ADVANCED CHEMICAL ROCKETS

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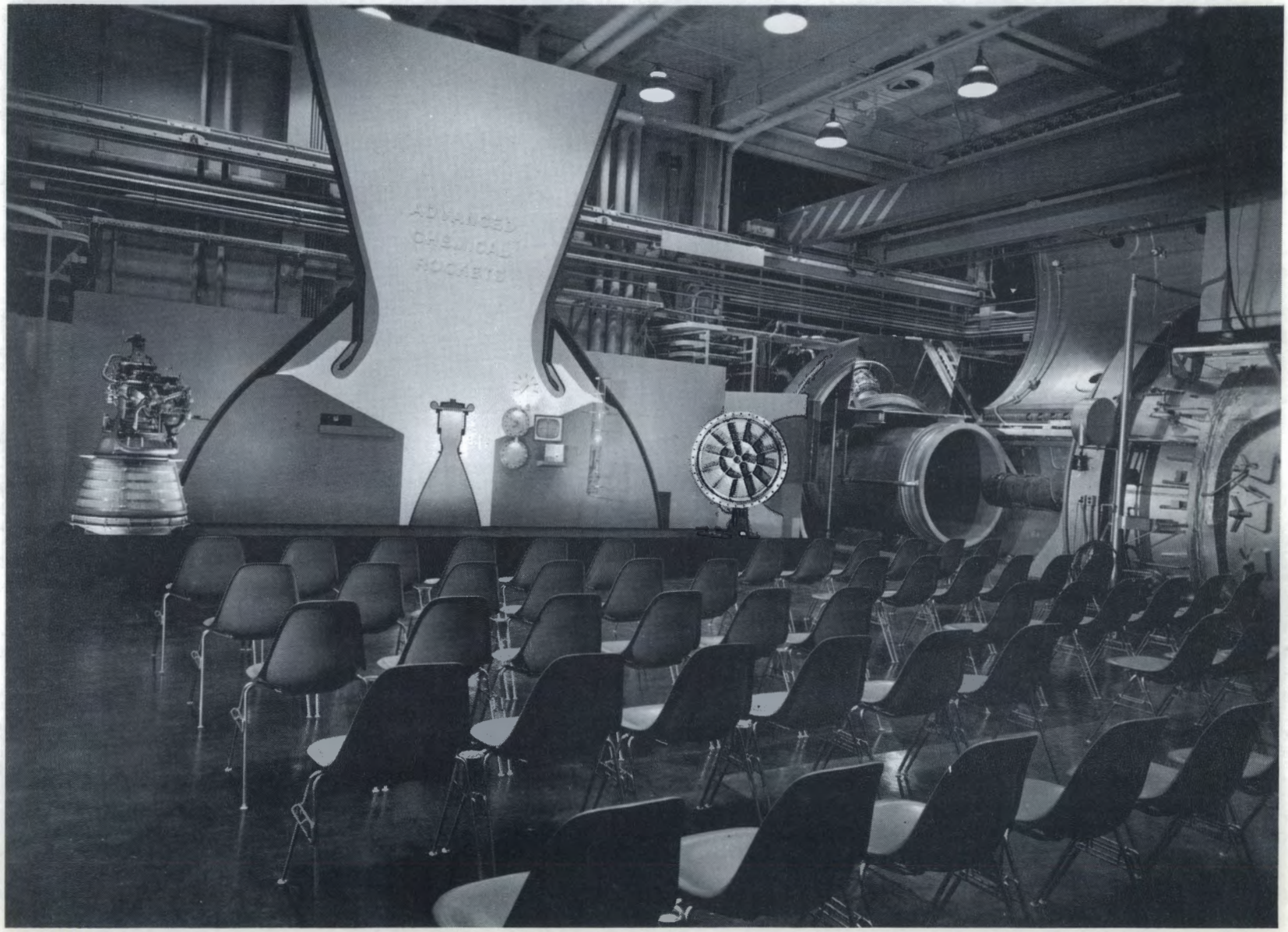
ADVANCED
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Welcome to the Propulsion Systems Laboratory. In this facility, we can provide the simulated flight conditions which are essential in our experimental research on new concepts and in our evaluation of propulsion problems. In the chamber on your right is a J-85 turbojet engine used for testing advanced exhaust nozzles for supersonic flight in the atmosphere. In the chamber on your left is a 10 000-pound-thrust rocket used for evaluating rocket nozzle materials.

Advancement in space, as in aeronautics, is paced by advancements in propulsion. This means that larger and better engines are a key part of our future aerospace program.

