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CLEANING AND CONTAMINATION CONTROL

By

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Cleaning requirements for adequate contamination control of space launch vehicles are becoming more and more important. There are several reasons for this. First, the vehicles and their associated systems are becoming very complicated and, second, because manned payloads are involved, the overall vehicle reliability must be very high. Probably, the one factor which has had the greatest impact on cleaning procedures is that of size. As the dimensions of individual vehicle stages increase, the size of most of the components increases in direct proportion, and cleaning procedures required for these large assemblies are very complicated. For instance, the propellant tanks of the first stage of the Saturn V vehicle are 33 feet in diameter, whereas those for some of the ICBM missile systems were only 10 feet. (Figure 1)

The types of contamination encountered in space vehicle systems are quite varied. For instance, in cryogenic propellant systems, moisture is a contaminant since any accumulation will form ice and cause freezing problems. In liquid hydrogen systems, air must be excluded since it will solidify and cause an explosion hazard. Generally speaking, however, contamination, as considered in specifying space launch vehicle cleaning requirememnts, can be categorized as particulate matter or residual hydrocarbons. Particulate contamination includes those solid particles large enough to affect the functional operation of the components in the system under consideration. Hydrocarbon contamination is usually associated with ozidizer systems and refers to those materials which are not compatible chemically with the particular oxidizer involved.

The establishment of specific limits for the various systems in space launch vehicles becomes quite complicated. Orifice size, clearance between moving parts, the fluids involved, and the amount of filtration which can be achieved in the system must be considered. Also, consideration must be given to whether the complete system can be cleaned and inspected after assembly or if individual components have to be cleaned and the cleanliness maintained during assembly. For instance, on hydraulic systems which are unusually small, individual components are cleaned. Then after assembly, the complete system is flushed with hydraulic fluid through a ground filtering system. Samples of the fluid are checked periodically until a specified particulate contamination limit is met on the whole system.

In the Saturn gas bearing system, both particulate matter and hydrocarbon contamination are controlled. This is because of the extremely close tolerances involved and the danger of picking up a small amount of hydrocarbon by the air which could be deposited on the gas bearings and gradually build up enough to cause a malfunction. Here again, limits are established for individual components, major assemblies, and the complete system. The LOX, fuel, and pneumatic systems are only checked as individual components because the size and complexity of the systems are such that flushing of completed systems is not possible.

As far as actual cleaning processes are concerned, they are the same as those used for any other cleaning operation. Solvent cleaning, vapor degreasing, alkaline cleaning, and acid pickling are all used in varying degrees. In specific cases, ultrasonic cleaning has been used to advantage. The primary difference is that a final flushing step is added. For this step, close control is required on the cleanliness of solutions and rinses. If hydrocarbon contamination is to be controlled, a final flush with a solvent is generally required. One of the early problems was that of obtaining, commercially, solvents to use for flushing which were sufficiently controlled so as not to leave harmful residues on the cleaned surfaces. However, in the past few years, industry has recognized the need for this type of cleaning agent, and several solvents are available which have very strict limits on residual contamination.

The methods used to determine actual levels of cleanliness must be carefully evaluated in the establishment of cleanliness requirements. When assembled systems cannot be checked because of complexity or size, individual components are evaluated by flushing with a solvent and analyzing the contamination picked up. Of course, this method has obvious drawbacks since it is the actual condition of the surface that is important, not what is flushed off the surface. The solubility of various contaminants in the particular solvent used will also affect the results. Nevertheless, this method has been used with considerable success.

More accurate results can be obtained when complete systems can be checked, particularly if the fluids which are used in actual service can be used for flushing the system. However, care must be taken since flow rates, operating pressure, and vibration levels are not usually duplicated.

Specific analysis techniques will vary, depending upon types and general levels of contamination being determined. For precise measurement of particulate matter, "Millipore" filter techniques are used. Fluid taken from the system being investigated or solvent which has been flushed over the surface of a component being checked is filtered through a "Millipore" filter. This filter is actually a cellulose membrane with precisely controlled pores. (0.5 mil is generally used.) The filter is then examined under a microscope, and the number and size of the retained particulate matter are determined.

