NUCLEAR PROPULSION

CHEMICAL PROPULSION

HEARINGS

BEFORE THE

SUBCOMMITTEE ON NASA OVERSIGHT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS U.S. HOUSE OF REPRESENTATIVES

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NOTE.—The chairman of the full committee and the ranking minority member, Hon. Joseph W. Martin, Jr., are ex officio members of all subcommittees.

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NUCLEAR PROPULSION

WEDNESDAY, MARCH 18, 1964

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on NASA Oversight,
Washington, D.C.

The committee met at 10:30 a.m., in room 214–B, Longworth House Office Building, Hon. Olin E. Teague (chairman of the subcommittee) presiding.

Mr. Teague. The committee will come to order.

The committee has taken considerable interest in all forms of propulsion and we are going to begin today on nuclear propulsion. We have Aerojet General, the General Atomic Division of General Dynamics, United Aircraft, Astronuclear Laboratory, Westinghouse Corp., and NASA.

We have asked each of you to present an 8-minute opening statement. Then it is going to be necessary to have an executive session. So after each of you have given your opening statement, I would expect the committee to go into an executive session for that portion of other testimony and questions members of the committee might want to ask.

Any comments or questions?

Would you state your full name and address, and names of the gentlemen with you, for the reporter.

Mr. House. My name is William C. House, vice president of the REON Division, Aerojet General Corp. I am the program director for the NERVA program. I am located at the Azusa plant of the Aerojet General Corp.

I have with me Dr. C. C. Ross, vice president, engineering, for Aerojet General Corp.

STATEMENT OF WILLIAM C. HOUSE, VICE PRESIDENT OF THE REON DIVISION, AEROJET GENERAL CORP., ACCOMPANIED BY DR. C. C. ROSS, VICE PRESIDENT, ENGINEERING, AEROJET GENERAL CORP.

Mr. House. We appreciate the opportunity to speak to you gentlemen today.

A discussion of the state of the art in nuclear rocket propulsion as it is represented by the NERVA engine must embrace at least four broad fields of technology. These are: the reactor, nonnuclear components, test facilities, and vehicle technology. Each area by itself could be the subject of a major discussion. Today I will touch on all four points, but will emphasize the nonnuclear components and test facilities. Westinghouse Astronuclear, who is our partner for the reactor on the NERVA program, will cover this item in more detail.

The time available for this summary limits the degree of detailed material to be presented. Therefore, I would like to refer you for more detail to the testimony of Mr. Harold B. Finger, manager of SNPO—the joint AEC–NASA Space Nuclear Propulsion Office—before the Joint Committee on Atomic Energy on February 19 of this year and again before the Subcommittee on Advanced Research and Technology, Committee on Science and Astronautics, House of Representatives, on February 26, 1964.

As you may recall, in November of 1962 the Kiwi B–4A reactor was tested with resulting damage to the core. It was postulated at that time that flow through the core probably induced vibration of the fuel elements. Component tests and full-scale tests during 1963 supported this postulation and the evidence became conclusive when the failure was duplicated in a cold-flow test. Based on this experience and knowledge, both the Los Alamos Scientific Laboratory and Westinghouse redesigned their respective core support systems. Both redesigns appear to be satisfactory based on the results of the recent cold-flow tests in Nevada. The Kiwi tests were completed in February and the NERVA tests on March 11, just a week ago. We are most pleased with the results. We believe that we understand the problem and that our current design is satisfactory from the point of view of vibration.

We were also concerned during the last year with the potential lifetime and reproducibility of fuel elements. Again I am pleased to report significant progress. One of these developments occurred as recently as a few weeks ago and undoubtedly will greatly enhance fuel element lifetime and ease of production.

I believe it is important to note that reactor neutronics are well understood for the solid-core graphite-type reactor. This has been quite well demonstrated in recent reactor criticality tests at both Los Alamos and Westinghouse. In addition, reactor control principles are well in hand as demonstrated in the Kiwi B–4A tests in November 1962, where complete control was maintained even when severe reactor damage had been incurred.

All this is not to say that all our problems are solved. There are at least three hot reactor tests planned for 1964, and it would indeed be fortuitous if we did not encounter new problems in thermal stresses, recycling capability, or something unforeseen. I do believe, however, that progress to date on the graphite solid-core reactor is such as to guarantee its earlier availability for flight application than any other known reactor type.

The nonnuclear components for the nuclear rocket present new problems in that they must withstand the radiation environment and some components, in addition, must function properly at temperatures as low as −425° F., coupled with the radiation problem. One such problem that gave us great concern at the outset of the program was the turbopump bearings. It is not possible to lubricate these bearings with ordinary lubricating oils because these will not withstand the radiation environment.

Test results to date are better than we had hoped for. The bearings have run under speed and load for over 1½ hours with no failure and in a radiation field for 10 minutes under the same condition with no damage. More tests will be conducted this year to increase our confidence level.

The turbopump itself presents no particular new problems other than that great care must be exercised to prevent excessive radiation heating of the parts. There is one problem in connection with hydrogen flow into the pump which I will touch on later in connection with the vehicle system.

The pressure vessel for the reactor is also a relatively straightforward engineering development but care must be taken with respect to radiation heating in flanges and bolts. Substantial experience is available from the LASL Kiwi tests. The nozzle has presented more difficulty and the problem centers around the very high heat transfer rates from the hot reactor exhaust to the nozzle cooling system. This, coupled with radiation heating, causes special design problems and fabrication techniques which have been the principal source of difficulty. At this time, however, we have at least three candidate nozzles for use, which gives us fair assurance that one or more of these will be qualified by late spring.

The principles of the engine control system design are well understood and borrow greatly from other engine programs. We face again the difficulty though, that our usual temperature and pressure sensors deteriorate in the radiation environment. We have a substantial effort underway to investigate instrumentation in radiation fields, and are hopeful that suitable modifications can be made to improve their life in the NERVA environment.

Valves, actuators, and seals which are a part of the engine flow or control system are also subject to potential difficulties in radiation and in the extremely low temperature environment of liquid hydrogen. Our effort in these areas has been somewhat limited, relatively speaking, since we are more confident of our ability to provide solutions. Prudent use of available funding has dictated that we emphasize the more crucial problem areas. It is probable that these items would not pace an engine development program even though some difficulties can well be expected. Interim measures of special shielding and so forth are always available to allow overall systems testing to proceed while the problems are being solved on such components themselves.

Proof of the state of the art, of course, is in testing the product and herein lies the importance of test facilities. The high cost of a complete nuclear rocket demands first, that we obtain the utmost data from every test, and second, that each engine be capable of a large number of repeated operations with a further capability of remote adjustment in either the facility or engine.

The test facility problem presents potential difficulties from two points of view. First, there is the long leadtime for design, construction, and activation. For example, the first engine test stand (ETS-1) was initiated in late 1960 and will become operational in late 1966 or early 1967. There have been some lags not associated with technology but even assuming a very rapid learning curve and careful scheduling, it would appear that 3 years represents a reasonable schedule for a new test stand. There are no vehicle facilities under design or construction. The engine maintenance assembly and disassembly building will take about 4 years from its inception to operational capability.

The second problem in connection with facilities is also related to the engine design. This concerns the art of operating the equipment and engine from remote positions due to the radiation hazard. We, of course, have learned much from LASL's test operations on test cells A and C and their maintenance assembly and disassembly building. However, we will be working with additional new devices such as turbopumps, valves, and instruments which have been designed for the first time for remote handling and disassembly. Suffice to say that when we are operating this equipment at optimum efficiency, we will indeed have improved the state of the art in this area.

As I have mentioned at the outset, vehicle technology or state of the art is part of a final nuclear rocket propulsion system. I also touched on this point in the turbopump assembly discussion. The problem arises from the radiation effects on the hydrogen propellant in the vehicle tank. The hydrogen is heated by the radiation and sets up convection currents in the tank and these in turn affect the propellant outlet conditions at the bottom of the tank where the propellant flows to the engine. This heat in the propellant, and possible bubble formation, seriously affect pump suction characteristics. It is not possible to analyze this system completely or to stimulate it by any other means than true nuclear radiation. Development of the flight tank flow baffle system is required and testing must be conducted with the complete system before it may be concluded that the flight engine is indeed ready for use. I mention this to point out that in nuclear rocket flight propulsion development, it is desirable to carry out the program with some degree of concurrency. Otherwise, if done on a sequential basis, a very long time will be required. Indeed, effort may well be expended on problems that are not real in the actual flight systems and other real problems will not be uncovered until a very late date.

In closing, I would like to summarize our statement in the following way:

Propulsion development has traditionally paced our major steps forward in flight. We are at the threshold of proving the feasibility of a new and far more efficient means of space propulsion. We believe the major problems areas have been identified and are near certain solution. This is particularly so in the nonnuclear areas, and in the nuclear areas our tests to date, as you have heard, are extremely encouraging. Because of this status of development we sincerely urge that you encourage NASA to work with undivided attention to complete the feasibility work and be prepared to assist in relaxing the constraints with regard to vehicle and facility programs so that our space effort may capitalize on this imminent breakthrough.

Thank you, gentlemen.

Mr. Teague. Any questions of Mr. House?

Mr. Bell. Mr. Chairman.

Mr. Teague. Mr. Bell.

Mr. Bell. Mr. House, do you feel that this reactor has pretty well worked out its bugs? In other words, as I believe you mentioned, and has been mentioned previously, you had some trouble with the graphite reactor.

Mr. HOUSE. That is correct.

Mr. BELL. That was caused primarily by many things, but I assume one of the results of it was that had a tendency to break up a little bit; isn't that correct?

Mr. HOUSE. Yes. There was vibration and we are pretty sure now that this was caused by the flow of hydrogen through the core in the cold conditions, which caused the fuel elements to shake or vibrate, and thus break up.

As I have said in my prepared statement, we in industry and LASL have had two cold flow tests since that date and these have shown that there is no vibration present in the redesigned core.

Mr. BELL. In other words, it is the vibration rather than the cold use of the propellant that has caused this to break up, in your opinion?

Mr. HOUSE. That is right. This was a mechanical problem rather than a nuclear problem, and we feel that we understand this type of thing.

Mr. BELL. What kind of proof do you have that you think this has been solved, the breakup of this reactor?

Mr. HOUSE. Well, the proof centers around the fact that neither the LASL reactor nor the Westinghouse reactor, which went through tests last month and this month, had any breakage in the fuel elements.

Mr. BELL. And they went through the same type of test?

Mr. HOUSE. Right.

Mr. BELL. I see.

How about the vehicle work, is that proceeding along as expected, or have you called a halt on that?

Mr. HOUSE. Well, I think you may be aware that in December or January, I am not sure of the exact date, that the RIFT [1] program at Lockheed was canceled so that we do not now have this parallel vehicle program going along with the engine development.

Mr. BELL. Why was that canceled, do you know?

Mr. HOUSE. I am not certain of that, sir.

Mr. BELL. Was it lack of funds, or something?

Mr. HOUSE. That is my understanding.

Mr. BELL. That is all, Mr. Chairman.

Mr. TEAGUE. Mr. Daddario.

Mr. DADDARIO. Mr. Chairman.

Mr. House, how do you use the word "sequential," on page 7, where you say, "If done on a sequential basis"? Do you mean in proper sequence? Are you talking about the sustained level of financing which keeps the thing going sort of up and down?

Mr. HOUSE. No, I am talking about the sequence of developments here. In other words, if we look at a bar chart in time, and we say we are developing the engine here and we come to the end of the engine development, I am saying that we want the vehicle program to start somewhere before the engine has been completely developed. Then the interface problems between the two systems can be worked out. Otherwise, if you wait until the engine is completed, and then start the combined testing of engine and vehicle you will discover new integration and interface compatibility problems. Perhaps you will also

[1] RIFT—reactor in flight test—the vehicle stage for the flight test of the NERVA engine.

find that you have solved some problems that you really didn't need to solve in the engine development tests alone.

Mr. DADDARIO. You then need sustained financing to do that, so that you won't have your program thrown out of whack?

Mr. HOUSE. That is correct.

Mr. DADDARIO. What is there in the program at the moment which would indicate that it is not being done on the basis that you believe to be necessary?

Mr. HOUSE. Well, as I indicated, the budget restraints essentially put the RIFT program out of being at this time.

Mr. DADDARIO. Then in the last paragraph where you talk about "be prepared to assist in relaxing the constraints with regard to vehicle and facility programs," what do you mean by that, are you going on a psychological aspect?

Mr. HOUSE. No, I am referring again to the RIFT situation. That program was canceled. As I indicated in my prepared summary, the long leadtime for the test facilities required to do these development jobs is going to be the item pacing the overall development unless action is taken to design and start construction of these very long leadtime facilities. And this is particularly true for the vehicle and engine development test area at NRDS.

Mr. DADDARIO. Then in that, so that it is clear, you are talking in support of a proper level of financing to do this, and you are not including in this last part involving constraints, though, psychological problems which involve the construction of the facilities necessary to do this work or disposal of the nuclear products, that type of thing?

Mr. HOUSE. No, sir.

Mr. DADDARIO. Thank you, Mr. Chairman.

Mr. TEAGUE. Mr. Fulton.

Mr. FULTON of Pennsylvania. We are glad to have you here.

You have spoken of the vehicle and facility program canceled, the RIFT program; how much longer will it take to get a successful operational vehicle if that cancellation remains?

Mr. HOUSE. Sir, I am afraid I cannot honestly answer that, because it is a question of when the program is reinitiated. I have no knowledge of when that will be. Consequently, it is at least a day-for-day-type thing.

Mr. FULTON of Pennsylvania. But if we do these things concurrently, which we could, we would save quite a bit of time because there is a long leadtime on both vehicle and facility programs; isn't there?

Mr. HOUSE. That is correct.

Mr. FULTON of Pennsylvania. How long a leadtime would you say that was?

Mr. HOUSE. Well, I estimate on the average that, on the basis of experience to date, a test facility will take about 3 years. So from the date you decide you are going to build a facility, it will be at least, 3 years before you can conduct a useful test in that facility.

Mr. FULTON of Pennsylvania. You have stated that there is an eminent breakthrough in this program, which is a very successful result; is that not right?

Mr. HOUSE. That is correct. We feel that by obtaining the specific impulse available to us with the nuclear rocket, there will be a definite breakthrough in space propulsion and in our ability to perform space missions.

Mr. FULTON of Pennsylvania. You would therefore recommend that this committee do not decrease the budget or recommend a decrease in budget authorization for the NERVA program at this time?

Mr. HOUSE. That is correct.

Mr. FULTON of Pennsylvania. What effect would it have if we did take a part of the money away after it has been cut, I believe, to $58 million for the current fiscal year?

Mr. HOUSE. Sir, it will just add that much more time. I can't, of course, account exactly for what those dollars will do in stretch out of the program, but it simply means a longer time before we will have an operational nuclear rocket and the development will cost more in the long run.

Mr. FULTON of Pennsylvania. With every evidence of success, because of the experiments that you people have, and the Westinghouse Astronuclear Laboratory have been performing, you do feel it is worth while that emphasis be placed on this NERVA program by the Subcommittee on Legislative Oversight?

Mr. HOUSE. Yes, I do.

Mr. FULTON of Pennsylvania. Thank you very much.

Mr. TEAGUE. Mr. Downing.

Mr. DOWNING. Tell me briefly, what are the tremendous advantages of this form of propulsion over the other types we have?

Mr. HOUSE. It relates to the specific impulse that one can obtain from the nuclear rocket, of course. In the lunar missions our preliminary studies indicate that 50 to 70 percent greater payloads can be achieved as an upper stage on the SATURN V launch vehicle. If you consider the interplanetary missions, depending on the specific year and time of year of flight, this improvement can be from two to five times the payload capability of the equivalent weight chemical system.

Mr. DOWNING. With nuclear propulsion would you have a continuous source of power that you could use at any time or would that power be exhausted, only taking a longer time than the present fuel system?

Mr. HOUSE. This is directly related to the specific impulse of the rocket and to its restart capability. The fact that we have approximately twice the performance of the best chemical system means in effect for the same thrust you can operate it twice as long. Also it is an inherent characteristic of the nuclear rocket that you can restart and refill the vehicle with propellant in space, if you elect to, and continue to operate the engine.

Mr. DOWNING. That is my point. Do you mean you could have continuous operation in space with nuclear rockets?

Mr. HOUSE. There is no limit at the moment, as we see it, on the duration. It is a question of tankage on the vehicle.

Mr. DOWNING. I don't believe I understand tankage.

Mr. HOUSE. Well, it is a question of how much propellant you can carry on the vehicle at any given time on any given mission. Without the ability to refill the vehicle tankage with propellant we are perhaps talking about the order of hours' duration.

Mr. DOWNING. I confuse it maybe with the *Enterprise*, which is nuclear propelled. Now, that can go for 3 years without any replacing of the cores, but that principle doesn't apply here, does it?

Mr. HOUSE. Well, so far as the core is concerned, it does apply.

Insofar as the propellant supply, no, because we cannot launch that amount of propellant with any current booster system. However, if we could assemble a large number of propellant tanks in orbit or one single very large tank we will have a much longer operational capability.

Mr. DOWNING. Would the same thing hold true with any other propellant?

Mr. BELL. Will the gentleman yield?

Mr. DOWNING. Yes.

Mr. BELL. I think perhaps maybe an explanation may be in order. As I understand this, is this not correct, you have your reactor core, and then you run your propellant through the reactor core which gives the amount of heat which makes the vehicle go. So you do have to have a certain amount of propellant to run through the core which gives your heat energy. Is that explanation a help to you?

Mr. DOWNING. In other words, you have got to carry some source——

Mr. BELL. Some source of propellant. But the point is, you have to carry a much lesser amount of propellant than you would with a chemical rocket. The reactor can carry you much farther into space with less propellant than a chemical rocket, but you do have to run some propellant through the core itself.

Mr. DOWNING. Thank you very much.

Mr. FULTON of Pennsylvania. Would the gentleman yield?

Mr. DOWNING. Yes, indeed.

Mr. FULTON of Pennsylvania. If we kept one of these nuclear reactor engines operating as an upper stage in space, possibly on a lunar-earth orbit, never bringing it down, we could do a rendezvous procedure, providing the propellant, because the reactor is good, as you have said on the *Enterprise* for 3 years. So that under those circumstances there might be a very long life to this particular vehicle which could be reused for other missions.

Mr. BELL. Will the gentleman yield? Would you yield on another point, Mr. Downing?

Also there is another aspect of this, that is of interest, I think. The fact that you are getting more toward the transportation area because actually, isn't it true, with a nuclear rocket as a second stage, you would not have to have so many stages?

Mr. HOUSE. That is correct.

Mr. BELL. In other words, you wouldn't have to have so much artillery that you would have to throw away. So it is actually an economy in that area, too.

Mr. DOWNING. My point is, if you could take conventional propellant and put enough of it up in space you could do the same thing, maybe not as well, but you could accomplish the same thing.

Mr. BELL. I didn't get the first part.

Mr. DOWNING. With the conventional propellant, chemical.

Mr. BELL. No, you couldn't accomplish the same thing, because you don't have the ability to go the distance with the size of the rocket itself. In other words, you don't need so much propellant to go to the Moon or to Mars. Whereas, with a chemical you need more propellant, you would have to have more tankage and more of them.

Mr. CASEY. Would the gentleman yield?

I think you are right if you could build your vehicle big enough to carry a sufficient amount of chemical propellants, but you would wind up with a vehicle much larger than the Empire State Building to accomplish the same thing, with what you might call a reasonable size vehicle, because you don't have to carry as much propellant.

Mr. FULTON of Pennsylvania. Will the gentleman yield further?

Mr. DOWNING. Yes, sir; that is the point.

Mr. FULTON of Pennsylvania. In order to get the upper stage saving, any pound on a second stage is approximately equal to 4 pounds that you don't have to use on a first-stage vehicle. Secondly, the ratio goes up 8 to 1 that you would save on the upper stage by nuclear or high energy chemical propellant. By reducing the weight of upper stages you would save 8 pounds for every 1 on the first stage.

Chairman MILLER. Would the gentleman yield to me?

Mr. DOWNING. Yes, Mr. Chairman.

Chairman MILLER. I was interested in your comparison with a nuclear-driven ship. I don't think they are comparable at all, because in the case of a nuclear-driven ship, all you are replacing with the nuclear energy is the source of heating to create steam to run a turbine. Now, many people think when they talk of nuclear power that there is something mysterious, that you can get some uranium, put it together, and then you can go here and there. It gives you a great source of heat, and you have got to then translate this heat into power. In the case of a ship or a generator, you use a conventional type of steam engine; with the nuclear energy replacing the fuel, the coal or the oil that went into it.

Now, in this case you are using the nuclear energy to heat the gas that will burn and give you a greater thrust, and so that I don't think that you can compare a ship with what we are doing here.

Am I right?

Mr. HOUSE. That is right.

Mr. DOWNING. I have a much clearer explanation of it now than I did before, Mr. Chairman.

Mr. TEAGUE. Mr. Casey.

Mr. CASEY. Mr. House, I want something cleared up for me.

On page 5 of your statement you refer to "test stand," which you say, "our first engine test stand was initiated in 1960," but is not completed yet; is that right?

Mr. HOUSE. That is right.

Mr. CASEY. What kind of test stand are you using now?

Mr. HOUSE. In answer to your first question, the engine test stand was designed specifically for the test of the NERVA engine. It is a large structure located at Jackass Flats in Nevada, at the Nuclear Rocket Development Station. It had to be constructed of aluminum as against standard steel-type construction because of the radiation effects, and, as I mentioned in the text, the problem of getting maximum amount of data requires a very special instrumentation setup for this test stand, as well as the ability to put the engine on the test stand and take it off remotely.

Mr. CASEY. You can't do that now?

Mr. HOUSE. No, sir.

Mr. CASEY. You don't have that kind of a test stand now?

Mr. HOUSE. Well, I think I should clarify a point here and I will answer your second question about the test stands we are using now. For the NERVA reactor development the two test stands that are in existence in Nevada, test cells A and C, are used. They have the reactor installed so that the exhaust plume goes upward. Now for the more elaborate engine test stand, we have the exhaust plume going downward. The reason for this is we want to simulate as closely as possible the vehicle configuration. Otherwise we may be creating new problems or trying to solve problems during engine development that we will not encounter with the vehicle in flight. For example, the feed line to the engine from the propellant tank must be relatively short and clear or we will have large losses there. To make up these losses we would have to put more pressure in the tank and thus the tank would get heavier than it need be. So, consequently, the engine test stand is designed to be as close to the flight arrangement as is possible to achieve on the ground.

Mr. CASEY. It that under construction now or just under design?

Mr. HOUSE. The framework is completed. The underground tunneling and the control room, the structure, itself, are all completed. In about a month the instrumentation will start to be installed into the stand, and this is perhaps a year's task.

Mr. CASEY. But you don't expect it to be in operation until late 1966?

Mr. HOUSE. That is correct. After the instrumentation is installed, there is a long period of checkout. These are very complex systems, and it takes a lot of time to check all installations. We will operate a cold-flow engine in the test stand to determine whether or not the instrumentation is working satisfactorily before we put a nuclear device in there.

Mr. GURNEY. Will the gentleman yield?

Mr. CASEY. Yes.

Mr. GURNEY. Is this test stand yours, Aerojet General's, or does it belong to the Government?

Mr. HOUSE. It belongs to the Government.

Mr. GURNEY. Can it later be used for other types of nuclear engine testing or only your engines?

Mr. HOUSE. It can be used for larger types than the one we now have. With certain modifications it will accommodate engines with other reactor types.

Mr. CASEY. Now, your next thing that I would be interested in is vehicle facility. I presume you mean a launch facility?

Mr. HOUSE. No; I am thinking of the vehicle static test stands necessary to check out now the complete vehicle and propulsion system with its guidance.

Mr. CASEY. With the engine attached?

Mr. HOUSE. Right.

Mr. CASEY. You have problems there similar to, even more so, than with your engine, I guess, because of the radiation and remote control of it, remote inspection and removal, and so forth; is that right?

Mr. HOUSE. That is correct.

Mr. CASEY. You say that is not under design at all?

Mr. HOUSE. That is correct.

Mr. CASEY. It has taken almost, it looks like it takes 6, almost 7 years—it will take 7 years evidently for the ETS–1 from its initiation to completion. How long do you think it will take on the vehicle test stand?

Mr. HOUSE. Well, of course, I think we have learned very much from this first major facility task, so I don't expect future test stands to take nearly as long. My guess is that it will be in the 3-to-4-year bracket to build the vehicle test facilities.

Mr. CASEY. Is there any indication that there is anyone fixing to move on a design for the vehicle test stand?

Mr. HOUSE. Not since the RIFT program was canceled earlier this year.

Mr. CASEY. Do you think they ought to be thinking a little bit about a design of the vehicle test stand now?

Mr. HOUSE. Yes. We are very much interested in it from the engine point of view as regards the tank system. We have an interface with this tank, as I mentioned, and we are concerned with the propellant-outlet conditions in the vehicle tank leading to the engine. Right now we are guessing, because the vehicle is not part of our responsibility; ours is only the engine. We need to know what these interfaces are likely to be so that we won't expend useless effort developing solutions that won't be used in the end.

Mr. CASEY. When you get to the stage you seem to be about to break through on the engine you ought to have the vehicle test stand ready so that you could work together on working out these problems, such as your fuel flow that you were talking about.

Mr. HOUSE. That is correct.

Mr. CASEY. Well, if we don't do something now on the vehicle test facility, you are going to get to a point where you are just going to have to stop and wait, won't you?

Mr. HOUSE. Yes. There will be a time when we will be at idle power, so to speak, waiting for something to happen.

Mr. GURNEY. Mr. Chairman.

Mr. TEAGUE. Mr. Gurney.

Mr. GURNEY. Pursuing that line of questioning, and letting the vehicle problem rest for a minute, when do you think you will actually have an actual working engine?

Mr. HOUSE. Well, sir, I must clarify some points so that everyone understands. Our plan at the moment, since this change in the budget at the first of the year, is to build a ground test experimental engine only. We do not now have a program aimed at a flight test engine. It is expected that in early 1967 we will have a ground test engine operating in this first engine test stand.

Mr. GURNEY. Well, do you mean by that that this would be a practical working engine, that you could then put into a vehicle, if the vehicle program went on?

Mr. HOUSE. It will be very close to it in its major configuration. However, many of the minor parts, such as valves and controls, etc., will not be flight type. We will be "making do" with present equipment, with extra shielding, special arrangements to avoid the radiation problem, etc. But, of course, the reactor, itself, the pressure vessel and nozzle, and other major components will be flight-type configurations.

Mr. GURNEY. How much thrust will this engine put out?

Mr. HOUSE. About 50,000 pounds of thrust.

Mr. GURNEY. Of course I realize this isn't your responsibility but you must have some notion about it. What kind of a vehicle would be necessary for this engine? To put it this way, would it require a vehicle much more radical than the kind we have now?

Mr. HOUSE. Well, the problem and the differences relate again to this issue of the liquid hydrogen in a tank which is subject to a radiation field. Now, this causes heating of the hydrogen and consequently you get convection currents flowing around inside of the tank. We can't really examine these without the radiation field. Thus you see there is a necessity for building this tank, whatever size or shape it may be, and locating the engine underneath it, so that the vehicle "sees" the expected flight environment. These are the problems we must resolve before we ever fly.

Mr. GURNEY. Well, I understand that, but I take it your answer is that while there are problems involved, nonetheless now they could be solved fairly readily if you went to work on it?

Mr. HOUSE. That is correct.

Mr. GURNEY. That is all.

Mr. TEAGUE. Is there anyone from industry scheduled to testify that could not come back this afternoon at 2 o'clock?

What about the level of funding as far as your particular company is concerned?

Mr. HOUSE. I think the level——

Mr. TEAGUE. The impact on the state of the art, and this thing.

Mr. HOUSE. I think the level of funding, considering the overall picture and taking into account there isn't a RIFT vehicle program going on, is adequate to do the job we must do in the immediate future. We can use more money now because, as I indicated, some of the more straightforward development tasks are being delayed because we would rather spend the money we have on the things that we think are more difficult. We can always do more work and carry those things along. It is a question of how much risk are you taking toward that eventual nuclear engine operational date.

Mr. TEAGUE. Thank you, sir.

We will next hear from Dr. Taylor of the General Atomic Division of General Dynamics.

STATEMENT OF DR. THEODORE B. TAYLOR, CHAIRMAN, HIGH ENERGY FLUID DYNAMIC DEPARTMENT, GENERAL ATOMIC DIVISION, GENERAL DYNAMICS, ACCOMPANIED BY BERNARD B. SMYTH AND VICE ADM. PAUL FOSTER

Dr. TAYLOR. Mr. Chairman, members of the committee, I am very glad to have the opportunity to talk to you about Project Orion, which is also called nuclear pulse propulsion project. With me are Mr. Bernard B. Smyth, assistant vice president of General Atomic, and Vice Adm. Paul Foster, who is a consultant to General Dynamics Corp.