The size of the liquid propellant rocket has been steadily increasing. But so has the development cost. In fact, we have reached a critical point where development costs for bigger rockets are fast becoming prohibitive. One of the reasons it costs so much to develop these large engines is that existing technology has been pushed close to the limit, forcing the use of "cut and try" methods. Some of the large engines have had to be modified and retested as many as 50 to 100 times before an acceptable design has been achieved.

The chemical rocket program at the Lewis Research Center is aimed at increasing our basic understanding of chemical rocket technology with a view to improving the performance, increasing the size, and reducing the development time and cost of tomorrow's rocket engines. We are conducting research in many problem areas such as rocket cooling, materials, propellant feed systems, propellant injection, and combustion instability. Today, I will discuss some of our work on combustion instability.

Of all the problems encountered in rocket engines, one of the most persistant and difficult is the problem of high-frequency combustion instability which we call screech. Nearly every engine

development program has been hindered by it.

First, let me point out the principal parts of a liquid-rocket engine. Here is a liquid-rocket engine cutaway. This is the injector where the propellants are introduced. Here is the combustion chamber where the propellants mix and burn. And this is the exhaust nozzle where the combustion products are expelled to produce thrust.

In any rocket, the combustion process is never entirely smooth, even during so-called steady-state operation. Inside the combustion chamber, the pressures, temperatures, and flows are continually fluctuating above and below some desired value.

As long as these fluctuations are completely random and do not exceed certain limits, the engine is considered to be operating stably.

Screech, on the other hand, is condition of resonance and occurs at well-defined frequencies that are driven and amplified by the combustion process itself. I can demonstrate this phenomenon rather easily in this apparatus, which we will use to simulate a rocket chamber. It is essentially nothing more than a straight tube open at both ends with a column of air inside, similar to an organ pipe. When I place this burner inside the tube, pressure waves resulting from the uneven burning process are propagated up and down inside the tube from the flame front. When the pressure waves generated by the flame couple with the natural frequency of the internal air column, the interaction will amplify the organ-pipe tone. You will hear the tone grow louder. You will also be able to see the sound pattern on this oscilloscope screen, as it is picked up by this microphone.

(Demonstration)

When an actual rocket goes into screech, the same sort of phenomenon occurs inside the combustion chamber. When this happens, there is an enormous increase in heat transfer caused by the gas

velocity oscillations which scrub away the protective boundary layer along the walls. This increase in heat transfer to the walls also takes place in our simplified apparatus. This dial indicates the tube wall temperature as measured by this thermocouple, which I will connect by this switch. You will notice the relatively high wall temperature during screech conditions. During this demonstration, I will interrupt the screech by partially covering the end of the tube.

When I stop the screech, the wall temperature will decrease. Of course, in an actual rocket, we would not attempt to stop screech by blocking the nozzle.

(Demonstration)

When a rocket chamber goes into screech, severe damage is caused by melting or burnout of the equipment. Engines have had as much as 1/4-inch solid stainless steel metal eroded from the chamber surface in less than 1 second. Here is a typical rocket injector. Here is the same type of injector after exposure to screech. Notice the damage incurred on this rocket injector after only 0.4 second operation in a screech condition.

At the Lewis Research Center, we are devoting considerable effort to better understanding of the nature and causes of combustion instability. We are also developing ways to prevent screech in rocket engines. One of the more promising ways to suppress screech is to absorb or cancel the acoustic waves in the rocket chamber before they can interact with the combustion process and develop into a screech condition. We call this acoustic damping. The application of acoustic damping to suppress screech is being explored both here at Lewis and elsewhere.

Acoustic waves can be either absorbed or generated by a device called resonator. In its simplest form, a resonator is nothing more than a chamber with an opening. An everyday example of a resonator is a bottle. Acoustic waves can be generated by blowing across the

neck of a bottle. A resonator can be made to work equally well in reverse. That is, instead of generating a particular tone or sound frequency, a resonator can also absorb sound waves. The sound frequency produced by blowing across the bottle is the sound frequency that is best absorbed in the reverse situation. This frequency is the "resonant frequency." If we attached resonators to a combustion chamber in the region of maximum pressure oscillations and if we tune these resonators so as to match the frequency of the acoustic waves we wish to absorb, these waves should be decreased or eliminated.

Let me demonstrate. Here is a resonator. This is the neck. This is the chamber. I can change the resonant frequency by moving this plug in and out to change the internal volume of the chamber. Here is the same type of resonator attached to our simulated rocket chamber. If I tune the resonant frequency of these resonators to match the acoustic frequency produced in the tube, the resonators should absorb or damp the acoustic waves and quiet the sound.

