you had in mind, we would appreciate it.

Dr. OLSTAD. Yes.

Mr. AIKEN. Yes.

Mr. GOLDWATER. We would also like to know the total cost.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. Thank you.

[The above-referred information to be furnished the committee follows:]

The design properties and qualities of propellers directly affect aircraft safety, fuel efficiency, noise, cost of aircraft ownership, and the utility of the airplane itself. Ninety-nine percent of all general aviation aircraft use propellers, and this fraction will remain substantially unchanged in the future because of the eminent superiority of propellers over jet propulsion at lower operational speeds.

Despite propeller importance in each area noted above, virtually no basic improvements have appeared in general aviation propellers in several decades, and the technology and design practices in this field are largely those of the World War II era and earlier. However, recent NASA research on airfoils, noise reduction, and composite structures, and the current activity in the field of high speed prop-fan research all point clearly to potential improvements that should be possible in low-speed propellers as well.

In fiscal year 1981, NASA proposed to the Administration a focused technology initiative to advance the technology level for propellers appropriate to the speed, power and operational requirements of general aviation aircraft. This program, the General Aviation Propeller (GAP) technology program has been strongly and consistently recommended by all sectors of the general aviation community since 1970. Endorsement has also taken the form of specific recommendations for this program by the Aeronautics Advisory Committee and its General Aviation Subcommittee. However, the program was not supported by the Administration for inclusion in the NASA fiscal year 1981 budget. The broad program objectives include increased fuel efficiency, reduced noise, improved structural life and Safety, and reduced weight.

A major specific objective of GAP is propeller aerodynamic efficiency improvement together with reduced interference and installation drag to achieve up to 10 percent by the development of improved blade airfoil sections and aerodynamic distributions optimized for the flight speeds, power loadings and operational requirements unique to general aviation. Design requirements for high subsonic speed propfans are significantly different, and the design approaches to satisfy those requirements will not provide satisfactory solution for the GAP regimes of concern.

A second major objective is noise reduction by as much as 5 decibels through application of recently developed propeller aerodynamic noise generation theories, and by the possible addition of tip devices (proplets) and by other configuration variations which show theoretical capabilities for noise reduction.

The third major objective of GAP is the improvement of blade structural properties and weight reduction through special applications of composite materials technology. This would achieve significant increases in damage tolerance and fatigue life, thus contributing to enhanced safety and reduced maintenance costs. Reduced weight, important as a performance factor, also reduces blade and hub structural loads. An additional objective in the use of composites is the tailoring of structural stiffness properties to achieve desired deflections and aeroelastic behavior to prevent blade flutter.

The GAP program would focus on three rather specific areas of interest to general aviation: low-speed/low power (less than about 250 knots and 350 horsepower), high speed/high power (turboprops greater than about 300 knots and 600 horsepower), and low-speed/high power (under about 100 knots and greater than 600 horsepower, as for advanced aerial applications aircraft). The program would be conducted largely through industry contracts and university grants, augmented by NASA in-house research and testing of contractor hardware in NASA facilities. Overall management of the program would be provided by the Lewis Research Center as lead Center, supported by the Langley Research Center for noise reduction and composite material technology.

The GAP program builds on precursor propeller aerodynamics, noise reduction and composite structural research conducted in NASA's R&T Base since the mid-1970's. Program planning is based in part on a recent industry contract study of research opportunities and cost-benefit tradeoffs for advanced general aviation propeller technology. It is anticipated that the GAP program would extend over a 5-year period and that program costs, based on 1981 dollars, would total approximately \$6 million. Program elements include both analysis and experiments and would proceed in logical steps or phases beginning with specific mission analysis and design criteria definition, to small scale model screening and evaluations for aerodynamics, acoustics and structural characteristics, followed by selected larger scale model performance and noise verification tests in ground facilities and wind tunnels. Flight test demonstrations are not included in GAP program plans at this time. Decisions on the desirability or need for flight tests would be made by the end of the program.

Mr. GOLDWATER. Thank you, gentlemen. I guess that is about all that we have.

Dr. OLSTAD. Thank you.

Mr. AIKEN. Yes, sir.

Mr. GOLDWATER. We would like to be able to submit to you some written questions.

Dr. OLSTAD. Yes.

Mr. GOLDWATER. Have you any problem with that?

Dr. OLSTAD. None at all.

Mr. GOLDWATER. Does anybody else have anything else to add? Is there anything we missed?

[No response.]

Mr. GOLDWATER. Does anybody want to raise any questions at this time?

[No response.]

Mr. GOLDWATER. The next subcommittee meeting will be tomorrow at 2 p.m. in room 2318.

Thank you, gentlemen.

Dr. OLSTAD. Thank you.

Mr. AIKEN. Thank you.

Mr. GOLDWATER. There being nothing further, the meeting stands adjourned.

[Whereupon at 4:15 p.m., the subcommittee adjourned, to reconvene at 2 p.m., the following day.]

[The prepared statement of Dr. Olstad follows:]

HOLD FOR RELEASE UNTIL
PRESENTED BY WITNESS
FEBRUARY 6, 1980

STATEMENT

of

Dr. Walter B. Olstad
Acting Associate Administrator for
Aeronautics and Space Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Transportation, Aviation
and Communications
Committee on Science and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

I appreciate the opportunity to appear before you today to present NASA's request for FY 1981 Aeronautics Research and Technology authorization and to review the proposed content of that program. It is a personal pleasure to testify for the first time in this capacity, and I look forward to a continuation of the excellent relationship with the Subcommittee enjoyed by my predecessors.

The FY 1981 budget proposal supports a primary concentration on strengthening the technology base in the disciplines which undergird all aeronautical systems development. The FY 1981 program also allows the Aircraft Energy Efficiency (ACEE) program to proceed toward its goal of reduced transport aircraft fuel consumption.

Two important enhancements requested in FY 1981 are in advanced rotorcraft and variable cycle engine technologies, both of which were augmented by the Congress in FY 1980. The rotorcraft enhancement is the initial step in a coordinated R&T plan designed to enable rotorcraft to achieve a major air transportation role with all the requisite characteristics of cost effectiveness, operational flexibility and passenger acceptance. The variable cycle engine enhancement maintains the U.S. pioneering effort toward a viable supersonic cruise propulsion system option, the key element in SST economics and environmental compatibility. Enhancements are also proposed in advanced turboprops and turbine engine hot section technology.

A major type of activity in the ongoing aeronautics program in FY 1981 will be the flight research conducted with the unique research aircraft which recently became operational: the Quiet Short-Haul Research Aircraft, the Tilt Rotor Research Aircraft, and the Highly Maneuverable Aircraft Technology remotely piloted research vehicle. Successful flight programs have continued since the time of the movie clips shown to the Subcommittee in October 1979. These programs will continue actively toward their goals of providing design data, airworthiness criteria data, and proof-of-concept documentation.

The FY 1981 Aeronautics R&T budget estimate necessary to support these activities, presented in Figure R-1, totals \$290.3 million. The reduction from the FY 1980 figure reverses the growth trend of recent years but is due to the planned fall off of several program requirements, primarily in the Aircraft Energy Efficiency (ACEE) program. The R&T Base funding is seen to increase by 10 percent. Note that Systems Technology Programs now include Systems Studies and Experimental Programs in our revised budget structure. Except for the reduction in funding for the ACEE program, as intended, efforts in this budget category are maintained at about the FY 1980 level.

Figure R-2 illustrates the relative funding allocations between the two major budget categories, on the left, and among the aeronautical applications upon which the technology is focused, on the right. Fundamental R&T, which is applicable to several or all vehicle classes, constitutes 37 percent of the total aeronautics budget. Fundamental R&T and each of the vehicle-oriented categories include both R&T Base and Systems Technology Program activity, being characterized by intended vehicle application instead of budget classification.

Figure R-3 displays the year-to-year funding trends for these application categories. Fundamental R&T is seen to increase in FY 1981 by 13 percent; Transport and Advanced Propulsion, which include ACEE, decline by about 25 percent each; and the allocations for General Aviation, Low-Speed and High-Speed Aircraft remain nearly constant from FY 1980 to FY 1981.

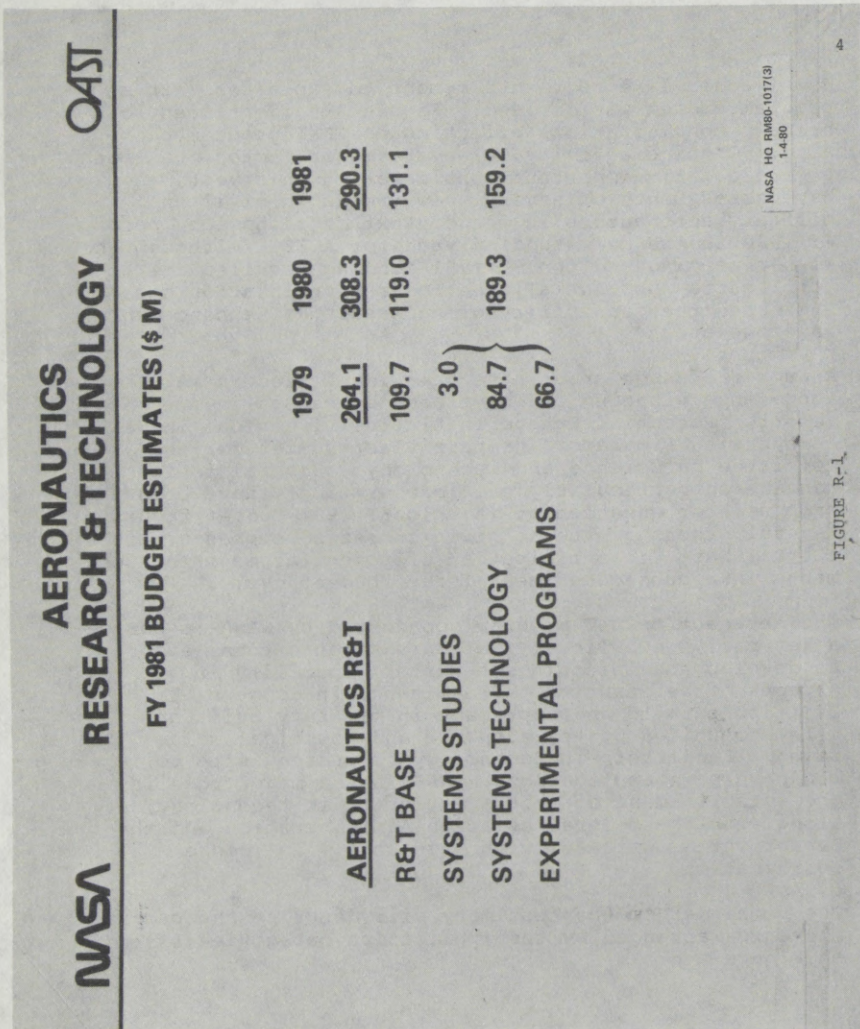
The ACEE program remains our largest single effort. After four years, the ACEE funding has peaked. More significantly, however, early results are already being reflected in new aircraft and engines now in development. Several are illustrated in Figure R-4, showing applications in major civil transports, turbine engines and military tanker aircraft.

Now I would like to take a moment to explain how this program budget was derived. Figure R-5 identifies four primary considerations affecting new R&T program planning. Ongoing activity, always a major factor, has been a particularly important consideration this year, as have assessments of several new trends in civil and military aeronautics in the context of technology needs. FY 1980 is the peak funding year for ACEE. Although the work remaining and the FY 1981 funding required are still quite substantial, the moderate relaxation has increased the feasibility of necessary R&T enhancement in other areas.

A number of such areas have been identified in NASA long-range planning and have been discussed in the report, "Potential Future Initiative Directions in NASA Aeronautics Programs," prepared last summer for the Committee on Science and Technology. Several topics considered particularly critical or timely have been proposed for enhancement in this FY 1981 budget request. Several others are being given increased emphasis within the R&T Base in anticipation of potential major enhancements in a subsequent near-future budget cycle.

The Aeronautics R&T program conducted by NASA is part -- a key part, we believe -- of our Nation's total effort to develop and maintain a superior capability in all aspects of aeronautics. Preeminence in commercial aviation markets and supremacy in military aviation are vital to United States economic and political well-being. Leadership in technology is prerequisite to leadership in applications. NASA has a major role in the establishment of that superiority in technology, along with the Federal Aviation Administration and the Department of Defense, with whom we are in close coordination.

The remainder of the testimony will describe the program elements arranged by the application categories listed on Figure R-6.



NASA

AERONAUTICS R&T - FY 1981

OASD

TOTAL R&D \$290.3M

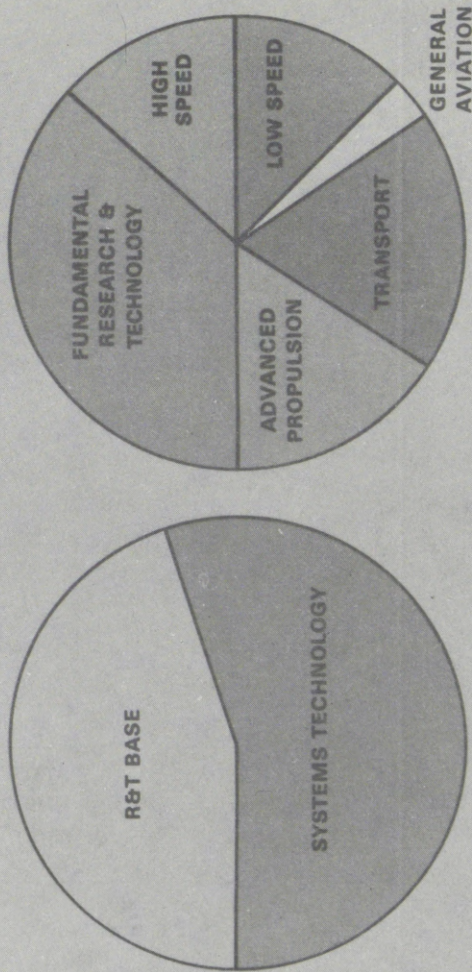
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FIGURE R-2

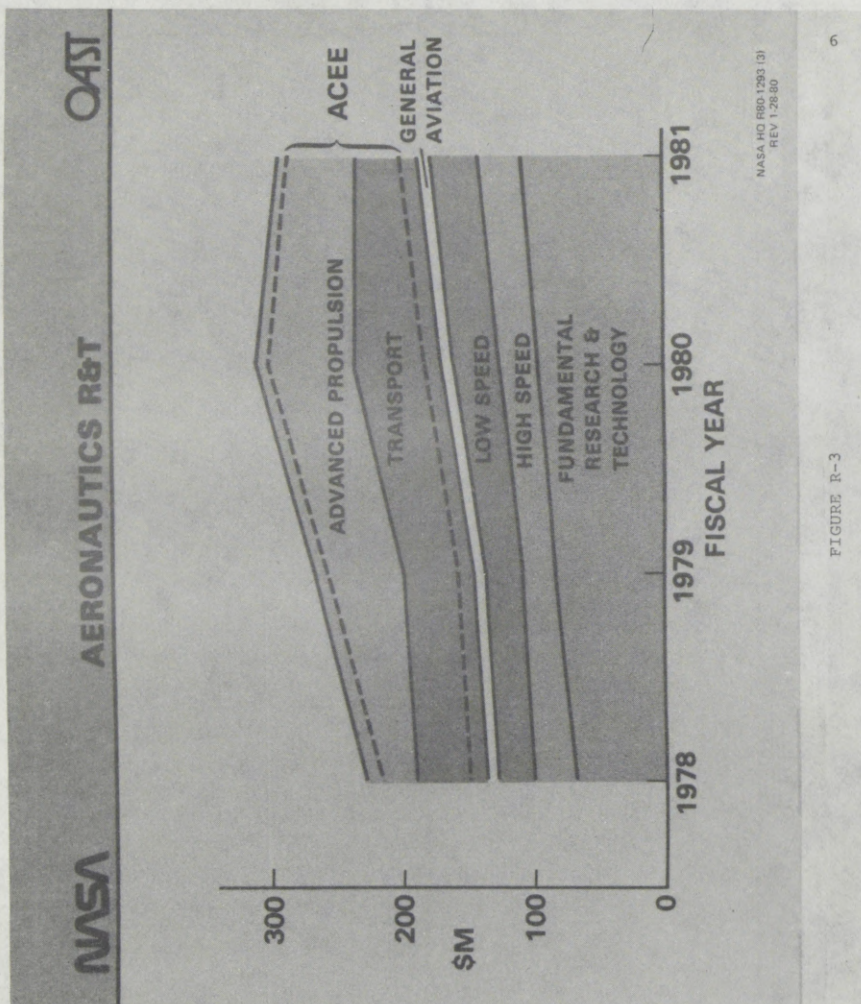


FIGURE R-3

ACEE Technology - Fuel Savings Examples

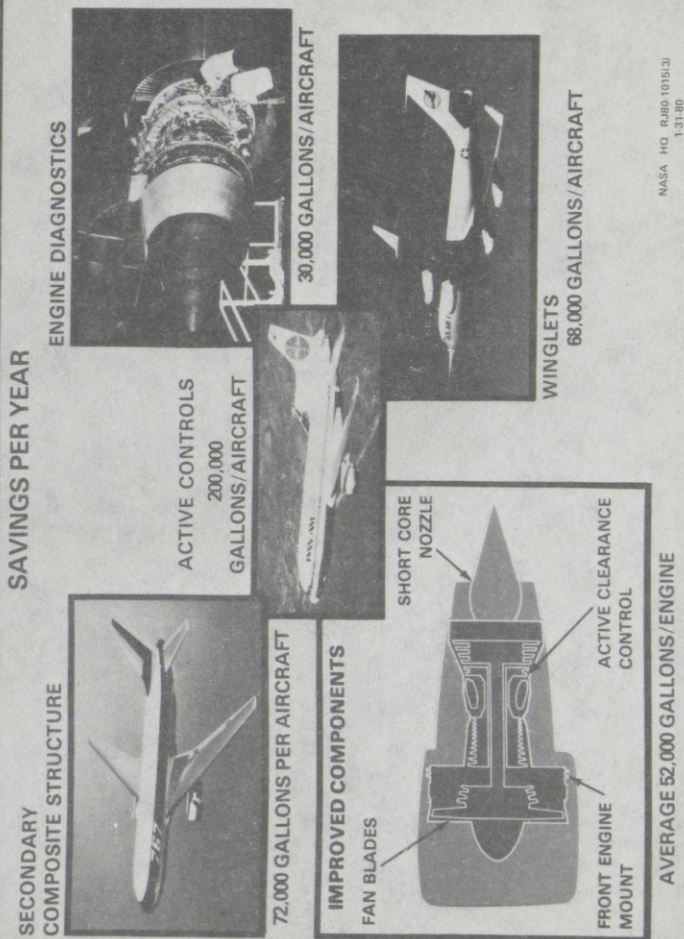


FIGURE R-4

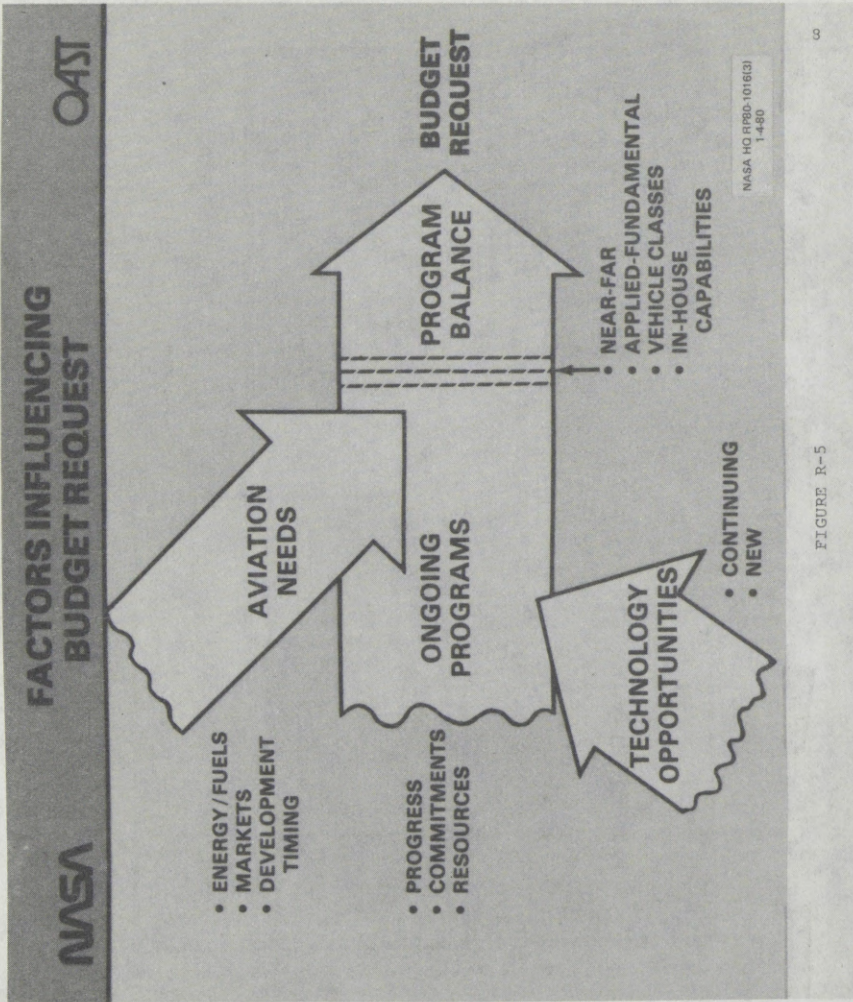


FIGURE R-5

NASA

AERONAUTICAL TECHNOLOGY

OAST

FUNDAMENTAL R&T

HIGH-SPEED AIRCRAFT

LOW-SPEED AIRCRAFT

GENERAL AVIATION

TRANSPORT AIRCRAFT

ADVANCED PROPULSION

NASA HQ RT90-1222(3)
1-17-80

FIGURE P-6

19

FUNDAMENTAL RESEARCH & TECHNOLOGY

Our Fundamental Research and Technology program includes a wide range of activities in aerodynamics, materials and structures, aeronautical propulsion, and avionics and human factors. These major disciplinary areas are illustrated in Figure R-7 with some recent research tasks. Before describing some of our planned activities, I want to emphasize the extent to which this element of our program depends on and utilizes the large pool of talent available in the country-- in NASA, industry, and the universities.

The scientific and technical personnel at the various NASA Centers constitute one important element of this pool. They are primary agents for the conduct of our research programs. Contracted programs complement in-house activities with the unique experiences of industry experts--a second element of the talent pool. The third element resides at universities and colleges in the collective body of professors and students. In addition to providing the nation with the scientists and engineers of the future, the academic community contributes to the research effort through grants and through special institutions, such as the National Research Council Research Associateships and others unique to NASA. I have selected an example of the latter, the Institute for Computer Applications in Science and Engineering (ICASE), to illustrate the functioning of these special institutions (Figure R-8).

ICASE was established in 1972 to involve university applied mathematicians and computer scientists in the research programs at the Langley Research Center. It is operated through a contract with the University Space Research Association, a consortium of 52 universities. The staff of twelve to twenty people includes leading university researchers, postdoctoral fellows, and term appointments of outstanding recent PhD graduates in applied mathematics.

Since 1972, there have been approximately 70 members of ICASE from 35 universities with appointments ranging from a few months to two or three years. As indicated in the figure, the primary research areas now being pursued at ICASE include numerical methods, applied computations, and STAR computer applications supporting research in fluid mechanics, structures, and acoustics. Although ICASE is structured around Langley interests, research on internal flow of direct interest to the Lewis Research Center has recently been initiated.



FIGURE R-7

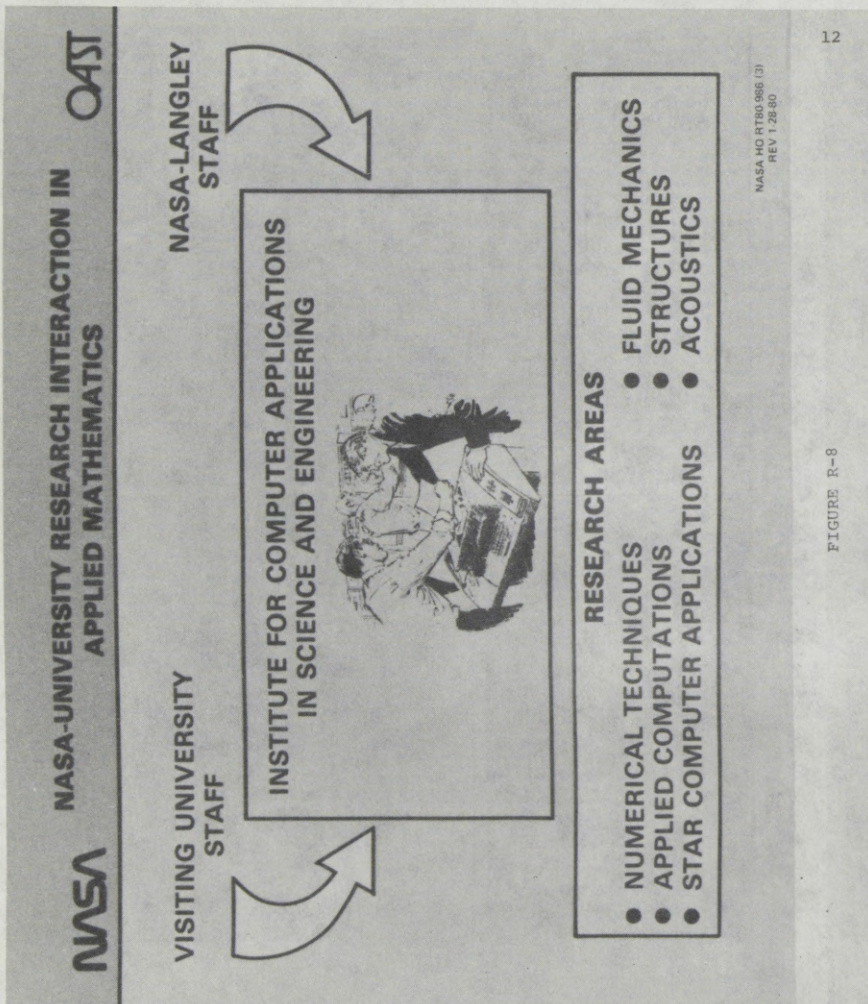


FIGURE R-8

Aerodynamics

Within the Fundamental R&T program, the objective of our aerodynamics research is the prediction and optimization of the aerodynamic characteristics of all aircraft types over their complete operating envelopes. Computational aerodynamics continues to receive major emphasis because of the demonstrated potential advantages of speed, economy and ease of use in exploring a wide range of configurations, performance and other aircraft parameters. As in the recent past, efforts will continue to extend the capability of computational methods to handle more complex three-dimensional aircraft configurations in the transonic viscous flow regime and to improve the computational efficiency of existing methods so that computer run times can be reduced with consequent cost savings.

New computational methods are being developed which are particularly well suited for operation on advanced large-capacity computers such as ILLIAC, STAR and CRAY. These computers are capable of performing many computations simultaneously ("vector" processing) in contrast to the more conventional and slower approaches involving a series of sequential scalar operations. These "vector" methods, when applied to aerodynamic flow at transonic speed around wing-body configurations such as the idealized model in Figure R-9, require two to ten times less computer cost than conventional procedures on serial computers. During FY 1981, additional refinements will be incorporated into existing "vector" codes, and conversions from serial to "vector" methods will be effected in current panel solutions for subsonic and supersonic flows, and in transonic supercritical airfoil design codes. Future applications of these "vector" methods will include large eddy simulation, entry aerodynamics, and transonic aerodynamic shape synthesis.

These computational advances are matched by similar advances in experimental flow measurements. During FY 1979, significant progress was achieved in the development of a non-intrusive infrared (IR) method for the detection of separated flow. As shown in Figure R-10, a fiberglass conical model immersed obliquely in a wind-tunnel stream at Mach numbers from 0.6 to 1.8 is surveyed through the circular window in the tunnel wall by an externally mounted infrared-sensitive imaging camera. The camera is coupled to a sophisticated oscilloscope to produce real time "TV-type" displays of the model surface temperature distribution, such as the thermal image shown in the lower left photograph. The positions of separated flow are readily detected as dark areas in the displays.

Compared to conventional oil flow approaches, this method is easier to use and, with the aid of the computer, can produce quantitative data. During FY 1981, the system will receive further validation using a 10-degree metallic cone model which has already been tested extensively in flight and in several wind tunnels.

Advances in computational and experimental techniques, such as those discussed above, enhance parallel research efforts on operational characteristics of efficient future aircraft. For example, NASA's continuing airfoil research program has the objective of providing more efficient airfoils for a wide range of applications. Figure R-11 shows three of the more promising current areas of airfoil research. Recent tests in the Langley Low-Turbulence Wind Tunnel have demonstrated that advanced, general aviation laminar flow airfoils have lift-to-drag ratios twice those of conventional airfoils. The general aviation industry is basing some of its new airplane designs on derivatives of these new NASA airfoils.

Efforts will also be continued to develop advanced rotorcraft airfoils. Recently, the drag divergence Mach number (Mach number beyond which drag increases substantially) at lifting conditions has been increased by as much as 14 percent relative to an airfoil in current use. This accomplishment provides for an increase in forward flight speed and payload capability. Opportunities exist for further improvements and future work will emphasize increasing maximum lift while retaining low drag characteristics.

Thick supercritical airfoils are being studied for possible application to future large spanloader cargo airplanes in which the payload is contained in the wings. These airfoils, illustrated at the bottom of the figure, are designed to cruise at a high Mach number with aerodynamic characteristics, such as low pitching moment, that are suitable for highly efficient, tailless airplanes. Of three spanloader airfoils being studied, wind-tunnel tests of the first confirm aerodynamic predictions. Construction and testing of the remaining two spanloader wind-tunnel airfoil models will be pursued in FY 1981.

Our research in hypersonic flight emphasizes structures, aerodynamics, and propulsion, and their integration. An essential goal of the program has been to define hypersonic aircraft configurations which have adequate range for a given payload. Aerodynamically, the lift-to-drag ratio (L/D) is the major factor in determining high-speed cruise range. Steady progress in aerodynamic configurations has been made in the last 10 years, resulting in more than 50 percent improvement in the maximum L/D for conventional hypersonic aircraft configurations, from near the lower limits to the upper limits of the range

shown in Figure R-12. Current research to increase L/D to our goal of 7 is based on the concept of interference lift. The idea is to develop configurations in which the high pressure field generated by the fuselage shock system is captured by the wing to generate additional lift. In FY 1981, two parametric models will be tested to determine the potential L/D improvements achievable with this concept.

In conjunction with the FAA, NASA has conducted research directed toward improving the air-traffic handling capability of our airports. One such program to minimize the wake vortex turbulence encountered by aircraft in the landing approach pattern has been given significant attention by NASA during the past few years. Recent flight tests on a B-747 aircraft, illustrated in Figure R-13, have indicated that the effectiveness of wing spoilers in alleviating wake turbulence can be enhanced by the simultaneous deployment of the ailerons. Jointly with the FAA, we plan to evaluate this concept on an L-1011 in 1980. In addition, a generalized wind-tunnel model is being used in our long-range research to minimize wake vortex effects of new aircraft.

The FY 1981 activity in the R&T Base will focus on developing a more fundamental understanding of how alleviation techniques produce their effects. This will be done through detailed review of available test data and analytical simulations of different alleviation configurations using existing analytical codes. Additional wind-tunnel tests and flight simulations will be conducted, as needed, to support this effort to develop procedures for establishing favorable new aircraft configurations.

NASA IMPROVED COMPUTATIONAL METHODS FOR AERODYNAMIC FLOW OAST

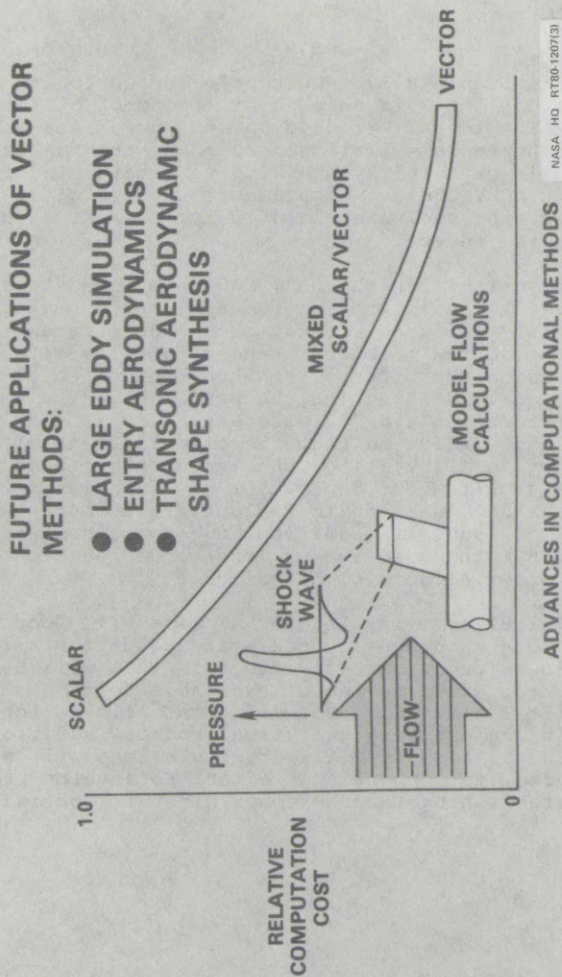
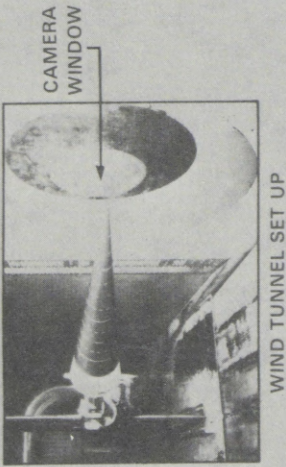


FIGURE R-9

INFRARED DETECTION OF SEPARATED FLOW

NASA

OAST



QUANTITATIVE
INTERPRETATION
OF THERMAL DATA

- VELOCITY
- PRESSURE
- DENSITY

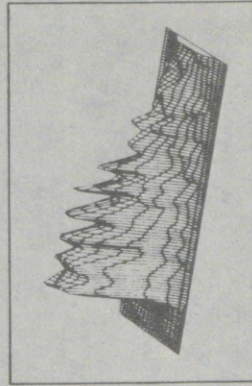
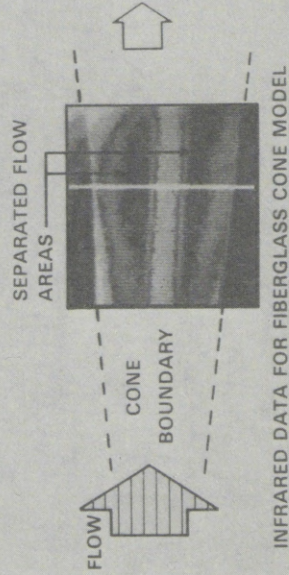


FIGURE R-10

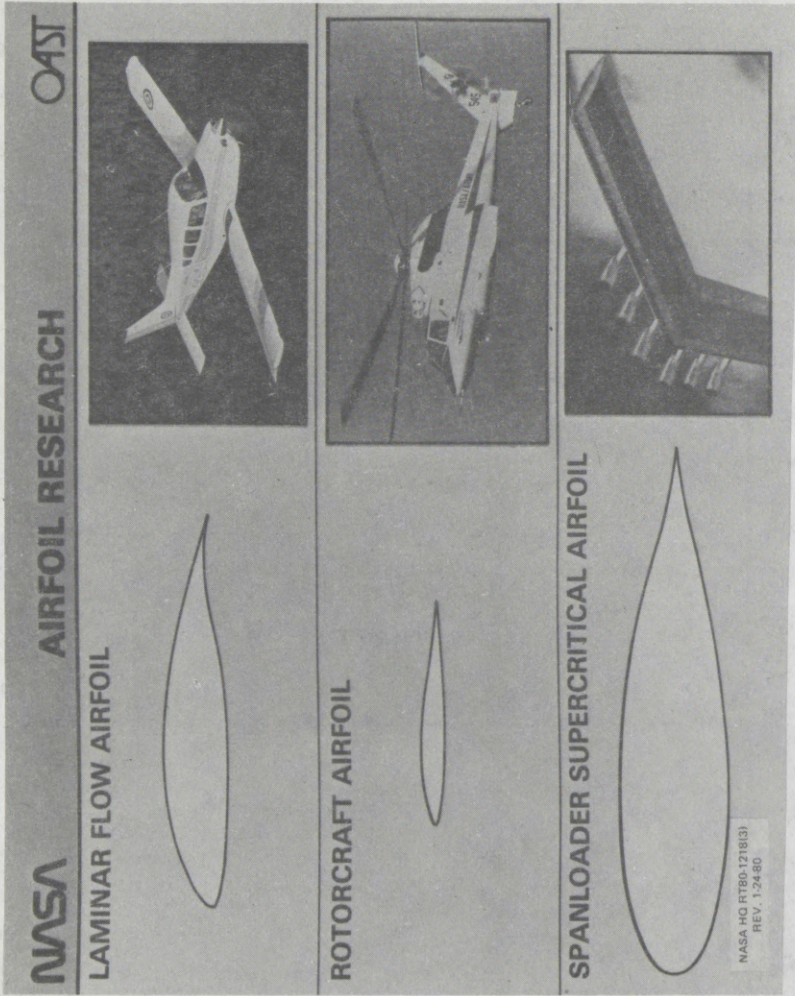
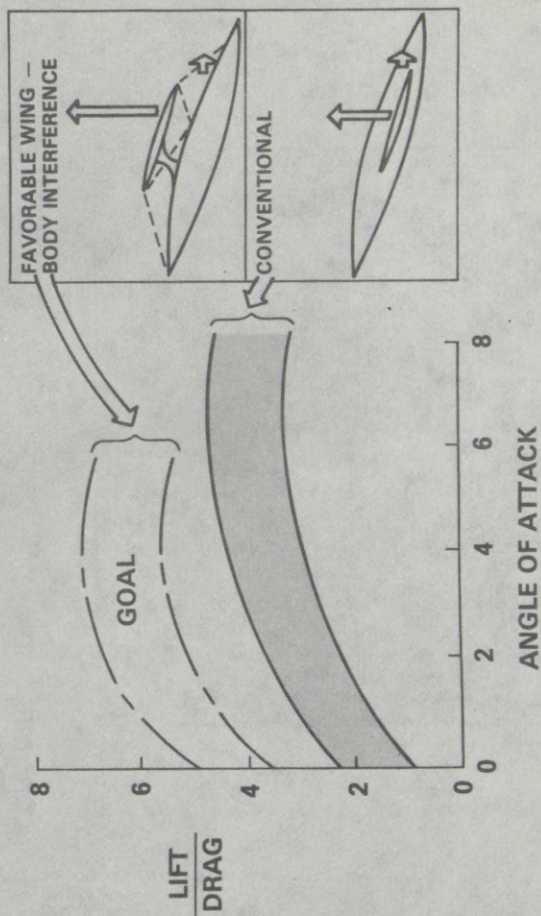


FIGURE P-11

HYPERSONIC CRUISE AERODYNAMICS

NASA

OAT



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REV. 1-22-80

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FIGURE R-12

NASA

WAKE VORTEX RESEARCH

OAST



FUTURE DIRECTION:

BASIC STUDIES OF MULTIPLE VORTEX INTERACTIONS

NASA HQ RT80-120313
REV 1-28-80

FIGURE R-13

20

Materials and Structures

Materials and structures research in FY 1981 will continue to emphasize advanced structural materials and concepts and develop advanced analytical methods and improved experimental techniques for future airframe and engine systems.

Recent research to increase performance, energy efficiency, and flight safety has given rise to the technologies of active and passive control of aeroelastic behavior of commercial and high performance military aircraft. These technologies all require accurate definition of the unsteady aerodynamic pressure distributions over airfoil surfaces. Our program in unsteady aerodynamics has, over the last decade, made significant contributions by developing analytical methods for subsonic and supersonic flows, and validating them experimentally in our unique wind-tunnel facilities.

Figure R-14 illustrates the current focus of our wind-tunnel test program on the complex unsteady flow phenomena at transonic speeds. The models shown and the testing sequence are designed to systematically increase complexity. During the coming year, we will initiate measurements of three-dimensional data for the rectangular wing to supplement the two-dimensional data obtained in previous years. The high aspect ratio supercritical wing model will provide data for evaluating the effects of sweep, taper, and control surfaces on three-dimensional pressure distributions. Future tests will focus on the effects of a wing-mounted engine nacelle and the pressure distributions associated with wing and horizontal tail combinations.

In future airframe design, the substitution of advanced composites for metals will be an important means of achieving significant weight reductions. Our fundamental composites technology program is aimed at a thorough understanding of behavior and at improved analysis methods. Figure R-15 depicts some of the major areas that will be addressed in FY 1981. The understanding, prediction, and detection by nondestructive evaluation (NDE) techniques of manufacturing flaws and in-service damage will be pursued to provide better analytical characterization of failure modes in composites.

The top chart of the figure illustrates our research on finite element structural analysis methods to predict both failure modes of composite laminates and damage propagation such as might occur during impact on aircraft panels by runway debris. The lower chart shows a computer-processed mapping of a damaged composite structure, using an ultrasonic imaging NDE technique. Emphasis is on establishing a numerical correlation between the

ultrasonic spectrum from an adhesive bond and its mechanical properties. This will permit the use of the method not only for damage detection, but also for quality control. Simultaneously with our efforts to understand and develop techniques for effective use of current composite materials, we intend to emphasize research on new resins and modifications of current epoxy materials to promote improved impact and fracture resistance and increased ease of processing. Resins will be made from three general polymer classes: one-phase thermosets that need no fillers, two-phase thermosets that contain a rubber or fiber toughener, and thermoplastics that are inherently tough polymers. Laminates will be made from these new resins and their properties correlated with those of the constituent resins and fibers.

In recent years, the finite element method has become the major structural analysis approach due to its versatility and its compatibility with modern computers. However, as vehicles have become more complex and mission requirements more demanding, the requirement for more detailed structural analyses has led to significant escalation in the cost and time for structural calculations. While developments in minicomputers and interactive graphics have provided short-term solutions for faster, lower-cost computer calculations, recent advances in microprocessor technology show even greater prospects for improved computational efficiency through special-purpose computers tailored to structural needs.

The research project illustrated in Figure R-16 is to demonstrate the feasibility of microprocessor applications to finite element calculations by developing a limited capacity Finite Element Machine (FEM). The equations governing the structural model are built into an array in which each low-cost microprocessor models the behavior at a node. Structural calculations are done in parallel rather than by conventional sequential computation approaches. Plans in FY 1981 are to complete the development of the prototype FEM and to apply it to the solution of several classes of structural problems to assess its potential.

The above topics illustrate our airframe structures research. I will now discuss some of the complementary efforts in turbine engine materials and structures research. Figure R-17 illustrates a current thrust in turbine blade erosion and corrosion research. The blade, shown in the upper right photograph, demonstrates the life-limiting effects of corrosion and erosion on vanes and blades. In the past we have investigated and developed an understanding of the separate effects of erosion and corrosion. Our current thrust is to determine their combined effect. The lower half of the figure illustrates a new facility which will combine a modified existing

burner rig with a small, single-stage, replaceable-blade turbine. This capability will permit the accurate simulation of combined erosion and corrosion mechanisms in a realistic turbine flow environment.

The high temperature and pressure environments of the engine "hot section", comprising the burner and high pressure turbines, are also responsible for material degradation and other problems which contribute to low component life and high maintenance costs. The top left chart of Figure R-18 shows qualitatively how the trend toward higher operating temperatures and pressures is expected to impact maintenance costs. The rest of the figure indicates the research areas we have been pursuing to promote longer life materials and reduce maintenance costs. In FY 1981, we will continue research on turbine blade materials which would last longer at higher temperatures. Two promising approaches are the application of tungsten fiber reinforced superalloys and oxide dispersion strengthened superalloys. We will also study the specific roles of strategic materials in superalloys. Alloying elements, such as cobalt, tantalum, columbium and chromium, are in short supply in the United States and their long-term availability from overseas sources is subject to change. An understanding of their roles will permit future research of new alloy compositions and processing techniques to reduce the use of these metals. In FY 1981, our effort will focus on identifying the role of cobalt. NASA's program on coating development will continue to explore the area of thermal barrier coatings to protect engine components from corrosive attack.

The use of advanced turbine engine materials will require better understanding of the structural behavior of the engine hot section and analytical methods for predicting this behavior. This challenging requirement will be the goal of the Hot Section Technology (HOST) program which we will augment in FY 1981. Figure R-19 illustrates some important aspects of this program. The top left chart represents "benchmark" component simulation tests and associated instrumentation developments which will be undertaken to establish a basis for the definition and analytical modeling of the hot section environment. The middle chart illustrates additional experimental tasks which will define the behavior and failure modes of constituent materials under different combinations of mechanical and thermal loadings. The lower chart signifies activities in structural modeling of the hot section components. These models will be integrated into total analytical simulations of the engine structure and provide a mechanism for eventually combining the various elements of the program into an advanced methodology for hot section component life prediction.

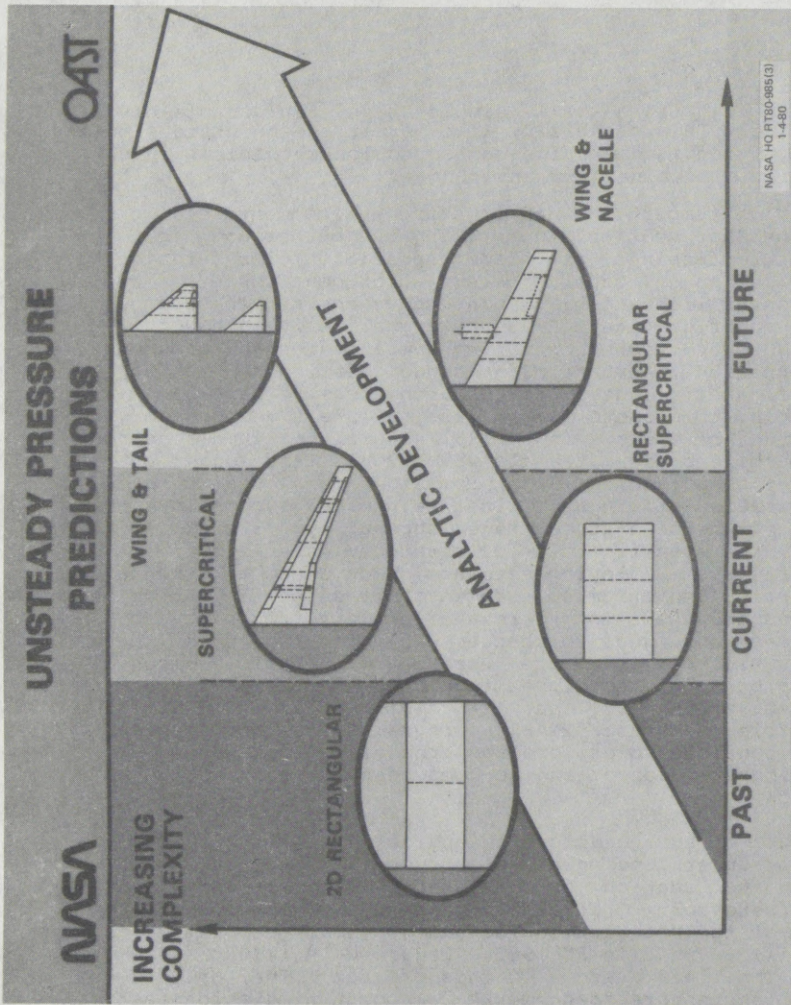
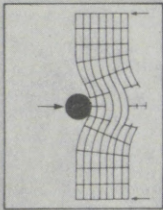


FIGURE R-14

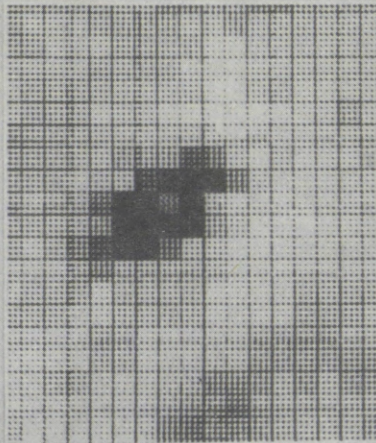
FY 1981 COMPOSITES PROGRAM

- **FAILURE PREDICTION**
- **NON-DESTRUCTIVE TEST METHODS**
- **QUALITY CONTROL METHODS**
- **DAMAGE TOLERANCE**
- **DURABILITY**
- **TOUGHER, MORE PROCESSIBLE RESINS**

IMPACT DAMAGE ANALYSIS



DAMAGE DETECTION

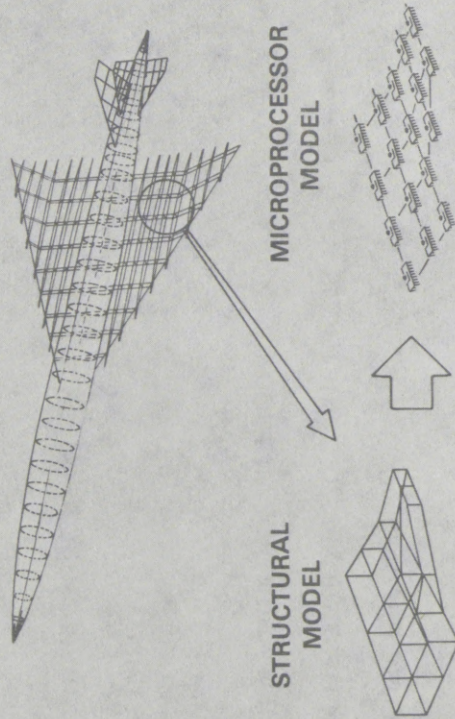


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FIGURE R-15

NASA **FINITE ELEMENT
STRUCTURAL ANALYSIS** **OST**

NEW CONCEPT FOR COMPUTATIONAL EFFICIENCY



NASA HQ RTD-580(3)
1-31-80

FIGURE R-16

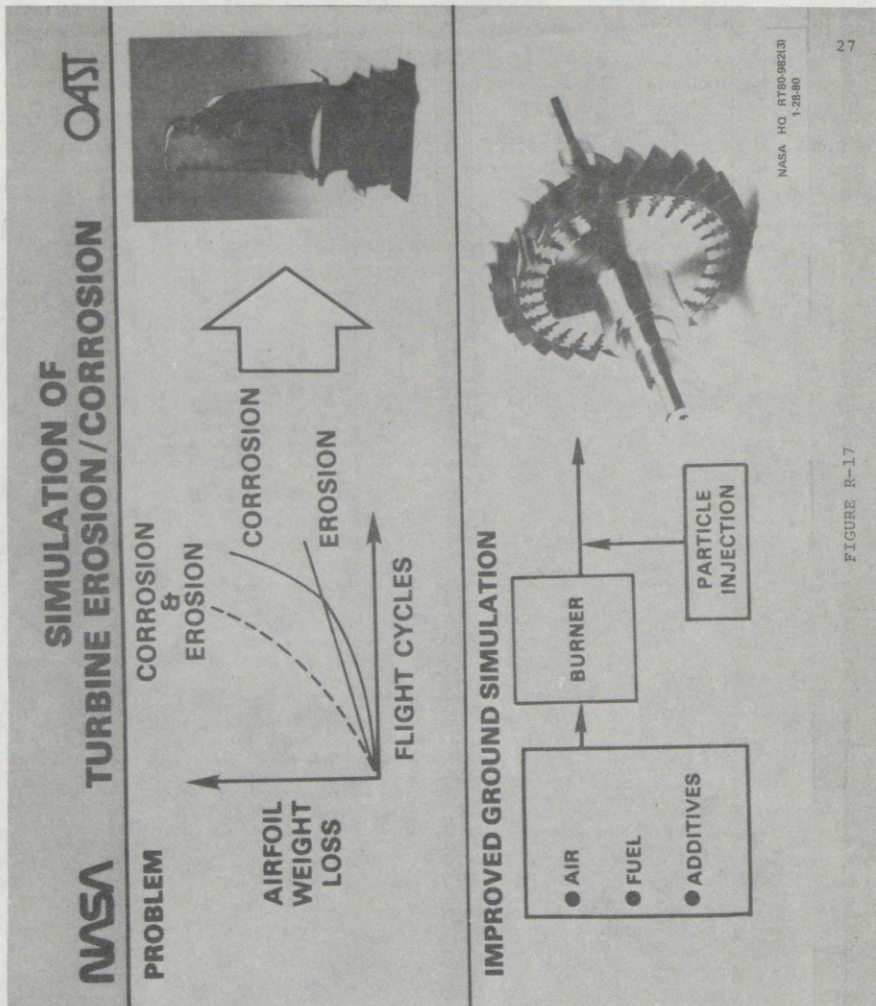


FIGURE R-17

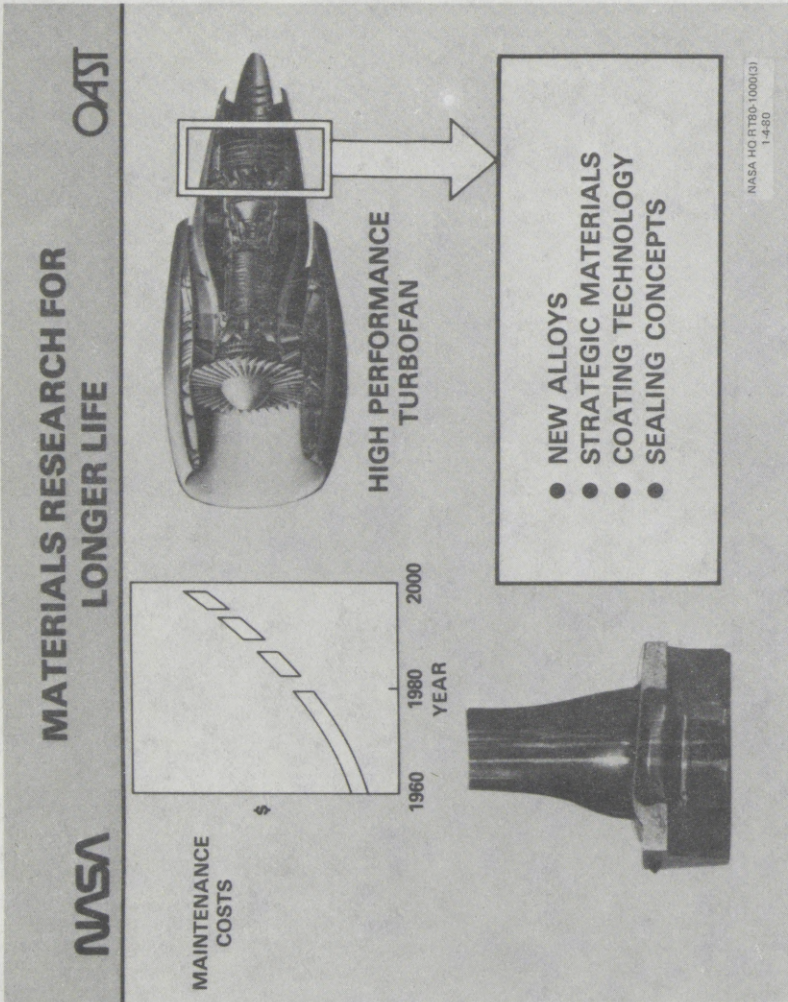
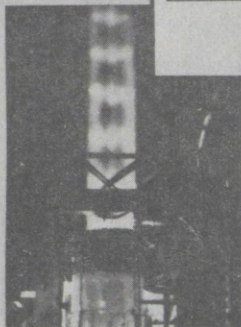


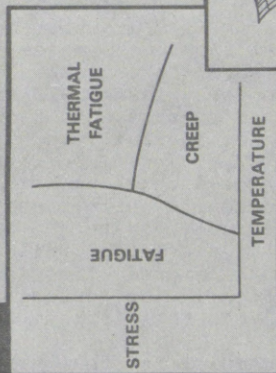
FIGURE R-18

NASA HOT SECTION TECHNOLOGY (HOST) OAST

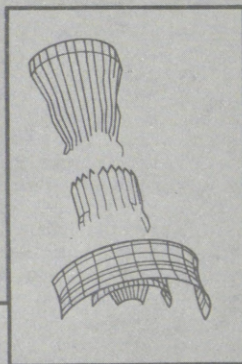
ENVIRONMENT SIMULATION



FAILURE MODES



STRUCTURAL MODELING



IMPROVED
LIFE PREDICTION METHODS
● INCREASED DURABILITY
● REDUCED MAINTENANCE COST

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1-17-80

FIGURE R-19

Propulsion

The aeronautical propulsion research and technology program is focused on improving the efficiency and safety and reducing the energy consumption, environmental impact and cost of propulsion systems for future aircraft. Fundamental studies will be conducted in FY 1981 to develop an improved understanding of the flow phenomena arising from the interaction of the propulsion system with the aircraft, including interference effects which may enhance performance efficiency, reduce drag and permit thrust reversing of the exhaust system.

Exhaust nozzle research will evaluate means of improving internal and external flow performance and to explore procedures for incorporating the exhaust system into the fuselage, wing, or pods. Figure R-20 shows a general wind-tunnel model used to study the flow phenomena associated with nozzle, boattail, and jet interactions. A major emphasis in FY 1981 will be theoretical studies, such as the first three-dimensional viscous code for predicting installed nozzle performance, to represent the complex flows associated with the aft end of the propulsion system. These efforts will contribute to technology needed for the prediction and minimization of propulsion system installation losses and for reducing adverse interaction with the airframe.

For predicting the complex internal flows in engine components, the FY 1981 program will place increasing emphasis on computational fluid mechanics research. Some aspects of this effort are shown in Figure R-21. The inviscid flow solution over a single blade in a cascade is shown in the upper left portion of the figure. It illustrates the FY 1981 effort in the development of two-dimensional analyses for non-viscous flow in axial and mixed-flow compressor and turbine-blade rows. New finite element and finite difference computational grids, such as the mesh geometry used for an inlet analysis illustrated in the bottom left portion of the figure, will be developed to improve computational speed and accuracy.

Analysis methods will be developed which permit the entire flow field in an annular duct and nozzle to be treated with a single set of viscous equations. Streamlines and velocity profiles within a transition duct are shown in the upper-right portion of the figure and in a mixer nozzle in the lower-right portion of the figure. The methods also address the mixing of the core stream with the fan stream and the viscous losses incurred in the mixing process.

Our studies of ways to improve the efficiency of small components used in jet engines for helicopters, general aviation aircraft, and missiles are continuing. As reported previously and indicated in the chart at the top right of Figure R-22, component efficiency of small engines using current technology is low because of problems inherent in their smaller size. Some examples are high viscous losses in small flow channels, and larger relative clearances that result in greater gas path flow leakage. To lessen these effects, 3-D viscous flow models are being developed to aid in the definition of better blade and passage designs, closer clearances, and variable area elements, such as nozzles and diffusers. It can be anticipated that overall system efficiency will be improved by going to higher temperatures and pressures; however, improved materials and cooling techniques will be required. As an example of the small component research efforts, a cooled radial inflow turbine concept is depicted in the lower chart with the major areas of emphasis noted.

Engine noise reduction is a major goal in our research program. We will continue studies to establish and validate procedures for engine noise reduction both at its source (fan, compressor and turbine, jet rotor/propeller, combustor) and in the engine duct through which it is transmitted. Since most research testing is done on ground test stands (static tests), it is important that ground test conditions accurately simulate those in flight. As reported in the past, we have underway a program to develop methods for accurate ground simulation of fly-over fan noise. Screens are installed in front of the fan and inlet boundary layer control devices, as shown on the right of Figure R-23, to modify ingested turbulence. A number of screens will be tested in FY 1981 on the JT15D engine, which is equipped with sophisticated instrumentation to measure the turbulence and noise output. As indicated in the figure, wind-tunnel and flight tests will also be conducted with the same engine to permit systematic evaluations of the static tests. Static tests with screens on the Quiet Clean General Aviation Turbine (QCGAT) engine will also be conducted to determine the degree of variability of the results from engine to engine.

Research on future aviation fuels is another timely area of NASA activity. As high quality crude feedstocks are depleted, we must turn to the higher-boiling range, heavier crudes typical of Alaskan oil and to syncrudes derived from oil shale and coal. Maintaining fuel specifications at today's Jet-A standards with these poorer quality feedstocks would require special costly processing and consume large amounts of refinery energy. An alternative is to develop engine and fuel system technologies to accommodate wider variations in fuel properties, such

as higher boiling and freezing points, lower heating value, higher aromatic content, reduced thermal stability, and increased fuel-bound nitrogen so that fuel specifications can be relaxed.

Conventional combustors and aircraft fuel systems operating on fuels with these properties would experience a number of problems, some of which are illustrated in Figure R-24. The higher fuel freeze-point would make most long-distance flights impossible without special fuel-tank heating. Gumming and carbon deposition caused by reduced thermal stability would clog passages in the fuel nozzles and result in poor fuel atomization and hot streaking. The larger content of aromatic compounds tends to produce a luminous flame which increases radiation and overheating of the combustor liner walls and promotes soot formation resulting in increased smoke emissions. Larger quantities of fuel-bound nitrogen would increase nitric oxide (NO_x) emissions at all operating conditions.

The principal thrusts of a comprehensive program to provide the capability of using alternative hydrocarbon fuels are noted in the figure. These include: fuel characterization and definition of the range of potential fuel property variations; definition and evaluation of advanced component concepts; tradeoff studies of fuel property variations, as compared to aircraft and engine technologies; evaluation of the effects of fuel property variations on current systems; and research on advanced engine and aircraft fuel systems. In FY 1981, our research will continue to develop a data base on fuel characteristics and to define the range of potential properties that can be accommodated in future aircraft engines. Efforts will continue to define and evaluate potential concepts for combustor and fuel systems to utilize these fuels. Tradeoff studies will be conducted to compare the effects of changing fuel properties on refinery operations and fuel availability with the costs of engine and aircraft fuel system technologies needed to utilize these fuels. These studies, which will be initiated in FY 1980, will provide direction for additional future research efforts which are required to assure successful utilization of broadened-property jet fuels.

The prospects for increased digital control of the propulsion system have been greatly enhanced by advances in microprocessor computer technology which have facilitated the packaging of highly sophisticated computational power into very limited spaces. One of our engine research efforts focuses on microprocessor real-time simulation of the engine at the individual component level, as indicated on the left top chart of Figure R-25. In the past, such a simulation would have required sophisticated computer

hardware which would be prohibitively expensive and massive. Microprocessors make it feasible to package this simulation in one small corner of a typical digital electronic control circuit board, as indicated in the figure. This simulation could improve the reliability of electronic control systems by an order of magnitude. The engine simulator would operate on the same control inputs as the engine control and would predict resultant engine operating conditions. In cases where the predicted and measured values of an important signal differ significantly, the control system would automatically reconfigure to operate without the erroneous sensor inputs. The simulator could also operate as an engine condition monitor by comparing actual engine conditions to predicted values to assess overall health and performance of engine components. Fabrication and test verification of a breadboard prototype of a microprocessor-based engine simulator will be conducted in FY 1981.