I bring regrets from Mr. Jim Nance, the project manager of Project Orion, who is unable to be here this morning because of a snow avalanche in the southern Utah mountains which has trapped him there for the last day or so.

I am Theodore B. Taylor, chairman of the High Energy Fluid Dynamics Department of General Atomic.

The department has the primary responsibility for all of the physics experimental and theoretical physics part of the Orion project.

Mr. TEAGUE. Dr. Taylor, I don't know how many members of the committee are familiar with Orion, maybe all of them are, maybe they aren't. Could you take a couple of minutes and tell the committee exactly what Orion is?

Dr. TAYLOR. Yes. I would like the permission of the committee to submit a written statement within 10 days to include both classified and unclassified information concerning the project, if I may.

Mr. TEAGUE. Without objection; but certainly we would like to have it in less than 10 days.

Dr. TAYLOR. Yes, we will get this to you within, I would say, 2 days.

Now, I have a model here of our latest version of nuclear pulse engine and a payload that it might carry. I can't in open session describe any of the numerical values or the parameters associated with this, but I can describe how it works. This consists of three sections, the bottom section from this point down is the engine, this middle section carries magazines which are filled with nuclear explosive charges which are the driving energy and driving impulse for the device, and then on top is a typical sort of payload. This configuration shown here is for a relatively modest manned expedition to Mars.

Now, to go into a little bit more detail about how this works. A number of nuclear explosive charges are stored inside these chambers. One by one they are placed inside a breach in the middle of the engine, and then they are ejected through a tube, through a hole in the center of the bottom of the vehicle, and they are exploded at a point somewhere below the surface. Some fraction of the material associated with the explosion is then intercepted by this strong circular disc which we call the pusher plate. This is just a flat disk. Now, you will notice that we are not making any attempt to confine or to contain the explosion products as a whole. We simply use that part of the explosion which is directed toward the bottom of the vehicle.

Now, this plate accelerates up very rapidly, so that if we tried to mount a structure on top of it, it would collapse. We therefore have two types of shock absorbers interposed between this pusher plate and the rest of the vehicle. The bottom part of the shock absorbers really act like a tire on an automobile. They take the first heavy shock as a car would feel striking a bump. There is an intermediate platform which is a relatively rigid structural member which is then connected to a number of relatively large shock absorbers which smooth out the impact, so it is then possible to talk of relatively sensitive instruments inside the device, and people.

This has been a very schematic picture of how the device works.

So far as launching it is concerned, there are two possible ways of doing it, at least. One way it can be done is simply to place this entire ship on top of a chemical booster and boost it up to such an altitude that the air density is low enough so that one can go into a nuclear propulsion phase. At that point, one starts exploding nuclear explosives below the vehicle and then it either ascends it into orbit or escapes from the earth's gravity so this is a relatively high thrust mode of operation.

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A second way in which this can be done is to place all or part of the vehicle in orbit with a chemical rocket. For example, we can imagine a situation where we leave off a large fraction of the weight, that is the propellant which is here and the payload, itself, and simply put the engine in orbit. If one has learned how to solve the rendezvous problem in orbit, it is then possible to add propellant capsules and the payload in orbit. So these are two rather different ways of operating the engine. The operation from orbit, obviously, requires a somewhat lower thrust in order to make it depart from orbit than the sending the vehicle into orbit.

Now, so far as the performance is concerned, we believe we can achieve with this type of an engine, all I can say in open session is that we can achieve, we believe, extremely high specific impulses, perhaps as high as 100,000 seconds. This is really very far out on a limb, the 100,000 seconds is very far out on a limb, but we don't see any physical processes which would limit the specific impulse to be very much lower than that. Actually getting to 100,000 seconds is another story.

The engine is a high thrust system in the sense that it can deliver a thrust which will accelerate all of the vehicles which we have studied at accelerations of at least one-tenth of a g., and in many cases more than a g., so that they can actually ascend into orbit.

Now, I would sum up the performance by simply making a categorical statement which I would hope to be able to justify in executive session this afternoon, at least to some extent. That is to say that we now strongly believe the use of this type of engine would open up the possibility of manned exploration of virtually all parts of the solar system, within a time which does not extend as far as the end of this century. We believe that it would be practical, using engines of this type, eventually to build single stage engines which could make relatively rapid roundtrips to the planet Pluto.

So far as the technical status of the project right now is concerned, I can say very little about this in open session. I will simply say that approximately $10 million of work, spanning about 6½ years, have gone into the project. Most of this work has been supported by the Air Force. It was initially supported by ARPA for about a year and a half, and then was transferred to the Air Force.

However, in the last half of 1963, the NASA supported a relatively small study of the use of the Orion engine concept for a variety of NASA missions. So we have done a lot of work on it.

So far as the people working on the project is concerned, there has been a consistent growth of confidence in the practicality and in the economic virtues, if you will, of the concept. So far as people not working more or less full time on the project, but examining it in some detail, I would say these types of people fall into two classes. There are individuals who have spent in some cases as long as a year or two working on the project as consultants, in other cases several weeks, which include, I would say, some of the greatest scientific minds in this country today.

Those who have examined the project in some detail have been confident enough in its practicality to consistently urge that greater effort be applied to it. These are individuals who have been mostly consultants to the project.

There is another class of technical reviews of the project which has been carried out by, at last count, I believe 16 technical committees. About half of them were ad hoc committees that were appointed by various agencies of the Government to explore the project and determine where it stood technically and in some cases to specify what should happen to it.

Now, in all of these technical reviews, as far as I am aware, no reason why one would expect this type of propulsion system not to work pretty much as we described it today has been proposed. There have been varying degrees of enthusiasm about the project, but nothing basically wrong with it has been pointed out.

Now, there are some unanswered questions which we have tried our best to answer, and I think the final answering of some of these basic questions will require some nuclear testing.

I would like to mention briefly, as best I can, the results of the study which was carried out for the Marshall Space Flight Center, extending over the last half of last year. Several important things happened during that study, primarily, I think, because Orion engines were being put in a mission-oriented context, so that we were asking what you could really do, in some detail, with these engines. As I am sure you all know, it has been difficult to specify purely military missions for space engines, for spacecraft, and, therefore, it was quite a bit easier to pick specific missions in response to the NASA questions.

I would simply sum up the results by saying that we were able to find very impressive uses for much smaller Orion engines than we had formerly discussed in the context of the Defense Department activities. We found that by use of nuclear pulse engines one can increase by a very important amount the payload which could be placed on the moon over that which can be placed using, for example, the Saturn C–5 launch vehicle.

So far as exploration of the solar system is concerned, it was very clear as a result of the study that manned exploration of the near planets with a rather small engine looked very likely, practical, and economical, compared, let's say, to the total space budget extending across something like the next 10 or 15 years. We believe this could be done for a rather small fraction of that number.

Now, there are a number of techniques that have been developed within the Air Force sponsored work for testing the feasibility, testing the practicality, proof testing, and final full-scale flight testing of Orion-type engines. I cannot describe what these developments are, but I think they are important enough so that some mention of them, at least, should be made in executive session.

The key element in these experimental techniques for proof testing the concept, I think, really come from the fact that we can separate the nuclear radiation effects from the high-temperature effects from the mechanical effects. We can observe them separately. They are very strongly decoupled in this system.

One property of Orion engines is that the engine, itself—that is, everything from the bottom of this plate up through the top—does not become appreciably radioactive during the flight. So that one could work with the engine after exposure to a relatively large number of explosions, such as required for full-scale flight.

I want to say a few words about the nuclear test ban treaty. This in many people's minds has raised the most important question about the project.

First of all, I would like to say that I really believe that the primary purposes of the test ban treaty, first, to try to find a way of inhibiting the nuclear arms race and, second, to remove the perhaps questionable health hazards coming from radioactive contamination of the atmosphere that both of these motives for test ban treaty are really not concerned with the Orion project. They are concerned with nuclear weapons development and testing of nuclear weapons in the atmosphere and in space.

I think it is correct to say that the Orion project has been caught in a sort of a web which was not constructed in order to catch it. Its prevention from development is not really in the spirit of the nuclear test ban treaty, provided means can be found for flying Orion vehicles without contaminating the atmosphere with radioactive materials above a clearly acceptable amount. We believe the probability of being able to do this is extremely high. At some degradation in performance it is certainly possible. In fact, to remove contamination altogether is not impossible.

The second point I would like to make about the test ban treaty is that it does not prevent underground nuclear testing, it does not prevent the type of work which has been going on, on this project for the last 6 years, and it does not prevent any mechanical testing of components or even of a full-scale engine with high explosive. Therefore I think it is fairly obvious that a large amount of feasibility testing and practicality testing can be done. In some people's minds, I would say in the minds of virtually all of the people working on this project at General Atomic, one could also carry through the proof-testing phase across a number of years without violating the nuclear test ban treaty.

After these years have passed, the world will be different from what it is today and in perhaps very important respects as they relate to the treaty.

It is possible that the treaty will no longer exist because one or more of the signers of the treaty has abrogated it. It is also possible that the nuclear test ban treaty will be as effective as the people who were most enthusiastically promoting it believed; in which case it makes much more sense than it does now, I believe, to ask the question: Could Orion engines be fully developed, either in cooperation with the Soviet Union or by changes in the treaty which would make it possible to carry it through?

The important point here is that extremely important work can be done on the project for a number of years without requiring any modification of the treaty at all.

Now I would like to conclude by saying that, in view of the importance of nuclear pulse propulsion to the nuclear—to the national space program, I believe that the projected firm level of funding for next fiscal year, which is $1 million from the Air Force—this is the only firm allocation of funds as far as I am aware today—is not logically compatible with the very high promise for a major increase in what we will be able to do in space offered by this type of propulsion.

I should emphasize, however, that whatever is determined across the next few months, I think—I am sure that all of us working on this project will argue that it should continue at whatever level is possible. I don't believe that there is a magic level of support which is low enough to warrant complete cancellation of the project. It has been described often as a project which tried to die and couldn't die; we have kept it alive, I think, primarily by real technical progress across these 6 years, even though the level of funding has not been as high as we thought it should be.

I believe that completes my prepared statement.

Mr. TEAGUE. Mr. Fulton has a question.

Mr. FULTON of Pennsylvania. You have inferentially stated that NASA has no money in the budget for Orion this year. Is that right?

Dr. TAYLOR. I don't know, actually, whether there is a formal allocation of money in the NASA budget for next year. I believe not.

Mr. TEAGUE. Mr. Finger can say.

Mr. FINGER. Any money that is in the NASA budget in this area is in the advanced study funding. The $100,000 study being supported out of Marshall that Dr. Taylor referred to came out of that advanced funding. It would be our plan to have funding something like that for a continued study in the 1965 budget.

Mr. TEAGUE. Thank you, sir.

Mr. FULTON of Pennsylvania. Would it be better to have this project under NASA for study and development as a research project so that you get away from the test ban on military vehicles?

Dr. TAYLOR. I think that it would ease the question that centers around the test ban because it would remove any clear indication that the project was being developed for military purposes.

However, the nuclear explosives devices that are being used for propulsion can, I think, correctly be called nonweapons nuclear explosives.

Mr. FULTON of Pennsylvania. As a matter of fact on size and on contamination factor the size of the explosion that you would have on the Orion would be in the level of a small military field tactical nuclear rocket or missile, would it not, so that it is not a great factor?

Dr. TAYLOR. I certainly believe that is true.

Mr. FULTON of Pennsylvania. My final question is this: What kind of an explosion are you getting? Does it give so many g.'s that it is not possible for manned flight? And when could we look for such a practical use as manned flight or exploration of the planetary system?

Dr. TAYLOR. Well, in answer to the first question, the purpose of this long shock-absorbing system is, in fact, to reduce the peak acceleration levels to the point where from about this point on up men could survive a flight. So it is designed from the beginning as a manned space vehicle.

So far as when it could become available for operational use, leaving ease or difficulty of funding questions aside, this is a very controversial question; our own estimates and a number of estimates which have been made within the Air Force indicate that one could be using engines of this general sort some time within the next 10 to 20 years. I think this pretty well brackets various people's estimates.

Mr. FULTON of Pennsylvania. That is all.

Mr. TEAGUE. Mr. Bell?

Mr. BELL. Dr. Taylor, when you speak of—to get this in its right perspective, when you speak of a specific impulse in this type of vehicle, you are talking about five or six or seven times the amount that is in chemical propulsion; isn't that right, at least?

Dr. TAYLOR. I really—I could only answer very much larger specific impulses.

Mr. BELL. Very, very much larger specific impulses?

Dr. TAYLOR. Yes.

Mr. BELL. In other words, this is the type of vehicle—however in the formative stage it may be—this is the type of vehicle that gets America away from artillery and gets it into the area of transportation? In other words, you are saving money in the sense that you are not dropping off other vehicles that cost millions of dollars to build in order to get somewhere; you are taking one vehicle and going there and coming back, right?

Dr. TAYLOR. That is right.

Mr. BELL. Now, as I understand it also from your testimony, and I am not sure about this, I understand that you get away, did you say, from the heat problem to a great degree, to the extent that this explosion is at the bottom of the plate and it leaves it quickly and there is no——

Dr. TAYLOR. Yes. I think one way to explain this is simply to say that it is a very similar situation to one in which one is trying to flick or move a glowing ember which has popped out of a fireplace onto a rug. If you pick up the ember and hold it, you burn your fingers, but if you flick it, if you give it an impulsive flick, you can get it back in the fireplace and you don't burn your fingers. The reason is that the length of time the high temperature is in contact with the surface one is trying to protect is extremely short. This is really the key to the whole concept.

Mr. BELL. So then perhaps you don't have to worry quite so much about just the exact type of materials to withstand the heat?

Dr. TAYLOR. That is correct.

Mr. BELL. But it must withstand considerable shock, of course. Is it not true that maneuverability in space would be enhanced by this type of vehicle?

Dr. TAYLOR. Yes, it would.

Mr. BELL. As a propellant, your propellant would be fissionable material; is that correct?

Dr. TAYLOR. As we mean propellant, the answer is "No." That is, the fuel could be fissionable material.

Mr. BELL. But you would——

Dr. TAYLOR. The propellant might be inert material, might be fissionable material, depending on the particular form of the concept. We can get—I don't believe I can answer this question clearly in open session.

Mr. BELL. That is all, Mr. Chairman.

Mr. TEAGUE. We will next hear from Mr. McLafferty of the United Aircraft Research Laboratories.

STATEMENT OF GEORGE H. McLAFFERTY, PROGRAM MANAGER, UNITED AIRCRAFT RESEARCH LABORATORIES; ACCOMPANIED BY GEORGE HAUSMANN AND JAMES PATTERSON

Mr. McLafferty. Mr. Chairman and gentlemen, my name is George H. McLafferty. I am program manager for the gaseous-core nuclear rocket program which has been in progress at the research laboratories of United Aircraft Corp. during the past 5 years.

I am accompanied by Mr. George Hausmann and Mr. James Patterson.

I am pleased to have the opportunity to appear before this committee today, since it is our belief that the gaseous-core nuclear rocket offers a most unusual potential for economic space transportation in the future.

Today I will discuss the basic features of gaseous nuclear rockets and the program which is being conducted to investigate their characteristics.

Because of security restrictions the discussion will be severely limited. It is, therefore, recommended that additional classified information be presented to the committee in an executive session so that you may judge for yourselves the status of the work on gaseous rockets.

First, many of the features of a gaseous nuclear rocket are no different from those of a solid-core nuclear rocket, and I have here a sketch which probably looks very similar to the sketches Mr. Harry Finger has shown you on solid-core nuclear rockets. (See fig. 1, p. 27, of accompanying prepared statement.) There is the usual array consisting of a tank, pump, turbine, and radiation shield. There is a cavity which is surrounded by a moderator reflector and a pressure shell. There is an exhaust nozzle. However, we have as a goal the same kind of performance as Dr. Taylor with his Orion project rather than the performance of a solid-core nuclear rocket. We would like to obtain values of specific impulse between about 1,500 and 3,000 seconds. Although we see ways of improving the specific impulse of gas-core rockets above 3,000 seconds, possible to 10,000 seconds, let's look at the relatively lower values first.

For a specific impulse of 1,500 seconds, the exhaust velocity would be about 45,000 feet per second, or about 30,000 miles an hour. The temperature upstream of the nozzle would be about 10,000° F.

For a specific impulse of 3,000 seconds, the exhaust velocity would be about 90,000 feet per second, or about 60,000 miles an hour, and the temperature upstream of the nozzle throat would be about 30,000° F. These are all quite high numbers compared to what you are used to.

Because the temperatures in this region are so high, it brings us to the first problem, which is protecting the walls from the hot gases. It is obvious that if you put gases at a temperature of 10,000° to 30,000° F. next to a solid material it will melt and boil in no time at all. Therefore, we must protect the walls by a cold film of gases.

We have done enough work to make us think we can protect the walls, and we can discuss the techniques we would use later in executive session if you wish.

The second problem is concerned with fuel-loss rate. In order to make a device like this work we have to have a certain minimum critical amount of nuclear fuel in it. This minimum critical amount is a function of the geometry and a lot of other factors, but for a diameter of approximately 8 feet it tends to be about 5 kilograms, or 11 pounds. We would have to have 11 pounds of nuclear fuel in the cavity, and this fuel would have to be in gaseous form because of the high temperature involved. If we consider an engine diameter of 25 feet, the amount of nuclear fuel required for criticality would be about 20 kilograms, or about 44 pounds, and again this would have to be in gaseous form.

If we were to let this nuclear fuel mix with the hydrogen propellant which comes out the nozzle, there would be a tremendous loss rate of fuel. For every pound of hydrogen coming out the nozzle at high velocity there would be roughly one pound of fuel along with it. Now, nuclear fuel is very expensive, about $7,000 a pound, so that if we were to use a configuration where the hydrogen and fuel were intimately mixed we would lose all the economic advantages we could gain by high temperatures and high specific impulses. Therefore the second problem is to find a means of keeping the nuclear fuel and propellant apart so that the propellant will go out the back at a high velocity and yet the fuels will stay in for an acceptable period of time.

Economic studies have indicated that we would like to keep the propellant-flow rate to something like 500 or a thousand times the fuel-flow rate. If we can do that we can have a truly economic space transportation system which would allow us to go single stage from the earth to nearby planets and some fairly distant planets. Development of such a rocket engine would completely revolutionize the cost of space transportation.

We have carried out a lot of work on several schemes to try to minimize the loss rate of nuclear fuel. I can't discuss these in open session, but I will give you some details later in a closed session.

As we have said, there are the two problems: Keeping the wall cool and keeping the fuel from flowing out the back. We are in a research phase in our attack on these two problems. We have been at it for 5 years, and we have spent about $2½ million.

Mr. FULTON of Pennsylvania. Mr. Chairman.

Before you leave the description——

Mr. MCLAFFERTY. Yes, sir.

Mr. FULTON of Pennsylvania. Could you distinguish this from a solid core?

Mr. MCLAFFERTY. Well——

Mr. FULTON of Pennsylvania. What is the chief difference?

Mr. MCLAFFERTY. The chief difference is the following: In a gaseous-core nuclear rocket the nuclear fuel is in gaseous form and hence its temperature is not limited, whereas in a solid-core nuclear rocket the fuel has to be in solid form which limits its temperature to 4,000° or 5,000° or 6,000° F. I am not sure exactly what temperatures are now planned for use in the solid-core nuclear rocket program. This limitation on the maximum temperature of solid materials is the factor which limits the temperature of the hydrogen propellant, and which, in turn, limits the velocity of the exhaust flow and limits the specific impulse to something on the order of 700 to a thousand seconds. However, if we can drive the exhaust temperature up 10,000° to 30,000° F., we can obtain the exhaust velocities which correspond to very high specific impulses and which are required to obtain economical space transportation. But at 10,000° to 30,000° F. the fuel has to be in the form of a gas.

Mr. TEAGUE. Mr. Bell.

Mr. BELL. May I ask a question here?

What prevents the, as you call it, fuel, the gaseous fusion, from going out with the propellant? Is there some reason? Is that classified?

Mr. MCLAFFERTY. That is classified, yes.

In the current research phase of the investigation, we have spent approximately $800,000 of company money. In the period 1961 to 1963 we spent a little over a million dollars of Air Force money. We are now in the middle of two different NASA contracts totaling about $600,000. We have spent approximately half the NASA money to date, and all of it will be used up by September of this year.

The $800,000 of corporate expenditure is a measure of the faith that United Aircraft Corp. has that such a device can be built. It is a major percentage of this total and is an example of free enterprise pushing something they think will work.

We have obtained encouraging results in this research phase of the work, which is all I can say in an unclassified session. However, we obviously must have a few problems left or we would be ready to build one right now. We feel that the research part of this program should continue for between 2 and 5 years more, and at the end of that time we hope we will be in a position to recommend a demonstration program or a development program. We do not think the country should be putting any money into a development program yet because it is too early to guarantee that this device will work the way we believe it will. We are pretty sure it will work but we cannot guarantee it to the point of recommending the expenditure of very large sums of money.

However, we have done some thinking about the Nation's ability to test gas-core nuclear rockets when such engines get to the demonstration and development phase. (See fig. 2, p. 29 of accompanying prepared statement.) We would use a facility that might operate something like this: The high-temperature exhaust gases from the gas-core nuclear rocket engine would be diluted by dumping in water from an upper pond during the test. The resulting mixture would be at a temperature of approximately 150° F., where the water would exist in the form of liquid rather than in the form of steam. The mixture would be carried down to a lower pond. If this engine produced a thrust of several million pounds and were tested for a minute, the total amount of water which would be required would be about 50 acre-feet. That means a pond having an area of one acre and a depth of 50 feet. I mention this to indicate that

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the amount of water required would fill a pond, but not a large lake.

At the end of the test, all of the water and fission products and any unburned fuel would be in the lower pond and would be pumped back over a period of time through a circuit to the upper pond. This circuit would include a separator, where all of the fission products and unburned nuclear fuel would be removed. By employing a separator we can completely prevent contamination of the atmosphere during routine tests of gaseous nuclear rockets.

Mr. FULTON of Pennsylvania. Where is your exhaust on that diagram?

Mr. McLAFFERTY. It is pretty much a closed system. That is, we would pump the exhaust products in the lower pond through the separator, remove the material we didn't want in the circuit, and dump the remainder back into the upper pond.

Mr. GURNEY. Have you done any testing yet?

Mr. McLAFFERTY. We have carried out fluid mechanics tests at low temperature to investigate the containment and wall cooling problems of gaseous nuclear rockets. I can describe the results of those tests to you in a closed session, if you wish.

We do not show this sketch to indicate that we want to build anything like this right now. We only show this sketch to indicate that we believe that the test problem will not limit development of gas-core rockets.

In conclusion, it is obvious that we are very enthusiastic about gaseous nuclear rockets. By this we don't mean that work should stop on more immediate space propulsion concepts. Chemical rockets and solid core rockets will have to be used for a number of years to come. In addition, a lot of the technology which is required for the development of gas-core rockets is being generated in the process of working on solid-core rockets, and in the process of working on high-pressure chemical rockets. Therefore we feel that this work should continue because we hope to be able to use the results in future work on gaseous-core nuclear rockets. The gas-core rocket in a sense is an advanced graphite reactor, because we would probably use graphite as a major material within the engine.

We do feel strongly, however, that the results to date indicate that the work on gas-core rockets should be accelerated. We have very encouraging results, which, if they continue, will lead to successful development of a gaseous nuclear rocket engine. Such a development would save the national space program many billions of dollars.

I believe that concludes the presentation.

Mr. TEAGUE. Mr. Bell.

Mr. BELL. I understand that, as you said, we are again developing the type of transportation that you have indicated in this type similar to Orion. You spoke about 2 to 5 years that it would take you to study this.

Mr. McLAFFERTY. We are now in a research phase. At the end of an additional 2 to 5 years of such research we would not have a flyable engine, but we would hope to have sufficient evidence to justify development of a flyable engine. In that sense we are behind the time schedule that the Project Orion personnel have talked about, where they are talking about when they would fly the engine. We are talking about when we would get the evidence necessary to justify a development program. We think our development program might be relatively easy to carry out, but the final flight date is uncertain.

Mr. BELL. As you may know, there has been in the form of an amendment a suggestion that the NASA allocate a certain amount, $1½ million, to be exact, additional funds for research in this area for gaseous-core development. Would that be a help to you?

Mr. HECHLER. Would you yield? That wouldn't be additional.

Mr. BELL. Excuse me; not additional. An allocation of the funds that NASA already has. It would be an additional indication to this particular job from funds NASA already has, which is gaseous-core research and development.

Mr. MCLAFFERTY. Yes, sir.

Mr. BELL. That will be of some considerable help to you, will it?

Mr. MCLAFFERTY. Oh, it would. We now have about $600,000 worth of contracts from NASA, but Mr. Finger's office, besides supporting us, supports work at the NASA Lewis laboratories, as well as at several other places. Their total, I believe, right now is considerably more than one and a half million dollars in advanced propulsion. But——

Mr. FINGER. Not on the gaseous core. There is about one and a half million dollars going into the gaseous core, including administrative operation.

Mr. BELL. This would be an additional one and a half million that was suggested to be used in this area, too.

Mr. MCLAFFERTY. This would undoubtedly help us. I am sure that it is probably good to assume that we wouldn't get all of it ourselves, but we could very effectively use any part of it that came our way.

We have outlined a program to the Space Nuclear Propulsion Office for fiscal year 1965, which would cover work in all these different fields, from the field of fluid mechanics, which still represents the key problem area, right through to some material work, some work on conceptual engine design and some work on the facility which might eventually be used to test gaseous nuclear rockets. We have recommended this level of effort at United Aircraft Corp. research on three bases: One, we have the people pretty much on hand with the training necessary for them to immediately start work on the various problems. This is important.

The second basis is that an enlarged level of effort would give the same output per dollar spent as now exists. It is not the kind of a program where, if you double the funding, you get 10 percent more information out of it. We feel that the output per dollar would be the same for the increased program as for the program we now have. The enlarged program would, as a result, squeeze down the research time so that we can get at the development earlier and get at the advantages to be gained by economic space transportation earlier.

The third basis is that we feel that this level of effort is warranted by the amount of money that would be saved in the national space program if a gaseous nuclear rocket worked.

Mr. TEAGUE. Mr. Fulton.

Mr. FULTON of Pennsylvania. Thank you.

You are not recommending that, for the purpose of the gaseous-core study, any one of these other programs of NASA, such as solid-core development, Orion, or high-energy chemicals, be deprived of needed funds and transferred over into this program, are you?

Mr. MCLAFFERTY. Our responsibility, we feel, is primarily to push for this program. But there is excellent work going on in many other fields, and the results of this work will be of great help to us in future years.

Mr. FULTON of Pennsylvania. So that if you get heat transfer work, nuclear calculations, high density hydrogen properties, as well as supporting research on metals, valves, nozzles, as we come up to this high level of thrust impulse, that the gaseous core will give us, that all goes really to help you on your program; doesn't it?

Mr. MCLAFFERTY. What we have tried to do is to separate the problems which are now facing solid-core rockets from the unique problems which face gaseous nuclear rockets. All of the information we would generate in an expanded program would be related to gaseous nuclear rockets, and we would assume that the other work would still be carried on.

Mr. FULTON of Pennsylvania. What you are doing is simply stepping up the pressure and temperature in the area of reference?

Mr. MCLAFFERTY. The hydrogen densities we would consider are higher than the hydrogen densities that are being considered in the other programs. This gets a little bit into the area of classified information, but we are talking of higher pressures and higher densities than are now being considered in the solid-core program.

Mr. FULTON of Pennsylvania. I agree on that; it is a difference in the order of magnitude. My point is should we not be doing the research as we go up to this magnitude all along? We shouldn't skip any one of these other programs.

Mr. MCLAFFERTY. Correct.

Mr. FULTON of Pennsylvania. Nor should we starve them, we should balance them out and, of course, that is an administrative function that is under Mr. Finger; is that not right?

Mr. MCLAFFERTY. Correct.

Mr. FULTON of Pennsylvania. Thank you.

Mr. TEAGUE. Any other questions?

Mr. DADDARIO. Mr. Chairman.

Mr. TEAGUE. Mr. Daddario.

Mr. DADDARIO. I think Mr. McLafferty has made an excellent statement which is really what we expect from United Aircraft Corp., which by chance happens to be——

Mr. TEAGUE. Mr. Daddario comes from Hartford, Conn.

Mr. DADDARIO. You said you think this program should be accelerated, and you have given some reasons as to why. I wonder as you look to the future and you fit into it the idea that you will have—we can develop through this process or another a single stage spaceship, what level of financing do you contemplate? What does the future look like in this particular area, what do we have to do, what should we prepare ourselves for from the standpoint of the financial stimulus needed to sustain the overall effort?