(Demonstration)

In the case of an actual rocket chamber, the use of a single resonator is not enough to absorb the acoustic waves. A group of resonators, arranged in the form of an acoustic liner, is needed to provide sufficient absorption. The same principle is used in acoustical ceiling tile. When properly designed, these liners have been found to be quite successful in absorbing acoustic waves in the combustion chamber. Here is an experimental acoustic liner we have tested on a 20 000-pound-thrust rocket engine. These holes correspond to the neck of the resonator. These spaces correspond to the chamber. When we ran a rocket without this liner, a very destructive screech condition was observed. At the same operating point with this acoustic liner installed, there was no screech observed.

We feel that our experimental findings will prove to be of considerable value in the design of advanced rocket engines of the future.

There are other ways to overcome combustion instability. One approach is to divide the combustion zone into a series of separate compartments by the use of baffles, such as these, to reduce the likelihood of a resonant chamber condition. This technique is not new. The rocket industry has used baffles for a number of years with some success. We are now learning how to use baffles more effectively.

Another approach to overcoming screech is by improving the propellant injection method. Here is a conventional injector element (fig. 1). A stream of liquid oxygen enters the combustion chamber through the center tube. Hydrogen enters through the surrounding opening. The propellants mix and burn in the combustion chamber. In small-scale experimental tests, we learned that there is an optimum adjustment of injection velocity of the hydrogen relative to the injection velocity of the oxygen which improves both the stability and the engine performance.

The results of our small-scale experimental work on baffles, injection techniques, cooling, ignition, and other related areas were incorporated in the M-1 engine.

This is the injector for the 1.5 million pound thrust liquid hydrogen - liquid oxygen M-1 rocket engine. It was designed in a joint effort between the contractor, Aerojet-General Corporation, and the Lewis Research Center. This is the largest hydrogen-fueled rocket ever built.

For the M-1, our objective was to build an engine that would work right the first time. From the first firing, this engine has demonstrated excellent performance, mechanical integrity, and screech-free operation.

Our experience with the M-1 engine indicates that our research can be applied successfully in the design of future rocket engines.

In a period of less than 8 years, major accomplishments have been achieved in the nation's space program. We have proved beyond

question that space exploration is feasible and that we can perform useful tasks such as weather surveillance. We have learned more about our planetary neighbors within the last few years than during man's entire prior existence. We have even reached the point where communications satellites have become a commercial enterprise. However, in our future programs in space, we are facing even greater challenges.

Let us talk about the propulsion system requirements for these future programs (fig. 2). These factors will become extremely important: (1) large payloads, (2) low cost, (3) launch readiness, and (4) high reliability. Future missions such as manned orbital space stations may require orbiting as much as 10 times the payloads of present-day vehicles. In order to meet these large payload requirements, the most important propulsion consideration is low cost. And here we must ask ourselves a very significant question. Are we reaching the point where payloads are so big that we cannot afford to launch them by the techniques we are now using?

Up to now, we have relied largely on liquid propellant rocket systems. We have done the job effectively, but at high cost. A liquid rocket propulsion system contains many components (fig. 3). The Atlas rocket, for example, contains over 300 000 parts. The remarkable record of reliability of the Atlas is a tribute to the people who designed and built it. Today's more modern liquid rockets, such as the Saturn, which can launch tens of thousands of pounds into orbit, are much bigger, more complex, and far more costly. But what about future requirements involving a million or more pounds in orbit and precise launch scheduling?

If we are to consider entry into this advanced phase of space exploration seriously, it is more important than ever to consider the economic side of the picture. We must look beyond our present methods of propulsion and explore different methods of fulfilling our requirements. One approach which has great potential is the solid propellant rocket motor.

The solid rocket motor (fig. 4) is truly a self-contained propulsion system consisting essentially of a case, a nozzle, a supply of solid propellant, and an ignition system. The case serves as a pressure chamber with the propellant cast against the case wall. The propellant burns along the inside surfaces. The propellant looks like this sample I am holding. In open air, the propellant burns rather quietly; but, when confined in the case at elevated pressure, the burning process is intensified and produces useful thrust.

Here is a sample of solid propellant which I will ignite. After a few seconds of unconfined burning, I will lower this simulated rocket case over the burning propellant. This will confine the burning, raise the pressure, and direct the combustion gases through this nozzle.

Solid rockets are not new. The Chinese used them as military weapons hundreds of years ago, but this centuries-old concept applied in a new way, using today's technologies, shows considerable promise for the future. The Lewis Research Center is exploring ways to adapt the solid rocket to meet our future propulsion needs. We are learning to solve the problems associated with scaling the solid rocket to large sizes.

