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NASA Contract NAS 5-302

PROJECT APOLLO

A Feasibility Study of an Advanced Manned Spacecraft and System

FINAL REPORT

VOLUME IV. ON-BOARD PROPULSION

Book 1 — Text and Appendix P-C

Program Manager: Dr. G. R. Arthur

Project Engineer: H. L. Bloom

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 5-302

May 15, 1961

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MISSILE AND SPACE VEHICLE DEPARTMENT

A Department Of The Defense Electronics Division

3198 Chestnut Street, Philadelphia 4, Penna.

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now but could be moderately reduced in the future with inducers. The present inlet conditions are:

1.	O_2 inlet pressure:	45 psia minimum @	176 R
		130 psia minimum @	209 R
2.	H_2 inlet pressure:	30 psia minimum @	39.2 R
		45 psia minimum @	43.0 R

For APOLLO, considerable care and complexity of propellant storage would be required. Even with booster pumps, like the PESCO pumps used to provide suction head pressures on Centaur, inlet tank pressures must be carefully maintained at sizeable net positive suction head. Further, transient bubbles must be cleared from the propellant lines during starts which would take more than 20 seconds.

Additional information on the Centaur is available in the following references:

(a) P&WA Installation Handbook, RL10 (LR115) Liquid Rocket Engine, dtd. December 1959, Revised 6-1-60

(b) Condensed Summary of Differences Between LR115-P-1 Engine and "Common Centaur and Saturn" LR115 Engine

(c) Specification No. 2222-E, "YLR115-P-1 Engine", Copy No. 87, dated 30 November 1960

(d) P&WA Installation Drawing No. 2024401, Sheets 1 & 2, dated 10-7-60

Because of the numerous incompatible requirements of the LR-115 (LR-10) Centaur engine, this engine is not recommended for the APOLLO mission.

4.3.3.2 NOMAD ENGINE

We have also briefly looked at the NOMAD engine for the APOLLO mission with assistance from Rocketdyne. While Rocketdyne was not selected as one of our study team members, this should not detract from future serious consideration of the NOMAD engine which was designed for manned space applications. Components and technology are available for using this engine on F_2/N_2H_4. According to Rocketdyne, this engine can be readily converted to F_2/H_2.

Numerous tests have been conducted on the components with F_2/N_2H_4, but work has now reached a moratorium until a specific use of the Nomad engine is found. The facilities have been shut down, but Rocketdyne indicates that these facilities can be re-activated to restart work with the Nomad components in a minimum time.

A brief design study was performed by Rocketdyne for both engines, one using F_2/N_2H_4 and the other using F_2/H_2 for the design specifications tabulated in Table I-4-XVIII.

TABLE I-4-XVIII. DESIGN STUDY GROUND RULES

1. Gross stage weight of 15,000 lb
2. Gross stage velocity increment of 7,500 fps
3. F_2/N_2H_4 weight mixture ratio ($\mathring{w}o/\mathring{w}f$) of 1.6, F_2/H_2 weight mixture ratio of 13.0
4. Two chambers required, zero gimbal angle thrust vectors of chambers pass through intersection of stage centerline and top of propulsion system envelope. Chamber gimbal excursion is ± 4 degrees.
5. Nominal altitude thrust per chamber is 12K at an expansion area ratio of 20 and a (Nozzle stagnation) chamber pressure of 150 psia. (Increased expansion area ratios can be provided by the addition of an uncooled extension to the chamber.) A chamber layout, with expansion area ratios of 20 and 40 defined, is included as Figure I-4-32 for any future design studies.
6. Stage usable propellant weights were calculated from $R = e,^{v/c}$ where R = mass ratio, v = 7500 fps, and c is based on the value of I_s stated in the following paragraph. Usable propellant weight is then Wg (R - 1/R), with Wg equal to 15,000 lb.
7. Nominal altitude I_s for the F_2/N_2H_4 system was conservatively assumed to be 357 seconds which was demonstrated in Nomad testing. A value of 368 seconds

TABLE I-4-XVIII. DESIGN STUDY GROUND RULES (Continued)

was a Nomad design objective and could be obtained were the program to be continued. A value of 437 seconds was assumed for the F_2/H_2 stage. This is 96.5 percent theoretical at a mixture ratio of 13. It was assumed that all stage thrust was coincident with the stage velocity vector.
8. Tank volumes were based on a factor of 1.04 x usable propellant weight to allow for ullage and outage.
9. Basic NOMAD hardware used to the maximum extent possible. This includes the use of the design NOMAD thrust chamber with F_2/H_2 at a mixture ratio of 13.0, this is feasible without any tube modifications.

Comparative parametric study results are shown in Table I-4-XIX showing dry and wet engine weights using nickel (Ni) thrust chambers, and improved aluminum (Al) thrust chamber assemblies. In both cases, tank pressure is about 300 psia; pressurization is by heated helium from storage at 4500 psia and -300 F. A reflux condensor is used atop the F_2 tank to prevent vaporization and consequent venting of F_2 prior to launching.

In summary, the NOMAD engine burning F_2/H_2 from pressurized tanks looks attractive from a payload capacity and performance standpoint. It achieves this advantage, however, using the highly reactive and toxic fluorine, which suggests a long and possibly expensive development program for manned space applications. At this time, it does not appear that the edge in performance over O_2/H_2 compensates for the difficulties in handling, storing, and successfully qualifying the fluorine-hydrogen engine.

