GENERAL DYNAMICS
Convair Division

11 December 1980

To: R. H. Thomas

xc: C. Adcock, R. Bithell, D. Heald, L. Norris, W. Rector, N. Viste

From: W. J. Ketchum

Subject: AFRPL Air Force Sortie Space System - GDC Evaluation

GDC evaluation of the AFRPL proposed concept was conducted to explore 1) initial conditions provided by the 747 carrier, 2) lifting ascent trajectory modeling and performance determination, 3) drop tank weight estimating based on Atlas hardware.

Data provided by AFRPL and Pratt & Whitney were used.

Initial Conditions - Analyses of the 747 carrier determined that initial conditions with JT9D augmentation (hydrogen burning) could provide a 10° flight path angle at Mach 0.8 and 41,400 feet. (This compares to unaugmented performance of 0° FPA, Mach 0.8, 35000 ft.) Initial climb from sea-level to 35000 ft is unaugmented and takes about 30 minutes. The orbital vehicle is then tanked and when ready for launch, the 747 is augmented and enters a climb to 40,000 ft in about 1 minute, then enters a pitch up (1.2 "g") to achieve buffet limited flight at 10° FPA and 41,400 ft after 20 sec. A pitch over is then initiated to achieve positive separation (0.2g) of the orbital vehicle.

Ascent Trajectory - The primary task involved the development of the lifting ascent trajectory in order to answer two questions: 1) Is the thrust level sufficient to overcome the transonic drag rise and 2) can the design attain orbital velocity with the available propellant and assumed weights and engine performance. A three-degree-of-freedom point mass trajectory program with a spherical rotating earth model was used to develop the ascent trajectory. This program (TRAJ3D) used mass property and propulsion characteristics of the tank/entry vehicle combination as provided by AFRPL and P&W. A crude estimate of the aerodynamic characteristics was used by using standard methods such as DATCOM etc. Zero-lift drag estimates were made assuming the configuration was composed of two cone cylinders at 10° angle of attack. 15 degree half angle cones were assumed and the base regions were assumed to be fully separated. Lift characteristics were made by assuming the configuration to be approximated by an elliptic cone with an 80° sweep in the plan view and a ratio of major to minor semiaxes of 3 with the major axes in the horizontal plane. The induced drag was assumed to be that for a full separated flat plate i.e.

$$\Delta C_{Di} = C_L \text{ TAN } \alpha$$

Utilizing the above characteristics, an ascent trajectory was developed by parametrically optimizing the angle of attack schedule to give the best combination of altitude, velocity, and flight path angle for attainment of a 100 n.mi. circular orbit. The best trajectory developed to date is as shown in the attached plots. A time history of altitude, velocity, flight path angle, dynamic pressure, axial load factor, and angle of attack are presented as a function of time. This represents a polar launch.

It is evident from the burnout conditions that the baseline system is deficient by ΔV = 650 fps of delivering 17000lbs to a 100 n.mi. orbit.

There are many configuration and performance parameters to vary to overcome the deficiencies noted. The list to be evaluated would include:

Inert weights
Propellant weights
Engine thrust
Engine Isp
Lift capability
Configuration drag

Drop Tanks - The 2 drop tanks assumed are basic Atlas E hardware. Each tank is 10' dia x approximately 60' long, having 4000 ft^3 capacity. Using 2 tanks with liquid hydrogen/liquid oxygen at 22 lb/ft 3 bulk density (6:1 MR) results in 176,000 lb propellant.

The basic Atlas E sustainer section tank system (without engine, hydraulics, guidance, electrical, etc) weighs 3300 lb each. Considering added structure support, etc. a total weight of 8000 lb for both tanks was used for our analysis. The low mass of these thin wall "balloon" tanks not only improves performance, but results in rapid cooldown for propellant tanking, (no insulation is used on the tanks).

Re-entry destruction of the tanks is enabled by pressurization - detonation after jettison to cause fragmentation.

Entry Vehicle Stability - Detail work has not yet been performed on the entry vehicle stability. The entry vehicle is to be patterned after lifting entry vehicles developed by AFFDL. Aerodynamic characteristics of the entry vehicle will be developed from data available on these high L/D entry vehicles. At first glance, the entry vehicle may have a stability problem during entry because of the aft location of the c.g. due to the engine installation. Some simple variable geometry concepts can be considered to alleviate any stability problems.

Conclusions & Recommendations - Based on a first cut analysis it appears to be a feasible system.

The trajectory shown can be greatly improved in the 0 - 150 sec time frame by improving the lift capabilities of the configuration. The estimated L/D in the transonic region at $\alpha = 40^\circ$ is about 1.0. A more refined analysis of this aspect is critical to the concept.

