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# 1978 NASA AUTHORIZATION

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**HEARINGS**  
**BEFORE THE**  
**SUBCOMMITTEE ON**  
**AVIATION AND TRANSPORTATION R. & D.**  
**OF THE**  
**COMMITTEE ON**  
**SCIENCE AND TECHNOLOGY**  
**U.S. HOUSE OF REPRESENTATIVES**  
**NINETY-FOURTH CONGRESS**

SECOND SESSION

ON

**H.R. 2221**

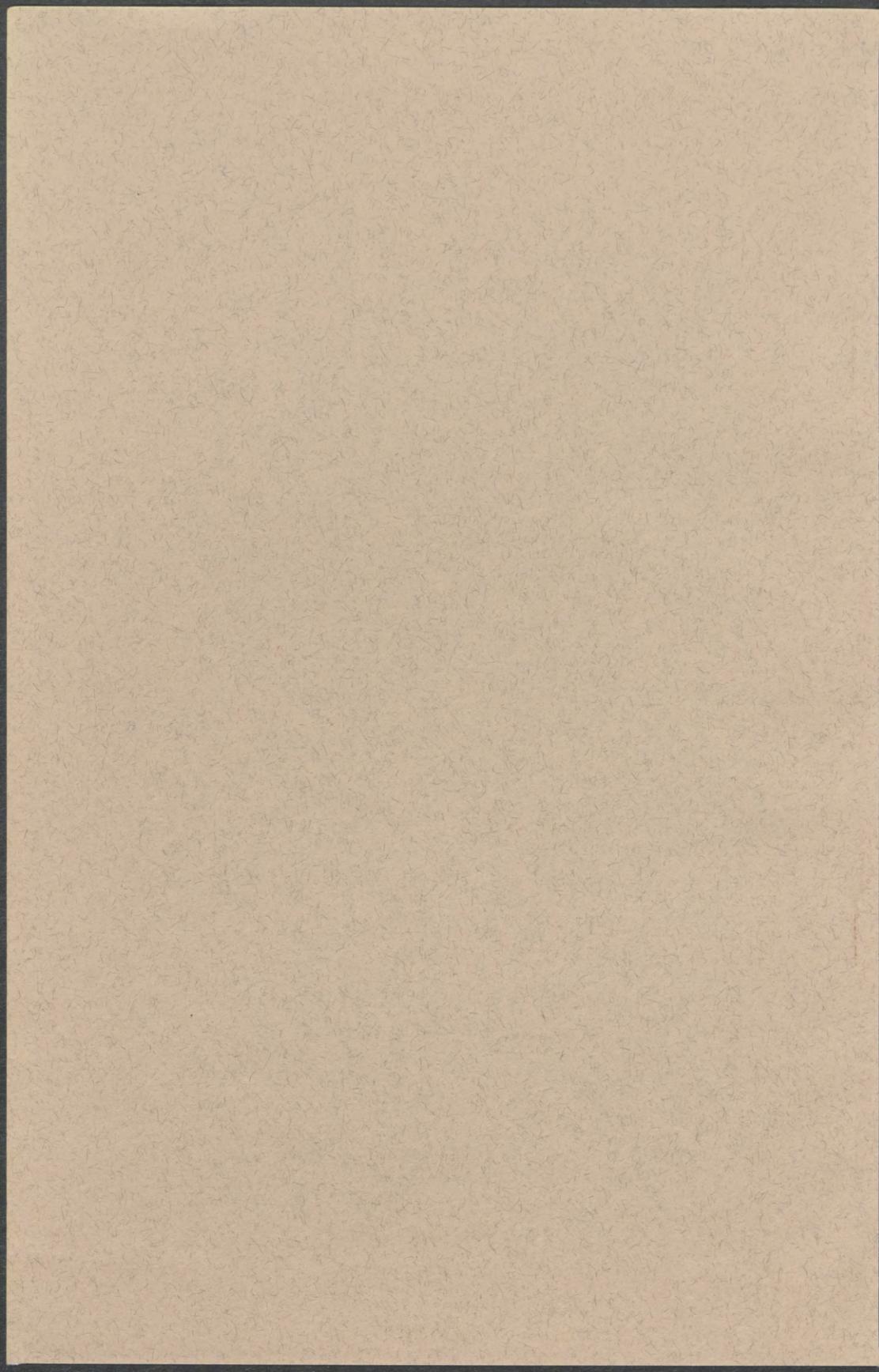
SEPTEMBER 14, 15, 1976

[No. 101]

**VOLUME II**  
**Part 1**

Printed for the use of the  
Committee on Science and Technology





# 1978 NASA AUTHORIZATION

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BEFORE THE  
SUBCOMMITTEE ON  
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U.S. GOVERNMENT PRINTING OFFICE

WASHINGTON : 1976

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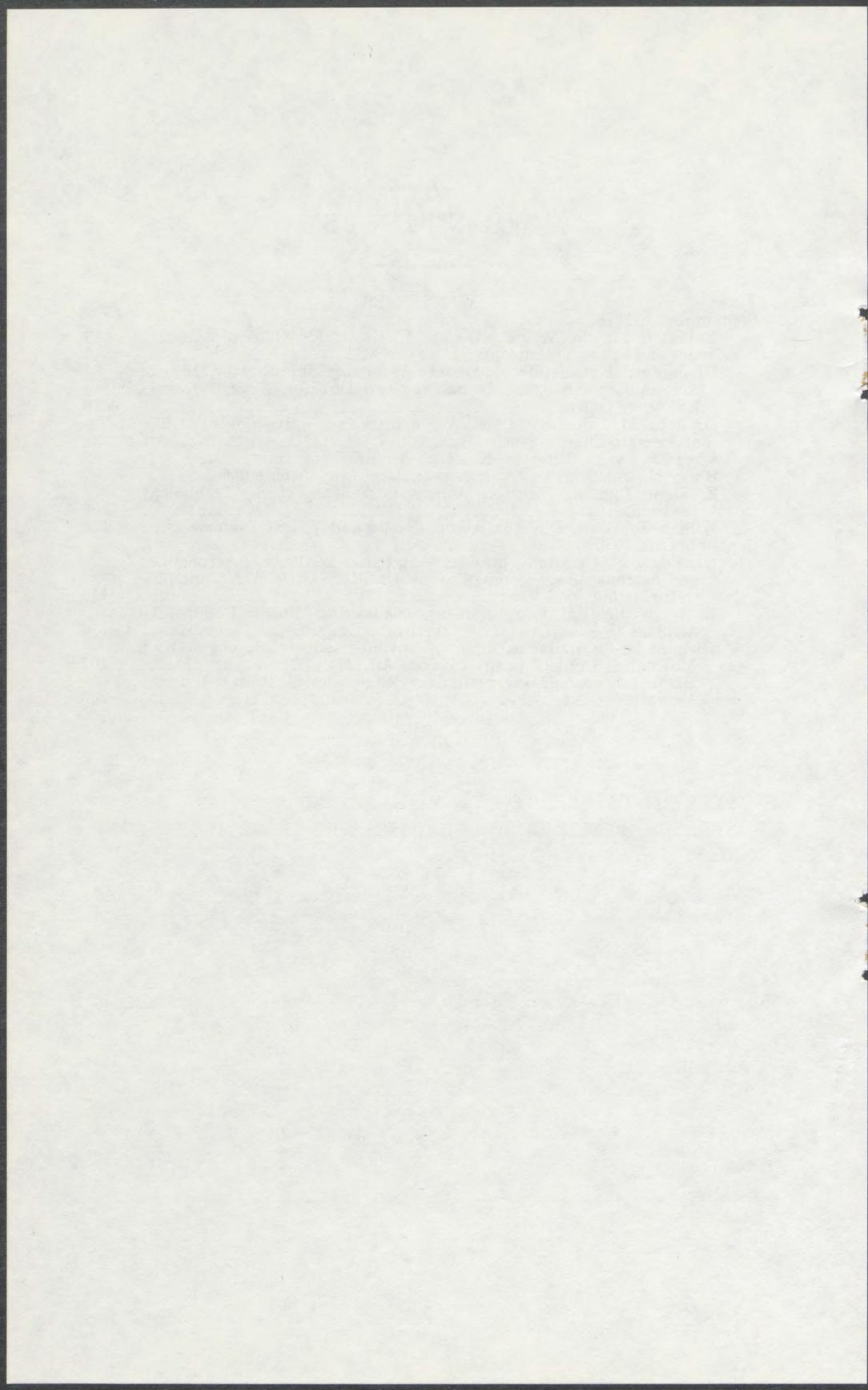
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## 1978 NASA AUTHORIZATION

TUESDAY, SEPTEMBER 14, 1976

U.S. HOUSE OF REPRESENTATIVES,  
COMMITTEE ON SCIENCE AND TECHNOLOGY,  
SUBCOMMITTEE ON AVIATION AND TRANSPORTATION R. & D.,  
*Washington, D.C.*

The subcommittee met, pursuant to notice, at 10 a.m., in room 2325, Rayburn House Office Building, Hon. Dale Milford, chairman, presiding.

Mr. MILFORD. The subcommittee will come to order.

Today, the Subcommittee on Aviation and Transportation R. & D. will begin its annual review of the NASA budget request.

This effort traditionally consists of two phases. The first phase, which we are starting today, consists of a thorough review of ongoing activities and future planning. The second phase will focus on the fiscal year 1978 budget request and will culminate, next spring, in the development and passage of legislation to authorize the 1978 NASA aeronautical program.

Today, our first witness is Mr. Robert E. Smylie, Associate Administrator of the Office of Aeronautics and Space Technology.

Mr. Smylie, welcome to the committee. We have your prepared statement which without objection will be accepted in full along with attachments in the record, and you may proceed as you see fit.

### STATEMENT OF ROBERT E. SMYLIE, ACTING ASSOCIATE ADMINISTRATOR, OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY (OAST), NASA

Mr. SMYLIE. Thank you, Mr. Chairman, and members of the subcommittee. My associates and myself are pleased that the subcommittee has chosen to hold aeronautics program review hearings again this year. In our judgment, the approach proved useful last year and enhanced the authorization process.

I would also like to say that I am pleased to represent the Office of Aeronautics and Space Technology as Acting Associate Administrator and I would like to assure you that I am in full accord with the program policies and directions which Dr. Lovelace pursued and worked out with the subcommittee during his tenure as the OAST Associate Administrator. I intend to continue as vigorously as possible our progress along these same avenues, always being responsive to new opportunities and new needs as they arise. Also with me today is Dr. James J. Kramer, who is now the Acting Deputy Associate Administrator of OAST as well as Director of the Aircraft Energy Efficiency Office.

In today's program review, we hope to bring you up to date on the progress we have made since February of this year, so that when we appear before you to discuss our proposed fiscal year 1978 program early next year, we will be able to concentrate on proposed new activities and future thrusts in the aeronautics program.

As was made clear in your excellent May hearings on the future of aviation, many issues challenge our national effort in aeronautics, but we see the need for aggressive technology advancement as essential in all solutions to these issues. NASA's mission, as I see it, is to provide the technology base to assure that future U.S. aeronautical developments—both civil and military—will be technologically second to none.

To accomplish our mission we must identify, and respond to, the technology needs of projected civil and military aviation undertakings, and we must conduct laboratory and flight demonstrations of technology focused toward known applications. As an independent research agency, however, we must also lead, explore, and create options for advances well beyond the planning horizon of potential user organizations. Our effort must therefore include a broad solid base of research in all of the relevant technical disciplines, as well as the experimental programs required to investigate or verify specific future technology opportunities. However, as circumstances change for the users of technology, so must NASA's role and extent of activity. Civil and military aeronautical systems have grown more and more sophisticated and complex. Competition calls for continued advances but, as aviation matures, such improvements become increasingly more costly to develop and acquire. The cost and the risk associated with generating and introducing new technology have in many instances grown too great to be borne by the industry as part of the traditional development process.

Unless the users are willing to, and can afford to incorporate significant technology advances in the design of new U.S. civil and military aeronautical systems, the superiority of our products will be dissipated, to the Nation's detriment. What this means to NASA is that we must now go further into technology demonstration, making more use of ground facilities, flight research aircraft and inservice demonstrations on operational aircraft, providing assurance that the technology can be utilized on an acceptable risk basis.

To support this activity we must maintain, and utilize effectively, the most modern facilities including wind tunnels, flight simulators, computers, and research vehicles. And we must continue to attract and develop the high quality scientists and engineers required to produce a superior national effort.

In terms of that last statement, at the urging of the committee some several years ago, we established a career development program that brings promising engineers and scientists at the centers into NASA Headquarters for a year's service. After that time they return to the centers with a broader and better understanding of the overall operations of NASA and the Government and are able to do their jobs better in the centers. This year's participants are with us here this morning and I would like to have them stand. I won't introduce them individually, but these are the members of the career development program serving in OAST this year. There is a total of 25 people in this program, some of whom are assigned to OAST and others to other NASA program offices.

Mr. MILFORD. For the record, Mr. Smylie, could you identify the gentlemen standing?

Mr. SMYLIE. I will have the gentlemen introduce themselves. They just arrived this week. The first one on the left—

Mr. DELOACH. Richard DeLoach from Langley Research Center.

Mr. ZUK. John Zuk from Lewis Research Center.

Mr. PAULK. Clyde Paulk from Ames Research Center.

Mr. MILFORD. Thank you very much.

Mr. SMYLIE. Returning now to my testimony.

Consistent with this policy and with the help and encouragement of this subcommittee, we defined and set in motion last year a major program in aircraft energy efficiency. It is off to a good start. Our efforts in this activity are now being directed toward planning and implementing the second phase of the program, and maintaining the necessary momentum. In addition to making certain the ACEE program stays on course, we have devoted considerable attention to examining other aeronautical areas in which other needs and opportunities exist. Our objective has been to define an aeronautics technology program which includes appropriate efforts in all aeronautical areas.

Specifically, we have identified technology needs in these others areas and are working to develop program plans for meeting the needs. In many of these areas there is active interest on the part of the military. We work closely with all the services to insure that the NASA capability is effectively utilized to assist them.

## **NASA AERONAUTICS PROGRAM REVIEW**

- **RESEARCH PROGRESS**
- **AIRCRAFT ENERGY EFFICIENCY**
- **NASA/MILITARY COOPERATIVE PROGRAMS**
- **AIRCRAFT NOISE AND EXHAUST EMISSION  
REDUCTION RESEARCH**
- **AVIATION SAFETY RESEARCH AND TECHNOLOGY**

## **SUPERSONIC TECHNOLOGY**

In order that the subcommittee may understand where we are and where we hope to go in aeronautics research and technology, we have selected several highlight areas in which to review our progress, status, and problems. The topics to be covered are listed in chart R76-4218(1) and include research progress, aircraft energy efficiency programs, NASA/military cooperative programs, aircraft noise and exhaust emission reduction research and aviation safety research and technology. In addition, at the specific request of the committee in a letter to Dr. Fletcher, we will provide special testimony on the status of supersonic technology.

In each of these areas we will discuss the state of the art, the opportunities that exist and the progress we have made in each of these areas.

Since the purpose of these hearings is to review progress in preparation for next year's authorization hearings, I thought it would be particularly meaningful to have the OAST individuals most concerned with the work present the progress in their areas to you themselves. Thus, you will see some people here today who are first timers as well as others who have been here several times before.

Dr. Kramer is not a first timer. He has been here before. I would like to have him cover with you the work that we have categorized under research progress.

We would be pleased to entertain questions at any point along the way or continue on as you see fit, Mr. Chairman.

Mr. MILFORD. If you are not under a pressing schedule, I suggest we go ahead and hear the testimony and then get to the questions, unless a question arises as we go.

[The prepared statement of Mr. Smylie follows:]

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PRESENTED BY WITNESS

SEP 14 1976

NASA AERONAUTICS PROGRAM REVIEW

Statement of

Robert E. Smylie  
Acting Associate Administrator

Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

We are pleased that the Subcommittee has chosen to hold Aeronautics Program Review Hearings again this year. In our judgment, the approach proved useful last year and enhanced the authorization process.

I am also pleased to represent the Office of Aeronautics and Space Technology as Acting Associate Administrator. The nomination and prompt confirmation of Dr. Alan M. Lovelace as NASA Deputy Administrator has been enthusiastically received by all of us in OAST, and we look forward to his continuing leadership in his new role. I can assure you that, having served as Dr. Lovelace's deputy, I am in full accord with the program policies and directions which he has pursued and worked out with the Subcommittee. In my current capacity, I intend to continue as vigorously as possible our progress along these same avenues. Also with me today is Dr. James J. Kramer, who is now Acting Deputy Associate Administrator of OAST as well as Director of the Aircraft Energy Efficiency Office.

In today's NASA Aeronautics R&T Program review, we hope to present a clear view of the progress we have made since February of this year, so that when we appear before you to discuss our proposed FY 1978 program early next year, we will be able to concentrate on proposed new activities and future thrusts. Because of time limitations here today, we will not be able to talk

about all of our program. Instead, we will discuss the highlights which are important for you to be aware of in preparation for next year's Authorization Hearings.

As was made clear in your excellent May Hearings on the Future of Aviation, many weighty issues challenge our national effort in aeronautics, but we see the need for aggressive technology advancement as essential in all solutions. NASA's mission, as I see it, is to provide the technology base to assure that future U.S. aeronautical developments -- both civil and military -- will be technologically second to none.

To accomplish our mission we must identify, and respond to, the technology needs of projected civil or military aviation undertakings, and we must conduct laboratory and flight demonstrations of technology focused toward known applications. As an independent research agency, however, we must also lead, explore, and create options for advances well beyond the planning horizon of potential user organizations. Our effort must therefore include a broad solid base of research in all of the relevant technical disciplines, as well as the experimental programs required to investigate or verify specific future technology opportunities. However, as circumstances change for the users of technology, so must NASA's role and extent of activity. Civil and military aeronautical systems have grown more and more sophisticated and complex. Competition calls for continued advances but, as aviation matures, such improvements become increasingly more costly to develop, acquire and operate. The cost and the risk associated with generating and introducing new technology have in many instances grown too great to be borne by the industry as part of the traditional development process. Unless the users are willing to, and can afford to, incorporate significant technology advances in the design of new U.S. civil and military aeronautical systems, the superiority of our products will be dissipated, to the nation's detriment. What this means to NASA is that we must now go further into technology demonstration, making more use of ground facilities, flight research aircraft and in-service demonstrations on operational aircraft, providing assurance that the technology can be utilized on an acceptable basis.

To support this activity we must maintain, and utilize effectively, the most modern facilities including wind tunnels, flight simulators, computers, and research

vehicles. And we must continue to attract and develop the high-quality scientists and engineers required to produce a superior national effort.

Consistent with this policy and with the help and encouragement of this Subcommittee, we defined and set in motion last year a major program in Aircraft Energy Efficiency (ACEE). It is off to a good start. Our efforts in this activity are now being directed toward planning and implementing the second phase of the program, and maintaining the necessary momentum. In addition to making certain the ACEE program stays on course, we have devoted considerable attention to examining other aeronautical areas in which similar needs and opportunities exist. Our objective has been to define an aeronautics technology program which includes appropriate efforts in all aeronautical areas.

Specifically, we have identified technology needs in these other areas and are working to develop program plans for meeting the needs. In many of these areas there is active interest on the part of the military. We work closely with all the services to ensure that the NASA capability is effectively utilized to assist them.

In order that the Subcommittee may understand where we are and where we hope to go in Aeronautics R&T, we have selected several highlight areas in which to review our progress, status, and problems. The topics to be covered are listed in the figure and include Research Progress, Aircraft Energy Efficiency, NASA/Military Cooperative Programs, Aircraft Noise and Exhaust Emission Reduction Research and Aviation Safety Research and Technology. Additionally, in response to the Subcommittee's invitation, we will be discussing Supersonic Technology in separate testimony, describing the state of the art and what opportunities exist in this important area.

## **NASA AERONAUTICS PROGRAM REVIEW**

- **RESEARCH PROGRESS**
- **AIRCRAFT ENERGY EFFICIENCY**
- **NASA/MILITARY COOPERATIVE PROGRAMS**
- **AIRCRAFT NOISE AND EXHAUST EMISSION  
REDUCTION RESEARCH**
- **AVIATION SAFETY RESEARCH AND TECHNOLOGY**

## **SUPERSONIC TECHNOLOGY**

Mr. SMYLIE. OK, fine. Dr. Kramer?

Mr. MILFORD. Dr. Kramer, we have your complete statement which will be accepted for the record along with all attachments and you may then proceed with your presentation as you see fit.

**STATEMENT OF DR. JAMES J. KRAMER, ACTING DEPUTY ASSOCIATE ADMINISTRATOR, OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY AND DIRECTOR, AIRCRAFT ENERGY EFFICIENCY OFFICE, NASA**

Dr. KRAMER. Thank you, Mr. Chairman.

I will excerpt my written testimony and present some highlights to you.

As Mr. Smylie pointed out, what I am going to cover for you is a broad area of research which includes most of our R. & D. base work. In addition I am going to talk briefly about a couple of our systems technology programs that you are already familiar with.

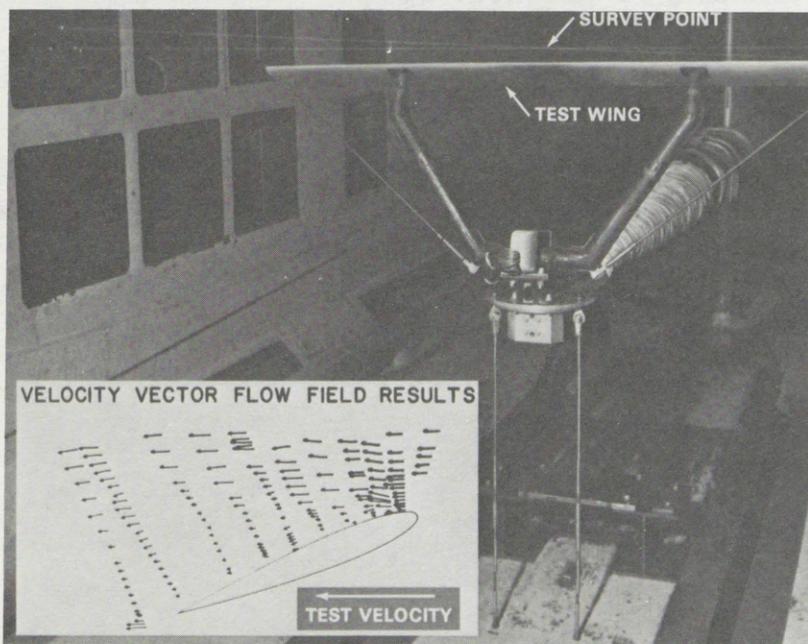


FIGURE 1

I would like to have figure 1, please.

The discipline areas that I am going to talk about are those of aerodynamics, materials and structures, aeronautical propulsion and avionics. The two other programs are those of general aviation technology and the quiet short-haul research aircraft.

In the first of these areas— aerodynamics—when we spoke to you last November, we pointed out that one of the major thrusts in our aerodynamics program was our work on airfoils. Since that time, we have expanded the family of supercritical airfoils and we have

completed the design of five new airfoils. We have the design of five other airfoils underway. Since we last spoke to you, we have tested five airfoils specifically designed for the blades of rotorcraft which we have not been active in previously.

We have also established an institute at Ohio State University to assist the general aviation community in their specific design problems associated with the design of airfoils for general aviation type aircraft.

We also pointed out to you last year that one of the big problems we have is in adequately modeling the separated flow region on airfoils. It is very clear to us that any kind of approach to this problem must be a combination of computational work as well as experimental work.

Shown in this picture is a particularly interesting experimental technique which has been developed over the last several years. You can see the airfoil mounted in a wind tunnel section and the two beams of light intersecting at a point. Those are two laser beams. The point at which they intersect is very precisely defined point in the flow field, and by proper interpretation of the signals from the scattered light of the laser beams, we are able to infer that the velocity of the air at that particular point in the flow field without introducing a mechanical device like a probe. It is a very powerful technique for getting us very detailed information about the complex flow field about an airfoil at a reasonably high angle of attack without interfering with the flow process at all. The kind of information we get out is shown in the inset in the lower left. Each arrow in the inset represents a data point in the flow field. It is pointed in the direction of the flow velocity vector and its length is proportional to the speed of the flow. This technique provides quite a detailed picture of the flow.

### PREDICTION OF LIFT COEFFICIENT VARIATION WITH ANGLE OF ATTACK FOR GA(W)-1 AIRFOIL

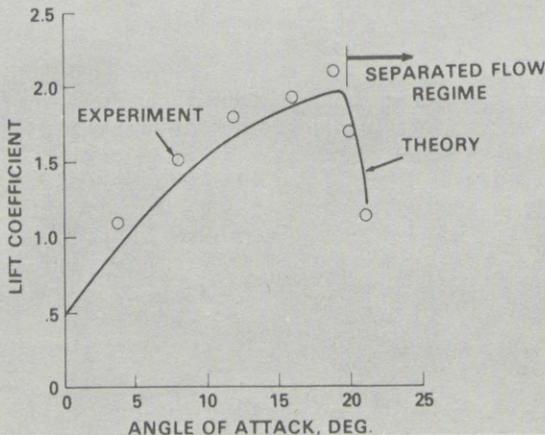


FIGURE 2

Figure 2. The reason we are interested in the detail of the flow of course is to predict the total performance of the airfoil as indicated by its lift coefficient as a function of angle of attack, and we do quite well in predicting our experimental results through theory until the point of separated flow. Beyond that point the flow process is very complex, and it is very difficult to model. However, we do have some promising techniques to predict the flow in the separated flow region but I am sure we will be working at this for some time to come—devising a really thorough computational model of the separated flow process.

I would now like to talk very briefly about the area of materials and structures. We have had interesting accomplishments in the fields of engine materials, improved high temperature polymers, structural dynamics and later on we will give you a report on the composite primary structures part of our aircraft energy efficiency program. I would like to tell you a little bit about some of the more fundamental work in composites that is carried out as part of our R. & T. base work in materials and structures.

### DAMAGE - TOLERANT COMPOSITES

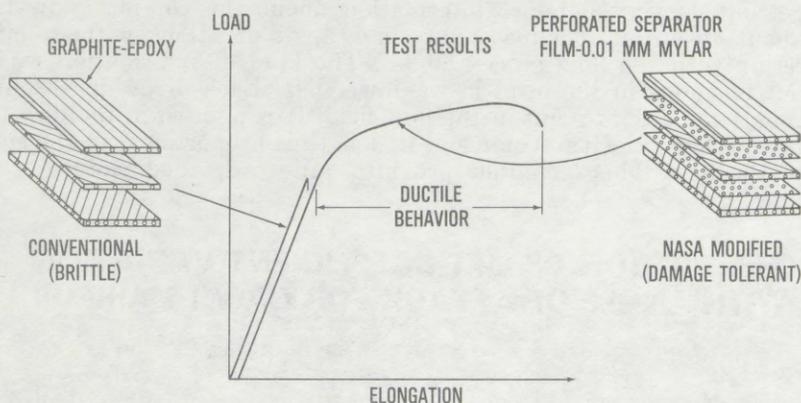


FIGURE 3

One of the problems associated with a composite structure is that it is particularly subject to failure after it has been damaged. We recently had a very interesting development which provides for improved performance of the composite material even after damage into a region which resembles that of a ductile behavior of metal. This is accomplished by inserting a perforated, very thin 0.4 mil mylar sheet between the plies of the composite structure. This mylar sheet has the capability for diffusing the local stress concentration and delaying the failure of the material at this point thus giving us behavior typical of a ductile material.

This has rather an important implication especially for a major program in composite structures.

Another area of great interest in composites is the use of composite materials in aircraft turbine and fan blades. Shown in figure 4 is a compressor blade from a J79 engine which has given us a lot of encouragement. In whirling arm tests with a 3-ounce bird, the blade on

the right has shown a greatly improved resistance to foreign object damage. That is the crucial problem of using composite structures in blades. I don't mean to give you the impression that this blade has been qualified. It has not been, but it is very promising and its superior performance results from the use of a larger diameter composite fiber; in this case, a boron filament in a more ductile aluminum matrix.

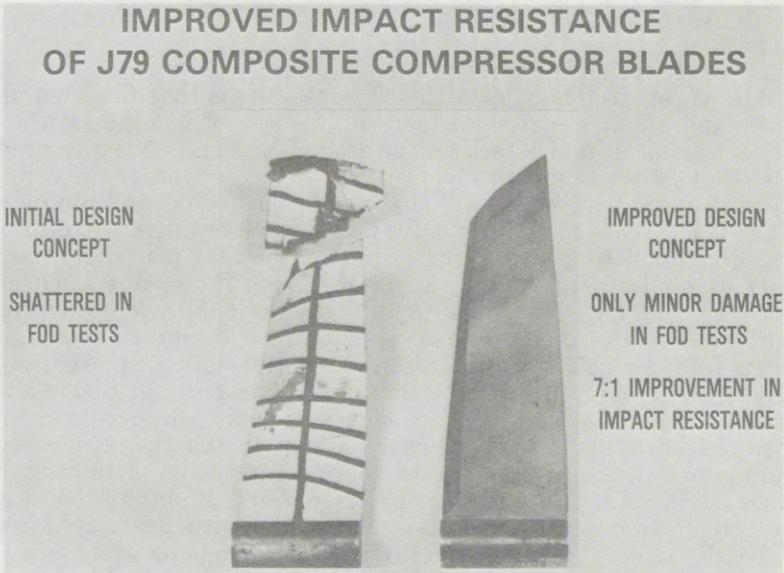


FIGURE 4

In aeronautical propulsion, we have given a lot of attention over the past couple of years to the question of alternate fuels, that is petroleum like fuels, but derived from shale or coal sources. In general, it appears that the fuels do not have a significant impact on the operation of the engine. However, when we look at alternate fuels from the total systems standpoint, it appears that these fuels from other sources may require a substantial investment in energy in the refining process if we are to stick with the same specifications for the boiling point and freezing point of aircraft jet fuels. It does appear that there are major energy savings possible with the relaxation of the specifications that we have now. We are looking at the relaxation of jet fuel specifications from the total systems standpoint with the idea to having an optimum energy efficient system including the refining process.

Mr. WYDLER. I do not quite understand that point. You say it does not make any difference what kind of fuel you use? What does that mean?

Dr. KRAMER. Well, it means that the engines operate quite satisfactorily from an internal aerodynamics standpoint and from an environmental standpoint, emissions standpoint, with the fuels that are derived from shale or coal, just as they would if they were derived from Oklahoma crude. The point is that one can process the fuels sufficiently such that it is within the specifications of aircraft jet fuels.

Mr. WYDLER. Fuel that is derived from coal?

Dr. KRAMER. Yes, sir.

Mr. WYDLER. You used that and it was satisfactory?

Dr. KRAMER. Yes, indeed.

Now the point though is that in the refining process, the energy efficiency part of it, as we go to lower quality crudes we find we have to invest more energy in the refining process in order to get within that same specification.

Mr. WYDLER. That would be commonsense. You would expect that to happen.

Dr. KRAMER. That is right.

Mr. WYDLER. The reason that interests me is that this committee is talking about a synthetic fuel bill, a piece of legislation which is under a great deal of attack on the grounds that it is going to produce fuel that is not economically justified. In other words, you will end up with a product, but it will cost more than the natural product. So what is the sense of it? The only thing I have been trying to impress on the administration and the Congress, for that matter, is the fact that we could justify doing this even though it was not as cheap as pumping out oil, if we were to tie it to national defense or even a national resource of some kind. Now you are giving us the angle of doing it for aircraft and other means of transportation. In other words, you have to justify it economically, it seems to me, and I have always tried to maintain that we should try to apply the development of synthetic fuel to national defense posture so that we could have a guaranteed source in case other sources get cut off. I haven't been successful in doing that in the legislation, but I am interested in what you are doing because it indicates you could use it for military aircraft.

Dr. KRAMER. That is correct, and actually our program is a joint program with the Aero-Propulsion Lab at Wright Field. They are our source of specimen fuels and they have participated in the program with us.

Mr. WYDLER. Thank you.

Dr. KRAMER. One other item in propulsion I would like to discuss is the unusual looking propeller mounted in a United Technology Corp. wind tunnel shown in figure 5. It is an eight-bladed propeller. The blades are swept back and they are very carefully designed very much like compressor blades or fan blades are. The reason for our interest in this propeller is again from the energy efficiency standpoint. One can show rather quickly by calculations that if you want an environmentally acceptable propeller which provides the proper level of service for an airline a turboprop could be a very energy efficient device.

Some of the test data from that test setup that I spoke of previously is shown in the next figure.

Mr. MILFORD. I can't help but notice that the propeller has startling similarities to some in World War I. [Laughter.]

Dr. KRAMER. You are quite right.

Mr. WYDLER. To me it looks like it hit the ground. It has got a bend in it a little bit. [Laughter.]

Dr. KRAMER. Power loading is the measure of the pressurization that the propeller does on the air and you want high-power loading to get a reasonable size propeller and to get a reasonable amount of

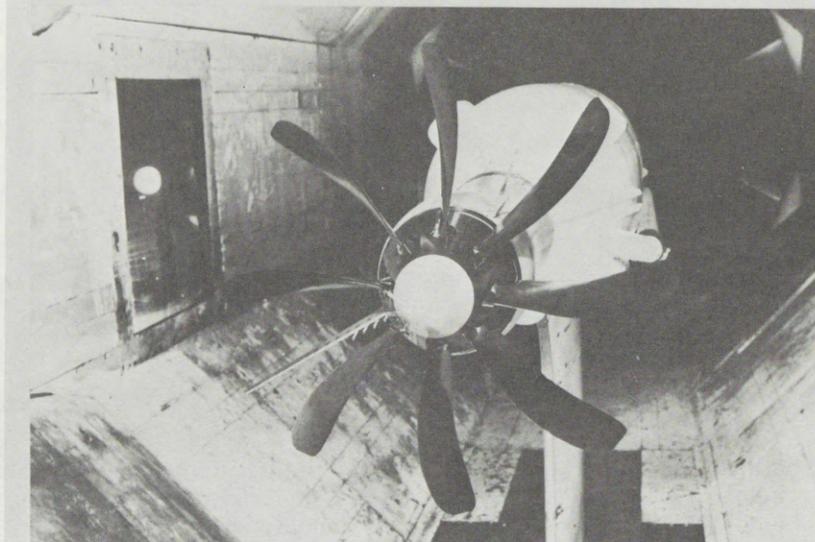
**ADVANCED SWEEP-TIP PROPELLER**

FIGURE 5

thrust. We are looking for a design point as shown in figure 6. You can see that we have the right trend in the data, but we are short on efficiency. However, we think we know why we are short and we are going into the tunnel again with modifications.

**ADVANCED TURBOPROP  
UNINSTALLED EFFICIENCY**

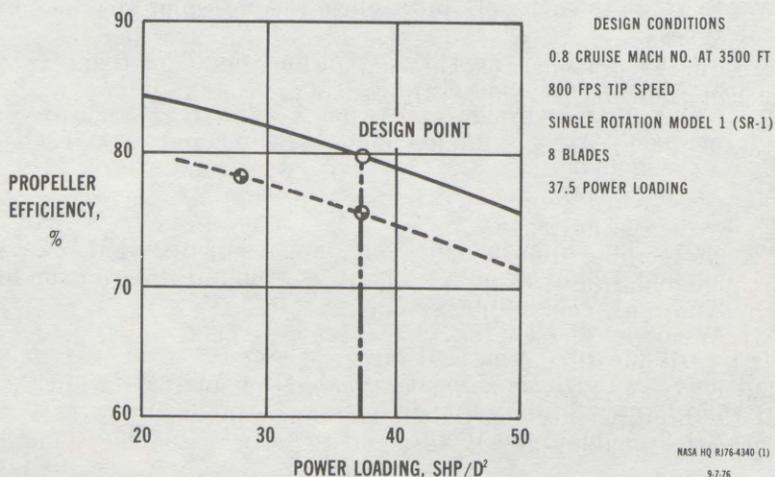


FIGURE 6

## ELECTRONIC VS. MECHANICAL CONTROL SYSTEMS

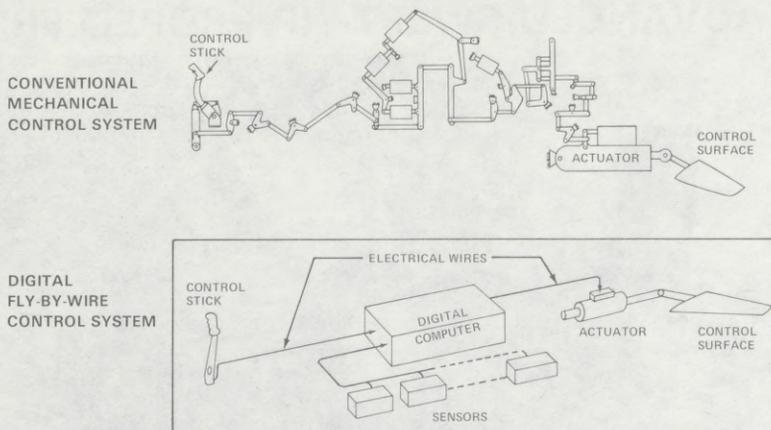


FIGURE 7

The last thing I want to talk about in the discipline area is that of avionics. We have been working with a digital fly-by-wire system for sometime now and it is illustrated schematically (figure 7) where you see the linkage between the control stick and the control surface as sensors and a digital computer leading to an actuator command and control surface function. That of course is contrasted with this complex mechanical system illustrated schematically above, and the possibility for making changes as one learns about the aircraft here are very obvious as you reprogram the computer rather than reengineering mechanical linkages. Of course, there are other advantages also.

Mr. MILFORD. For the record, how does this system differ from the one that is already flying in the F16?

Mr. SMYLLIE. The F16 is an analog system rather than digital and as such is not nearly as flexible in terms of reprogramming or optimization for given flight regimes as the digital system is and will be.

Mr. MILFORD. Is your work in this field theoretical or are you going to prototypes?

Dr. KRAMER. Well, the next figure will tell you about that.

Mr. MILFORD. Excuse me. Go ahead.

Mr. LLOYD. Mr. Chairman, excuse me. I want to go back to your prop for a second. Are you talking about mach 0.8 and 3,500 feet?

Dr. KRAMER. 35,000.

Mr. LLOYD. 35,000?

Dr. KRAMER. Yes.

Mr. LLOYD. Oh, I am sorry. I was going to say—what are you doing at 3,500? What would you say is your altitude maximum?

Dr. KRAMER. On the prop?

Mr. LLOYD. Yes, 40,000?

Dr. KRAMER. Probably in that range. 35,000. 0.8 mach and 35,000 feet altitude is a tough assignment with the prop and we are not there with the experimental data that we have on hand.

Mr. LLOYD. You are not there?

Dr. KRAMER. We are not there. That is the objective.

Mr. LLOYD. Where are you at the present time?

Dr. KRAMER. We are about  $3\frac{1}{2}$  efficiency points short with our first model. That would seriously degrade the energy efficiency aspect at mach 0.8 and 35,000 feet. If you were to back off with that prop that has been tested to say in a mach range on the order of 0.6 to 0.7, then you would be able to show an efficient propulsion system superior to that which is possible with a turbofan system.

Mr. LLOYD. Of today?

Dr. KRAMER. Of today; yes.

Mr. LLOYD. In other words, you really are approaching current 707 standards?

Dr. KRAMER. That is correct.

Mr. LLOYD. In altitude efficiency, speed efficiency, and so forth.

Dr. KRAMER. Right.

Mr. LLOYD. This will be what type of jump over the current, say  $1\frac{1}{2}$  bypass engines that you have now?

Dr. KRAMER. Well, relative to those it would be an efficiency improvement on the order of 40 percent or perhaps even more. Relative to the high bypass ratio engines which are used on wide body aircraft, it would be somewhere in the range of 15 to 20 percent. We just simply do not know enough about the total system to give you a more precise number on that.

Mr. LLOYD. Do you have an interest on the part of the airlines to go back to turboprops?

Dr. KRAMER. It is a fairly mixed response from the airlines. Some of the airlines are very concerned about—

Mr. LLOYD. Give me their response. I am interested in it.

Dr. KRAMER. Pardon me.

Mr. LLOYD. What I am trying to do is to replace the 707 type aircraft. But there is a trust in the attitudes of people currently in Congress and in the trades about the possibility of retrofitting the engines. Well that to me, is so inefficient and so wasteful and so lacking in vision and foresight in the aeronautical area. Yet we know that within the next few weeks for instance there will be amendments to bills being introduced by Members of this Congress with the idea that they are going to reduce problems of noise and yet all they will be doing is perpetuating aircraft at the state of the art 20 years ago with their inefficiencies. So what I am really saying is does this pose a response to that kind of thing?

Dr. KRAMER. It is a question of timing. It will if it is successfully developed. Then we see the possibility of having a very efficient turboprop kind of engine technology available for application sometime in the mid-1930's. You could not go out today and place an order for an efficient turboprop propulsion system. The technology simply is not in the bank, the engine companies are not ready to move out on an item like that. We are talking about the very near term for engines such as 20,000 to 30,000 pound thrust class engines, CFM56 or JT10D would all be something in the order of 5 years. The turbo-prop system could be, so that if it were a near term decision it would surely—

Mr. LLOYD. The higher bypass engine of course brought greater efficiencies. We can anticipate in the use of composites some potentially major changes that would increase the efficiency of the engine by 20 or 30 percent. I mean it is a possibility.

Dr. KRAMER. Yes. Those same benefits would accrue to the turbo-prop system also, since they use the same basic core of technology, and the advantages in what we call low spool technology. If our technology extrapolations are correct, the turboprop will always show an advantage over the turbofan system.

Mr. LLOYD. In other words, you do not see any hesitancy in going forward with this type of development?

Dr. KRAMER. We are quite enthusiastic about it as a technology. Now, some couple of years from now, we may sit down and very soberly assess that technology and see whether we are ready to start putting a complete turboprop experimental engine together to see if this thing really does go together in a reasonable vehicle.

Mr. LLOYD. Thank you. You were with the supercritical wing.

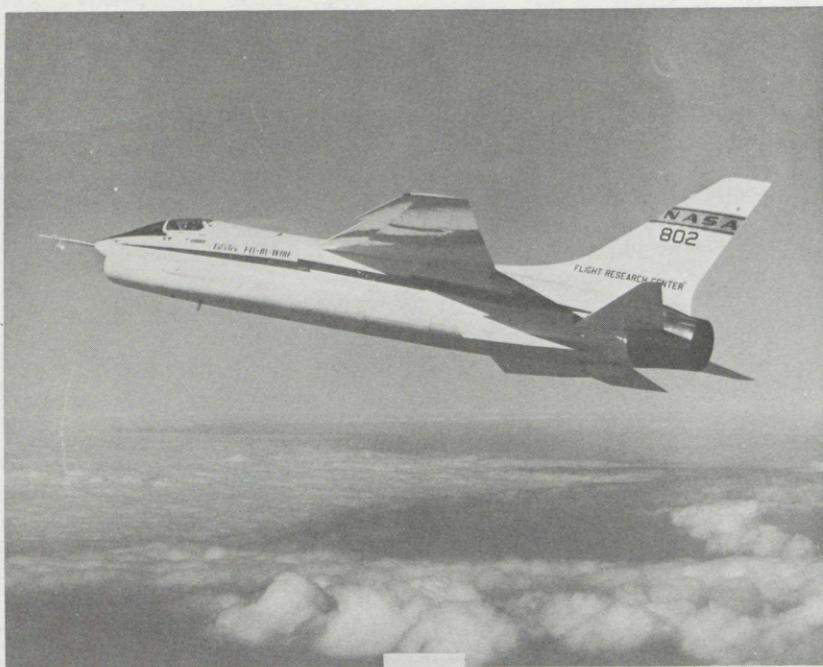


FIGURE 8

Dr. KRAMER. What I picture here (fig. 8), Mr. Chairman, is an F-8 which has been modified and is being flown out of our Dryden Flight Research Center. It first flew August 27 and we are scheduling extensive flight tests with this system over the next 2 years.

It is a system specifically designed to generate research information on digital fly-by-wire systems as a generic entity rather than anything specifically peculiar to the F-8. So in response to your question, we are not developing a prototype, but we are flying the system in a for-real airplane.

The last two items that I want to cover are general aviation technology and the QSRA program.

## ANALYSIS AND TESTING IN NASA CRASH SAFETY PROGRAM

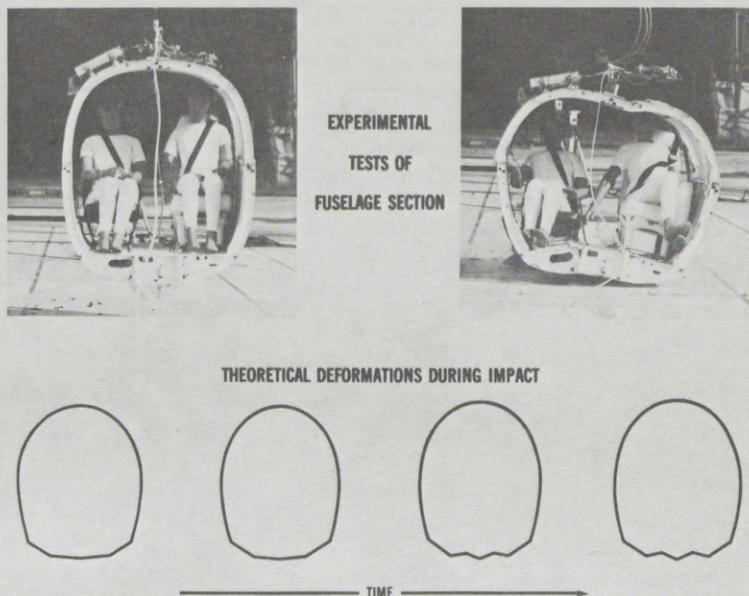


FIGURE 9

In general aviation, one of the areas that we have been looking at has been the crashworthiness of the fuselage and the seat restraint system. We are using the crash facility at Langley that was developed for Apollo program to cause high speed impacts of these fuselages. We have some surplus airplanes that were made available to us which are being used in these crash tests (figure 9). The idea is to make efficient use of the structure which is in the fuselage in any event and try to optimize the crashworthiness such that we have minimum impact on the passenger or the pilot in the event of a crash. We have gone through some 10 crashes at speeds up to 60 miles an hour, and we are looking forward to further activity of this scale and going to higher velocity of crashes.

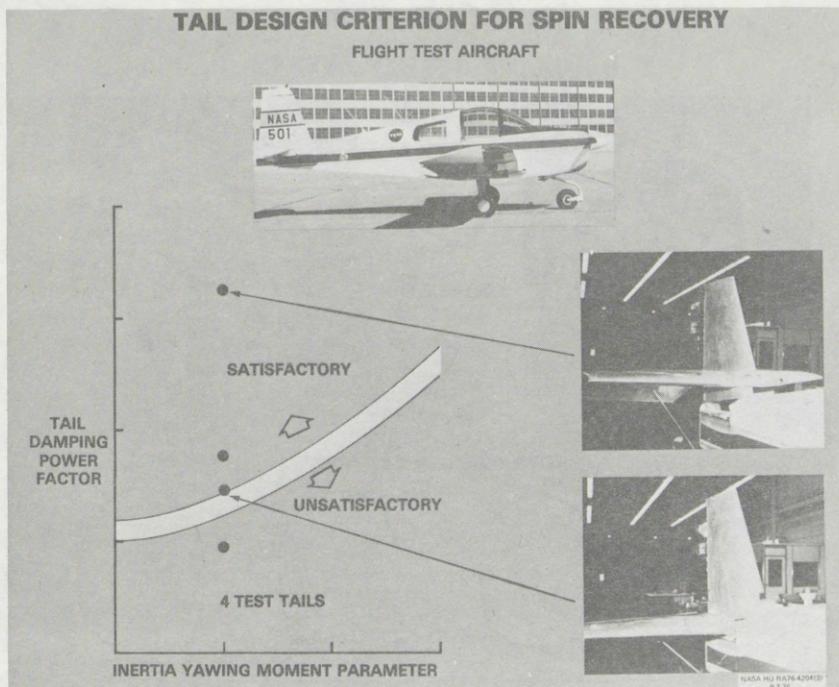


FIGURE 10

Another area in general aviation in which we have been quite interested has to do with work on stall/spin (fig. 10). We designed four tail configurations, shown as the black data points, and we predict that their capability as measured by tail damping power factor in recovery from a stall/spin situation will be in the satisfactory regime as shown or unsatisfactory behavior based on our theoretical predictions of stall/spin recovery behavior. We purposely designed four tails which cover this entire range. These tails have been tested in the spin tunnel on model-sized aircraft, and we are also building the tails to put on this Yankee made by Grumman American. This particular choice was because it is a small airplane and is relatively inexpensive to modify. We will flight-test these four tail configurations which have been tested in the tunnel. We will test them in full scale on that airplane and those tests will start sometime around the end of this year.

Mr. MILFORD. Would you define tail damping power factor?

Dr. KRAMER. Well, I can tell you what it is very generally, but I can't define it specifically.

What it has to do with is the amount of tail surface which is still effective when the airplane is at a high negative nose-down angle of attack. It measures the amount of effective rudder area available for spin recovery, so it is a ratio of areas determined in part by the vertical position of the horizontal stabilizer. In a stalled position the separated flow off the horizontal tail tends to blank the upper part of the vertical fin, leaving you the bottom part of the vertical fin relatively undisturbed and therefore effective. So it is a measure—the total factor then is a ratio of rudder surface area, total horizontal

vertical surface area and the relationship where the horizontal intersects the vertical.

Mr. MILFORD. That being the case, what difference does it make on the location whether it is the lower end of the fuselage or above it?

Dr. KRAMER. Well, if it is low, then when the airplane is at a high angle of attack, the separated flow off the leading edge of the horizontal tail tends to render the upper surface ineffective from a control standpoint, whereas the flow below on this side on the pressure side of the airfoil is not separated and that part of the vertical is effective. Therefore, you want to move the tail up, like this, to get effective vertical tail surface area even when the airplane is at a high angle.

Mr. MILFORD. What you say is the flow is being blocked by the wings?

Dr. KRAMER. It separates off the horizontal.

Mr. LLOYD. You lose rudder control rather than altitude.

Dr. KRAMER. Yes, that is correct.

Mr. LLOYD. Excuse me, Mr. Chairman, I am sorry.

Mr. MILFORD. Go ahead, Dr. Kramer.

Mr. LLOYD. Excuse me. I have a question.

The Navy had a problem with this on the T34C. They were having spin problems, and they put skates or stall fences or pressure holders to hold the air in against the tail. Had you looked at that system?

Dr. KRAMER. I do not think it was looked at for this specific application. The idea here was for a—

Mr. LLOYD. Apparently what it does is that it allows you to lower your red line and keep what advantages you have for structure and other things by holding the air in.

Dr. KRAMER. That is correct. You have to keep the flow stuck to the surface so that it is indeed effective.

Mr. LLOYD. I was just pointing out that their system, with these skates, achieved this. The only reason I am so sure is I have flown the airplane and I have spun it, and it had the problem. I have spun it without it and I have spun it with it, and the recovery techniques are infinitely greater with that type of thing. I had never realized that a skate would provide that kind of aerodynamic damping effect to the air.

Dr. KRAMER. It is basically a flow guidance device.

Mr. LLOYD. Yes.

Dr. KRAMER. I will go on then and wrap up with the QSRA discussion.

Oh, excuse me. One other item in general aviation—we are looking at the technology requirements for efficient aviation—we are looking at the technology requirements for efficient application, aerial application of pesticides, fertilizers for agricultural application (fig. 11). We have been looking at this quite extensively over the past year. We are still in the program definition phase.

The Quiet Short-Haul Research Aircraft (QSRA) was approved by you gentlemen some years ago. As part of our total quiet short-haul program we have been working with the Air Force using the AMST as a test item and you will hear more about that in a subsequent presentation. I would like to concentrate on the QSRA airplane, itself.



FIGURE 11

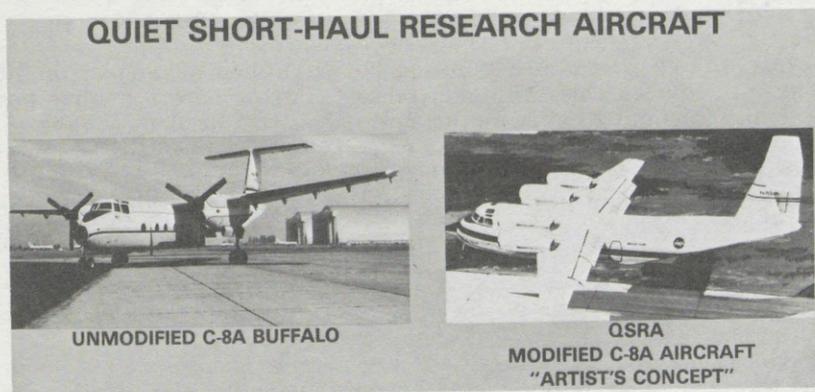


FIGURE 12

Figure 12 shows an artist's concept of the QSRA. Last February 27, we signed a contract with Boeing to modify a C-8A Buffalo airplane. Into this configuration we are using four Lycoming YF-102 engines and the over-the-wing blowing mode to develop the short-haul capability of the QSRA airplane. We expect the rollout on that airplane in May of 1978 and the contracted flight test will be completed in July and it will be turned over then to the Ames Research Center for NASA flight tests beginning in August of 1978.

That is the extent of my remarks.

[The prepared statement of Dr. Kramer follows:]

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RESEARCH PROGRESS

Statement of

James J. Kramer  
Acting Deputy Associate Administrator

Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

Although all of the work to be reported here today will deal with the progress of research in NASA's aeronautical programs over the past year, the remaining sections of the testimony will cover work which tends to be focused toward providing technology advances in a particular problem area. On the other hand, most of the work to be reviewed in this section is part of the Research and Technology Base phase of our program which tends to be discipline oriented in nature. Even though this work provides the technology foundation for the focused programs, its application is typically much broader than the focused technology work you will hear about later. The underlying objective of this fundamental work is to advance the technology base in order to provide a capability for the future and it is from this work that the Systems Technology and Experimental Programs of the future arise. Because this fundamental work is the underpinning of all our future aeronautical advances, it is the most important element of our program.

I will discuss this work by discipline, that is: Aerodynamics, Materials and Structures, Aeronautical Propulsion and Avionics. Because of time limitations, I will only be able to highlight a few accomplishments in each discipline but I am hopeful that this will convey to you a sense of the accomplishments that take place regularly in these very fundamental and fruitful

research areas. After describing this work, I will then describe some significant accomplishments in General Aviation Technology and report the status of the Quiet Short-Haul Research Aircraft Program since these subjects will not be covered separately in the testimony.

### Aerodynamics

In November of last year, we described to you the status of our airfoil research program. You may recall that this work is aimed at generating high performance airfoils for the complete spectrum of fixed- and rotating-wing aircraft. It involves the coupling of modern computational aerodynamic and optimization techniques for the analyses and design of advanced airfoils, with selective wind tunnel testing to validate specific designs. During the past year, the NASA supercritical airfoil family has been augmented by five new designs, and the design of five additional ones has been initiated. For each design, computed airfoil characteristics are made available, covering both design and off-design conditions over the entire speed range of interest. Progress in the low speed airfoil program centered around validation wind tunnel tests of four thick general aviation type airfoils, and the establishment of a low speed airfoil design and development center at Ohio State University to aid the U.S. industry with its specific design problems. Five rotorcraft airfoils were also tested in this period to determine their transonic characteristics, and the design of an entirely new family of rotorcraft sections was initiated. Finally, design work has been initiated on advanced airfoils for turbine-driven propellers designed to cruise at .8 Mach number, and on a 22 percent thick airfoil for large cargo aircraft.

Last year, we noted that a major weakness in our analyses and design capability was an inability to calculate airfoil characteristics at conditions which involve extensive regions of separated flow. This weakness impacts our capability to predict the maximum lift capability of airfoils, as well as their post-stall behavior, characteristics which are important not only for performance, but in stall/spin and other safety-related problems. During the past year, progress has been made in overcoming a specific shortcoming in the area of separated flow calculations, namely the lack of adequately detailed experimental data needed to model and verify the physical aspects of the flow

which must be accounted for in the calculation procedures. A nonintrusive optical technique (shown in use in Figure 1) using lasers, has been developed and applied at Langley and Ames to quickly map out, in a quantitative fashion, the entire velocity field about airfoils tested at separated flow conditions. Lasers are uniquely suited to this task because the point at which two laser beams intersect provides an extremely accurate point of focus in the flow field. As the focal point of the lasers is scanned through the field, accurate measurements of the flow velocity at specific locations are obtained without interfering with the flow and without the need for complex and expensive instrumentation built into the model. In the figure, the laser beams are visible above the wing surface and some of the measured velocities are shown in the inset. Each arrow represents a data point, which defines the direction and magnitude of the flow velocities at that point.

A number of approximate and more exact computational procedures are being worked on, using models of the separated flow field which are evolved from data such as those just discussed. One such procedure shows promise of predicting lift well into the stalled region, as indicated in Figure 2. Work on more sophisticated, less empirical procedures is underway and will ultimately provide better analysis and design capability for separated flow conditions.

#### Materials and Structures

Significant progress has been made during the past year in the field of materials and structures research and technology, particularly in engine materials, improved high temperature polymers, structural dynamics and in composite materials applications.

In the area of composites technology, you will hear more about the Aircraft Energy Efficiency Composites Primary Structures program to provide the technology for utilization of composites to increase the energy efficiency of aircraft. However, I want to report the progress in our R&T Base composites technology which is focused toward a better understanding of and more fundamental studies of composites.

In this basic program, major improvements in the strength of composites even when cracked or damaged by impact have been achieved by the incorporation of a thin (0.4 mil thick) perforated mylar film between the

laminae of a composite. This causes a diffusion of local stress concentrations and allows individual filaments to reach higher average stress before fracture. Tests conducted on graphite-epoxy panels identically damaged by cracks through the composite demonstrated a 50 percent improvement over panels without the mylar film. Figure 3 illustrates the damage-tolerant concept and compares test results for conventional and modified panels. As is evident, the "modified" composite offers significant improvement over the "conventional" composite.

We have also made progress in improving composites for application to turbojet engine fans and compressor blades where their major problem has been susceptibility to foreign object damage (FOD). A 7-1 improvement over initial design concepts has been demonstrated in whirling arm tests of J-79 first stage compressor blades impacted by 3-ounce birds. These improved blades used large diameter (8 mil in lieu of 4 mil) boron fibers and a more ductile aluminum matrix. Test results with the initial concept and the improved concept are shown in Figure 4.

#### Aeronautical Propulsion

During the past two years NASA has been evaluating the characteristics of alternative liquid hydrocarbon jet engine fuels derived from sources other than petroleum, i.e., coal or shale. Preliminary evaluations, completed about a year ago, using jet fuel derived from shale indicated that engine performance, and combustion and emission characteristics were essentially the same as when operating on conventional petroleum-based jet fuel. The NASA program has since been broadened to stress the total systems importance of improving engine energy efficiency. This includes consideration of the effects of broadened aircraft fuel specifications on the refinery energy expended in producing aviation turbine fuels as well as on the aircraft engine itself. This specification broadening has taken the form of relaxation of freezing point and boiling point values. NASA has been evaluating the effect of this relaxation through combustion tests, and studies of the impact of relaxed fuel specifications on engine and aircraft fuel systems. Some changes to the fuel tankage may be necessary to accommodate the higher freezing point. There is no present indication that combustion chamber changes will be required to accommodate the more luminous flames associated with the broadened specification jet fuels.

Experimental results from the NASA/Air Force Full-Scale Engine Research (FSER) program are now becoming available. The joint program, undertaken to provide technology for future development of commercial and military engines, was initially directed at the problems associated with aeromechanical instabilities (flutter) in fan and compressor blading. During the first half of 1976, testing of the F-100 engine, shown in the Lewis Research Center Propulsion Systems Laboratory test facility in Figure 5, generated a significant amount of fan flutter and associated aerodynamic data. These data are being analyzed to determine the operating conditions which cause flutter and the shift in flutter boundaries which occur with varying operating conditions. Flutter boundary shifts have successfully been correlated with both pressure and temperature parameters. The data from these programs are providing a sound experimental basis for detailed analytical studies of the flutter phenomenon.

Recent transport aircraft system studies have shown that advanced turboprop powered aircraft offer the potential for significant fuel savings over high bypass turbofans employing the same core engine technology for each. A key element of the advanced turboprop system is a propeller capable of operating at efficiency levels approaching 80 percent in the cruise range associated with turbofan powered aircraft. This cruise range is normally Mach 0.8 at 35,000 feet. To investigate whether these efficiency levels could be achieved with more advanced propeller designs, an eight blade swept tip propeller was recently tested in a high speed wind tunnel. Figure 6 shows this propeller installed in the wind tunnel. Test results, as shown in Figure 7, indicate that the target efficiency of 80 percent was nearly achieved. Higher efficiencies are expected through modifications to the original design.