PROPULSION/AIRFRAME FLOW FIELD INTERACTION

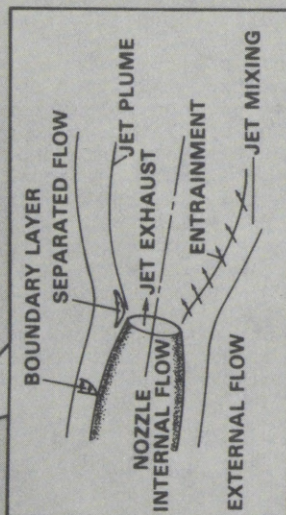
NASA

OAST

WIND TUNNEL
MODEL



AFT END
FLOW ANALYSIS



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FIGURE R-20

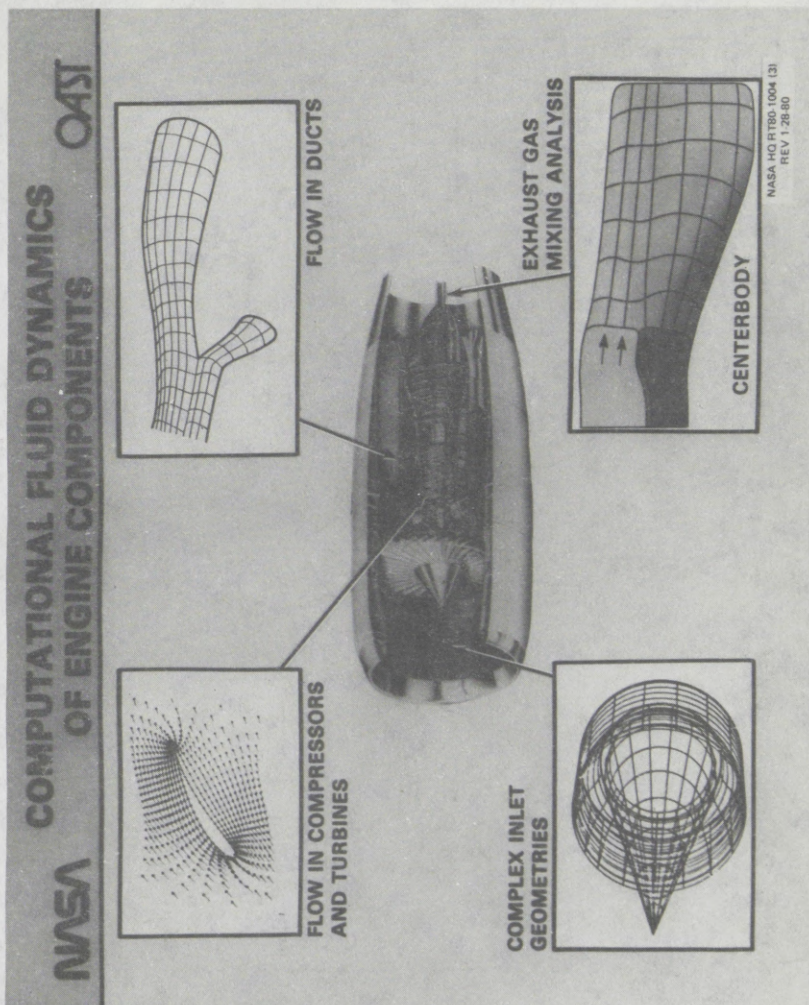


FIGURE R-21

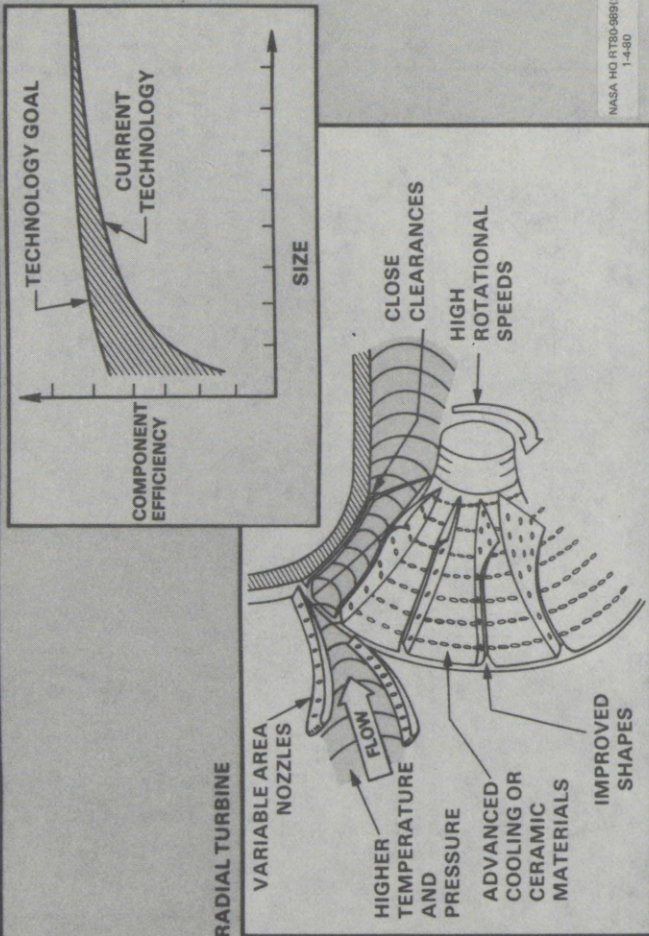


FIGURE R-22

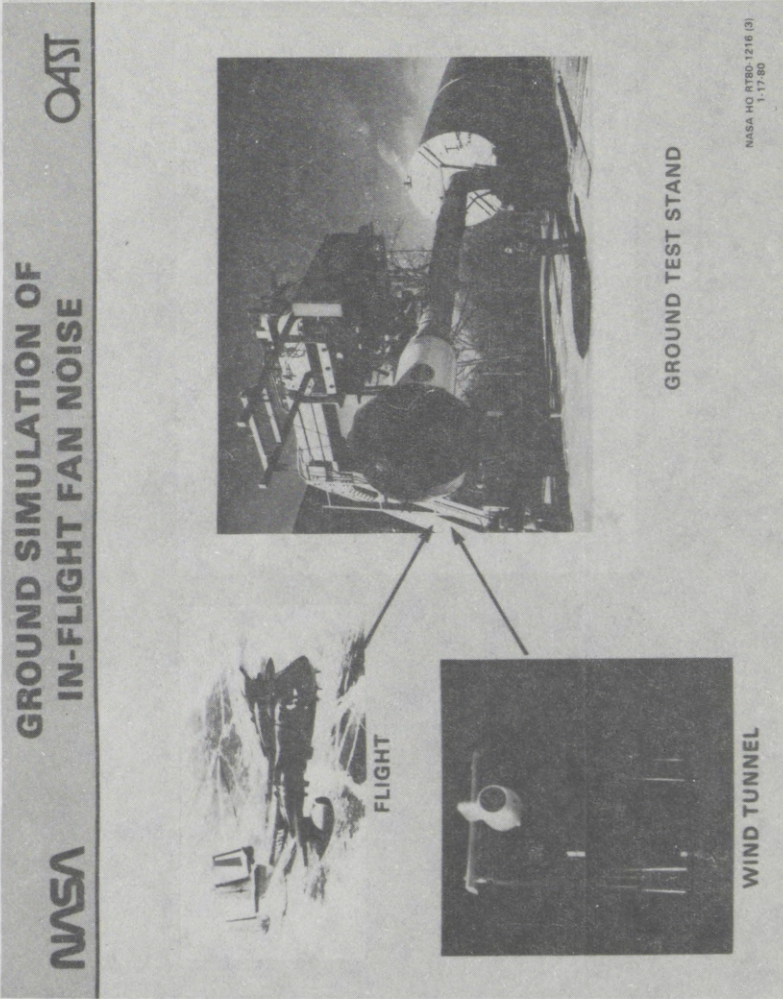


FIGURE R-23

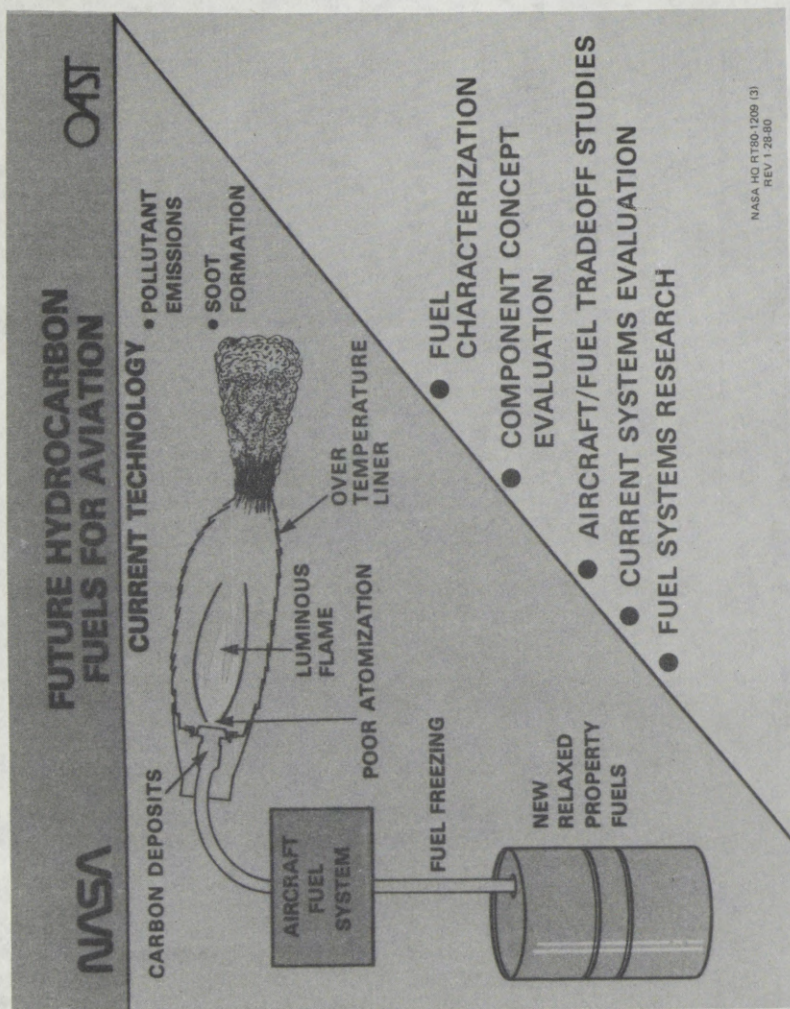


FIGURE R-24

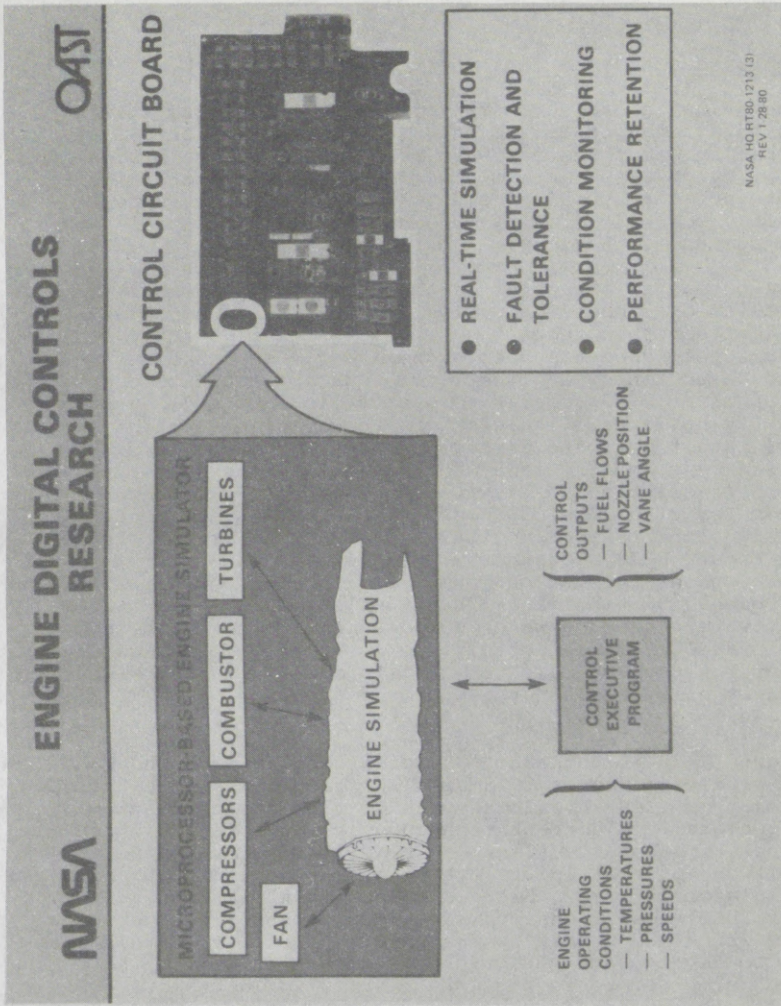


FIGURE R-25

Avionics and Human Factors

The avionics and human factors research program is aimed at promoting greater safety, increased aviation system capacity, improved hardware reliability and maintainability at affordable costs, and improved aircraft performance through advancements in flight controls technology, cockpit display and instrumentation, and flight management technology.

The potential impact of advances in microprocessor electronics on propulsion system controls has a corollary in flight controls technology where system redundancy for fault tolerance has been significantly impacted by microelectronics applications. Current fault tolerant systems provide schemes to detect, isolate and "by-pass" faulty hardware. There exists, however, the potential for latent software errors in the flight computers which would be common to each of the redundant channels. A current solution to the problem is to use a back-up computer with dissimilar software; for instance, an analog back-up to a digital system. This is illustrated in Figure R-26, together with a new concept under development in our program. It is based on the principle of embedding dissimilar "back-up" software in the primary software structure which would be activated in the event of a failure. The dotted line in the figure indicates that the back-up computer and its dissimilar software can be eliminated in the proposed approach. In FY 1981, the new concept will be evaluated in flight.

Figure R-27 illustrates our joint program with the FAA to provide advances in digital control systems certification processes through the use of advanced simulation techniques. A current technique is illustrated in the upper right of the figure. The flight hardware and software of the digital system are connected to an advanced simulator facility which is then "flown" through "all possible" conditions and maneuvers in the flight envelope for which the system is designed. The effort in this area is to develop and automate procedures for conducting such simulations so that the results would be more reliable and errors would be detected early. The increased simulation reliability would lessen the need for extensive follow-on flight evaluation and result in significant verification cost reductions.

Other aspects of simulation research for FY 1981 are indicated in Figure R-28. The left illustration, showing a typical air traffic control facility and one of our simulators, depicts research on simultaneous full mission aircraft operation simulations using full crews in high fidelity terminal area scenarios. It involves the integration of a number of aircraft simulators of various types with simulated air traffic control. The capability

will be used to study aircraft operations in future terminal area environments as part of the flight management research effort.

The reduced visibility effects research program, shown in the middle of the figure, involves the identification of cues used in flight and of the effects of degraded visual conditions, such as fog, on a pilot's ability to respond to those cues. Alternative methods of generating degraded visual scenes in aircraft simulators which are now being developed will be evaluated. On the right of the figure are shown some results of an experimental comparison of an approach/landing maneuver as performed in a simulator and in an aircraft, as an example of the methods being studied for flight simulation validation.

Simulation plays a key role in two research programs which are being conducted in coordination with the FAA: CDTI (Cockpit Display of Traffic Information) and HUD (Head-Up Display). NASA's overall CDTI program is designed to investigate the advantages and disadvantages of the CDTI concept in the context of the 1985-1995 air traffic environment. The interactive process of designing, evaluating and refining candidate displays is well underway. In the coming year, candidate procedures will be developed which maximize the potential advantages of the displays. Systems performance measures will also be developed with which the candidate displays and procedures can be evaluated. Research efforts in FY 1981 will focus on workload measurement methodology, airborne systems integration, and ATC system concept definition.

Although Head-Up Displays have been in use for some time by the military and by some foreign airlines, little systematic exploration of their advantages and disadvantages with respect to civil transport operations had been undertaken prior to NASA's current efforts. The fundamental issues being addressed are: can the pilot switch his attention back and forth between the display and the outside scene rapidly enough to land safely? Does the addition of the HUD scene place too great a workload on the pilot? Does the HUD distract the pilot's attention from important aspects of the outside scene? NASA has already developed and evaluated alternative HUD displays in the laboratory and in partial simulation tests. A full mission simulation evaluation will be completed in FY 1980. Should the findings of this evaluation warrant it, further investigations will be conducted in FY 1981, primarily in the areas of very low visibility approaches and the use of HUD's in conjunction with automated landing systems.

Research on community response to aircraft noise is illustrated in Figure R-29. The goal of the research is the development of analytical models for assessing the probable response of a neighboring community to airport noise. We are developing a modeling capability for predicting the annoyance of individuals to different combinations of noise levels and exposure rates. This is illustrated by the equal annoyance contour plots shown in the left chart. We have developed an airport noise footprint modeling capability as illustrated in the right chart. A method of modeling the population distribution within the community is being developed. These models will be integrated into an overall model for community noise impact assessment.

NASA is continuing the Aviation Safety Reporting System (ASRS) and its associated research. To date, the ASRS has cataloged over 21,000 reports and 650 Alert Bulletins have been issued since the program's inception. In June 1979, the FAA modified the waiver of disciplinary action provisions of the ASRS. Initial indications show significant changes in the demography of the reports, such as an increase in the proportion of reports coming from air traffic controllers. NASA plans to continue to operate and evaluate ASRS through September 1981. We are now developing recommendations as to whether the ASRS should continue beyond that point, and if so, what NASA's role should be. These plans are consistent with the recommendations of the ASRS Advisory Subcommittee.

In this discussion of our Fundamental Research and Technology programs, emphasis has been given to research on basic understanding of phenomena and the development of analytical and experimental methods to provide a strong, advanced technology basis for future aeronautical systems and to support our focused vehicle systems studies. The vehicle and systems technology activities will be discussed next.

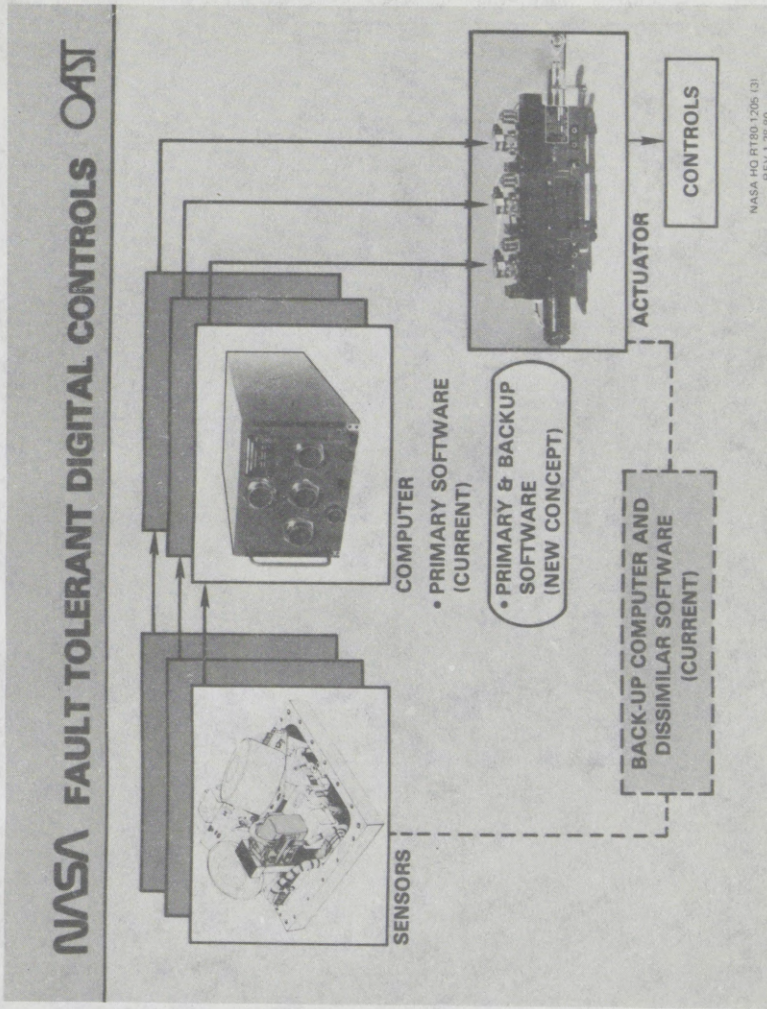


FIGURE R-26

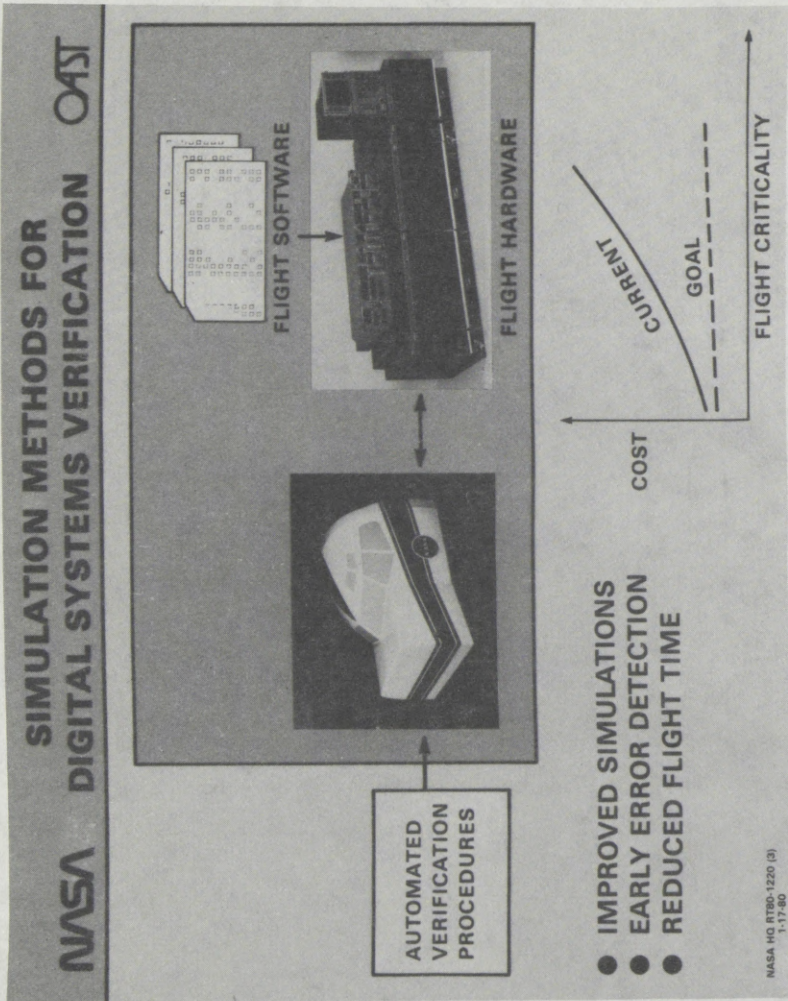


FIGURE R-27

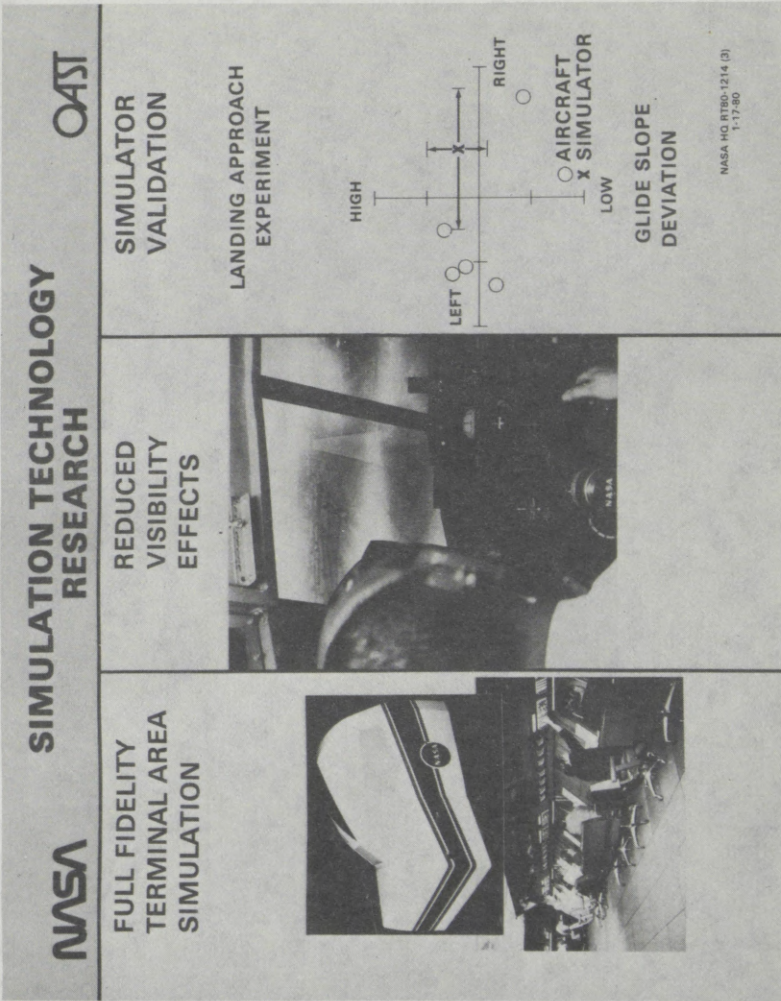


FIGURE R-28

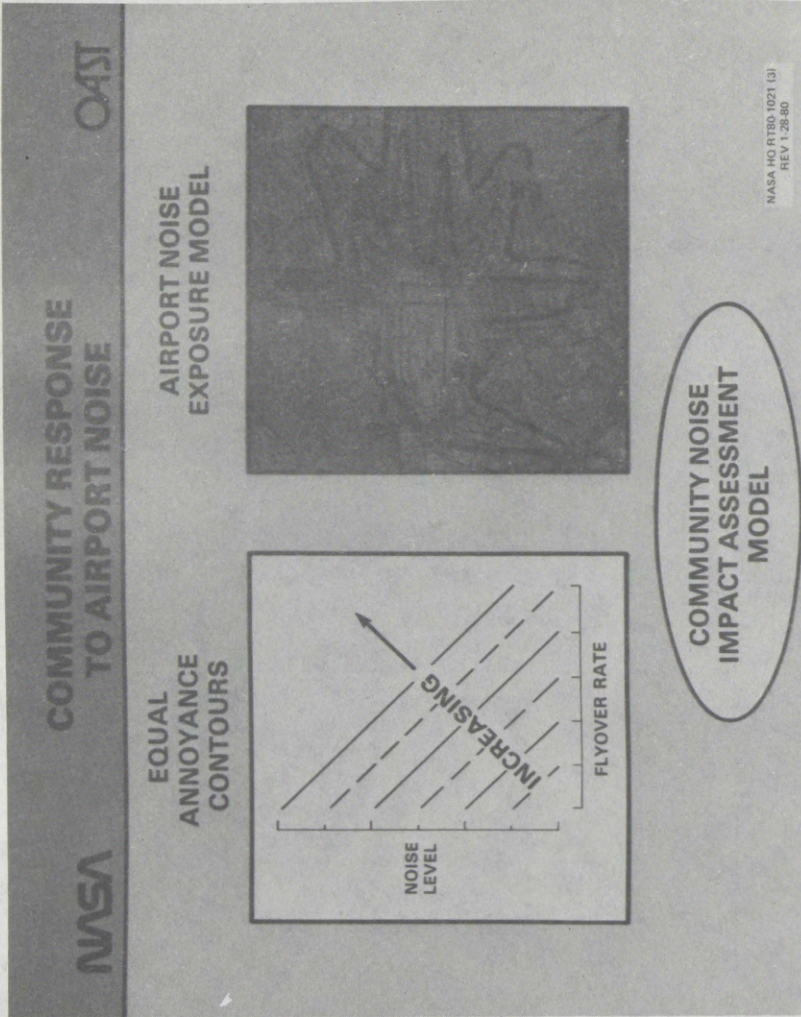


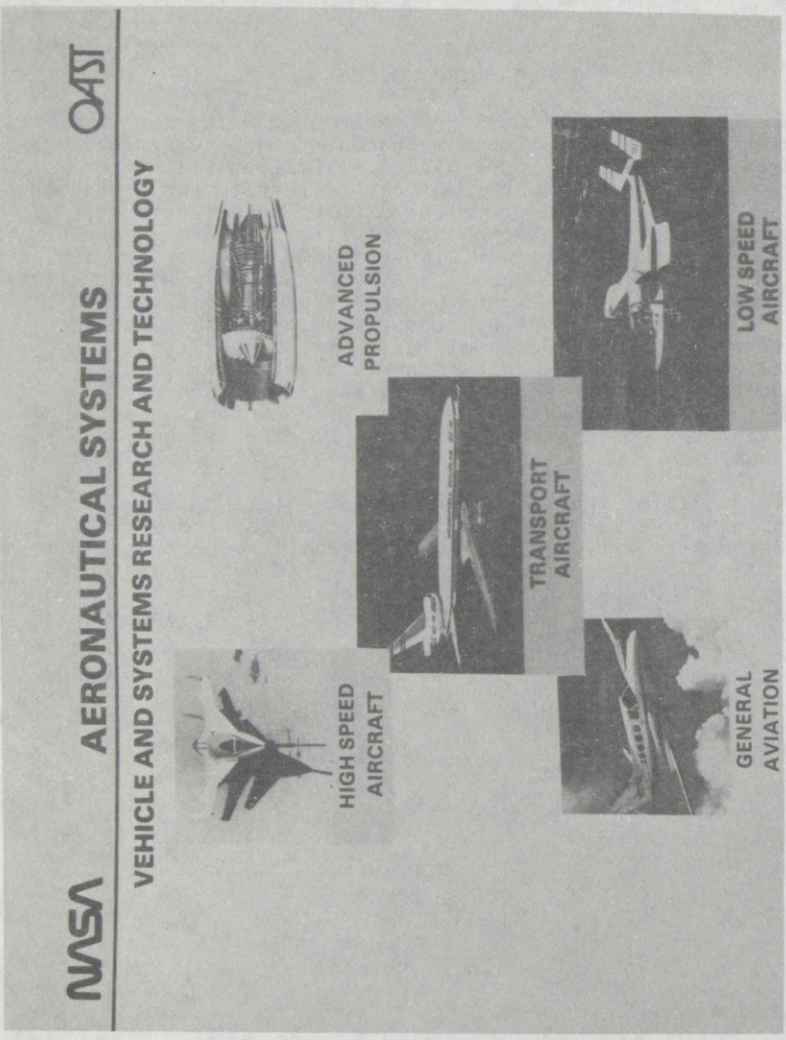
FIGURE R-29

VEHICLE TECHNOLOGY

Vehicle and systems technology research is being directed at the broad range of problems that are characteristic of particular aircraft configurations, flight regimes or mission requirements. These efforts integrate the advanced concepts and techniques from the discipline oriented research into focused technology efforts for each of the vehicle categories shown in Figure R-30.

Identification of the technology needs and opportunities to be addressed in these programs is accomplished with the aid of a continuing series of system studies and analyses, as well as constant coordination with the aeronautical community including industry, airline, and military planners. These studies also serve as a mechanism for assessing the costs and benefits of projected technology advances.

The remainder of the Vehicle Technology section is organized by vehicle application--High-Speed Aircraft, Low-Speed Aircraft, General Aviation and Transport Aircraft--plus a separate section on Advanced Propulsion Systems Technology, which includes the propulsion elements of the Aircraft Energy Efficiency (ACEE) and Variable Cycle Engine (VCE) technology programs.



NASA

AERONAUTICAL SYSTEMS

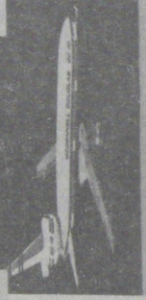
VEHICLE AND SYSTEMS RESEARCH AND TECHNOLOGY



HIGH SPEED
AIRCRAFT



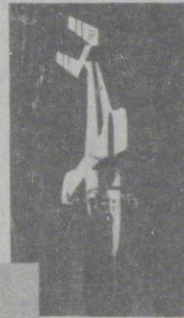
ADVANCED
PROPULSION



TRANSPORT
AIRCRAFT



GENERAL
AVIATION



LOW SPEED
AIRCRAFT

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FIGURE R-30

High-Speed Aircraft

The high-speed aircraft areas address high-performance military vehicles and supersonic cruise civil aircraft. In FY 1981, analyses, wind-tunnel tests, simulations and flight tests will be performed to advance the important technologies applicable to these aircraft. Many of the activities will take place as joint programs with the military services, and will use the unique facilities and technical expertise developed by NASA. The research and technology effort includes exploration of new aerodynamic configurations and advanced control concepts broadly applicable to high-speed aircraft, while the systems technology activities concentrate on specific applications. Within the high-speed aircraft area, there are four major program elements: Aerodynamics and Flight Dynamics; Supersonic Cruise Research; Advanced Flight Experiments; Highly Maneuverable Aircraft Technology.

Aerodynamics and Flight Dynamics: The ongoing efforts in the high-speed aircraft R&T program include research on flight dynamics and aerodynamics for combat vehicles and missiles as well as support to the Department of Defense and other government agencies. In FY 1981, the flight dynamics effort will continue to emphasize the important stall/spin area and will concentrate on development of technology for the design of spin resistant high performance military aircraft. Two aspects of this technology are important and interactive--aerodynamic configuration features which affect the aircraft's stability and control characteristics at high angles of attack, and flight control system features which can automatically sense departures from controlled flight and supply stabilizing control inputs. Both of these aspects will be investigated as part of the effort to achieve the goal of spin resistance. In this research, experimental tests will utilize free-flight scaled models which incorporate the response features of automatic flight control systems, some tested in wind tunnels and others dropped from helicopters. Close coordination will be maintained with the military services to correlate the results of full-scale aircraft stall/spin flight tests with the predictions based on scaled model wind-tunnel and drop tests.

In both the aerodynamics and flight dynamics work, new configurations which offer potential benefits over a wide speed range will be investigated, such as those shown in Figure R-31. There has been renewed interest in swept forward wing technology because of the possibility of using composite structures to prevent the unfavorable aeroelastic response exhibited by conventional materials. In the NASA wind-tunnel test program on swept-forward wing technology, we are also testing swept-back wings with the same aerodynamic parameters so that direct

comparisons can be made to assess the benefits of forward sweep. We will also continue tests of advanced aerodynamically integrated configurations such as the canard two-dimensional nozzle model shown in Figure R-31. Two-dimensional nozzles with thrust vectoring/reversing capability show potential for reducing drag at subsonic and supersonic cruise conditions, increasing instantaneous maneuverability and agility, and reducing runway length requirements. For effective utilization on high-performance aircraft, they must be integrated in the overall aircraft design. In FY 1981, we will investigate some of the integration factors as they relate to aerodynamic performance, stability and control throughout the operational speed range.

Supersonic Cruise Research: The Supersonic Cruise Research (SCR) program continues to make steady progress in the delineation of the technologies that are necessary in any future civil or military aircraft designed for efficient and sustained supersonic cruise operations. These technologies and the significant advancement made in this program were presented and discussed in a major three and a half day conference held at the NASA/Langley Research Center last November. Some forty-three papers by NASA, industry, the Office of Technology Assessment and the British Aerospace Corporation provided the invited audience of almost 275 with a "picture" of the state of these technologies and the potential for the design and marketability of this class of aircraft. Further progress in this program and the companion efforts in VCE technology were recognized to be critically dependent upon continued funding support sustained at or higher than the current levels.

Efforts in FY 1981 will continue in each of the critical technologies. A significant effort will be directed to the design and construction of a new set of highly refined, complex and sophisticated wind-tunnel models. Preliminary design work is now underway on a new low-speed model. If all of the important features can be incorporated in this model, we will move into final model design and award a contract for fabrication in FY 1981.

In addition, we are now beginning the layout of a new high-speed wind-tunnel model. This model will incorporate the features of the axisymmetric, variable area inlet types (bicone and translating centerbody) now under study in the program. These inlet types, along with the podded nacelles necessary for installation of variable-cycle engines, significantly influence the drag characteristics in the transonic-low supersonic speed range. Construction of this model will also begin in FY 1981.

The NASA inhouse program on advanced supersonic wing planforms will be augmented through construction and wind-tunnel testing of a new curved leading edge. This technology on low drag, curved leading edges has evolved through extensive analysis of existing supersonic wind-tunnel data. Experimental verification will be accomplished by testing a series of wings and wing/body configurations, systematically verifying the analysis over the supersonic speed range. Construction of most of these test articles will be accomplished in FY 1981.

The materials and structures area of the program continues to be an area where extensive improvements in the technology are paying off in reduced aircraft weight with significant reductions in aircraft construction costs. This class of aircraft is particularly sensitive to weight as it strongly influences inflight performance, fuel consumption, operating economics and the cost of manufacturing. The program addresses many aspects of the problem and includes design methodologies, flutter suppression and high-altitude turbulence effects. The bulk of the SCR effort is, however, focused on the unique problem of long life aircraft structures at elevated temperatures. As shown in Figure R-32, materials of construction for this application are obviously limited, and major emphasis has been placed on the maturation of both advanced titanium metal alloy technology and advanced high temperature composites. Application studies are used to guide the materials and structures technology program. In FY 1981, the titanium characterization effort will be completed and work will be directed to the design and fabrication of larger panels for thermal, cyclic and stress testing. A variety of advanced processing techniques will be employed, including superplastic forming with concurrent diffusion bonding, advanced adhesive bonding and cold forming of beta alloys of titanium. The composite structures and testing program will be expanded to extend the assessment of advanced composite materials from the shuttle program to long life aircraft requirements.

The technology of propulsion airframe integration has been expanding since the inception of this area in the SCR program in FY 1979. The systems analysis of bicone and translating centerbody inlet types has been completed. Neither has a clear and obvious advantage over the other in the Mach 2.1 to 2.3 speed regime, and the data base is inadequate to perform off-design sensitivity and trade-off studies. As shown in Figure R-33, two specific areas of interest to be addressed in FY 1981 are in high-speed inlet performance and low-speed aero/acoustic performance. While some data exist on the translating centerbody inlet at or near design conditions, data are not available for control system design at supersonic off-design conditions or at angle-of-attack. These data, along with extensive

internal pressure mapping and flow distortion data, will be acquired in the 10x10-Foot Supersonic Wind Tunnel at NASA Lewis Research Center. The aero/acoustic performance of a typical axisymmetric, variable-area inlet with and without blow-in doors will also be performed in the Lewis 9x15-Foot Tunnel. These data will be acquired over a range of subsonic flows consistent with the two VCE engine concepts now under study. These data will be used to correlate with noise suppression data taken from the YF-12 flight tests last summer prior to its retirement.

Finally, an added area of SCR research will be addressed in FY 1981. Over the last several years, the SCR program has provided the FAA with noise/economic trade-off data for use in the International Civil Aviation Organization (ICAO) SST noise regulation activities. During the recent international meetings, the ICAO agreed to continue analysis of evolving technologies in variable cycle engines, advanced operational procedures, and jet noise suppression devices for application to SST noise standards in the post-1985 time period. NASA has agreed to conduct selected studies to provide data to the FAA as required to support the U.S. position in this activity.

Advanced Flight Experiments: In the Advanced Flight Experiments area, several ongoing programs will result in advanced technology flight research activities. The Advanced Fighter Technology Integration (AFTI) program, jointly sponsored by the Air Force and NASA, has two current ongoing projects. The first, the AFTI-16 project, is modifying an F-16 with an advanced digital fly-by-wire control system and adding canards for direct force control. The primary Air Force objective of this project is to couple the flight control system and direct force control capability to enhance controls technology for military missions. NASA is interested in evaluating the advanced control techniques, the aerodynamics of the direct force control and the man/machine interface. The Air Force is responsible for modifying the aircraft while NASA is responsible for wind-tunnel tests, flight research instrumentation and aircraft support. Flight planning, piloting and data analysis are joint responsibilities. First flight on the modified F-16 is planned for FY 1981.

The second project under the AFTI program is the Mission Adaptive Wing (MAW). Under this project, a supercritical wing design has been developed that allows great variability in wing camber using smooth leading and trailing edge devices, so that the airfoil can assume many shapes, optimized for the various mission segments. When coupled with a variable sweep wing, this variable camber concept is capable of providing near optimum airfoils over a very large flight envelope. Using the already highly instrumented F-111 Transonic Aircraft Technology (TACT) aircraft, the

joint NASA/USAF project will evaluate the MAW in the real and dynamic world of flight. The NASA role in this program, as shown on Figure R-34 is to provide the wind-tunnel testing and to conduct the flight research activities. During FY 1981, the aircraft will begin modification to the MAW concept. NASA will conduct wind-tunnel tests to further refine the aerodynamic performance and piloted-simulations to define the control system modifications required to utilize the MAW efficiently.

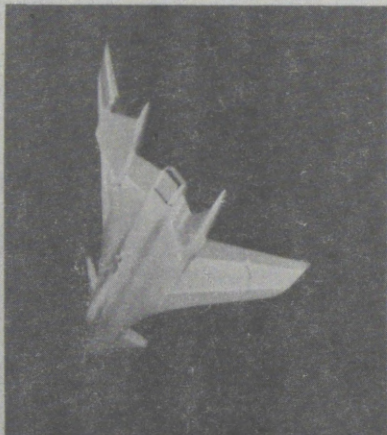
Another project being conducted under the advanced flight experiments is a continuation of the F-14 high angle-of-attack flight research. In FY 1981, the effort in this project will concentrate on the effects of external stores, i.e., pylons, fuel tanks, etc. on the high angle-of-attack characteristics. Also under the flight experiments area is work on integrating propulsion and airframe controls. Studies will be performed to quantify potential payoffs and to establish technical requirements of advanced integrated systems which must be developed and demonstrated in flight before such systems will be incorporated in future high performance aircraft. Integration now appears promising because of the development of full-authority digital electronic propulsion controls and data bus technology.

Highly Maneuverable Aircraft Technology: The Highly Maneuverable Aircraft Technology (HiMAT) program, the fourth major program element in the High Speed Systems Technology area, will continue flight research activities in FY 1981. As illustrated to the Subcommittee in October, the first flight on the HiMAT vehicle number 1, on July 27, 1979, was highly successful. Since that time, additional flights have been directed to expanding the flight envelope as is the case with any new vehicle (Figure R-35). In mid-FY 1980, the second HiMAT vehicle will enter flight status. During FY 1981, the emphasis will be on obtaining extensive research data in the areas of aerodynamics, stability and control, structures and aeroelastic tailoring. Flight data in these technology areas will verify or identify shortcomings in our predictive capability and provide the foundation for establishment of a data base for future application of the technologies.

CONFIGURATION RESEARCH



FORWARD SWEPT WING



CANARD AND
TWO-DIMENSIONAL NOZZLE

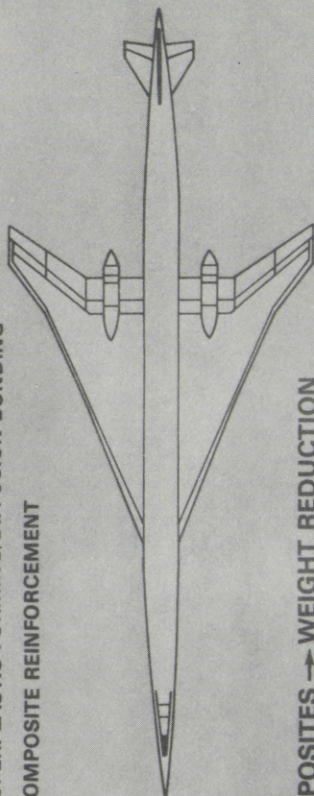
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FIGURE P-31.

APPLICATION STUDIES

TITANIUM PANELS → COST REDUCTION

- ADHESIVE BONDING
- SUPERPLASTIC FORMING/DIFFUSION BONDING
- COMPOSITE REINFORCEMENT



COMPOSITES → WEIGHT REDUCTION

- THERMAL CHARACTERISTICS
- GRAPHITE/EPOXY
- INTERMEDIATE TEMPERATURE MATRIX

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FIGURE P-32

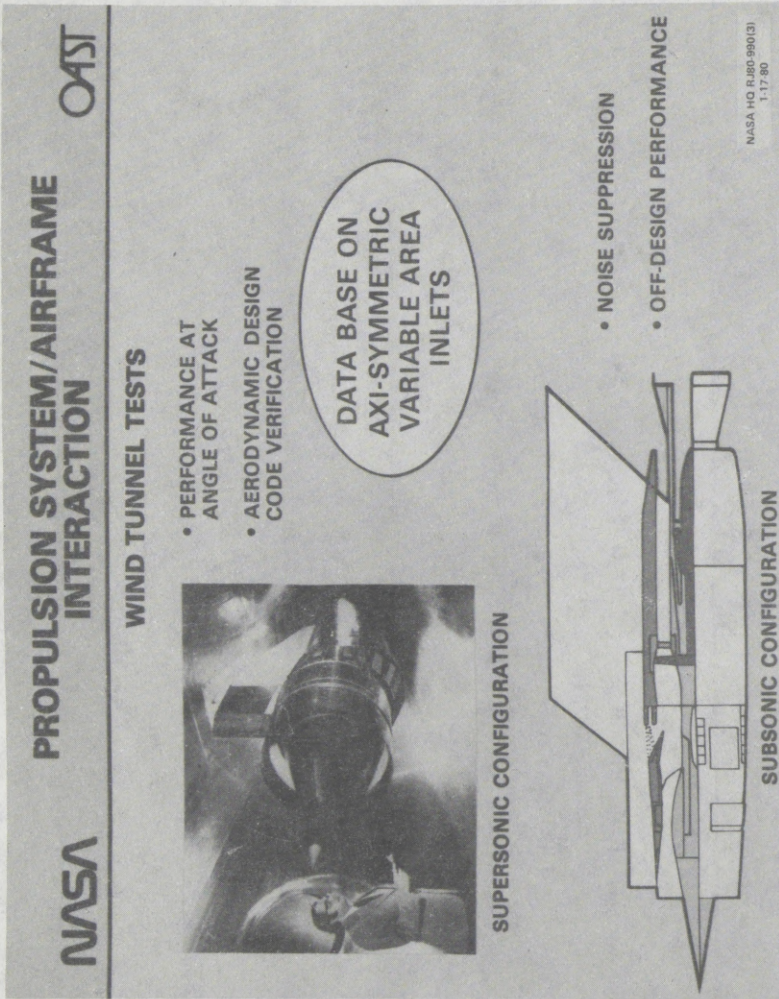
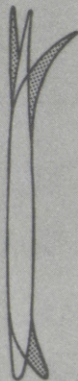


FIGURE P-33

MISSION ADAPTIVE WING

VARIABLE CAMBER FOR:

- OPTIMUM CRUISE SHAPE
- GUST LOAD ALLEVIATION
- MANEUVER CONTROL
- ROLL CONTROL



CONCEPT



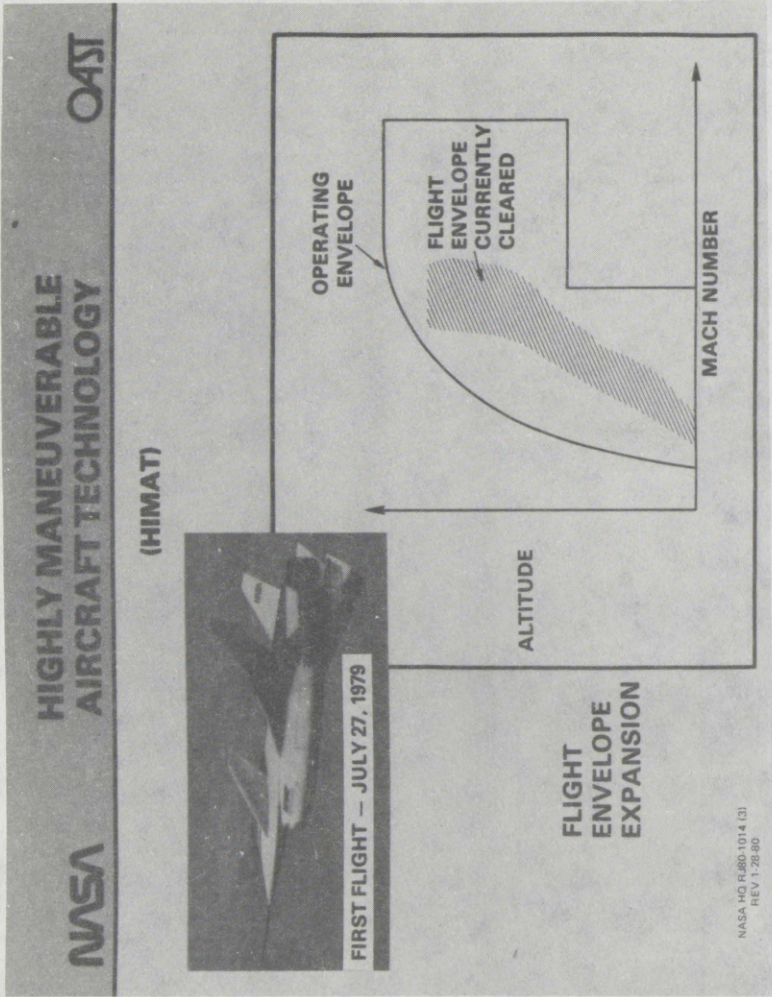
WIND TUNNEL TESTS



FLIGHT TESTS WITH USAF

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FIGURE R-34



Low Speed Aircraft

The Low Speed Aircraft program encompasses Research and Technology Base, Studies, and Systems Technology activities for a class of aircraft which includes rotorcraft, vertical and short takeoff and landing (V/STOL) aircraft, short takeoff and landing (STOL) aircraft and lighter-than-air (LTA) vehicles.

The rotorcraft program is a major element of the NASA aeronautics activity with such recent accomplishments as the delivery of the two NASA/Army Rotor Systems Research Aircraft and the successful full-scale wind tunnel testing and flight testing of the NASA/Army XV-15 Tilt Rotor Research Aircraft. Based on an extensive program planning effort involving industry advice, a long-range rotorcraft research plan is providing the basis for specific program enhancement proposals.

The ongoing program in V/STOL is focused on developing a sound technology base in aerodynamics, propulsion and control, and the program is being carried out in close coordination with the Navy. While the emphasis on STOL has declined somewhat in the recent past, there are signs of renewed interest for military applications. The very successful experimental program with the Quiet Short-Haul Research Aircraft continues at the Ames Research Center.

Research activity in lighter-than-air vehicles emphasizes the technology needs of hybrid airship concepts, especially in aerodynamics and flight dynamics. Increased activity in this area is envisioned, including cooperative programs with the Coast Guard and Navy.

Rotorcraft Research: New analytical techniques will be developed to handle unsteady aerodynamics, hub and fuselage drag, and three-dimensional flow in the vicinity of the rotor blade tip. Experimental studies will also include small-scale model testing to explore the influence of blade airfoil and platform changes on performance loads, vibration, and noise.

In the Rotorcraft Operating Systems program, emphasis will be placed on further exploration and development of concepts that will allow rotorcraft to operate under instrument meteorological conditions with the same flexibility and utility that they currently have under visual meteorological conditions. FY 1981 activities will include the application of flight director techniques to airborne radar display systems for use in overland and overwater approach guidance systems. Initial studies will begin on the application of the Navstar Global Positioning System to commercial helicopter operations; and flight tests to define the operating criteria for helicopter

Microwave Landing Systems will continue. Software and hardware will be prepared for use in XV-15 area navigation experiments. NASA will also support the Federal Aviation Administration in their Northeast Corridor flight experiments by working to make test aircraft available to carry out this important activity.

The Rotor Systems Research Aircraft (RSRA) have begun their baseline flight activities at the Ames Research Center, and a number of promising rotor system concepts are being evaluated analytically and experimentally in both ground-based and flight experiments as part of the Advanced Rotor Systems/RSRA Operations program. In FY 1981, flight tests with the two RSRA aircraft (Figure R-36) will obtain baseline data on the aircraft with their total systems as delivered, including the 5-bladed rotors. Design and modification activities will be initiated to adapt a modern 4-bladed rotor system for evaluation on the RSRA. Tests of a series of advanced research rotors, begun in the 40x80-Foot Subsonic Wind Tunnel in FY 1980, will be resumed in FY 1981 when the tunnel is back in operation after extensive modification. The characteristics of rotor blade tip designs to improve acoustics and performance will be further evaluated on an AH-1G research helicopter. In addition, conceptual design and small-scale ground-based experimental evaluations will continue on several promising advanced rotor concepts, with the possibility that some of the features may command the thorough flight evaluation in the future which RSRA can provide.

In the XV-15 Tilt Rotor Research Aircraft (TRRA) Flight Investigations program about 50 hours of proof-of-concept flight testing with the Number 2 aircraft (Figure R-37) will have been completed at Bell Helicopter Textron during FY 1980, and the remainder of that testing will be done by the government (NASA/Army/Navy) at the Dryden Flight Research Center. The refurbishment of the Number 1 aircraft will have been completed at the Ames Research Center to return it to flight status after having been tested in the 40x80-Foot Wind Tunnel. The joint XV-15 proof-of-concept and concept evaluation flight test phases as currently planned will be completed in FY 1981. These programs will verify the rotor/pylon/ wing dynamic stability over the entire envelope of operation, thoroughly document the aircraft flight and operating characteristics, evaluate the potential of the tilt rotor concept to perform military and civil missions, and provide flight engineering data upon which certification criteria and design standards can be based. Technology and conceptual design studies of advanced tilt rotor blades and control systems appropriate for possible future tests on the XV-15 will be continued.

In another effort, wind-tunnel tests of a representative hybrid airship model will be initiated to assess the

efforts of such design variables as size and location of the rotors and shape of the airship hull, propulsion-aerodynamic interactions, scale effects, and configuration drag.

A key element in the FY 1981 rotorcraft activity will be the continuation of the Advanced Rotorcraft Technology program begun in FY 1980 with add-on funds provided by Congress. This focused effort is the initial research enhancement defined in the comprehensive NASA advanced rotorcraft technology plan developed in 1978 by a special government/industry task force. The emphasis in the FY 1981 enhancement is on experimental verification of advanced analytical methods in the areas of rotor performance, noise, airframe vibration, engine components, and high power drive system gear design (Figure R-38). In addition, there will be an increased effort in the area of all-weather guidance and navigation systems. The FY 1981 activity will build upon the ongoing rotorcraft programs and will provide the basis for the selection and detailed preparation of follow-on ground-based and flight test activities. The FY 1981 activities include the initiation of a series of systematic small-scale and large-scale rotor tests and analytical investigations to form a sound base of technical data, scaling laws, and analytical verification leading to improved design methodology.

A special task of the Advanced Rotorcraft Technology effort will focus on structural vibration prediction (Figure R-39). This activity, based on a state-of-the-art review in FY 1979, will involve a NASA/industry team effort to carry out unified analyses of selected helicopter airframes using the NASTRAN finite-element computer program. These analytical prediction efforts will be followed by shake tests of one or more airframes. The objective is to systematically assess the available capability to predict helicopter dynamic response, document this capability, and later assess the need for additional research before combining airframe and rotor system analyses.

Another segment of the FY 1981 rotorcraft enhancement will augment the research in rotorcraft operating systems with special emphasis on remote-site operations capability (Figure R-40). Flight evaluation will begin of a number of promising guidance and navigation subsystems that have valuable potential for improving all-weather operations, especially to remote, overland sites. On-board systems to be evaluated will include airborne radar, avionic displays, inertial systems, low-airspeed sensor, and transceivers coupled to low-cost ground equipment.

V/STOL Aircraft Research: V/STOL aircraft research activity in FY 1981 will emphasize propulsion, which continues to be the area of greatest technology need. Representative

large and small-scale model tests will be carried out principally at the Lewis Research Center in appropriate static and wind-tunnel facilities to evaluate advanced thrust-deflector nozzles, ejectors, and inlets designed for the very low speed, transition, and hover operations of this class of aircraft without unduly compromising the performance in high-speed cruise.

As part of the overall effort to add to a V/STOL advanced technology data base for designing future research, prototype, and operational aircraft initial high-speed evaluations will be completed in FY 1981 of four twin-engine fighter concept layouts without propulsion installed in small-scale wind-tunnel tests (Figure R-41). Fabrication will also begin on new models of the four concepts incorporating propulsion simulators for later study of propulsion/airframe interactions. A model of an advanced single-engine fighter concept will also be acquired for high-speed evaluation. Initial full-scale low-speed tests of a high-speed fighter configuration and of a subsonic V/STOL aircraft design using twin tilting turbofan propulsion units with vanes in the exhaust for aircraft control in V/STOL flight will be completed in FY 1980. Alterations will be made to the fighter model in FY 1981 to incorporate the different thrust/lift propulsion concepts for investigation on the static test facility at Ames Research Center, and in the new 80x120-Foot Wind Tunnel when it becomes operational. Propulsion control math modeling efforts begun in FY 1980 will be completed in FY 1981, leading to a generalized representation that can be used in future V/STOL flight simulation investigations.

Ground-based investigations of V/STOL flight dynamics characteristics including tradeoff studies between control system complexity and transition/hover/vertical-landing performance, and tests of advanced perspective displays for improving aircraft operational performance and safety will continue using moving-base simulators. Studies will be undertaken to define flight research options which may be realistically achievable for validating much of this ground-based simulation in the full dynamic environment of V/STOL flight under poor weather conditions and other operating constraints.

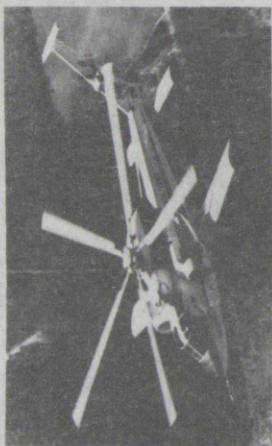
STOL Aircraft Research: The NASA activity in Quiet Propulsive Lift Technology focuses on STOL aircraft and is now concentrated on flight tests using the Quiet Short-Haul Research Aircraft (QSRA) illustrated in Figure R-42. Proof-of-concept and flight envelope documentation tests completed in early FY 1980 with this research aircraft show that it meets or exceeds all of the STOL performance predictions and goals. Following participation in Navy mission evaluations later in FY 1980 to assess the feasibility of adapting propulsive-lift STOL technology to a shipboard environment, NASA

will use the QSRA in a program extending previous STOL research studies to the high-lift flight regime in which the QSRA has a unique test capability. In this multi-year program, experiments will be initiated in FY 1981 to validate design and certification criteria for approach-path performance, stability and control, handling qualities, and operational safety margins at high lift coefficients (3.5 to 5.5), and investigate advanced terminal-area navigation and guidance concepts and operational techniques for application to civil and military operational STOL aircraft.

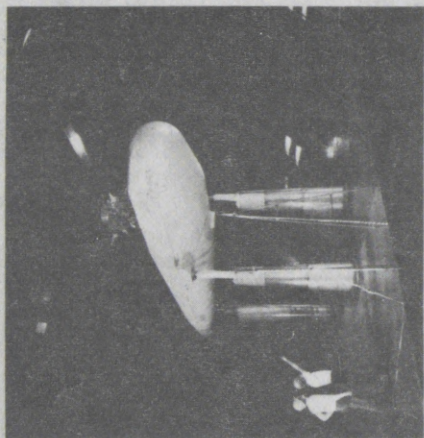
NASA

ROTOR SYSTEMS RESEARCH

Q4ST



**FLIGHT RESEARCH
ROTOR SYSTEMS
RESEARCH AIRCRAFT**



**GROUND-BASED RESEARCH
LARGE-SCALE TUNNEL MODEL**

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1-1-80

FIGURE P-36

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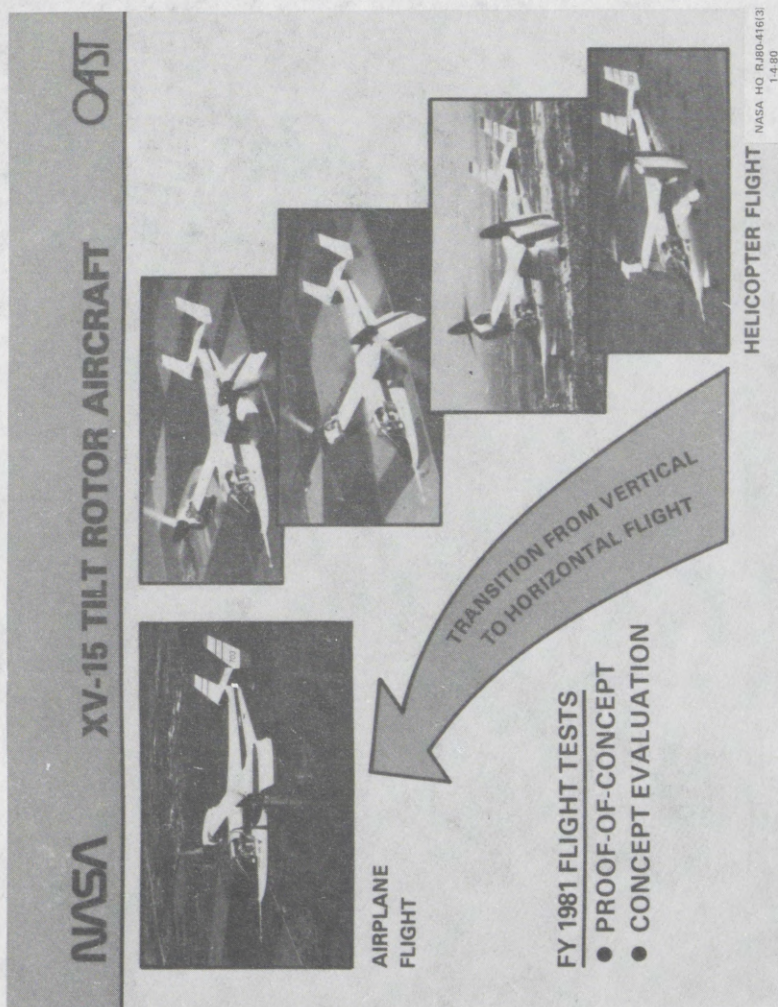


FIGURE R-37

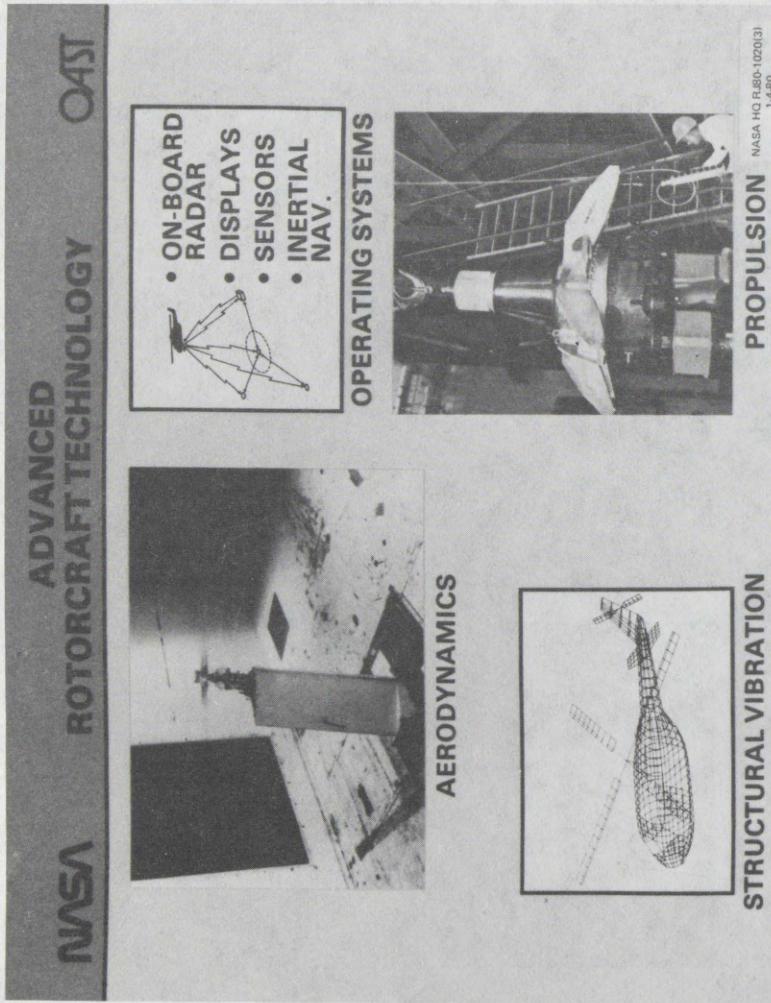


FIGURE R-38

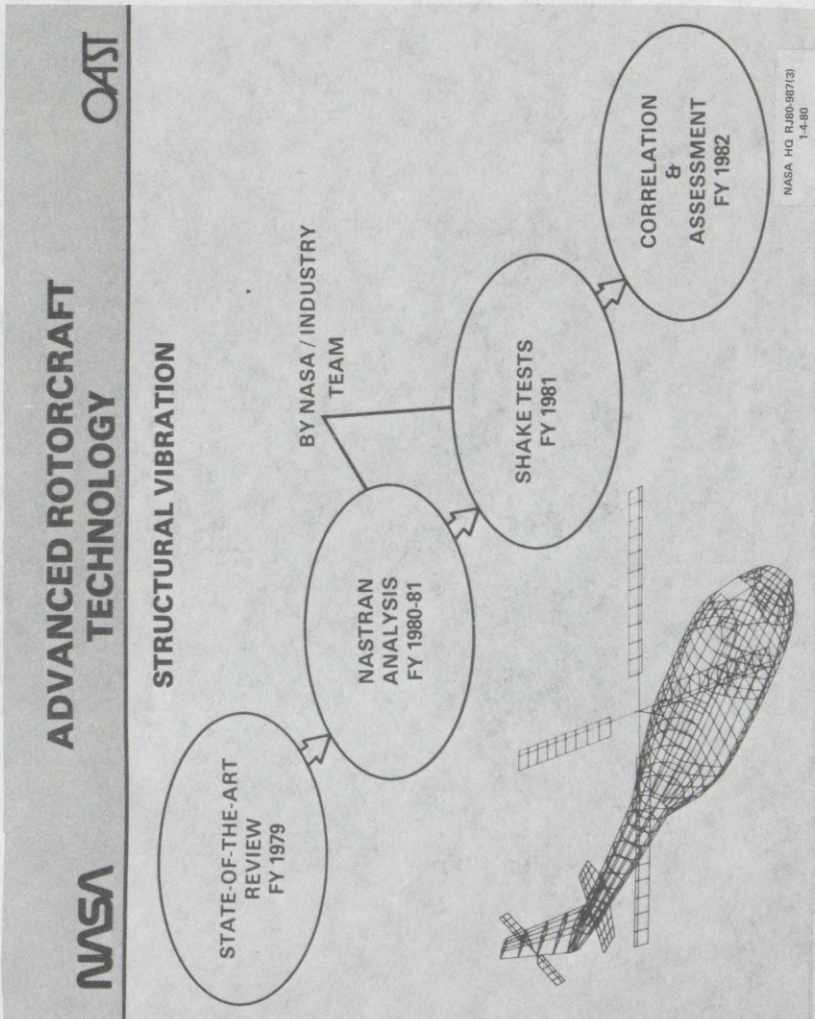
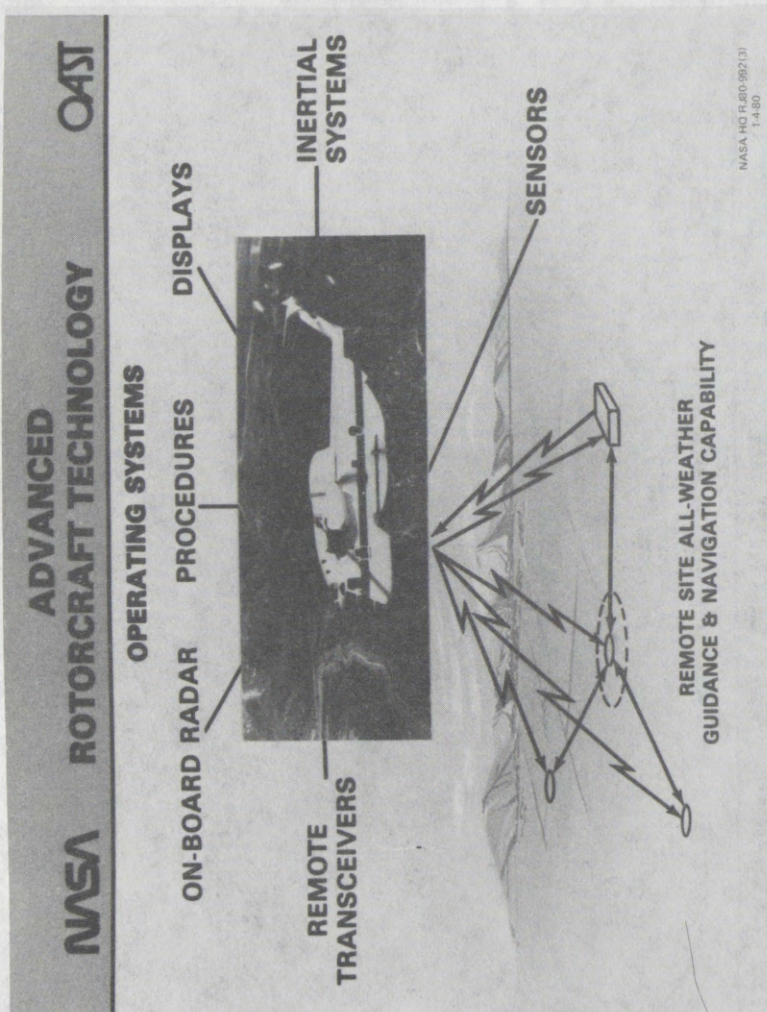


FIGURE R-39



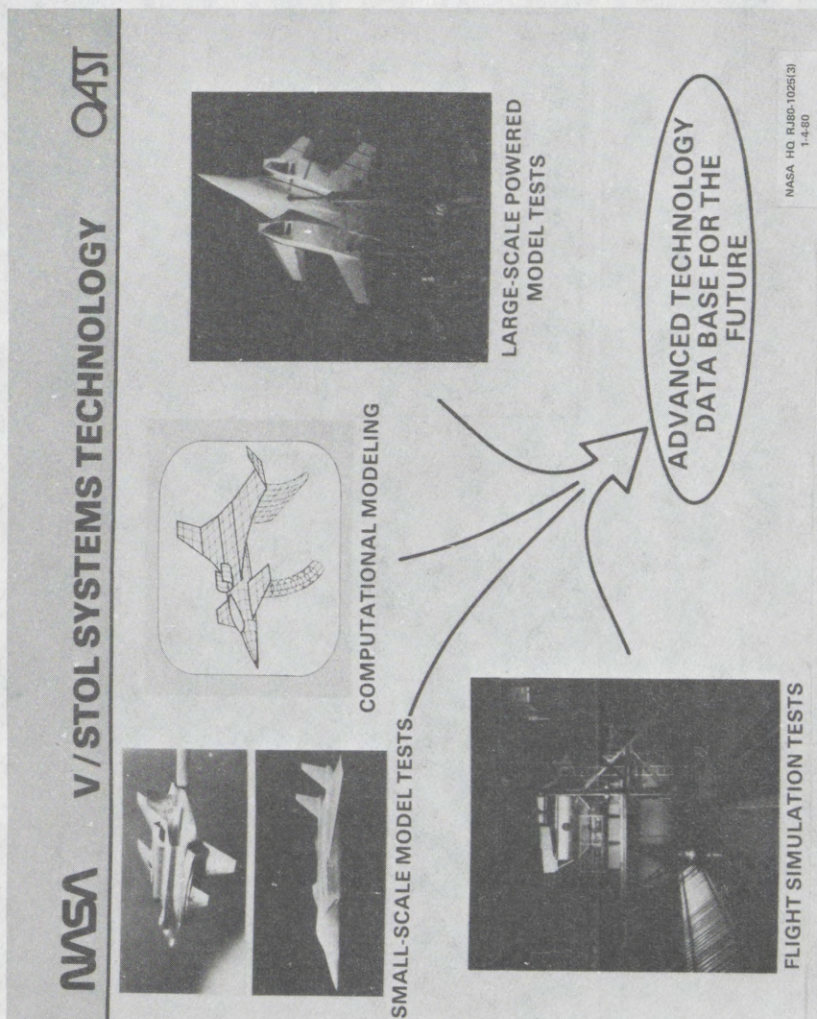
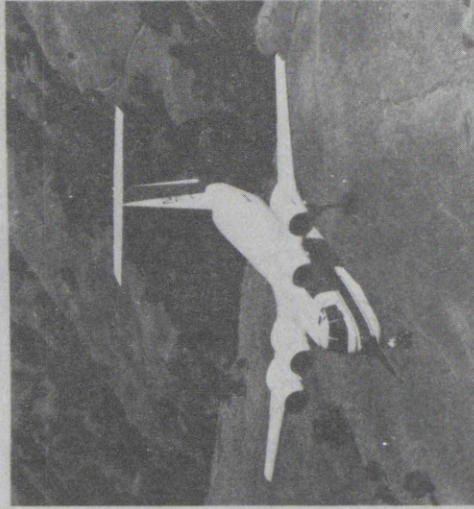


FIGURE R-41

NASA QUIET PROPULSIVE-LIFT TECHNOLOGY QAPT

SHORT TAKE-OFF AND LANDING FLIGHT EXPERIMENTS PROGRAM



QUIET SHORT-HAUL
RESEARCH AIRCRAFT

- DESIGN & CERTIFICATION
CRITERIA
- ADVANCED
NAVIGATIONAL
& GUIDANCE CONCEPTS
- OPERATIONAL
TECHNIQUES

NASA HQ R-80-0931D1
1-480

FIGURE P-42

70

General Aviation

Improvements in energy efficiency, safety, environmental impact and utility continue to be the central objectives of the NASA research and technology program to be undertaken in FY 1981 for the benefit of general aviation. As in previous years this program includes a broad range of activities in aerodynamics and flight dynamics, materials and structures, propulsion, avionics, flight controls and human factors. The research to be conducted in FY 1981 is the logical continuation or extension of FY 1980 activities oriented toward needs expressed by the general aviation industry and user community.