Bill
W. J. Ketchum

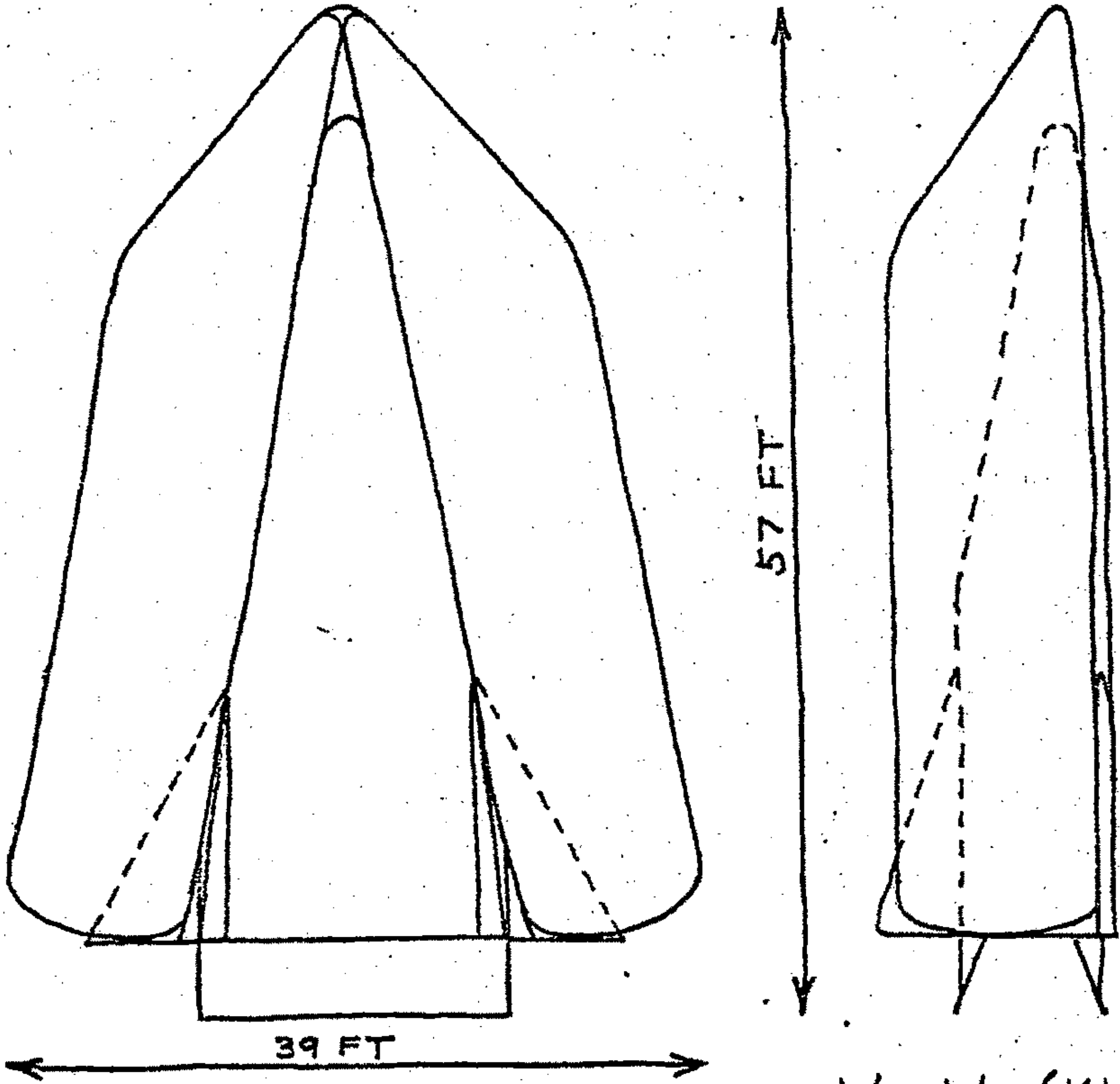
P&W

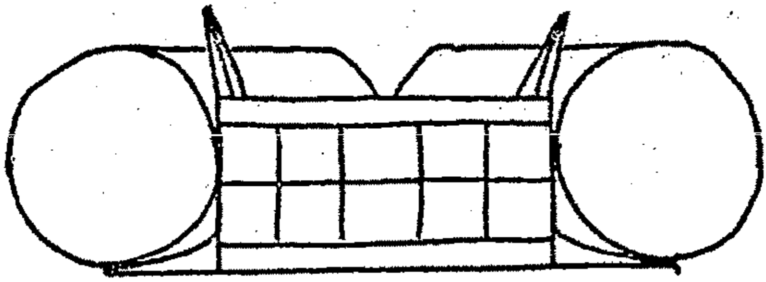
JT9D 7R4G2   Engine in 747-200 nacelle.
No air bleed, no power extraction
M_N = .8, 35,000'
Max continuous power (= max climb power at this condition)
assumptions as listed on page 2.