### Avionics

In avionics, I will limit my remarks to a brief report on the development of a Digital Fly-By-Wire (DFBW) capability for future aircraft. This capability would permit complete replacement of the mechanical/hydraulic linkages between the pilot's stick and the control surface actuators by an all-digital electronic system as shown in Figure 8. Such a fly-by-wire system can augment the basic airframe stability to permit new and improved aircraft designs with increased performance and operational flexibility. The inherent adaptability

and configuration insensitivity of DFBW systems will also allow considerable production and operational cost savings over analog or mechanical flight control systems.

Under NASA's program, a triply redundant DFBW system has been successfully developed and ground tested during FY 1976. The first flight of the system installed in an F-8 research aircraft took place on August 27, 1976 (Figure 9).

We plan to conduct F-8 flight tests with the DFBW systems over the next two years. Initial evaluations will concentrate on validation of the redundancy and flight control software, and follow-on flights early next year will assess performance gains obtainable with advanced transport control laws implemented on the DFBW systems.

In my foregoing remarks, I have attempted to provide a flavor for the research progress in our discipline oriented work. I would now like to briefly note progress in General Aviation Technology and bring you up to date on the status of the Quiet Short-Haul Research Aircraft.

#### General Aviation Technology

Research and technology activities oriented toward improving the safety, utility and environmental compatibility of general aviation aircraft continue to receive growing emphasis in the NASA aeronautics program. Several specific projects have reached significant milestones.

First, in the area of safety, the full-scale crash testing effort at Langley has completed 10 simulated crashes. The maximum conditions reached to date have been a 45 degree impact angle at 60 miles per hour. Data from these tests are being incorporated with theoretical structural design studies to provide improved design procedures for crash protection as illustrated in Figure 10. On March 16-18, 1976, a workshop was held to disseminate the results of the first crash tests. Industry participation now includes the evaluation of new seat and restraint systems.

Also in the area of safety, progress has been made in the NASA Stall/Spin program. As shown in Figure 11, four test tails have been tested in this activity to provide a spin recovery design criterion for future

aircraft design. This program has been complimented by industry on its content, and they have encouraged us to accelerate the program as much as possible. In response, we will do all we can do to provide this technology earlier than previously had been planned.

As indicated in February, an aerodynamic drag reduction project for general aviation aircraft has been initiated. We have prepared and published a summary report of past drag reduction efforts that are relevant to current general aviation aircraft and we are now initiating work to build on this foundation of information.

We have also initiated flight test efforts concerned with the development of an attitude command stability augmentation system for general aviation airplanes. Separate control surfaces for this stability augmentation system were incorporated in a modified Beech Model 99 airplane (Figure 12) so that the airplane handling qualities and gust response could be enhanced without interfering with the pilot's control functions.

The Separate Surface Stability Augmentation (SSSA) System was implemented through a joint University/Industry/NASA program under which the University of Kansas designed and fabricated the SSSA systems, and, together with NASA, defined and conducted the flight test program. Beech Aircraft Corporation provided the research airplane and its modifications, and Boeing carried out the necessary flutter analysis and flight test data reduction. Extensive flight tests of the SSSA system, completed in FY 1976, have generated the design base for the implementation of similar systems into future general aviation airplanes to allow safer flight in adverse weather conditions.

Experimental programs are showing progress with the Advanced Technology Light Twin (ATLIT) flights tests now under way and the flight demonstration of the hydrogen enrichment concept is on schedule for a flight demonstration in December 1976.

Finally, the study exploring the viability of a NASA role in technology development for aerial application has been completed (Figure 13). Results of the study indicate that significant advances are needed for both short- and long-term improvements in the accuracy and efficiency of aerial applications of agricultural chemicals. We are now in the process of defining what NASA could and should do to help in this area.

### Quiet Short-Haul Research Aircraft

The Quiet Short-Haul Research Aircraft (QSRA) was initiated in FY 1974 with a major quantitative flight research operations goal of limiting the 90 EPNdB noise footprint to an area less than one square mile. The QSRA will also have the lift and control capability to investigate a wide range of low-speed flight conditions. The data obtained from the QSRA flight research program, together with the information obtained from the NASA participation in the Air Force Advanced Medium STOL Transport (AMST) program (to be discussed later), will provide propulsive-lift technology data for design and certification criteria for use in development of future quiet short-haul transport aircraft.

On February 27, 1976, NASA awarded a contract to the Boeing Commercial Airplane Company for the design, construction and test of one QSRA. Figure 14 is an artist's concept of the QSRA. The experimental aircraft will be constructed by modifying an existing government-furnished DeHavilland C-8A Buffalo aircraft which includes removing the existing straight wing and two turboprop engines and replacing them with a new swept wing and four existing government-furnished AVCO-Lycoming YF-102 turbofan engines. Both the aircraft and the engines for the QSRA were acquired from other government programs which were completed. The new wing and turbofan engines will be configured to provide a versatile flight capability for propulsive-lift research.

The QSRA schedule includes rollout of the aircraft by May 1978, completion of contractor flight checkout by July 1978 and initiation of the NASA flight test and research program in August 1978.

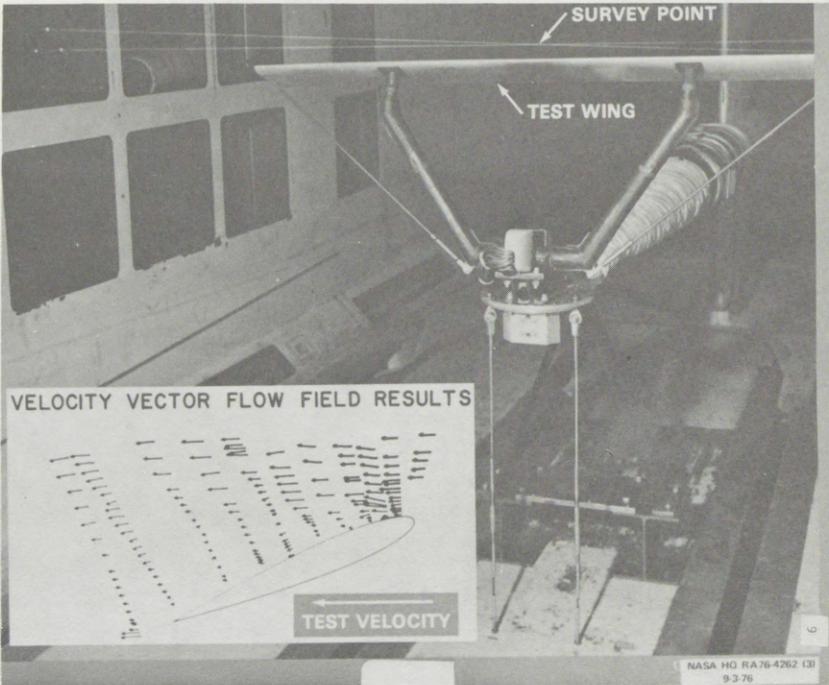


FIGURE 1

### PREDICTION OF LIFT COEFFICIENT VARIATION WITH ANGLE OF ATTACK FOR GA(W)-1 AIRFOIL

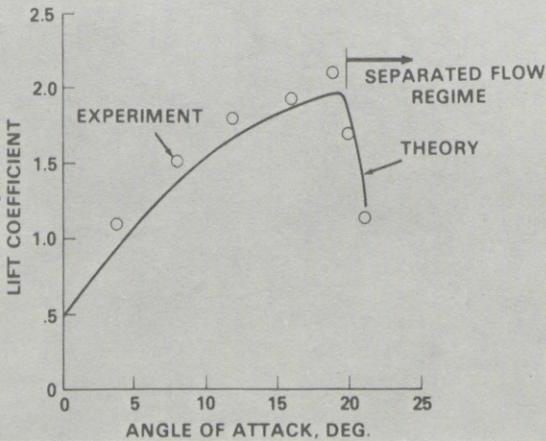


FIGURE 2

## DAMAGE - TOLERANT COMPOSITES

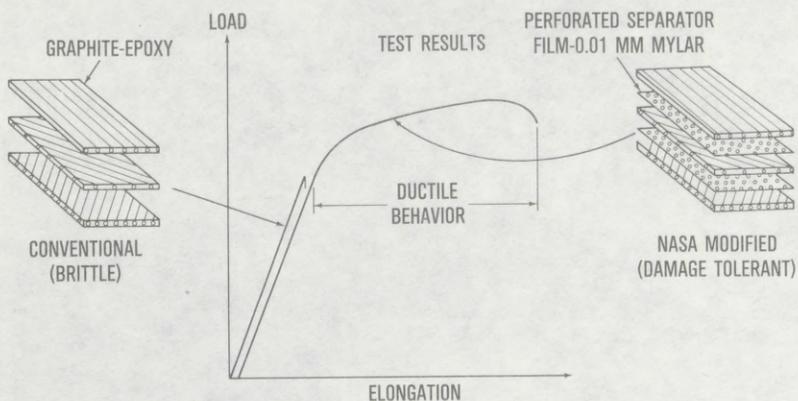


FIGURE 3

IMPROVED IMPACT RESISTANCE  
OF J79 COMPOSITE COMPRESSOR BLADESINITIAL DESIGN  
CONCEPTSHATTERED IN  
FOD TESTSIMPROVED DESIGN  
CONCEPTONLY MINOR DAMAGE  
IN FOD TESTS7:1 IMPROVEMENT IN  
IMPACT RESISTANCENASA MD 28276-1185 1-77  
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12

FIGURE 4

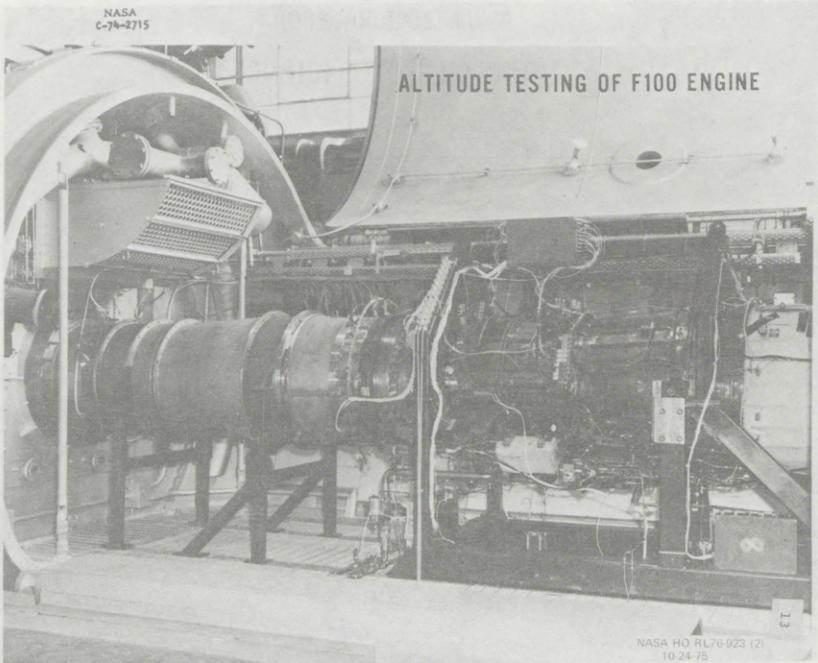


FIGURE 5

NASA National Aeronautics and  
Space Administration

Headquarters  
Washington, D. C.

## ADVANCED SWEEP-TIP PROPELLER

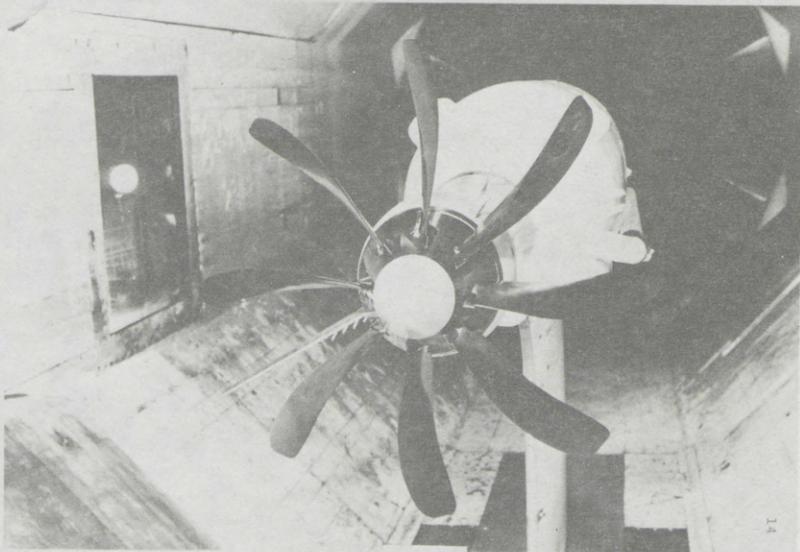


FIGURE 6

NASA HQ H276-4201 (1)  
9-2-76

FIGURE 6

## ADVANCED TURBOPROP UNINSTALLED EFFICIENCY

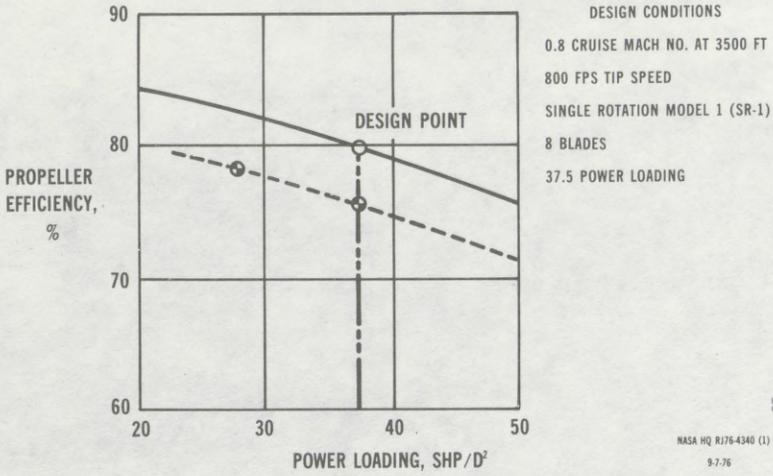


FIGURE 7

### ELECTRONIC VS. MECHANICAL CONTROL SYSTEMS

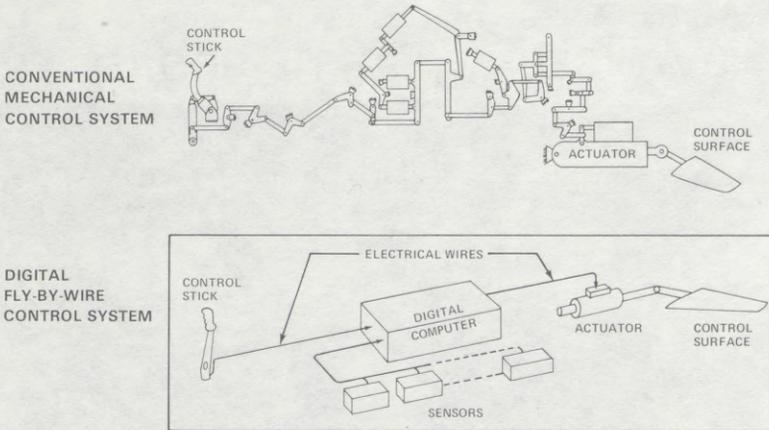


FIGURE 8

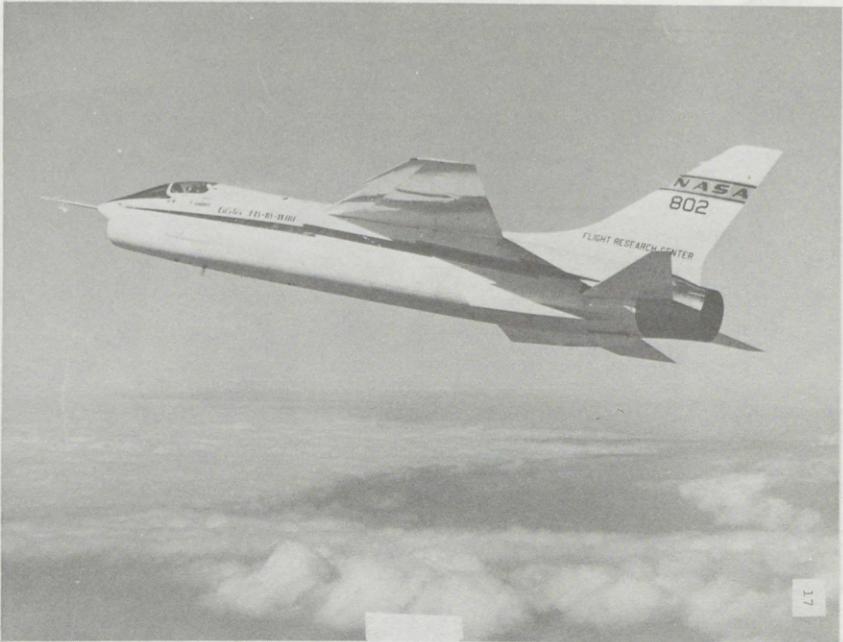
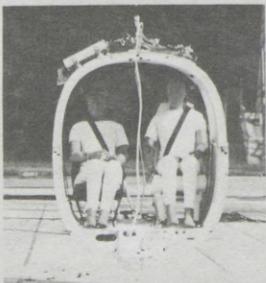
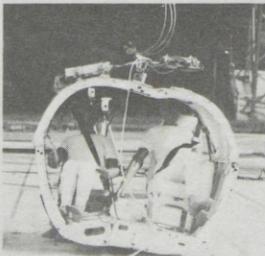


FIGURE 9

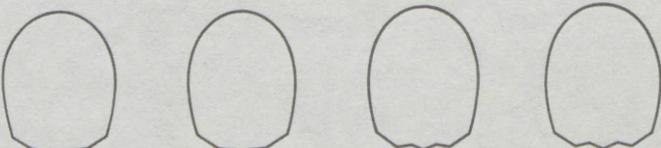
**ANALYSIS AND TESTING  
IN NASA CRASH SAFETY PROGRAM**



EXPERIMENTAL  
TESTS OF  
FUSELAGE SECTION



**THEORETICAL DEFORMATIONS DURING IMPACT**



TIME →

18

FIGURE 10

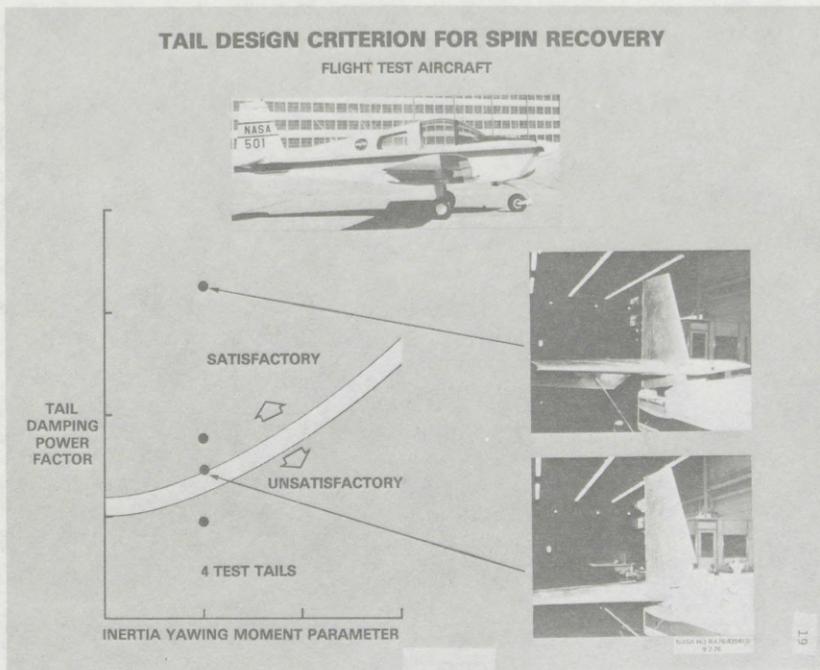


FIGURE 11

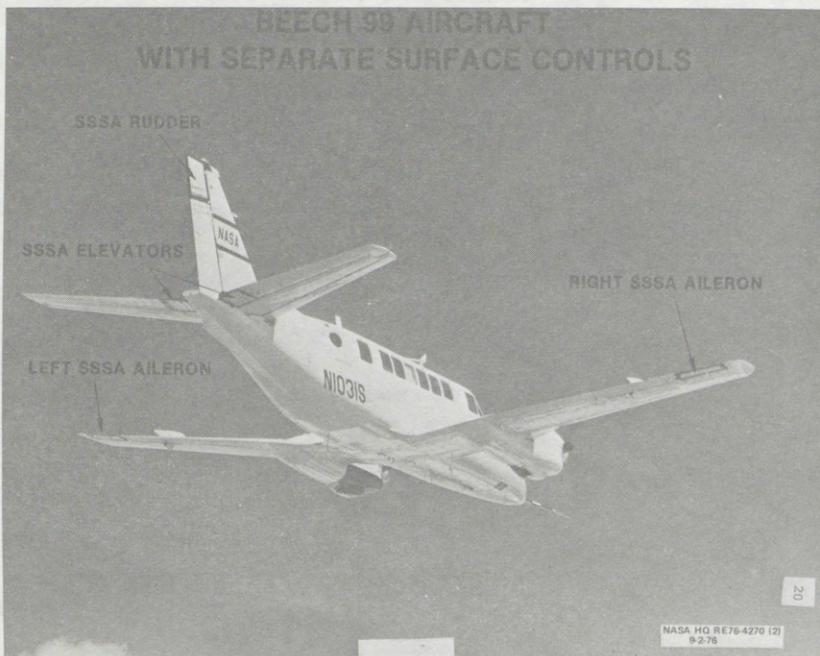


FIGURE 12



FIGURE 13

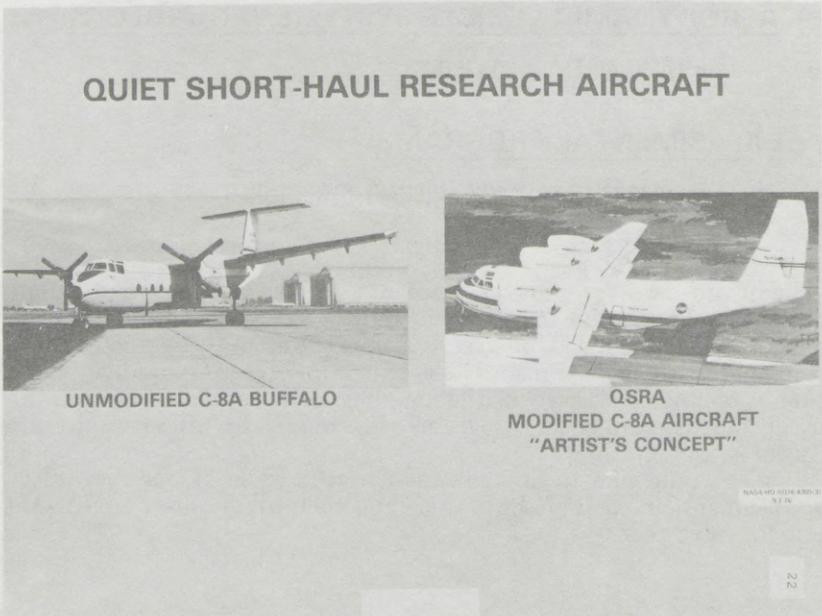


FIGURE 14

Mr. SMYLLIE. If there are no questions at this time, I would like to introduce Dr. John M. Klineberg, who is a member of our Aircraft Energy Efficiency Office.

Mr. MILFORD. Dr. Klineberg, we have your complete statement which will be accepted for the record along with attachments.

**STATEMENT OF DR. JOHN M. KLINEBERG, CHIEF, AERODYNAMICS AND ACTIVE CONTROLS BRANCH, AIRCRAFT ENERGY EFFICIENCY OFFICE, OAST, NASA**

Dr. KLINEBERG. Thank you.

The elements of the aircraft energy efficiency program are shown here in figure 1. This is the way they appear in our fiscal 1977 budget.

## **AIRCRAFT ENERGY EFFICIENCY PROGRAM**

### **PROPULSION SYSTEMS TECHNOLOGY**

- ENGINE COMPONENT IMPROVEMENT
- ENERGY EFFICIENT ENGINE

### **CIVIL AIRCRAFT SYSTEMS TECHNOLOGY**

- ENERGY EFFICIENT TRANSPORT

### **AERODYNAMIC VEHICLE SYSTEMS TECHNOLOGY**

- LAMINAR FLOW CONTROL

### **EXPERIMENTAL PROGRAMS**

- COMPOSITE PRIMARY AIRCRAFT STRUCTURES

FIGURE 1

There are two propulsion elements under propulsion systems technology, the engine component improvement program and the energy efficient engine. Under civil aircraft systems technology there is the energy efficient transport element. Under aerodynamic vehicle systems technology there is the laminar flow control program. As one of our experimental programs, is composite primary aircraft structures.

What I would like to do today is describe some of our recent accomplishments in each of these areas and then briefly discuss NASA's plans for next year.

## ENGINE COMPONENT IMPROVEMENT

### ENGINE DIAGNOSTICS

- FAN NICKS
- COMPRESSOR TIP WEAR
- WARPED COMBUSTORS
- SEAL LEAKAGES
- ERODED TURBINE BLADES

### PERFORMANCE IMPROVEMENT

- ABRADABLE SEALS
- IMPROVED TURBINE
- MATERIALS AND COATINGS
- CLEARANCE CONTROL
- EXHAUST NOZZLE MIXER

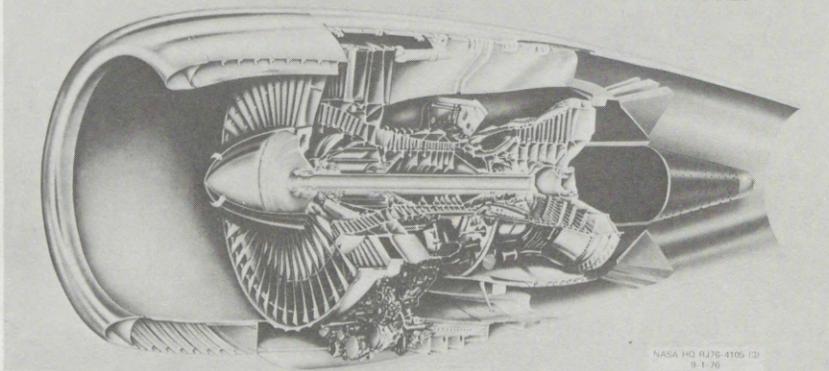


FIGURE 2

Starting at the top (fig. 2)—the engine component improvement program is directed at near-term improvements that can be incorporated into current engines to reduce fuel consumption. The program is divided into two basic elements—engine diagnostics and performance improvement. The purpose of the engine diagnostics portion is to develop methods to reduce the deterioration of performance that occurs over the life of an engine. Contracts are currently being negotiated with the engine companies and the airlines for a series of ground tests and inflight monitoring of new and used aircraft engines to identify the sources of both short- and long-term performance deterioration. Some of those sources are listed in the figure. For example, nicks in the fan blades, compressor tip wear, warped combustors, leakages throughout the engines and eroded turbine blades. This information then will be used to develop design criteria which will improve existing engines and help in the design of future engines to make them less sensitive to inservice deterioration.

The second part of the engine component improvement program is the performance improvement element. This is aimed at developing components which would reduce the fuel consumption of current engines and be ready for introduction into new production versions of those engines in the 1980 to 1982 timeframe.

Several potential fuel saving devices have already been identified and are listed here, for example, abradable seals, improved turbine components, better materials and coatings, clearance control throughout the engine and one element which I would like to discuss now—the exhaust nozzle mixer.

## MIXER TECHNOLOGY

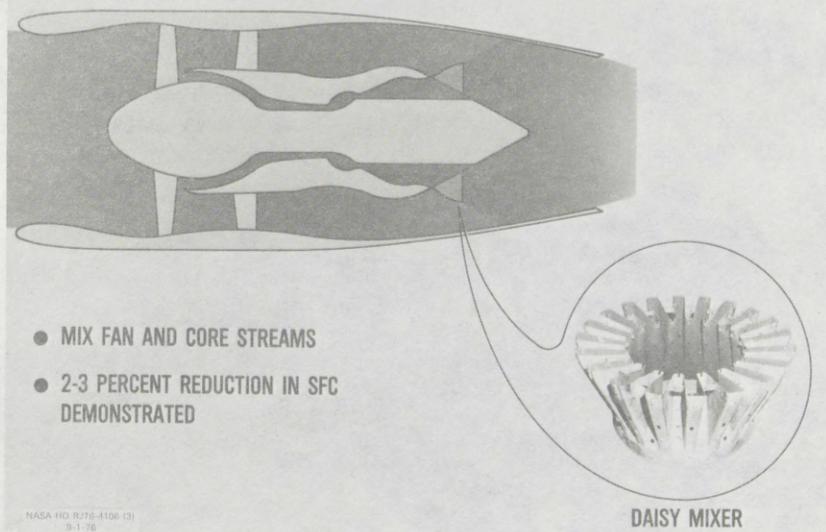


FIGURE 3

As shown in figure 3, we have recently completed tests at the Lewis Research Center of the so-called daisy mixer. What the mixer does—it is located here in the engine—is mix the hot core flow with the colder fan bypass flow. We have measured—with this device on the engine—2- to 3-percent reduction in specific fuel consumption.

Mr. LLOYD. Why is that?

Dr. KLINEBERG. Part of the reason is primarily better propulsive efficiency. You do not have the high stream velocity right at the exit and low stream from the bypass air. The air is completely mixed, so there is a more uniform exit velocity.

Mr. LLOYD. I was under the impression, and maybe I demonstrate a fantastic misunderstanding here, that the longer you can hold that stream together out there, in a column of air pushing that, the more efficiency you are going to get. Is that true?

Dr. KRAMER. Well, the phenomenon that is being described here—

Mr. LLOYD. Well, in other words, I presume that this thing acts as a diffuser.

Dr. KRAMER. It does not act as a diffuser. It does not accelerate mixing downstream of the nozzle plane. What it does is accelerate the mixing within the engine envelope, and it mixes the relatively low velocity fan air with the hot core flow. From an optimum propulsive efficiency standpoint, what one wants is to have—

Mr. LLOYD. The column of thrust gases coming out is as uniform as it would be whether you have this or not. Is that true?

Dr. KRAMER. Yes, it is the same, the external mixing process is just the same as before.

Mr. LLOYD. OK. Now I am back to the question again. Why is this more efficient? Why are you picking up the 2- to 3-percent efficiency?

Dr. KRAMER. If you want to have the optimum efficiency, what one wants—

Mr. LLOYD. Oh, I know what you want to accomplish. I understand the goals. I just don't understand the principle.

Dr. KRAMER. Well, the principle is, one has essentially the best propulsive efficiency when the exiting air is the same velocity as the forward flight speed of the airplane. If viewed in absolute terms, the air does not move because the airplane moves forward and relative to the airplane the air is moving backward, but the air is quiescent. That is the most efficient process you can have.

What one does with this mixer is to exchange some of the energy between the slow moving fan air, the exhaust air and the fast moving core exhaust air to get an average velocity which is closer to this ideal. The result is improvement in the propulsive efficiency at the expense of some increased internal drag and what you see there is the net effect.

Dr. KLINEBERG. The flow then across this plane, of course, is more uniform than it would be without the mixer.

I would like to turn now to the second propulsion system technology area—the energy efficient engine program. This program is aimed at providing a technology base for significant reductions in fuel consumption for all new turbofan engines.

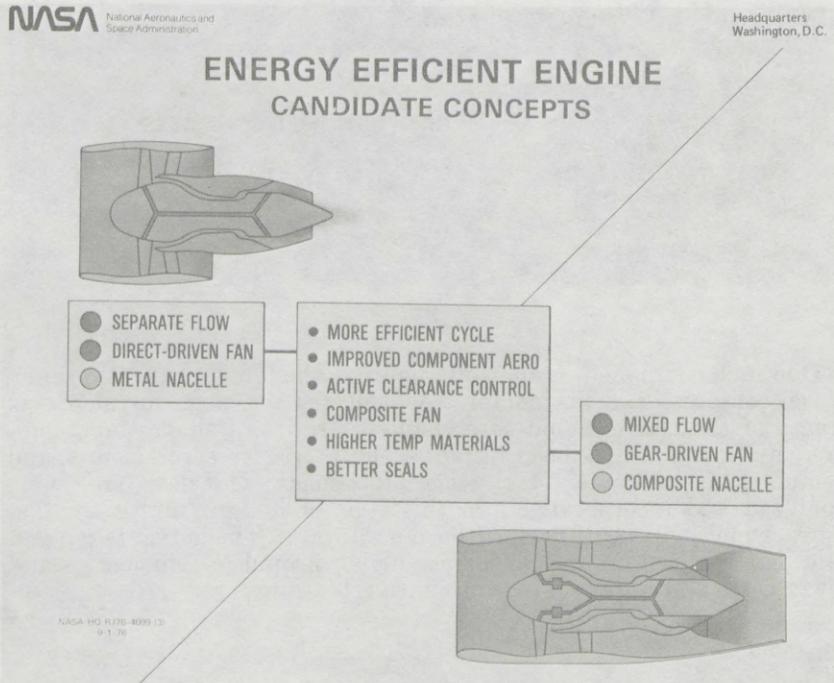


FIGURE 4

Results of two preliminary design studies are summarized here in figure 4. Both designs require a more efficient cycle, improved component aerodynamics, active clearance controls, composite fan blades, higher temperature materials, and better seals. Differences in the two concepts appear—here this is relevant to our discussion of a few minutes ago. In this case we have what we call separate flow, so there is a hot gas here and cooler gas there and a direct-driven fan in here with a metal nacelle.

This design has a composite nacelle and a mixed flow exhaust, as we described before, with a gear-driven fan.

These improvements cannot be provided by current technology; therefore, technology advances must be pursued in every component of the engine.

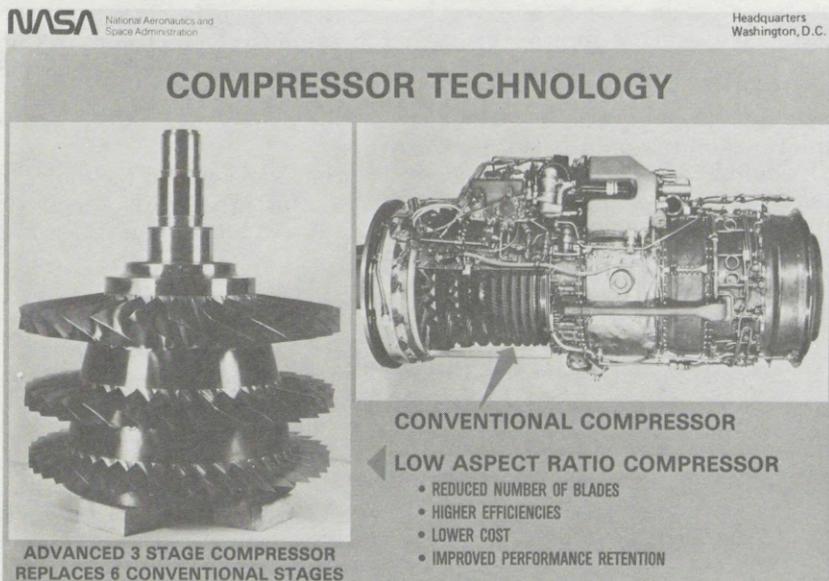


FIGURE 5

One such component is shown in figure 5, the low-aspect ratio three-stage compressor. This compressor will replace an equivalent six stages of the conventional core engine. A series of single-stage compressors have recently been tested at the Lewis Research Center and demonstrated extremely high-stage efficiencies. The data are being analyzed and incorporated into this type of design, multistage designs, which will be tested in the near future. The advantage, as I said, is a reduced number of blades, higher propulsive efficiencies and lower costs and improved performance retention.

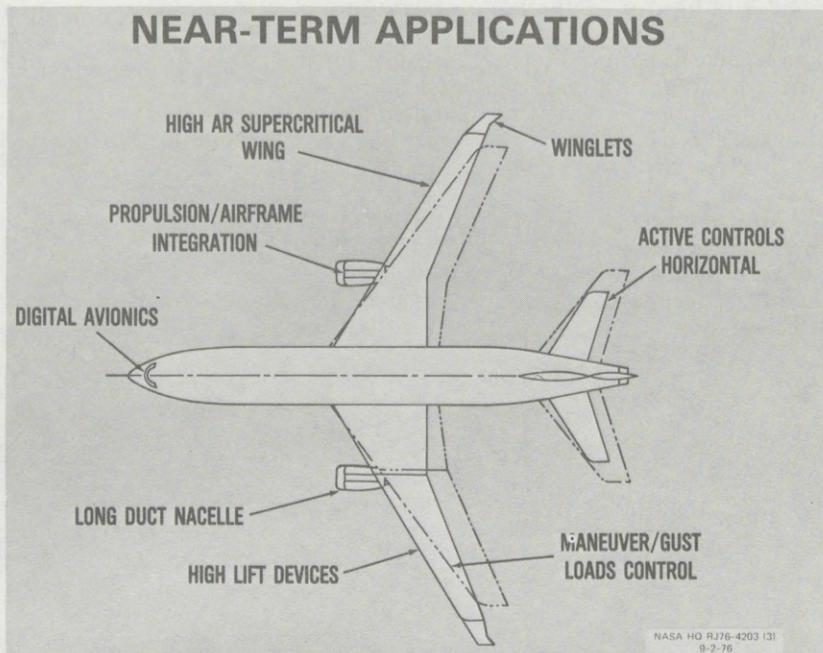


FIGURE 6

I now turn to the energy efficient transport element which is focused on the development of advanced technology for near-term application to derivative and new transport aircraft (fig. 6).

Several potential near-term improvements are shown here in the figure. In the blue background is a typical current wide-body aircraft and shown superimposed in yellow is what we could do in the very near term to improve the efficiency of this kind of aircraft. For example, we could have high aspect ratio wings with supercritical sections and winglets, improved propulsion system integration, digital avionics for more accurate flightpath control.

Mr. LLOYD. Could I interrupt you there?

Could we just automatically apply this to a DC-10 or L-1011? I presume that is what you are drawing.

Dr. KLINEBERG. Not just automatically. There are technology developments that have to be pursued in all of these areas, but this is a relatively near-term application.

Mr. LLOYD. In other words, you could change the production line on that. Could you retrofit it?

Dr. KRAMER. With an appropriate development program leading into it.

Mr. LLOYD. I mean it wouldn't be economically feasible?

Dr. KRAMER. It depends on how many you could sell.

Mr. LLOYD. You could take the current design and use 50 percent of it?

Dr. KRAMER. It will not pay on a retrofit basis.

Mr. LLOYD. It will not. OK.

Dr. KLINEBERG. These are mostly changes that you would make in a future production line of the derivative version.

Just to finish, a long duct nacelle and some improved high lift devices are also necessary and the active controls technology which will allow decreased structural weight in the wing and also which will allow a smaller horizontal tail.

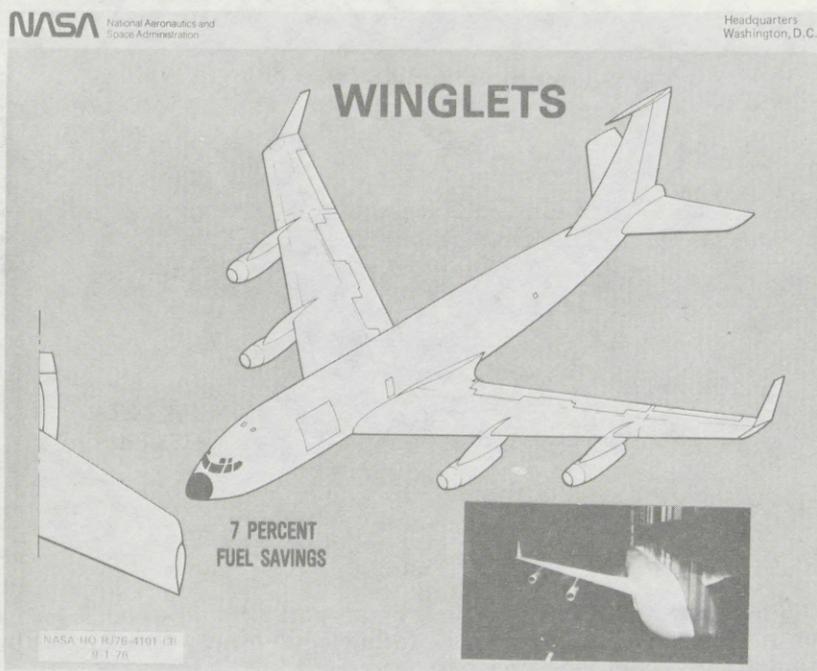


FIGURE 7

I would like to discuss now recent results in two areas, one on winglets and some of the work we are doing in active controls (fig. 7).

The Langley Research Center has recently completed over 1,100 hours of wind tunnel tests on the application of winglets to the KC-135, or the Boeing 707, as shown here. Approximately 20-percent reduction in induced drag was measured which translates into approximately 7-percent fuel savings.

Mr. LLOYD. Just with the winglet. You did not change the basic wing?

Dr. KLINEBERG. In this case, we did not, no. We did not have to. Just for the winglet.

NASA and the Air Force intend to proceed with a joint flight test program at the Dryden Flight Research Center to verify these performance gains. The flight tests will provide valuable full-scale data on winglets and will also contribute toward the design of winglets for application to derivative or new wide-body transports.

Mr. MILFORD. Before you leave there, for just a moment, would you do a little educating if possible.

Exactly what is the principle involved in the winglets that would produce a 7-percent fuel savings?

Dr. KLINEBERG. Well, the winglet is shown here from the top. It is not an endplate. It is a very carefully tailored airfoil section. What

it does on a swept wing is work in the crossflow. It works in the flow coming around the wing to produce lift, and that lift vector is tilted in a forward direction that actually produces thrust which can be looked at as a reduction in the induced drag, or the drag due to lift, of the wing. Now what it also does, however, is increase the bending moment on the wing and this is why it does not—for all aircraft—have retrofit possibilities, because of the way the wing is stressed.

Mr. MILFORD. You are going to have to beef the wing.

Dr. KLINEBERG. You will have to beef up the wing and then you get into the economic question: Is it worth changing the structure of the wing?

Mr. MILFORD. So it is not a matter of just adding the tips?

Dr. KLINEBERG. No, but in the case of the KC-135 the structural analysis we have done does show that one could do that. It does have retrofit possibilities.

Mr. LLOYD. You get more efficiency but you put more load on the wing?

Dr. KLINEBERG. That is right, and it is out at the tip so that you get a bending, it is translated into a bending moment—

Mr. LLOYD. Structurally you would have to beef the wing up for some aircraft.

Dr. KLINEBERG. For some aircraft is what I am saying. It depends really on how that aircraft is designed.

Mr. LLOYD. Does the efficiency go down as the sweep of the wing is reduced?

Dr. KLINEBERG. It is not as sensitive to sweep as it is to the loading on the wing. It works much better with what is called an elliptic loading which is where there is a fair amount of the lift carried at the tips of the wing, and that is true for the early jets. It is much less true for the modern aircraft which have washout at the tips and are highly swept, because as you can see, it is really a local effect. It works on the flow right at the end of the wing.

Mr. LLOYD. Thank you.

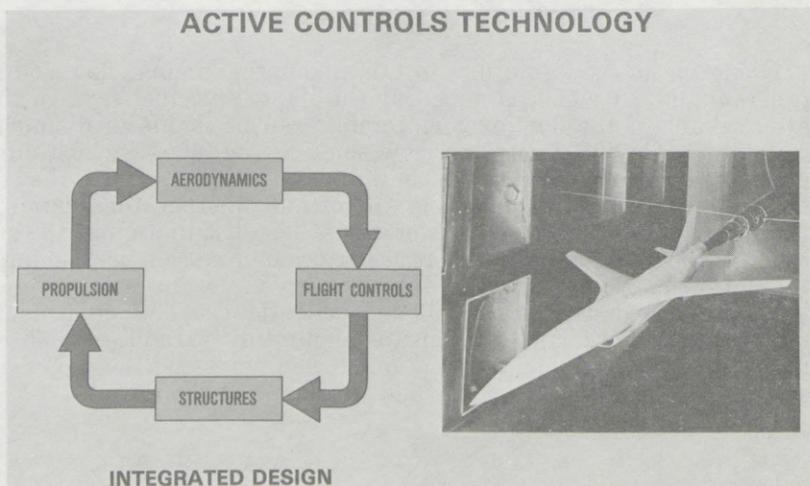


FIGURE 8

Dr. KLINEBERG. I turn now to the other element I wanted to discuss under this program, active controls technology. Shown in figure 8, in the wind tunnel at Langley is a model of a Firebee II drone with a modified research wing. We are preparing to flight test this vehicle early next year, which will include an active control system for maneuver load, gust load, and flutter suppression. The current efforts are directed toward the design of an all-new research wing which will be more representative of an advanced transport configuration. In that case, this will be the first time we perform something that is called integrated design which will include the flight control system in the early design phase. This program will then provide the first realistic assessment of integrated design procedures resulting in flight hardware.

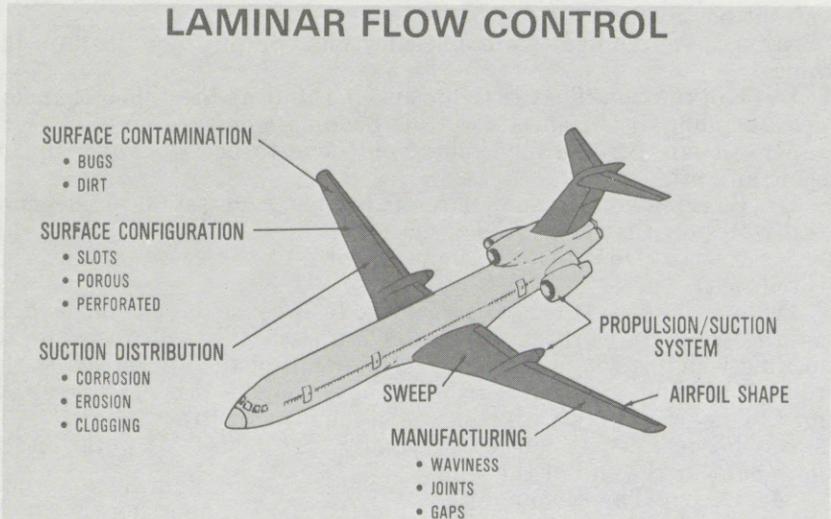
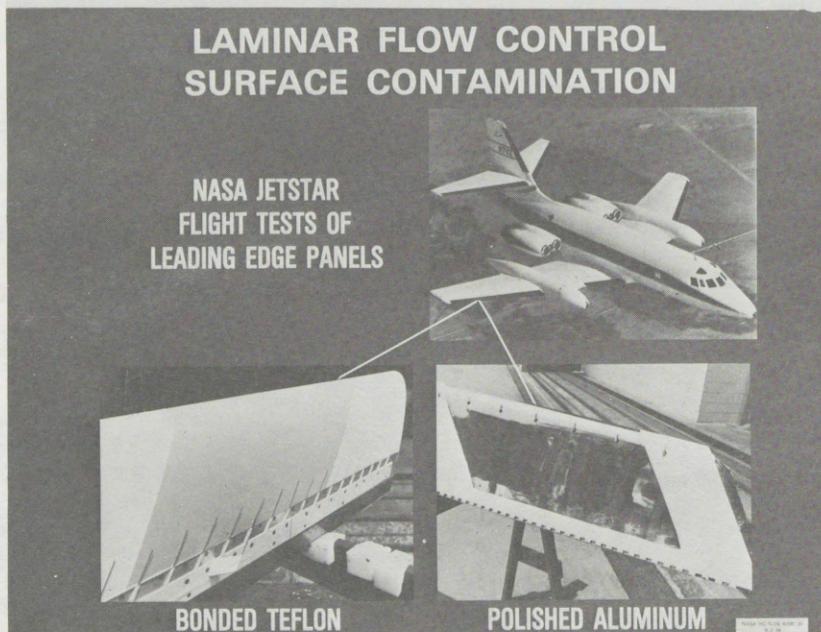


FIGURE 9

Going on now I would like to talk about the laminar flow control program (fig. 9) which is aimed at the impressive fuel savings that are available if the flow over an aircraft can be maintained smooth, or laminar. On this figure we show some of the factors which affect laminar flow. For example, the contamination of the surface, the configuration of the surface is very important whether the suction is through a porous surface or perforations. The distribution of the suction and particularly such factors as corrosion or erosion or clogging of the slots or pores. Also manufacturing is very important and waviness, joints, and gaps disturb the flow and make it more difficult to maintain laminar flow. There are also configuration variables which are important. For example, the location of the pumps and the propulsion system, the sweep of the wing, and the shape of the airfoil.


**FIGURE 10**

Now one of the most important problems is the problem of surface contamination. We recently, just this week, initiated tests of a Lockheed JetStar at the Dryden Flight Research Center to investigate various leading-edge materials that show promise of alleviating this problem. As shown (fig. 10), here is a polished aluminum section and on the left here a bonded Teflon material. Several nonstick coatings and spray-on materials will be investigated in addition to the bonded Teflon panel shown here.

Now, the remaining element of the aircraft energy efficiency program is composite primary aircraft structures (fig. 11). The objectives of this program is to provide the technology for substantial reductions in air transport fuel consumption through the use of composite materials to reduce the weight of new aircraft. The current program is shown here in the figure. It includes the design, development, certification and flight service of three secondary components, three moderate-sized primary components and a wing. Increasing experience with these new materials and processes is obtained through certification and flight service of the small components followed by the moderate-sized primary components and then followed by the wing. Each of the three commercial transport companies will be responsible for one secondary and one moderate-sized primary component to insure that a wide diversity of structural concepts will be investigated.

I would like to turn now and discuss these top two components, the DC-10 rudder and the L-1011 vertical fin, as shown in figure 12.

## COMPOSITE PRIMARY AIRCRAFT STRUCTURES

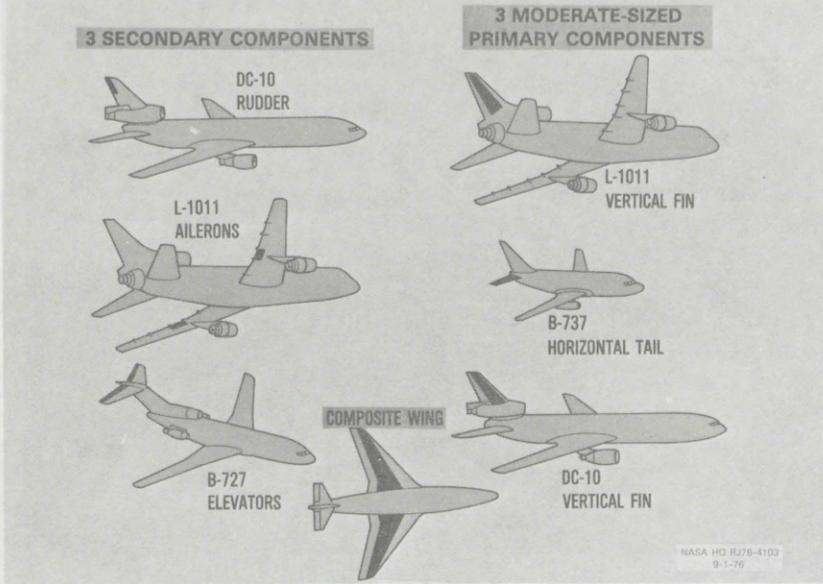


FIGURE 11

## COMPOSITE STRUCTURAL COMPONENTS



FIGURE 12

The DC-10 rudder is approximately 32-square-feet in area. It weighs 57 pounds and it saves 37 percent of the metallic part that it replaces. A major milestone in the composite primary aircraft structures program was passed when the composite rudder was certificated by the FAA this past May. A total of 10 rudders have been fabricated to date and three have been installed on commercial transports. The moderate-sized components are typified by this L-1011 vertical fin shown on this slide. This fin is approximately 150-square-feet in area and saves 25 percent of the metallic part it replaces. In this program which is now in the development phase, a major test article, approximately this size here, is currently being fabricated and will be used to verify manufacturing processes, assembly procedures and inspection techniques.

The five technology programs shown here constitute the elements of the NASA aircraft energy efficiency program. The program is just starting and promises to be an exciting one. We look forward to keeping you informed of our progress in the future. Thank you.

Mr. MILFORD. Thank you very much.

[The prepared statement of Dr. Klineberg follows:]

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PRESENTED BY WITNESS

AIRCRAFT ENERGY EFFICIENCY

Statement of

John M. Klineberg  
Chief, Aerodynamics and Active Controls Branch  
Aircraft Energy Efficiency Office

Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

As mentioned in our February testimony, during most of calendar year 1975 NASA worked closely with the major airframe and engine manufacturers, the airlines and other government agencies to identify those technology advancements which have the greatest potential for saving fuel in future air transports. The result of that planning activity was the formulation of a ten-year, multiphased program plan for the aggressive development of technology for more energy-efficient transport aircraft.

The NASA Aircraft Energy Efficiency Program consists of five focused technology programs. These program elements appear in NASA's FY 1977 budget as shown in Figure 1. Although these programs are new for FY 1977, they build on substantial ongoing NASA research and technology efforts in aircraft energy efficiency, since efficiency is--of necessity--a direct result of advancements in aeronautical technology. In addition, some of NASA's related FY 1976 programs have been redirected as a result of the planning activity and the approval of these FY 1977 program elements. This statement describes some of the recent accomplishments in each of these areas and briefly discusses NASA's plans for FY 1977.

As shown in Figure 1, there are two major programs under Propulsion Systems Technology. The Engine Component Improvement program is directed at near-term improvements that can be incorporated into current engines to reduce fuel consumption, and the Energy Efficient Engine program is a longer-range effort to demonstrate technology for the next generation, more fuel-efficient, turbofan engine.

The Engine Component Improvement program has two basic parts: Engine Diagnostics and Performance Improvement, as shown in Figure 2. The purpose of the Engine Diagnostics activity is to develop methods to reduce the deterioration in performance that occurs over the life of an engine. Contracts are currently being negotiated with the engine companies and airlines for a series of ground tests and in-flight monitoring of new and used aircraft engines to identify the sources of both short- and long-term performance deterioration. This information will then be used to develop design criteria which will improve existing engines and aid in the design of future engines to make them less sensitive to in-service deterioration. Some of the more common sources of performance degradation are listed in the figure.

The Performance Improvement portion of this program is aimed at developing components which would reduce the fuel consumption of current U.S. commercial engines and be ready for introduction into new production versions of these engines in the 1980-1982 time period. Several potential fuel-saving candidates have already been identified and are listed in the figure. Work is underway to evaluate the potential of some of these concepts. For example, engine tests of an exhaust mixer were recently completed at the Lewis Research Center. This "daisy" type mixer, shown in Figure 3, creates individual chutes to mix the hot core stream with the fan bypass air flow. Performance data taken at simulated flight conditions indicate a reduction in specific fuel consumption of approximately 2-3 percent over the complete range of operation.

The second propulsion element, the Energy Efficient Engine program, will provide the technology base for significant reductions in fuel consumption for all-new turbofan engines. Results of two preliminary design studies are summarized in Figure 4. Both engine designs require a more efficient cycle, improved aerodynamic performance, better seals, reduced clearances, and

higher-temperature materials. Differences appear in the treatment of the exhaust mixer, the fan drive, and the nacelle. Current technology cannot provide these fuel-saving improvements and technology advances must be pursued in every component of the engine.

One such engine component is shown in Figure 5: a 3-stage, low aspect-ratio inlet compressor assembly. An equivalent conventional compressor, as shown on the right, would require up to six stages with about three times the number of blades. A series of single-stage compressor configurations recently tested at the Lewis Research Center demonstrated high stage efficiencies. These data are being analyzed and incorporated into multi-stage designs, such as the one shown in the figure, which will be tested in the near future. During the first phase of the Energy Efficient Engine program, similar technology advances will be made in each component of the engine.

The Aircraft Energy Efficiency program includes two technology programs aimed at improvements in aircraft configurations. The first, the Energy Efficient Transport program, shown in Figure 6, is focused on the development of advanced aerodynamics and active controls technology for near-term application to derivative or new transport aircraft. Several potential improvements are indicated in the figure: efficient high aspect-ratio wings incorporating supercritical sections, winglets, advanced high-lift devices, improved propulsion system installation, and active controls for lower structural weight; and reduced-area horizontal surfaces, also made possible through the use of active controls.

Most of these advances have near-term application. For example, during the past six months the Langley Research Center has completed over 1100 hours of wind-tunnel tests on the application of winglets to the KC-135, shown in Figure 7. Significant fuel savings, on the order of 7 percent, have been estimated as a result of adding winglets. NASA and the Air Force intend to proceed with a joint flight-test program at the Dryden Flight Research Center to verify these performance gains. The flight tests will provide invaluable full-scale data on winglets, particularly at off-design conditions, and will contribute toward the design of winglets for derivative and new wide-body transports.

In active controls technology, wind-tunnel tests have recently been completed of a Firebee II model with a modified research wing, as shown in Figure 8. The flight tests of the drone, including an active control system for gust load, maneuver load, and flutter suppression, are scheduled to begin next year. Current efforts are directed toward the design of a second research wing which will be representative of an advanced transport configuration. This wing will be an "integrated" design in the sense that the structure will directly reflect the advantages of incorporating active controls in the early design phase. This program will provide the first realistic assessment of integrated design procedures resulting in flight hardware.

The second aerodynamic activity, the Laminar Flow Control (LFC) program, is aimed at the impressive fuel savings that are available if the flow over an aircraft can be maintained smooth, or laminar. This can be achieved by applying suction through slots or holes located along the wing and tail surfaces of the vehicle. Figure 9 indicates some of the factors which affect laminar flow: surface contamination; suction distribution; manufacturing tolerances; and configuration variables, such as the wing sweep, airfoil section and the location of the propulsion system. The major emphasis of the program during FY 1977 and 1978 will be on the engineering investigations, analyses, design studies, and component tests necessary to evaluate alternative LFC design concepts.

One of the most critical problems is that of surface contamination: the adhesion to the leading edge of the wing of dirt or insects which disturb the smooth flow over the surface. As shown in Figure 10, NASA has recently initiated flight tests of a Lockheed JetStar to investigate various leading-edge materials which show promise of alleviating this problem. A polished aluminum panel is used as a baseline, and several non-stick coatings and spray-on materials will be investigated, in addition to the Teflon panel shown in the figure.

The remaining element of the Aircraft Energy Efficiency program is the Composites Primary Aircraft Structures program. The objective of this program is to provide the technology for substantial reductions in air transport fuel consumption through the use of composite materials to reduce the weight of new aircraft. This effort was initiated in FY 1975 and has been expanded as part of the

Aircraft Energy Efficiency Program to ensure early introduction of composite structures.

The current program, as indicated in Figure 11, includes the design, development, certification and flight service of the following components: three composite secondary structural components, three moderate-sized primary structures, and wing. Increasing experience with these new materials and processes is obtained through certification and flight service of the small components, leading successively to the moderate-sized components, and followed by the wing. Each of the three commercial transport companies will be responsible for one secondary and one moderate-sized component to ensure that a wide diversity of structural concepts will be investigated. Extensive development, analysis and testing will verify the concepts. Each of the six components will be produced in sufficient quantity to validate manufacturing process and cost predictions.

The first of the secondary components, the DC-10 upper aft rudder segment, is shown on the left in Figure 12. The rudder is approximately 32 square feet in area, weighs 57 pounds and saves 37 percent of the weight of the metallic part it replaces. A major milestone in the Composite Primary Aircraft Structures program was passed when the composite rudder was certified by the FAA in May 1976. A total of ten rudders have been fabricated to date and three have been installed on commercial airline transports. The moderate-sized components, which weigh between 500 and 1000 pounds, are typified by the L-1011 vertical fin shown in the figure. The composite fin is approximately 150 square feet in area and saves 25 percent of the weight of its metallic counterpart. This program, which was initiated in July 1975, is now in the development phase. A major test article to simulate a section of the fin is currently being fabricated and will be used to verify manufacturing processes, assembly procedures, and inspection techniques.

The five technology programs described above constitute the elements of the NASA Aircraft Energy Efficiency program. Certain technology developments will have relatively near-term application: improved performance and less deterioration in existing turbofan engines; evolutionary aerodynamic improvements and the limited use of active controls; and lower-weight secondary structural components made of composite materials. There are also

elements with longer-term potential: new engines with considerably higher cycle efficiencies; flight-critical, highly-reliable active control systems; laminar flow control for substantial drag reduction; and composites in primary aircraft structures. NASA is confident that these programs will greatly contribute toward the design of derivative and new transport aircraft that are significantly more energy efficient than today's transports.

# AIRCRAFT ENERGY EFFICIENCY PROGRAM

## PROPULSION SYSTEMS TECHNOLOGY

- ENGINE COMPONENT IMPROVEMENT
- ENERGY EFFICIENT ENGINE

## CIVIL AIRCRAFT SYSTEMS TECHNOLOGY

- ENERGY EFFICIENT TRANSPORT

## AERODYNAMIC VEHICLE SYSTEMS TECHNOLOGY

- LAMINAR FLOW CONTROL

## EXPERIMENTAL PROGRAMS

- COMPOSITE PRIMARY AIRCRAFT STRUCTURES

FIGURE 1



National Aeronautics and  
Space Administration

Headquarters  
Washington, D.C.