In aerodynamics and flight dynamics, emphasis will be on safety and energy efficiency objectives. As indicated in Figure R-43, research on stall/spin phenomena in light aircraft will include experimental investigations of both high and low wing aircraft as well as less conventional configurations which show promise for both safety and efficiency, such as the canard model illustrated undergoing spin tunnel testing. Our research will continue to seek a more complete understanding of design innovations shown in previous tests to reduce stall/spin sensitivity. One such promising concept illustrated is the segmented, drooped-wing leading edge modification which, under the correct circumstances, can reduce the abruptness and severity of stall and prevent the development of unrecoverable flat spin modes. Long-range objectives of the stall/spin program include the evolution of the analytical techniques and design methods industry needs for the design of safer aircraft. Toward this end, program emphasis will shift toward simulation and analytical development as more experimental data become available. As illustrated, simulator studies of flight motions based on aerodynamic characteristics and responses derived from wind-tunnel and flight tests will be conducted to develop better understanding of both the physical phenomena involved and the human factors related to stall/spin incidents.

Other aerodynamics research is aimed at increased energy efficiency. This includes further work on cooling drag reduction, propulsion integration improvements, and preparations for flight tests of an aircraft fitted with a low-drag wing which incorporates recent advances in natural laminar flow airfoil design. The success of such low-drag airfoils will depend on achieving smooth contours and surfaces through appropriate applications of composite materials.

Research in propulsion for general aviation in FY 1981 will emphasize internal combustion engine and propeller improvements, as noted in Figure R-44. Engine research

objectives include greater fuel efficiency, reduced weight, lower maintenance requirements and greater reliability. In addition to research to improve conventional types of spark ignition reciprocating engines, we will continue work on less conventional engine types which show great promise. These include supercharged two-stroke cycle diesel engines, as illustrated, and stratified charge rotary combustion engines. And because efficient supercharging is vital to improved performance of each of these advanced engines as well as current types, we plan to continue the research started in the 1980 program on turbosuperchargers. Supporting all this work on different engine configurations will be continuations of basic research in the areas of ignition and combustion chamber processes, engine cycle modeling, fuel injection, improved cooling and cooling drag reduction.

Propeller research, as indicated in the figure, will emphasize higher aerodynamic performance for greater energy efficiency using advanced blade planforms and airfoils, and new concepts for reducing tip losses. Advanced computational methods for the achievement of increased performance and reduced noise will also be under development, while approaches to superior aeroelastic behavior, lower blade weight, greater structural damage resistance and improved fatigue life will be studied based on composite structural design concepts. Propeller and nacelle integration studies will also be extended in an effort to develop design techniques to reduce installation and nacelle interference.

The Demonstration Advanced Avionics System (DAAS) project indicated in Figure R-45 is entering the ground and flight test stages. This program has been the focus of NASA's efforts to advance the technology for integrated avionics systems for general aviation navigation and flight management. Such systems can improve general aviation safety and utility but must be reliable and economically compatible with the general aviation market to gain acceptance. Thus reliability, maintainability and low cost are major requirements. The DAAS concept incorporates design modularity and utilizes data bussing, distributed inexpensive microprocessors, shared electronic displays and data entry devices, and low-cost sensors.

The instrument panel for the DAAS installation is shown in the figure. The Integrated Data Control Center (IDCC) is used for alphanumeric messages and serves as the primary interface for the pilot with DAAS. The IDCC has several functions: one is to call up various functional checklists stored in DAAS; another is to execute specific functions such as autocourse, and a third is for data entry. The DAAS design is being modified to include

a Discrete Address Beacon System (DABS), as recommended by the FAA, to provide a ground data link capability. During FY 1980, DAAS design and hardware fabrication will be completed, and system bench tests initiated. During FY 1981, bench tests will be completed and the system will be installed in Ames Research Center's Cessna 402B aircraft (Figure R-45) for flight test checkout and validation.

In other areas of avionics and human factors, during FY 1981 NASA will begin investigation of an integrated fluidic flight control system for general aviation that will hold attitude, altitude, heading and velocity, and provide glide slope tracking. Advanced synthetic voice response digital technology will be investigated as a means of increasing general aviation communication capacities. Also, methods will be studied for using the azimuth and elevation measured by a microwave landing system (MLS) to fly curved paths without the need of expensive distance measuring equipment (DME).

The objective of the continuing general aviation crash-worthiness program is to develop technology for improved crash safety and occupant survivability in general aviation aircraft (Figure R-46). This research covers three basic areas and is being conducted with the cooperation of the FAA. One research area is energy absorbing structural concepts for improved load limiting seats and fuselage subfloors in which our previous research demonstrated that major improvements over conventional seat designs are possible. The current program includes evaluations of several load-limiting subfloor structures and improved, second generation load limiting seats. Several of these evaluations will be conducted at the FAA's Civil Aeromedical Institute (CAMI) sled test facility.

The second area of research in structural crashworthiness is the development of nonlinear structural analyses to predict large deflection elasto-plastic structural response. Methods developed to date show increasingly good agreement with test data.

A third research area is controlled crash tests of full-scale aircraft. These tests provide basic data on loads and structural behavior in a realistic environment for studying the effectiveness of load limiting design concepts, and they provide a basis for the correlation and improvement of analytical methods. During FY 1981, three full-scale aircraft crash tests at 60 to 90 mph will be conducted at NASA's Langley Research Center. These three crash tests will be conducted separately with the second generation load-limiting seats, load-limiting lower fuselage subfloor structure, and then with the combined load-limiting seats and subfloor structure.

Also in FY 1981 we will continue to develop and improve the mathematical models for predicting structural response and occupant loads under crash conditions, as indicated in the figure. The Seat/Occupant Model for Light Aircraft computer program provides a mathematical simulation of occupant, seat, and restraint system behavior in a crash situation, and the Dynamic Crash Analysis of Structures computer program provides a mathematical simulation of the seat and subfloor structure. While both programs have independently been correlated and validated by comparisons with experimental results, we will improve the accuracy and efficiency of both programs in FY 1981 and extend their capabilities by developing them into a combined occupant/seat/structural analysis as indicated in the figure. The combined program will then be validated by comparison with dynamic test data.

In related studies, NASA has been assisting the FAA in evaluating the crash-activation characteristics of Emergency Locator Transmitters (ELT) which general aviation aircraft must carry. These studies will be completed in FY 1981 and a report of recommendations for ELT improvements will be submitted to the FAA through the Radio Technical Commission for Aeronautics (RTCA) special committee studying ELT operational problems.

In the area of agricultural aerial applications, primary efforts are continuing to improve aerial application dispersal and distribution systems. Research is currently underway to determine aircraft wake interactions with a variety of dispersal materials and to determine how to modify aircraft wake characteristics to improve dispersal swath control. Initial flight evaluation of the effects of wake modification devices on airplane performance, handling qualities, and dispersal patterns will be conducted during FY 1980, and these flight tests will continue during FY 1981 to verify the results of full-scale wind-tunnel tests. During FY 1981, model tests will be conducted in the wind tunnel and vortex flow facility to investigate the effect of wing span loading modifications for increasing the swath width of dispersants, and flight tests will be conducted to verify the wind-tunnel model testing techniques and analytical work for particle dispersion.

The utility and productivity of an agricultural airplane can be enhanced if it is specifically designed for the requirements of the task. During FY 1981, advanced agricultural aircraft configurations, such as the joined wing concept shown in Figure R-47, will be studied and tested in the vortex flow facility and wind tunnels. This joined wing configuration promises to be an improvement over current agricultural aircraft by providing direct lift control with better lift-to-drag ratios in

turns, superior turn efficiency, better maneuverability, higher dispersant volume capacity, and increased safety. In this configuration, the pilot sits in the tail of the aircraft above the dispersant.

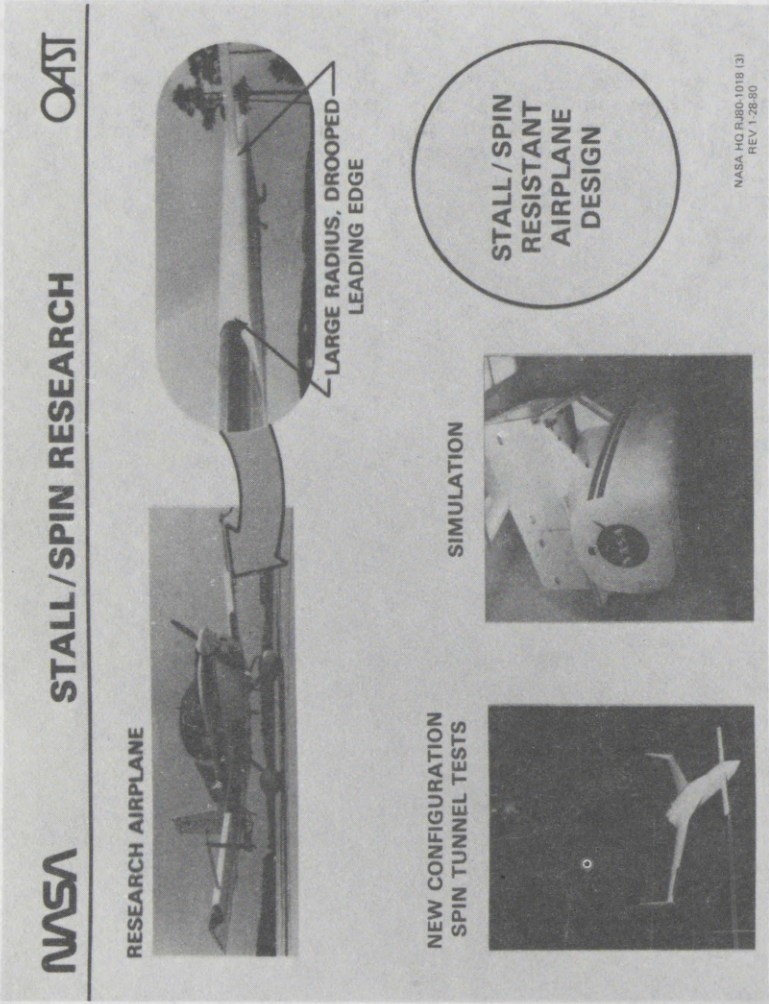


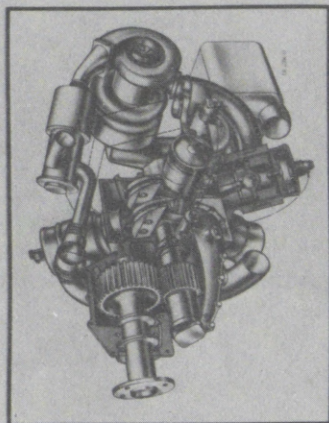
FIGURE R-43

ADVANCED PROPULSION TECHNOLOGY

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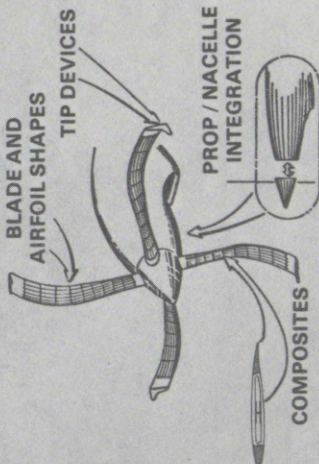
INTERNAL COMBUSTION ENGINE RESEARCH



SUPERCHARGED DIESEL ENGINE

- GREATER FUEL EFFICIENCY
- REDUCED WEIGHT
- LOWER MAINTENANCE
- GREATER RELIABILITY

LOW-SPEED PROPELLER RESEARCH



AERO / ACOUSTIC PROPELLER

- IMPROVED EFFICIENCY
- REDUCED NOISE
- INCREASED SAFETY
- LIGHTER WEIGHT

NASA HQ R-80-101E (3)
REV 1-28-80

FIGURE R-44

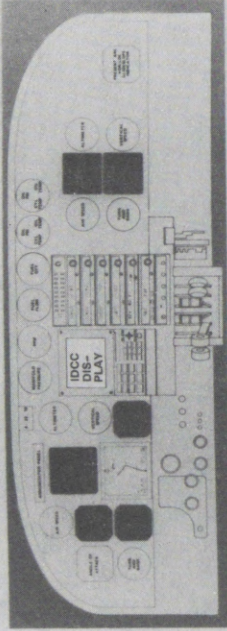
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ADVANCED AVIONICS

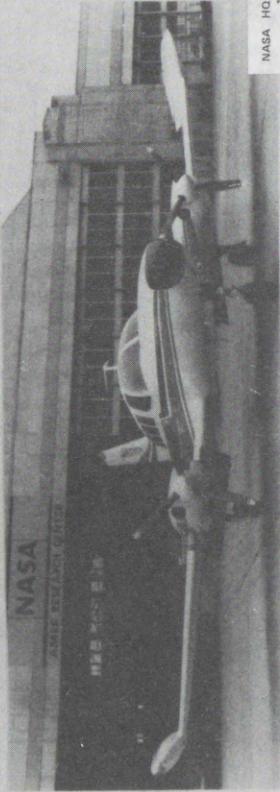
CAST

DEMONSTRATION ADVANCED AVIONICS SYSTEM (DAAS)

INSTRUMENT PANEL

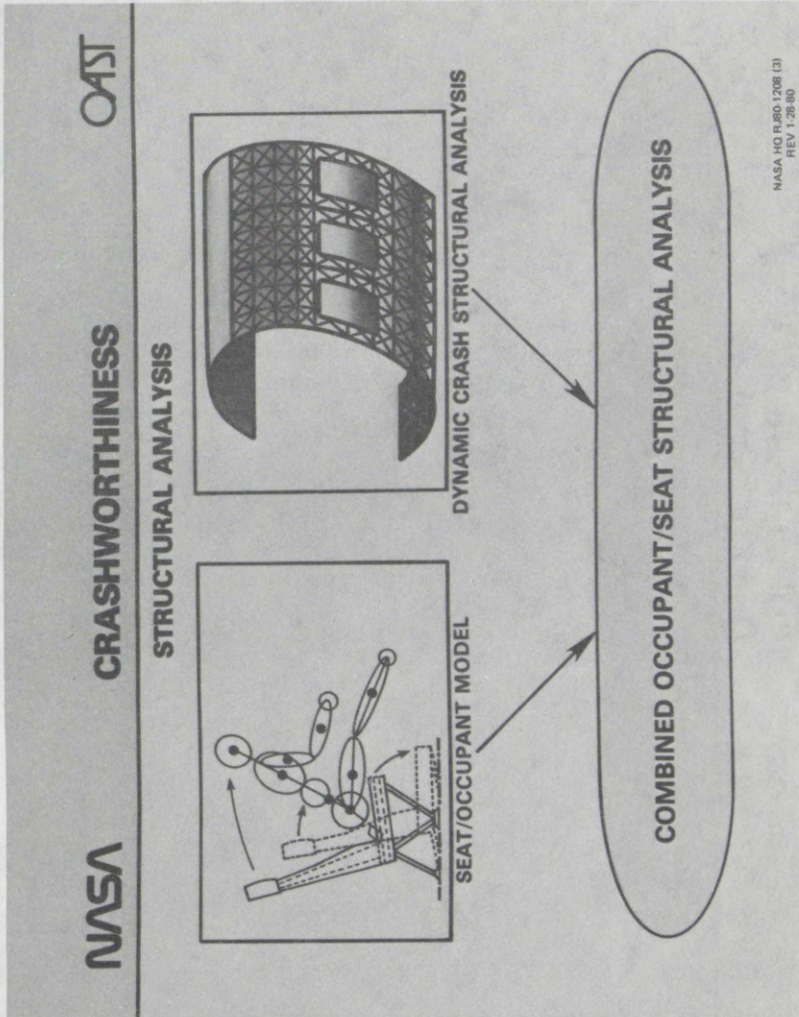


CESSNA 402 TEST AIRCRAFT



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1-4-80

FIGURE R-45



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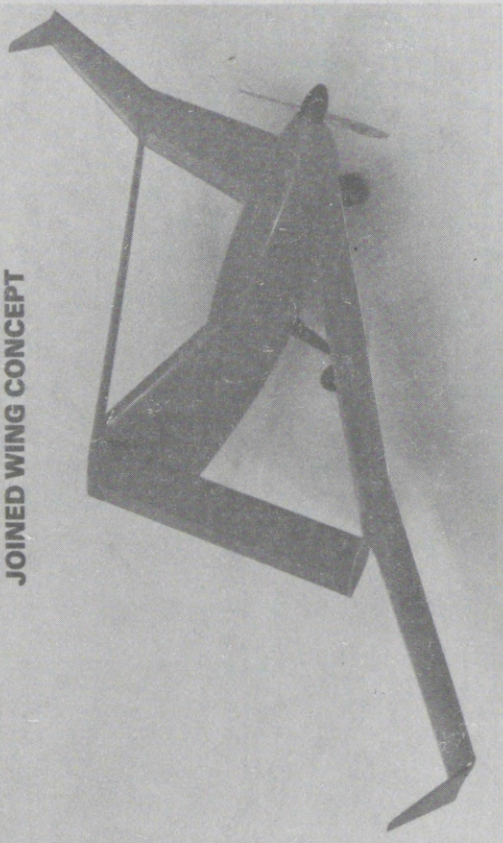
FIGURE R-46

AGRICULTURAL AERIAL APPLICATIONS

NASA

O4ST

JOINED WING CONCEPT



- IMPROVED SAFETY
- IMPROVED DISTRIBUTION AND SWATH CONTROL
- LOWER APPLICATION COSTS

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FIGURE R-47

Transport Aircraft

The Transport Aircraft research program for FY 1981 includes Research and Technology activities to enhance aviation safety; the Terminal Configured Vehicle effort; and three Aircraft Energy Efficiency thrusts, namely, Energy Efficient Transport, Composite Primary Aircraft Structures, and Laminar Flow Control. The emphasis will continue to be on technology which supports near-to mid-term applications to derivative and new energy-efficient aircraft which will be compatible with the changing operational environment in the Nation's airspace system.

Aviation Safety Research: The NASA Safety Research and Technology program is concerned with establishing a base of safety-oriented technology for improving the understanding of safety hazards and their consequences; for developing operating techniques that can lead to reduction in aircraft accidents; for increasing occupant survivability when accidents do occur; and for establishing criteria for design of more efficient aircraft systems. The program consists of multidisciplinary activities in three major areas: meteorological research, aviation operations safety, and operating efficiency improvement.

Meteorological research serves as the basis for understanding the effects of atmospheric processes on safe, efficient operation of aircraft and their systems. Severe turbulence, rapid changes in wind intensity and direction (wind shear), and icing conditions affect aircraft control and structural integrity. The effects of lightning discharge on advanced solid-state electronic components and composite materials structures have yet to be determined. In FY 1981, meteorology research will include continuation of flight tests with a specially equipped F-106 airplane to obtain natural lightning discharge data. This information is essential for developing criteria for protecting microelectronic systems and structures of composite materials, and for improving non-destructive ground-testing techniques. A B-57 airplane will obtain low altitude, gust gradient and wind shear data to improve the forecasting of hazardous conditions in takeoff and landing operations. Icing research will include investigation of ice accretion characteristics of helicopter rotors and the effect of icing on rotor performance and structural integrity. In addition to the gathering of basic icing data, various advanced ice protection concepts will be explored.

Post-crash fires produce the highest casualties in aviation operations. Because of the relative ease of ignition and the rapid rate of flame propagation associated with the fuel mist produced in a crash, passenger survival time is drastically reduced. An assessment of the practicability of using a British-developed antimisting kerosene (AMK)

fuel, in a commonly used turbine engine (JT8D), is being performed in conjunction with a United States (FAA) - United Kingdom Memorandum of Understanding. In FY 1981, studies will involve: investigating AMK use in other engines and their fuel systems; determining the feasibility of modifying aircraft for AMK use; and assessing the impact of AMK on future engine design. Rheological studies of AMK will continue to establish methods of measuring its "fire-inhibition" quality and determining the potential of other AMK formulations. Other activities, such as fire modeling and toxicology research, will continue to assist in establishing criteria for predicting crash survival limitations, understanding fire dynamics, and materials testing. The related Fire Resistant Materials Engineering (FIREMEN) activity will be completed in FY 1981 with full-scale burn tests of new seat materials.

Improvements in operating efficiencies of ground directional control and braking systems are warranted as evidenced by recent incidents involving tire and other landing system failures. A unique NASA Takeoff and Landing Loads Track Facility, Figure R-48, will be utilized to determine the effect of blown tires, damaged wheels, and runway pavements on landing gear system dynamics, braking, and aircraft directional control. The conduct of continued wear and friction tests of new tire tread formulations should result in improved tires. New landing gear system concepts, such as active control and air cushion, will be explored in response to the needs of advanced heavier future aircraft. Results from Landing Loads Track investigations of braking system characteristics will be applied in support of corroborating flight tests. Activities to improve ground handling will include continued development of a simulator for researching ground operational problems. An FY 1981 Construction of Facilities proposal would upgrade the Landing Loads Track capability in order to handle landing speeds, system weights and gear types more typical of today's advanced aircraft.

Terminal Configured Vehicle: The Terminal Configured Vehicle (TCV) program will continue in FY 1981 to provide a focus for significant progress in increasing the efficiency, accuracy, and safety with which a transport aircraft can be operated and the ease with which a future operational environment can be accommodated. The activities are aimed at establishing that the recent advances in cockpit displays and digital avionics technology have achieved a state of readiness suitable for advanced aircraft and new models of current aircraft.

Figure R-49 portrays the principal activities in FY 1981 which lead to more efficient flight management and air traffic control compatibility. These activities will utilize the advice and cooperation of airlines, the aviation manufacturing industry, and the FAA. This involvement is crucial to the acceptance and early application of technology. Industry expertise will assist in

the development and readiness assessment of on-board system concepts, procedures, and interfaces. FAA will provide guidance concerning interfaces with the future air traffic control (ATC) systems and will participate jointly and actively in several of the FY 1981 tasks. FAA participation is expected in assessing the potential of cockpit display of traffic information (CDTI); use of ground-to-air data links; and integrated digital guidance, navigation, and control systems. With such digital systems, the aircraft can be maneuvered to acquire and accurately track defined terminal area flight paths in four-dimensions for minimizing fuel use, airspace requirements, and noise using the elements and procedures of an advanced ATC system. Another TCV activity will be the development and demonstration of reduced runway occupancy time through more precise automatic flare and touchdown in adverse wind conditions, high speed runway turnoffs, and turnoff guidance. Using technology advances in information display, digital processing, digital equipment implementation and system architecture, and elements of the man-machine interface, an advanced cockpit for more efficient utilization of the aircraft and crew will be defined.

Energy Efficient Transport: Turning now to the first of three Aircraft Energy Efficiency (ACEE) program thrusts, the Energy Efficient Transport element will progress during FY 1981 to the demonstration phase in several of its major projects. As illustrated in Figure R-50, one such effort is the verification of the performance benefits from reduced longitudinal static stability. Completion in FY 1980 of the aerodynamic and structural design of a small horizontal tail for the L-1011 will be followed in FY 1981 by fabrication and ground testing of the flight test article. Flight tests in FY 1982 are expected to validate a five percent increase in cruise fuel efficiency.

Effectiveness of the basic aerodynamic concept of winglets has been confirmed through flight tests on the KC-135. However, the net gains from their use on an existing airplane is highly dependent on the specific structural and aerodynamic design. As illustrated, winglets on the DC-10 show considerable promise for cost effective retrofit. Aerodynamic and structural design of the DC-10 flight test winglets will be completed in FY 1980 with fabrication and initiation of flight tests planned in FY 1981. Based on wind-tunnel tests and preliminary structural design, a net increase in efficiency of three percent is forecast.

Also depicted in Figure R-50 is a major flight test program which will provide data on the in-flight loads imposed on the engine nacelle and pylon. Indications are that aerodynamic and inertial loads imposed on the nacelle and pylon are transferred to the engine, resulting in deflections that constitute a principal source of engine

performance degradation. An extensively instrumented nacelle, pylon and engine will be flown on a B-747 to obtain data to verify the concept. Pressure and acceleration measurements will be correlated with simultaneous measurements of the engine internal clearances. The flight program will also provide the first comprehensive flight survey of flow characteristics around the nacelle, pylon and wing junctures. Data acquisition will be completed late in FY 1980 with analysis and reporting in FY 1981.

In-house efforts related to the Energy Efficient Transport program and in active controls technology in FY 1981 will highlight system checkout and verification of ultra-reliable computers and completion of the assembly and ground check out of an Advanced Research Active Control Wing in preparation for FY 1982 remotely piloted vehicle flight tests.

Composite Primary Aircraft Structures: The Composite Primary Aircraft Structures element of the ACEE program includes the development of three secondary and three medium size primary (tail) structures and a supporting activity to assess the risk of accidental release of carbon fibers. Two of the secondary components, the DC-10 rudder and B-727 elevator, and the risk assessment program are being completed in FY 1980. The two secondary components have been certified by the FAA and are entering airline service. The risk assessment results indicate that the potential economic damage from accidental release of fiber from aircraft structures, even for the extensive use predicted in the next 20 years, is insignificant. The third secondary structural component, the L-1011 aileron, will enter scheduled airline service during FY 1981.

During FY 1981, the primary composite components move into the flight and full-scale ground testing phase (Figure R-51). Limited serial production and flight service will provide manufacturing and maintenance data. The B-737 horizontal stabilizer flight testing, to begin at the end of FY 1980, will continue during FY 1981. The DC-10 vertical stabilizer will be test flown and certified by the FAA in FY 1981.

Static and fatigue ground testing of full scale DC-10 and L-1011 vertical stabilizers will be completed in FY 1981, and the B-737 horizontal stabilizer will be tested to destruction. The laboratory durability testing equivalent of 10 years' simulated service will be completed on L-1011 vertical stabilizer spar and cover segments. Five complete shipsets of the B-737 horizontal stabilizer will be completed and prepared for flight service.

Laminar Flow Control: In FY 1981, focus in the Laminar Flow Control (LFC) program will be on the most critical issues which must be addressed in order to bring LFC technology from the laboratory to industry acceptance for new long-range transport aircraft production in the 1990's. The areas of emphasis, as depicted in Figure R-52, will focus on industry concerns and consist of three main activities. The first is the development, fabrication, and test of two leading edge wing box concepts. The scope of the activity involves laminarization of a spanwise section of a leading edge of a JETSTAR aircraft wing. Flight tests later will provide a comparison of the effectiveness of the two concepts in controlling the growth of disturbances in the boundary layer. Data will be obtained with respect to insect protection/deicing systems performance, erosion, foreign body damage, and effects of atmospherically-induced disturbances such as gusts and ice particles on laminarization.

The second principal activity involves the demonstration of manufacturability and splice effectiveness of two wing surface panel concepts, including the related ducting. One concept is a slotted configuration involving discrete suction channels, while another features a porous surface with uniformly distributed suction.

The third area of emphasis will be testing of an advanced supercritical-type swept airfoil with pressure distribution tailored for laminarization. Investigations will be made of various aerodynamic aspects concerning attainment of laminar flow at high subsonic speeds. Several types of wing surface panels will be used.

The successful completion of these LFC activities prior to the end of FY 1984 will represent a major step toward eliminating concerns as to the feasibility of this element of the ACEE technology program.

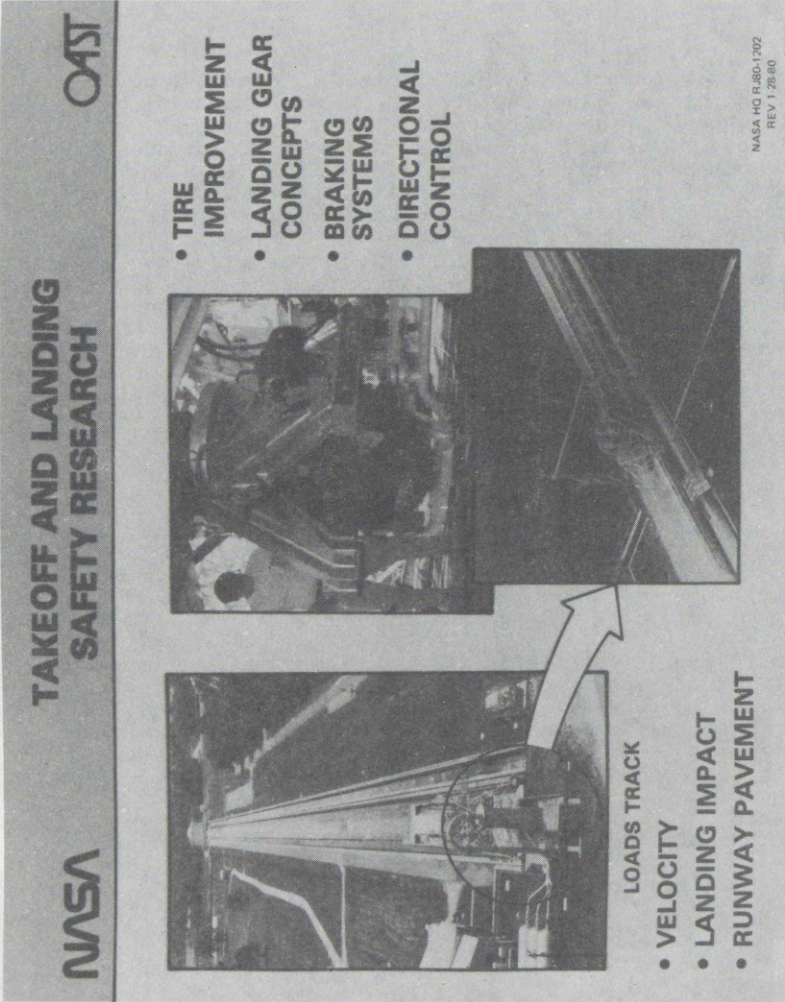


FIGURE R-48

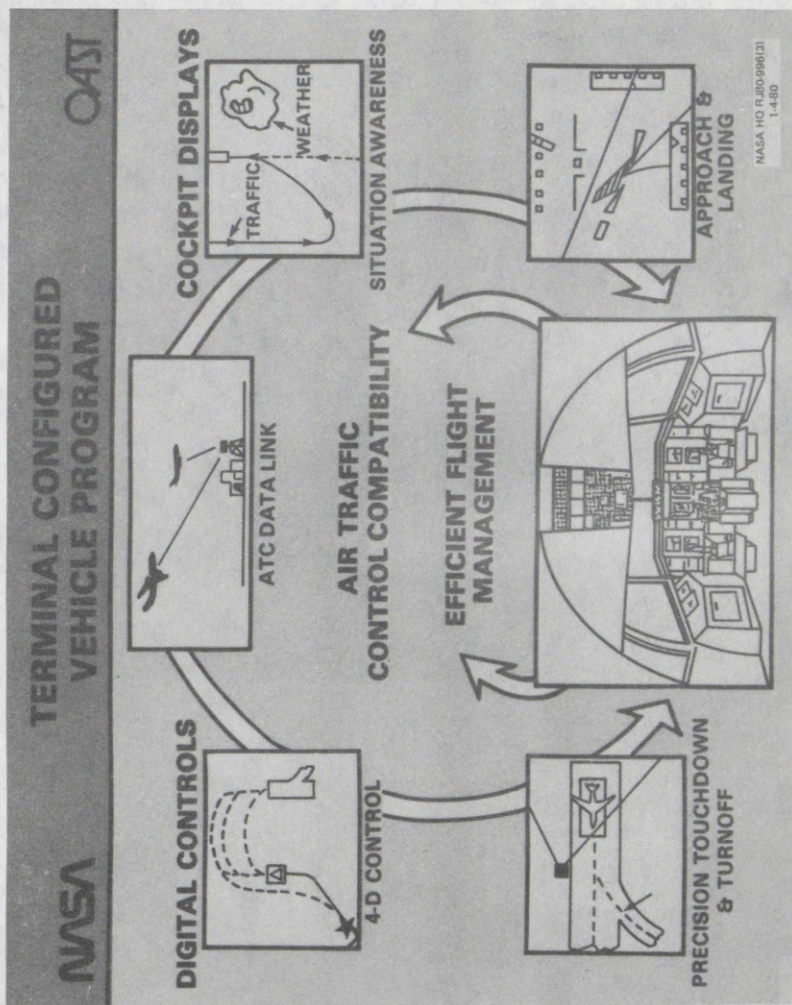


FIGURE R-49

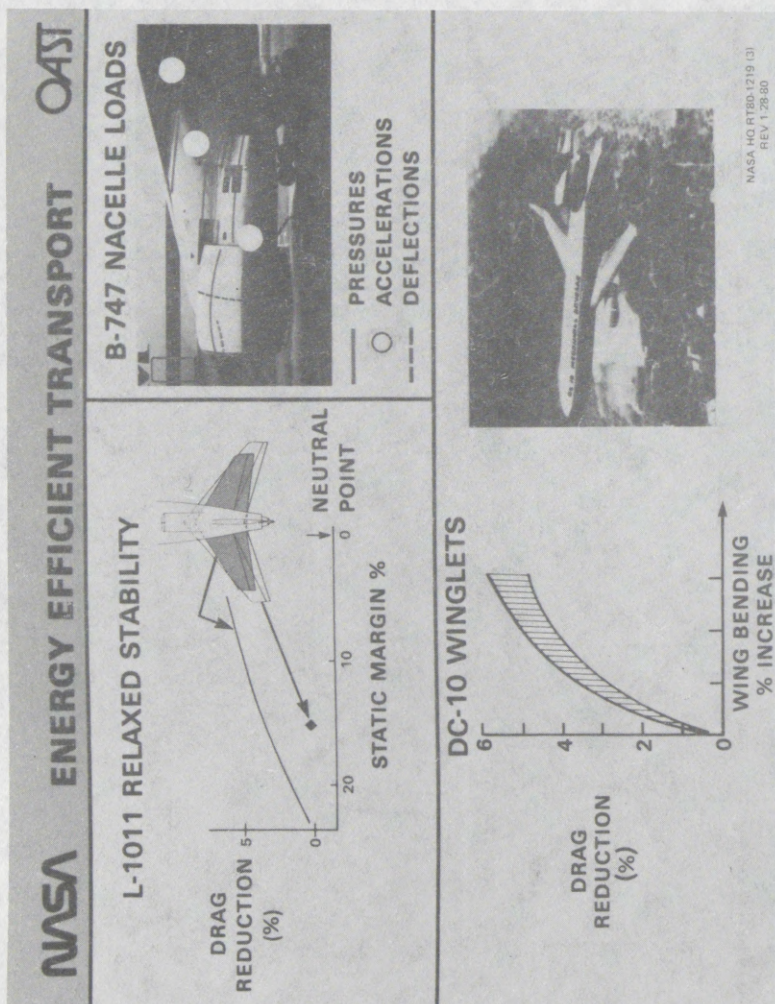
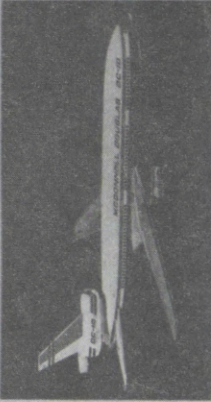


FIGURE R-50

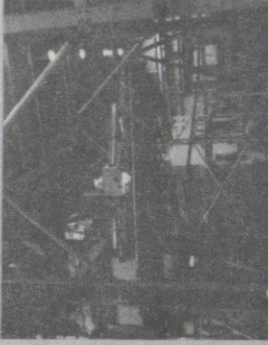
COMPOSITE PRIMARY AIRCRAFT STRUCTURES

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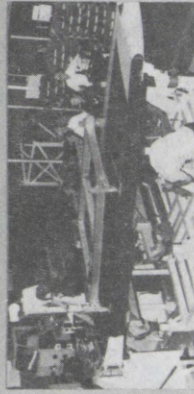
NASA



FLIGHT TESTING



FULL-SCALE TESTING



LIMITED PRODUCTION

- STRUCTURAL VERIFICATION
- OPERATIONAL DATA
- MANUFACTURING COST DATA

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FIGURE R-51

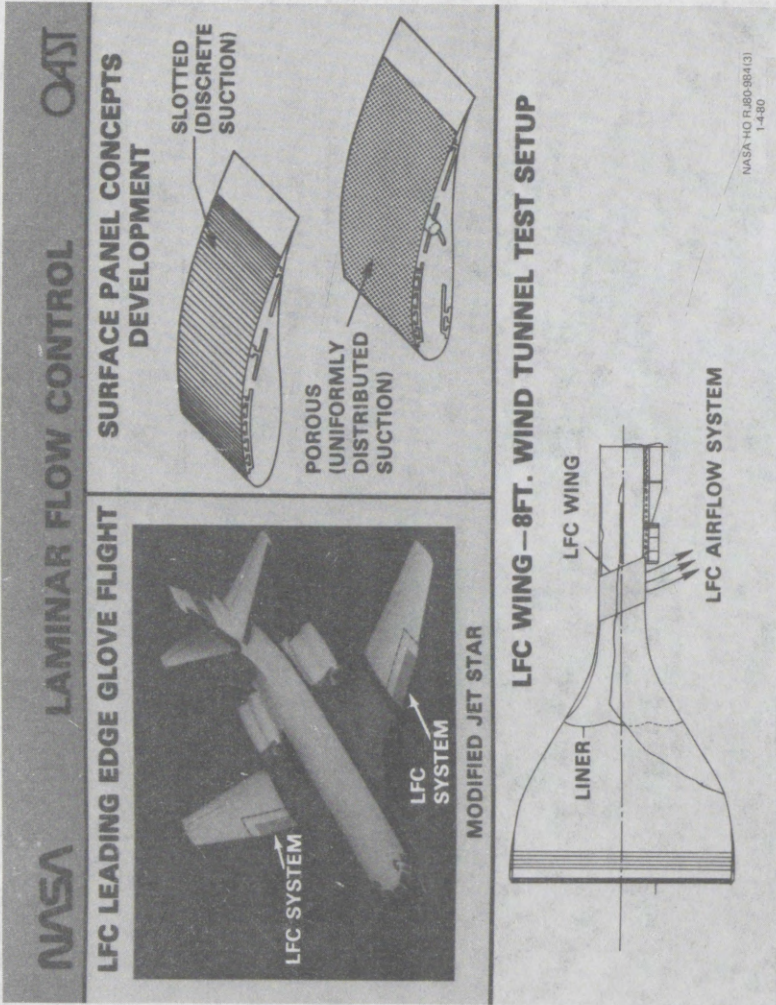


FIGURE R-52

Advanced Propulsion Systems Technology

In FY 1981 the Advanced Propulsion Systems Technology efforts will continue to focus on the development and demonstration of technology for improving the energy efficiency of future civil transport aircraft and for demonstrating engine system feasibility for future supersonic cruise and high performance aircraft. The principal ongoing effort in FY 1981 is the Energy Efficient Engine program, one of the propulsion elements of the Aircraft Energy Efficiency (ACEE) program. Engine core and low-spool components will undergo full-scale testing in preparation for integrated engine system performance tests that will be conducted later in the program. An FY 1981 enhancement, Advanced Turboprop Systems - Phase 2, will be initiated to evaluate the structural characteristics of an advanced design, high-speed propeller concept using large-scale hardware. Enhancement of the Variable Cycle Engine (VCE) effort will be initiated in FY 1981 to continue technology developments critical to engine performance with primary focus on low-spool, variable-flow component and exhaust nozzle system technology for improved efficiency and reduced noise.

Energy Efficient Engine: The Energy Efficient Engine (EEE) program is directed toward the development of the technology base for future commercial turbofan engines that offer a 12-15 percent reduction in fuel consumption, at least 5 percent reduction in direct operating costs, 50 percent improvement in performance retention, and reduced emissions and noise levels compared to current high-bypass ratio commercial turbofan engines. Progress continues in the component development and integration phase, which concentrates on the advancement of component systems technologies to the high performance levels essential to the attainment of predicted EEE fuel savings.

During FY 1981, the major engine components will be evaluated in full-scale rig experiments. As the results of these tests become available, the component designs for the core systems and integrated core/low-spool (ICLS) systems will be updated for subsequent fabrication and testing. In Figures R-53 and R-54, representative full-scale component activity is illustrated. The first six stages of the General Electric (GE) ten-stage high pressure compressor are shown in Figure R-53. The compressor is typical of the design of both EEE compressors. It features highly loaded, highly efficient, wide chord, low aspect ratio airfoils for increased life, improved performance retention, and reduced number of airfoils. These characteristics also result in short and stiff compressor

blades with reduced bending, which permits closer running clearances. The first six stages will proceed through component development tests of the complete ten-stage compressor in FY 1981. The tests will be conducted in the facility shown in Figure R-53 to validate predicted data such as that illustrated. The tests will also determine airfoil resonance, flutter, and critical speed characteristics. Variable vane schedules will be optimized for maximum overall efficiency and surge margin. The effect of circumferential and radial inlet distortion on the surge characteristics will be examined. Reynolds number effects on performance will be identified. Compressor performance sensitivity to tip clearance will also be determined.

A typical EEE combustor is shown in Figure R-54. It is an advanced, highly efficient, two-stage, annular combustor designed for low emissions. The combustor is very short and, therefore, contributes significantly to the short length and low weight of EEE. The combustor is designed for substantially longer life than current configurations even though it operates at higher temperature and higher pressure levels. The longer life is achieved principally by the use of a segmented liner employing advanced cooling schemes.

The combustor will be tested in the facility shown in Figure R-54 to substantiate predicted data such as that illustrated. The tests will define performance and durability characteristics of the combustor at various simulated engine operating conditions of idle, takeoff, climb, cruise, and approach. Tests will also identify combustor exit temperature distributions and ground start capabilities. Altitude relight and stability characteristics will be evaluated in sector combustor tests. In addition to the high-pressure (core) component tests that will be in progress in FY 1981, low-pressure component tests will continue for the fan and low-pressure turbine.

During FY 1981, component-focused supporting technology efforts in areas such as high-pressure turbine thermal barrier coatings, ceramic shrouds, and high-speed bearings will be completed in support of the core system and ICLS system designs. Fabrication of the GE core system and ICLS system will be initiated in FY 1981.

Engine Component Improvement: The Engine Component Improvement (ECI) program focuses on two areas: engine performance improvement to develop advanced components to reduce fuel consumption in current CF6, JT8D, and JT9D engines and engine diagnostics to identify the sources and causes of performance deterioration in the CF6 and JT9D high-bypass turbofan engines.

FY 1980 is the last funding year for this program. During the October hearings, we reported that ECI is already showing signs of being very successful. Work has been completed on 7 of 16 advanced technology concepts selected for development, and 4 concepts (Figure R-55) are in production in response to airline orders. The new fan concept improves the CF6 engine fan aerodynamic efficiency by modifying the shape of the blades and reducing blade tip clearances, using a fan case stiffener. The new fan will reduce engine specific fuel consumption (SFC) by 1.8 percent and is estimated to save one billion gallons of fuel over the next 25 years. The short core nozzle concept reduces the CF6 engine weight and engine nozzle scrubbing drag. The concept will improve engine SFC by 0.9 percent and is predicted to save 200 million gallons of fuel over the next 25 years. The new front engine mount reduces local CF6 engine compressor case distortion by providing a more uniform distribution of engine loads in the forward structure. This change allows the compressor to operate with reduced blade-to-case tip clearances. The new mount will improve engine SFC by 0.1 percent and is estimated to save 70 million gallons of fuel over the next 25 years. The active clearance control concept reduces JT9D high pressure turbine (HPT) blade-to-case tip clearance by modifying the fan air delivery and distribution system that cools the HPT case. The concept will improve engine SFC by 0.7 percent. It is predicted to save over 300 million gallons of fuel over the next 25 years.

In FY 1981, the performance improvement technology effort will continue to develop improved cooling schemes for the JT8D HPT blades and the CF6 turbine active clearance control systems, advanced thermal barrier coatings for the JT9D HPT vanes and outer air seals, improved blade tip clearance in the JT8D compressor and CF6 HPT, reduced CF6 compressor bleed requirements, and improved JT8D exhaust nozzle efficiency.

Some of the ECI performance improvement technology has substantially contributed to the engine SFC benefits in the new derivative CF6-80 and JT9D-7R4 engines, which were recently ordered for the new Boeing 767 aircraft. Some of the performance improvement technology will also be incorporated in the new derivative JT8D-209 engine, which powers the new DC-9 Super 80 aircraft.

In the engine diagnostics activity, we have been highly successful in developing useful CF6 and JT9D engine performance deterioration information for industry. A number of airlines have already applied the information to engine refurbishment and engine maintenance management programs. An engine SFC improvement of 1.0 percent has been demonstrated, and as much as a 50 percent reduction in costly unscheduled engine removal rates has been

achieved. In FY 1981, the engine diagnostics program will continue to evaluate the sensitivity of component performance to parts deterioration through engine ground tests and flight tests.

As we mentioned to you in October, we expect the total fuel savings to be realized by the engine performance improvement and engine diagnostics programs to be 9 billion gallons over the next 25 years.

Advanced Turboprop: The Advanced Turboprop program will develop technology for efficient, reliable, and acceptable operation of advanced turboprop-powered aircraft at cruise speeds ranging from Mach 0.7 to 0.8. The technology generated in this program will be applicable to short-haul/ medium-haul/long-haul transports, cargo aircraft, high-speed business aircraft, and military long-endurance and long-range subsonic aircraft.

In FY 1981, we will initiate Phase II of the Advanced Turboprop program, as illustrated in Figure R-56. Phase II will build on the extensive small-scale high-speed propeller aerodynamics, acoustics, and structures technology data base developed during Phase I and will establish the fabrication feasibility and structural integrity of large-scale propellers in 8 to 10-foot diameters. The final Phase I propeller design will be a near optimum match of aerodynamic, acoustic, and aeroelastic characteristics to meet the program goals for performance and user acceptability. The propeller blades will be characterized by a highly swept planform shape and thin airfoil sections to minimize compressibility losses and propeller noise during high-speed cruise. Because of the high-sweep and thinness of the blades, structural limits will strongly influence the design of the large-scale high-speed propeller. Therefore, in FY 1981 an extensive analysis and design activity will be undertaken to integrate the aeroacoustic and aeroelastic characteristics of the large-scale propeller. In addition, high-speed wind tunnel methods will be evaluated for future use in Phase II.

As shown in Figure R-56, work in subsequent years will include the fabrication of the large-scale propeller, the design and assembly of a modified propeller drive system, and the performance of static propulsion system checkout tests followed by low-speed and high-speed aeroelastic and aeroexcitation tests. While the primary emphasis in Phase II will be on the definition of the structural dynamics of large high-speed propellers, there will also be work in other technology areas. Further advanced turboprop model installation aerodynamics tests will be made. The development of fuselage acoustic technology will continue with tests and upgrading of analytical capability. Conceptual engine design and preliminary designs of

advanced gearboxes and pitch-change systems will also be evaluated.

Variable Cycle Engine: The Variable Cycle Engine (VCE) Technology program is progressing from the initial assessment of the feasibility and readiness of critical component technologies to development and demonstration of the principal variable cycle concepts. Ongoing activities have successfully demonstrated the performance capabilities and environmental characteristics of components unique to these propulsion system concepts for future advanced supersonic cruise aircraft. We are currently preparing both the General Electric and Pratt & Whitney Aircraft VCE test systems for major experimental investigations of the aero/acoustic performance of the advanced components depicted in Figure R-57.

The General Electric system, which utilizes the YJ101 engine, has been modified to relocate the last stage (rear block) of the split fan from the low spool to the high spool of the compressor system. This relocation provides both performance and weight advantages in addition to the ability to extend airflow at low throttle settings for enhanced acoustic benefits during takeoff at community cut-back and approach flight conditions. The full engine demonstration of the aero/acoustic performance of this configuration will also include an early assessment of the additional noise reduction benefit to be provided by incorporating a simple mechanical suppressor on the outer stream of the coannular nozzle. Analyses indicate that approximately 5 PNdB of additional suppression can be achieved by incorporating a 20 shallow chute suppressor with minimal aerodynamic performance penalties.

The Pratt & Whitney system, built upon the F100 engine, will be configured for an aero/acoustic performance evaluation of the duct burner operating in conjunction with the coannular ejector nozzle exhaust system. Tests will provide large-scale verification of the coannular nozzle jet noise reduction. In addition, a correlation of internal noise measurements with far field measurements will be made in order to specifically identify the contribution of the duct burner to the overall engine noise signature.

As we progress from these basic technology efforts into the FY 1981 program, major emphasis will focus on the development and demonstration of the critical low-spool technologies unique to these variable cycle propulsion systems. New concepts will be investigated, and promising concepts identified in prior years will be developed further to achieve noise reductions greater than have been demonstrated to date.

These activities are pictorially displayed in Figures R-58 and R-59 for each discrete phase of the VCE Technology program. In addition to the component efforts already discussed, the FY 1976-1980 program included demonstrations of a low emissions duct burner and both forward and rear variable area bypass injectors (VABI).

The FY 1980 augmentation provided by Congress has permitted a focused expansion of the fundamental acoustic technology base. This activity constitutes an important precursor to the FY 1981 program because further advances in fundamental jet noise suppression technology are required if advanced supersonic cruise aircraft are to meet subsonic aircraft noise rules. Specifically, these efforts will include aero/acoustic model evaluations of mechanical suppressor concepts on the outer stream of a coannular ejector nozzle system including forward velocity effects. A scale model investigation of the jet noise reduction provided by a thin high-temperature low velocity gas stream (thermal acoustic shield) surrounding a primary jet exhaust will also be evaluated, including a determination of the design variables that influence the thermal acoustic shield noise suppression effectiveness. This augmentation will also permit utilization of the VCE test systems to assess the effectiveness of an acoustically treated shroud when operating in conjunction with a suppressed coannular plug nozzle and to conduct an early first evaluation of the forward radiated fan noise of a VCE when operating with a low noise supersonic inlet.

In FY 1981, the General Electric efforts relative to the double bypass engine concept (Figure R-58) will extend the development of mechanical suppressors for the outer stream of the coannular plug nozzle and other promising advanced acoustic suppression techniques. Selected designs will be incorporated into system demonstrations to verify performance and fully characterize operational limits. Design and fabrication of an advanced front block fan will be initiated. This component must be capable of providing efficient aerodynamic performance over a wide range of airflows in order to realize the maximum acoustic suppression capabilities of the double bypass cycle. Performance of this advanced fan design will subsequently be verified in a component rig test. Design studies of an advanced low pressure turbine will also be initiated during this period, as will preliminary activities relative to an inlet/engine acoustics test in a low-speed simulated flight environment in the Ames 40x80-Foot Wind Tunnel to verify that the coannular noise benefit is maintained in a forward velocity field.

Pratt & Whitney efforts in FY 1981 relative to the variable stream control engine concept (Figure R-59) will also

focus on the development of mechanical suppressors operating in conjunction with an acoustically treated ejector nozzle system and other promising advanced acoustic suppression techniques. A significant effort will be initiated relative to an advanced duct burner system for this propulsion concept. This will include analytical and flow visualization studies plus sector rig screening tests of the most promising candidate configurations. The selected designs will then be incorporated into the test system for demonstration of component/system performance and environmental characteristics. Analytical studies and experimental investigations of high area ratio fan duct diffuser contours which permit efficient diffusion of fan discharge flow consistent with close coupling of the duct burner system will also be initiated during this period.

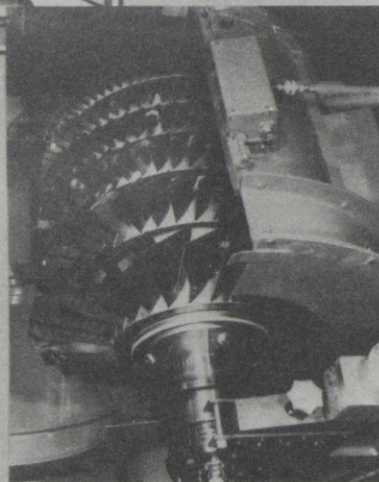
In summary, the VCE technology program has made significant progress in demonstrating the availability and viability of critical component technologies unique to these advanced propulsion concepts. The FY 1980 augmentation, with emphasis focused on fundamental acoustic technology, and the FY 1981 program, which continues key low-spool technologies and advanced suppression techniques, represent a logical extension of NASA's efforts to provide an expanded supersonic propulsion technology base for future civil and military supersonic cruise aircraft.