Our principal effort is the 260-inch-diameter solid rocket program, which is being conducted by the Aerojet-General Corporation under NASA-Lewis management (fig. 5). This rocket measures 22 feet in diameter by 85 feet long. It is loaded with 1.6 million pounds of propellant. The colored part of the rocket, shown on the slide, is the part you see in full-scale cross section on the backdrop. Shown is the nozzle and that part of the case to the thrust ring.

Two of these motors have been test fired to date. Each motor produced $3\frac{1}{4}$ million pounds of thrust for approximately 2 minutes, the highest thrust ever attained by a single rocket motor.

Let us look at the technological problems associated with building solid rocket motors in very large sizes. I will take two of the components of the motor, the case and the propellant, to illustrate the kinds of problems that are being solved.

The case of the 260-inch rocket is currently made of maraging steel plates welded together. We have successfully improved our welding techniques in order to avoid brittle fractures in these welds. Another stop on your tour today discusses more about this subject of brittle fracture and the catastrophic consequences that can result if it is ignored. In addition to the maraging steel approach, we are investigating high-strength materials which are so tough that they can sustain very large imperfections without fracturing. One of these new, tougher materials was developed for submarine applications.

The 260-inch motor case (fig. 6) is built in a shipyard, bringing a long established segment of American industry to the aerospace effort. Shipyard construction allows us to use existing skills and equipment. Complex, new fabrication facilities are not required. Because the solid rocket cases are a small portion of total shipyard work, manpower can be allocated for rocket work only when we need it. This greatly reduces the overhead costs.

Another cost advantage accrues from the reuse of the motor cases in our development program. Or, should we need to adjust the size of our motors, we can add or subtract center sections.

Now let us talk about the propellant. It is a homogeneous mixture of oxidizer crystals such as ammonium perchlorate, metal additive powders such as aluminum, and rubber binders. These ingredients are, themselves, low-cost chemicals that are used in many other industries. For this reason, special plants do not have to be built in order to obtain them in the quantities we need. We process the propellant, using tools that have already been developed. For instance, the mixer, which is used to blend the propellants for the 260-inch program, was developed for use in the baking industry.

For space vehicle applications, it is necessary to tailor precisely the rate and duration of thrust application. However, there is no throttle in a solid rocket. The propellants are already built into the combustion chamber. Therefore, once a solid rocket is ignited, the thrust depends on two factors; the burning rate of the propellant and the exposed burning surface area. The burning surface area (fig. 5) is controlled by adjusting the shape of the hollow inner core of the propellant. This is done by inserting a carefully shaped mandrel into the center of the empty case. The propellant is poured into the case around the mandrel. After the propellant is cured, the mandrel is withdrawn, leaving an exposed surface which has been tailored for the desired thrust.

The second factor, the burning rate, can be controlled by varying the size of the individual fuel and oxidizer particles and by using additives.

In general, present day solid rockets use relatively slow-burning propellants. However, the propellants in the 260-inch rocket must be consumed at the rate of almost 1 million pounds per minute. This has required substantial increase in burning rate. Methods of propellant formulation have been established to accomplish this.

By close production control, precise burning rates can be established. By shaping a solid propellant having a precise burning rate around a carefully designed core, we can build in thrust control to meet a given thrust time requirement.

Just how precisely a specified thrust time requirement can be met has been demonstrated in the test firings of the 260-inch motor. On this slide (fig. 7), the dashed line represents the predicted performance. The solid line shows the actual measured performance. The two lines are almost identical.

Now you will see a brief movie on the 260-inch rocket program.

(Motion picture clips)

Now let us return to the four requirements for future propulsion systems (fig. 8).

Solid rockets can be built to launch very large payloads. For example, seven 260-inch motors, each 140 feet long, can be used as the booster stage of a vehicle to place 1 million pounds into earth orbit.

In regard to cost, a system such as this would cost one-fifth as much as a system developed by our traditional methods. Based on the present-day cost experience in the 260-inch program, and allowing for guidance and control system programs, a large solid motor system could be built today for about $1.50 per pound. With cost reduction technologies applied, this figure will drop further.

The ability to prepackage the motor, store it on the launch pad for long periods, and fire it without elaborate countdown procedures, provides the launch readiness essential for space rescue missions.

The fourth requirement, that of high reliability, results from the inherent simplicity of the solid motor and the few components.

In summary, we have shown that the solid rocket is a serious contender for the big space jobs that lie ahead. In the large low-cost solid motor, we see a path to our future in space. We have already demonstrated that we can build solid rockets in the sizes and with the reliability we desire, and at a price which we can afford.