Where less precise measurements on particulate matter can be tolerated, normal "Whatman" filter paper is used. In this case, many of the very small particles are absorbed in the filter paper mass, and only the larger particles are counted (100 microns). This method gives more of a quality level of cleanliness rather than a quantitative count of particulate contamination. However, where precise measurements are not required, this method has proven very effective.

The method found to be the most reliable for the determination of hydrocarbon contamination, which is very important for LOX systems, is based on gavimetric techniques. A given quantity of solvent, after being flushed over the surface to be checked, is evaporated to dryness, and the amount of contamination is measured by determining the weight of residue picked up by the solvent. There are several reasons why this method is used. First, it gives a quantitative result and provides good quality control for contamination levels. It gives average results for very large surfaces and is adaptable to a wide variety of components and cleaning techniques. As long as the contaminant is fairly soluble in the solvent used, different types of contamination can be determined without any change in method or technique.

I would now like to discuss several specific system cleanliness requirements to illustrate the levels of contamination which we are trying to control and the different methods used to determine these levels. Hydraulic system requirements are shown in Table I. As can be seen, allowable particulate contamination varies considerably according to complexity of the part. One thing illustrated by this table is the control of cleanliness required throughout the assembly of the system: the cleanliness of individual components are controlled; then, major assemblies are cleaned separately; and, finally, the complete system is cleaned.

A system with somewhat different requirements, but handled generally in the same manner as the hydraulic system, is the gas bearing system. This system supplies gas to the air bearings used on the gyros in the guidance system. The cleanliness requirements are shown in Table II. Here, as in the hydraulic system, requirements are placed on individual components and on the assembled system. On individual components, the "Whatman" filter method is used because a general quality level is required - not an absolute count. For assemblies, the "Millipore" filter method is used, and more exact counts equivalent to complete system requirements are obtained. In addition to particulate contamination, a limit on condensable hydrocarbons is also specified. In determining conformance to these requirements, a specified volume of gas is passed through the system. The gas is then passed through a "Millipore" filter for determination of the particulate contamination. The amount of condensable hydrocarbons is determined by bubbling the gas through carbon tetrachloride and analyzing the hydrocarbon pick-up by infrared techniques.

Considerably different requirements are specified for liquid oxygen, fuel, and pneumatic systems. These requirements are shown in Table III. Here, the requirements are placed on individual components without any specific check made on complete systems. This, of course, is dictated by the size and complexity of these systems. Because of the size range of the particulate matter which is being controlled, all particulate counts are made by the "Whatman" method. For the liquid oxygen systems, a requirement for hydrocarbon residue, or nonvolatile residue as it is generally classified, is also specified.

Since the only absolute control for these systems is on the individual components, considerable attention must be placed on assembly techniques and contamination control used during vehicle assembly. Of course, final cleaning is performed on components which are as close as possible to the completed stage. For instance, propellant tanks are cleaned after installation of all the interior structure and measuring probes. Also, careful attention is placed on cleanliness during component build-up so that all excessive contamination has been removed prior to final cleaning. Careful attention also is placed on reducing possible inaccessible "traps" where contamination might be lodged.

The big problem in this type of operation, of course, is the human element. We must depend upon the many individuals who are responsible for connecting all of the many components together into major sub-assemblies and, finally, into completed systems. This is further complicated because of the large size of many of these parts and the handling procedures necessary just to move some of them. As an aid for controlling contamination during final assembly, temporary polyethylene structures have been used. The structure is placed over the end of the stage where the assembly operations are taking place, and filtered air is blown into the compartment. This maintains a slightly positive pressure inside the area and provides a relatively clean atmosphere during assembly of the major components into the vehicle stage.

