GEORGE C. MARSHALL SPACE FLIGHT CENTER

SPACE SHUTTLE AUXILIARY PROPULSION CONFIGURATIONS AND TECHNOLOGY

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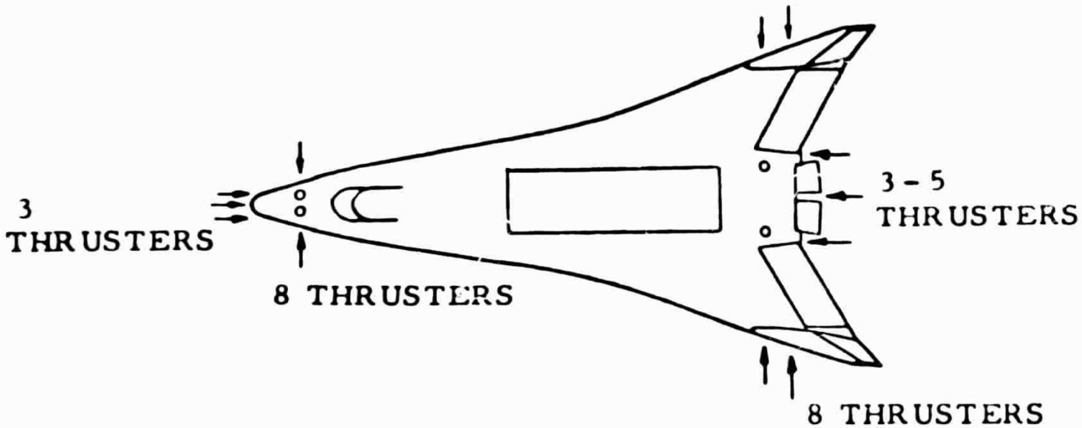
SPACE SHUTTLE AUXILIARY PROPULSION SYSTEM

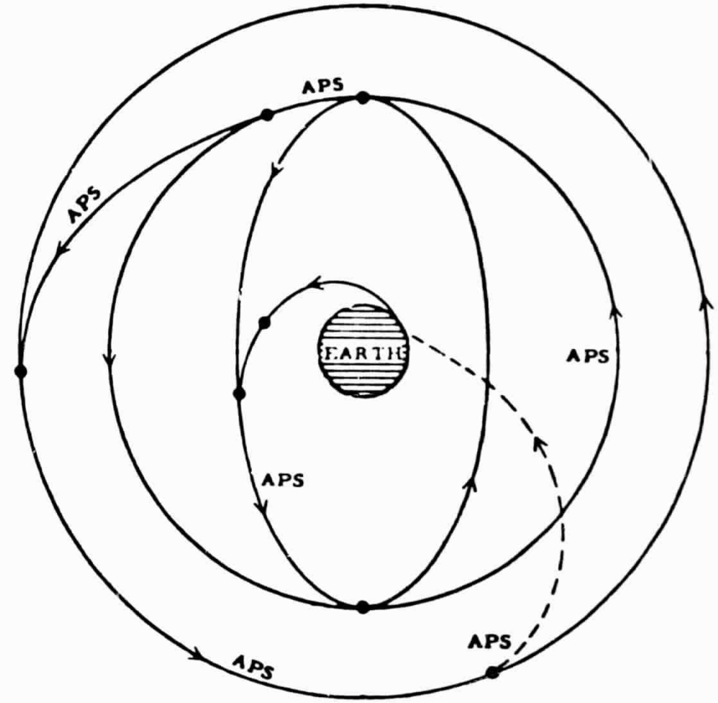
- DEFINITION AND LOCATION
- REQUIREMENTS AND DUTY CYCLE
- STUDY CONFIGURATIONS
- TECHNOLOGY
- SCHEDULE

The Booster Vehicle requires an Auxiliary Propulsion System for attitude control during the period after main propulsion shutoff and during re-entry of the earth's atmosphere. The system must provide vehicle control in the pitch and yaw planes and also for roll. Approximately 16 thrusters will be necessary to accomplish this and provide redundancy in the event of malfunction. For the Orbiter Vehicle, an Auxiliary Propulsion System will be required, not only during the vehicle's re-entry of the earth's atmosphere, but also during the on-orbit period. During this period, requirements exist for maneuvering in space, circularizing the orbit, on-orbit attitude control, orbital rendezvous and also for de-orbiting from earth orbit. These requirements necessitate vehicle control in the pitch and yaw planes, as well as for roll and translation. For this reason, and for redundancy purposes, there will be approximately 22 to 24 thrusters for the Orbiter. For both vehicles, there will be a forward, as well as an aft, installation of thrusters.

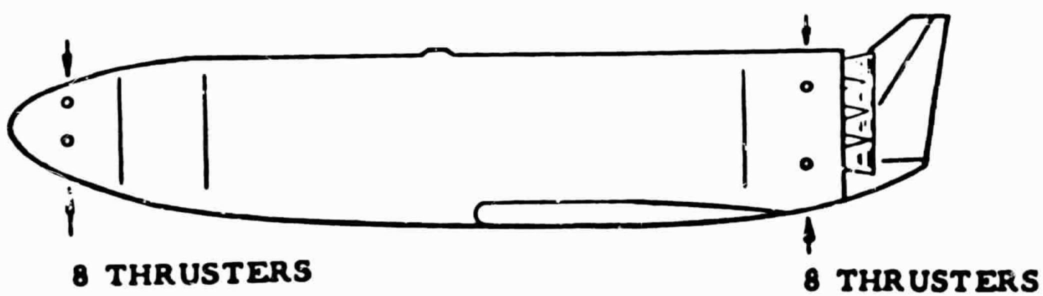
AUXILIARY PROPULSION THRUSTER LOCATIONS

ORBITER





BOOSTER



The Auxiliary Propulsion System in both the Booster and the Orbiter will utilize hydrogen and oxygen, the same propellants used for the Main Propulsion System. This will simplify the propellants logistics as well as yield excellent performance. These propellants are especially good when considering corrosiveness of other propellants and the many reuses required of the system. Since the Orbiter will utilize its system for extended periods while in orbit, its propellant requirements may be as much as 12 times greater than that of the Booster. This will vary depending on the amount of time in orbit, corrections, and maneuvering activity required. The period of intermittent use for the Booster will be only approximately 5 minutes in comparison to 7 days for the Orbiter.

REQUIREMENTS AND MISSION DUTY CYCLE

BOOSTER

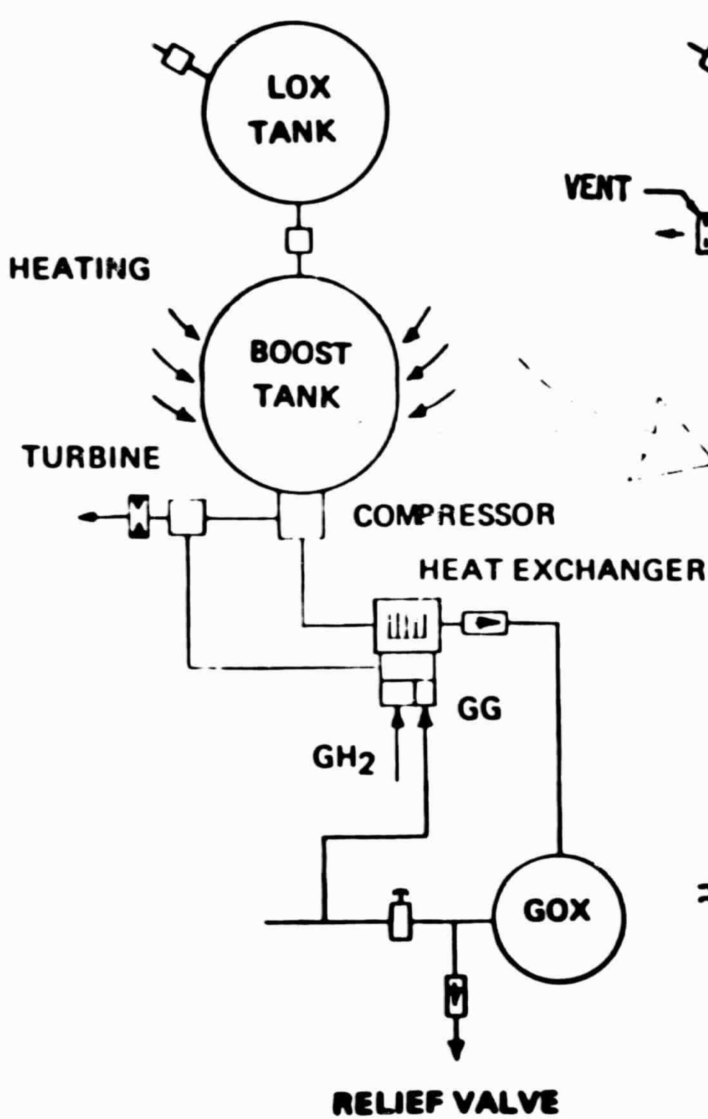
• TOTAL IMPULSE RANGE	1,240,000-3,250,000 NEWTONS-SEC (280,000-730,000 LBF-SEC)
• PERIOD OF INTERMITTENT USE	≈5 MINUTES
• MINIMUM LIFE	>100 FLIGHTS