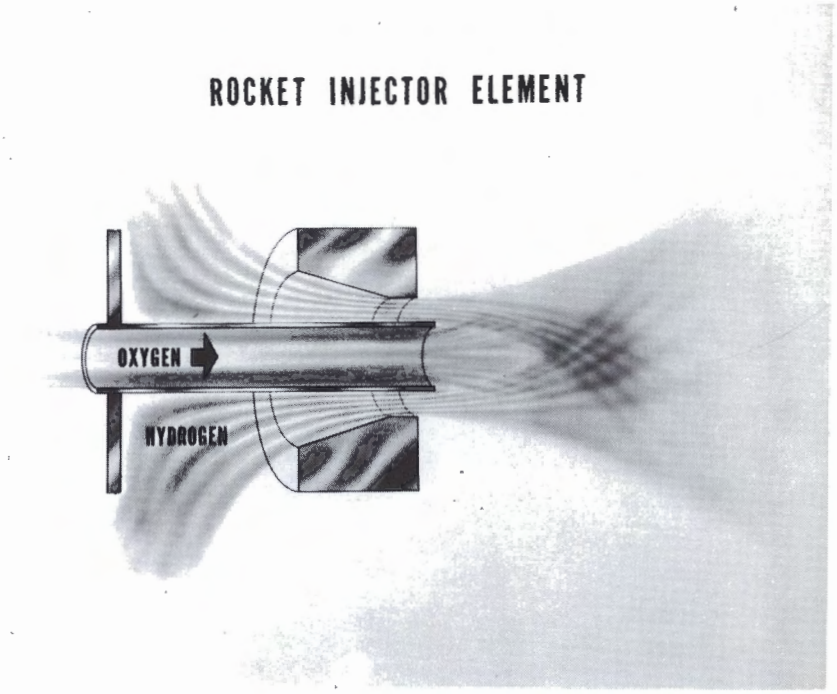


Figure 1

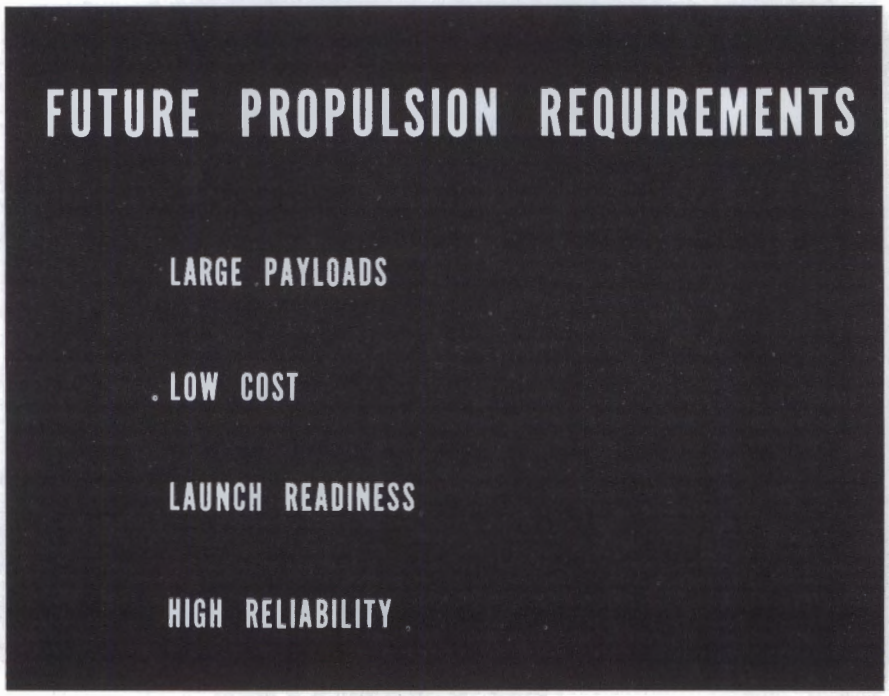


Figure 2

Figure 3

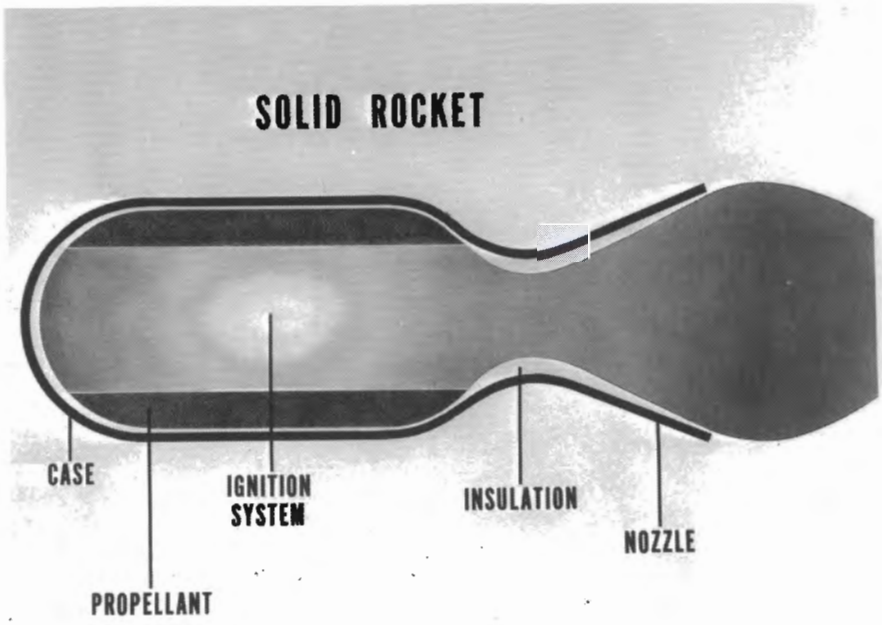


Figure 4

