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FEASIBILITY OF FLOX

FOR PERFORMANCE IMPROVEMENT ON THE S-IC

Ag 32651

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FEASIBILITY OF FLOX FOR PERFORMANCE IMPROVEMENT ON THE S-IC

The Boeing Company conducted the subject investigation from May through September 1964, as authorized by TAO-22. Propulsion Division (RP&VE-P) provided technical supervision for the study.

Marshall Space Flight Center

This brochure summarizes pertinent findings developed during the investigation, briefly presents the potential impact of FLOX on Saturn V and outlines recommendations for general follow-on studies.

Details of the study are contained in document D5-11464-1, "TAO-22, Investigation of the Feasibility of FLOX for Performance Improvement on the S-IC" which will be available December 4, 1964.

Note: The term "FLOX" or "percent FLOX" as used in this study refers to the fluorine content in the total oxidizer quantity, i.e.,

$$\frac{\text{Pounds of Fluorine}}{\text{Pounds of Fluorine + Pounds of Oxygen}}$$

STUDY SEQUENCES

A detailed technical statement of work was negotiated with MSFC Propulsion prior to initiation of the study. Ideas and suggestions were solicited from other MSFC technical areas, Kennedy Space Center, NASA Lewis and knowledgeable contractors, primarily Rocketdyne and General Dynamics-Astronautics.

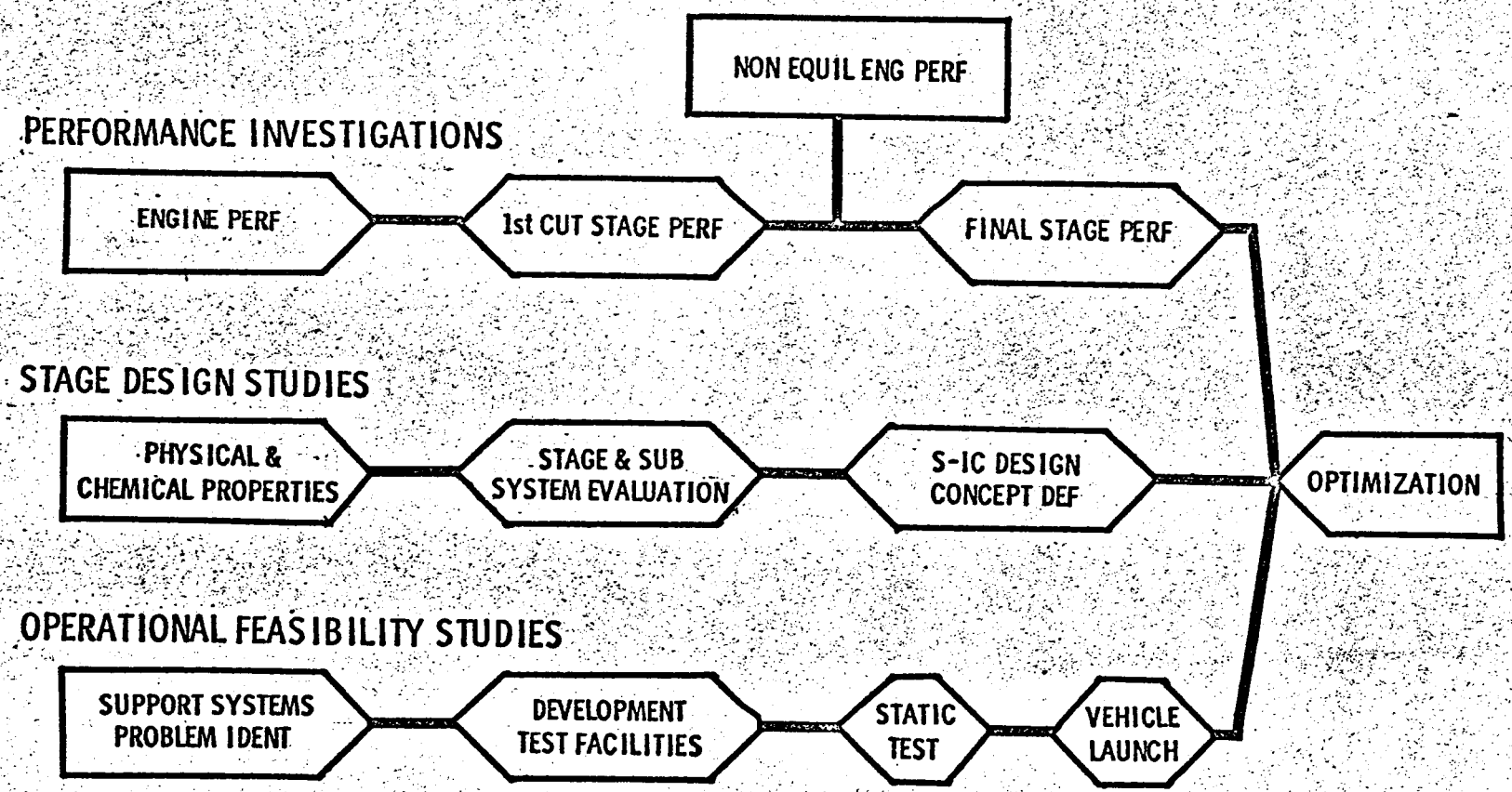
The study sequence chart shows the major elements of study defined in the detailed work statement. "Performance" and "Stage Design" investigations were to include indentification of problems and where appropriate, propose solutions or recommendations. In the "Operational Factors" area, the investigation was to include an identification of the problems, but not necessarily a definition of magnitude or proposed solutions.

Performance investigations were initially devoted to engine investigations in terms of mixture ratio, percent FLOX, thrust, specific impulse response and design oriented factors such as NPSH and turbopump power requirements. Rocketdyne conducted detailed investigations on F-1 engine performance and cycle limitations with varying combinations of % FLOX and mixture ratio during a related-concurrent program. Final stage performance was based on F-1 engine performance predicted on the basis of actual gas flow characteristics (i.e., neither shifting nor frozen composition).

"Stage Design" studies, especially in the area of material compatibility, were largely based on published reports, substantiated to a limited degree by Boeing and other R&D programs. Physical and thermodynamic characteristics unavailable from literature were calculated based on accepted theory of the fluid behavior (liquid fluorine-oxygen) and on data obtained from a Boeing funded research contract to Stanford University - Research Institute.

As expected, studies of "Operational Factors" indicated that toxicity was the primary feasibility factor. Review of the current literature, direct coordination with authorities in the field plus analytical attempts to define cloud behavior during the dynamics of normal launch or vehicle failure led to the conclusion that, except for cold FLOX spills, none of the existing approaches exactly matched Saturn V operation. As a result, a method was selected that yields a "judgement factor" relative to launch feasibility, but does not adequately fix cloud behavior nor define specific launch time periods.

STUDY SEQUENCES



OUTLINE

The chart on the opposite page shows the content of this brochure. Some factors not specifically defined in the original work statement are included in order to provide a more complete story.

Specifically, Saturn V growth aspects ranging from minimum vehicle change to configurations that assume certain modifications to both the engine and stage are discussed.

Although S-IC FLOX feasibility is believed probable from this study, many areas requiring further investigation have been identified and are recommended for further study.