NASA

ENERGY EFFICIENT ENGINE

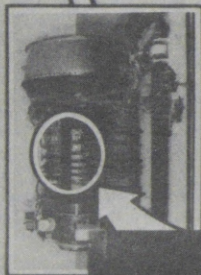
OAST

COMPRESSOR DEVELOPMENT AND INTEGRATION



HIGH PRESSURE
COMPRESSOR

NASA HQ R-80-1007(3)
1-4-80



COMPRESSOR RIG

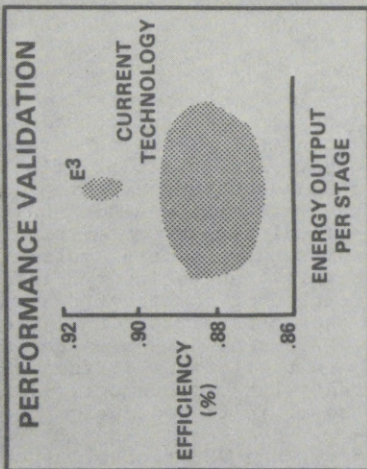


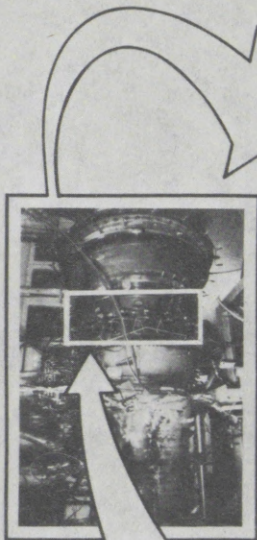
FIGURE R-53

COMBUSTOR DEVELOPMENT AND INTEGRATION



ANNULAR COMBUSTOR

NASA HQ RJ80-1005(3)
1-4-80



COMBUSTOR RIG

PERFORMANCE
VALIDATION

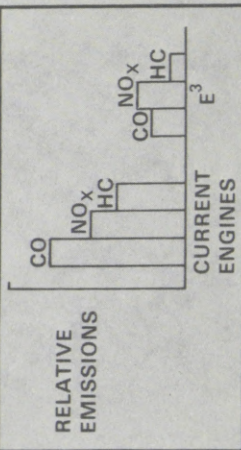
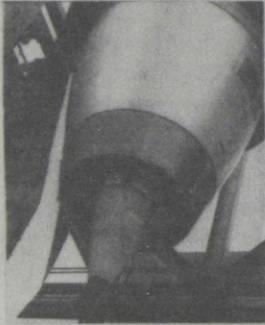


FIGURE R-54

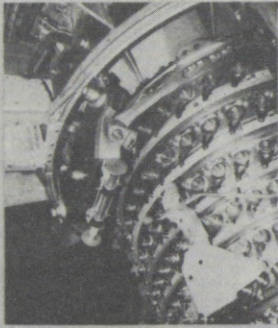
NASA ENGINE COMPONENT IMPROVEMENT



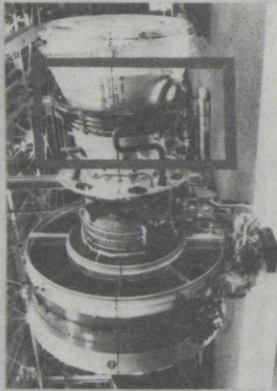
NEW FAN



SHORT CORE NOZZLE



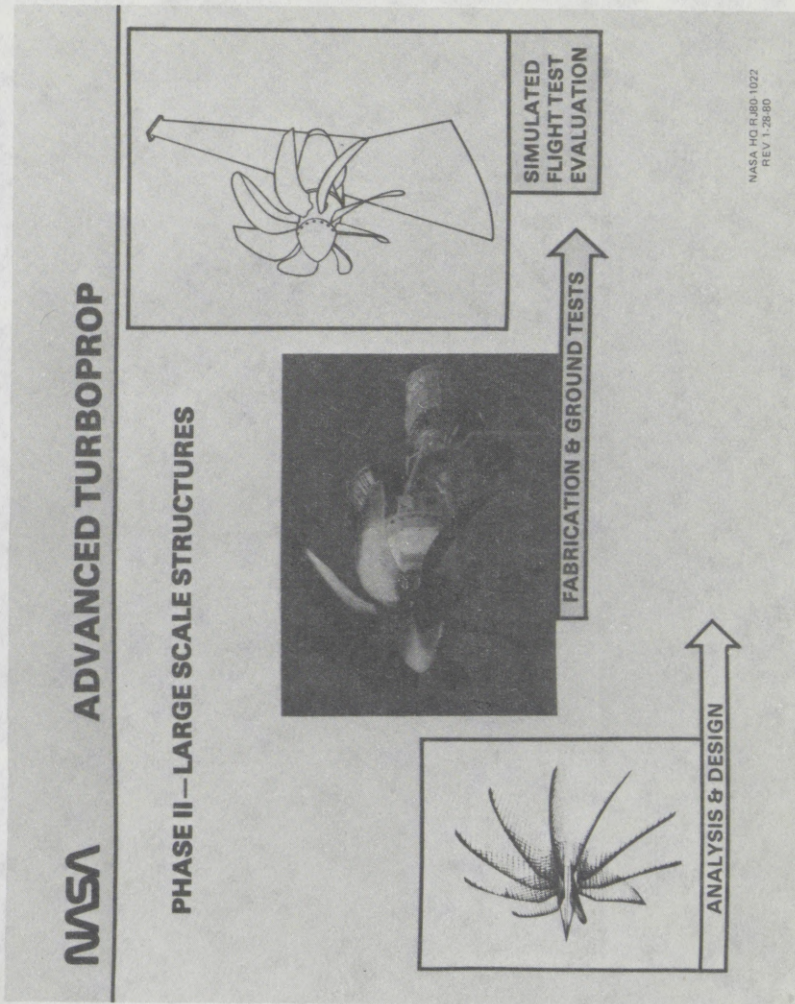
FRONT ENGINE MOUNT

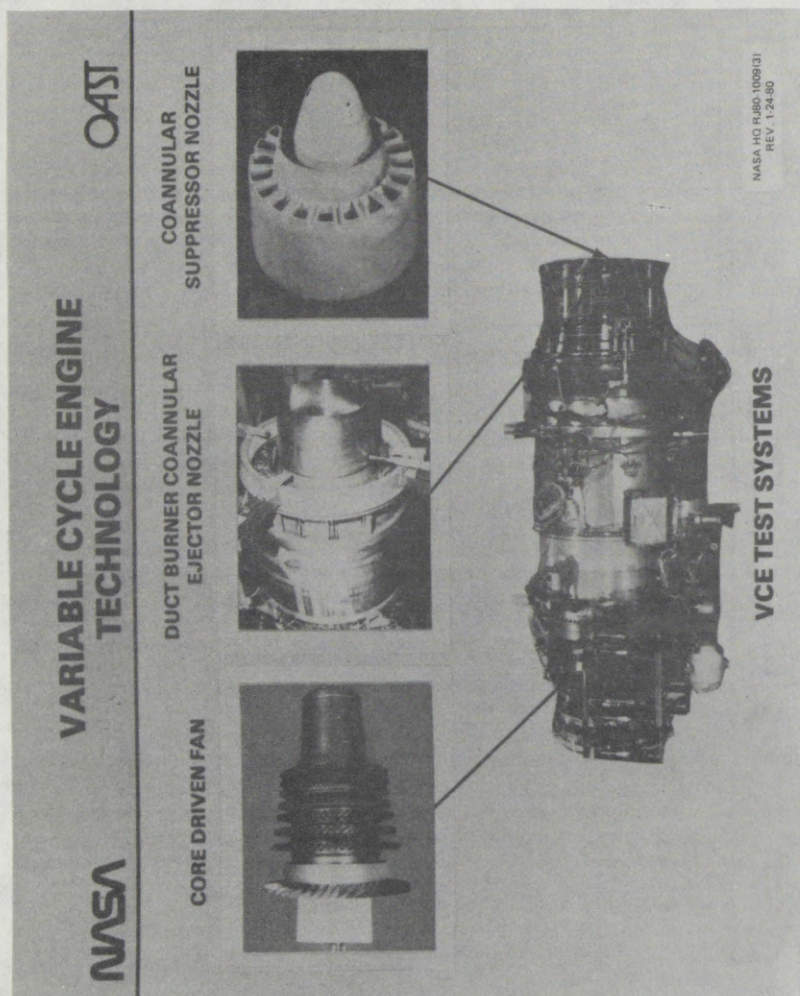


ACTIVE CLEARANCE CONTROL

**9 BILLION GALLON
FUEL SAVINGS**

NASA HQ RL80-1020(3)
1-480





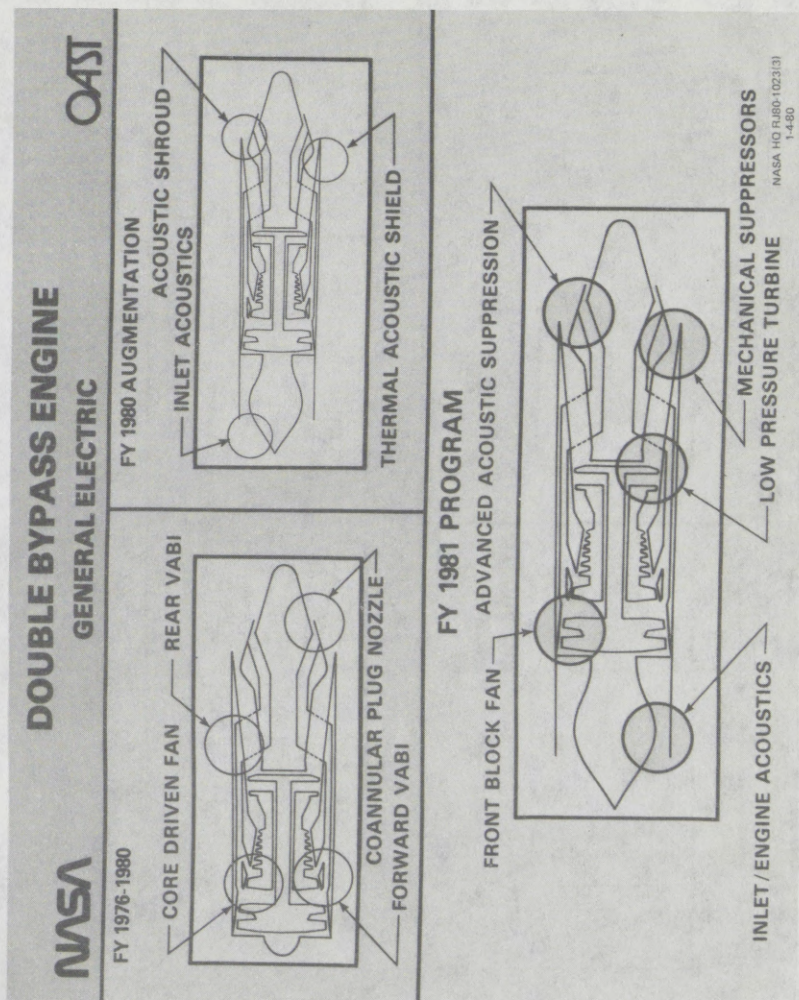


FIGURE R-58

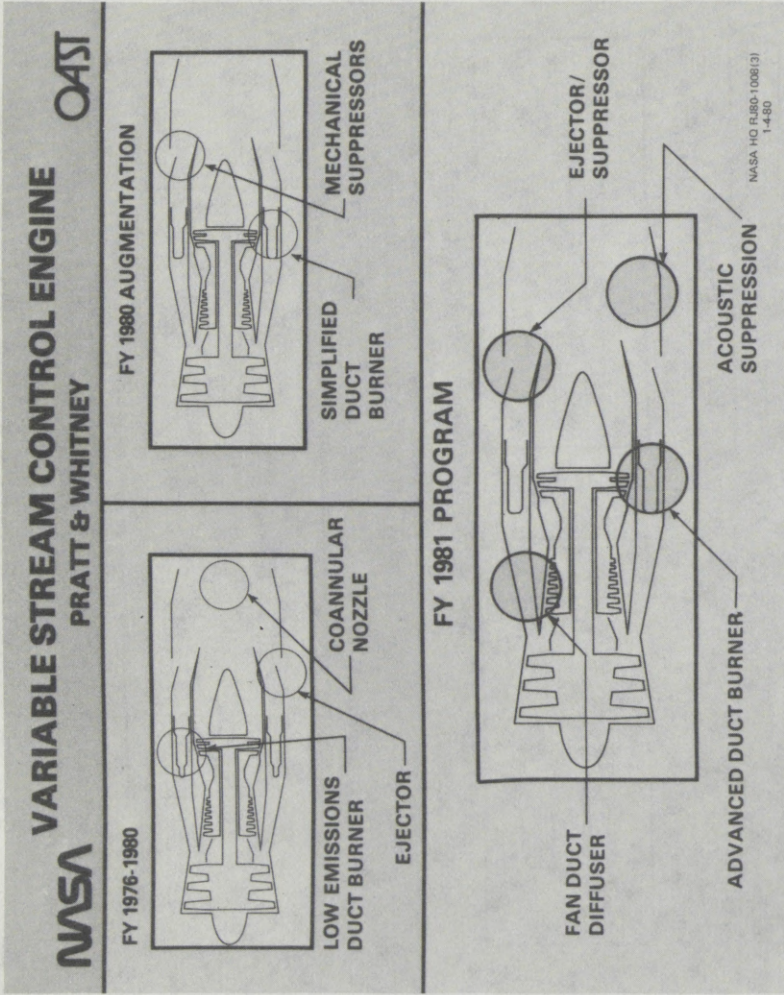
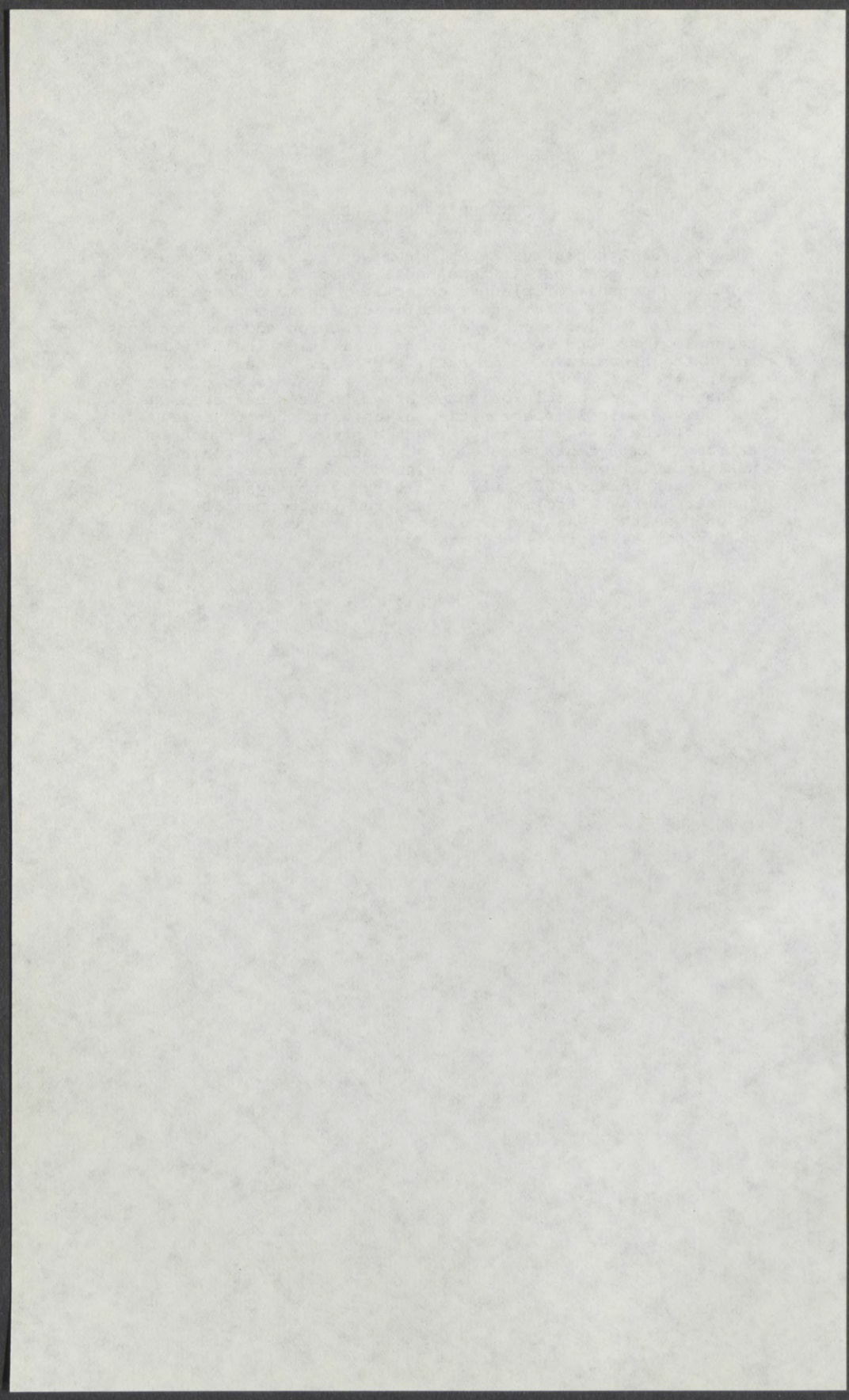


FIGURE R-59

CONCLUDING REMARKS

The FY 1981 Aeronautics R&T program we have proposed contains a strong effort in fundamental research, the continued pursuit of planned objectives in major ongoing programs such as ACEE, and significant enhancements in rotorcraft, variable cycle engine, turboprop and hot section technologies. Our recent planning activities indicate these to be the areas in need of early emphasis. We are also laying the R&T foundations for future endeavors in other fundamental or vehicle-oriented areas to be undertaken when the technological opportunities align with the projected needs of the user community. Such a strong R&T effort is extremely important because of our national need for a healthy aviation industry, continued preeminence in the world marketplace, effective military weapon systems, greater energy efficiency, and reduced environmental impact. We propose that NASA continue to play a major role in meeting these national objectives.



1981 NASA AUTHORIZATION

THURSDAY, FEBRUARY 7, 1980

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND COMMUNICATIONS,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2 p.m. in room 2318, Rayburn House Office Building.

Mr. GOLDWATER. The subcommittee will come to order.

Tom Harkin, the chairman of the subcommittee, has asked me to chair the hearing today. He is tied up in an Agriculture Committee mark up. He will try to get here later, but he wanted me to extend his apologies for not being here now.

Today the subcommittee will continue hearings on the fiscal year 1981 NASA aeronautics budget request.

We learned yesterday that NASA is proposing four augmentations to their on-going program. Each of these responds to national research needs in a specific area of aeronautics.

In addition to these four, NASA proposed 11 other augmentations to OMB. All of them appear to have a high degree of merit. Unfortunately, OMB denied the necessary funding—a total of \$37 million. Had these been approved, the NASA aeronautics program still would have been below the 1980 level, in real terms. As it is, the request represents a decline, in actual dollars, of about 6 percent.

So to gather additional information on these items, the subcommittee has invited a series of four expert witnesses from outside the agency. Each will address certain selected programs and issues. We will also be receptive to any additional comments from interested parties outside of government. We will hold the record open for that.

I want to welcome Mr. F. A. Cleveland, corporate vice president, engineering; of Lockheed Corp., Burbank, Calif. With Mr. Cleveland is Daniel Brewer, manager, hydrogen program; advanced commercial systems design.

Gentlemen, proceed as you wish.

STATEMENT OF F. A. CLEVELAND, CORPORATE VICE PRESIDENT, ENGINEERING, LOCKHEED CORP.; ACCOMPANIED BY G. DANIEL BREWER, MANAGER, HYDROGEN PROGRAM, ADVANCED COMMERCIAL SYSTEMS DESIGN, LOCKHEED CALIFORNIA COMPANY, BURBANK, CALIF.

Mr. CLEVELAND. Thank you, Mr. Chairman.

We appreciate the opportunity to identify and discuss this one par-

ticular area that we consider to be a national R. & T. need. We always appreciate the perceptiveness of this committee in technological areas and the opportunity to discuss them with you.

As you indicated, my associate has been identified with this liquid hydrogen program for many years. Lockheed's earliest experience in liquid hydrogen exploration dates back to some of the early Kelly Johnson work in the 1950's. Since then of course the United States has had a wealth of experience with liquid hydrogen as it has been employed in the national space program.

We have submitted rather complete written testimony and today we intend that our joint presentation to you will take something of the order of 20 minutes, perhaps a little less.

I thought that sometimes the words of others state a particular situation better than our own, which may be sometimes considered biased.

I think the last time I appeared before this committee as president of AIAA, I offered a quote from Kipling. I will be a little more current today by suggesting that the editor of *Air Transport World*, a man by the name of Jim Woolsey, with whom you are probably acquainted, had an editorial not too long ago, three sentences of which seemed to me to set the stage for the presentation which Mr. Brewer will make. He said first, "Fuel, the most retarded of all airline technologies, has become the key to the future of the world's air transport industry." A couple of sentences later he said, "The main attraction of petroleum then was that it was readily available and cheap. It no longer has either of these characteristics. Its only virtue now is that it has no alternatives." And last he said, "Aviation breached the sound barrier many years ago. Now we must pick up where we left off in the 1960's and develop the technology to get through the fuel barrier."

I think those few sentences characterize the area that we want to emphasize for your consideration. To continue with the paraphrasing of the testimony that we presented, using a few viewgraphs for clarity, I would like to turn this over to Dan Brewer, after which time we are, of course, available for questions at your pleasure. Thank you.

Mr. BREWER. Thank you, Al.

The written testimony which was submitted earlier provides some details concerning the need for an alternate fuel development program and an explanation of why liquid hydrogen is recommended for priority attention.

We will give a brief description of the program which has been proposed and, finally, a review of the status of the efforts to implement that plan.

In the next 15 minutes or so I would like to review the highlights of our statement for you, emphasizing what we consider to be the critical elements.

This slide illustrates the problem (fig. 1).

It plots the annual crude oil production in the world in billions of barrels as a function of years. Superimposed on those two plots, that is the maxima and minima, are aircraft life cycles, showing 10 years each for design and development and for production. It assumes the aircraft is in use for 20 years after it has been produced.

The message here is that the peaks of those maxima and minima curves of the world's annual production of crude oil occur in one

decade from 1990 to the year 2000, after which crude oil base products will be both very costly and limited in availability.

As you see, the bars representing the life cycle of the aircraft extend far beyond either of the peaks, so the message is clear. There is a very serious problem pending for the air transport industry.

During the past 7 years Lockheed has done a number of studies under NASA auspices, which have resulted in aircraft designs as illustrated here.

This particular design (fig. 3) is for a 400-passenger, 5,500-nautical-mile range airplane. The external configuration is quite conventional, and a lay observer seeing the airplane at an airport or flying through the air would have no inkling as to its fuel.

Right at the moment, the only thing I would like to emphasize is the location of the fuel in the fuselage. There is no liquid hydrogen contained in the wings, as is the practice on current fuel aircraft.

The tanks to carry the liquid hydrogen which, incidentally, is stored as a saturated liquid at only 37° above absolute zero, have to be very carefully insulated.

The tank configuration is a cylinder, which is the nearest approximation we can come to a sphere, for the purpose of minimizing the weight of the structure and of the insulation system, and also minimizing the weight of the gaseous hydrogen which would boil off as a result of heat leaks into it.

The location of the tanks fore and aft serves beneficially to minimize the tail size, because it offers center of gravity control.

We feel that we have a very good handle on the weight and the complication of the fuel system required in such an aircraft such as we just saw—that is, as far as design and analysis is concerned.

The weights shown in the top two lines, the gross weight and the fuel weight for a liquid hydrogen airplane, liquid methane fueled airplane, and synjet fueled airplane, represent our best estimate as to what such aircraft will weigh and how much fuel they will take. The overall weight advantage for the hydrogen airplane is obvious.

Incidentally, I should point out that the aircraft represented for each fuel is separately analyzed. Each aircraft is optimized for its specific mission and fuel. Three separate airplanes are represented here. The weight advantage is perhaps illustrated by the point that the lighter the weight the less specific energy is required to lift that airplane to a cruise altitude and to accelerate it to cruise speed.

Noise is lower for the liquid hydrogen-fueled airplane by about five EPNDB. In lay terms, that says that the liquid hydrogen airplane would be about half as objectionable as the counterpart synjet-fueled aircraft to people who live around airports.

The next two items, direct operating cost and total process energy, are calculated based on fuel costs and thermal efficiency for manufacturing the fuel from coal. These values were picked from NASA Report TM 80155. It is reference 8 in the written testimony.

Looking first at total process energy, we emphasize that in this case all three of the fuels are assumed to be made from coal. The total process energy is expressed in tons of coal that are required to manufacture each of the fuels and to thereby enable the airplane to fly its designed mission. That is, carry 400 passengers for 5,500 nautical miles—there was a zero left off the range value on the slide.

Here again, you can see that the liquid hydrogen airplane has about a 10 percent advantage over liquid methane and about a 35 percent advantage over synjet in terms of the number of tons of coal that would have to be dug out of the ground.

Now, direct operating cost shows a slight disadvantage for the hydrogen airplane. To illustrate how that looks in relative terms, let's take a look at the next slide. [Slide.]

Once again, let me emphasize that the costs of the fuels were taken from NASA work which was performed under contract by the Institute of Gas Technology and by Linde. The results of the NASA contract cost studies were put together by NASA in report TM 80155 and are reflected here by the blackened symbols on the chart, for example, liquid hydrogen is shown \$11 per million Btu.

I should point out first, that direct operating cost is shown on the vertical axis and cost of fuel on the horizontal axis. For handy reference, at the top of the chart I have shown the cost of jet A fuel in cents per gallon.

In January of this year, airlines were paying about 80 cents per gallon, which is about \$6.40 per million Btu, in rough terms. Coming back then, \$11 per million Btu for liquid hydrogen, is to be compared to about \$8.47 and \$8.85 per million Btu for synjet and liquid methane, respectively.

In spite of the very decided cost disadvantage of hydrogen, you can see, by projecting a horizontal line across to direct operating cost, that the cost differences shown in the previous chart really are not that significant. To all intents and purposes, the direct operating costs that the airlines would experience are virtually the same with any of the fuels.

One other point to make from this curve is that you can see these lines diverge in the future. That is, the slope of the two lines representing LCH_4 and synjet compared to the slope of the LH_2 line. Since the slope of the hydrogen line is flatter, it can be expected that in the future, as costs and labor and capital equipment increase, and the cost of fuel goes off to the right, the cost of liquid hydrogen as a fuel will increase at a slower rate than either of the other two.

This curve at the bottom illustrates a potential technology advantage that liquid hydrogen has. It is a technology that would provide capability of laminar flow control—LFC—by wall cooling.

We are not using this possibility of LFC in any of our other presentation material here or considerations, because it is too far in the future. It is a theoretical possibility, but so little experimental work has been done on it that we don't predicate any of our assumptions on that basis. [Slide.]

The next two charts now—this is one of the two—summarize the effect of using liquid hydrogen in aircraft.

We have already discussed the effect on aircraft weights; however, I haven't mentioned that LH_2 aircraft will have smaller wings and a larger fuselage.

The noise advantage has been mentioned. For supersonic transports, because the liquid hydrogen version compared to its jet A fuel counterpart would be so much lighter and it would have a smaller wing, its sonic boom overpressure calculates to about one-half-pound-per-square-foot advantage.

The advantage as far as pollution for hydrogen, of course, is obvious and has been well publicized. The advantages are summarized here. There are no hydrocarbons, no oxides of carbon, and no sulfur. There are no particulates or smoke, in other words, no combustion odors around the airport. In addition, there is a very strong possibility of reduced nitrous oxide (NO_x).

With hydrogen most of the exhaust product is water vapor. The hydrogen-fueled airplane would be expected to have approximately twice as much as equivalent design of synjet-fueled aircraft. [Slide.]

Here again we have already touched on two or three of these items. We have not mentioned engine life or engine maintenance. It is forecast that hydrogen fueled aircraft engines will last up to 30 percent longer than corresponding jet A engine. Also, they will require less maintenance than their synjet fueled counterparts.

I would like to focus a little bit on safety and on availability. In the safety area, there are a number of aspects that can be discussed, but one of the significant ones is what happens in the event of an airplane crash.

Now, what I would like to address is the crash where people would survive the impact. Typically, this might be represented by a case where the airplane lands, a landing gear collapses and punctures the jet A fuel tanks in the wing, and a fire ensues. The kerosene spreads and envelops the fuselage in flame and so on.

Relative to the experience that we all know about with kerosene or jet A, in the case of the hydrogen fuel version, first of all, the tanks are in the fuselage and they are designed as pressure vessels so that they are inherently better able to withstand an otherwise survivable crash impact, that is, there is less likelihood of a tank being ruptured.

Let's ignore that and assume the tank is ruptured anyway. In the event of a major spill, liquid hydrogen tends to evaporate very rapidly. It only has to increase in temperature about 3.9° before the gaseous hydrogen becomes buoyant, relative to air at standard atmospheric conditions, so it will rapidly dissipate. Thus the fuel won't spread as far, nor will it persist as long.

When the fire is initiated, and it almost certainly would ignite in the event of a crash severe enough to rupture the tank, the fire would last only about one-tenth as long. This is because the combustion rate of hydrogen and air is very high. To summarize, the hydrogen fire won't spread as far, it won't last as long, and its emissivity is very low. That is, its thermal radiation in a lateral direction is very low, again, about a factor of one-tenth.

What this means in practical terms is that the people or structure located near the fire would not be nearly as adversely affected, relative to a jet A fuel spill, because the diameter of the heat affected zone is much less. Thus, the liquid hydrogen fire would be far safer, both to the people in the airplane that survive the impact, and also to the people and property in the surrounding area if the crash happens to be in an urban area.

There is another aspect about safety that I would like to mention. I am dwelling pretty long on this, but I think it is very important. It is one of the criteria, one of the questions, people invariably ask us: Isn't hydrogen hazardous?

It is a very high energy fuel and has to be handled with respect, but the experience in the space program has shown that it can be handled very safely. NASA planned a very extensive spill test program, I think about 1 year ago, in which 1,500-gallon quantities of hydrogen would be spilled successively, under carefully instrumented conditions, so they could get data on how the vapor spreads from the spilled liquid, what the temperatures are and so on. They also planned to do some analyses to formulate a computer program with which the results of such spills of LH_2 could be represented, and also to conduct some tests to study the detonability of hydrogen under various conditions. This amounted to about a \$2 million program. The NASA Advisory Council strongly endorsed and supported the need for this program.

It is my understanding that as a result of budget pressures, that program has now been cut back to about one-half a million dollars.

We would like to add our recommendation that this is a very vital program and urge that serious consideration be made to restoring that budget for this NASA in-house program.

Let me emphasize that these comments regarding the NASA safety program are extemporaneous and are not part of our written testimony.

Mr. GOLDWATER. If you have a leak and the fumes get into the cabin, don't you have a good possibility of explosion or fire?

Mr. BREWER. Yes; that is entirely possible. There are two points to be made about that. One is, in order for the gaseous hydrogen to get into the passenger compartment, you have to rupture two bulkheads, two pressure bulkheads. The tank itself has to rupture. In the designs that you saw there is a separate bulkhead that separates the passenger compartment completely from the compartment in which the tank is located. So it would take a very strong impact for both of those bulkheads to be ruptured. Accordingly the possibility of passenger survival in the event both of these bulkheads are ruptured is fairly small.

A second point is, the design is such that in the compartment surrounding the tank, that is, at both ends of the tank, there are sniffers which sense the presence of gaseous hydrogen. As soon as a leak developed that might release gaseous hydrogen in this area, a purge system would come on and it would vent the gaseous hydrogen. In short, I guess the answer is, there are engineering ways around that potential trouble.

Mr. GOLDWATER. I know that when you spill liquid hydrogen or liquid natural gas it vaporizes fairly quick and the chance of explosion are remote. But if you capture that into an enclosed system like a cabin of an airplane, the fuel-air ratio would very well be gained and an explosion would be possible.

Mr. BREWER. That's correct. The probability of a gaseous hydrogen-air detonation in a confined area is quite high. That is an unfortunate characteristic of hydrogen, but what we are saying is, we think we can design around that so that in most probable situations it wouldn't happen.

One further point about this NASA spill test safety program. We feel it is a vital program and, we urge reconsideration of the budget in fiscal year 1981 to include another half million dollars, plus plans

for \$1 million in fiscal year 1982, in order for the complete NASA program as originally planned, to be continued.

Now, we haven't talked about availability at all. Let me be brief about that. It is covered reasonably well in our written testimony.

The point is that hydrogen can be manufactured from water using nearly any kind of energy source which might be available, nuclear, solar, or hydroelectric. Whatever is available anywhere around the globe. Because of this, hydrogen can be considered a truly universal fuel. On the other hand, both synjet and methane are dependent on the availability of fossil material for their manufacture in large quantities; coal, oil shale, and tar sands are limited in distribution around the globe. [Slide.]

In Stuttgart last September we proposed a program involving two phases. Phase I was research and development, phase II was a demonstration to accomplish the objectives listed there. Under phase I, we would do technology development for processes for manufacturing hydrogen and for the development of the components and systems that are needed in the aircraft.

Phase II was intended to follow in series with phase I. As of this point in time it has not been defined and is not called upon to be defined until near the end of phase I. That is, how extensive it is and what it consists of. But it would have the objectives of developing airport facilities and procedures. Also, it would give all the certifying agencies that might be involved in any part of the process a basis for writing specifications. Finally, one of the most important things, is to provide a basis for public confidence and safety in the large scale use of hydrogen. [Slide.]

A schedule that was proposed for this program is illustrated here. I would like to focus on just phase I because, as I say, phase II is undefined.

The schedule shown is what was proposed at the Stuttgart symposium, but it is not necessarily what might be used. More detailed planning is currently in progress. Phase I is shown here as a 2½ year program.

I think the major point that I would like to make is that, in view of the urgency that we can see in terms of the first chart which showed the growing unavailability of world crude oil and the long time required for development and use of the aircraft, we need to get started right away in order to avoid this pinch point where we have thousands of aircraft and no fuel to use in them.

A 2½-year program starting in mid-1981 would bring us down to the end of 1983. That is getting uncomfortably close to the point in time when we have to make a decision. [Slide.]

The final chart is one that shows costs estimated for phase I, the research and development program. Over this period we have suggested a budget like \$65.5 million which would bring us to the point where we could intelligently make a decision about phase II and could then decide what the scope and the magnitude of the phase II program would be.

Fiscal year 1981 would require expenditures of something like \$8 million. Fiscal year 1982—I am reading the column on the extreme right. Fiscal 1982 would be \$36 million, fiscal 1983 would be \$21.5 million.

This total is divided up roughly in the ratio you see there for sub-totals in the boxed area. About \$28.5 million for the airframe and engine combination, and about \$37 million for the hydrogen manufacture, liquefaction, and airport storage and handling facilities.

This program is needed urgently, we feel, in order to get started on phase I so that we can establish a credible basis for an ultimate examination of what alternate fuel should be used in the air transport industry.

Thank you.

Mr. GOLDWATER. Thank you, Mr. Brewer.

This is a project that you have been working on for some time, I assume.

Mr. BREWER. Yes, indeed.

Mr. GOLDWATER. I understand that most of this analysis has been based largely on theory.

Mr. BREWER. Correct.

Mr. GOLDWATER. And very little actual hardware or extensive research. You are saying to us that you feel it is a viable program and that we ought to have some kind of government effort in this area.

What kind of support do you have from industry on this?

Mr. CLEVELAND. It is kind of a mixed bag. Of course, I am a little reluctant to speak for other companies, but other airframe companies do not appear to be as interested in the subject as we.

Whether or not that is a valid lack of concern or not is conjectural and represents a fundamental difference of opinion.

As you said, most of the experience with liquid hydrogen has been in the space program, which is not the same thing as flying aircraft. And so there are uncertainties, but we feel that they are gradually being disposed of, and a program like this would permit getting far enough along in the R. & D. that we would be able to make a rational decision when that decision is needed, based on factual data and not paper.

Mr. GOLDWATER. If one were to believe your aircraft life cycle chart and the available supply of production, it is something that industry ought to be concerned about as well as the government.

These same kind of charts were used I think back before the Second World War by, I think, Senator Mahoney, who was crying alarm about running out of oil. I think we don't absolutely know how much fossil fuel or oil there is in the ground and at what price, but nevertheless, we ought to be thinking about this, because this chart could very well be true.

Mr. CLEVELAND. And of course, the chart doesn't even speak to what you just mentioned, which is: At what price? When the day comes when it is in fact cheaper to use an alternate fuel—we presume hydrogen, although maybe something else would come along—then again we would have to run head over heels into finding out some of these things to be sure that that was in fact a viable alternative. That is, on a price basis alone, not just exhaustion.

Mr. GOLDWATER. Just one observation. I suspect that no pilot will want to fly this commercial airline.

Mr. CLEVELAND. I don't know. We had a bunch of astronauts who rode all the way to the Moon on liquid hydrogen.

Mr. GOLDWATER. Well, they are trained to be accustomed to deprivation. There is no way I can see where the stewardesses could get up to the cockpit. [Laughter.]

Mr. CLEVELAND. Is that bad?

Mr. GOLDWATER. Just an observation.

Mr. BREWER. You are certainly correct. In this design shown, there was no access from the pilots station to the cabin compartment. That does not say it can't be accommodated. If the airline shows some need for flight station members to have access to the cabin compartment, for whatever reason, it is entirely viable to have a tunnel—

Mr. GOLDWATER. I am not so sure that the need is with the airlines as it is with the pilots.

Did you look at the cost of converting our national system of storage and distribution? Did you ever get into that?

Mr. BREWER. No. We haven't looked at the national system. We had a contract from NASA to look at the cost of converting the airport in San Francisco, SFO, to use liquid hydrogen in their long-range airplanes. The cost represented there was \$340 million, to put a liquefaction plant on the airport at San Francisco, build the storage facilities and all of the infrastructure required at the airport to handle LH_2 -fueled airplanes. So that might be considered a representative price per major air terminal.

Mr. GOLDWATER. How much per airport?

Mr. BREWER. \$340 million.

Mr. GOLDWATER. I thought that's what you said.

What do you say to critics who say that liquid hydrogen takes more energy to produce than it gives off?

Mr. BREWER. That's true. However, what people do not say is that it costs more to manufacture any of the alternate fuels from coal, in terms of energy. That chart that we saw of the total process energy is based on an overall thermal efficiency of 60 percent for making hydrogen from coal. It is 63 percent for making liquid methane from coal, and 54 percent for making synjet from coal.

Mr. CLEVELAND. Actually, I think you will find that it costs more energy to make the coal or the oil to begin with, when it got planted in the ground, than we get back out of it, if that is a valid criticism, and I am not sure it is.

Mr. GOLDWATER. Mr. Royer.

Mr. ROYER. Thank you, Mr. Chairman. I think you have asked most of the questions.

I was wondering if you have an indication as to how much of our present sources of energy are consumed in this industry. Do you have a figure?

Mr. CLEVELAND. By the liquid hydrogen manufacturing industry today?

Mr. ROYER. No. I am talking about the aviation industry. The amount of crude oil that is being used in that industry in comparison with the overall supply that we are using.

Mr. BREWER. The fuel used by the air transport industry is about 4 percent of the total petroleum used in this country.

Mr. ROYER. I see. So 4 percent is the total consumption in this particular industry. I guess the thing that was running through my mind,

and I certainly don't like many parts of the allocation system that have been developed over the years, if we don't have some alternatives in the other industries where they can lessen their consumption of crude oil? Then, somehow, we can make our crude last a little longer and give you more time to develop the technology as to this type of fuel. If I understand correctly, existing technology has to be improved, as far as the transportation, storage, and safety of this fuel?

Mr. CLEVELAND. I am not sure if it has to be improved or pinned down better. We don't see anything that could in any way be categorized as the need for a breakthrough like we do in many areas—lasers and hypersonic aircraft and so on. They require breakthroughs of some sort, but not as far as we can see, to go to this kind of a system.

Mr. ROYER. So what you are saying then, if I understand it correctly, is that you need the funds to refine what you have already done as far as the breakthrough is concerned.

Mr. CLEVELAND. Yes, sir.

Mr. ROYER. One question that has troubled me, and I think the gentleman from California asked this question, is the safety question. We have the same problem in the nuclear area. Somehow I think we have to be able to make sure that the public truly understands where we are and just what those safety problems are.

Mr. CLEVELAND. And we needed to know a little surer than we do. As Dan has told me, nobody, to our knowledge, no one has ever been killed during the entire operation of the use of liquid hydrogen in the U.S. program.

Second, as a kind of anecdote: Just as the Hindenburg disaster, which was such a flaming motion picture debacle, killed some 36 people. All of these people died from jumping to escape the crash, or from, as far as can be determined, the burning of the diesel fuel for the engines, plus one guy who had an engine fall on him. There was no one who died from the combustion of the hydrogen which was the entire buoyant feature of the Hindenburg.

I am not sure that that is significant, but it is indicative.

Mr. ROYER. Is there a possibility early on of studying how the public becomes informed on this, so that the concerns in their mind are not fixed early and become hard to remove? Is there anything in your programs that respond to that particular concern?

Mr. CLEVELAND. Probably one of the best is some kind of a demonstration program involving some use of aircraft. For example, you could in fact convert an airplane and operate it on some kind of a scheduled basis. Whether it is military or commercial is not really the important thing. The important thing would be some period of day-after-day activities of operating an airplane on a scheduled basis so that this familiarity would begin to grow and demonstrations could be given of the various aspects that are involved.

It would be an educational process, certainly, and it would take time, certainly, because that is the way the public is. It takes time to communicate.

Mr. ROYER. Just to follow up on that a little bit. What was the exact term you used when you said we have to do a little more?

Mr. CLEVELAND. I said that we needed to pin down and get more facts on the technologies.

Mr. ROYER. Yes. But as far as safety was concerned, you made a statement, and it seemed to me that you used a phrase that we have to be a little more sure, or something to that effect.

Mr. BREWER. Well, there are lots of unknowns, uncertainties about how hydrogen will react under various conditions. One of the essential points of this NASA spill test program that I made mention of is to explore those kinds of things.

Mr. ROYER. The chart on the wall provided for a 2½-year program. In your best judgment, at the end of that program, will these questions all be answered? That's probably asking too much, but what is your best judgment?

Mr. BREWER. If that 2½-year R. & D. program is consummated, plus this NASA spill test program they are separate—the NASA spill test program is funded to roughly half a million dollars for fiscal year 1980 and those tests will start next month. If those are done, plus the fiscal year 1981 test that I mentioned for which they need allocation of an extra half a million, plus the work in 1982, if everything together is done, then yes, we should have the answers that we can—

Mr. CLEVELAND. Experience would say we would probably have 9 out of 10 of them by then, if not all 10.

Mr. ROYER. That's 90 percent. That's not bad.

Mr. CLEVELAND. That would be a pretty good batting record.

Mr. ROYER. I think, Mr. Chairman, that concludes my questions. I yield back the balance of my time.

Mr. VOLKMER. I notice that the tanks are included within the fuselage. Do you have any idea of the weight of those things?

Mr. BREWER. Yes; we do. Unfortunately, I don't have a weight breakdown with me. Those tanks obviously weigh quite a bit more than the allocation for holding the kerosene in the current airplanes.

Mr. VOLKMER. That's what I thought.

Mr. BREWER. But the weight of the tanks and the insulation of them is all included in the weight of the airplanes shown there on table 2.

Mr. VOLKMER. That would be the weight of full tanks then?

Mr. BREWER. Full tanks.

Mr. CLEVELAND. The gross weight shown in there is the maximum takeoff gross weight.

Mr. BREWER. There is also another item listed in that same table called operating empty weight.

Mr. VOLKMER. All right. Have you discussed that at all with any of the major airlines?

Mr. BREWER. Yes, sir. We sure have.

Mr. VOLKMER. Is there any feeling there as to the approach you are taking?

Mr. BREWER. Well, we have had responses that vary from, "yes, let's go," to "no. Let's put it off as long as possible." It would be hard to say what a consensus of the U.S. industry is.

Mr. VOLKMER. If I can remember right you are asking for around \$8 million for R. & D. for 1981.

Mr. BREWER. For 1981.

Mr. VOLKMER. On this idea.

Mr. BREWER. Yes.

Mr. VOLKMER. About how much has Lockheed spent so far on this? Would you give me an approximation?

Mr. BREWER. Yes. Over the last 7 years we probably have put between \$300,000 to \$500,000 in it.

Mr. VOLKMER. Did you talk to NASA about this?

Mr. BREWER. Yes, sir.

Mr. VOLKMER. As to having this included in their budget for 1981?

Mr. BREWER. NASA has a 5-year plan which is for cryogenic fuels. It lists dollars about the same as has been listed here. There isn't a direct one-to-one comparison, but the same general size. I don't think any of that program is listed for fiscal year 1981, however.

Mr. VOLKMER. In other words, you really haven't sold NASA on this idea yet, as far as they are concerned?

Mr. CLEVELAND. Well, they have provided for much of the study work that has been done to date. They have shifting priorities and urgencies and we don't pretend to understand their complete budget problem. But, as of right now, the amount of money that they have committed in their planning does not include this.

Now, there was a working group which came out of this Stuttgart meeting to which we have alluded which included people from Rolls Royce; General Electric; British Aerospace; Lockheed; L'Air Liquide, France; NASA; DFVLR, which is the German NASA. There is one sentence that came out in their final report which speaks to that. This was unanimous.

The group felt that a strong statement should be made as to the importance of really continuing to generate the technology for liquid hydrogen and not just on an ordinary business basis.

Mr. VOLKMER. Thank you, Mr. Chairman. I have no other questions.

Mr. ROYER. Mr. Chairman, I had one other question, if I may.

Do we assume from the charts that you showed and that Mr. Goldwater referred to which are based on present consumption in all categories, that we would run out at a certain period?

Mr. CLEVELAND. Yes.

Mr. ROYER. So, if we can provide alternatives in other areas, that could stretch out that timespan.

Mr. CLEVELAND. Yes, sir. The point is, once having determined what we are recommending, it is on the shelf and it is available when in fact the real dates show up, whether they are those or something slightly different.

Mr. ROYER. Don't misunderstand me. I certainly support the research and development in these alternate sources. I was just trying to figure out which ones we need to zero in on to get the quickest results.

Mr. BREWER. I wonder if I can make a comment to a part of your question that wasn't answered.

The point is, since the air transport industry uses a small fraction of the total petroleum, why not have somebody else take the initiative to develop an alternative and let air transport keep using this little fraction which is theirs. I think one of the significant aspects of that is that it makes far greater sense to start up a small user with an alternate fuel than it is a big user, because of the entire logistics problems. If it is necessary to develop a whole new infrastructure for a tre-

mendous operation, of course, there are far greater headaches and it is much more expensive and you have to do things on a crash basis. For a small user like aircraft, it is made to order.

Mr. GOLDWATER. Just one last question.

What is happening in other countries in this area?

Mr. CLEVELAND. They are a part of these international working groups which were established in Stuttgart and they are having their meetings, as this one that I mentioned. Rolls, MBB and so on—those people are going through meetings with their governments and/or airlines and/or engine and airplane people, talking about what they want to do to share this, because, as Mr. Brewer pointed out, this is a great international type of opportunity and you can't very well take off from New York in a liquid hydrogen-powered airplane and land in Paris where there is no liquid hydrogen available. I should say, you can only do that once.

Mr. GOLDWATER. But are other governments or industry putting money into this?

Mr. CLEVELAND. They are in this discussion period, as far as I know now.

Mr. BREWER. It is too early to say they are putting money into it, but there is very strong interest that has been exhibited in Canada, England, France, and Germany in participating in this overall program we have shown here on the schedule and budget.

Mr. GOLDWATER. Well, we sure do want to thank you, Mr. Cleveland and Mr. Brewer, for making this presentation.

[The prepared statement of Mr. Cleveland follows:]

A PROGRAM FOR DEVELOPMENT OF LIQUID HYDROGEN FOR AIRCRAFT

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Presented to:

United States House of Representatives
Subcommittee for Transportation,
Aviation, and Communications

The Honorable Thomas Harkin, Chairman

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F. A. Cleveland
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Production of the world's petroleum is generally assumed to follow a bell-shaped curve^(1,2) which will reach a peak and start its decline in the 1990's, see Figure 1. At the same time, demand for energy will continue to increase due to growth of the less developed nations, despite any realistic conservation measures and improvements in utilization efficiency which may be achieved by the industrial nations.

Due to this growing mismatch between supply and demand, competition in world markets for the limited oil available will result in severe international trauma. Unless alternate sources of energy are developed, the less developed nations will be priced out of the market. Similarly, industries whose products are most sensitive to the cost of petroleum will be critically affected.

The air transport industry is a case in point. At the current price of Jet A fuel, 80 cents/gallon in January 1980, fuel purchases by U.A. international air carriers account for approximately 57 percent of their direct operating cost. As the price inevitably climbs higher, there is little doubt it will have an increasingly serious adverse effect on airline revenue passenger miles; hence, on the economic vitality of the industry and its infrastructure.

This is the short-range view of the problem. In ten to fifteen years the situation will go from bad to worse. When the rate of increase of annual production of crude oil in the world begins to fall off, i.e., just before the peaks are reached in the curves of Figure 1, there simply will not be enough crude oil to supply the needs of all economic sectors at any price. The available petroleum will be used for those applications which provide the highest return on investment, or those which are accorded special consideration because of priority need, e.g., medicines, special chemicals, military requirements.

For those petroleum users like the commercial air transport industry which cannot be expected to qualify under either category, the only recourse is to develop an alternate fuel. The viable alternatives for aircraft are synthetic aviation-grade kerosene (synjet), liquid methane (LCH_4), and liquid hydrogen (LH_2). A summary comparison of advantages and disadvantages of each is presented in Table 1.

It is apparent that liquid hydrogen provides significant advantages. The fact that it can be manufactured from water anywhere on the face of the earth using any source of energy which may be locally available, is one of the most impressive recommendations for its use in the aircraft application.

The basis for these conclusions regarding hydrogen is a comprehensive series of design studies which has been conducted under NASA sponsorship since 1973. The NASA-sponsored work has included aircraft conceptual design studies^(3,4,5,6,7); assessment of the most promising processes for manufacturing each of the alternate fuels^(8,9,10); determination of the requirements at airports so aircraft fueled with the cryogenic candidates (LH_2 and LCH_4) can be properly serviced^(11,12); and analysis and design of fuel systems for aircraft fueled with these cryogenic liquids⁽¹³⁾. The investigations have included analysis of aircraft designed for a wide range of cruise speeds (subsonic, supersonic, and hypersonic), sizes (passenger capacities ranging from 130 to 800 people, and cargo capacities of 125,000 lb and 250,000 lb.), and ranges (1500 n.mi. to over 10,500 n.mi.).

SUBSONIC TRANSPORT AIRCRAFT

The aircraft design which has received the most attention and has served as a baseline for studies of airport requirements and for the aircraft fuel system analysis is shown in Figure 2. This LH_2 -fueled aircraft is designed to carry 400 passengers, provide a maximum range of 10,190 km (5500 n.mi.), and cruise at Mach 0.85. The design incorporates all the technology improvements which are being developed for operational service in the 1990 decade; e.g., supercritical airfoil, active controls, composite structure, and advanced engine concepts.

Externally there is little to distinguish the configuration from current, conventionally-fueled subsonic transport aircraft. Internally there are some significant differences although the average passenger would not be aware of it. The 400 passengers are accommodated in a double-deck compartment located in the approximate center of the fuselage. Tanks insulated to contain the liquid hydrogen fuel without excessive boiloff are placed both forward and aft of the passenger compartment, where they occupy the full circular cross section of the fuselage. This arrangement provides several advantages. With cryogenic fuel it is important to minimize the surface-to-volume ratio of the container so both the weight of the structure and its insulation, and the potential for heat leak to the fuel can be held to minimum values. The design illustrated represents a realistic approximation of that goal. In addition, the concept of tanks located fore and aft of the passenger compartment provides for minimal shift of the aircraft center of gravity as passenger load varies and as fuel is consumed. This directly benefits the design by minimizing tail size requirements.

The cargo compartment is located below the passenger section in conventional fashion. Fore and aft extensions of the lobe which encloses the cargo hold provide structural protection for the underside of the fuel tanks in the event of a wheels-up landing or a tail scrape incident, and also provide a space through which electrical and hydraulic lines, control cables, and ducting can pass.

Refueling is accomplished at the aft tail cone of the fuselage. Connection is made there with two lines from the airport supply system through a special hydrant fueller vehicle. One line provides liquid hydrogen, the other is a vapor return line. All gaseous hydrogen

displaced by LH_2 as it enters the aircraft tanks is returned to the airport liquefaction plant for reprocessing. In the aircraft, corresponding LH_2 refueling and gaseous hydrogen vent lines are located in a tunnel shown atop the fuselage in Section AA of Figure 2.

LH_2 Engine Design

Engine studies performed during the LH_2 Fuel System Study (Reference 13) resulted in definition of a twin-spool, direct drive turbofan engine having a 40:1 overall pressure ratio with a single stage fan providing a 1.7:1 pressure ratio. The overall bypass ratio is 10:1 in cruise. Design rotor inlet temperature is 1482°C (2700°F). An objective of the study was to discover means for exploiting the characteristics of hydrogen in the most practicable manner to provide maximum performance. The resulting engine design used the cryogenic hydrogen in the following ways:

- Cooling of turbine cooling air. The cryogenic fuel is used to cool the high pressure turbine cooling air so it is possible to reduce the compressor bleed from 7 to 3.2 percent and still satisfactorily cool the turbine section. As a result, higher turbine efficiency can be realized.
- Cooling engine oil. This eliminates the need for a separate air inlet and thus reduces drag.
- Cooling cabin air. This affords the potential of eliminating the conventional aircraft air conditioning system.
- Use of core engine exhaust to heat the fuel to 678K (1220R) before injection into the combustor. The decrease in engine effectiveness which would normally result from removing heat from the exhaust is more than made up by the increase in work output from both the fan and core engine sections as a result of the increase in enthalpy of the fuel/air combustion products applied to both the high- and low-pressure turbine stages.

The four heat exchangers required to perform these functions all fit within the engine nacelle and weigh a total of approximately 109 kg (241 lb). The benefit derived is estimated to provide a reduction in specific fuel consumption of about 8 percent. This advantage is additional to the nominal 280 percent which stems from the fact the heat of combustion of LH_2 is 2.8 times that of Jet A fuel.

Fuel Containment System

The question of how best to contain the low density cryogenic fuel on board the aircraft was studied extensively. The design ultimately selected used an integral tank carefully insulated to provide the optimum tradeoff between insulation system weight and the amount of gaseous hydrogen which would be allowed to boil off during a typical operational day. The basis for selecting the optimum compromise was direct operating cost (DOC).

The analysis disclosed two candidate insulation systems which were nearly equally efficient and attractive. These were:

- Microspheres (hollow borosilicate spheres nominally 80 microns in diameter) contained in an annulus surrounding the tank. The annulus is pumped to a soft vacuum (0.1 torr).
- Rigid, closed cell plastic foam applied on the external surfaces of the tank and encased in a vapor barrier to prevent cryopumping of air.

Both of these insulation systems were recommended for experimental development so that ultimately a choice can be made between them on the basis of more adequate information than currently exists.

Aircraft Fuel System

In addition to the study of engines and fuel containment systems, the requirements of the following elements of the complete aircraft fuel system were established:

- Engine fuel delivery system
- Fueling/defueling systems
- Vent/pressurization systems
- Fuel management system
- Fuel jettison system
- Purge system

A complete description of these aircraft subsystems is provided in Reference 13. Some highlights of the considerations involved in their design, and of their design features, are as follows.

The engine fuel delivery system consists of everything that is required to deliver fuel from the tanks to the engines. Its principal elements are boost pumps located in each tank compartment, valves to control the flow, lines, a high pressure pump mounted on the engine, and a fuel control system to monitor the engine performance and make adjustments as necessary in the fuel flow so engine output is in accordance with demand as established by throttle settings at the flight station.

The fuel tanks forward and aft of the aircraft passenger section are both divided into two compartments so that each of the four engines can be supplied fuel from a separate compartment. There are three boost pumps in each tank compartment. This contrasts with only two which are required for conventionally fueled aircraft. The extra pump is

necessary with cryogenic fuel because airlines like to be able to fly even though one boost pump might be disabled. With conventional jet fuel, if one boost pump is out, the airplane can still take off with only one boost pump per engine operative because the engine pump will not cavitate even though kerosene is supplied only by gravity, as would occur if the second boost pump should fail. In the case of cryogenic hydrogen, if the second boost pump should fail and if there is no third pump, the fuel would vaporize in the line and the high pressure pump would cavitate, thus starving the engine and causing a flameout. The third boost pump in each compartment is therefore needed to allow takeoffs with one pump inoperative.

The boost pumps and the high pressure engine pump are both centrifugal designs. The boost pumps are three-stage, variable speed, driven by 270 Vdc motors. They are designed to provide a pressure increase of 317 kPa (46 psi) at all operational flow conditions. The engine-mounted high pressure pump is a two-stage centrifugal design, shaft-driven from an engine auxiliary gearbox at a fixed-speed ratio. It is designed to receive the hydrogen as a saturated liquid at a minimum of 345 kPa (50 psia) and deliver it at 517 kPa (750 psia) at the takeoff power setting which requires maximum fuel-flow rate.

The fuel-delivery line which carries fuel from the boost pump to the engine pump is 25.4 mm dia (1.0 in.) stainless steel. This tube is insulated with closed cell foam 38.1 mm (1.5 in.) thick which, in turn, is enclosed in a 101.6 mm dia (4.0 in.) aluminum tube. The outer tube provides a vapor barrier for the closed cell foam to prevent air from cryopumping; it also provides mechanical protection.

The engine fuel control system was devised to provide proper control of fuel-flow rate in accordance with engine operating conditions, command signals, and the local thermodynamic properties of the fuel. Since under all engine operating conditions, except for idle, the engine pump delivers fuel at a pressure higher than the critical pressure of hydrogen, 1293 kPa (187.5 psi), there is no problem with phase changes. Because of the relatively large capacitance of the fuel system downstream of the high pressure pump, due to the presence of the four heat exchangers previously mentioned plus the compressibility of the hydrogen, the engine fuel-control valve was located just upstream of the point of injection into the combustor. A turbine-type flowmeter would be located just upstream of the flow modulating valve.

Operating and Servicing Characteristics

Some of the unique fuel-related aspects of operating and servicing LH_2 -fueled aircraft include the following:

- At properly equipped airports, LH_2 -fueled aircraft can be refueled at gate positions exactly like conventionally fueled aircraft, i.e., while housekeeping operations are performed, passengers boarded, and cargo loaded. Turnaround time is estimated to be the same with either fuel. Servicing personnel will require some training in proper use of new refueling equipment.

- Liquid hydrogen should be maintained in the aircraft tanks at all times except when the aircraft is to be out of service for an extended period, e.g., more than a week, or during inspection or repair of the tanks.
- Routine visual inspection of the fuel tank structure from inside the tank should be performed at least every 8000 hours of flight service (approximately every other year), consistent with airline practice for all primary structure. This, of course, requires defueling, inerting, and flushing the tanks with air. Refueling requires careful flushing with gaseous nitrogen to remove air, then with gaseous hydrogen to remove nitrogen, before start of filling with LH_2 .
- The aircraft fuel tanks are pressurized to an absolute value, 145 kPa (21 psia), which is maintained at all times while there is LH_2 in the tanks.
- Gaseous hydrogen (GH_2) supplied by boiloff from liquid in the tanks is used to pressurize the fuel tanks. If pressure drops below 112 kPa (18 psia) additional GH_2 can be supplied by vaporizing LH_2 in a special heat exchanger. If tank pressure exceeds 159 kPa (23 psia), GH_2 is vented through a lightning-protected vent near the top of the vertical stabilizer.
- An out-of-service aircraft should be connected to a vapor return line whenever possible to permit return of cold GH_2 to an appropriate ground facility, preferably the airport liquefaction plant.
- Hangared LH_2 -fueled aircraft should be connected to an external GH_2 vent line to accommodate boiloff hydrogen from the fuel tanks. To guard against collection of GH_2 within the hangar in event of an inadvertent leak in the aircraft fuel system the hangar roof should be vented or a domed plastic canopy connected to an exhaust fan should be placed over the aircraft.

Comparison with Synjet and Liquid Methane Aircraft

The characteristics of aircraft fueled with the other alternate fuels, synjet and LCH_4 , were established with each designed to perform the same mission as the subject LH_2 airplane, and using identical technology and guidelines. Table 2 presents a comparison of pertinent features of these aircraft.

The operating cost and energy parameters shown in the table were derived on the basis that each of the alternate fuels would be manufactured from coal. The fuel costs and process thermal efficiencies which were the basis for calculating these parameters were taken from Reference 8, based on work performed for NASA by the Institute of Gas Technology and by Linde Division of Union Carbide Corp., using specified guidelines. The values reported in Table 2 reflect use of the most cost effective and efficient processes for manufacturing each fuel. It must be noted that other studies have produced results with costs which are both higher and lower than those shown here. For example, Reference 8 also lists data from unpublished work by The Boeing Commercial Airplane Company which shows higher

costs for LH_2 and lower cost for synjet. However, review of the data available indicates inconsistencies between overall process efficiencies and the costs, relative to the NASA-supervised analyses which were performed by reputable companies actively engaged in synthetic fuels research and development, and in production of cryogenic liquids.

Relative to this subject, it was the consensus of a symposium, "Hydrogen in Air Transportation," held in September, 1979 in Stuttgart, West Germany,

"That the cost of using liquid hydrogen in air transport, and particularly the comparison of costs among the potential alternate aircraft fuels, is undetermined now and a major study effort is justified to reach valid comparative fuel and operating costs. This is also international in scope and specific differences among countries should be analyzed."*

We concur in this statement of the need for a comprehensive evaluation of costs and have included this study as a task of a proposed research and development program discussed subsequently.

As seen in Table 2 the LH_2 -fueled aircraft is more attractive in nearly all of the design and operating parameters which are generally of interest in comparing competitive designs; it is considerably lighter and quieter, uses smaller engines which would require less maintenance and would last longer, has a shorter wing span, and requires less coal to manufacture the fuel needed to fly the design mission, i.e., lower Total Process Energy. The exception is that the synjet and LCH_4 aircraft are able to show slightly lower direct operating cost (DOC) in spite of the more efficient operation of the LH_2 fueled design, because of the lower cost of manufacturing the alternate fuels, relative to hydrogen. The relative significance of these considerations is discussed in the following sections.

Direct Operating Cost. - The fuel prices noted at the bottom of Table 2 were taken from data in Reference 8 assuming coal to be available for \$18.00 per ton. The price shown for LH_2 reflects use of the continuous steam-iron process for producing gaseous hydrogen from coal and water, advanced liquefaction techniques which have been identified, plus cost credit for sale of by-products produced during both the coal gasification and hydrogen liquefaction processes.

To put the DOC values listed in the table in perspective, a plot of DOC as a function of fuel price is shown in Figure 3. This illustrates that there is actually very little significant difference in DOC between aircraft designed to use any of the three fuels at current estimated prices; however, because of the divergence of the plots as shown, as the cost of coal, labor and capital equipment increase in the future, the DOC of the LH_2 aircraft will increase at a lower rate, thereby gaining the advantage.

*See Appendix A for the complete statement of the Ad Hoc Executive Group of the Stuttgart symposium.

For completeness, a price estimated for synjet manufactured from oil shale is also shown on Figure 3. If the problems currently recognized as obstacles in the way of satisfactory development of processes for releasing kerogen from the shale in commercial quantities can be overcome, those countries with significant deposits of oil shale will be able to operate their Jet A-fueled aircraft very competitively for a few decades. Unfortunately, the occurrence of oil shale throughout the world is not general enough that this option can be considered a satisfactory solution for the air transport industry.

Neither is it a satisfactory long-term answer in view of the fact oil shale is a nonrenewable resource. Bartlett (Reference 14) has very clearly stated the folly of depending on the vast shale deposits in Colorado and Wyoming as a long-term solution for our petroleum needs. For example, he has shown that assuming an annual growth rate of only 3 percent in the U.S. consumption of petroleum, and assuming a very optimistic figure of 103.4×10^9 barrels of oil recoverable from U.S. shale deposits, this resource plus the portion of our ultimate total production potential of 200×10^9 bbl. of crude oil which remains will be depleted in only 35 years!

For a discussion of the line on Figure 3 labeled " LH_2 with LFC by Wall Cooling,"† indicating substantially lower values of DOC for LH_2 aircraft, see the subsequent discussion of "Laminar Flow Control."

Total Process Energy. - Total process energy is the amount of energy required to manufacture the fuel needed by an aircraft to fly a specified mission. For example, in the present case where coal is assumed to be the basic resource used to manufacture each of the alternate fuels, the number of tons of coal required to produce the block fuel needed by an aircraft for its design mission is a convenient measure of total process energy. The LH_2 -fueled aircraft is shown in Table 2 to require 8 percent less coal than the methane-fueled airplane, and 33 percent less than the synjet-fueled design using thermal efficiencies from Reference 8.

It is emphasized that the evaluation of Total Process Energy is heavily dependent on the efficiency of the coal gasification process used to produce the alternate fuel. In the same way that DOC is a function of the cost associated with the process selected for evaluation, different processes could produce a different correlation and rating of the three aircraft fuels.

Pollution. - In the parameters which are probably most important in the long view; pollution, safety, and global availability of the fuel, LH_2 is strongly preferred. The combustion of hydrogen and air produces only water vapor and nitrogen as significant exhaust products, plus a small amount of NO_x . The carbon-containing alternate fuels also produce noxious products such as unburned hydrocarbons, smoke, and oxides of carbon and sulphur, in addition.

Safety. - Hydrogen-fueled aircraft are generally accorded high marks by knowledgeable safety experts⁽¹⁵⁾. Although this surprises many people who have been conditioned by oft-told tales of spectacular fires and disasters, careful examination of evidence shows hydrogen to be burdened with an undeserved adverse reputation. Hydrogen is a high energy fuel and,

as such, must be handled with respect. Nevertheless, in event of a crash, airline passengers who survive the impact, as well as people and property in the immediate area, will be considerably safer if the aircraft is fueled with LH_2 rather than either LCH_4 or synjet.

The consequences of a spill of aviation grade kerosene are well known. Spilled kerosene will spread as the terrain allows, usually encompassing a large area. It burns relatively slowly for a long time, with high radiation, and creates great clouds of black smoke.

Liquid methane is rated hazardous because, when spilled in large quantities, it will lie on the ground for an extended period before its temperature increases sufficiently that it will rise and dissipate in the atmosphere. The temperature of the gaseous methane must increase nearly 56°C (100°F) before its density becomes lighter than that of air at standard conditions. Under certain atmospheric conditions a cloud of gaseous methane resulting from spilled LCH_4 can be blown several tens of miles across the landscape by prevailing winds. All of the area traversed by the cloud is susceptible to fire and explosion damage comparable to that experienced in Cleveland in 1944. This unfortunate characteristic is largely responsible for the severity of laws and regulations which have been passed by various municipalities, states, and even the federal government in the United States regarding shipment and storage of LNG. In view of these governmental restrictions, it is considered unlikely that storage of large quantities of LCH_4 would be permitted at airports of major air terminals.

By contrast, liquid hydrogen need gain only about 2.2°C (4°F) to achieve buoyancy in air at standard atmospheric conditions. Considering this in conjunction with hydrogen's much greater temperature differential between the saturated liquid condition at one atmosphere (-423°F for hydrogen and -258°F for methane) and standard atmosphere, it is clear that a cloud of spilled hydrogen would not persist for long on the ground; it would dissipate rapidly and thus minimize the area on the ground exposed to a combustible mixture. Further, in event of fire from a spill of hydrogen, the ensuing deflagration would be about one-tenth the duration and lateral radiation from the flame would be significantly less. The result would be hazard to a far smaller area than would be the case for an equal-energy spill of methane or kerosene.

The properties of hydrogen which lead to this contradiction of expectation are its low density, its low boiling point, its high diffusion velocity in air, and its low emissivity. The probability of a fire with any of the three fuels is rated about equal for practical purposes.

Another very significant factor leading to greater safety for LH_2 -fueled aircraft passengers compared with those in conventionally-fueled vehicles, relates to the design and location of the fuel tanks. As shown in Figure 2, in a LH_2 design the fuel will be carried in tanks located in the fuselage, fore and aft of the passenger compartment. The tanks will be designed as pressure vessels to withstand a burst pressure of 46 psi. Synjet, like conventional Jet-A fuel, will be carried in the wing box which is capable of withstanding pressures in the range of 25 psi. In a substantial fraction of airline accidents in which people survive the impact the wings are punctured or torn, releasing fuel which usually ignites and burns. In a survivable crash the fuselage is less apt to suffer damage so severe that the hydrogen tanks would be ruptured.

Global Availability. - A fuel which is to be used in commercial transport aircraft must be readily available throughout the world. Hydrogen meets this requirement because, in addition to being producible from coal and other fossil materials, it can also be made directly from water using nearly any energy source. Since methane and synthetic kerosene require a source of carbon, those areas of the world which have little or no fossil fuels would be little better off if either of those alternatives were selected for future aircraft than they will be when the peak of crude oil production is reached.

An argument frequently heard in the United States is that the U.S. has enough coal and oil shale to satisfy foreseeable domestic needs for several hundred years and that, therefore, we should plan to produce synjet and postpone the necessity of converting aircraft to a new type fuel.

The fallibility of this argument to the law of exponential growth in a finite environment (Reference 14) has already been illustrated (p 8). The U.S. coal which will ultimately be produced will last a maximum of only 99 years at the 5 percent growth rate for production which is the goal of the present administration. Note that this rate of growth will by no means satisfy the U.S. requirement for energy as oil production diminishes. Development of renewable sources of energy, in addition to emphasis on conservation, must be accorded a very high priority in our future planning.

Another reason this argument should not be allowed to prejudice consideration of options for choosing an alternate fuel for aircraft which will operate globally is that due consideration must be given the fact that 75 percent of the world's coal is contained in only two countries (the USSR and the United States)⁽¹⁶⁾, and that the coal is distributed with little regard for those locations which are favorite airline destinations.

The environmental consequences of mining and processing coal make the possibility very remote that those countries with ample coal deposits will be willing to share the resource with others to any appreciable extent. One need only consider the difficulties and lack of success encountered in the United States in the last few years when we have been striving to expand our coal production to meet domestic needs to illustrate the magnitude of the problems, and to emphasize the improbability of also producing sizable quantities of coal or coal-derived products for export.

Similar considerations apply to arguments that oil shale and tar sands represent resources from which Jet A fuel for commercial aircraft can be derived to meet future worldwide needs. Although these fossil resources exist in large quantities in North America 1) they are finite, 2) they are not widely distributed globally, and 3) environmentally and economically acceptable means for recovery of the usable petroleum product in suitably large quantities have not been demonstrated. It is probable that recovery methods will be developed for oil shale and tar sands in the future which will permit use of the hydrocarbon in industries which can afford to pay high prices for their raw material, e.g., the petrochemical industry. Typically, this industry provides products which cost 10 to 100 times the value of the raw material; this includes large-volume plastics, fibers, agricultural chemicals, drugs, and specialty chemicals. These industries can obviously afford to outbid the air transport industry for the feedstock necessary to produce aviation grade kerosene or LCH₄.

Selection of hydrogen as the fuel for future transport aircraft has the advantage that it completely eliminates dependence on fossil materials. Where coal exists, it can be used to produce hydrogen economically. However, in areas where there is no coal, hydrogen can be produced by direct splitting of the water molecule, either by electrolysis or by one of the closed cycle thermochemical processes which are currently under development. The energy for these nonfossil processes can be solar, nuclear, hydraulic, geothermal, or any of a number of other possibilities. The cost of the resultant LH_2 may be higher than that produced from coal and water but that economic burden should be an acceptable trade-off for the freedom gained from being independent of any other nation for such a vital product as aviation fuel.

Other Considerations. - The other advantages shown for the LH_2 -fueled aircraft in Table 2 are considered to be important but perhaps not of the overriding significance accorded the above. Low gross weight is important in increasing runway durability at existing airports, and in minimizing design requirements for new installations. In addition, of course, lower gross weight means less stringent requirements for wheels, tires, and brakes in aircraft design specifications. Shorter wing span is important in reducing crowding at commercial airport gate terminals where the problem is already assuming critical proportions at the busier airports. The importance of reducing noise of aircraft during takeoff and landing is clearly recognized. The subject LH_2 aircraft is expected to be up to 5 dB quieter than the competitive aircraft, thus producing a perceived noise level about half as objectionable.

Laminar Flow Control

As attractive as they appear, the performance, cost, and energy characteristics shown in Table 2 for the LH_2 -fueled airplane can be significantly improved by a technique which, to date, has only been tentatively explored and so has not been included in evaluation considerations. This is the concept of achieving laminar flow control (LFC) by cryogenic wall cooling. An excellent review of the theory, experimental evidence to date, a description of how it might be applied to a LH_2 -fueled aircraft, and the benefits to be derived is presented in Reference 17.

The concept involves using the heat sink of the LH_2 fuel to cool an intermediate fluid, e.g., gaseous nitrogen, which is then circulated through special passages in the aircraft skin to reduce the temperature of the skin to approximately 167 K (300R). A diagram illustrating the cooling concept is shown in Figure 4. Air flowing over these cooled surfaces will remain laminar, subject to limitations of Reynold's number, surface-to-ambient air temperature ratio, surface roughness, and transverse pressure gradients. Experimental evidence to date confirms the theory but testing has been limited and a comprehensive research and development effort is needed.

