SPACE VEHICLES

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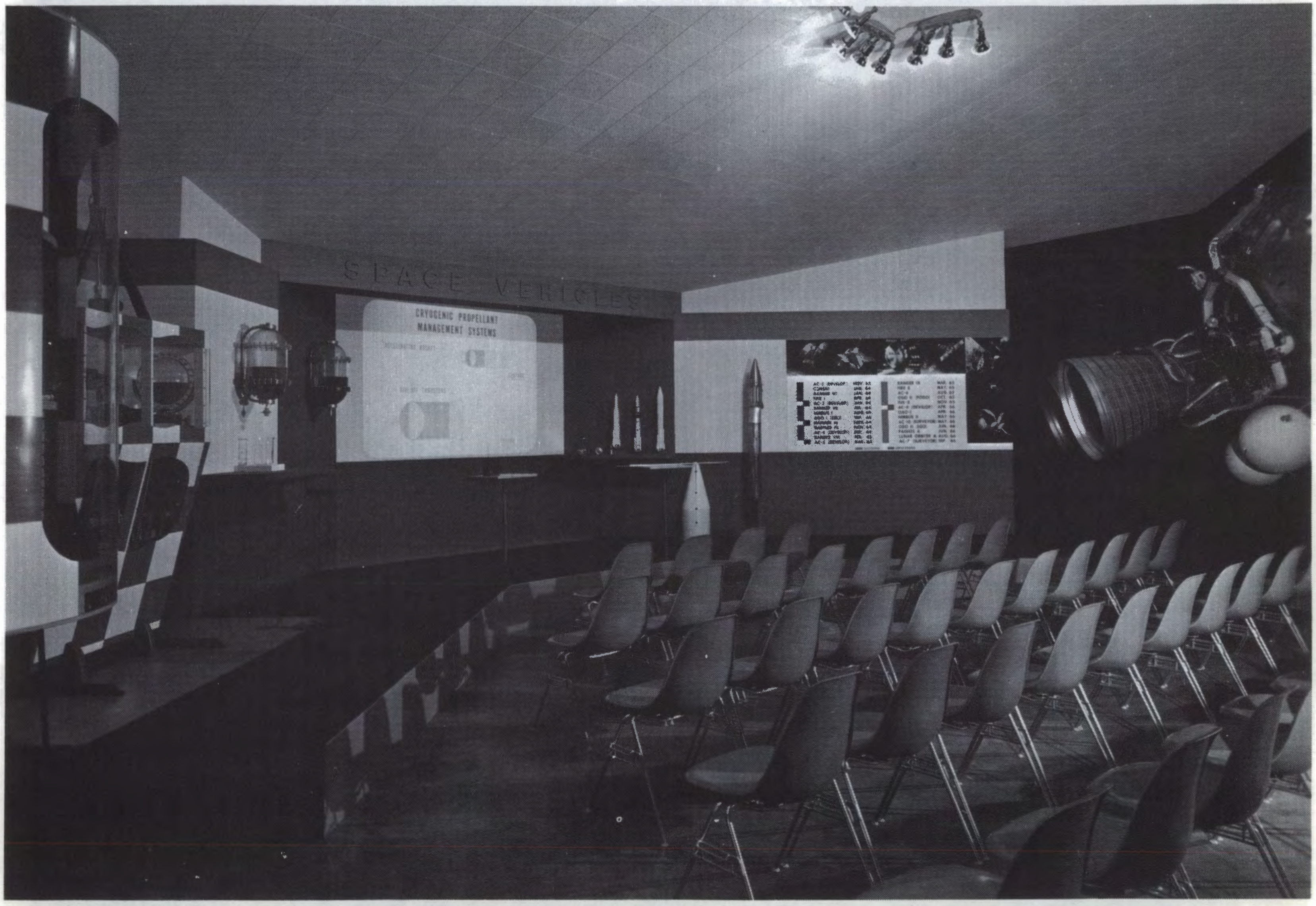
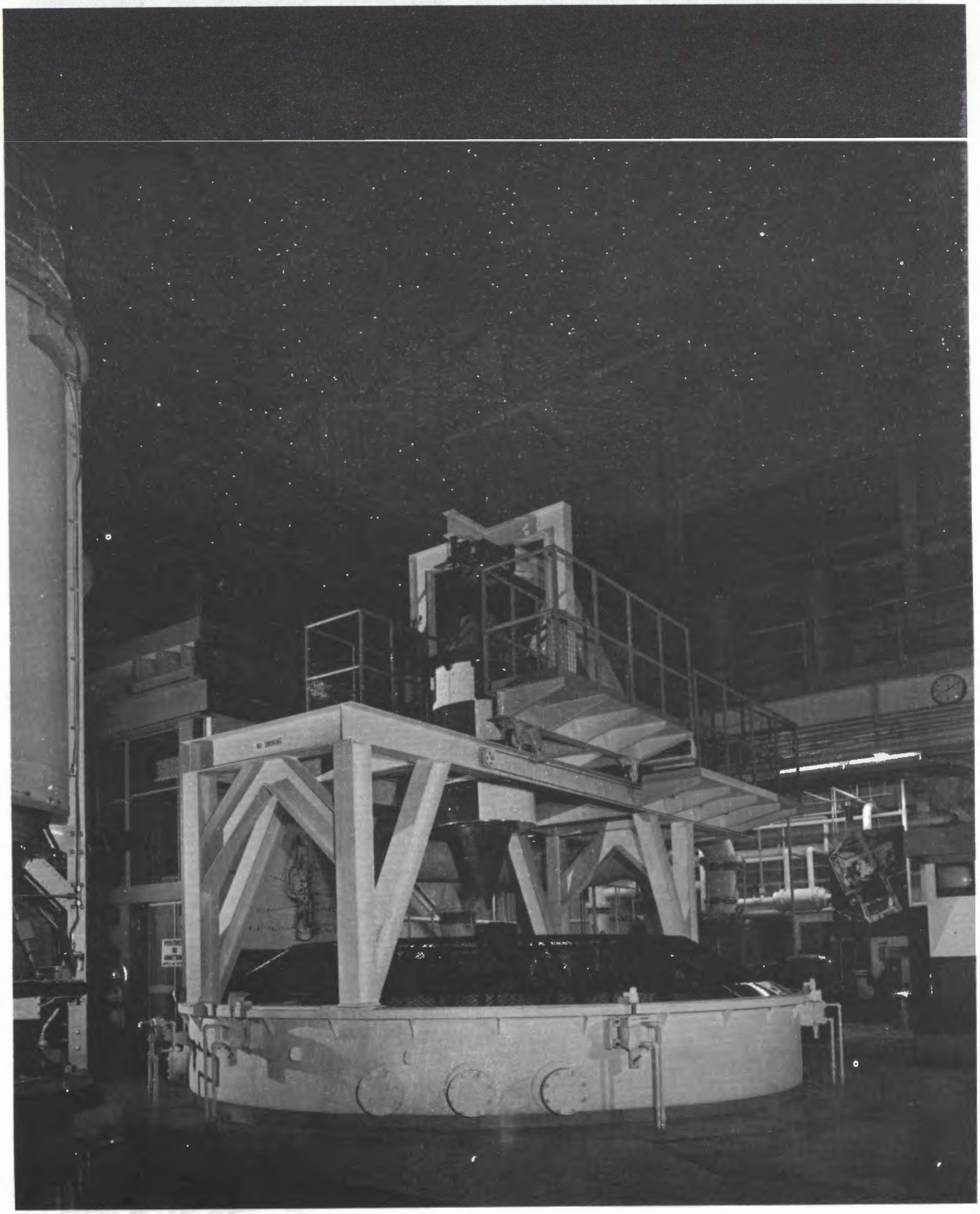