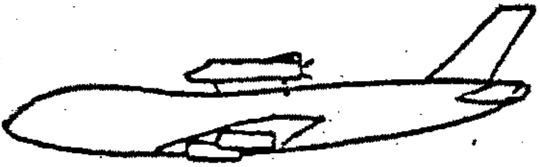
	Basic Engine Without Afterburner	With Operating Afterburner
Core W_a = 123.9 lb/sec	P_T at nozzle: 8.92 psia	
	T_T at nozzle: 1323°R	
W_f (JP)	2.25 lb/sec	2.25 lb/sec
Duct W_a = 576.7 lb/sec	P_T at nozzle: 8.96 psia	
	T_T at nozzle: 533°R	
Total W_a = 700.3 lb/sec	P_T at nozzle	8.03 psia
	T_T at nozzle (mixed) 682°R	3,172°R
Molecular wt	29	25.3
γ	1.4	1.21
H_2 fuel flow	0	15.2 lb/sec
Gross thrust	29,301 lb	68,615 lb
Inlet momentum drag	16,884	16,884
→ Net thrust	12,417 lb	51,731 lb
Jet nozzle throat area	26.8 sq. ft.	73.4 sq. ft.

AFRPL

AN AIR FORCE SORTIE SPACE SYSTEM







Weights ($K lb_m$)	
Space Vehicle (dry)	17
Propellant (Space Veh.)	15
Drop Tanks (dry)	12
Propellant (Drop Tanks)	176
Total (at launch)	220

Table 1. Propellant Characteristics

	MR	BULK DENSITY (LB/FT^3)	VOLUME$^{(1)}$ (FT^3)	
LO_2/LH_2	6.5	23	15217	
LF_2/LH_2	12	36	9722	
DUAL FUEL				
LO_2/LC_3H_8 *	3.3	62	2822	10113 (2)
LO_2/LH_2	7.0	24	7291	

(1) ~ 350000 LB PROPELLANTS

(2) 50/50 PROPELLANT SPLIT

* SUBCOOLED

Table 2. 400K GLOW SSTO Characteristics (ΔV = 28500 FPS)

	CURRENT MATERIALS	25% DRY WEIGHT REDUCTION		
	LF_2/LH_2	LF_2/LH_2	LO_2/LH_2	DUAL FUEL
MF	.86	.89	.86	.88
ISP-SEC	495	495	470	438 (Avg)
PL-LB	12560	25620	5500	5593
BURNOUT -LB (W/O PL)	54241	41181	55230	47328
PROPELLANT LB	333,199	333,199	339,270	347,079

Table 3. "FLOX" CHARACTERISTICS

	MR O/F	OXIDIZER DENSITY LB/FT^3	BULK DENSITY LB/FT^3	ISP SEC	MF	PL LB
LO_2/LH_2	6.5	71	23.5	470	.86	5506
30% FLOX/LH_2	8	77	27.1	475	.869	10993
50% FLOX/LH_2	9	81	29.5	479	.874	14330
70% FLOX/LH_2	10	86	32	483	.88	18064
LF_2/LH_2	12	94	36.6	495	.89	25620

"Review of the literature and contacts with personnel engaged in past and present programs using fluorine indicate that the catastrophe at the Rocketdyne Reno test site stands alone. In addition, the AMPS program to which that facility was apparently devoted was cancelled not after the incident involving fluorine but after a later one, also highly destructive, involving oxygen. Some other facilities have operated continuously with fluorine for a decade.

"JPL has successfully decontaminated subassemblies containing complex components having tortuous passages with water and successfully re-used them in fluorine service.

"Safe handling of large quantities of fluorine has been demonstrated by Rocketdyne, Aerojet, Pratt and Whitney, Convair, LMSC, and others. Convair performed a study for AFRPL of a hydrogen-fluorine orbit-to-orbit stage to be operated with the Shuttle from VAFB.

"All this experience, and the continuous development of small systems by JPL and execution of a large test program at LMSC for over a decade have demonstrated feasibility.

"For reusable launch vehicles, however, which must be repeatedly maintained and reflown by military personnel, it is felt that fluorine is, at present, impractical."

"It is possible to build a sound fluorine system and keep it sealed (dry) for one use, but repeated exposure to servicing in the atmosphere has not been demonstrated. The reactivity of fluorine with water leads to concern that the current state of technology could not reduce the risk associated with repeated exposure to an acceptable level."

The foregoing points out that the primary obstacle to repeated use of a liquid fluorine system is keeping it dry and clean.

RECOMMENDATIONS

Since the potential performance advantages of liquid fluorine for an SSTO is very significant, it is recommended that efforts be continued to answer the following:

1) Methods and systems for maintaining dry, clean reusable liquid fluorine systems.

2) Evaluation of the overall effect of HF in the atmosphere, considering other simultaneous contributions. (industrial, freon, hydrocarbons, volcanism, etc)

3) Engine design and operation philosophy (bearings, etc.)