Mr. McLafferty. This is a very difficult question to answer. The research program funding which we recommend is very modest compared to the funding required for a development program, but represents a vigorous effort compared to that of most research programs. When we get beyond the research stage, the rate of expenditure would go up in the same order of magnitude as that for solid-core nuclear rockets. It might be somewhat greater than that for solid-core nuclear rockets because many of the problems are more complicated. But, on the other hand, because we have so much inherent performance, we may be able to build structures, cases, and so on, without worrying about weight as much as is normally done in solid-core nuclear rockets and may be able to build things cheaper per pound.

Therefore, whether the costs are much greater, or somewhat less than for a solid-core nuclear rocket program, is almost impossible to answer right now. However, I think if you take the order of magnitude cost numbers that Mr. Harold Finger has talked about, you would come to about the right figure.

Mr. Daddario. Thank you, Mr. Chairman.

Mr. Fulton of Pennsylvania. One more question.

Mr. Teague. Mr. Fulton.

Mr. Fulton of Pennsylvania. What period of time are you talking on successful development? How far in the future will this be, the gaseous-core rocket and the engine vehicle?

Mr. McLafferty. The most intelligent thing I could say is that we don't really know.

Mr. Fulton of Pennsylvania. About 1990? I have heard that mentioned; is that correct?

Mr. McLafferty. I would hope that it would be substantially before that. It is difficult to envision a gaseous nuclear rocket in flight within 10 years since it would take an awful lot of good fortune and an awful lot of funding to get it going in that time. But some time after 10 years the possibility of an operational gaseous nuclear rocket begins to rise, and if it is going to work at all, it should certainly work by 1990.

(The complete prepared statement of Mr. George H. McLafferty is as follows:)

[Report, UAR–C41, Mar. 17, 1964]

Review of the Gaseous-Core Nuclear Rocket Program at United Aircraft Corp. Research Laboratories, East Hartford, Conn.

Mr. Chairman and gentlemen, my name is George H. McLafferty. I am program manager for the gaseous-core nuclear rocket program which has been in progress at the Research Laboratories of United Aircraft Corp., during the past 5 years. I am pleased to have the opportunity to appear before this committee today, since it is our belief that the gaseous-core nuclear rocket offers a most unusual potential for economic space transportation in the future. It is particularly encouraging to us that this subcommittee has the foresight to review such advanced concepts as gaseous nuclear rockets at a time when so much emphasis is being placed on the more conservative and immediate objectives in space propulsion. It is our firm conviction that a balanced program directed toward the development of existing propulsion technologies for the fulfillment of immediate objectives, together with a program covering research in advanced technologies, is essential to the orderly growth of economic space transportation.

By way of introduction, the Research Laboratories of United Aircraft Corp., which I represent, are an autonomous unit of United Aircraft Corp., which operates as a central research organization in support of the technical activities of the six divisions of the corporation. Research in advanced propulsion, which is conducted to supplement the activities of the Pratt & Whitney Aircraft Division and the United Technology Center of United Aircraft Corp., is characterized by the investigation of systems and components having potential performance which represents a highly advanced state of the art. In the area of advanced rocket technology our primary efforts over the past 5 years have been concentrated on research directed toward the determination of the feasibility of the gaseous-core nuclear rocket.

Today I will discuss the motivations for the investigation of gaseous-core nuclear rockets, the principal problem areas associated with the development of this concept, and the need for expediting our national program in gaseous-core nuclear rocket technology. Because of security restrictions, only limited information regarding the progress which has been made to date under the United Aircraft Corp. program can be presented in this statement. To provide a realistic assessment of the state of the art relative to the feasibility of this concept, it is srongly recommended that such information be presented in executive session.

MOTIVATION FOR GASEOUS-CORE NUCLEAR ROCKETS

Our ultimate goal for manned space flight in the solar system is the single-stage spaceship which would have the capability of traveling from the earth to points in space and back to earth. Since such a vehicle could be used and reused, the economic advantage over current-generation multistage nonreuseable vehicles is readily apparent. As stated by Maxwell W. Hunter, Jr., in the February 1963 issue of Nucleonics magazine, "Only with the development of a spaceship of this simplicity, economy and versatility of operation can we foresee the economic feasibility of really large-scale manned space operations with whatever permanent manned bases on the moon or planets are necessary."

The attainment of single-stage space vehicles is critically dependent on the development of high-thrust propulsion systems having high values of specific impulse—that is, pounds of thrust for each pound of propellant which is utilized every second. The most advanced chemical rockets have values of specific impulse approaching 500 seconds and solid-core nuclear rockets of the type currently being investigated under Project Rover have projected values of specific impulse approaching 1,000 seconds. The successful development of such solid-core nuclear rockets will have a profound influence on our future capabilities for economic space travel. However, the fulfillment of our ultimate goal for single-stage spacecraft will require the development of propulsion systems having values of the ratio of thrust to weight greater than unity and specific impulses considerably greater than those afforded by the solid-core nuclear rocket. By way of example, the Saturn V vehicle which will be used to place our astronauts on the moon will require a takeoff gross weight of approximately 6 million pounds to perform the mission and return the 8,000-pound command capsule to the earth's surface. The use of solid-core nuclear rockets for this mission would allow a return capsule weight of approximately 25,000 pounds for early engines and up to 70,000 pounds for more advanced engines. On the other hand, an advanced nuclear propulsion system with a thrust-to-weight ratio of 20 and a specific impulse of 2,500 seconds would permit the delivery of a 1-million-pound capsule back to earth for the same vehicle initial gross weight as for the chemical system. In the case of the nuclear rockets, it has been assumed that chemical rockets would be utilized to boost the vehicles outside the earth's atmosphere and thereby minimize nuclear radiation hazards. Although this complication reduces the payload relative to that which could be obtained using a true single-stage configuration, the resulting economic disadvantage is relatively slight.

DESCRIPTION OF GASEOUS-CORE NUCLEAR ROCKET CONCEPT

The attainment of values of specific impulse greater than that afforded by the solid-core nuclear rocket with hydrogen propellants is dependent on the degree to which the velocity of the expelled gas can be increased. Although it is possible to attain extremely high values of exhaust velocity by the electrostatic acceleration of charged particles, which is the principle of plasma and ion electric rockets, the resulting ratio of thrust to the sum of engine and power supply weight is extremely low. The only means for increasing specific impulse while still retaining high values of the ratio of thrust to weight is to increase the exhaust velocity by increasing the gas temperature. Since the gas temperature in a solid-core nuclear rocket is necessarily limited by the structural characteristics of the fuel elements at elevated temperatures, it is apparent that further increases in temperature will require the containment of nuclear fuel in gaseous form.

In the concept of the gaseous-core nuclear rocket being investigated at United Aircraft Corp. Research Laboratories, energy from gaseous nuclear fuel located within a cavity is used to heat the propellant gas to very high temperatures. As shown in figure 1 these high-temperature gases are then expanded through

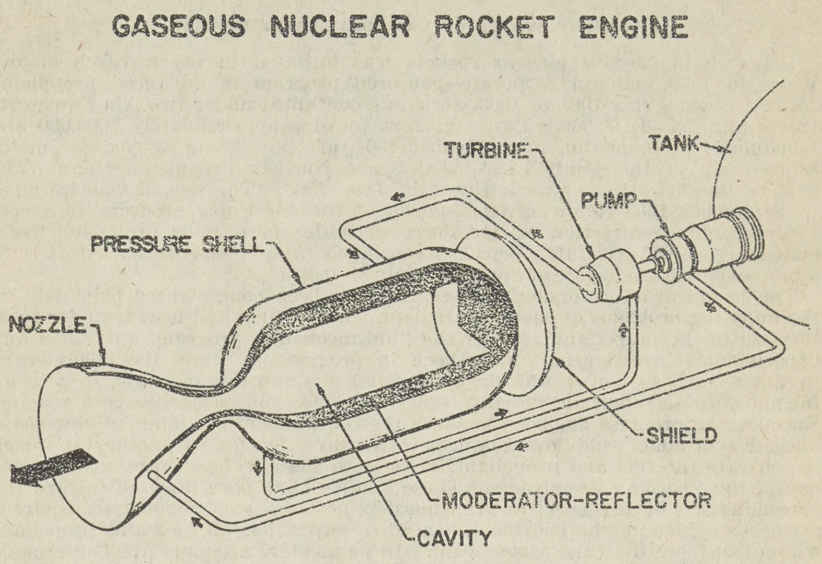

FIGURE 1

a nozzle to attain extremely high exit velocities and corresponding high values of specific impulse. For values of specific impulse between 1,500 and 3,000 seconds the corresponding average temperatures immediately upstream of the nozzle throat would be between 10,000° and 30,000° F. Since gas temperatures of this order of magnitude adjacent to the walls would cause rapid melting and boiling of the structural material, a relatively cool film of gas must be located between the hot gases and the wall.

An equally imposing problem which must be overcome to permit development of gaseous nuclear rockets is that of minimizing the loss of nuclear fuel from the cavity. Studies of nuclear criticality indicates that the amount of fuel which must be stored in the cavity varies from approximately 5 kilograms (11 pounds) to 20 kilograms (44 pounds) for engines having diameters between 8 and 25 feet. If this gaseous fuel is permitted to mix with the propellant, fuel loss rates approximately equal to the propellant flow rates would result. Because of the high cost of nuclear fuel (approximately $7,000 per pound) such a fuel loss rate would be intolerable.

The Research Laboratories of United Aircraft Corp. have been conducting theoretical and experimental investigations to develop flow configurations which will minimize the loss rate of nuclear fuel in full-scale engines. These investigations have concentrated on a particular flow configuration which counteracts many of the mechanisms which cause loss of fuel from gaseous nuclear rockets. The principle of operation of this flow configuration and the details of the flow patterns within the engine are classified.

Although the estimates of specific impulse and thrust-to-weight ratio for the specific engine configuration under investigation are also classified, generalized analyses to determine the performance potential of gaseous nuclear rockets have been available in the open literature for many years. These analyses indicate the possibility of values of specific impulse between 1,500 and 3,000 seconds and values of thrust-to-weight ratio considerably greater than unity. In addition, if secondary coolant loops can be used to transfer heat to space by means of a space radiator, values of specific impulse approaching 10,000 seconds may be possible. While hydrogen has been considered the natural propellant because of its low molecular weight, it is interesting that water, ammonia, and methane offer certain attractive advantages where overall vehicle system characteristics are considered.

CURRENT STATUS OF UNITED AIRCRAFT PROGRAM

Research in gaseous nuclear rockets was initiated in the research laboratories in 1959 under a corporate-sponsored program in advanced propulsion technologies. From 1961 to 1963 work was continued under two Air Force contracts totaling $1,150,000. Two contracts, totaling approximately $600,000 and scheduled for completion in September 1964, are now being carried out under sponsorship of the joint NASA/AEC Space Nuclear Propulsion Office. The first of these contracts was initiated in June 1963. The second was initiated in September 1963 following termination of the Air Force program as a consequence of a redirection of Air Force activities in nuclear propulsion technologies. United Aircraft Corp. has continued to supplement this effort with a total expenditure to date of approximately $800,000.

The technical effort under this program has been concentrated primarily on the imposing problems of fuel containment, wall cooling, and heat transfer from the fuel to the propellant. Under the fluid mechanics program, analytical and experimental investigations have been in progress to study the behavior of mixtures such as iodine and air, smoke and air, and dye in water to gain an insight into the mechanisms involved in the flow of gases into the reactor. Encouraging progress has been made in the containment of a simulated gaseous nuclear fuel under cold-flow conditions. An investigation of another approach to separate the fuel and propellant in the core has also been in progress under one of the two NASA contracts. These studies have been directed toward the determination of the spectral transmission properties of various transparent materials which might provide the needed separation of fuel and propellant without melting the transparent wall. In particular, attempts are being made to determine if the radiation damage to the transparent walls can be annealed out at an adequate rate by finding an operating temperature hot enough to remove the damage but not hot enough to sap the strength of the material.

Encouraging progress has also been made in the determination of heat transfer rates to the propellant and to the rocket structure. Unique concepts also have been evolved for cooling the nozzle component of the rocket with a minimum penalty in overall rocket performance. Although security restrictions prevent a detailed discussion of the progress which has been made to date in determining the feasibility of this gaseous-core nuclear rocket concept, it can be stated that no serious obstacles have been encountered which would discourage continued enthusiastic pursuit of this program.

FUTURE PROGRAM

On the basis of the encouraging progress which has been made to date and in consideration of the extreme performance potential of the gaseous-core nuclear rocket, it is strongly recommended that the current program be accelerated and amplified. In particular, additional efforts should be directed toward extending the present successes in experimental work to areas which more closely represent the conditions which are expected to exist in an actual rocket system. Following a 2- to 5-year period of such additional experiments, it is anticipated that sufficient technology will have been developed to permit consideration of tests of an actual rocket engine with gaseous nuclear fuel. A sketch of a facility which might be used in such tests is given in Fig. 2. In this test arrangement, water

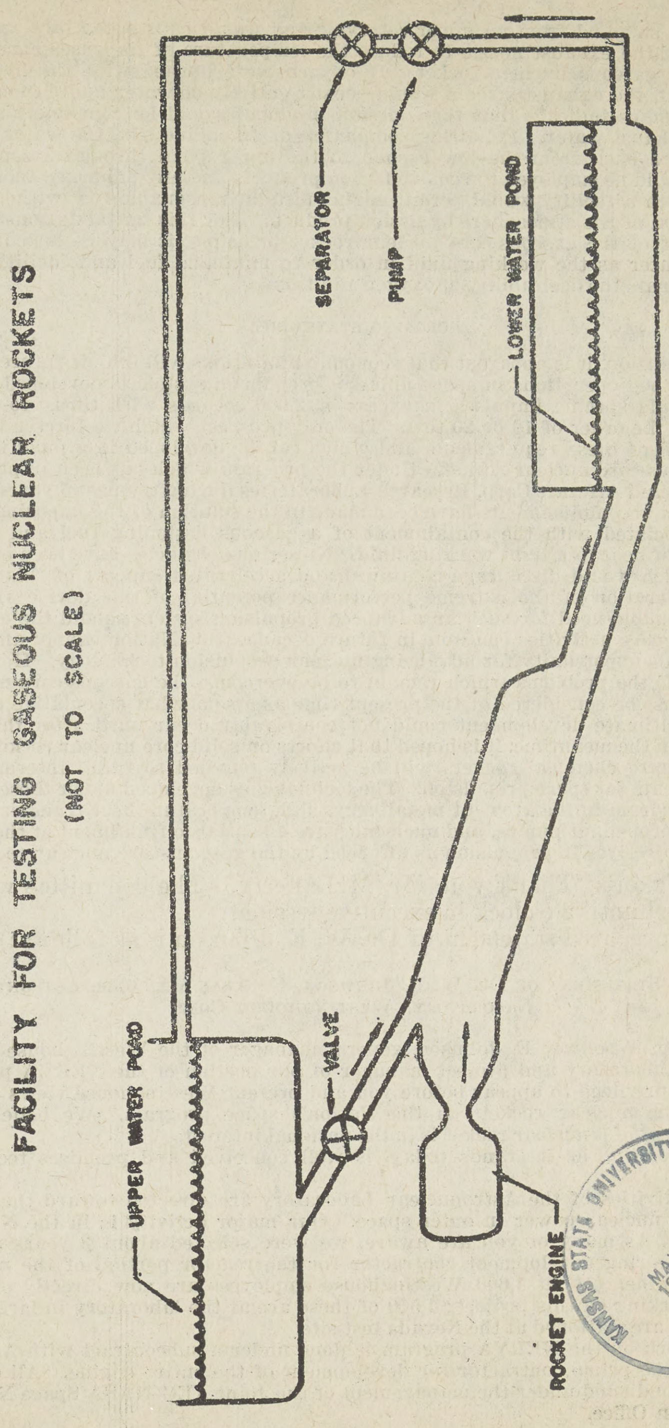
FACILITY FOR TESTING GASEOUS NUCLEAR ROCKETS
(NOT TO SCALE)
UPPER WATER POND
VALVE
ROCKET ENGINE
SEPARATOR
PUMP
LOWER WATER POND

FIGURE 2

would be supplied from an upper reservoir and would be injected into or downstream of the exhaust nozzle to reduce the temperature of the gases emanating from the gaseous nuclear rocket. If oxygen were burned with the hydrogen propellant, the exhaust stream would consist entirely of water and fission products. Studies indicate that these fission products would be completely soluble in the exhaust water. Following completion of an engine test, the water would be pumped back from the lower pond to the upper pond through a separator which would be employed to remove fission products and any unburned fuel. The use of such a facility would permit engine tests at reasonable cost without contamination of the atmosphere by fission products. For this initial demonstration and proof of the gaseous-core nuclear rocket principle, it may be expedient to utilize water as the working fluid in order to minimize fuel and facility costs and eliminate the desirability of oxygen addition.

CLOSING STATEMENT

In conclusion, it is apparent that economic limitations will inhibit future large-scale manned operations in space unless a propulsion system is developed which will provide specific impulses in excess of 2,000 seconds with thrust-to-weight ratios on the order of 10 or 20 to 1. The only prospect which we foresee for the fulfillment of these requirements and which can be developed in ground tests is the gaseous-core nuclear rocket. Under the program which has been in progress at the United Aircraft Corp. Research Laboratories during the past 5 years, truly significant accomplishments have been made in the solution of the imposing problems associated with the containment of a gaseous fissioning fuel and in the transfer of heat to a light working fluid. No serious obstacles have been encountered which would discourage continued and accelerated support of this effort. In consideration of the extreme performance potential of this device and the unquestionable need for such an advanced propulsion system should the current trend in space activities continue in future decades, this Nation cannot afford to neglect this opportunity for advancing nuclear propulsion technology. However, because of the problems which remain to be overcome, the gaseous-core nuclear rocket must be considered at the present time as a somewhat speculative device, and its ultimate development could not conceivably occur until after the next decade. In the meantime, it is hoped that efforts on solid-core nuclear rockets and high-pressure chemical rockets will be actively pursued to fulfill intermediate requirements for space propulsion. The technologies developed under these latter rocket program in the areas of metallurgy, high-temperature heat transfer, high-pressure propellant pumps, and nucleonics are essential to fulfillment of the more distant objectives in propulsion as afforded by the gaseous-core nuclear rocket.

Mr. TEAGUE. Thank you, Mr. McLafferty. The committee will be adjourned until 2 o'clock in executive session.

(The prepared statement of Dr. W. E. Johnson is as follows:)

PREPARED STATEMENT OF DR. W. E. JOHNSON, GENERAL MANAGER, ASTRONUCLEAR LABORATORY, WESTINGHOUSE CORP.

I am Dr. Woodrow E. Johnson, general manager of the Westinghouse Astronuclear Laboratory and project manager of our portion of the NERVA project.

It is a privilege to appear before you and present Westinghouse views on the role of the nuclear rockets in the Nation's space program. We believe the development of a nuclear rocket is in the national interest.

The program, as it stands today, is well conceived and promises technical success.

The activities of the Astronuclear Laboratory are directed toward the application of nuclear power in outer space. Our major activity is in the NERVA program. As many of you are aware, we were selected about 3 years ago as the engineering development contractor for the reactor portion of the nuclear rocket engine. About 1,600 Westinghouse employees are now directly or indirectly working on this project; 1,500 of these are at the laboratory in large, and about 100 are stationed at the Nevada test site.

Our work on the NERVA program is done under a subcontract with Aerojet-General, the prime contractor for development of the entire engine. All of this work is conducted under the management of the Joint AEC–NASA Space Nuclear Propulsion Office.

Because of our broad experience in the field of nuclear technology, we were particularly interested in becoming associated with the nuclear aspects of the space program. Our experience includes the continuing development of reactors for naval propulsion—starting with the *Nautilus*—as well as the development of power reactors for the utility industry, such as Shippingport, Yankee, and many others.

Development of a well-engineered, reliable, and practical nuclear reactor for any application is a tough technical job. It cannot be done in a matter of months, but rather it requires continuous and orderly development over a period of years.

The application of nuclear power to rocket propulsion is no exception. In fact, because of the high demands placed on it, the nuclear rocket reactor is as difficult a job of reactor development as anyone has undertaken to date.

At full power the reactor will produce more heat than any nuclear powerplant operating today; yet, in size it is among the smallest of reactors. The operating temperature must be over twice that of any reactor operating today.

Although many different technologies have been explored for employing nuclear power in rocket propulsion, the most attractive thus far is the solid-core hydrogen-cooled unit, employing uranium-bearing graphite as the reactor structural material.

This system was under development at the Los Alamos Scientific Laboratory for several years and led to the Kiwi group of reactors and reactor tests. The basic nuclear design and materials incorporated in this system permits much of the reactor development knowledge and experience of the Nation to be directly applied to the program.

As the starting point in the design and development of a flight-type reactor, the Space Nuclear Propulsion Office called for an exhaustive review of the various designs prepared by Los Alamos. The Kiwi B–4 became the preferred basic design since it capitalized to a maximum extent on the accumulated experience. While Los Alamos proceeded with the initial version, leading to the Kiwi tests, our Astronuclear Laboratory undertook redesign to incorporate flight-type requirements. These programs of Los Alamos and Astronuclear have paid big dividends through a two-way exchange of information as design and test work proceeded.

The technical problems in this reactor system can be broadly grouped into three categories:

(1) Structural design;
(2) Fuel development; and
(3) Nuclear and thermal design.

Major progress has been made in all three of these areas.

Mechanical design

From the beginning of the program, it was evident that mechanical design would be a major problem. A structure which can withstand rapid changes in temperature—from low liquid hydrogen temperatures up to the high temperature of gas emanating from the nozzle—requires much detailed study.

This requirement was emphasized late in 1962 when the Kiwi B–4A reactor test indicated a severe vibration problem within the core. Although potential solutions were already manifesting themselves, at the time of the tests, the Space Nuclear Propulsion Office decided to undertake an aggressive analytical and experimental program to insure that this problem would not occur in later tests.

The NERVA reactor, designated the "NRX–A," was redesigned on the basis of information gained from these experiments and the design was thoroughly analyzed during 1963. Experiments with components were undertaken to establish all the design features before large-scale tests were undertaken. Wherever possible, reactor components were subjected to the environmental conditions they would experience within the operating reactor.

Success of this program was indicated by the successful cold flow tests performed on the NRX–A1 reactor in Nevada on March 5 and March 11, 1964, and which are continuing. The tests verified the essential correctness of the careful design work which is required to assure stability and structural integrity under the startup conditions of the reactor.

Fuel development

The principal design requirements for the nuclear fuel can be summarized as:

(1) Uranium-bearing graphite in nuclear optimized proportions;

(2) Sufficient area to allow the required heat transfer to the hydrogen, yet retaining enough structure to maintain structural integrity; and

(3) Adequate resistance to high temperature, high velocity hydrogen corrosion.

The development of a satisfactory nuclear fuel is a continuing program for any type of reactor. Initially the fuel must meet minimum requirements. It must then be steadily and continuously improved to meet higher and higher operational demands. The development of the Kiwi and NRX–A fuel has just about reached the region of minimum demand. Much work yet remains before it can be said that a fully satisfactory fuel has been developed for future demands. Real progress is being made, however, and it appears that today's basic concept can be expanded to meet all future requirements.

Nuclear and thermal design

The nuclear and thermal design problems are also well on the way to being solved.

The first fueled core of the NRX–A design has been undergoing criticality and other nuclear tests at the Westinghouse reactor test facility at Waltz Mills, Pa. The initial criticality experiment proved out within 1 percent of the total required loading of uranium. This is a major technical achievement for a reactor as advanced in concept as the NRX–A.

The nuclear and thermal transients imposed on this design have required extensive laboratory tests. These tests subjected components, subassemblies, and assemblies to as many of the operational factors as could be simulated in the laboratory. As a result, solutions have been found. The program can now confidently direct its attention to problems of high temperature, high heat flux, and to nuclear operation.

The cold tests now underway in Nevada have proven the mechanical design. The total NRX–A design, however, can be evaluated only by a thorough nuclear test operation of the reactor. The first of these is scheduled for August of this year. The components and fuel for this test reactor are now being manufactured and assembled, and the will be shipped to Nevada in June.

Only when the hot test has been successfully completed will we be confident that we have satisfactorily solved the basic problems. This must be done not once but many times, in order to be confident that we not only have a solution but a solution which will be substantiated time after time in space applications.

In closing, let me say Westinghouse is convinced that nuclear rockets are indispensable to space propulsion, for the 1970's and beyond. From our experience to date, we believe that the NERVA program, based on a solid-core hydrogen-cooled reactor, will be successful. We feel that substantial progress has been made, no little part of which has been due to the technical management of the project by joint AEC–NASA Space Nuclear Propulsion Office.

We are confident that the nuclear tests to be carried out during the remainder of this year will be as successful as the cold test, and that 1964 will be the success year of a nuclear rocket program.

Thank you, Mr. Chairman.

CHEMICAL PROPULSION

THURSDAY, MARCH 19, 1964

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on NASA Oversight,
Washington, D.C.

The subcommittee met at 2 p.m., in room 214–B, Longworth House Office Building, Hon. Joseph E. Karth presiding.

Mr. Karth. The meeting will be in order.

I assume a quorum is present. Hearing nothing to the contrary, a quorum is present.

Let me first of all apologize to the witnesses. There are quite a number of rollcall votes and quorum calls going on this afternoon which was not previously known to us, so we must apologize for breaking away so often as we have in delaying the meeting.

I understand that it has been suggested by the staff that each of the witnesses today give an 8-minute summary of their statement. And then there may be some questions on the part of the counsel or the members of the subcommittee and we will begin in alphabetical order with Dr. Kirchner, who is the vice president and general manager of the solid rocket plant at Aerojet-General.

Dr. Kirchner, are you prepared to proceed at this point?

Dr. Kirchner. Yes, Mr. Chairman.

Before I proceed I would like to introduce Dr. Ross, who is our corporate vice president of engineering. And Dr. Moise, who is our assistant program manager of the M–1 program in Sacramento.

I have a prepared statement here which I would like to leave. I am not going to read it.

Mr. Karth. If there are no objections, Doctor, it will become a part of the record and you may summarize your prepared statement.

(The prepared statement of Dr. Kirchner is as follows:)

Prepared Statement by Dr. Werner R. Kirchner, Vice President, Aerojet-General Corp.

CHEMICAL ROCKET PROPULSION

Advanced Technology

I would like to present the viewpoint of Aerojet-General Corp. concerning several pertinent areas of consideration in space chemical propulsion. I would like to review propellants and propulsion concepts based on requirements of each stage of a space vehicle, discussing current state of the art, near-term advances in state of the art, and longer term potential advances, and conclude with some recommendations. The discussion will involve both propellants and engine features with emphasis on programs such as the M–1, the 260-inch solid rocket and the high-pressure feasibility work which relate to these questions.

I would like to first discuss the deep-space stages which are used beyond the earth-orbital-boost operation. For these stages, performance improvement is extremely important since reduction in stage weight is amplified many times in reducing boost vehicle requirements. The current state of the art is represented by the service module and LEM propulsion systems which utilize nitrogen tetroxide/amine fuels with the pressure-fed, ablative and radiation-cooled thrust chamber concepts. The service module propulsion system incorporates multiple restart capability and LEM descent engine involves multiple restart and throttling capability.

Near term state-of-the-art advances in in-space propulsion will involve utilization of first hydrogen/oxygen and later fluorine/hydrogen propulsion systems which provide more than a 100-second gain in specific impulses compared to current systems. This will result in a reduction of approximately 40 percent in weight of all preceding stages. Higher pressure pump-fed engines may be applied to these systems and throttling and restart will also be required for the more advanced engines. Near term state-of-the-art improvements are also required in the area of long-term storage of high-energy propellant. This will come about by improved storage capability for hydrogen and initial utilization of mild cryogenic propellants (such as oxygen-difluoride/diborane, fluorine/hydrasine). Longer range improvements in in-space propulsion may involve use of the beryllium/hydrogen/oxygen propellant combination which has the potential of yielding over 500 seconds delivered specific impulse. This would reduce preceding stage weight approximately 50 percent relative to current nitrogen tetroxide/amine systems. The technology of burning beryllium should benefit considerably from encouraging work currently underway in the development of aluminized jelled storable propellants for military application. For specialized missions involving severe storability requirements, the high-temperature oxygen difluoride/diborane propellant combination may be developed. The oxygen difluoride/diborane system would reduce preceding stage weight approximately 35 percent relative to nitrogen tetroxide/amine system.