OUTLINE

- TAO - 22 PERFORMANCE SUMMARY
- FLOX RELATIONSHIP TO SATURN V GROWTH
- FLOX DESIGN & OPERATIONAL FACTORS
- RECOMMENDED FOLLOW-ON STUDIES

PERFORMANCE ANALYSIS - VEHICLE DEFINITION

The chart on the opposite page presents some significant "stopping points" developed in the FLOX application studies. These configurations are approximate and are not necessarily recommended designs because detailed design, performance, and resource analysis may indicate some other combinations of engine rating, propellant loading, etc. as superior. However, these configurations are considered representative and may be used with reasonable confidence for judging the merits of FLOX. The following performance charts describe the analysis that led to the definition of these vehicles.

VEHICLE DEFINITIONS

FLOX PERFORMANCE ANALYSIS

- EXISTING ENGINE (1522K)-OFF LOADED OXIDIZER TANK
- EXISTING ENGINE (1522K)-FULL OXIDIZER TANK
- EXISTING ENGINE WITHIN COOLING LIMITS (1625K)-FULL OXIDIZER TANK
- MODIFIED CHAMBER COOLING (1800K & 2000K)-EXISTING TANKAGE
- MODIFIED CHAMBER COOLING (1800K & 2000K)-RELOCATED BULKHEADS

ENGINE ANALYSIS TECHNIQUES

Excluding materials compatibility, certain limitations exist with use of FLOX on the F-1 engine. In this study, no changes are proposed in gas generator, turbine or turbopump, although modifications in the thrust chamber cooling tubes and localized increase in structural strength are necessary for maximum performance cases. The chart on the opposite page is an illustration of the many avenues open for engine-stage optimization analysis. The typical presentation of performance (thrust and specific impulse) as a function of mixture ratio (oxidizer to fuel) and the variation resulting from different fluorine concentrations is used. The lines drawn on the performance map indicate the engine variables used in the analysis.

The current F-1 turbopump output schematic is on the left portion of the chart. This output would produce operating mixture ratios along the line "W_V = F-1" as the percent FLOX increased, unless the turbopump is orificed or otherwise restrained. The increase in mixture ratio results because liquid fluorine is more dense than LOX.

The line, "MR = Const." illustrates operation wherein the oxidizer output is restricted or the fuel output is increased as the percent FLOX is increased.

The line intersecting each percent FLOX at its peak illustrates the case where the fuel flow is restricted (or the oxidizer is increased) as percent FLOX is increased. This line results in best performance and was used for examination of the following cases:

Existing F – Thrust held to existing F-1 engine level (1522K)

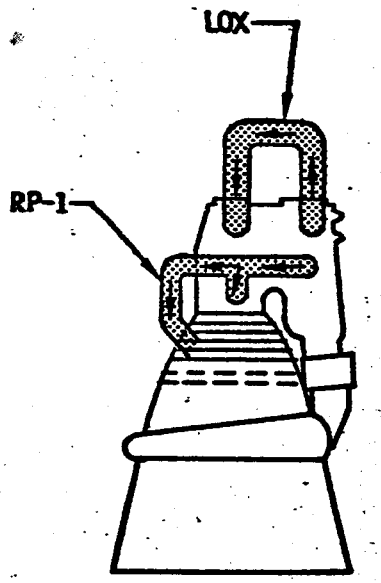
Existing P_c – Main chamber pressure held to existing F-1 levels

Existing $\dot{W}$ – Total propellant mass flow rate held to existing F-1 engine flow rate.

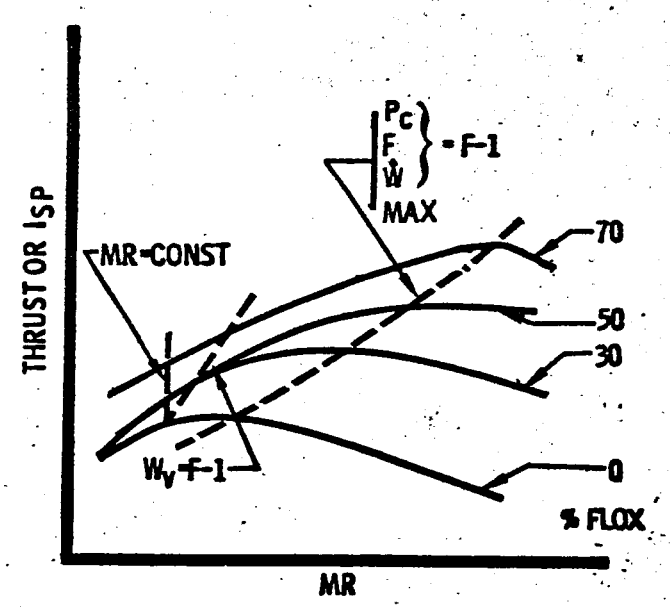
Maximum – Performance is limited to F-1 engine capability at maximum gas-generator power available (turbine inlet temperature limit).

As the study program progressed, it became apparent that the operating conditions of primary interest were: the existing thrust (F), existing total flow rate (W) and maximum performance.