Preliminary calculations indicate that 75 percent of the surface area of the wing, the forward 20 percent of the fuselage, and the engine nacelles can be cooled to the required temperatures with the fuel flow rates of the subject LH_2 -fueled aircraft. Conservative evaluation of the net benefits which could be realized are summarized in Figure 4. The effect on

DOC is illustrated on Figure 3. Because the cold aircraft skin would freeze water vapor in the air, this system of achieving LFC would only be used during cruise conditions at altitudes above 25,000 to 30,000 ft, where moisture content is not significant.

Cryogenic wall cooling is feasible with LH_2 fuel. However, with LCH_4 , because of its lower specific heat, and less temperature differential with which to work, the concept is only marginally feasible at a reduced effectiveness. Thus, cryogenic wall cooling to achieve LFC provides LH_2 with a unique advantage and a decided margin of superiority in evaluation of the economic and energy parameters.

Of course, one must not overlook the fact that laminar flow control can also be achieved by suction through slots in the aircraft wing surfaces. In this case the fuel used is irrelevant. However, cryogenic wall cooling offers the advantage that it is not susceptible to plugging of slots and should be a more reliable, more easily maintained system. In addition, the suction process requires expenditure of energy. Cryogenic wall cooling adds energy to the fuel by virtue of the heat removed from the aircraft skin. Altogether, the potential benefits to be derived from cryogenic wall cooling make it a concept which should be developed and exploited for use with LH_2 -fueled aircraft. A program to experimentally determine the feasibility and to explore limitations of the concept has been proposed.

SUPERSONIC TRANSPORT AIRCRAFT

Studies similar to those described for subsonic aircraft, but far less extensive, have been made to investigate the potential of LH_2 as a fuel for supersonic transport aircraft^(2,3). The results have been even more favorable than those shown for subsonic aircraft. A LH_2 -fueled Mach 2.7 SST capable of carrying 234 passengers 7780 km (4200 n.mi.) is illustrated in Figure 5. Table 3 provides comparative data for LH_2 and Jet A, or synjet-fueled, supersonic aircraft. It should be noted that these data are taken from Reference 3, a study performed in 1975. In the interim, as a result of continuing analyses, design improvements have been evolved for Jet A-fueled SST concepts but no further studies have been performed on LH_2 -fueled counterparts.

Current projections are that a second-generation SST will probably not be developed so as to be ready for initial operational use until after 1990. The unlikely prospects for continued economic availability of conventional Jet A fuel for very long after that date, combined with the significant advantages which can be realized if LH_2 is adopted as the fuel, make a strong case for initiating development of SST aircraft technology based on use of liquid hydrogen.

SUMMARY OF EFFECT OF USING LH_2 IN AIRCRAFT

A qualitative summary of the effect the use of liquid hydrogen has on long range aircraft design and performance, compared to equivalent designs of Jet A-fueled vehicles is as follows:

● Aircraft Dimensions	Smaller wing Larger fuselage Reduced gross weight
● Noise	Reduced engine noise Lower sonic boom over-pressure for SST's
● Pollution	No hydrocarbons, CO_x , SO_x , particulates or odors. Reduced NO_x Approximately twice as much H_2O
● Energy	Lower total process energy*
● Cost	Lighter, less costly airplane Longer engine life — less maintenance Lower life cycle cost*
● Safety	Equal or better
● Availability	Can be made from water using any energy source

It is apparent there are considerable benefits to be gained by using LH_2 to fuel future transport aircraft. On the other hand there is tremendous pressure to continue using kerosene-type fuel for as long as it can be made available on an economic basis.

The path of least resistance is to continue using the current fuel as long as it is available, broaden the specification to achieve a greater yield of usable product per barrel of crude oil, and start manufacturing synthetic Jet A from coal, shale, and/or tar sands. This minimizes the problem of changeover of equipment and facilities at airports and fuel storage areas, as well as in the aircraft themselves.

*Relative to coal-derived synthetic Jet A fuel.

With its tremendous fossil resources this course is especially attractive to many in the United States. Unfortunately, this option trades short term and local advantages for long term worldwide problems. It will require very positive and dedicated leadership to initiate a change to any other fuel, even though the alternative promises significant benefits.

A PROPOSED DEVELOPMENT PROGRAM

It must be emphasized that the advantages claimed for LH_2 are based largely on theory and analysis. Experimental development and demonstrations are needed to verify the practicability of the designs. Although experience with LH_2 in the U.S. space program provided a good background for evolution of the aircraft designs, the aircraft application is sufficiently different that new component designs and operational procedures must be developed. In addition, and of equal importance, improvements in production processes for manufacturing and liquefying hydrogen which have been identified need to be developed and demonstrated.

It is urgent that an aggressive research and development effort be started immediately to provide a basis for an intelligent decision for that time in the near future when an alternate fuel for transport aircraft must be selected.

This need is illustrated on Figure 1 where bars indicating elements of the life cycle of large transport aircraft of advanced design are superimposed on the plots of annual world production of crude oil previously examined. A plot of the annual production history and the future predicted for crude oil in the United States is shown for reference in the lower left corner of the figure.

The aircraft life cycle bars were arbitrarily positioned to indicate a start of design just five years in the future, in 1985. The message is clear. The aircraft whose design is initiated in that year will barely reach operational use before the pinch of oil availability from the most optimistic projection of world production begins to be experienced in 1995.

When this ultimate oil pinch begins, caused by depletion of world supply rather than artificial constraints imposed by a cartel, there will be a critical requirement for synthetic jet fuel manufactured from coal, shale, and tar sands to be supplied for the existing fleet of transport aircraft. New aircraft which are designed for introduction into service subsequent to the recognized limits of the world's crude oil should be designed for a replacement fuel selected on the basis of careful evaluation of long term considerations.

It is apparent the air transport industry needs to make a decision concerning this long term alternative within the next three to five years. In order for liquid hydrogen to be a viable candidate an aggressive research and development program must be started immediately to demonstrate that its theoretical advantages can be realized.

Such a program was proposed at an international symposium, "Hydrogen in Air Transportation," held in Stuttgart, West Germany in September, 1979⁽¹⁸⁾ under the auspices of DFVLR, the German aerospace research organization whose charter is similar to the U. S. NASA. The program consisted of two phases. Phase I was a research and development effort focused on development of technology needed to both manufacture LH_2 efficiently and use it effectively in aircraft. Phase II was a demonstration program which involved building and flying four LH_2 -fueled wide-body aircraft between the United States, Western Europe, and the Middle East carrying cargo in a simulated commercial airline environment to provide operational experience which would establish a basis for confidence on the part of the airlines, the regulating agencies, and the general public that LH_2 can be successfully employed as an aircraft fuel.

Specifically, the program was planned to serve five major objectives:

- Establish technical feasibility and illustrate the efficiencies of advanced processes for manufacturing and liquefying hydrogen.
- Develop component and system technology required to use LH_2 effectively as a fuel in aircraft.
- Develop airport facilities and procedures for servicing LH_2 -fueled aircraft.
- Provide a realistic basis for establishing design specifications, and operating and maintenance procedures for aircraft and associated airport equipment to meet government and airline requirements.
- Provide a basis for public confidence in the safety of large scale LH_2 storage and handling facilities, and in LH_2 -fueled aircraft.

The program was proposed for international participation because of the need that any alternate fuel for the air transport industry must be capable of being manufactured and used on a worldwide basis.

Implementation

Implementation of the program was predicated on the assumption of government funding. The fundamental rationale generally used in the United States to determine whether or not a given case warrants such support as follows:

"... government intervention is justified if the private sector operating by itself will not produce goods and services in a combination or at an overall level that is most beneficial to society." (19)

The development of a new fuel for the worldwide air transport industry is an undertaking which meets this rationale as well as the three specific criteria usually used in assessing the validity of a request for government support:

1. The benefits to society exceed the costs. In the present case the potential benefits include:
 - more efficient use of resources
 - improved environment
 - new employment possibilities
 - new products and services
 - improved trade balances.
2. The net benefit far exceeds that from alternatives.
3. There is inadequate incentive for industry, per se, to undertake the development.

Without government support the industry would probably follow the line of least resistance and simply continue using conventional Jet A fuel, or a derivative thereof, until the supply problem becomes untenable. By that time it would be too late to begin the orderly development necessary for selection of a preferred alternate fuel.

A unique feature of the proposed program is that it is international in scope and involves cooperative effort on the part of at least four governments. The problems associated with undertaking a technology development program involving four different countries are recognized. It would be far simpler to deal with only one government. However, in this case where the product will have worldwide application, it is thought that the involvement of multiple governments will have beneficial effects. One, there should be a mutual reinforcement of interest and resolve during the program; two, the results of the development will be more widely dispersed with a higher level of understanding; three, with hydrogen manufacture and liquefaction plants, plus airport facilities, already in place in four strategic cities the expanded use of LH_2 fuel in aircraft following this development phase will be greatly expedited.

Although the requirements of the subject program are unique there are many precedents for cooperative international activity which involve buying goods and services; the European Space Program, INTELSAT, and existing programs under the International Energy Agency are examples.

Schedule

A feasible schedule for the program proposed in Stuttgart is shown in Figure 6. Assuming a start in mid-1981, Phase I could be completed by the end of 1983. This would include the research and development of technologies needed to establish firm designs of aircraft and engine systems, hydrogen manufacture and liquefaction processes, and equipment needed at airports to properly service LH_2 -fueled aircraft.

Near the end of Phase I a decision would be reached concerning the scope and requirements of Phase II. At the Stuttgart symposium the thought was expressed that such a comprehensive demonstration program as was proposed might not be required to convince potential user airlines that LH_2 was a practicable fuel. It was suggested that a much simpler program involving perhaps a single airplane performing a well planned demonstration flight program might satisfactorily accomplish the objectives.

A minimum program, for example, would consist of converting an existing transport aircraft to LH_2 by mounting tanks in the payload area, installing necessary fuel lines and systems, and suitably modifying the engines. Existing hydrogen manufacture and liquefaction facilities can be employed, eliminating the necessity of building new plants to demonstrate advanced processes. This program could be performed in very much less time and at considerably less expense than the program proposed at Stuttgart.

Tradeoffs of advantages versus cost for various alternatives for Phase II will be studied during the Program Planning and Organization task shown at the top of the schedule in Figure 6. A decision to proceed with the selected option is required near the end of 1983. The decision would commit the participating governments to build the agreed-upon aircraft, plus hydrogen production and airport facilities needed to support the approved program.

Cost

A rough estimate of the cost of Phase I, the research and development effort, is \$65.5 million as shown in Table 4.

This money would be spent approximately as follows:

	\$ Million
FY 1981	8
FY 1982	36
FY 1983	21.5

As stated in the next section, a better assessment of these costs will be derived as a result of action currently underway by a Working Group.

Inasmuch as Phase II of the program is not defined at this time it would be meaningless to attempt to estimate a probable cost.

STATUS OF THE PROGRAM PLANNING EFFORT

At the Stuttgart symposium a multinational Ad Hoc Executive Group was formed to serve as the means for implementing the consensus of the symposium. Membership of the Ad Hoc Executive Group (AHEG) is as follows:

Willis M. Hawkins, Chairman

E.E. Ecklund

N. Gore

G.G. Kayten

F. J. Plenard

E. Simon

A.S. Strub

K. Wilkinson

C.J. Winter

Sr. Vice President for Aircraft,

Lockheed Corporation, USA

Department of Energy, USA

Transport Canada

NASA Headquarters, USA

L'Air Liquide, France

Lufthansa, West Germany

Commission of the European Communities

British Airways, England

DFVLR (Stuttgart), West Germany

A seven point statement, attached hereto as Appendix A, was evolved and voted by the AHEG. Acting on the mandate of the symposium that an international research and development program should be implemented, steps have been taken to formulate such a program and present it to the associated governments for consideration. A Working Group met in Washington during the week of 21 January 1980 as an initial step in preparation of a draft of an R and D program. A final draft is to be ready for presentation at the next meeting of the AHEG, scheduled for 11 April 1980 in Montreal, Canada. This final draft will provide a better estimate of total program cost and schedule requirements than the values presented herein.

When approved by the AHEG the program will be presented to the Executive Committee for the Hydrogen Programme of the International Energy Agency, and to the International Air Transport Association, for their coordination and interest.

In addition, each member of the AHEG will explore the interest of his own government in participating in the development activity and will obtain a commitment for funding agreed-upon items. In this regard, the Congress will be asked to provide funds for items in the program which NASA and DOE agree are appropriate for U.S. development. It is hoped that the urgency of the program will permit first year funds in the amount of \$8 million to be made available as a part of the FY 1981 budget, and for plans to be made for funding the remainder of the program, contingent upon formal requests being submitted by NASA and DOE.

SUMMARY

The world's supply of petroleum will ultimately be depleted. Most recent estimates by industry experts indicate the peak of crude oil production will be reached in the 1990-2000 decade.

It is timely that positive, aggressive action be taken to select a fuel for future use in transport aircraft. The choice should be made in full recognition of all the economic, sociological, and technological ramifications which will be involved. Particularly, global aspects need to be considered. Local advantages or short term benefits which might require another change within a few decades should not be allowed to dominate the considerations.

On the basis of conceptual design studies and theoretical analyses liquid hydrogen has been shown to be a very attractive candidate. Experimental data and operational experience are required to determine its practicability and desirability as a fuel for transport aircraft.

A comprehensive program is proposed which will develop technology needed to manufacture and liquefy hydrogen efficiently, and to use it effectively in aircraft. In addition, some type of demonstration program involving use of LH_2 -fueled transport aircraft is recommended to provide operational experience.

The proposed program will provide technical data needed to properly evaluate liquid hydrogen relative to other candidate fuels. Of equal importance, it will also serve to inform and persuade the general public of the many outstanding advantages to be gained through its use, and to establish a basis for public confidence in its safety.

Funding amounting to \$8 million for FY 1981 is needed for early initiation of the research and development program.

APPENDIX A

SUMMARY STATEMENT
AD HOC EXECUTIVE GROUP
INTERNATIONAL SYMPOSIUM – HYDROGEN IN AIR TRANSPORTATION

SEPT 11-14, 1979

It is the sense of this symposium:

1. That the use of liquid hydrogen as a commercial air transport fuel has sufficient long term promise to justify a substantial research and development program.
2. That this program should include research in support of certifying authorities and users, and development applicable to fuel manufacture, distribution, and airport development.
3. That such a program should be international in scope.
4. That the cost of using liquid hydrogen in air transport, and particularly the comparison of costs among the potential alternate aircraft fuels, is undetermined now and a major study effort is justified to reach valid comparative fuel and operating costs. This is also international in scope and specific differences among countries should be analyzed.
5. If an adequate aircraft, power plant, and facilities research program is conducted, a "Demonstration Airline," as proposed, is not essential to determine the acceptability of liquid hydrogen fueled transport aircraft.
6. That the present Ad Hoc Executive Group of this symposium remains active to define alternative mechanisms by which the R&D Program and its international implementation may be defined. If a follow-on symposium is required the Ad Hoc Executive Group should seek its sponsor and schedule its occurrence.
7. That the motivation for considering the use of liquid hydrogen is the optimal use of energy with a potential saving in operating cost. Thus the Ad Hoc Executive Group should seek association with energy agencies as well as purely aeronautical organizations.

TABLE 1. — SUMMARY COMPARISON OF ALTERNATE AIRCRAFT FUELS

Synjet	Liquid Methane	Liquid Hydrogen
<u>ADVANTAGES</u> ● No change required in aircraft, engines or air terminal systems. ● Cost and energy advantage if made from shale.	● At current price of coal, is marginally better in cost.	● Global availability ● Safety ● Minimum pollution of the environment. ● Reduced noise ● Advantage in direct operating cost in future as coal price increases. ● Potential significant improvement in cost and energy with technology development. (LFC by wall cooling) ● Airport accommodation (lower gross weight, shorter wing span, quieter) ● Longer life, lower maintenance for engines.
<u>DISADVANTAGES</u> ● Fossil resources are not universally available. ● Environmental pollution ● Noise ● Airport accommodation ● Ultimate high cost and unavailability	● Fossil resources are not universally available. ● Requires new fuel infrastructure, airport facilities, training. ● Environmental pollution ● Noise ● Airport accommodation ● Ultimate high cost and unavailability	● Requires new fuel infrastructure, airport facilities, training. ● Near term cost will be high in areas where fossil fuels are unavailable.

TABLE 2. — COMPARISON OF ALTERNATE FUELED SUBSONIC AIRCRAFT
(400 Passengers; 5500 n.mi. Range; Mach 0.85)

		Liquid Hydrogen (LH ₂)	Liquid Methane (LCH ₄)	Synjet
Gross Weight	lb	372,200	497,300	511,600
Block Fuel Weight	lb	47,670	130,030	159,900
Operating Empty Weight	lb	227,750	256,100	236,700
Wing Area	ft ²	3,195	4,144	4,093
Span	ft	170	193.1	192
Fuselage Length	ft	215.6	201.3	197
Specific Fuel Consumption (Cruise)	lb/hr	0.202	0.494	0.603
Lift/Drag (Cruise)	—	17.4	19.21	19.13
Thrust per Engine	lb	30,350	39,800	41,600
Aircraft Price	\$Million	43.39	48.10	44.53
Direct Operating Cost*	¢/seat n.mi.	2.18	2.17	2.15
Energy Utilization	Btu/seat n.mi.	1,118	1,271	1,337
Total Process Energy	tons of Coal	205	222	272
Noise, Sideline Flyover	EPNdB EPNdB	87.2 89.2	N.A. N.A.	87.8 94.2
Emissions		H ₂ O, NO _x , N ₂	CO _x , SO _x , NO _x , HC, N ₂ Smoke, H ₂ O	CO _x , SO _x , NO _x , HC, N ₂ Smoke, H ₂ O
*Based on fuel costs as follows: (All derived from coal at \$18/ton)		LCH ₄ — 8.84 per 10 ⁶ Btu Synjet — 8.47 per 10 ⁶ Btu LH ₂ — 11.01 per 10 ⁶ Btu		

TABLE 3. — COMPARISON: LH₂ AND JET A SUPERSONIC TRANSPORT AIRCRAFT
(Mach 2.7; 4200 n.mi.; 234 Passengers)

		LH ₂	Jet A	Ratio $\left(\frac{\text{Jet A}}{\text{LH}_2}\right)$
Gross Weight	lb	394,900	762,200	1.93
Operating Empty Weight	lb	245,200	317,400	1.29
Block Fuel Weight	lb	85,390	330,590	3.88
Thrust Per Engine	lb	52,820	86,890	1.64
Wing Area	ft ²	7,952	11,094	1.39
Span	ft	113	133.5	1.18
Fuselage Length	ft	340.2	297	0.87
Field Length Required	ft	7,800	9,490	1.22
Lift/Drag (Cruise)	—	7.42	8.65	1.17
Specific Fuel Consumption (Cruise)	$\frac{\text{lb}}{\text{hr}}/\text{lb}$	0.575	1.501	2.61
Aircraft Price	\$10 ⁶	45.5	61.5	1.35
Energy Utilization	Btu/seat n.mi.	4,483	6,189	1.38
Noise, Sideline	EPNdB	104.0	108.0	—
Flyover	EPNdB	102.2	108.0	—
Sonic Boom Overpressure	lb/ft ²	1.32	1.87	1.41

TABLE 4. — PRELIMINARY ESTIMATE OF PHASE I COSTS
\$ Million (1979 Dollars)

TECHNOLOGY DEVELOPMENT	
AIRCRAFT	
Airframe	22.2
Engine	6.3
Sub Total	28.5
GROUND FACILITIES	
H ₂ Manufacture*	25.0
H ₂ Liquefaction	6.5
LH ₂ Storage and Airport Facilities	5.5
Sub Total	37.0
Total	65.5
*Estimate based on use of continuous steam-iron process	

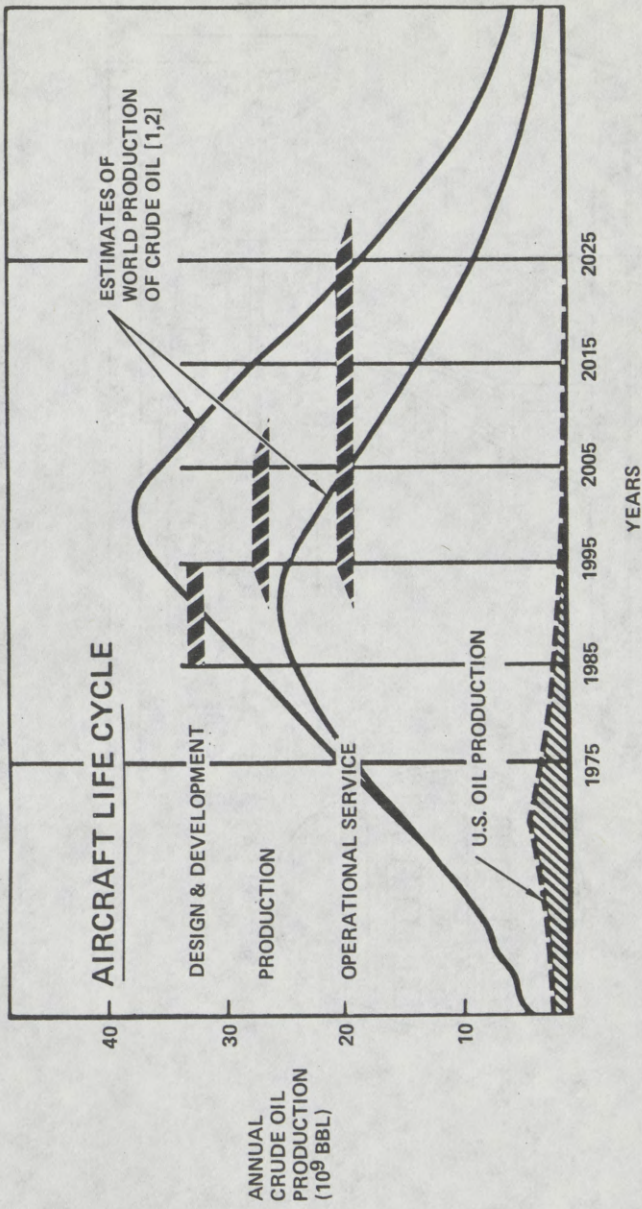


Figure 1. — Correlation of life cycle of new transport aircraft with forecasts of oil availability.

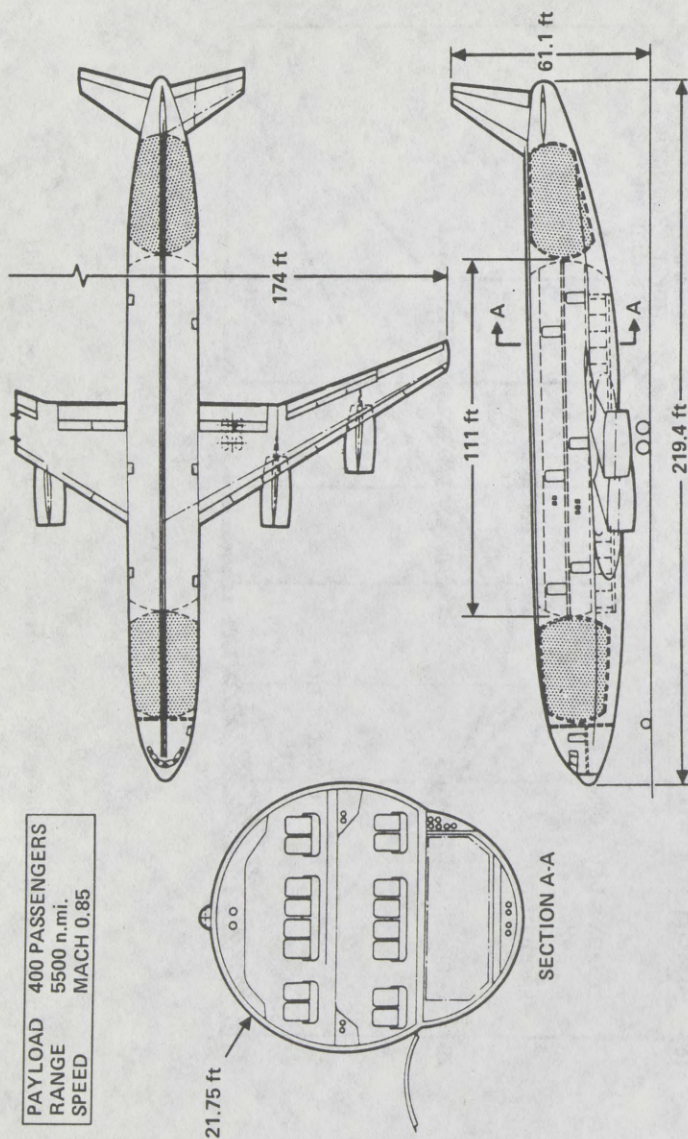


Figure 2. — Subsonic LH₂-fueled passenger transport.

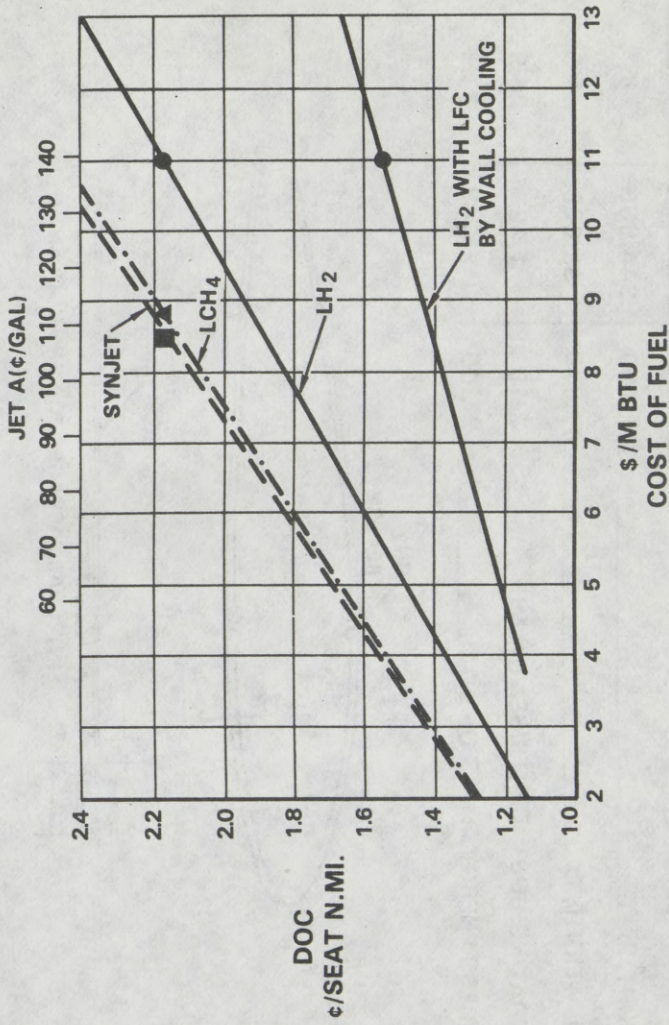


Figure 3. — Direct operating cost vs cost of fuel.

(400 PASSENGERS; 5500 N.MI.; MACH 0.85)

	ORIGINAL VALUE	WITH LFC BY WALL COOLING	IMPROVEMENT (PERCENT)
GROSS WEIGHT, lb	372,200	344,630	8
BLOCK FUEL WEIGHT, lb	47,670	33,665	41.6
DIRECT OPERATING COST, CENTS/SEAT N.MI.	2.18	1.72	26.9
TOTAL PROCESS ENERGY, TONS OF COAL	205	148	38.5

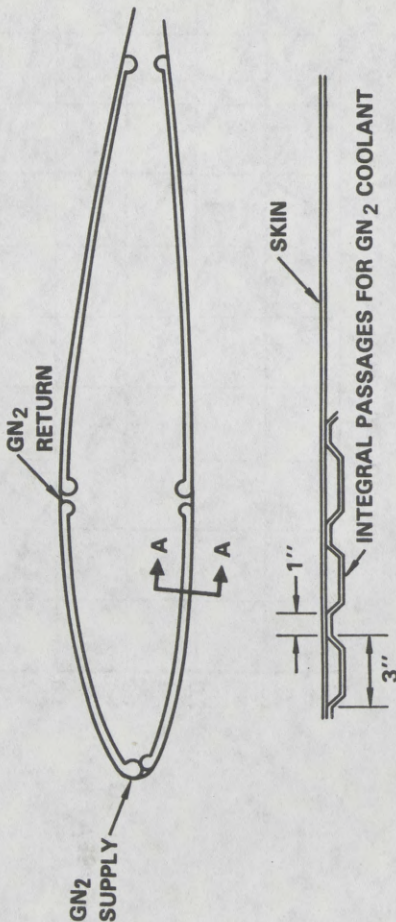
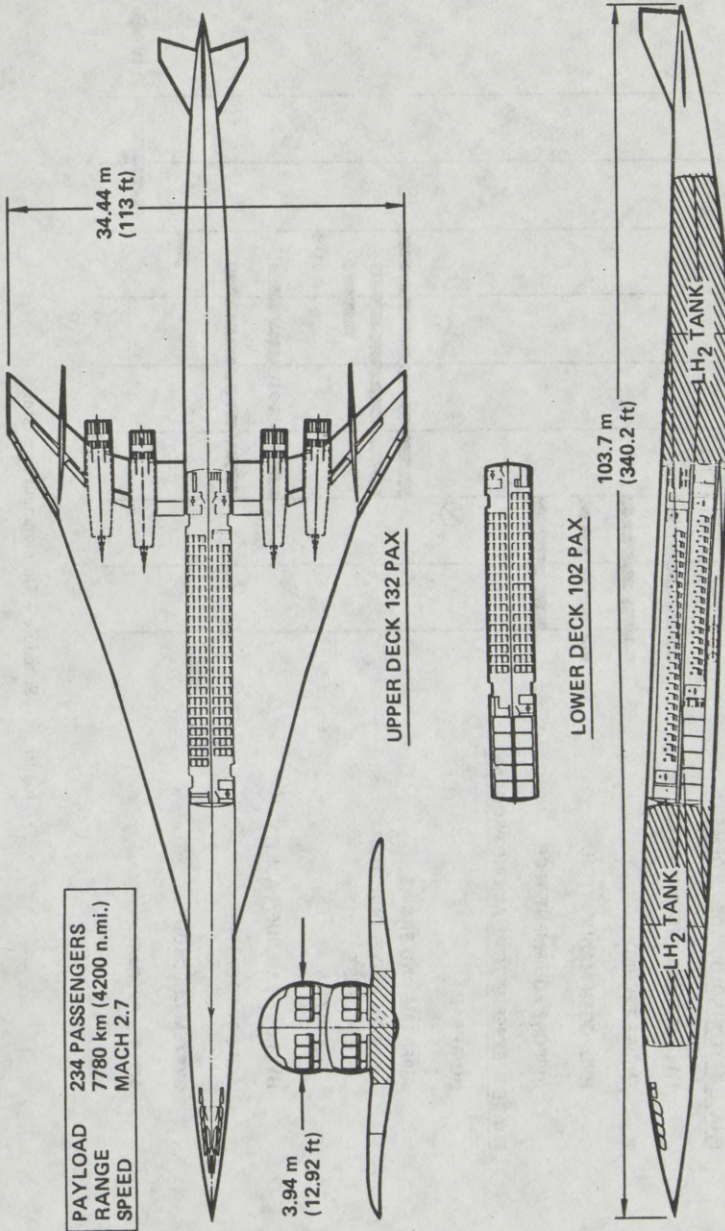


Figure 4. — Laminar flow control by cryogenic wall cooling

Figure 5. - Mach 2.7 LH₂-fueled SST.

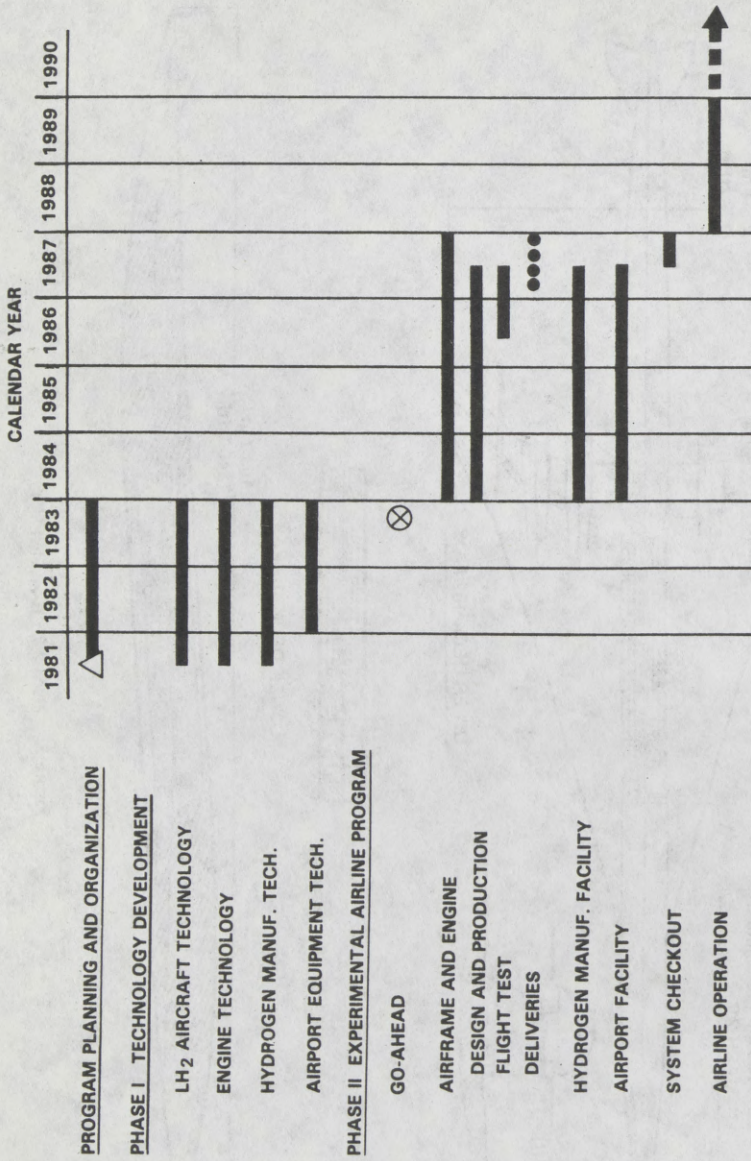


Figure 6. — Schedule — Development Program.

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STATEMENT OF MAURICE E. SHANK, DIRECTOR OF ENGINEERING TECHNOLOGY, COMMERCIAL PRODUCTS DIVISION, PRATT & WHITNEY GROUP, UNITED TECHNOLOGIES CORP.; ACCOMPANIED BY WILLIAM SENS, MANAGER OF ADVANCED ENGINE PROGRAMS, PRATT & WHITNEY AIRCRAFT GROUP

Mr. GOLDWATER. Our next witness is Dr. Maurice E. Shank, director of engineering technology, Aircraft Commercial Products Division, Pratt & Whitney. Dr. Shank, we want to extend the appreciation of the subcommittee for your hospitality this week in hosting Tom Harkin, Scott Crossfield, Joe Tymcyszyn, and Tony Taylor. I wish I could have made the trip; I understand it was quite educational.

Dr. SHANK. We are sorry you couldn't. Perhaps, sir, you can come another day.

Mr. GOLDWATER. Thank you. You may, proceed as you wish.

Dr. SHANK. I thank you for the opportunity to appear before you today to discuss NASA's aeronautics program.

I am accompanied by Mr. William Sens who is manager of our advanced engine programs.

I represent Pratt & Whitney Aircraft group, the largest unit of United Technologies Corp. Pratt & Whitney Aircraft designs, develops, and markets commercial and military aircraft engines on a worldwide basis.

I am director of engineering technology for the company's commercial products division. I am also a member of NASA's Aeronautics Advisory Committee, and chairman of its ad hoc subcommittee on advanced aeronautical propulsion technology requirements. With this background I believe that I can bring a broad perspective to a discussion of NASA programs in the propulsion area. I particularly would like to discuss these programs in terms of national needs.

There are at least four key national needs which must be met through a broad base of research and technology in aeronautics (fig. 1).

They are, one, development of competitive products. Two, conservation of fuel. Three, substitution for and conservation of critical metals. And four, assurance of a favorable balance of trade.

Aerospace products are the second largest export item in U.S. trade. This trade will be even more vital to the Nation during the 1980's, when the worldwide transport aircraft market is expected to average more than \$10 billion (1979 dollars) annually.

Other countries recognize the benefits of capturing a sizable portion of such a market, and they are committing their resources to this investment. A healthy NASA aeronautics budget is one way to stimulate the high-risk research which can be exploited in technical products necessary to compete in the worldwide market. NASA and industry must make investments sufficient to meet national needs.

Without strong Government support for innovative research and technology, U.S. world leadership in the commercial transport sector will decline. Large expenditures by the private sector also are required. If this support is not forthcoming, economic consequences will include fewer jobs and increased trade deficits. The technical consequence will be a loss in U.S. leadership.

Unfortunately, the trend of overall research and development expenditures as a percentage of gross U.S. national product is declining. At the same time, other nations, Russia, West Germany, and Japan, for example, have increased these expenditures (fig. 2).

We, at United Technologies Corp., are committed to investing substantial amounts in R. & D. As of the end of 1978, when ranking figures were last published, of the top ten companies in research and development spending in the United States, United Technologies ranked first in R. & D. investment measured as a percentage of total sales.

In 1979, the company invested more than \$500 million on research and development. Pratt & Whitney Aircraft's portion of this United Technologies' investment came to more than \$1 million a day.

United Technologies expects to spend more than \$3.5 billion on corporatewide research and development over the next 5 years.

Despite large commitments by the aircraft industry in R. & D., and the additional support provided from the Government sector through NASA's aeronautics budget, there is growing evidence that the once unquestioned leadership of the United States is in danger. Erosion of the Nation's commercial aircraft market share already is upon us.

In 1979, firm orders were announced for more than 120 of the Airbus widebody aircraft manufactured in Europe. This placed Airbus Industrie second among widebody airframe manufacturers in the world market. In the face of this challenge, a concerted effort is necessary to maintain the nation's competitive leadership.

Mr. GOLDWATER. If I may interrupt you, it looks to me like you are proceeding to read this entire document.

Dr. SHANK. Yes, sir.

Mr. GOLDWATER. Is there any way that you can summarize some of this or expedite it? By the time you get through with the entire document and we ask questions, there won't be any time for the other witnesses today.

Dr. SHANK. All right, sir. I will certainly do that.

NASA has supported a great many worthwhile programs. Two of the programs I would like to mention in passing are the JT-8D refan and engine component improvement programs.

In the JT-8D refan program NASA and Pratt & Whitney Aircraft joined to demonstrate the technology for lower noise and improved fuel efficiency for a derivative model of the JT-8D engine. This was a very successful program. The JT-8D-209 engine, developed with Pratt & Whitney Aircraft funds, stemmed from this program and is being introduced on the McDonnell Douglas DC-9 super 80 sold to Swiss Air.

This program clearly met national needs by creating a competitive U.S. aeronautical product with reduced energy consumption for the international market.

I would note here that the contract arrangement with NASA on the refan program included a cost recoupment, which means that our company will pay back funds to the Government based on the number of engines we sell.

My second example, is the engine component improvement program (fig. 3). The goal of this program is to reduce the fuel consumption

of current high-volume, production engines, such as our JT-2D and JT-9D engines. Many performance improvement concepts were evaluated. Several concepts have been demonstrated to date and are starting to be introduced into airline service. We expect that these will result in a savings of 6.4 billion gallons of fuel for engines sold through 1990.

We are also looking at the causes of performance deterioration of high-bypass ratio engines which power such aircraft as the Boeing 747 and DC-10. This program is not yet complete, but has produced excellent information which will enable us to recommend improved procedures to airlines. It is estimated that these improved procedures will save an additional 2.2 billion gallons of fuel during the lifetime of the engines.

I would like now to address three items of the NASA fiscal 1981 aeronautics program. These are advanced turboprop, the variable cycle engine, and the hot section technology program.

We believe that the NASA fiscal year 1981 advanced turboprop program augmentation is an excellent program (fig. 4). The key to this program is the propeller. It has been shown that advanced turboprop designs using modern, highly efficient propellers offer a potential of 15 to 20 percent in fuel savings for several commercial aircraft applications. This fuel savings is relative to a 1990's high bypass ratio turbofan such as the NASA energy efficient engine. For some short haul and military patrol aircraft such turboprop designs may yield savings of up to 30 to 40 percent. A program of this potential, should be pursued vigorously, in view of the rapidly escalating fuel costs and concern about fuel availability.

The present turboprop program is progressing well. Much remains to be done to verify the technology. It is necessary to fabricate and test a large-scale propeller for the advanced turboprop to establish its structural integrity. Wind tunnel and flight tests are needed to verify in-flight performance and freedom from cabin noise and vibration. This program should be pursued as long as the technical progress remains favorable.

The fiscal 1981 advanced turboprop phase II program covers the earlier portion of the above effort. However, even assuming a fully successful program and appropriate follow-on efforts, the technology would not be ready until the 1990's. We believe this program should be accelerated to provide technology readiness at an earlier date. Because of the large potential fuel savings and the increasing concern about fuel conservation, we suggest striving to have the technology ready in the mid-1980's so that it could be available in suitable aircraft in the early 1990's.

The next figure shows the variable cycle engine, known as VCE, a program which NASA proposes to increase in 1981 (fig. 5). We have made significant progress in the VCE program in the past year.

It is our opinion that adequate funding is required to protect our long-range transport market against the possible incursion of a second-generation foreign supersonic transport. In the event that the United States decides that this should become a national objective, our options, therefore, would not be foreclosed.

We have made good progress in demonstrating good efficiency levels in the duct burning program and we have verified that there are ways

of getting substantial noise reductions relative to the first generation of SST designs.

The fiscal 1981 VCE program will begin the process of verifying and improving the component technology.

The third program I would like to single out for endorsement is the hot section technology program (fig. 6).

The hot section of a gas turbine engine, as you are aware, includes the combustor and the turbine. Certain parts in the hot section are exposed to gas temperatures well above the melting point of the metal structures. Even with cooling, their life is limited. The alloys employed require use of critically scarce metals.

Emphasis on fuel efficiency drives engine design toward higher operating gas temperatures, higher pressure ratios, and higher rotating speeds. These trends create a more severe hot section environment, requiring more complex combustor and turbine parts. Historically, hot section upkeep for modern high-bypass ratio engines accounts for 60 percent of the engine's maintenance cost. The objective of the hot section technology program is to develop analytical tools and the technology to extend the life of hot section parts, thus conserving critical metals and reducing the cost of hot section maintenance by 30 percent. A program of this type will contribute significantly to the competitiveness of the U.S. commercial engine in the world market.

Next I would like to discuss the research and technology portion of the NASA aeronautics budget and its importance to the maintenance of a strong U.S. technology base (fig. 7).

The R. & T. base budget supports innovation and knowledge-building. The R. & T. base is the wellspring of ideas. It is here that the foundation of technological advancement is established. We see a serious danger in the recent trend of reduced funds for R. & T. efforts.

In an era of sharply rising costs and increasingly scarce critical metals, industry has been faced with the necessity to devote its finances to more immediate product line development and short-term projects in order to stay competitive in the short run. NASA is the only U.S. agency with a charter to preserve U.S. leadership in commercial aeronautics. Despite this mandate, only 2.9 percent of the total 1980 NASA budget of \$4.1 billion (excluding research and program management) goes into the aeronautics R. & T. base. I am aware of the fact that the R. & T. base is planned to be increased for the coming fiscal year, but this portion of NASA's budget has declined in terms of real dollars over the last decade (fig. 8).

We do not understand the reason for this declining R. & T. base, but it would appear that it is because shorter-term systems or experimental programs appear to have more immediate and visible payoffs. We believe that this depletion of the R. & T. foundation will have serious consequences in the future. The trend should be reversed.

Research and technology is a searching process and success is not always assured. I would like to cite just one success from NASA's R. & T. base which made practical today's fuel-efficient, high-bypass ratio engines. This was the technology performed in the 1950's to develop compressors capable of efficient handling of a higher velocity airflow over the compressor blades.

That work on the transonic flow compressor became the basis of today's aircraft engine high-speed compressor design. It made possible

the modern, efficient high-bypass ratio fan, leading to U.S. supremacy in the engine field. However, at the time this research was undertaken, there was no way to predict its eventual outcome.

We would urge the Congress to increase the funding provided in NASA's budget for the R. & T. base, to turn declining support into increasing support in the years to come.

I would like to mention briefly some other aspects of NASA's aeronautics programs and future needs in aeropropulsion.

The largest of NASA's propulsion programs is the energy efficient engine program. It is a 5.5-year effort to develop the technology base for the design of more fuel-efficient engines in the mid-1980's. This effort has been underway for just 2 years now and, while it is still early in the program, the results from our design work and testing indicate that the program will provide verified concepts for a firm footing for fuel-conserving engines in the mid-1980's.

Further component improvement is necessary beyond that if we are to remain competitive in the world market. NASA has planned a follow-on program called advanced commercial engine technology, that would provide initial verification of further design improvements. We strongly endorse this program as a means to provide further technology for future fuel savings.

Looking beyond the proposed fiscal year program for the variable cycle engine, we see an important requirement to conduct high temperature validation tests under the demanding conditions of supersonic flight.

The variable cycle engine, under cruise conditions, operates at hot section gas temperatures about 300 to 400 degrees hotter than today's engines. It will be a formidable task to achieve durability at these temperature levels while maintaining an acceptable level of cooling air (fig. 9).

The VCE high temperature validation program is required in order to substantiate the required advanced materials and cooling technologies in an engine environment. This program would have valuable fallout for both military and advanced subsonic commercial applications.

A vital program which NASA and industry have been advocating is entitled "Aircraft Technology for Future Fuels." We are now in a period where the supply and quality of aviation fuels is taking a turn for the worse. There is increasing dependence on imported crude oil and higher carbon-content, or aromatic crudes. Refinery capability to produce specification jet fuel from higher carbon-content crudes is limited. Therefore, our airlines increasingly have been using fuels requiring specification waivers. The future is at best uncertain in terms of the supply and quality of aviation turbine fuels and soon it may be necessary for our engines and airlines to use fuel derived from oil shale, tar sands, or even coal.

A NASA future fuels program is needed urgently by industry to demonstrate the technological feasibility of using petroleum-based fuels of broad specifications in aircraft fuel systems and engines. It is important to determine as early as possible the effects of these fuels on the engines in use today. In a later phase of this program, data would be generated to demonstrate the acceptability of future engine

components and aircraft fuel systems using synthetic fuels or petroleum fuels having much wider variations in properties.

The last program for future consideration which I will discuss deals with the crisis in critical metals.

As you are aware, the United States is a have-not nation when it comes to certain critical metals. Two such metals are chromium and cobalt. Without chromium we cannot make a durable, efficient gas turbine engine. Chromium imparts oxidation-resistance and strength to high-temperature parts. We are dependent on Africa and the Soviet Union for chromium.

Cobalt is a unique metal in its ability to withstand high temperatures and stress in the hot sections of a jet engine. The United States imports 97 percent of its cobalt. Our major source of supply is in a country with a history of instability—Zaire. Other critical metals used in our engines and on which we are heavily import dependent are tungsten, titanium (because of a lack of processing capacity in the United States) and columbium.

NASA should take a strong role in the conservation of critical aerospace metals by establishing a program of research to cover the field of alloy substitution and modification, reduction of raw materials input by such techniques as casting parts close to finish size, metal powder technologies and development of new alloy and coating concepts.

Problems relating to fuels and metals scarcity are national in scope and are appropriate for funding via R. & T. It is insufficient to address these problems solely via the industrial community.

To summarize, I hope I have made it obvious that the United Technologies Corp. and Pratt & Whitney Aircraft strongly support the fiscal year 1981 programs proposed by NASA. They fit well into the overriding goal we all support, namely, meeting vital national needs.

That concludes the summary of my statement, Mr. Chairman, and I would be happy to answer any questions you may have.

Mr. GOLDWATER. Thank you very much, Dr. Shank.

Obviously, United Technologies is making a contribution to the advanced turboprop, the hot section technology, and all of those programs supported by the committee. I think many of us are as disturbed as you are over the declining NASA aeronautics budget. If there was ever a time when we need to put more resources into these things to meet some of the changing sociological and economic conditions, today is the day. That is why your testimony is very important.

I have just a couple of questions I wanted to ask you.

On Monday, during the subcommittee's trip to Pratt & Whitney, your people were asked about the supersonic program and its funding levels. In essence, they responded that we would never be in a position to build such an aircraft in the United States if we continued at this same level of funding. I wonder if you would be able to elaborate on this. Also what do you feel is needed to get moving?

Mr. SENS. Well, the current level of funding is not adequate to fund the kind of technical work needed to substantiate the technologies required to start on the development of a viable supersonic transport. To do so would take a significant increase in the level of support in both the engine and airframe companies in order to establish tech-

nological feasibility or readiness to start a supersonic transport development program in the foreseeable future.

Mr. GOLDWATER. Yesterday NASA testified that the economic cross-over point from turboprops to propfans is about at the 1000-mile range. That is, below 1000 miles, a conventional turboprop is better, and above 1000 miles a propfan is better. Do you agree with that?

Mr. SENS. I am not sure what they meant by the 1000 miles, whether that was an average stage length or design range for the airplane.

Mr. GOLDWATER. I think they are talking about stage length.

Mr. SENS. I am not aware of any study that would prove the point one way or the other. However there is something that goes beyond the economics. That is, one of the objectives of the propfan program is to achieve passenger comfort in terms of cabin noise, vibration in a propfan-powered airplane that is equivalent to turbofan-powered airplanes. If we can achieve those goals I am sure that even if the economics were not quite as good as the turboprop-powered airplane that you would use a propfan-powered airplane down to ranges, I would say, on the order of 1- to 2-hundred miles. But in answer to your question, I am not aware of any study which indicates that turboprops would be better economically than a propfan up to anything like the 1000-mile stage length.

Mr. GOLDWATER. Mr. Royer.

Mr. ROYER. First of all, I just wanted to ask a question. I am a little bit confused that we have all these different alphabets. What is the difference between R. & D. and R. & T? Does the end result get you something different?

Dr. SHANK. Research is research. You are concerned with the difference between technology and development.

Mr. ROYER. I guess that is the point, but I am wondering if the end result is going to be anything different. Isn't the idea of research and development to get better technology?

Dr. SHANK. Research and technology span the task of formulating early concepts, verifying these, and expanding these into a technology which you can then apply to a product. Development follows the start of design of the product. It is beyond anything NASA deals with. The development following the initiation of design provides a reliable product which you can sell to a customer and support in the field. NASA's business is not development.

Mr. ROYER. I understand that. But I know that they do research and some of their programs are called research and development. I have seen some of them, or at least it seems to me that I have in some of these different hearings. I know there is a fine line but—

Dr. SHANK. I don't recall ever seeing the term development applied by NASA to aeronautics programs.

Mr. ROYER. Let me ask you this: In your judgment, between the variable cycle engine and the turboprops, which would you feel would have the most potential at the earliest date, assuming other things were not taken into account. I am thinking now of consumption, the efficiency from that standpoint and also the noise problem.

Dr. SHANK. Which would have the earliest potential for application?

Mr. ROYER. Yes.

Dr. SHANK. Either one could be developed on any time scale you

choose. They could both be ready at the same time. You could have them by say 1990—

Mr. ROYER. Suppose you then factor in energy. Most of the new engines that are fuel efficient also turn out to be noise efficient as well.

Dr. SHANK. One of the objectives of developing a supersonic engine would be to achieve stage III noise levels.

Mr. ROYER. So you are saying that whenever we get to the desired point as to energy efficiency these engines would also qualify under the stage III noise standard.

Dr. SHANK. I don't think they would be acceptable unless they did.

Mr. ROYER. I understand that, but the question I am trying to get answered is, is there a specific type of engine that can get there sooner than the other?

Dr. SHANK. I don't think we can make—

Mr. ROYER. We are not far enough along.

Dr. SHANK. You mean between the advanced turboprop—

Mr. ROYER. Yes.

Dr. SHANK. Either one. You could have the technology ready for an early 1990 use, if you put the funding in. You could use the turboprop earlier.

Mr. ROYER. That is what I am trying to get an answer to. From that standpoint, you could develop the turboprop earlier, assuming funding was available. What about when you throw in the noise factor? Does that alter either engine's capability of optimum development faster?

Dr. SHANK. Well, it is probable that you would get there more readily on the noise with the turboprop.

Mr. ROYER. I have a final question then. Did I understand you correctly, that you feel the funding for NASA is sufficient for the variable cycle engine to verify the concept to a decision point, so it could be made?

Mr. SENS. The fiscal 1981 new-start program would be the start of a program that could bring the technology to the point where you would have technology readiness. However, follow-on programs with further increased funding such as NASA has presented to you in thin white paper will be required.

Mr. ROYER. Most of the criticism we receive is that the funding is not adequate. You are saying it is only adequate to verify the concept, but certainly additional funding would be necessary to advance the technology.

Mr. SENS. Yes. For instance of the programs that Dr. Shank discussed, the hot section demonstration program, is one of the programs that are needed to develop the technology base required.

Mr. ROYER. Thank you, Mr. Chairman. I yield back the balance of my time.

Thank you for your testimony.

Mr. HARKIN. Thank you very much, Mr. Royer.

I want to extend my welcome and thank you for your gracious hospitality last Monday for myself and the subcommittee staff. It was a very good day that we had up at Pratt-Whitney and I think we learned a lot and it gave us a lot of information on which we can base some more of our deliberations on this budgetary process this year.

One question, though, that I feel compelled that I have to go over with you has to do with the variable cycle engine, in which I am greatly interested, as you know. One of the things that we went over on Monday with you up at Pratt & Whitney was the funding of the variable cycle engine. I guess what I want to do is to get for the record your comments on the present level of funding for the variable cycle engine. Is it adequate to verify the concept to the point where a production decision could be made? Now, leaving aside the production decision aspects of it, do we have enough right now or do you feel that we need more to bring along the concept to the point where a decision could be made?

I just wonder if you could address that question, Bill.

Mr. SENS. The current level of funding is not adequate to get us to the point of technology readiness. And, yes. It would require more funding to do it. The fiscal 1981 program is a start in that direction. It would have to be followed on with funding of other efforts, such as the hot section technology demonstration, plus further follow-on efforts to reach the point of readiness where we could make a logical decision for a go-ahead on a commercial-type program.

Mr. HARKIN. Do you feel pretty good about the variable cycle engine? I mean, do you feel, technologically speaking, that these problems that face us in supersonic flight—the noise, environmental problems—are technological problems that can be addressed over time?

Mr. SENS. Yes. I am convinced the technical problems can be addressed. The most difficult problem is the one that we discussed Monday, which is getting good engine durability at the very high operating gas temperatures in the burner and turbine of the supersonic transport engines. These problems need to be addressed before we can reach a point of readiness. They are the ones that I am confident can be solved.

Mr. HARKIN. So that in relationship between the host program and the variable cycle engine, both of those should continue on?

Mr. SENS. Yes. The host program develops the basic design technology that is needed to make an engine design for a good hot section demonstration program. You need the host program to generate the technology to provide the design that you are going to build.

Mr. HARKIN. I am sure you have seen the budget, the proposed budget here for the aeronautics program. OMB left \$2.5 million, the total amount, that was recommended to them for Host. But the variable cycle engine, that was cut from 6.5 down to 4.5. Would it be your feeling that adequate funding of the variable cycle engine has to go along in parallel with the Host program? Can they be disjointed, for example?

Mr. SENS. I think the Host program would lead into a later phase of the VCE program that addresses the hot section durability questions. There is work that can go on in parallel on the two programs and the Host program will feed into the later phases of the VCE program.

Mr. HARKIN. I don't have any further questions.

The staff informs me that we have a lot of the SST people in the audience. I am just wondering if anyone would like to make any comments for the record right now.

Mr. HOPE. Jack Hope, a consultant; with all of the industry, both airframe and engine, during the past 2 years. I would like to verify that we all agree with Bill's statement on the level of funding, that it will not verify technology—getting it ready for production. I think all of the industry will agree to that statement.

Mr. ROYER. I had pursued that question a little earlier. I thought I heard you say, for what we are attempting to do, it was adequate, but further down the line it was not sufficient. Did I misunderstand you?

Mr. SENS. You misunderstood me. The current level of funding will never get us to technology readiness. The proposed augmentation is a start toward getting there, but will require further additional efforts.

Mr. HARKIN. I am glad we got it cleared up.

Mr. WILSON. Jim Wilson, McDonnell Douglas Corp.

We would like the opportunity to make a statement at a later time. Would it be possible to leave the record open for a statement at a later time?

Mr. HARKIN. Certainly. We will leave the record open for a statement by McDonnell Douglas.

Again, thank you very much for an enjoyable and interesting day on Monday.

Bill, I would recommend that sometime you go up there and see what they are doing. It is very exciting.

Dr. SHANK. It was our pleasure. You are welcome any time, sir. And I want to thank you for the opportunity to testify.

[The prepared statement of Dr. Shank follows:]

**FISCAL YEAR 1981
NASA AERONAUTICS
AUTHORIZATION**

**Statement of
United Technologies Corporation
Pratt & Whitney Aircraft Group**

Prepared for

***Committee on Science and Technology
U.S. House of Representatives
Subcommittee on Transportation, Aviation, and
Communications***

Honorable Tom Harkin, Chairman

1114

FISCAL YEAR 1981
NASA AERONAUTICS AUTHORIZATION

STATEMENT OF
UNITED TECHNOLOGIES CORPORATION
PRATT & WHITNEY AIRCRAFT GROUP

February 7, 1980

by

Dr. M. E. Shank
Director, Engineering Technology
Commercial Products Division

Prepared for
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND COMMUNICATIONS
HONORABLE TOM HARKIN, CHAIRMAN



Mr. Chairman and members of the subcommittee:

I thank you for the opportunity to appear before you today to discuss NASA's aeronautics program.

I represent Pratt & Whitney Aircraft Group, the largest unit of United Technologies Corporation. Pratt & Whitney Aircraft designs, develops and markets commercial and military aircraft engines on a worldwide basis. I am Director of Engineering Technology for the company's Commercial Products Division. I'm also a member of the NASA Aeronautics Advisory Committee, and chairman of its ad hoc Subcommittee on Advanced Aeronautical Propulsion Technology Requirements. With this background, I believe that I can bring a broad perspective to a discussion of NASA programs in the propulsion area. I particularly would like to discuss these programs in terms of national needs.

Figure 1 shows that there are at least four key national needs which must be met through a broad base of research and technology in aeronautics. They are: (1) development of competitive products, (2) conservation of fuel, (3) substitution for and conservation of critical metals, and (4) assurance of a favorable balance of trade.

NATIONAL NEEDS

- **Competitive products**
- **Conservation of fuel**
- **Conservation of critical metals**
- **Favorable balance of trade**

Figure 1

Aerospace products are the second largest export item in U.S. trade. This trade will be even more vital to the nation during the 1980s, when the worldwide transport aircraft market is expected to average more than ten billion dollars (1979 dollars) annually. Other countries recognize the benefits of capturing a sizeable portion of such a market, and they are committing their resources to this investment. A healthy NASA aeronautics budget is one way to stimulate the high-risk research which can be exploited in technical products necessary to

compete in the worldwide market. NASA and industry must make investments sufficient to meet national needs.

Without strong government support for innovative research and technology, U.S. world leadership in the commercial transport sector will decline. Large expenditures by the private sector also are required. If this support is not forthcoming, economic consequences will include fewer jobs and increased trade deficits. The technical consequence will be a loss in U.S. leadership. Unfortunately, the trend of over-all research and development expenditures as a percentage of gross U.S. national product is declining. At the same time, other nations - Russia, West Germany, and Japan for example - have increased these expenditures as shown in Figure 2.

DECLINING U.S. R&D EXPENDITURES

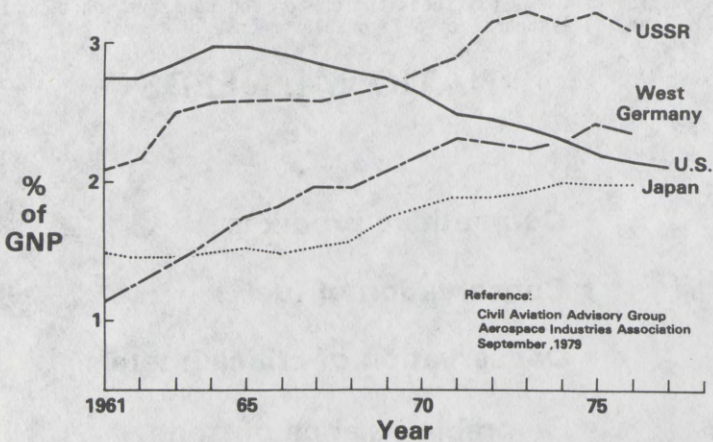


Figure 2

We, at United Technologies Corporation, are committed to investing substantial amounts in R & D. As of the end of 1978, when ranking figures were last published, of the top ten companies in research and development spending in the United States, United Technologies ranked first in R & D investment measured as a percentage of total sales. In 1979, the company invested more than 500 million dollars on research and development. Pratt & Whitney Aircraft's portion of this United Technologies' investment came to more than one million dollars a day.

United Technologies expects to spend more than three-and-one-half billion dollars on corporate-wide research and development over the next five years.

Despite large commitments by the aircraft industry in R & D, and the additional support provided from the government sector through NASA's aeronautics budget, there is growing evidence that the once unquestioned leadership of the United States is in danger. Erosion of the nation's commercial aircraft market share already is upon us. In 1979, firm orders were announced for more than 120 of the Airbus widebody aircraft manufactured in Europe. This placed Airbus Industrie second among widebody airframe manufacturers in the world market. In the face of this challenge, a concerted effort is necessary to maintain the nation's competitive leadership.

Before turning to a discussion of NASA's fiscal 1981 programs, I would first like to say a few words in praise of the JT8D Refan and Engine Component Improvement programs, two recent NASA projects in the field of aeropropulsion. I believe they have yielded and are continuing to yield good results in meeting national needs.

In 1972, NASA and Pratt & Whitney Aircraft joined in a program to achieve lower noise and improved fuel-efficiency levels for derivative models of the JT8D engine by introducing more advanced technology in the engine's fan section. The JT8D is the most widely used engine in free-world commercial aviation--more than 11,000 have been sold or are on order. The NASA/Pratt & Whitney Aircraft JT8D Refan Program was very successful because we were able to demonstrate the potential for significantly lower noise levels and lower fuel consumption. With the demonstration of this technology in hand, we worked with airline and airframe manufacturers to define a derivative JT8D engine which would best meet their needs for the decades ahead.

The JT8D-209, which was developed with Pratt & Whitney Aircraft funds, is that derivative engine. Its introduction into airline use will be on the new McDonnell Douglas DC-9 Super 80 aircraft which is scheduled to enter service later this year. The engine has lower noise levels than earlier JT8D engines, and preliminary analysis of flight test data shows that the aircraft will be significantly quieter than that required by government regulation for a derivative aircraft. Indeed, we have high confidence that this derivative aircraft will meet the more stringent noise regulations required for new type aircraft. In addition, fuel consumption per seat mile is reduced on the order of 20% at cruise conditions. The first airline to introduce the DC-9-80 will be Swiss Air.

The NASA JT8D Refan Program clearly met national needs by creating a competitive United States aeronautical product for the international market and by reducing energy consumption. It should be noted that the contract arrangement with NASA on the Refan Program included a cost recoupment, which means that our company will pay back funds to our government based on the number of engines we sell.

My second example of a beneficial, NASA-sponsored program is the Engine Component Improvement Program. The goal of the program is to reduce the fuel consumption of current high-volume, production engines, such as the Pratt & Whitney Aircraft JT8D and JT9D engines. Many component performance improvement concepts are being evaluated. Several concepts have been demonstrated to date and are starting to be introduced into airline service. We expect that these component improvements will result in a total fuel savings of more than 6.4 billion gallons for engines sold through 1990 (Figure 3).

CONSERVING FUEL THROUGH NASA'S ENGINE COMPONENT IMPROVEMENT PROGRAM

Total Potential savings: 8.6 billion gallons

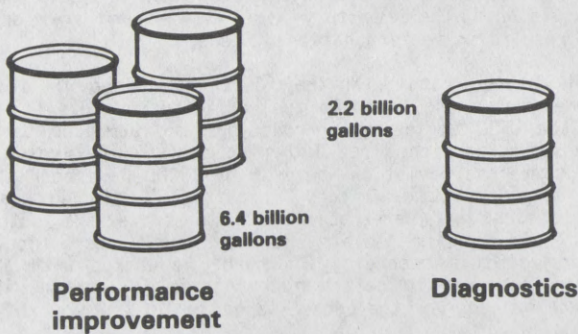


Figure 3

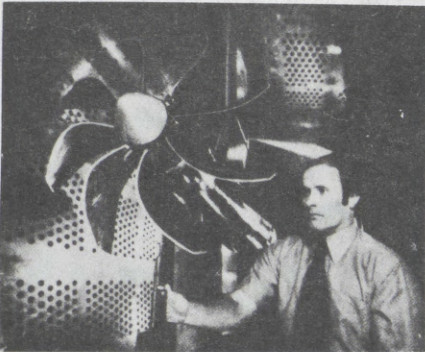
This program also investigates the causes of the performance deterioration of high-bypass ratio engines, which power such aircraft and the Boeing 747 and McDonnell Douglas DC-10. Although not yet complete, the program already has produced information which will enable us to recommend improved maintenance procedures to the airlines. It is estimated that these improved procedures will save an additional 2.2 billion gallons of fuel during the lifetime of the engines (Figure 3). The knowledge gained from this program will also benefit the performance and fuel efficiency of future engines.