SPACE VEHICLES
CRYOGENIC PROPELLANT
MANAGEMENT SYSTEMS


NO SMOKING

SPACE VEHICLES

CENTAUR AND AGENA DEVELOPMENT SUPPORT

As you tour the Lewis Research Center, you won't see any launch pads or rockets being readied for flight. Yet the design, manufacture, and operation of NASA launch vehicles for unmanned scientific missions is a major responsibility of this Center. The launch vehicles we are concerned with are the Atlas/Agena, Thor/Agena, and Atlas/Centaur. During the last 4 years, Lewis used these vehicles on a total of 26 missions involving many different types of spacecraft. Some of them are on display here - the Nimbus weather satellite, the OAO telescope satellite, the OGO geophysical observatory, and the lunar photographic probes, Ranger, Surveyor, and Lunar Orbiter. We also launched Mariner, which took the first closeup pictures of the surface of Mars.

The success of a launch vehicle is plainly measured by how well it performs in flight. Over 300 000 parts must perform perfectly if the vehicle is to do its job of putting the spacecraft on an accurate trajectory. Our record is indicated by these charts: 22 out of 26 launches have been successful. Although this is an 85 percent success record, it is still 15 percent short of our goal. Flight success does not come easily. It requires extreme care and perfection and attention to detail at every point.

It was this attention to detail which resulted in the first successful solution to one of the biggest engineering challenges we have had, the development of the Centaur second stage. Centaur uses liquid hydrogen and liquid oxygen for propellants. Research on this propellant combination was pioneered at Lewis 15 years ago, but the application to a large rocket had never been achieved prior to Centaur.

As you probably know, liquid hydrogen boils at 423° below zero, a much lower temperature than liquid oxygen or liquid nitrogen. Consequently, the tanks and piping must be thoroughly insulated not only to prevent the liquid hydrogen from boiling away, but also to prevent any contact of the cold surfaces with air, which would freeze instantly into solid air-ice. This air-ice can completely bind up mechanisms and other moving parts of a rocket vehicle, preventing them from working correctly.

This extreme cold creates other problems. For example, on an early development flight of a Centaur vehicle, a failure was traced to this hydraulic pump coupling. Even though the coupling was ground tested many times, it failed in flight because of embrittlement from the extremely cold environment. This example indicates the kind of engineering challenge to be met in every launch.

Another characteristic of liquid hydrogen is its very low density; it weighs only about 1/2 pound per gallon. To use this propellant in Centaur, we had to make the tank unusually long so that enough propellant mass could be carried for a mission. The aerodynamic characteristics of this long Atlas/Centaur shape were not well known, and therefore a model was tested in a Lewis supersonic wind tunnel. This model was used. The test results indicated that when the actual vehicle flies through the jet stream, the wind forces in combination with the steering forces necessary to bring the vehicle back on course could cause as much as 6 million inch-pounds of bending moment on the vehicle. The Atlas had not been flown before with this much bending load, and we were not sure that either the Atlas or the Centaur could take it. Both of these rockets are made of thin sheet metal like this, only about 15 thousandths (or so) inch thick. Pressure in the propellant tanks is needed for longitudinal strength and rigidity. Therefore, to assure that the structures were adequate, a full-size vehicle was tested in a unique facility at Plum Brook, which was described in the motion picture you saw this morning. The tests proved that a wide latitude of high-velocity winds could be tolerated. A check of upper-air wind conditions precedes each launch to assure us that the actual flight condition does not exceed the design limits.

In a normal flight sequence, the Atlas is staged, or separated, when its propellants are depleted. To separate the two stages, we use a shaped explosive cord, which we insert into a groove around the interstage adapter to cut through it. After the adapter is severed, eight small retrorockets mounted on the aft end of the Atlas (show on model) pull the Atlas away from the Centaur (demonstrate). When we first decided to use this type of separating system, we had to be sure that the stages would separate smoothly so that they would not hang up or interfere with each other. To verify the operation, we set up a full size model of the Atlas-Centaur in one of our altitude chambers.

(Show motion picture film clips.)

The model was equivalent to the real vehicle in weight and mass distribution. It was mounted horizontally, like this, by a cable and gimbal arrangement from an overhead moving carriage that allowed the stages to move just as they would in flight. The tests showed that although the shaped explosive worked well in cutting the Centaur free of the Atlas, the retrorockets (show) on the Atlas did not always fire when they were supposed to. Further testing of the retrorockets showed that the problem was in the igniter (show). After the igniter was redesigned to burn more effectively (show), the entire separation system was again tested, and the Atlas separated from the Centaur exactly as intended. This system has performed flawlessly on every Atlas-Centaur flight.