ENGINE ANALYSIS TECHNIQUES



F-1 ENGINE SCHEMATIC

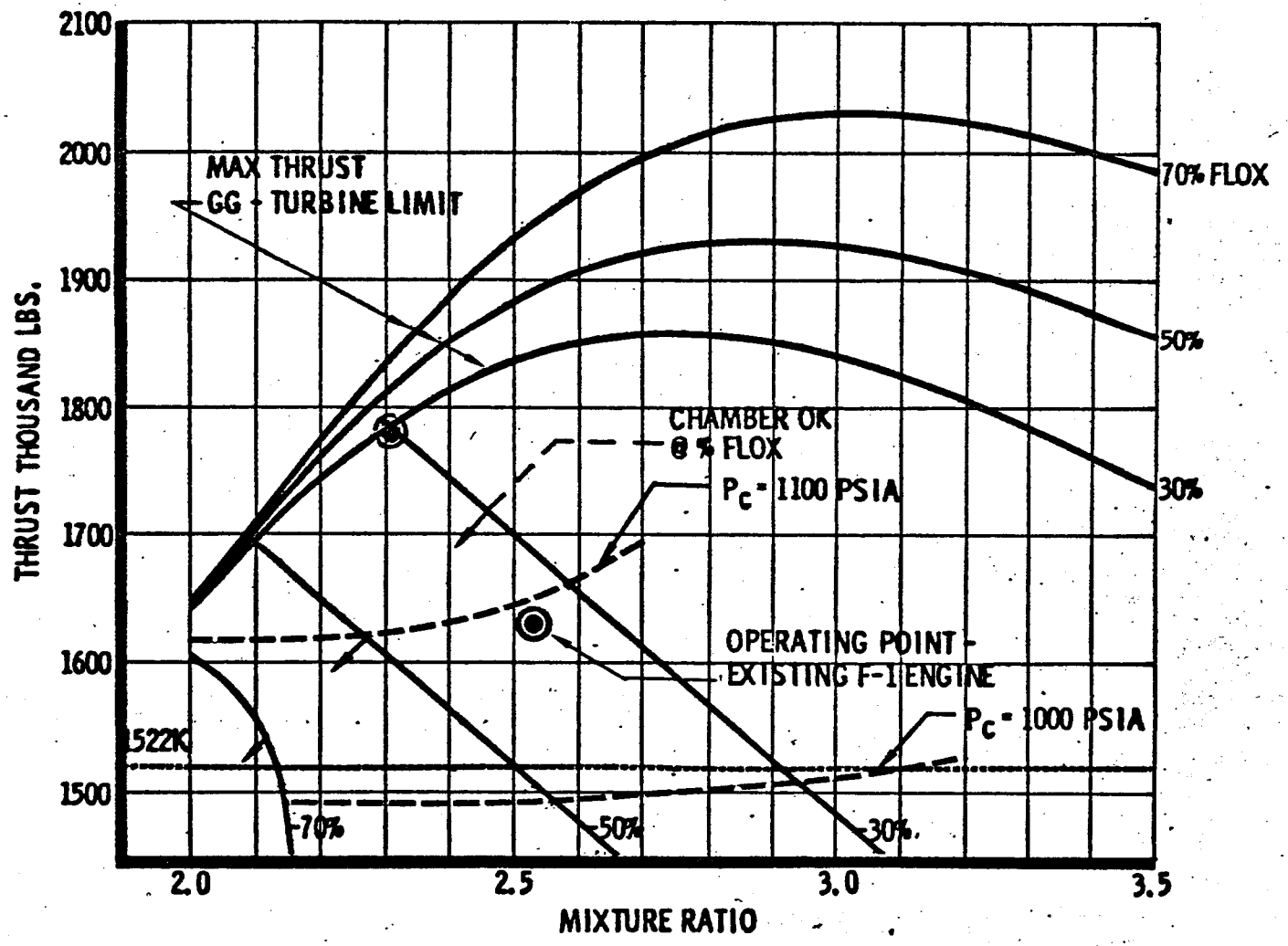


F-1 ENGINE PERFORMANCE WITH FLOX

This chart shows the predicted thrust of the F-1 engine with varying mixture ratio and percent FLOX. The region of interest at this point in the discussion is the capability of the existing engine and the matching performance point on the S-IC stage. The diagonal lines labeled "Chamber OK @ % FLOX show the capabilities of the existing F-1 engine up to main chamber cooling, the first limitation. The point at 1780K thrust mixture ratio 2.3, and 30% FLOX clearly indicates the significant benefit derived from FLOX relative to achieving thrust uprating on the F-1. In the interest of clarity, corresponding specific impulse curves are not shown. Later charts that present specific vehicle performance list the corresponding specific impulse improvement. Also, ΔIsp cross plots of the more significant engine operating conditions are contained in the back-up data in the last section of this brochure. As reference only, calculated values of chamber pressure are plotted on the curve.

The line drawn across the curve at approximately 1522K and the spot point at 1625K (MR 2.54) are references to two vehicle performance points to be shown on the following pages.

F-1 ENGINE PERFORMANCE WITH FLOX



VEHICLE PERFORMANCE-EXISTING ENGINE & VEHICLE

Vehicle performance data throughout this section is referenced to the increase in LOR payload over and above that available from the S-IC full-tank configuration (propellant overload). The term "theoretical payload increase" is the gain that would be achieved if vehicle inert weight remained constant. Recognizing that this case cannot exist with increased thrust or propellant loading and more significantly with payload mass and volume increase, a factor was developed to allow quick correction of the theoretical results to values more representative of actual or net performance gain. A chart contained in the "back-up" section shows the payload corrections used in the study.

The basic curves on this illustration show the increase in theoretical payload (over the LOR Mission) that could be achieved by using FLOX while holding thrust to the existing F-1 level. When considering the existing engine and stage, several limitations exist in terms of (1) current S-IC tankage - left hand limit line, (2) engine thrust chamber cooling limit as labeled, (3) thrust to weight ratio at launch as labeled and (4) not directly shown, a loading limit in the oxidizer tank based on the capability of the S-IC structure. The (upper) point on the engine limit line (ΔPL 17,000 lbs) is the case in which the oxidizer tank is full and the fuel tank is filled to a level resulting in a T/W of 1.17 at launch. The fuel tank off loading is 16% at this point because of the mis-match of engine and stage.

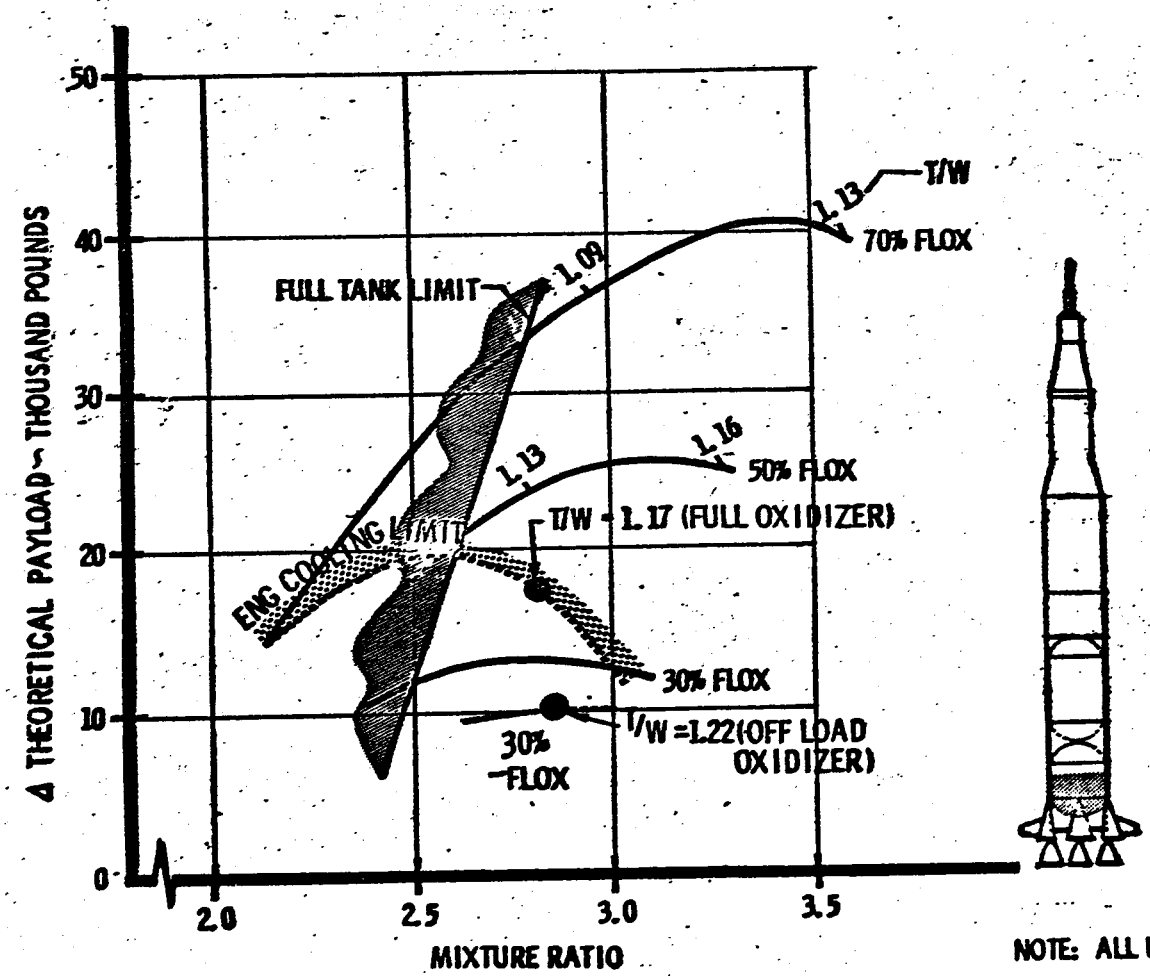
The lower spot point represents the case in which both tanks are off-loaded sufficiently to assure that liquid loads are equal to or less than the overloaded S-IC. No allowance has been made for the probable favorable conditions such as ullage pressure. Therefore, actual payloads for the unchanged engine and stage will probably be between these points.