On the second-stage propulsion systems NASA has chosen to utilize the optimum propellant combination, hydrogen/oxygen, for current development efforts as well as for advance state-of-the-art efforts. Although hydrogen/oxygen is admirably suited to NASA requirement, military boosters have utilized and will continue to utilize storable instant-ready propellant systems. NASA decision to utilize hydrogen/oxygen rather than oxygen/kerosene in second-stage systems reduced first-stage weight requirements by 30 percent. Modest gains in efficiency (about 6 percent) could be achieved by utilizing fluorine/hydrogen in second stages but handling and utilizing large quantities of this toxic and rather expensive propellant does not pay off in second-stage application. Other possible second-stage propellant combinations such as oxygen-difluoride/diborane or fluorine/hydrazine do not exceed the hydrogen/oxygen payload capability and involve the above-mentioned problems. Although hydrogen/oxygen has a relatively low density over all vehicles, size is not greatly affected when this combination is used in the second stage of a vehicle with the same first- and second-stage diameter. State-of-the-art advances in second-stage propulsion are being achieved through the development of higher thrust and more advanced hydrogen/oxygen propulsion systems. Current state of the art is represented by the 15,000-pound-thrust RL–10 engine which was successfully flown on the Centaur and Saturn I flights and the 200,000-pound-thrust J–2 engine which will be utilized on the S–4B and S–2 stage.

A significant advancement in the state of the art is represented by the million-and-a-half-pound-thrust M–1 engine which operates at a chamber pressure 50-percent greater than the J–2 and three times that of the RL–10. This engine involves development of a high-pressure, high-flow hydrogen pump requiring a 75,000-horsepower-drive turbine. The M–1 engine has the highest specific impulse of any of the hydrogen/oxygen engines currently under development. Major components of the M–1 engine are currently undergoing tests with testing of the complete engine slated for fiscal year 1966. Over 50 percent of the M–1 development facility has been completed at the present time. All but two engine test stands will be completed with fiscal year 1965 funding.

The M–1 schedule based on continuation of current funding levels through fiscal year 1968 will result in initial engine availability in 1971. The M–1 program could be accelerated by application of additional support, for instance, if more funding were made available from fiscal year 1965 on, M–1 PFRT could be moved up to calendar year 1968.

Booster propulsion systems today are represented by the H–1 engines for Saturn I which utilize oxygen/RP, the Titan II engines which utilize nitrogen tetroxide/amine fuel, and the Titan III engines which utilize solid propellant boosters with rubber-extended propellants of the polybutadiene family. Whether solid or liquid, the booster propellants are based on currently available large-scale production of simple chemicals for the propellants, extensive operational experience, and relatively low cost. The oxygen/RP–1 propellant combination costs approximately 2 cents a pound, the hydrogen/oxygen approximately 7 cents a pound, and solid propellant approximately 32 cents a pound.

The current large solid rocket propellants are rubber-extended propellants of the polybutadiene family. These solid propellants are characterized by a sea level specific impulse of 245 sec, excellent strength and storability, and relatively low cost.

As is true of liquid propellants, the primary factor in selection of solid propellants for booster application since large quantities are involved is cost. As an example, assuming a typical space booster mission for a solid rocket first stage, a 10-point increase in specific impulse (from the current 245 sec to 255 sec) would have to be achieved with an increase in propellant cost of less than 18 cents per pound to be economically advantageous. Investigation of higher performance propellants with competitive cost is a continuing activity. Because of the cost restraint, however, this work is centered around commonly available chemicals that do not require new industrial complexes and sophisticated processing techniques in order to achieve production.

The current program on the 260-inch-diameter motors will demonstrate the feasibility of large solid rocket motors as space boosters. The short-length motor will generate 3 million pounds of thrust, the highest thrust level ever achieved in a single motor. With only increase of motor length, this thrust level can be increased to 7 to 10 million pounds.

The advances in mission capability that the large solid rocket offers are—

(*a*) High thrust capability for large payloads.

(*b*) Short development cycle.

(*c*) Relatively low development cost.

(*d*) Compact (high density) propulsion system.

(*e*) Simplicity, and therefore high potential reliability.

Studies by NASA, Boeing, Aerojet-General, and others have shown that a launch vehicle using the 260-inch-diameter short-length motor and the NASA/Douglas S–IVB stage can satisfy these requirements. Results of the Boeing study indicate that this vehicle can launch payloads 100 percent greater than the Saturn I–B at costs per pound of payload that are 50 percent less.

Another promising application of the 260-inch-diameter motor is its use as a strap-on unit to increase booster capability, a concept that has been proven in recent successful launchings of the thrust-augmented Thor. Two 260-inch-diameter motors strapped onto the Saturn V vehicle increase payload capability into low Earth orbit for approximately 250,000 pound to over 400,000 pound, again with significant decrease in cost per pound of payload in orbit.

Beyond uprating of the current stable of large launch vehicles, the large solid rocket motor finds application in the post-Saturn vehicle class when combined with the M–1 engine. Large solid boosters with a M–1 powered second stage can deliver a million pounds to orbit, enough capability to make manned interplanetary exploration a reality.

The current program, ending in July 1965, will demonstrate the feasibility of the basic 260-inch-diameter motor. The next logical step in the program is to demonstrate through further development firings the additional subsystems that are required to make the 260-inch-diameter motor a complete propulsion system ready for final development and flight qualification. The primary elements of this program are demonstration of—

(*a*) Thrust vector control.

(*b*) Nonhazardous thrust termination combined with a malfunction detection system for manned rating.

(*c*) Seven million pound thrust nozzle and exist cone design.

Another improvement in booster performance currently undergoing investigation is the addition of about 30 percent fluorine to oxygen in current oxygen/RP engines such as the Atlas. The 20- to 30-percent payload gain achievable by this method may prove worthwhile if toxic exhaust products do not present too many difficulties.

It should also be recognized that the direct translation of the development of the large hydrogen/oxygen will lend itself to application in a clustered fashion for large boosters. This will probably occur when booster recovery techniques are developed and applied. First stage adaptations of M–1 engine fit this requirement.

Longer term advances in first-stage propulsion can be achieved through the use of very high chamber pressures (3,000 pounds per square inch) and utilization of engine cycles where the turbine drive system is in series with the combustion chamber eliminating pumping losses. Initial work both with storable propellants and hydrogen/oxygen on the high-pressure advanced cycle engines has been encouraging. Partial cycle demonstration has been accomplished, pumping capability has been demonstrated in a small scale and combustion chamber work on a smaller scale is encouraging. In order to proceed from the current status of such work to the point where enough engineering information is available for incorporation of these features in an engine such as M–1, adequate support for medium-scale advanced technology work for a period of approximately 4 years is essential. These advanced engine concepts will increase the payload of a two-stage to orbit system between 10 and 15 percent if used in both stages. The largest payoff for such improvements is in single staged to orbit vehicles characterized by an appreciable gain in the reliability of the overall system and reflected by a 20- to 30-percent payload gain relative to a conventional hydrogen/oxygen powered vehicle.

SUMMARY

In summary I would like to point out that the progressive evolution of the most appropriate chemical propulsion for future space missions is dependent upon a careful balance of attention to research efforts, which will provide the long-term advances; development which capitalizes on the fruits of previous research, and applications which dictates the best integration of available and advanced vehicles for the accomplishment of space missions.

This optimum balance should also satisfy a very important parameter; namely, the availability of the overall resources. Toward this end, let me mention several steps which in our judgment could attain such a balance:

In the research area

1. Advanced liquid engine concepts should be further pursued since additional significant performance gains on the order of 30 percent or so can be gained from this endeavor. The solution of problems associated with the development of an engine which will operate at two to three times the operating pressure of present engines is therefore very pertinent to the overall plan to do the "research homework" now for future vehicles.
2. The addition of beryllium to the hydrogen/oxygen system as a new in-space propellant can produce approximately 70 seconds of additional impulse over the hydrogen/oxygen system and the problems do not appear to be formidable. Certainly, continued research in this area would be well placed.
3. A storable propellant must be developed for upper stage, long-term deep-space missions and for motors to be utilized in lunar base operations. The oxygen difluoride/diborane system appears to have promise.
4. Investigation of the hydrogen/fluorine propellant system is also appropriate and the solution of attendant materials compatibility problems should be attached as early as possible to permit utilization of this propellant system.

In the development area

Let me mention several points: The importance of adequate support in the development area prior to establishment of a firm application can best be emphasized by pointing out that without similar support to the F–1 in its initial phases, the current Saturn V schedule would be impossible and without J–58 turbojet development prior to firm application, the A–11 airplane would not be flying today.

1. A major developmental program related to the space program is the M–1 engine. This engine has incorporated the gains made in previous research investigation and includes improvement learned in the development of other liquid engines. The continued progress of this engine to flight status represents an orderly translation of our learning into a firm vehicle to handle the next generation of space missions.
2. Gains in liquid propellant impulse may be attained in the immediate future by the blending of fluorine with oxygen to be used in conjunction with an available fuel such as R.P. A 20- to 30-percent increase in payload may result.

3. The 260-inch solid rocket motor currently in the current feasibility demonstration stage should, upon proof of its ballistic capability in simple static firing, advance to the next stage of development which would provide the motor with thrust vector control system, a manned rating status which would require the demonstration of a nonhazardous thrust termination technique and a malfunction detection system.

Finally when applications are considered the following points are suggested:

1. The prime consideration in lower stage units is cost. Present propellants are well characterized, and satisfactory and available. The substitution of boosters which will do more for the money is important. The utilization of the 260-inch boosters for the Saturn vehicles can greatly increase the payload capabilities.

2. The most efficient use of engine and propellant systems will provide the greatest assist to the space program therefore, the upgrading current propellants by the addition of additives which can be used in the same engine represents an immediate gain.

FURTHER STATEMENT OF DR. WERNER R. KIRCHNER, VICE PRESIDENT, AEROJET-GENERAL CORP.

Dr. KIRCHNER. Thank you very much, Mr. Chairman.

So introducing the Aerojet-General Corp. viewpoint, I would like to confine my remarks to the propellants and propulsion concepts, based on the requirements for each stage of a space vehicle.

And I would like to reference the state of the art, the near-term advantages which could be realized and also some of the long-term gains and conclude with certain recommendations. I would like to also point out that the remarks which we are going to make here, that they are all probably viewed through the prism of the M–1 program, the high-pressure liquid engine and also the 260-inch, solid-propellant rocket. Going back to the stages I would like to start with the chapeau, and this is with the deep-space stages and point out the particular state of art presently is confined to probably two engines and this is the LEM and the Apollo service module which are being propelled by a fuel system with nitrogen tetroxide and amine fuels.

Now, I think as a rather important impact here because the reduction in weight and specific impulse in these particular stages have a rather transcending effect on the subsequent stages. The engines are described as pressure-fed systems, utilizing ablative combustion chamber and as far as performance is concerned, characterized by multiple starts and throttling capability.

When we look at the near-term advantages here, we view them in the propellant area in the introduction of hydrogen-oxygen system, hydrogen-fluorine system, in which a gain of 100-seconds impulse could be realized, resulting in a reduction in the preceding stages of about 40 percent.

The engine features, I think in the near-term future are going to be still characterized probably by higher pressure pump-fed systems and still have the throttling and restart capability. As far as other advantages are concerned I think we are probably just looking for long storage and this would be in the improvement for the hydrogen and probably the utilization of mild cryogenics such as oxygen difluoride or diborane or fluorine and hydrazine. On the longer range improvement we visualize the introduction of the tri-propellant systems here and we are looking quite diligently at systems such as beryllium, hydrogen, and oxygen, where I think specific impulse over 500 seconds could be realized and we believe this is going to be our immediate, probably spin-off, advantage, which could be realized by the investigations of the aluminized propellants in the N_2O_4 and amine systems.

As far as the second-stage propulsion is concerned, we believe that the selection by NASA of the introduction of the hydrogen-oxygen system was an extremely fortunate one in which we believe that the immediate gains of about 30 percent in weight reduction of the vehicle could be recognized over the nitrogen tetroxide and amine systems which are being employed extensively for the storable system for some of the weapons systems.

On other systems we are looking probably at oxygen-difluoride again here and diborane and again with fluorine and hydrazine as possible contenders.

The current state of art, as far as engines are concerned I think are characterized by three; namely, the RL–10, J–2, and the M–1, the 15,000-pounds, 200,000-pounds and one-and-a-half-million-pounds thrust engines, which I think represent a very good spectrum as far as vehicles are concerned.

I would like to just mention one point here that the entire program for the last one-and-a-half-million-pound thrust engine in the lox-hydrogen class, I think the engine availability is now scheduled for 1971. We believe that with application of additional effort that this could be moved up and probably on a 1968 availability, which would not be out of question.

This brings me to the booster systems where the present systems, as far as propellants are concerned are characterized by lox-RP, nitrogen tetroxide and amine system such as on the Titan II, lox-hydrogen, of course, for M–1, and the heterogeneous combination system where we have the Titan II engines.

I would like to point out here for these applications that the propellants are based on simple chemicals where the extensive processing experience is being utilized to a great extent and primarily in general confined to nontoxic materials.

Also, I would like to point out here that low cost, of course, is of primary importance. If we look at energy release, for instance, of the solids, I have in my report here 245, we actually for the large 260 we are talking about 247, which is equivalent in vacuum specific impulse of 283.

I would like to also point out that the aspects of the economics here are, of course, most important, because if we really consider the increase of 10 units in specific impulse in these particular propellants you have to be below an 18-cent price increase for the solids in order to even gain the advantages on the first stage. So, as you can see here, we are working really in very narrow margins. So, again, I would like to reiterate here that our recommendation would be for the very large boosters, chemical boosters, regardless of whether they are liquid or solid, that they should center around commonly available chemicals and not sophisticated processing involved. The 260–inch unit, for example, is an example of it and 3-million-pound thrust engine which is going to be the largest in this country here I think is just the horizon. We believe by the simple extension in length we can extend the thrust rate in here up to 7- or 10-million-pounds thrust.

The advantages which we like to state here, that I think are high in the solid area, is the high thrust capability, short development cycle, relatively low development cost, and probably high density of the overall propulsion system and probably the simplicity, which, of course, might be reflected, also, by impressive increase in reliability. We looked over a Boeing study here which states that the introduction of the solids in this particular area could be accomplished by yielding a vehicle which would have 100-percent greater payload capability with a 50-percent reduction in cost taking the example of the Saturn I–B.

One of the things which we like to leave here; this is the necessity for the development of thrust vector control system for these units which presently are, in the overall program, not introduced yet. I would like to also mention in the booster systems that there might be a spin-off of the program in M–1, introducing the units around a plug nozzle and combining it with a recovery system might yield an advantage here. I would like to also mention the introduction of single stage to orbit, you will note in the writeup here would probably be specially realized if we would consider the high-pressure engines. Summarizing here, I would like to just leave the thought that we look at our progressive evaluation of all the chemical propulsion in space with a rather careful balance in which we are taking the research efforts which provide the long-term advances in one consideration, the development where we are capitalizing on the fruits of the previous research and the application is the third one, and to our best integration for available propulsion systems.

Here we also would like to make sure that we are optimizing here within the confines of the available resources.

So that reminds me of the description of a muu-muu, the shapeless dress which somebody said this is identified as a body which maintains a bank account, you know it is in there, but you don't know how much. We believe that with the overall analysis of all these four components, we could probably come up with fairly reasonable recommendations.

And these are in the research areas, we would like to recognize the gain of the 30 percent in systems by the utilization of the advanced high-pressure engines, the work centered around the tripropellant system with beryllium and hydrogen and oxygen and storable upper stage where OF_2 and diborane or hydrogen and fluorine is a very good candidate. In the development areas we would like to just make one point here and this is that the support of the programs without the immediate applications, I think should be encouraged. I would like to point out here we probably wouldn't have a Saturn V vehicle if the work hadn't been done on the F–1 in advance, for example, also we wouldn't have probably today our A–11 fighter if the work on the J–58 engine wouldn't have been encouraged without the recognition that actually at the time the work was done there was application for it. So we believe the M–1 is our example in this particular area. The blending of fluorine with oxygen is another one, and the introduction of the solid 260-inch rocket with introduction of TVC and the man rating of the system as a very important consideration.

In the applications which we would like to encourage everybody around us especially to make sure that the application of the 260-inch solid propellant booster is being considered because the gains which we already are seeing now, whether this is in the application of the Saturn I–B or of the Saturn V, I think are quite impressive, if we consider the half-length or the full-length boosters in the basement of these particular vehicles.

Mr. Chairman, this is all I have to say on behalf of Aerojet.

Mr. KARTH. Thank you very much, Doctor.

During your presentation you made a recommendation, maybe I didn't understand it correctly, but I think I did, you said that insofar as large boosters are concerned we should stay within the state of the art rather than develop the more sophisticated high energy propellant systems. Did you mean this for development, or did you mean it also for research and development?

Dr. KIRCHNER. If I understand your definition of research and development I would say yes, this is actually for the immediate engines for the applications for vehicles. I would stay with the simple chemical systems.

Mr. KARTH. What do you designate as the simple?

Dr. KIRCHNER. I would consider lox-hydrogen as one, I would consider polybutadiene as one. In the storable areas I think N_2O_4 and the amines. But these are systems quite well defined and I think as far as the processes are concerned they are quite reproducible and they are not going to introduce a significant development angle in the large engines.

In addition to that, I think the aspects of costs are, of course, very important because, of course, we are utilizing these materials in millions of pounds.

Mr. KARTH. Wouldn't you include also in that group hydrogen-oxygen?

Dr. KIRCHNER. Yes, sir.

Mr. KARTH. How about fluorine-oxygen?

Dr. KIRCHNER. Well, I think if we look at the cost of fluorine, probably presently I would probably not consider it. I would also, because of the large quantities and utilizing this material in the, let's say, immediate stages, I would be probably concerned a little bit about the toxic aspects of the system.

Mr. KARTH. You would also place fluorine-hydrogen in the same position, I assume?

Dr. KIRCHNER. Yes.

Mr. KARTH. How about the diboranes?

Dr. KIRCHNER. As far as the storability of the propellants are concerned I think they are most impressive and I think the work should be encouraged especially in the area of upper stages. I think the payoff, as far as energy release, I think is quite important and I think utilizing it in also small quantities there I think the aspect of cost could be very well accommodated.

Mr. KARTH. So you are recommending that we do considerable research in these areas where more sophisticated propellants are involved, but insofar as the development of large boosters are concerned we should stick with the state-of-the-art propellants, is that what you are saying?

Dr. KIRCHNER. Yes, sir.

Mr. KARTH. On page 4 of your prepared testimony—I have tried to skip through this very rapidly, you say the M–1 program could be accelerated by application of additional support, for instance, if more funding were made available.

Dr. KIRCHNER. Yes, sir.

Mr. KARTH. How much additional support?

Dr. KIRCHNER. Well, I think probably if we could, let's say, double the effort in this particular area, this would be, starting in 1965.

Mr. KARTH. Then we would hit the calendar year 1968 date as opposed to the 1971 date, is that right?

Dr. KIRCHNER. Yes, sir.

Mr. KARTH. By doubling the effort this year and maintaining that effort for the next several years?

Dr. KIRCHNER. Yes, sir. I am talking about the fiscal year 1965 actually now.

Mr. KARTH. Now, the M–1, that is hydrogen-oxygen, isn't it?

Dr. KIRCHNER. Yes, sir.

Mr. KARTH. And you include that as one that is within the state of the art?

Dr. KIRCHNER. Right. As far as fuel systems are concerned, I think they are quite well characterized.

Mr. KARTH. You talk about the longer range improvements in space propulsion by the use of beryllium or aluminum-hydrogen-oxygen combination?

Dr. KIRCHNER. Yes.

Mr. KARTH. I wonder if you could better identify this longer range definition. What do you mean by longer range? What time frame are you thinking about for this propellant system of the future?

Dr. KIRCHNER. I think probably I would place it in, as far as the aluminum systems are concerned, I think we are doing quite a lot of work already now on the storable system with nitrogen tetroxide and the amine system. We identify them as gel propellants and I believe in the next 3 years we probably are going to see some fairly good hardware coming through the test area.

Mr. KARTH. There have been some tests already made by the military with these propellants?

Dr. KIRCHNER. That is right, the aluminized system. This is an effort which is still quite limited but it is exploratory, in which we are utilizing the Titan hardware and we are using the tripropellant system for the evaluation now. The problems I think are probably going to center around certain heat transfer programs around the nozzle area, but we believe that this particular effort you can directly translate to the beryllium, where beryllium hydrogen oxygen system, where you have really quite an impressive gain. This would be one of the rather simple chemical systems still, and yet—because you don't have to especially embark on unusual marshaling of industry, and give you a propellant which has a specific impulse of 500 seconds.

Mr. KARTH. I understand with modest modification of our present stable of vehicles, the so-called aluminized gel storable propellants could be used. Is that your understanding of the advancement we have made?

Dr. KIRCHNER. On aluminum, yes. On beryllium there is very little work done yet. But I think the point being that we are working now on components in Aerojet in the introduction of this, this tripropellant system.

Mr. KARTH. Is it true that with modest modification of our present boosters that we could use the aluminized gel storable propellant?

Dr. KIRCHNER. This is visualized that this would require modest modification; as far as really supporting it by actual evidence we don't have too much of it under our belt.

Mr. KARTH. Would you say it would require greater modification than the flox, for example?

Dr. KIRCHNER. Well, I would feel that it probably might require more.

Mr. KARTH. But the net result is that the payload again would be substantially more, would it not?

Dr. KIRCHNER. Well, between floxing the engine and aluminum I guess this program might be pretty close to it. Wouldn't you say, John?

Mr. MOISE. That is right. The gain with aluminum in a storable system might be comparable to the gain in floxing a lox-RP system, would not be greater, but some of the other metals, for instance, the aluminum hydride which may come along in the storable systems would provide a substantial gain.

Mr. KARTH. Mr. Bell?

Mr. BELL. I have no questions, Mr. Chairman.

Mr. KARTH. Mr. Wilson?

Mr. WILSON. Dr. Kirchner, in your analysis of using these various propellants that you are describing beyond the current systems, have you made an analysis of the tradeoff in dollars per pound of payload that might be achieved by the near future propellant systems that you have been talking about, both solids and liquids, on such systems as the Saturn V?

Dr. KIRCHNER. We did it on a similar system and in which, as far as the solids are concerned, I think 18 cents a pound breakoff point we recognize on the 10-second impulse; I think the most impressive gains are around a factor of four, which you can do for a third stage and I think this is more or less in relation to the same figures which Mr. Tischler mentioned in his testimony here a few days ago.

Mr. KARTH. I wonder if I could interrupt to ask a question at this point. If we used as much solid propellant as we do with the state-of-the-art liquid propellants today, what would that do in terms of reducing the cost for solids?

Dr. KIRCHNER. As far as the reduction of costs of solids are concerned, I think when you look at the 260-inch engine, I think they already are fairly low. We are talking about something in the neighborhood of one and a half dollars a pound of total hardware, which I think represents already a very low-cost item for space propulsion.

So the extension in the additional use I think probably is going to be fairly limited.

Now, I don't know whether I have answered your question, Mr. Chairman, but we already——

Mr. KARTH. You say on page 6 of your statement the results of the Boeing study indicate that the 260-inch-diameter launch vehicle, will launch payloads 100 percent greater than the Saturn I–B at costs of currently planned payload that are 50 percent less. I am not sure what kind of a yardstick Boeing used in determining the cost of the propellant. So my question was that if we used as much solid as we today use liquid which normally should make the propellant cheaper, would it still further reduce that figure, and, if so, how much?

Dr. KIRCHNER. I think we have to compare now the costs, the comparison was made for the Saturn I–B, if I recall correctly and I don't think—I think the gains, it depends when the introduction of the solid would be made as far as then retrieving, let's say, from the funds allocated for the I–B to begin with.

Mr. KARTH. Well, it has always seemed to me that we have spent so little really in the development of solid propellants, and that had we made a little greater effort in this field that we might now be enjoying a substantially lesser cost in the use of solid propellants and as a result of that it might even encourage greater speedup of development of the large solids. Would you agree with that statement?

Dr. KIRCHNER. Yes, sir. I think the point of view is very well, I think, also recognized in the industry and I am pretty sure that Dr. Ritchey would also underwrite it.

Mr. KARTH. Thank you very much, Dr. Kirchner, we appreciate your appearing before the committee.

RESPONSE TO PREPARED QUESTIONS FROM THE SUBCOMMITTEE ON NASA OVERSIGHT COMMITTEE ON SCIENCE AND ASTRONAUTICS OF THE HOUSE OF REPRESENTATIVES

(By Dr. Werner R. Kirchner)

Question. Aerojet: "What are your latest ideas in the area of advanced propulsion? What are the chief advantages of a staged combustion engine over more conventional engines? Have you ever experienced combustion instability in a stage combustion engine? If not, isn't this an immediate tremendous advantage over our present engines? Shouldn't it reduce blow-ups and generally shorten engine development time? Are there advantages this system has over the present Saturn and M–1 engine system?"

Answer. Aerojet's latest ideas in the area of advanced propulsion for boosters involve the use of high chamber pressure and a staged combustion engine cycle. High chamber pressure provides higher engine specific impulse by permitting a higher expansion ratio nozzle to be used. The staged combustion cycle, with the turbines in series with the combustion chamber, eliminates energy losses normally required to drive the turbine. These two effects can result in specific impulse gains of about 20 seconds relative to conventional engines. Our advanced technology work with liquid oxygen/liquid hydrogen for NASA, and with storable propellants for the Air Force has produced encouraging results both with respect to staged combustion cycles and high-pressure operation. Initial results indicate that combustion instability may be eliminated by stage combustion; however, it should be pointed out that a great deal more testing must be accomplished before conclusive results can be assured in an area as complex as combustion instability. If these results continue to be encouraging as we anticipate, the absence of serious stability problems which has also characterized current liquid oxygen/liquid hydrogen engines, such as the RL–10 and J–2, should continue when the more advanced systems are developed. There are some indications that combustion of gaseous rather than liquid propellant such as occurs in regeneratively cooled liquid oxygen/liquid hydrogen engines minimizes stability problems. It is extremely important to carry on the high-pressure advanced technology work at an increased level of support for the next few years so that a firm engineering basis will be provided for incorporation of these modifications for future improvements into such engines as the M–1.

Question. Aerojet: "Do you foresee any major technical problem areas in your advanced engine configuration which have yet to be solved? If so, what are they? Have you been given any NASA funds to tackle these problems? How *much funding have you put into this effort, company funds versus NASA or DOD funds?"*

Answer. We do not foresee any major technical problem areas in the advanced engine that cannot be solved with sufficient advanced technology effort; however, considerable engineering data remains to be determined. Primary areas of further effort include demonstration of the completed staged combustion cycle in both transient and steady state operations, pump feasibility work on both axial flow and centrifugal flow pumps to provide a firm basis for deciding the best type of pump for large high-pressure engines, and technical work in the combustion chamber cooling areas to determine the most desirable approach to this problem. To date $2 million in NASA funded activity, $10 million in DOD funded activity, and well over half a million dollars of company sponsored work has taken place at Aerojet.

Question. Aerojet: "Do you feel that this advanced engine concept will result in a heavier, or lighter engine per pound of thrust than the lower pressure system? For what reasons? Will the overall booster system be lighter, too, or must the tanks and other items of the booster be heavier with such an engine?"

Answer. The advanced engine concept will probably result in a slightly heavier engine per pound of thrust than a lower pressure system. This is due primarily to the increased turbopump weight associated with very high power turbopumps. The overall booster systems will be lighter since the increase in engine efficiency more than compensates for the engine weight. These advanced engine concepts will increase the payload of a two-stage to orbit system between 10 and 15 percent if used in both stages. The largest payoff for such improvements is in single staged orbit vehicles, where a 20 to 30 percent payload gain relative to a conventional hydrogen/oxygen powered vehicle may be achieved.

Question. Aerojet: "Do you believe that as the newer technology develops, with its larger and more powerful engines, we will see a trend toward fewer booster stages and fewer engines per stage? Isn't there a trend toward 'single stage to orbit'?"

Answer. The trend toward larger and more powerful engines will certainly result in improved reliability; for instance, we would like to cite two examples: (1) the substitution of a single M–1 for the five J–2's in the S–II stage would produce not only a more powerful stage but a more reliable one with a single engine, (2) the first stage of the Saturn I–B vehicle requires eight H–1 liquid engines. They could all be replaced by a single short length 260-inch diameter solid motor. If this were done, the payload of the Saturn I–B vehicle could be increased to anywhere from 50,000 to 80,000 pounds into orbit, representing over a 100-percent increase. This is a distinct advantage in considering the question of simplification of booster stages by reducing the number of engines required. At the same time, because of the relatively low cost of the solid rocket and because of the very significant increase in payload, the operating cost of the vehicle expressed in dollars per pound of payload in orbit could be reduced by up to 50 percent.

By utilizing more powerful and efficient engines and high specific impulse propellants, such as liquid oxygen/liquid hydrogen, two-stage-to-orbit boosters are quite adequate today even if weight were added for recoverable systems. Eventually, it is expected that single-stage-to-orbit boosters will be possible due to advances in both the technology of liquid oxygen/liquid hydrogen engines and stage construction; when this occurs, inherent reliability will be greatly improved. Another important aspect of single-stage-to-orbit boosters is that when developed in a recoverable version, they can be recovered at the launch site after orbiting, eliminating the booster recovery transportation problem.