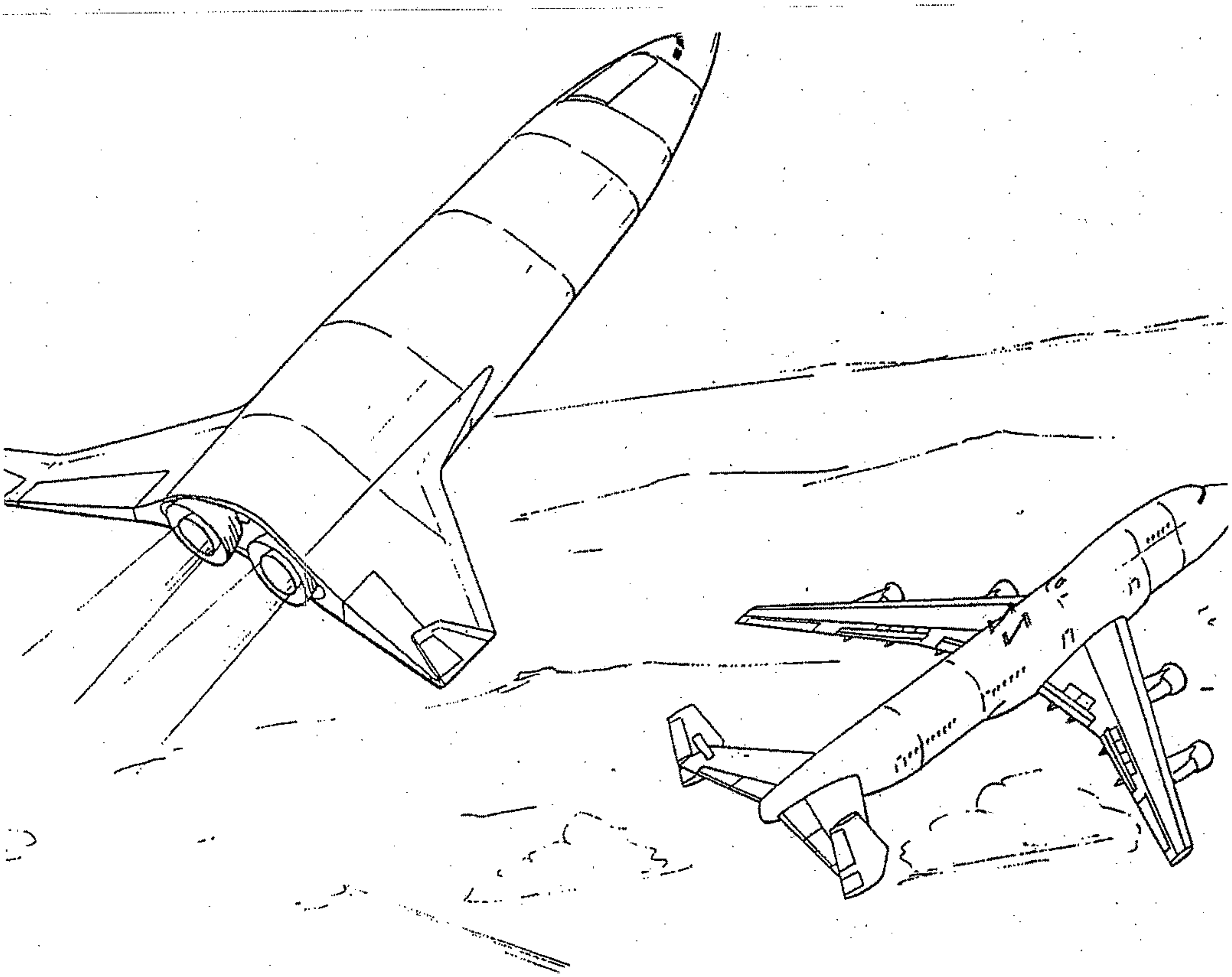


Figure 1

AIR LAUNCHED SSTO

Figure 2

SSTO PERFORMANCE