The summary at the right hand side of the chart tabulates the corrected payload and other pertinent data for the two configurations using the existing 1522K thrust rating. The column at the left covers the "off-loaded oxidizer and fuel tank case" in which it is estimated that no S-IC structure "beef-up" is required. Note that the S-IC propellant loading is 50,000 pounds below the full tank (overload) LOX-RP-1 vehicle.

The column (extreme right) covers the case where the oxidizer tank is filled to minimum ullage and the fuel load is increased. In this case, mixture ratio is allowed to shift along the engine limit line to higher percentages of FLOX. The maximum performance point was arbitrarily selected when thrust to weight at launch was reduced to approximately 1.17.

As noted on the chart, the engine operating point with FLOX in either case is approximately 92% of the total propellant flow rate used in the existing F-1 engine.

VEHICLE PERFORMANCE
EXISTING ENGINE & VEHICLE



EXISTING ENG & VEHICLE 1522K THRUST

	OFF LOADED OXIDIZER	FULL OXIDIZER
ΔPL(CORR)	10,000	14,000 LBS
ΔWP	-50K	+ 200K
% FLOX	30%	37%
L WT.	6.23	6.52
T/W	1.22	1.17
ΔI_{SP}	21 SEC	24 SEC
$\dot{W}$ - % OF EXIST. F-1	92%	92%

NOTE: ALL UNITS LBS EXCEPT AS NOTED

VEHICLE PERFORMANCE-EXISTING ENGINE-FULL OXIDIZER

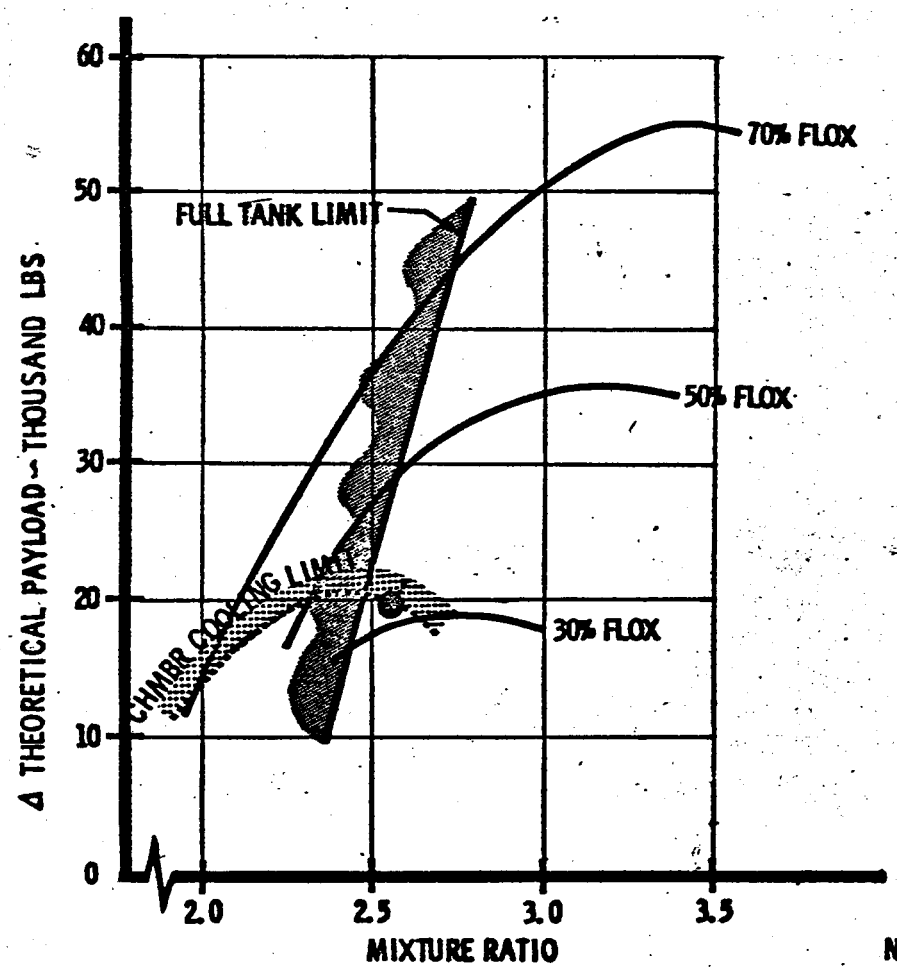
The previous chart showed the performance available when operating at 1 522K thrust, is considerable derating. This chart shows performance available when utilizing the increased thrust capability of the existing F-1 engine and the current S-IC tank volumes.

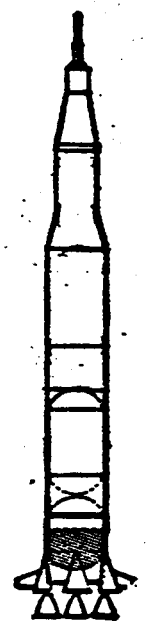
The S-IC full tank limit line is again shown on the left-hand side of the curve. The F-1 engine chamber cooling limitation line describes maximum payload at varying mixture ratios and percent FLOX. The peak performance (ΔPL = 20,300#) occurs at a mixture ratio of 2.54 and approximately 38 percent FLOX. This operating point was shown on the previous engine performance curve and has been calculated as operating at approximately 98 percent of the existing F-1 engine total propellant flow rate.

The corrected payload increase (ΔPL = 17,000#) and other pertinent data are shown on the summary at the right.

The S-IC oxidizer tank is filled to minimum ullage; however, the fuel tank is off-loaded approximately 6 percent.

VEHICLE PERFORMANCE
EXISTING ENGINE - FULL OXIDIZER
THRUST 1625K





EXIST. ENG WITHIN COOLING LIMITS

ΔPL (CORR)	17,000
ΔWP	250K
%FLOX	38%
LWT.	6.70M
T/W	1.21
ΔI_{SP}	22 SEC
THRUST	1625K
$\dot{W}$ - % OF EXIST. F-1	98%

NOTE: ALL UNITS LBS EXCEPT AS NOTED

F-1 ENGINE FLOX PERFORMANCE-MODIFIED CHAMBER COOLING

In the previously examined cases, no engine changes other than possible incompatible materials were considered. Rocketdyne has reported to MSFC that the cooling limitation could be removed from the engine by modification of main chamber cooling tubes. This modification involves a change in coolant (fuel) velocity through the tubes to improve heat transfer and an increase in the amount of fuel passed through the cooling network prior to injection into the main chamber.