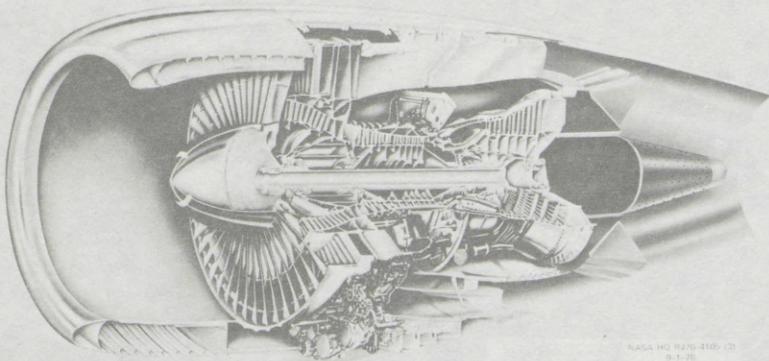
## ENGINE COMPONENT IMPROVEMENT

### ENGINE DIAGNOSTICS

- FAN NICKS
- COMPRESSOR TIP WEAR
- WARPED COMBUSTORS
- SEAL LEAKAGES
- ERODED TURBINE BLADES

### PERFORMANCE IMPROVEMENT

- ABRADABLE SEALS
- IMPROVED TURBINE
- MATERIALS AND COATINGS
- CLEARANCE CONTROL
- EXHAUST NOZZLE MIXER



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FIGURE 2

# MIXER TECHNOLOGY

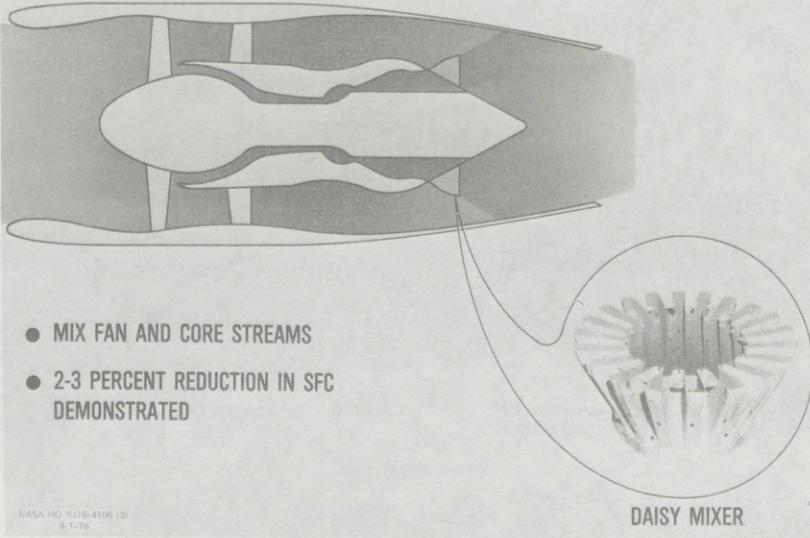


FIGURE 3

# ENERGY EFFICIENT ENGINE CANDIDATE CONCEPTS

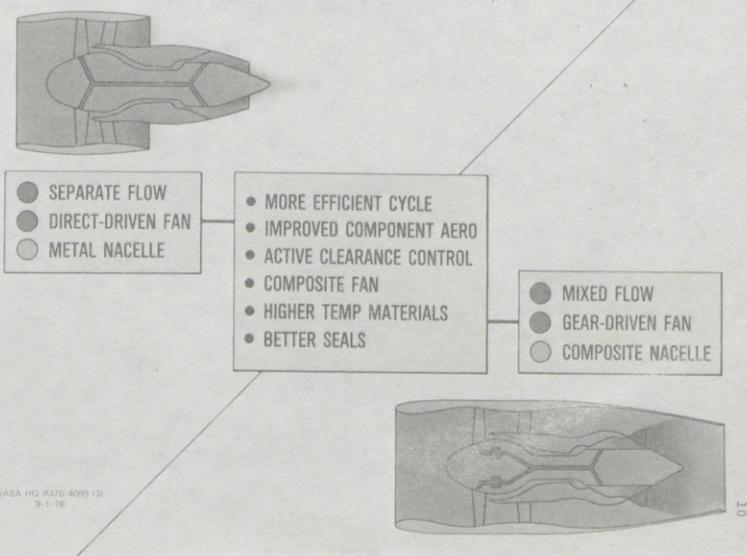
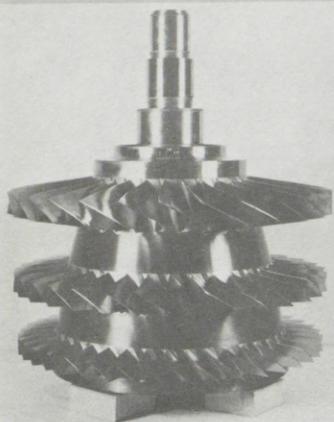
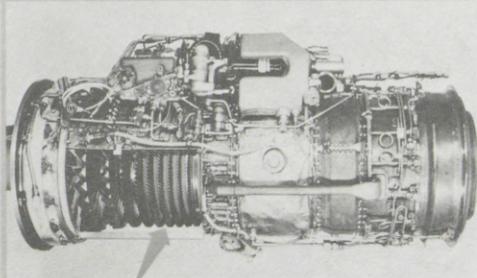


FIGURE 4

## COMPRESSOR TECHNOLOGY



**ADVANCED 3 STAGE COMPRESSOR  
REPLACES 6 CONVENTIONAL STAGES**



**CONVENTIONAL COMPRESSOR**

### ◀ LOW ASPECT RATIO COMPRESSOR

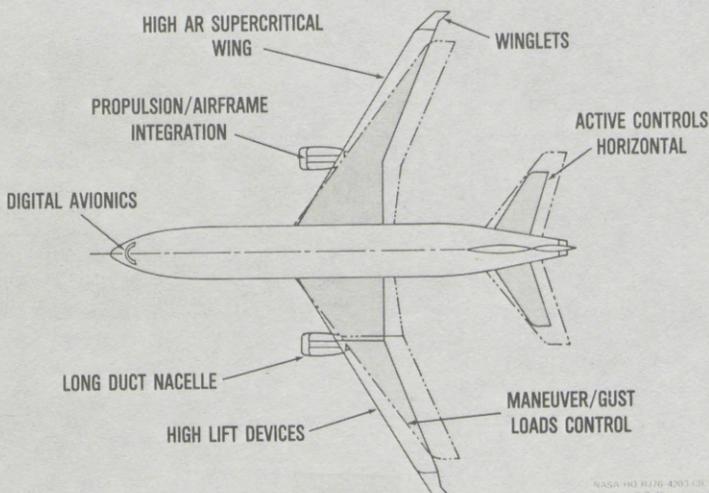
- REDUCED NUMBER OF BLADES
- HIGHER EFFICIENCIES
- LOWER COST
- IMPROVED PERFORMANCE RETENTION

11

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9-7-76

**FIGURE 5**

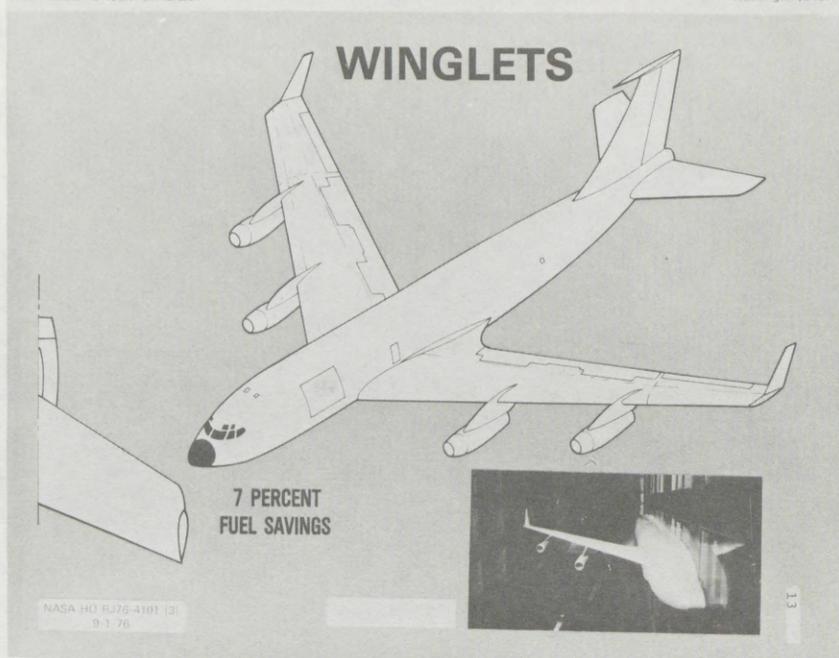
## NEAR-TERM APPLICATIONS



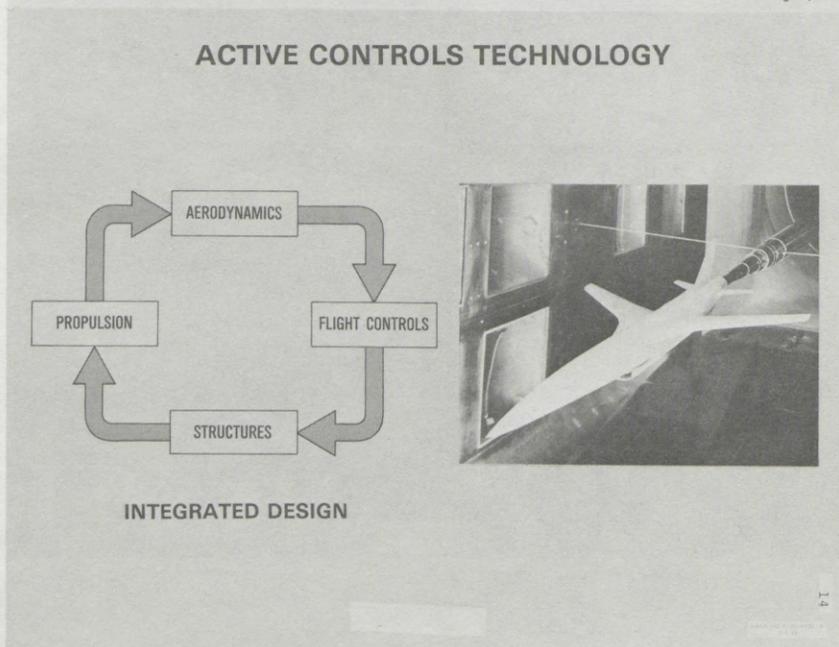
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**FIGURE 6**



**FIGURE 7**



**FIGURE 8**

## LAMINAR FLOW CONTROL

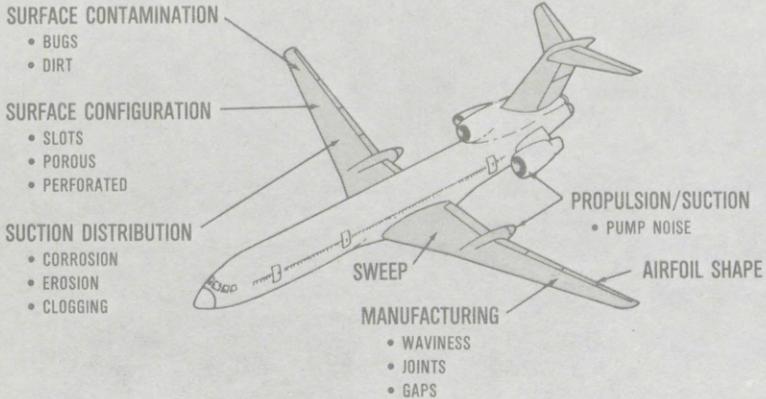
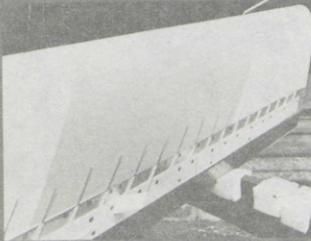


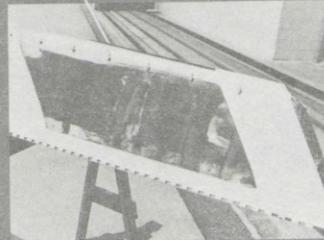
FIGURE 9

## LAMINAR FLOW CONTROL SURFACE CONTAMINATION

NASA JETSTAR  
FLIGHT TESTS OF  
LEADING EDGE PANELS



BONDED TEFLON



POLISHED ALUMINUM

FIGURE 10

## COMPOSITE PRIMARY AIRCRAFT STRUCTURES

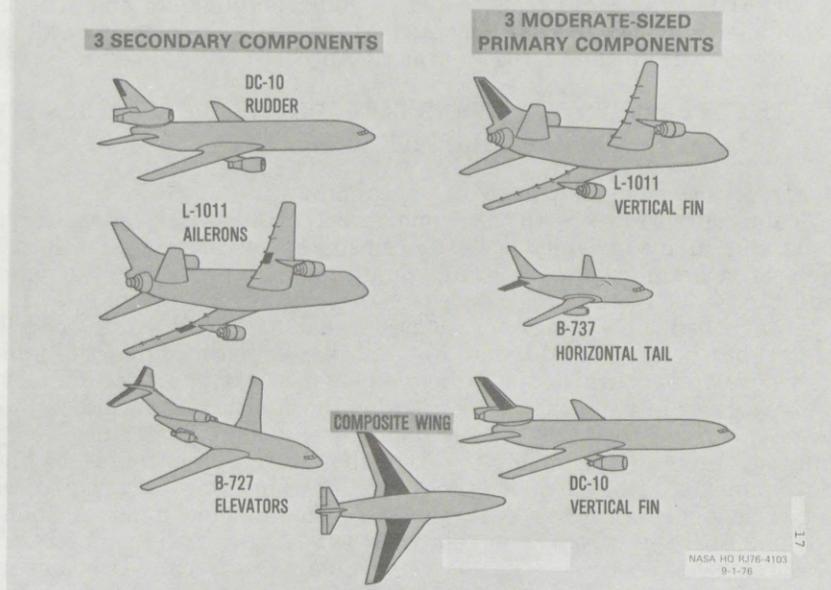


FIGURE 11

## COMPOSITE STRUCTURAL COMPONENTS



FIGURE 12

Mr. SMYLIE. Our next testimony is on our NASA military cooperative programs, Mr. Chairman, Mr. A. J. Evans, director of our research aircraft programs will now present this testimony.

Mr. MILFORD. Mr. Evans, we have your complete statement with attachments which will be accepted at this point for the record. If you would care to summarize or you may proceed as you see fit.

**STATEMENT OF ALBERT J. EVANS, DIRECTOR, RESEARCH AIRCRAFT PROGRAMS OFFICE, OAST, NASA**

Mr. EVANS. Thank you, Mr. Chairman.

I am going to talk with you about the NASA military cooperative programs many of which were described to you in some detail last February. I will attempt to bring you up to date on the progress made and the status of the programs.

I have listed here (fig. 1) the programs that I am going to talk about, but before I do, I would like to talk about the support of military development which is a principle part of our support for military. This work is in response to requests of the military for wind tunnel tests and other facilities use on their development programs. Every military program at some time or other during the course of the development is tested at a NASA facility. This work is typified, as shown in figure 2, by the Navy F-14 at Langley and involves about 18- to 20-percent of our available wind tunnel test time in the NASA research center facilities. This is very valuable to NASA. It brings us face to face with the problems of application of advanced technology and since the military is a user of advanced technology, working with them enhances getting new technology into new vehicles.

So much for that, I will proceed now and talk about our cooperative programs. First is the rotor systems research aircraft. You will recall that is a unique vehicle and the principal feature is it has a balance system inside the structure between the test rotor and the vehicle itself; so we can measure all of the forces on a test rotor much as we can in a wind tunnel except that it is in the real environment of flight.

## **NASA/DOD INTERACTIVE PROGRAMS**

- **SUPPORT OF MILITARY DEVELOPMENTS**
- **DOD/NASA COOPERATIVE EFFORTS**
  - **ROTOR SYSTEMS RESEARCH AIRCRAFT**
  - **TILT ROTOR RESEARCH AIRCRAFT**
  - **HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY**
  - **ADVANCED MEDIUM STOL TRANSPORT**
  - **LIFT/CRUISE FAN AIRCRAFT TECHNOLOGY**
  - **HYPERSONIC AIRCRAFT TECHNOLOGY**

**NASA SUPPORT OF MILITARY**  
**NAVY F-14 IN LANGLEY TRANSONIC DYNAMICS WIND TUNNEL**

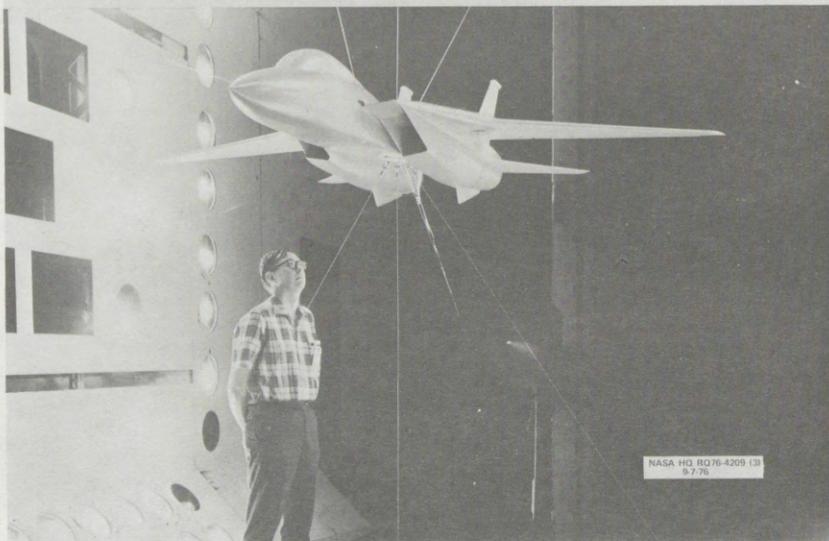


FIGURE 2

**ROTOR SYSTEMS RESEARCH AIRCRAFT**  
**JOINT NASA/ARMY PROGRAM**



FIGURE 3

The vehicle is shown here—figure 3—during the rollout ceremony last June. The scheduled first flight is planned for next week, I believe they are scheduling now on the 21st, which is 1 week from today. We hope to make that. The Government flights will begin about next November 1977.



FIGURE 4

The tilt rotor research aircraft is shown in figure 4 as it was being transported from the assembly plant to the systems test hangar. It is shown here with the nacelles tilted to the hover position. The rotors are not shown, since they are not necessary for the systems test. However, they have been fabricated and are ready for installation.

Subsequent to the picture shown here, during the test we ran into some problems in the control requiring some design change. Those things have been resolved. Prior to that there was a transmission problem in some of the gearing but that has been rectified and new transmissions are being assembled at the present time.

The first flight of this aircraft is scheduled for about next March and will be available, like the RSRA, about November 1977 for Government research flights.

Looking at highly maneuvering aircraft technology—you may recall this is a program in which we are attempting to integrate various technology advances into a superior maneuvering vehicle like the

## HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY (HIMAT) PROGRAM

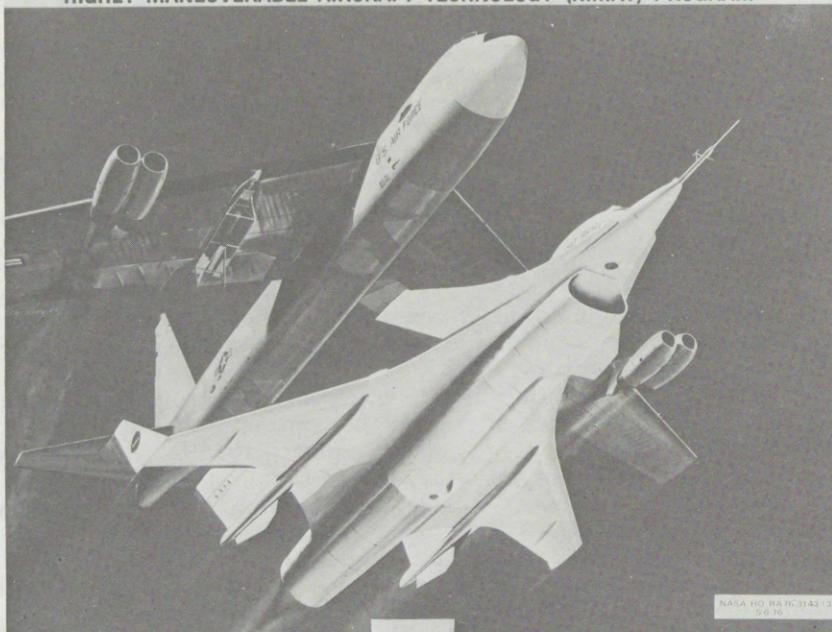


FIGURE 5

fighter. The vehicle shown in figure 5 appears as it will be dropped from the B-52, about April 10, the scale of a full-scale fighter. The idea of the program is to integrate such things as advanced wing airfoil shapes, advanced materials in advanced structures, coupled with the utilization of active controls and the integration of the propulsion system. This hasn't been attempted to this degree before.

### HIMAT PROGRAM DEFINITION OF GOALS

M 0.90

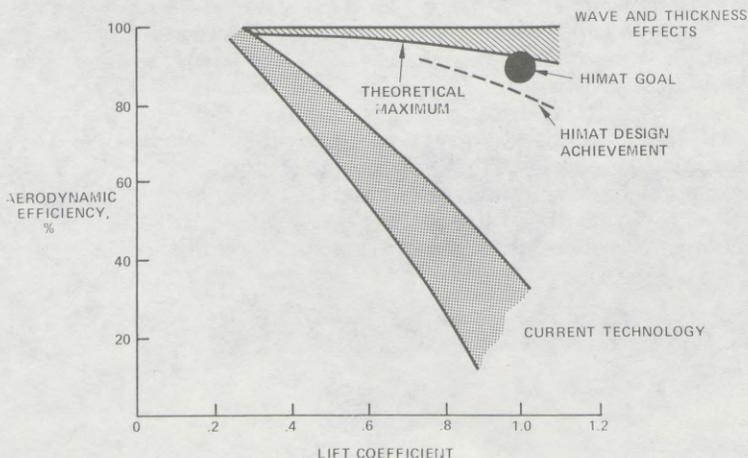


FIGURE 6

I would like to describe significant progress we have made subsequent to our hearings last February. Figure 6 is a chart depicting the aerodynamic efficiency plotted versus the lift of the airplane. You can imagine this as angle of attack. Efficiency obtainable by current technology is shown. The peak efficiency you can hope for and this, of course, is 100 percent.

Today, aircraft are designed to approach maximum efficiency at a given design point and at angle of attack the efficiency deteriorates as shown. However, if we can vary the geometry of the vehicle and use the effects of propulsion, and active controls, and so forth, hopefully we can maintain high efficiency with variation in lift or angle of attack.

For the HIMAT program, we set a goal as shown. One problem we had was that there was no design methodology available for integrating the current technology.

A team was put together involving people from Langley Research Center, Ames Research Center, and the contractor's design team to solve the problem. They worked for about 6 months, developed a design methodology and we were able to obtain a predicted design performance such as shown. This is where we were at the preliminary design review in May.

This is a significant achievement and could be applicable to all classes of aircraft, although there is some work needed to make it applicable in a general sense to all classes of aircraft.

The HIMAT program is proceeding well. The final design will be reviewed in mid-November and the fabrication of the vehicle will be accomplished during fiscal year 1977.

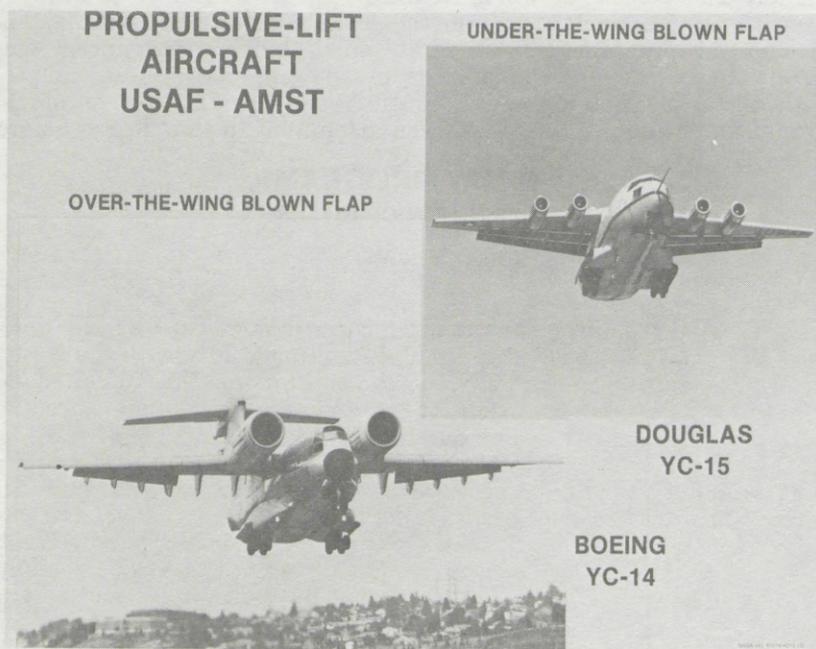


FIGURE 7

Figure 7 depicts the AMST, the advanced medium STOL transport program. This is a cooperative NASA/Air Force program. We are working piggyback on the Air Force flight program. We have installed instrumentation to measure the acoustic effect of the jets on the structure, the heating effects of the jet exhaust on the wing, the noise in the fuselage and the cabin, and also on the sound under the flight path.

The YC-15 has completed its flight test and the data is now being analyzed and compared with traditional techniques from analysis and wind tunnel tests. We are just beginning flights with the YC-14 and they will be conducted in the next few months.

**NASA**

National Aeronautics and  
Space Administration

Headquarters  
Washington, D.C.

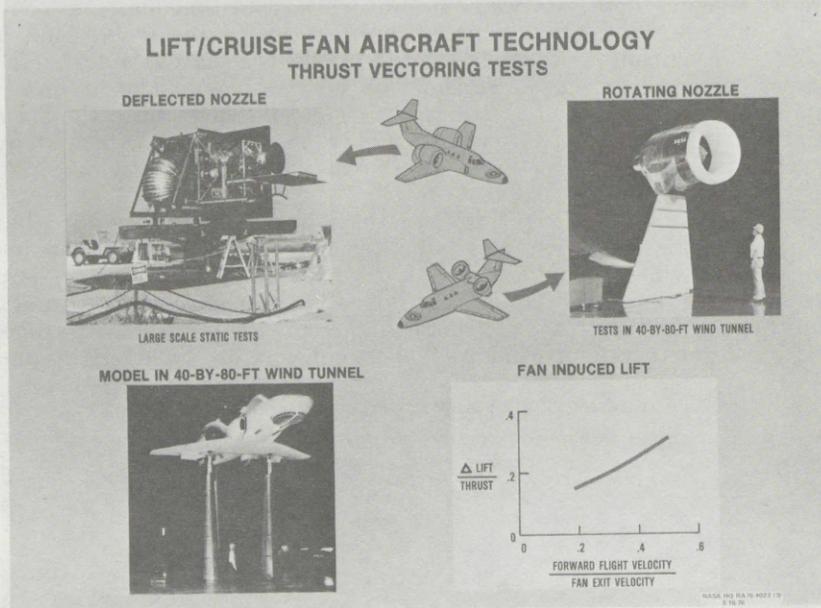


FIGURE 8

Turning now to lift/cruise fan aircraft technology shown in figure 8, this is a program that we have been conducting jointly with the Navy. NASA, of course, has conducted studies on lift-fan aircraft for many years and the lift fan is currently emerging as a very good contender for high performance subsonic aircraft.

The Navy has become interested within the last 2 years and we were working jointly with them on the technology in this area. In fact, the Navy study was completed last June on the use of VTOL and the Navy recommended highly that the lift-fan concept be pursued.

Shown in the chart is a sketch of what a typical airplane might look like. There are large fans mounted in the nacelles and in the concepts shown there are fans mounted also in the nose for pitch control. One concept shows the thrust deflected downward through the nozzle for obtaining lift and for the others the nacelles are rotated.

These fans can be driven either by shafting or by hot gases conducted to turbines mounted on the tips of the blades. In any case, all the concepts use either the titled nacelle or the deflected nozzle and we are looking at both. Shown are photos of large-scale test vehicles on a sound test standard in the 40 by 80-foot wind tunnel.

We are also looking at various conceptual designs—shown is C model in the 40- by 80-foot wind tunnel. Also shown is some data which shows some of the value of the concept. Shown is the lift achieved that is in excess of the lift obtainable simply from the thrust of the fans. These large fans draw air over the wing and, in doing so, create lift.

Mr. WYDLER. Let me ask you something. I was at an airshow out in Nassau County where they had a plane called the Harrier. What are we learning here that we could not learn from that aircraft?

Mr. EVANS. We have flown that aircraft quite extensively. That is a different concept. It takes fan air and deflects it and also takes the jet-core air and deflects it. It is a very good concept. The lift fan is more efficient because of the augmentation obtainable from the large fans. In other words, the power put into the fans is augmented by turning the fans and getting a greater efflux of air than you would just by ejecting the jet exhaust.

Mr. SMYLYE. A. J., isn't this the situation, if I may interrupt, that the Harrier aircraft is a pretty good airplane for the peculiar mission that the Marines need for close air support on the beaches. It is a low payload, short range, but very effective, maneuverable aircraft. And for the further Navy needs for higher payload and longer range, you have got to get for a more efficient concept of VTOL flight and

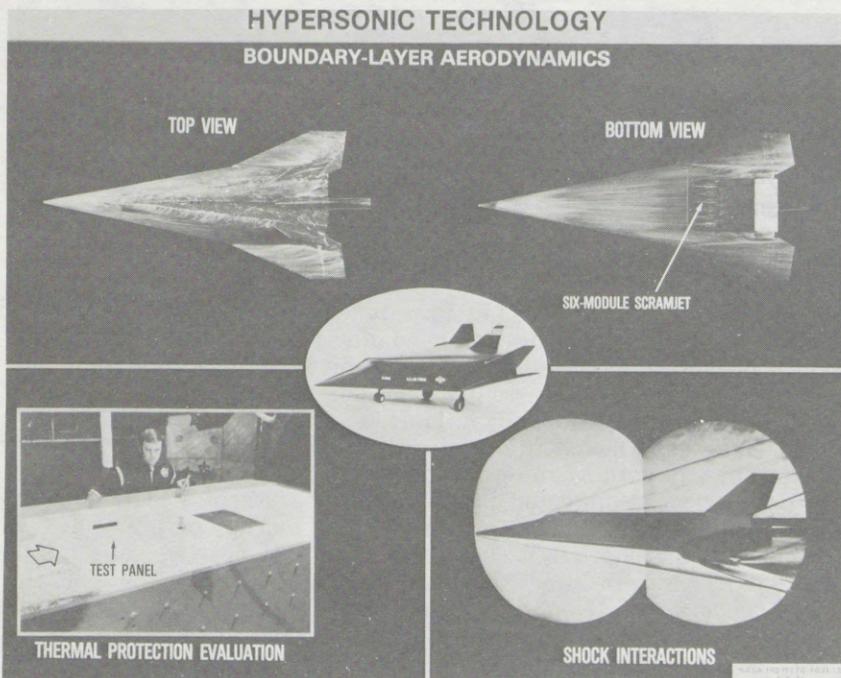


FIGURE 9

this is a concept toward doing that. So each airplane, or each concept, has its own peculiar mission applicability. But we are flying the Harrier aircraft in the U.S. military.

Mr. EVANS. This technology is forming the basis for some preliminary design studies that will take place during fiscal year 1977, again jointly with the Navy.

Finally, turning to hypersonic aircraft technology, shown in figure 9, this is a program in which we have been working jointly with the Air Force. Shown is an illustration of some of the technology being pursued.

Today we are studying hypersonic boundary layers and the interactions of the shock waves, the configurations and integration of propulsion system in the configurations. At hypersonic speeds, the body of the airplane becomes an integral part of the propulsion system. It is very thoroughly integrated. We are also looking at thermal protection systems and structural concepts for the vehicle. Shown is an illustration of a promising configuration.

Preliminary design studies of various configurations will be undertaken in fiscal 1977 and will provide the foundation and a basis for making a decision with regard to future planning for a research aircraft.

That concludes what I have to say.

Mr. MILFORD. Thank you, Mr. Evans.

[The prepared statement of Mr. Evans follows:]

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PRESENTED BY WITNESS

SEP 14 1976

NASA/MILITARY COOPERATIVE PROGRAMS

Statement of

Albert J. Evans  
Director, Research Aircraft Programs

Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

This statement will provide a report of progress subsequent to NASA's Authorization Hearings held in February 1976 for programs which are conducted cooperatively with the military and will briefly outline current plans for FY 1977.

As indicated in Figure 1, NASA's military oriented programs can be placed in two classes: the first is support in response to direct requests by making facilities and technical capabilities available to a military service in support of specific development programs. The second class is cooperative efforts to which both agencies contribute and for which there is usually a written agreement. Six major cooperative programs are listed in Figure 1 and each is discussed in some detail later herein.

Referring to NASA's support of military developments, such support, which is typified by NASA wind-tunnel tests of the F-14 (Figure 2), has utilized about 18 to 20 percent of NASA's available wind-tunnel test time over the past few years. This association with new military programs is important to NASA. Most military developments involve the application of advanced technology and NASA's involvement provides a unique opportunity to participate in its application.

The remainder of this statement will be a progress and status report of our cooperative activities.

The joint Army/NASA Rotor Systems Research Aircraft (RSRA) are currently being made ready for initial flight test at the contractor's facility. Rollout of the first vehicle took place on June 7, 1976. A photograph of the vehicle taken at the rollout ceremony is presented in Figure 3.

A unique feature of the RSRA is the special load measurement capability built into the vehicle's primary structure. For the first time, a helicopter will be available that has been designed from the start with research capability in mind. Devices have been built into the main rotor support structure to enable accurate measurement of rotor forces in flight just as is done with a wind-tunnel balance system. Wing, tail rotor, and auxiliary engine force measurement systems are also incorporated in the vehicle. This will allow the lift and drag of the rotor system being tested to be measured and controlled in level flight and during maneuvers. The calibration of the measuring systems will be accomplished in FY 1977.

The first hover flight of the RSRA is scheduled for mid-September. The schedule for the remainder of the program to the initiation of flight research with the RSRA in late 1977 is presented in Figure 4.

Another joint Army/NASA program is the Tilt Rotor Research Aircraft. A photograph of the Tilt Rotor Research Aircraft being transported to the contractor's ground-test facility for systems tests is shown in Figure 5. The engines are shown tilted in the hover position. The 25-foot rotors, although not shown in the photograph, are completed and ready for installation for ground tie-down tests scheduled for about January 1977.

Since last February's Authorization Hearings, we have experienced difficulties in the fabrication of the engine-to-rotor transmission gearing but these have been resolved and initial hover flights by the contractor are scheduled during March 1977.

Figure 6 presents a milestone schedule of events for the remainder of the program to the initiation of NASA/Army proof-of-concept flights in late 1977.

The Highly Maneuvering Aircraft Technology (HiMAT) Program is a joint Air Force/NASA effort to integrate advanced technology concepts into a superior fighter aircraft design and to flight test a scaled, unmanned, remotely piloted model of the vehicle. A sketch of the HiMAT vehicle being dropped from its B-52 "mother ship" is shown in Figure 7. The HiMAT vehicle is about a 4/10-scale model of a full-scale fighter aircraft. Subsequent to our Authorization Hearings, significant progress in the HiMAT program has resulted in a substantial contribution to advancing the state of the art of design methodology.

A goal of the HiMAT program is to combine technology advances in several technical disciplines in such a way as to effect favorable interaction between them, e.g., advanced aerodynamic wing concepts, new structural design concepts to utilize the unique characteristics of new materials, and advanced aircraft control concepts. Specifically, the goal, as illustrated in Figure 8, is to obtain a design value of aerodynamic efficiency about twice that currently achieved with good designs, i.e., to approach the maximum obtainable as indicated by theory.

Traditional design procedures and methodology could not accommodate the needed integration of the various disciplines. To solve this problem, a Government/contractor team was established with participation by the Ames Research Center aerodynamics and design personnel who were developing new computer design techniques, Langley Research Center aerodynamics and structural design personnel and the contractor design teams.

Six months of concentrated effort by the Government/contractor design team resulted in the refinement of design methodology that has achieved the HiMAT design overall performance characteristics very near the goal, as shown in Figure 8.

The techniques and methods developed and used in designing HiMAT can be made applicable to the design of most other classes of aircraft. The effort required to go from the specific case (HiMAT) to the general case (all classes of aircraft) should not be underestimated. What we have accomplished in the HiMAT program, however, is a significant step.

The HiMAT program is proceeding very well and according to the schedule shown in Figure 9. The Preliminary

Design Review (PDR) was held May 10-12, 1976. The next major milestone is the Critical Design Review (CDR) scheduled for mid-November. Construction of the vehicle will be essentially completed during FY 1977.

NASA's participation with the Air Force in the Advanced Medium STOL Transport (AMST) flight-test evaluation program affords NASA the opportunity to acquire flight data for such STOL transports in addition to supporting the Air Force's development of the prototypes. This participation includes planning and conducting of specialized flight experiments for which special NASA instrumentation has been installed. In addition, NASA will have access to all the flight data being obtained by the Air Force. A picture of the two AMST aircraft is shown in Figure 10.

NASA participation in the USAF AMST flight evaluations is yielding valuable research data and has also been of direct benefit to the Air Force program. Since our Authorization Hearings last February, aerodynamic and acoustic loads have been measured on the McDonnell-Douglas YC-15 in critical areas of the flaps and fuselage. These measurements will be compared with predicted values (based on static test data and analytical methods) for aid in development of improved methods for design for acoustic fatigue. Handling qualities and operational techniques of the YC-15 are currently being assessed by NASA pilots with various levels of stability augmentation for comparison with STOL handling qualities criteria and flight simulation results.

Flyover noise measurements as a function of flight path are being made and sideline noise levels during takeoff and landing will be determined. Measurements will be made of the acoustic environment in the aircraft crew compartment and in the main fuselage area to assess the effects of acoustic treatment of the fuselage walls.

A series of flight measurements on the YC-14 similar to those obtained during the YC-15 flight test program will begin in early FY 1977 and will include flight characteristics, aeroacoustic loads in critical areas of the flaps and fuselage, nacelle internal acoustics and fuselage cabin and exterior noise.

The primary interest among the military in VTOL Technology lies with the Navy. The Navy's needs provide a focus for NASA's research efforts and in recent years,

we have had a joint activity with the Navy in pursuing VTOL propulsion, aerodynamics, and control system technology.

The lift/cruise fan concept has emerged as one well suited for Navy purposes because of its potential for providing VTOL capability for high-speed, high altitude, long-range aircraft.

Two lift/cruise-fan configurations are shown in Figure 11 in the center of the figure. In both of these configurations, a lift-fan is mounted in the nose of the aircraft for trim and pitch control in hover and low-speed flight. The nose fan and the fans in the rear nacelles can be powered either by hot gases ducted to drive a tip-turbine at the outer edge of the fans or they can be driven by shafting. Some proposed vehicle designs do not incorporate a remote nose fan; however, all use either a deflected exhaust to provide lift from the main nacelles or the nacelles are tilted to thrust downward.

Refinement of the conceptual vehicle design studies, which were described during our FY 1977 Authorization Hearings, is continuing. Also continuing are fan design studies. These studies and analyses are part of a Navy/NASA Lift Cruise Fan Aircraft Technology program, which is broadly illustrated in Figure 11. Static ground stand and wind-tunnel tests have been conducted on the deflected nozzle shown in a ground-test stand in the upper left of the figure and on the tilt nacelle shown mounted in the 40 X 80-Foot Wind Tunnel at the Ames Research Center in the upper right of the figure. In addition, low-speed wind-tunnel tests have been completed on models of three aircraft design concepts. Tests of a large-scale powered model, shown mounted in the Ames 40 X 80-Foot Wind Tunnel in the lower left of Figure 11 have been conducted and some results of the tests are presented on the lower right. These test results show that the engines, in drawing air over the wing and into the inlet, create a  $\Delta$  lift on the wing, as shown in the figure. This is a synergistic benefit, or bonus lift, which increases as forward flight velocity (aircraft speed) is increased.

Finally, I will mention that NASA's Hypersonic Technology Program is proceeding as described last February. Studies and experimental tests, some of which are illustrated in Figure 12, are directed primarily to aerodynamic configurations and thermal protection

concepts. The results of this work are being used to provide the basis for three contracted preliminary design studies to define the configuration, cost, and technical risk areas for a hypersonic research aircraft. The preliminary design studies will be conducted during FY 1977 and will provide information necessary for a decision by the Air Force and NASA as to whether to proceed with planning for a research aircraft in the future.

## NASA/DOD INTERACTIVE PROGRAMS

- SUPPORT OF MILITARY DEVELOPMENTS
- DOD/NASA COOPERATIVE EFFORTS
  - ROTOR SYSTEMS RESEARCH AIRCRAFT
  - TILT ROTOR RESEARCH AIRCRAFT
  - HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY
  - ADVANCED MEDIUM STOL TRANSPORT
  - LIFT/CRUISE FAN AIRCRAFT TECHNOLOGY
  - HYPERSONIC AIRCRAFT TECHNOLOGY

FIGURE 1

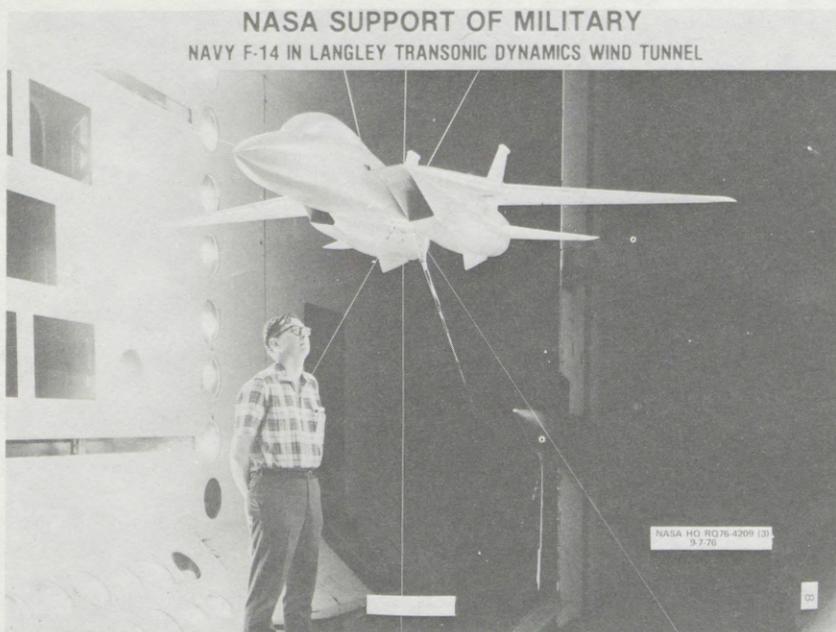


FIGURE 2

**ROTOR SYSTEMS RESEARCH AIRCRAFT  
JOINT NASA/ARMY PROGRAM**



**FIGURE 3**

**ROTOR SYSTEMS RESEARCH AIRCRAFT  
JOINT NASA/ARMY PROGRAM**

**MILESTONE SCHEDULE**

- **ROLLOUT OF AIRCRAFT NO. 1** **JUNE 1976**
- **FIRST HOVER FLIGHT (HELICOPTER CONFIGURATION)** **SEPTEMBER 1976**
- **FIRST FLIGHT IN COMPOUND CONFIGURATION  
(WING AND AUXILIARY ENGINES ADDED)** **MARCH 1977**
- **START GOVERNMENT FLIGHT RESEARCH** **NOVEMBER 1977**

**FIGURE 4**



FIGURE 5

## TILT ROTOR RESEARCH AIRCRAFT JOINT NASA/ARMY PROGRAM

### MILESTONE SCHEDULE

- |   |                |
|---|----------------|
| • EXPLORATORY HOVER FLIGHTS   | MARCH 1977     |
| • TRANSITION AND FORWARD FLIGHT TESTS OF NO. 1 AIRCRAFT IN 40- BY 80-FT WIND TUNNEL | JUNE 1977      |
| • BEGIN CONTRACTOR FLIGHT TEST PROGRAM  | SEPTEMBER 1977 |
| • START GOVERNMENT PROOF-OF-CONCEPT FLIGHT TEST PROGRAM                             | NOVEMBER 1977  |

FIGURE 6

## HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY (HIMAT) PROGRAM

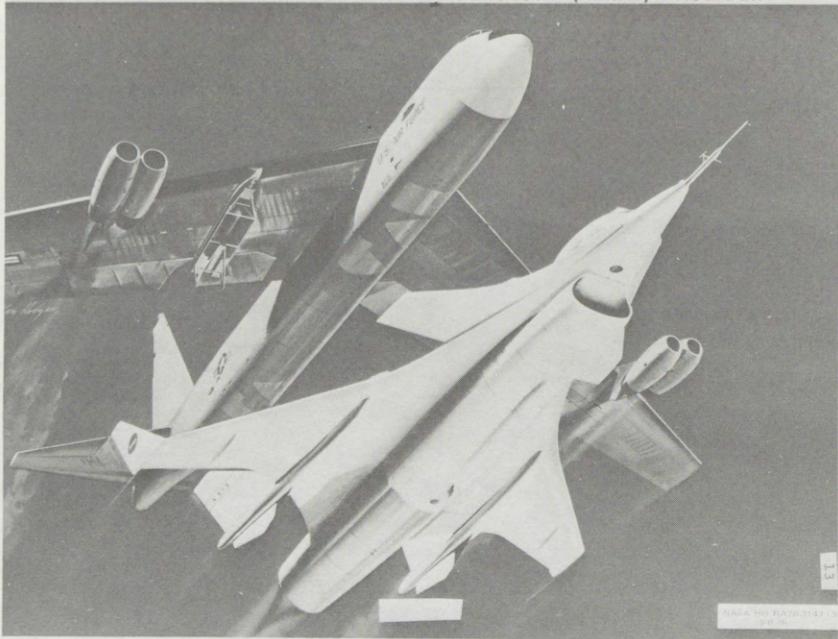


FIGURE 7

## HIMAT PROGRAM DEFINITION OF GOALS

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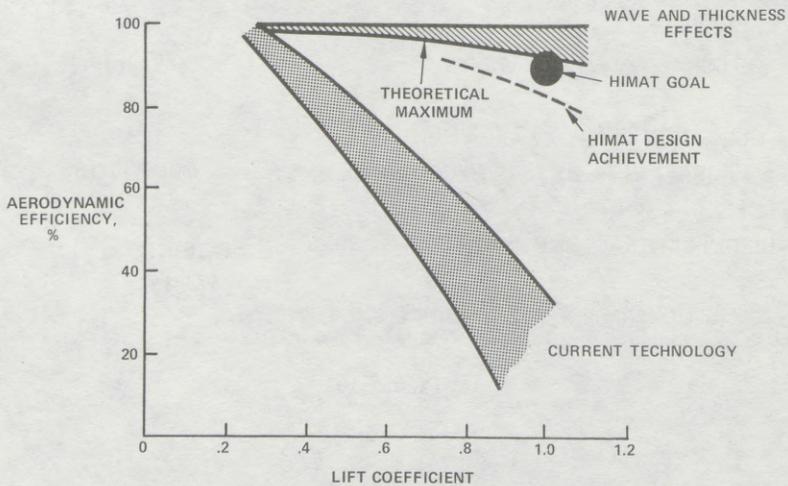


FIGURE 8

# HIMAT PROGRAM SCHEDULE

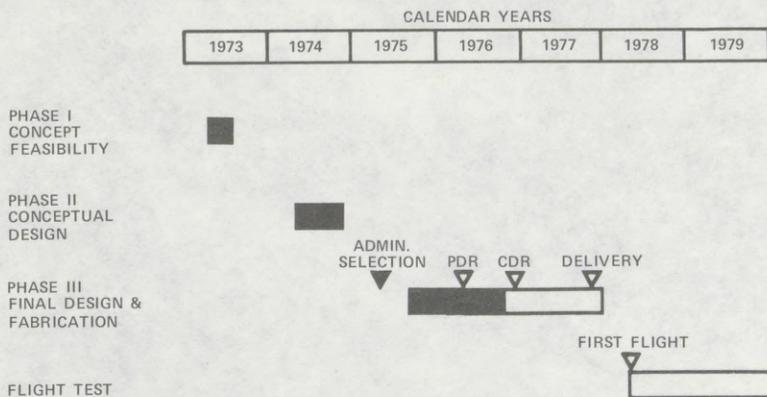


FIGURE 9

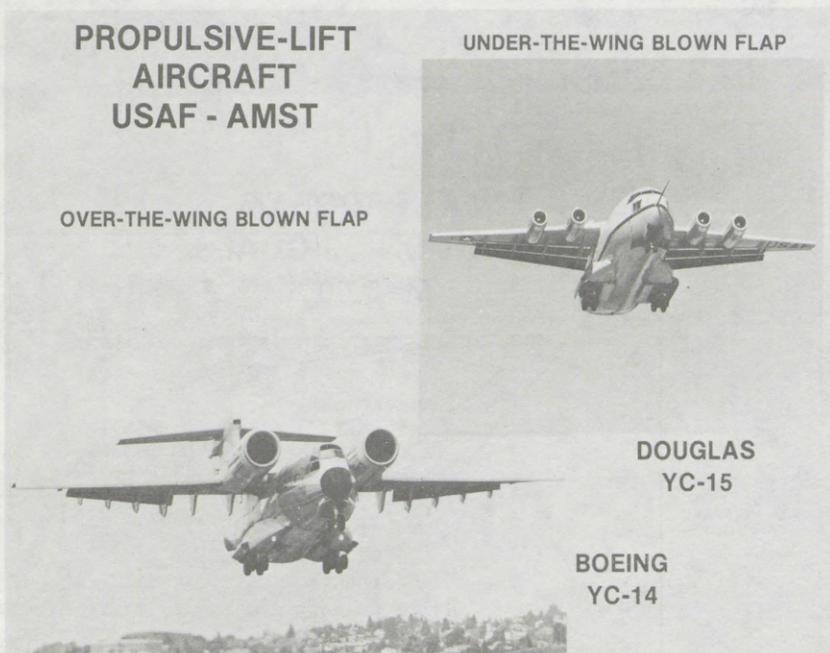
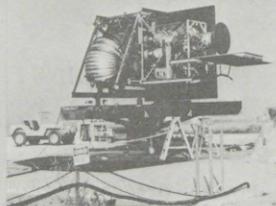


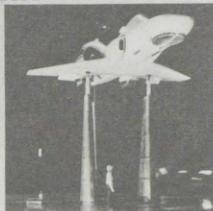
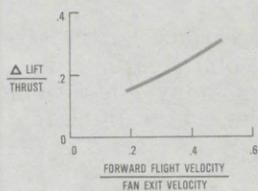
FIGURE 10

**LIFT/CRUISE FAN AIRCRAFT TECHNOLOGY  
THRUST VECTORING TESTS**
**DEFLECTED NOZZLE**


LARGE SCALE STATIC TESTS


**ROTATING NOZZLE**

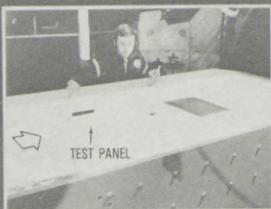

TESTS IN 40-BY-80-FT WIND TUNNEL

**MODEL IN 40-BY-80-FT WIND TUNNEL**

**FAN INDUCED LIFT**

 NASA 183 18A 16 8027 10  
17

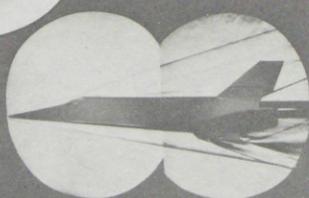
**FIGURE 11**
**HYPERSONIC TECHNOLOGY  
BOUNDARY-LAYER AERODYNAMICS**
**TOP VIEW**

**BOTTOM VIEW**


SIX-MODULE SCRAMJET



TEST PANEL

**THERMAL PROTECTION EVALUATION**

**SHOCK INTERACTIONS**
**FIGURE 12**

Mr. SMYLLIE. If there are no questions at this time, our next speaker, Mr. Chairman, is Mr. Harry Johnson, Director of the OAST aeronautical propulsion division, who will update you on our programs and progress in aircraft noise and exhaust emission reduction research.

Mr. MILFORD. Mr. Johnson, we have your complete statement with attachments which will be accepted at this point for the record. You may proceed in any way you would care to.

#### STATEMENT OF HARRY W. JOHNSON, DIRECTOR, AERONAUTICAL PROPULSION OFFICE, OAST, NASA

Mr. JOHNSON. Thank you, Mr. Chairman.

I do not think I need to state the importance of this subject to this committee. You have been very supportive of our programs, and we have attempted to respond with a variety of activities over a variety of different topics ranging from basic research to large-scale hardware demonstrations.

On past occasions I have attempted to describe the details of the program in some depth. I do not think it is appropriate for me to try to do that today, and I would like to concentrate my presentation on four topics that I think might interest you as an interim report for today.

#### AIRCRAFT NOISE AND EXHAUST EMISSION REDUCTION RESEARCH SELECTED TOPICS

Psychoacoustic studies.

Quiet, clean, short-haul experimental engine (QCSEE).

Quiet, clean, general aviation turbofan (QCGAT).

Piston engine emissions reduction for general aviation.

FIGURE 1

These four topics that I will describe are shown here in figure 1. I will give you a brief update on progress in our psychoacoustics program at the Langley Research Center and then talk briefly about three experimental hardware programs for noise and emission reduction which are conducted out of the Lewis Research Center.

### PSYCHOACOUSTIC STUDIES AT LANGLEY RESEARCH CENTER

- EFFECT OF PERSONAL BACKGROUND/ENVIRONMENT ON SUBJECTIVE EVALUATION
  - VIRGINIA AND NEW YORK RESIDENTS TESTED
  - PERSONAL ATTITUDES ARE SIGNIFICANT
  - OTHER GROUPS WILL BE TESTED

FIGURE 2

The program at the Langley Research Center on psychoacoustics has had a variety of different approaches (figure 2). Recently we have completed studies which examined some of the effects of personal backgrounds of individuals, their own orientations and their living environments as they respond to noise and annoyance of aircraft noise.

Thanks to you gentlemen we have been able to identify residents of New York who, along with residents from the Hampton, Va. area, have been subjected to the same kind of laboratory noise exposures. Differences and similarities in their reactions were noted. This first phase of the work is completed, and, in fact as one might expect, there have been differences in attitudes and responses depending on individual backgrounds. The results are being digested and will be reported publicly. This work will be continued.

Mr. WYDLER. May I clear up one thing about those tests. Do I understand that you have a certain limitation on the noise level you can subject those people to?

Mr. JOHNSON. Yes, sir, there are limitations on the noise.

Mr. WYDLER. What are the limitations?

Mr. SMYLLIE. 95 dBA, I believe.

Mr. WYDLER. Could we understand why it is limited to 95?

Mr. SMYLLIE. Let me respond to that and ask Mr. Lyman to add to it if there is anything further to add.

The research facility is set up based on industrial standards for extended noise exposure so that 95 dBA for 4 hours continuous exposure is the OSHA requirement, and the research facilities are operated on the basis of the OSHA requirement for continuous exposure to noise levels. So we have adopted that standard for use in that facility. I might note also that most of our research is aimed at the effect on people inside residences. The maximum levels there which we have used in our Columbia studies—based on what the exposure is in the true environment—indicate about 86 dBA is sufficient. Thus, we are well within the capability to handle the noise exposure levels inside residences.

Mr. WYDLER. What do you have to say, Mr. Lyman?

Mr. LYMAN. I would say essentially the same thing that Mr. Smyllie did.

Mr. WYDLER. You tell me why do you limit it to 95 dBA?

Mr. LYMAN. All NASA facilities are man-rated if you will. This man rating process involves a fairly rigorous analysis of the design features and the operative procedures. Industrial standards are applied routinely during the course of this analysis to insure that it is safe in a man-rated sense.

Mr. WYDLER. What do you mean by safe?

Mr. LYMAN. It satisfies known criteria for human exposure. It could involve, for example, such things as stress analysis of the structure of the floors. Are they adequate to support the weight of the people that would be there? Are the welding practices safe? So it is man rated in the sense that it is safe for human involvement.

The noise level within the laboratory was set at 95 dBA because it corresponded with the OSHA standard for safe continuous exposure at a given noise level, that is, 95 dBA for 4 hours. In the laboratory we never expose people to any noise level for more than perhaps a moment

or two, let us say a maximum of 1 minute. So 95 is arbitrary but absolutely safe from the point of view of any possible hearing damage consideration.

Mr. Smylie did mention that our concern is directed toward understanding how people respond to noise within their homes. We are concerned about people's attitudes about noise formulated within the home. That is where the general attitudes about noise are developed.

Typically, say 1 mile from the end of the runway and inside the home, 86 dBA is totally adequate to study all the conditions. So within the Langley facility you might say we have the capability to go even higher than what people are normally exposed to in their homes.

Mr. MILFORD. Are you possibly saying that there might be a possibility of subjecting the U.S. Government to certain liabilities if you exceeded these limits?

Mr. LYMAN. Yes, these are based on industrial standards—

Mr. MILFORD. If by staying at this level you are able to determine scientifically what you are looking for, but by going above that level, you might subject the Government to liability for hearing damage or claims of hearing damage?

Mr. LYMAN. There are two points to that answer. First of all the 95 dBA is totally adequate for us to conduct all of our research. Getting into the realm of human research, one can extend the exposure into regions which are considered potentially unsafe or unknown with respect to the consequences to the subjects. But there are very carefully prescribed rules and regulations about how you expose people to conditions that may harm them in some way.

In this particular system we are not even approaching these conditions.

Mr. MILFORD. Thank you.

Mr. WYDLER. Well, I congratulate you on the care you take. It is only a shame that we do not take as much care for the people that really have to live around the airport. We are willing to expose them to much more noise than that apparently. It is very nice that in the laboratory conditions you took this into account, but it makes you wonder why the heck the Government allows the areas around these airports to be exposed to a greater level than that in their own homes. Thank you.

Mr. JOHNSON. I would like to proceed into one of our experimental programs.

## QCSEE PROGRAM OBJECTIVE - TECHNOLOGY FOR ADVANCED HIGH BYPASS RATIO PROPULSION SYSTEMS

- FOR JET-STOL
  - UNDER THE WING BLOWN FLAP
  - UPPER SURFACE BLOWN FLAP
- FOR FUTURE CTOL
- TECHNOLOGY OBJECTIVES
  - LOW NOISE: 90 EPNdB FOOTPRINT < 1 SQ. MI.
  - LOW EMISSIONS: 1979 STANDARDS
  - LOW WEIGHT:  $T/W > 6$
  - LOW FUEL CONSUMPTION: TSFC 0.32

FIGURE 3

The first of these is QCSEE, as it is usually called which refers to the quiet, clean, short-haul experimental engine (fig. 3). This is in its third year, being developed for NASA under contract by the General Electric Co.

The technical objectives of this program are really all tied into the concept of developing and demonstrating technology for high bypass ratio propulsion systems primarily aimed at the jet-STOL applications that have been described in earlier testimony. Dr. Kramer and Mr. Evans described certain types of these aircraft, with both under-the-wing and over-the-wing engine applications. Nevertheless there are many technological features of the QCSEE engine which will find their way, we suspect, into advanced engines for conventional or CTOL type engines.

This program's technology objectives for noise correspond to a 90 EPNdB aircraft noise foot print area contained within 1 square mile around the airport. For low emissions, QCSEE will incorporate technology to meet at least the 1979 standards proposed by the EPA for this type of aircraft. Its high efficiency is represented by high thrust to weight ratio, that is, high for this type of engine, and by low fuel consumption. One of the benefits of the high bypass ration, of course, is reduced fuel consumption at lower speeds.