ORBITER

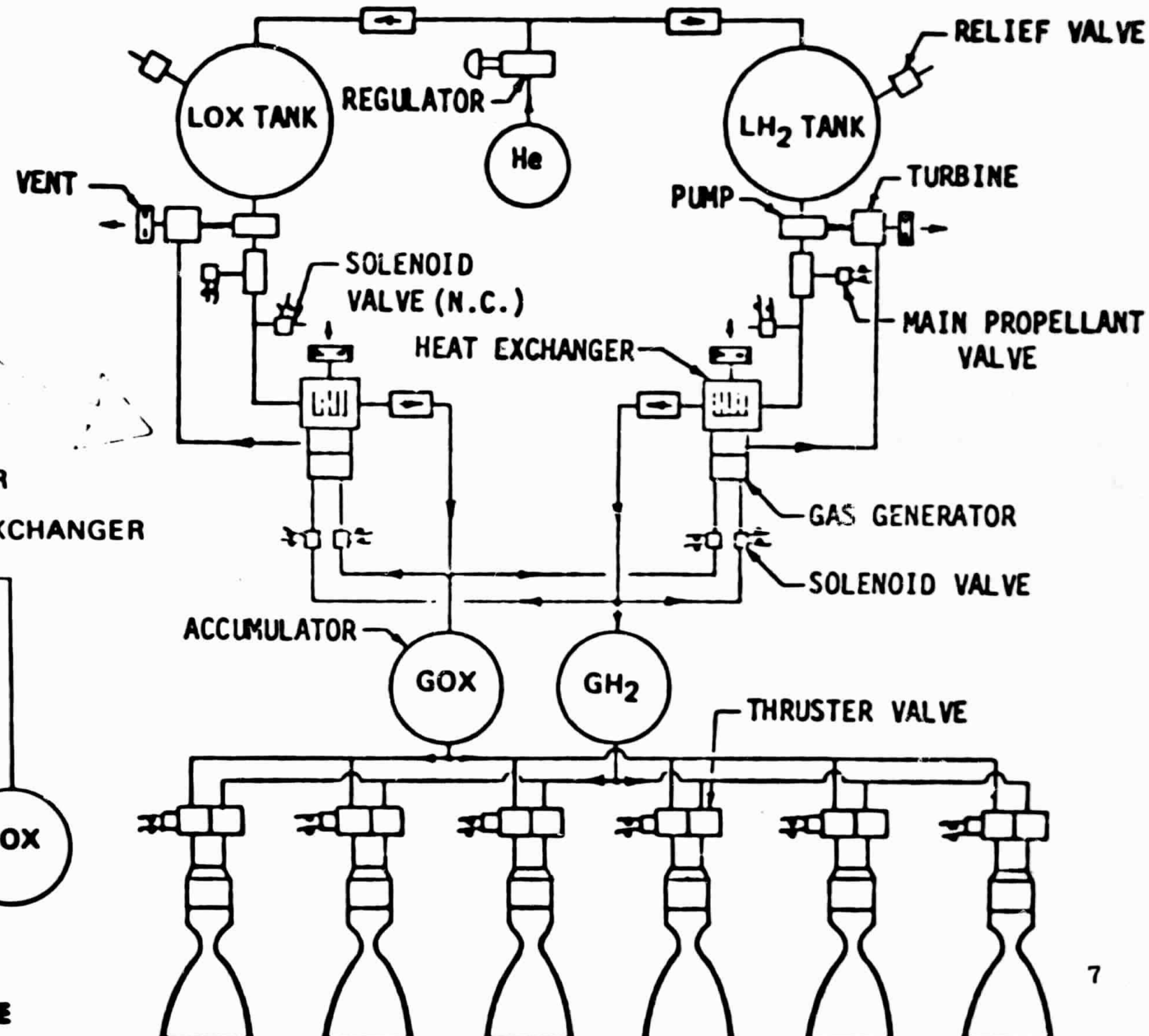
• TOTAL IMPULSE RANGE	5,540,000-54,000,000 NEWTONS-SEC (1,250,000 - 12,100,000 LBF-SEC)
• PERIOD OF INTERMITTENT USE	≈7 DAYS
• MINIMUM LIFE	>100 FLIGHTS

The two basic types of Auxiliary Propulsion Systems under consideration are the so-called "High Pressure System" operating with a thruster P_c of 210 to 344 N/cm^2 (300 to 500 psia) and the "Low Pressure System" operating at about 10.3 to 34.4 N/cm^2 (15 to 50 psia). Both systems are being studied to determine trade-off factors for reliability, performance, weight, and cost. From this information, an evaluation will be made and one system selected for a design initiation. From the system schematics, it appears that the High Pressure System is the more complex; however, when installation space, performance, and weight are very significant, as in the Space Shuttle, the trade-offs must be carefully considered before a choice can be made. The High Pressure System will require turbopumps to raise the pressures and deliver the propellants through heat exchangers to the gas accumulators. Here, the gas will be stored at about room temperature and 1030 N/cm^2 (1500 LBF/in^2) pressure for use as required by the thrusters. An alternate system under consideration might utilize a compressor instead of a pump for the oxidizer side. Adequate conditioning of the gas to the compressor might be assured by utilizing the boost tank after propellant depletion as a heat exchanger.