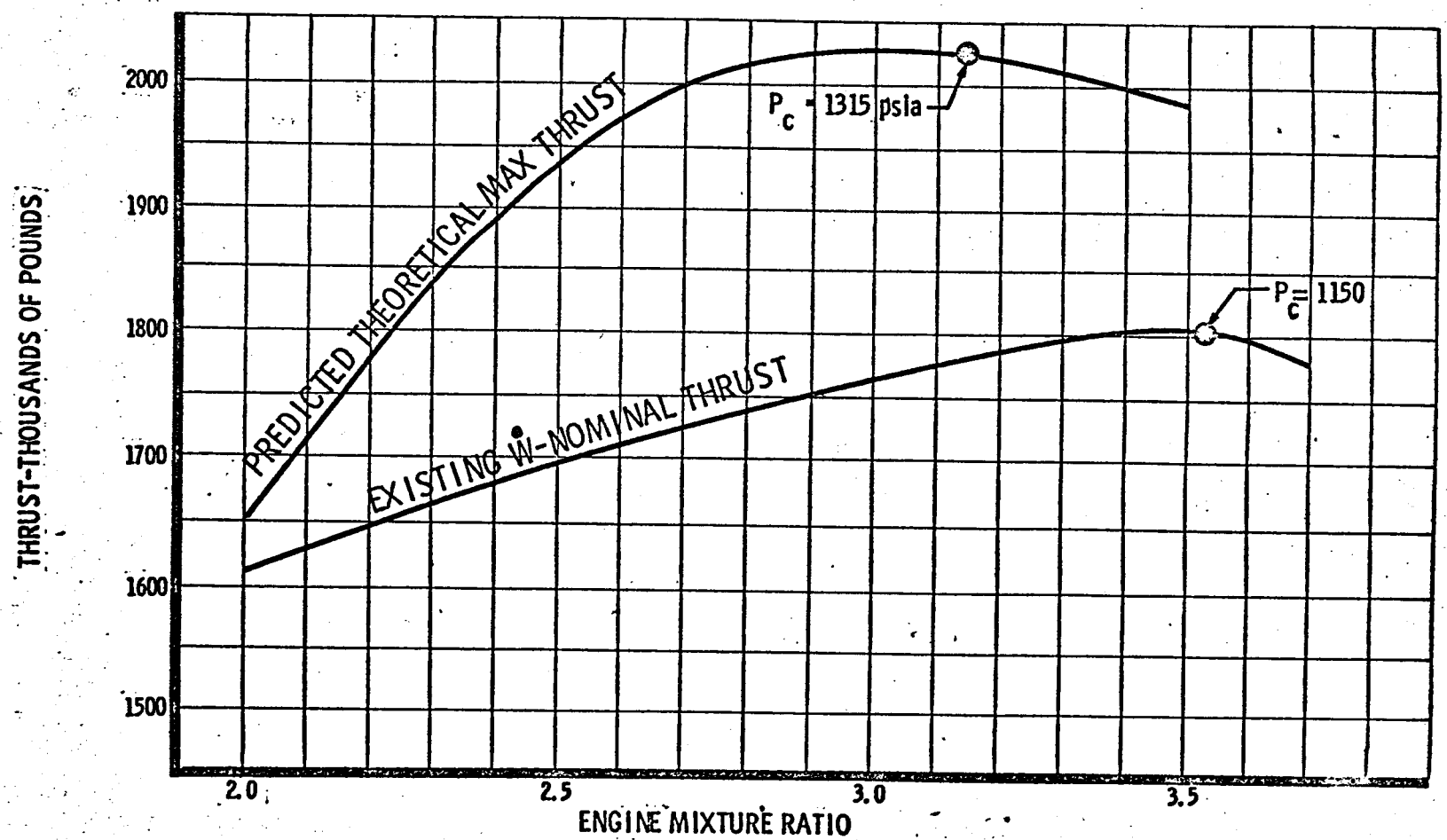
If the cooling modification is accomplished, the next major barrier or limitation in F-1 engine performance (thrust) growth is the gas generator power availability.

The curve, opposite page, shows FLOX performance of the F-1 with modified cooling tubes in the chamber.

Two specific cases were selected at 70 per cent FLOX for vehicle studies. The top line is the maximum available from the F-1 within the current gas generator turbopump limitation. The second case is considerably below maximum and is labeled "Nominal" and describes the performance available when the total propellant weight flow-rate is held equal to the existing F-1 engine. It should be noted that lower percentages of FLOX at various mixture ratios can be selected if intermediate operating points prove desirable.

F-1 ENGINE FLOX PERFORMANCE

(Modified Chamber Cooling 70%Flox)

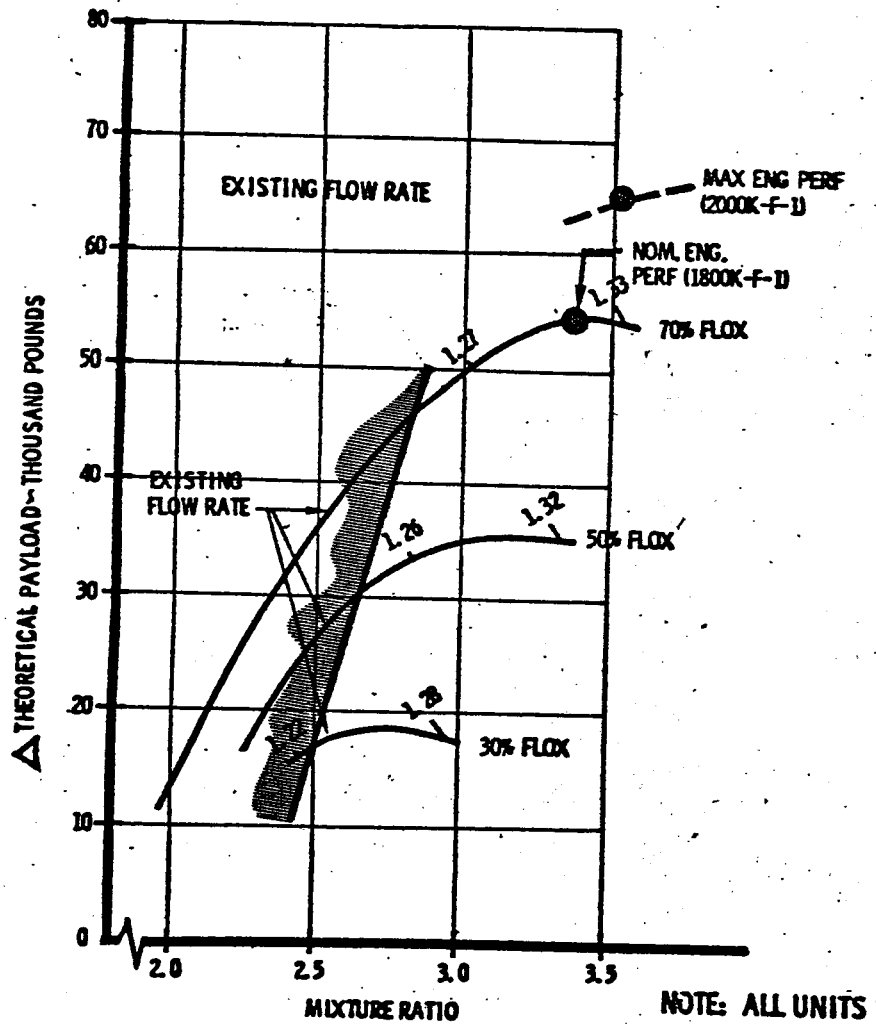


VEHICLE PERFORMANCE-EXISTING TANKAGE-MODIFIED CHAMBER COOLING

The basic curves, opposite page, show theoretical vehicle performance with modified engine chamber cooling at 30, 50, and 70 percent FLOX for the "Nominal" (i.e., existing propellant weight flow-rate) engine rating. Also shown is a spot point of the performance available at the maximum engine rating (2000K) discussed on the previous page. The engine rating in terms of propellant flow referenced to the existing engine is 100 percent for the "Nominal" and 113 percent for the "Maximum" case. The S-IC fuel tank is off-loaded approximately 29 percent for the "Nominal" rating and 22 percent for the "Maximum" case.