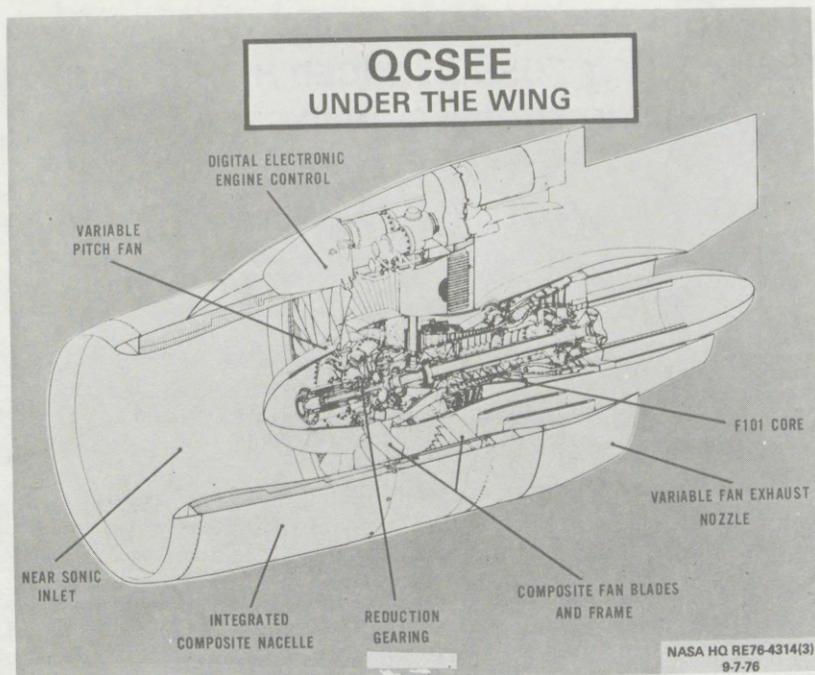


FIGURE 4

## QCSEE PROGRAM ADVANCED TECHNOLOGY

- LOW NOISE
  - HIGH BYPASS RATIO - LOW JET VELOCITIES
  - LOW FAN PRESSURE RATIO AND TIP SPEED
  - NEAR-SONIC INLET
  - OPTIMAL ACOUSTIC TREATMENT
  - INTERNAL DESIGN FEATURES
- LOW EMISSIONS
  - CLEAN COMBUSTOR DESIGN

FIGURE 5

The configuration is shown in figure 4, and some of the technological features that I would like to describe next are shown in figure 5. Low noise is produced by a variety of technological approaches. Very high bypass ratio produces low jet velocities. Low fan pressure ratio and tip speeds provide low forward emanating noise, augmented by the abilities of the near-sonic inlet to further contain noise which might otherwise come from the front of the inlet. Optimal acoustic treatment applications within the engine, and other appropriate internal design features further minimize the generation or emission of noise from the engine.

Low exhaust pollutant emissions are achieved, as I mentioned, through the use of appropriate technology from companion programs in clean combustors.

## QCSEE PROGRAM ADVANCED TECHNOLOGY

- COMPOSITES FOR LIGHT WEIGHT
  - FAN BLADES - LOW INERTIA
  - INTEGRATED STRUCTURAL/ACOUSTIC NACELLE AND FAN FRAME
- LOW PRESSURE RATIO, VARIABLE PITCH FAN
  - RAPID THRUST CHANGES (ACCELERATION)
  - THRUST REVERSING BY REVERSE PITCH
  - LOW NOISE SETTINGS
- INTEGRATED DIGITAL ELECTRONIC ENGINE CONTROL
- EFFICIENT, LIGHT WEIGHT REDUCTION GEARING

FIGURE 6

Other QCSEE objectives (fig. 6) include the use of composite structures for light weight, high stiffness and other advantages which were described in previous testimony. Ultimately the fan blades in the engine will be composites because of the low weight and low inertia features that they provide, but at the present time our principal objective has been to utilize the capabilities of composites for integrating structural properties and acoustic properties elsewhere. This has been done in this part of the engine (fan case).

The use of variable pitch fan blades is another attractive feature of this engine because it permits thrust modulation without changing wheel speed. This also provides for thrust reversing by changing the pitch, as done in propellers, without the addition of separate thrust reversers. Variable pitch also provides for minimizing noise generated by the fan for a given operating condition.

The use of a completely integrated digital electronic engine control system is a first in this engine. This engine also requires, because of the low fan tip speed, the use of efficient light weight reduction gears, of a type which has not been used in aircraft up to this point.

Mr. MILFORD. Let's go to the integrated digital electronic engine controls. What are you controlling?

Mr. JOHNSON. Well, there are a variety of features, Mr. Chairman, which must be controlled in this engine in addition to the normal shaft speeds and fuel flow. There is also, for example, a variable exit nozzle which is needed for this very low pressure fan to optimize the thrust production at any one particular condition. This must be adjusted to be compatible with the other features of the engine operation. Also the control of the pitch on the fan must be integrated so that it does not become a hunt-and-try process for setting the fan pitch for a given mode of operation. So you can see that in addition to the normal features that any engine would require for fuel flow control, there are these other mechanical devices which need to be integrated.



FIGURE 7

The first engine, the under-the-wing configuration depicted in figure 7, has been delivered in the last days of August to the GE Peebles test site, and it has been run successfully. This is a photograph of it.

Mr. WYDLER. What do you mean by run successfully?

Mr. JOHNSON. I mean that it has run without any incidents or problems which indicate that there is anything wrong with the design or manufacture of it, only very minor things such as the usual requirements—

Mr. WYDLER. You are not talking about the amount of thrust or noise you are getting out of it at this point.

Mr. JOHNSON. Noise levels have not been run yet, just functional tests insofar as my information is concerned. I don't believe there have been noise or emission measurements taken up to this point.

**QCSEE**  
**COMPOSITE STRUCTURE INTEGRATED ACOUSTIC**  
**NACELLE (FAN FRAME)**

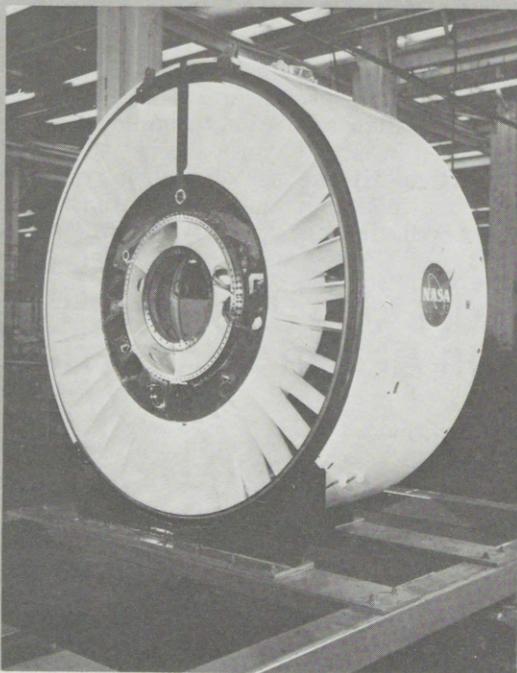


FIGURE 8

Figure 8 is a photograph of the integrated composite section of the fan case showing fan exit guide vanes which are integrated into it. This is a first. This is a very highly efficient, stiff, lightweight, composite structure.

Now I will turn to the second experimental program which was just initiated.

Mr. WYDLER. If I could just ask you now, what do you think it is going to do as far as noise is concerned?

Mr. JOHNSON. Well, to interpret the noise goals that we have set, as I mentioned earlier, you have to look at the airplane noise equivalent, not the engine noise. The airplane equivalent is approximately a 90 EPNdB noise footprint area of 1 square mile. This is the equivalent of about 95 EPNdB at 500 foot sideline, for example. If you tried to compare it—although it is a little difficult to do this exactly with conventional takeoff and landing operations—it would be approximately 25 to 30 EPNdB lower than present FAR 36 standards at the critical measurement points.

This would apply to the kind of applications that we would imagine for jet-STOL. Of course, there are steeper approaches and takeoffs which help this problem as well as just the lower noise generated within the engine itself. It is not as simple an answer, unfortunately, as I would like to be able to give.

Mr. WYDLER. It proves that when you have jet noise reduction it helps to have operating procedures integrated with the engine itself because you get the maximum amount of jet noise reduction.

Mr. JOHNSON. Yes, sir, that is correct.

Mr. WYDLER. OK. Thank you.

Mr. JOHNSON. This next project, which is just beginning, is an effort on our part to demonstrate the applicability and the usefulness in small engines—which will be used in and are used in general aviation—some of the noise and exhaust emission technology features which have been successfully used in large engines such as the type we have been talking about—particularly the use of higher bypass ratio fans and optimal acoustic treatment, low emission combustors and other features which would be useful, but typically not present, in these engines today. [figure 9].

## QUIET, CLEAN TURBOFAN ENGINES FOR GENERAL AVIATION

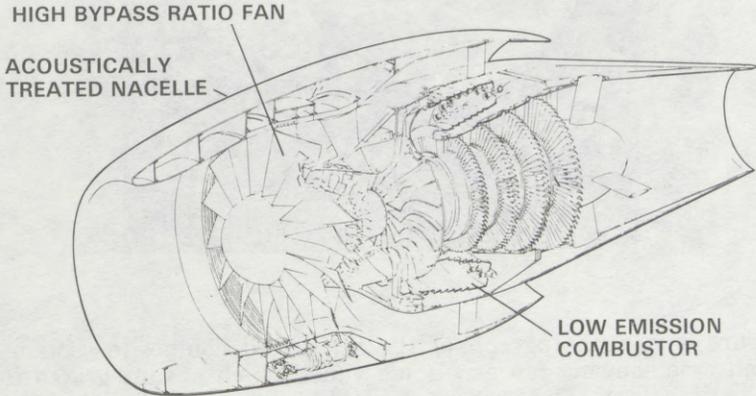


FIGURE 9

## QUIET, CLEAN GENERAL AVIATION TURBOFAN ENGINES

NOISE GOAL : FAR 36-20 EPNdB

EMISSIONS GOAL : BETTER THAN EPA 1979 STANDARDS

CONTRACTOR	AVCO LYCOMING	GARRETT AiRESEARCH
BYPASS RATIO	8.2	4.0
STATIC THRUST	1600 LB	4200 LB
CRUISE CONDITIONS MACH/ALTITUDE	0.6/25,000 FT	0.8/40,000 FT.

FIGURE 10

Figure 10 is a chart depicting first of all the noise goal as set forth in this project. It is approximately 20 EPNdB lower than present standards for aircraft using this type of engine. The emission goal would require the use of clean combustor technology, and would be equivalent to the 1979 standard.

We are, just now, this week, entering into negotiations with the AVCO-Lycoming Williamsport Division and the Garrett AiResearch Manufacturing Co. of Arizona for two experimental engines. These have different applications as ultimate objectives.

The AVCO-Lycoming approach is for a relatively low thrust engine which, by virtue of its very high bypass ratio design would be best suited for a mach 0.6 and 25,000 altitude cruise condition. This part of the general aviation market has never been exploited.

On the right is the Garrett AiResearch engine. It is a higher thrust engine as typically used in higher performance business jets, but with a higher bypass ratio fan than is currently used. It is suitable for the typical operating conditions for this type of airplane.

These programs are just now beginning; we expect to be under contract before the end of the year, and the experimental engines will be delivered to Lewis in 1979.

## EMISSION REDUCTION RESEARCH FOR GENERAL AVIATION PISTON ENGINES

- JOINT FAA/NASA PROGRAM
  - EFFECTS OF MINOR ADJUSTMENTS
- NASA CONTRACTS AND IN-HOUSE RESEARCH
  - HARDWARE DESIGN CHANGES
  - ADVANCED ENGINE DESIGNS

FIGURE 11

Finally, I will make some comments about another program [figure 11] which we embarked upon 2 years ago and which is currently receiving considerable attention. As a matter of fact, today and tomorrow a technology symposium is being held at the Lewis Research Center, hosted by NASA, in which industry, government, universities and other individuals in the private sector are participating, discussing the state of emissions reduction technology, results of experiments and the implications of the use of the technology. NASA, FAA, EPA, are all there today and tomorrow as well. As I said, the industry that is interested and involved in this problem.

The particular problem results from the fact that, generally speaking, piston engines used in general aviation, because of their design characteristics, have to be run fuel rich during low altitude operations [on the ground and during takeoff]. The additional fuel just does not

burn and the engine emits carbon monoxide and unburned hydrocarbons. Typically, engines that exist today will not meet the standards that have been set by the EPA for newly manufactured engines after 1979. So we have joined with the FAA in a program [figure 12] characterize engines that typically exist today and to explore what can be done through minor modifications or minor changes to fuel/air ratio.

## FAA/NASA JOINT PROGRAM - G.A. PISTON ENGINE EMISSIONS

### PHASE I

- PERFORM BASELINE EMISSION CHARACTERIZATION OF FIVE REPRESENTATIVE ENGINES BY EACH CONTRACTOR
- DETERMINE EFFECTS OF VARYING FUEL/AIR RATIOS AND IGNITION ON EMISSION LEVELS AND ENGINE OPERATION

### PHASE II

- ANALYSIS AND CONCEPTUAL DESIGN OF MINOR ENGINE MODIFICATIONS

### PHASE III

- LIMITED TESTING OF PROPOSED MODIFICATIONS

FIGURE 12

In addition to this we have a longer range effort. We are undertaking studies of more advanced techniques which could involve more extensive changes, or in some cases even new engine types which have not been used in this application before.

Some of the results of the NASA/FAA program are shown. These results, shown in figure 13, are for three sample engines which have been run. Now a little explanation is necessary, first of all, about the engines. Three types of engines are shown—the low performance normally carbureted types, the fuel injected types and finally the top of the line—turbosupercharged injected engines. Each one has its special problems.

## GENERAL AVIATION PISTON ENGINE EMISSION REDUCTION

(SAMPLE EMISSIONS AS PERCENT OF EPAP CYCLE 1979 LEVELS)

ENGINE TYPE	PRODUCTION ENGINE BASELINE			PRODUCTION ENGINE SET FOR LEAN OPERATION		
	CO	HC	NO <sub>x</sub>	CO	HC	NO <sub>x</sub>
CARBURETTED	255%	78%	13%	188%	65%	26%
FUEL INJECTED	218%	65%	2%	145%	62%	25%
TURBOSUPERCHARGED, INJECTED	300%	245%	4%	240%	230%	7%

FIGURE 13

Setting up the engine as it came with manufacturer's recommendations for operation, tests were run by each of the major manufacturers of these engines, Lycoming and Continental. These results are typical emission levels which were measured for these engines, expressed in terms of the allowable EPA landing and takeoff cycle standard for 1979. It seems that carbon monoxide is a problem in all of them and unburned hydrocarbons are a problem at least in one of them.

It was then examined what could be done through simply leaning the engine fuel/air ratio without endangering its use or causing its use to become hazardous, by fuel leaning during taxi modes but never leaning to a point where it really operated less than with a stoichiometric equivalence ratio of one, in other words, maximum power efficiency conditions. It was found that this could in fact reduce the production of carbon monoxide and to a limited extent unburned hydrocarbons as well. Those kinds of adjustments would not be adequate to meet the standards, and so obviously something else must be done if those standards have to be met.

Mr. WYDLER. Why did your last column go up?

Mr. JOHNSON. The oxides of nitrogen typically result from higher efficiency operations and this is an expression of the fact that we are operating with greater thermal and propulsive efficiency in these engines. It is an unfortunate byproduct. It is a common problem in a jet engine as well; in fact, it is seen in its extreme form in a jet engine.

Passing momentarily to an indication of the kind of things that NASA's more advanced technology and research programs are examining, this is a list of some of the things that we will be looking at. I won't try to explain each one, but they are all aimed either at increasing combustion efficiency in order to reduce carbon monoxide and unburned hydrocarbons or they are aimed at other things such as general improvements in the operation and usefulness of engines for general aviation. The items listed in figure 14 are modifications to conventional piston engines.

## NASA RESEARCH - G.A. ENGINE EMISSIONS (CONTRACT AND/OR IN-HOUSE)

- MODIFICATIONS TO CONVENTIONAL ENGINES
  - VARIABLE VALVE TIMING
  - HIGH ENERGY/VARIABLE/MULTIPLE SPARK IGNITION
  - FUEL VAPORIZATION
    - ULTRASONIC/THERMAL/AIR INJECTION
  - PULSED FUEL INJECTION
  - IMPROVED COOLING DESIGN
  - COMBUSTION CHAMBER DESIGN
  - HYDROGEN INJECTION/MIXED FUELS
  - ADVANCED ENGINE DESIGN

FIGURE 14

## NASA RESEARCH - G.A. PISTON ENGINE EMISSIONS REDUCTION (CONTRACT AND/OR IN-HOUSE)

- UNCONVENTIONAL AIRCRAFT ENGINE TYPES
  - DIESEL (2 AND 4 STROKE)
  - ROTARY COMBUSTION
  - STIRLING CYCLE

FIGURE 15

Figure 15 indicates some of the things that we are looking at for unconventional aircraft engine types; that is to say, aircraft engines which have not traditionally been used in aircraft. For example, both two-stroke and four-stroke diesel engines, the rotary combustion engine, and finally a new engine cycle which is referred to as the Stirling cycle, which has many interesting features. I won't try to describe it at this point, but it has potential advantages particularly with respect to emission reduction, significant improvement in the fuel consumption, and a broader range of fuel opportunities.

That concludes my report. Thank you.

Mr. MILFORD. Thank you very much, Mr. Johnson.

Mr. WYDLER. Thank you, Mr. Johnson. You have done an excellent job in this area.

Mr. JOHNSON. Thank you.

[The prepared statement of Mr. Johnson follows:]

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PRESENTED BY WITNESS  
SEP 14 1976

AIRCRAFT NOISE AND EXHAUST EMISSION REDUCTION RESEARCH

Statement of

Harry W. Johnson  
Director

Aeronautical Propulsion Division  
Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

During the February hearings we reported on our overall noise and pollution reduction programs and recent accomplishments. Today I would like to update that report and comment on certain specific activities and plans that should interest you.

First, a few words about program coordination. Coordination of our noise and emission reduction programs with other Government agencies is important because we want our research to address significant, timely issues, and to insure that research results gain maximum exposure. We continue to maintain close coordination with the Federal Aviation Administration (FAA) and Environmental Protection Agency (EPA) and to assist them in their assessments of technology readiness for regulatory purposes. Some recent examples include our review of FAA proposed noise abatement policies, and our consultation with both FAA and EPA on proposed exhaust emission standards for SST aircraft. We are also participating in two of the EPA's reactivated

noise assessment committees, chairing the Aircraft Noise Research Panel and having representation on the Noise Effects Research Panel.

Turning now to the general status of our noise and emission reduction programs, I would remind you that they cover a broad scope of research and technology. Research stresses the search for basic understanding of underlying principles, so that clues to possible ways to minimize both noise and pollutant emissions can be found. Building on research, technology programs explore the feasibility and potential effectiveness of realistic applications of attractive concepts for noise and pollution reduction. Today I will limit my report to a few highlights that should interest you (Figure 1).

Operational Techniques for Approach Noise Abatement. A promising technique now being studied for reducing community noise exposure along the approach path is based on delayed landing flap deployment. The concept is illustrated in Figure 2. This technique permits the engines to be throttled back and generate less noise as the aircraft decelerates along the approach glidepath, until the optimal time for landing flap deployment is reached. As we reported in February, flight tests and guest pilot evaluations of the Delayed Flap Approach in the NASA CV-990 aircraft had demonstrated significant fuel savings and noise benefits and the technique had received good pilot acceptance. Boeing and Douglas have now completed studies of the applicability of this technique to the B-727, DC-8, DC-9 and DC-10 aircraft, and their preliminary results suggest both fuel and noise benefits comparable to the CV-990 test results. With this encouragement we are beginning studies of the relative safety associated with this procedure.

Plans are also being made jointly with the FAA to assess the compatibility of the Delayed Flap Approach procedure with the Air Traffic Control (ATC) system. Real-time simulation experiments will be conducted in FY 1977 at Ames Research Center using airline

pilots and FAA controllers as participants. In addition, the FAA is planning a simulation at the National Aviation Facilities Experimental Center (NAFEC) in the Spring of 1977 to examine ATC procedures which promote fuel conservation in the approach phase of flight. The FAA has indicated that the Delayed Flap Procedure compatibility with ATC can be examined as part of that simulation. Finally, in addition to these plans, noise abatement flight procedures for advanced aircraft operating in an upgraded ATC system will continue to be one of the goals of the Terminal Configured Vehicle Program underway at the Langley Research Center.

Psychoacoustics Studies. Comprehensive studies are in progress at the Langley Research Center to understand how a person's previous experience with aircraft noise influences annoyance. Such knowledge will permit better use of laboratory data in predicting community response to aircraft noise and operations, and thus will be useful to the regulatory agencies as well as to those concerned with local airport operation and airport vicinity land use.

The experiment consists of a series of tests involving various aircraft sounds which the subjects judge as to loudness and annoyance, plus several tests to assess each subject's noise sensitivity and attitudes about aircraft noise and other environmental concerns. To better interpret the results, we are also documenting the character of each subject's neighborhood noise environment.

The first phase of the study has been completed. Selected Virginia residents having limited previous aircraft noise experience and New York residents having more extensive aircraft noise history of exposure have been tested.

Since February, we have also completed a study at Columbia University to assess the extent to which we could relate laboratory responses to community responses. One finding worth noting is that a

relationship between acceptability and annoyance is emerging which seems to relate to the fact that most people do not really expect a totally annoyance-free environment. A second finding of the study is that laboratory subjects tend to judge those test conditions comparable to their worst-day home experiences as equivalent. This finding offers new insight as to how community reaction to the total aircraft noise and operating environment should be assessed. Along this line we have also reanalyzed community response data from previous NASA studies. The reanalysis is examining the question of whether level and number of operations should be considered separate parameters in assessing overall community response.

While we consider the above findings important, they are tentative at this time. Over the coming year we will be working to refine and build upon them so as to provide better methods for assessing and predicting community response.

NASA's Quiet, Clean Short-Haul Experimental Engine (QCSEE) program at the General Electric Company is now in its third year. The first of two engines (shown in Figure 3) is currently under test and will be delivered to our Lewis Research Center next year. The second engine configuration is now being assembled and will enter test early next year.

The primary objective of the QCSEE program is to demonstrate major noise reduction technology along with other propulsion innovations in ground tests of both under-the-wing and over-the-wing engine configurations representative of possible future jet-STOL transports. The QCSEE engine noise objective is to provide the technology for a 4-engine, 150-passenger STOL aircraft to obtain noise levels less than 95 EPNdB at the 500-foot sideline distance.

The most significant advanced technology features we are incorporating in QCSEE are shown in Figure 4. I would call your attention particularly to the

variable pitch fan blades and the digital electronic engine control being incorporated in this engine; and to the fact that QCSEE will be the first engine ever to employ an advanced, acoustically designed, all-composite nacelle which is structurally integrated with the engine fan frame (Figure 5). We will continue to update you on our progress in this important program, which is demonstrating technology not only for future jet-STOL but also for advanced CTOL aircraft engines as well.

Quiet, Clean, General Aviation Turbofan (QCGAT). We are now entering into negotiations with both AVCO-Lycoming and Garrett-AiResearch for the experimental phase of the Quiet, Clean, General Aviation Turbofan program (Figure 6). This program will demonstrate the application of modern technology for noise and exhaust emission reductions in small turbofan engines. Our previous technology programs have addressed primarily the much larger engines used in commercial transport aircraft.

Figure 7 lists the basic QCGAT program objectives and the two different engine types we plan to investigate. The program with Lycoming will focus on the lower thrust, lower cruise mach number and altitude range of high performance general aviation, for which very high bypass ratio engines would be applicable. This engine will be based on the Lycoming LTS101 core. The AiResearch program will focus on the upper end of the high performance general aviation spectrum with respect to thrust level, cruise mach number and altitude. The engine will be based on the AiResearch TFE 731 turbofan. Both experimental engines should be completed and delivered to the Lewis Research Center in early 1979.

Piston Engines Emissions Reduction for General Aviation. Since 1973 we have been working with FAA to investigate what can be done to reduce exhaust pollutant emissions in existing types of internal combustion engines used by general aviation. Up

to this point, emphasis has been placed on studying relatively minor adjustments and changes which might be implemented in a relatively short time. The joint FAA-NASA program is supporting investigations by AVCO-Lycoming and Teledyne-Continental, with additional testing done at FAA's NAFEC facility. The first phase of the program is now essentially complete, and all data are under evaluation by NASA, FAA, EPA, industry and universities.

The test result examples shown in Figure 8 indicate that the baseline engine levels of unburned hydrocarbons (HC) and oxides of nitrogen ( $\text{NO}_x$ ) in the naturally aspirated engines met the EPA landing and takeoff cycle requirements for 1979, while carbon monoxide (CO) levels were excessive. While their CO levels could be reduced through optimal mixture leaning, they were still higher than required by the 1979 standard. It was found that the turbo-supercharged engine could not be adjusted to reduce either CO or HC levels to the extent required by future standards. A technical symposium is being held at the Lewis Research Center this week to bring together all interested parties to exchange test results and to discuss the implications.

NASA programs to investigate piston engine emission reductions requiring more extensive engine design modifications are also being conducted through contracts and in-house research. Contracts have been negotiated with both of the aforementioned manufacturers to study longer range engine modifications of their choice which may have the potential of reducing exhaust emissions significantly as well as improving efficiency. Concepts under consideration will include variable valve timing, ultrasonic fuel vaporization, improved ignition, better engine cooling, and pulsed fuel injection systems.

In addition to these contracts, work at our Lewis Research Center is being initiated to study advanced

concepts in emission reductions and engine efficiency improvements which industry may not be able to pursue in the near future. This research will also study whether engine modifications may be necessary to permit the use of fuels derived from shale and coal.

In concluding these comments on our noise and emission reduction research, I would like to note also that our continuing program to investigate techniques for reducing emission levels in gas turbine engines is also proceeding on schedule. Our clean combustor programs have generated valuable laboratory data which has been provided to industry and to the EPA. These clean combustor programs are now in the engine demonstration phase. Complementary to this important work, which has been addressed primarily to operational conditions for engines in the airport environment, we have also initiated a program to investigate the special problem of reducing NO<sub>x</sub> emissions during high altitude cruising flight. The results of this research would be useful in the event that it should ever be necessary to reduce aircraft emissions of NO<sub>x</sub> in the upper atmosphere so as to eliminate any possible adverse effects such emissions might have on the ozone layer. We will keep you posted on future progress in this work.

## AIRCRAFT NOISE AND EXHAUST EMISSION REDUCTION RESEARCH SELECTED TOPICS

- OPERATIONAL TECHNIQUES FOR APPROACH NOISE ABATEMENT (DELAYED FLAP)
- PSYCHOACOUSTIC STUDIES
- QUIET, CLEAN, SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)
- QUIET, CLEAN, GENERAL AVIATION TURBOFAN (QCGAT)
- PISTON ENGINE EMISSIONS REDUCTION FOR GENERAL AVIATION

FIGURE 1

### DELAYED FLAP DEPLOYMENT FOR NOISE ABATEMENT APPROACH

(COMPUTED CENTERLINE NOISE, B727-200/JT8D-9)

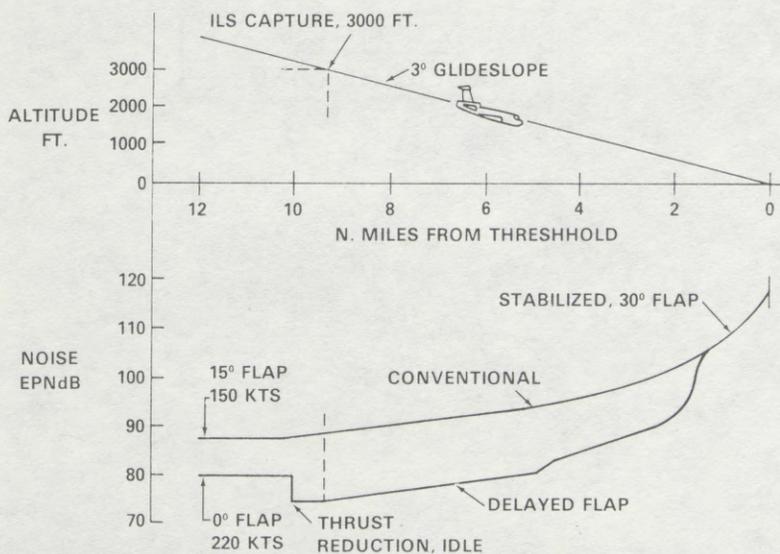
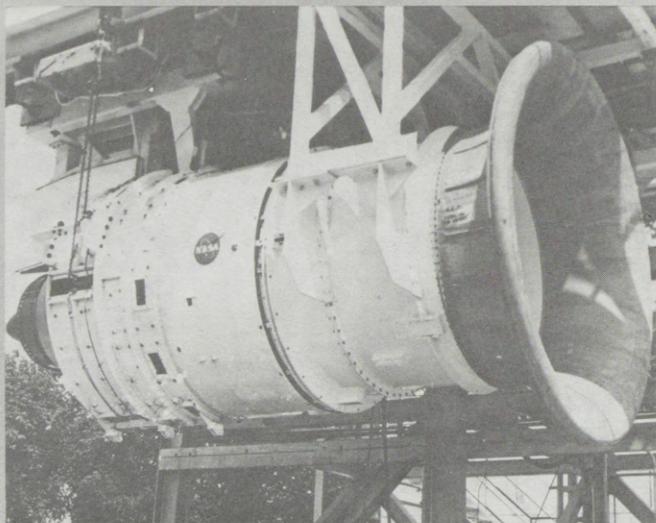


FIGURE 2

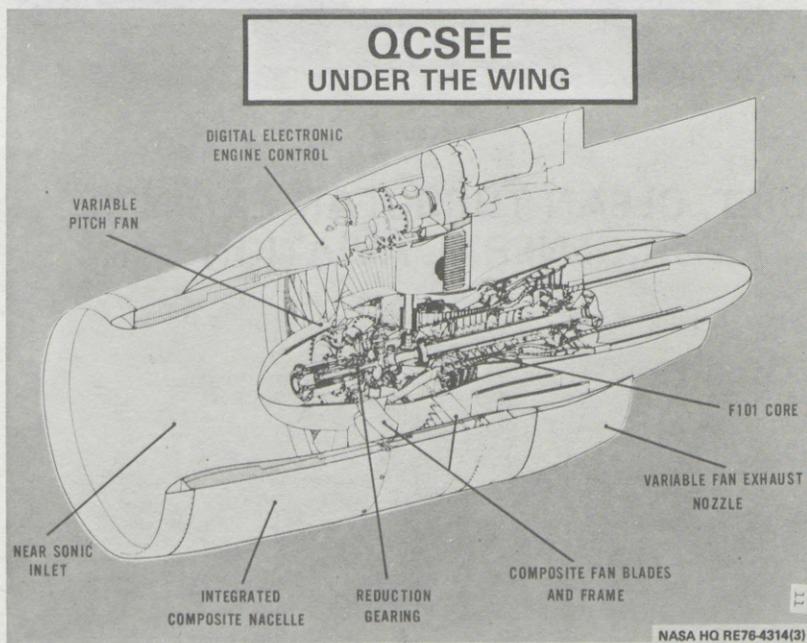
## QCSEE UNDER-THE-WING TEST INSTALLATION



NASA HQ RL76-4306(2)  
9-7-76

10

FIGURE 3



NASA HQ RE76-4314(3)  
9-7-76

11

FIGURE 4

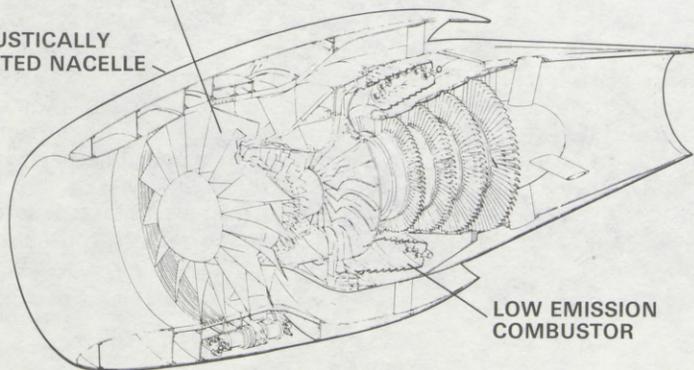


FIGURE 5

## QUIET, CLEAN TURBOFAN ENGINES FOR GENERAL AVIATION

HIGH BYPASS RATIO FAN

ACOUSTICALLY  
TREATED NACELLE



LOW EMISSION  
COMBUSTOR

FIGURE 6

## QUIET, CLEAN GENERAL AVIATION TURBOFAN ENGINES

NOISE GOAL : FAR 36-20 EPNdB

EMISSIONS GOAL : BETTER THAN EPA 1979 STANDARDS

CONTRACTOR	AVCO LYCOMING	GARRETT AIRESEARCH
BYPASS RATIO	8.2	4.0
STATIC THRUST	1600 LB	4200 LB
CRUISE CONDITIONS MACH/ALTITUDE	0.6/25,000 FT	0.8/40,000 FT.

FIGURE 7

### GENERAL AVIATION PISTON ENGINE EMISSION REDUCTION

(SAMPLE EMISSIONS AS PERCENT OF EPAP CYCLE 1979 LEVELS)

<u>ENGINE TYPE</u>	<u>PRODUCTION ENGINE BASELINE</u>			<u>PRODUCTION ENGINE SET FOR LEAN OPERATION</u>		
	<u>CO</u>	<u>HC</u>	<u>NO<sub>x</sub></u>	<u>CO</u>	<u>HC</u>	<u>NO<sub>x</sub></u>
CARBURETTED	255%	78%	13%	188%	65%	26%
FUEL INJECTED	218%	65%	2%	145%	62%	25%
TURBOSUPERCHARGED, INJECTED	300%	245%	4%	240%	230%	7%

FIGURE 8

Mr. SMYLLIE. Thank you, Mr. Chairman.

Our next testimony on the subject of aviation safety research and technology is presented by Mr. Gene Lyman who is Director of the Aeronautical Man-Vehicle Technology Division and will particularly highlight the aviation safety reporting system which has been implemented since we last testified here.

Mr. MILFORD. Mr. Lyman we have your prepared statement which will be accepted at this point for the record. You may proceed as you see fit.

STATEMENT OF E. GENE LYMAN, DIRECTOR, AERONAUTICAL MAN-  
VEHICLE TECHNOLOGY DIVISION, OAST, NASA

Mr. LYMAN. Thank you, Mr. Chairman.

We have presented many facets of NASA's aviation safety research and technology to this committee in the past, and today I would like to address my remarks to topics that are more designed to look to the future and anticipate safety problems that may be forthcoming.

I will be speaking to three areas of our research program—atmospheric phenomena, aircraft tire materials, and the aviation safety reporting system.

The first—atmospheric phenomena. Newer aircraft designs will incorporate substantial applications of microelectronics and non-metallic materials. Lightning poses a potential hazard to the safe operation of these newer aircraft.

We have a continuing comprehensive research program in this area looking at the effects of lightning on such things as fuel systems, electrical systems, and materials. During the fall we will be publishing a comprehensive design guideline that compiles the results of our work to date and this information will be made widely available to the aircraft manufacturing industry for their use.

Mr. MILFORD. Mr. Lyman, how many cases do you have on record where lightning was a factor in an accident?

Mr. LYMAN. I cannot answer that question.

Mr. MILFORD. I can—one, maybe.

Mr. LYMAN. I can think of two maybe and three others maybe also, but I cannot answer that question absolutely.

Mr. MILFORD. Go ahead.

Mr. LYMAN. The next area in our atmospheric phenomenon program is concerned with the effects of turbulence in the atmosphere. We have had underway for about 5 years a comprehensive data collection program, collecting information about turbulence in the atmosphere.

The information has been used by us to generate mathematical models, improved mathematical models of the atmosphere. These models have found application already for improved representation of the atmosphere in flight simulators used for pilot training.

Also the information, the models will be used by the aircraft industry for the purposes of improved designs, alleviation of gust loading, and improved service lifetimes.

The next area which I wish to speak of is the aircraft tire materials program. We began this program in 1969 concerned with the potential hazards associated with aircraft tire failure and concerned with surface/tire friction characteristics.

Within the last 2 years scientists at the Ames Research Center have developed a material incorporating natural rubber and a new polymer, polyvinyl butadiene that has been incorporated into a recap material. This material is now under evaluation at the landing loads track at the Langley Research Center, and it is also being investigated on an FAA 727 aircraft. The material is meeting our earliest objectives, if you will. It is offering the promise that we expected.

In addition, we have derived additional benefits from this program that include an improved understanding of the chemical and mechan-

ical properties associated with tire failure. We have developed an improved, tougher kind of material, and it appears that the material is more cost effective, per unit of operation, than materials presently in use.

## AVIATION SAFETY REPORTING SYSTEM

### OBJECTIVES

#### TO DESIGN AND IMPLEMENT:

- A CONFIDENTIAL REPORTING SYSTEM
- A SYSTEM FOR STORAGE AND RETRIEVAL OF DATA
- AN ANALYTICAL SYSTEM FOR STUDY OF THE DATA
- A RESPONSIVE SYSTEM FOR COMMUNICATION

#### TO SERVE:

- REGULATORY AND OTHER AGENCIES
- AIRLINES AND COMMERCIAL OPERATORS
- AVIATION MANUFACTURERS
- PILOTS AND AIR TRAFFIC CONTROLLERS
- AVIATION SAFETY R&D GROUPS

FIGURE 1

I would like now to turn to the aviation safety reporting system (figure 1). We have mentioned in the past to this committee that we are undertaking this program, but today is the first opportunity we have had to report on it in detail, telling something about how it works and our experience to date.

We operate the program under the terms of a Memorandum of Agreement with the Federal Aviation Administration. Our responsibilities under the Memorandum of Agreement are to design and implement (1) a confidential reporting system, (2) a system for the storage and retrieval of safety data, (3) an analytical system for the processing and study of that data, and finally (4) the system for the communication of the findings.

We implemented the system on April 15, 1976, so the first item is underway. We are in the process of designing items 2 and 3, and item 4 is underway as well. We are in the process of communicating findings at the present time.

The system is designed to serve the total aviation community including the regulatory and other agencies—this would be FAA, NTSB. It also serves the airlines, commercial operators, manufacturers and the pilots and controllers and research and development groups such as ours. That is, NASA would use information from the system to help focus its research efforts to insure they are addressing the most critical problems.

The aviation safety reporting system is an early warning system. It collects reports from pilots, controllers and others working in the

system. The basic philosophy here is that they are in the position in many cases to first see and recognize a potential hazard to safety.

A tenet of the program is that it is corrective, not punitive. Therefore, a person can report in confidence that he is not jeopardizing himself or any other person by reporting.

Mr. WYDLER. What kind of things would you report?

Mr. LYMAN. The problems reported to date cover a wide spectrum of operating conditions found in the national aviation system ranging from airport markings through to weather balloons. It covers a total spectrum of experiences that might be found in the aviation system.

Mr. WYDLER. How about, for example, if airplanes are constantly being stacked up over an airport, trying to get down. Would that be something that you would be reporting?

Mr. LYMAN. It would depend on the circumstances of that and yes we have received reports that speak to it in part. If for example, someone thinks there is a procedure that is used in the holding process he might submit a report if he perceives it has a safety threat. We cannot tell people out there what a safety threat is, they have to perceive it. So anything that comes into someone's mind as a problem or a potential problem—

Mr. WYDLER. That fascinates me. Would it be a safety hazard to the general public for airlines, if it is their responsibility, or the airport operator, if it is his responsibility, to schedule so many airplanes into an airport at a certain time that they could not possibly land them without putting them in long holding patterns and letting them fly around in that fashion. Would that be considered a safety hazard?

Mr. LYMAN. I have no evidence that it has been considered a safety hazard.

Mr. SMYLIE. In terms of the system that we are talking about, the aviation safety reporting system, we depend on the people operating in the system to report to us what they perceive as problems. If somebody in the system perceives that as a safety problem, they might report it.

Mr. WYDLER. I am not talking about whether you have had bad weather or some unusual circumstance might come into play. I am talking about whether this is done as routine practice to have so many planes trying to get down at the airport at the same time. They know physically they will never be able to do it. They can just look at the schedule and tell that. They just have to put them all in holding patterns, land them one at a time and bring them all in that way. That always seemed to me to create a safety hazard. Nobody seems to worry about flying people around in the air for a considerable period of time.

Mr. LYMAN. I would say I am not aware of any particular event that came about as a result of that circumstance. We would only have to say that if somebody involved observed a procedure or a condition involved in that process that posed a hazard, he could report it, and within the context of that, one could look at the specifics and take some appropriate form of corrective action.

Mr. WYDLER. Another thing that bothers me. A few weeks ago we had a controller slowdown in the New York airport. I do not know what they were fighting about, but whatever the argument was they

decided they would have a slowdown. That is alright except that, it was explained, all they were doing was following the book so to speak, keeping the prescribed distance between the planes on landing and takeoffs. Why do we have rules like that if we do not really need them. That is the thing that struck me. In other words, we must have rules on the books that they violate normally. So I just wonder to myself why do we put those requirements in there if we do not expect them to live up to them in the first place.

Mr. SMYLLIE. Mr. Wydler, I am not personally cognizant of the differences that went on in that circumstance so it is pretty hard for me to address—

Mr. WYDLER. It is all sort of hearsay that I got from the crews of the plane but it strikes me as odd that we would set forth a group of standards for them to follow and then routinely expect them to violate the standards. Why don't we make it realistic as to what we really expect them to do. They would not be able to fall back on this business of saying we are going to do it now according to the book. Why do we put it in the book. That is what struck me as rather odd about the whole situation.

Mr. SMYLLIE. Yes, sir. I have no evidence as to whether when doing it normally that they are in fact violating the rules. It is a matter of how rigorously you assure yourself that the rules are not being violated and you can work that to what you want to I would suppose. But I am not cognizant to that well enough to comment intelligently on it.

Mr. WYDLER. I am sorry, Mr. Chairman.

Mr. MILFORD. Would you proceed?

Mr. LYMAN. I would like to speak somewhat about how the system operates. We have at the NASA Ames Research Center a mailbox at the local post office. Voluntary, confidential reports are mailed through the mail into this post office box. They go through no government mailroom or clerk or so on. They come straight to the operators of the system. They are received and they are screened. We screen for three things. There are two classes of reports that are not under the purview of the safety reporting system, they are ones that might pertain to alleged criminal offenses or ones that pertain to aircraft accidents. Those reports if they come in are forwarded to either the National Transportation Safety Board or the Department of Justice, whoever has jurisdiction. I might mention in passing, to date we have received only one that apparently involves a criminal offense. It was forwarded, and it was a passenger who reported by the way; and there have been about 17 that have come in that have involved aircraft accidents.

Once that screening is done for those two classes, we look at the report from the point of view of the immediacy of the urgency of the reported condition. If it is considered urgent in our screening process it is flagged and it is sent to a subject matter specialist who is responsible for a detailed analysis of that report.

The report comes in with the name, address, and telephone number of the reporter. We have found in previous work that there is infinite value of being able to speak to the person who is involved in something so you can really find out what happened. He may not in fact be able to provide sufficient detail in writing. The telephone call gives us the

opportunity to seek it out and perhaps arrive at the true meaning, or the more subtle factors, that led to the condition that he was involved in.

Once the analyst has made contact by telephone if he thinks it is necessary, he does what we call deidentify the report. He edits the report to remove from it the names of all individuals who might be identified as a result of this report being in existence. If it is an urgent condition, he prepares a synopsis that NASA forwards to the FAA. The synopsis of an urgent situation, or a bulletin, is deidentified. There is no information in the report that would allow the FAA or any other person for that matter to identify who the reporter was. The analyst also prepares the report for computer coding. That means the information from the report is ultimately passed into the computer data base.

I might mention that the purpose of the computer data base is to allow the aviation community over the long haul to look for the more subtle, hidden problems that may exist within the system and to identify them, if you will, in an early warning sense before they do lead to an accident.

To date, since April 15, we have received over 2,300 reports. It averages out at the present time about 100 a week. We have been able to send to the FAA 159 bulletins, that is, topics that appear to require immediate attention. The FAA has been able to take very meaningful action in a large number of cases to correct situations. They involve areas such as airport safety, the designation of airways, and navigation facilities. It has also involved improvements they have been able to make in the area of air traffic control procedures and operations.

We have recently distributed, and are in the process of distributing nationally, a pamphlet that summarizes the program. It is designed to be given to pilots and controllers throughout the system. I would like to let you all have one of these. As either workers in the aviation system, or participants one way or the other, you may find a situation that you wish to report. The report form is in the back of the booklet, and we will keep your identity confidential, too.

Mr. MILFORD. I would ask unanimous consent that the pamphlet appear in the record at this point.

[The pamphlet follows:]

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**NASA**  
**Aviation Safety**  
**Reporting System**

a voluntary, confidential program

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## Aviation Safety Reporting System

The National Aviation System is both efficient and complex. It has an outstanding safety record, but situations and conditions can develop that pose a threat to safety. Pilots, controllers, and others using and working in the system have the best opportunity to recognize and report these problems before someone has an accident.

To provide this capability, the FAA asked NASA to design and run an Aviation Safety Reporting System (ASRS) in support of the FAA Aviation Safety Reporting Program.

The ASRS acts as an early warning system. Safety reports describing problems are submitted by pilots, controllers, and others in the system. Safety information is extracted and sent to those who can do something about the problem—hopefully in time to prevent an accident.

By being the central point for collecting safety reports, ASRS can also detect trends which alert the aviation community to hidden problems. For this reason, each ASRS safety report is considered not only for the information it contains alone, but also for what it contains when compared to all others.

---

## Report Form

Attached to this pamphlet is a preaddressed, postage paid reporting form. When you encounter a situation that you believe threatens aviation safety, you are urged to complete the form and send it to NASA.

The form is structured to identify specific data regarding the situation. Additional space is provided for you to describe other details.

The report form also provides space for your name, address, and phone number. NASA has found in previous safety analysis projects that valuable information may be found during a conversation between a safety analyst and the person involved in an incident. By talking to you NASA may discover subtle factors that led to the problem.

NASA will return the identification portion of the form to you as quickly as possible—hopefully in the mail within two days. This will let you know that the report was received and that the problem you identified is receiving attention.

---

## ASRS Operation

The operation of ASRS is straightforward. As each safety report is received, it is promptly given to an expert safety analyst. He examines the report and decides whether or not he needs to call you for more information.

If the analyst does call, you can be assured he is an expert in the subject you described in your report. NASA has employed experts in all phases of aviation, including air traffic control, general aviation operations, and airline operations.

When the analyst has obtained the information he believes necessary, he removes the identification portion of the report and mails it back to you. He also removes all other information that could be used later to trace the report back to you or to any other person. NASA calls this step "de-identification".

The analyst then codes the de-identified information and enters it into the ASRS computer. If the problem you encountered poses an immediate threat to aviation safety, pertinent de-identified information is promptly relayed to the FAA so they can take appropriate action to correct the problem.

The ASRS computer is designed to continuously examine the coded information from your report and all others. This allows NASA and the aviation community to discover subtle changes and uncover hidden problems. Also, the effectiveness of corrective actions can be evaluated.

NASA will routinely provide the results of its study of the coded ASRS information to all segments of the aviation community. Additionally, you will see the results of these studies reported from time-to-time in aviation magazines and publications.

---

## Safeguards

The ASRS is a voluntary reporting program. NASA has designed it so that you can report in confidence without being concerned that the information you have provided will be used against you or anyone else. There are only two exceptions to this: (1) criminal activities like hijacking, sabotage, or smuggling; or (2) actual aircraft accidents. NASA has to pass those reports to the proper government officials with all identifying information.

The FAA has taken a number of steps to make the ASRS a meaningful safety reporting system. The three steps of most concern to you relate to what enforcement action FAA might take if there is a possible violation of the Federal Air Regulations (FAR).

First, FAA will never request and NASA will never report if alleged violations of FARs are revealed in a safety report. Second, FAA will never ask NASA the identity of an individual submitting a safety report. And third, for unintentional FAR violations, FAA will not take disciplinary action when a timely safety report has been sent to ASRS.

The FAA will continue to enforce the FAR for intentional acts that threaten safety whether or not an ASRS safety report has been submitted. However, the FAA would have to learn of these acts through means other than the ASRS.

The FAA has sent Advisory Circular No. 00-46A to all certificated airmen. The AC sets forth the policy about ASRS and enforcement action. It should be read if you have questions about the enforcement policy.

In the event of possible enforcement action by FAA, there are two safeguards

available to show that you have reported to ASRS. The first is the identity slip that NASA returned to you. It will be date stamped by NASA.

The second is a separate computer file kept by NASA that notes only the date, time, location, and type of incident of each safety report received. An entry will be kept in this file for 45 days after the incident. If FAA believes enforcement action may be appropriate, it asks NASA to check the "45-Day File" to see if a safety report has been submitted. If it has or if FAA does not ask NASA within 45 days of the incident, enforcement action will not be taken except for those intentional acts that threaten safety.

As a final safeguard, NASA has organized a committee of aviation safety experts to advise NASA on the design and operation of ASRS. Within the committee there is a security group that examines ASRS periodically to assure that individual confidentiality is being protected. Members of the security group are associated with AOPA, ALPA, and PATCO. Whether or not you are associated with one of these organizations, your personal interest is their concern.

The Aviation Safety Reporting System is your way to further aviation safety. You use and work in the National Aviation System routinely. You are the first to observe potential threats to safety. A few moments of your time may well save lives.

Don't put yourself in the position of having to say—IF I HAD ONLY REPORTED—

# REPORT!

before  
it's  
too  
late

**IDENTIFICATION STRIP:** Please fill in all blanks. This section will be returned to you promptly; no record will be kept.

TELEPHONE NUMBERS where we may reach you for further details of this occurrence:

AREA \_\_\_\_\_ NO. \_\_\_\_\_ HOURS \_\_\_\_\_ TYPE OF OCCURRENCE/INCIDENT: \_\_\_\_\_

AREA \_\_\_\_\_ NO. \_\_\_\_\_ HOURS \_\_\_\_\_ \_\_\_\_\_

DATE OF OCCURRENCE \_\_\_\_\_

TIME (local, 24-hr. clock) \_\_\_\_\_

NAME \_\_\_\_\_

ADDRESS \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(This space reserved for NASA receipt stamp)

Please fill in appropriate spaces and circle or check all terms which apply to this occurrence or incident.

1. Location: (Geographic (including State), airport, runway, ATC facility and sector, navigation aid reference, etc.)

2. Type of operation:

SCHEDULED AIR CARRIER	SUPPLEMENTAL CARRIER	CORPORATE AVIATION	MILITARY: ARMY	
DOMESTIC OPERATION	CHARTER OPERATION	PERSONAL BUSINESS	NAVY/CG/MC	
INTERNATIONAL OPN.	UTILITY OPERATION	PLEASURE FLIGHT	AIR FORCE	
AIR TAXI	AGRICULTURAL OPN.	TRAINING FLIGHT	GOVERNMENT	

3. Type of aircraft:

FIXED WING, LOW	RETRACTABLE GEAR	RECIPROCATING	GROSS WT.: <2500	25,000-50,000
HIGH WING	CONST. SPEED PROP	TURBOPROP	2500-5000	50,000-100,000
ROTARY WING	FLAPS	TURBOJET	5000-12,500	100,000-300,000
NO. OF SEATS:	NO. OF ENGINES:	WIDE BODY JET	12,500-25,000	OVER 300,000

4. Second aircraft TYPE: (if two aircraft involved)

5. Reported by: PILOT CREWMEMBER CONTROLLER OTHER (specify)

If pilot: TOTAL HOURS: \_\_\_\_\_ HRS. LAST 90 DAYS: \_\_\_\_\_

6. Light conditions: DAWN DAYLIGHT DUSK NIGHT 7. Altitude: \_\_\_\_\_ FEET MSL.

8. Flight plan: IFR VFR DVFR SVFR NONE 9. Flight conditions: VFR IFR

10. Flight phase: PREFLIGHT TAXI TAKEOFF CLIMB CRUISE DESCENT  
HOLDING TRAFFIC PATTERN APPROACH LANDING MISSED APPROACH

11. Airspace: POSITIVE CONTROL AREA (PCA) TERMINAL CONTROL AREA (TCA) ON AIRWAYS  
AIRPORT TRAFFIC AREA UNCONTROLLED AIRSPACE

12. Air Traffic Control: GROUND TOWER DEPARTURE CENTER APPROACH FSS NONE

13. Weather factors: RESTRICTED VISIBILITY TURBULENCE THUNDERSTORM AIRCRAFT ICING  
CROSSWIND PRECIPITATION NONE OTHER (specify)

14. (Circle all which you believe apply to this occurrence)

AIRPORT AIR TRAFFIC CONTROL AIR NAVIGATION FACILITY AIRCRAFT  
FLIGHT CREW AERONAUTICAL PUBLICATIONS/CHARTS OTHER (specify below)

15. NARRATIVE DESCRIPTION: (Please describe the occurrence as clearly and precisely as possible. Include information on: what happened . . . how was the problem discovered . . . what actions were taken . . . was evasive action required . . . what factors contributed to the situation . . . why do you believe the situation occurred . . . your suggestions as to how to prevent a recurrence.  
USE BOTH SIDES OF THE FORM, AS REQUIRED.)

Continue on other side.

NATIONAL AERONAUTICS AND  
SPACE ADMINISTRATION

STAPLE  
OR TAPE  
HERE

AVIATION SAFETY  
REPORTING SYSTEM

NASA has established an Aviation Safety Reporting System to identify problems in the aviation system which require correction. The program of which this system is a part is described in detail in FAA Advisory Circular 00-46A. Your assistance in informing us about such problems is essential to the success of the program. Please fill out this postage free form as completely as possible, fold it and send it directly to us.

The information you provide on the identity strip will be used only if NASA determines that it is necessary to contact you for further information. **THE IDENTITY STRIP WILL BE RETURNED DIRECTLY TO YOU. NO COPY OF THE STRIP OR RECORD OF YOUR IDENTITY WILL BE KEPT.**

This report will not be made available to the FAA for civil penalty or certificate actions for violations of the Federal Air Regulations. FAA has agreed to waive disciplinary action, with the exceptions described in Advisory Circular 00-46A, if you have reported the occurrence under this program. Your identity strip, stamped by NASA, is proof that you have submitted a report to the Aviation Safety Reporting System. We can only return the strip to you, however, if you have provided a mailing address. Equally important, we can often obtain additional useful information if our safety analysts can talk with you directly by telephone. For this reason, we have requested telephone numbers where we may reach you. Thank you for your assistance.

*Note: Aircraft accidents should not be reported on this form. Such reports should be filed with the National Transportation Safety Board as required by 49CFR830.*

National Aeronautics and  
Space Administration

**Ames Research Center**  
Moffett Field, California  
94035

Official Business  
Penalty for Private Use \$300

An Equal Opportunity  
Employer

Postage and Fees Paid  
National Aeronautics and  
Space Administration  
NASA-431



FIRST CLASS

AVIATION SAFETY DATA DO NOT DELAY

NASA Aviation Safety Reporting System  
Post Office Box 189  
Moffett Field, California 94035

**NASA**

15. NARRATIVE DESCRIPTION (continued): *(Use additional sheets if necessary)*

Fold as indicated, fasten with staple or tape as shown, and mail. Thank you for your cooperation.

Mr. WYDLER. What brought this about?

Mr. LYMAN. Why did we generate the pamphlet?

Mr. WYDLER. Why did you generate the program?

Mr. LYMAN. For some years there has been conversation within the aviation safety community that there would be value in having an immunity reporting system wherein pilots and controllers could report in some sort of an atmosphere where they would not be threatened about situations they encountered. The TWA 514 accident out at Round Hill in 1974 led to the firm belief in some minds that it was about time to have such a program. The FAA began one in May of 1975. There were difficulties with their program. Some people did not trust the FAA, if you will. That if they had the identity of the reporters they would use the information in some punitive sense. The FAA felt strongly that such a program was needed and they asked us to do it.

We had some previous experience at a much more informal level on incident reporting and interviewing of people.

Mr. WYDLER. It is a suggestion box, that is really what it is.

Mr. LYMAN. It could be considered a suggestion box.

Mr. WYDLER. It is a little more formal, but I mean basically it is.

Mr. SMYLLIE. It is somewhat more sophisticated.

Mr. LYMAN. Substantially more sophisticated.

Mr. MILFORD. In your screening process, are you taking steps that would prevent groups from prostituting the system. Let us say for example you have a competing aircraft manufacturer that could attempt to put a competitor out of business through the use of these reporting forms in some way. Do you have a screening process set up in some way that would prevent the system from being prostituted?

Mr. LYMAN. From the first day of the program in our design of it, we viewed the existence of the data base as a potential time bomb if you will. The data could be used constructively or destructively, that is, used properly or used improperly. We considered that at length. What we have done that prevents that kind of a situation from occurring is, you will note it on the report form, collect information about product in a categorical sense, not a specific product sense. Therefore no one could go into the data base to derive information that might have been planted in order to create the kind of situation you describe.

Mr. MILFORD. Well, I did not necessarily mean to confine it to product—

Mr. LYMAN. Or service or air carrier.

Mr. MILFORD. It could be done in an air traffic control system for example. It could be done in several ways I could think of. What I am saying is are you cross checking to prevent an organized effort from prostituting the—

Mr. LYMAN. Let me answer that in several ways.

We were concerned about it and a lot of the people that we talked to were concerned that people would load the system in that sense to highlight labor/management issues. I am happy to report right now that we do not have evidence that the system is being used that way.

But we have taken it into account. The data base, the computer data base will be designed and used over the long haul to continuously examine the body of data. There will be if you will a nominal level of

activity that pertains to areas or subject matter or perhaps facilities in the ATC system. If at some point in time there is the desire to load this system by a set of people and all of sudden they start submitting reports, the computer would be able to pick it out as an anomaly or a change to the base line if you will. So we would have a piece of information that there is a change from the norm. We are in a position then to check further to see whether or not there has been a change in practice or some other event that has occurred—are they in the middle of a contractual problem. We could sort it that way, so hopefully we could always provide the answer about what it was within the proper context.

Mr. MILFORD. OK. Thank you.

Mr. LYMAN. I would like to conclude with one thing.

We entered this program with the aviation community with the understanding that it was a collaborative effort. We have received their full support, cooperation and assistance and we look forward to continuing to receive it. I also would say I look forward to continuing to receive your support for these programs.

Mr. MILFORD. I am familiar with the program, and I am one of the boosters of it. I think it is a very worthwhile contribution, although I would agree it is perhaps a little bit out of the realm of NASA's role in the development of technology. Nonetheless, it is a needed function and I am in total agreement with the program.

Mr. SMYLYE. Perhaps we should add in those terms, Mr. Chairman, we agree with you on that point, and the program is designed such that after an experimental period of some several years we can turn the system over to a separate contractor to the FAA. We do not have to stay in it forever. But there is substantial research data coming from it at this point.

Mr. WYDLER. Mr. Chairman, it is getting late. I am going to have to leave, but I just want to say, I would like to submit my questions. I have some for most of the witnesses here today for the record. They can be answered that way.

Mr. WILFORD. Without objection any member will be able to submit questions and both the questions and the answers will appear in the record up to the point where our record itself is closed.

Mr. WYDLER. I just want to ask Mr. Lyman a question, not related to the testimony here today.

Have you got any possible theory for how that air crash over Yugoslavia took place?

Mr. LYMAN. No, sir.

Mr. WYDLER. What would the odds be of something like that? Everybody must have been asleep including the pilots of the plane and the air traffic controllers. It just sounds so impossible. Assuming everybody was asleep, it still shouldn't have happened. So I just cannot quite conceive of how that could have taken place. Do you think it was done intentionally by somebody?

Mr. LYMAN. I do not have any specific information about that. I could not even speculate.

Mr. WYDLER. I mean as an expert. I am asking you to testify.

Mr. LYMAN. As an expert, I won't touch it with a 10-foot pole. [Laughter].

Mr. SMYLIE. We really have no firsthand information on that.

Mr. WYDLER. I know.

Mr. SMYLIE. I would hesitate to speculate. It happens in the aviation community, I guess several times a year, though there are air-to-air——

Mr. WYDLER. Is that a very busy section?

Mr. SMYLIE. Yes, that is a very busy area. It is said to be one of the busiest in the world. There is a lot of air traffic. In fact I think there was another aircraft which witnessed it.

Mr. MILFORD. I would submit that we are getting out of our jurisdiction. Would you proceed, Mr. Smylie.

[The prepared statement of Mr. Lyman follows:]

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SEP 14 1976

AVIATION SAFETY RESEARCH AND TECHNOLOGY

Statement of

E. Gene Lyman  
Director, Aeronautical Man-Vehicle Technology Division

Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

As aviation has evolved over the years, NASA and its predecessor organization NACA, have played a key role in the furtherance of safety. In fact, as the substantial gains in performance, efficiency and comfort were being realized, tremendous challenges concerning the safety of air transportation system were being met and disposed of. Consider, for example, work done in the 1940's to reduce the hazard of aircraft icing and work done in the 1950's and 1960's to reduce runway slipperiness hazards and the hazards of turbulence upset encounters.

The point is not that NASA has a historical role in aviation safety but rather, as aviation advances, new problems emerge that challenge the integrity of the system. Consider in this context current issues such as wake vortex alleviation, wind shear detection, crash fire prevention, and human error minimization.

On the one hand we as a Nation must be proud of our achievements in aviation - a highly efficient transportation system with the best safety record in the world. On the other hand we must be frustrated - greater demands on the system's efficiency lead to perplexing safety problems difficult to solve and, in many cases solutions difficult to implement.

We must, however, put aside our frustration and continue to forge ahead, not only to resolve problems that emerge

as a result of a single accident, but also to anticipate problems and correct them before an accident occurs. In previous testimony before this Subcommittee we have presented information on many facets of NASA's Aviation Safety Research and Technology program. Today we will highlight activities oriented toward alleviating the problems that may be expected to occur in the not-so-distant future. In particular, we will discuss the topics of atmospheric phenomena, tire materials, and the aviation safety reporting system.

#### Atmospheric Phenomena

Newer aircraft design concepts employ substantial application of microcircuit and computer technologies, as well as more extensive use of nonmetallic materials as secondary and primary structures. Lightning poses a major potential hazard to safe operation of these newer aircraft.