While the performance characteristics of large solid rockets do not lend themselves to single-stage-to-orbit devices, they do definitely lend themselves to very appreciable simplification and reduction in the number of engines required in two-stage-to-orbit vehicles. A two-stage-to-orbit launch vehicle employing a single large solid rocket motor for each stage would probably have a far fewer total number of engines than the presently conceived single-stage-to-orbit liquid propellant vehicles that require a cluster of liquid engines to achieve the required thrust level.

Question. Aerojet: "Do you feel that high density, but higher cost per pound, advanced propellants might be more economical in the long run in our space program? What effect does propellant cost have on development and operation of a booster system? A number of technical people have said that for upper stages, at least, the propellant cost, however high per pound, is still very incidental when *compared to the overall system cost. Is this true of the lower stages too? In the case of a very large booster—any one which has a capability of placing a million pounds of payload in a low Earth orbit—could you design a booster system no taller than the Saturn–V booster, which itself puts some 250,000 pounds in orbit, and using high-density propellants and advanced propulsion technology, put that million pounds in orbit instead? If it is true that we could ultimately save the price of building an oversized launch pad, which might cost about $1 billion each, NASA might justify spending for greater propulsion development funds right now in advanced propulsion development to effect the later savings."*

Answer. High costs per pound advanced propellants are certainly justified in the deep space stages to be used in our space program where large gains can be achieved with systems requiring relatively small engines and small amounts of propellants. The most important parameters in these systems is specific impulse, with density of some importance, and for extended missions (6 months to 2 years) space storability is also important. For example: the high cost of beryllium in the beryllium/hydrogen/oxygen system can be justified by its 500-second specific impulse potential for missions which do not require extended space storability. For extended trips, the cost of such propellants as oxygen difluoride/diborane is more than justified compared to the lower performance obtainable from Earth storable propellants. The most effective way such advanced propellants reduce booster costs is by extending the effectiveness of existing boosters and providing greater capability for a given size of new boosters. It does not appear to be desirable to use these propellants directly in first or second stage applications due to very high cost and toxicity considerations. It should be pointed out that development of the M–1 engine for use in the first and second stages of the large Post-Saturn vehicle studies have indicated the requirement for large diameter payloads approaching 70 feet permitting reasonable length boosters even with the low-density, high-performance, liquid hydrogen/liquid oxygen propellant combination. Even more compact vehicles can be obtained if solid propellants are used in the first stage and liquid oxygen/liquid hydrogen in the second stage of a two-stage, with the second stage the same diameter as the first stage. For instance a booster utilizing four short-length 260-inch-diameter solids in the first stage and two M–1's in an upper stage would place over 400,000 pounds in orbit and would be shorter than the first two stages of the current Saturn V launch vehicle. In summary, the highest performance propellant, almost regardless of its cost, should be used in deep-space stages, while the first two stages of the launch vehicle should utilize high performance conventional propellants which are relatively inexpensive.

Question. Aerojet: "Has your company studied recoverable booster systems? How do they look at present? How much are you being funded by NASA in this area presently? Does the recoverable booster system result in different selection criteria for propellants than the nonrecoverable systems? Has NASA funded any of your studies on air augmentation?"

Answer. Our company has conducted two rather extensive recoverable booster studies. One system, the Astroplane, provided a single-stage-to-orbit recoverable booster with aerodynamic capability providing glide landing. This booster is based on the utilization of M–1 liquid oxygen/liquid hydrogen engines. The concept is promising but very careful attention must be paid to system weight or any other single-stage-to-orbit recoverable booster. The other system studied, Sea Dragon, involved a two-stage, pressure-fed, water recoverable booster concept. It attacked the booster recovery problem by going to very large systems, which were easily handled and launched from the water and recovered in the ocean, after a free fall. These studies also indicated promising results but considerable more work is required to prove the concept. In addition to these studies of recoverable booster systems, Aerojet has provided propulsion information to airframe contractors to support their studies of the 10-passenger carrier, aerospace plane, Post-Saturn vehicles and other recoverable systems.

The lower system operating costs of recoverable boosters tend to emphasize propellant costs by lowering other operating costs when compared to expendable systems. The relatively low cost liquid hydrogen/liquid oxygen systems appear to be well suited for recoverable boosters since its 7-cents-per-pound cost coupled with high specific impulse, which allows for accommodation of additional recoverable system weight, is unmatched by any other propellant combination. In addition to low cost and high performance, liquid oxygen/liquid hydrogen systems have the following advantages: a nontoxic exhaust which minimizes launching problems, no residual propellant engine cleaning problem since both propellants boil, and finally the excellent coolant properties of hydrogen for use in protecting systems during reentry. We have made preliminary studies to determine if air augmentation can improve overall systems performance. Air augmentation studies as well as our recoverable booster studies were company sponsored. Our air augmentation studies were initiated as a result of our own thoughts and some suggestions from NASA.

Question. Aerojet: "What type of propellants, or what propellant combinations, best suit storage in space? On a future trip to the planet Venus, what percentage of fuel in a liquid hydrogen tank would remain in a typical round trip, with a month's time circling the planet, for the earth-approach, velocity-matching engine? If the answer is 'Low,' or 'None,' this makes a good case for space storable propellants, doesn't it? Are high-energy propellants more important for these longer trips, too?"

Answer. For the relatively small volume propellant tanks involved in the unmanned planetary exploration missions, storability of the deep cryogenics such as liquid hydrogen is quite difficult even with good insulation techniques. For a vehicle accomplishing the Earth-approaching, velocity-matching mission only, a small quantity of liquid hydrogen would remain in the tanks. For such applications, high energy, space storable propellants become extremely important.

Question. Aerojet: "What elements of the M–1 engine provide advances in the state of the art? What advances does the 260-inch-diameter large solid rocket program provide? For future in-space propulsion requirements, what areas of propellant development should be investigated?

Answer. The M–1 provides major increases in the state of the art with respect to thrust since it is 7½ times the size of J–2; with respect to chamber pressure it is 50 percent greater than J–2 and three times as great as the RL–10; and whose specific impulse is greater than any other hydrogen engine currently under development.

The gas generator, which provides a mixture of hot steam and hydrogen to drive the 100,000 horsepower turbopumps, has a flow rate approximately three times the total flow through the RL–10 rocket engine. The liquid oxygen cooled oxidizer turbopump bearings and liquid hydrogen cooled fuel turbopump bearings, the largest and heaviest load carrying bearings of this type under development. The liquid oxygen bearings have been run over 30 minutes and fuel bearings more than 20 minutes at greater than design load. The continued development of the M–1 to flight status represents an orderly translation of our learning into a firm vehicle to handle the next generation of space missions.

For future in-space propulsion the following propellant combinations should be actively investigated: beryllium/hydrogen/oxygen for its extremely high specific impulse makes it useful in missions involving not more than a couple of months of space storage missions; and such combination as hydrogen peroxide/hydrazine-beryllium hydride which is storable for extremely long periods of time and has high specific impulse.

Concerning the 260-inch large solid rocket program, there are two specific areas where component technology is being advanced. The first of these is in the use of maraging steel for rocket combustion chamber. This material is particularly well suited to large solid rockets by virtue of its good ductibility at high-strength levels and because it does not require conventional heat treatment of the complete unit; and therefore, eliminates the need for new, very large heat-treat facilities.

The second area in which technology is being advanced is in the use of ablative plastic insulating material in the nozzle throat. By virtue of the large size of these motors, some dimensional change in the nozzle throat diameter is allowable without significantly affecting the motor performance. This opens the door to use of the ablative plastic materials in the throat region rather than refractory materials such as tungsten or graphite. The advantages of the ablative plastics are: no inherent size limitation, better quality control than is obtainable with graphite, lighter weight than is obtainable with tungsten, and elimination of thermal stress problems. Ablative plastic materials have already been well characterized by use in the exit cone sections of nozzles in the newer models of the Polaris and Minuteman motors.

From the standpoint of large solid rocket technology, the primary aim of the program is to assemble existing solid rocket component technology into this new large unit rather than to push the state of the art in all areas. The program will demonstrate the solid rocket industry ability to perform this integration of technology and to solve the manufacturing and facilitization problems attendant upon the production of such a large monolithic unit.

As mentioned earlier, space-vehicles studies indicate a need for numerous specialized rocket motors for in-space tasks. We do not wish to overlook the necessity to develop high-energy solid propellants for possible application where the unique advantages of the propellant and/or the solid rocket motor make its use desirable. Some of the systems worthy of study are binder systems incorporating new additives such as beryllium, beryllium hydride, and aluminum hydride. Aerojet has already made firings of such propellants. The incorporation of certain high-energy oxidizers should also be explored. Encapsulation techniques to permit the incorporation of highly reactive ingredients should be continued, and further studies to improve the basic structure of polymers are warranted to tailor the propellant properties to meet the environment of space.

1. Question. "When will present 260-inch, half-length development program be completed?"

Answer. "July 1965."

2. Question. "To the best of your knowledge, does NASA have a follow-on program? What will it entail and when will it begin?"

Answer. "We understand that NASA is currently planning a follow-on program for the 260-inch-diameter motor. It is our understanding that this program will be funded from fiscal year 1966 funds, which would indicate a probable go-ahead date for the follow-on work of January 1966. It is our further understanding that this follow-on program will be aimed at demonstrating thrust-vector control and other subsystems that will be required for flight applications of the 260-inch-diameter motor and that the program will probably include refurbishing, reloading, and refiring the two short-length 260-inch-diameter motor chambers that we are fabricating under the current contract. This follow-on program using the refurbished short-length 260-inch-diameter motors can be identified as an interim program prior to proceeding with the program for fabrication and static testing of the full-length 260-inch-diameter motor. Such demonstration of the full-length, 260-inch-diameter motor would be the logical next step following this interim program unless a specific application for the 260-inch-diameter motor is determined, in which case the most logical course of action is to move directly to development, flight rating, and production of the specific motor required for that application. It is our belief that we can move directly into a development and production program on the 260-inch-diameter motor as soon as the first short-length motor firing under the current program has been successfully concluded."

3. Question: "The present program will be complete in July 1965 and the follow-on was planned for January 1966. Why such a long gap? How does the gap affect you if it is assumed you are selected for a follow-on?"

Answer. "It is our understanding that time gap between completion of the current program and initiation of the follow-on program is a matter of how soon fiscal year 1966 funding can be made available. A 5- to 6-month gap between programs will create a significant problem in maintaining the experienced engineering force and trained labor that will be available at completion of the current contract as an integral team. Since this program constitutes the sole effort at our Dade County plant, there does not appear to be any way of using other work as a gap filler. Furthermore, in Sacramento, where our engineering work for the 260-inch-diameter motor program is carried out, a reduction in labor and engineering force is already underway as a result of decreasing workload. Thus, it would be difficult to temporarily assimulate the engineers from the program into other programs and call them back again upon initiation of the follow-on work."

4. Question: "What would you recommend to fill the gap until a full-length follow-on contract was provided?"

Answer. "We believe that the program we understand NASA is studying is a logical follow-on effort and if funded at the rate of $15 to $20 million per year (per contractor if more than one contractor is carried in the interim phase) will achieve the very useful result of demonstrating thrust-vector control and other necessary subsystems on the large solid rocket motor so that the motor will be immediately adaptable to a flight program. We do believe that a gap between the current and follow-on programs should be avoided from the stand-points of economy and technical continuity. One way in which this could be accomplished is to provide a small increase in fiscal year 1965 funding such that the follow-on program could be initiated upon completion of the current program rather than waiting for fiscal year 1966 money to become available. This funding could be used to initiate refurbishment of the chamber of the first 260-inch-diameter short-length motor and to initiate the necessary subscale development work attendant upon full-scale thrust-vector control demonstration. Three to five million dollars would be adequate for this purpose."

Mr. Carpenter, manager of the Callery Chemical Corp., would you summarize your statement and without objection your prepared statement will be submitted for the record.

Mr. CARPENTER. Thank you, Mr. Chairman. I appreciate the chance to present our views on chemical propulsion. I have a prepared statement which I shall submit for the record and which I will briefly summarize at this time.

(The prepared statement of Mr. Carpenter is as follows:)

PREPARED STATEMENT OF RICHARD A. CARPENTER, MANAGER, WASHINGTON OFFICE, CALLERY CHEMICAL CO.

Mr. Chairman and members of the subcommittee, Callery Chemical Co. welcomes the opportunity afforded us to comment once again on the state-of-the-art in propellant chemistry. Our company's principal business is research, development, and production of chemical ingredients for propellants. Typical of the chemical propellant industry, Callery does not make rocket engines. Therefore, the plans and requirements from Government agencies and industrial contractors determine our efforts and success. The frustrations, delays, and disappointment of the past years might suggest that prudent chemical management would reject chemical propulsion as an unprofitable business. However, the technical basis for the eventual use of high energy chemicals is sound. Further, studies from the systems engineers continue to indicate, as did Mr. George H. Stoner of the Boeing Co. just this month, "I might sum up the lessons inherent in the previous discussion of launch vehicle system parameters. The way to keep launch vehicle costs down in any program of expendable launch vehicles for transport to space includes the following sequence of events: First, choose the best propulsion system available—the highest specific impulse." Callery believes that the conservative policy on advanced propulsion, and not technological inadequacy, is the principal reason that better propulsion systems are not available today.

SUPERIOR CHEMICAL PROPELLANTS ARE ESSENTIAL TO PREEMINENCE IN SPACE

The technical basis for developing advanced chemical propellants is rooted in the laws of physics and chemistry. These say, simply, that the rocket engine is the only means of achieving the high velocities necessary to escape the Earth's gravity and move about in space. They state further that when the payload weight fraction of a rocket is established, then a minimum specific impulse is also set, or the required velocity cannot be reached at all. Thus, a statement of national policy to be preeminent in space quickly resolves itself into a requirement for high specific impulse engines. Without improved propellants, our space program will be restricted to small payload weight fractions on top of gigantic, expensive Nova-type launch vehicles.

The obvious desirability of high specific impulse propellants led to the derivation of more specific mechanical and thermodynamic equations which stated that the most important properties of a chemical propellant are low molecular weight and high energy content. The chemist turned to the periodic chart of the elements and selected hydrogen, the light metals (lithium, beryllium, aluminum, boron), carbon and nitrogen, and oxygen and fluorine as the most promising atoms to incorporate into liquid or solid propellants. In the past 10 years the chemical industry has thoroughly explored these elements and compounds. The performance of the new chemicals has been compared with conventional petroleum derived fuels and liquid oxygen or nitrogen tetroxide oxidizers. Several combinations show remarkable improvement and have been developed to the extent that large scale production has been demonstrated. No commercial, nonpropellant use exists for most of these special chemicals so the Government becomes the only customer and must bear the cost of development. Nevertheless, economical processes have been worked out, pilot plants built, safety and handling procedures developed. Availability of these advanced propellants should no longer be in question.

The complete and exhaustive nature of this research phase in the past few years also makes it clear that no new, radically improved chemicals will turn up in the future. After all, there are only so many elements and combinations possible. So we need not hesitate in applying these chemicals for fear of obsolescence.

It is frequently stated that we have no knowledge that Russia is developing exotic propellants and since their record in propulsion achievement is very good, perhaps the United States should be content with conventional fuels. The reply to this may be seen in the recent announcement that Russia is concentrating great resources to expand its chemical industry in the next few years. Though their political laws are different from ours, the laws of thermodynamics are universal and we can conclude that lack of ability, not lack of interest has delayed their development of high-energy propellants. The chemical industry of the United States is one of our strongest assets and we should exploit the achievement of large scale production of improved chemical fuels and oxidizers.

THE APPLICATION OF ADVANCED PROPELLANTS MUST COMMENCE

The research phase has been the beginning and the end for most advanced propellants. There are several reasons for this. The next phase is application of the propellant to a flight weight system to demonstrate the reliability which space mission designers demand before they will choose a new propulsion unit. This is much more expensive than research. The conservative policy is to not begin this phase unless it can be demonstrated convincingly that the added impulse is needed for the mission. Alternative choices of a bigger booster or decreased payload are available.

The Apollo program may be used to illustrate the quandary of the mission designer. Today we read of constant efforts to shed payload weight, such as substituting harnesses for seats, because of the marginal performance of the conventional propellants selected for Apollo propulsion. It is too late now to substitute higher impulse propellants. There was actually little choice in propellants several years ago when Apollo design was frozen. We will meet this same frustration in future space missions if we do not advance propulsion state-of-the-art so that designers have a real choice among propellants.

Another roadblock to a logical advance of the application phase is the annual fiscal policy of the Government which makes it very difficult to spend a dollar now to save several dollars a few years in the future. We believe that if the United States is going to spend $40 billion in rocketry during the next 10 years, propulsion expenditures should be emphasized at the start, even if we can't detail the exact missions. The vital relationship of specific impulse to the cost of payload in orbit, or on course in space, assures that an early investment in propulsion would pay off with interest.

Last year, before this committee, Callery commended the chemical program of the Advanced Research Projects Agency of the Department of Defense. We suggested that this well coordinated Government-management concept be extended to the propellant application phase. This has not occurred and the ARPA Chemistry Office is, in our view, being prematurely disbanded. The military services may or may not carry out specific application of some of the important research results and adapt them for weapons systems. NASA has testified that it was depending on the ARPA propellant chemistry program for advanced systems. Thus, the unfortunate demise of this DOD program presents a challenge to NASA propulsion planning. Both industry and Government benefited by having a focal point office for such advanced technology.

A VARIETY OF ADVANCED PROPULSION SYSTEMS IS REQUIRED

Another deterrent to aggressive application of new propellants, and a possible explanation of the conservative policy, is the apparent disagreement as to what propellant is best. You gentlemen have undoubtedly been exposed to arguments of solid versus liquid, segmented versus monolithic, cryogenic versus storable, until it must seem that the industry itself is very unsure of what to do. Actually, the impression created is erroneous. A variety of propulsion systems is needed, each advanced to the utmost state-of-the-art.

Although less important than specific impulse, other properties influence propellant selection. These include, among others, density, storability and ease of handling. To illustrate, a recent study was made substituting different propellants in Apollo, while holding the volume of the vehicle constant. In this study, diborane-oxygen difluoride provided a significant gain in payload weight whereas oxygen-hydrogen actually reduced payload weight when substituted for the conventional propellants. This difference in effect on payload of two equally high energy propellant combinations is due to the low density of liquid hydrogen.

Military requirements of wide temperature extremes, instant readiness, transportability and long shelf life necessitate different propellants than do peaceful space missions. NASA will be able to utilize exotic chemicals to a greater extent than the Department of Defense.

An area where gains from new chemicals could be particularly significant is in high energy, high density, space storable propulsion for upper stages. Mr. A. O. Tischler told this committee last week, "—the value of specific impulse continues to increase exponentially with each succeeding stage." Callery is intensely interested in the possibilities shown by diborane as a fuel because of its high specific impulse and increased density and storability, relative to liquid hydrogen. According to reports over the past several years, interplanetary exploration, maneuvering in orbit, deep space probes and the advanced Apollo type missions would greatly benefit if an engine using diborane with oxygen difluoride were available. There are formidable but not insurmountable problems in developing this engine, e.b. containment of high combustion temperatures, which are common to all advanced systems. We believe the pace of this engine development is not governed by technical limitations and that accelerated funding is fully justified.

In our emphasis on rockets, the related area of air-breathing propulsion should not be forgotten. Even a rocket going to Mars will unavoidably burn a large percentage of its fuel within the Earth's atmosphere. The frictional drag of this air could be negated and, indeed, turned to advantage if supersonic combustion ramjets and air augmented rockets were developed. Here, again, special chemical fuels which react quickly and energetically with atmospheric oxygen are required for maximum performance.

Improvements in rocket hardware should not be confused with improvements in chemical propellants. Better engines will result from higher chamber pressures, torroidal chambers, plug nozzles, etc. However, all of these mechanical advances can be added on top of the gain from improved propellants. The possibilities of better hardware should not interfere with using the very best propellants in the new engines.

The promise of nuclear propulsion has been an excuse for not developing advanced chemical propulsion. This is wrong because nuclear rockets will not replace chemical rockets in most applications even when they become available 15–20 years from now. Nuclear propulsion will not be used for launch vehicles but only for moderate thrust, midspace acceleration where the high specific impulse can cut mission time and repay the great cost.

AN AGGRESSIVE POLICY IS CALLED FOR

In summary, the accomplishment of the objectives of our national space program will require high specific impulse propellants. The chemical industry has developed a variety of ingredients which are superior to those in use today. These chemicals can be selected for application with the assurance that they can be produced and handled on a large scale. The United States needs a complete range of propulsion engines, each tailored and perfected for the particular assignment. We recommend a change in propulsion policy from conservatism to aggressive exploitation.

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FURTHER STATEMENT OF RICHARD A. CARPENTER, MANAGER, WASHINGTON OFFICE, CALLERY CHEMICAL CO.

Mr. CARPENTER. The American chemical industry, of which Callery is a part, is second to no other in the world, and stands ready to contribute to our national space program in any way possible. The scientific basis of rocket propulsion states that high specific impulse chemical propellants are essential to preeminence in space. Without improved propellants, we will be restricted to small payloads on top of gigantic, expensive Nova-type launch vehicles.

It is frequently stated that we have no knowledge that the U.S.S.R. is developing exotic propellants and since Russia's record in propulsion achievement is very good, perhaps the United States should be content with conventional fuels. The reply to this may be seen in the recent announcement that Russia is concentrating great resources to expand its chemical industry in the next few years. Though their political laws are different from ours, the laws of thermodynamics are universal. We can conclude that lack of ability and not lack of interest has delayed their development of high-energy propellants. The chemical industry of the United States is one of our strongest assets. We should exploit the achievement of large-scale production of improved chemical fuels and oxidizers.

The obvious desirability of high specific impulse propellants has led to the derivation of specific mechanical and thermodynamic equations, which state that the most important properties of a chemical propellant are low molecular weight and high energy content. The chemist has selected, from the periodic chart of the elements, hydrogen, the light metals—such as lithium, beryllium, aluminum, boron—carbon, and nitrogen, and oxygen and fluorine as the most promising atoms to incorporate into liquid or solid propellants. In the past 10 years the chemical industry has thoroughly explored these elements and compounds. The performance of the new chemicals has been compared with conventional petroleum-derived fuels, and liquid oxygen or nitrogen tetroxide oxidizers.

Several combinations show remarkable improvement and have been developed to the extent that large-scale production has been demonstrated. No commercial, nonpropellant use exists for most of these special chemicals so the Government becomes the only customer, and must bear the cost of development. Nevertheless, economical processes have been worked out, pilot plants built, safety and handling procedures developed. Availability of these advanced propellants should no longer be in question.

The complete and exhaustive nature of this research phase, in the past few years, also makes it clear that no new, radically improved compounds will turn up in the future. So we need not hesitate in applying these chemicals for fear of obsolescence.

The progress of a new propellant from the test tube to use in a space mission involves years of engineering development. The transition from the research phase to application studies must occur, to give the mission designer enough confidence to accept the new propellant. Yet, the cautious policy today demands a specific mission requirement before application engineering may start. Any such approved mission has a time schedule which precludes lengthy propellant development, and so a compromise is made and existing fuels are used. The circle is completed on program after program and no new propulsion unit becomes available.

The Apollo program may be used to illustrate the quandary of the mission designer. Today we read of constant efforts to shed payload weight, such as substituting harnesses for seats, because of the marginal performance of the conventional propellants selected for Apollo propulsion. It is too late now to substitute higher impulse propellants. There was actually little choice in propellants several years ago when Apollo design was frozen. We will meet this same frustration in future space missions if we do not break out of this planning policy to a new concept of building the very best propulsion technology.

As we stated at a similar hearing a year ago, history shows that whenever a better engine was ready, the mission quickly materialized to use it. It is NASA's duty to provide the Nation with superior capabilities which it would not otherwise have. This should be done separately from the accomplishment of any specific ventures such as the lunar landing mission.

This committee is to be complimented on its continued emphasis of research and technology, in what might become just a vast hardware program.

We believe that if the United States is going to spend $40 billion in rocketry during the next 10 years, propulsion expenditures should be emphasized at the start. The vital relationship of specific impulse to the cost of payload in space, assures that an early investment in propulsion would pay off with interest.

Last year, before this committee, Callery commended the chemical program of the Advanced Research Projects Agency of the Department of Defense. We suggested that this well-coordinated Government-management concept be extended to the propellant application phase. This has not occurred and the ARPA Chemistry Office is, in our view, being prematurely disbanded. The military services may, or may not, carry out specific application of some of the important research results and adapt them for weapons. NASA has testified that it was depending on the ARPA propellant chemistry program for advanced systems. Thus, the unfortunate demise of this DOD program presents a challenge to NASA propulsion planning. Both industry and Government benefited by having a focal-point office for such technology.

A variety of advanced propulsion systems is required. You have heard arguments of solid versus liquid, segmented versus monolithic, cryogenic versus storable, until it must seem that the industry itself is unsure of what to do. Actually, the impression created is erroneous. A variety of propulsion systems is needed, each advanced to the top state of the art.

Mechanical improvements in hardware such as higher chamber pressures, toroidal combustion chambers or plug nozzles will increase payload capability 5 to 10 percent. In addition, the superior propellants now ready for application, offer 30- to 40-percent gains in payload or velocity. It is obvious where our development effort should be concentrated.

An area where gains from new chemicals could be particularly significant is in high-energy, high-density, space-storable propulsion. Callery is intensely interested in the possibilities shown by diborane as a fuel, because of its high specific impulse and increased density and storability, relative to liquid hydrogen. According to reports over the past several years, interplanetary exploration, maneuvering in orbit, deep space probes, and the advanced-Apollo-type missions would greatly benefit if an engine using diborane with oxygen difluoride were available. There are formidable, but not insurmountable, problems in developing this engine; for example, containment of high combustion temperatures. These are common to all advanced systems. We believe the pace of this engine development is not governed by technical limitations and that accelerated funding is fully justified.

In our emphasis on rockets, the related area of airbreathing propulsion should not be forgotten. Even a rocket going to Mars will unavoidably burn a large percentage of its fuel within the Earth's atmosphere. The frictional drag of this air could be negated and, indeed, turned to advantage if supersonic combustion ramjets and air-augmented rockets were developed. Here, again, special chemical fuels which react quickly and energetically with atmospheric oxygen are required for maximum performance.

In summary, the accomplishment of the objectives of our national space programs will require high-specific-impulse propellants. The chemical industry has developed a variety of fuels and oxidizers which are superior to those in use today. These chemicals can be selected for application with the assurance that they can be produced and handled on a large scale. The United States needs a complete range of rocket engines, each tailored and perfected for the particular assignment. We recommend a change in propulsion policy from conservatism to aggressive exploitation.

Thank you.

Mr. KARTH. Thank you very much, Mr. Carpenter. I might just say that it is obvious you are aware of the attitudes of some of the members of this committee insofar as it relates to NASA doing or putting forth a greater effort in research of high specific impulse, more sophisticated propellants.

Mr. CARPENTER. Yes, sir.

Mr. KARTH. The fact of the matter is, year after year we have authorized more money than NASA has requested in this particular area. Some of us—I am not sure that the message has been received as we would like to have it received at NASA, but I am not sure that they understand how serious the committee feels about it. Some of us feel very strongly about the fact, for example, that if we don't do greater research in some of these high-energy-propellant areas we may well in the future be caught the same way as we were caught when the first sputnik was launched.

Now, we do agree, of course, that we should continue to make our present-day vehicles as reliable as we can for the programs that are now in the budget, but that while we are doing this we should also pay more attention to the more sophisticated, higher specific impulse, high-energy propellant, in terms of basic research at least.

So you are apparently familiar with the attitude of this committee. And I might say it is the only reason we are having these hearings. This is the "Oversight Subcommittee" and there is a feeling, not to be redundant but to better indicate for the record what the feelings of the committee are, that more attention should be paid to this area by the NASA.

I understood you to say that you thought it was too late to even think about floxing the booster stage for Saturn V, is that correct?

Mr. CARPENTER. My remarks on the Apollo were related to the Apollo module, the payload, not the booster stages of that system.

Mr. KARTH. Yes. But if we flox the basic booster system, of Saturn V, of course, our payload margin would not be nearly so marginal.

Mr. CARPENTER. That would help.

Mr. KARTH. Do you feel that it is too late to think about doing considerable and rather extensive research in this area?

Mr. CARPENTER. No.

Mr. KARTH. Are you aware of what the margin is on the Apollo program as of now?

Mr. CARPENTER. Not in detail; no, sir. I know that they have problems and that we have all read in the press about some of these.

Mr. KARTH. We do have some prepared questions and I wonder, rather than taking the time of the committee at this point, if I could just submit these written questions to the various industry representatives who are here, ask you to prepare an answer, and then we will make the question and the answer part of the record. So Dr. Kirchner, I have some written questions here I would like to present to you.

Dr. KIRCHNER. Thank you very much.