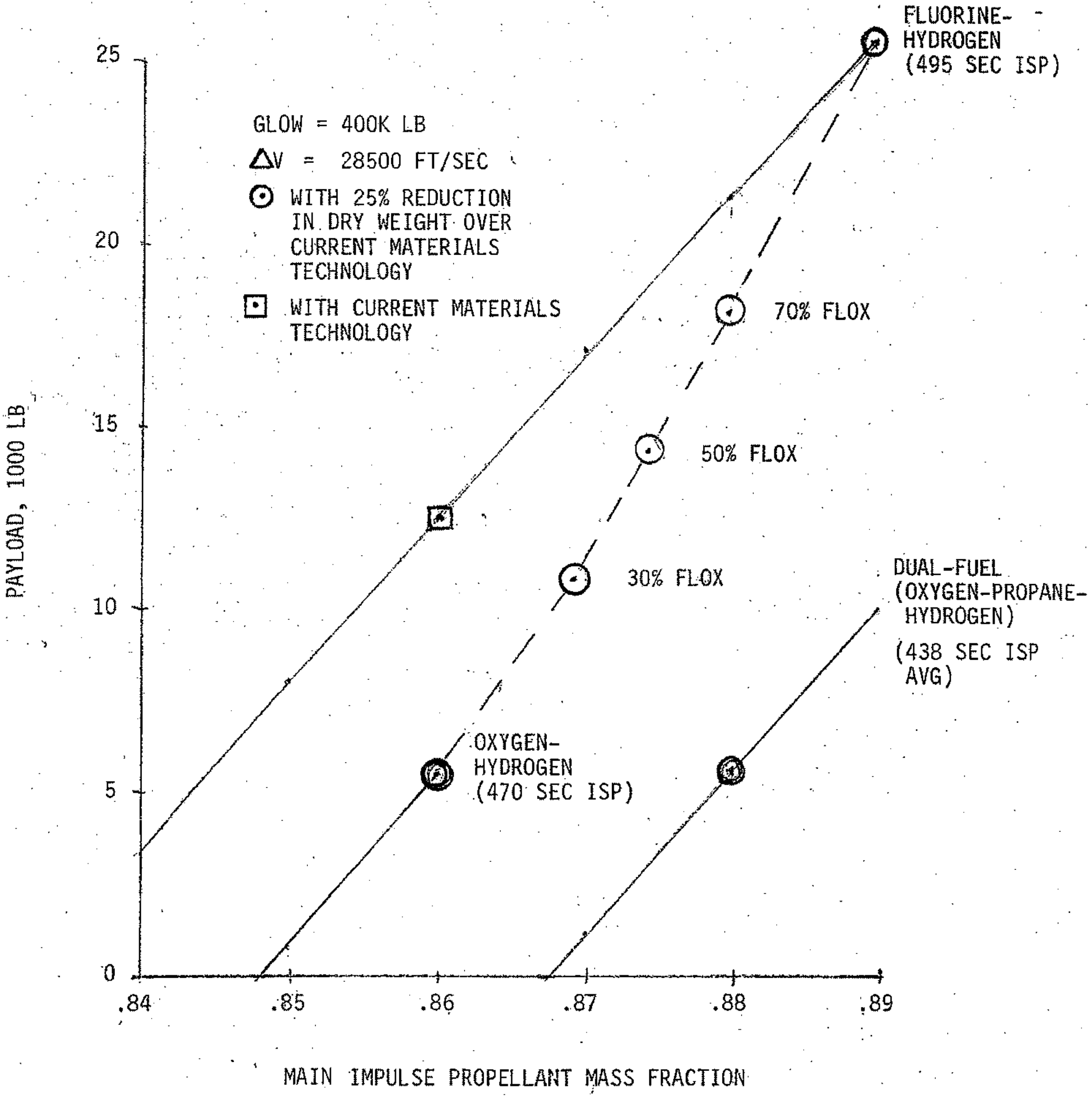
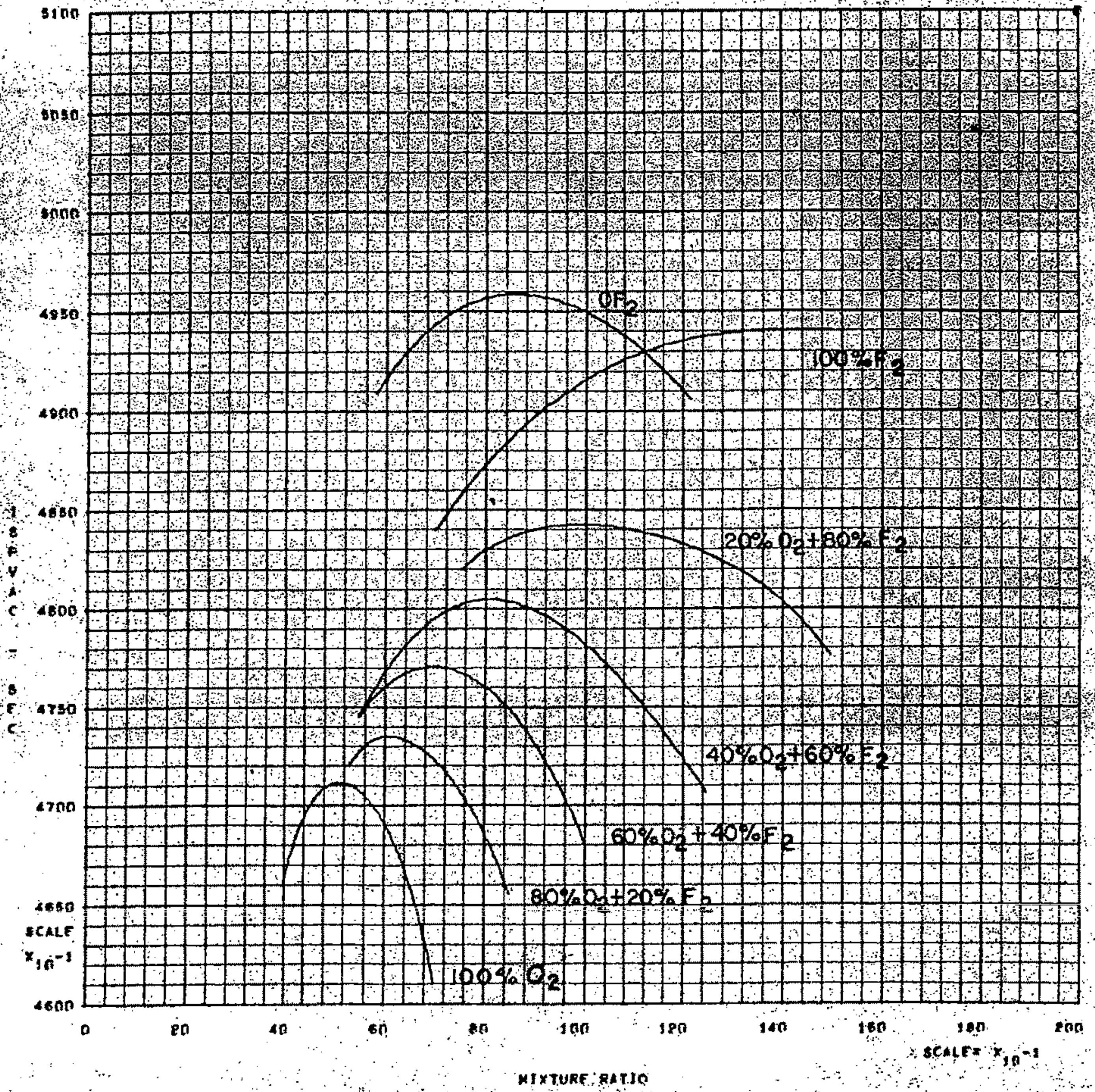