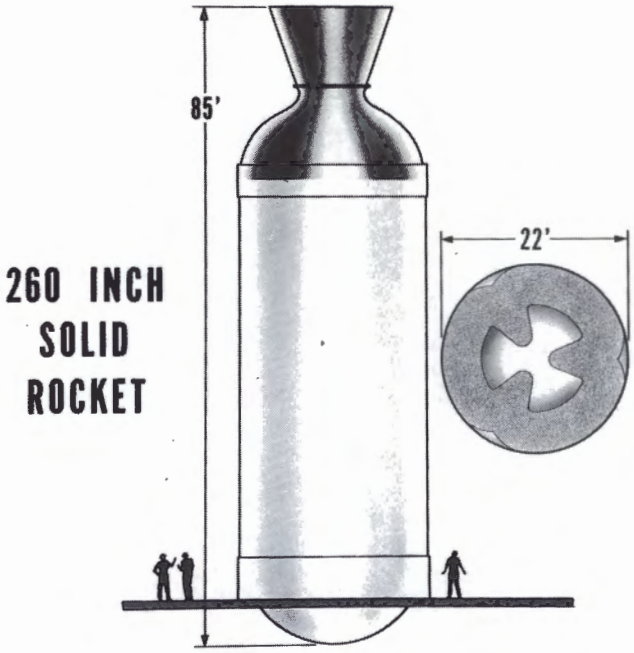


Figure 5

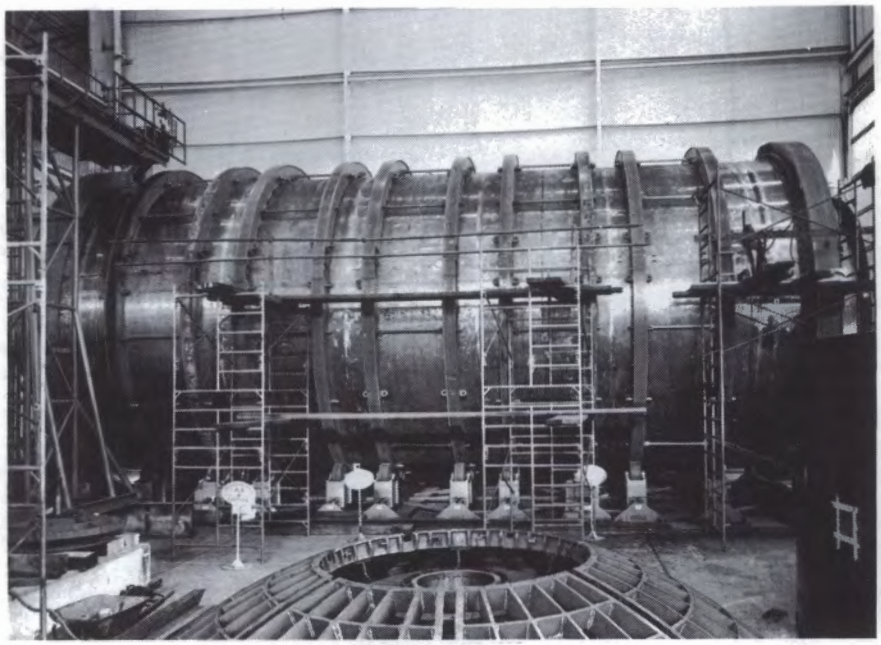


Figure 6

260 INCH SOLID ROCKET PERFORMANCE

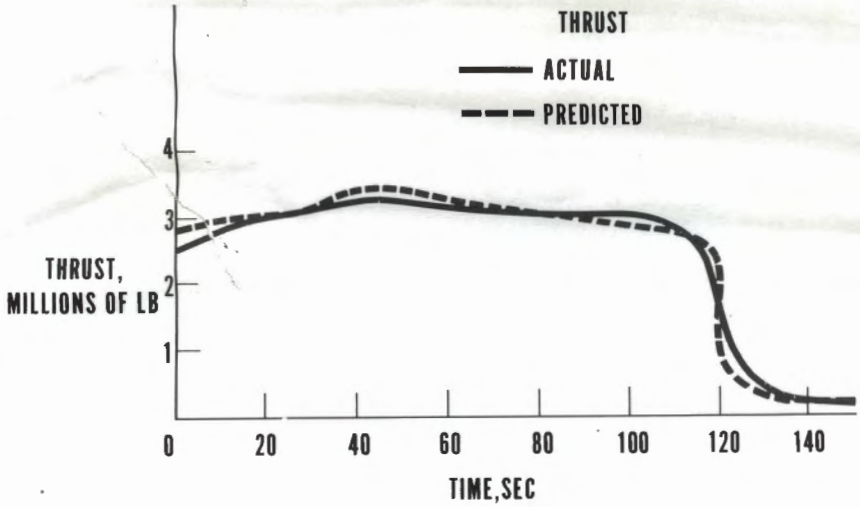