Recognizing the potential hazards, NASA has been conducting a continuing comprehensive research program to provide improved knowledge of lightning effects. Emphasis is being given to understanding the effects of lightning on fuel systems, electrical systems and materials. During the Fall of 1976, we plan to publish design guidelines that summarize our efforts to date. These guidelines will be made widely available to the aviation manufacturing industry.

In another area of our atmospheric phenomena research program, we are making substantial progress in developing mathematical models of the turbulent structure of the atmosphere. Our models are based upon a comprehensive flight data collection activity that spans a period of five years. The models are finding application in flight simulators used for pilot training. They will also find utility in the design of new aircraft by permitting better prediction of gust loading, service lifetimes, and ride quality. The models will also permit improved design of active control systems for gust load alleviation.

#### Aircraft Tire Materials.

In 1969, NASA undertook a research program to provide improved aircraft tire materials. Our motivation was to reduce the hazard associated with tire failure and to improve the tire/surface friction characteristics. In the last two years, scientists at the Ames Research Center have developed a material incorporating natural

rubber and a new polymer, polyvinyl butadiene. The blend has been formulated into a recap material that is now under investigation at the Langley Research Center Landing Loads Track and is being field tested on an FAA 727 aircraft. Our test results to date are very promising, and we are optimistic that we are meeting our original objectives. In addition we are providing these additional benefits:

- (1) A better understanding of the chemical and mechanical processes that lead to tire failure.
- (2) A longer wearing, rougher tire material.
- (3) A less costly, per unit of operation, material than the current state of the art.

#### Aviation Safety Reporting System.

On April 15, 1976, NASA began receiving safety reports submitted by pilots, controllers, and others using and working in the National Aviation System. NASA receives, processes, and analyzes these reports under the terms of a Memorandum of Agreement with the Federal Aviation Administration (FAA).

We had noted in previous testimony that we were undertaking this program in cooperation with FAA, but this is the first opportunity to present in some detail how it works and our experiences to date.

NASA's objectives under the Memorandum of Agreement are to design and implement (1) a confidential reporting system which can be used by any person in the National Aviation System; (2) a computer based system for storage and retrieval of processed data; (3) an interactive analytical system for routine and special studies of the data; and (4) a responsive system for communication of data and analysis to those responsible for aviation safety. The responsible parties include regulatory and other agencies, airlines and commercial operators, aviation manufacturers, pilots and air traffic controllers, and aviation research and development groups. NASA falls within the latter group, and we look forward to the use of the information to assure that our safety research activities are addressing critical issues.

The Aviation Safety Reporting System (ASRS) is an early warning system. Voluntary, confidential safety reports are submitted to NASA by pilots, controllers, and others.

The ASRS is based on the philosophy that people working in the National Aviation System are the first to recognize safety problems and that these problems can be corrected - hopefully before an accident - if the proper parties are informed. A tenet of the philosophy is that the ASRS is corrective, not punitive. Therefore, people can report in confidence that they are not jeopardizing themselves or anyone else.

ASRS operation is straightforward. Report forms are received by NASA and screened to ascertain the urgency of the reported condition. The reports are also screened to remove reports not under the purview of ASRS, i.e., criminal offenses or aircraft accidents. Any such reports are forwarded to the proper agency, either the Department of Justice or National Transportation Safety Board. After screening, the reports are given to a subject matter specialist for analysis.

The analyst performs several functions. He makes telephone contact with the reporter when additional information is required. He then processes the report to remove any information that would later allow the identification of the reporter or any other person. Reports identifying conditions requiring immediate attention are summarized and the information transmitted to FAA or any other party in a position to take action.

Information from all "de-identified" reports are coded and processed for computer analysis. From the computer analysis phase of ASRS, we hope to identify the hidden subtle conditions that pose a threat to aviation safety.

To date we have received about 2300 reports. The information from about eight percent of these has been forwarded to FAA and others for action and information.

The FAA has been able to take significant corrective action to enhance aviation safety as a result of ASRS. These actions include steps to increase airport safety, changes in procedures for improved coordination between air traffic facilities, and redesignation and improved service of navigation facilities. The specifics of many of these actions will be summarized in the quarterly ASRS report. The first quarterly report is now at the printers and will be released in about ten days.

To conclude, the ASRS is a challenging venture for NASA. We entered into it with an understanding with the aviation community that it was to be a collaborative program. We have from the inception of ASRS until the present

received their full cooperation and support. We look forward to continuing to receive it. We also look forward to your support in this major experiment to further aviation safety.

Mr. SMYLYE. Yes, sir, Mr. Chairman.

As our concluding report today, at your request by letter to me on August 11, we would like to present the state of the art in supersonic technology including the time table and the resources required to permit a decision—a national decision concerning a future U.S. supersonic transport.

Mr. Bill Aiken, who is the manager of our Supersonic Cruise Aircraft Research program and the director of our Aerodynamics and Vehicle Systems Division will present that report.

Mr. MILFORD. Thank you. Mr. Aiken, we have your complete statement with attachments which will be accepted for the record at this point. You may proceed.

**STATEMENT OF WILLIAM S. AIKEN, DIRECTOR, AERODYNAMICS AND VEHICLE SYSTEMS, OAST, NASA**

Mr. AIKEN Thank you.

Mr. Chairman, Mr. Wydler, as you know in July of 1972, NASA initiated a supersonic technology program to advance the technology in those areas critical to the environmental, technical and associated economic problems of past and present supersonic cruise aircraft. The primary motivation was simply to keep the options open for the development of such an aircraft in the future if the United States so chooses to do so. Four years later, having involved the research efforts of over 60 organizations throughout the country and publishing these results in some 260 technical reports, we are in a position to report on the current state of technology.

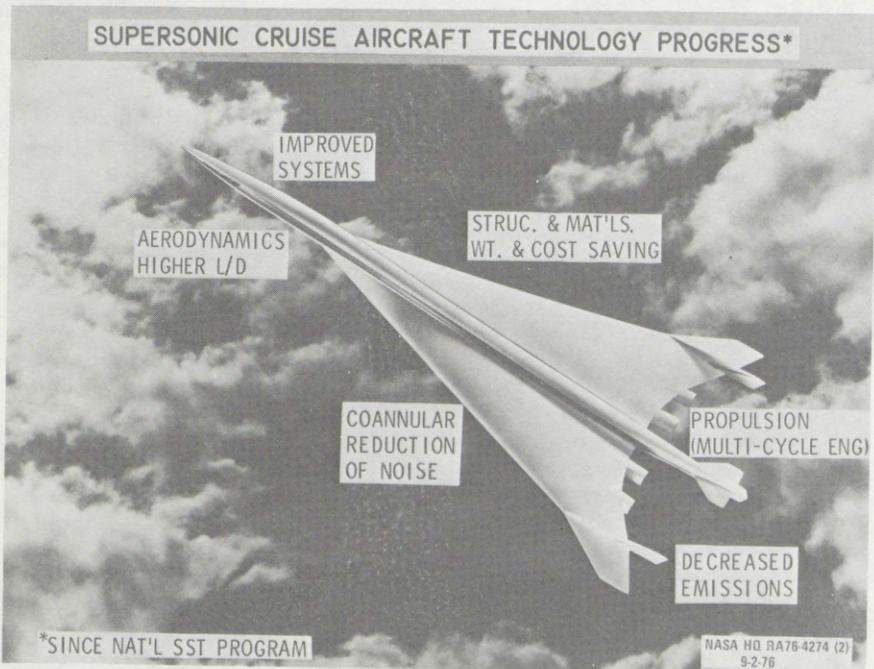


FIGURE 1

Significant progress has been made in the areas identified in figure 1. In the aerodynamics area, we have demonstrated much higher lift-to-drag ratios; in the materials and structures area, significant possibilities for weight and cost savings; and in the propulsion area, with the multicycle engine concept and the effect of noise reduction through a coannular process, we see hope for noise reduction and decreased emissions.

**NASA** National Aeronautics and  
Space Administration

Headquarters  
Washington, D.C.

## VARIABLE CYCLE ENGINE CONCEPT

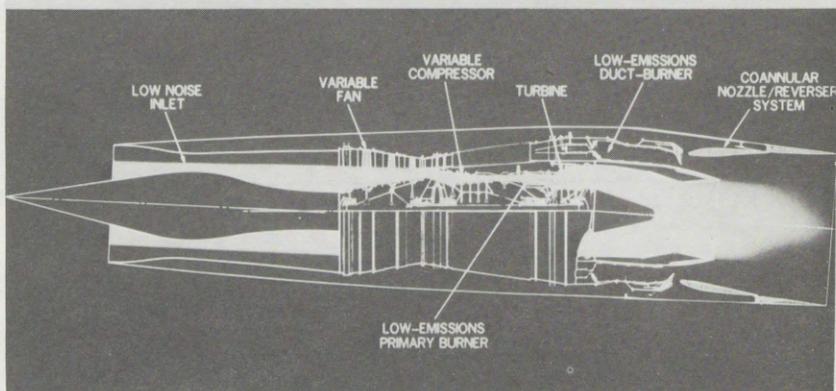


FIGURE 2

Our studies on propulsion have narrowed the many options potentially available to a very few multicycle engines, which not only have reduced noise and emissions, but also favorable fuel consumption characteristics. One of the promising variable cycle engine concepts is shown in figure 2. The important features of this engine are the coannular, dual stream nozzle which appears to offer an inherent 8-9 EPNdB noise relief without mechanical suppression; a variable fan and compressor which make it possible to maintain good performance at off-design conditions; and the low emission burners or combustors.

The potential payoff of the inherent coannular/annular noise suppression of such variable cycle engines is illustrated in figure 3. This chart shows the maximum range in nautical miles as a function of noise level for a 270-passenger supersonic aircraft utilizing a conventional turbojet cycle or a set of variable cycle engines. And you can see here that there is a potential 8 to 9 EPNdB noise reduction possible at constant range or for a given noise level, for instance FAR 36, a tremendous potential for increasing the range of such aircraft. The Concorde, of course, is spotted up there just for reference.

## POTENTIAL OF COANNULAR/ANNULAR NOZZLE INHERENT NOISE SUPPRESSION

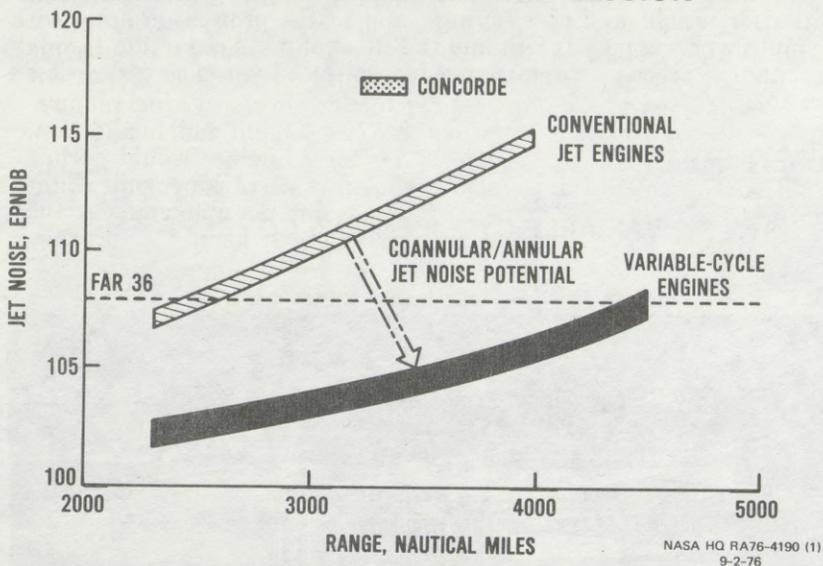


FIGURE 3

## IMPROVEMENTS IN ENGINE SPECIFIC FUEL CONSUMPTION

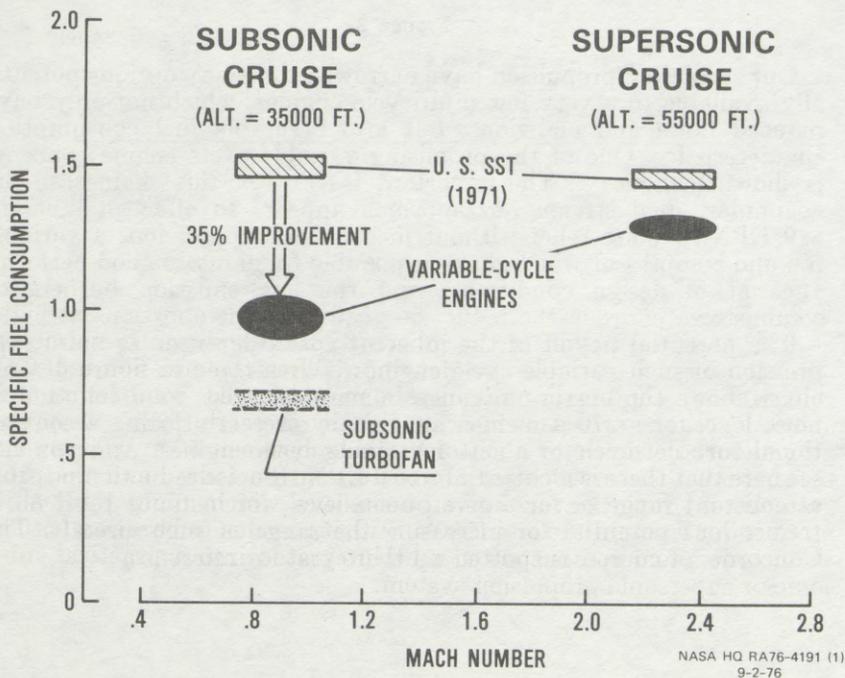


FIGURE 4

The potential improvement in off design performance for the advanced technology engines is illustrated in figure 4. Typically, at subsonic cruise conditions, the conventional turbojet engines employed in the 1971 U.S. SST had fuel consumptions about this level, and these variable cycle engines promise a 35 percent improvement at subsonic speeds. Now this is particularly important because this 35 percent improvement provides for important reductions in reserve fuel requirements which are based largely on subsonic cruise flight and, in addition, the reduced fuel consumption offered by these engines would permit efficient subsonic flight on overland segments where supersonic flight is precluded by regulation. There are also some possible gains at the supersonic cruise speeds that we are talking about here.

### STATUS OF CRUISE NO<sub>x</sub> EMISSIONS

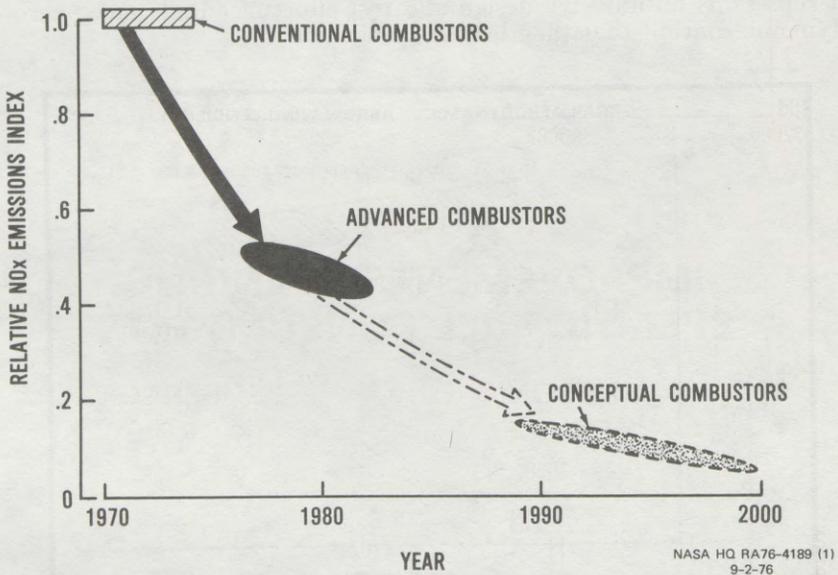


FIGURE 5

The NASA effort in the reduction of nitric oxide emissions at high altitude is illustrated in figure 5, which simply shows in terms of number of years where we are right now. With the emission index of conventional combustors rated as one, advanced combustors developed in other programs indicate that by the early 1980's we probably should be down to about something between 50 to 60 percent better than the conventional combustors in use today, and the program is also investigating some possibilities which might put us at much lower levels in the late 1980's. Still, it remains to be seen whether these conceptual combustors can be integrated into a practical subsonic or supersonic propulsion system.

In aerodynamics the mission performance of a supersonic cruise aircraft is critically dependent on the levels of aerodynamic efficiency or lift-drag ratio throughout the speed range. To date, the program has supported the construction and testing of some 13 major wind tunnel models. The one shown off to your right is a cast of a model which was used in a joint NASA/industry cooperative wind tunnel program conducted at the ANSA Ames Research Center. This was cooperative between NASA and Douglas.

The results of these tests essentially validated the advanced arrow-wing characteristics first defined by NASA in the 1960's. The significant result of this test program is shown in this figure 6 where we have lift-to-drag ratio plotted against mach number. Our advanced arrow-wing research indicated a band of theoretical possibilities, and we are this close from the Douglas designed model which indicates quite a bit of improvement over a Concorde which operates about in the same mach number range. This is a very important result in that it represents an industry design and test effort of an advanced aerodynamic concept that they believe could be built.

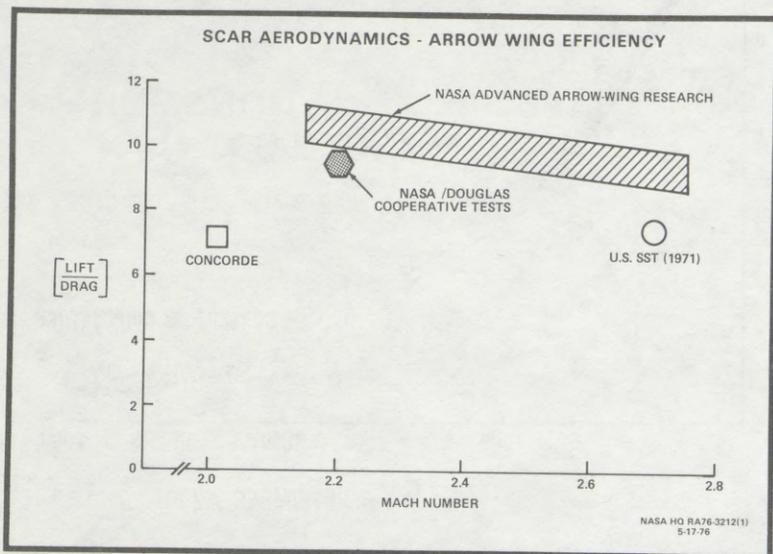


FIGURE 6

In structures and materials, we have made considerable progress in developing more rapid analytical methods for structural design and analysis in order to address the flutter problems of arrow-wing aircraft. Advanced composite materials are being developed for high temperature applications, and panels are being tested on the YF-12 airplane. While these important programs are continuing, our immediate attention has been drawn to a new superplastic titanium fabrication process under development in the Air Force B-1 program. This process offers hope for substantial reductions in the cost of titanium structures with some smaller, but still significant, reduction

in weight. I have a couple of small samples here of some of these superplastic forms. This is all done in one diffusion bonding process, and it is a very complicated form. When this all can be done at one time, a tremendous amount of cost can be saved because of the replacement of rivets and stringers which now are produced separately. These are very small-scale samples, but pieces almost as big as this table have been made already. We believe that this process is a key element for the future development of supersonic cruise aircraft.

I would like to turn now to a discussion of the requirements for technology readiness.

The Concorde, TU-144 and the 1971 U.S. SST were essentially based upon engine, airframe and structures technologies developed in the early 1960's.

While the Concorde and the TU-144 are admittedly advanced technical achievements, they have the obvious shortcomings of very high-noise levels, and marginal range and payload which impact their overall economic viability. Engine emissions are a problem but are considered to be somewhat more amenable to solution. The 1971 version of the U.S. SST was really an experimental airplane, not a prototype, and it is hard to say what its characteristics would have been if it had gone into production.

## GENERAL SPECIFICATIONS FOR AN ADVANCED SST

<b>NOISE</b>	• LOWER THAN CURRENT FAR-36
<b>ENGINE EMISSIONS</b>	• SATISFY EPA CLASS T-5 STANDARDS • CRUISE NO <sub>x</sub> LEVELS 1/6 OF CONCORDE
<b>RANGE</b>	• 4200 TO 4500 NAUTICAL MILES
<b>PAYLOAD</b>	• 250 TO 300 PASSENGERS
<b>DESIGN CRUISE SPEED</b>	• MACH NUMBER 2.2 TO 2.7
<b>FARE STRUCTURE</b>	• LOWER THAN CURRENT FIRST CLASS
<b>DIRECT OPERATING COSTS</b>	• DOC 50% LOWER THAN CONCORDE

FIGURE 7

The problems to be faced to provide advances significant enough to insure economic and environmental acceptability for future supersonic transports are directly related to the characteristics we wish to specify. It is our view that the general specifications as shown in figure 7 must be met. Recognize these are goals now.

The noise should be lowered below current FAR-36 for aircraft of this size. Engine emissions must satisfy those EPA is setting up for

class T-5 standards. Cruise  $\text{NO}_x$  levels should be  $\frac{1}{2}$  those of Concorde. The range should be on the order of 4200 or 4500 nautical miles. The payload should be 250 to 300 passengers. Design cruise speed somewhere between mach 2.2 and 2.7. We are still keeping options open in the study. In regard to the fare structure, we believe that lower-than-first-class fares are necessary for the economic viability of such vehicles, and direct operating costs should be something like 50 percent lower than for Concorde.

## INFLUENCE OF TECHNOLOGIES ON KEY ENVIRONMENTAL AND ECONOMIC FACTORS

TECHNOLOGY	NOISE	POLLUTION	RANGE	PAYLOAD
ENGINE CYCLE	PRIMARY	PRIMARY	PRIMARY	SECONDARY
AIRFRAME				
AERODYNAMICS	SECONDARY	—	PRIMARY	SECONDARY
STRUCTURES AND MATERIALS	SECONDARY	—	SECONDARY	PRIMARY
CONTROLS	—	—	SECONDARY	SECONDARY

FIGURE 8

The impact of these key technologies which must be further developed to assure that we reach such goals is shown in figure 8 where I have noted the technology in terms of engines, aerodynamics, structures and materials, and controls against some of the major problem areas—noise, pollution, range and payload. As noted, the engine cycle is the key to minimizing noise and pollution and extending range, and it has somewhat secondary effect on the payload. The propulsion engine problems are further complicated by the need to achieve good subsonic performance without the sacrifice of supersonic performance, as I mentioned earlier.

What is needed then is an engine cycle which combines the best characteristics of the turbofan and turbojet cycles such that noise on takeoff and landing is equivalent to a turbofan; subsonic fuel consumption is sufficiently low to complete long-range missions with one engine out, or to operate from interior destinations where long subsonic legs are required; supersonic fuel consumption is sufficiently low to provide ranges of 4,200 to 4,500 nautical miles with payloads 3 times those of Concorde, and while meeting these characteristics, pollution levels must not exceed the levels stated on an earlier chart.

## VARIABLE CYCLE ENGINE TECHNOLOGY

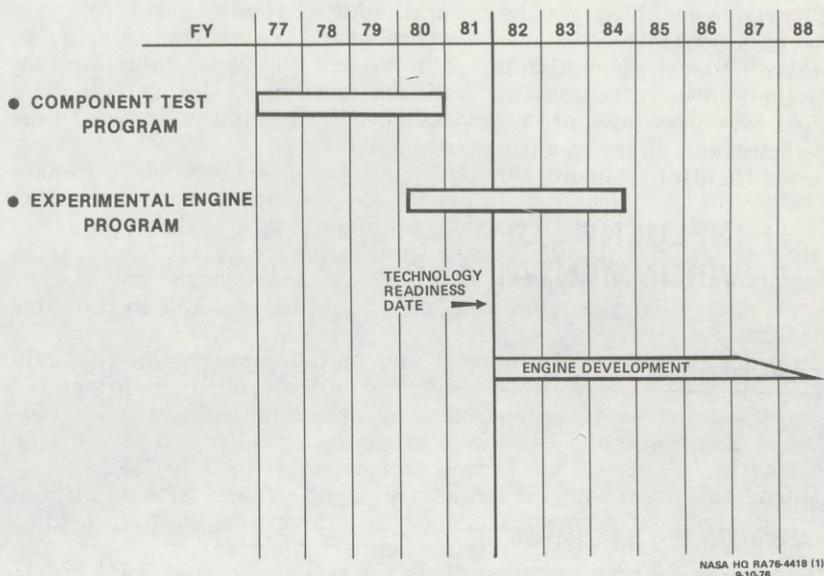


FIGURE 9

The development of this uniquely U.S. engine technology requires, as shown in figure 9, a component technology program which can be completed in this time period of 3 to 4 years; the initiation of a variable cycle experimental engine program in fiscal year 1980 which would run for 4 years; and then, if one were serious about an SST, you would have technology readiness out in the 1981-1982 time frame, and engine development could be geared to this same time frame. Now remember, this is an experimental engine program that we are talking about. In this early stage of engine development, we are talking about preliminary designs and not the actual hardware which will be phased later.

With this schedule, technology readiness would be achieved in the fiscal year 1981 to 1982 time frame and engines would be ready for first flight in the fiscal year 1987 to 1988 time frame.

The next technology challenge occurs in the aerodynamics and configuration development area. The state of the art here is more advanced than that of propulsion, and I have noted that we have configurations that have been validated by wind tunnel tests and analysis which have one-third more lift-to-drag ratio than either the Concorde or the 71 SST, permitting the required design range of 4,500 miles in the 250- to 300-passenger payload class to be met. Further improvements in aerodynamic characteristics are required to permit more rapid climbout and lower speed approaches and landings to minimize noise. Configuration development through an expanded series of wind tunnel tests can be completed by the fiscal year 1981 to 1982 time period to match the propulsion system technology readiness.

The advanced aerodynamic configurations available do pose some additional structural problems, and additional structures research must be carried out over the next several years. We will concentrate this activity on large-scale titanium structures of advanced design and on high-temperature composites. And the technology for such lighter weight structures again can be developed for readiness by fiscal year 1981 to 1982.

The controls area is an important one, but has a secondary impact on range and payload in comparison to the other disciplines. But active controls for load alleviation, minimum static stability and ride quality enhancement will be used in an advanced SST. These technologies are being developed in other NASA programs such as the aircraft energy efficiency program and should be available in the same time frame.

In order to continually monitor and match aerodynamics, propulsion, structures and controls programs and establish an integrated base for a technology readiness decision, a significant systems studies effect is also required. These studies would logically lead to a design specification/engine cycle selection in fiscal years 1981 to 1982.

It is at this point that the industry and the airlines, with or without direct government support, could begin a design competition leading to the development of an advanced supersonic transport.

The resources required to provide for technology readiness by the early 1980's are estimated to be of the order of \$500 million. About \$100 million each would be required in aerodynamics, structures, controls, integration studies and variable cycle engine technology. Such an investment, coupled with an airframe design/engine cycle selection activity beginning in fiscal year 1982, could probably permit the development of an environmentally acceptable, economically viable supersonic transport with an entry into service date by about 1990.

That concludes my testimony.

Mr. MILFORD. Thank you very much.

We have had a vote bell so that our questions will probably come to you at a later time. If you could receive those and submit answers for the record we would appreciate it.

Mr. Smylie, we appreciate you bringing your team in this morning. We will be communicating further with you by mail on the questions.

Mr. SMYLIE. OK. Mr. Chairman, we appreciate your time and attention to this important technology area.

Mr. WYDLER. Good report.

Mr. SMYLIE. Thank you, sir.

[The prepared statement of Mr. Aiken follows:]

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SEP 14 1976

SUPERSONIC TECHNOLOGY

Statement of

William S. Aiken, Jr.  
Director

Aerodynamics and Vehicle Systems Division  
Office of Aeronautics and Space Technology  
National Aeronautics and Space Administration

Before The

Subcommittee on Aviation and Transportation R&D  
Committee on Science and Technology  
House of Representatives

Mr. Chairman and members of the Subcommittee:

This testimony is in response to your request to address the current state of advanced supersonic transport technology and NASA's views on the resources required to bring the critical technologies to a point where a national decision to build an acceptable advanced supersonic transport could be made in the 1980's.

In July of 1972, NASA initiated a supersonic technology program to advance the technology in those areas critical to the environmental, technical and associated economic problems of past and present supersonic cruise aircraft. The primary motivation was to keep the options open for the development of such aircraft if the United States ever chooses to do so in the future. Four years later, having involved the research efforts of over sixty organizations throughout the country and publishing these results in some two hundred and sixty technical reports, we are in a position to report on the current state of technology and the resources and schedules required to advance to a point of technology readiness.

Significant progress has been made in the areas identified in Figure 1. In aerodynamics we have demonstrated higher lift to drag ratios, in structures and materials weight savings with attendant lower costs seem possible through new titanium fabrication processes. In propulsion, our studies have narrowed the many options potentially available to a very few multicycle engines which not only should have reduced noise and emissions, but also have favorable fuel consumption characteristics.

Propulsion Progress. The goal of the propulsion program has been to identify advanced propulsion cycles which concurrently solve the noise, off-design performance/fuel consumption and emission problems which are characteristic of conventional turbojet engines (such as those used in Concorde, TU-144 and the 1971 U. S. SST). All of this must be done while retaining excellent supersonic performance. Four years of study have now led to the definition of several multi-cycle or variable-cycle engines which appear to have the potential for meeting these goals.

One of the promising variable cycle engine concepts is shown in Figure 2. The important features of this engine are the coannular, dual stream nozzle which appears to offer an inherent 8-9 EPNdB noise relief without mechanical suppression; the variable fan and compressor which make it possible to maintain good performance at off-design conditions; and the low emission burners or combustors.

The potential payoff of the inherent coannular/annular noise suppression of such variable cycle engines is illustrated in Figure 3. This figure shows the maximum range as a function of noise level for a 270-passenger supersonic aircraft utilizing a conventional turbojet engine or a variable-cycle engine with inherent coannular/annular noise relief. Variable-cycle engines permit a dramatic increase in range for a given noise level, or a substantially lower noise level for a given range. Somewhat similar data have been presented in the past, but the results were qualified since they were based on small-scale model tests at static conditions. However, after further tests at large scale, the coannular/annular noise reduction potential is still holding up.

The potential improvement in off-design performance for the advanced technology engines is illustrated in Figure 4. Typically, at subsonic cruise conditions the conventional turbojet engines employed in the 1971 U. S. SST and the Concorde have specific fuel consumptions more than twice those of the current high bypass subsonic turbofan engines. The 35 percent improvement in fuel consumption indicated for the variable-cycle engines provides important reductions in the reserve fuel requirements, which are based largely on subsonic cruise flight. In addition, the reduced fuel consumption offered by these engines permits efficient subsonic flight

on overland segments where supersonic flight is precluded by regulation. For example, a 650,000-pound supersonic cruise aircraft with conventional turbojet engines would burn approximately 50,000 pounds of fuel for each hour of subsonic cruise flight. The 35 percent reduction in fuel consumption would result in a 17,500-pound fuel saving per hour of subsonic operation.

The NASA effort in the reduction of nitric oxide ( $\text{NO}_x$ ) emissions at high altitude is illustrated in Figure 5. With the  $\text{NO}_x$  emission index of conventional combustors taken as unity, we see that the new technology combustors have emissions some 45 to 55 percent those of conventional combustors. Note also in the lower right of the figure that NASA has defined some conceptual combustors that could have extremely low emission indices. It still remains to be seen whether these conceptual combustors can be integrated into a practical subsonic or supersonic propulsion system.

Aerodynamic Progress. The mission performance of a supersonic cruise aircraft is critically dependent on the levels of aerodynamic efficiency or lift-drag ratio throughout the speed range. Consequently, a major emphasis in the aerodynamics program has been to upgrade both the low-speed and supersonic lift-drag ratios from the marginal values of the 1971 U. S. SST. Of course, we have tried to do this upgrading within the constraints of a practical supersonic aircraft configuration. To date, the program has supported the construction and testing of some 13 major wind tunnel models. The results of these tests essentially validated the advanced arrow-wing characteristics first defined by NASA in the 1960's. The significant result of this test program is shown in Figure 6. The level of supersonic lift-drag ratio achieved is slightly below the NASA research band but some 30 percent higher than the value for the Concorde and the 1971 U. S. SST. This is a very important result in that it represents an industry design and test effort on an advanced aerodynamic concept that could be built. Other studies, i.e., the use of wing-body blending, indicate that the full L/D potential of the advanced arrow-wing may still be realized.

Structures & Materials Progress. We have made considerable progress in developing more rapid analytical methods for structural design and analysis in order to address the flutter problems of arrow-wings. Advanced composite materials are being developed for high temperature applications and panels are being tested on the YF-12. While

these important programs are continuing, our immediate attention has been drawn to a new superplastic titanium fabrication process under development in the Air Force B-1 program. This process offers hope for substantial reductions in the cost of titanium structures with some smaller, but still significant, reduction in weight. Since cost and weight are extremely critical to the viability of future supersonic cruise aircraft, we have become directly involved in the study of this new process. We believe that this process is a key element for the future development of supersonic cruise aircraft.

I would like to turn now to a discussion of the critical technologies which would be required for technology readiness.

The Concorde, TU-144 and the 1971 U. S. SST were essentially based upon engine, airframe and structures technologies developed in the early 1960's.

While Concorde and the TU-144 are admittedly advanced technical achievements, they have the obvious shortcomings of very high noise levels, and marginal range and payload which impact their overall economic viability. Engine emissions are a problem but are considered to be somewhat more amenable to solution. The 1971 version of the U. S. SST was really an experimental airplane, not a prototype, and it is hard to say what its characteristics would have been if it had gone into production. As designed it would have been unacceptable from a noise standpoint and while its payload was at a level sufficient to provide the required productivity, its range would have been marginal.

The problems to be faced to provide advances significant enough to insure economic and environmental acceptability for future supersonic transports are directly related to the characteristics specified. It is our view that the general specifications as shown in Figure 7 must be met.

The impact of key technologies which must be further developed to assure success are shown in Figure 8.

This rough-cut analysis indicates that the propulsion system has a primary impact on three of the major areas of concern (noise, pollution and range) with a somewhat secondary impact on payload. The propulsion or engine

problems are further complicated by the need to achieve good subsonic performance without the sacrifice of supersonic performance.

The engine cycle most efficient for supersonic cruise is a straight turbojet which is noisy and has very poor subsonic fuel consumption characteristics. On the other hand, the high bypass ratio turbofans used on the current wide-body aircraft have very poor supersonic fuel consumption characteristics as well as high drag. What is needed, then, is an engine cycle which combines the best characteristics of the turbofan and turbojet cycles such that:

- (a) noise at takeoff and landing is equivalent to a turbofan;
- (b) subsonic fuel consumption is sufficiently low to complete long range missions with one engine out, or to operate from interior destinations where long subsonic legs are required;
- (c) supersonic fuel consumption is sufficiently low to provide ranges of 4200 to 4500 nautical miles with payloads 3 times those of Concorde; and
- (d) while meeting the characteristics noted above pollution levels must not exceed the levels stated previously.

This is a large order but as reported in February 1976, studies of potential engine cycles conducted by G. E., P&W and NASA over the past several years have finally narrowed the field to a few variable cycle engines which hold promise of filling the bill. The development of this uniquely U. S. engine technology requires:

- (a) a component technology program which can be completed in three years;
- (b) the initiation of a variable-cycle experimental engine program in FY 1980 which would run for four years; and
- (c) the initiation of the actual development program for a variable-cycle engine midway in the course of (b) and which would take 6 years to complete.

With this schedule, technology readiness would be achieved in the FY 81-82 time frame and engines would be available for first flight in FY 87-88. There is nothing that could be done to further accelerate the development process unless noise constraints were to suddenly disappear.

The next technology challenge occurs in the aerodynamics/configuration-development area. The state of the art here is much more advanced than that of propulsion. We have configurations which have been validated by wind tunnel test and analysis which have 1/3 more L/D ratio (less drag) than either the Concorde or the 1971 U. S. SST design permitting the range and payload to be increased to the 4200 to 4500 n. mi. and 250-300 passenger requirements. These ranges/payloads are dependent, of course, on achieving the predicted variable-cycle engine performance characteristics but increased aerodynamic efficiency is also required to keep the total aircraft weight within reasonable bounds ( $\sim 750,000$  lbs.) which consequently has a favorable impact on take-off noise. Further improvements in aerodynamic characteristics are required to permit more rapid climb-out and lower-speed approaches and landings to minimize noise. Configuration development through an expanded series of wind tunnel tests can be completed by the FY 81-82 time period to match propulsion system technology readiness.

The advanced aerodynamic configurations available today do pose some additional structural problems and additional structures research must be carried out over the next several years. The concentration of this activity would be on large-scale titanium structures of advanced design (the design approaches have been developed but not tested to date) and on high temperature composite structures wherever they may be utilized to advantage. The flutter problems must be solved by continued wind tunnel tests and the application of active control technology. The structural weight has a primary impact on payload, since every pound of structural weight saved can be utilized for payload or fuel. Minimizing structural weight also keeps the gross weight within bounds and thus noise levels down. The technology for lighter-weight structures can be developed for readiness by FY 81-82.

While the controls area is an important one, it has a secondary impact on range and payload in comparison to engine, aerodynamic and structures technologies. Active controls for load alleviation, minimum static stability

and ride quality enhancement will be used in an advanced SST. These technologies being developed in other NASA program areas (such as ACEE) will be available in the FY 81-82 time frame. An advanced SST requires a combined inlet/engine/airframe control system to optimize engine performance and minimize cruise drag and atmospheric temperature gradient effects. This work is well underway with the YF-12 cooperative control program which could be completed by FY 1980.

In order to continually monitor and match aerodynamics, propulsion, structures and controls programs and establish an integrated base for a technology readiness decision, a significant systems studies effort is also required. These studies would logically lead to a design specification/engine cycle selection activity in FY 1981/82.

It is at this point that the industry and the airlines (with or without direct Government support) could begin a design competition leading to the development of an advanced supersonic transport. There would be a continuing need for a supporting technology program but the main emphasis would shift to development.

The resources required to provide for technology readiness by the early 1980's are estimated to be on the order of \$500 million. About \$100 million each would be required in aerodynamics, structures, controls, integration studies and variable-cycle engine technology. Such an investment coupled with an airframe design/engine cycle selection activity beginning in FY 1982 could probably permit the development of an environmentally acceptable, economically viable supersonic transport with an entry into service date by 1990.

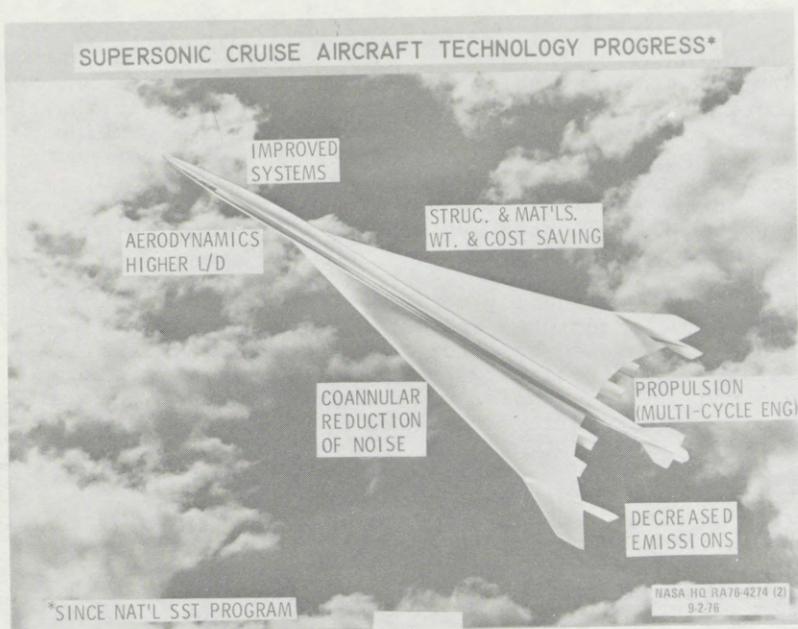


FIGURE 1

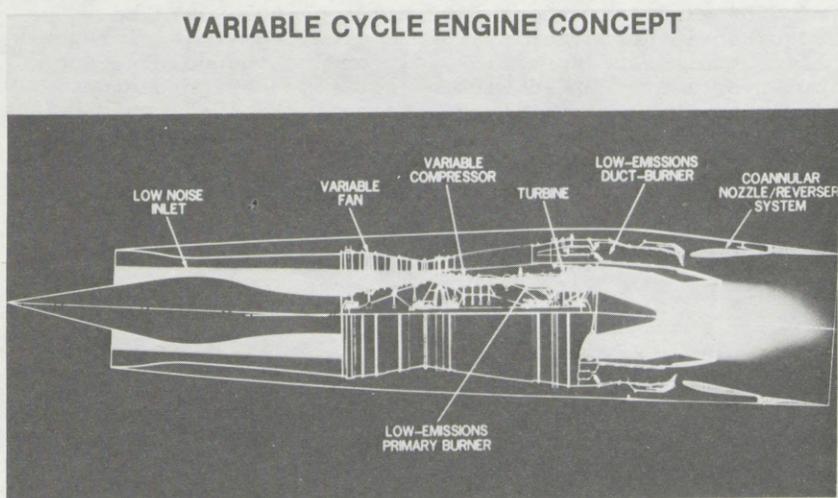


FIGURE 2

## POTENTIAL OF COANNULAR/ANNULAR NOZZLE INHERENT NOISE SUPPRESSION

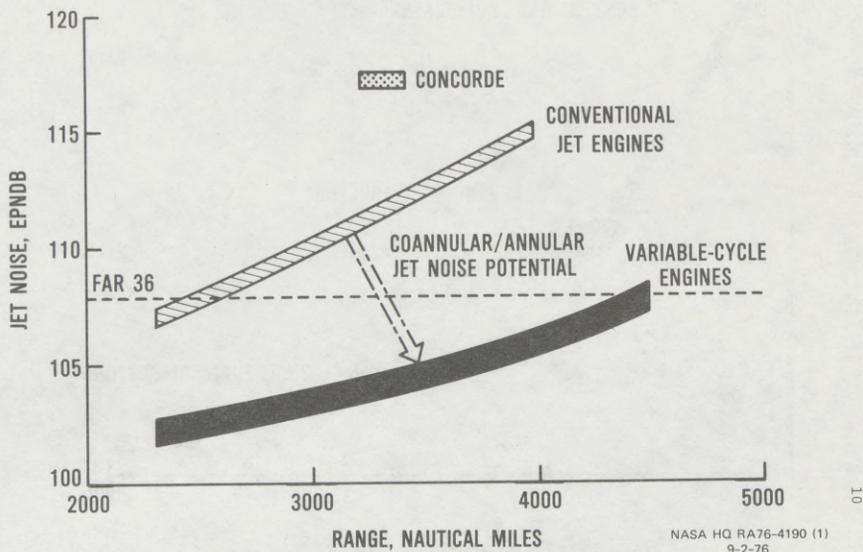


FIGURE 3

## IMPROVEMENTS IN ENGINE SPECIFIC FUEL CONSUMPTION

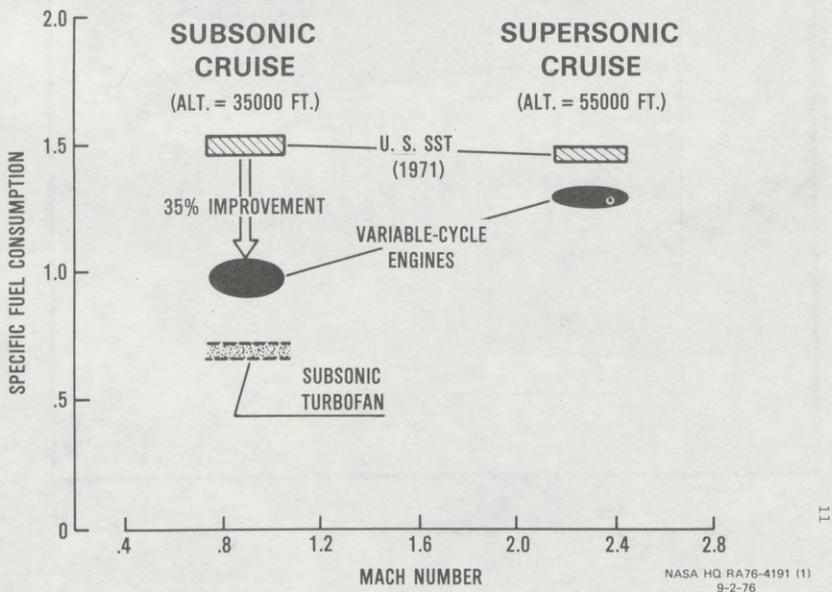


FIGURE 4

## STATUS OF CRUISE NO<sub>x</sub> EMISSIONS

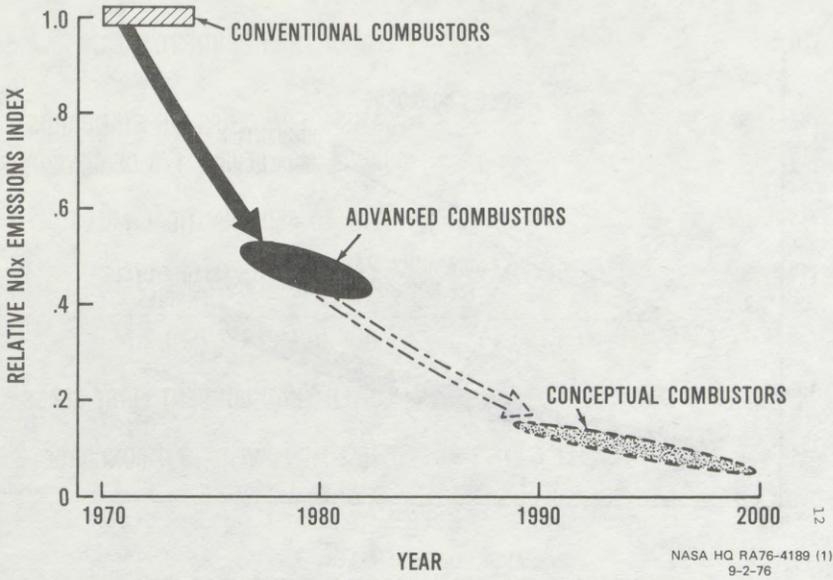


FIGURE 5

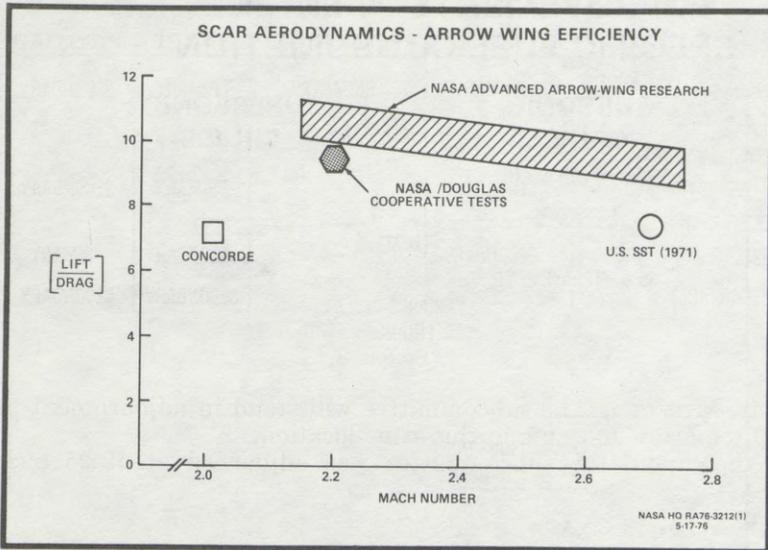


FIGURE 6

## GENERAL SPECIFICATIONS FOR AN ADVANCED SST

<b>NOISE</b>	• LOWER THAN CURRENT FAR-36
<b>ENGINE EMISSIONS</b>	• SATISFY EPA CLASS T-5 STANDARDS • CRUISE NO <sub>x</sub> LEVELS 1/6 OF CONCORDE
<b>RANGE</b>	• 4200 TO 4500 NAUTICAL MILES
<b>PAYLOAD</b>	• 250 TO 300 PASSENGERS
<b>DESIGN CRUISE SPEED</b>	• MACH NUMBER 2.2 TO 2.7
<b>FARE STRUCTURE</b>	• LOWER THAN CURRENT FIRST CLASS
<b>DIRECT OPERATING COSTS</b>	• DOC 50% LOWER THAN CONCORDE

FIGURE 7

### INFLUENCE OF TECHNOLOGIES ON KEY ENVIRONMENTAL AND ECONOMIC FACTORS

TECHNOLOGY	NOISE	POLLUTION	RANGE	PAYLOAD
ENGINE CYCLE	PRIMARY	PRIMARY	PRIMARY	SECONDARY
AIRFRAME				
AERODYNAMICS	SECONDARY	—	PRIMARY	SECONDARY
STRUCTURES AND MATERIALS	SECONDARY	—	SECONDARY	PRIMARY
CONTROLS	—	—	SECONDARY	SECONDARY

FIGURE 8

Mr. MILFORD. The subcommittee will stand in adjournment until 9:30 tomorrow morning in this same location.

[Whereupon, the subcommittee was adjourned at 12:25 o'clock p.m.]

THE UNIVERSITY OF CHICAGO

PHYSICS DEPARTMENT

REPORT OF THE

COMMISSION ON

THE PHYSICS DEPARTMENT

OF THE UNIVERSITY OF CHICAGO

FOR THE YEAR 1960-1961

PREPARED BY

THE COMMISSION

ON THE PHYSICS DEPARTMENT

OF THE UNIVERSITY OF CHICAGO

AND THE

PHYSICS DEPARTMENT

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FOR THE YEAR 1960-1961

## 1978 NASA AUTHORIZATION

WEDNESDAY, SEPTEMBER 15, 1976

U.S. HOUSE OF REPRESENTATIVES,  
COMMITTEE ON SCIENCE AND TECHNOLOGY,  
SUBCOMMITTEE ON AVIATION AND  
TRANSPORTATION R. & D.,  
*Washington, D.C.*

The subcommittee met, pursuant to notice, at 9:30 a.m., in room 2325, Rayburn House Office Building, Hon. Dale Milford, chairman, presiding.

Mr. MILFORD. The subcommittee will come to order.

During hearings before the subcommittee on the future of aviation, we heard many witnesses say that the United States should build a economically viable, environmentally acceptable, advanced supersonic transport. With this in mind, the subcommittee, as part of its fiscal year 1978 NASA authorization process, has decided to inquire into the areas of technology that must be advanced before the United States can undertake such a project. Accordingly, we have invited four witnesses with different perspectives to present their views on technology needs as well as possible timetables for technology availability.

Our first witness this morning is Dr. Edgar M. Cortright, president, American Institute of Aeronautics & Astronautics.

Dr. Cortright, we welcome you to the committee again. We have your complete prepared statement with attachments which at this point will be accepted for the record and you may proceed as you see fit in the way of your presentation.

### STATEMENT OF DR. EDGAR M. CORTRIGHT, PRESIDENT, AMERICAN INSTITUTE OF AERONAUTICS & ASTRONAUTICS—AIAA; ACCOMPANIED BY DR. JERRY GREY, AIAA ADMINISTRATOR, PUBLIC POLICY

Dr. CORTRIGHT. Mr. Chairman, it is a pleasure to be here again. I always enjoy coming before this committee, having done so for many years. If you do not mind, I will read this statement because it is a brief one and then be available for questions. I hope you would feel free to interrupt me at any time with questions.

Mr. MILFORD. Yes, fine.

Dr. CORTRIGHT. As you may remember, Mr. Chairman, I appeared before this subcommittee last May 6 to report to you the results of the AIAA's recent conference on the role of technology in civil aviation R.T. & D. policy. One of the points I stressed at that time was the

need for an active research and technology program on which to base the future development of an economically sound, environmentally acceptable, second-generation, civil supersonic transport aircraft, and I outlined for you several of the technology areas which the participants at our conference believed to be important in achieving that development goal. I am grateful to you for the opportunity you have given the AIAA today to enlarge upon that brief commentary.

The AIAA is the technical society whose 25,000 engineer, scientist, and student members represent areas of knowledge from all sectors of the aeronautical field, and my statement today reflects considerable input from this diverse constituency. I would like to call to your attention the many past and current publications of the institute which have contributed to civil supersonic aircraft technology. One excellent example is the cover story in this recent May 1976 issue of *Astronautics and Aeronautics* titled: "Shaping Supersonic Cruise." This is a copy of that magazine.

The technology requirements for civil supersonic cruise aircraft fall into four categories: Aerodynamics, including total configurations; structures and materials; propulsion; and control systems.

The current NASA program designated supersonic cruise aircraft research, or SCAR, encompasses all four of these in considerable depth, and has been strongly endorsed by the AIAA based on prior reviews by the society. I will not attempt to review the entire program in the limited time available to me, but perhaps I can point out several key areas which we at the AIAA believe deserve additional emphasis.

Let me talk first about aerodynamics and configurations. The main goal of current supersonic cruise aerodynamic research is to reduce fuel consumption by improvements in aircraft lift/drag ratio, both during supersonic cruise and subsonic flight. A secondary goal is to reduce the sonic-boom overpressure.

Two developments have received recent emphasis as having major potential impact on L/D. The first of these is blending the wing with both the fuselage and the engine nacelles to reduce drag. The second involves powered lift aimed at improving low-speed L/D without causing supersonic cruise performance to suffer. Both concepts are relatively old ideas, but their impact on supersonic cruise aircraft economics, both in terms of increased range and reduced fuel consumption appears from the limited test data to be quite significant. Accelerated evaluation testing will be necessary during the next few years to ascertain the full extent of performance improvement achievable, to aid in determining the optimum configurations for best performance and economy, and to further identify and solve the attendant structural, stability, and control problems which may arise.

Continued attention to sonic boom reduction is still an area for active interest, because of the present boom-inspired ban on overland civil supersonic aircraft flights. Considerable potential marketability enhancement would be offered by overland flight corridors which would be reopened to boom-free aircraft. Current efforts in this direction are almost solely theoretical, but they have resulted in analytical methods for aerodynamic shaping which minimize sonic boom overpressures for any given aircraft. Funding limitations have precluded adequate experimental testing to both evaluate the analytical predictions and to determine the impacts of boom minimization

on other key aircraft parameters, such as L/D ratio, in the various flight regimes, controllability, structural integrity, et cetera. A relatively small increase in support for efforts in this area could conceivably generate potentially valuable results.

One other perennial aircraft configuration innovation continues to nag at our technical consciences: The prospect for utilization of liquid hydrogen, rather than conventional jet fuels, for supersonic cruise aircraft. While virtually all prior studies have shown that hydrogen cannot match up to hydrocarbon jet fuels economically, even for subsonic flight, I do not believe we have yet cast our crystal ball view far enough into the future. The AIAA certainly does not recommend a major technology effort in this area, but the prospects for a future in which hydrogen might be manufactured from water by off-peak electric power generated by solar, nuclear, or ocean-thermal plants are becoming more and more real. When we talk about initiating a supersonic cruise aircraft development program in the mid-1980's, to be operational perhaps 10 years later, we are not much in advance of some predicted dates for wide-scale nonaircraft utilization of hydrogen. I, therefore, suggest that we continue to maintain a small but viable research and technology program in hydrogen-fueled supersonic aircraft, just to be sure we will be ready to utilize this new fuel when and if the proper time comes.

Now let me turn to structures and materials. Reduced aircraft mass offers one of the best avenues for improvement in aircraft economics via both increased payload capability, or increased range, and reduction in aircraft cost. There are far too many promising research and technology prospects in this area for me to cover and I am sure some of the other speakers will get into them later, but two which seem to offer the biggest rewards for supersonic cruise aircraft are composite materials and new titanium fabrication methods.

Quoting from the proceedings of the AIAA's conference on the role of technology in civil aviation R.T. & D. policy—I have a copy here:

Success of an advanced supersonic transport system by the year 2000 may depend substantially on the accomplishments of the next decade in developing and proving composite systems for elevated temperature applications.

Although some fund-limited work is proceeding under NASA's SCAR program, and to a considerably greater degree in a number of Department of Defense aircraft developments, specific applicability of composites to civil supersonic cruise aircraft, as well as optimization of their use, needs to be established at a much more rapid pace than is now being pursued.

Titanium structures have been under scrutiny for some time; the Soviet TU-144 first-generation supersonic transport has already exploited them to a considerable degree. A spinoff from the Department of Defense's B-1 bomber program, however, appears to open a highly promising path to far higher efficiencies in using this metal in relatively near-term civil supersonic aircraft. This process, superplastic forming, has reduced the cost of fuselage structural components in the B-1 by as much as 60 percent. Evaluation of its potential and its impact on design optimization in civil aircraft structures should proceed as rapidly as possible.

There is one all-inclusive technology development in this area which I cannot help but cite at this time, although it does appear to be adequately funded: the use of computer-aided analytical methods. These methods are first applied to the analysis of complex aircraft structures, but are now utilized for the design of complete aircraft configurations; one such program is the IPAD being sponsored by the Langley Research Center. The impact of these relatively new techniques, both in fast turnaround between design iterations and in improved modeling and simulation, cannot be overestimated. They will continue, I hope, to constitute a key element in the SCAR program.

I now turn to propulsion, Mr. Chairman. Perhaps the key factor in the ultimate acceptability of a second-generation civil supersonic cruise transport is the success of engine development. Aside from economics, where the engine plays significant roles in its effect on fuel consumption, maintenance, and aircraft first cost, the principal public concerns about supersonic aircraft are engine noise and engine effluent impacts on the upper atmosphere. The need to meet all these often conflicting requirements in flight regimes varying from takeoff/landing to efficient subsonic cruise imposes a heavy burden on the engine designer.

Again, I have not sufficient time to cite all the promising developments, so I have singled out only three of the most exciting ones: New multiple-cycle engine configurations, significant noise reduction potential via the coannular nozzle, and major reductions in engine-exhaust nitric oxides.

The multiple-cycle engine has long been recognized as virtually the only approach which offers any hope for meeting the widely disparate performance and environmental needs of a civil supersonic cruise transport. The considerable complexity of such engines continues to be the primary barrier, resulting in poor reliability, high cost, and excessive mass. Two recent innovations in multiple-cycle engine designs which appear capable of meeting the stiff requirements are the variable stream control engine, basically a duct-burning turbofan employing extensive internal flow control, and the rear-valve variable-cycle engine, which uses a nozzle-entrance valve variable-cycle engine, which uses a nozzle-entrance valve to approximate either turbojet full-power operation or turbofan part-power operation. Both these engine concepts need extensive ground and flight testing for their evaluation and continuing evolution; a continuing program of research to identify other new approaches should also be supported.

Adequate noise reduction is, of course, one of the major obstacles which must be unequivocally overcome before any civil supersonic transport can be successfully developed. Although much effort has been devoted to mechanical noise suppression devices and acoustical liners, the only real hope for major exhaust-jet noise alleviation during takeoff lies in controlling the relative velocities of the jet components.

A true breakthrough in this area appears to be the coannular nozzle, which inverts the usual turbofan flow pattern by placing the cold flow at the exhaust-jet core with the hot flow surrounding it. Noise reduction of 8 to 12 EPNdB has been achieved with this configuration on static engine tests. However, past history has revealed

much less noise reduction actually achieved in flight than on static engine tests, so it is very important that the coannular nozzle be subjected to flight test evaluation at the earliest opportunity. This will require additional program support.

Reduction of nitrogen oxides is another prerequisite to commercial supersonic operations, based on results of the climatic impact assessment program (CIAP) studies. Various combustion techniques have been explored, and a number of approaches appear to be successful in achieving order-of-magnitude NO<sub>x</sub> reductions, at least in the primary engine combustor. However, quoting from *Aeronautics and Astronautics*, May 1976, ". . . several more years of laboratory work followed by combustor development and demonstration will be needed before it is known what value is realistically achievable." Thus a substantial increment in program support will be needed here.

The DOD's proposed aeropropulsion systems test facility will provide the necessary freejet environment needed for much civil supersonic-cruise transport engine testing. However, sufficient test-facility program support will be needed for NASA to construct proper test hardware for its proposed 5-year testbed engine program, and hopefully there will become available an adequate engine test facility capable of simulating such difficult flight conditions as engine forebody distortion at transonic speeds. Such testing constitutes a significant budgeting deficiency in the civil supersonic cruise propulsion research effort.

Turning to control systems, as in the other technology areas I have cited, I select two areas to highlight from among the many possibilities: the control-configured vehicle concept and multiple-cycle engine controls.

Active aircraft control systems, which control the dynamic response of aircraft by means of time-phased compensating inputs from the various control elements, offer dramatic mass-reduction potential benefits; for example, in size of empennage surfaces, reduction of dynamic loads and consequent fatigue strength requirements, and wing mass reduction via flutter control. Other operational benefits include maneuver and gust-load alleviation, relaxed static stability and landing-impact requirements; and so forth. Active controls, in effect, replace metal with black boxes. They make a rather flimsy structure capable of adjusting itself to compensate for airloads.