Another system we tested is the nose cone, which protects the delicate spacecraft during its ride through the Earth's atmosphere. This is a scale model of the Centaur nose fairing. When it is jettisoned during flight, it separates something like this. The nose fairing is mounted on the vehicle at this point. It is attached by two hinges opposite each other and located 90° from the split line. First, several latches on the split line are released. The jettison action is provided by the two nitrogen gas bottles which generate 3000 pounds of thrust, driving the two fairing halves, weighing 1000 pounds each, apart and away from the vehicle which is traveling at 5000 miles per hour. The deflector bulkhead, seen here, protects the spacecraft from the exhaust gases emitted from the nitrogen bottles. After the fairing halves rotate through an angle of 35^{o}, the hinges are disengaged and the two fairing halves fly away from the vehicle. The jettisoning has to be a smooth, clean maneuver so that the vehicle's motion is not disturbed and there is no collision with the spacecraft or other vehicle hardware. In order to insure that the separation system work properly and also to find out whether gas from the thrust bottles could damage the delicate solar panels of the spacecraft, a full-scale test was set up in the Lewis high-altitude test chamber.

(Show motion picture film clips.)

From these tests we learned that the hinge design was adequate and that the separation dynamics were satisfactory. However, these tests revealed that the deflector bulkhead failed to protect the spacecraft, and, of course, the bulkhead was redesigned. A number of the other areas required minor rework, and since then the nose-fairing jettison system has performed without a hitch.

We have given you a small glimpse of the extensive ground testing and of the attention to detail that is required for a successful performance of two typical launch vehicle systems. Equal attention is given to all other areas, including guidance, propulsion, steering, etc. Some of the specific problems encountered in coasting spaceflight and how they are being solved will now be described.

ZERO GRAVITY PROPELLANT MANAGEMENT

We have been discussing the role of the Lewis Research Center in the development of vehicles designed to place a payload at a certain time and place in space within given velocity limits. We would now like to shift your attention toward research performed at the Lewis Center which contributed to the successful design and development of the Centaur vehicle and others in the NASA program, such as the upper stages of Saturn and the Apollo service module. The research we have chosen to highlight concerns the problem of liquid propellant management in coasting flight. This is a condition in which the vehicle and propellants have no weight and is commonly called zero gravity.

On Earth we are accustomed to liquids positioned in the bottom of containers and to gases in the top as in this model propellant tank. Thus if we wish to remove liquid from the tank, we need only incorporate an outlet at the bottom. For the situation in which the liquid tends to evaporate and increase the pressure in the tank, the excess pressure can be relieved by providing a vent at the top. In coasting flight or in zero gravity, we lose this tendency for liquids to settle to the bottom of the tank. This condition gives rise to considerable concern about the position and behavior of the liquid and vapor because of its bearing on the ability to restart the rocket engine or to vent off excessive tank pressure. The first efforts in zero-gravity research were therefore directed toward a study of the zero-gravity configuration of the liquid and vapor in a propellant tank.

This first movie shows the actual behavior of the liquid and gas in a spherical tank when changing from a 1-g to a zero-g condition. The liquid is one which wets the walls and therefore tends to spread. In zero-g, this spreading action makes the liquid climb the walls until it encloses the vapor. There is no preferred location for this vapor and it may come to rest over the tank outlet, as it does here, preventing successful restart of the engine. The zero-gravity configuration for a partly filled cylindrical tank is shown in the next movie sequence.

(Show motion picture film clips.)

Here the liquid does not completely enclose the vapor but remains in the bottom of the tank, forming a hemispherical surface. Each of these configurations is understandable and predictable from consideration of the energy interchange that takes place as the liquid spreads over the solid. The resulting configurations each represent a condition of minimum surface energy.

The results of this research indicated that the liquid position and configuration were dependent on the shape of the tank. It therefore appeared promising to study the possibility of controlling the position of the liquid and vapor by the use of internal baffles. A simple baffle is shown in this movie. It consists of a tube mounted over the tank outlet with holes provided to allow the liquid to flow between the tank and tube. For a baffle of this type, a wetting liquid takes the position wherein liquid fills the tube over the tank outlet and the remaining liquid is positioned around the tube. You will note that the tube also positions the vapor at the tank vent.