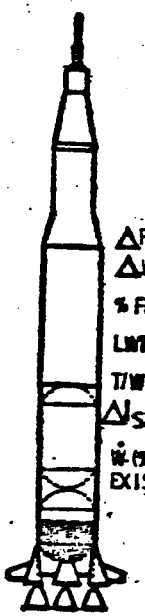
The summary chart at the right is a tabulation of the pertinent corrected payload data.

VEHICLE PERFORMANCE



-EXISTING TANKAGE

-MODIFIED CHAMBER COOLING



	FULL OXIDIZER TANKS 1800K	2000K
ΔPL (CORR)	45,000	54,000
ΔWP	440K	510K
% FLOX	70%	70%
LWT	6.80M	6.8[illegible]
T/W	1.32	1.46
ΔISP	54 SEC	52 SEC.
Ẇ-% OF EXISTING F-1	[illegible]	113%

NOTE: ALL UNITS LBS EXCEPT AS NOTED

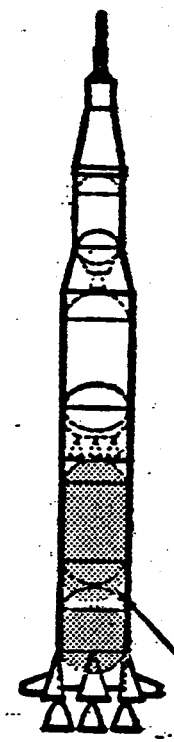
VEHICLE PERFORMANCE-MODIFIED TANK VOLUME

All the performance data presented in previous discussions have been based on the current S-IC tank volume. The fuel tank has been off-loaded to varying degrees to obtain maximum performance. The chart, on the opposite page, shows the corrected performance available for the "Nominal" and "Maximum" engine performance ratings when the bulkheads are moved, within the present stage length. This will allow optimum propellant loading, i.e., matching of stage and engine mixture ratio. The following chart shows that moving the bulkheads increased the corrected payload by 6000 and 8000 pounds, "Nominal" and Maximum" respectively, and lowered the thrust-to weight at launch from 1.32 to 1.25 (Nom. engine rating) and 1.46 to 1.37 (Max. thrust case).

VEHICLE PERFORMANCE— MODIFIED TANK VOLUME

MODIFIED F-1 CHAMBER COOLING
EXISTING S-IC LENGTH

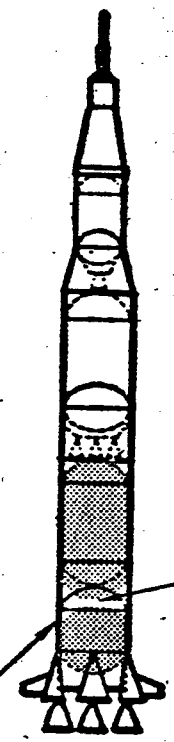
1800K (NOM F-1)



Δ PL(CORR) 51,000 LBS

Δ w_p 850 K LBS
% FLOX 70%
L WT 7.21M LBS
T/W 1.25
Δ Isp 54 SECS
$\dot{W}$=100% OF EXIST F-1

2000K (MAX F-1)



Δ PL(CORR) 62,000 LBS

Δ w_p 860 K LBS
% FLOX 70%
L WT 7.23M LBS
T/W 1.37
Δ Isp 54 SECS.
$\dot{W}$=110% OF EXIST F-1

NEW BULKHEAD LOCATIONS

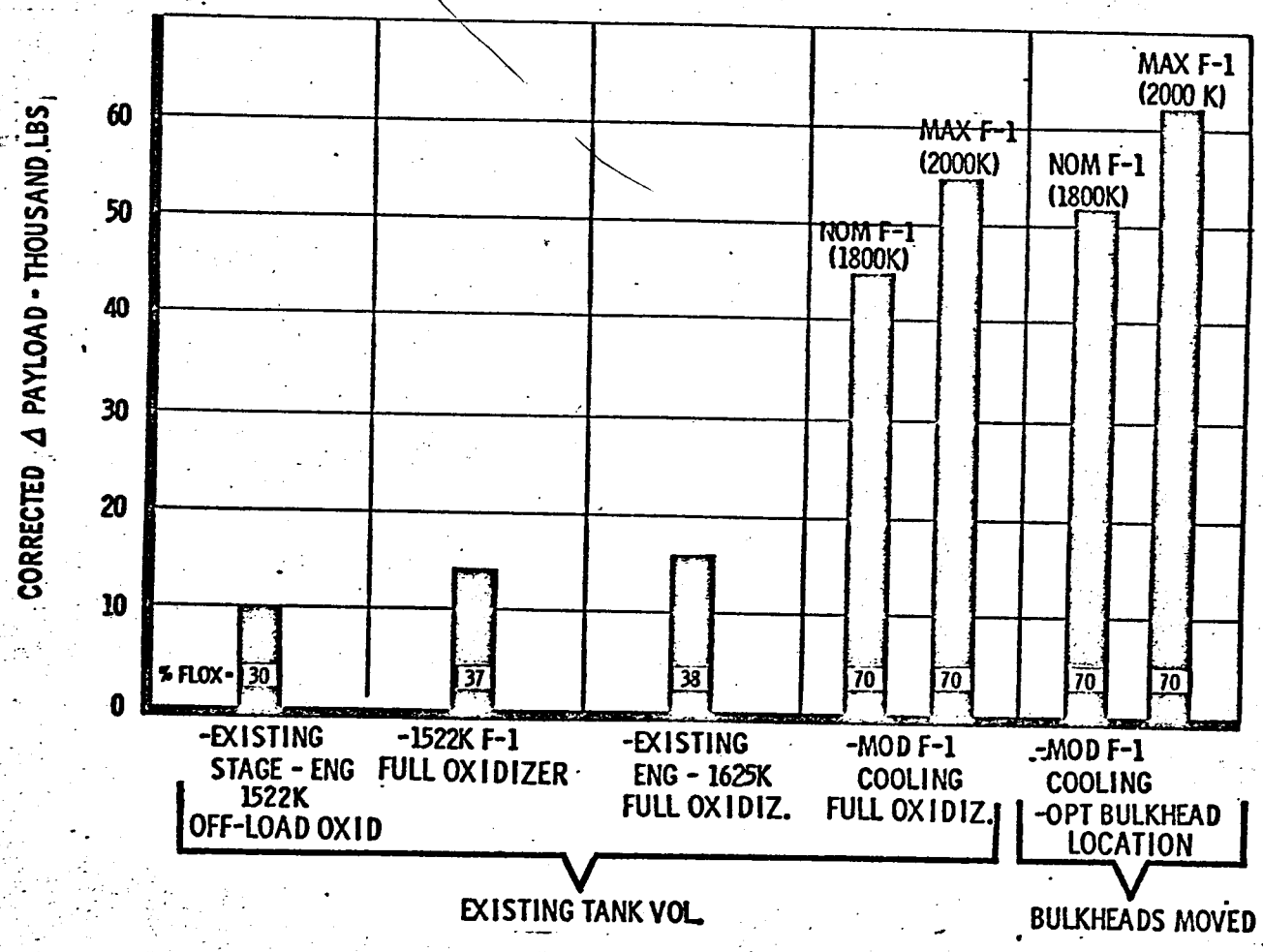
FLOX PERFORMANCE SUMMARY

For convenience, the performance of vehicles discussed on previous pages is shown on the bar graph on the opposite page.