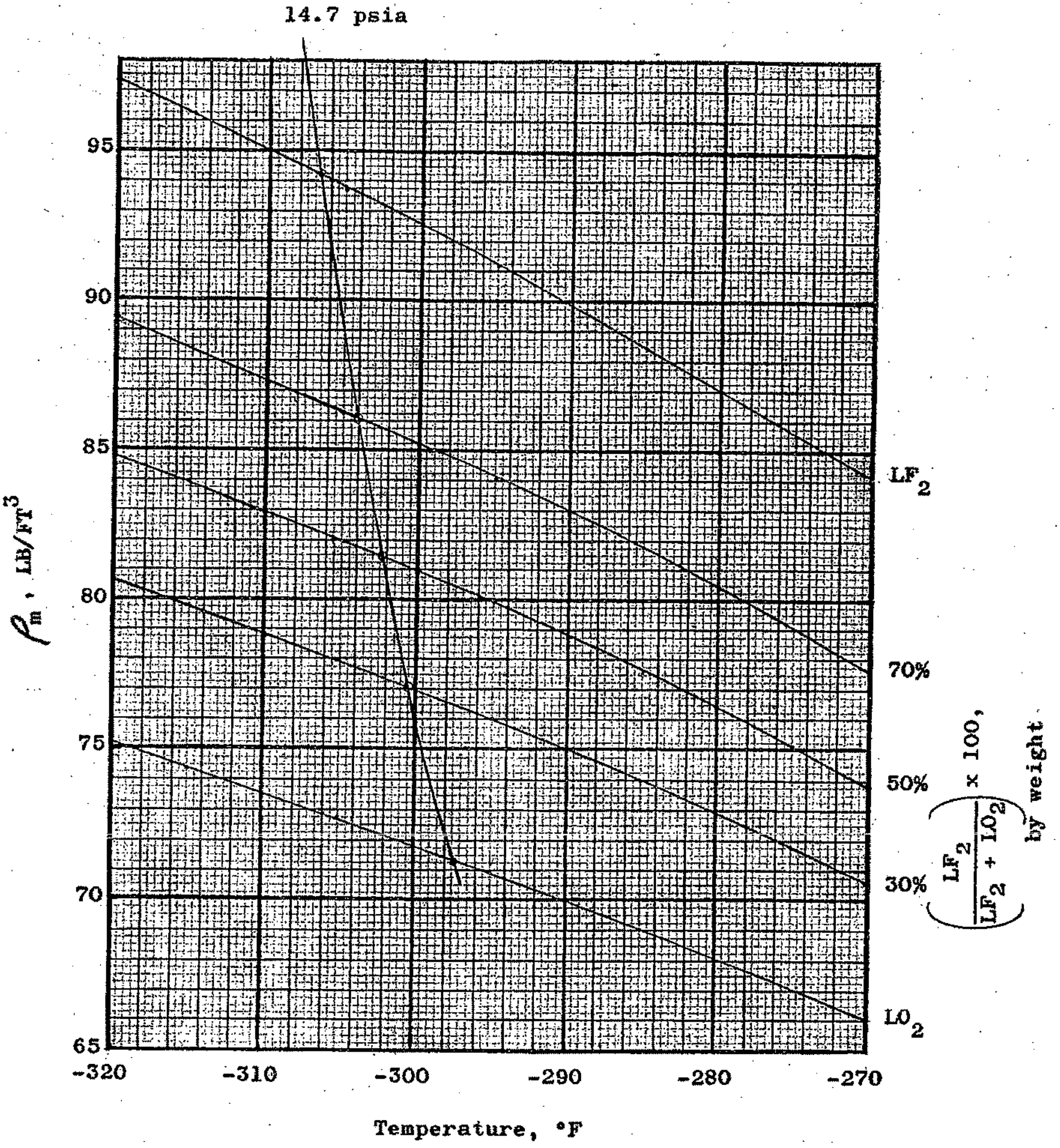
Figure 3 - Engine Performance



RES BURNED WITH LH2 EQUILIBRIUM FLOW E=100 , PC=3000 PSIA

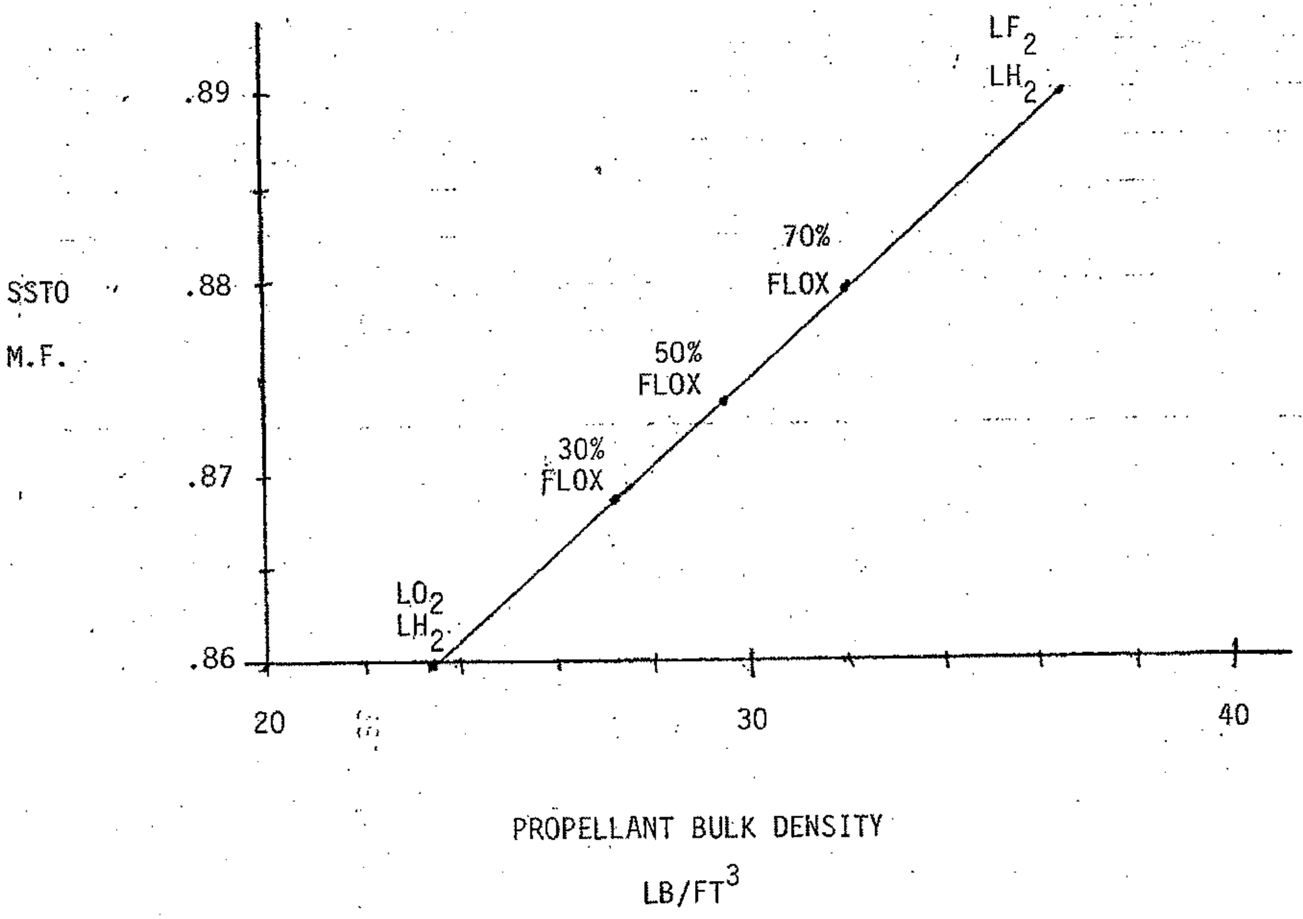
Figure 4 - Propellant Density

Ref: GD/A-BHV64-014