By way of illustration, I would like to discuss a few typical vehicle components and the cleaning procedures used. Figure 2 shows the Saturn S-IC fuel tank. The first step in cleaning this tank is to vacuum clean all surfaces as free as possible of metal chips and dirt particles. This is followed by spot wiping all noticeable marks and areas which have heavy contamination. The tank is then positioned in a vertical test fixture which is used both for cleaning and hydraulic leak testing of the tank. A special spray cleaning system is then attached in which four revolving high pressure spray nozzles are moved slowly up and down inside the tank. A warm detergent solution is used for cleaning, followed by a de-ionized water rinse. Particulate contamination is determined by sampling the rinse water. Following cleaning, the tank is dried with warm filtered air.

Figure 3 shows the LOX tank, which is cleaned in the same manner as the fuel tank except that a final flush with trichloroethylene is required to remove hydrocarbon residue. Analysis for the pick-up in non-volatile residue is made on samples taken from the final solvent flush.

Figure 4 shows a component used in the propellant lines on the S-IC stage. Its function is to allow the propellant lines to expand or contract as the engines gimbal during flight without an appreciable change in volume. In addition, the component is capable of correcting for misalignment in the propellant line system. In all, the component has five corrugated bellows sections and weighs approximately 750 pounds. This component illustrates one of the most difficult types of parts to clean. The complexity of the part, the corrugated, flexible bellows, and the physical size of this part make for an extremely difficult configuration to clean. My main point in showing this part is to emphasize the need for close contamination control during fabrication of this part. During each fabrication step, careful attention must be given to maintaining a high degree of cleanliness. Several intermediate cleaning processes are required during fabrication since experience has shown that adequate cleaning of this part after final assembly is impossible unless proper control of cleaning has been exercised during fabrication.

In summary, I would like to say that cleanliness and the control of contamination in the various systems of space launch vehicles have and will continue to receive considerable attention. We believe the contamination limits we have developed are realistic and are based on the operational requirements of the various systems. Of course, we do have problem areas. Probably the biggest need at the present time is for improved analytical techniques, particularly those applicable to large, complex systems.

TABLE I

HYDRAULIC SYSTEM CLEANING REQUIREMENTS

	Particle Size - Microns (100 ml sample)				
Item	10-25	25-50	50-100	Over 100 + Fibers	Method
1. High Pressure System	2,150	530	60	10	Millipore
2. Low Pressure System	4,300	1,060	120	10	Millipore
3. Detail Components	300	50	8	1	Millipore
4. Assemblies	2,150	530	60	10	Millipore