But the use of active controls requires essentially perfect reliability for civil aviation applications. Hence, although the military has successfully applied this principle to some degree, extensive studies, hardware and electronics development, and flight demonstrations will be needed during the next decade to achieve the civil-aviation operational benefits of active controls.

In the engine control area, because the necessarily complex multiple-cycle engines demand control of at least twice as many functions as do current subsonic systems, the development of full-authority digital electronic fuel-control systems is essential. Current Air Force and Navy programs to develop such controls for military engines could contribute substantially to this requirement; however, NASA support is needed to evaluate their suitability for civil supersonic-cruise transport applications.

In summary, Mr. Chairman, we at the AIAA believe that a second-generation supersonic-cruise transport aircraft development will be necessary to maintain U.S. economic viability in the international aviation market. Such an aircraft must be economically sound, environmentally acceptable, and competitive in the world market with foreign second-generation supersonic aircraft, both for aircraft customers and airline passengers. We have already made impressive research and technology strides, both in performance capability and in environmental requirements, but a continuing research and technology program is essential today to achieve this goal. We believe that additional support, at the very least in the areas I have cited in this statement, will be needed to keep the program viable.

Thank you very much, Mr. Chairman, for this opportunity to present the Institute's views. Dr. Jerry Grey, who is accompanying me today, will be available to assist me in answering any questions that we can.

Mr. MILFORD. Thank you, Dr. Cortright.

First, those publications that you referred to. The first one, "Shaping Supersonic Cruise," does that publication deal entirely with the subject we are holding hearings on here?

Dr. GREY. No, there are several articles. This is the monthly magazine of the AIAA, *Astronautics and Aeronautics*, and this particular issue includes several major articles on supersonic-cruise aircraft.

Mr. MILFORD. And the second publication, Dr. Cortright?

Dr. CORTRIGHT. It is entitled "The Technical Basis for a National Civil Aviation Research Technology and Development Policy." It is a product of an AIAA Workshop Conference held at Crystal City, Va., in March 1976, sponsored by the Scientific Technological and International Affairs Office of the National Science Foundation.

Mr. MILFORD. You mentioned in the SST research that "lift over drag ratio" was one of the areas that would be very important. I would ask if the same research over reducing L/D conducted in the SST program, would that same factor apply to subsonic also?

Dr. CORTRIGHT. The aerodynamics of supersonic flight are considerably different than subsonic flight and in general the work on increasing L/D at supersonic cruise is unrelated.

Mr. MILFORD. It would not be related?

Dr. CORTRIGHT. It would not be related to increasing L/D for subsonic cruise except in this sense. In building an aircraft, you have to look at both, so in general the configuration will be compromised to deliver the best total performance taking into account both the needs of supersonic and subsonic flight. The aircraft spends a lot of its time at subsonic speeds and expends a lot of its fuel at subsonic speeds,

Mr. MILFORD. In your remarks concerning the use of hydrogen, many of those who are concerned about environmental problems will welcome that news. If you went to a hydrogen system, would this also ease some of our environmental pollution problems?

Dr. CORTRIGHT. The products of combustion of a hydrogen engine are primarily water vapor, however, depending on the temperature of the combustion chamber and how the entire combustion cycle is handled, you can also produce oxides of nitrogen. In general, however, the answer has got to be yes. The pollutants from a hydrogen-fueled engine will be less severe than from a hydrocarbon-fueled engine.

Mr. MILFORD. If we spend time and money in the hydrogen research project then it would perhaps supply answers to some of the environmental problems, whether we ever build an SST or not.

Dr. CORTRIGHT. I personally am a strong supporter of the country continuing to look at hydrogen as a portable fuel, looking forward to the day when we may have large amounts of electricity available from some of the sources I have cited and possibly also from fusion reactors. In that event I believe hydrogen could become a very viable portable fuel.

Mr. MILFORD. On page 8 of your testimony you discussed; "However, sufficient test-facility program support will be needed for NASA to construct proper test hardware for its proposed 5-year testbed engine program, and hopefully there will become available an adequate engine test facility capable of simulating such difficult flight conditions as engine forebody distortion at transonic speeds." We have considerable investment in engine test facilities at Lewis. Are you saying that we do not have adequate facilities to carry out the tests that you are talking about?

Dr. CORTRIGHT. When I was with NASA, which was a year ago, the Lewis Research Center did not have adequate facilities to simulate the conditions of a supersonic transport engine, and was preparing a program to acquire those facilities or utilize present and projected military facilities. I presume that is still the case.

Mr. MILFORD. What particular facility do we still need?

Dr. CORTRIGHT. I believe the mass flow and pressure capabilities of the engine test facility and the connected pipe test facility at Lewis are still below the requirements of the supersonic cruise engine, although military facilities are being built which could probably meet those needs.

Mr. MILFORD. Does industry have such facilities?

Dr. CORTRIGHT. Not of that capability.

Mr. MILFORD. Would it be feasible for the aviation industry to develop those facilities, the engine manufacturers?

Dr. CORTRIGHT. Yes.

Mr. MILFORD. It would be feasible?

Dr. CORTRIGHT. Yes, it would. In fact, when NASA or the DOD developed major aviation testing facilities in the past, the aviation industry companies utilized the facilities extensively.

Mr. MILFORD. That was not my question.

My question was, at least what I am trying to get to, should the taxpayer make an investment for such a facility then, or should they be done by industry themselves?

Dr. CORTRIGHT. I understand your question now.

In the past a large fraction of the aircraft testing facilities have been funded by the Government, either the Department of Defense or NASA, because of the very high cost of such facilities and the requirement that everyone have access to them. In other words, they have become national facilities available to all companies. In general the facilities exceed the financial capability of any one company, so if companies were to build them they would require industry consortiums of some sort.

Mr. MILFORD. In other words, it would be a type of facility that could be readily used by any engine manufacturer?

Dr. CORTRIGHT. I would say so.

Dr. GREY. I would like to add that the Department of Defense's aeropropulsion test facility, although its present configuration probably would not accommodate the kind of testing we are talking about, could be modified to perform this kind of testing, since it does have the basic mass flow and pressure capabilities.

Mr. MILFORD. You just anticipated my next question.

Dr. GREY. But there are no plans as yet to do this modification for such a program. It probably is premature at this time, but it is something that we need to plan for in the future.

Dr. CORTRIGHT. I would like to endorse that thought, that that would be the first thing to look at. The NASA Lewis Center classically supports the industry in civil engine development, but in this case might be done more economically via the Air Force facility. Please note, however, that I am not sure of that.

Mr. MILFORD. From your observations, do you feel that the coordination between NASA and DOD research is as good as it should be? Could it be improved?

Dr. CORTRIGHT. I have never seen any form of cooperative venture that could not be improved, Mr. Chairman, but I have always felt that it was adequate to good when I worked for NASA and with the Department of Defense. There are numerous coordinating committees and bodies that exist both within the groups themselves and in outside organizations such as the AIAA. I believe the communications are good and the mutual support is very good. For example, if the Department of Defense needs NASA support or NASA needs the Department of Defense support, it is readily supplied.

Mr. MILFORD. Could you think right offhand of any means of improving it? If you care to, you may submit the answer to the question for the record at a later time if you would like to give it thought.

Dr. CORTRIGHT. I would like to say at this time that offhand, and I have thought a lot about this over the years, I cannot suggest means of improving the coordination, but I will give it additional thought and if I come up with anything I will be happy to submit it.

Mr. MILFORD. Dr. Cortright, thank you very much for your testimony here this morning. Some of the members may wish to submit questions for answers to be supplied for the record at a later time if you would be willing to supply the answers. We would leave the record open for a reasonable period of time so that the members who could not be present this morning could read your testimony and submit those questions.

Thank you.

Dr. GREY. Thank you, sir.

Mr. MILFORD. The Chair now recognizes Mr. H. W. Withington, vice president, engineering, Boeing Commercial Airplane Co.

Mr. Withington, welcome to the committee. We have your prepared statement with attachments which will be accepted for the record at this point, and if you would like to read your statement or proceed in whatever fashion you care to.

**STATEMENT OF H. W. WITHINGTON, VICE PRESIDENT, ENGINEERING, BOEING COMMERCIAL AIRPLANE CO.**

Mr. WITHINGTON. Mr. Chairman, I think that in view of Dr. Cortright's very excellent testimony covering a lot of the same material

that I was going to cover, that I will probably not read mine, but I would like to use my charts to augment and support some of the information that he has provided.

Mr. MILFORD. Fine.

Mr. WITHINGTON. Although you have given my title in the company at the present time, perhaps of more interest in this testimony is the fact that I have been involved in supersonic technology for some 25 of my 35 years with Boeing and I have been connected in one way or other with the U.S. SST program right from the very beginning. In fact when the program was finally canceled, I was in charge of it for Boeing, so it is with a great deal of pleasure that I testify on this subject which is very close to my heart, believe me.

Mr. MILFORD. Okay, sir.

Mr. WITHINGTON. We certainly appreciate the opportunity to present our views on the subject of supersonic technology. I am going to concentrate on some key technical areas that will influence our ability to meet the environmental and economic goals. I would like to describe the progress that we have made since the U.S. SST program was canceled in 1971 and to outline the steps that I think are necessary to improve our capability so that we really will be ready for a second generation SST.

Now, the first chart (see prepared statement, p. 165), shows the key areas that I intend to talk about. There are many more than these, but I think these are the real critical ones. I am going to talk about aerodynamics, propulsion, and I think along with Dr. Cortright, propulsion is probably the biggest single key to a successful program. Structures and materials are very important and I noted Dr. Cortright did discuss this new situation relative to the jet noise—the coannular nozzle effect. Those are the areas that I am going to talk about. In fact, we have made quite a bit of progress since 1971, but I also feel there is considerable more progress required before we are ready to go with a viable second generation program.

The next chart (see prepared statement, p. 167), shows the progress that has been made in aerodynamic efficiency, lift over drag versus mach number. In 1971 we were talking about  $L/D$  in the order of 7, which is the same as the Concorde, however, in the intervening 5 or 6 years we have been able to make about a 20 percent improvement in  $L/D$  in the supersonic area and a little bit of improvement in the transonic area.

This has been mostly a result of refining the wing and the wing-body intersection, and I think that is a very significant improvement. However, we have got more to do and the next chart (see prepared statement, p. 169), will indicate that we feel that there is further improvement possible supersonically. I would like to think that with further effort we can increase that improvement by another order of magnitude similar to what we have done since 1971. I think it is important and that is one of the areas that is going to have to be worked on. We will use sophisticated analytical methods. We have got to do a lot of wind tunnel testing and in addition it may be necessary to prove some of this in flight.

In the area of structures, we were proposing to use a titanium honeycomb panel such as in the upper left of that figure for our wing skin. At the time of the SST program, we were able to use this type of structure only in fairly thin gages. Since that time we have

done a lot more work and we have expanded that technology significantly. In particular, the lower right hand part of that chart (see prepared statement, p. 171), shows that we have been able to increase the gages of the material that we can use considerably and therefore make much more extensive use of this structure in the wing. This is a very efficient structural material for wings such as used on an SST.

Here is an area where we have had a good start and we have made good progress. We still have to continue to improve not only the ability to do it, but the ability to do it cheaply and economically so it is competitive with aluminum used in subsonic aircraft. In the future we have got to continue on not only in these specific areas, but as Dr. Cortright mentioned there are some other sophisticated approaches to using titanium that are appropriate. There is more work required in new and improved alloys. I was in Russia about a year ago and had the opportunity to visit the Light Metal Institute in Moscow and had a 2-day briefing by them on their status of titanium and I had a couple of my experts along with me. Frankly, we were shown data on some alloys of titanium that appear to be superior to those available to us. We have ordered some of this material. Here is an area where we certainly can do more work.

Mr. MILFORD. You might check with the Japanese right now. They could help you, I believe.

[Laughter.]

Mr. WORTHINGTON. They may have better access than we have.

Another important structural material is in the composite area. There has been a tremendous amount of emphasis on composites in subsonic aircraft. NASA has some excellent programs. This same type of material can be extended into the supersonic area. However, at the temperatures associated with the high mach numbers (2.7 is the area that we would like to be at), the matrix material that you have to put these fibers into is not adequate. The work that is being done for the subsonic airplanes is certainly appropriate, but it does not go far enough to be useable at the high temperature associated with mach numbers on the order of 2.7 or so. The temperatures that we are going to be dealing with are 400 or 450 degrees and the current matrix materials are simply not that good. These composites have the good potential but we need to do more work in the matrix materials to be able to use them. There are programs and they should be continued.

We have to learn how to put the composites together into aircraft structures. I think probably one of the most important things is to learn to build composite structures economically in our factories and to learn how they can be maintained and repaired in the field. This is also a key part of the composites that we need to work on.

The next subject I want to talk about is propulsion. This is a picture [see prepared statement, p. 179], of a JT-8 engine which some 5 years ago Boeing took and modified to make it into a variable-cycle engine. This was a significant test. We had invented an air valve that could shift the flow from the inner to the outer annulus. We put this together on a JT-8 engine, ran it on a test stand where we could actually vary the bypass ratio while the engine was running. It was quite dramatic. The observed noise and thrust changed with the change in bypass

ratio, so we feel that we have demonstrated that at least it is feasible to consider a variable-cycle engine. The concept has been discussed in detail with NASA, Air Force, and the engine companies, and you certainly heard from Dr. Cortright that this concept is a very important one. I think that without a doubt we are going to have to have some form of variable-cycle engine to make a supersonic transport viable.

The next chart [see prepared statement, p. 181], shows the progress we can make from an analysis standpoint. We can get a slight improvement supersonically, maybe a couple of percent with a variable-cycle engine. But the thing that is most dramatic is that the subsonic performance of this variable bypass ratio engine is considerably better than the engine that we had in 1971. There is a 35 percent improvement subsonically. This is extremely important because, as I remembered the fuel reserves that we had to carry on a North Atlantic crossing in our supersonic airplane amounted to about 70,000 pounds which is about equal to the payload. This type of reduction of subsonic specific fuel consumption will make a significant change in that reserve. If I remember the numbers right, it was like about 20,000 pounds of fuel that you did not have to carry across the ocean. This of course could immediately be transferred into increased payload. So this is the kind of improvement that you can get with a variable-cycle engine.

A little later I am going to talk about another aspect of this which is that we can do a better job on noise with a variable-cycle engine as well.

In the future we feel that we can improve still further. I think the engine companies might object to our talking about as big as a 15 percent improvement in supersonic fuel consumption, but I guess I would like to put the challenge to them. I think they can get part of that. You know the airframe people always want the improvement to come from the engine companies. [Laughter.]

I have tried to leave the impression that an improved propulsion system is by far the most important part of a viable second generation SST. If I have a single major concern it is that we are not putting enough effort into this. We have good ideas, but in my opinion the effort that is going into it is really below the level of effort that is going to result in success. I do not think we could have a production variable-cycle engine within 10 years at the rate we are going. We are going to have to increase our effort in this area. We have to be more definitive of our plans. It is a key area, but it is also going to be an expensive area, but it is very important.

Now let me just speak briefly to the noise situation relative to the variable-cycle engine.

Dr. Cortright referred to this rather new phenomena. The upper velocity profile [see prepared statement, p. 185], shows a standard straight jet for reference. A relatively low bypass ratio engine has a slower cooler air mass on the outside and you get the velocity profile shown in the second figure and this at the low bypass ratio is good for 3 PNdB in noise reduction. However, we have found lately that if we can invert that velocity profile and put the high velocity on the outside that we can get a significant additional reduction. We do not quite understand this completely, but the test data statically shows

that this is true. We need to do more tests on this and I certainly agree with Dr. Cortright, this data today is mostly static data and we are going to have to do this at forward velocities to be sure that this effect still is maintained.

Now, one final thing that we can do to improve noise characteristics around the airport are to work on the operational techniques that are used during the takeoff run and the climb out [p. 25, prepared statement]. This is one of the things that you can do better with modern technology. You can adjust your takeoff procedures so that you can optimize where you want the lowest noise level. If you have a particular airport that has a noise problem out in the community, you can takeoff with the maximum power, cut back, use an optimum flap schedule, and put the airplane into a higher aerodynamic efficiency position and lower the noise in the community. If the critical area is on the airport itself, you can takeoff at somewhat less than full power and climb out more slowly. So you have got some options with modern technology that can be used to further reduce the noise.

To summarize the noise situation the current technology together with some form of a multi-cycle powerplant can result in an aircraft that will meet the current noise requirements of FAR-36. but it does take a variable-cycle engine and some of these operational techniques that I have talked about. The further programs that have to be done in this area are indicated here. We have got to continue the forward velocity testing, this inverted jet profile has got to be explored. There are other noise sources within the engine that have got to be understood, and we are certainly going to have to have flight testing to prove but these operational procedures that I have talked about. One of the airplane programs that NASA has now, this TCV airplane that they have down at Langley is well equipped and would be an ideal test bed to check out some of these operational procedures.

In the short time that I have had, Mr. Chairman I have tried to outline the progress that has been made, and I have also tried to indicate the efforts that we feel are required to realize the potential that is offered in these various areas of technology. These areas have a major impact on this country's capability to provide an economically successful and an environmentally acceptable supersonic transport. I think that collectively these technologies do offer us the potential to produce a transport that could be technically—considerably superior to either the existing Concorde or TU-144 or its possible derivative. I think there is a great deal of work that remains to be done. I have tried to identify these areas. I think they are generally agreed upon by NASA in the programs that they have.

You may have noted that I have not addressed the subjects of the SST program timing or the operational economics per se. Boeing believes that it is not appropriate to do so until the state of technology readiness is brought to a point that economic evaluation can be accomplished with confidence in the results. I think too much could be at stake to make gross estimates based on unvalidated technical analysis.

Much of the required research is costly. This is particularly true in the propulsion area and that is certainly the area that is recommended for the highest priority because the need for a substantial dedicated effort and because of the very long leadtimes involved.

The NASA program is certainly proceeding in the right direction; however, our rate of accomplishment will depend on the resources that are made available.

I believe that if we are to maintain the option to have a truly viable U.S. SST, we must increase the rate of expenditures on supersonic technology.

In closing, I would like to say again that I appreciate the opportunity to come before this committee to present our views. Thank you.

[The prepared statement of Mr. Withington follows:]

# Supersonic Transport Technology Status

TESTIMONY BEFORE THE  
HOUSE OF REPRESENTATIVES  
SUBCOMMITTEE ON  
AVIATION AND TRANSPORTATION R&D

September 15, 1976

H. W. (Bob) Withington  
Vice President—Engineering

***BOEING*** COMMERCIAL AIRPLANE COMPANY  
SEATTLE, WASHINGTON 98124

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Mr. Chairman and members of the subcommittee:

The Boeing Company appreciates the opportunity to present its views on the subject of the technology needed to ensure that future United States supersonic transports are environmentally acceptable and economically successful.

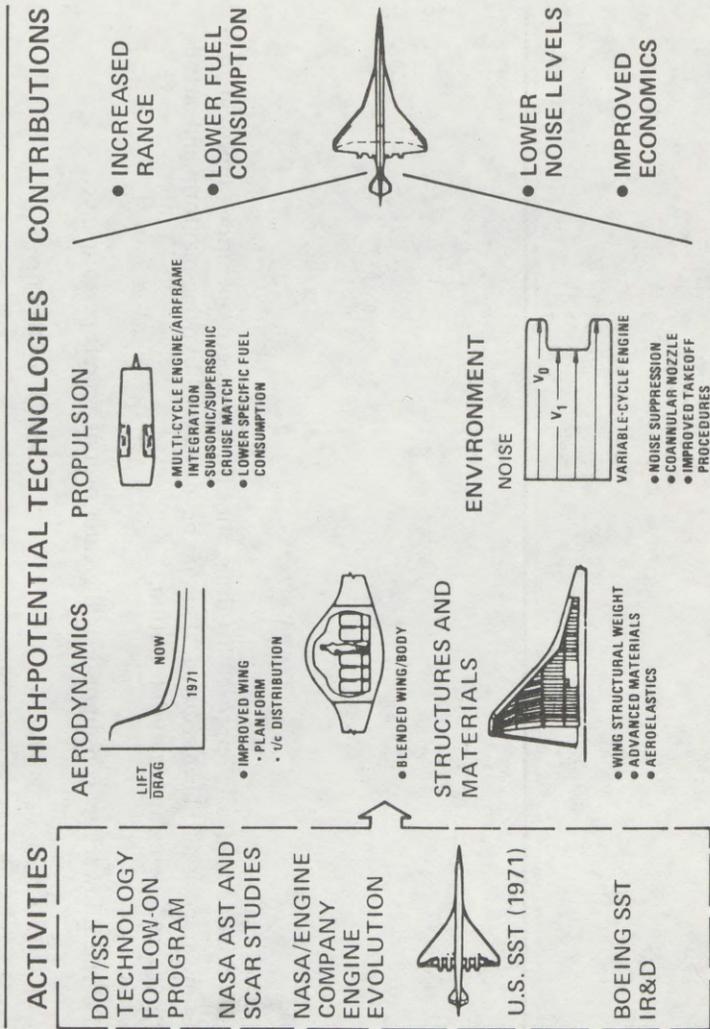
I intend to concentrate on some of the key technical areas that will largely influence our ability to meet environmental and economic goals. I will describe the progress made since the cancellation of the U.S.-SST program in 1971, and outline what are required as the next steps of development to bring each technical area to the needed state of readiness. Good progress has been made, but much remains to be done.

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In the five years since the cancellation of the U.S.-SST program, technical areas that offer very promising advancement potential have been identified. Efforts funded by DOT, NASA, and industry have been very productive. I will summarize the status in the four most important areas shown on the chart: aerodynamics, structures and materials, propulsion, and environment. With proper validation, significant improvements can be expected with respect to range, fuel consumption, and environmental and economic characteristics of a second-generation supersonic transport.

# KEY TECHNOLOGIES

Activities and Contributions

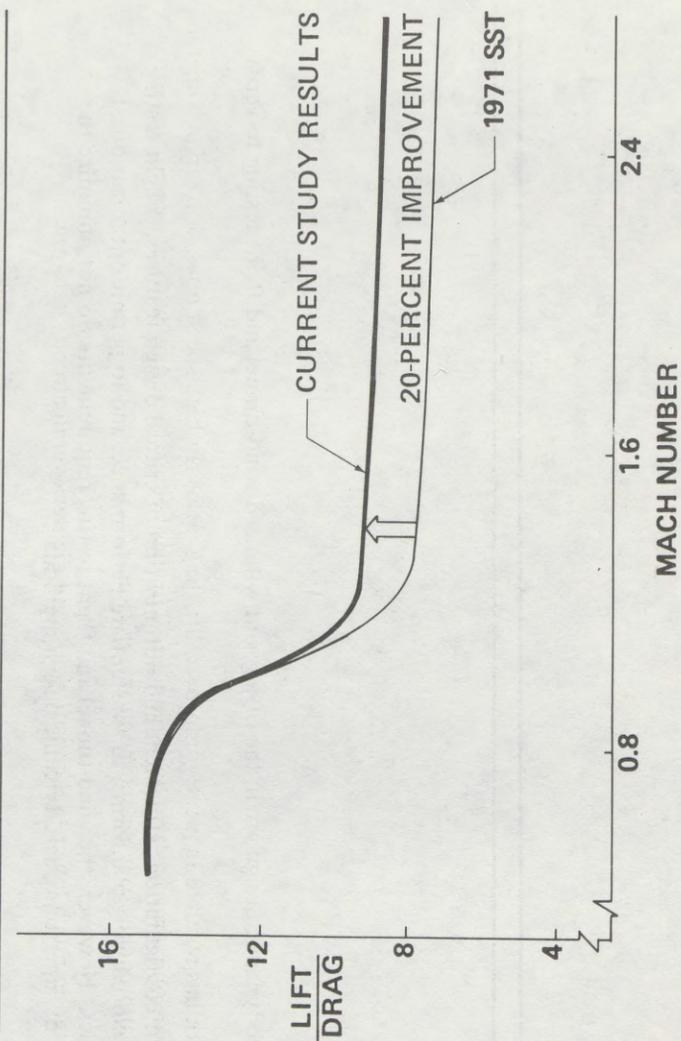


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Recent aerodynamic design work has resulted in greatly improved lift/drag ratios for high-speed operation (approximately a 20-percent improvement). Transonic drag has also been reduced. This has been achieved by wing-planform and airfoil-shape refinements, and by new approaches to wing and body integration.

These improvements have resulted in much lower fuel consumption and greater overall aircraft performance.

Aerodynamics  
**AERODYNAMIC EFFICIENCY**  
Progress to Date



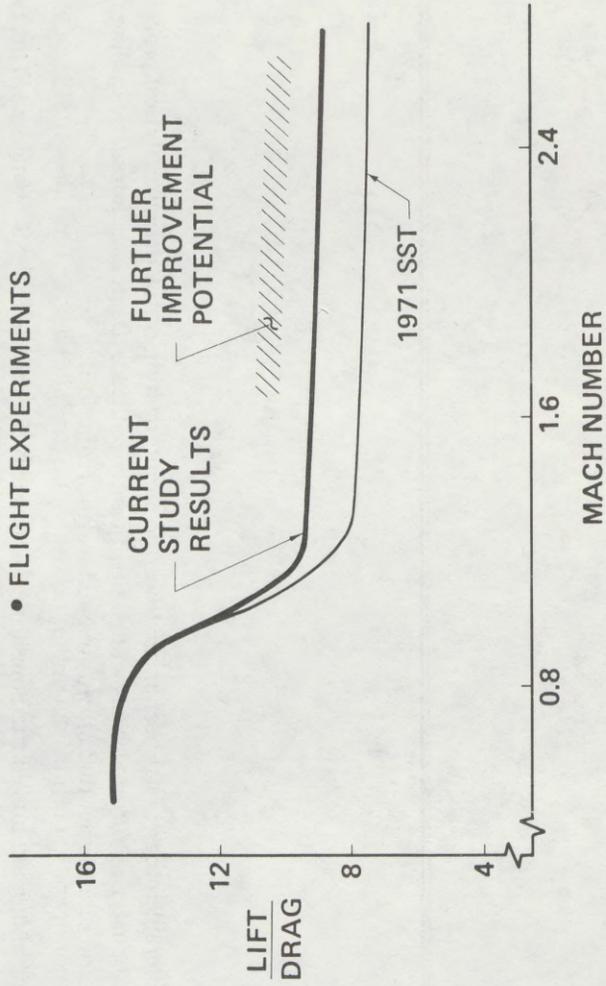
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Still further improvements in aerodynamic design are in the offing, but will need wind-tunnel and flight testing to verify performance.

Wind-tunnel testing is required for configuration refinement and optimization of critical design features. Flight testing is required to introduce more advanced wing planforms, to substantiate performance, and to permit optimization of stability and control characteristics. However, the wind-tunnel and flight testing requirements do not minimize the need for continued development of supersonic, aerodynamic design methods.

Aerodynamics  
**AERODYNAMIC EFFICIENCY**  
Readiness Requirements

- ANALYSIS METHODS
- WIND-TUNNEL TESTING
- FLIGHT EXPERIMENTS

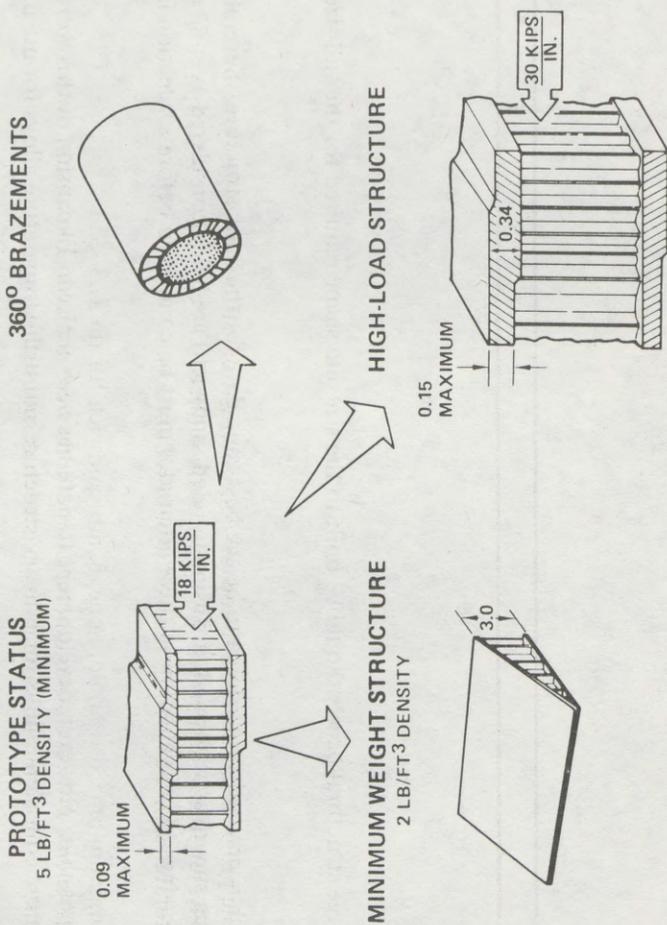


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In the area of structures, considerable progress has been made toward computerization of the design analytical process. As a result, the time and cost of analyzing future designs will be significantly reduced. Decreased automatic-cycling time results in the optimization of structural design that affords marked weight reductions.

In 1971 there was hope of using aluminum-brazed titanium-honeycomb sandwich for the U.S.-SST structure. This type of structure would have been very efficient. However, manufacturing methods were not available at that time to build the heavy-gage, complex-shaped panels. Since then, this capability has been demonstrated.

Structures  
**TITANIUM HONEYCOMB-SANDWICH DEVELOPMENT**  
 Progress to Date



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To determine producibility and cost, large structural panels should be built to the size and shape required for the full-size airplane.

The aluminum-brazed titanium sandwich is presently considered to be the best candidate for the basic structure. Several other manufacturing processes (including superplastic-formed, diffusion-bonded sandwich) are being considered as alternates for possible cost and weight savings. The evaluation of these alternates must be completed before a selection is made.

New and improved titanium alloys are possible. However, development to date has been limited. Expansion of this work could result in availability of tougher, more consistent alloys for primary structure and high-temperature alloys for use in the vicinity of the engines.

Structures  
**TITANIUM TECHNOLOGY**  
Readiness Requirements

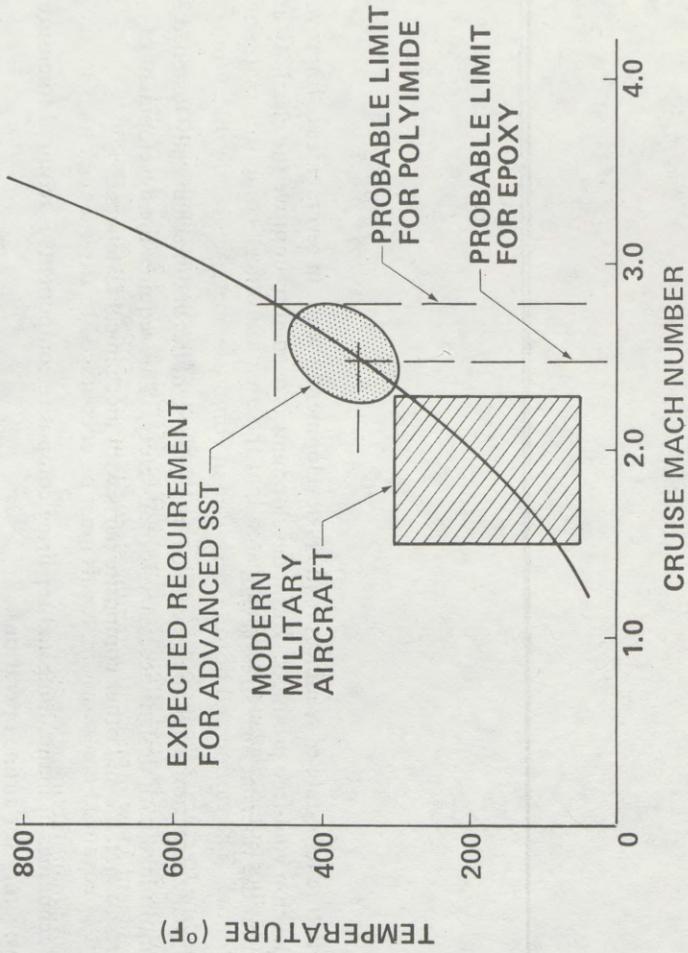
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- CONSTRUCTION OF ADDITIONAL LARGE PANELS TO VERIFY MANUFACTURABILITY AND DETERMINE COSTS
- CONSTRUCTION AND EVALUATION OF ALTERNATE DESIGNS AND PROCESSES
- ADDITIONAL WORK ON NEW AND IMPROVED ALLOYS

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Design studies for both subsonic and supersonic airplanes have indicated that the use of advanced-composite materials offer significant weight-saving potential. The carbon and boron fibers used in composite materials retain their strength at the high temperatures corresponding to cruise speeds above Mach 3.0. However, currently available matrix materials, such as the epoxies that must surround the fibers, lose strength above 300 to 350°F (Mach 2.3 to 2.4). Polyimide matrix materials now under development show promise of retaining strength up to 450°F, which corresponds to Mach 2.7. Continued development of advanced-composite materials must be encouraged to exploit their high strength-to-weight characteristics and improve manufacturing costs.

Structures  
**ADVANCED COMPOSITES**  
 Progress to Date



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To bring advanced-composite structure to a state of readiness requires developmental work in several areas. Improvement of resin processing is needed to develop void-free products. Resin development is needed to improve the elasticity and eliminate the micro-cracking around the fibers at high stress levels.

Composite components of the airplane structure would be assembled into subassemblies and mechanically fastened into major assemblies to provide the multi-load path designs necessary for fail-safety. This requires the development of designs for joining composite parts to metallic and other composite parts with mechanical fasteners.

In addition, the knowledge and techniques of maintaining and repairing composite components is required to ensure that this type of structure will be satisfactory for airline operations.

Structures

## ADVANCED COMPOSITES

Readiness Requirements

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EXPERIMENTAL WORK DIRECTED TOWARD:

- VOID-FREE MATRIX DEVELOPMENT THAT ELIMINATES MICRO-CRACKING
- DESIGNS FOR METAL-TO-COMPOSITE JOINTS WITH MECHANICAL FASTENERS
- THERMAL CYCLING EFFECTS ON MECHANICAL PROPERTIES
- FRACTURE TOUGHNESS CHARACTERISTICS
- MAINTENANCE AND REPAIR PROCEDURES AND TECHNIQUES

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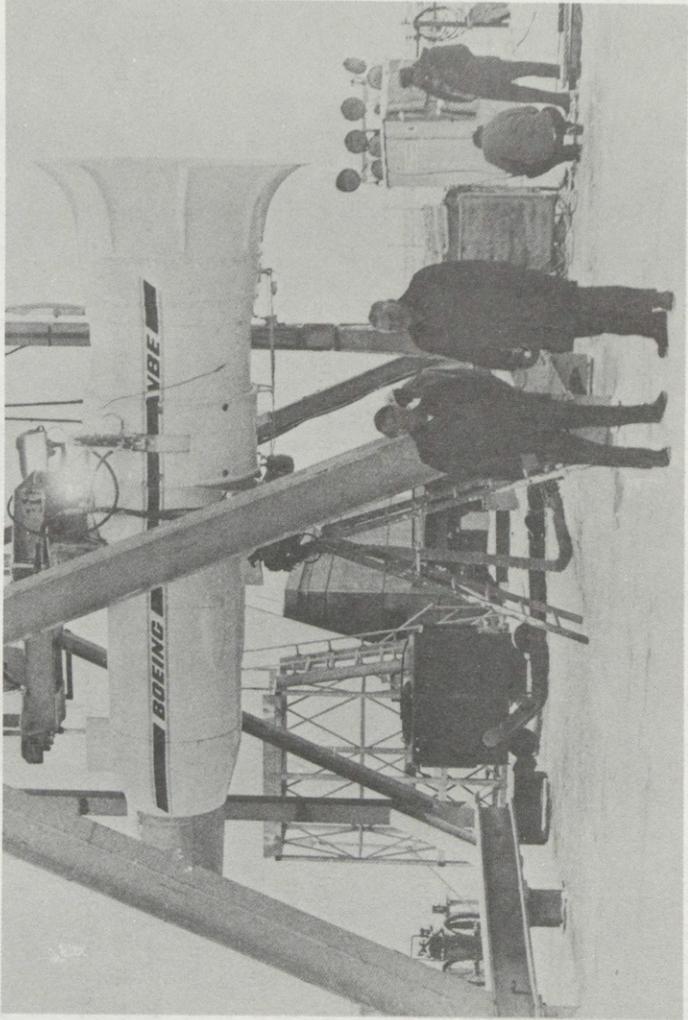
I would like to emphasize that propulsion technology advances undoubtedly offer the greatest potential performance and economic benefits.

In 1971, Boeing initiated a company-sponsored research program to support the engine companies in the identification of supersonic multi-cycle engine (MCE)\* concepts. The MCE engine is designed to operate efficiently, both supersonically and subsonically, providing great operating flexibility and fuel economy. The Boeing program ultimately resulted in the successful demonstration of this revolutionary concept. During the past 5 years, Boeing has cooperated with the NASA, the Air Force, and engine manufacturers in developmental studies of this engine and the results to date have been very encouraging.

As you will see, the MCE also shows promise of substantially reduced noise.

\*The term multi-cycle engine (MCE) refers to a concept also designated variable-cycle engine (VCE).

Propulsion  
**BOEING VARIABLE-CYCLE ENGINE TESTING**



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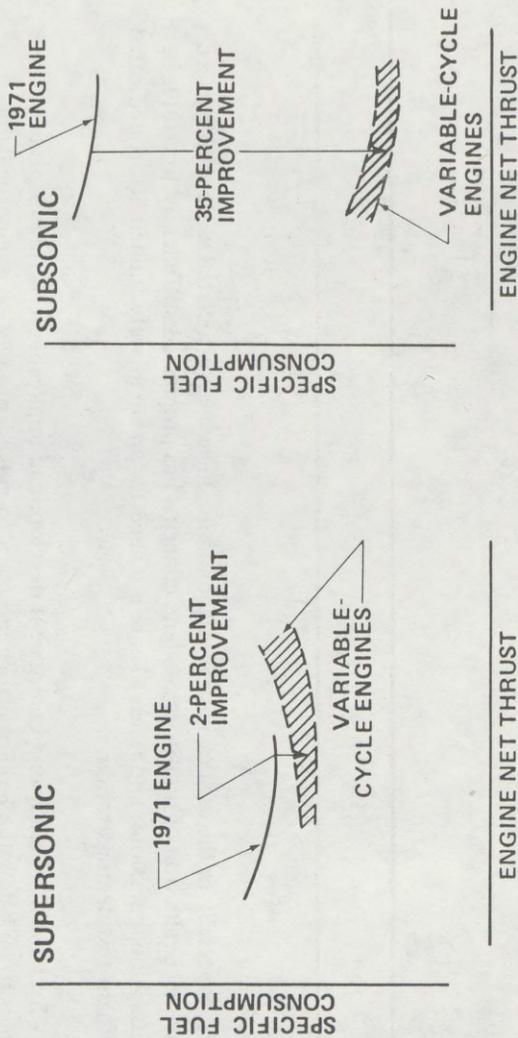
Three candidate multi-cycle-engine concepts have been identified and analyzed. These concepts would provide substantial improvements in fuel consumption, at all operating conditions, over the SST engines defined in 1971. In addition, they would provide marked improvements in weight, emissions, and jet-noise characteristics.

## Propulsion

# VARIABLE-CYCLE ENGINES

## Progress to Date

- AUGMENTED DOUBLE-BYPASS VARIABLE-CYCLE ENGINE (GE21/J11)
- VARIABLE-STREAM-CONTROL DUCT-HEATING ENGINE (P&WA VSCE-502)
- REAR-VALVE VARIABLE-CYCLE ENGINE (P&WA VCE-112)



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Most major airplane developments, especially in the area of improved economics, have been associated with and/or paced by a propulsion system improvement. Evaluation of multi-cycle-engine concepts has progressed sufficiently to establish major improvements in fuel consumption, emissions, and noise. There is a need for an adequately funded effort dedicated to detail design, fabrication, and flight test demonstration.

Within NASA, plans are underway for continued study and component development applicable to various aspects of the MCE program. This activity appears to be below the level of effort necessary to make a production engine available, even within 10 years. Design approaches have not been demonstrated, nor has a firm plan for the development of such an engine been established.

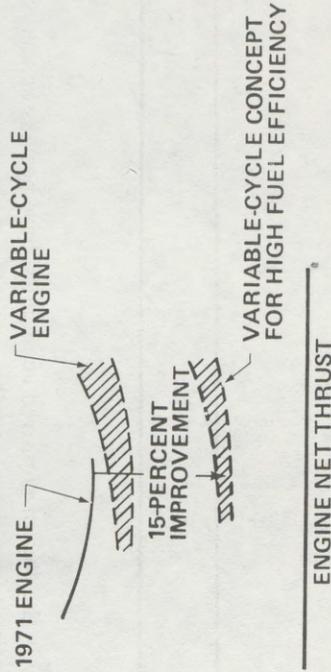
I believe that the needed action includes the steps noted on the chart. The foreseeable fuel-efficiency improvements, for both subsonic and supersonic operation, warrant stepped-up development of the multi-cycle-engine concept.

Propulsion  
**VARIABLE-CYCLE ENGINES**  
 Readiness Requirements

- SET CLEAR AND LOGICAL DESIGN GOALS
- DETERMINE BEST VARIABLE-CYCLE ENGINES
- VALIDATE DESIGN AND ITS INTEGRATION
- DETERMINE MOST LIKELY ENGINE
- FLIGHT DEMONSTRATE TECHNOLOGY AND ENGINE

SUPERSONIC

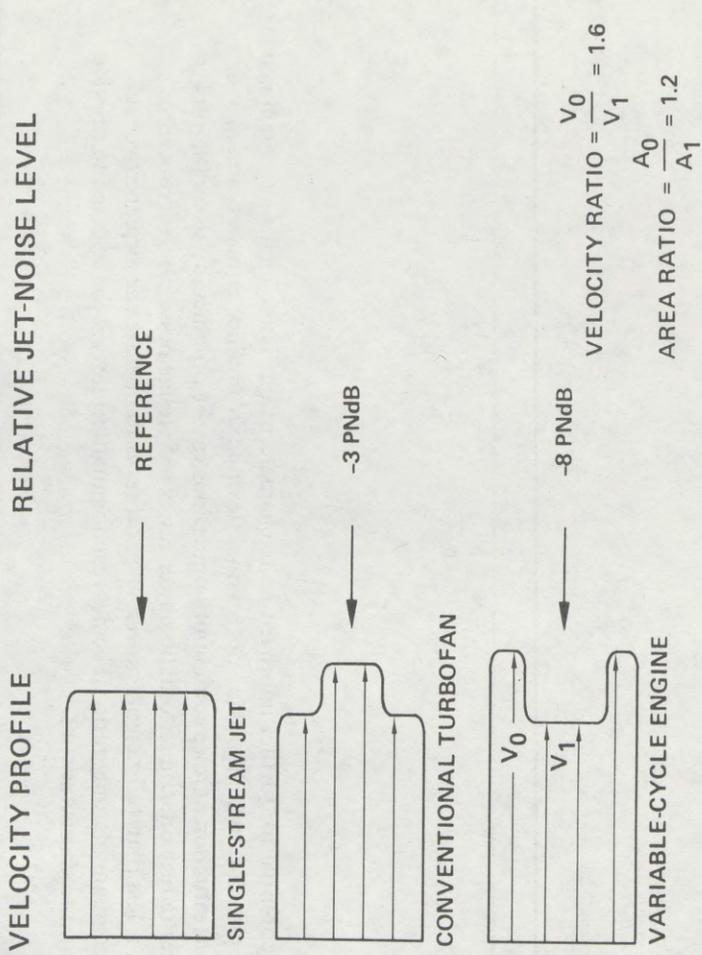
SPECIFIC FUEL  
 CONSUMPTION



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A significant breakthrough has occurred on the important subject of jet noise. Engine exhaust-velocity profile-shaping tests have shown substantial jet-noise reduction relative to a single-stream jet. The chart shows that a conventional turbofan is up to 3 PNdB quieter than a single-stream jet; the multi-cycle engine with inverted velocity profile can be made 8 PNdB quieter than a single-stream jet. Results of wind-tunnel flight-simulation tests show noise reductions nearly equal to those that have been measured statically. Testing of the inverted-velocity-profile phenomenon is continuing.

Propulsion  
**COANNULAR NOZZLE NOISE AT CONSTANT THRUST**  
 Progress to Date



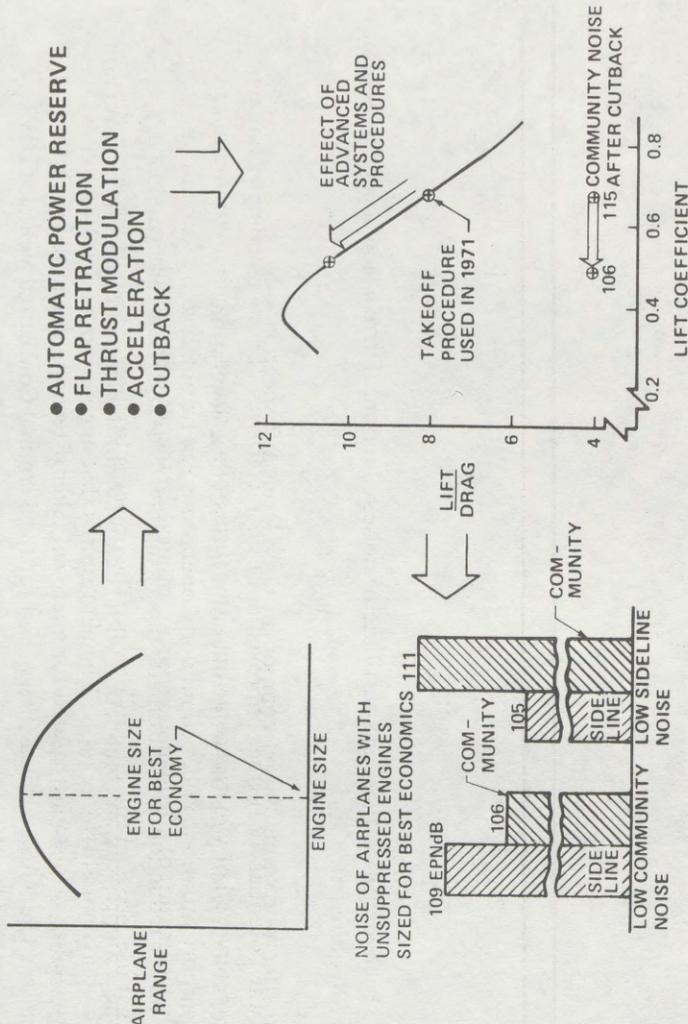
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Advanced takeoff procedures offer the potential for further improved noise characteristics. These include programmed throttle, flaps and automatic power reserve, all of which provide operational flexibility to reduce either community or sideline noise, depending upon the airport situation. Quiet community operations can be obtained by using full-power takeoff, early flap retraction, early power reduction, and automatic power reserve. Sideline noise can be reduced by using selected takeoff procedures that use less than full takeoff power. The object is to operate the airplane over the community as near as possible to the maximum lift/drag ratio. The net result is that engines can be selected to provide the best airplane range, while improving noise characteristics.

# Environment

## ADVANCED FLIGHT PROCEDURES

### Takeoff Noise Reduction



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Several candidate approaches have been identified that can contribute to noise reduction. There is now a need to address these approaches in greater depth. Required are:

- Tests to establish free-stream effects on coannular jet component noise levels and spectra.
- Tests to establish the effect of velocity/temperature jet profiles on far-field noise generation.
- Tests to identify the noise characteristics of engine-noise sources, other than the jet component.
- Tests and analysis of mechanical suppressors, in conjunction with coannular nozzles, for additional noise reduction.
- Flight tests to establish the reliability of systems required for improved takeoff techniques and to verify the operational procedure technique. The NASA airplane being used for the Terminal Configured Vehicle (TCV) program is an appropriate test airplane for this work.

Environment  
**NOISE REDUCTION**  
Readiness Requirements

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- FORWARD VELOCITY TESTING
- PROFILE SHAPING
- COMPONENT-NOISE IDENTIFICATION (REAL ENGINES)
- SUPPRESSION OF COANNULAR NOZZLES
- FLIGHT TESTING FOR SOUND MEASUREMENTS AND PROCEDURE VALIDATION

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Mr. Chairman, I have outlined the progress that has been made and the efforts required to realize the potential offered in several areas of technology. These areas have a major impact on this country's capability in providing an economically successful and environmentally acceptable supersonic transport. In the time allowed, it has not been possible to cover other areas of importance. Collectively, they offer the potential for the United States to produce a transport that could technically outmode the existing, or foreseeable derivatives, of the Concorde or TU-144 designs.

Much work remains to be done. I have identified the areas that should be pursued for greatest benefit, and the work that is necessary to bring them to a validated status.

You may have noted that I have not addressed the subjects of SST program timing or operational economics, per se. Boeing believes that it is not appropriate to do so until the state of technology readiness is brought to a point that economic evaluation can be accomplished with confidence in the results. Too much could be at stake to make gross estimates based on unvalidated technical analysis.

Much of the required research is costly. This is particularly true in the propulsion area—the area that is recommended for highest priority attention—because of the need for a substantial, dedicated effort, and because of the lead time involved.

The NASA program is certainly proceeding in the right direction. However, our rate of accomplishment will depend upon the resources that are made available. I appreciate having the opportunity of presenting Boeing's views here today.

H. W. Withington

Mr. MILFORD. Thank you, Mr. Withington.

During your testimony I made a facetious remark about where you might go to obtain the latest Russian alloys and metals, but I do find it extremely distressing that this country has to go over to Japan and tear down a Russian airplane in order to find out why they are flying higher and faster than we are. I find that extremely distressing.

Let me get into the variable-cycle engine. Did I understand that Boeing actually has modified the standard JT8 engine into a variable cycle?

Mr. WITHINGTON. Yes; we had invented a valve, if you will, which would change the inner annular flow; in other words, a bypass ratio engine has two flow areas, it has an outer flow from the fan and an inner flow from the core engine, and we built an air valve that would exchange that inner flow to the outer flow, and this is what is needed for one of the concepts of a variable-cycle engine.

Well, to prove that we could make that thing work, we built one and we put it on this JT8 engine so that we could demonstrate that we did have an idea that wasn't just a paper idea. In other words, it could be built and it could operate. Now, it certainly was not a flight hardware type of deal, but it did work on an existing engine, and we could run that engine and actually shift gears, if you will.

We could change bypass ratio while the engine was running. So we took that idea to the engine companies and to NASA, and this concept is one of the ideas that is now being explored in depth by the engine companies and NASA. Now there are other ideas as well, but my reason for bringing this out was to indicate Boeing's concern that this type of an engine was really a requirement and we wanted to do some work on it. So that was, if you will, our contribution. We had an idea, we put it into hardware, and we checked it out. Now that JT8 engine is certainly not an engine for a supersonic airplane, and we would not say that it was, but at least we demonstrated that we could build this air valve and it would work.

Mr. MILFORD. For the record at this point would you give a simplified explanation, such as a layman could understand, of what we are trying to accomplish, what principle we are trying to attain in the variable-cycle engine. Why it makes it more efficient than one we could go buy right now.

Mr. WITHINGTON. Well, I would like to say it this way. If you are only interested in supersonic performance, a pure turbojet is a very efficient cycle for mach 2.5 or so. It is the best cycle that you could use, a pure turbojet. But that is a pretty poor engine subsonically. Subsonically you would like to have a high bypass ratio engine. In fact, today's bypass ratio engines have bypass ratios of 5 or so, whereas a pure turbojet has a zero bypass ratio. It is a pure jet. So what you are trying to do is take the advantage of having a simple turbojet at zero bypass ratio engine supersonically, but convert that to at least a low bypass ratio engine subsonically, and this gives you two real important things. It gives you far better fuel consumption subsonically for holding, and I talked about the reserves, and it also gives you a chance to meet the noise requirement. This dual cycle or variable-cycle engine gives you the ability in effect to shift gears. You have got two engines in one. Now it is certainly more complicated, but I

think with a dedicated effort it could be made to work. You will have some testimony later on from Mr. Sens of Pratt & Whitney, and I think probably he is perhaps a better witness on the details of the engine, but we are real interested in it. As I say, we have tried to do some work——

Mr. MILFORD. Perhaps it would be best that I direct these questions to Pratt & Whitney.

Mr. WITHINGTON. Well, we have been working very closely with both Pratt & Whitney and G.E.

Mr. MILFORD. Mr. Wydler?

Mr. WYDLER. I just wanted to ask one question. What other countries in the world are working on a variable-cycle engine?

Mr. WITHINGTON. Well, it is no secret that we are working on it.

Mr. WYDLER. Well, that is obvious.

Mr. WITHINGTON. And I know that the Concorde people are well aware of it and have done studies as to what they might do for the Concorde.

Mr. WYDLER. You mean Britain and France?

Mr. WITHINGTON. Yes.

Mr. WYDLER. How about the Soviet Union?

Mr. WITHINGTON. I have no knowledge of what they are doing in the engine business. Again perhaps Bill Sens might know from Pratt & Whitney. I do know what their engine programs are.

Mr. WYDLER. As far as you do know though, nobody else is actually doing any development of such an engine?

Mr. WITHINGTON. I think we are doing more on it in this country than anybody else. As far as I know we are, because I think it is so important.

Mr. WYDLER. Thank you.

Mr. MILFORD. Mr. Lloyd?

Mr. LLOYD. Thank you, Mr. Chairman.

Mr. Withington, you referred to the possibility of reduction of power on takeoff. You went by it rather quickly, but I think it is a very important point to cover. Have you discussed this with the pilots as to their reactions to this?

Mr. WITHINGTON. Yes, and this is obviously one of the areas of considerable concern. I think it is a relative situation though. The reason I mentioned automatic power reserve——

Mr. LLOYD. Let me interrupt for a minute. I fully understand when you use the term relative. If you are a pilot of an aircraft, and you are in a takeoff mode, everything is go, do you really feel that you are going to go at 92 percent? If anything goes wrong such as a wind shear, then who is going to make the explanation to the boards that we went off with less than 100 percent power. In other words, what I am saying to you is that I just do not think the pilot will cut back maybe 10 to 15 percent. Frankly, I would not.

If I took the bird, up, I do not care what the regulations are, I will go for 100 percent. I want to know what that engine is going to develop and what that airplane is going to take and I want to know it now or I am not going to go. I really believe that when you make such a suggestion that you may be creating a problem by suggesting that pilots can cut back the power any time they want to. They do not need to worry about it. We can reduce noise that way. The lay people believe

that it is possible, but it can't be done safely. I really think at this point that it is more important that we solve the problem through technology than to be even alluding to a possible cutback of power on takeoff, at least with the equipment we are talking about. People do not think that what you are talking about is an engine of the future. They immediately apply it to the engines that we are using right now. I really feel that strongly about it.

Mr. WITHINGTON. I recognize your concern. I would like to state that our concept of automatic power reserve is an attempt to provide additional power that is not used on the day-to-day basis and to provide a highly reliable sensing mechanism to add that power when necessary. This is in the process of certification now. The engine companies are making a completely legal certification of that extra power, however, as you know in the modern high temperature engine, if you use an awful lot of high power your hot parts life is not great and your maintenance costs are high. So it is economically better to operate at lower temperatures, but from a safety standpoint on an occasional use it is completely legal and completely appropriate to do this if you have the proper equipment in the airplane to handle it. This is why I mentioned in here this would require the automatic power reserve to make this a feasible process.

Mr. LLOYD. Well, I am sorry, if you said or even alluded to it, I somehow missed it. I am really finely tuned to that one situation, and I really think that we must be extremely cautious how we address that kind of a problem. Right now you and I both know that probably we are going to have accidents. There will be a great hue and cry for sensing devices to insure the fact that there will be no midair collisions.

I have reviewed the accidents myself—the Boston shear and the New York shear—I have had an opportunity to actually fly a simulator through those shears myself. Just that kind of an exposure says to me that it is not something that is fleeting. It really does not come down to pilot error. Pilots are overwhelmed with the immensity of a weather phenomena that they just simply have not been prepared for. I think that to even remotely indicate that these things cannot bring disaster, the public reacts by the baby in the bath water routine. Everything goes out and that solves the problem as far as they are concerned. The point that I am making obviously is that I think there has to be great caution. At anytime when a man of your background, experience, and leadership position even remotely alludes to something like that, I think that we have to really couch it in the words of—we are not there yet. Current engines cannot do this, and I am sorry that I am making such a point of it. You probably think I have a fetish on it. I live with this thing out there in the general public, not that you do not. I am sure that you are very cautious of your public image as far as Boeing is concerned, but I am conscious of the fact that if you were to try to sell an SST, which is what you are trying to do at the present moment and more power to you, you could not do it with the American public right at the present moment with the attitude that exists and if you do not know that, I will be glad to share that with you.

Mr. WITHINGTON. Having lived through the U.S. SST program I certainly agree with you—you could not sell it today. I agree.

Mr. WYDLER. You would have to think of a new name for one thing. If you call it an SST, you start off with three strikes on you. [Laughter.]

Mr. WITHINGTON. I think probably I as much as anybody else in this room am aware of that particular problem having lived through 5 years of it.

However, I did think that from a technical standpoint we would be derelict if we did not explore all ways of trying to achieve a solution to our problem. I did not have time to go into detail on this, perhaps at some future time if you have the opportunity, I would like to discuss this automatic power reserve because to us it is a way of providing additional capability and additional safety.

Mr. LLOYD. I would be most pleased to hear it personally and I am sure the chairman would also. I guess I am really goosey when it comes to this kind of presentation because I hear my colleagues on the floor are putting more effort and energy into worrying about how they are going to retrofit a 727 which may be some happiness to you. If they are retrofitting and "reskinning," I think we take three giant steps backward to take a couple of tippy toes forward sometimes in the aviation industry. A 707 is 20 year old technology, and we are going to retrofit those. I am not putting Boeing down. It is a great airplane, the standard in the industry. But I think we have to get on with things, I think that one of the things that we have to do in aviation is to keep people somehow glued to the future. The key factor in a lot of this stuff is that we do not allow the future concepts to bleed back into older equipment that has been around and that somehow we are going to save money and make something efficient with it. I think that you would be the first to say as a builder of these airplanes that that is a pretty sad way to go.

Mr. WITHINGTON. We certainly do not recommend retrofitting old 707's and DC-8's.

Mr. LLOYD. You said what I wanted you to say. [Laughter.]

Mr. WITHINGTON. I think they have served their time rather well, and I think it is time to move on.

Mr. WYDLER. Well, Mr. Chairman, if I might comment on that. I would buy that if I believed for an instant that that is how the industry felt, if I thought they really were going to stop using the 707's and DC-8's, that would be fine with me to say do not retrofit them. If they want to come up with that plan of operation, I will buy it. But they are going to use them, and I bet you they will be using them well into the 1980's and probably to the end of the 1980's, and they will still be flying them in and out of our airports and still be driving the people crazy. So just to assume that because they are old that they are not going to use them any more, that is fine to say, but I think it is totally unrealistic. I do not think the airlines have any intention of retiring the planes. They are going to keep right on using them. I think it was Boeing, themselves, that came down here and told us—you made the planes too good. They did not wear out and they kept using them over and over. You were sorry yourself you made them so good. [Laughter.]

They did not have to replace them. They just kept using them. So it is one thing to say it is a 20-year-old airplane, that may be true with some of them, but they are going to use them, and they are going to keep using them. If they are going to do that, then I think they should bring them up to date. They put new interiors in them to make it nice and comfortable for the passengers. They waste a lot of money

doing that and they do not complain too much about it, but when it comes to maybe bringing the engines up to date a little bit, making it more liveable for the people, they think that is a terrible waste of money. I do not. I do not agree with my colleague on that at all. I would agree with them if they are not going to use them any more. That is fine with me, of course. Do not bring them up to date. But if they are going to use them, and everything I have ever heard is they are going to use them and use them and use them, then they should have to bring them up technologically to where they can give the people the degree of relief from noise, that is capable of being produced. I do not find that is a waste of money any more than it is to redecorate them and put new interiors in them to make it more pleasant for the passengers that ride in them. That might be considered a waste of money, too.

I also want to say this about what my colleague said. I am not a pilot, but I understand his concern about reducing noise on takeoffs. Now as a practical matter we have a great many different types of operating procedures on takeoffs at our Nation's airports. We do a great many things about noise reductions and cutbacks. I have not heard of any accidents resulting from that myself, but I know if he is concerned about that, I wish he would get concerned about what they want to do with the SST when they are going to take it off, if they ever do, from Kennedy Airport, New York. They want to take the plane up to 100 feet off the ground and turn it 26 degrees. Again I am not a pilot, but I will take a thrust cutback of some amount rather than go through that kind of a maneuver on a takeoff. They tell me that is a perfectly safe maneuver. Pilots tell me that. The FAA tells me that. If that is safe, then I would say a little cutback on the power certainly must be safe, and I would worry about the serious things that they want to do, not the things that may give some people around airports a little relief. That is always a very dangerous thing to do. Stack people up over the airports for 5 hours because you are trying to get so many airplanes down on the airport. They cannot possibly land them. They fly them around up there in the air sometimes 3, 4 hours, all these planes flying around. That is not a dangerous situation. What is dangerous is trying to do something to reduce the noise impact on the community. That always becomes enormously dangerous right away.