ALTERNATE COMPRESSOR SYSTEM

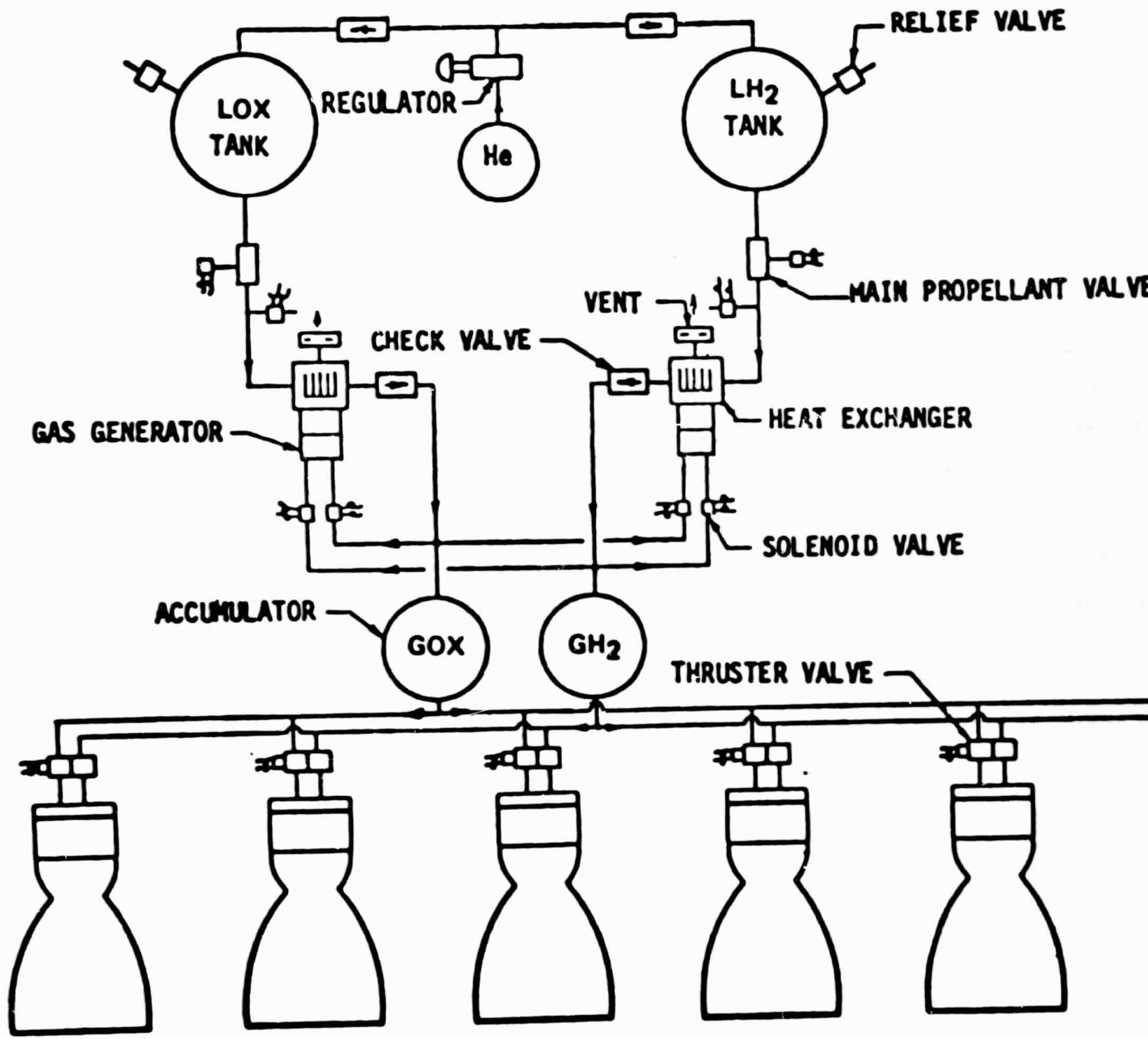


HIGH PRESSURE SYSTEM



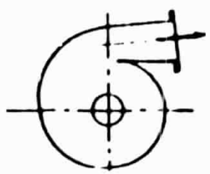
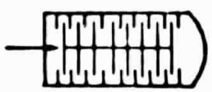
The "Low Pressure System" would not utilize turbomachinery although heat exchangers, as well as gas generators, would be needed as in the "High Pressure System." The major disadvantage to this system is that the size of the thrusters become large in order to obtain the thrust required, and, thus present an installation problem.

LOW PRESSURE SYSTEM



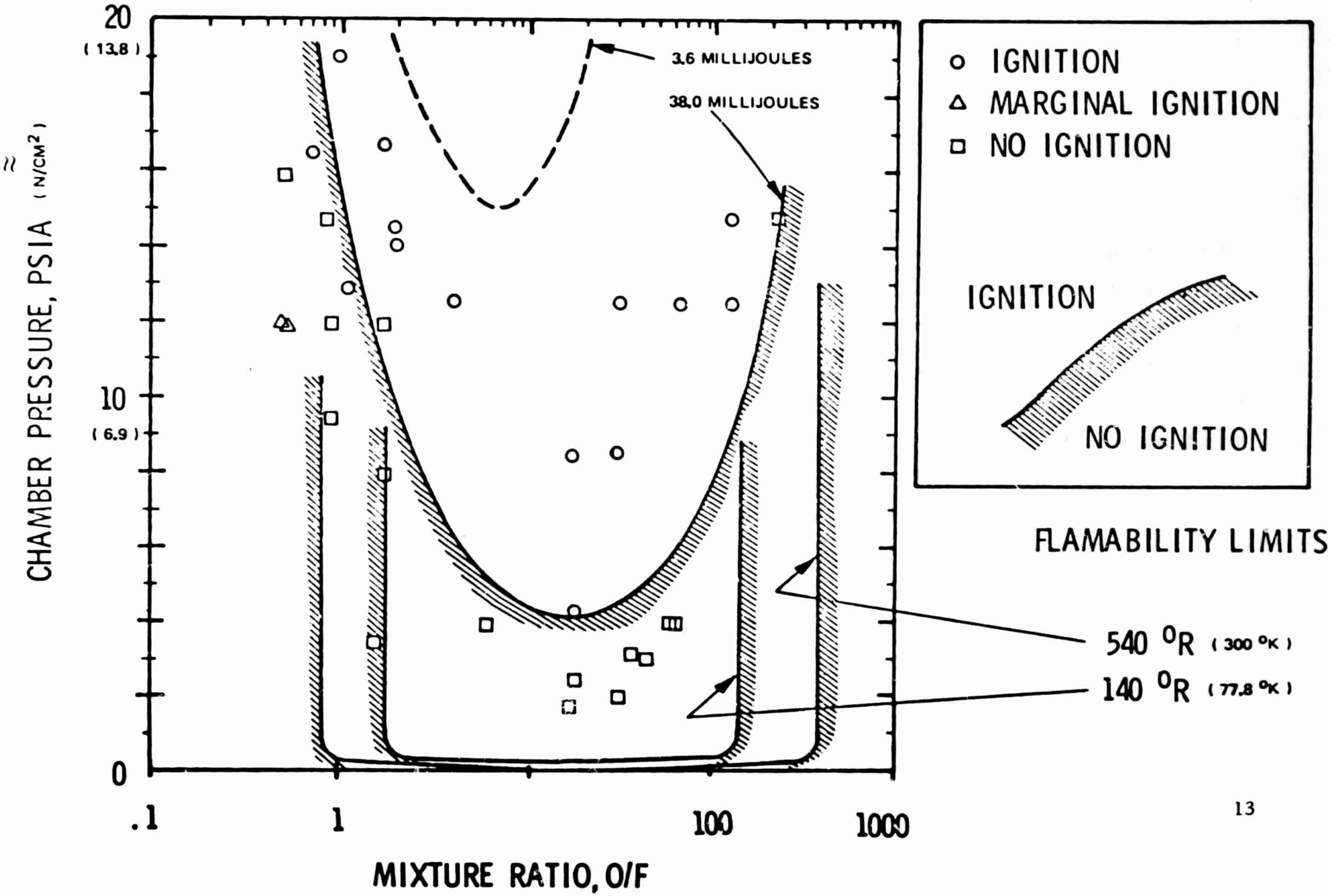
Many of the component requirements in both of the two basic systems are not "state-of-the-art" and, therefore, intensive technological activities are required to provide the necessary design criteria. Components such as accumulators, thrusters, valves, regulators, pumps, turbines, gas generators, and compressors will probably be investigated as technology tasks when the Auxiliary Propulsion System becomes better defined. The operating conditions for these components are only approximate at this time; however, a number of potential problems are anticipated.