Now, I would like to address three items of the proposed NASA Fiscal Year 1981 Aeronautics Program. These are the Advanced Turboprop, the Variable Cycle Engine, and the Hot Section Technology programs.

We, at Pratt & Whitney Aircraft Group, strongly believe the NASA Fiscal Year 1981 Advanced Turboprop Program Augmentation is an excellent

program. The key to this program is the propeller. Advanced turboprop designs (Figure 4) using modern, highly efficient propellers offer a potential of 15-20% in fuel savings for several commercial aircraft applications relative to a 1990's high bypass ratio turbofan such as the NASA Energy Efficient Engine. These turboprop designs may even yield savings of 30% to 40% for some short-haul and military patrol aircraft studied. A program with this potential payoff should be pursued vigorously in today's environment of rapidly escalating fuel costs and concern about future fuel availability.

DEVELOPING NEW TURBOPROP CONCEPTS TO SAVE FUEL



- 15 to 20 percent savings

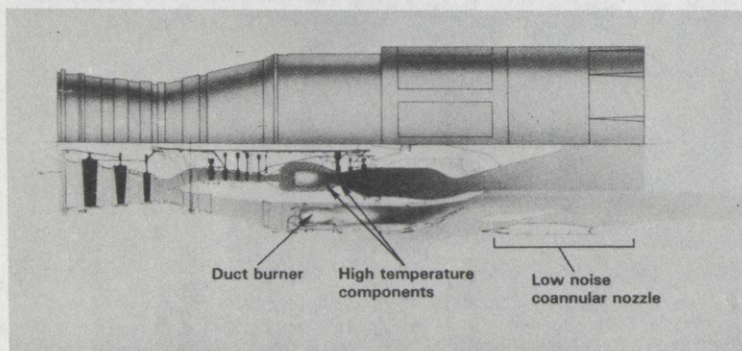
Figure 4

The current Advanced Turboprop technical program is progressing in a very satisfactory manner. Initial model performance testing in the NASA/Hamilton Standard Propfan program shows great improvement in propeller efficiency at high subsonic speeds, and substantial progress has been made in lowering noise levels. Much remains to be done, however, to verify the technology to the point where industry would be prepared to proceed with a commercial engine program. Fabrication and test of a large-scale propeller for the advanced turboprop is required to establish its structural integrity. Wind tunnel or flight tests of this propeller are needed to verify its in-flight performance and its potential for freedom from cabin vibration and noise. Finally, flight test of a commercial transport aircraft modified to incorporate experimental turboprop engines powering the advanced propeller is required to verify the over-all performance of the turboprop/airplane combination, and to demonstrate a satisfactory level of cabin noise and passenger comfort.

We feel that this program should be pursued as long as the technical progress remains favorable. The Fiscal 1981 Advanced Turboprop Phase II program covers the earlier portion of the above effort. However, even assuming a fully successful program and appropriate follow-on efforts, the technology would not be ready until the 1990s. In our opinion this program should be accelerated to provide technology readiness at an earlier date. Because of the large potential fuel savings and the increasing concern about fuel conservation, we suggest striving to have the technology ready in the mid-1980s so that it could be available in suitable aircraft in the early 1990s.

The schematic drawing in Figure 5 shows the Variable Cycle Engine (VCE), a program which NASA proposes to increase in Fiscal Year 1981. We have made significant progress in our Variable Cycle Engine Program with NASA in the past year, and we endorse NASA's plan for the further step with this engine.

PROTECTING OUR OPTIONS FOR A SUPERSONIC TRANSPORT



Critical technology requirements

Figure 5

Studies based on technology development, since the proposed United States Supersonic Transport (SST), indicate that a commercial SST may be possible in the 1990s, predicated upon a vigorous program of technology development. Adequate funding is required to protect our long-range transport market against the possible incursion of a second-generation foreign supersonic transport. In the event that the United States decides that this should become a national objective, our options, therefore, would not be foreclosed.

The present NASA/P&WA Variable Cycle Engine Program has shown very encouraging results in regard to both performance and noise. Tests of the duct burner component have already demonstrated efficiency levels 2.5% above the program goals. Also, nozzle model tests have verified an eight decibel noise reduction for the Variable Cycle Engine relative to the first-generation SST engine nozzle design.

The NASA Fiscal Year 1981 program for this engine will begin the process of verifying and improving component technology. The P&WA proposed effort will concentrate on improved designs of the duct burner, jet nozzle, and noise suppressor to improve flight performance and noise levels. The noise goal will be to achieve those levels required for new subsonic aircraft. These technical areas will be addressed by testing improved designs of the duct burner and by performance and noise tests of improved design nozzle/suppressor models.

We strongly endorse this NASA Fiscal Year 1981 VCE program.

The third program I would like to single out for endorsement is the Hot Section Technology Program.

The hot section of a gas turbine engine (Figure 6) includes the combustor and turbine. Certain parts in the hot section are exposed to gas temperatures well above the melting point of the metal structures. Even with cooling, their life is limited. The alloys employed require use of critically scarce metals.

BENEFITS FROM HOT SECTION TECHNOLOGY PROGRAM – (HOST)

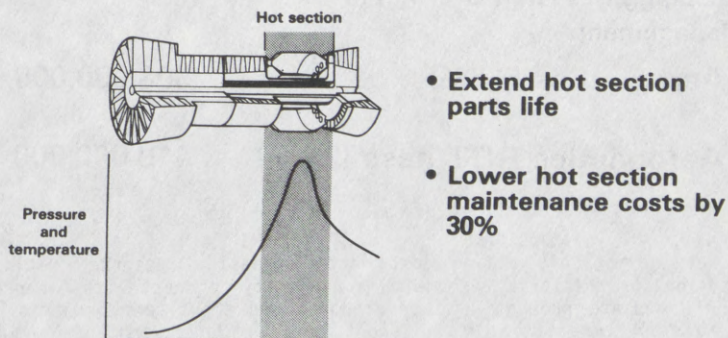


Figure 6

Emphasis on fuel efficiency drives engine design toward higher operating gas temperatures, higher pressure ratios, and higher rotating speeds. These trends create a more severe hot section environment, requiring more complex combustor and turbine parts. Historically, hot section upkeep for modern high-bypass ratio engines accounts for 60% of the engine's maintenance cost. The objective of the Hot Section Technology Program is to develop analytical tools and the technology to extend the life of hot section parts relative to those in first-generation high-bypass ratio engines, thus conserving critical metals, and reducing the cost of hot section maintenance by 30%. A gain of this type will contribute significantly to the competitiveness of U.S. commercial engines in the world market.

Phase I of the program, which is included in the Fiscal Year 1981 NASA request, will produce basic analytical models and tools that can be used in the design of improved hot section parts. In a subsequent phase, demonstration and design verification testing will be conducted.

Next, I would like to discuss the Research and Technology portion of the NASA Aeronautics Budget (Figure 7) and its importance to the maintenance of the strong U.S. technology base. The R & T base budget supports innovation and knowledge-building. The R & T base is the wellspring of ideas. It is here that the foundation of technological advancement is established. We see a serious danger in the recent trend of reduced funds for R & T efforts.

FY 1980 NASA BUDGET

Total NASA budget	\$4,108,000,000
excluding Research & Program Management	
Aeronautics (7.5%)	308,000,000
Aeronautics R&T base (2.9%)	119,000,000

Figure 7

In an era of sharply rising costs and increasingly scarce critical metals, industry has been faced with a necessity to devote its finances to more immediate product line development and short-term projects in order to stay competitive in the short run. In the government sector, NASA is the only U.S. agency with a charter to preserve U.S. leadership in commercial aeronautics. Despite this mandate, only 2.9% of the total 1980 NASA budget of \$4.1 billion (excluding Research and Program Management) goes into the aeronautics R & T base.

Furthermore, this portion of NASA's budget has declined in terms of real dollars in the past decade.

We do not fully understand the reason for NASA's declining R & T base (Figure 8), but perhaps it is because shorter-term systems or experimental programs appear to have more immediate and more visible payoffs. Depletion of the R & T foundation that is applicable to future systems or experimental programs can contribute to these serious consequences: (1) the return from future systems and experimental programs will slow down; (2) the cost of such programs will increase because the technology necessary for their success may have to be acquired in the course of the programs; extra time will be required for completion and (3), the success of such future programs may become questionable because the necessary, underlying technology will never be acquired. This lessens the ability of the U.S. aircraft industry to improve its state-of-the-art technology in the worldwide competitive market.

DECLINING NASA AERONAUTICS R&T BASE BUDGET

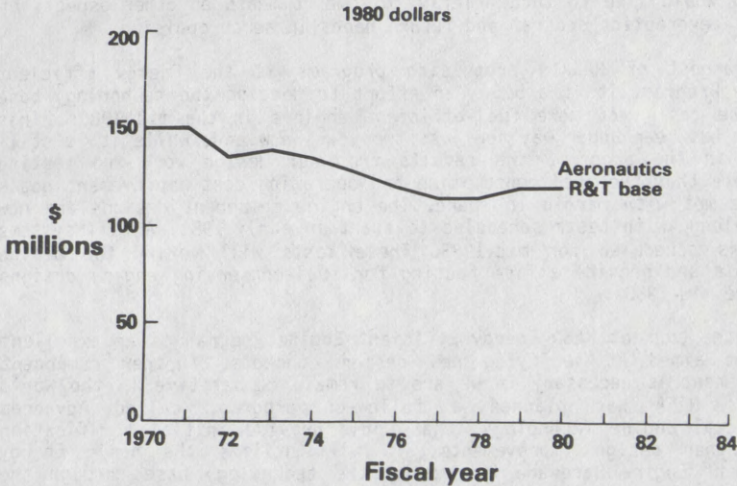


Figure 8

Research and technology is a searching process and success is not always assured. I would like to cite just one success from the NASA R & T base which made practical today's fuel-efficient, high-bypass ratio engines. This was the technology performed in the 1950s to develop compressors capable of efficient handling of a higher velocity

airflow over the compressor blades. That work on the transonic flow compressor became the basis of today's aircraft engine high-speed compressor design. It made possible the modern, efficient, high-bypass ratio fan, leading to U.S. supremacy in the engine field. However, at the time the compressor research was undertaken, there was no way to predict its eventual outcome.

In the early days of gas turbine engine development, it was thought that one had to maintain the airflow over compressor blades at essentially subsonic speeds. This limited both the rotational speed and the pressure ratio that could be developed, and resulted in compressors being much larger than they now have to be. A NASA team at the Lewis Research Center pioneered in the fundamental design of supersonic flow compressors for high Mach number flight. Working with members of the aircraft industry and with test support from Langley Research Center's, the team verified the value of new design concepts. This work led to highly efficient compressor designs.

We would urge the Congress to increase the funding provided in NASA's budget for the R & T base - to turn declining support into increasing support in the years to come.

Now, I would like to turn briefly to some comments on other aspects of NASA's aeronautics program and future needs in aer propulsion.

The largest of NASA's propulsion programs is the Energy Efficient Engine Program. It is a 5.5 year effort to develop the technology base for the design of more fuel-efficient engines in the mid 1980s. This effort has been under way for just two years now and, while it is still early in the program, the results from our design work and testing indicate that the fuel consumption and operating cost improvement goals can be met with margin to spare. The engine component designs are now well along, with tests scheduled to start in early 1981. A full systems test is scheduled for mid-1983. These tests will verify the design concepts and provide a firm footing for fuel-conserving engine designs for the mid-1980s.

While the current NASA Energy Efficient Engine Program is an excellent program aimed at verifying new design concepts, further component improvement is necessary if we are to remain competitive in the world market. NASA has planned a follow-on program, called Advanced Commercial Engine Technology, that would provide initial verification of further design improvements. It will utilize the basic Energy Efficient Engine hardware to improve the technology base through the verification of improved components and new materials. We strongly endorse this program as a means to provide further technology leading to future fuel savings.

Looking beyond the proposed Fiscal Year 1981 program for the Variable Cycle Engine, we see an important requirement to conduct high temperature validation tests under the demanding conditions of supersonic flight.

The Variable Cycle Engine, under cruise conditions, operates at hot section gas temperatures about 300 to 400°F hotter than today's engines (Figure 9). It will be a formidable task to achieve durability at these temperature levels while maintaining an acceptable level of turbine cooling air.

CRUISE OPERATING TEMPERATURE COMPARISON

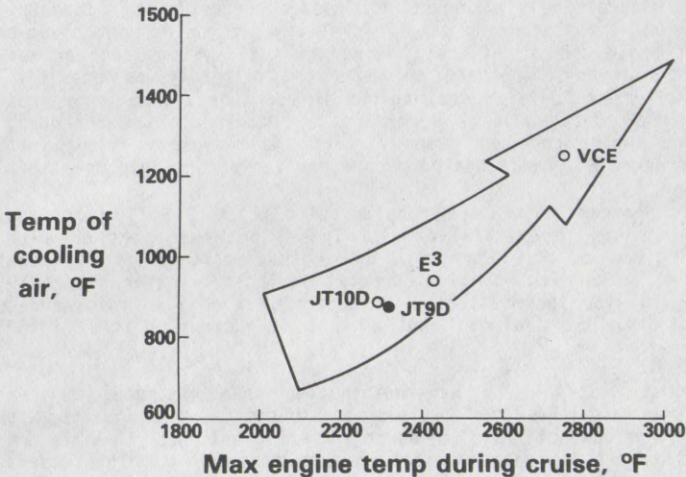


Figure 9

The VCE High Temperature Validation program is required in order to substantiate the required advanced materials and cooling technologies in an engine environment. This program would have valuable fall-out for both military and advanced subsonic commercial applications.

A vital program that NASA and industry have been advocating is entitled "Aircraft Technology for Future Fuels". We now are in a period where the supply and quality of aviation fuels is taking a turn for the worse. There is increasing dependence on imported crude oil and higher carbon-content, or aromatic crudes. Refinery capability to produce specification jet fuel from higher carbon-content crudes is limited. Therefore, our airlines increasingly have been using fuels requiring specification waivers. The future is at best uncertain in terms of the supply and quality of aviation turbine fuels and soon it may be necessary for our engines and airlines to use fuel derived from oil shale, tar sands, or even coal.

Higher carbon-content fuels make engine parts run hotter and as a

result the parts do not last as long. In addition, there probably are other adverse effects that will appear as broader-content, petroleum-based fuels and fuels from oil shale, tar sands, and coal make their debut. These effects could have an unfavorable impact on gaseous emissions, smoke, and ignition characteristics of engines. While we have confidence that we can develop engine parts to accommodate higher carbon-content fuels, such development may be far more expensive and disruptive to airline operations than attacking the problem at the refinery level.

A NASA Future Fuels Program is needed urgently by industry to demonstrate the technological feasibility of using petroleum-based fuels of broad specifications in aircraft fuel systems and engines. We think it is very important to determine as early as possible the effects of these fuels on the engines in use today. In a later phase of this program, data would be generated to demonstrate the acceptability of future engine components and aircraft fuel systems using synthetic fuels or petroleum fuels having much wider variations in properties.

The last program for future consideration which I will discuss deals with the crisis in critical metals. This was the subject of a recent address given by Mr. Harry J. Gray, chairman and chief executive officer of United Technologies Corporation, to the American Society for Metals. With your permission, I am attaching a copy of this address to my testimony, Mr. Chairman, but I want to summarize it's highlights here.

The United States is a have-not nation when it comes to certain critical metals. Two such metals are chromium and cobalt. Without chromium, we cannot make a durable, efficient gas turbine engine. Chromium imparts oxidation-resistance and strength to high-temperature parts. We are dependent on Africa and the Soviet Union for chromium.

Cobalt is unique in its ability to withstand high temperatures and stress in the hot sections of a jet engine. The U.S. imports 97% of its cobalt. Our major source of supply is in a country with a history of instability -- Zaire. Other critical metals used in our engines and on which we are heavily import-dependent are tungsten, titanium (because of lack of processing capacity in the U.S.) and columbium.

I believe that those few points from Mr. Gray's address show that there is much to be done by government and industry in establishing an effective mineral policy to protect our sources of vital raw materials. NASA should take a strong role in the conservation of critical aerospace metals by establishing a program of research. The program should cover the field of alloy substitution and modification, reduction of raw materials input by such techniques as casting parts close to finish size, metal powder technologies, and the development of new alloy and coating concepts.

Problems relating to fuels and metals scarcity are national in scope and are appropriate for funding via R & T. It is insufficient to

address these problems solely via the industrial community.

To summarize my remarks today, I hope that I have made it obvious that the United Technologies Corporation and Pratt & Whitney Aircraft strongly supports the Fiscal Year 1981 programs proposed by NASA. They fit well into the over-riding goal we all support, namely, meeting vital national needs.

The Advanced Turboprop - as I mentioned - offers the potential of a 15 to 20 percent savings in fuel consumption.

The Variable Cycle Engine Program will keep America's options open for a second-generation supersonic transport. The program will develop technology for supersonic flight that addresses the need for fuel efficiency and environmental concerns.

The Hot Section Technology Program provides an opportunity through directed research in several technical areas for improvement in parts life and hot section maintenance cost. This will make our products more attractive on the world market.

If anything, there is a need for a real dollar increase throughout the NASA aeronautics budget and especially in its R & T base funding. Considering what the country has at stake in terms of jobs and trade value, we must not falter in protecting our leadership.

I shall be happy to answer any questions you may have. Thank you very much.

Mr. HARKIN. Our next witness is Charles W. Ellis, vice president, business administration and military program management of the Boeing Vertol Co., Philadelphia, Pa. He is accompanied by Mr. William B. Peck, director of product development and research.

Gentlemen, welcome to the subcommittee.

Without objection, your entire statement will be made a part of the record, and please feel free to proceed in any manner you so desire.

STATEMENT OF CHARLES W. ELLIS, VICE PRESIDENT, BUSINESS ADMINISTRATION AND MILITARY PROGRAM MANAGEMENT, BOEING VERTOL CO., PHILADELPHIA, PA.; ACCOMPANIED BY WILLIAM B. PECK, DIRECTOR, PRODUCT DEVELOPMENT AND RESEARCH

Mr. ELLIS. Mr. Chairman, gentlemen, it is a privilege to be here to support a strong, expanded and aggressive NASA program in rotorcraft technology. What I would like to do today is briefly review the situation in the rotorcraft marketplace, that has played a significant factor in our aerospace export balance of trade, talk briefly about the status of a very strong foreign competitive effort, and give you my views on the role that NASA rotorcraft technology efforts can play in assuring an improvement and a sustenance of our position in this field.

As you are aware, helicopters are currently used extensively in many international civil markets (fig. 2).

I have listed them here. I won't belabor them.

In addition, there has been a strong foreign military market for U.S. products because we have led the world in rotorcraft technology.

Just as an example, in the last two major models that Boeing Vertol has produced, about 20 percent or some 350 aircraft, which would have a value in today's dollars of over \$2 billion, have been sold to countries outside the United States.

So the rotorcraft export market has been an important market for the U.S. helicopter companies and has played a not insignificant role in the balance of U.S. trade. As an example of what is being done in the export market and in the commercial helicopter market, Boeing is offering a commercial transport aircraft which carries 44 passengers for approximately 500 miles (fig. 6).

To show you what this means in the competitive world, I have chosen the issue of direct operating cost (fig. 11).

The upper line represents today's 18- to 25-passenger helicopters that are used in the offshore oil business to carry people to the offshore oil rigs. Our new aircraft incorporating the latest technology that is available in the United States today cuts operating costs approximately in half, for normal operating ranges.

In order to look at what could be done with an aggressive technology program, with larger, more productive rotary wing aircraft, I have selected as an example a passenger version of the Army's terminated heavylift helicopter program. This data shows you that in fact it should be possible to achieve helicopter operating economics that are comparable to the operating economics of fixed wing aircraft that are used in shorthaul commuter airline operations.

Mr. HARKIN. If I might interrupt here.

What is HLH?

Mr. ELLIS. That is the designation for the U.S. Army's heavylift helicopter.

Mr. HARKIN. When you say typical fixed-wing shorthaul transport, are you talking about the commuter type, that would be around the 50-passenger range?

Mr. ELLIS. The upper band of that line is the NORD 262/Twin Otter type aircraft; the lower band is the 737 type aircraft. Thus it represents aircraft in the 20- to 120-passenger sizes.

Mr. HARKIN. I see the gap there, but I don't know what your axis is divided up into.

How far apart are you talking about from that 234 line to your typical fixed-wing shorthaul transport?

Mr. ELLIS. Typical numbers for the 234 are 20 to 30 cents per seat-mile. Typical numbers for the heavylift helicopter line are in the 8—5 to 8 cents per seat mile.

So it is about a 3 to 1 reduction in seat-mile cost.

Mr. HARKIN. Between the 234 and that other line down there?

Mr. ELLIS. The heavylift, the 225-passenger line.

Mr. HARKIN. I am talking about the shorthaul transport.

Mr. ELLIS. The upper end of that line is about 15 to 20 cents per seat-mile.

Mr. HARKIN. About 15 cents per seat-mile. And the 234 was what?

Mr. ELLIS. Twenty to thirty. Let's say 25 as an average. That is about a 40-percent reduction.

Mr. HARKIN. Thank you.

Mr. ELLIS. The point to make here is, with an aggressive development of rotorcraft technology, we can achieve substantial reductions in operating costs, and we can provide aircraft that can compete economically in the shorthaul market, and thus expand the rotorcraft market.

I would like to talk now briefly about the foreign competition.

And I have selected to show you the growth in foreign helicopter imports to the United States (fig. 14). We started in the early seventies with a helicopter market that was essentially solely a U.S. preserve. We have seen a rapid growth—and this is actual data through 1978—a rapid growth in foreign imports and all the data that I have suggests that that trend will continue.

It is coming about because the foreign manufacturers who are heavily subsidized by their governments, are very aggressively developing rotorcraft, using improved technology, to meet civil and military market needs. Consequently, they are being very successful in penetrating a marketplace that has been solely ours.

Now, at the same time that the foreign competitors are developing their technology, the source of U.S. helicopter technology is effectively drying up.

That base has been the U.S. military helicopter development program. Since the fifties and sixties, there has been a steady decline in the number of new military helicopter programs that have come along to supply the impetus to develop the new technology that has, in the past, kept us in the lead in helicopter sales.

Today we don't have the military technology base being developed. I believe that a proper role for NASA is to substitute for military activities in the development of a rotorcraft technology base that can enable us to maintain a strong competitive position in the helicopter world.

I would just like to talk briefly about what NASA can do (fig. 16).

There are a number of deficiencies in our rotorcraft technology today and those deficiencies require work in both improving basic technology and in increasing the percentage of science as opposed to black art in helicopter development.

Many people will compare helicopter development to fixed wing development by saying that fixed wing is 90 percent engineering science and 10 percent art and that helicopter development is 10 percent science and 90 percent art.

I don't think it is quite that bad. But there are a number of areas where we do need improved technology to expand the usefulness of the helicopter. I might just point out the first item there, noise reduction. We are about to be faced with an FAA certification regulation on helicopter external noise. And yet virtually no technology exists for noise prediction in the helicopter case.

In the case of the fixed wing aircraft, close to \$100 million was spent in developing noise technology. That has not been the case in the helicopter area.

The contributions that NASA can make (fig. 17) are basically in providing theory and design methodologies in the areas of rotor aerodynamics, aeroelasticity, acoustics, and so on; validating the methodology through using their wind tunnels and their flight experimental capability; and carrying out vehicle configuration studies to identify the promising concepts that can use those technologies to improve the productivity of rotary wing aircraft.

We have made a projection of the impact of such an aggressive rotorcraft technology program, focused on those shortcomings and believe that if we initiate a strong program in the eighties, we can expect to see a one-third increase in our sales in the 1990 decade (fig. 22).

That certainly represents a very good return on a national investment.

Last year the NASA Aeronautics Advisory Committee recommended about \$17.5 million of new-initiative rotorcraft programs to be initiated in the NASA 1981 budget (fig. 23). The current budget submitted contains about \$5 million of that recommended \$17.5 million new-initiative activity.

In summary I would like to urge the committee to support an expansion of this NASA rotorcraft initiatives program for the benefits that it can bring to U.S. industry in maintaining its competitive position in the helicopter market around the world.

Mr. HARKIN. Thank you very much, Mr. Ellis.

I would like to get through a couple of questions before we have to break and I have to go over and vote.

Just to reiterate then, you would agree that the potential future export market, as you just indicated there, would justify a larger effort on our part in the rotorcraft funding. Let me just give you some comparisons here.

Civil helicopter exports in 1978 were \$208 million versus \$2.5 billion for civil transport. The level of rotorcraft funding, \$25.9 million in fiscal year 1981, which was what you were requesting, to be compared with the transport funding of \$100 million, almost one-fourth, whereas the exports were what, \$208 million versus \$2.5 billion.

I guess what you would say is that it is going to catch up later on.

Mr. ELLIS. I think if you looked back in the history of NASA, you would find that the total expenditures on the fixed wing transport are much, much more than the 10 to 1 ratio of export dollars because there has been a long history of technology development for the fixed wing industry.

There has not been such a development for rotary wing.

Mr. HARKIN. One of your charts shows the rotorcraft imports to the U.S. going up considerably, going up from \$5 to over \$30 million, I guess.

What are the percentage figures on that?

Mr. ELLIS. In 1978, it has grown to approximately 20 percent of the U.S. market.

Mr. HARKIN. What would it have been in 1976?

Mr. ELLIS. I don't have that number, but it was certainly much smaller than that.

Mr. HARKIN. In other words, you are saying the slope of that line is much greater than the slope of the total aircraft sales?

Mr. ELLIS. That is my belief; yes, sir.

Mr. HARKIN. Would you care to comment on the transfer of NASA's rotor aircraft work from Langley to Ames?

Mr. ELLIS. I think it doesn't make very much difference where the work is located as long as it is located in a single center and with strong guidance. I believe it has developed that strong centralization in the transfer to Ames.

Mr. HARKIN. How do you rate the relative merits of the tilt rotor, the advancing blade concept, and the X wing for high-speed flight?

Mr. ELLIS. Well, I think the tilt rotor aircraft is an aerodynamically very efficient aircraft. It has had enough experimental work done on it and being done on it, to be a relatively moderate-risk kind of a vehicle, but one that suffers from the mechanical complexity of tilting the rotor system.

The other end of the spectrum, the X wing aircraft offers considerable promise, but is a relatively high-risk technology that needs development and demonstration. If it works, it can be very promising. A lot of work has to be done to know whether it will work at all.

The advancing-blade concept system enjoys the advantages of mechanical simplicity, but it is aerodynamically a less efficient vehicle than either of the other two.

Mr. HARKIN. But a lower risk concept?

Mr. ELLIS. I would say that ABC is probably at this point somewhat higher risk than the tilt rotor because of the problems of vibration in high-speed flight. That is a personal opinion.

Mr. HARKIN. Thank you, Mr. Ellis.

[The prepared statement of Charles W. Ellis follows:]

STATEMENT OF
Charles W. Ellis
Vice President
Boeing Vertol Company
to the
Subcommittee on Transportation, Aviation, and Communications
of the Committee on Science and Technology
· U. S. House of Representatives
February 7, 1980

Mr. Chairman and Members of the Committee:

I am appearing here today in support of a strong, aggressive NASA Program in rotorcraft research. I plan to review for you the expanding applications of rotorcraft, the growing worldwide market and expansion of foreign competition and the role NASA can play in developing the technology that will assure continued U.S. leadership of the international rotorcraft market in the 80's and 90's.

HELICOPTER PRESENT AND FUTURE APPLICATIONS

Helicopters are currently in extensive use in the civil sector in many applications. Examples of some of these areas are:

- o Resource Exploration (off-shore and on-shore oil drill rigs, remote mining)
- o Forest Management and Agriculture (logging, forest fire fighting, seeding, insect and disease control)

- o Construction in Environmentally Sensitive Areas (power transmission towers, pipelines, urban and industrial construction)
- o Public Service (police work, ambulance service, disaster relief)
- o Passenger transport (off-shore oil, business, urban)

These applications will expand rapidly in the 1980's and beyond. Their expansion will be enhanced significantly by advanced rotorcraft technology. I wish to review briefly some of our present activities at Boeing Vertol in order to better address future projections. Our products now in military service include the CH-46 (Figure 3) which carries 17 troops in service with the U.S. Navy and Marine Corps and the CH-47 (Figure 4) Chinook which carries up to 44 troops in service as the Army's Medium Lift Transport. We have built some 600 CH-46's and almost 1000 CH-47's. Of these aircraft, approximately 300 have been delivered to foreign governments and are deployed around the world as shown in Figure 5. We are now developing a civil derivative of the Chinook, our Model 234 (Figure 6), which will carry 44 passengers or up to 14 tons in the utility configuration. We will deliver the first of these aircraft later this year to British Airways Helicopters for the transport of work crews to North Sea oil rigs. Because of its ability to transport a large number of passengers over a long range, our Model 234 will provide the capability for faster, lower cost operation than the present system which uses smaller, shorter range helicopters.

The off-shore oil support market will remain as the fastest growing market for all helicopters. With the supply of oil from the Middle East uncertain and readily available supplies on land dwindling, Figure 7, there is steadily increasing pressure to explore further from shore in more demanding environments. If we look at the worldwide off-shore oil projections, we see that the North Sea with 100 billion barrels has approximately one seventh of the worldwide off-shore reserves, and that there are two major developing areas: South America with an estimated 82 billion barrels, and the Far East with 207 billion barrels of oil. In

the North Sea alone, the required helicopter passenger seat miles are predicted to increase by two to four times by 1990. This increase will saturate both the terminal area as well as Air Traffic Control Systems unless larger, more productive helicopters replace the present transportation systems. In the Gulf of Mexico, the situation is even more acute. Over 400 small helicopters are presently operating there, mostly under Visual Flight Rule regulations. As distances from shore increase and all weather flight is required, the whole Air Traffic Control system will be paralyzed unless larger capacity helicopters are available to reduce the number of aircraft movements. Figure 8 shows the increase in passenger mile generating capability of the Boeing Model 234, together with a 60 passenger growth configuration of the Model 234. It also shows the quantum jump in capability that would be offered by a passenger transport version of the Army's Heavy Lift Helicopter (HLH), which would have had three times the load carrying capability of the Chinook. The HLH Advanced Technology Component Development Program was sponsored by the Army in the early 1970's. Because of lack of a firm Army requirement, the flight vehicle program was terminated in 1975 prior to flight. Figures 9 and 10 show some of the HLH assets which were stored by the Army. NASA is exploring the use of these assets in a jointly sponsored NASA/ARMY large helicopter flight research activity. This program is included in the NASA planned rotorcraft program. In my opinion, this is the sort of activity that represents a significant national effort for NASA, since with the termination of the Army's HLH program in 1975, technology development for large helicopters ceased in the U.S. The Soviets, on the other hand, continue to pursue large helicopter development gaining experience in the technology as well as the utilization of large helicopters. With the potential for expanded mission capability from increased vertical lift well identified, this void in U.S. technology development should be reassessed and an appropriate R&D program pursued as a national commitment.

Harvesting timber by helicopter provides the opportunity to manage inaccessible forest lands. Many forested areas cannot be accessed by roads because of environmental reasons and high road building costs. Helicopters minimize road building and thus provide the means to manage more areas of forest lands. Today, only a few percent of the nation's timber is harvested by helicopters -- constrained largely by the limited number of helicopters available and by the operating economics of the 1960's technology embodied in these machines. The

Forest Service estimates that some 5 billion board feet of timber could be supplied annually from the currently unused, inaccessible timberland if economic and environmentally sound harvesting systems could be developed. (The total U.S. sawtimber harvest in 1976 was 38 billion board feet.) Logging by helicopter can provide this much needed increase in the annual sawtimber harvest, and the development of technologies which provide better productivity, increased payload, and improved operating economics can make this possible. In addition, the opportunity for heli-logging in the U.S. represents only about 10% of the opportunity worldwide, so that the international market for logging helicopters represents a significant challenge.

One of the prime markets for utility helicopters is electrical power construction. Over 10,000 miles of new and rebuilt electrical transmission lines are constructed each year in the U.S. in the 200 KV+ category and this is only 5% of the worldwide activity. Helicopters are used in a very small percentage of powerline construction today, but ecological pressures and the spiraling cost of labor will force the use of helicopters in a greater percentage of such construction. We estimate that 40 to 60 percent of the time and cost can be saved over conventional construction methods. The development of large civil helicopters can open up entirely new markets in the construction fields and on-shore drilling for the transportation of equipment and completed projects from assembly sites directly to the final locations.

As helicopters prove their reliability and safety of operation in the transport of off-shore oil rig crews, they will gain acceptance for the commercial, short-haul passenger transport market. As shown in Figure 11, large helicopters have substantially better operating economics and can compete with fixed-wing transport seat-mile costs while offering operations independent of large airports. This, together with technology generated improvements in productivity and ride quality, could finally make helicopter civil passenger transport a reality. Figure 12 shows the number of passenger miles flown by fixed-wing aircraft in the North American short-haul market (trips of 300 miles or less). If helicopters captured 10% of this market the number of helicopters in passenger service would be over 300. Worldwide, the potential is larger still. Helicopters can reduce airport congestion and requirements to build new airports. They also

eliminate the long taxi, car or train ride at both ends of the trip. Helicopters can significantly reduce travel time between city center as far as 400 miles apart (Figure 13).

In summary, we see a major penetration of helicopters into every facet of energy exploration and development, and other utility markets, as the need and cost of energy requires a quantum increase in national effort. We see the possibility of safe, dependable inter-city transport by helicopters in the North East Corridor, in Europe (for example, London to Paris/Brussels/Amsterdam) and in the San Francisco/Los Angeles/San Diego area. This need will become increasingly acute as existing airports approach capacity and ground connection time exceeds flight time. All of this potential market growth requires aggressive efforts to improve productivity and reduce operating costs through the development and use of advanced rotorcraft technologies.

FOREIGN COMPETITION

The U.S. position as world leader in helicopters is being effectively challenged by foreign manufacturers. Foreign rotorcraft are highly competitive, high technology aircraft, developed with substantial government assistance. These aircraft have made a significant penetration of helicopter markets in both the U.S. and international arena.

Figure 14 shows the growth of foreign helicopter imports to the United States over the past four years, a growth of over 4.3 times! Firm data for 1979 is not yet available but continued growth is indicated. This appears to be a result of a philosophy which is especially evident in the European manufacturers; helicopters employing advanced technology are specifically designed for civil markets, and may later be adapted for military applications. In the United States we do not have, or advocate, direct government subsidies to individual manufacturers. In the 1950's and 1960's aggressive U.S. military rotorcraft development provided the technology base for the U.S. helicopter industry (Figure 15). An expanded NASA research program, available to all U.S. firms, can partially substitute for the reduced levels of U.S. military helicopter development seen in the 1970's and expected to continue into the foreseeable

future. Such a research program can help to offset the strong foreign rotorcraft thrust.

NASA ROTORCRAFT TECHNOLOGY PLANNING

In 1978 NASA created a special rotorcraft task force consisting of representatives of NASA, DOD, and FAA to assess rotorcraft technology needs and opportunities and prepare a plan which would be responsive to them. This task force, with the assistance of the helicopter industry, helicopter operators and guidance from a select ad hoc committee of the National Research Council's Aeronautical and Space Engineering Board, developed planning for a comprehensive ten year Advanced Rotorcraft Technology program. The technology gaps identified by this group are as follows (Figure 16):

- o Noise Reduction
- o Vibration Reduction
- o Reliability and Maintainability Improvement
- o All Weather Capability
- o Safety Improvements
- o Flying/Ride Quality Improvement
- o Productivity Improvement
- o Reduced Fuel Consumption

New NASA rotorcraft initiatives build on ongoing programs at the Ames, Langley, and Lewis Centers in generic research and augment ongoing work in rotorcraft aerodynamics, operating systems, power transfer, and flight testing. Major emphasis is placed on unique NASA facilities and capabilities which can be categorized into the three major areas shown in Figure 17.

While it is impractical to review or comment here on the full range of activities proposed by NASA in the Advanced Rotorcraft Technology, I would like to highlight a few of the areas which I consider to be particularly important -- areas in which NASA expertise can be particularly helpful. These are summarized in Figures 18, 19, 20 and 21.

Boeing Vertol studies indicate that it is possible to increase helicopter productivity by 40%. This can be achieved by improved rotor and airframe aerodynamics, which can increase cruise speeds to 185 knots; improved vibration, noise and ride qualities control techniques, which can make those speeds practical; reduced empty weight (and initial cost) from the use of advanced composite structures; and reduced fuel consumption from improved engine technology. At the same time, it should be possible to reduce operating costs by 25%, through both reduced initial cost, reduced fuel costs, and improved component reliability. These factors can combine to make the overall economics of helicopters more favorable, reducing the total cost per unit of work to 54% of current levels.

Our national rotary wing research programs should be carefully aimed at achieving these potential gains. If they are successful, we can expect to see an acceleration of growth in helicopter useage and hence in worldwide helicopter sales. Figure 22 shows the potential market growth that a properly structured technology development and demonstration program can reasonably be expected to achieve. It is important to emphasize that research efforts must begin in the 1980's if the benefits predicted for the 1990's are to materialize.

SUMMARY

The professional staff at Boeing Vertol has participated in an ongoing review of the NASA plan for new initiatives in the rotary wing field. I have appeared here today to speak in support of these new initiatives and to encourage Congress to support an aggressive NASA rotorcraft research program. The industry needs both the improved technology and the innovative development of more productive configurations if the United States is to continue to compete successfully in the rotary wing world. The NASA plan has the strong endorsement of the industry, DOD, and the civil helicopter operators. NASA's new initiatives are welcomed by all who recognize the deficiencies of past NASA rotorcraft activities, resulting from the overwhelming emphasis on space programs over the past 20 years.

In summary, I wish to strongly urge that Congress continue to support an aggressive NASA Rotorcraft Program. The recommendations of the 1978 Rotorcraft Task Force for augmentation of the rotary wing technology efforts in the years 1980 through

1989 have not been fully implemented. In 1980, Congress included \$5 million in this category, which is being used to start some much needed new programs. Last summer, members of the NASA Aeronautics Advisory Committee recommended that the 1981 budget contain approximately \$18 million in new rotorcraft initiatives to continue the impetus of the program (Figure 23). I urge you to support a 1981 budget which provides this level of funding for this important national activity.

AGENDA

- ROTORCRAFT MARKETS
- FOREIGN COMPETITION
- NASA ROTORCRAFT
TECHNOLOGY ROLE

FIGURE 1

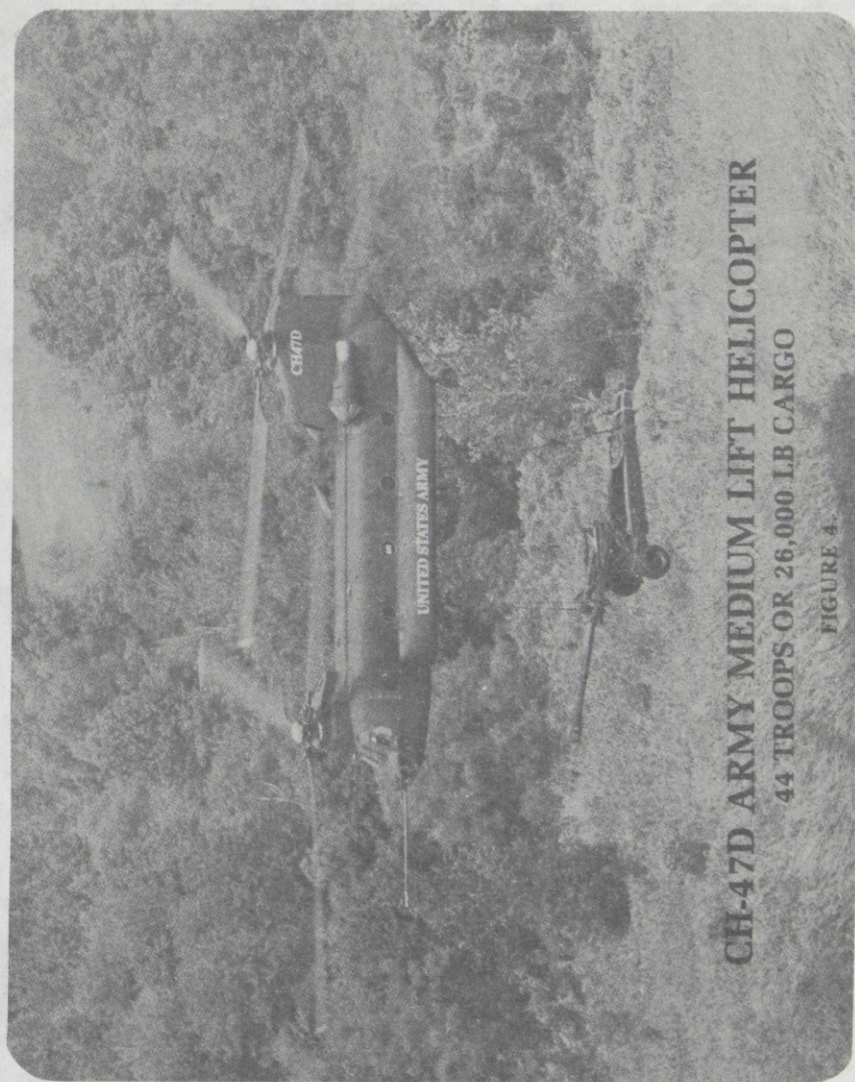
INTERNATIONAL ROTORCRAFT MARKETS

- RESOURCE EXPLORATION
- FOREST MANAGEMENT AND AGRICULTURE
- CONSTRUCTION
- PUBLIC SERVICE
- PASSENGER TRANSPORTATION

FIGURE 2



FIGURE 3.



CH-47D ARMY MEDIUM LIFT HELICOPTER
44 TROOPS OR 26,000 LB CARGO

FIGURE 4.

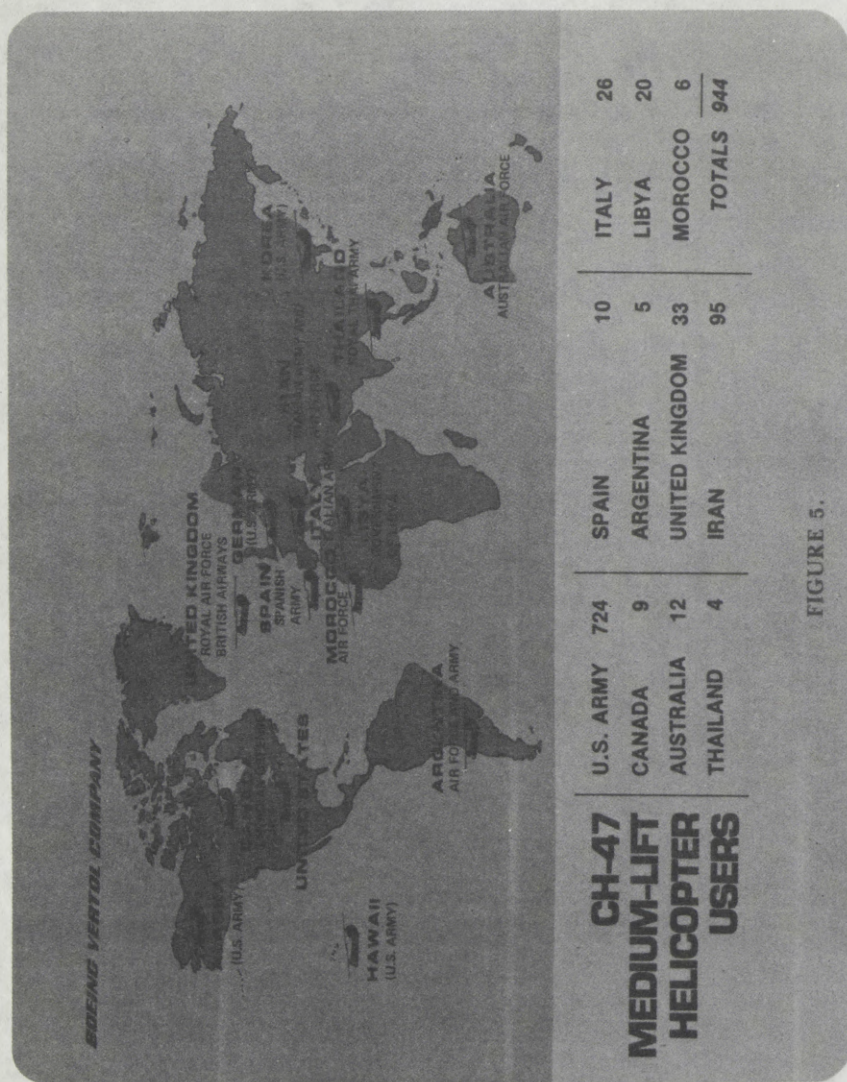


FIGURE 5.

COMMERCIAL CHINOOK
44 PASSENGERS OR 28,000 LB CARGO

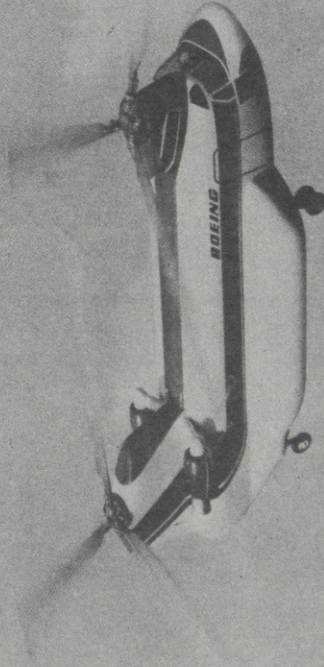


FIGURE 6.

PREDICTED FREE WORLD OIL PRODUCTION

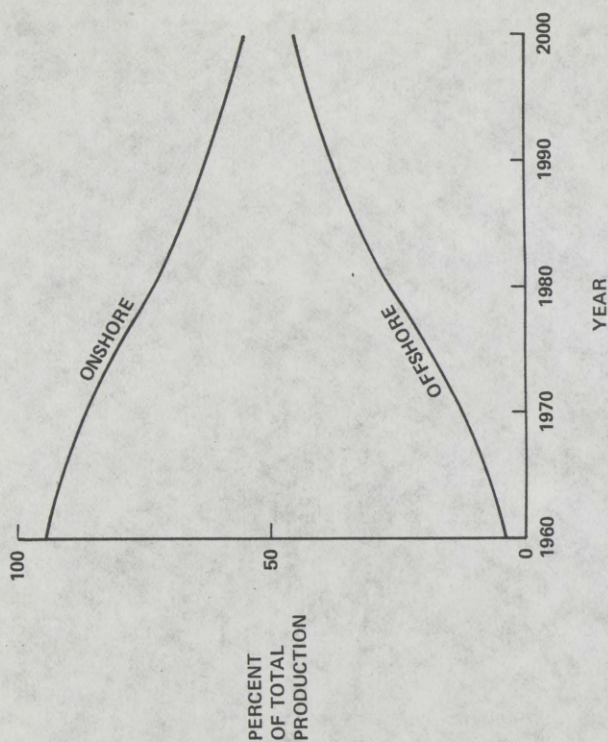


FIGURE 7

PASSENGER-MILE GENERATION CAPACITY OF LARGE HELICOPTERS

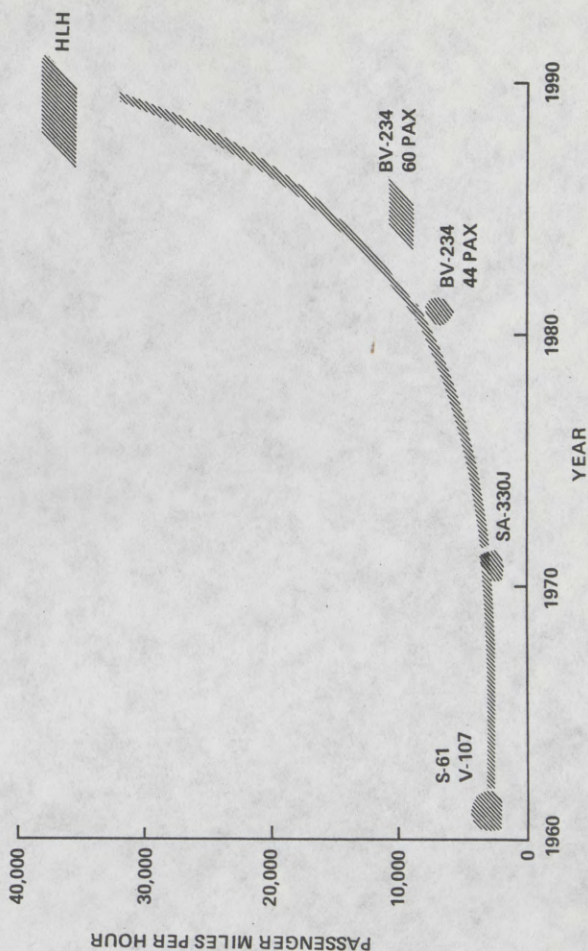


FIGURE 8

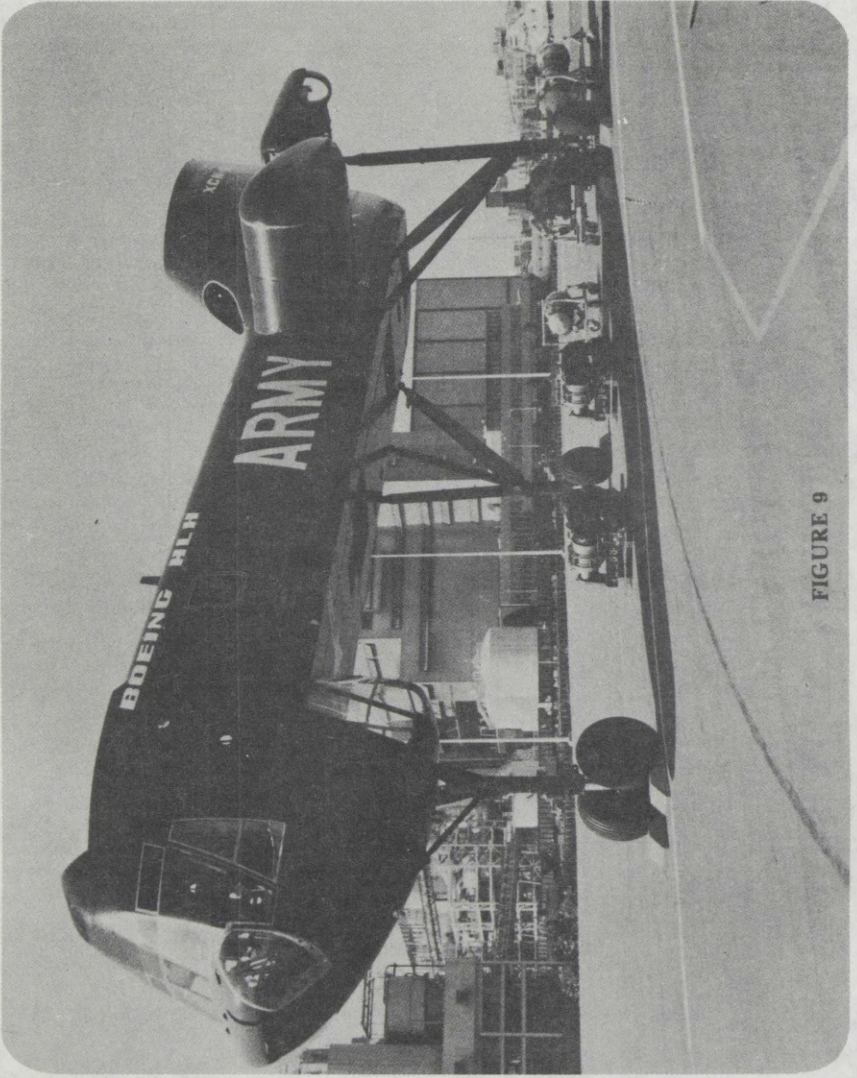


FIGURE 9

HLH AFT TRANSMISSION

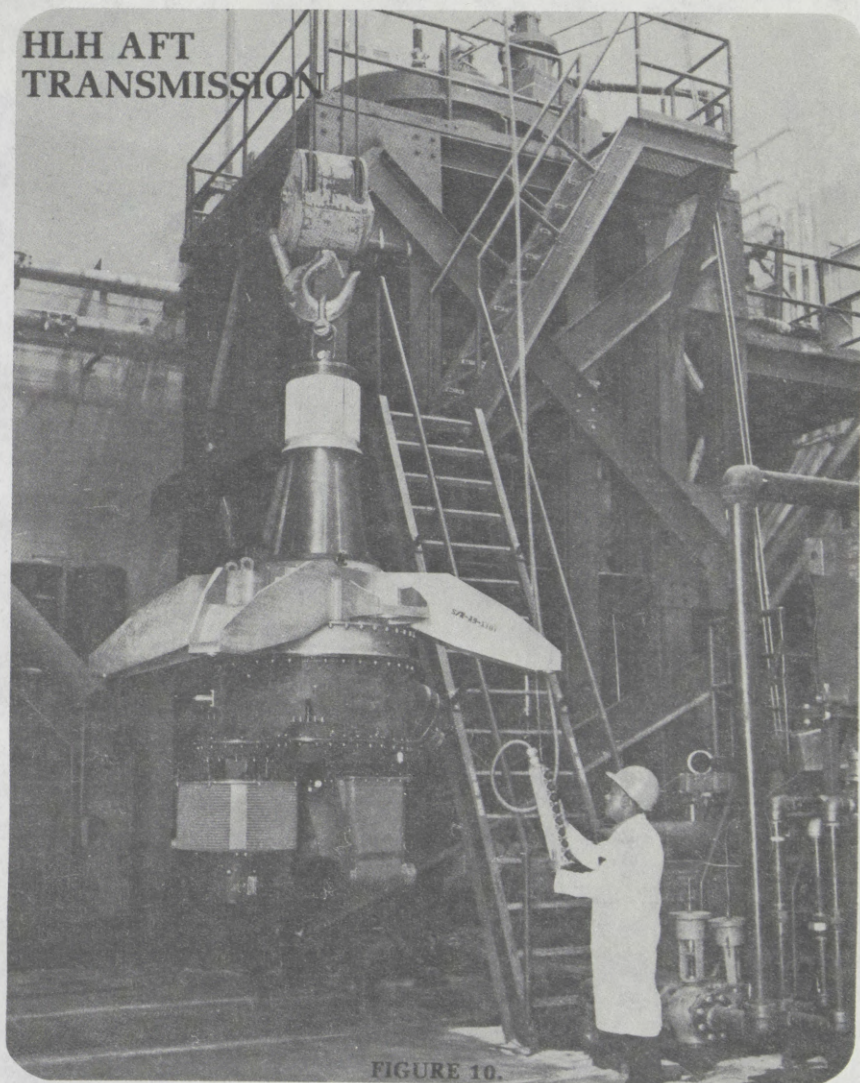


FIGURE 10.

COMPARATIVE DIRECT OPERATING COST

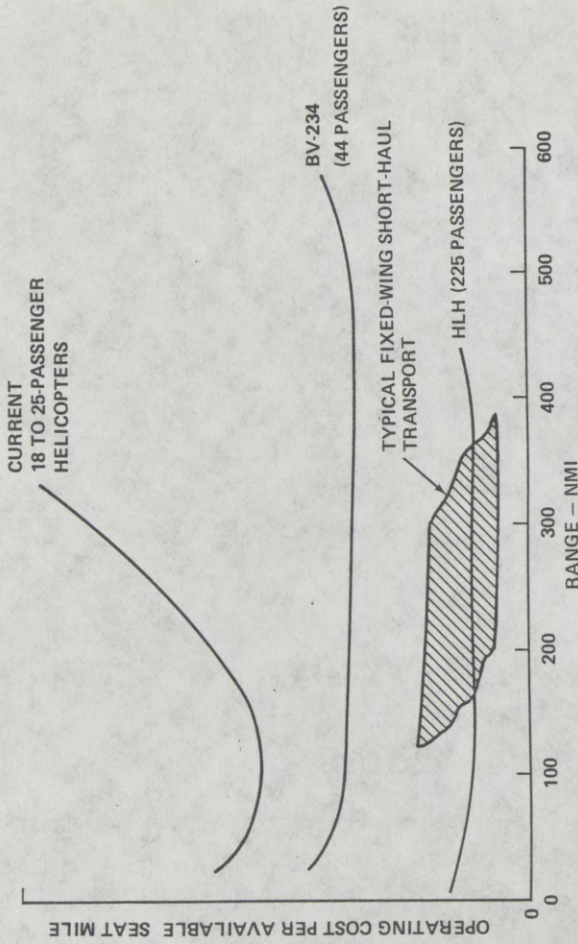


FIGURE 11

U.S. FIXED WING SHORT HAUL PASSENGER-MILES GROWTH (≤ 300 MILES)

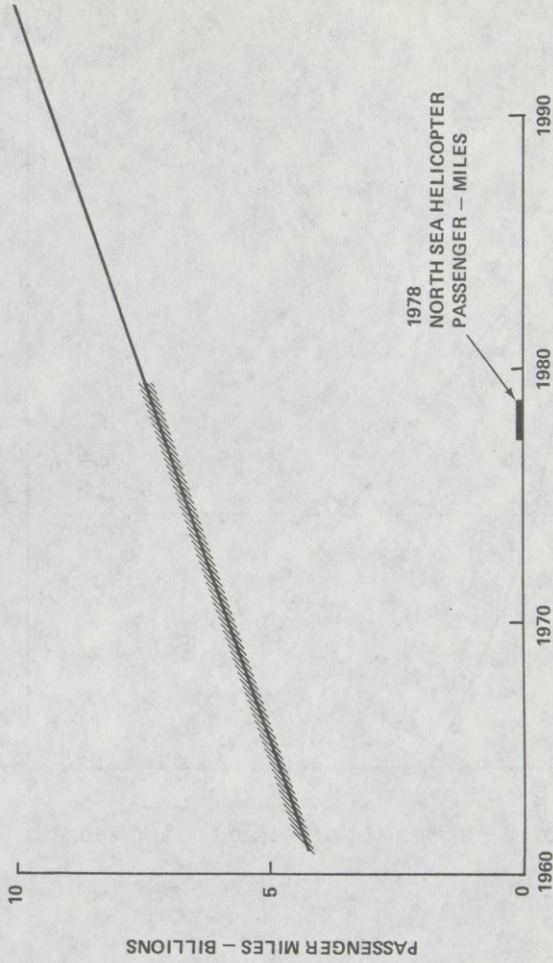


FIGURE 12

HELICOPTER VERSUS FIXED WING BLOCK TO BLOCK ELAPSED TIME

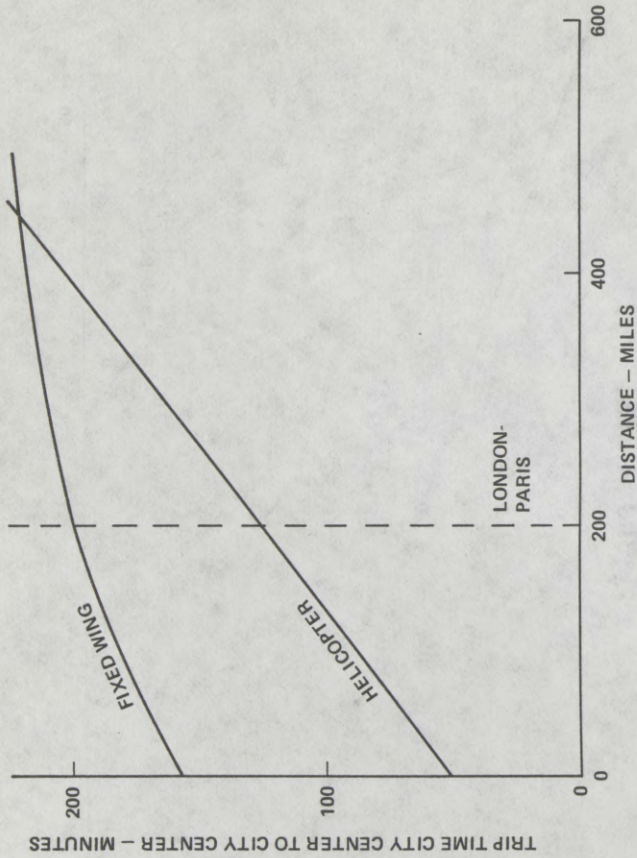


FIGURE 13

CIVIL ROTORCRAFT IMPORTS TO U.S. (NON-U.S. DESIGNED)

DATA SOURCE:
AIA FACTS AND FIGURES
1979-1980

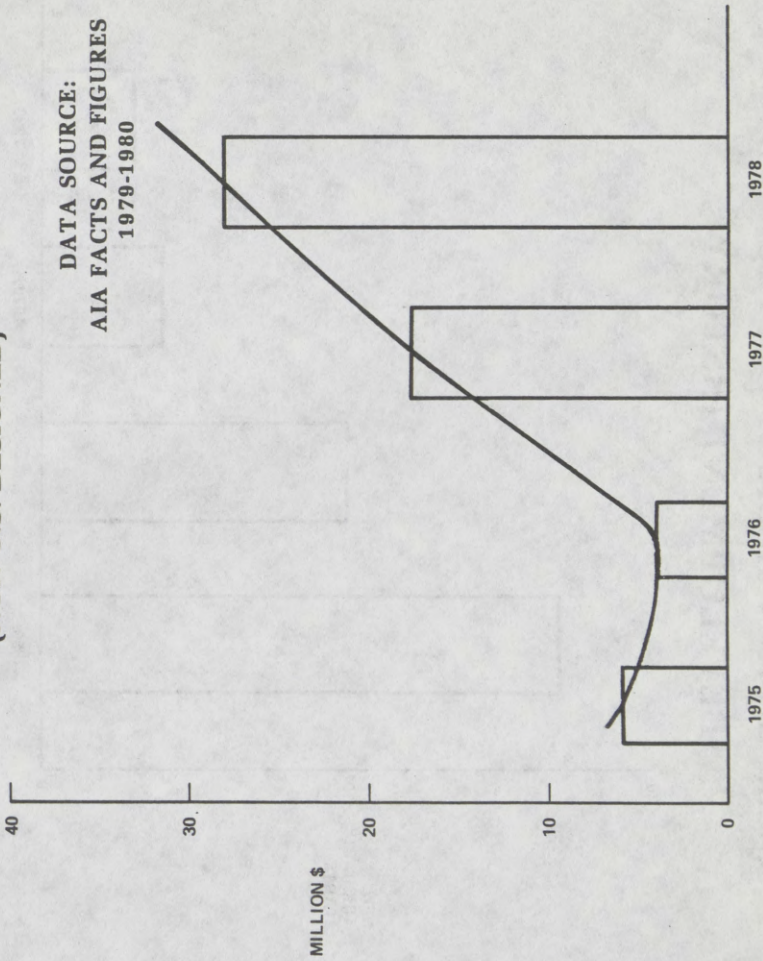
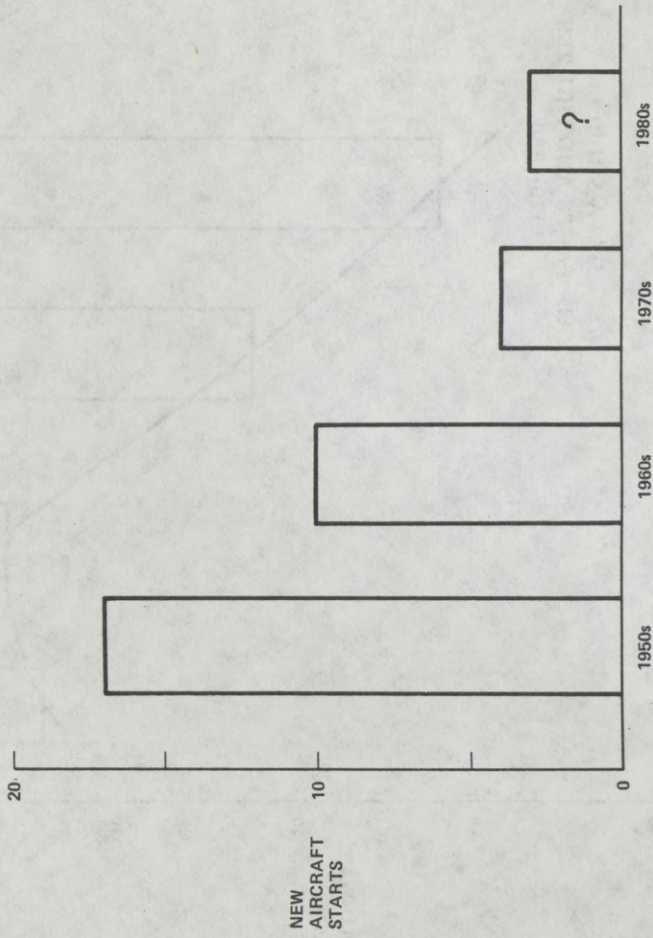


FIGURE 14

U.S. MILITARY HELICOPTER AND V/STOL DEVELOPMENT HISTORY*



*DOES NOT INCLUDE V/STOL TEST BEDS

FIGURE 15

ROTORCRAFT TECHNOLOGY NEEDS

- NOISE REDUCTION
- VIBRATION REDUCTION
- RELIABILITY AND MAINTAINABILITY IMPROVEMENTS
- ALL WEATHER CAPABILITY
- SAFETY IMPROVEMENTS
- FLYING/RIDE QUALITY IMPROVEMENTS
- PRODUCTIVITY IMPROVEMENTS
- REDUCED FUEL CONSUMPTION

FIGURE 16

TECHNICAL AREAS WHICH REQUIRE NASA RESEARCH

- **THEORY AND DESIGN METHODOLOGY**

ROTOR AERODYNAMICS, AEROELASTICITY, ACOUSTICS,
FLYING QUALITIES, PASSENGER COMFORT AND
PROPULSION SYSTEMS

- **VALIDATION OF THIS METHODOLOGY**

WIND TUNNEL AND FLIGHT EXPERIMENTS

- **VEHICLE CONFIGURATION STUDIES TO IDENTIFY
MOST PROMISING NEW CONCEPTS**

FOLLOWED BY PROOF-OF-CONCEPT FLIGHT DEMONSTRATION
OF THE MOST ATTRACTIVE CONFIGURATIONS

FIGURE 17

EXAMPLES OF ROTORCRAFT TECHNICAL DEFICIENCIES AND POTENTIAL FOR SOLUTIONS

TECHNICAL DEFICIENCY	POTENTIAL SOLUTION
— INDUSTRY IS HEAVILY DEPENDENT ON EMPIRICAL METHODS FOR PREDICTION OF COMPLEX AERODYNAMIC AND AEROELASTIC INTERACTIONS • PERFORMANCE IMPACT • STRUCTURAL IMPACT • FLYING QUALITIES IMPACT • PROGRAM COST AND SCHEDULE IMPACT	— NEW COMPUTER CAPABILITY IS AVAILABLE FOR PREDICTION — BROAD SPECTRUM OF WIND TUNNELS AND FLIGHT RESEARCH AIRCRAFT ARE AVAILABLE FOR VALIDATION

FIGURE 18

EXAMPLES OF ROTORCRAFT TECHNICAL DEFICIENCIES AND POTENTIAL FOR SOLUTIONS

TECHNICAL DEFICIENCY	POTENTIAL SOLUTION
— ROTARY WING RIDE QUALITIES INFERIOR TO FIXED WING AIRCRAFT • HIGH PILOT WORK LOAD • HIGH NOISE AND VIBRATION FOR PASSENGERS	— RAPID ADVANCES IN MICRO PROCESSOR TECHNOLOGY CAN BE APPLIED TO FLIGHT CONTROL SYSTEMS • REDUCE PILOT WORK LOAD • REDUCE VIBRATION AND GUST RESPONSE — IMPROVED MATERIALS CAN REDUCE TRANSMISSION NOISE — IMPROVED ROTOR DESIGN CAN REDUCE AERODYNAMIC NOISE

FIGURE 19

EXAMPLES OF ROTORCRAFT TECHNICAL DEFICIENCIES AND POTENTIAL FOR SOLUTIONS

TECHNICAL DEFICIENCY	POTENTIAL SOLUTION
— ROTORCRAFT FLIGHT SPEEDS ARE IN THE 120 TO 150 KNOT RANGE • LIMITS CIVIL ROTORCRAFT PRODUCTIVITY • INFERIOR TO REPORTED SOVIET MILITARY HELICOPTERS	— PROMISING NEW CONFIGURATIONS ARE AVAILABLE TO TEST, BUT PROGRESS IS PAINFULLY SLOW DUE TO FUNDING LIMITATIONS

FIGURE 20

EXAMPLES OF ROTORCRAFT TECHNICAL DEFICIENCIES AND POTENTIAL FOR SOLUTIONS

TECHNICAL DEFICIENCY	POTENTIAL SOLUTION
ROTORCRAFT PAYLOADS ARE LIMITED TO APPROXIMATELY 30,000 POUNDS. LOGGING, CONSTRUCTION AND RESOURCE EXPLORATION NEED LIFTS UP TO 75,000 POUNDS. (RUSSIAN ACTIVITY REPORTED IN THIS SIZE CLASS)	DEMONSTRATION OF LARGE HEAVY LIFT CONFIGURATION NEEDED TO EVALUATE OPERATIONAL CHARACTERISTICS. CURRENTLY UNFUNDED.