TABLE II

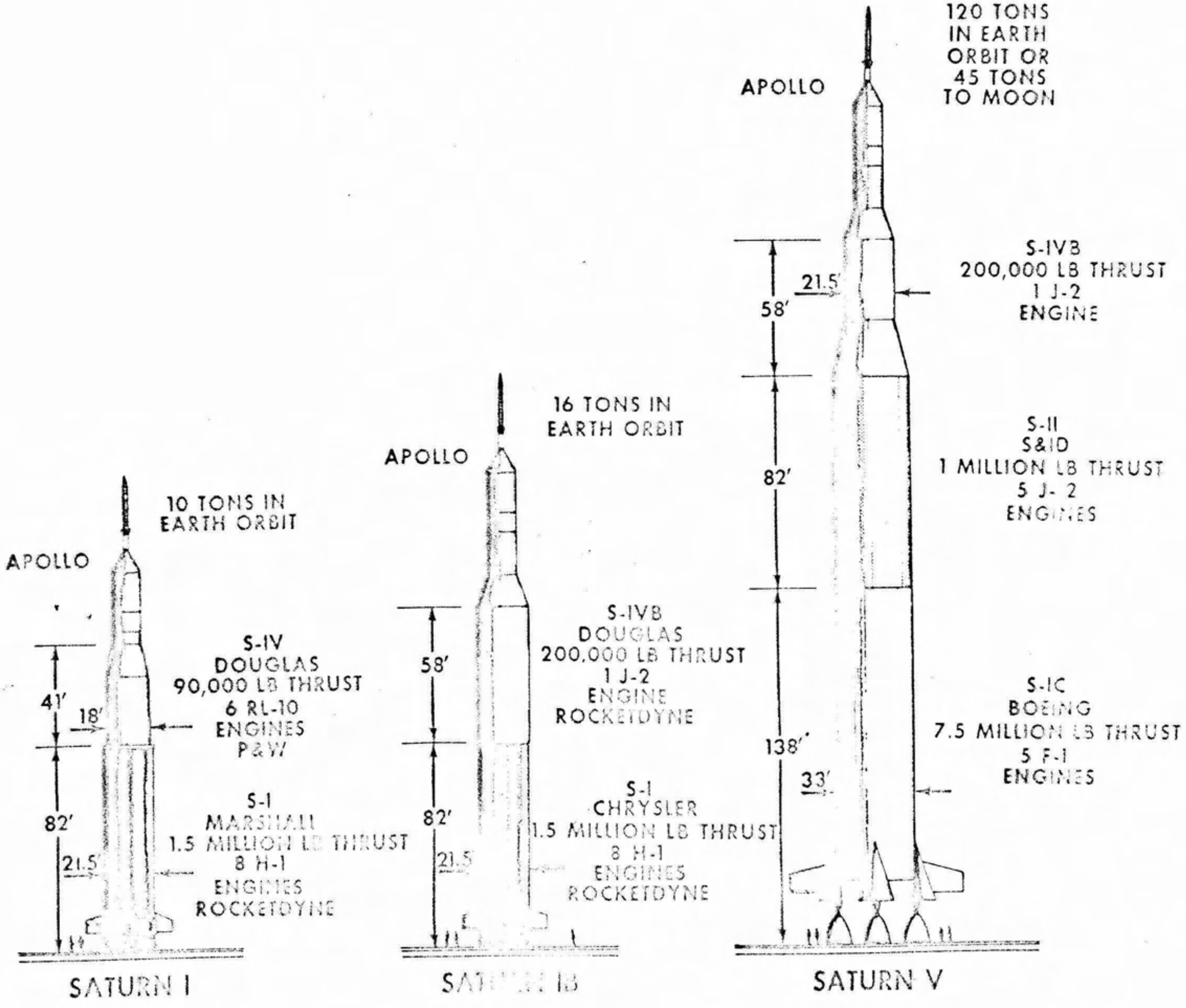
GAS BEARING SYSTEM CLEANING REQUIREMENTS

Item	Sample Size	Method	Particles	Hydrocarbon
System & Assemblies	30 ft^3 of gas	Millipore	20 - 20-40 microns 3 - 41-80 microns 1 - 81-100 microns 0 - over 100 microns	0.2 ppm
Components	250 ml Solvent	Whatman	Max. size - 20 microns	0.001 g/ft^2