I have listened to that baloney now as a member of this Congress for about 10 years and I do not buy it for a minute. They will do anything to compromise safety as long as it is economically to their advantage. But when it is costing them a little money, then it becomes a big problem to do this. It always becomes a safety problem. So I just wanted to put that in the record so it does not look like I am sitting here and agreeing with some of the comments that are being made. I think we should get rid of the 707's and the DC-8's, it is fine with me, but if we are not, we should retrofit them.

Mr. MILFORD. Far be it for the Chair to inhibit the first amendment rights of any of our members, but I would suggest that we are not within our jurisdiction. If we could, please, stay with R. & D. We have two more witnesses and a short period of time.

Do you have any further questions, Mr. Lloyd, on the subject at hand?

Mr. LLOYD. I think you answered it. I do not think I fully concur with my colleague from New York. I think, I would only say this, you have to review the flight characteristics and the numbers on the airplane itself to determine whether or not a 26-degree bank is not a critical maneuver—

Mr. MILFORD. If the gentleman would yield, I believe that is within the jurisdiction of the Aviation Committee on Public Works and Transportation and we do have a problem here on time. If we could proceed and stay on our subject. Do you have any questions on the R. & D.?

Mr. LLOYD. No, sir. I want the Chair to know that I am not leaving mad. I have another thing I have to do at a quarter of, so if I leave and come back, it does not show any anger on my part. [Laughter.]

Mr. MILFORD. Just two quick questions, finally. You touched briefly on the operations cost of a new generation SST and stated that you would not care to make estimates on operations costs. I would agree insofar as any detailed estimate. Would you be able to state whether or not present technology and what we could develop in the way of new technology would be sufficient for such a company as Boeing to product an economically viable SST?

Mr. WITHINGTON. The present state of technology that we are pretty sure of today, would in our opinion not produce a viable supersonic transport. We are not good enough yet to commit a program in Boeing's opinion. We are not there yet. By that I mean that we feel that we have got to be competitive with the subsonics. We do not think a successful program results in doing a very few airplanes for a very special part of the market. In our business we want to build lots of airplanes, and to build lots of airplanes it has got to be completely competitive with the subsonics, and we do not believe today that the technology has arrived at the point where we have sufficient confidence that we could build a viable, economic airplane today.

Mr. MILFORD. Perhaps I did not phrase my question properly. I would agree with you that present technology would not allow it, but do you feel that we have the ability to develop the necessary technology that could produce it?

Mr. WITHINGTON. We have the ability to extend from where we are today. Now the amount that we are going to extend depends on the resources we put into it, and the thing that concerns me is that we are putting approximately \$10 million a year or so in the supersonic, and we are putting in many many times that in subsonic and I am afraid that the gap is getting greater rather than less. In other words, if we want to maintain an option to that a good supersonic airplane, we are going to have to put more effort into it. I think we have got the potential of doing it, but we are not in my opinion getting there fast enough.

Mr. MILFORD. Well, I totally agree with that. But when you go to the American taxpayer and ask them to put more money into it, you have to be able to give some assurances that there will be a payoff down the line. My question is, is it worth making the investment; is there reason to believe that by making the investment we could eventually come out with an economically viable SST.

Mr. WITHINGTON. I have a great deal of faith in the future. I have seen it happen. I would have to say that we should as a country

spend more money than we are doing now because I think the probability is good enough that we can come up with the technology to do it. Now I cannot sit here today and prove that. In 1952 I could not have proven to you or this committee that the 707 would be an economic airplane either. So I see somewhat the same situation.

Mr. WYDLER. Could I put one caveat into what you testified to. You are going to make the same mistake I am afraid that was made in the 1960's regarding the SST. They started out building a plane and thinking of the air regulations that were in effect at the time they were designing it. By the time they finished the plane, we had different regulations. To think of meeting FAR-36 limits as being what will be in effect at the time this plane will probably be built like the late 1980's or something like that, I do not think is realistic. I think you better start out with—if those rules and regulations in my opinion will be much more stringent by the time that plane gets into the air.

Mr. WITHINGTON. That is why I made very clear that that is where we are today. I agree with you, we have to go further.

Mr. WYDLER. OK.

Mr. MILFORD. Thank you very much, Mr. Withington, we appreciate your time.

Mr. WITHINGTON. Thank you.

Mr. MILFORD. The Chair now recognizes Mr. Richard D. Fitzsimmons, director of advanced supersonic engineering, McDonnell Douglas Corp., Douglas Aircraft Co.

Mr. Fitzsimmons, we have your prepared statement and attachments which will be accepted at this point for the record, and you may either read your statement or proceed as you care to.

**STATEMENT OF RICHARD D. FITZSIMMONS, DIRECTOR, ADVANCED SUPERSONIC ENGINEERING, McDONNELL DOUGLAS CORP., DOUGLAS AIRCRAFT CO.**

Mr. FITZSIMMONS. Thank you very much, Mr. Chairman.

I think that I have a rather comprehensive statement. I would like to read quite a few excerpts. I have taken out some of it for the sake of time.

Mr. MILFORD. Fine.

Mr. FITZSIMMONS. Mr. Chairman, and members of the committee, it is indeed a privilege to come before you today and address the question, "What technology is needed to make sure an advanced supersonic transport is environmentally and economically acceptable?"

I would like to point out that like the previous speaker, the SST is something that I have been working on for many years. My first publication on the supersonic transport question was in 1950, some 26 years ago.

Since termination of the U.S. SST program in 1971, NASA has tried to keep a small effort alive that would hopefully lead to the building of a technology base for an advanced supersonic transport.

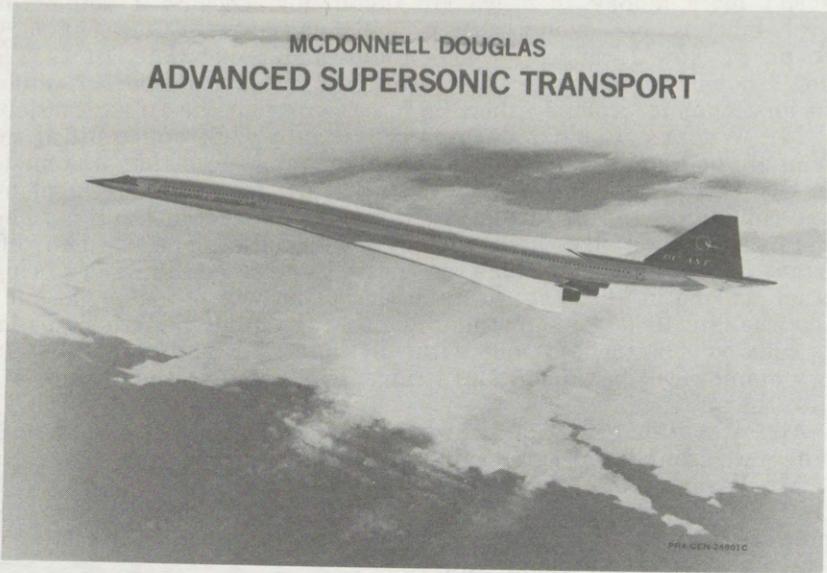
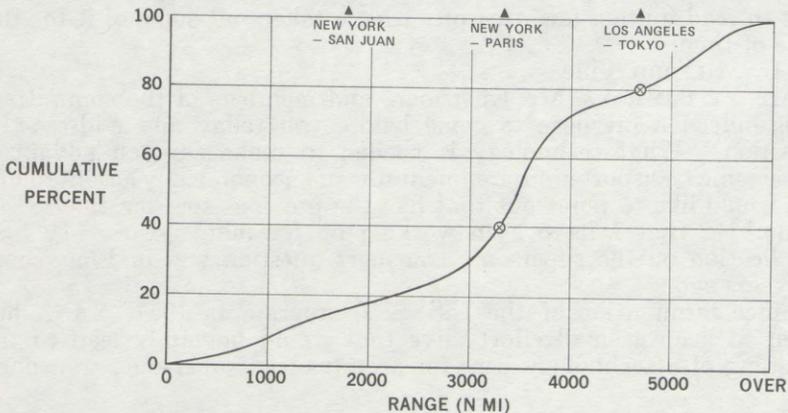


FIGURE 1

For 4 years, we at McDonnell Douglas have participated in advanced design studies to identify for NASA those areas of technology development required to make possible an economically sound, environmentally satisfactory advanced supersonic transport (figure 1). We think those findings are relevant and I would like to review some of them for you today.

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FIGURE 2

The NASA contract studies included a market requirements analysis. One of the significant results is shown (figure 2). The free-world overwater routes and the passenger business projected for them through the year 2000 were determined. The importance of being able to design a 4,500-nautical-mile-range airplane to do 80 percent of the business as compared to 3,300 nautical miles or 40 percent of that business is most significant. Both the Concorde and the last U.S. SST were 3,300-nautical-mile-range type designs. The advanced technology capabilities identified in the cooperative NASA/industry design studies show that a 4,500-nautical-mile-range can be realized.

The Douglas/NASA studies, which proved to be more conservative than either of the other competitors, showed a large potential market for an advanced supersonic transport from the mid-1980's to the end of the century. Our estimate was that 400 aircraft would be needed, even making allowances for high fuel costs and higher operating costs. Assuming a purchase price of approximately \$510 million per airplane in 1976 dollars, this represents a \$33 billion market. The figures are almost equivalent to the total free-world value of all the civil aircraft sales in history up through 1976. This is an important market and the U.S. should try to capture a major part of it.

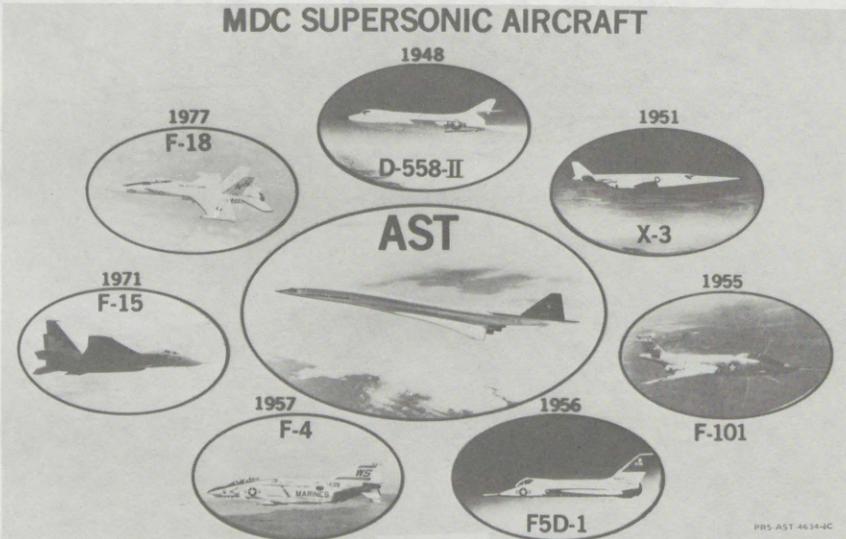


FIGURE 3

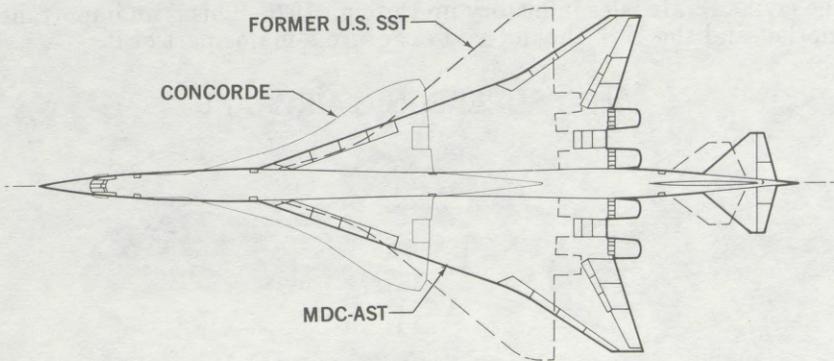
Our Nation has a wealth of experience upon which to draw for a mach 2.2 type transport design (fig. 3). Knowledge gained starting with the Douglas D-558 II, the first aircraft to go over mach 2, through more than two decades of supersonic aircraft programs on airplanes like the F-4, some of the work on the old U.S. SST, the B-58 and the B-70, the current F-14 and our McDonnell Douglas F-15 and F-18 fighters. Most of the knowledge from these programs can be applied directly to the development of a mach 2.2 type advanced supersonic commercial airplane.

Recent studies show that what is required now is not costly new invention, but rather technology validation of particular design details that show to be optimum but have never been used before on U.S. aircraft. Today's study results are exciting.

Probably the best way to describe the technology status is to compare our study results with the Concorde and with the former U.S. SST. The resulting configuration would be much larger and utilize a more efficient planform shape. It is called an arrow wing due to the cutout in the trailing edge (fig. 4). The 1971 concerns over structural stiffness and flutter problems of arrow wings have now been pretty much allayed and sizable improvements in performance are possible.

DOUGLAS AIRCRAFT COMPANY

## MCDONNELL DOUGLAS AST



PR5-PL-30385

FIGURE 4

## AST CHARACTERISTICS SUMMARY

GROSS WEIGHT (LB)	750,000
WING AREA (SQ FT)	10,000
PLANFORM	ARROW WING
PASSENGERS	273
CRUISE SPEED (MACH)	2.2
L/D AT CRUISE	10.3
RANGE (N MI)	4,590
ENGINES	4 MINI-BYPASS TURBOJET
SFC AT CRUISE (LB/HR/LB THRUST)	1.35 (INSTALLED)
THRUST/ENGINE MAX (LB)	74,700
NOISE	< FAR PART 36
STRUCTURAL MATERIAL	70 PERCENT TITANIUM 30 PERCENT ALUMINUM
TAKEOFF FIELD LENGTH (FT)	10,700
LANDING FIELD LENGTH (FT)	5,650

PR5-AST-4446D

FIGURE 5

To understand how supersonic technology has progressed in 4 years, a baseline McDonnell Douglas AST has been identified (fig. 5). Any of several engine cycles could be selected. The minibypass engine has been selected for this particular baseline. It does have a relatively heavy mechanical noise suppressor, but it is easily understood. It undoubtedly represents the least risk and probably could be certified early.

## SUPERSONIC TRANSPORT TECHNOLOGY COMPARISON

	SST (1971)	AST (1976) *	IMPROVEMENT
SPEED	MACH 2.7	MACH 2.2	
RANGE	3100 N MI	4590 N MI	48% FARTHER
PASSENGERS	261	273	5% MORE
ENGINE	TURBOJET WITH AFTERBURNER	MINI-BYPASS TURBOJET — DRY	
PROPULSION EFFICIENCY (M/SFC)	1.74	1.74	NO CHANGE
AERO EFFICIENCY (L/D)	7.2	10.3	43% INCREASE
STRUCTURAL WEIGHT EFFICIENCY	100% TITANIUM (420°F)	70% TITANIUM + 30% ALUMINUM (240°F)	4% BETTER
TAKEOFF AND LANDING NOISE	112 EPNdB AVERAGE	105 EPNdB AVERAGE	BETTER THAN FAR PART 36

\*1980 GO-AHEAD

PR6-AST-4784A

FIGURE 6

A comparison is shown of this design in the former U.S. SST (fig. 6). The big differences are in range and in noise. A 48-percent increase in range to 4,500 nautical miles is shown and the aerodynamics improvements provide almost all of that range extension.

There is no improvement shown for the engine propulsion efficiency, in spite of all the publicity given to the advanced engine cycles. The big gain in the propulsion area is in noise, and all designs we consider today would meet or improve over FAR Part 36. These low noise levels have been realized in paper designs without sacrificing any efficiency at cruise, which in itself is a major accomplishment.

A new capability has been developed in the last 2 years because of computers. We can now analyze the internal structure of a new design, and the external aerodynamics, in a matter of 2 weeks and know that our design results are creditable. The internal structural analysis, involving well over 5,000 individual structural members, allows many critical load conditions to be checked. Each member can be sized for strength, aeroelasticity, safe-life, fatigue, and damage tolerance, and a flutter analysis is included as well. In 1971, this process took as much as 6 months. This is real progress and one we are quite proud of. We now think we can identify where the real technology payoffs can exist through this kind of analyses.

## SUPERSONIC TRANSPORT TECHNOLOGY COMPARISON

	CONCORDE	AST (1976) *	IMPROVEMENT
SPEED	MACH 2.02	MACH 2.2	9% FASTER
RANGE	3150 N MI	4590 N MI	45% FARTHER
PASSENGERS	108	273	2.5 TIMES
ENGINE	TURBOJET WITH AFTERBURNER MINI-BYPASS TURBOJET — DRY		
PROPULSION EFFICIENCY (M/SFC)	1.70	1.74	2% INCREASE
AERO EFFICIENCY (L/D)	7.6	10.3	35% INCREASE
STRUCTURAL WEIGHT EFFICIENCY	ADVANCED ALUMINUM (200°F)	70% TITANIUM + 30% ALUMINUM (240°F)	4% DECREASE
TAKEOFF AND LANDING NOISE	116 EPNdB AVERAGE	105 EPNdB AVERAGE	BETTER THAN FAR PART 36

\* 1980 GO-AHEAD

PRG AST 4701A

FIGURE 7

A comparison with the Concorde is also shown (fig. 7). Here, in addition to the improvements in aerodynamics and noise, improvements in payload and in speed are shown. Both are primary variables in the economic equation. All hourly operating costs are divided by speed and by payload to obtain operating costs per passenger-mile, which is the way you buy your ticket. A 9-percent increase in speed and a 250-percent increase in payload offer dramatic improvements and we feel are absolutely necessary for the attainment of satisfactory economics.

Much has been written about the advancements required for the propulsion system to make a supersonic transport viable. There was nothing wrong with the propulsion efficiency of the 1971 engine on the U.S. SST. However, it did not meet society's requirements for noise and emissions. This chart shows that the Olympus engine on the Concorde provides a cruise propulsion efficiency only 2-percent lower than the best of the advanced engines that resulted from the NASA-funded engine studies of the past 4 years. The big difference is in noise and in weight. Thermodynamics is a reasonably well-known science and the ideal engine cycle for supersonic cruise efficiency has not changed. The component efficiencies of the 1971 turbines and compressors also were high, so improvements have not come easily. The challenges the U.S. industry research teams have had since 1971 are to meet or improve over the community noise requirements without losing supersonic cruise propulsion efficiency.

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## ENGINE CYCLE SELECTION

### 750,000 LB AIRPLANES

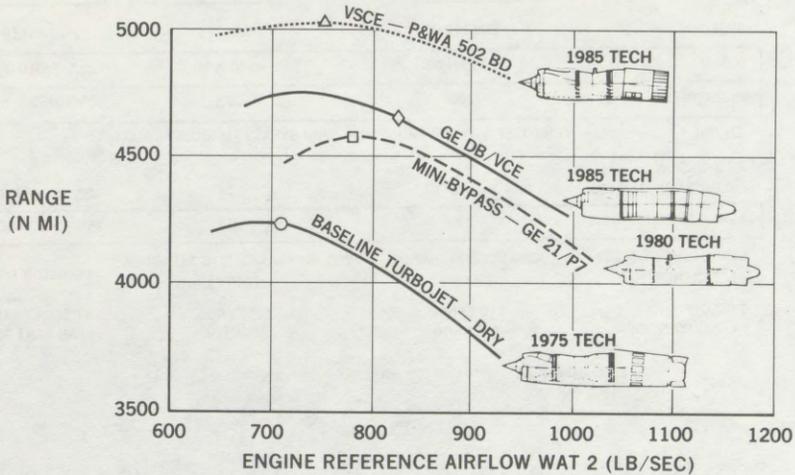
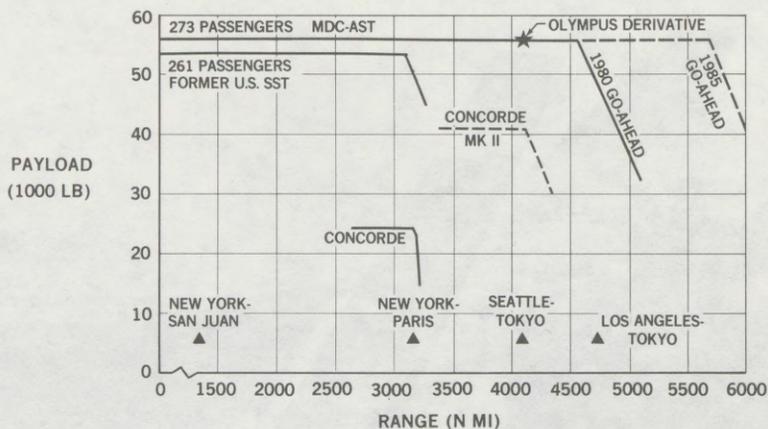


FIGURE 8

A chart (fig. 8) from our recent NASA engine integration studies shows how much improvement has been realized compared to the 1975 baseline turbojet utilizing the GE-4 engine technology but modified to meet FAR Part 36 noise levels. Any of a variety of engine cycles offer up to 480 miles additional range, mostly due to the decreased engine weight. This was realized by use of advanced technologies including higher turbine temperatures, improved component efficiencies, inherent coannular sound suppression which is on the three upper engines presented on the chart, and improved methods of engine operations.

## PAYLOAD-RANGE



PR5-AST-4768B

FIGURE 9

The payload range that results from these advanced design studies shows most impressively how the advances in technology could pay off (fig. 9). Opening up the Pacific can become a reality and supersonic travel there can have tremendous appeal to the public. A range extension is shown for 1985 go-ahead type designs utilizing advanced technology. Here we would utilize a lightweight variable-cycle engine, coupled with use of composites for secondary structures and for strengthening our metal baseline design. This opens up very sizable range extensions matching the longest range commercial airplanes in society today. These are possibilities.

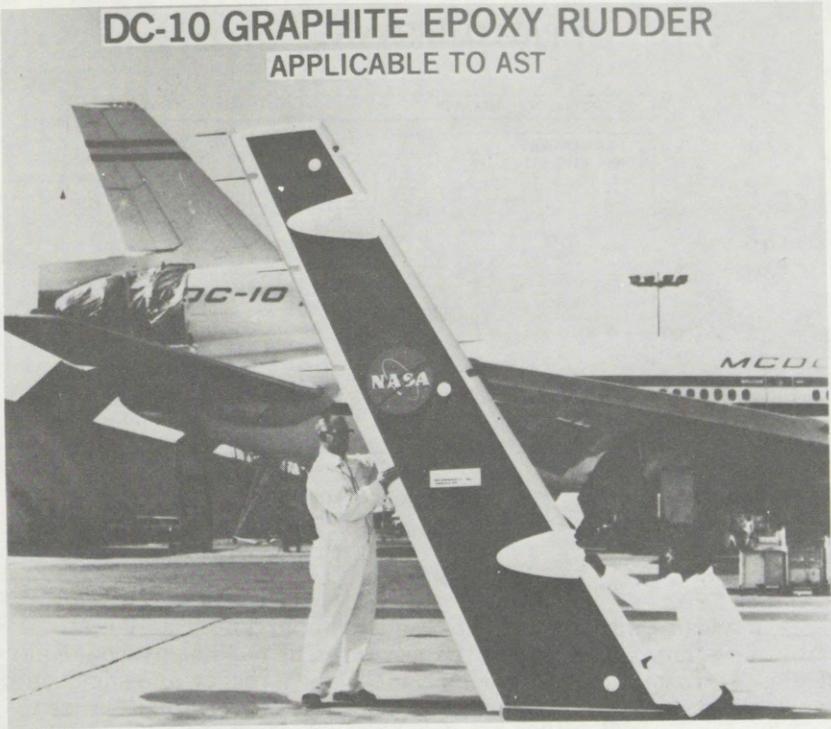


FIGURE 10

The NASA DC-10 composite rudder applications as shown here (fig. 10) should be continued as the technology here is directly applicable to the lower mach number range of mach 2.2 for an SST. This was also shown by some of our previous speakers.

When the U.S. program was terminated in 1971, the Congress, the executive branch and the U.S. industry recognized the need to continue supersonic technology efforts to preserve this Nation's capacity and readiness for possible competition with foreign aircraft builders. The U.S. airframe and engine manufacturers have carried on this work using their own funds supplemented with contract funds from NASA and DOT (fig. 11). NASA has been funding an average of six people each at General Electric, Pratt & Whitney, Boeing, Lockheed and Douglas. Obviously, analytical work and almost no testing has resulted. In 1974 NASA requested a \$28 million budget for AST contractor effort.

## IMPACT OF NASA AST FUNDING CUTBACK

### CY 73

MDC FUNDED AST R&D AT 8 TIMES NASA CONTRACT LEVEL

### CY 74

MDC AST R&D REDUCED 70 PERCENT BECAUSE OF NASA CUTBACKS

### CY 75 AND CY 76

MDC AST — HOLDING ACTION ONLY

	FISCAL YEAR (\$ MILLIONS)						
	FY 71	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77
NASA SCAR BUDGET	0	1.1	11.7	*9.7	9.6	8.9	8.0
MCDONNELL DOUGLAS AST BUDGET	0	0	1.9	2.1	0.9	0.6	**

\* CUTBACK FROM \$28M

\*\* (INCL COLLABORATION WITH  
BRITISH AIRCRAFT CORPORATION)

FIGURE 11

With NASA requesting this large budget back in 1974, McDonnell Douglas initiated a large scale, company funded, supersonic technology effort. The company program that resulted was 8 times the NASA contract effort. We had 110 people on the program. With the NASA advance design contract effort diminished in later years to the current 6-man level, the obvious answer has been for our management to cut company expenditures. The NASA AST effort was described at one NASA/Industry advisory meeting as little more than window dressing. Fortunately, NASA AST systems study funding will increase next month; however, it is at the expense of aerodynamics and structures technology funding.

NASA's AST budget for fiscal 1977, called SCAR, is \$8.9 million. If this Nation is to do anything serious in AST, the fiscal year 1978 budget must be expanded to a level approaching \$105 million, to do the engine and airframe advanced development we identify for a McDonnell Douglas type airplane development program. This is just for one airplane manufacturer and one engine manufacturer. This is also just for the first year. The second year, as you can see on the chart (figure 12) requires \$375 million; the third year \$525 million; and the fourth year \$175 million. We estimate that between now and 1980, the date at which we would anticipate making a commitment to go ahead on a production program, an expenditure of \$1.2 billion is involved or \$2.4 billion for a competitive program

## AST PROGRAM — ADVANCED DEVELOPMENT

(1976 \$ — MILLIONS)  
(PER ENGINE AND PER AIRPLANE MANUFACTURER)

	FISCAL YEAR	1977	1978	1979	1980	1981	TOTAL
<b>AIRPLANE</b>							
TECHNOLOGY		(8)*	15	55	55	5	130
TECHNOLOGY DEMONSTRATOR RIG		—	40 (CRIT)	110	250	100	500
<b>ENGINES</b>							
ENGINE (PRESENT TECHNOLOGY)		(10)*	30	150	160	10	350
EXPERIMENTAL ENGINE (ADV TECH V.C.E.)		—	20	60	60	60	200
		(18)*	105	375	525	175	\$1180

\* FUNDED (USAF, NASA, INDUSTRY)

PR6-AST-4840

FIGURE 12

## CONCLUSION

THE TECHNOLOGY EXISTS TO BUILD AN  
ECONOMICALLY VIABLE, ENVIRONMENTALLY  
SOUND SUPERSONIC TRANSPORT GIVEN  
A VIGOROUS VALIDATING DEVELOPMENT TEST  
EFFORT, WITH A FIRM AND LASTING COMMITMENT  
OF NATIONAL INTEREST BY OUR AEROSPACE  
INDUSTRY, OUR GOVERNMENT AND OUR PEOPLE.

PR4-AST-4265

FIGURE 13

Having said all this, what is the status of advanced supersonic technology today as we see it at McDonnell Douglas? In contrast to some of the other testimony, it is our official position and these words are from our report to NASA, quote, "The technology exists (fig. 13) today to build an economically viable environmentally sound supersonic transport if given a vigorous validation development test effort, with a firm and lasting commitment of national interest by our aerospace industry, our Government, and our people."

There are a lot of qualifiers in that paragraph. The "vigorous validation development test effort" means at least \$1 billion per competitor. A "firm and lasting commitment" means that the start and stop of the last U.S. SST program must be prevented as the losses of critical industry resources including manpower, facilities, and time,

was unconscionable. Because the U.S. Government halted the last U.S. SST program, it may well be that the U.S. Government may have to take the leadership role in initiating a new U.S. supersonic transport. No manufacturer is capable of obtaining a commitment from the people and from the Government that an advanced supersonic transport is in the national interest. Without this commitment, we believe the AST will not move ahead, at least not here in the United States.

There are three technologies that give us primary concern (fig. 14):

## RECOMMENDED NASA TECHNOLOGY

### TOP PRIORITY ITEMS

#### 2.2 MACH

- INTEGRATED NOZZLE/SUPPRESSOR/REVERSER  
NOISE AND PROPULSION TESTS
- LARGE SCALE TITANIUM HONEYCOMB TESTS (WING)
- LARGE SCALE TITANIUM STIFFENED SKIN TESTS (FUSELAGE)
- COMPREHENSIVE TESTING OF ARROW WING  
AERODYNAMICS — CLEAN WING
- LOW SPEED VALIDATION TESTING
- INLET TESTS — PERFORMANCE AND CONTROLS
- ELEVATED TEMPERATURE — TIME TESTING  
ALUMINUM AND EPOXY COMPOSITES
- FLUTTER MODEL TESTING

PLUS

ENGINE TESTS

PRG-AST-4839

FIGURE 14

First, is full-scale noise results. We need to know these results before we can pick an engine cycle.

The airplane advanced development totals \$130 million and would include the aerodynamics, systems studies, et cetera—traditional NASA efforts but on a much expanded scale. The emphasis would be on development testing, not on research. We recommend \$500 million be spent demonstrating the designing, manufacturing, and testing of major components, in lieu of the more costly technique of flying an experimental airplane.

For the engines, we believe \$50 million must be funded in fiscal 1978, \$210 million in fiscal 1979, \$220 million in fiscal 1980, and \$70 million in fiscal 1981 for each engine type. That would include funding of the engine component developments, development of a low-emission combustor, demonstration of full-scale noise characteristics including forward flight effects, and building an experimental engine demonstrator. The variable-cycle engines may or may not be included in

this technology plan as the timing of the airline requirement for a supersonic transport will dictate the level of technology that can be incorporated in the first airplane. Because advanced technology variable-cycle engines do offer such promise, a separate activity on these type engines should be continued regardless of what happens to the baseline advanced supersonic transport program.

This development program would take the industry to the point where a commitment to a production program could be made, which means that airlines will have placed orders, specific engines will have been selected, detailed specifications identified, and firm prices established.

Second, the need to know weight and manufacturing costs for titanium honeycomb wing structure. When you think that we are talking about an airplane wing area with 10,000 square feet and on both sides we are looking at 20,000 square feet, all of which would be titanium honeycomb wing structure, a technique not used on any U.S. airplane to date.

Third, precise flying characteristics of an arrow wing in flight are required. This advanced technology developed by NASA has not been demonstrated on an airplane.



FIGURE 15

I mentioned that in 1971 McDonnell Douglas had 110 engineers on the AST program. At that time we started 17 small test programs, which we believed were critical to an early AST go-ahead. All but one, noise, were canceled. That noise program is still going on on company

funds and work is underway at the unique Rolls Royce spinrig noise test facility in England (fig. 15). This shows a picture of it and we will be testing in that facility next month.

The use of large amounts of titanium honeycomb structure is critical to the range, the weight, and the costs of an advanced supersonic transport design, and as I said no airplane has ever been built that utilizes this concept (fig. 16). Management must know much more about costs and weight and this requires fabrication experience on major components if not on complete wings. Many people believe that the supersonic B-1 will provide the technology for a U.S. SST. The AST requirements are 100 times more severe if not more so. Military and civil requirements have been diverging in recent years (fig. 17). The military requires dash-oriented vehicles, the civilian requirement is for cruise vehicles. For the AST, 35,000 hours cruising at elevated skin temperatures is a requirement for the structural design. On the B-1, the structural requirement is for relatively few hours at temperature, since the design missions are mostly subsonic.

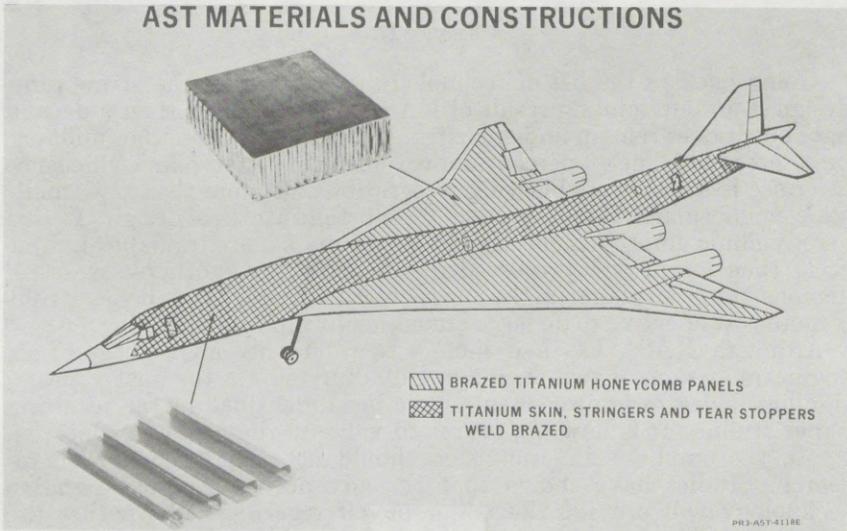


FIGURE 16

## DIVERGENCE OF MILITARY AND CIVIL DESIGNS

	<u>B-1</u>	<u>AST</u>
OPERATING LIFE (HR)	13,500	50,000
HOURS AT TEMPERATURE (AERO HEAT)	390	35,000
(°F)	265	250
MATERIALS % TITANIUM	21	63

PRO-51-117A

FIGURE 17

Going back to the list of technology requirements, the arrow wing design is an outstanding result of NASA research more than a decade ago, but it does remain undemonstrated on an airplane, either military or commercial. The 43 percent improvement in aerodynamic efficiency at cruise is a result of this wing integration and more than one small-scale wind tunnel test is needed to substantiate this design. If this aerodynamic improvement should prove to be unattainable for an SST, then we probably must defer the SST for another decade. A demonstrator airplane might be required although we believe that is more cost effective to do large amounts of wind tunnel testing.

Although NASA has had money to fund only an average of six engineers at each of two engine manufacturers over the past 4 years, significant design improvements have been identified in the resulting paper studies. It is now important to validate these design concepts. Again the emphasis in propulsion should be on testing, not on research. Studies have shown that the advancement in basic engine technology will provide the major payoff regardless of whether the eventual AST engine is a straight jet, a low-bypass turbojet, or a variable-cycle engine.

There may well be a demand for two distinct engine cycles—a low bypass turbojet utilizing proven technology and a follow-on variable cycle engine utilizing the advancements today being identified in NASA technology studies. These latter engines will require extensive validation before they can be placed in day-to-day airline service.

There are additional areas of technology where much development work must be accomplished, each critical to the success of the program. These include work on the inlet; work on the fuselage, again using titanium skin and stringer; work on graphite epoxy composites and into the higher temperature area of polymilites; design, test and development of aluminum for utilization on secondary structures capable of 35,000 hours of operating life at elevated temperatures. We talked a little while ago about the fact the Russians have better titanium metals for use at elevated temperatures. They also have a more advanced aluminum than we have available in the United States.

NASA has carried tests only up to 10,000 hours life and as far as we know, the British CM001 aluminum used on the Concorde also offers significant advantages over any U.S. aluminums. The French, the British and the Russian airplanes use these advanced aluminums. This area should be addressed by NASA as it has future military ramifications as well.

Low-speed validation tests, another important area, should be expanded as take-off climb performance is critical to noise and therefore to eventual engine cycle selection.

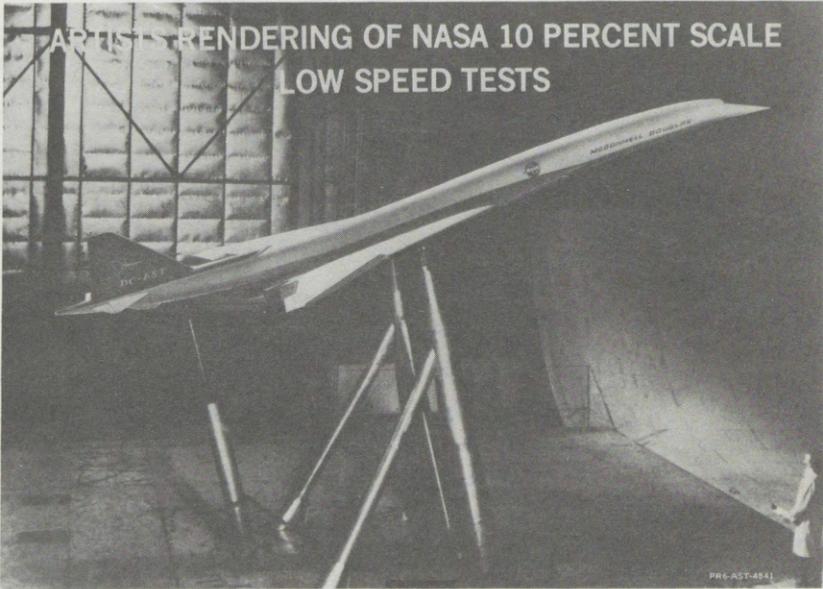


FIGURE 18

DOUGLAS AIRCRAFT COMPANY

## AST HIGH SPEED MODEL IN THE NASA-AMES SUPERSONIC WIND TUNNEL

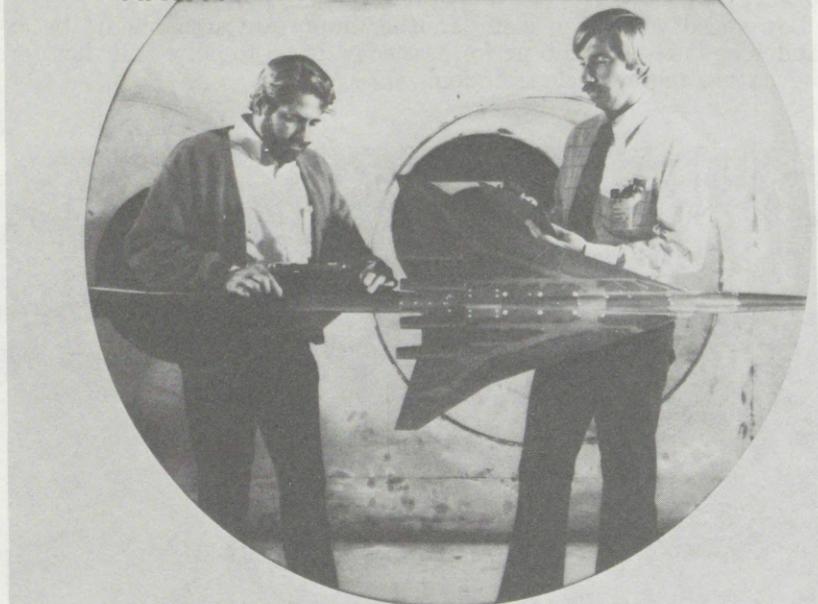


FIGURE 19

Fortunately, NASA was able to fund McDonnell Douglas to test an arrow wing design that reflected a fully integrated airplane for an airline. This fiberglass model you see over on the desk which was shown to you yesterday [figure 18] by NASA was made in a plaster of paris cast taken from the stainless steel wind tunnel model that you see depicted on the screen in the NASA wind tunnel test program [figure 19]. Douglas put a quarter of a million dollars of its own money into this test effort and NASA contributed \$279,000 and the test facility and test manpower. We figure the total value of this program represented about \$1¼ million if we would have to buy it on the open market. This model design is unique as it represents a configuration, optimized completely by computer, before it was ever tested in the wind tunnel. It was optimized internally for structural strength, aeroelastics, stiffness, and flutter, and externally for aerodynamic cruise performance, stability, and control. This is a capability of which we are quite proud and represents a degree of sophistication not available 4 years ago. The test results confirmed the analytical predictions within a very few percent, very satisfying to us on our first AST design in 10 years.

In summary, NASA had done well in SCAR technology work over the past 4 years with the pitifully low funding level available. Substantial progress had been made in analytical methods and in design analysis. No significant development testing has been possible except in a few selected areas. Industry, at least McDonnell Douglas, has had to carry much of the testing costs on private capital.

If NASA is to act in the leadership role for the United States on an AST, then the present \$8 million programed for fiscal 1977 should be raised to \$210 million in fiscal 1978 and a firm and lasting commitment made for an advanced supersonic transport.

It must be recognized as being in the national interest, and a program of advanced development testing formulated that totals approximately \$2 billion and leads to airline orders and program go-ahead possibly in 1980.

The emphasis needs to be on development, not on research, and testing is the underlying requirement of most of our recommendations.

Thank you very much, Mr. Chairman. We hope you will be able to put the A for "Aeronautics" back in NASA, a goal many of us have had, and we also hope that you could make the SST fashionable again. The Concorde operations are expanding. It is starting to have an impact on the U.S. airlines, and the U.S. aircraft industry is receding, unfortunately.

Thank you very much.

[The prepared statement of Mr. Fitzsimmons follows:]

STATEMENT OF  
RICHARD D. FITZSIMMONS  
DIRECTOR OF ADVANCED SUPERSONIC ENGINEERING  
MCDONNELL DOUGLAS CORPORATION  
DOUGLAS AIRCRAFT COMPANY  
LONG BEACH, CA.  
BEFORE THE  
SUBCOMMITTEE ON AVIATION AND TRANSPORTATION R&D  
COMMITTEE ON SCIENCE AND TECHNOLOGY  
U. S. HOUSE OF REPRESENTATIVES  
NASA ADVANCED SUPERSONIC TECHNOLOGY PROGRAM  
15 SEPTEMBER 1976

Mr. Chairman, and Members of the Committee, it is indeed a privilege to come before you and address the question, "What technology is needed to make sure an Advanced Supersonic Transport is environmentally and economically acceptable?"

Since termination of the U.S. SST program, in 1971, NASA has tried to keep a small effort alive that would hopefully lead to the building of a technology base for an Advanced Supersonic Transport (AST), Figure 1.

For 4 years, McDonnell Douglas has participated in advance design studies to identify for NASA those areas of technology development required to make possible an economically sound, environmentally satisfactory Advanced Supersonic Transport. We think those findings relevant and I would like to review some of them for you.

The NASA contract studies included a market requirements analysis. One of the significant results is shown, Figure 2. The free-world overwater routes and the passenger business projected for them through the year 2000 were determined. The importance of being able to design a 4500-nautical-mile-range airplane to do 80 percent of the business as compared to 3300 nautical miles or 40 percent of that business is most significant. Both the Concorde and the last U.S. SST were 3300-nautical-mile-range aircraft. The advanced technology capabilities identified during the past 4 years in the cooperative NASA/Industry design studies show that a 4500-nautical-mile range can be realized.

The Douglas/NASA studies, more conservative than either Boeing or Lockheed, show a large potential market for an Advanced Supersonic Transport from the mid-1980s to the end of the century. Estimates are that 300 aircraft would be needed, even making allowances for high fuel costs and higher operating costs. Assuming a purchase price of approximately \$110 million per airplane, this represents a \$33 billion market through the year 2000. This is almost equivalent to the total free-world value - \$42 billion - of all the civil aircraft sales in history up through 1976. This is an important market and the U.S. should capture a part of it.

Our nation has a wealth of experience upon which to draw for a Mach 2.2 transport, Figure 3 — knowledge gained starting with the Douglas D-558 II, the first aircraft to go over Mach 2.0, through more than 2 decades of supersonic aircraft programs on our McDonnell Douglas F-4, plus work on the former U.S. SST, B-58, and B-70 programs; the current F-14 and our McDonnell Douglas F-15 and F-18 fighters; and others. Most of the knowledge from these programs can be applied directly to the development of a Mach 2.2 advanced supersonic commercial airplane.

Recent studies show that what is required now is not costly new invention, but rather technology validation of particular design details that show to be optimum but have never been used before on U.S. aircraft. Today's study results are exciting.

Probably the best way to describe the technology status is to compare our study results with the Concorde, and with the former U.S. SST. The resulting configuration would be much larger than the Concorde and utilize a more efficient planform shape than the Concorde or the former U.S. SST, Figure 4. It is called an arrow wing due to the cutout in the trailing edge. The 1971 concerns over structural stiffness and flutter problems of arrow wings have now been allayed and sizable improvements in performance are possible.

To understand how supersonic technology has progressed in 4 years of research, a baseline McDonnell Douglas AST has been identified, Figure 5. Any of several engine cycles could have been selected for the baseline. The mini-bypass engine with a relatively heavy multielement jet noise suppressor has been selected as it is easily understood, undoubtedly represents the least risk, and could probably be certified early.

A comparison is shown of the Advanced Supersonic Transport of 1976 and the former U.S. SST, Figure 6. The big differences are in two areas, range and noise. A 48-percent increase in range to 4590 nautical miles is shown, and the aerodynamics improvement provides almost all of that.

There is no improvement shown for the engine propulsion efficiency, in spite of all the publicity given to the advanced engine cycles. The big gain in the propulsion area is in noise, and all designs considered today would meet or

improve over FAR Part 36. These low noise levels have been realized in paper designs without sacrificing any efficiency at cruise, which is a major accomplishment.

A new capability has been developed in the past 2 years because of the increased capability computers offer. We can now analyze the internal structure of a new design, and the external aerodynamics, in a matter of 2 weeks and know that our results are creditable. The internal structural analysis, involving over 5000 individual structural members, allows many critical load conditions to be checked. Each member can be sized for strength, aeroelasticity, safe-life, fatigue, and damage tolerance, including a flutter analysis. In 1971, this process took as much as 6 months. This is real progress. We can now truly identify those technologies where the greatest benefits occur.

A comparison with the Concorde is also shown, Figure 7. Here, in addition to improvements in aerodynamics and noise, improvements in payload and in speed are shown, both of which are primary variables in the economics equation. All hourly operating costs are divided by speed and by payload to obtain operating costs per passenger-mile. A 9-percent increase in speed and a 250-percent increase in payload are dramatic improvements and, we feel, absolutely necessary for the attainment of satisfactory economics.

Much has been written about the advancements required for the propulsion system to make a supersonic transport viable. There was nothing wrong with the propulsion efficiency of the 1971 engine on the U.S. SST. However, it did not meet society's requirements of noise and emissions. This chart, Figure 7, shows that the Olympus engine on the Concorde provides a cruise propulsion efficiency only 2 percent lower than the best of the advanced engines that resulted from the NASA-funded U.S. engine studies of the past 4 years. The big difference is in noise and in weight. Thermodynamics is a reasonably well-known science and the ideal engine cycle for supersonic cruise efficiency has not changed. The component efficiencies of the 1971 turbines and compressors were high, so improvements have not come easily. The challenges that U.S. industry research teams have had since 1971 are to meet or improve over the community noise requirements without losing supersonic cruise propulsion efficiency.

A chart, Figure 8, from our recent NASA engine integration studies shows how much improvement has been realized compared to a 1975 baseline turbojet design, which utilizes GE4-level technology (former U. S. SST engine) modified to meet FAR Part 36 noise levels. Any of a variety of engine cycles offer up to 480 nautical miles additional range, mostly due to the decreased engine weight realized by use of advanced technologies including higher turbine temperatures, improved component efficiencies, inherent coannular sound suppression, and improved methods of engine operations.

The payload range, Figure 9, that results from these advance design studies shows most impressively how the advances in technology could pay off. Opening up the Pacific can become a reality and supersonic travel there can have tremendous appeal. A range extension is shown for 1985 go-ahead which reflects utilization of a lightweight variable-cycle engine, coupled with use of composite secondary structures like flaps, floor beams, and fillets. The NASA DC-10 composite rudder program, Figure 10, should be continued as the technology is directly applicable to the AST at Mach 2.2.

Let me digress a moment to talk about the so-called "cancer risk" that was so controversial in 1971. The \$25 million Congress allocated to FAA for the Climatic Impact Assessment Program (CIAP), involving over 1000 scientists throughout many countries over 4 years, was invaluable. Now that real information is becoming available, it is known that an SST will not be an environmental monster and that the cancer scare of 1971 was overplayed. For whatever degree of climatic disturbance might result from high-altitude commercial flight, solutions seem assured.

## PRESENT AST PROGRAMS

When the SST program was terminated in 1971, the Congress, the Executive Branch, and the U.S. Industry recognized the need to continue supersonic technology efforts to preserve this nation's capacity and readiness for possible competition with foreign aircraft builders. U.S. airframe and engine manufacturers have carried on this work using their own funds, supplemented with contract funds provided by Congress through NASA and DOT, Figure 11. The DOT support has since stopped. Government support for these efforts has been authorized by Congress each year since, although the level of effort has been small and has actually been decreasing year by year.

NASA has been funding an average of six people each at General Electric, Pratt & Whitney Aircraft, Boeing, Lockheed, and Douglas over the past 4 years. Obviously, analytical work and almost no testing has resulted. For FY 1974, NASA requested \$28 million for AST contractor effort. With NASA requesting a large AST budget, McDonnell Douglas in 1973 initiated a large-scale Company-funded supersonic technology effort. The Company program that resulted was eight times the Douglas/NASA contract effort. Douglas had 110 people on the program. With the NASA advance design contract effort diminished to the current six-man level, the obvious answer has been for management to cut Company expenditures. The NASA AST effort was described at one NASA/Industry advisory meeting as little more than window dressing. Fortunately, NASA AST systems study funding will increase next month; however, this will be done at the expense of aerodynamics and structures technology funding.

A concern of the commercial airplane and engine manufacturers at present is that we see a lack of focus in the utilization of authorized NASA AST contractor funds. Approximately 25 percent of the authorized funds have been directed to industry. The remainder is awarded to other organizations, companies, or universities — who do produce good results — but many of whom, for one reason or another, may never be involved in the continuing stream of AST development work. We view this lack of focus as injurious to the overall national AST effort as we try to compete with other nations.

NASA's AST budget for FY 77, called Supersonic Cruise Aircraft Research (SCAR), is \$8.9 million. If this nation is to do anything serious in AST, the FY 78 budget must be expanded to a level approaching \$105 million, to do the engine and airframe advanced development we identify for a McDonnell Douglas type airplane development, Figure 12. This is just for one airplane manufacturer and one engine manufacturer for the first year; the second year requires \$375 million, the third year \$525 million, and the fourth year \$175 million. We estimate that between now and 1980, the date at which we would anticipate making a commitment to go ahead, an expenditure of \$1.2 billion is involved, or \$2.4 billion for a competitive program.

The airplane advanced development totals \$130 million and would include the aerodynamics, systems studies, etc., - traditional NASA efforts but on an expanded scale. The emphasis would be on development testing, not on research. We recommend \$500 million be spent demonstrating the design, manufacturing, and testing of major components, in lieu of the more costly flying of an experimental airplane.

For the engines, we believe \$50 million must be funded in FY 78, \$210 million in FY 79, \$220 million in FY 80, and \$70 million in FY 81 for each engine type. That would include funding of the engine component developments, development of a low-emission combustor, demonstration of full-scale noise characteristics including forward flight effects, and building an experimental engine demonstrator. The variable-cycle engines may or may not be included in the present technology plan as the timing of the airline requirement for a supersonic transport will dictate the level of technology that can be incorporated in the first airplane. Because advanced technology variable-cycle engines do offer such promise, a separate activity on these type engines should be continued regardless of what happens to the baseline Advanced Supersonic Transport program.

This would take the industry to the point where a commitment to a production program could be made, which means airlines will have placed initial orders, specific engines will have been selected, airplane detail specifications will have been defined, and prices will have been established.

Having said all this, what then is the status of advanced supersonic technology today?

As a result of our NASA/Industry studies, our position is as follows:

"The technology exists to build an economically viable, environmentally sound, supersonic transport given a vigorous validation development test effort, with a firm and lasting commitment of national interest by our aerospace industry, our Government, and our people." (Figure 13)

There are a lot of qualifiers in that statement. A "vigorous validation development test effort" means at least \$1 billion per competitor. A "firm and lasting commitment" means that the start and stop of the last U.S. SST program must be prevented as the loss of critical industry resources including manpower, facilities, and time, was unconscionable. Because the U.S. Government halted the last U.S. SST, it may be that the U.S. Government will have to take the leadership role in initiating a new U.S. supersonic transport. No manufacturer is capable of obtaining a commitment from the people and from the Government that an AST is in the national interest. Without this commitment, we believe a U.S. AST will not move ahead.

## TECHNOLOGY REQUIREMENTS

There are three technologies, Figure 14, that give us primary concern:

1. Full-scale noise results are needed before an engine cycle can be selected.
2. Weight and manufacturing costs must be known for titanium honeycomb wing structure.
3. Precise knowledge of the characteristics of an arrow wing in flight is required.

I mentioned that in 1973 McDonnell Douglas had 110 engineers on the AST program. At that time 17 small test programs were started, each believed critical to an early AST go-ahead. All but one, noise, were cancelled. That program is still on-going and work is underway at the Rolls Royce noise test facility in England, Figure 15, and at NASA Ames.

The use of large amounts of titanium honeycomb structure is critical to the range, weight, and costs of the airplane and no airplane has ever been built that utilizes this concept, Figure 16. Management must know much more about costs and weight and this requires fabrication experience on major components if not on complete wings — many people believe that the supersonic B-1 will provide the technology for a U.S. SST. The AST requirements are 100 to 1000 times more severe. Military and Civil requirements have been diverging in recent years, Figure 17. The Military requires dash-oriented vehicles, the Civil requirement is for cruise vehicles. For the AST, 35,000 hours cruising at 250°F skin temperatures is a requirement for the structural design. On the B-1, the structural requirement is for relatively few hours at temperature, since the design missions are mostly subsonic.

The arrow wing design, Figure 14, an outstanding result of NASA research more than a decade ago, remains undemonstrated on an airplane, either military or commercial. The 43-percent improvement in aerodynamic efficiency at cruise is a result of this wing integration and more than one small-scale wind-tunnel test is needed to substantiate this design selection. If this aerodynamic improvement, as a result of broader testing, should prove

to be unattainable, then an SST probably must be deferred until further research is accomplished, as this aerodynamic efficiency is basic to the overall success for an Advanced Supersonic Transport design. A demonstrator airplane might be required, although we believe it to be more cost-effective to do a large amount of wind-tunnel testing.

Engine cycle selection deserves almost a separate paper. Although NASA has had money to fund only an average of six engineers at each of two engine manufacturers for the past 4 years, significant design improvements have been identified in the resulting paper engine studies. It is now important to validate these design concepts. Again the emphasis should now be on development testing and not on research. The studies have shown that the advancement in basic engine technology will provide the major payoff regardless of whether the eventual AST engine is a straight jet, a low-bypass turbojet, or a variable-cycle engine.

For the variable-cycle engines, much development work needs to be done to see that large losses do not occur where exhaust streams are mixed or where leaks could develop. Also, development of highly efficient low-emission burners must be accomplished as recommended by CIAP. Compared to today's commercial engines, large excursions in inlet airflow, nozzle areas, and core airflow of the engine pose new problems that look easy to solve on "paper studies." Without demonstrating that these features will not be problems, no airline or airframe manufacturer can seriously consider committing such engines to production.

There may well be a demand for two distinct AST engines: a simple low-bypass turbojet engine utilizing proven technology, and a follow-on variable-cycle engine utilizing the advancements being identified today in NASA technology studies. These latter engines may require extensive validation before they can be placed in airline operation.

There are additional areas of technology where much development work must be accomplished, each crucial to the success of the program. These include the following:

1. Design, test, and flight development of an operational mixed compression axisymmetric inlet

2. Design, test, and development of a major structural section of fuselage utilizing titanium-stiffened titanium sheet including full double curvature requirements associated with area ruled fuselages
3. Design, test, and development of composites (graphite or boron epoxies) for utilization on secondary structures, fairings, and other low-load structures
4. Design, test, and development of aluminum for utilization on secondary structures, capable of 35,000 hours of operating life at elevated temperatures of 250°F. NASA has carried tests up to 10,000 hours life and as far as we know, the British CM001 aluminum used on the Concorde offers significant advantages over any U.S. aluminums. This area should be addressed by NASA as it has future military ramifications as well.
5. Low-speed validation tests, Figure 18, should be expanded as take-off climb performance is critical to noise and therefore to eventual cycle selection.

Fortunately, in the past 4 years, NASA was able to fund McDonnell Douglas to test an arrow wing design that reflected a fully integrated airline airplane, Figure 19. This fiberglass model you see before you today, was made in a plaster of paris cast taken from that stainless steel wind-tunnel model. McDonnell Douglas put \$250,000 into this test effort, and NASA contributed \$279,000 and the test facility and test manpower. We figure the total value of this program represented about \$1-1/4 million. This model design is unique as it represents a configuration, optimized completely by computer, before it was ever tested in the wind tunnel. It was optimized internally for structural strength, aeroelastics, stiffness, and flutter, and externally for aerodynamic cruise performance, stability, and control. This is a capability of which we are quite proud and represents a degree of sophistication not available 4 years ago. The test results confirmed analytical predictions within 5 percent, very satisfying to us on our first AST design in 10 years.

## SUMMARY

In summary, NASA has done well in Supersonic Cruise Aircraft Research technology work over the past 4 years with the pitifully low funding level available. Substantial progress has been made in analytical methods and in design analysis. No significant development testing has been possible except on a few selected subjects. Industry, at least McDonnell Douglas, has had to carry much of the testing costs on private capital.

If NASA is to act in the leadership role for the United States on AST, then the present \$8 million programmed for FY 77 should be raised to \$210 million for FY 78 and a firm and lasting commitment made for an Advanced Supersonic Transport. It must be recognized as being in the national interest, and a program of advanced development formulated that totals approximately \$2.2 billion leading to airline orders and a program go-ahead in 1980.

The emphasis needs to be on development, not on research, and testing is the underlying requirement of most of our recommendations.

Thank you! We hope you will be able to put the "A" for Aeronautics back in NASA and also make the SST fashionable again. Concorde operations are expanding! The U. S. aircraft industry is receding!

Mr. MILFORD. Thank you very much, Mr. Fitzsimmons. I would personally agree with you very much in your last paragraph. I would also like to see the first A put back into NASA..

On your technology comparisons with the 1971 SST model and later with the Concorde, you do not seem to really give a hearty endorsement to our present efforts in the variable-cycle engine development. If I heard your testimony correct, you stated that we really only attain about a 2-percent increase in efficiency. Did I understand that correctly?

Mr. FITZSIMMONS. Yes, and I think you have seen that before from other testimony. That is at the design cruise point.

Mr. MILFORD. But that pertains only to the design cruise point and would not apply in the subsonic range—takeoffs, climbs and what have you, would it?

Mr. FITZSIMMONS. No, the 2 percent relates only to the supersonic cruise efficiency.

Mr. MILFORD. Yes.

Mr. FITZSIMMONS. There is a large gain available in the subsonic mode as presented by other speakers. This is a very big offering and will offer greater flexibility in the operation of an airline airplane.

Mr. MILFORD. There also seems to be a difference of opinion in at least within two of our majors as to whether now is the time to get on with the building of one of these things.

Mr. FITZSIMMONS. Yes, I think that we do see things differently. At McDonnell Douglas we have been in continuous production of supersonic airplanes for over 20 years. We are talking about building an airplane at the design speed of about mach 2.2 as I showed, about 9 or 10 percent faster than the Concorde, not up in the higher mach number range of the last U.S. SST. We think that the technology requirement to go all the way to mach 2.7, as was done in the last program, makes that program a decade away. We think the pressure on the United States will be to satisfy the public demand for supersonic travel if there continues to be a demand for Concorde operations. The public will dictate what is successful in the marketplace. If they want supersonic travel, we think that we should pull in our horns a little bit regarding design mach number and go with the technology that we could handle today. We think that the technology is ready for the lower mach number designs. We think that it will still take a lot of development testing in areas such as materials, emissions, and noise, and work on the engine components.

Mr. MILFORD. If you went ahead with the engine that you are proposing now and our development work continued in the variable-cycle engine, would it be feasible to retrofit or change engines at some point down the line or would we get into a total redesign problem?

Mr. FITZSIMMONS. The engines could be interchanged; however, I think you have misread my testimony, if you think we have picked an engine cycle, Mr. Chairman. We have not picked an engine cycle. We think that is a decision that should be made in 1980. We think that we should pursue the advancements of the best engine cycles but it does look to us like the engine manufacturers would not be able to offer the variable-cycle engines—1985 technology—in 1980, and if a decision to go ahead in 1980 was required, we would take whatever the best engine offering was that either Pratt & Whitney

or General Electric could put forth at that time. It might well take the form of a variable-cycle engine. But that decision must await further technology development.

Mr. MILFORD. You alluded to the role that the U.S. Government might play in the development of an AST. Could you spell out what you see as the Government role?