Mr. KARTH. And if you would provide the answers to the committee staff we will make them part of the record. And also, Mr. Carpenter, I have some for you, if you will do likewise. I also have some prepared questions for the Rocketdyne and Thiokol people.

Mr. Bell, do you have any questions?

Mr. BELL. No, Mr. Chairman.

Mr. BOONE. I have a question, Mr. Chairman, if I may.

Mr. KARTH. Mr. Boone.

Mr. BOONE. Mr. Carpenter indicated that if we would put more money into, I believe, the oxygen-difluoride diborane system we could increase its availability. Is that correct? I understood you to say that.

Mr. CARPENTER. It is necessary to move from the research stage in developing an engine for these chemicals into applications engineering before the mission designer can get enough confidence in the combination to use it. That is where the additional funding is justified.

Mr. BOONE. Are you suggesting then that we fund an engine before we have a mission for it?

Mr. CARPENTER. Yes, sir.

Mr. BOONE. And in the diborane area. What size of an engine are you thinking of, second stage for Saturn?

Mr. CARPENTER. No, sir; this would be an engine in my estimation, in the 20,000- to 50,000-pound-thrust category that would have its first application in the upper stages.

Mr. Boone. I would like to ask one other question, Mr. Chairman. Dr. Kirchner indicated that the floxing of the Atlas, for example, was not an engine he would suggest as avaliable now for specific missions.

Now, it is my understanding that the M–1, for example, or at least the hydrogen oxygen technology that it uses has been under development for at least 10 years. Do we have to go through this sort of process for the oxygen difluoride diborane systems? Is this true, first of all, with hydrogen oxygen? I think the technology has at least been investigated for the past 10 years. Is there some way in which we can speed up this period of time or do we have to go through this long, hard, arduous process for the newer chemicals that are coming along? I ask either of you.

Mr. Carpenter. Please answer.

Dr. Kirchner. OK.

Well, I think first of all when you say that there was quite a lot of lox-hydrogen work done in the past, you are referring it to the programs of the M–1, I think it is all a question of for the lox-hydrogen system what is being done is actually really scaling up, and in a sense probably you are presently interpolating more than extrapolating as far as the fuel system is concerned. I believe that it is just a straightforward program now in the sense that you have engineering problems associated with just scaling it up to the very large sizes.

When you talk about different propellant systems I think the question is probably a little bit different. I think first of all you have to identify the material very well, you have to produce it very reproduceably in order to make it useful for the propulsion industry, because you know that as far as the accept or reject criteria are concerned or the influence of even slight impurities in the system has a transcending effect on the operation of the rocket. The third one when you are talking about a new sophisticated fuel system, I think you have to keep in mind that then there is associated engine development, different injector designs, and so on, are coming in. If you have a heterogeneous system that compounds the entire fraction. So the introduction of a radically new propellant system I think has all these other ramifications which I believe the lox-hydrogen system already has behind it.

Mr. Karth. Dr. Kirchner, isn't it true that one of the reasons some of these steps forward in the development of higher energy fuel burning engines has come about as a result of us doing too little basic research and then going immediately into the development stage as opposed to a better research program, which is really what we are attempting to sell NASA on now, I think, that they do a lot more basic research in many of these areas before suddenly it appears to them that they have got to develop an engine using a more sophisticated propellant in which there has been really very little basic research done. And it is my considered opinion that this might be the reason for the huge costs normally associated with the development of an engine using higher energy propellants. Putting greater emphasis on the basic research, then we might find that the development of these engines would be substantially less. Do you agree with this?

Dr. Kirchner. Yes, I do. I think the very intelligent assessment of the basic, let's say, propellant system and the identification of it plus the production cycle, and so on, in small quantities, so that when you throw the test tubes away and you are going into production, pilot or full-scale production that there is not a change in this, this I think very often in many cases in the past beat us in the sense that we had to do basic development work of the propellant system in parallel with the development of the engine work. If you agree with that concept, then really what we are saying is that by spending more money now in the basic research area it might well cause NASA to save money in the long run in the development of engines that use higher energy propellants, is that right?

Dr. KIRCHNER. I certainly agree with you, Mr. Chairman.

Mr. KARTH. Are there any further questions?

Mr. BOONE. Yes, Mr. Chairman.

The problem that worries me is I believe the limiting factor now on the diborane difluoride bit is the materials problem. So I assume you mean by basic research that we not limit it to the chemical aspects but certainly all disciplines related to the propulsion field.

Mr. CARPENTER. Well, Mr. Boone, what I am trying to say is that we are ready to produce this chemical to the specifications which Dr. Kirchner might set, so that I am not saying that the additional money should be spent on the chemical; I am saying the chemical is ready and we should go on and get the system ready to use it. Let's capitalize on our position in having this chemical capability.

Mr. BOONE. Then are you aware of the NASA program in this particular area?

Mr. CARPENTER. Certainly.

Mr. BOONE. Mr. Tischler, I believe, made some comment to our subcommittee earlier this year and they do have a program. Would you comment on it, or is this appropriate, Mr. Chairman?

Mr. KARTH. I would like for the witness to comment on it if he finds it not too awkward.

Mr. CARPENTER. No. We think that the program is not sufficiently funded. And that additional funding, additional effort in getting this engine developed is justified.

Mr. BOONE. And how much fund increase are you suggesting? What scale of program would you like to see?

Mr. CARPENTER. Well, I have seen estimates from propulsion contractors that indicate a graduated, year-by-year graduation of funding which would be at least double or triple the present expenditures.

Mr. BOONE. Thank you, Mr. Chairman.

Mr. KARTH. Mr. Patten?

Mr. PATTEN. No questions.

Mr. BELL. No questions.

Mr. KARTH. Thank you very much, Mr. Carpenter. We appreciate your appearing before the committee.

RESPONSE TO PREPARED QUESTIONS FROM THE SUBCOMMITTEE ON NASA OVERSIGHT, COMMITTEE ON SCIENCE AND ASTRONAUTICS, OF THE HOUSE OF REPRESENTATIVES

(By R. A. Carpenter)

Question. Why do you feel that the diborane/OF_2 combination is better for space booster applications than the competing "space storable" propellants? Do you know of anything new on the horizon—any new chemical combination—that looks like it would be a better combination to use in space than OF_2/diborane?

Answer. Callery has examined the propulsion requirements for future NASA and DOD missions as reported by Government agencies and contractors. The need is for high specific impulse, high bulk density, space storable propellant combinations. Diborane with oxygen difluoride provides a unique and superior system. Specific mission analyses, listed in the references in my prepared statement, show diborane-oxygen difluoride to be better than other propellants on the basis of payload or velocity increment. This combination has been the target for other propellant developers for several years. Callery has also tried to find a better combination. None has turned up from any source.

Question. Has your company or NASA tested this combination under vacuum conditions to see if it still ignites at zero ambient pressure? Is the ignition transient short enough so that there won't be starting problems later with the larger engines?

Answer. Diborane-oxygen difluoride has been found to be hypergolic from sea level to simulated space conditions with very short ignition transients.

Question. High combustion temperatures seem to be your only major problem in this OF_2/diborane combination. What do you believe are the chances that an ablative material which can shield the motor structure at this 7,000° temperature will be found? Are there other means of keeping this high heat off the walls of the combustion chamber?

Answer. We have studied the problem of containment of high temperature combustion reactions and believe that a successful chamber can be built. Solution of this problem may involve a combination of techniques—ablation, film cooling, zone combustion, regenerative cooling with the oxidizer, transpiration cooling, and improved metals and alloys.

Question. To date in the diborane program, how much of this fuel has NASA ordered altogether? How many minutes would it take this total amount to go through an engine the size of the J–2 (200,000-pound thrust) engine?

Answer. Research quantities of a few hundred pounds, enough for feasibility demonstration in the small test engines.

Question. How much diborane can the existing two plants produce in a year? What would the price per pound drop to if NASA ordered 200,000 pounds of it per month?

Answer. The Government-owned plant at Muskogee, Okla., can produce 4 to 6 million pounds per year. The plant at Callery, Pa., can produce 15,000 pounds per year. Large-scale production would result in a price of about $2 to $2.50 per pound.

Question. With the DOD–ARPA propellant chemistry program closing, what do you think NASA should do to "fill the gap" left in the space chemical program? How much was ARPA spending per year? How much is NASA now spending in chemical research?

Answer. I believe NASA should increase and centralize its chemical competence to get the most benefit from the chemical industry. The nature and operation of the ARPA chemistry office was well conceived. We understand ARPA funding amounted to about $25 million per year. In the sense of chemical propellant research, NASA is spending very little, because of its dependence, up to now, on the DOD program.

Question. What do you believe would aid NASA in getting more help from the chemical industry to augment the effort it obtains from the aerospace industry?

Answer. The chemical industry has much to offer the space program. But, unlike the aerospace industry, it is oriented toward the commercial market. Thus it requires a special effort to establish a working linkage between NASA problem areas and industry solutions. Having a central focal point office within NASA, for chemical technology, is recommended.

Mr. KARTH. The committee would now like to hear Mr. Samuel Hoffman, president of the North American Aviation, Rocketdyne Division. Would you care to proceed?

Mr. BELL. Mr. Chairman, if I may I would like to take this opportunity to welcome Mr. Hoffman——

Mr. KARTH. Please do.

Mr. BELL (continuing). Whose plant is in a neighboring district to mine, but I believe he actually lives in my district. Am I not right?

Mr. HOFFMAN. That is right.

Mr. BELL. It is a pleasure to have you here and to hear your remarks today and I admire you further for braving the Washington weather for that lovely weather out in southern California.

Mr. HOFFMAN. Thank you, Mr. Congressman, and Mr. Chairman.

STATEMENT OF SAMUEL K. HOFFMAN, PRESIDENT, NORTH AMERICAN AVIATION, ROCKETDYNE DIVISION

Mr. HOFFMAN. I might say the Washington weather is very lovely right now, nothing to complain about.

I prepared a written statement, copies of which I have left with your staff. It, in itself, was a summary. I will try to summarize the summary, if I may.

I will concentrate my remarks mostly on work which we have done or are doing at Rocketdyne and will cover only those highlights which I believe will be of greatest interest to you and your committee.

Incidentally, I have had the opportunity of reading the rather complete report to the committee by the NASA Director of Chemical Propulsion, Mr. Tischler, and it is my belief that it is in general accord with the propulsion industry's views and recommendations. Any disagreements would be a matter of degree. I suspect that we would not have any very great disagreement. In general, we would like to do more, faster, than the money available probably will permit.

With that general remark, I will turn first to booster engines. Of most significance in the past year, I think, would be the fact that there has been a continued demonstration of booster reliability. There have been no booster engine failures although this has been a very active year. In past hearings there has been a great deal of attention given to reliability, and I think the industry, NASA, and the country as a whole should be pleased with what has been accomplished.

Perhaps the most spectacular demonstration of reliability was the fifth consecutive Saturn booster flight just a few months ago.

Another significant milestone that has been reached is that the practicality of hydrogen vehicles has been demonstrated, both by the Centaur and the Saturn IV upper stages, operating on Atlas and Saturn I boosters, respectively.

Last year, operating duration of the hydrogen-fueled J–2 engine was specified at 250 seconds. We did not have test stand capacity for demonstrating the increased rating to 500 seconds. This longer operating time has subsequently been achieved and repeatedly; in fact one engine now has accumulated over 10 times that duration.

This shows that the potential is there for J–2 to be an equally reliable engine, equally reliable in terms of the ones we have flown to date.

The delivery of the first J–2, 200,000-pound thrust engine to Douglas for vehicle mating tests will occur within the next few weeks.

Last year a major subject for discussion was F–1 combustion vibration—combustion instability, if you will.

I am happy to report that no instances of combustion vibration not deliberately created for test purposes have occurred in F–1 since January of 1963.

We have a dynamically stable engine and I think it is fair to state that we have done more than we had really expected we could do in this regard. The F–1 today has a higher degree of stability than we might have expected, in other words a one-cycle dynamic recovery rather than one of 10 to 40 milliseconds. The dynamic stability problem is in hand, the engine is dynamically stable.

F–1 performance is good. Our goal now is to increase performance up to the maximum potential at this chamber pressure and still maintain dynamic stability. This we are confident of doing. We have about 4 percent to go and, over a period of time—next year, perhaps—I hope that I can report we have achieved this ultimate goal.

As you no doubt know, the first F–1 engine was delivered to NASA at Huntsville last fall. It has been operated there satisfactorily by NASA personnel for a period of some months.

In addition to the large, liquid rocket engines which are used to boost payloads into space, requirements exist for controlling spacecraft attitude and maneuvers. This has led to the development of a new class of rocket engines, called attitude control engines, which have characteristics very different from the large booster engines and involve difficult new problems in design, manufacture, and test. The thrust required for such engines is small, about 10 to 150 pounds. The required number of small engines is relatively large, ranging from 8 to 32 per spacecraft.

The attitude-control engine must be capable of many starts, stops, and restarts, and must be able to give good performance over very short firing periods, as brief as 10 milliseconds duration. These small engines use storable liquid propellants of the nitrogen tetroxide and hydrazine family and employ ablative materials (similar to reentry heat shields) to contain the hot combustion gases while maintaining a cool exterior surface.

This is one of the types of engines I think Mr. Carpenter is referring to when advocating use of higher performance propellants. We in the engine industry and NASA are well aware of this requirement. Higher performance propellants are in the plans and I am sure we will do more in this area.

The engines we are working on are attitude control and maneuver engines for the Gemini, Apollo Command Module, and Transtage of Titan III.

Some 150 of these engines have been shipped and initial flights have been satisfactory.

Although these are small engines, no one should for a moment think they are easy to develop and produce. In fact, the contrary is true.

This is a new field of endeavor.

Our present engines are satisfactory for initial requirements. However, the requirements are becoming stiffer. We can, will, and should be doing more work in this field.

Another engine in this category is the LEM landing engine which Dr. Kirchner referred to. This engine is similar to other space engines in that it uses an ablative thrust chamber. In addition, it requires throttling, in this case over a 10-to-1 range from 1,000 to 10,000 pounds of thrust. One of the new ideas that has been used on this particular engine is throttling by means of helium injection.

I am happy to say that this development is proceeding quite satisfactorily, going along very well.

Briefly, as to future trends, Rocketdyne certainly advocates and would like to push advanced propellant research, both liquid and solid. Expanding on some questions that were asked here a moment ago, it is my opinion that unfortunately one does have to get through the rather tortuous process of selection, building up a chemical supply, and then, finally, testing the propellants in engine hardware before either the propellants or engines are ready to go into production.

When we say there should be more basic research, we mean not only in the chemical industry laboratories, not only in developing the facilities to produce the new materials but we also mean the material and metallurgical work required for the hardware that will have to burn the propellants. Intelligent early work on the design of the design of the hardware, is required so that the engine design as well hardware, is required so that the engine design as well as the propellant chemicals can be brought together in such a way that they supplement one another. Then, if we include all of this as basic research, this should indeed be pressed.

Mr. KARTH. We are talking about doing more basic research in all of these things, you can't just do it in one and neglect, in my opinion, the other. We are talking about doing greater amounts of basic research in all of these areas which would be applicable to the more sophisticated higher energy fuel. I am sorry. I just wanted to make sure that you understood our position.

Mr. HOFFMAN. Of course, in any of these programs, there are two extreme methods one may follow and an infinite variety of programs in between.

One way is to proceed with extreme caution over a long period of time. This way is likely to be costly and perhaps take so long that by the time the first ideas are about to be developed, you have new ones. You are always skipping to the new ideas. This is an extreme to be avoided.

Mr. KARTH. That is if you become so cautious that you only do basic research in one or two isolated areas.

But we are talking about doing greater amounts of basic research in many different areas. We are talking about doing it in four or five or maybe a dozen of the higher specific impulse, more sophisticated fuels area.

Then it seems that you can intelligently arrive at a conclusion after you have done adequate basic research in these many areas, as to which one you should proceed with, which two or which three you should proceed with.

So I certainly agree that you can be too cautious. But that is not what I personally have in mind. I think that when you are that cautious it costs you probably more money in the long run.

Mr. HOFFMAN. Yes. The other approach, with greater hazard, is to proceed faster, and I frankly say I am of the latter school of thought. I would prefer to go faster at a little more risk, providing the gain is great.

Of course for a very slight gain I would not take a very great risk.

In the case of the flox work. When we say "flox" we are generally speaking in the neighborhood of 30-percent fluorine and 70-percent liquid oxygen. Mr. Tischler gave a complete curve in his report, and shows that the payloads can go up, or may go up, anywhere from 18 to 80 percent. So, when one has certain upper stages and existing lower stage vehicles it certainly seems like a very proper proposal, and one that should be pushed vigorously, to use flox in the lower stage lox/JP engines, and thereby gain this additional margin for doing the bigger job that we now have ahead of us in terms of weight-lifting capability.

The preliminary work has been done with flox; it is in the very early stages. Flox, in contrast to using fluorine alone, makes a mixture more like a normal propellant. It takes some of the sting out of handling the fluorine, which by itself is very active, causing problems with materials and toxicity problems if it gets loose. It is quite true that there is an exhaust problem. We believe this can be handled and support the program to proceed with floxing of the engines for missiles and boosters.

There are a variety of nozzle and thrust chamber designs. These have been listed and described in Mr. Tischler's report. I hope and expect that this work will be pursued vigorously.

I think of particular interest, somewhat in the nature of a breakthrough, could be the segmented thrust chamber concept for big liquid engines.

The torroidal thrust chamber concept is shown in Mr. Tischler's report. In combination with the aerodynamic spike nozzle it would give very high performance without having to go to as high operating pressure as has sometimes been advocated.

I think that I might just add in regard to advanced technology that there are enough new ideas now that the next year or so could be particularly fruitful. I think we should be pushing with particular vigor in the early stages, where the work is not as expensive as later on and we could have proven new concepts for radically new engines.

The segmented idea, for example, would mean that we could manufacture extremely large liquid engines with current facilities, both as regards manufacturing and test.

I think with that I conclude my remarks and thank you very much.

Mr. KARTH. Thank you very much, Mr. Hoffman.

Mr. Fulton.

Mr. FULTON of Pennsylvania. You think this committee then is on the right track when we are urging emphasis on adequate research and development in the solid fuels and the liquid fuels, particularly on the high energy and high pressure engines, and also on the various proposals on the nuclear fuels as well as the engines. Are we proceeding in the right direction when we say that within the budget there should be adequate funds to fund these particular programs, looking ahead not the first 2 years, but 3, 5, 8 years from now?

Mr. HOFFMAN. I think the answer to all of those questions is "Yes," Mr. Congressman.

Mr. FULTON of Pennsylvania. So that you would urge that we continue on this particular policy so that the emphasis be made on research and development as well as on facilities and on these other current generation engines and vehicles.

Mr. HOFFMAN. I don't believe anybody could disagree with that and I believe this is NASA's program.

Mr. FULTON of Pennsylvania. Actually, what I am saying to you is that we feel that NASA should drop its so-called conservative policy and emphasize research and development in these areas.

We are urging that they go faster on their research and development and follow through on these various fields. Would you agree with that?

Mr. HOFFMAN. I think perhaps if there has been any leaning one way or the other, that it has been on the side of conservatism; I think that we should go faster.

However, I am sympathetic with the problem I am sure they have; one I have in my own organization. A program is always tempered by what we have in the way of facilities; by that I mean money.

Mr. FULTON of Pennsylvania. Well, this committee 2 years ago, gave an added $1 million on high energy propellants. I think 5 years ago it was my amendment that added $10 million for research in the solid fuels budget request.

Then last year it was $2 million on high energy propellants which Congress gave, again on my amendment, and this year this committee has adopted another amendment, $3 million for high-energy liquid propellants and $1 million for added solid fuel research.

The money certainly can be used if we provide the money, can it not, on the basis that what you people have been testifying certainly is encouraging, isn't that correct?

Mr. HOFFMAN. Yes, sir.

Mr. FULTON of Pennsylvania. Would you say more than "Yes"?

Mr. HOFFMAN. We will be happy to do further and more work on propellants in either the solid or liquid area.

Mr. KARTH. It is equally hard to get them off Santa Claus' lap.

Mr. FULTON of Pennsylvania. We aren't saying this in any way of disputing, but we are doing it in a method of emphasis, so that as we go up the scale of specific impulse we have a lot of these problems solved on the research and development level before we come to the engine and the vehicle.

Don't you think that is very wise?

Mr. HOFFMAN. Yes.

You know, my problem with my people is I can't get them to say either "yes" or "no"; they always land in between with a lot of explanation.

Mr. FULTON of Pennsylvania. But your "yes" means really yes, exclamation point—yes.

Mr. HOFFMAN. Yes, I believe this is correct, we should do more basic research on propellants, particularly by the definition that we discussed here a few minutes ago.

RESPONSE TO PREPARED QUESTIONS FROM THE SUBCOMMITTEE ON NASA OVERSIGHT COMMITTEE ON SCIENCE AND ASTRONAUTICS OF THE HOUSE OF REPRESENTATIVES

(By Samuel K. Hoffman)

1. *Question. "It is understood that your organization has a new, advanced, high-pressure, segmented engine of novel configuration which portends great promise for future liquid-propulsion boosters. Are there any basic technical problems yet to be solved on this engine? How much funding has NASA given you on this engine to date?"*

Answer. Rocketdyne's proposed segmented engine offers many very attractive advantages. A basic unit segment of say 200,000- to 1-million-pounds thrust can be manufactured and tested with existing facilities. Any number of such segments can then be joined together in circular or polygonal arrangement to provide a complete assembly with any desired thrust up to 10 or 20 times the basic unit value. This segmented engine concept is particularly adaptable to be combined with the aerodynamic spike nozzle into a compact, efficient engine.

The rugged nature of Rocketdyne's unique chamber design makes it especially suitable for high-pressure operation. Initial feasibility efforts explored the heat transfer and aerodynamics characteristics of the novel thrust chamber. Small-scale, hot-firing segment test results have been very encouraging, showing high combustion performance and corroborating cold flow and heat transfer data. A current NASA program is directed toward developing a basic full-size element or partial segment of a thrust chamber for use in advanced-high-thrust, high-chamber-pressure, oxygen/hydrogen rocket engines. Experience to date indicates that there are no serious technical problems which should prevent demonstrating the concept in a complete engine assembly.

The initial work was started 3 years ago and the concept has been brought to the present state of promising feasibility under NASA funding. Recently Air Force funding has been added to investigate the application of this concept to storable propellants. As a next step, the segmented-thrust-chamber concept must be integrated with appropriate turbopumps and valves to give an overall engine building block. As yet there has been no funding for building and testing an engine.

2. Question. "Have you made any studies related to uprating the payloads of the Saturn I–B and Saturn V booster systems? Were these studies NASA funded or company sponsored? What increase can you get in payload landed on the Moon by reasonable upgrading of Saturn V? How do you go about achieving this increase?

Answer. Rocketdyne is continually studying improvements that can be made to the H–1, F–1, and J–2 engines to allow payload increases for the Saturn vehicles. Our efforts in this regard are coordinated with Marshall Space Flight Center and with Saturn vehicle contractors and have been supported both by engine contracts and by company funds.

Studies of what can be done to the engines without changes in propellant tank capacities or other extensive vehicle changes show that Saturn I–B orbital payloads can be increased by about 40 percent and Saturn V escape payloads by as much as 27 percent. This can be accomplished by uprating thrust on each of the engines, increasing J–2 nozzle expansion ratios by a moderate amount, and by the use of flox in the H–1 and F–1 engines. In current deliveries H–1 has already been uprated from 188,000-pounds thrust to 200,000 pounds. In the normal course of their development, F–1 and J–2 can also be uprated by 10 to 20 percent in thrust.

Further vehicle payload increases can, of course, be made by such vehicle changes as would allow major increase of J–2 nozzle expansion ratio and the use of six rather than five J–2's on the second stage of Saturn V.

3. Question. "Has your organization been granted by NASA any funds with which to study either recoverable booster systems or air augmentation of engines? Do your studies show that these are feasible ideas?"

Answer. The reusability of liquid rocket engines is well established by numerous ground tests demonstrating reliable life many times that required for a single flight. The problem of a reusable booster is, therefore, a systems one requiring a method of safe return that does not involve addition of undue weight complication and expense to the booster vehicle.

NASA and the Air Force have system studies underway in their own groups and with various contractors. We are supporting these studies with necessary rocket-engine information and are hopeful that space ferries of the future will avail themselves of the full reuse potential of liquid rocket engines.

Air augmentation is a rocket innovation that offers attractive gains by increasing the thrust of a rocket system during the period when it operates within the atmosphere. The practical attainment of gainful thrust augmentation requires the development of short augmentation ducts of low aerodynamic drag and the attainment of intimate mixing of rocket gases with air.

Realization of this theoretical gain offers a considerable challenge to the designer. Currently Rocketdyne is studying a method of augmentation which will avoid some of the problems of the conventional schemes.

Mr. KARTH. Could we ask that same question very shortly of the gentlemen to your left and right, Mr. Carpenter and Dr. Kirchner, what do you gentlemen say?

Dr. KIRCHNER. Well, as far as basic research is concerned on propellants, I believe—we touched upon some of the subject, Mr. Congressman, before you came into the room. We generally came to the conclusion or there were certain suggestions made here that certain particular programs could be accelerated and the differential between basic research, development, and application wasn't made but it was just referred to the programs, themselves. We felt, for instance, the high-thrust, lox-hydrogen program could be greatly augmented if additional funds would be placed in the forthcoming fiscal year.

We believe that when we are talking from, let's say, a microscopic point of view, as far as money is concerned, allocated for NASA, for the application of the large solid boosters, we believe that we could be doing quite a lot more than is being done now. We believe that this is probably the largest chemical propulsion system in the world which I think even is not a development program but is just placed in a feasibility corral. From that standpoint I think staccato funding, which we are looking at in a sense of having the funds applied now for feasibility, and then we are waiting, we are getting our binoculars out and we are going to look for the application of it, and then we are going to apply some additional money, I think as far as the industry is concerned, represents a most painful program, because, in a sense, actually it fluctuates quite a lot, where I think a lot of these things could be done really in parallel. This would mean the introduction of engines, of a complete engine or motors, as the solid people call it, with all the gingerbread around it, this is vector control system, thrust termination, all these things. These particular elements are not present now in the program, and we are looking over the next, let's say, next generation of the programs or extension of the programs, we don't see in the planning portion.

So from that standpoint, if I might add here, I think that your support or another rinsing dry of the proposition in that particular area could really extend the art in this country immensely.

Mr. CARPENTER. We believe that the important relationship of specific impulse to the cost of payload in orbit supports our position that we should spend money early, now, on improved propulsion which would be saved many times over in the course of what we know is going to be a long and extended national space program.

Now is the time to get the best propulsion that the chemical industry and the aerospace industry can provide.

Mr. FULTON of Pennsylvania. The only alternative is to build bigger rockets with small payloads and low-grade fuels; is that not right? right?

Mr. CARPENTER. That is correct.

Mr. FULTON of Pennsylvania. And that is expensive.

Mr. CARPENTER. That is correct.

Mr. BELL. Will the gentleman yield?

Mr. FULTON of Pennsylvania. Yes.

Mr. BELL. Just to give a little further emphatic "yes" on behalf of Mr. Hoffman, I am reading from his statement on page 7:

Continued propellant research for both solid and liquid engines is essential to future progress.

Mr. FULTON of Pennsylvania. Thank you.

Mr. KARTH. Mr. Patten.

Mr. PATTEN. I was interested in what you had to say about the M-1. I thought that program was slowed down, Dr. Kirchner?

Mr. KARTH. I think the funding level was reduced.

Dr. KIRCHNER. That is right. I think it is a program now which actually hovers between a coherent engine development program and a component development program, and from that standpoint I think it represents probably the lowest effort in which you might have, let's say, an understandable program.

Mr. KARTH. Dr. Kirchner, do you think by traveling the route we are traveling on the M-1, for example, that if it is really our intention to develop this engine for useful purposes and for future programs, it will cost us more money the way we are going; that is by reducing the NASA request, or not?

Dr. KIRCHNER. I think offhand in our analysis it would indicate in the long run it is going to be a more expensive program, because you are treating with time here, and you are extending the time into the 1970's, and from that standpoint I think we have noticed that aggressive and well-supported programs, with all the necessary elements in the entourage next to them, are usually I think quite effective. I think this is particularly true with some of the military program.

I would like to cite programs, for instance, like the Minuteman and the Polaris, where there was quite a lot of steam put right in the beginning, and the program was put on the road in a very fast fashion, and I think the results paid off very well.

Mr. KARTH. That is all, Mr. Hoffman, thank you very much.

The next witness will be Dr. Harold Ritchey, the vice president of Thiokol Chemical Corp.

Dr. Ritchey, would you care to give a statement? I don't have before me a prepared statement. Do you have such?

Dr. RITCHEY. With your sufferance, Mr. Chairman, and members of the committee, it will be available Monday. Time is a little short, and I didn't run fast enough in getting it prepared.