FIGURE 21

**FREE WORLD COMMERCIAL HELICOPTER SALES WITH AND
WITHOUT NASA FUNDED RESEARCH
— FORECAST THROUGH 2000
1979 \$**

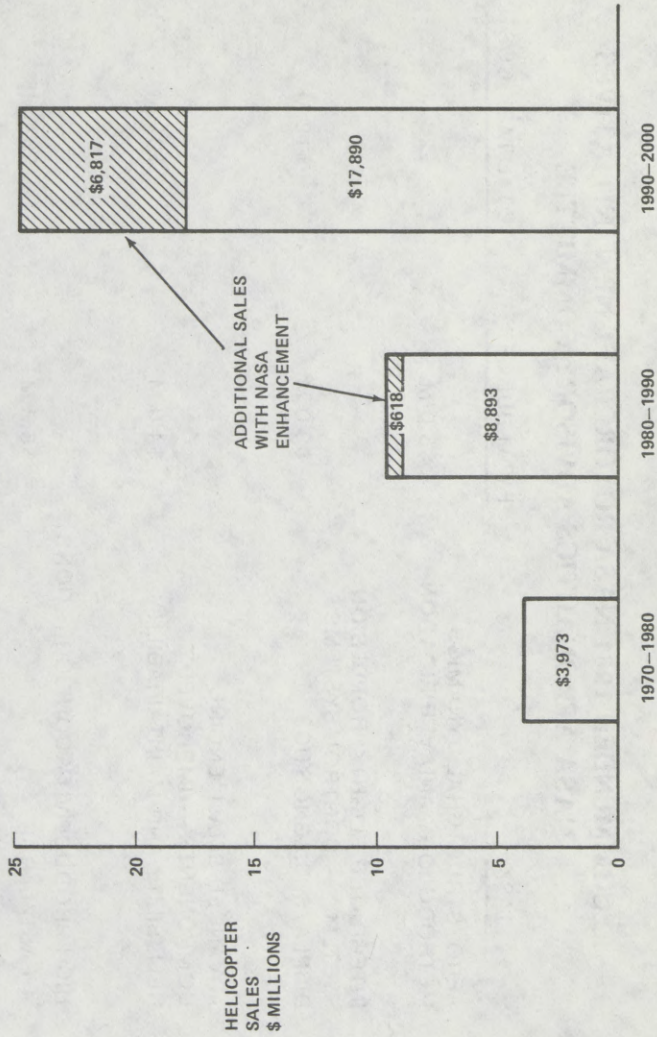


FIGURE 22

SUMMARY

RECOMMENDED 1981 NASA ROTORCRAFT NEW INITIATIVES NASA AERONAUTICS ADVISORY COMMITTEE

<u>TASK</u>	<u>FY'81 BUDGET</u>	<u>TOTAL TASK COST</u>
AERO/STRUCTURAL DYNAMICS METHODODOLOGY AND VERIFICATION	\$5.0 M	\$26 M
INTEGRATED FLIGHT/PROPULSION SYSTEMS — CONTROL SYSTEMS, DISPLAYS, DIAGNOSTICS	\$3.0 M	\$12 M
ADVANCED SMALL ENGINE COMPONENTS — IMPROVED RELIABILITY AND MAINTAINABILITY	\$4.0 M	\$33 M
HIGH PRODUCTIVITY CONFIGURATIONS — FAST/LARGE	\$5.5 M	\$31 M
<u>TOTAL</u>	<u>\$17.5 M</u>	

FIGURE 23

Mr. HARKIN. Our next and final witness for today, Dr. John Gibbons, Director, the Office of Technology Assessment.

STATEMENT OF DR. JOHN H. GIBBONS, DIRECTOR, OFFICE OF TECHNOLOGY ASSESSMENT, WASHINGTON, D.C.

Mr. HARKIN. Dr. Gibbons, we welcome you.

I see you have Mr. Maxwell with you again today. I welcome you, also, Bob.

Dr. GIBBONS. Thank you.

I also have Dr. Lee Dickinson with me.

Mr. HARKIN. Thank you. I see you have a prepared statement.

Without objection, the entire statement will be made a part of the record. You may proceed in the manner you desire.

Let me extend another welcome and thank you for all of the assistance you have given this committee, full committee and subcommittee, in the past, in helping us more clearly see what—the paths at least that are in front of us.

Dr. GIBBONS. Thank you, Mr. Chairman. It is a pleasure to be with you again.

I will speak from the written testimony and I also have a bit of an additional statement that I will submit for the record.

You will recall last October, that we reported on the OTA study of advanced high speed aircraft. The OTA study is intended to provide Congress with information on potential benefits of advanced subsonic or supersonic transport aircraft and whether they warrant the Federal Government increasing its level of support in that program. The report on the study that I just mentioned is in the final review process.

The conclusions are much the same as we reported to you in October.

The second part of our assessment examines the financing and program management alternatives for advanced high-speed aircraft and the findings of that part of the study are those that I am reporting to you today. The remaining two areas of our assessment, which will be completed late this spring, have to do with air service to small communities and also air cargo.

By the term "advanced high-speed transport aircraft," we are referring to a long-range commercial aircraft, either subsonic or supersonic, that might be introduced in the next 10 to 20 years. The aircraft would represent major technological advances over present aircraft. It would not involve simply extrapolations or minor improvements over the existing wide-body aircraft or the new versions that will appear in the 1980's, such as the Boeing 767 and 757. In other words, the new aircraft would incorporate major new structural materials and processes or new propulsion systems and/or it would also be an aircraft that would cruise in a higher flight regime. The reason for examining financing and management alternatives at this time is to better understand the major barriers to the commercial development of such a product, even if the technology were acceptable.

With any new type of high technology programs there are several major risks involved. One is obviously the risk of being able to develop

the technology satisfactorily. This would include such components as safety, speed, payload, and fuel efficiency.

Another risk is obviously the market for that product, and a third is the cost, the risk that the cost may exceed estimates and therefore preclude an adequate return on the investment.

After a certain period of time, the costs of development and manufacturing hopefully begin to be offset by revenues from sales of a new aircraft system. It is extremely difficult, if not impossible, however, to determine with certainty beforehand either the range of these costs or the expected revenues—in other words, the rate at which the initial investments are returned to the investors and profit begins.

Combining both projected revenues as well as estimated expenditures, leads one to a cash flow curve, as shown on the wall (fig. 1).

Adding the left-hand side together produces the right-hand side.

You will note that the combined effect of market uncertainty and technical uncertainty can lead one to a median projection of profitability in the long run, but also a very realistic opportunity that the project may never recover in terms of the investment.

Additional research, however, may reduce some of these uncertainties, and it could lead you, as shown in the next figure, to a situation in which the bands of uncertainty are sufficiently narrow that you have a much better opportunity to decide whether or not the investment is worth the corresponding risk.

The OTA study, after review by our advisory panel and by our working group members, has found that if Congress should wish to maintain the advanced supersonic transport option, then it may well be that existing Federal research and development support is not sufficient to accomplish that objective. The potential manufacturers of these advanced aircraft generally agree that the present technology is just not far enough along to make a decision to build such an aircraft. While they think it is conceivable to build an airplane that would meet today's environmental standards, and would be economically viable in unsubsidized competition, the overall risk is much too great. Until further technology advances and validation are accomplished, and until a variety of economic questions are resolved, an advanced supersonic transport is simply not a prudent business investment at this time.

Did you wish to stop at the second bell, Mr. Chairman?

Mr. HARKIN. I think this is probably a good place to break.

We will stand in recess.

[Recess taken.]

Mr. HARKIN. The subcommittee will resume sitting.

Dr. Gibbons, again I am trying to recall your statement before I left, but it seemed to me that you said that the existing support may not be sufficient to accomplish the objective of maintaining the supersonic transport option.

Dr. GIBBONS. That is correct, Mr. Chairman.

Mr. HARKIN. Then, it seems to me you said that until we have further advances or validations accomplished so we can get to another certain point, until we resolve some economic questions, the AST is not a prudent business investment.

Dr. GIBBONS. That is correct.

Mr. HARKIN. How do you get to the point of making the decision unless you put some more money into the program to maintain the option?

Dr. GIBBONS. I think that is exactly right. Our point is, if we do intend to maintain the option for the future, it will require a continued investment at a level probably higher than has been in the recent past, in terms of R. & D. And, in addition to that statement, the present conditions are such that the risks of moving ahead to a commitment to production are too great, but if we want to hold on to the option of doing that, it will require not only additional investment over time, but probably a more intensive kind of investment.

Mr. HARKIN. OK.

I think I have that clear. Thank you very much.

Please proceed.

Dr. GIBBONS. Mr. Chairman, in undertaking the financial part of this assessment, OTA assumed that the advanced high-speed aircraft program through its production phase would be viable. That was our starting premise, that is, we assumed that the returns expected by the suppliers of capital would at least be equal to those of other investments of equal risk and magnitude, which could be undertaken as alternatives.

In addition, as a part of the overall viability of the program, we find that there are at least four important criteria which must be satisfied besides the technical characteristics which I mentioned earlier. These criteria are public acceptance, customer acceptance, the airline ability to purchase the new aircraft, and the aircraft manufacturers' ability to finance this program. Public acceptance refers to the nonmarket risks of uncertainties in regulatory practices by the public and by the Government. Customer acceptance refers to the fact that the fares for advanced high-speed aircraft, specifically for supersonic aircraft, will probably have to be 20 to 30 percent higher than the corresponding subsonic fare.

Now, this assumption implies that the customer will have to be willing to pay this higher premium to ride on the supersonic aircraft.

We believe that the aircraft manufacturers' assertion that if fares are kept to no more than 20 to 30 percent higher than subsonic, then it will be acceptable, is probably correct. At least to date we have had no indication that the airline operators disagree with that assertion. Industry representatives have indicated with a reasonably vigorous technology improvement an AST could be built in the 1990's with total operating costs of about 20 to 30 percent higher than subsonic aircraft of the same new generation. The higher costs would imply the need for supersonic fares higher than the subsonic fares, higher in a sense, by approximately the percentage judged to be tolerated as a limit by the consumer.

So, it looks as though the numbers may be defensible.

In terms of the airline's ability to purchase, that is, can the airline afford to buy the plane? As you know, a major argument for an advanced supersonic transport is that it is about twice as productive as an equivalent subsonic aircraft. Therefore, given the same number of total aircraft, the AST could do about twice as much work as an equivalent subsonic aircraft.

Our studies, and those by some aviation industry people, indicate that the purchase price ratio, that is, the price of an AST relative to an improved subsonic aircraft is on the order of 2.5.

Well, the combination of higher price offset by a factor of 2 in greater productivity indicates that the airlines would require about 25 percent more capital to purchase an AST fleet, compared to a subsonic aircraft fleet.

In terms of the aircraft manufacturers' ability to finance the program, it would be worthwhile to return to the cash flow curve similar to the one I showed you previously (fig. 3).

Studies by the manufacturing industry have indicated that the maximum negative cash flow for an advanced supersonic program could be in the range of \$6 to \$10 billion in terms of 1979 dollars.

Based on an examination of past programs OTA believes that these estimates could in fact be low by a considerable amount. The program costs, when spread over a 10- to 15-year development and production period, are large in comparison to even those of the largest aircraft manufacturers' financial assets.

For instance, an examination of all of the combined programs of Boeing, Lockheed, and McDonnell Douglas over the past 20 to 25 years, shows that while they were able to acquire total funds in this time up to \$1 billion a year, the average was about \$300 million a year. The important parameter is in the magnitude of the investment at risk in relation to the industry's assets.

I shall return to that in a few moments.

We considered several program management and financing alternatives involving the industry with or without government involvement. The alternatives we considered included traditional U.S. commercial airplane programs, domestic joint ventures, international joint ventures, and a new corporation such as Comsat.

The likelihood of private financing was considered for each of these alternatives and Government financing options were also examined. The result of our studies, which were not done in great detail, was that even if the technological issues and uncertainties are resolved for new aircraft incorporating major technological changes, it is not at all clear that the "option" could or would be implemented.

However, if it is implemented, it will almost undoubtedly require some major innovative risk sharing arrangements among several private institutions and national governments.

In addition to the traditional U.S. commercial airplane program, that is the single corporate manufacturer, who is in fact not likely to be viable for the present consideration, there are several other options which have been explored in a preliminary way. These are a domestic joint venture, an international joint venture, and a new type Comsat corporation.

For domestic joint ventures, two or more U.S. companies might combine portions of their resources in a joint venture for a specific period of time for the purpose of producing an advanced air transport vehicle. Logically at least one of the joint ventures would be an aerospace company. Other joint venturers might be competitive aerospace companies and/or companies with different but valuable resources to

contribute to the joint venture. Such additional resources might be purely financial, such as a bank or an insurance company, or another major manufacturing company such as an automobile manufacturer. Some of the potential partners might be barred by current law or by regulation from joining such a venture, through antitrust proceedings.

It is, however, possible for the Congress, if it wished to do so, to alter that situation during the years before such a venture would have to be formed. A joint venture would act as a separate company whose owners are the joint venturers. No equity would be issued by the joint venture to outsiders. It may, however, borrow funds on its own right.

There are past experiences in American industry for joint ventures. They are often formed for the development of a new technology product that bridges the technological specialties and capabilities of the several participating companies. They are also formed to merge the financial strengths of several companies in the same line of business.

The major financial impact of such a venture on participating corporations is the reduction of risk exposure for each participant. We believe that the Alaska Pipeline Corporate activity is a very important illustration of this latter type of joint venture.

Now, with respect to international joint ventures, this option is similar in concept to a domestic joint venture. Two or more legally separate organizations in two or more countries would agree to commit funds, facilities and services to an enterprise for their mutual benefit. The international joint venture, however, presents a host of managerial problems in addition to those faced by a domestic joint venture. Of course, if one is developing a technology for sale in the international market, it can also provide some very positive benefits in the same regard. Such a program involves many complexities in communications, design philosophy, differences in language, problems of international law, economic problems of foreign exchange, and different escalation rates.

I might also mention that the joint venture among the European partners or the Airbus has certainly proven to be a very satisfactory arrangement; an important precedent to be thought of in our own studies of AST.

One of the foreign partners might be a government-owned or controlled corporation, and thus, having access to capital resources beyond private markets. The motive for such sponsorship could be to assure participation of foreign producers in the production phase of the aircraft. The U.S. participant would thus trade some of its risk exposure during the development phase for reduced expectation of profits during the production and sales phase. This is a practice currently followed by U.S. manufacturers in financing aircraft development. Sub-contractors often engaged in the development of components and subassemblies at their own risk with the expectation of recouping their expenditures during the production phase.

The international joint venture thus appears to be a financially viable organizational mechanism, at least from the point of view of the participating U.S. aircraft company or companies.

The establishment of a new corporation for the purpose of pro-

ducing advanced air transport vehicles is yet another option. Such a corporation might be modeled after Comsat. That is, it might be established by legislation in order to fulfill a perceived national need. A Comsat-like company would have the advantage of central management control that has proved so successful in other aerospace programs.

The most difficult managerial problems would be encountered at the beginning of the new corporation's life. That is, building and organizing, acquiring human resources, making contractual obligations and arrangements with aerospace and other companies, in order to effect a smooth transition from development to production. Although, such a company might be successful, as Comsat indeed has been, in taking a developed technology into commercialization, and financing a developmental effort via a new formed corporation dependent solely on private markets for its resources, this appears to be highly improbable. Investors will finance a venture even a risky one, if the expected return is in line with the risk exposure.

A developmental effort, however, does not carry with it any direct return. Rather, it implies the possibility of entering into production if the developmental effort is successful. The link is judged to be too loose to encourage investors and lenders to finance the new corporation.

Again, solutions to this dilemma might be found in governmental sponsorship through grants, developmental contracts, loans and perhaps even cost-sharing.

Now, Mr. Chairman, I would like to summarize the major findings.

First of all, the aircraft must be environmentally acceptable with regard to community noise and emissions. An AST must also overcome possible negative public reaction to a high-energy use vehicle. That is, we must be assured that nonmarket factors can be successfully managed.

Second, the customers must show their acceptance of a supersonic aircraft by their willingness to pay a higher fare. But we believe, as we mentioned to you in October, that the fare may be only of the order of 20 to 30 percent above subsonic fares, in the new kind of aircraft.

Third, the airlines must be interested and able to purchase the new aircraft when they are available.

As we pointed out earlier, the purchase price of a future fleet of supersonic aircraft may be only about 25 percent greater than a future fleet of subsonic aircraft that provides the same seat miles of service per unit time.

Fourth, viable alternatives must be available for financing and managing a program for not only the development, but the production of an advanced high speed aircraft.

There are three major risks involved in this. The risks are technological, market, and operating costs.

According to members of the aircraft industry, the maximum cumulative cash flow to an AST program—that is, after the generic research and development phase, could be on the order of \$6 to \$10 billion, which is very large in relation to the current assets of our aircraft manufacturers. However, if we are concerned with the situation here that may exist 10 to 20 years in the future, that situation could

change for the industry over that period of time. The results of the generic R. & D. phase should provide a solid technological base, as a basis for decisionmaking. This, in turn, should provide data to reduce the technical and cost uncertainties and assist in deciding whether or not to move into the specific R. & D. phase and on into production.

In considering the various phases of an advanced aircraft program, the funds required increase dramatically from the completion of the generic R. & D. phase and the beginning of the postcertification phase. The major technological or development risk continues until well after the first flight has taken place.

At the same time, the financial risk exposure decreases from extraordinarily high levels to levels which may be within the tolerance limits of large public security offerings. However, financial experts have stated they are certainly not sure that even the postcertification production financing could be undertaken by the private sector for a project of this magnitude.

The cost of an advanced high speed air transport program, whether subsonic or supersonic, will be large in comparison with previous subsonic programs. The significant concerns of this type of program are the magnitude of both the technological and the financial risks. Each risk, by itself, might be manageable or tolerable, but the combination constitutes an unacceptable private risk. The largest equity offering made since 1956 was a \$1.4 billion offering by the American Telephone & Telegraph in 1971. This is about \$2.2 billion in 1978 dollars. That is certainly well below the projected funding requirements of a new AST program.

Furthermore, with a maximum (negative) cash flow of an AST program on the order of \$10 billion, this would be more than twice the equity of the three U.S. airplane manufacturers combined. The largest total funds acquired by the major aircraft manufacturers; that is, Boeing, Lockheed, and McDonnell Douglas, in any 1 year, was a little over \$1 billion. That was in 1966 (\$2.1 billion in 1978 dollars) and was from both internal and external sources.

Further, the aircraft manufacturing industry almost went under with the development and production of the wide-body aircraft. Of the three companies involved in this rather highly successful venture, only Boeing seems to be now out of the woods. Therefore, it appears highly unlikely that any single company could undertake a program of this nature by itself, due to the market, technological, and financial risks.

Therefore, we are dealing with a whole new ball game, not only because of the technological problems, but also because of the financial and managerial hurdles. However, several alternatives appear plausible and interesting. They are: domestic ventures, international joint ventures and a new corporation concept.

The international or domestic joint ventures appear in appropriate way to spread the risk through the sharing of costs. However, a domestic or international joint venture in the specific R. & D. phase makes no sense if there is no plan to continue the joint venture into the production phase.

A new corporation, similar to Comsat, might be a good way for managing a major new advanced commercial aircraft development.

However, Cosmat acquired a proven technology and a relatively well-defined and rapidly expanding market. Therefore, extrapolation of this experience to an AST must be done with a great deal of care.

That ends my summary of my remarks, Mr. Chairman. Thank you for the opportunity to be with you.

Mr. HARKIN. Thank you very much, Dr. Gibbons, for what I feel, with that elaboration on the program management alternatives, is a very good and very comprehensive statement of the different options.

As I said in the beginning, the Office of Technology Assessment has been very good in the past, has been excellent, as I said, in laying out the paths.

Why don't you tell us which path to take?

Dr. GIBBONS. I think my chairman, Mo Udall, said what he would like around the town are a few one-handed scientists because they keep saying "on the other hand——"

Mr. HARKIN. On the other hand; that is right.

A couple of questions.

I don't want to belabor it, but regarding the Comsat concept, what barriers do you envision might exist, let's say, if a private group tried to do it without any government help? Private.

Dr. GIBBONS. I should think if the uncertainties that we mentioned to you were clarified, similar to the degree of uncertainties that existed when Comsat was set up, then that is a possibility.

What we feel is an important difference is that the technology that Comsat was working with, was rather well defined. The costs were rather well understood. Further, the markets were relatively well understood and known to be rapidly expanding.

So, there are many important differences in terms of the risk perception of those investors—in the case of Comsat, we were dealing with specific technologies and programs, as compared, say, to the many unknowns associated with an advanced supersonic aircraft.

Mr. HARKIN. In thinking about an AST, I think there are obviously certain givens. So it seems to me the countries that would be interested, the people that would be interested in things like that would be countries with expanding economies, good rates of growth, and the need to travel more rapidly. I guess you think about a place like Japan or maybe Brazil.

Dr. GIBBONS. Australia.

Mr. HARKIN. Australia.

The Arab countries.

I am wondering if it would be worth perhaps our initiating some kind of a discussion with those countries, to see if they might be interested in something like that. I don't know if that has ever been done.

Mr. MAXWELL. Mr. Chairman, one of the things that you didn't mention in the countries that you were listing was England or France. Of course, their experience with the Concorde has left them both with some very conservative approaches to the economics, but also some very good operating experience with supersonic aircraft. Officials of both British Aerospace and Aerospatiale have indicated that they might be interested in some sort of a joint venture. They don't know how it would be brought about. In addition, as you know, Aerospatiale

has West Germany involved, and there are other countries like Japan that, I think, might very well be receptive to such a proposal.

Dr. GIBBONS. I might add, Mr. Chairman, I think in studying this program, we are studying a new and very fascinating class of situations, where new technology opportunities may take us into a realm where we can probably only afford one manufacturer in order to have it profitable. That manufacturer may have to take the form, for a variety of reasons, of an international consortium, and it could have very interesting ramifications for mutual economy interdependence among certain of the world's industrial nations, particularly those that are separated from each other by long, overwater routes.

So, I think your suggestion of looking ahead at the ultimate utilization of AST technology in terms of the likely interested parties and initiating some discussions among them about that mutual interest is a very excellent suggestion.

Mr. HARKIN. I am wondering if there is anyone in the audience that might have any comments on this idea of a joint venture with other countries? Has it been discussed? Talked about?

Mr. HOPE. Jack Hope, again.

As you know, Mr. Chairman, I have managed an international joint venture, in that particular case, for General Electric, and I have been approached by people in both England and France about the possibility of a joint venture with the United States.

As you know, they have canceled their Concorde treaty. The Concorde was a treaty between France and England and with the lack of potential future sales they have canceled the treaty. That leaves each country independent to do what they choose to do in the future in the area of supersonic transportation. They, as far as I know, have no firm plans. They don't want to stop it. They don't want to jump into a new venture, but they want to follow what we are doing and participate with us if they can, and we have been approached to see if we can develop some ideas. Also I have been working with all of the U.S. manufacturers in the last year to see if we can develop a mechanism or a format where we can discuss the very options that Dr. Gibbons has put forward.

It is very informal so far, and we are just developing a discussion. But it is a very challenging situation, and I would hope that if we went ahead with the joint venture we could protect the proprietary rights of each company and still maintain competition. You don't want to discourage competition by having one monopoly, but it is possible by a joint venture, to have cooperation on a single program and yet maintain competition in all other areas.

Mr. HARKIN. Any further comments?

Well, thank you again very much, Dr. Gibbons.

That concludes our testimony for the day.

The subcommittee will stand adjourned until the call of the Chair.

[The prepared statement of Dr. Gibbons follows:]

Statement of
Dr. John H. Gibbons
Director
Office of Technology Assessment
Before the
Transportation, Aviation, and Communication Subcommittee
of the House Science and Technology Committee on
the Office of Technology Assessment Study of the
"Impact of Advanced Air Transport Technology"
February 7, 1980

Mr. Chairman and Subcommittee Members:

It is a pleasure to respond to your request to testify on the OTA study of the financing and management options for new commercial air transports. One question that has arisen is related to the feasibility of bringing new products to commercialization once NASA's technology validation efforts are completed.

You will recall that last October I reported on OTA's study of advanced high speed aircraft. This study was intended to provide the Congress with information on whether the potential benefits of advanced subsonic or supersonic transport aircraft warrant the Federal Government increasing the level of its support during the next step, which would be to further advance and validate the technological concepts which have been identified. The report on this study is now in the final review process. The findings are essentially the same as I indicated in October.

The second part of this assessment examines the financing and program management alternatives for advanced high speed aircraft. The findings of

this second part are the basis for my testimony today.

The remaining two areas of our assessment include an analysis of the air service to small communities and air cargo. We expect our work on these two studies to be completed this spring.

One of the major questions raised in the conduct of the first study centered around the financing of new advanced high speed transport aircraft and the options for managing such a project. We are talking about a long range commercial air transport, either subsonic or supersonic, that might be introduced in the next 10 to 20 years. This aircraft would be much further advanced technologically than aircraft planned for introduction in the mid 1980s such as the Boeing 767 and 757. It would not be an improved version of an existing widebody aircraft, like a B-747, DC-10, or L-1011, but an aircraft that would incorporate new structural materials and processes or a new propulsion system, or one that would cruise in a higher flight regime. Such a program for either an Advanced Subsonic Transport (ASUBT) that represented a major advance in technology, or an Advanced Supersonic Transport (AST), would require a large investment (much larger than any recent or past commercial aircraft program), and it would involve significant risk and uncertainty. The reason for examining financing and management alternatives at this time is to better understand the potential barriers to the commercial development of such a product even if the technology were acceptable.

With any new type of high technology program there are several major risks involved. One is the risk of being able to develop the technology to build a product that will satisfy a given technical performance objective, such as safety, speed, payload, and fuel efficiency.

Another is the risk in the assessment of the market for the product.

A third is the risk that the costs may exceed estimates and therefore preclude an adequate return on the investment.

The costs of development and manufacturing of a product continue to mount over time. After a certain period, the costs begin to be offset by revenues from sales. It is extremely difficult, if not impossible, to determine with certainty beforehand either the range of costs or the expected revenues. The combining of both projected revenues and estimated expenditures produce the typical cash-flow curve, as shown in the figure 1, along with the uncertainty associated with both expenditures and revenues. The bottom of the curve on the right side of the figure indicates the maximum cumulative cash flow required in the program.

The uncertainty (as indicated by the ranges) of both revenues and expenditures is reflected in the uncertainty of estimating the maximum negative cash flow value. One way of reducing the uncertainty is to undertake a larger effort in the early stages of the program (i.e., generic research and development). This is shown in figure 2. While this may or may not reduce the total program cost, it should improve the understanding of the technology and, in turn, contribute to reducing the uncertainty surrounding the maximum negative cash flow. Furthermore, the increased effort in the generic R&D buys more time in which to further explore the market.

This idea that generic R&D is desirable is consistent with the findings of the OTA advanced high speed aircraft assessment. Specifically, as it related to an advanced supersonic transport program, we found that it appears appropriate to carry out a generic research and development program

FIGURE 1 - TYPICAL CASH-EXPENDITURE CURVE

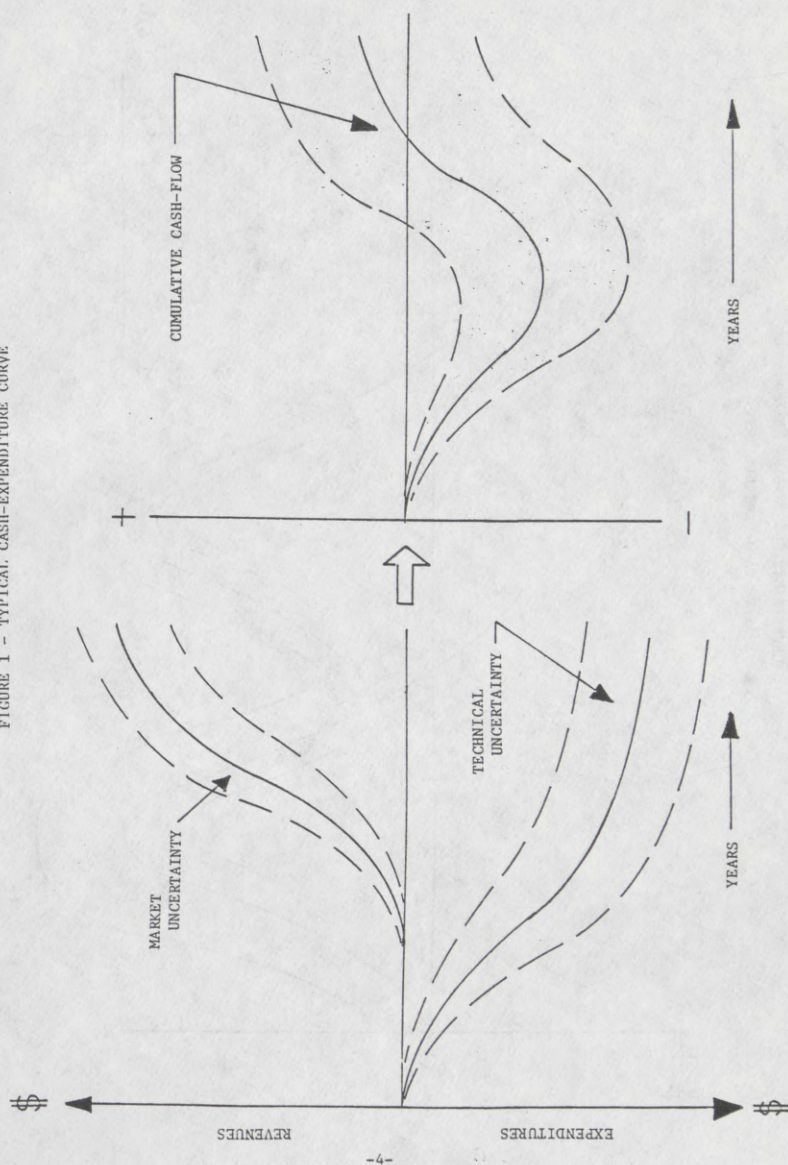
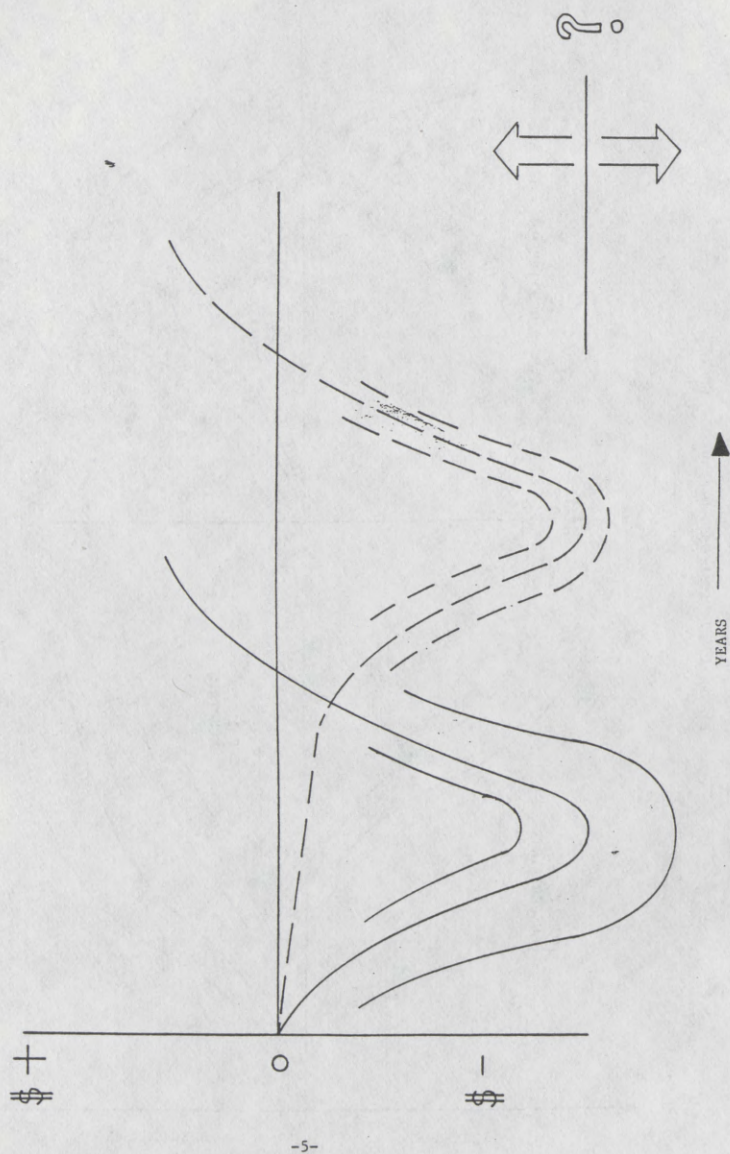


FIGURE 2 - IMPACT OF GENERIC RESEARCH AND DEVELOPMENT
ON UNCERTAINTY SURROUNDING MAXIMUM
NEGATIVE CASH EXPENDITURES



to further validate the technologies.

The OTA study, after review by Advisory Panel and Working Group members found that if Congress should wish to maintain the supersonic transport option, then it may well be that existing Federal Research and Development support is not sufficient to accomplish this objective.

In this regard I would like to remind the subcommittee of our perspective on the advanced supersonic transport AST. As we stated before you in October of last year the situation is not one in which aircraft manufacturers have designed a supersonic airplane that they consider a justifiable risk. In fact, the potential manufacturers generally agree that the technology is not far enough along to make a decision to build such an aircraft. While they think it is conceivable to build an airplane that would meet today's environmental standards and be economically viable in unsubsidized competition, the overall risk is still too great. Until further technology advances and validation are accomplished, and until a variety of economic questions are resolved, an AST is not a prudent business investment.

STUDY ASSUMPTION

In undertaking the financial part of the assessment we assumed that the advanced high-speed aircraft program (through the production phase) would be viable. That is, the returns expected by the suppliers of capital would be

at least equal to those of other investments of equal risk and magnitude which could be undertaken. In addition as part of the overall viability of the program there are four important criteria which must be satisfied: public acceptance; customer acceptance; airline ability to purchase new aircraft; and the aircraft manufacturers' ability to finance the program.

PUBLIC ACCEPTANCE

If a new subsonic or supersonic aircraft is going to be successful in the market place, it must have public acceptance. One requirement is that it must be environmentally acceptable. For example, the aircraft must satisfy the concerns about community noise levels and must overcome public reaction to a high energy intensive vehicle.

CUSTOMER ACCEPTANCE

For a new subsonic aircraft, there is a broad base of actual experience to gauge customer acceptance. The problem is largely fare level. The tougher question is the supersonic aircraft where average fares are likely to be higher. While estimating customer reaction to a new combination of higher-fare-for-better-service (shorter flight times) is far from an exact science, the aircraft manufacturers assert that if fares are kept no more than 20-30% higher than subsonic, then patronage should be high. To date airline operators have not disagreed with this assertion.

Industry representatives have estimated that with a reasonably vigorous technology improvement, an AST could be built in the 1990s with total operating costs (T.O.C.) on the order of 20 to 30 percent greater than subsonic aircraft for the long range market. These higher costs would imply the need for supersonic fares higher than subsonic fares. If customers

perceive the benefits from this aircraft to be greater than the increased fares, this would indicate their acceptance.

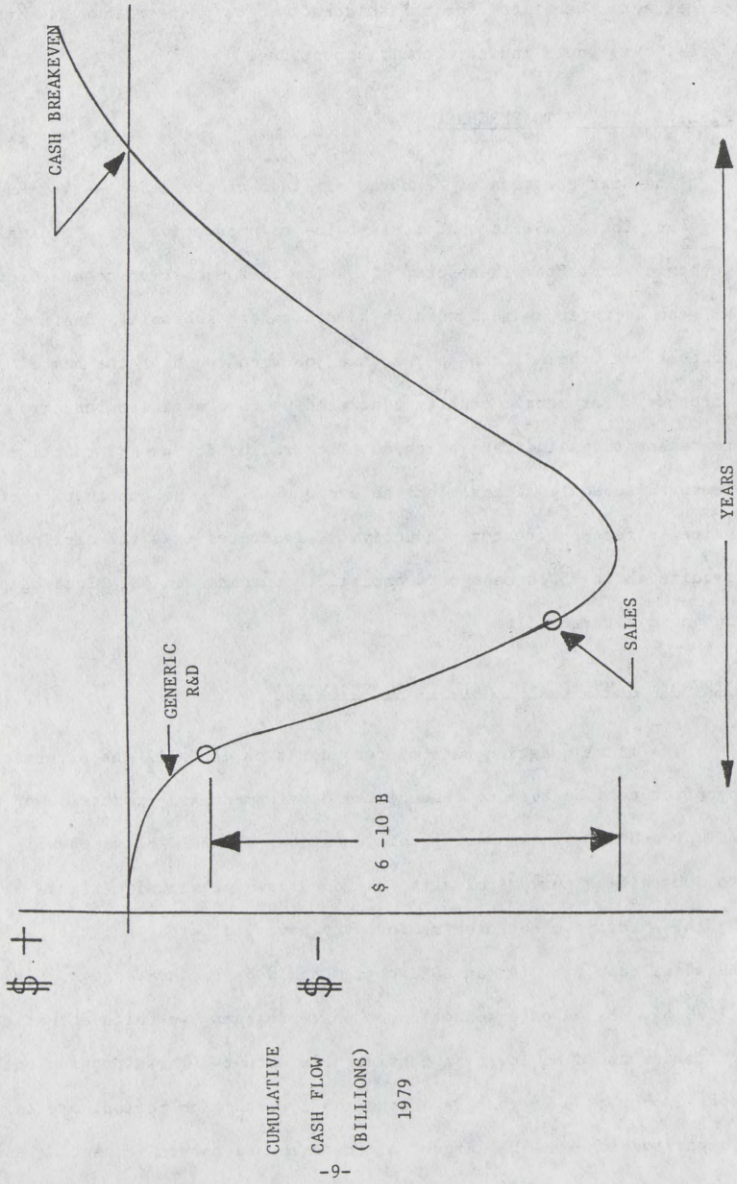
AIRLINE ABILITY TO PURCHASE

The next question is "can the airlines afford it?" As you know, the argument for an AST is that it is twice as productive as an equivalent subsonic aircraft. Therefore, given the same number of total aircraft, the AST can do twice as much work as an equivalent subsonic. Stating this another way, the AST can do the same job with one half the number of aircraft. Parametric studies conducted by some aviation industry representatives indicate purchase price ratios for an AST relative to an improved subsonic aircraft on the order of 2.5. The combination of higher price, offset by greater productivity, indicates that the airlines would require about 25 percent more capital to purchase an AST fleet compared to a subsonic aircraft fleet.

AIRCRAFT MANUFACTURER ABILITY TO FINANCE

The final question needing consideration is "will the aircraft manufacturers be able to finance the development and production of either an AST or ASUBT?" In answering this question, it would be worthwhile to return to a cash flow curve similar to the one shown previously (figure 3). Studies by the aircraft manufacturing industry have indicated that the maximum negative cash flow for an AST program could be in the range of \$6-\$10 billion (1979 \$). Based on examination of past programs, we believe that these estimates could be low by a considerable amount. These program costs when spread over a 10-15 year development and production period, are large in comparison to even the largest aircraft manufacturers' financial assets. For example, the total revenues, both commercial and military, for the Boeing

FIGURE 3
CASH FLOW CURVE FOR ADVANCED TRANSPORT AIRPLANE PROGRAM



1979

Company in 1978 equaled \$5.5 billion with a net profit of \$320 million. The revenues and net profit for Lockheed for the same year were \$3.5 billion and \$65 million while for McDonnell Douglas they were \$4.1 billion and \$160 million. Furthermore, an examination of all the programs of the three aircraft manufacturers over the last 20-25 years, shows that while they were able to acquire total funds* during this time up to \$1 billion per year, the average was about \$300 million per year. The important parameter is the magnitude of the "investment at risk" in relation to the industry's assets. We must keep in mind, however, that we are considering a program to be initiated maybe 10-20 years from now at which time the aircraft industry financial resources may be much different than today.

PROGRAM MANAGEMENT ALTERNATIVES

We identified and examined a number of program management alternatives involving the industry with or without Government involvement. Four of these appeared to be alternatives which may be feasible for conducting a future high-speed aircraft program. They included: Traditional U.S. Commercial Airplane Program; Domestic Joint Venture; International Joint Venture; and a New Corporation (COMSAT) concept. The likelihood of private financing was considered for each of these alternatives and Government financing options were also examined.

* Defined as the total monies resulting from the aircraft manufacturers' internal sources (depreciation and net profit), both advance and progress payments, and monies from lenders and investors (long-term debt and equity).

STUDY FINDINGS

Let me now summarize for you our major findings from this study.

For any commercial aircraft program to succeed it has to satisfy four important criteria. These are public acceptance, customer acceptance, airline ability to purchase the new aircraft, and the aircraft manufacturers' ability to finance a new advanced high-speed aircraft program.

The aircraft must be environmentally acceptable with regard to community noise and emissions. An AST also must overcome a possible negative public reaction to a high energy use vehicle.

Secondly, the customers must show their acceptance of a supersonic aircraft by their willingness to pay a higher fare, on the order of 20 to 30 percent higher than subsonics, for the improved service.

Thirdly, the airlines must be able to purchase the new aircraft when the time comes for their introduction. As we pointed out earlier, the purchase price of a future fleet of supersonic aircraft may only be 25 percent greater than a future fleet of subsonic aircraft. This as you recall is due to needing only half as many ASTs to do the same amount of work as future subsonics with the purchase price ratio of supersonic to subsonic aircraft on the order of 2.5.

Fourth, viable alternatives must be available for financing and managing a program for developing and producing an advanced high-speed aircraft. There are three major risks involved in this - technological, market and operating costs. According to members of the aircraft manufacturing industry, the maximum cumulative negative cash flow to an AST program (after generic R & D) could be on the order of \$6-10 billion, which

is large in relation to the current assets of aircraft manufacturers. However, we are concerned with an aircraft program that may not be initiated for 10 to 20 years, and the financial position of the industry may change significantly in this time. Nevertheless, we did examine several ways of financing, as well as managing, the various phases of such a program.

The following presents more specific findings based on this analysis:

- o The results of the generic R&D phase should provide a solid technological data base. This in turn should provide data to reduce technical and cost uncertainties and assist in deciding whether to move into the specific R&D phase. Furthermore, the increased effort in the generic R&D buys more time in which to further explore the market.
- o In considering the various phases of such a program the funds required increase dramatically between the completion of the generic R&D stage and the beginning of the post-certification stage. The major technological or development risk continues until after the first flight has taken place. At the same time, the financial risk exposure decreases from extraordinarily high levels to levels which may be within the tolerance limits of large public security offerings. However, financial experts have stated that they are not sure that even the post-certification production financing could be undertaken by the private sector for a project of this magnitude.
- o The cost of an advanced high-speed air transport program (ASUBT or AST) could be large in comparison to previous subsonic programs. The significant concerns of this type of program are: the magnitude of the technological and financial risks. Each one by itself may not be

enough to preclude a manufacturer or supplier of capital from investing, but together they may constitute an unwarranted risk.

- o The largest equity offering since 1956 was \$1.4 billion offered by American Telephone and Telegraph in 1971. This represents \$2.2 billion in 1978 dollars, well below the projected funding requirements of a new AST program. Furthermore, with a maximum negative cash flow for an AST program on the order of \$6-10B, this is more than twice the equity of the three airframe manufacturers combined.
- o The largest total funds acquired by the major aircraft manufacturers - Boeing, Lockheed, and McDonnell-Douglas - in any one year was \$1.1 billion in 1966 (\$2.1 billion in 1978 dollars) from both internal and external sources. Further, the aircraft manufacturing industry almost went under with the development and production of the wide body aircraft. Therefore, it appears unlikely that any single company could undertake a program of this nature by itself due to the market, technological, and financial risk.
- o Therefore, we are dealing with a whole new ball game - due not only to the technical problems, but also because of the financial and management hurdles. However, several alternatives appear attractive:
 - Domestic Joint Ventures
 - International Joint Ventures
 - New Corporation Concept
- o International, or domestic, joint ventures appear an appropriate way to spread the risks (through sharing of costs). However, a domestic or international joint venture in the specific R&D phase makes no

sense if there is no plan to continue the joint venture into the production phase.

- o A new corporation, similar to COMSAT, may be a good way for managing a major new advanced commercial aircraft development. COMSAT acquired a proven technology. This may or may not be necessary for a future program.
- o It is not clear, at this time, whether the financing of an advanced high speed commercial aircraft program will be possible without government support. However, joint ventures, both domestic and international, do represent one way that such a program might be financed and managed.

Mr. Chairman, this ends my testimony. We will be glad to answer any questions you may have.

[Whereupon, the subcommittee was adjourned at 5:12 p.m., subject to reconvene at the call of the Chair.]

APPENDIX I

QUESTIONS AND ANSWERS FOR THE RECORD

RESPONSES TO WRITTEN QUESTIONS SUBMITTED BY HONORABLE
GOLDWATER DURING THE FEBRUARY 6, 1980, HEARING TO
DR. OLSTAD

QUESTION R-1:Propfan Research

Please state how and when the following technical problems will be addressed in your propfan research program:

- a. blade fatigue if the propfan is mounted in front of a swept wing, due to differing angles of incidence of airflow across the propeller disc.
- b. structural problems associated with curved wing surfaces near the nacelles (necessary to accommodate swirl from the propfan).
- c. distortion of flow into the inlet due to the high solidity of an 8 or 10 blade propeller.
- d. noise at ground level from a propfan at high altitude cruise (reference the same problem with the old B-36 bomber).

ANSWER R-1:

a. Conventional propeller installations upstream of a wing have always resulted in cyclic variations in incidence angles for the propeller blades as they rotate about the propeller axis due to the wing upwash and to aircraft pitching maneuvers. For the higher-speed (Mach 0.7 to 0.8) advanced turboprop, the aircraft wing is likely to be swept which will result in a more complex flow field and higher order variations in incidence angles. The response of the thin, highly-swept advanced turboprop propeller blades to the resulting unsteady aerodynamic loads is one of the key questions that will be addressed in the advanced turboprop program.

As part of the Phase I effort, a two-foot propeller mounted on a nacelle and swept-wing model will be wind tunnel tested in the summer of 1980. During this test, blade stresses will be measured and compared to similar tests of an isolated propeller to obtain a first order evaluation of the wing-induced unsteady aerodynamic loads.

In the proposed FY 1981 enhancement (Advanced Turboprops-Phase II), a large-scale advanced turboprop propeller will be built and wind tunnel tested in late CY 1985 and CY 1986 to determine its response to a simulated wing-installed flow field. Blade stresses will be measured and fatigue life will be calculated. While the large-scale propeller is being fabricated, a two-foot aerodynamically-scaled model will be built and tested to

measure performance and evaluate flutter boundaries. This model will also be tested with the nacelle and wing model (first used in Phase I) to determine, to first-order accuracy, the structural response expected from the large-scale propeller to the wing flow field. This propeller wing test will be conducted in CY 1983.

In a future enhancement (Advanced Turboprops-Phase III) currently planned for FY 85 final verification of the structural response to a wing flow field of a large-scale propeller would involve aircraft testing of a wing-installed advanced turboprop propeller. This test is planned for late CY 1988.

b. In June 1980, a powered semispan model will be tested at Ames to experimentally evaluate the installation losses for a representative propeller, nacelle, and wing configuration that has not been tailored to account for any of the slipstream effects. Next, in late 1980, the above test results will be used as a baseline for appropriate analytical techniques to define two alternate wing/nacelle modifications designed to improve the installation characteristics. In Phase II, the selected wing/nacelle designs will then be tested to confirm the design methodology, the benefits of leading edge modifications, and the associated wing loading environment.

If the results of these tests are promising, wing modifications will be made to the Phase III test bed aircraft. Since these modifications are limited primarily to the wing leading edge and do not affect the wing box structure, we do not expect a major structural problem in this area. Of course, the aircraft modification design effort in Phase III will analyze the configuration for potential structural problems prior to aircraft modification.

c. Since the 8- or 10-bladed propeller in a turboprop engine has a lower solidity than the fan in a turbofan engine, the solidity effect on flow distortion in a turboprop is expected to be less than in a turbofan. We therefore do not expect this to be a problem during normal operation. However, during reverse-thrust operation of the propfan, solidity is expected to have a noticeable effect on flow distortion. Therefore, reverse-thrust tests of 2-foot diameter propfans are planned for 1981. In addition, reverse-thrust tests of the large-scale propfan are planned for 1985, both statically and at low-speed in the Ames 40 x 80 wind tunnel.

d. The B-36 bomber was a pusher-propeller configuration with the propeller ingesting wing-wake. It is likely that this contributed to the B-36's noise problem. The propfan is expected to be in front of the wing. Also, the propellers on the B-36 were not properly synchronized so that "beating" resulted between engines. The use of syncrophasing on a propfan-powered aircraft should eliminate any "beating" noise problem.

Aside from the "beating" noise problem, there was, at one time, a possible noise problem at ground level from a propfan at high-altitude cruise. One study of a Mach 0.8 propfan-powered aircraft conducted in 1976 indicated that during cruise at high altitude, shock waves would form at the propeller blade tips and propagate to the ground. Since that time, the theory for predicting propeller noise has been improved and substantiated by wind tunnel acoustic data on small-scale propellers (1978-1979). The theory and data now indicate that with proper blade sweep, shock waves do not form at the propeller blade tips. Thus, the noise problem on the ground due to high-speed, high-altitude flight of a propfan-powered aircraft is not expected. Confirmation of this will be obtained in 1988 as part of the Phase III program when the propfan-powered testbed aircraft will be flown. In addition, a first order assessment will be obtained from the JetStar tests scheduled for September of 1980.

QUESTION R-2:

Operational Techniques to Reduce Noise

Several years ago NASA Ames did research on a decelerating approach, a delayed flap approach, and a reduced flap approach:

- a. Please send copies of the NASA reports on these techniques.
- b. Summarize the improvements in approach noise levels achieved by each technique as compared to the conventional approach procedure.
- c. These techniques apparently have not been used by U.S. operators. The programs seemed to die at the point where NASA tried to hand them off to FAA. What happened?

ANSWER R-2:

NASA's program to investigate delayed flap approach procedures for noise abatement and fuel conservation consisted of three main activities conducted during the period 1974-1977:

1. Simulation and flight test investigations of a delayed flap approach using NASA's CV-990 aircraft, which is a four-engine jet transport representative of the DC-8 and B-707 class aircraft.
2. Contract studies and simulations to assess the applicability of the delayed flap approach to example aircraft of the current (1975) fleet. This included retrofit designs and cost analysis for the B-727.
3. A joint analysis with FAA by simulation of the realistic dynamics of air traffic in an airport environment

where a mix of aircraft types and approach procedures exists.

Reports describing these activities are attached.

A series of measurements were made during some of the simulations and flight tests to compare the noise, fuel, and time benefits while using different types of operational procedures which included the conventional, the ATA reduced flap, and the delayed flap or decelerating approaches. The conventional approach is one that is stabilized in airspeed and landing flap throughout most of the approach, and is representative of the way approaches were flown several years ago, prior to the airlines efforts in noise abatement. The reduced flap approach is the current recommended Air Transport Association (ATA) landing procedure; the first portion of the approach is flown at a reduced flap setting and landing flaps are not extended until reaching 1000 feet altitude. The delayed flap approach uses the conventional ILS profile except for higher and decelerating airspeeds. The power is reduced to idle during the early part of the approach. The flap extensions and landing gear extension are delayed until later than normal. At a predetermined altitude above the runway, the power is added to approach power and a normal stabilized approach is flown from this point down. The altitude at which the approach is stabilized can be varied by the pilot. The instrumentation in the aircraft tells the pilot when to reduce power to idle, when to extend the flaps, when to extend the landing gear, and when to stabilize the approach with approach power. The results of these experiments are summarized below:

CV-990 BENEFITS COMPARISON

	<u>CONVENTIONAL APPROACH</u>	<u>REDUCED FLAP</u>	<u>DELAYED FLAP</u>
Fuel used (kg)	420	370	240
Elapsed time (min)	5.2	5.1	4.1
90 dB noise contour (km ²)	22	17	5

B-727 BENEFITS COMPARISON

Fuel used (kg)	350	290	170
Elapsed time (min)	6.5	6.1	4.5
90 dB noise contour (km ²)	5.6	4.0	1.3

Results shown that significant benefits may be obtained using the delayed flap approach technique. A generally favorable response was obtained from a group of guest pilots from the air transport industry and FAA. The procedure could be introduced incrementally. The parameters are under the control and selection of the pilot and they can be adjusted appropriate to the weather and congestion in the terminal area.

However, there are disadvantages in implementing the delayed flap procedures. The disadvantage to the airlines is cost. The installed cost of the added cockpit instrumentation was estimated in February 1977 to be between \$61K and \$88K for the B-727 depending on the number of shipsets involved. The disadvantage from the pilot's standpoint is the departure from a fully stabilized approach throughout the final approach path. From the standpoint of the ATC system, the difference in speeds between aircraft flying conventional and delayed flap approaches was a source of some controller difficulty. However, no controller problems were found when all aircraft were executing the same type of approach. Also the delayed flap procedures require a distance measuring equipment (DME) colocated with the instrument landing system (ILS).

The technology development associated with those operational techniques have been proven and the data is readily available. The development activity has been closely coordinated with the FAA and the air transport industry. It is FAA's role to assess the overall operational benefits/disadvantages of this technology development and make any decisions with respect to implementation.

QUESTION R-3:

Human Response to Noise

Part of your Human Factors R&T program for FY 81 will "continue to assess the utility of community response models through laboratory and field studies. This work is designed to produce a model for use in evaluating the noise abatement resulting from aircraft modifications, aircraft operations and land use strategies."

- a. What steps are you taking to make sure FAA and airport operators gain the full benefit of your research?
- b. The Noise Abatement Preferential Runway System at JFK Airport is scheduled to be updated soon. Will you or your research be helpful to them in their efforts?

ANSWER R-3:

- a. The objective of Langley Research Center's airport community noise impact modeling program is to develop the technology for noise impact assessment and minimization in airport communities. Focus for this program is an airport

community computer simulation model called ALAMO (Aircraft noise Levels and Annoyance Model) which is capable of overlaying distributions of aircraft noise level (foot-prints) on the population distributions of any U.S. airport community. Recently-developed psychophysical relationships between noise exposure level and subjective response are then invoked to predict the overall impact of airport noise on the surrounding community. Outputs of the program include a prediction of the number of residents expected to be "highly annoyed" by the airport noise. The ALAMO model can be used to quantify the degree of noise impact reduction which can be achieved by various candidate noise abatement strategies. For example, a number of runway selection alternatives might be compared with the imposition of a night curfew to see which strategy results in the greatest reduction of highly impacted residents. In a similar manner, various fleet mix and land-use alternatives can be assessed to determine which has the greatest potential for alleviating noise impact. Since each noise abatement strategy will have a cost associated with it, the ALAMO model can be used to determine an appropriate distribution of limited airport noise abatement resources.

The ALAMO model development effort began in late 1978 and the baseline configuration of the model has been operational for less than a year. During and subsequent to the development of the model, the following specific steps have been taken to insure that the FAA and airport operators gain full benefit of this research effort:

1. On August 27, 1979, the ALAMO development effort was described in a briefing held at FAA Headquarters in Washington for the Noise Abatement Division of the Office of Environment and Energy.

2. On September 26, 1979, the Noise Metrics Subcommittee of the SAE A-21 Aircraft Noise Committee met at Langley Research Center to hear a review of the community noise impact program. In attendance were representatives of the FAA, the EPA, numerous airport operators, and several of the major airlines.

3. A detailed description of the airport community response model was presented at the 98th meeting of the Acoustical Society of America, held in Salt Lake City November 26-30, 1979.

4. On December 14, 1979, a review of the LaRC program on human response to noise was held for the Director of the FAA's Office of Environment and Energy and his staff. This briefing was held at the Langley Research Center.

5. A workshop on the effects of time of day on subjective response to aircraft noise is currently planned for March 11-12, 1980. Invitees include airport operators, airline representatives, and members of the

EPA and the FAA, as well as prominent acoustics researchers and consultants throughout the United States and abroad. This workshop is being sponsored jointly by the FAA and the NASA and will be held at Langley Research Center.

b. Regarding the scheduled update of the JFK Noise Abatement Runway System, a meeting has been scheduled for March 14, 1980, at JFK in which members of the Langley Research Center's Acoustics and Noise Reduction Division will meet with the Director and staff members of the FAA's Eastern Region to explore possibilities for future cooperation in upgrading the runway selection system currently operational at JFK. This meeting has been called at the request of the Noise Abatement and Environmental Officer of the FAA Eastern Region. We believe that the results of our research can be of material use in their consideration for upgrading at JFK.

QUESTION R-4:

Heads Up Display (HUD)

On page 41 of your FY 81 budget testimony you list three fundamental issues addressed by your HUD program (pilot switching his attention between the HUD scene and outside, pilot workload, and pilot distraction). When I was in France last June to fly their HUD, I was given the distinct impression that all three of these questions had been answered long ago. They have extensive experience with HUD in passenger service and reported no problems with switching, workload, or distraction.

Apparnetly you are saying that these three fundamental questions are unanswered, and part of your FY 81 budget will go toward finding the answers. On the other hand, these three questions are clearly related to safety of flight. Bearing this in mind, would you please comment on the following statements:

a. U.S. citizens are currently allowed to fly on French airliners without being warned by NASA that the pilot may not be able to "switch his attention back and forth between the display and the outside scene rapidly enough to land safely" (quote from page 41 of NASA written testimony).

b. The FAA will probably certify the DC-9-80 with a HUD prior to the beginning of FY 81 (i.e., before the three safety questions are answered). And the NASA HUD work is part of a joint program with FAA.

c. Other parts of the NASA organization have elected to install a HUD in the Space Shuttle with the three fundamental safety questions still unanswered.

It seems to me that somebody must be marching out of step, and it may be OAST. In any case, I'd like to get to the

bottom of this issue. Would you please provide me with an explanation of your HUD program and how it relates to the rest of the international aviation community?

ANSWER R-4:

I am pleased to have the opportunity to provide you with more detailed information on OAST's Head-up Display (HUD) research than was possible in the written testimony.

BACKGROUND AND RATIONALE FOR NASA'S PROGRAM

Our HUD research program began in late 1976, following extensive discussions among various segments of the civil transport industry which culminated in September 1975 with a request from the Administrator of the FAA for NASA participation in a program to "produce data upon which we can make a determination regarding the safety potential of head-up displays." At the same time, the NTSB issued Safety Recommendations A-76-122 through A-76-128 covering air carrier approach and landing accidents. In these recommendations, the Board stated that they "could reach no conclusions regarding the use of heads-up instrument display (HUD) in the low visibility environment" and urged further study and evaluation.

Following a preliminary review of available research and operational experience, we concluded that there were several significant areas where information about the potential safety impact of HUD for civil transport operations was either nonexistent or insufficiently documented to allow regulatory agencies to take appropriate action. Accordingly, we entered into a formal agreement with the FAA in March 1977 and immediately a joint FAA/NASA project team undertook a more comprehensive review to determine the specific areas where additional information and research was necessary and to set priorities for ordering our research. During this phase of the program, we reviewed all available literature and established communication with foreign and domestic aircraft manufacturers and operators, including the DOD. Our personnel made numerous visits and have flown most currently available HUDs in simulators and aircraft, including the TC-125, CSF-193 and PERSEPOLIS HUDs on the Mercure simulator at Velisey, on the Caravelle aircraft and the Nord 262 aircraft at Bretigny. Project personnel rode jumpseat to observe the use of HUDs on both of the two commercial users of HUDs in civil jet transport operations (Air Inter and Pacific Western Airlines). In addition, our people have simulator experience with several military HUDs including the F-14 and F-18, and have also flown a HUD on a Queen Air and on the B-737 simulator and aircraft. Each of the visits to the various organizations included in-depth discussions with cognizant personnel in order to learn as much about the accumulated, but in many cases undocumented, operational experience as possible.

Although it may be an over-simplification of a very complex area, I believe we can summarize the results of this comprehensive review of research and operational experience as follows:

1. Present civil operational experience with HUDs has been limited to two extreme cases:

- a. the use of a simple, non-IFR flight-path type HUD for making visual approaches into crude, unequipped airports (Pacific Western Airlines);

- b. the use of a relatively simple electro-mechanical HUD as a monitor and back-up system for Cat IIIa autoland operations (Air Inter).

2. Present limitary operational experience with HUDs has been primarily directed toward weapons delivery and terrain-following, both of which have little direct relevance to civil operations. The military experience with HUDs in approach and landing operations has been very limited, although our project personnel did gain some valuable insights into certain problems associated with some specific display designs.

On the basis of this information, we became convinced that one major objective of our program should be to develop basic principles and design guidelines which would increase the operational utility of HUD for civil operations. Another major consideration was to explore advanced HUD concepts which would expand the operational envelope to include the entire range of civil transport approach and landing operations, including precision and non-precision instrument approaches and visual and circling approaches during various adverse environmental conditions such as wind shear and low visibilities. Furthermore, we determined that it was desirable to approach this advanced display effort as being largely a problem of achieving a fully integrated flight information display which would be functionally and operationally compatible with the advanced electronic head-on displays which will be found in the next generation of transport aircraft currently under development.

Given these general guidelines for HUD design, several issues become apparent. For example, what will be the effect upon pilot workload of changing the information content of the HUD? Will this changed information content have an impact upon the pilot's ability to switch his attention between the symbology and the outside visual cues? Anecdotal data from the military experience with HUDs suggests that display fixation may be a serious problem under certain circumstances. Although this does not appear to be a problem with present civil HUDs, it is possible that if display complexity is increased and if the operational envelope is expanded to include additional approach types and operations such as terminal area maneuvering, there may be significant effects upon the

pilot's ability to attend to important features of the outside world. The range of possible effects include both beneficial effects (the use of HUD improves pilot awareness of the outside visual cues, e.g., conflicting traffic), and detrimental effects (the more complex display may place so many demands upon pilot workload and attention that awareness of outside visual cues may be reduced).

Other issues raised by these considerations include questions of potentially significant economic and safety impact. For example, what will be the impact of advanced HUD technology upon flight crew training requirements? What is the impact upon flight crew operating procedures, including monitoring and pilot callouts? What are the effects of certain failure modes (e.g., unintended localizer offset) upon the safety of flight operations using these advanced HUD concepts?