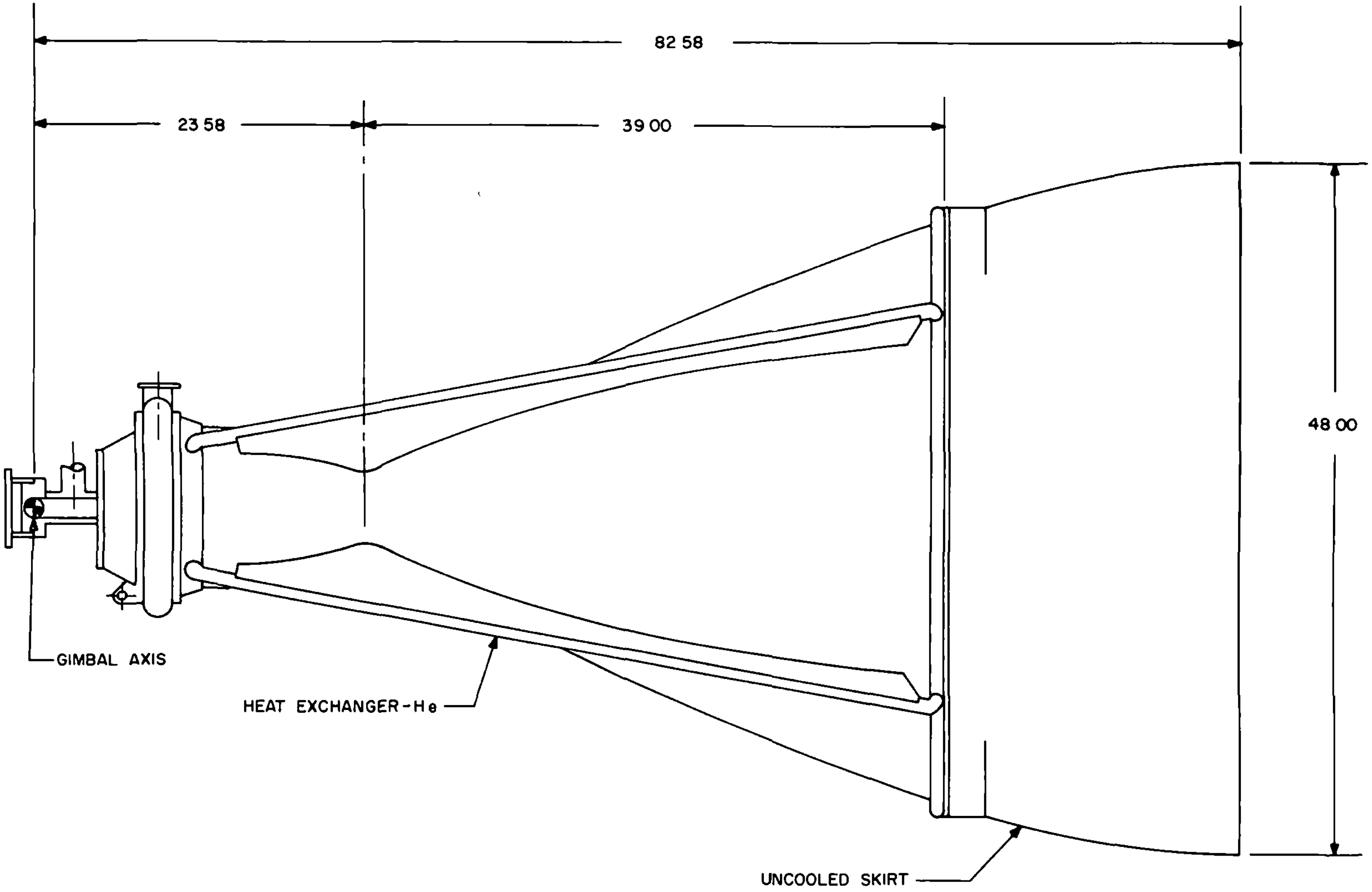

Figure I-4-32. Rocketdyne proposed NOMAD 12k thrust chamber

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TABLE I-4-XIX. PARAMETRIC STUDY RESULTS SHOWING APOLLO PROPULSION SYSTEM WEIGHT BREAKDOWN FOR A 15,000-LB VEHICLE, ΔV = 7500 ft/sec

F_2/N_2H_4 System		Weight (Lb) With Ni TCA	Weight (Lb) With Al TCA
Thrust Chambers (2)		380	232
Oxidizer Tank)) Fuel Tank)		148	148
Pressure Tank (2)		119	119
Plumbing		63	63
Tank Supports		35	35
Helium		18	18
	Dry Engine Weight*	763	615
	Propellants	7200	7200
	Wet Engine Weight*	7963	7817
F_2/H_2 System			
Thrust Chambers (2)		380	232
Oxidizer Tank & Manifold		167	167
Fuel Tank		156	156
Pressure Tank (2)		119	119
Plumbing (lines, valves, reg., etc.)		70	70
Tank Supports		45	45
Helium		18	18
	Dry Engine Weight*	955	807
	Propellants	6300	6300
	Wet Engine Weight*	7255	7107

*Weights do not include tank insulation, attitude control, structure for engine supports, etc.