Mr. KARTH. We understand. If you would make it available to the committee staff they will make it then a part of the record.

Mr. FULTON of Pennsylvania. I would like to welcome Dr. Ritchey, and the other members.

STATEMENT OF DR. HAROLD W. RITCHEY, VICE PRESIDENT, ROCKET OPERATIONS, THIOKOL CHEMICAL CORP.

Dr. RITCHEY. I am delighted with the opportunity to talk about chemical propulsion today, Mr. Chairman. Chemical propulsion is a matter of very critical importance to our space exploration efforts as all of us know. For the next 15 years, which is roughly, you might say, the foreseeable future, I think it is a very safe prediction that all of our space vehicles will contain chemical propulsion and most of them will be propelled exclusively by chemical means.

For the brief discussion in the time that I have been allowed here, I have picked two specific areas which we have studied for a number of years, and into which we have invested very substantial corporate moneys in the form of research and development effort, and also in the form of capital investment and facilities which are used to support the research and development effort that is now going in these two fields.

For the other areas of chemical propulsion I would like to compliment Mr. Tischler on the testimony that he gave about 10 days ago, and say that I am in very substantial concurrence with it.

I would also like to compliment the members of the committee for their attitude toward aggressive research and advancement of the state of the art, and advancement of technology programs.

The effect on our space program, of the lack of knowledge, can be extremely debilitating. We always find ourselves in the position of having to take what we know now and design a space vehicle to do a particular job, when if we only had some advanced technology available to us at the time the job could be done in a much more reasonable and competent manner.

There is a very marked timelag in the achievement of advanced technology as all of you know. It is not something you can buy off the shelf like a can of beans, but something that you have to pay for and then wait sometimes many years before it actually becomes available to you.

I am concerned with the philosophy that pervades in some places that may be called a technical maginot line philosophy. The idea that you can relax in some security behind some sort of bastion and you don't really have to try any more. Certainly there is no such bastion in technology. In order to insure continuation of our space program and insure our relative position in space exploration, we certainly have to run as hard as we can in the direction of pushing back the frontiers of knowledge. The two areas of technology that I mentioned I wish to discuss are those of high-energy storage liquids for upper stages and large solid-propellant boosters.

In regard to the first I must say that I think the hydrogen-oxygen work that is now going on is certainly very well conceived and that the propulsion systems that come from this work are certainly going to be extremely useful. However, hydrogen and oxygen is not storable and there are many advantages to the attainment of a storable high-energy propellant system for upper stages and for on-board propulsion of our space modules.

In this regard, we have studied a number of different materials and find that oxygen difluoride, OF_2, as the oxidizer, combined with a number of potential fuels, such as hydrocarbons, ammonia, hydrazine, and diborane, certainly offer some tremendous potential. They offer the potential of the attainment of higher incremental velocity or Delta V, as we call it in the trade, from a given stage or the potential of increasing the payloads.

With the advantage of storability, it appears that for a great number of potential applications the OF_2 propellant system is actually—offers a higher Delta V capability or greater payload capability than the hydrogen/oxygen system primarily because of higher density and perhaps an equal or slightly better capability than the hydrogen-fluorine system.

The space storability feature is certainly an extremely attractive one for the very long and extended space missions such as the exploration of the nearby planets or other missions that might require long duration in outer space.

Space storability combined with the hypergolic nature of OF_2, in other words, its ability to take fire immediately upon meeting up with the oxidizer in the combustion chamber, both of these together offer potential for actually improving the system's reliability and the on-off capability and multiple restart as compared to some of the other high-energy propellant programs.

We have been engaged in work for approximately 2 years in actually testing OF_2 with a number of propellants. We have had a number of firing tests, varying from 150 pounds of thrust up to 2,000 pounds of thrust, with no real difficulties, with perhaps the exception of that of survival of the combustion chamber and nozzle or the cooling problem which was mentioned earlier.

We believe that with the properly conceived pilot program that a very useful propulsion system could be available in about 5 years time. Propulsion system with let's say about 25,000 pounds of thrust, with on-off capability, and throttling capability, such as might be required for an item such as a Mars excursion module. Such an effort would require about 5 years of development effort, and, in our estimate, about $80 million of development funding.

For the coming year, fiscal 1965, we recommend that these problems, particularly of combustion containment, be explored on about a $5 million per year funding level; with chambers of significant thrust capability around the 10,000-pound class.

In the other area of interest, that of large solid-propellant boosters, we have discussed many times the need for such devices, and I think this is a good example of a statement I made earlier, and that is that the lack of technology at the time a system is designed sometimes can have a very debilitating effect. The lack of our ability to achieve high thrust and lift heavy loads into space has perhaps been the largest single limiting factor in our space exploration program.

The work that is going on in large liquids once again I think is very well conceived, and being very well executed. My comment to this is we should have the largest liquid engines we can possibly develop because they are very useful with the higher energy propellants in upper stages; no matter how big they get we can always put large solid boosters underneath them to provide the first-stage thrust.

For example, we are now working on a 260-inch-diameter solid booster. The full-length engine would be 135 feet, approximately, in length; four of these when clustered together could lift and, with properly designed high-energy liquid upper stages, could place approximately 1 million pounds of payload into a 100-nautical-mile orbit.

I think it is very important to emphasize that at the present time an engine is under construction which will develop 3 million pounds of thrust for 110 seconds. This is double the thrust of the F–1 or the Saturn I. According to present plans, after the program has been in existence 14 months, which will be this coming August, the first 3-million-pound-thrust static test will be conducted in a 156-inch size. There will be an additional 3-million-pound-thrust test using the 260-inch half-length size at the 18-month period and still a third test at the 24-month period. All this is being done I think in a rather rapid schedule, and on a very austere budget. We mentioned in previous testimony there might be some fallout for this. Dr. Kirchner has already mentioned the possibility of applying this to the Apollo program to increase the load-lifting capability from around 32,000 pounds for the Saturn I–B to perhaps something very close to double that, or certainly within the 50,000- to 60,000-pound range. According to the Boeing studies, the half-length first stage 260-inch could be adapted to this mission for about $65 million development cost, and when combined with the third stage of the Saturn V, the S–IV–B, would just about cut in half the approximately $600 per pound payload in orbit figure which is associated with the Saturn I–B program.

The current program, as I mentioned, is a rather poor-boy type and there are some follow-on works that need to be planned immediately. Thrust vector control, in the form of fluid injection or gimbaled nozzles, needs to be added to the half length 260-inch engine. In the 3-million-pound-thrust class, the full length 260-inch motor should be designed and plans should be made immediately for its demonstation. There should also be immediate planning and funding for the preflight rating tests for adapting both the half-length and the full-length engine to vehicle utilization.

With a properly funded program and proper continuity in the present plan, the half-length motor could be delivered for a flyable vehicle in mid-1966 and the full-length motor could be delivered for a flyable vehicle in the third quarter of 1967.

The current program is planned up until a year from this coming July and then there is a 6-month gap which poses some considerable problems in the form of an idle plant and a work force and development team which has no work planned for them at the present time for a 6-months period. There should be immediate planning to fill up this gap after the first 260-inch test in January 1965 and, of course, there should be additional planning and funding for the continuation program which includes a continued application study of large solid boosters for space applications, an effort which, incidentally, is beginning to taper off where instead it should actually be increased. There should be effort to integrate the components into the flyable vehicle, in particular the integration of the thrust vector control system into the motor, and there should be supporting engine development to meet the schedules which I mentioned earlier.

We believe that the full length could be delivered in the third quarter of 1967. To get the full-length, 260-inch engine into a flyable item for the follow-on deep space missions will require from $100 to $120 million in funding with an additional approximately $22 million in facilities and such a device could be made available late this decade or early in 1970's for a man-rated space vehicle exploration program.

Gentlemen, that finishes my verbal contribution and I am available for any questions that might come up in addition to these that have already been written.

We will write out our answers to the questions that have been submitted and I thank you very much.

(The complete prepared statement of Dr. Ritchey is as follows:)

PREPARED STATEMENT OF DR. HAROLD W. RITCHEY, EXECUTIVE VICE PRESIDENT, ROCKET OPERATIONS, THIOKOL CHEMICAL CORP.

I. INTRODUCTION

Gentlemen, I am gratified with the opportunity to appear before you and discuss the subject of chemical propulsion. Chemical propulsion is indeed of utmost importance to our space exploration program and will continue as the prime propulsion means for the foreseeable future, which is certainly 10 to 15 years.

Because of the long-term applicability of chemical propulsion it is indeed of critical importance that we make every effort to push the acquisition of new technologies. The most advanced technological knowledge is needed when decisions are made in regard to the type of vehicle which will be used for future space missions. The effect of not having this knowledge is that of imposing severe limitations on the mission capability. We have already encountered such limitations in many of our currently planned space programs. We must avoid a philosophy that might be called the technological maginot line; a philosophy of relaxing behind some sort of secure bastion, which in the case of technology will never exist. Continuous and aggressive pursuit of new knowledge is of critical importance.

The areas that we specifically want to cover today involve high-energy, space-storable upper stage propulsion systems and large solid propellant boosters. Both have a profound role to play in this Nation's future space exploration efforts.

I expect to concentrate my remarks today on two specific areas which we have studied for a number of years and have funded with our own corporate research and development money, as well as with extensive corporate capital which has gone into facilities designed for these programs. Perhaps I can best cover the other areas by saying that I am in a very substantial agreement with the testimony which Mr. Tischler gave to this committee on March 4, 1964.

II. HIGH ENERGY SPACE STORABLE PROPULSION

I want to begin this discussion of high energy space propulsion systems by emphasizing a need to pursue high energy propellant technology on a broad front. There is no "best" approach for every need that can be projected for the future. Our space program planning needs flexibility and the capability of making intelligent decisions as to direction of future efforts long before those efforts are committed. This means a well established, far seeing, adequately funded and properly executed program of acquiring high energy propellant technology for upper stage propulsion. The payoff in terms of increased payload, reduced size and cost of booster vehicles and launch facilities has been recited to you too often to warrant any further elaboration. The payoff is tremendous. In this regard, the work that has been underway for several years involving liquid oxygen-liquid hydrogen propulsion systems for booster stages has been well conceived, well executed, and will undoubtedly have significant application to future requirements. The NASA is to be complimented for their efforts in these areas.

Our interest in pushing on with high energy space storable systems stems from studies that we began back in 1960. These showed the need developing rapidly for very high energy space storable propulsion systems—systems based upon propellants which would compete performancewise with liquid oxygen-hydrogen and fluorine-hydrogen—yet which would be capable of prolonged space storage.

Our efforts showed the clear cut advantage of pursuing work with propellant systems based on oxygen difluoride (OF_2) with fuels such as diboranes, as well as a variety of hydrocarbons and amines. These systems, as shown in figure 3, p. 71, have temperature ranges which can be established by passive means in space so as to preclude performance losses from insulation or boiloff.

By virtue of this "no-loss" storage, the use of auxiliary systems for tank venting is precluded. This, coupled with hypergolicity, provide the vehicle designer with a highly reliable propulsion capability for prolonged space storage, safe multiple restart, etc.

The high density, coupled with the high specific impulse of these OF_2 systems, also provides the vehicle with a very high payload capability, one which is quite competitive with the nonstorable propellants.

It should be noted that Thiokol has advocated this concept since 1960, and we welcome the fact that other organizations have arrived recently at the same conclusions. Studies at Aerospace Corp., Aerojet General, and Boeing, among others, confirm the extreme promise of these OF_2 systems for space applications.

Acting on our studies, we made significant efforts beginning in 1961 to confirm the feasibility of realizing these advantages in practice. As we reported to this committee last year, our company-funded results were most encouraging and led to initial NASA support in mid-1962. This work further confirmed the promise of the OF_2/Diborane system, and it has been extended through 1963 and we are currently contracted to continue through mid-1964.

Unfortunately, these funding levels have been below what could profitably be spent in this area. Despite this, however, there has been very significant progress made—the most recent being what I would like to review for you now.

We were contracted to explore at the 150-pound thrust level the suitability of existing ablative-refractory materials for combustion chambers for use with these propellants, as well as the ignition and heat transfer characteristics of these propellants. At the 2,000-pound thrust level we were to evaluate the performance and durability of injectors, conduct heat transfer measurements, and perform a design study for a long duration 2,000-pound thrust combustion chamber.

In the course of these efforts, 47 firings at 150-pound thrust and 25 firings at 2,000-pounds were conducted. The firings were generally made for durations long enough to achieve test objectives, yet conserve propellants. However, at 150-pound thrust, a 44-second firing was achieved successfully, and at 2,000-pounds thrust, a 20-second firing was achieved successfully. A good deal of technology has resulted.

The highlights can be summarized as follows:

1. Present state-of-the-art ablative materials behave in a predictable manner with OF_2/Diborane. As a result it is projected that the durability of existing ablative materials with these propellants is approximately equivalent to that of the slica-phenolic materials with N_4O_4/50-50 Hydrazine-UDMH blend, used as Apollo.

2. OF_2/Diborane is reliably hypergolic over extreme ranges of environmental and operating conditions and propellant states.

3. OF_2/Diborane delivers high specific impulse with values ranging in the 95–99 percent of theoretical shifting equilibrium. The specific impulse is insensitive to very wide variations in mixture ratio.

4. High performance 150-pound thrust injector designs can be scaled to deliver high performance at the 2,000-pound thrust level.

5. The cooling capability of OF_2 is greater than predicted by analysis.

6. OF_2 and Diborane have been handled safely at Thiokol with the procedures we have developed.

7. Preliminary designs have been developed for 2,000-pound thrust, moderate duration combustion chambers. Additional effort needs to be expended in the area of very long duration, i.e., 500–2,000 seconds, chambers.

Our most recent contract makes a start in the area of the recommendation of item 7, and is also oriented toward an evaluation of the recombination characteristics of these propellants in high area ratio nozzles, an area in which our analyses show combination to look very favorable.

In essence then, we conclude from our efforts thus far that there is no apparent reason to preclude OF_2/Diborane from consideration as an attractive high energy, storable propellant system. The principal problem, noted in item 7 above, needs to be pursued on a meaningful scale of thrust, i.e., approximately 10,000 pounds, and at a funding level wherein meaningful data can be generated in a reasonable time. We see no reason for withholding this kind of effort, and every reason for systematically augmenting what is now being done with a more concerted effort. This should involve in addition, feed system considerations, throttling capabilities, and an exploration of other fuels with OF_2 so as to broaden the base of choice available in the high energy, storable propellant area.

In this latter regard, we have, of course, continued to augment NASA support, with corporate support, and firmly believe that an entire family of OF_2 based systems can be projected. Hypergolic ignition and high performance have been demonstrated with these other fuels, and some very attractive combustion containment techniques have been conceived. We are convinced that this path offers the real possibility of some very attractive and highly useful propulsion systems.

Thiokol wishes to compliment this committee for its foresight in increasing the NASA budget once again by $3 million for additional work in these areas. Our rate of technological growth here is presently limited by funding considerations—not by any laws of nature. We are sure that this funding can and will be wisely expended for these purposes.

As regards funding, it is our view that a high performance engine based on OF_2, i.e., space storable and capable of throttling, with initial thrust levels in the 20,000–30,000-pound range, can be developed for use in approximately 5 years at a cost of approximately $80 million. A funding level for continuation of the current efforts as we have outlined them in fiscal year 1965, would be approximately $5 million. This money needs to be spent in an integrated manner which focuses effort on the ultimate use of the propellants, and should not be dissipated in a variety of related technologies which bear only remotely on such use.

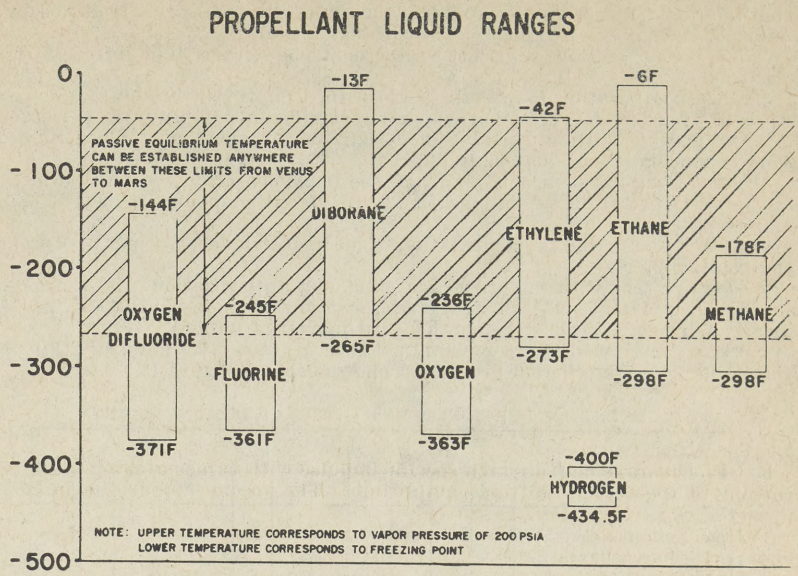


FIGURE 3

Assuming that the fiscal year 1965 effort continues to look as favorable as it does now, we see it leading to a more ambitious demonstration effort in fiscal year 1966–67, followed by the flight engine development discussed above, through 1970.

III. LARGE SOLID PROPELLANT BOOSTER

The large solid booster demonstration program is a good example of the basic philosophy which was presented earlier. Perhaps the most deterring factor in the national space effort has been the lack of available high thrust capability. The payloads that could be lifted into space were weight limited, which naturally imposed restraints on the planning of that program. On the other hand, if aggressive research and development had been applied, there is little doubt that the large thrust capability represented by large solids could have been made avaliable. The current program is establishing large solids, 260 inches in diameter with 3-million-pounds thrust, and these are only half-length when related to the optimum design. We hope to continue with full-length 6-million-pound-thrust motors in the same diameter. Four of these motors, clustered together as a vehicle first stage, will place nearly 1 million pounds of payload in a 100-nautical-mile orbit. This, of course, assumes that suitable high-performance liquid upper stages are made available. This larger motor will be about 135 feet in length, weight 3,571,000 pounds and its burning time will be 110 seconds.

Admittedly there is no approved mission now for such a motor, or such a vehicle. However, unless the program can continue at a well planned, nonsporadic pace the "decision-time" for a larger vehicle may arrive—without sufficient evidence that a mission can be planned with confidence, at reasonable costs, and within a reasonable time.

The current 260-inch short-length motor (3-million-pound thrust) program is now proceeding. We are actually fabricating the large case and nozzle hardware. The major scientific, laboratory, and verification-of-technology portions of this program are virtually complete. We have the utmost confidence that in August of 1964, the first 3-million-pound thrust motor, in a 156-inch diameter, will be successfully tested—only 14 months after program initiation. The first 260-inch motor with 3 million pounds of thrust and 110 seconds burning time, will be tested in January 1965 and the second in June 1965. This gives us three major tests at 14 months, 18 month, and 24 months respectively from program initiation, and at a very low program cost. This program will demonstrate that high thrust solids can be provided on a short schedule at low cost—a statement we have made to you many times. We believe that this effort should continue without interruption to include many of the accessories required for the motor to be of use in a vehicle. These things include:

1. The incorporation of thrust vector controls—either fluid injection or the gimbaled nozzle.

2. The incorporation of certain performance improvements—of the type not necessary for demonstration but which will significantly improve the effectiveness in a vehicle application (insulation design improvement, nozzle weight reduction, refinement of case materials, etc.).

3. The accomplishment of a plan, and the implementation necessary to proceed to the demonstration of full scale (6- to 10-million-pound thrust) 260-inch-diameter motors.

4. The planning and implementation of an inclusive development and preflight engineering effort.

We believe that with the proper planning, and authorization, that the 260-inch short-length motor could be delivered for flight tests in mid-1966. The full-length motor could be delivered in the third quarter of 1967.

We have mentioned "proper planning" several times. To illustrate this point, the schedule for the current program is shown below in figure 4.

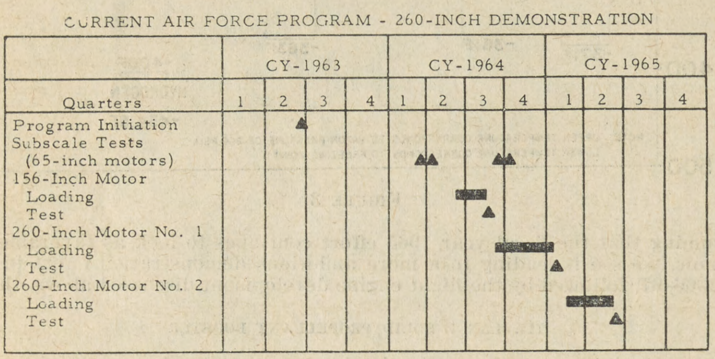


FIGURE 4

It can be observed that this program is complete in June 1965. If a continuing program is not planned and authorized by that time, there could easily be a 6-month gap devoted to planning, bidding, and funding. The program would possibly start again in January 1966. The manpower requirement would be approximately as shown in the graph below in figure 5.

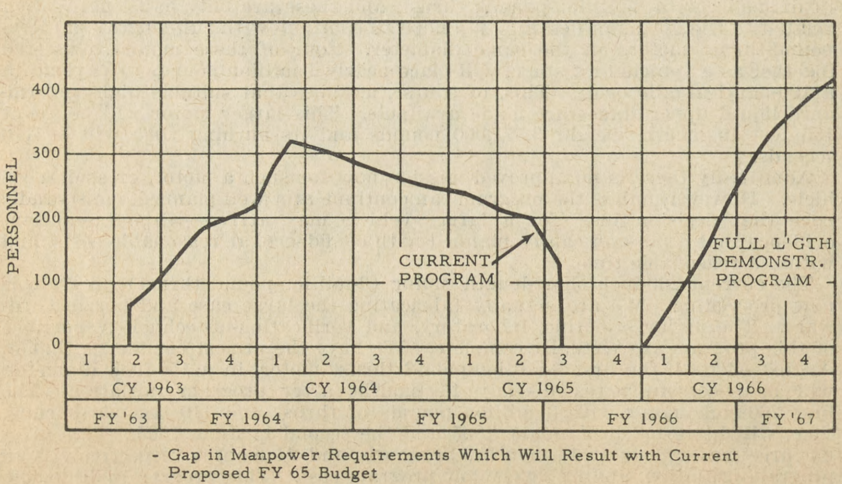
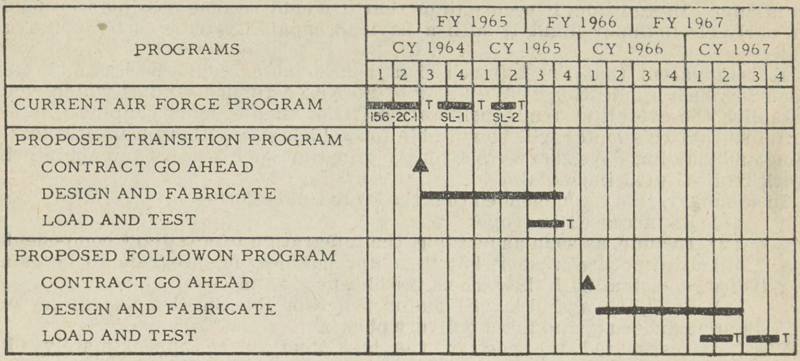


FIGURE 5

This shows that the manpower "team" would have to be dispersed and the program shut down, since there is no other work for these people to do. This all results in a waste of technology and experience which, we believe, is not in accordance with the desires of either this committee or the NASA—and certainly not in accordance with Thiokol's plans. One possible plan to demonstrate the large full-length 260-inch motor is shown in the following schedule (see fig. 6):



Schedule Showing the Relationship of the Short Length Demonstration Program, the Proposed Transition Program, and the Full Length Demonstration Program

FIGURE 6

This schedule shows that the go-ahead for continuing effort should be ready in mid-1964. This will require two things:

(*a*) A program scope.

(*b*) Additional fiscal year 1965 funding authorization.

It is our recommendation that a program be planned to include the testing of at least two full-length motors. This program would provide for the integration of auxiliary devices such as TVC and other flight-necessary devices. The proposed transition program shown above is as follows:

(*a*) The design of full-length motors (6 million pounds thrust) and a structural and ballistic performance analysis;

(*b*) The refurbishment of a short-length motor case and the reloading of this case. A TVC system test on this reloaded motor.

This program, we estimate, would cost a minimum of $7 million.

Finally, we would like to recognize a possible early application for the 260-inch short-length motor. Both the Air Force and NASA have funded several systems contractors for studies directed toward the determination of potential launch vehicles which would use the 156- and 260-inch-diameter solid propellant motors. Thiokol has contributed heavily in these studies by providing propulsion information. The significant findings of these studies are as follows:

The current analysis shows the following vehicles and their payload carrying capability:

Saturn I: 22,500-pound payload capability. Deleted from operational status.

Saturn IB: 33,500-pound payload capability. Planned for Apollo preflight tests.

Titan III: 25,000-pound payload capability.

Saturn V: 220,000-pound payload capability.

An examination of this indicates a payload gap exists between the 33,500-pound payload S–IB and the 220,000-pound payload Saturn V. This payload gap has a tendency to force the Apollo, Gemini, MOL, and MORL programs to design and develop their spacecraft toward time-consuming and expensive miniaturization approaches. Although entirely feasible, such weight-reduction activity can cause problems in meeting schedules and cost commitments. A possible solution has been shown as a result of the previously cited studies. The 260-inch-diameter Saturn IB vehicle can be modified to incorporate the short length 260-inch motor as the first stage. This modified vehicle will lift approximately 50,000 to 60,000 pounds to a 100-nautical-mile orbit, approximately double the currently planned capability. Furthermore, a major study contractor has completed a study comparing the cost effectiveness of this modified Saturn IB to the currently planned vehicle. The study shows that cost for placing payloads in orbit could be reduced from an estimated $576 per pound to $298 per pound. Certain technical organizations within NASA are impressed with the simplicity and inherent reliability suggested by this modified Saturn IB vehicle. The first stage has a single solid motor, and the second stage has a single liquid engine, all of which will reduce engineering complexities to a minimum. In addition, it occurs to us that it would become possible to consider an early circumlunar flight if such a payload capability were to become available.

It is apparent that the 260-inch short-length motor could be available very soon for such applications. We know of no NASA-funded studies which would establish the overall system consideration. It is time to start shaping this program so that this motor will be suitable for vehicle use without a useless loss of time and funding. We therefore strongly urge that such studies and engineering work be instituted immediately.

In summary, it is recommended that the large solid effort—

(1) Be increased in scope;

(2) Include, as soon as possible, the integration of auxiliary components;

(3) Incorporate a short-length motor engineering program to be established consistent with the earliest possible need; and

(4) Establish a full-length motor program for the demonstration, preflight engineering, and flight delivery phases.

We have estimated the cost of the last item to be approximately $100 to $120 million plus about $22 million for additional facilities. Compared to other types of propulsion programs we believe this to be a bargain.

Mr. Karth. Thank you very much, Dr. Ritchey.

What Saturn vehicle could be accommodated as a second stage by the clustering of four 260-inch solids that you referred to moments ago?

Dr. Ritchey. The clustering of the 260 full length? Actually there is no Saturn system that I know of that is currently planned that would lift a payload as heavy as this one. This will provide about——

Mr. Karth. I think you misunderstood my question. Which one of the Saturn vehicles could be accommodated with a clustering of four 260-inch as a basic booster?

Dr. Ritchey. Any of the Saturn missions could be accomplished by the proper clustering of either 156- or 260-inch-diameter solid boosters.

Mr. Karth. What if you clustered four 260-inch? Would this accommodate the Saturn V, for example, as the second stage, too?

Dr. Ritchey. It would more than accommodate the Saturn V insofar as payload lifting capability is concerned.

Mr. Karth. What would four 156-inch solid engines clustered accommodate; which one of the Saturns?

Dr. Ritchey. As I recall the studies, the Saturn V mission can be accomplished by just about—just about be accomplished by a single 260-inch-diameter full-length engine serving as a first stage. You still need the high energy liquid upper stages that are now planned for the Saturn. Four of the 156-inch-diameter engines is somewhat more than would be needed for the Saturn C–5 first stage. In fact, I believe about three of them are about what is required for that, the 156-inch size.

I have one of the program managers here, Mr. Preston Craig.

Mr. Craig. We have studied this problem in some degree and feel that if the 260-inch motor is being considered an augmentation to the Saturn V, it would be perhaps nearer optimum to consider three or four shorter length motors of perhaps 4 million pounds thrust each.

As far as the 156-inch is concerned, in that same application, I believe it comes out in the neighborhood of four to five of these engines, full length, would do that same job.

Dr. RITCHEY. We will make note of your question, Mr. Chairman, and provide you a specific answer when we return the questions. The question was, What combination of large solid boosters would we recommend to provide the function of the Saturn first stage, Saturn V first stage; is that right?

Mr. KARTH. Well, that is a good question, too, but really what I was attempting to ascertian, Doctor, was how large a solid rocket engine first stage would be required to accommodate fully one of our present Saturn vehicles or those that we have under consideration as a second stage.