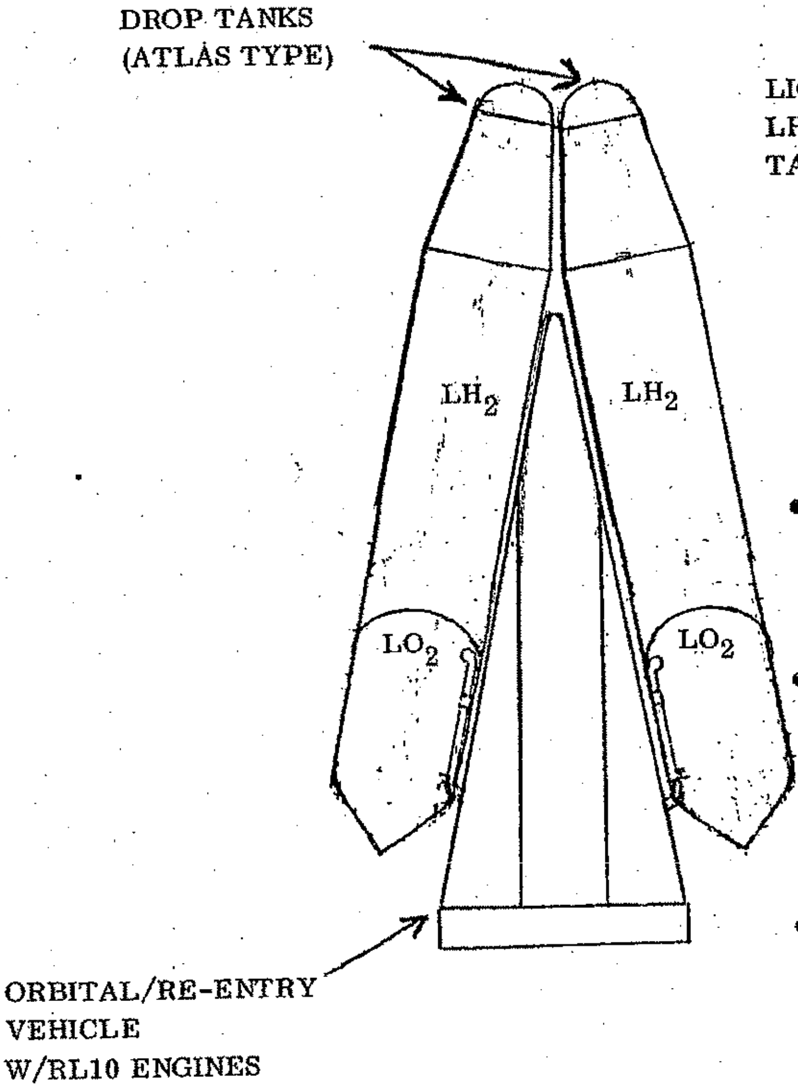
DENSITY - FLOX

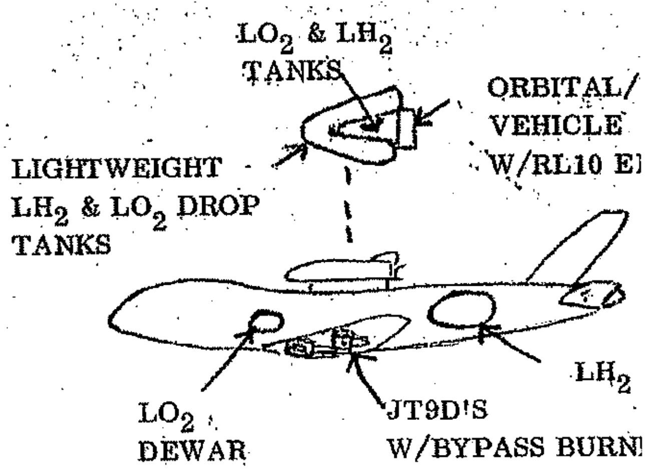
Figure 5 - SSTO Mass Fraction



AIR FORCE SORTIE SPACE SYSTEM

(AFRPL CONCEPT)





- 747 JT9D BYPASS (H_2) BURNING.
  - ACHIEVE HIGH ALTITUDE FO
    OF ORBITAL VEHICLE.
- LIGHTWEIGHT DROP TANKS FOR OR
  - PLANFORM FOR LIFTING AS
  - TANKED AT HIGH ALTITUDE/
  - NO INSULATION.
  - TANKS DESTROYED ON RE
- RL10 ENGINES FOR ORBITAL VEHIC

DROP TANKS STRUCTURAL ATTACHMENTS