Summarizing, the three left-hand bars show the LOR performance increase available from FLOX application with no engine change. The remaining four bars show the performance if the engine chamber cooling tubes are modified and applied to the S-IC using the existing tank volumes and the optimized tank sizing.

A chart with more detailed information on these vehicles is contained in the back-up section.

FLOX PERFORMANCE SUMMARY



PERFORMANCE SUMMARY-VEHICLE UPRATING

Plotted on the chart on the opposite page as a function of total launch weight are the LOR payload increases that can be achieved by various means of uprating the Saturn V. These data are based on Boeing studies and the payload increases are relative to the overloaded (full tank) Saturn V.

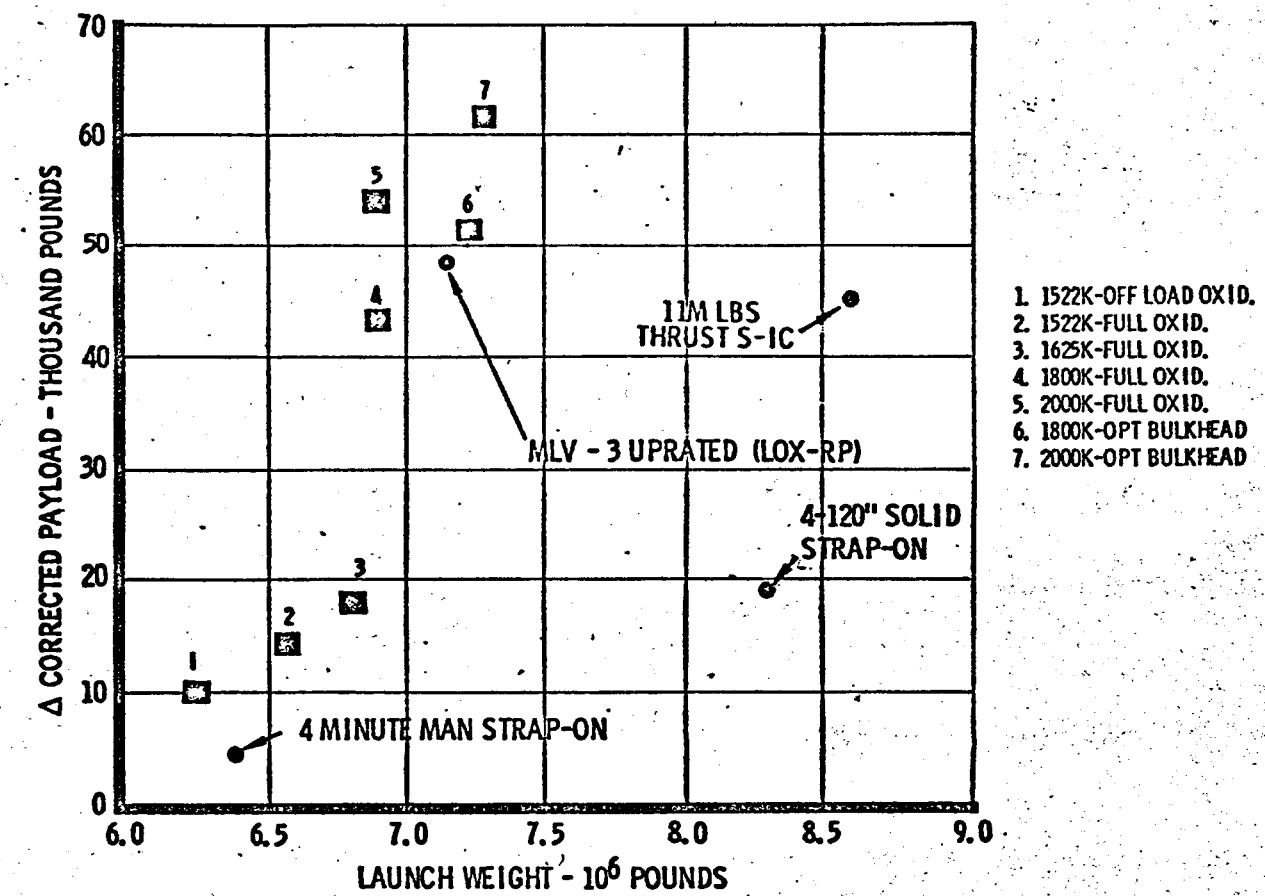
The four Minuteman and four 120-inch solid strap-ons are on a standard length Saturn V configuration. The vehicle labeled MLV-3 has five 1800K F-1 engines on the first stage and high-pressure 315K thrust engines on the second and third stages. The vehicle labeled 11 million pounds liftoff thrust has the same upper stages as the Saturn V. Each of the study configurations with uprated engines have length increases (up to 36 feet, first stage and 28 feet, upper stages) to allow greater propellant loadings.

The FLOX vehicles, designated by the square symbols, include all the configurations discussed on the previous pages. All are within the present S-IC envelope.

These data illustrate the versatility of FLOX and indicate the large performance increments available from "no change" and "modest change" approaches.

PERFORMANCE SUMMARY

VEHICLE UPRATING



FLOX RELATIONSHIPS TO SATURN V GROWTH

The previous chart showed that a wide range of payload increase is available from FLOX. Also, the previous discussions dealt only with the existing length S-IC stage. As a part of the Boeing R&D program, a quick examination was conducted to assess the impact of FLOX on the total Saturn V growth picture. The following two charts describe the analysis.