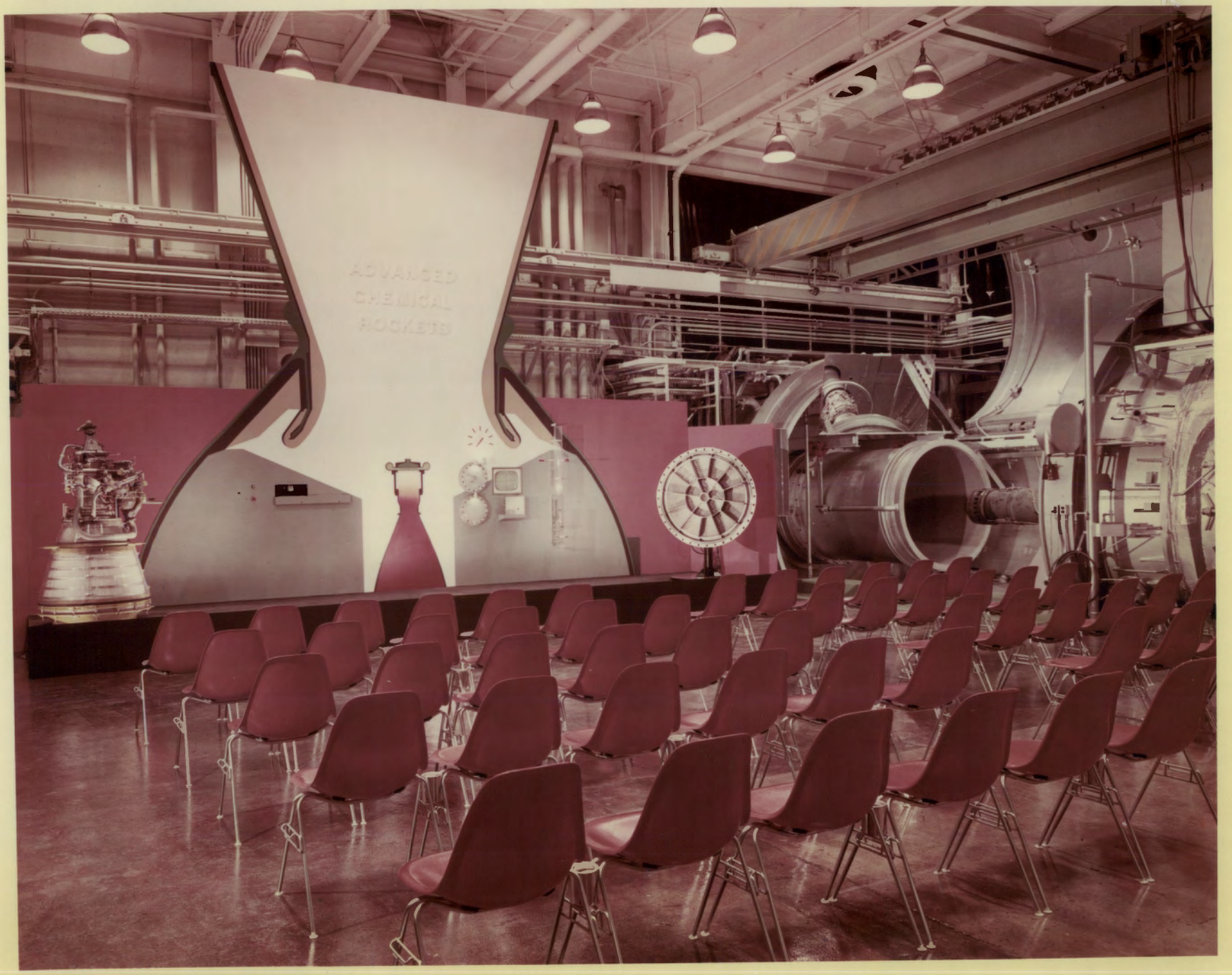
Figure 7

FUTURE PROPULSION REQUIREMENTS

LARGE PAYLOADS	—	500 TONS
LOW COST	—	80% DISCOUNT
LAUNCH READINESS	—	PREPACKAGED
HIGH RELIABILITY	—	FEW PARTS