MAJOR COMPONENTS

ITEM	OPERATING CONDITIONS	POTENTIAL PROBLEMS
 ACCUMULATORS	$P \approx 1030\ N/CM^2$ ($1500\ LBF/IN^2$) $T \approx 300\ ^oK$ ($540\ ^oR$)	WEIGHT AND LIFE
 THRUSTORS	$F \approx 6680$ NEWTONS (1500 LBF)	IGNITION, LIFE, AND COOLING
 VALVES	$\dot{W}_o \approx 1.27$ KG/SEC (2.8 LBM/SEC) $\dot{W}_f \approx 0.318$ KG/SEC (0.7 LBM/SEC) $P \approx 414\ N/CM^2$ ($600\ LBF/IN^2$)	LEAKAGE AND LIFE
 TURBOPUMP	$\dot{W}_o \approx 5.75$ KG/SEC (12.7 LBM/SEC) $\dot{W}_f \approx 1.72$ KG/SEC (3.8 LBM/SEC) $P_d \approx 1380\ N/CM^2$ ($2000\ LBF/IN^2$)	WEIGHT AND PERFORMANCE PROPELLANT CONDITIONING
 COMPRESSOR (LOX SIDE, ONLY)	$\dot{W}_o \approx 5.75$ KG/SEC (12.7 LBM/SEC) $P_d \approx 1380\ N/CM^2$ ($2000\ LBF/IN^2$)	WEIGHT AND PERFORMANCE

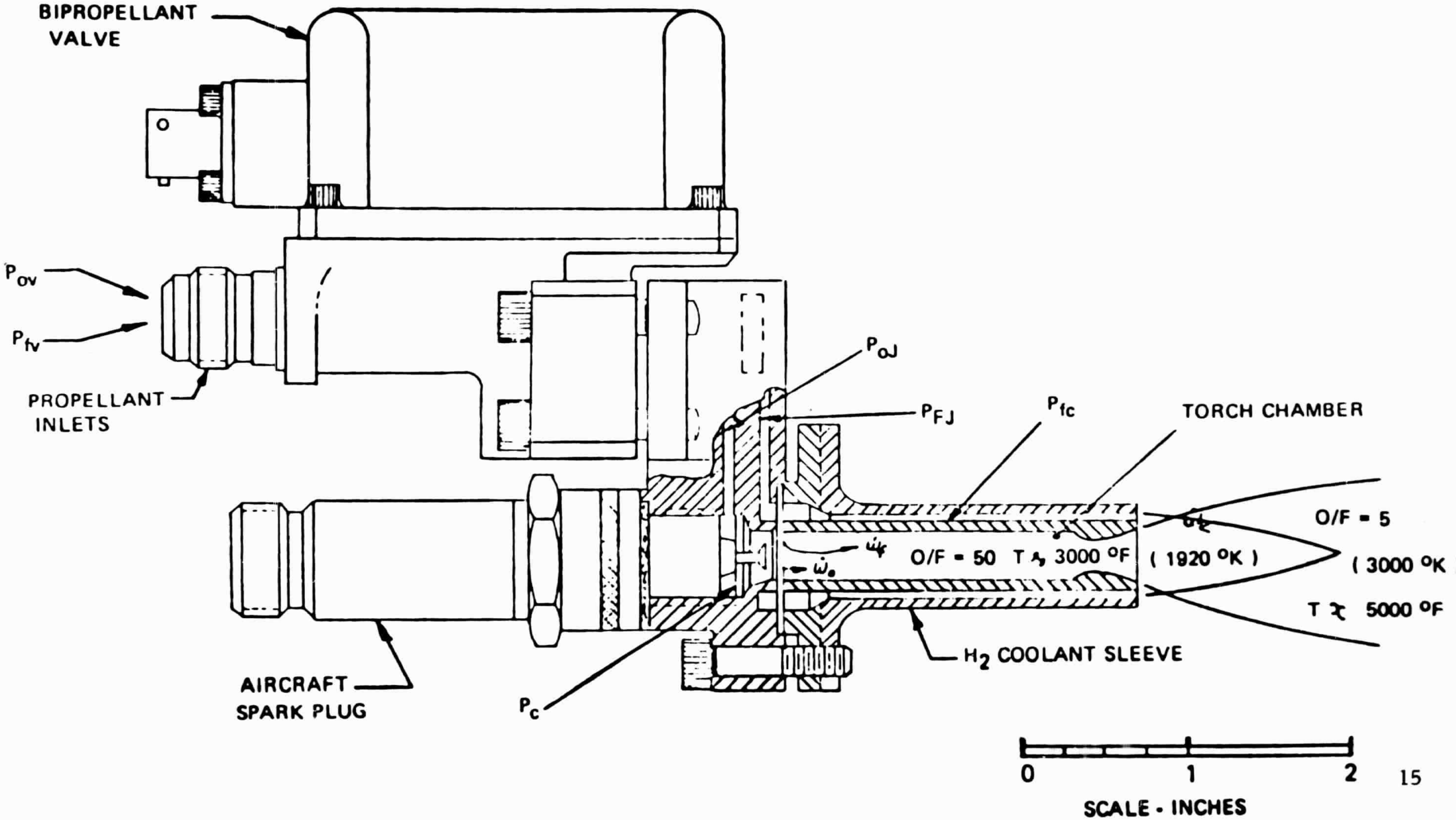
Since the propellant combination is not hypergolic, a technique for reliable ignition must be provided for the thrusters. This is compounded since many thousands of pulses are required during the life of a thruster. Spark devices are under investigation, but consideration must be given to minimizing the energy required from both the power, thus weight, as well as radio interference. Tests with candidate designs have yielded good results with very low spark energy levels.

SPARK IGNITION LIMITS



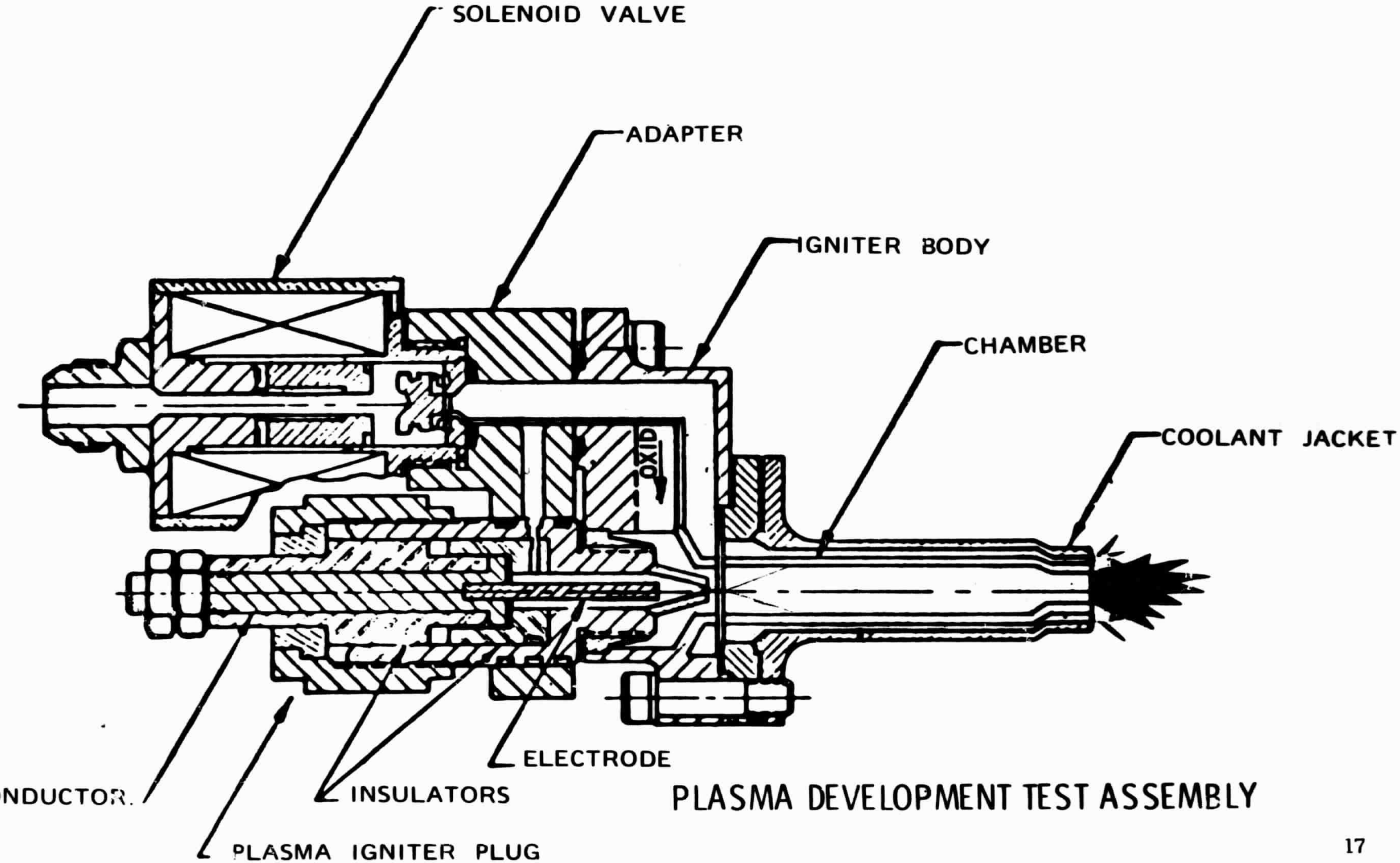
The spark ignition device illustrated is typical of types presently under investigation and is similar to that frequently used for oxygen and hydrogen propellant engines in the past. The reliability of this type system has been very good; however, much electrical complexity is required. In this device, the propellants are provided at the spark plug tip at low flow rates and mixtures conducive for good ignition. The resulting hot gas is then discharged into the center of the thruster main injector, thus providing a hot gas torch for ignition there. A small hydrogen coolant flow around the barrel provides for wall cooling of the igniter.