Our entire HUD research program was planned on the basis of the information discussed above. To insure that we had, in fact, identified significant issues, we held a series of workshops at Ames in which representatives from U.S. and foreign manufacturers, airlines and pilot groups participated. These workshops were intended to continue the dialog we had developed during the background review. The guidance and support we have received from the aviation community during the course of this program have been extremely helpful.

I have enclosed a table showing the level of NASA effort expended on the program. At the present time, the only remaining activity is a simulation exercise scheduled for April which will further explore various visual illusory situations during approach and landing operations, including the so-called "black hole" approach. As the table shows, the FY 81 plans are for \$25K with an associated 1.5 man-years of effort. These FY 81 resources are to cover data base analysis and report writing which may be necessary this fall.

I want to make clear that this represents only a completion of those activities undertaken in response to the FAA's request. We will continue to explore advanced HUD concepts as a part of our general aeronautical human factors research in advanced displays and integrated flight information systems. As a part of this research we have tentative plans, as I mentioned in the testimony, to further explore the use of advanced HUD concepts in very low visibility approaches.

ANSWERS TO SPECIFIC QUESTIONS

I believe that the discussion above addresses the specific questions you raised in your letter of February 12, 1980. However, I would like to summarize the discussion item by item:

a. Attention switching does not appear to be a safety of flight problem with current, limited-application civil HUDs. This is, of course, reflected in the fact that the French have certificated a HUD for use as a monitor and back-up for Cat IIIa operations. Certainly if we had found any data to the contrary we would have taken steps to insure that this information was disseminated to all concerned parties. Moreover, I am confident that the FAA, who is working closely with us, would quickly take appropriate action.

b. My understanding of current FAA intentions with regard to certification of the DC-9-80 HUD is that they intend to initially certify the HUD on a "non-interference" basis, i.e., no additional credit (such as lower landing minima) will be given. Furthermore, the DC-9-80 HUD was designed in the context of CAT IIIa autoland operations. The FAA approach is entirely consonant with existing data and operational experience. As more is learned through additional research, including the FAA flight evaluations which are scheduled to begin this summer, and through accumulated DC-9-80 operating experience, the FAA may be in a position to certify the HUD for new roles, and to do so with a thorough understanding of significant design and operational constraints.

c. The Space Shuttle is a unique aircraft, operated by highly-trained astronaut pilots flying a very constrained, highly-specialized flight profile. The issues involved in deciding to use HUD in these operations differs considerably from those which must be addressed in the context of civil air transport operations. There are, of course, overlapping areas of importance to both, and OAST personnel have been exchanging information and ideas with Shuttle personnel on this matter.

I hope this additional information has helped to clarify our program objectives and approach, and to place this program in the overall context of the design, certification and use of HUDs for civil transport operations. We believe our HUD activities have resulted in significant contributions to the aviation community's knowledge of the potential advantages and disadvantages of HUD, and we would be pleased to have you visit Ames to discuss further details of the program and its findings with NASA and FAA project personnel.

APPENDIX II

ADDITIONAL STATEMENTS FOR THE RECORD

Statement of Clifton F. von Kann
Senior Vice President - Operations and Airports
Air Transport Association of America
Before the House Committee on Science and Technology
Subcommittee on Transportation, Aviation and Communications
March 3, 1980

Scheduled Airline Viewson the FY-1981NASA Research and Technology Program

My name is Clifton F. von Kann. I am Senior Vice President - Operations and Airports of the Air Transport Association of America, which represents virtually all of the U. S. scheduled airlines. I appreciate the opportunity to comment on that part of the FY-1981 NASA budget request dealing with Aeronautics Research and Technology.

General Comments

The scheduled airlines as operating entities depend heavily on others for much of the Research and Development work necessary to improve the safety and efficiency of airline flight operations. FAA and NASA are the two government agencies most involved in the conduct of this work -- FAA primarily in the provision of improved, more efficient air traffic control, communications and navigation services, and NASA in the development of basic improvements to engines and airframes and in the human factors research area. There are, of course, areas of common interest in

the research conducted by the two agencies; and there are numerous cooperative efforts involving both organizations.

The next generation of airline aircraft now on order will benefit greatly from past NASA research work. Substantial gains in fuel economy and reductions in noise emissions will be realized. Both areas of improvement are important to the airlines. The rapidly escalating price of aviation jet fuel dictates maximum effort in seeking improvements in operational efficiency. The U. S. airlines will spend approximately \$10.6 billion during 1980 for 11.2 billion gallons of fuel. By the end of 1980 airlines expect to be paying approximately \$1.10 per gallon for jet fuel; the average price per gallon over the entire year will approximate \$.95 per gallon. In 1979 the average over the year was \$.58 per gallon; and in 1978 the average over the year was \$.39 per gallon. These dramatic operating cost increases, coupled with continuing uncertainties over availability of adequate fuel supplies, has caused increased concern by aviation users and indicates the need for increased emphasis in NASA's research work directed towards improvements in fuel efficiency.

Reduction in noise generated at the source -- by both engines and airframe -- is also an important objective in the view of the airlines. Airport neighbors continue to press for reductions in noise exposure in communities adjacent to airports. These pressures typically lead to measures which result in operating inefficiencies -- circuitous

departure and arrival routes, restrictions in number of flight operations, or reductions in hours of operation at an airport. These are measures which lead to less efficient use of energy resources and thereby exacerbate fuel supply and price problems. Source noise reduction offers the most promising long term reduction in the impact of noise on airport neighbors, and research in this area must be pursued vigorously. However, the easiest solutions have already been found, and further reductions are becoming increasingly difficult to identify.

A point of clarification. This statement emphasizes measures related to improved efficiency of operations -- measures to improve capacity and reduce delays -- which will in turn lead to reductions in amount of fuel consumed to produce needed air transportation services. However, this emphasis is not intended to slight research by NASA related to improvements in safety. To the contrary, safety related research provides the underpinnings for everything we do in the airline industry. Our concern for safety and vital safety related research is always our highest priority.

My objective in presenting this statement is to advocate a stronger NASA Research and Technology program that will assure needed improvements for the future. In addition to benefits which may accrue to the airline industry, a vigorous NASA program is also vital to maintaining U. S. strength and leadership and in the ability of our manufacturers to supply civil and military aircraft that are

attractive to potential users throughout the world. Any weakening of U. S. aeronautical Research and Development efforts could adversely affect the U. S. industry's preeminent position in the world market and contribute further to erosion of the U. S. balance of payments position. For these reasons, the reduction in the NASA Aeronautical Research Budget Request to \$290 million in FY-1981 is a source of concern, particularly in the face of a domestic inflation rate running close to 13% on an annual basis. A source of even greater concern to the airlines is the reductions made by the Office of Management and Budget in the program enhancements proposed by NASA management in several safety and efficiency related areas. These OMB reductions came to light during questions put to Dr. Walter B. Olstad of NASA by this Committee on February 6, 1980. We believe several of the reductions were ill advised, and we will comment to that effect in subsequent remarks.

I would like to turn now to certain specific aspects of the proposed NASA FY-1981 program. For convenience, my comments have been divided into three categories: Efficiency, Safety, and Environmental Concerns, recognizing that there may be some overlap between these categories. My comments apply to research work proposed by NASA within both the Research and Technology Base and Systems Technology Program areas; it is difficult to differentiate between the two areas.

Efficiency

As I previously noted, rapid escalation in the cost of

aviation fuels and uncertainty over adequacy of future supplies highlight the need for research that will improve the efficiency of flight operations both for airlines and for other airspace users. Much of the work in this category will benefit all airspace users. A few areas merit specific comment:

- There are a number of promising research programs being conducted under the Energy Efficient Transport part of the Aircraft Energy Efficiency Program (ACEE) that are of interest to the airlines. Investigations into reduced longitudinal static stability -- the smaller L-1011 horizontal stabilizer, winglets on the KC-135 and DC-10 aircraft, testing of secondary and primary aircraft structure constructed of composite materials, the development of ultrareliable computers for use in active control (and other flight management) systems, and the investigation of in-flight loads on a JT9D engine nacelle and pylon -- with the objective of improving engine efficiency -- are all programs with important potential payoffs in terms of improved efficiency. On the other hand, the airlines are pessimistic about potential payoffs from application of laminar flow control concepts on airline type aircraft, other than natural laminar flow, and do not agree that priority should be accorded to this effort.

- Airlines note with concern apparent OMB unwillingness to endorse proposed new NASA initiatives or enhancements in composite materials applications and related research to improve understanding of the behavior of these materials and methods of analysis required in order to use them.
- We have a similar concern about OMB unwillingness to support NASA efforts to progress more rapidly with investigations into so-called wide specification fuels. Complete and thorough research into the possible effects that may result from use of fuel with different specifications must precede its possible use by many years. Therefore, we believe it is important that this research be advanced in priority, along with research into use of composites in aircraft structures.
- We are pleased to learn that NASA and FAA will undertake further cooperative investigations of means to reduce the intensity of wing tip vortices generated by large airplanes. Airlines believe this work is of the highest priority since it may lead to regaining airport capacity that has been lost due to increased longitudinal spacing behind "heavy" aircraft sequenced for the approach to land. The valuable work that was accomplished to date on split flap and split spoiler configurations

on the B-747 has not yet led to a basic understanding of the problem that will permit the airframe designer to predict the results of a particular design approach. We are still in the cut-and-try stage. Further work involving active controls on an L-1011 airframe should improve understanding of another possible solution. We are pleased to learn that NASA intends to pursue the B-747 and L-1011 work even further in an effort to understand why the alleviation results are produced, and how a designer may better predict the effects of proposed airframe changes intended to reduce the energy in the wing tip vortices.

Wing tip vortex alleviation has proven to be a frustrating problem, particularly in view of the fact that solutions could not be defined in time to incorporate cost effective fixes in new generation airplanes such as the B-767 and B-757. Unfortunately, the most promising fix that has been investigated to date increases approach noise and fuel consumption, thereby lessening interest in adoption of the technique. This result should not discourage further efforts. To the contrary, the airlines believe that successful conclusion of work in this area is one of the most important tasks that should be pursued by NASA and FAA; and we strongly urge that this work be given the highest possible priority.

- Energy Efficient Engine research work has already produced payoffs in terms of efficiency improvements and holds promise for additional beneficial results. The program objectives include producing a technology base for development of future turbofan engines that burn 12 - 15% less fuel for a given mission. The Hot Section Technology (HOST) program enhancement is welcome and should lead to improved understanding of engine component stresses under high temperature creep fatigue conditions. Similarly, the Materials for Advanced Turbine Engines (MATE) program investigations of new design super alloy turbine disks and turbine blades should lead to beneficial reductions in specific fuel consumption.
- Although airlines are not generally enthusiastic about maintaining airplanes with large propellers and related gearbox mechanisms, the NASA investigations into the fuel efficiency and noise reduction advantages of advanced turboprops deserves strong support. Such airplanes show promise of 15 - 25% reductions in fuel burn compared to turbofan powered airplanes of comparable technology level. The advanced turboprop program should be pursued aggressively.

Safety

Now let us turn to important NASA research programs

which are primarily oriented to improved safety of operations. As previously noted, airlines view the key safety investigations as vital. Of necessity, many of these programs are carried out in cooperation with the FAA. I would like to highlight the following programs of special interest to the airlines:

- Timely research in the Human Factors Research and Technology program area, to establish a Research and Technology Base for solutions to human factors problems in the cockpit and in air traffic control facilities, is strongly supported by the airlines. Human factors research related to the airplane has focused on the role of the human with advancements in flight controls technology, cockpit displays and instrumentation, and flight management technology.
- Important studies have been completed -- and others are under way -- that will utilize the full mission simulation capability at the Ames Research Center. The airlines believe that the potential of this NASA capability for improving our understanding of the interaction of human beings and complex automated systems has just been tapped, and that numerous new ways to exploit this capability will be found. These include investigation into basic factors leading to criteria for minimum as well as maximum workload, and into potential human complacency

resulting from more and more sophisticated warning systems.

- Two important programs also utilizing NASA's simulation capability involve investigations of the Head-Up Display (HUD) and the Cockpit Display of Traffic Information (CDTI). The HUD work involves a systematic examination of the advantages and disadvantages of such devices under airline operating conditions, with emphasis on the approach-to-land phase of flight and problems unique to landing under Category I and better visibility conditions. This program deserves strong support. Further, we note with concern that no commitment has yet been made by NASA or FAA to undertake the next phase of the initial HUD research program. This phase would involve comparison of the utility of the best head-up display with similar information cues presented head down -- on the instrument panel -- on advanced electronic instruments. The airlines believe such a comparison is imperative in order to respond more fully to the unanswered questions about the value of a head-up display in airline operations. It should also be noted that the HUD work has utilized an oculometer technique recently developed by NASA Langley to measure eye position. Further development of the oculometer is needed to turn it into a full capability research tool.

The CDTI research, intended to investigate the advantages and disadvantages of the CDTI in the future air traffic environment, evokes little enthusiasm from the airlines who have yet to see prospects for any immediate application of such a concept. However, this program is important, in order to learn about the potential advantages and disadvantages such devices may have in the future Air Traffic Control system. Therefore, the airlines recommend timely completion of the CDTI research and operational evaluation program, so that FAA and the industry will be in a better position to make decisions about the future of the concept.

Both the HUD and CDTI programs are being conducted cooperatively with FAA, and we urge the Committee to insure that adequate funds are available within the budgets of both agencies to insure completion of these programs without unnecessary delay.

- Great progress has been made in reducing the number of accidents due to failure of hardware and software that is used both in the airplane and in air traffic control. However, much additional research work is needed to better understand the sources of human error that lead to accidents; both in the air and on the ground. NASA's research in the human factors

area has been invaluable, and the airlines strongly support its continuation. However, we note with concern the decision by OMB to eliminate a NASA requested enhancement in this area -- specifically, to increase the number of NASA personnel working on human factors problems. We believe this decision was short-sighted. There is no other organization that enjoys NASA's reputation for unbiased research in this area and no other organization that has demonstrated its competence to work in problems related to real world aviation operations. Furthermore, plans to increase the level of automation in the Air Traffic Control system during the coming decade will necessitate numerous investigations into the implications of such further automation. Most of the emphasis to date has been on research related to problems in the cockpit; less has been done on numerous questions that will arise in connection with the Air Traffic Control system. Although it might be argued that FAA should be responsible for conduct of this research, the airlines believe that NASA will have to play an important role in this area, and additional researchers will be required to undertake this work. Therefore, the airlines urge reconsideration on the issue of additional manpower for human factors-related research, and the lead times that will be

required to acquire competent personnel and get them working productively.

- The Aviation Safety Reporting System (ASRS) continues to reveal significant patterns and trends in the causes of accidents; and it is important that this work be continued. NASA's contribution has been outstanding and we believe they are uniquely qualified to remain the agent responsible for the collection and analysis of these safety reports.
- In the Avionics and Flight Control Systems Technology area, NASA investigation of the advantages that may be gained from recent advances in microprocessors on flight controls technology needs to be pressed forward in cooperation with FAA and the users. Significant advantages in system redundancy for fault tolerance may be possible, by elimination of backup computers and/or computer programs that are required to avoid latent software errors. New technology may make it possible to utilize backup software in the primary computer. This software would be activated in the event of a full or partial failure in the primary system. Another corollary program of interest concerns the need to advance simulation techniques available to validate the software used in digital control systems. The objective of such an effort would be to develop and automate procedures

for conducting simulations so that the results would be more reliable and errors would be detected early, thereby reducing the need for extensive flight evaluation and improving the efficiency of the validation process.

- Training of airline flight crews in flight simulators has reached the point where all -- or nearly all -- of the training can be accomplished in the simulator. NASA has contributed significantly to this level of achievement by working cooperatively with FAA and airlines to validate improvements in simulation capability that are necessary to successfully accomplish the training of an experienced airline airman entirely in a visual simulator. One promising element in the current simulation research program that could lead to improved quality of the visual scene presented during approach to landing under limited visibility conditions involves definition of the best means of simulating reduced visibility effects. This program includes identification of visual cues used by pilots during approaches to landing under poor visibility conditions, and investigation of the utility of alternative methods of generating low visibility visual scenes. In addition, useful studies are planned

of simulator motion washout characteristics and the advantages of distributive computer configurations applicable to the simulation task.

- The Terminal Configured Vehicle (TCV) System effort should provide a necessary aircraft facility, available to programs striving to improve efficiency of aircraft operations in busy terminal areas representative of the future National Aviation System environment. The TCV aircraft must continue to be supported in cooperation with FAA.
- Several NASA research programs related to meteorology are of particular interest to the airlines. Unforecast and unexpected clear air turbulence encounters continue to be a problem. An effective airborne warning system is needed to prevent injury to passengers and crew members, and to maximize passenger comfort. Continued research into promising detection techniques, such as use of microwave radiometers, should be pursued in cooperation with FAA. Collection of additional data on low altitude gust gradient and windshear encounters should be continued to improve the ability to forecast hazardous conditions during takeoff and landing operations. Research into the effect of lightning discharges on composite aircraft structures, microprocessors and other elements of

microelectronic systems should be continued in view of the increased use of these materials and systems in new aircraft.

- Finally, the capabilities of the NASA/Langley Landing Loads Test Track should be utilized to learn more about the dynamics and effects of blown tires and failed wheels on aircraft performance during takeoff and landing operations, as well as defining the operating characteristics of braking and antiskid systems more thoroughly. The capabilities of this track should be expanded to enable the full range of weight and speed characteristics of current and future generation aircraft to be investigated in both the takeoff and the landing modes.

Environmental Concerns

In my introductory remarks I noted the importance of continued basic research efforts to reduce noise generation at the source -- in the engine core, in the engine ducts, and noise generated by the airframe as it moves through the atmosphere. Modeling studies should continue to enable airframe and engine designers to predict the noise generation characteristics of alternative design configurations. There is some evidence that noise control technology may have taken us just about as far as we can expect to go in reducing noise levels generated by large transport type aircraft without

incurring unacceptable performance penalties. If this is the case, the airlines believe it is necessary to identify a floor beyond which further gains cannot realistically be expected barring a major technological breakthrough, not now foreseen.

The NASA program includes additional work in the modeling of community response to noise generated by aircraft. Laboratory and field studies will be required. The work is intended to develop a model that can be used to evaluate cumulative noise level reductions that might result from aircraft modifications, changes in aircraft flight operations, and alternative land use strategies. Airlines are not optimistic about the worth of this modeling effort. In part, it appears to overlap FAA efforts to refine the FAA Integrated Noise Model. Inevitably, prediction of annoyance due to noise in the community rests upon a set of assumptions about how people react to given cumulative noise levels. There is not sufficient agreement among various researchers on these important assumptions to permit a high degree of confidence in the reliability of the annoyance estimates produced by the model. Therefore, we believe the NASA work on human response to noise should focus less on modeling and more on why individuals react negatively to certain noise levels and what those annoying noise levels are. In addition, more work needs to be done on refining the noise metrics used to describe the impact of aviation noise on airport neighbors and, more specifically, in refining the nighttime penalty that is incorporated in a number of these metrics. At the

present time, the most commonly used metric, Day/Night Sound Level (Ldn) weights each nighttime operation as though it were ten daytime operations. There is a substantial body of evidence indicating this weighting factor is too large. This research should be carried out in cooperation with FAA, and several such programs are already under way.

Summary

In summary, we believe that the \$290 million FY-1981 NASA Aeronautics Research and Technology budget should be significantly increased in order that the areas of research enumerated in the foregoing discussion receive adequate funding. The airlines recommend that as a minimum the FY-1981 budget level of \$308 million should be restored. We note that such an augmentation would only restore about one half of the purchasing power lost to inflation during the past year. However, a \$308 million budget level, coupled with the planned decrease in Aircraft Energy Efficiency (ACEE) program expenditures, should enable NASA to execute an aeronautical research program more closely attuned to the needs of the aviation community.

Thank you, Mr. Chairman.

Statement of
Richard D. FitzSimmons
Director Advanced Engineering-Commercial
Douglas Aircraft Company
McDonnell Douglas Corporation
to the
Subcommittee on Transportation,
Aviation, and Communications

Subject: NASA Supersonic Technology Program

During February 1979 the subcommittee was briefed by Douglas on the progress and needs for the supersonic technology program. Developments during the year have been significant and we think it is timely to provide an updated status to the committee at this time.

In aerodynamic technology additional analysis of the data results from the wind tunnel tests have resulted in an improved aerodynamic efficiency (L/D) of 8%. The result is now an improvement of 36% over the Concorde aerodynamic technology level. The specific improvements are identified in Figure 1. In low-speed aerodynamics the NASA 10% scale model of the Douglas baseline configuration has been tested with a deflected leading edge configuration. These data are currently being analyzed to validate the estimates used for takeoff performance, noise studies and for the active control systems studies. Again significant advances over the Concorde performance levels are indicated.

In the propulsion/acoustics technologies the mechanical suppressor flight test program (Figure 2) has been completed. The noise suppression result of 16 EPNdB for takeoff (Figure 3) is excellent and subsequent testing of the flight test hardware in the NASA Ames 40 x 80 ft. tunnel has shown minimum propulsion losses for the suppressor (Figure 4). This is the validation needed to assure that a low-bypass turbojet-powered airplane could be designed to meet at least FAR Part 36 (Stage 2).

In the structures technology analysis continues to show significant weight and manufacturing cost advantages of fabricating the titanium wing panels by the superplastic forming/diffusion bonding (SPF/DB) sandwich process rather than the aluminum brazed titanium honeycomb process. Also for the fuselage the SPF/DB sandwich process now is shown to result in very large weight and some cost savings over conventional titanium processes (Figure 5). The development of the SPF/DB sandwich process has resulted in the fabrication of perfectly smooth prototype panels approximately 36 x 36 inches (Figure 6).

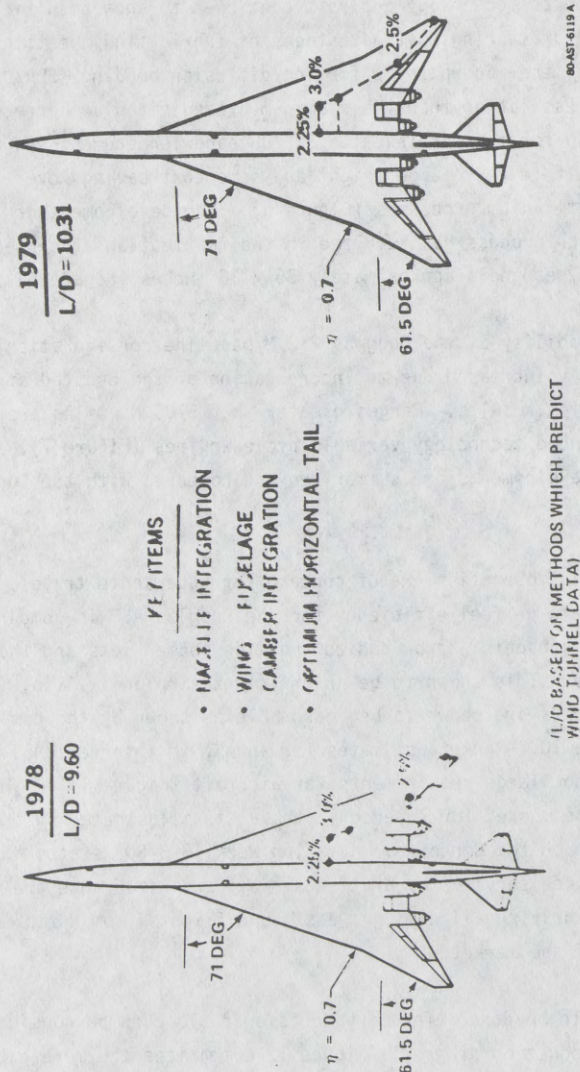
The range capability of the Douglas 2.2 M baseline configuration (AST) is considerably increased due to incorporation of the updated structural and aerodynamics results. Ranges greater than 5700 N. miles are possible with the advanced technology variable cycle engines (Figure 7). The most recent developments are summarized and compared with the Concorde in Figure 8.

The economics of operation are of concern for supersonic travel. The most recent data on fuel efficiency for the Douglas AST is compared in Figure 9 with subsonic narrow bodied and wide bodied jets and the Concorde. The AST is shown to be an efficient airplane. Also, its operational costs are shown to be reasonable as shown by the comparative data of Figure 10. Market estimates for an AST in international operation continue to show large requirements for aircraft (Figure 11). The sensitivity of the market for supersonic travel is illustrated by the recent fare reduction on the Concorde. Aviation Week (3-3-80) states "North Atlantic Concorde services by British Airways and Air France are being credited with driving all daylight eastbound flights from North America to Britain off the market".

Much remains to be done before any decision could even be considered for a U.S. AST production program. Figure 12 summarizes the more pacing items for the airframe. The largest problem is in the structures area where the application of SPF/DB titanium sandwich must be developed to a practical case which can only be done by fabricating and testing large components, such as wings and fuselages. The Douglas recommendation is for NASA to increase the supersonic technology validation testing effort financing by at least a factor of two so a proper decision could be made to protect U.S. participation in any future supersonic transport production activity. An excerpt from a letter to the NASA Administrator from the President of Douglas seems appropriate in closing (Figure 13).

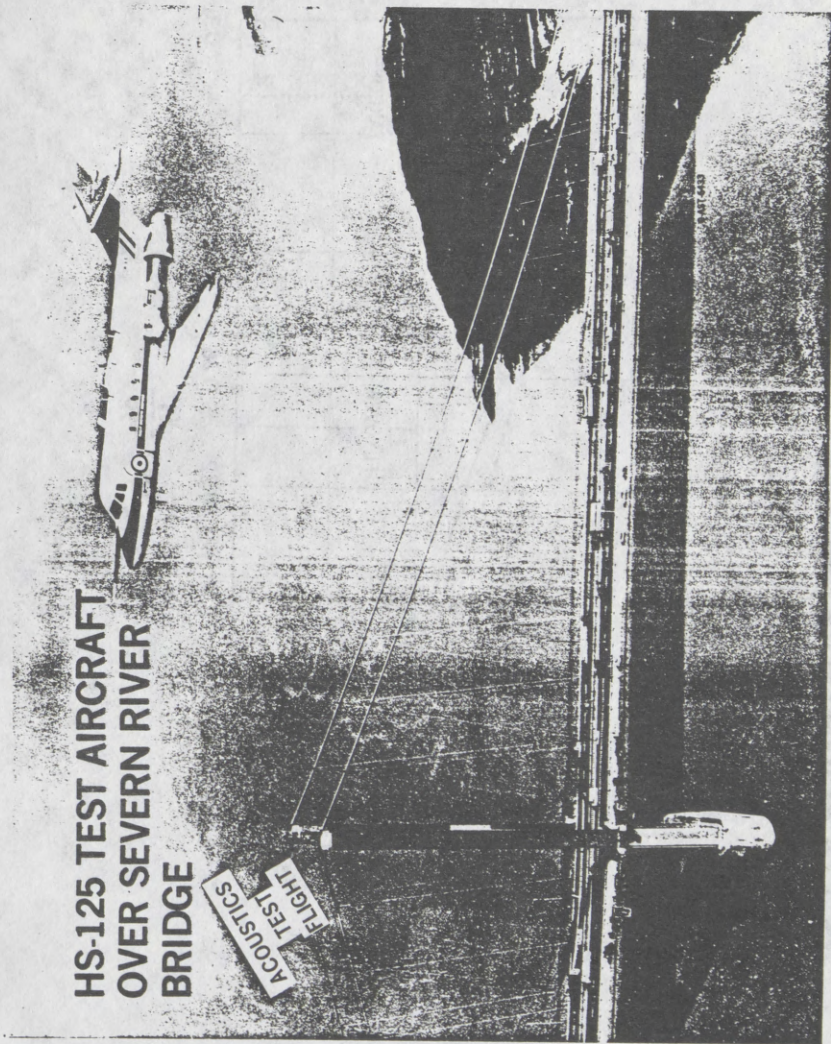
1979 REFINED AERODYNAMIC CONFIGURATION

1218



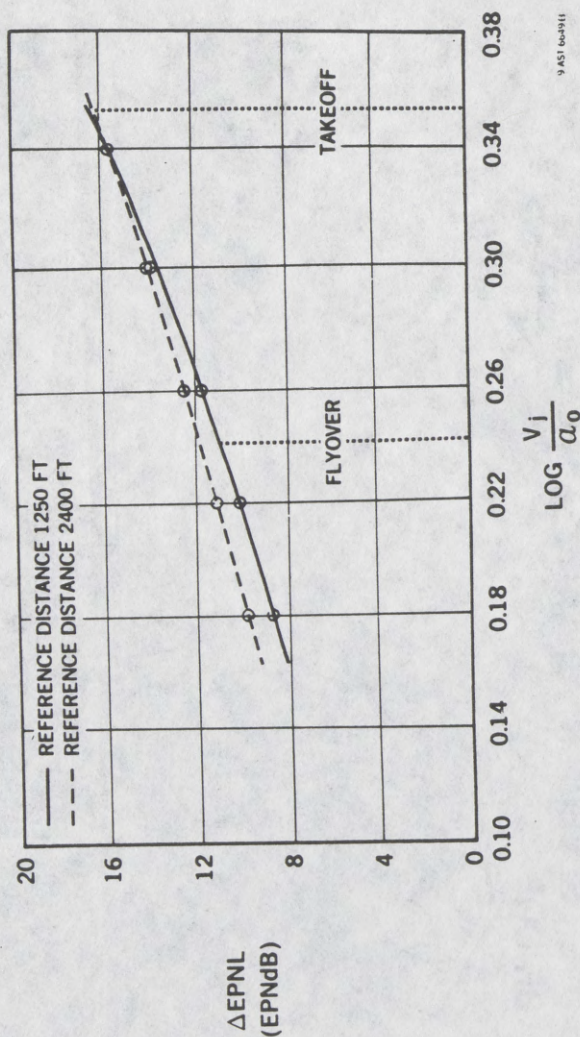
(L/D BASED ON METHODS WHICH PREDICT WIND TUNNEL DATA)

FIGURE 1.



HS-125 FLIGHT TEST SUPPRESSION RESULTS

EPNL CONICAL — DAC 12L/24T + EJ
NOZZLES SCALED TO 37.5 INCHES
172 KNOTS



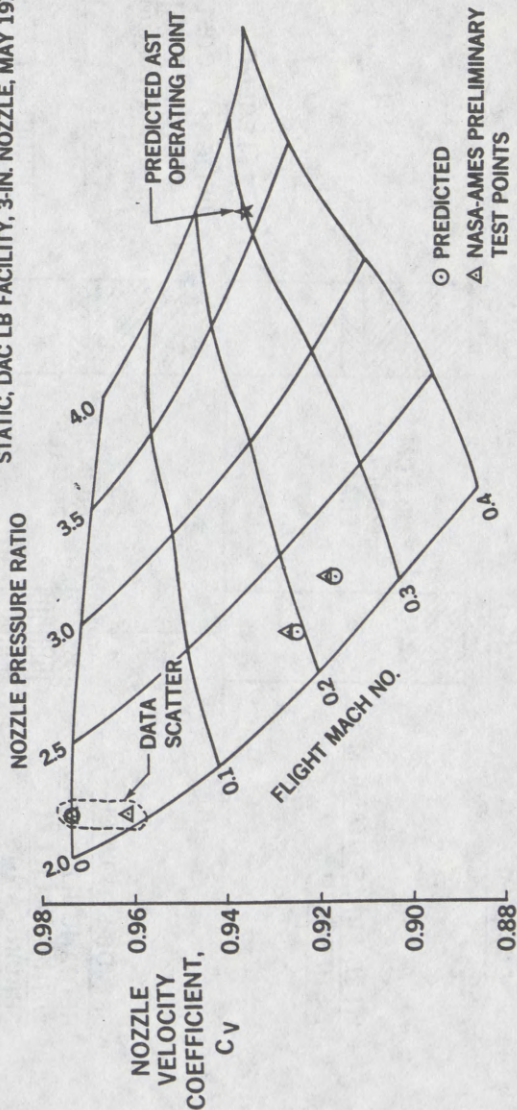
9-551 (a-2)(11)

FIGURE 3.

MDC AST NOZZLE PERFORMANCE

12-LOBE/24-TUBE SUPPRESSOR/LINED EJECTOR

DATA SOURCES
0.2 TO 0.4 M, DIANE TESTS, 6-IN. NOZZLE, 1974
STATIC, DAC LB FACILITY, 3-IN. NOZZLE, MAY 1977



9 AST 6648B

FIGURE 4.

WEIGHT AND COST COMPARISONS

FUSELAGE 101.6- BY 304.8-CM (40- BY 120-IN.) BASE

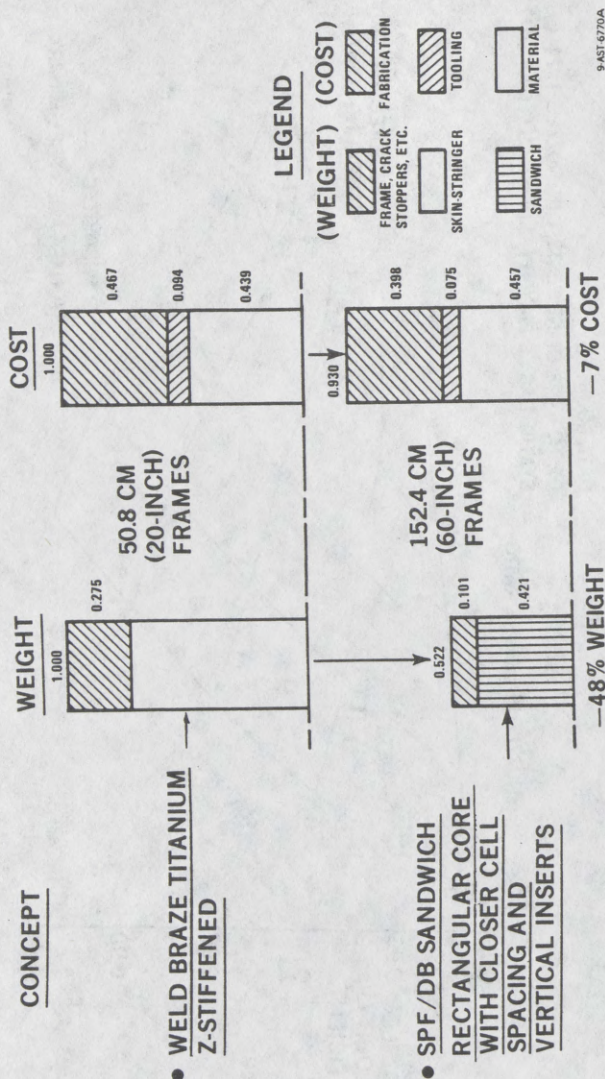


FIGURE 5.

SPF/DB TITANIUM ACCOMPLISHMENTS

MCDONNELL DOUGLAS

PROTOTYPE SPF/DB SANDWICH RECTANGULAR PANEL FORMED
IN MDC 42-INCH-SQUARE FIXTURE

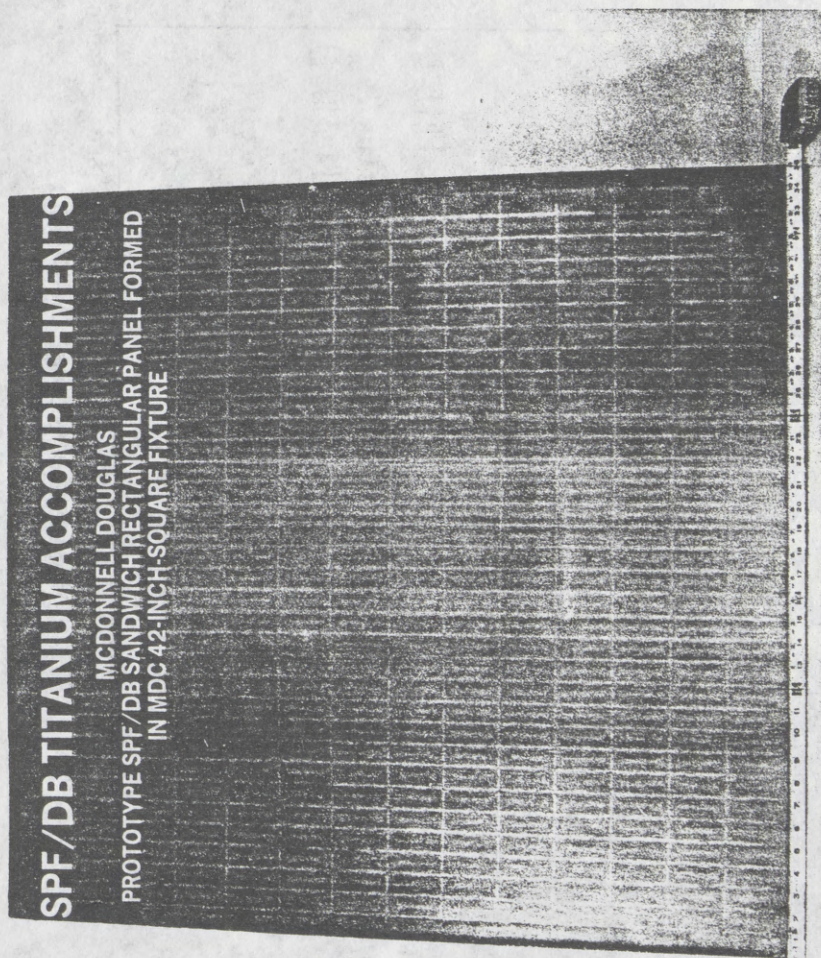


FIGURE 6.

AIRFRAME/ENGINE INTEGRATION SUMMARY

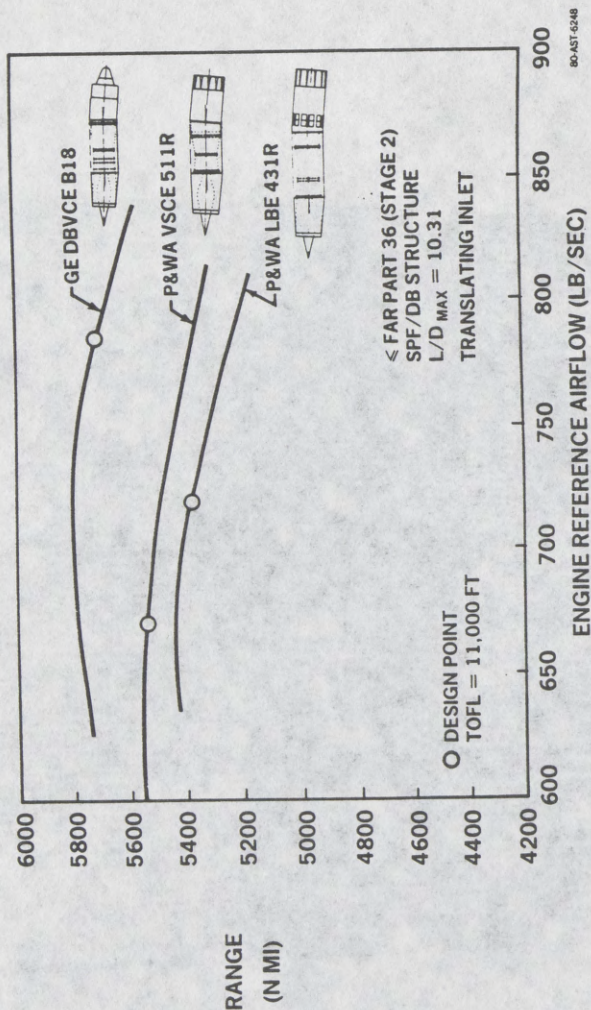


FIGURE 7.

SUPERSONIC TRANSPORT TECHNOLOGY COMPARISON

	CONCORDE	MDC BASELINE (1979)*	IMPROVEMENT
SPEED	MACH 2.02	MACH 2.2	9% FASTER
RANGE	3400 N MI	5705 N MI	68% FARTHER
PASSENGERS	100	225 TO 300	3 TIMES
STRUCTURES	ALUMINUM (WT FRACT = 0.279)	78% TITANIUM, 22% ALUMINUM/COMPOSITES (WT FRACT = 0.253)	
ENGINE	TURBOJET WITH AFTERBURNER	MINI-BYPASS TURBOJET OR VARIABLE CYCLE	
PROPULSION EFFICIENCY (M/SFC)	1.70	1.74	2% INCREASE
AERO EFFICIENCY (L/D)	7.6	10.3	36% INCREASE
TAKEOFF AND LANDING NOISE	116 EPNdB AVERAGE	108 EPNdB OR BETTER	FAR PART 36 OR BETTER
MARKET	PREMIUM CLASS	FIRST-CLASS AND FULL-FARE ECONOMY	500 ACFT

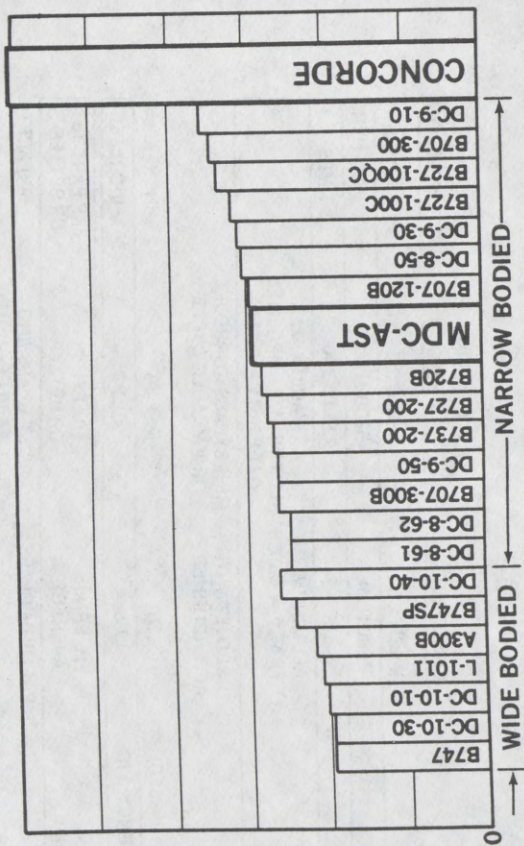
*1983 GO-AHEAD

9-AST-4421 E

FIGURE 8.

FUEL EFFICIENCY COMPARISON

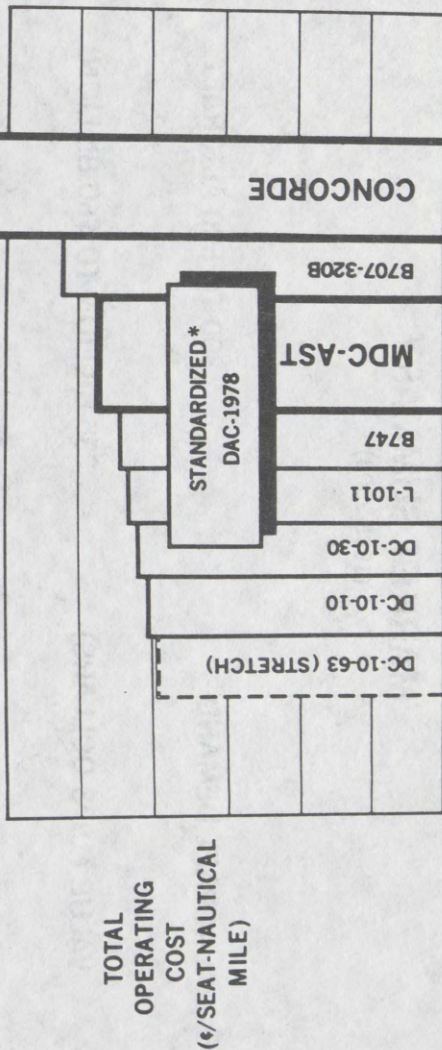
FUEL
CONSUMED
PER
1000 ASM'S



SOURCES:
CAB FOURTH QUARTER 1978 (SUBSONIC AIRCRAFT)
DOUGLAS (AST, CONCORDE)

FIGURE 9.

TOTAL OPERATING COST COMPARISON INTERNATIONAL



* STANDARDIZED TO SAME RANGE, SAME SEAT SPACING

FIGURE 10.

945T 6771 A

MARKET SUMMARY

(1985-2004)

AIRCRAFT DEMAND

300 TO 500 AIRCRAFT

VALUE (1978 DOLLARS)

\$35 BILLION TO \$60 BILLION

FIGURE 11.

9-AST-4458

CRITICAL TECHNOLOGY ITEMS

DEVELOPMENT LEADING TO FABRICATION AND TEST OF TITANIUM WING AND FUSELAGE MAJOR ASSEMBLIES

- FABRICATE (INCLUDING DEVELOPMENT OF EFFICIENT ATTACHMENTS) AND SERVICE-TEST MAJOR AIRCRAFT SPF/DB COMPONENTS
- FABRICATE AND TEST SMALL, MEDIUM, AND LARGE SPF/DB SANDWICH ASSEMBLIES

NOISE-SUPPRESSION TESTING

- COANNULAR IN-FLIGHT — MODERATE AND LARGE SCALE
- IMPROVED MECHANICAL IN-FLIGHT — MODERATE SCALE
- MECHANICAL IN-FLIGHT — LARGE SCALE

HIGH SPEED

- FABRICATE AND TEST NEW HIGH-SPEED WING TO VALIDATE 10 PERCENT IMPROVED DESIGN
- FABRICATE AND TEST HIGH-SPEED MODEL TO VALIDATE FUSELAGE CLOSURE AND UPSWEEP
- OPTIMIZE TAIL TWIST AND CAMBER — HIGH-SPEED MODEL TESTS

LOW SPEED

- DESIGN AND TEST LOW-DRAG HIGH-LIFT SYSTEMS AT HIGH REYNOLDS NUMBERS
- DESIGN AND TEST IMPROVED LATERAL CONTROL SYSTEMS

INLET TESTING

- ACOUSTIC LINER AND BICONE LEAF SEAL — MODEL SCALE
- LOW-SPEED ACOUSTIC AND PERFORMANCE UP TO CHOKE — MODEL SCALE
- LOW- AND HIGH-SPEED FLIGHT VALIDATION OF INLET PERFORMANCE — LARGE SCALE

NOZZLE TESTING

- SUPERSONIC PERFORMANCE — MODEL SCALE
- ACOUSTIC LINER RESEARCH — MODEL SCALE
- LOW- AND HIGH-SPEED FLIGHT VALIDATION — LARGE SCALE

CONFIGURATION INTEGRATION — TO EVALUATE SCALE OF TECHNOLOGY READINESS

80-AST-6060

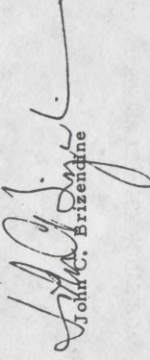
FIGURE 12.

LETTER TO NASA ADMINISTRATOR

JUNE 1979

RE: ADVANCED SUPERSONIC TRANSPORT TECHNOLOGY R&D

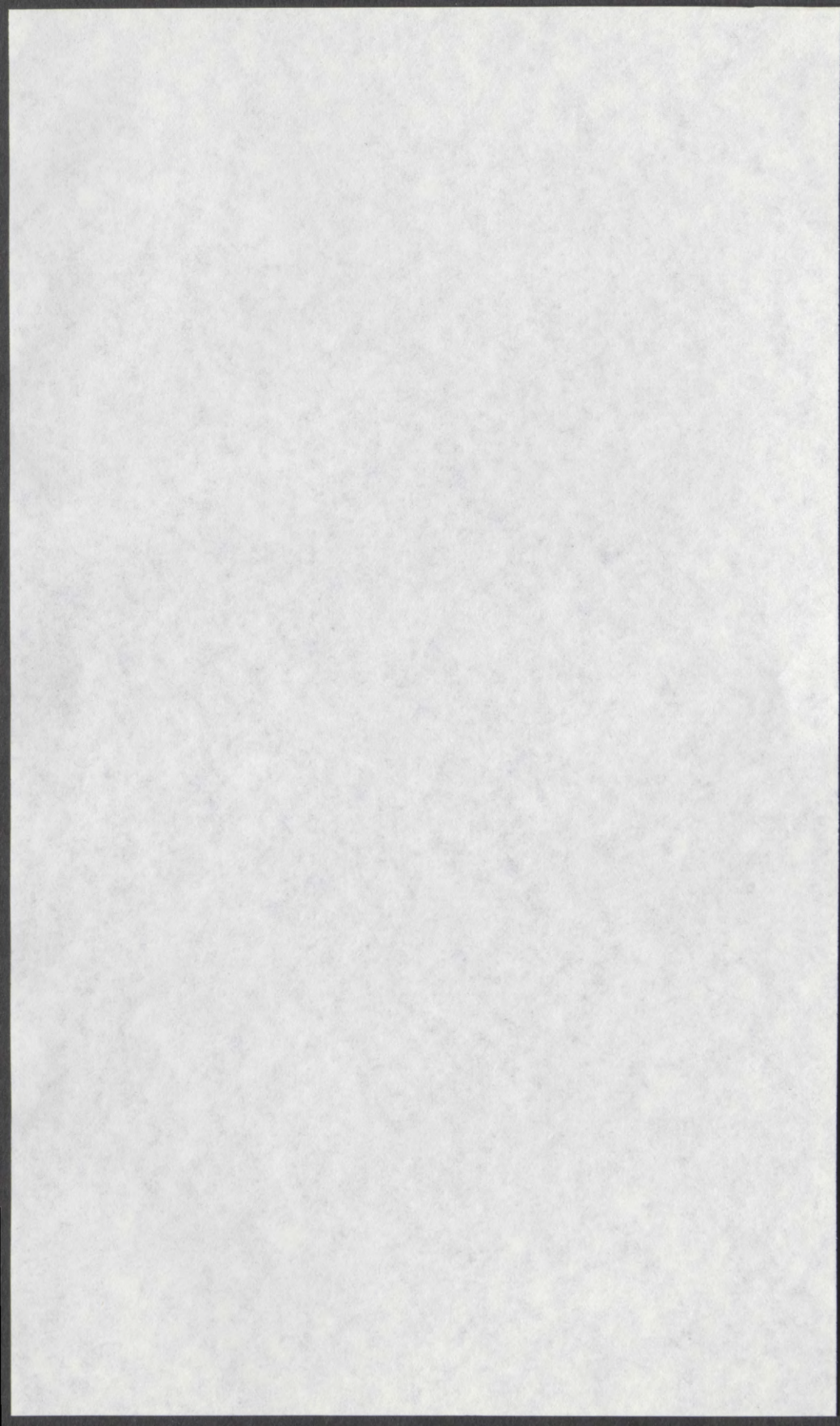
... the critical stage today remains the funding of the high risk technology validation research efforts that lead to a state of technology readiness for U.S. industry. This is a proper obligation of NASA for unique programs that are in the national interest. . . .

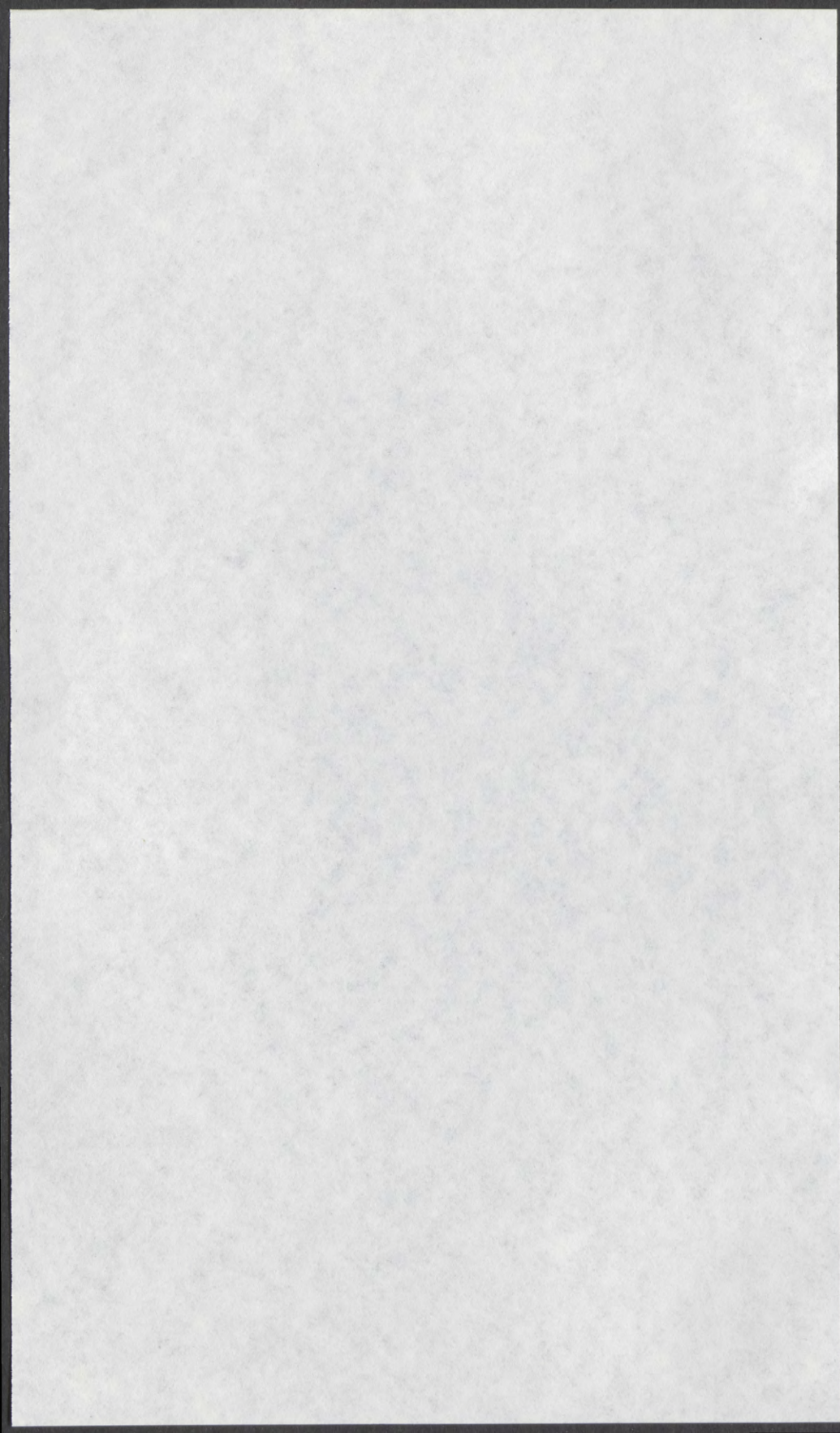

John C. Brizendine

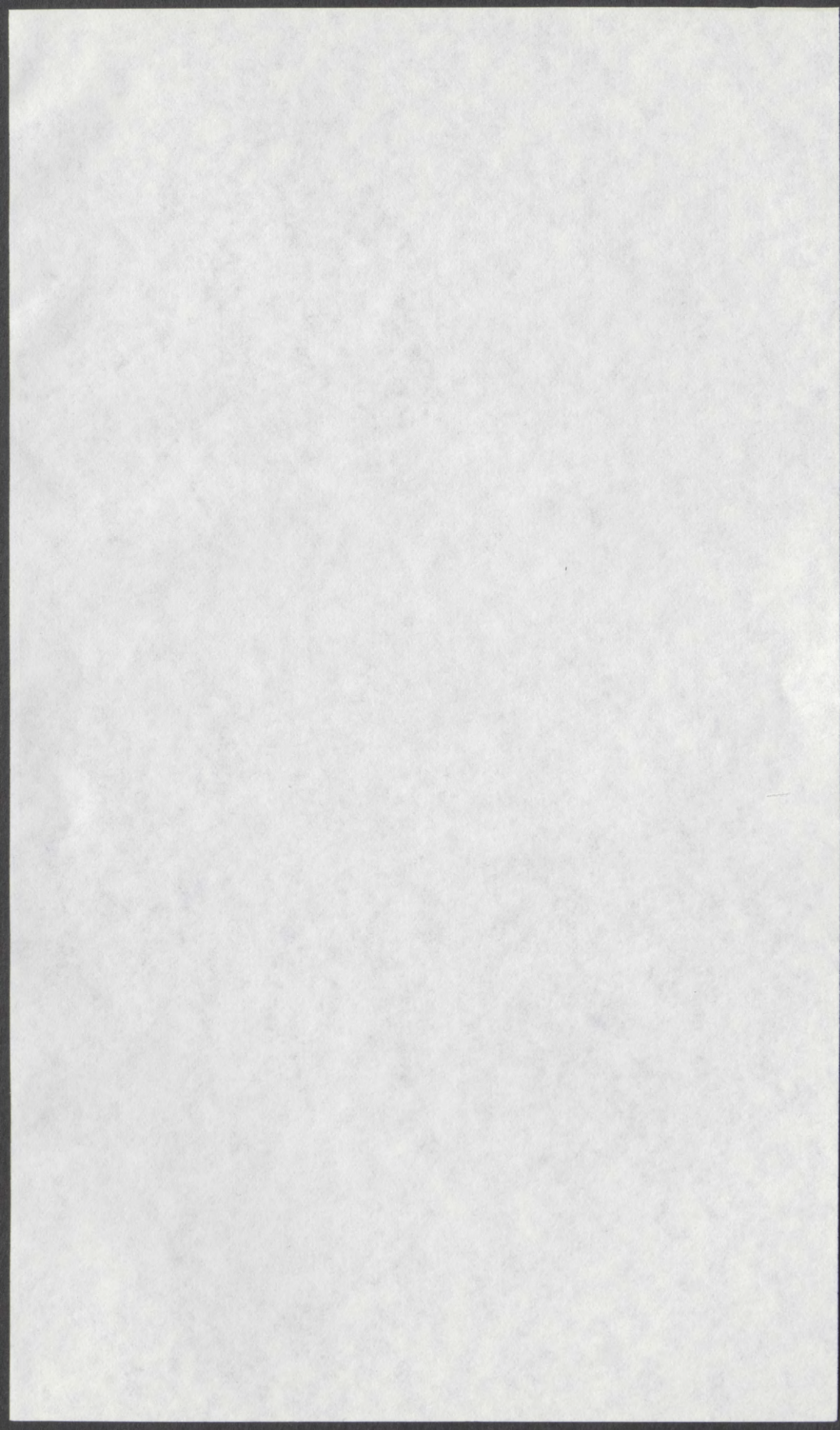
PRESIDENT — DOUGLAS AIRCRAFT COMPANY

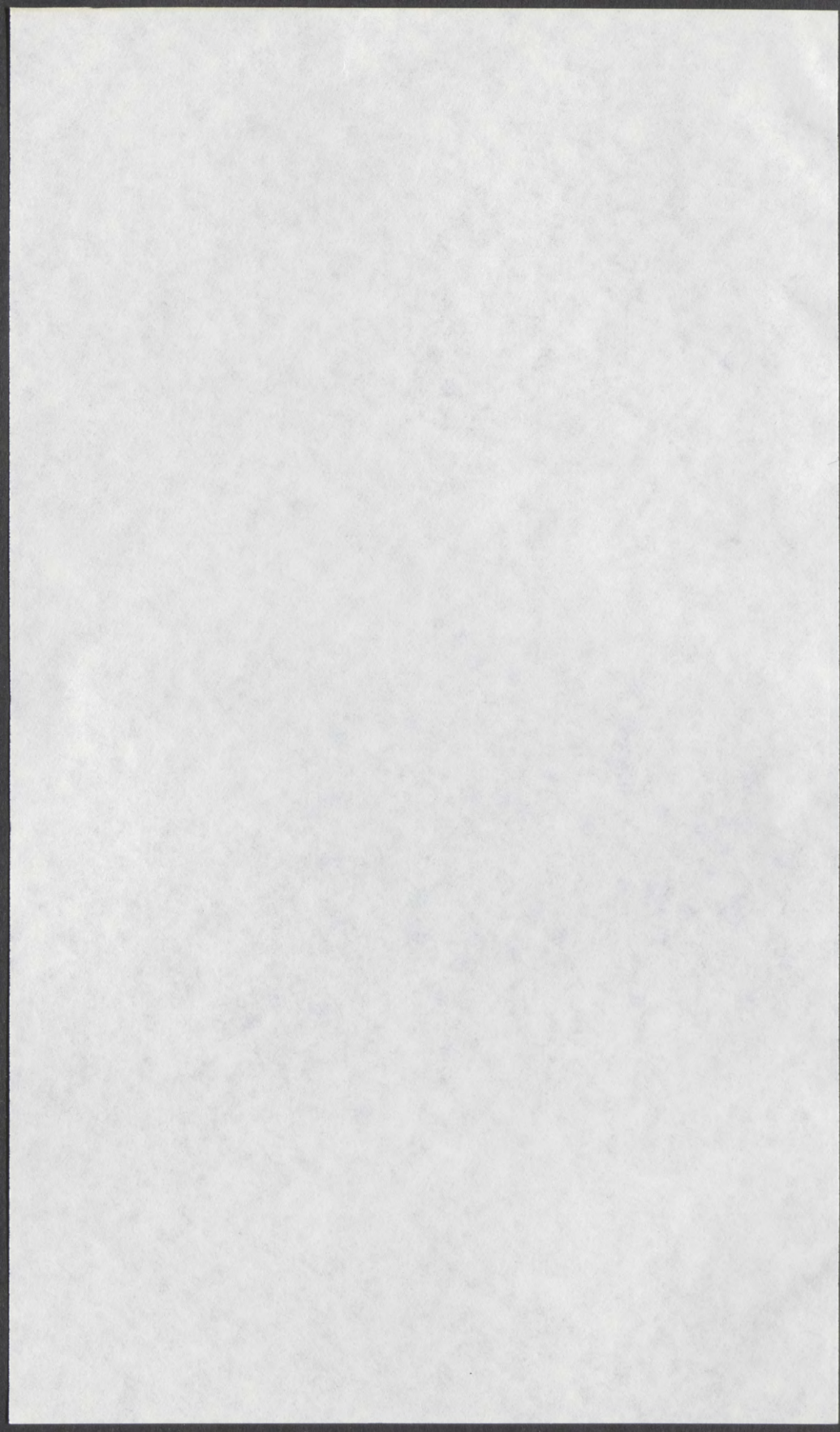
9 AST 6675A

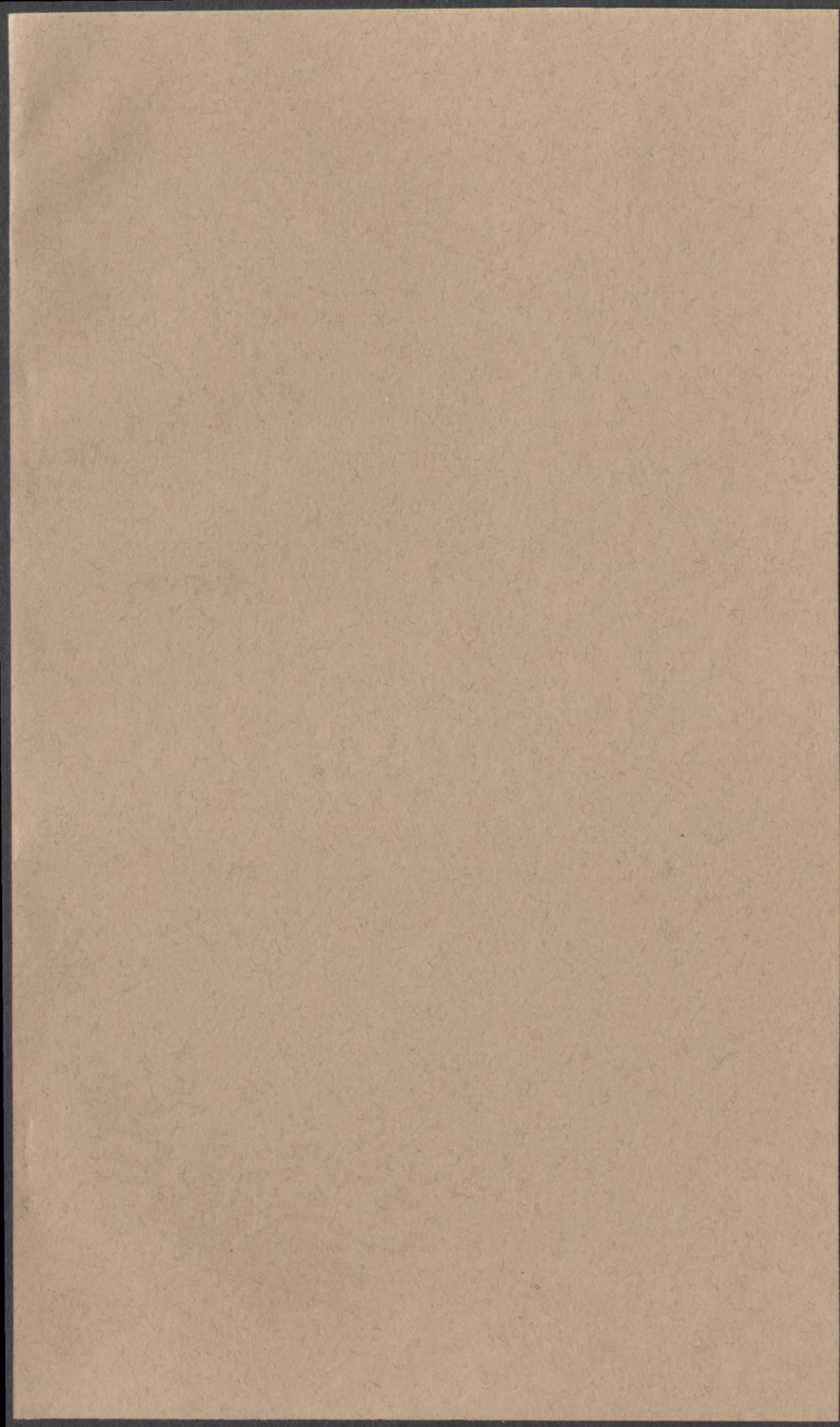
FIGURE 13.













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