Mr. FITZSIMMONS. I wish I could.

Mr. WYDLER. It is money, isn't it?

Mr. FITZSIMMONS. Yes; policy usually means money.

Mr. MILFORD. Let me state it in this way. I believe that in the development of a new aircraft, manufacturers go through a cycle of first a marketing survey to determine what particular type, how large, how fast. They then, as I understand it, go through a design phase, then a prototype phase, testing.

Mr. FITZSIMMONS. Yes, but it can take different forms for different programs.

Mr. MILFORD. I would not want to see the U.S. Government building Douglas airplanes, but I would like to see the U.S. Government, and this is a personal opinion, advancing aeronautics so that Douglas, Lockheed or Boeing could pick up on a competitive basis to utilize the technology developed or assisted by the United States. I am really trying to pin down just what can the Government do that would not violate that principle.

Mr. FITZSIMMONS. I think the expansion of the development activity, through NASA, is directly appropriate for use by our industry and is consistent with the charter of NASA. NASA could fund the kinds of programs, not just in research, but also in the much more expensive area of development testing, and while that has not historically been something they have pursued, we think as the DOD usually has done it, NASA should expand their role in the development testing area, which, in a sense, will minimize the financial risk that the manufacturers would have to take. We are in a position where the industry is not capable of carrying on new programs today. For the first time in some 30 years no development programs are underway in the United States for new civil transport aircraft, and this is due primarily to the financial structure of the airline industry and the civil aircraft manufacturing industry.

Accordingly, we think that NASA should expand their role in the development area.

Mr. MILFORD. Should it be expanded to the point of following the principles or the practices in the military of say a design competition for a civil air transport aircraft? A competition that can be participated in by—

Mr. FITZSIMMONS. We have not thought through going that far yet. We are still thinking about building very major pieces of structure, however. We are not, if you recall my testimony, advocating flying a prototype airplane. We would much prefer to do more extensive testing, for example, a major wind tunnel testing program, a more massive structural testing program, than to actually build an airplane. We think these tests should be done by more than one manufacturer, so yes, they should be competitive.

Mr. MILFORD. What wing structures are used in the B-1? You mentioned the titanium honeycomb structure that is needed in civil SST, but where is titanium used in the B-1?

Mr. FITZSIMMONS. Well, it is basically an aluminum structure airplane. It has titanium in the center wing carry through structure and out to the pivot. Some titanium is used for bulkheads and support fittings. It has titanium in the areas around the tailpipe and on areas subjected to exhaust-induced elevated temperatures. But it is basically an aluminum airplane. It would not do the kind of mission that we need to do for an AST, sustained supersonic cruise for 70 percent of each flight.

Mr. MILFORD. Mr. Wydler?

Mr. WYDLER. I just do not know if the things that you want from the Government are possible to get. For example, what do you mean when you say, "firm and sure commitment toward the aircraft." What does that mean? How do you get that from a government?

Mr. FITZSIMMONS. Well, I am not sure how we get it. We are dependent on annual funding, of course, from the Government, but I think if we are to see the development of an SST in the United States, it is going to have to take a new form. I do not see the financial wherewithal of an individual civil aircraft manufacturer to carry such a program forward just as it could not have been done in the 1971 program. That took a uniquely structured program between industry and government.

A lasting commitment—I do not know that there is an answer to that, but we surely ought to seek one.

Mr. WYDLER. You know what one Congress does, the other can undo. That is the nature of our Government unfortunately or fortunately, whichever way you look at it.

Mr. FITZSIMMONS. And this is why it may be better for an AST program to take the form of a Government-backed loan or something like that, which is a little less susceptible to an annual funding requirement.

Mr. WYDLER. Well, you are talking now in terms of hundreds of millions of dollars. I do not know how realistic that is in the next fiscal year. But if I understand what you are saying, you are suggesting that the Federal Government come up with about a billion dollars or more, and I presume what you mean is that we give it to McDonnell Douglas and you are going to do all this testing and development work and then when you are through, you will say we think we can build the aircraft. I presume we will reach that point. Then you will go ahead and build the aircraft, but of course at that point you are going to ask us for the money, I presume, to build it.

Mr. FITZSIMMONS. We did not address that question.

Mr. WYDLER. How do you picture it working? I am trying to picture it exactly in my own mind how this thing will work. In other words if we come up with these hundreds of millions of dollars, and I guess it gets to the billion dollar stage, McDonnell Douglas will do this development work. Isn't that the idea?

Mr. FITZSIMMONS. Yes, that is, but let us say, give it to the industry.

Mr. WYDLER. At some point or other you would say, well, we have got the engine in shape, we think it is ready, we have got the wings in

shape, and we can go ahead with that. Then what would happen at that point?

Mr. FITZSIMMONS. Then the high risk areas could conceivably be over, and management could go to the banks or the free marketplace. You would have airline orders in hand and you would be committing on firm price basis to manufacture the airplanes. It would be a program that would follow the normal commercial type of program.

Mr. WYDLER. And at that point it would be all McDonnell Douglas.

Mr. FITZSIMMONS. Conceivably, it could be just industry at that point, but we have not studied that question. No, we have not said that it would be all McDonnell Douglas. We think it ought to be a competitive program. We think that it would be wise to carry a minimum of two contractors through that kind of a program. We would want to carry two-engine companies as well. It may be, that we will be forced to go to a multinational type program where we end up joining forces with friends overseas.

Mr. WYDLER. I am a little bit suspicious of that competitive type program in this field. I will tell you why. I was not really in on it that much, but I remember it was Boeing and Lockheed that were competing. I remember Boeing came out with a design that was a swept wing. They could move the wing and Lockheed came out with a design of its own, and they awarded it to Boeing, and then it looked like to me Boeing built the Lockheed airplane. Isn't that really what happened last time?

Mr. FITZSIMMONS. I defer to Mr. Withington, if he wants to——

[Laughter.]

Mr. WYDLER. I never could understand that kind of competition. I do not really know what happened there, but I know they ended up looking like the Lockheed airplane, anyway.

Mr. FITZSIMMONS. If you take a look at the program that we were talking about which we are saying is somewhere around \$33 billion for airplanes, you could even extend that further and say that the airlines when they operate that fleet of airplanes would really be looking at total revenues that run about \$160 billion over the life of the AST program. So saving a couple of percent in the overall operating costs of supersonic aircraft easily outweighs the initial cost of competitive programs even though in today's frame of reference they look like very large numbers. Healthy competition is the basis of our private enterprise system.

Mr. WYDLER. I would agree with you to this extent. We are having the same kind of a struggle right now with something called the synthetic fuels bill which is essentially a question if the Federal Government is going to go in and subsidize a new industry, in this case, to convert coal into a gaseous form for use by the American public. There are a lot of Members of the Congress who ask what justification we have to go in and give Government money to these companies to develop this new process. Of course the companies say, look, if you do not finance it, we are not going to do it, because it is something new and there is no way we could possibly get a loan from a bank to do this kind of a thing. It is too risky and so forth. We are having great trouble. It is out of this committee, too. Now it seems to me we are in the same bind here because again it would all end up in private

hands. If it works they will keep it. If it does not work presumably they will say okay you can have it. I think it should be layed out in cold terms so the people know exactly what they are borrowing before they buy it, how much it is really going to cost? How much of a commitment has to be made on the part of the Government to do it? Let the people know right from the outset, not sort of kind of pull them in a little bit at a time. Then if you can sell that then maybe you will have the firm commitment you are talking about.

Mr. FITZSIMMONS. What we have consistently recommended to NASA, over the last 3 years in our systems studies, is that work should be done to try to conceive just what kind of a program should evolve for a U.S. AST. So far we have not been able to devote any effort to this.

Mr. WYDLER. I think from what you gentlemen have testified to here you have done most of the necessary thinking as to the concept of what we are trying to do. It is a question now of whether you want to make the financial commitment or not to carry it out.

Mr. FITZSIMMONS. We thought it appropriate to provide some numbers so that you could see the magnitude of the problem.

Mr. WYDLER. We appreciate it. Thank you.

Mr. MILFORD. Mr. Lloyd?

Mr. LLOYD. Thank you very much, Mr. Chairman.

It seems like I am really picking on my colleague from New York and I do not mean to. He indicated that you have set the numbers. I do not think you have set the numbers at all. I do not think that you have decided that an SST has to go 2.7 or 2.2. As a matter of fact is it perfectly feasible within the state of the art at the present moment there would be a practical SST, at the figure 1.6. As a matter of fact that is a major breaking point for all supersonic airplanes, and 1.6 would be an infinitely more efficient airplane.

Mr. FITZSIMMONS. I should say that we have done the studies and the speed should be above or equal to the existing supersonic transports in the world.

Mr. LLOYD. In other words, 2.2.

Mr. FITZSIMMONS. Well, they are both just a shade over mach 2. The Concorde and the TU-144.

Mr. LLOYD. What kind of a heat rise do you get at 2.0 on the leading edge of the wings, the fuselage, the tail surface, in other words, the impact surfaces?

Mr. FITZSIMMONS. Well, it is lower than what we have shown you here, which was done for mach 2.2. We use 255 degrees. At mach 2 it is about 190 to 200 degrees.

Mr. LLOYD. Even aluminum can handle those kinds of temperatures, can't it?

Mr. FITZSIMMONS. When you say it can handle it—it does have a tendency to creep. We do not like to design airplane structure that has a tendency to creep. Neither do the British or the French. This is why they developed the CM001 and 002 aluminums.

Mr. LLOYD. Isn't that possible for us to duplicate? Couldn't we come up with an aluminum hardness and—

Mr. FITZSIMMONS. Sure we could do that, but it would still leave us with a temperature-limited airplane that is subject to some creep, and over a long period of time you do—you have to protect the airplane.

Mr. MILFORD. For the record, would you define creep?

Mr. FITZSIMMONS. Creep is when the material changes shape permanently from repeated stress and/or exposure to high temperature.

Mr. MILFORD. OK.

Mr. LLOYD. Your own F-15 uses honeycomb composite panels that you are using with your wings for instance. Could those same panels of composite material be effective in an SST?

Everything I am doing, by the way, is in the frame of reference of a 2 airplane, not 2.2, not 2.7, not 1.6, but 2.

Mr. FITZSIMMONS. The use of the F-15 structure does not provide us the specific background for an SST design, because the F-15 is a dash-oriented airplane. It spends most of its time below its high-speed-design mach number.

Mr. LLOYD. The F-15 can certainly exceed 2.

Mr. FITZSIMMONS. Oh, yes, sir.

Mr. LLOYD. But only for very short periods of time.

Mr. FITZSIMMONS. Yes. So you get a different set of requirements when you design the structure.

Mr. LLOYD. The temperature rise does not get up there. The airplane reaches the speed and has departed before the temperature rise occurs to where you get a creep in the structure. But in the upcoming development of structural material, I have recently looked at the space shuttle, I think that there must be some applicability of some materials, that there may be some applicability. In other words, what I am saying is, is there a possibility that we can begin to look at ceramics over metals to handle the temperature rise and use metals deeper in the structure with a temperature bleedoff capability so that we could have our cake and eat it too?

Mr. FITZSIMMONS. I would have to say that, yes, we do try to look at all of the developing technologies. We have space activities in the McDonnell Douglas Corp. and we use the best things that they develop and exercise those through our designs, but we still come back with titanium honeycomb structure being the optimum for the kind of AST airplanes we are talking about. It is worth about 20 to 25 percent weight saving and, accordingly, it is important.

Mr. LLOYD. Yes, it is.

Mr. FITZSIMMONS. We have no proof of this predicted weight saving either from military or commercial airplanes.

Mr. LLOYD. You were quite emphatic that there were few tradeoffs from the B-1 as a supersonic airframe. In AST payload range, there are no great advantages there. What about the swing-wing concept? Does that have applicability or is that just not commercially feasible in the areas that we are talking about?

Mr. FITZSIMMONS. Well, because the airplane tends to be point designed and is very critically dependent upon its weight fraction, or payload-to-gross-weight ratio, the weight that you pay to provide that pivot is pretty hard to justify. Accordingly, our numbers say that the swing wing is not the optimum design. We keep looking at it, a fixed wing seems to be the type of design that is optimum.

Mr. LLOYD. And you do not at this point anticipate any major shift in that design concept. That in all probability, we have narrowed it down, the numbers, to a point here if you really are going to do that, that is the design. You are now locked into that design?

Mr. FITZSIMMONS. No, we do not lock in until an airline buys it. We could change the design the last day, but for now this is the way the computer tends to lead us for our baseline design.

Mr. LLOYD. I accept that. I was not trying to pin you down on specifics. I just wanted to bring out a point. The point that I have been trying to make is that the spinoff in technology is not as great as people assume it is. That the optimum efficiencies of airframe design and metal is fairly well dictated at the present moment and is foreseeable in the 10-year future. You are not going to get major breakthroughs in this. The engine concepts that are predictable at the present moment; whether it is a multicycle engine, or a low-bypass-ratio engine. We already know fairly well the areas of the numbers to say this is probably what you are going to have to deal with. I think this is the point that Mr. Wydler was alluding to and I am trying to emphasize the fact that you really do know. We could sit here for a couple of days. We could read. We could go back and redesign the airplanes and we would always come back to basically what we have got right now. We know where we are going. So these are the numbers we have to deal with. In that light, the economics now that with those major dollars required, the only person who is going to do it is the U.S. Government, if it is going to be done at all. That commitment then of the Government has to be an ongoing commitment. We cannot skirt the whole thing and say, well, after all we really are a leader and any time we want to build an SST we can just build it.

All we have to do is just let McDonnell Douglas, or Lockheed, or Boeing go forward and do it. The only thing that will create that atmosphere is the dollars and the optimum commitment of governmental agencies, whether it is NASA or whoever else it may be, or better yet an act of Congress that will provide the impetus for the building of those vehicles. Without that, it will not be done. Is that correct?

Mr. FITZSIMMONS. That is our view.

Mr. LLOYD. I do not like the words I just used, but I think that is—

Mr. FITZSIMMONS. We do not like them either.

[Laughter.]

We would prefer not to be dependent on the Government for our future programs but that becomes less plausible every day, and more so for an AST.

Mr. LLOYD. Mr. Chairman?

Mr. MILFORD. Thank you, Mr. Lloyd.

Mr. Fitzsimmons, we appreciate very much your taking the time to come and appear before this committee.

Mr. FITZSIMMONS. It is our pleasure. Thank you.

Mr. MILFORD. The Chair now recognizes Mr. William H. Sens, manager, preliminary engine design, Pratt & Whitney Aircraft.

Mr. Sens, we have your prepared statement and attachments which will be accepted for the record at this time and you may either read your statement or proceed in any fashion that you feel comfortable with.

STATEMENT OF WILLIAM H. SENS, MANAGER, PRELIMINARY  
ENGINE DESIGN, PRATT & WHITNEY AIRCRAFT

Mr. SENS. I appreciate the opportunity to be able to present the testimony for Pratt & Whitney today on the propulsion technology needed in order to make an economically acceptable and ecologically acceptable supersonic transport. My predecessors have discussed much of the subject matter that I am planning to cover, particularly on the variable-cycle power plants. However, I would like to present my testimony, even though somewhat repetitive, as an engineman's point of view may be somewhat different. I will not read the text, but will use the charts from the text.

First of all, I would like to say that we share the committee's concern about the rate of technology development aimed toward the second generation supersonic transport in this country.

Foreign export of commercial aircraft and powerplants have been a very favorable source of business for the industry and very favorable for the country's balance of trade over the past several decades. Although we do not foresee the Concorde or the TU-144 being a serious threat to this business because of their economic and ecological limitations, these efforts are providing the French, British, and the Russians with the technical teams and the capability from which they could launch a second generation transport that would be a real threat. We feel very strongly that we in this country must develop the technology aimed at a second generation supersonic transport aircraft so that we will be able to launch a development which can meet this competition whenever it appears necessary to do so.

Second, I would like to endorse the NASA programs aimed at the supersonic cruise aircraft. We think their direction is good; however, they are woefully underfunded. I will get into this more later on.

Third, I would like to briefly mention the fact that at least in the propulsion area a lot of the technology that we have been and will be working on as a part of the NASA AST program will have application to DOT requirements.

First I would like to report briefly on the progress that has been made since the last time we testified to your committee on the subject of supersonic technology approximately 2½ years ago. At that time we were fairly early in the NASA sponsored AST program, which had as its objective a study of powerplant cycles and particularly variable-cycle engines. The objective was to determine which cycles had the best potential; to identify the needed technologies for those cycles, and to initiate in a limited way component work aimed at substantiating those needed technologies.

Unfortunately because of the relatively low level of funding—roughly one-fifth of what was recommended—we have not proceeded very far on the component substantiation. However, what we have done has been most valuable and encouraging.

First of all, I would like to discuss the cycle studies that we have made—the different types of engines that we looked at. The first chart (fig. 3, prepared statement, p. 245), shows some representative types

of engines that we have evaluated. Actually in the study we evaluated over 100 different cycles. If you will look at the chart, the top three configurations shown use valves to achieve cycle variability. This is the type of valving that Mr. Withington discussed with you earlier. We worked cooperatively with Boeing in studying a large number of engine configurations using these valves. The one on the left shows the configuration which incorporates the valve in the front end of the engine similar to the configuration run in the JT8D test that Mr. Withington described. The second one shows a configuration utilizing two valves, and the third configuration was one which incorporated the valve in the back end.

The purpose of the valve in all cases is to be able to shift the cycle in going from the subsonic to the supersonic flight regime. Of the valve cycles studied, the rear-valve VCE shown on the right was the one that looked the best in our evaluations and the one that we are continuing to study.

The next line, as you move down the chart, covers the low bypass engines of the type that Dick Fitzsimmons utilized in his airplane; a turbofan cycle with a duct heater, which is the cycle that we pursued in our competition for the first generation SST engine, and separate engines for takeoff and supersonic operation. We looked at a configuration, which you have already heard something about, called the variable stream control engine which I will discuss further later on. We have looked at the use of supersonic fans. We have evaluated the use of engines that would fit in with an augmented wing lift concept. We have even looked at inter cooling and reheat cycles as possibilities as well as an engine that we call the turbofan ramjet that converts from a turbofan subsonically to ramjet operation at high speed. These configurations are the ones covered. Out of all of these the variable stream control engine, the one just above the lower left-hand quadrant is the one that has been identified as the cycle having the most potential. Closely behind that is the rear valve VCE engine.

I would now like to discuss further the variable stream control engine; what it is and what its principles are. Fortunately, we have been working on a movie that describes the operations of this engine cycle better than I can in words. We received the first edition of it yesterday. It is not a finished copy, but I think it presents the story so well that with your indulgence I would like to show it to you and then discuss the characteristics of the engine further.

Mr. MILFORD. OK.

[At which time a movie was shown.]

Mr. SENS. The next chart (fig. 4, prepared statement, p. 246), shows a cross section of the variable stream control engine which you heard described. Indicated on it are the components that are unique to the variable cycle engine and to supersonic cruise operation that will require additional technology development. The fan has variable stators in order to achieve the necessary airflow control, low emission burners are required in the primary burner and the duct heater; the turbine and burner sections have to be developed to operate at turbine temperatures that are several hundred degrees in excess of current engines if we are to get the best possible efficiency out of the engine at supersonic climb and cruise conditions; and the coannular nozzle which in addition to providing good performance and noise reduction

by use of the inverted velocity profile, also is required to provide for reverse thrust on landing. These are the components that are of particular concern and need further technology development in connection with the variable stream controlled engine.

The next chart (fig. 7, prepared statement, p. 247), is a summary of the improvements that the variable stream controlled engine could provide relative to a scaled-first generation turbojet engine. For the purposes of comparison the turbojet has been scaled to the same airflow size and thrust under takeoff conditions.

In this comparison the improvement shown is somewhat less than shown by my predecessors in that we show a slight increase in fuel consumption relative to the straight, unaugmented turbojet cycle at supersonic cruise, and also somewhat less improvement in fuel consumption at subsonic conditions. The exact numbers will vary a little depending on the comparison that is made and perhaps we are just a little more conservative.

What these improvements mean in terms of the overall airplane is shown in this chart (fig. 8, prepared statement) which plots range versus sideline noise for an advanced supersonic transport. Here we have held the airplane gross weight constant at 762,000 pounds for the comparison. The comparison is between the first generation turbojet engine scaled to the proper size and the variable stream controlled engine. The variable stream control engine provides about an 8 EPNdb reduction in noise level and at the same time a 25-percent range increase relative to the first generation turbojet. This is quite substantial.

The corresponding improvement in direct operating costs for these aircraft relative to the Concorde is shown on the next chart (fig. 9, prepared statement, p. 248), I will not guarantee the exact value of the numbers, but I think they are approximately correct. They show about a 40-percent reduction in operating costs for the advanced airplane using a scaled first generation engine, and an additional 20 percent reduction by utilizing the variable-cycle variable-stream control engine. This provides an overall reduction of over 50 percent in direct operating costs relative to the Concorde.

This may get the airplane economics into the range where competing with the subsonic aircraft for first class and business economy travel is a real possibility.

Now, I would like to discuss the model testing that we have conducted on the coannular nozzle under NASA sponsorship. The curve shows the noise benefit that was demonstrated for the coannular nozzle in our static testing of small-scale models. The model results were projected to full engine size noise levels in plotting this curve. The small-scale model static test results substantiate the 8 EPNdB noise reduction shown in the aircraft system comparison studies.

It has been mentioned earlier that the static results do not always hold up in flight. In order to get an early check on flight effects NASA funded small-scale model tests in a wind tunnel to find out what the performance and the noise levels of the coannular jet were at simulated flight conditions, at takeoff and climb-out air speeds. This is a picture of one of the coannular nozzles installed in the wind tunnel.

The next chart (fig. 11, prepared statement, p. 250), shows that these wind tunnel tests verified the same jet noise reduction at the

climb-out speeds of the airplane as were achieved statistically. This is extremely encouraging. There is much more small-scale testing required to obtain the information necessary to optimize the nozzle design and noise attenuation. Also a very necessary step is to conduct tests of large-scale nozzles both statically and in flight.

So, we have made an encouraging start. The preferred cycle has been identified and we have scratched the surface of technology substantiation. However, a great deal of work remains to be done in order to substantiate the technology to the degree necessary to launch a full-scale engine and airplane development program.

The technology requirements for the advanced variable-cycle engines are shown in the next chart (fig. 12, prepared statement, p. 251). First the testing of the coannular nozzle needs to be extended into larger scale under static and inflight conditions. In the area of low emissions, we need to develop high efficiency primary and duct burner systems compatible with the low volume and weight required for a supersonic engine and ones that will meet the emission requirements.

The emission requirements are an area of real concern on our part because the high altitude emission levels that have been discussed as potential requirements under CIAP are on the order of six times lower than the best combustion technology that has been demonstrated as a part of NASA's clean combustor program. Ed Cortright mentioned earlier that there have been laboratory tests that indicate that an order of magnitude reduction in  $\text{NO}_x$  emissions is possible. However, these are just laboratory tests, they do not represent burners that have the necessary small volume to fit into the engine. They are just concepts at this point, and it will be a long time before we can determine whether it is possible to translate this kind of technology into an engine type burner.

At the same time there is a lot of disagreement as to whether or not  $\text{NO}_x$  emissions are really a problem in the stratosphere; and if it is a problem, what levels of  $\text{NO}_x$  are really required to be tolerable. This question has to be resolved before we can know whether the technology for a level of acceptable emissions is in hand or not. In the meantime, a lot of effort should be put into developing low emissions technology.

The variable stream control engine requires a number of variable geometry components. These same variable geometry components would be required for the aft valve engine which is the second most attractive cycle. Development of these components would be necessary as a part of the technology program. As I mentioned earlier the turbine temperatures at climb and cruise are several hundred degrees higher than we are operating at today in commercial service. Fortunately there are other NASA and DOD programs that are aimed at developing technology for higher temperature burners and the turbines. These programs cover both improved materials and improved cooling. However they are not directed at developing the needed life for commercial operation. A technology program is needed to translate the new higher temperature technology into components with commercial life potential directed at the SST.

Integrated propulsion system refers to integration of the propulsion system into the airplane structurally, the matching of the inlet and the exhaust nozzle flow and performance and the drag of the nacelle-airplane combination. This is an area that requires detailed design

and test coordination between the engine and the airframe manufacturers. It has to start in the early part of the technology program, otherwise we may wind up picking an engine that is not best suited for the airplane.

The need for an electronic control system to regulate the large number of variables in the variable cycle engine has already been mentioned. There are NASA and DOD programs supporting the development of electronic control technology. This technology would need to be applied to specific requirements of the SST program.

The timing of the needed propulsion technology program is shown in the next chart (figure 13, prepared statement). The program is phased so that the initial work is conducted in small-scale-component rigs, and on the components that are most pivotal in determining the feasibility and its performance. We are now in this initial phase. The coannular nozzle module tests that I mentioned earlier have been conducted. Recently a duct burner study program has been instituted to screen out the possible low emission duct burner configurations. We have recommended to NASA an early initiation of a main burner program aimed at reducing emissions within the scope of the volume and temperature levels required by the SST engine.

The next step would be to run large scale component rig tests on the duct burner and coannular nozzle. This can be accomplished at relatively low cost by using a modified F-100 engine to provide the primary and secondary gas streams to test the duct burner and coannular nozzle combination. This arrangement would give the right conditions of temperature pressure and velocity in the streams entering the burner and nozzle components. This is a relatively low cost program that would give an early answer relative to the emissions performance and noise of the large scale duct burner and coannular nozzles. Our intent would be to test initially at static conditions, and then as a test bed engine on an airplane, or test in the Ames 40-by-80-foot wind tunnel to check the noise and performance characteristics under flight conditions.

The next step would be to start a demonstrator engine program is required to conclusively demonstrate the performance and operational characteristics of the variable-cycle engine. This would require testing the key engine components in component rigs in order to substantiate their performance and to minimize the risk and cost of the overall demonstrator engine test program. The engine airframe integration effort must be continuous throughout the program to make sure that the component and engine work was properly directed.

The next chart (fig. 14, prepared statement, p. 254), shows our concept of a variable stream control engine demonstration. It would use the high-spool from the F-100 engine and to that would add the variable starter fan and its drive turbine, and the duct heater and coannular nozzle to make a complete demonstrator engine. It would also incorporate the electronic control.

The recommended program has as its objective the substantiation of the engine concept and its technology to the degree necessary to be able to launch a full scale development program. Its general timing would be readiness for development go-ahead in the 1982 to 1985 time period. The timing would be determined by the level of funding and by the competitive pressure to get a program launched. At the current rate of funding in the supersonic technology program we would never

reach the readiness point for development go-ahead. To reach that point would require approximately \$300 million per propulsion contractor.

In summary, our efforts to date under NASA sponsorship have identified a cycle, the variable stream control engine, as having superior noise and performance characteristics. The noise benefits and performance of the coannular nozzle have been demonstrated by small scale testing both statistically and under simulated flight conditions. The results of the program to date indicate the possibility of meeting the overall goals of developing the technology that would provide an economic and ecologically accepted airplane. The effort going into this technology development must be substantially accelerated if we are to get to the point of technology readiness in the 1982 to 1985 time period.

I thank you for the opportunity to submit this testimony.  
[The prepared statement of Mr. Sens follows:]

**TECHNOLOGY REQUIREMENTS  
FOR AN  
ADVANCED SUPERSONIC TRANSPORT**

**Statement of  
United Technologies Corporation  
Pratt & Whitney Aircraft Group  
Commercial Products Division**

prepared for

***Committee on Science and Technology  
Subcommittee on Aviation and Transportation R&D***

***Honorable Dale Milford, Chairman***

TECHNOLOGY REQUIREMENTS  
FOR AN  
ADVANCED SUPERSONIC TRANSPORT

STATEMENT OF  
UNITED TECHNOLOGIES CORPORATION  
PRATT & WHITNEY AIRCRAFT GROUP  
COMMERCIAL PRODUCTS DIVISION

September 15, 1976



by

William H. Sens  
Manager, Preliminary Engine Design

Prepared for  
COMMITTEE ON SCIENCE AND TECHNOLOGY  
SUBCOMMITTEE ON AVIATION AND TRANSPORTATION R&D  
HONORABLE DALE MILFORD, CHAIRMAN

**PRATT & WHITNEY AIRCRAFT**



Division of  
**UNITED  
TECHNOLOGIES™**

EAST HARTFORD, CONNECTICUT

I appreciate the opportunity to present Pratt & Whitney Aircraft's views on the technology needed to ensure an environmentally and economically acceptable advanced supersonic transport.

First, I would like to say that Pratt & Whitney Aircraft shares the Subcommittee's concern about the adequacy of our technology development for an advanced supersonic transport. The U. S. aircraft industry has dominated the Free World commercial transport aircraft market. This market has had a very favorable effect on the U. S. balance of payments over the last two decades. We are concerned that our future dominance of this market could be threatened if we do not prepare ourselves to enter the market with a viable advanced SST at the appropriate time. It is likely that the first-generation SST's developed by the French and British and by the Russians will not be environmentally acceptable nor profitable. However, these programs are developing the expertise and the experienced teams that could provide the base for the development of a viable second-generation aircraft. The U. S. must be prepared to meet such a challenge.

Second, Pratt & Whitney Aircraft supports NASA's aeronautical R&D activities aimed at generating the technology for advanced supersonic cruise aircraft. However, these programs are not currently adequately funded to provide the technology in a timely fashion. I will discuss the technology programs and funding which in our view are needed to provide the basis for timely development of a viable advanced SST propulsion system.

One further facet of the NASA Advanced Supersonic Technology program that should not be overlooked is the potential military spin-off. Much of the propulsion technology developed as a part of this program would apply to advanced military systems. Also, a viable SST could well find a useful military role.

Before proceeding with our answers to your specific question, Mr. Chairman, it might be useful to briefly review the progress that has been made since our previous statement to the Subcommittee on Aeronautics and Space Technology in February 1974 on the subject of the NASA Advanced Supersonic Technology (AST) Program.

At that time, the AST program had just entered its initial study phase. The program was directed toward three basic objectives:

1. To conduct study programs to evaluate powerplant types, advanced technology capabilities, and ecological and economic factors,
2. To recommend engine types warranting further study, technology programs, and airframe/installation programs, and
3. To obtain a data base for guiding future design decisions.

The initial study indicated that substantial reductions in aircraft noise and operating cost could be achieved relative to the first-generation SST aircraft by application of advanced propulsion concepts. Two engine types offering the greatest potential for the supersonic

transport at that time were an advanced duct burning turbofan engine and the variable-cycle engine. There were several approaches to the variable-cycle engine that were sufficiently attractive to be evaluated further. The variable-cycle engine offered the potential for providing turbofan performance and low noise at subsonic speed combined with the low fuel consumption of the turbojet at supersonic speed.

The technology needed to establish the feasibility of each of the engines was identified (shown in Figures 1 and 2). Included were:

- Development of technology for a duct burner to heat the air leaving the fan,
- Development of technology for a high performance jet nozzle that would also provide noise suppression and thrust reversal,
- Development of a low-emission primary burner as well as components that might be peculiar to the final variable-cycle engine configuration (such as diverter valves).

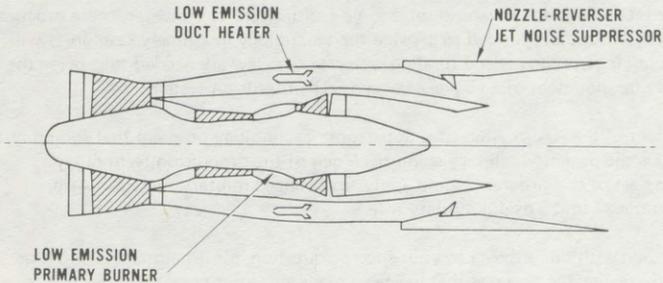


Figure 1 Required Component Technology for Duct-Heating Turbofan

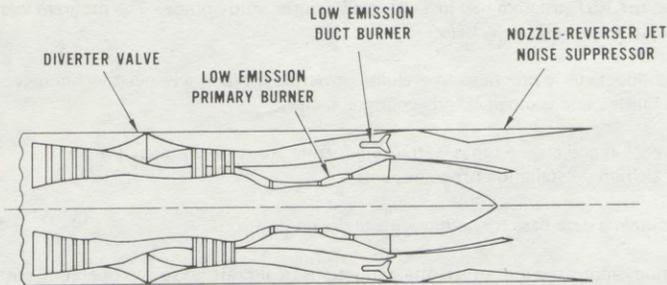


Figure 2 Required Component Technology for Variable-Cycle Engine

A funding level of approximately \$5 million per propulsion system contractor was recommended by Pratt & Whitney Aircraft for this effort.

The funding level provided was significantly lower than that recommended; however, I am pleased to say that we have made significant progress under the current NASA program.

First, over 100 different engine cycle configurations were studied and evaluated. I will not attempt to describe these concepts here, but the scope of the study is indicated by the general types of configurations illustrated in Figure 3. Several variable cycle engine configurations were found to give a very significant improvement relative to the first generation SST engines. The most attractive configuration identified was the Variable Stream Control Engine (VSCE).

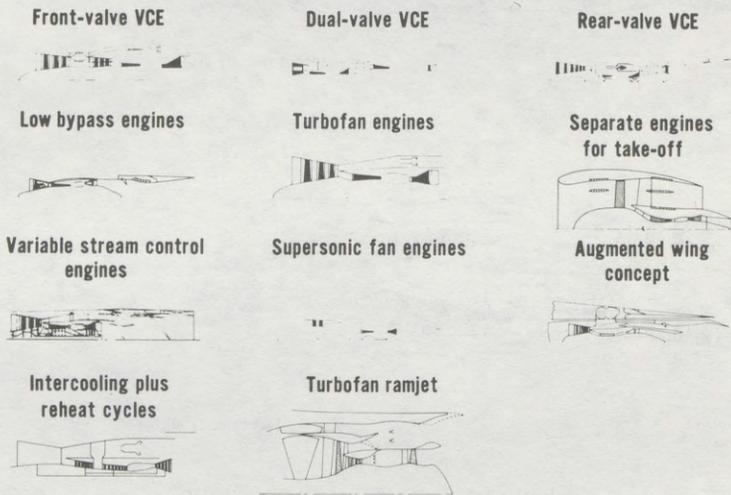


Figure 3 General Types of Engines Evaluated for Advanced Supersonic Transport Applications

The Variable Stream Control Engine is illustrated in Figures 4, 5, and 6, which show the flow through the engine at take-off, subsonic cruise, and supersonic cruise, respectively. The engine exhausts with concentric jet streams and employs variable geometry components. The engine cycle is selected to provide a fan stream jet velocity that is significantly higher than the primary engine stream velocity during take-off. This feature, as I will show later, is very important in providing effective and efficient noise suppression. Also, this concept, through appropriate control of the fan and primary stream components, achieves the performance of a moderate bypass ratio turbofan engine at subsonic speeds, and closely approaches the best achievable supersonic cruise fuel consumption of an augmented turbojet engine.

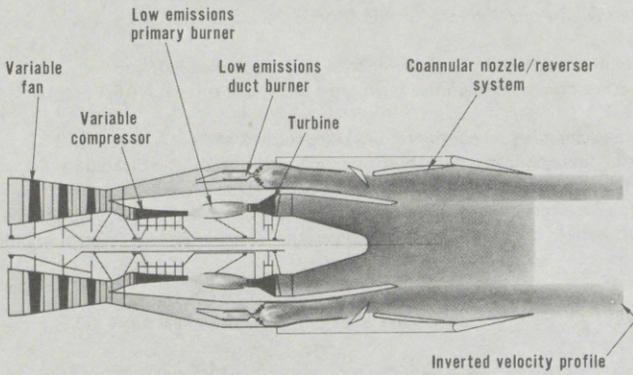


Figure 4 Variable Stream Control Engine at Take-off Conditions

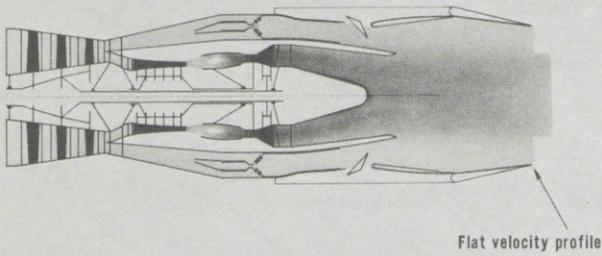


Figure 5 Variable Stream Control Engine at Subsonic Cruise Conditions

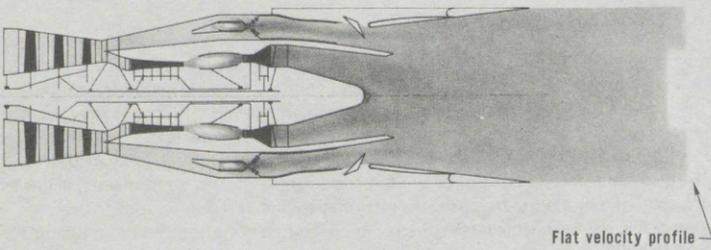


Figure 6 Variable Stream Control Engine at Supersonic Cruise Conditions

The improvements provided by the VSCE study engine relative to the first-generation SST engine is shown in Figure 7. The 8 dB take-off noise reduction results from the coannular nozzle jet noise suppression. The 25 percent weight improvement results from the two-stream engine configuration where as much airflow bypasses the engine core as passes through it, thereby reducing the size and weight of the engine core; and from the use of advanced technology components. The 20 percent lower fuel consumption at subsonic cruise is due to the VSCE engine operating as a conventional turbofan at these conditions. At supersonic cruise conditions, the VSCE fuel consumption is approximately three percent higher than that of the turbojet because of cycle differences.

<b>Take-off noise</b>	<b>8 EPNdB reduction</b>
<b>Specific fuel consumption at</b>	
<b>Subsonic cruise</b>	<b>20 percent reduction</b>
<b>Supersonic cruise</b>	<b>3 percent increase</b>
<b>Engine weight</b>	<b>25 percent reduction</b>

**Note: Comparisons made by scaling first-generation turbojet engine to flow size of variable stream control engine**

*Figure 7 Improvement Provided by Variable Stream Control Engine Relative to First-Generation Supersonic Turbojet Engine*

The improvement in subsonic fuel consumption provided by the VSCE is particularly important with respect to meeting the environmental factors, since the VSCE-powered SST will be capable of cruising subsonically without a loss in range capability over land where supersonic cruising is prohibited by noise constraints.

The overall effect of the VSCE characteristics on supersonic transport airplane performance is very significant, as shown in Figure 8. The VSCE offers both a 25 percent improvement in airplane range, and an 8 dB reduction in noise during take-off. Consequently, practical airplane range with acceptable noise levels appears possible with this technology.

The estimated economic benefits of the VSCE are illustrated in Figure 9. The VSCE offers a 20 percent reduction in direct operating cost relative to a comparable airplane using scaled first generation SST engines.

Advanced Supersonic Transport takeoff gross weight=762,000 lb

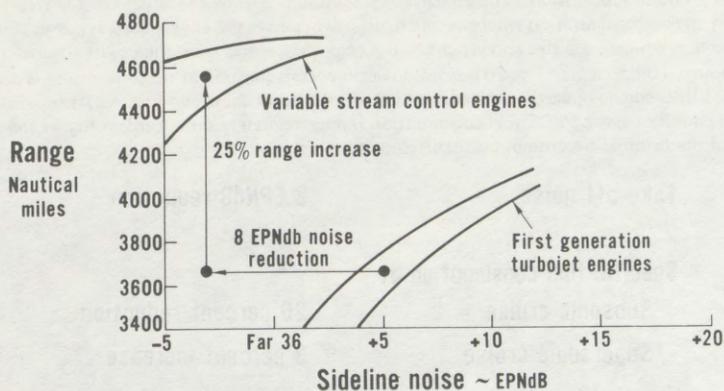


Figure 8 Potential Impact of Advanced Supersonic Technology on Aircraft Range and Noise

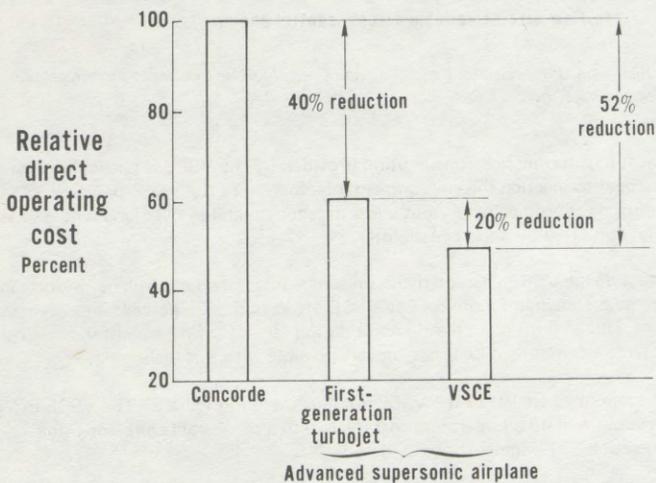


Figure 9 Potential Impact of Advanced Supersonic Technology on Economics

The estimated reduction in direct operation cost per seat mile of the advanced SST relative to the Concorde is over 50 percent. This large improvement is due to the increase in airplane size in addition to the improvement in aircraft and powerplant technology. This improvement may be sufficient to permit the SST to compete effectively with the wide body subsonic aircraft for the first class and full economy fare long-range passenger business.

So the results of the powerplant studies have been encouraging, with the VSCE concept showing considerable potential benefit relative to equally advanced technology versions of the turbojet cycle engine. We therefore strongly recommend that technology development efforts be directed exclusively at the variable stream control engine at this time.

The investigation of the critical component technology has progressed more slowly than originally planned due to funding limitations. Nevertheless, significant progress has been achieved. One of the critical questions several years ago was our ability to attain effective and efficient jet noise suppression using the coannular nozzle concept. In pursuit of this goal, Pratt & Whitney Aircraft has been conducting noise and performance tests on small-scale models of the VSCE coannular nozzle under NASA sponsorship. A typical model is shown in Figure 10. Results from static tests of the model nozzles showed that an inherent reduction in jet noise occurred when the outer fan stream was operated at the high jet velocities of the VSCE cycle. This noise reduction was achieved without the use of additional parts and the thrust losses usually associated with jet noise suppressors. With encouragement from these early tests, NASA sponsored testing of the nozzle models in a wind tunnel to verify the noise reductions under simulated flight conditions. The resulting data substantiated the data obtained statically, as shown in Figure 11. These results substantiated in small scale that the coannular nozzle would provide noise reductions of approximately 8 dB relative to a single-stream turbojet operating at the same airflow and thrust level. This is a real technical break through.

NASA has also funded a low-emission duct burner program. You will recall that the duct burner provides the capability for varying the temperature of the outer stream, and is one of the critical components in terms of demonstrating performance and emissions feasibility. This program is barely underway, and it will be another year before research burner rig testing will be conducted.

In summary, the work completed to date has achieved two major accomplishments:

1. We have identified a powerplant configuration, the VSCE, that has the potential of a very significant improvement in performance, weight, and noise relative to the first-generation SST powerplants,
2. We have substantiated the coannular nozzle noise benefits and performance levels by small-scale model tests simulating both static and flight conditions.

However, the task of developing the needed propulsion technology to the point where a development program could be launched with acceptable risk is truly formidable; and it will be costly. With this background, we now can ask what further propulsion technology work needs to be conducted in order to provide a firm base for the development of an environmentally and economically acceptable advanced SST.

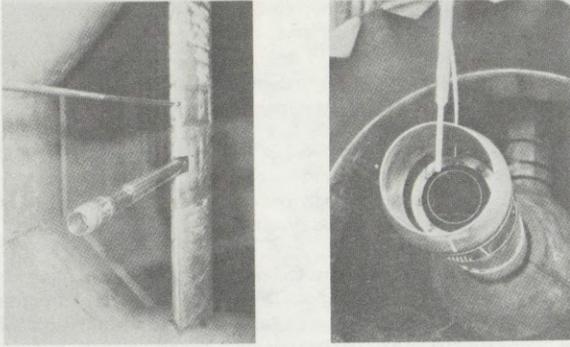


Figure 10 Typical Four-Inch Diameter Subscales Coannular Nozzle Model Installed in Wind Tunnel

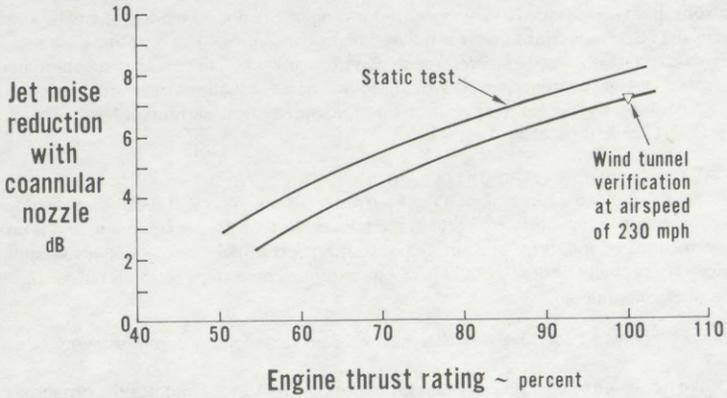


Figure 11 Coannular Nozzle Noise Reduction Relative to Single-Flow Nozzle Based on Scale Model Tests

The list of needed propulsion technologies is shown in Figure 12, and the programs required to develop these technologies are shown in broad terms in Figure 13. They consist of:

1. Feasibility demonstration of those components most critical to the success of the Variable Stream Control Engine using small scale rig tests. These components include the low-emissions duct burner, the main burner, and the coannular nozzle.
2. Development of the critical technology for the duct burner and the coannular nozzle in large scale tests in an engine environment.
3. Substantiation testing of demonstrator engine components.
4. Substantiation of the variable cycle engine concept by demonstrator engine testing.

- **Low noise – high performance coannular nozzle**
- **Low emissions – high efficiency burner systems**
- **Variable geometry components**
  - **Nozzle/ejector/reverser**
  - **Inlet**
  - **Fan**
  - **Compressor**
- **High temperature burners and turbines  
with commercial life**
- **Integrated propulsion system**
- **Electronic control system**

*Figure 12 Technology Requirements for Advanced Variable Cycle Engines*

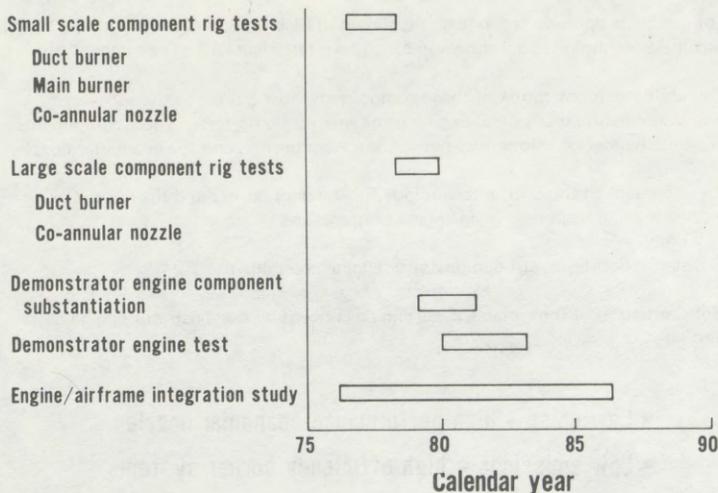


Figure 13 SCAR-VCE Technology Program

These programs would be conducted sequentially, with the small scale rig tests preceding the full scale rig and engine tests. This is a low risk approach where the preliminary testing and screening is accomplished in relatively inexpensive component rigs. The engine/aircraft integration study must be conducted by both the propulsion and airframe manufacturers concurrent with the engine technology development. This is necessary to ensure that all of the engine/airframe interfaces are appropriately understood and resolved, and that the propulsion system design is tailored to give the best overall aircraft system performance and economics.

We are currently in the small scale rig phase of the above program. A program to conduct additional coannular nozzle model performance and noise tests has recently been initiated by NASA. This program will provide additional data to help optimize and evaluate coannular nozzle configurations. A duct burner program is in progress to screen advanced combustor concepts and to recommend concepts for test evaluation in follow-on NASA programs. In addition, we have recommended to NASA a main burner program that would be directed toward reducing emissions beyond our current capabilities.

The next step will be to conduct large scale tests to demonstrate the noise and thrust characteristics of the nozzle, and to determine the emissions, performance, and noise characteristics of the duct burner. These components are pivotal for the success of the variable cycle

engine. It is visualized that this large-scale component testing would use a modified F100 engine to supply gas streams at the appropriate temperatures and pressures to the duct burner and coannular nozzle system. Testing would be conducted at an outdoor facility capable of measuring both noise and emissions under static conditions. This large scale component rig could then be tested in the NASA-Ames large low speed wind tunnel to evaluate the noise and performance characteristics of the coannular nozzle under flight conditions.

Rig test substantiation of the demonstrator engine components is required prior to testing the demonstrator engine in order to minimize program cost and risk. This is particularly important in the high temperature burner and turbine components. All of the supersonic cruise engines require a turbine inlet temperature several hundred degrees hotter than today's most advanced subsonic transport engines. The higher temperatures are necessary to attain best performance at supersonic climb and cruise conditions. Fortunately, the development of improved materials and cooling for the engine hot section is already being funded under other NASA and DOD programs. However, the development of the AST engine to achieve commercially acceptable durability and performance at these temperatures will be extremely difficult. The hot section design and component testing will require special emphasis in the demonstrator engine.

Demonstrator engine testing is required to determine how the various components perform in an engine environment, and to reduce the risk in the subsequent engine development program to an acceptable level. The demonstrator engine program is currently visualized as a two-step program. The first step would test the low pressure components unique to the variable cycle engine (inlet, variable stator fan, low pressure turbine, duct burner, coannular nozzle, and electronic control system) using an F100 engine high pressure rotor, as illustrated in Figure 14. A second demonstrator would substantiate advanced high pressure components (high pressure compressor, high temperature main burner, and high pressure turbine). At least several hundred hours of performance, mechanical, and acoustic testing should be conducted under both sea level and simulated altitude operation in order to provide reasonable substantiation for a development go ahead.

Extensive study of the propulsion system integration into the aircraft is required. This is a cooperative effort between the airframe and powerplant manufacturers; and includes structural integration as well as matching of the inlet and engine airflow characteristics, and the aerodynamics interrelationship of the powerplant nacelle and the airplane. This is an extremely complex interrelationship particularly for a supersonic cruise aircraft. Many years of cooperative effort involving detailed design and performance studies, inlet and nozzle models tests, and wind-tunnel testing of the overall airplane/propulsion system are required in order to arrive at a viable overall system.

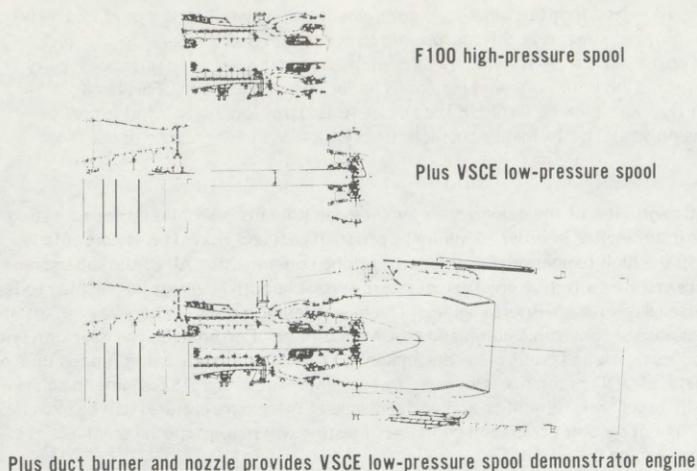


Figure 14 Variable Cycle Engine Low-Pressure Spool Demonstrator Approach

One added technical concern relates to the emission levels that can be tolerated in the stratosphere. Frankly, we do not see how any of the SST engine cycles could meet the currently proposed altitude emission levels for supersonic transports for service introduction in the 1980's. Also, there seems to be disagreement, at present, as to whether or not the discharge of nitrogen oxides into the stratosphere is a real problem, and, if it is a problem, just what reduction in nitrogen oxides would be required to make their effects tolerable. This question must be resolved before the ecological acceptability of an advanced SST can be judged.

The programs that I have briefly described would bring us to the point where we would be prepared technically to proceed with a full scale SST powerplant development program. It would take until 1982 to 1985 to carry out the recommended predevelopment program, depending on the level of funding provided and assuming a go ahead within the next year. It is estimated that approximately \$300 million in 1978 dollars per propulsion contractor would be required to carry out this effort in a satisfactory manner.

In summary, we have identified the Variable Stream Control Engine configuration with its coannular nozzle as having superior performance and noise characteristics. The noise suppression and performance characteristics of the coannular nozzle have been substantiated in small scale rig testing. This powerplant, along with projected advanced aircraft technology, has good promise of meeting the goals of economic and ecological viability for an advanced SST. However, the task of developing the needed technology, and substantiating it to the degree necessary to permit initiation of development with a high degree of confidence, will be formidable and costly. We are looking forward toward working with the Government to meet this challenge.

Mr. LLOYD. Thank you very much for joining us today, Mr. Sens. As you pointed out, I think some of your predecessors did steal some of your thunder although your film, basic as it was, was very very enlightening, at least as far as I am concerned in understanding what it is you are trying to accomplish with the engines. Obviously nobody can guarantee where we are going to go, but you used a figure of \$300 million per developer which brings me back to a very basic question for the future of engine development. Incidentally, if you wish you can interrupt me. I am just trying to get a response out of you.

One of the things I am very much concerned about is the fact that all of a sudden we are not allowing, because of the antitrust situation, Pratt & Whitney and GE for instance to collaborate, yet it is possible for GE to go overseas and collaborate on an engine.

Do you feel this policy needs to be reviewed if we are achieve a breakthrough?

Mr. SENS. Are you addressing this question to the technology development part of the program?

Mr. LLOYD. Do you feel that the policy of the United States, that of allowing no manufacturer whether airframe or engine to work with another manufacturer is conducive to the achievement of solutions to the engine problems we will be facing?

Mr. SENS. I think I have to concur with the comments that I think Dick Fitzsimmons made—that competition is beneficial. I do not think at this stage of the game that combining the efforts of the contractors would be in the best interest of the user contractors or the country. Now what happens when you get to the point where you are ready to launch at full-scale development is something else again. I think that would have to be reviewed in light of the environment at that particular time.

Mr. LLOYD. Now, you used the term \$300 million. Do you feel that we would get some meaningful engine development at that point?

Mr. SENS. That really is what we would call predevelopment. It would involve engine testing. We would test the demonstrator engine. It would have to be tested over a wide range of conditions to simulate the environment that is going to be exposed to in the airplane, but it would not be what we would call a development engine per se. A development engine would be one that we would proceed on once the decision has been made to go ahead with the development of an airplane engine combination for a production airplane.

Mr. LLOYD. I am trying to get the horse and the cart somehow alined in some meaningful fashion. Do you think that engine development should precede airframe development, or do we need a simultaneous decision that we go with the airframe, or do we in our great manners tell somebody to build an airframe and then in the meantime we scurry around to find an engine that might or might not work?

Mr. SENS. This is a traditional problem because as a generality it takes longer to develop an engine than to develop an airplane. So it is always difficult to get an engine started in time.

Mr. LLOYD. Commitment to an SST then would begin with the engine, but if we went with the engine, let us say we put \$600 million into this and we never did go to the airframe. I cannot conceive of us not doing that, but let us say it happens that way. Do you think that there would be a trade-off that would be beneficial to engine develop-

ment in other areas, military application, for example, to warrant that kind of financial investment on the part of the United States?

Mr. SENS. Much of the technology that would be developed as a part of the \$300 million program would have application to future DOD engines and requirements. High temperature technology is common. The use of augmenters such as the duct heater is something that is being currently studied in connection with future military requirements. So yes, I think that it would have a fallout.

Mr. LLOYD. Do you feel in the metallurgical areas that we will not see any major breakthroughs in the development of engines so that we can sustain the higher temperatures? You talked about a 200° rise in the hot section of the engine which right now is unacceptable. What breakthrough would we have to have? Would we have to go to ceramics?

Mr. SENS. Well, it is really a combination of things. It takes first of all development of better basic materials for the turbine blades and vanes and burner liners. Developments of this nature are in progress under company and Government funding.

Second, it takes the development of more efficient cooling schemes so that we can cool the metal down to close to the same temperature as we are running today even though the gas temperature has gone up several hundred degrees. This must be done without paying an excessive penalty due to the cooling air requirements. These kind of developments are also in progress under Government-funded and company programs.

Third, I do not foresee the use of ceramics as the basic structural material, but as a thermal barrier coating. Its function as a thermal barrier casting is to reduce the metal temperature as a result of the insulating quality of the ceramic material. This also is being pursued in programs funded by NASA and DOD.

Mr. LLOYD. In other words, what you are really saying is that not only are the temperatures achievable, but they are achievable really within the state-of-the-art that we have now.

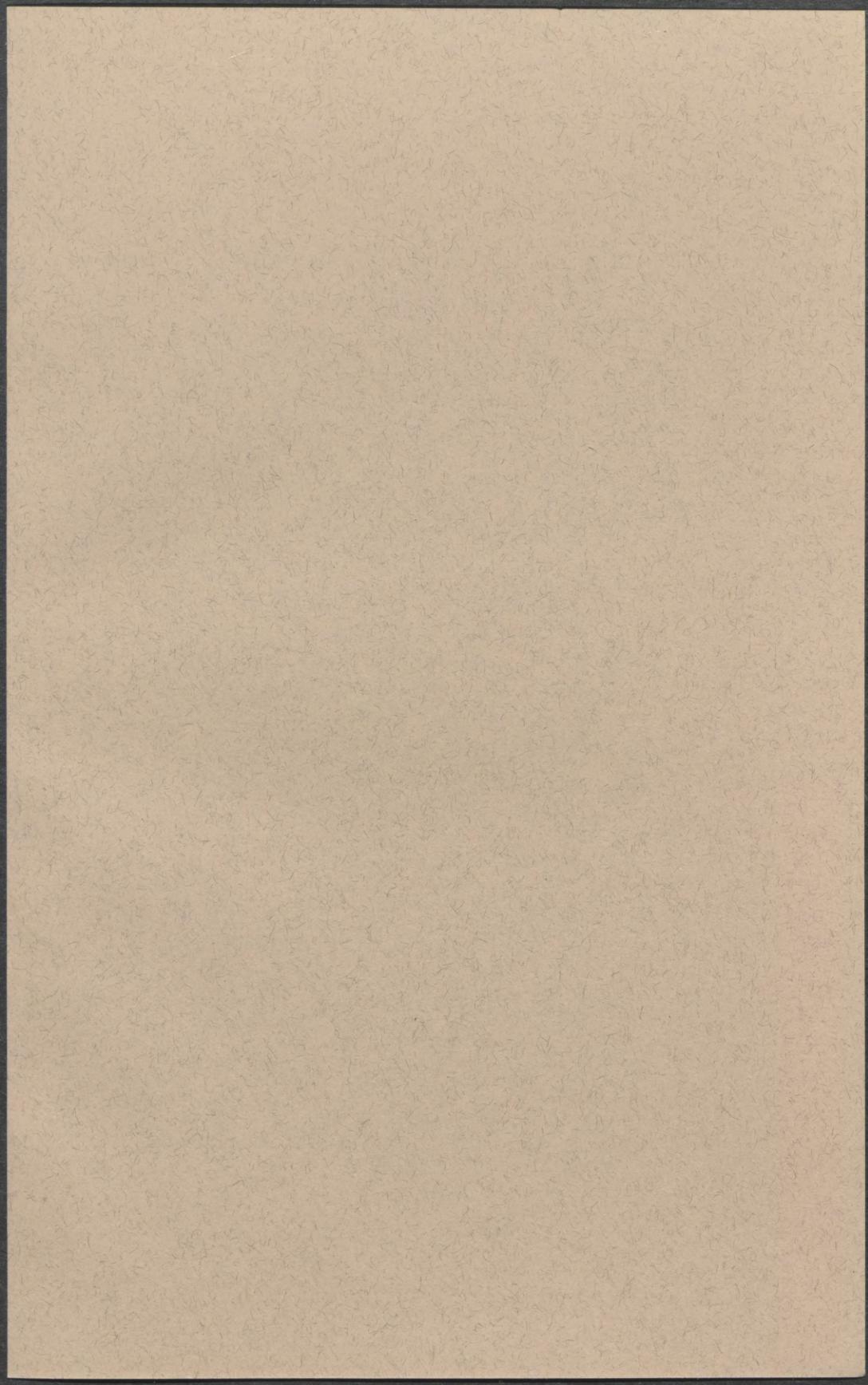
Mr. SENS. The state-of-the-art that is being developed, but not yet in hand. In other words these better materials are in the laboratory, but they are not in the engines yet. We are running tests of ceramic-coated parts, but it is in the technology development stage.

Mr. LLOYD. Anybody else have any questions?

Well, I thank all of you today. It has been very enlightening. I appreciate very much your attendance and contributions.

I will declare this meeting adjourned until 10 a.m., September 21 in this room when we will continue with the FAA R. & D hearings.

[Whereupon, the subcommittee was adjourned at 12:20 p.m.]





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