H_2/O_2 SPARK IGNITER



The next device illustrated is an attempt to reduce the energy required for ignition by the use of a plasma arc igniter. Hydrogen is passed over the hot electrode and this results in temperatures that will achieve auto ignition when the hydrogen is injected into an oxidizer environment. As in the case of the spark device, the resulting hot gas is then discharged into the center of the thruster main injector. This approach has not shown any improvements over the spark igniter from an electrical energy standpoint. The electrode is; however, less subject to damage due to overheating than the spark plug.

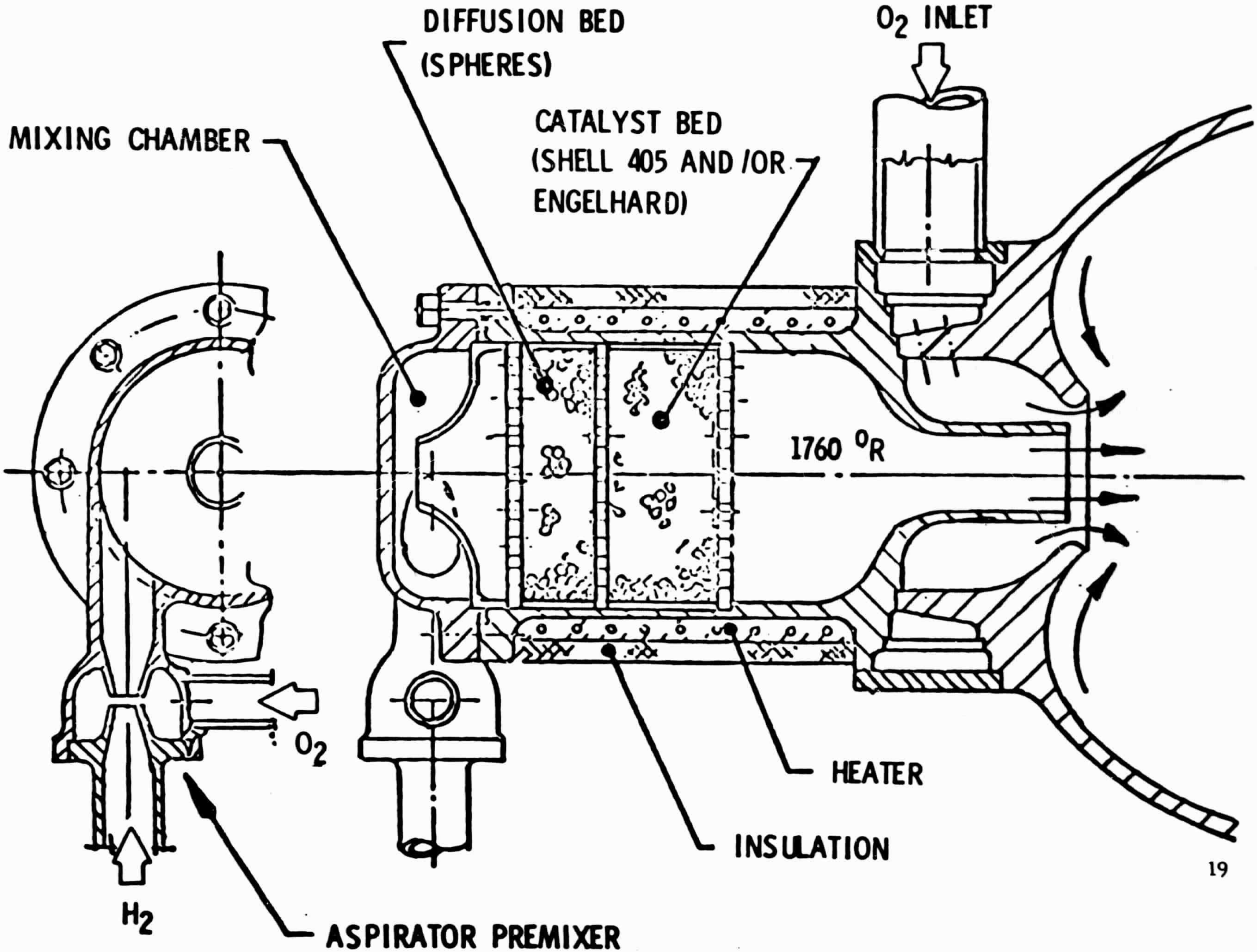
APS ENGINE PLASMA ARC IGNITER



PLASMA DEVELOPMENT TEST ASSEMBLY

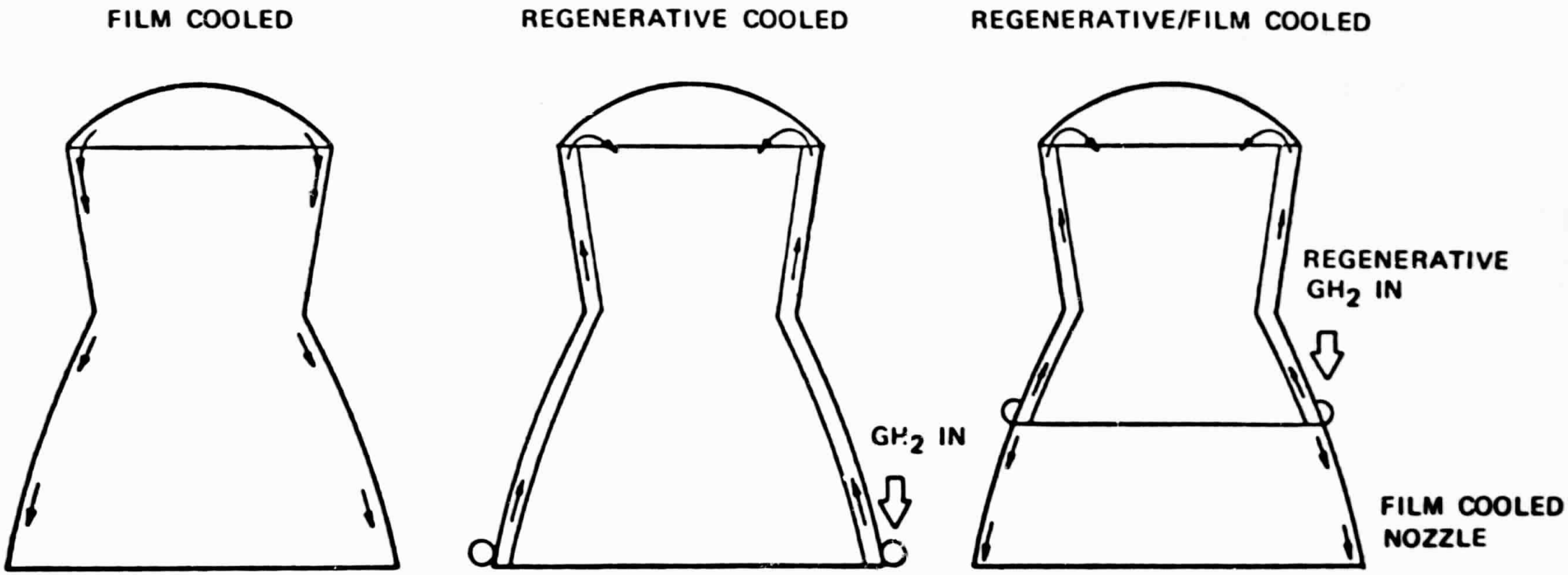
The catalytic pilot igniter illustrated is typical of types currently under investigation. In this device, a small flow of hydrogen and oxygen are premixed and then passed through the catalyst bed where reaction takes place, resulting in gas temperatures of approximately 975°K (1760R). This hot gas is then discharged into the center of the main thruster combustion chamber, thus providing a hot torch igniter for ignition there. The main advantage of this system is that no spark energy is required for ignition; however, the catalyst bed may require heating to perform properly. Also, a hydrogen lead at start and a hydrogen lag at cutoff is required to assure that oxidizer does not enter the bed while it is hot and, thus, result in damage.