Geometries of this type cannot position the liquid under conditions of minor disturbances resulting from docking or attitude control action. They do, however, have the ability to recover the liquid into the desired position following a disturbance. This movie shows the same tank with the tube mounted so that the initial configuration of the liquid was 90^{o} away from the desired position as if displaced by some disturbance. Following entry into a zero-gravity environment, the liquid moves around until the desired position over the tank outlet is obtained.

Another geometry which has good ability to position liquid and vapor is shown in this movie sequence. It is a sphere mounted off-center in the direction of the tank outlet within the spherical main tank. As in the last movie, the liquid is initially positioned 90^{o} away from the desired location. If the inner sphere is mounted on webs, the ability to exclude the vapor bubble from the tank outlet is very good over the entire filling range, as would be required in an orbital fuel transfer operation.

Thus far we have presented results suitable for space vehicles in a zero-gravity environment with no more than small disturbances. However, for many space missions, the vehicle will not be in zero-gravity but rather in a very low gravity field. As an example, the Agena, Centaur, and Saturn vehicles, which coast in low Earth orbits, will be in a low gravity field as a result of atmospheric drag. In these vehicles it becomes important to know what happens to the propellant under these low gravity conditions.

We know that the liquid surface or interface is capable of resisting some acceleration disturbance. For instance, I cannot invert a glass of water without the interface breaking and the liquid running out, or I cannot invert a smaller cylinder. But, I can invert a small glass tube partially filled with liquid without the liquid running from the tube.

Theory predicts that the critical size at which the liquid will run out of the cylinder depends on the gravity or acceleration level and on the properties of the liquid. For instance, if we were in orbit such that the acceleration level were very small, this tube could be much larger and the liquid would still not run out. This relation is shown on the chart (fig. 1) where acceleration is plotted against tank diameter. Part of our zero-gravity research was involved in experimentally obtaining this information. We did this for a wide range of liquids at gravity or acceleration levels of 1 g, 0.1 g, and 0.01 g. Only in this region will the liquid remain in the bottom of the cylinder. The estimated drag acceleration in low Earth orbits, although very small, is about 10 times greater than the critical for most vehicles. In each case the liquid propellants will move to the front of the tank. If this were allowed to occur, the engine could not be restarted and the tank could not be vented.

Screens which operate on the principle of the small tube can also be used to retain liquid over the tank outlet. This is demonstrated by the tank model on the stage. The model tank is fitted with a fine mesh nylon screen stretched across the tank diameter at about this point. Even though the tank is turned on its side or upside down, the tendency of the liquid to wet the fine-mesh screen is sufficient to retain liquid at the tank outlet, thereby permitting engine restart. You can see, however, that the screen does not prevent the liquid from covering the vent. The Agena vehicle uses a screened pump to provide restart capability. However, the Agena vehicle does not require venting. The Centaur and the Saturn use cryogenic propellants and do require venting. None of the geometries that we have discussed prevent the liquid from covering the vent under low-gravity conditions and thus are not satisfactory for Centaur and Saturn.

Therefore, for these vehicles different propellant management systems were required. The systems are similar and are summarized on this chart (fig. 2). Each system positions the propellants during the entire coast period by the application of an acceleration sufficient to overcome the drag. This procedure maintains the propellants in the bottom of the tank. In the case of the Centaur, this acceleration is produced by small rocket engines, which burn for the 25-minute coast period. The Saturn system obtains thrust from properly directing the gases from the propellant boiloff.

The facilities used to obtain the information shown today were the 100-foot drop tower, an airplane flown on a ballistic trajectory, and ballistic rockets. A typical ballistic rocket and payload are located to your left. In the time available today, we have presented only some of our research results. New vehicles and missions continually present additional problems. Research to solve these problems will be conducted in our newest facility, a 500-foot drop shaft. This typical experimental package will allow us to conduct studies of pumping, heat transfer, and slosh dynamics in zero-gravity or low-gravity environments.

We would now like to describe the facility and to conduct a test drop. The presentation will be continued in the drop area to your right.