TABLE III

LIQUID OXYGEN, FUEL,& PNEUMATIC COMPONENTS CLEANING REQUIREMENTS

System	Particles - Microns (per sq. ft. of surface)	Hydrocarbon (per sq. ft. of surface)
Fuel & Pneumatic Systems	0 greater than 2500 1 between 700 and 2500 5 between 175 and 700	None
LOX - Components	Same as Fuel	0.001 gram
LOX - Tanks	Same as Fuel	0.005 gram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21.5′
S-1
MARSHALL
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8 H-1
ENGINES
ROCKETDYNE
SATURN I
APOLLO
16 TONS IN
EARTH ORBIT
S-IVB
DOUGLAS
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ENGINE
ROCKETDYNE
58′
82′
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S-1
CHRYSLER
1.5 MILLION LB THRUST
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ENGINES
ROCKETDYNE
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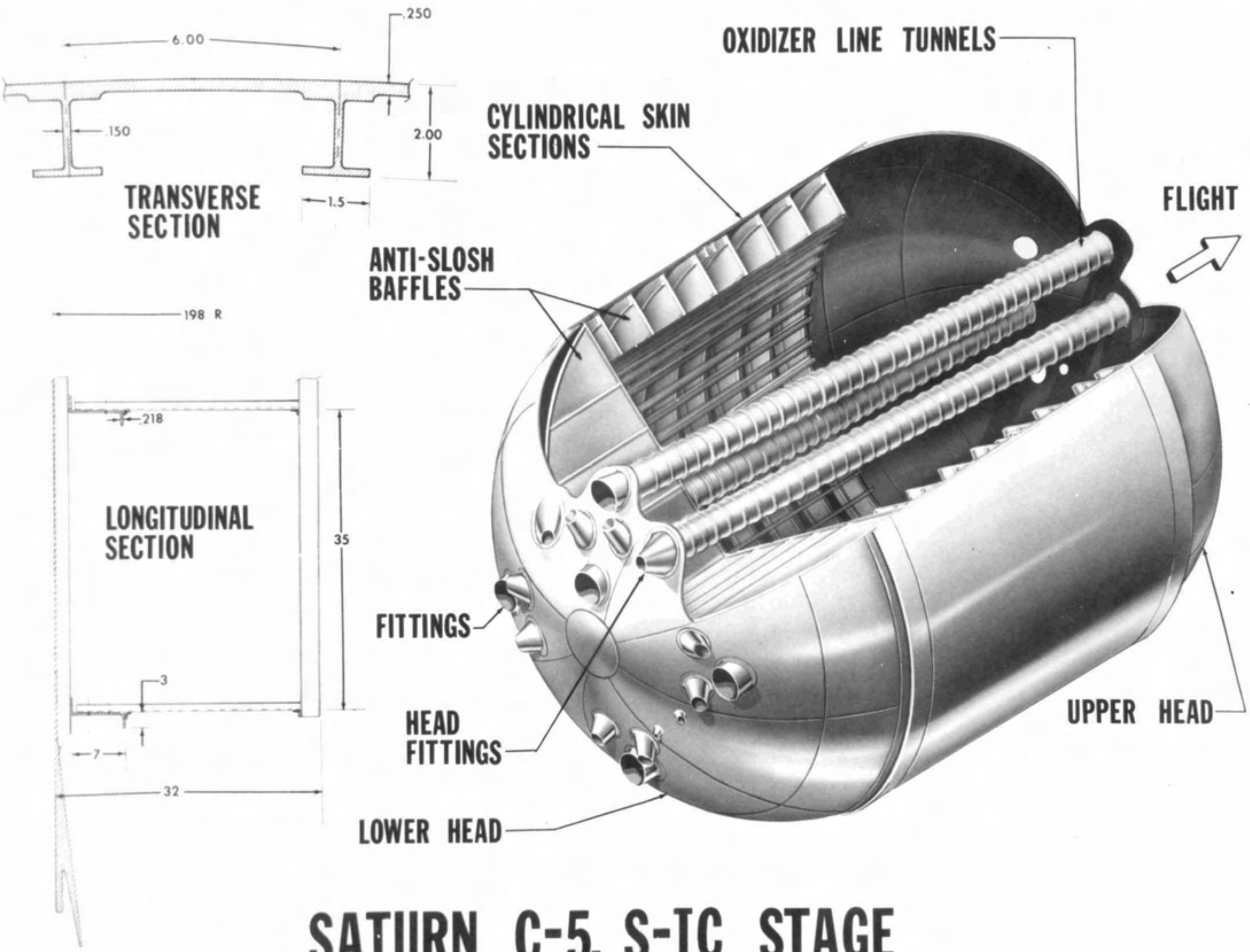
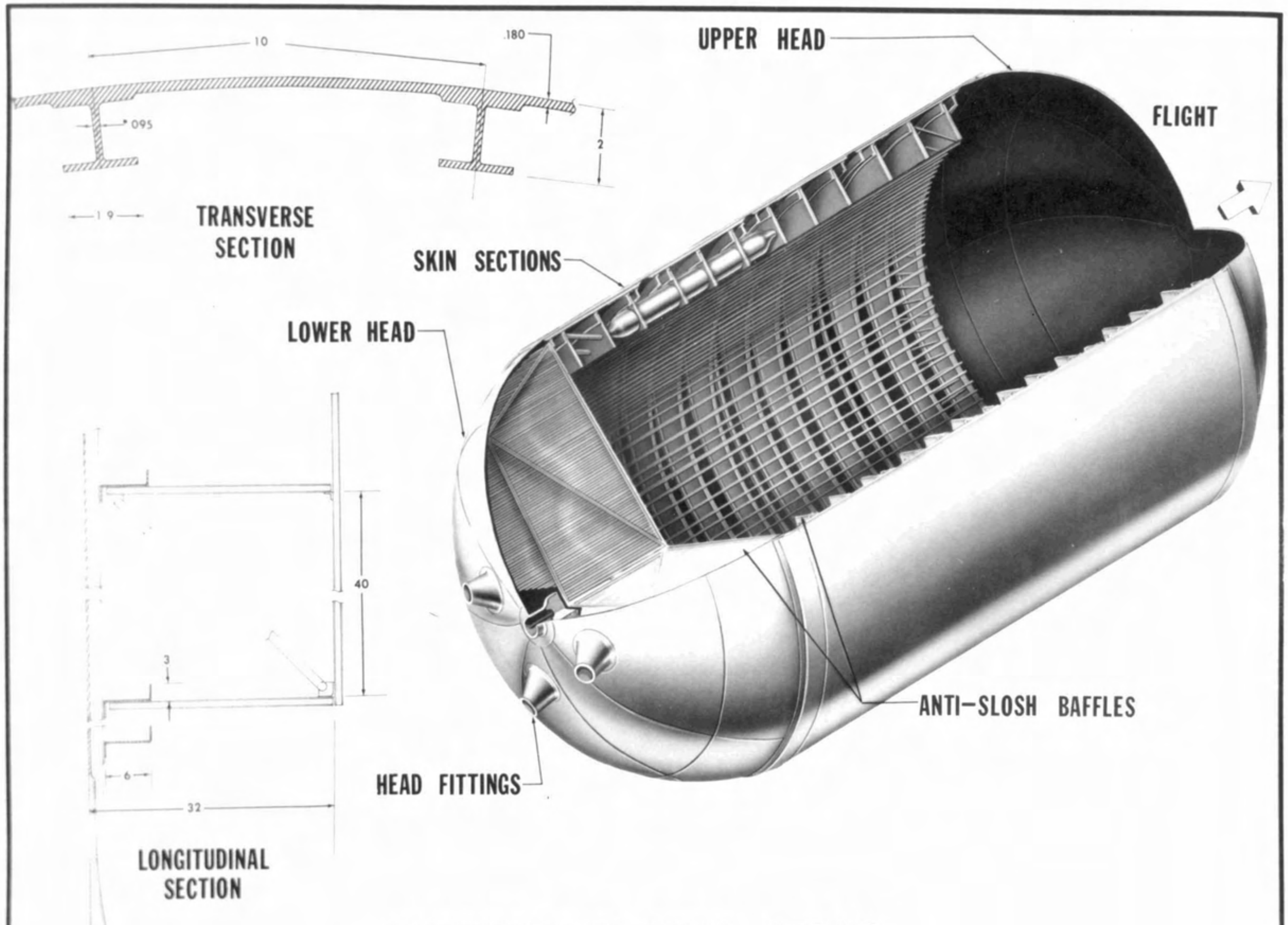


SATURN C-5, S-IC STAGE
FUEL TANK ASSEMBLY



SATURN C-5, S-IC STAGE
OXIDIZER TANK ASSEMBLY