TYPICAL CATALYTIC PILOT IGNITER



The types of cooling techniques illustrated for the high pressure chamber are film, regenerative and a combination of both. The cooling will be provided by gaseous hydrogen initially at approximately 300°K (540°R). The trade-off considerations here will be between performance, cooling and long life. For the film cooled approach, a curtain of hydrogen protects the chamber wall from overheating, whereas in the regenerative cooling approach, the wall is unprotected on the hot gas side, but depends on the cool hydrogen on the inside wall for removing the heat and maintaining acceptable wall temperatures.

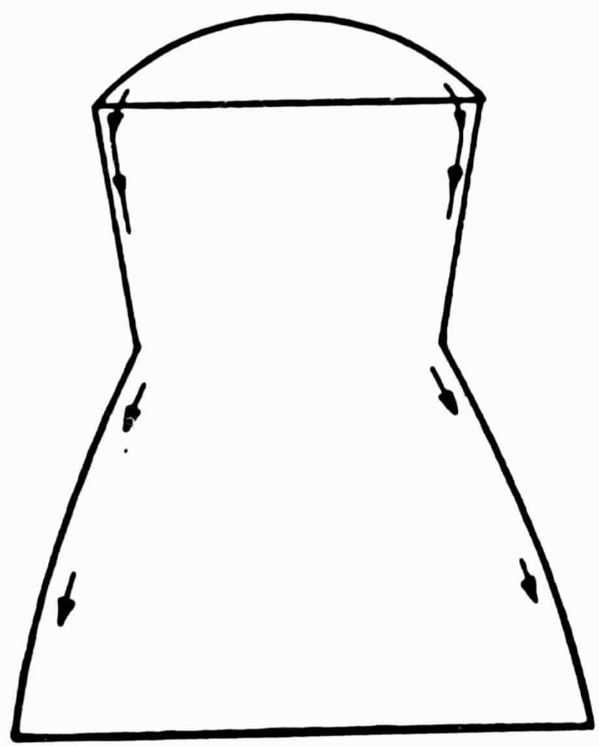
CANDIDATE HIGH PRESSURE CHAMBER COOLING



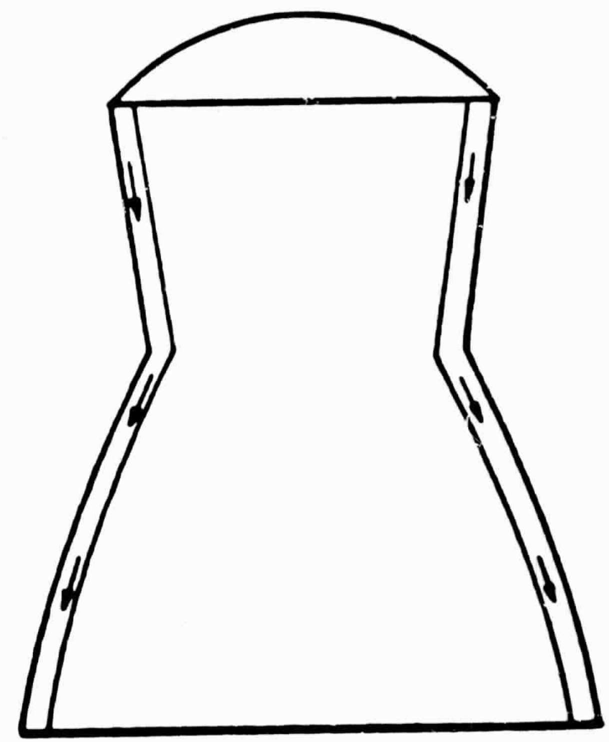
The types of cooling techniques illustrated for the low pressure chamber do not include the regenerative type because of the pressure drop required. For the film cooled approach, a curtain of hydrogen protects the chamber wall from overheating and in the dump cooled approach this is accomplished by cool hydrogen passing through the chamber wall.