Figure 8

NASA
C-66-3902



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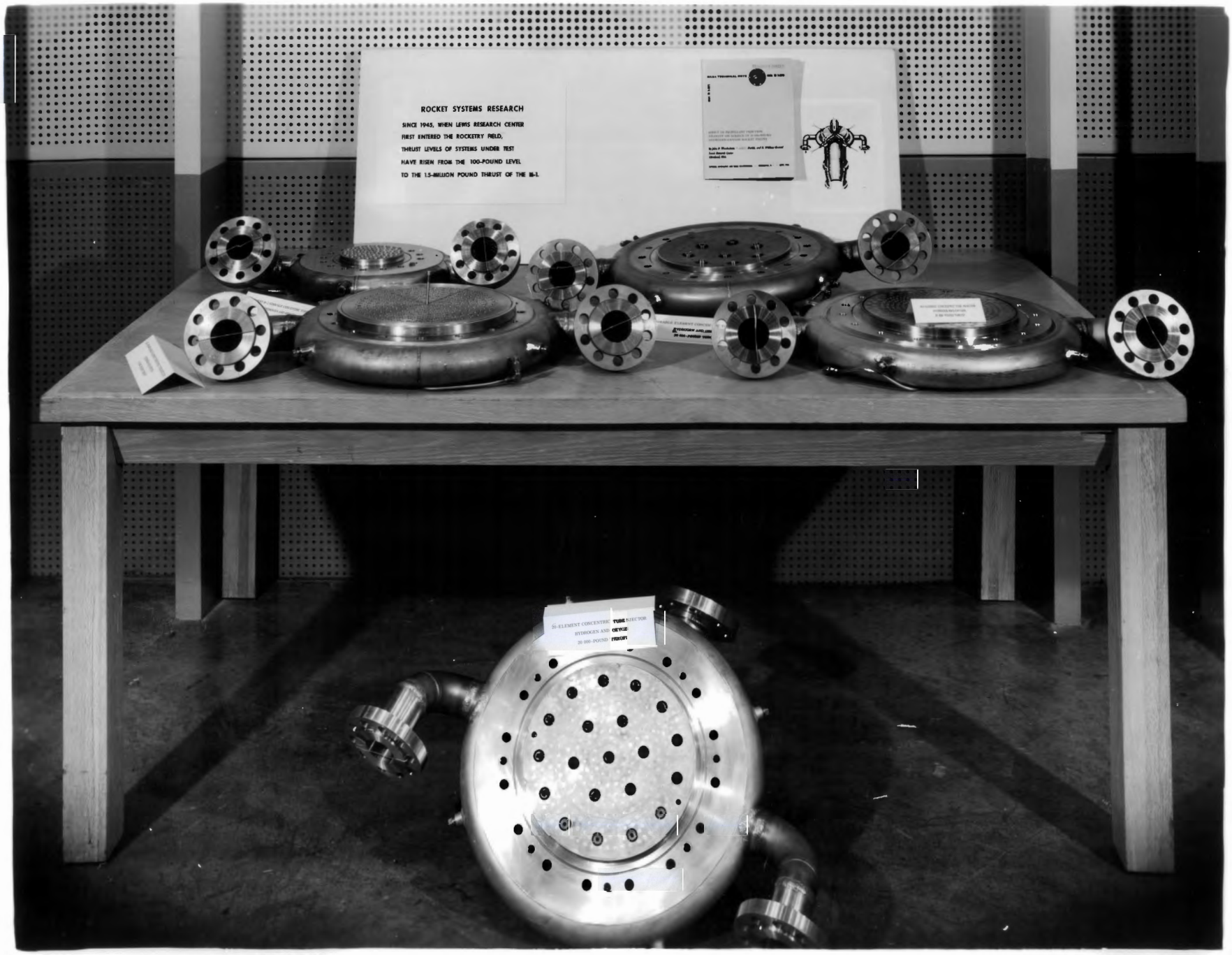
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