Dr. RITCHEY. I see.

Mr. KARTH. Do you understand my question?

Dr. RITCHEY. Yes; I understand the question.

Mr. KARTH. You can answer this for the record.

Dr. RITCHEY. You put the whole Saturn system on top of a solid booster, is your question?

Mr. KARTH. Yes.

Dr. RITCHEY. I believe that the cluster of four full-length, 260-inch diameter boosters is just about right for that kind of an application.

Mr. KARTH. For the Saturn I, I–B, or V?

Dr. RITCHEY. Saturn V.

Mr. KARTH. Saturn V.

Dr. KIRCHNER. May I add something here, Mr. Chairman?

Mr. KARTH. Dr. Kirchner, yes.

Dr. KIRCHNER. I think if we take the Saturn V and take the second and third stages, the S–1, 1–B or S–2 liquid engines and you put two 260 strap-on solid propellant rockets on it, more or less the same as the Titan III vehicle, you are getting a Saturn V with 100-nautical-mile orbit mission with a payload of 460,000 pounds, which I think is something greater by about 200,000 pounds than we presently have on the Saturn V.

That is one straightforward application in which you take the technology more or less from the Titan III program and translate it by having a heterogeneous solid and liquid system.

Mr. KARTH. I understand.

Dr. KIRCHNER. If you take the short version of the 260-inch rocket, the one which both Thiokol and Aerojet are developing now, with a 3-million-pound capability and make this a direct substitution as the basement engine for the Saturn I–B, you again get a doubling of your payload, and I think where presently the payload is recognized as about 32,000 pounds, I think figures of about 50,000, 60,000, or even 70,000 pounds can be realized.

Mr. KARTH. The nuclear rocket people were here yesterday and indicated to the committee that a basic nuclear rocket engine in the large thrust field is feasible. Would you care to comment on that?

Dr. KIRCHNER. Maybe we could have Dr. Ross comment on this.

Dr. ROSS. I didn't hear the question, sir.

Mr. KARTH. I say, the nuclear rocket people were before the committee yesterday and indicated that it was entirely feasible, probably indicated that it was possibly one step beyond feasibility, that we could use a nuclear rocket engine as a basic booster.

Would you care to address yourself to that?

Dr. Ross. I don't think we would really propose a nuclear engine as a booster. There are just too many problems. It fits more as a high specific impulse high energy, if you will, upper stage.

Mr. Karth. Is that the general consensus? Mr. Hoffman, would you agree with that?

Mr. Hoffman. Yes.

Mr. Karth. Dr. Ritchey? Is there unanimous consent at the table?

Dr. Ritchey. Yes.

Mr. Bell. May I ask you a question? Is your question geared to the type of rocket propulsion that is implied with Project Rover, a hard core reactor; is that what you are talking about, or are you talking about other types of nuclear propulsion?

Mr. Karth. I am talking about those things that the nuclear rocket people were talking about yesterday and that, of course, was one of the principles that they talked to us about.

The other one, of course, was the gaseous core and the——

Mr. Bell. Orion.

Mr. Karth. The Orion theory.

Mr. Bell. Were you answering on all those counts or were you answering just on the Project Rover?

Mr. Karth. I think they said they would not recommend a nuclear rocket to be used as a basic booster. This is my opinion.

Dr. Ross. I would consider my answer would apply to all.

Dr. Ritchey. If I may make a remark, Mr. Chairman, I feel the problems of obtaining a workable hot core nuclear reactor rocket such as the type that we are now developing are vastly compounded by an order of magnitude or more, by trying to attain high thrust.

Mr. Karth. Thank you.

Mr. Fulton of Pennsylvania. Would you explain that a little bit, explain your comment a little bit?

Dr. Ritchey. Well, high thrusts are attained only by high mass flow, and high mass flow and hot gas compounds the problem of temperature differentials in the solid core, it compounds the problems of core support, aerodynamic drag on the core itself, and it compounds the problems of heat transfer and all these three things put together make the whole thing worse when you try to get high mass flows through the solid core reactor of the present type.

Mr. Fulton of Pennsylvania. So in what area of time would you say that the gaseous core would become practical?

Dr. Ritchey. At the high rate of gas flow?

Mr. Fulton of Pennsylvania. The gaseous core type, what area of time, how long will it be yet before we could have any practical vehicle for flight?

Mr. Karth. Is the gentleman talking about a basic booster?

Mr. Bell. I don't think he is really relating his question properly—he is talking about the reactor.

Dr. Ritchey. I am talking about the solid core reactor exclusively in my comments.

Mr. Fulton of Pennsylvania. My next question is, on the gaseous core, when you are speaking of time, trying to get high thrust, of course, the highest thrust is the gaseous core, and on that basis I say then in what period of time would a gaseous core type be feasible or practical? I think somebody said it was 1990. What is your idea?

Dr. RITCHEY. Well, I think that I more or less expressed my feelings early in my verbal presentation when I said that for the foreseeable future our space vehicles are going to be propelled by chemical propulsion and that is at least for the next 15 years. I hesitate very much to predict what might be done by 1990.

Mr. FULTON of Pennsylvania. That would apply both to the other two types, the Orion as well as the solid core; is that right?

Dr. RITCHEY. That is my opinion.

Mr. BELL. Will the gentleman yield?

Your feeling, however, is that research and development effort should continue in this nuclear field?

Dr. RITCHEY. Very definitely.

Mr. FULTON of Pennsylvania. Yes. I want to say that I feel that too. I didn't want to infer that we weren't going to go ahead with it.

You have Reaction Motors in New Jersey, I believe, that has been working on the research on diborane. I am sure that Mr. Patten, of New Jersey, will be interested in this particular question.

Mr. FULTON of Pennsylvania. I ask how the experiments have been going and if the money in New Jersey is running out in June? Doesn't your contract expire in June?

Dr. RITCHEY. The present level of effort does expire, I believe, in June, and also it is relatively small, about $50,000 per month, which should really be scaled up if the OF_2 and diborane system or the OF_2 system with any other energetic fuel does achieve flyability in let's say the late 1960 time frame.

Mr. FULTON of Pennsylvania. How have the experiments been coming?

Dr. RITCHEY. They have been extremely gratifying to date. We have made a large number of tests for a new system of this kind. Actually, 47 tests in the 150-pound-thrust range, and 25 tests in the 2,000-pound-thrust range. And, as I mentioned, about the only problem we have encountered that appears to have any severity at all appears to be the problem of the combustion containment or chamber cooling.

This is certainly an area that needs beefing up insofar as development effort is concerned.

Mr. FULTON of Pennsylvania. You have had no trouble with the gassing, the way they did with diborane in the turbojets? You have no trouble with that?

Dr. RITCHEY. No, sir. The combustion products, disposition of them, offers an entirely different opportunity to use solids as an exhaust, example, as compared to what you might get in a turbojet——

Mr. FULTON of Pennsylvania. So the rocket field is entirely different; the defects we run into there do not apply to here?

Dr. RITCHEY. We have two differences. For one thing, we don't have to worry about deposition on the blades; second, the combustion products are volatile anyway. If we had fluorine in the atmosphere instead of oxygen, probably the zip fuels, as they were called in those days, would be much more applicable to turbojets than they are with an oxygen atmosphere.

Mr. FULTON of Pennsylvania. The gentleman from Oklahoma, Mr. Albert, the majority leader, has in his State the Muskogee plant of Callery Chemical, is that not right?

Mr. CARPENTER. That is correct.

Mr. FULTON of Pennsylvania. That plant is to manufacture diborane in large quantities. Could I ask you what the present status of that plant is? Is it not on hot standby under the U.S. Air Force and costing about $400,000 to $500,000 a year to keep it that way?

Mr. CARPENTER. It is not hot standby. The Air Force instructed us last year to place it on a caretaker status. The amount, the dollar volume, is correct.

Mr. FULTON of Pennsylvania. So that while that plant is being held we are having a U.S. Government expense of about $400,000 to $500,000 a year waiting on these experiments to be performed to see if they turn out at Reaction Motors of Thiokol in New Jersey, is that not right?

Mr. CARPENTER. Yes, sir.

Mr. FULTON of Pennsylvania. How long do you think it will take you on those experiments, might I ask, Dr. Ritchey? How long would it take you on your experiments and how much money do you think it is going to take? What rate should we be giving you? I have increased this high-energy fuel allocation several times over the last 2 years by amendment, and we are doing it again, this committee has adopted another amendment for $3 million for this purpose.

For diborane and OF_2.

Dr. RITCHEY. We think this is a very commendable action on the part of the committee and one that certainly is very necessary in order to bring this system along to a flyable status at the time that will be needed for deep space missions. We are suggesting a reasonable fund level for this area in fiscal 1965 is $5 million.

In the following years, to make this flyable, available for a flight vehicle in a 5-year time, will require about $80 million to put together PFRT and development work.

Mr. FULTON of Pennsylvania. You are not including in that $5 million the flox contract that we have with Pratt & Whitney on the Centaur, are you?

Dr. RITCHEY. No, sir; I am not.

Mr. FULTON of Pennsylvania. So it is outside that.

Under our budget figures that has sometimes been put in with this high-energy fuel, but you mean that in addition?

Dr. RITCHEY. Yes, sir. This is the OF_2 diborane and other fuels program only, which should be carried on at a rate of about $5 million in fiscal 1965 in order to establish and achieve proper progress.

Mr. FULTON of Pennsylvania. Do you believe that it shows every promise of a worthwhile expenditure and an expenditure that we can profit by in the future through reduction of the size of the boosters and the increase of the size of the payload?

Dr. RITCHEY. The payoff here, potential payoff, is very, very attractive, because of the higher fuel densities and oxidizer densities, the size of the vehicle for a given mission is reduced quite substantially. This has a very favorable effect on cost, not only of the vehicle but also of the facilities that are needed in the launching complex. And for that reason it would appear that the total cost of performing the mission can be reduced substantially by the use of OF_2 and an energy fuel, even though the propellant combinations themselves may be somewhat expensive as compared to the more conventional propellants.

Mr. FULTON of Pennsylvania. But these two propellants are compatible so that you do not have to insulate one from the other, as you do in hydrogen and oxygen, and also they are space storable, are they not?

Dr. RITCHEY. They are space storable, they do have to be kept in separate tanks because they react spontaneously on contact; in other words, hypergolic.

Mr. FULTON of Pennsylvania. They do not need to be insulated from each other; of course you must have to keep them separate?

Dr. RITCHEY. They are storable at the same temperatures. OF_2 and diborane has a wide overlap in temperatures in which both of them are liquid and can be started at the same temperature.

Mr. FULTON of Pennsylvania. Might I ask Mr. Carpenter on this point?

If we do use hydrogen in outer space with a temperature of maybe 220° or 240° below zero, we nevertheless have to keep hydrogen from boiling around 423° to 426° below zero, is that right?

Mr. CARPENTER. It will boil, and you have to vent the vapors or provide a refrigeration system, to return them to the liquid state.

Mr. FULTON of Pennsylvania. And is there about 100°-odd where oxygen is frozen and the hydrogen would be boiling?

Mr. CARPENTER. That is correct. Both of them have temperature problems there.

Mr. FULTON of Pennsylvania. So that if we did have a vehicle in outer space that had both hydrogen and oxygen we would not only have to insulate it, the fuel tanks from the outside, but we would have to insulate them from each other; is that not correct?

Mr. CARPENTER. Yes, or the oxygen would freeze at the boiling point of liquid hydrogen.

Mr. FULTON of Pennsylvania. How long would hydrogen last before it would boil away?

Mr. CARPENTER. Well, this depends, of course, on how much insulation weight you are willing to put on board, and an analysis of a particular mission would have to be made to answer your question in any more detail.

Dr. KIRCHNER. Mr. Tischler provided a very nice plot in which he shows for a typical mission in 6 months—in a 6-month cycle you are actually losing something in the neighborhood of practically 50 percent of your hydrogen. Isn't that correct?

Mr. TISCHLER. It is more than that, possibly. You would lose about 50 percent of your payload capability. Loss of hydrogen has to be predicted and accounted for even before that.

Mr. FULTON of Pennsylvania. Then on a landing on the moon, if you have hydrogen, if you get ten-thousandths to twenty-thousandths of inch crack there might be danger of leakage, is that correct?

Mr. CARPENTER. The low temperature of liquid hydrogen imposes severe requirements on the metal container and the brittleness of metals is a problem.

Mr. KARTH. We have considerable empirical statistics on this, do we not?

My interest perhaps not being quite the same as the gentleman from Pennsylvania's, perhaps, I wonder if I could ask this point: How much money do you think it would take to flight develop the 260-inch solid engine?

Dr. RITCHEY. The estimated cost of bringing the full-length, 260-inch engine to a flyable status with manned rating is from $100 to $120 million in R. & D. work, with an additional $22 milion in facilities required to support the follow-on production effort so that these could be provided at a reasonable rate for space missions.

Mr. KARTH. Dr. Kirchner, have you made any analysis of this so that you could answer the question?

Dr. KIRCHNER. We made similar analyses and I think our figures are very close to what Dr. Ritchey mentioned. In fact, we have identical programs, as you know.

Mr. KARTH. Yes.

Dr. KIRCHNER. And they are both funded, and the scope is identical. So the extrapolation of our experience and Thiokol's experience I think is very close.

Mr. KARTH. So your answer is that to develop a 260-inch solid propellant rocket motor to flight stage would cost approximately $120 million, is that correct?

Dr. RITCHEY. Yes, sir.

Mr. KARTH. Mr. Fulton?

Mr. FULTON of Pennsylvania. When you talk about clustering a 260-inch booster, say four, or some such number, it raises the question, what kind of a pad or what kind of a system you are going to boost them on. My question is this: Does it take any particular kind of a pad other than just a larger pad than the types we have now, or do you need a special pad?

And then have you given any thought to—I am from the Navy—to having a sea launch for that type of a vehicle?

Dr. RITCHEY. There has been a lot of consideration of sea launching that type of a vehicle, and certainly it is not beyond the bounds of feasibility. However, I believe that in general, the types of handling equipment that are already planned would be adequate to bring these boosters together and to assemble them.

There would be certainly consideration given to the size of the structure and the gantry cranes must be the necessary height to accommodate that. But even so the propellant density involved here is going to reduce the size very substantially below the size of a similar vehicle using all liquid propellants.

Mr. FULTON of Pennsylvania. One question to Mr. Carpenter and to you, too, sir; if we do move into higher energy liquid propellants, one of the results would be that you could use the same installations with high energy engines, and you would then not only have longer life and less obsolescence of the installations on the ground and the various equipment, but you would likewise have a longer life for the current generation of boosters and vehicles.

Would that not be correct?

Mr. CARPENTER. Yes; that is correct.

Dr. RITCHEY. I believe that is a very correct observation.

Mr. FULTON of Pennsylvania. So that we do get a saving in many ways if we will move into high compression and higher energy fuels, liquid, and likewise we get quite a saving if we press on in solids as well as in nuclear high energy propulsion, is that not right?

Dr. RITCHEY. I would certainly subscribe to that.

Mr. FULTON of Pennsylvania. Do you subscribe to that? Could somebody just say "Yes"?

Mr. HOFFMAN. I subscribe to that policy.

Mr. FULTON of Pennsylvania. Mr. Carpenter.

Mr. CARPENTER. Yes, sir.

Mr. FULTON of Pennsylvania. Dr. Ritchey, do you?

Dr. RITCHEY. Yes, sir.

Mr. FULTON of Pennsylvania. Dr. Kirchner.

Dr. KIRCHNER. Yes, sir. Although I think as far as appreciation for the installations, as far as launching facilities are concerned, it might be limited here in this group because you are addressing your remarks to a number of people who are mostly interested in propulsion, itself. So from that standpoint, at least, I am speaking for myself, the degree of intelligence in which I take relative numbers as far as dollars and installations are concerned, they must be flavored by a little ignorance.

Mr. FULTON of Pennsylvania. Well, there are variations, but what we are talking about is moving up to get more push per pound with this present generation of vehicles and even on the solids, moving into a different order of magnitude rather than a different type of equipment, isn't that correct?

Dr. KIRCHNER. If you keep the volume constant and if the launching facilities are more or less volume limited, the increase in the energy of the various systems and the stages, of course, is in the right direction, because this would, by definition, not change the design criteria of the launching facility and will give you a progressive evolution and increase in the payloads. So from that standpoint I think we all agree that this is a step in the right direction.

Mr. KARTH. Mr. Patten?

Mr. PATTEN. No questions.

Mr. KARTH. Mr. Bell?

Mr. BELL. Dr. Ritchey, you talked about solid propellant in your questions from Mr. Fulton. I understand at one time that we had a problem with solid propellants as the first stage in the fact of the warning system; if an abort was about to happen, for example, on a solid type of vehicle there wouldn't be adequate warning time to remove an astronaut in a solid whereas there would be in a liquid. Now I understand this problem has been licked. Is that correct?

Dr. RITCHEY. Well, I think that with the studies that have been made and the analysis which followed this earlier opinion—which was not generally held, incidentally—this problem has been defined and solutions have been found in sufficient magnitude so that it is no longer considered as serious as it was at one stage.

Mr. BELL. It no longer is considered serious?

Dr. RITCHEY. Yes.

Mr. BELL. Is it your feeling that, generally speaking, if you could follow a line of demarcation of some kind that you would say that solid propellants are generally better suited for earlier stages and liquid for the higher or wouldn't you like to get into that argument?

Dr. RITCHEY. No; I would sustain that argument. Very heartily. This is the general conclusion that we have come to in all the studies that we have made of how solids and liquids should best be utilized.

Mr. BELL. Your feeling is they should be utilized in that fashion?

Dr. RITCHEY. In that fashion, right. In fact, if you look at what we have done in the past, where we have used liquids on the bottom and solids on top, you might say we built them upside down.

Mr. BELL. No further questions.

Mr. KARTH. The fact of the matter is we have converted quite a number of upper stages that were previously liquid to solid, have we not, so it does serve two purposes, really, doesn't it, the solids I mean.

Dr. RITCHEY. Solids have been used in the upper stages primarily because they are available. A number of problems associated with using liquids in space, igniting them, operating them under zero gravity conditions——

Mr. KARTH. I am not sure I stated that accurately. What I meant to say is that quite a number of vehicles that were initally liquid have been converted to solid.

Dr. RITCHEY. These are primarily the military vehicles and I think we have an entirely different set of requirements generated for military applications. Simplicity, maintenance, ruggedness, instant readiness, things of this kind, that have made the solids of very great importance in applicability to the military missions. In the space exploration missions I think we are talking about an entirely different set of requirements which change the ground rules completely.

Mr. KARTH. But the reliability question which was the No. 1 question for quite some time probably caused us to tread hesitantly on following further development of solids. It has pretty well been laid to rest, that question, hasn't it?

Dr. RITCHEY. I think certainly the experience that has been demonstrated in the large solid booster area would tend to put to bed the reliability problem. The experience people have had with brand new engines that have never been fired before, first time firings, has been excellent. I believe this has generated a very much greater degree of confidence in almost everyone's mind. I think that the demonstration tests that are coming up of the 260-inch booster will serve the same purpose; both Aerojet and ours are approaching those static tests with a very high degree of confidence that the very first ones will be successful.

Mr. KARTH. Are there any further questions?

There being no further questions, I want to on behalf of the committee, thank all of you very much for appearing before the committee and making the statements you have and we will appreciate it greatly if you will answer the questions as expeditiously as possible. I might also state before we adjourn that after the staff and the members review the testimony that has been given the last 2 days we may find it necessary to ask you to come back, if you will. Until that time, the meeting is adjourned and again we thank you very much.

(Whereupon, at 4:21 p.m., the subcommittee was adjourned.)

RESPONSES TO PREPARED QUESTIONS FROM THE SUBCOMMITTEE ON NASA OVERSIGHT, COMMITTEE ON SCIENCE AND ASTRONAUTICS OF THE HOUSE OF REPRESENTATIVES

(By Dr. Harold W. Ritchey)

1.A. Question. Will there be a need for high-energy, space-storable, propellant boosters for our post-Apollo space missions?

Answer. There is a very definite need for space storable, high-energy propulsion systems. Without them we will always be limited in payload, require immense boosters for even these limited payloads, and we have a very limited costly space exploration program for many decades to come.

B. Question. What propellant combinations might you recommend for these applications? What advantages do the OF_2/Diborane combination have over these other combinations?

Answer. Our studies show that combinations based on oxygen difluoride as as the oxidizer, used with a variety of fuels capable of space storage are very attractive. These fuels involve Diborane, many hydrocarbons, and amine fuels. OF_2 used as the oxidizer in a hybrid also looks attractive. The significant point here is one of freedom of choice which OF_2 based systems provide. The principal advantages of these systems are high payload capability, competitive with the most energetic nonstorables, coupled with storability, hypergolicity, and hence, inherently high reliability.

C. Question. What is this "delta-V" of a booster stage?

Answer. "Delta-V" is the velocity increase that can be imparted to a payload by a particular stage. For a given payload weight and stage weight, you want to maximize delta-V.

D. Question. Are you aware of any other space storable propellant combinations which have either a greater specific impulse or greater "delta-V" than OF_2/Diborane?

Answer. There are some nonstorable propellants such as F_2/H_2 and O_2Be/H_2 which have higher specific impulse than OF_2/Diborane. However, they are not space storable. Of equal significance, they lose much of the payload or delta-V advantage which high specific impulse promises, because they are nowhere near as dense as OF_2/Diborane (DB). This difference in density is sufficient to make OF_2/DB almost the best payload propellent system of all known bipropellants (actually equivalent to that of F_2/H_2), yet having the no-loss, space-storage capability. It should be noted that this equivalency with F_2/H_2 neglects boiloff losses or insulation weight penalties which would degrade F_2/H_2 performance for extended space missions.

2. A. Question. What are the major difficulties that this combination (OF_2/Diborane) presents?

Answer. The principal problem with OF_2/DB is the containment of combustion products for durations in the 500–2,000-second range. The question of nozzle reaction kinetics needs experimental evaluation, although our analyses show that good results will be obtained. The exhaust is too hot to have solids or liquids condensing in the nozzle, so that two-phase flow will not occur. There was some question in 1962 regarding constancy of performance over broad ranges of mixture ratio. Our recent work shows this not to be of concern. High, flat performance has been demonstrated at 2,000 pounds thrust with several injectors. The handling of the propellants has proven to be no problem using the procedures developed at Thiokol.

B. Question. How do you expect to go about investigating the chemical recombination problem, for example?

Answer. We have approached the problem by chemical kinetic analysis techniques used successfully on other propellant systems, and we are embarking on our present NASA program to do high-altitude, large-area-ratio nozzle firings. These data will feed into our own analyses as well as those being handled for NASA by United Aircraft, supported by NASA work at New York University on OF_2/DB reaction kinetics.

C. Question. Has your company been given the job to investigate chamber cooling problems?

Answer. In part—as an element of our previous and current efforts. This work needs drastic expansion as noted in our statement.

D. Question. Are you going to employ ablatives, or clever design, or a combination of these methods, or—just how are you approaching the cooling problem? Do you know whether or not NASA has other work going on to solve this 7,000° F. chamber problem?

Answer. Our approach to the cooling problem will involve a combination of approaches—combined in the cleverest manner we know how. There is no reason to cringe at 7,000° F., provided you don't try to get the chamber materials that hot, and there are many common techniques, and several proprietary ones for precluding this. NASA does have a broad technology program related to high-temperature chambers, I believe, at Marquardt. How specifically oriented it is toward the OF_2/DB or hydrocarbon problem, I do not know. However, I would expect the answer to the OF_2/DB, etc., containment problem to come most directly from a specifically oriented effort to attack this problem, by an organization having significant motivation in this area and making use of advanced technology fallout from a broad chamber effort. The success or failure of these chamber efforts is too intimately tied to areas such as injector configuration, and detail knowledge of propellant character to be handled in separate bits and pieces, and then assembled.

3. A. Question. When might the OF_2/Diborane engines be available for booster stages, assuming that adequate funding were available for your program?

Answer. We believe, as noted in the paper, that a 5-year cycle would be required to bring to fruition a flight-type OF_2 engine, capable of throttling, having thrust levels in the 20,000–30,000-pound range. An engine of more limited objectives such as fixed thrust could probably be available in 1968.

B. Question. What sample program might you recommend for use, say, in a Mars or Venus probe vehicle?

Answer. We recommend a fiscal year 1965 effort of approximately $5 million to cover the work described in our presentation, expanding it if continuing feasibility is shown, into a substantial demonstration effort in fiscal year 1966–67, and finally into flight engine development through 1970.

C. Question. How large a thrust engine would that take? How much money and time might that require to, say, PFRT such an engine, assuming that the problems associated with this combination will successfully be overcome without too great a difficulty?

Answer. A series of studies is now in process under NASA sponsorship in this area. In working with various prime contractors, we find thrust levels varying between 10,000 and 30,000 pounds, and throttling ratios between 5 and 10 to 1. Other applications can be projected with throttling ratios of 50 to 100:1. A 5 or 10-to-1 throttling engine carried through the program of (B) above, would cost about $80 million.

4. Question. There is quite a difference in propellant costs between these various propellant combinations. Liquid hydrogen/liquid oxygen combination would cost about 15 cents per pound—OF_2/Methane would be about 30 cents per pound—and that OF_2/Diborane would cost (in the same large quantities as the previous figures) about $2 per pound. Why would it then be economical in the long run to go to OF_2/Diborane in place of the liquid hydrogen/liquid oxygen combination—disregarding the storability factor?

Answer. The costs of propellants is only one element in total mission costs, and in the case of upper stages, only a very small factor. Energy pays off in upper stages because for given payloads, the availability of high energy upstairs drastically cuts down the size and weight of the boosters and the launch facility to handle the vehicle. It is here where tremendous cost savings are realizable. It is not the least bit unreasonable to markedly increase the propellent cost in the upper stages to gain maximum energy and cause a drastic overall vehicle cost reduction.

5. A. Question. When will the present half-length 260-inch diameter engine program be completed?

Answer. The present contracted half-length program will be completed in June 1965.

B. Question. Does NASA have a follow-on program on this engine?

Answer. To my knowledge, NASA has no definite plans—at least between June 1965 and January 1966. At that time there is talk of a full-length demonstration program.

C. Question. What will it entail, and when will it begin?

Answer. No official information has been given to us by the NASA. However, we hear that there is a desire for both the 260 inch contractors to finish testing, then there would be a bidding, an evaluation, etc. This, we believe, would consume the 6-month gap.

D. Question. Now you said this program will be completed in about June 1965 and the follow-on will begin in January of 1966, or so. Why such a long gap—or has NASA indicated the reason to you? How would such a long gap affect your efforts, that is, assuming your company gets the follow-on contract? What might you recommend to fill this period?

Answer. Our activity at the space booster plant, where most of this work is being done, is highly specialized on large boosters—the plant is designed for this special purpose. There is no other work suitable as a "gap" filler. In my opinion, the team would have to be dispersed, or at least decimated to a dangerously low level. I must say that at least a bare minimum effort should be authorized to include, as that minimum, the design and analysis of the full-length motor, plus the reloading of one of the short motor cases. The reloaded motor would be tested using some form of TVC. I recommend a more solid program, however, which would directly proceed on a full-length program plan as well as the short-length motor with TVC. Our estimate is that to do the absolute minimum an additional $7 million will be required—to do the recommended, about $15 million.

6. A. Question. Do you believe that adequate supporting research funds are available to support the 260-inch program?

Answer. No; I do not. From what we can gather $13 million has been authorized for fiscal year 1965 to do large motor work. This will not more than cover the existing obligations to Thiokol and "brand X" for completing their current contracts.

7. A. Question. Has the half-length, 260-inch, solid motor possible launch vehicle application?

Answer. Yes. The most probable application is the use of the short-length motor with the Saturn S–IV–B to augment the payload range from about 32,000 pounds to say 50,000 to 60,000 pounds. The Boeing cost effectiveness numbers are significant enough that this modified Saturn might be economically feasible.

B. Question. Do you know of any NASA-sponsored, or "inhouse" NASA, studies which might indicate how such boosters might fit into the overall space program?

Answer. Only one, at the Martin Co. This study, as far as we can determine, is for post-Saturn-type vehicles and is mostly concentrated on liquids.

C. Question. When do you estimate the half-length and full-length solid motors might be available for launch vehicle use, assuming adequate funding?

Answer. The half length by mid-1966 for delivery—late 1966 would be the flight date. The full-length motor could be delivered in late 1967—assuming the program "gap" problem is solved.

8. A. Question. Has your organization been granted any contracts by NASA to study recoverable booster systems? Have you received any NASA funds to study or experiment in engines utilizing "air augmentation"?

Answer. No.

B. Question. Do your studies show that either of these ideas is feasible?

Answer. Our studies show some interest is warranted in an air-augmented system. We have done some work in air-augmented solids—some people call this the ducted-solid.

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