CANDIDATE LOW PRESSURE CHAMBER COOLING

FILM COOLED

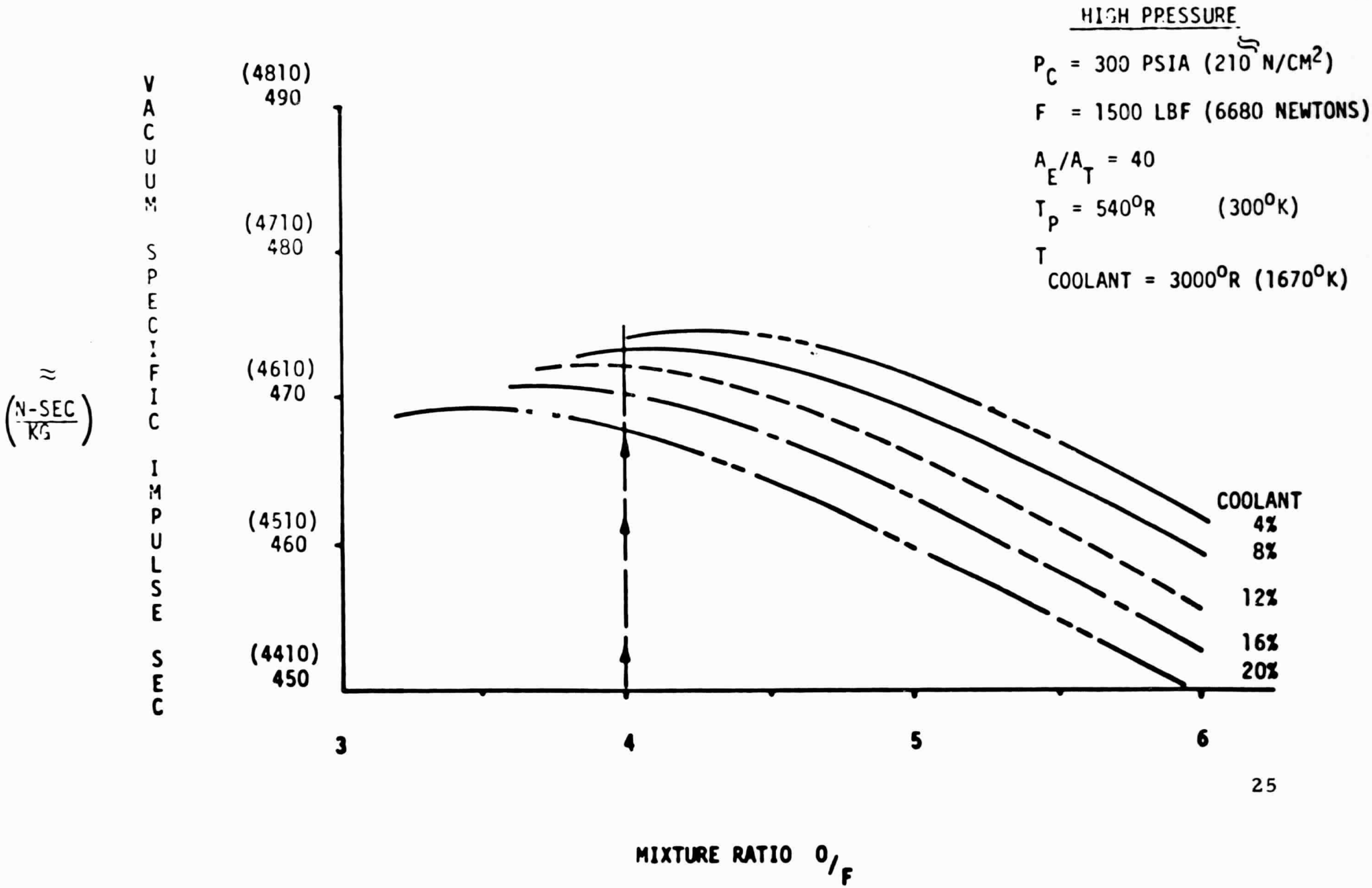


DUMP COOLED



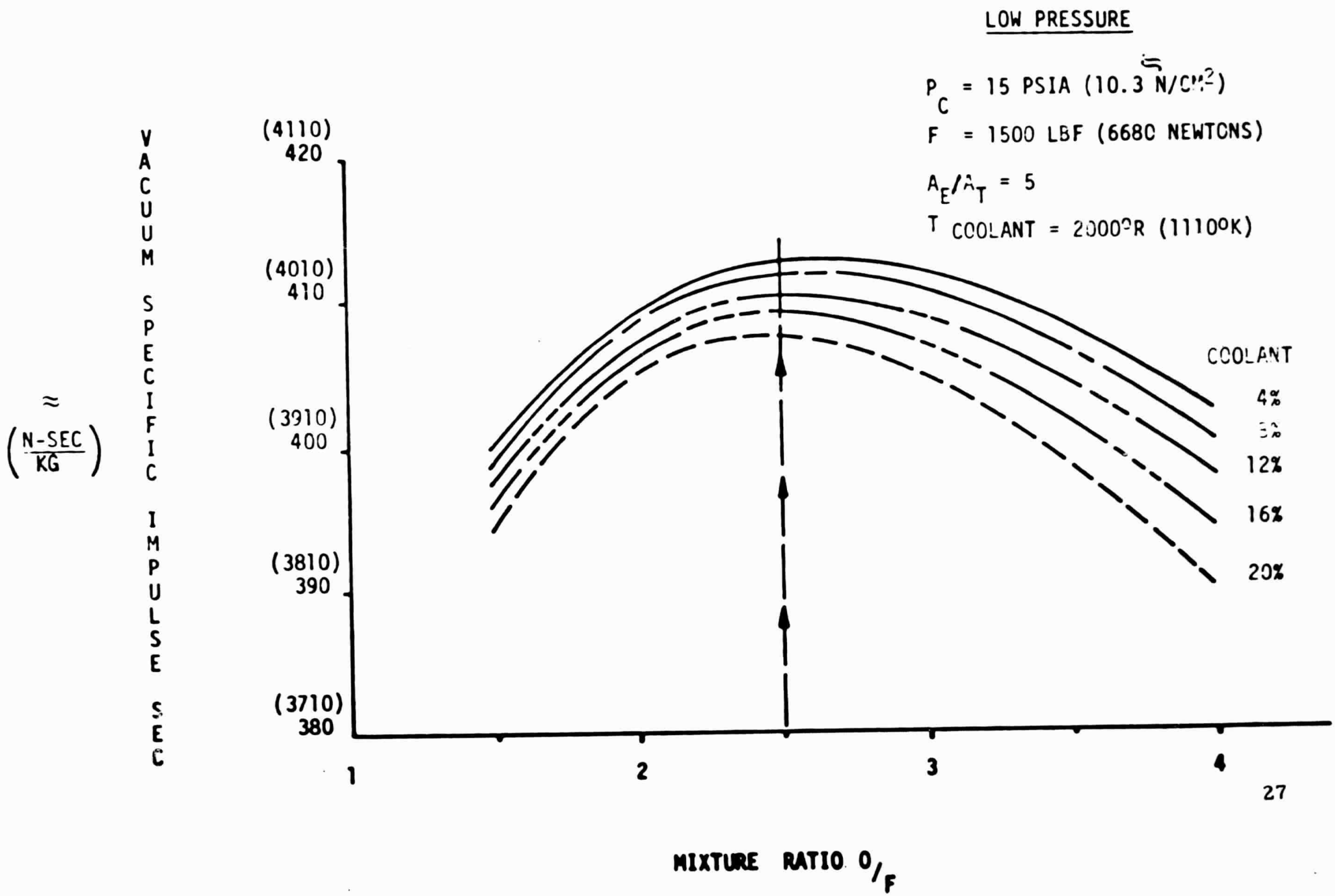
For the high pressure thruster, considering the probable coolant flow rate requirements, this chart indicates that the best performance will be obtained at a mixture ratio of approximately 4. This has been chosen for the thruster technology work being initiated.

COOLING EFFECT ON THEORETICAL PERFORMANCE



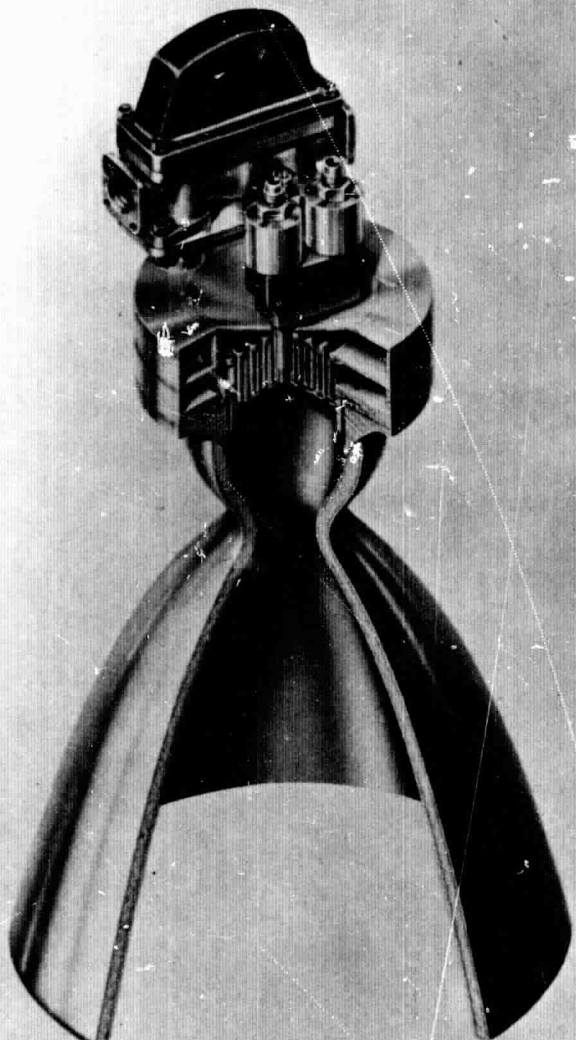
For the low pressure thruster, when considered as in the previous case, the best performance, this chart indicates, will be obtained at a mixture ratio of 2.5. This has been chosen for the thruster technology work being initiated.