(Demonstration)

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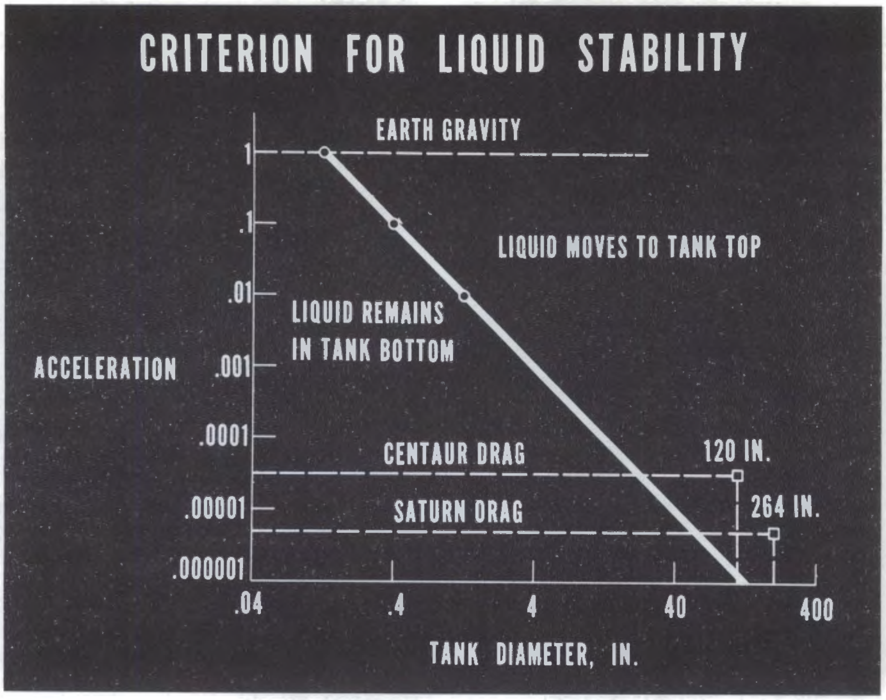

Figure 1

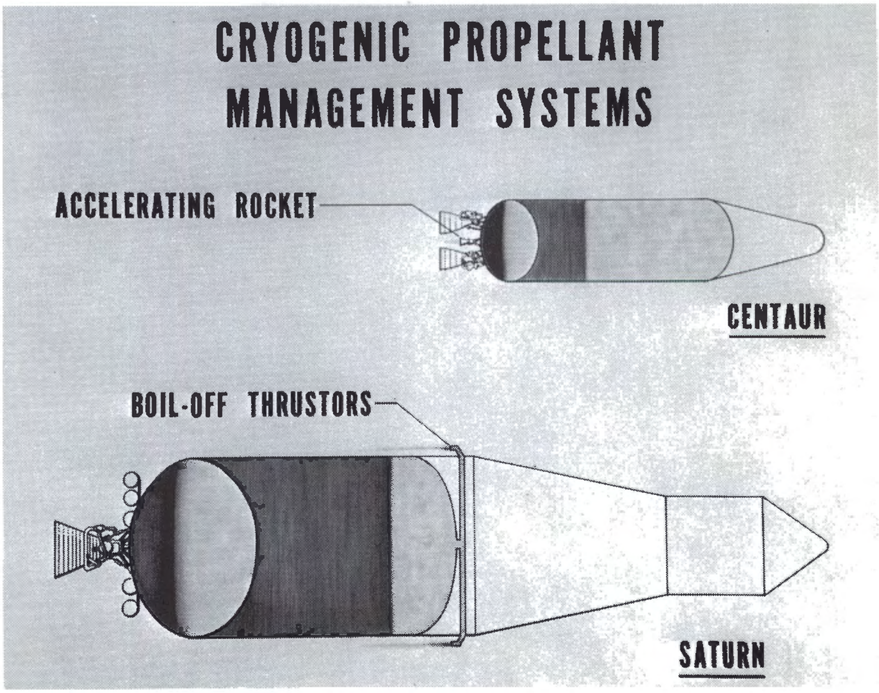

Figure 2

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