COOLING EFFECT ON THEORETICAL PERFORMANCE



To allow technology to be investigated on thrusters of a size and design closely representing that ultimately to be used in the Space Shuttle, the preliminary requirements shown in the illustration were established. Thrusters are to be designed and tested utilizing different ignition and cooling techniques such as those previously described. From the resulting data, the Space Shuttle thruster design will evolve. A typical design for the high pressure thruster currently under consideration is also shown in the illustration.

HIGH PRESSURE AUXILIARY ENGINE

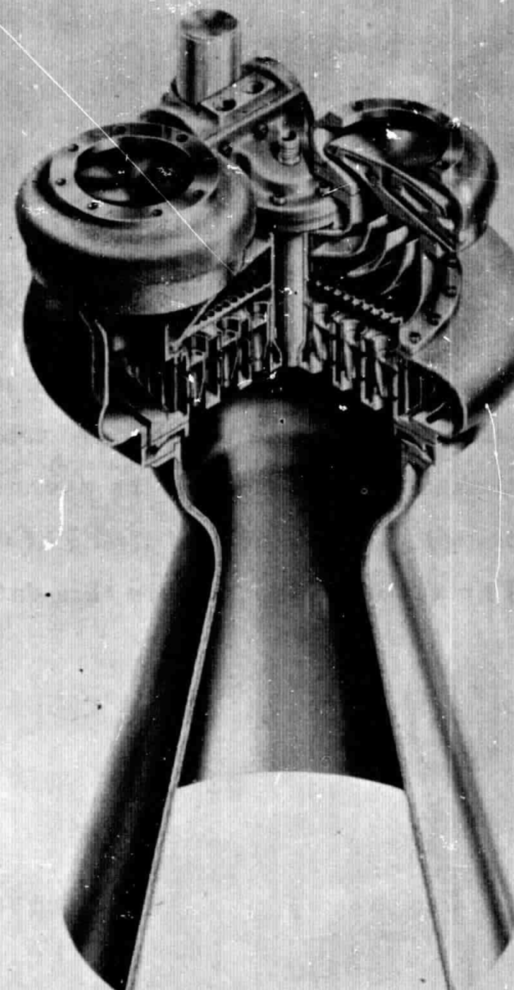


THRUST	1500 LBF	(6680) NEWTONS
CHAMBER PRESSURE	300 PSIA	(206) N/CM^2
INLET TEMPERATURE (GO_2/GH_2)	540°R	(300°) R
INLET PRESSURE GO_2	375 PSIA (MAX)	(257) N/CM^2
GH_2	375 PSIA (MAX)	(257) N/CM^2
MIXTURE RATIO	4.0	
AREA RATIO	40:1	
SPECIFIC IMPULSE (GOAL)	435	(4258) $\frac{N \cdot SEC}{KG}$

A typical low pressure thruster is shown in the illustration along with the preliminary requirements that were established for purposes of technology investigations. The expansion ratio has been reduced in this case to facilitate the space problem of installation. This results in a performance reduction of the thruster from that shown for the high pressure thruster.

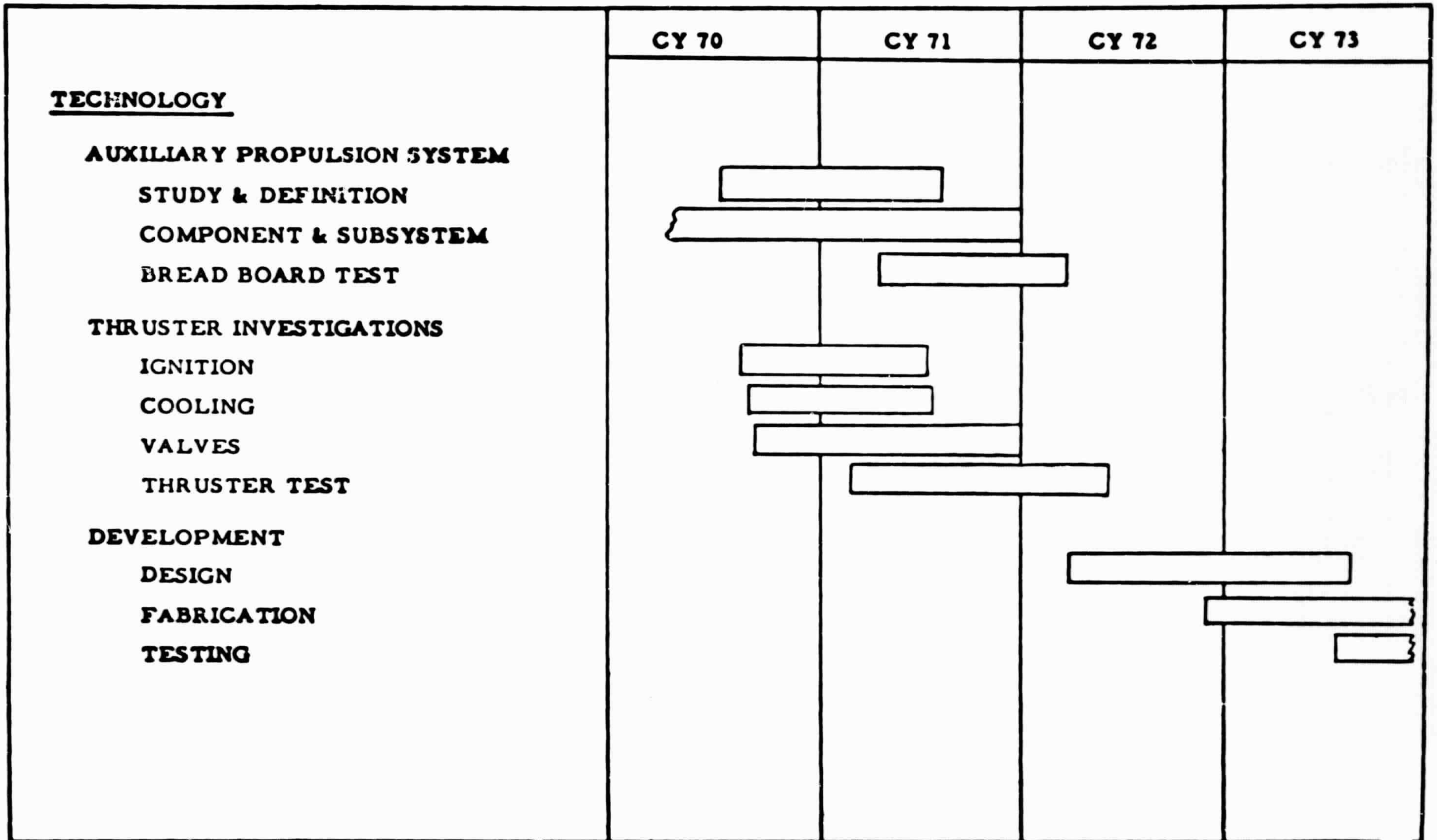
LOW PRESSURE AUXILIARY ENGINE

THRUST	1500 LBF	(6680) NEWTONS
CHAMBER PRESSURE	15 PSIA	(10.3) N/CM^2
INLET TEMPERATURE (GO_2/GH_2)	540°R	(300°K)
INLET PRESSURE GO_2	25 PSIA (MAX)	(17.1) N/CM^2
GH_2	20 PSIA (MAX)	(13.7) N/CM^2
MIXTURE RATIO	2.5	
AREA RATIO	5:1	
SPECIFIC IMPULSE (GOAL)	375 SEC	(3665) $\frac{N\text{-}SEC}{KG}$



The schedule for the technology work, as shown on the next chart, will permit the Auxiliary Propulsion System studies and breadboard testing to be completed by early 1972, in time for technological inputs in the event a flight design is initiated. Also, the thruster technology, as well as test firing of thrusters representative of the flight design, will be accomplished before this date.

SCHEDULE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