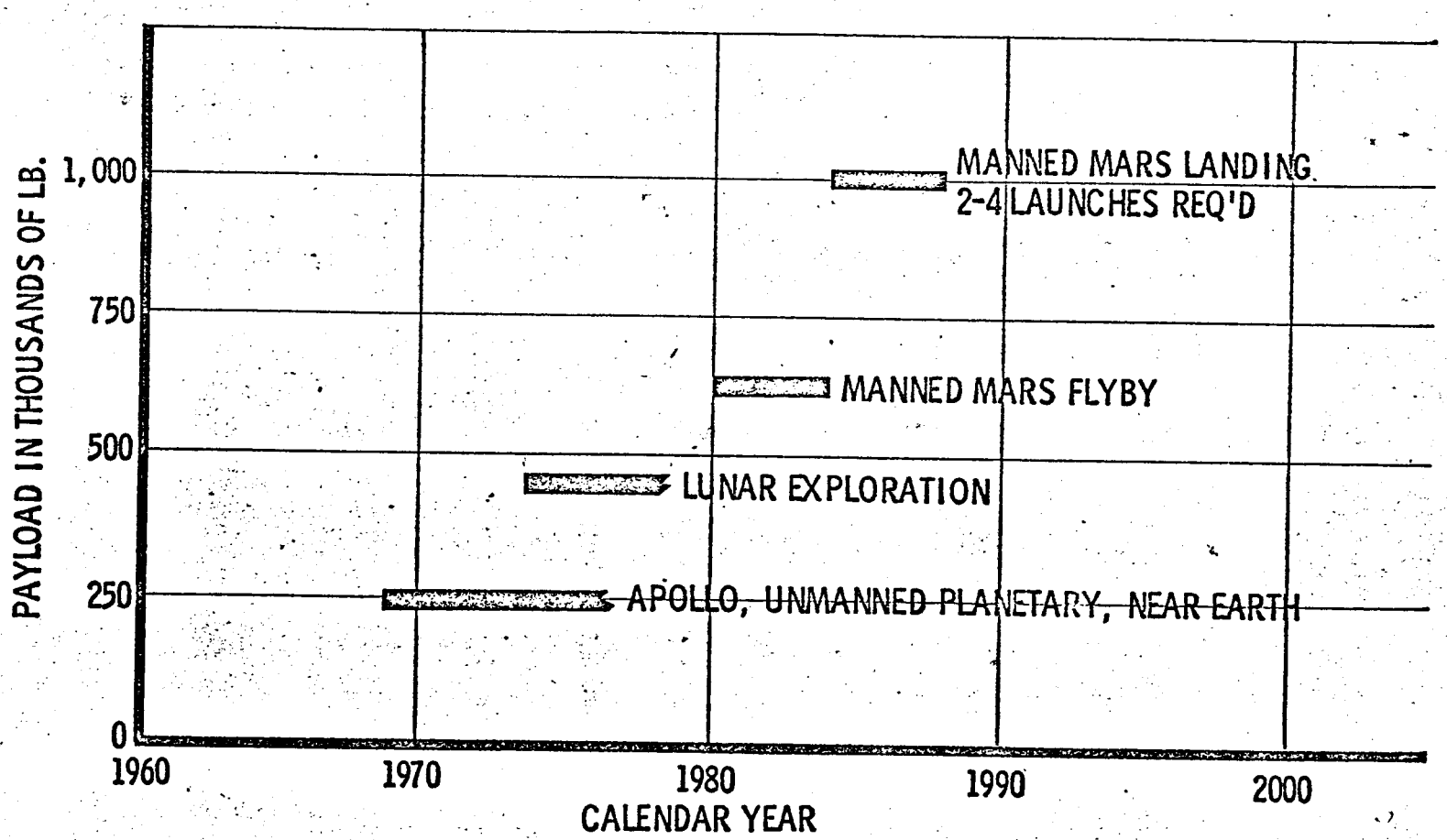
FLOX RELATIONSHIP TO SATURN V GROWTH

PAYLOAD REQUIREMENTS

One possible sequence of missions that require increased orbital payload capability from Saturn V are shown on the chart as a function of calendar time. The magnitude of the payloads and time estimates are not presented for debate on anticipated growth, but rather as a yardstick to judge the suitability of the system to meet a growth or "building block" concept of performance increase.

PAYLOAD REQUIREMENTS

(100 N MI EARTH ORBIT)



SATURN V GROWTH

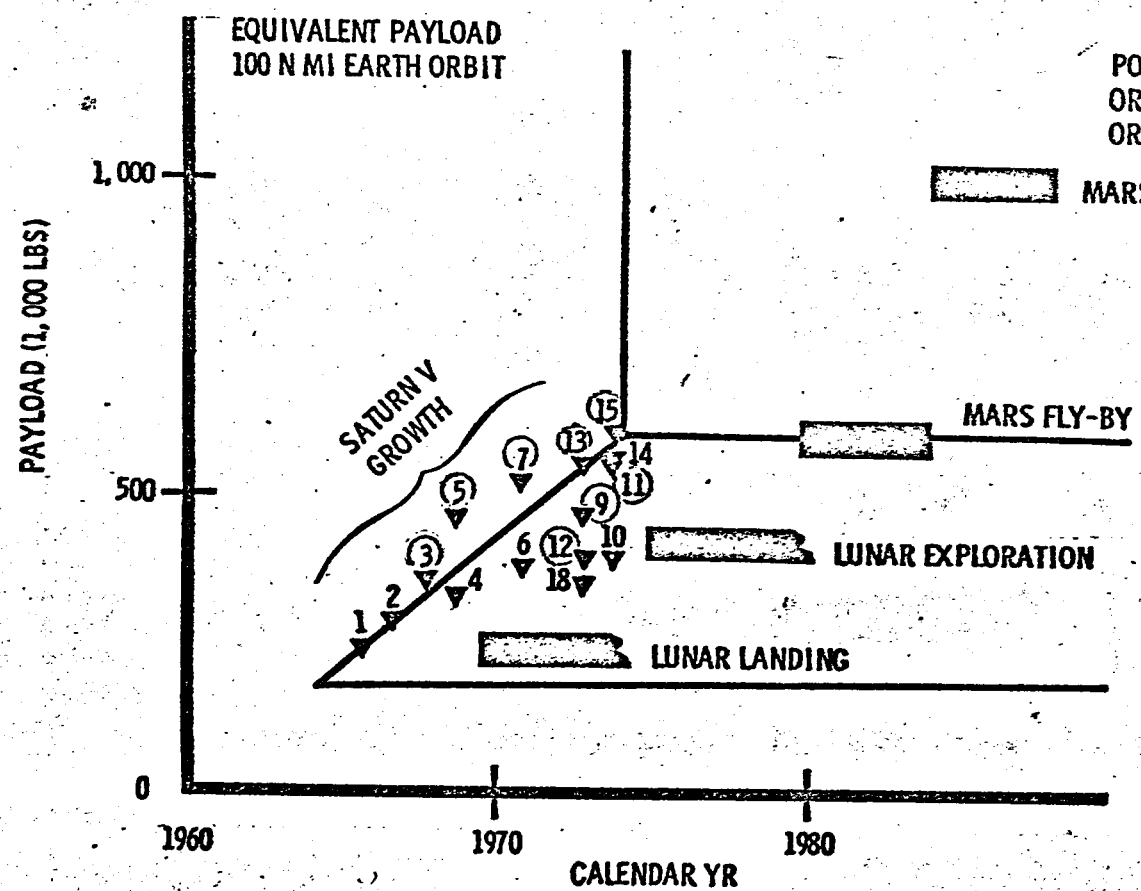
This chart repeats the estimated payload requirements from the previous chart and spots the performance of 15 configurations (building blocks) for Saturn V growth. The FLOX vehicles are indicated by circles i.e., numbers 3, 5, 7, etc. A chart showing general definition of these 15 vehicles is contained in the "back-up data" section. FLOX performance in each case is the "Nominal" 1800K F-1 operated at the existing total weight flow rate and 70% FLOX.

It can be seen that FLOX can play an important part in long-range growth and that a major extension of Saturn V growth is possible.

Not covered is similar technology (FLOX-fluorine) on the upper stages. Addition of fluorine to LOX-hydrogen does not yield the significant specific impulse improvement noted with LOX-RP-1; however, the density increase (propellant loading) and thrust increase on a given engine from FLOX or fluorine with hydrogen should result in significant additional performance over that shown on the S-IC.

In summary, the performance potential from FLOX is of major significance; and although much of the work shown is based on theory, the actual results are expected to be in the range defined from this study. The remaining questions related to FLOX use are the design and operational factors. These areas are covered on the following pages.

PAYLOAD POTENTIAL



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STAGE DESIGN

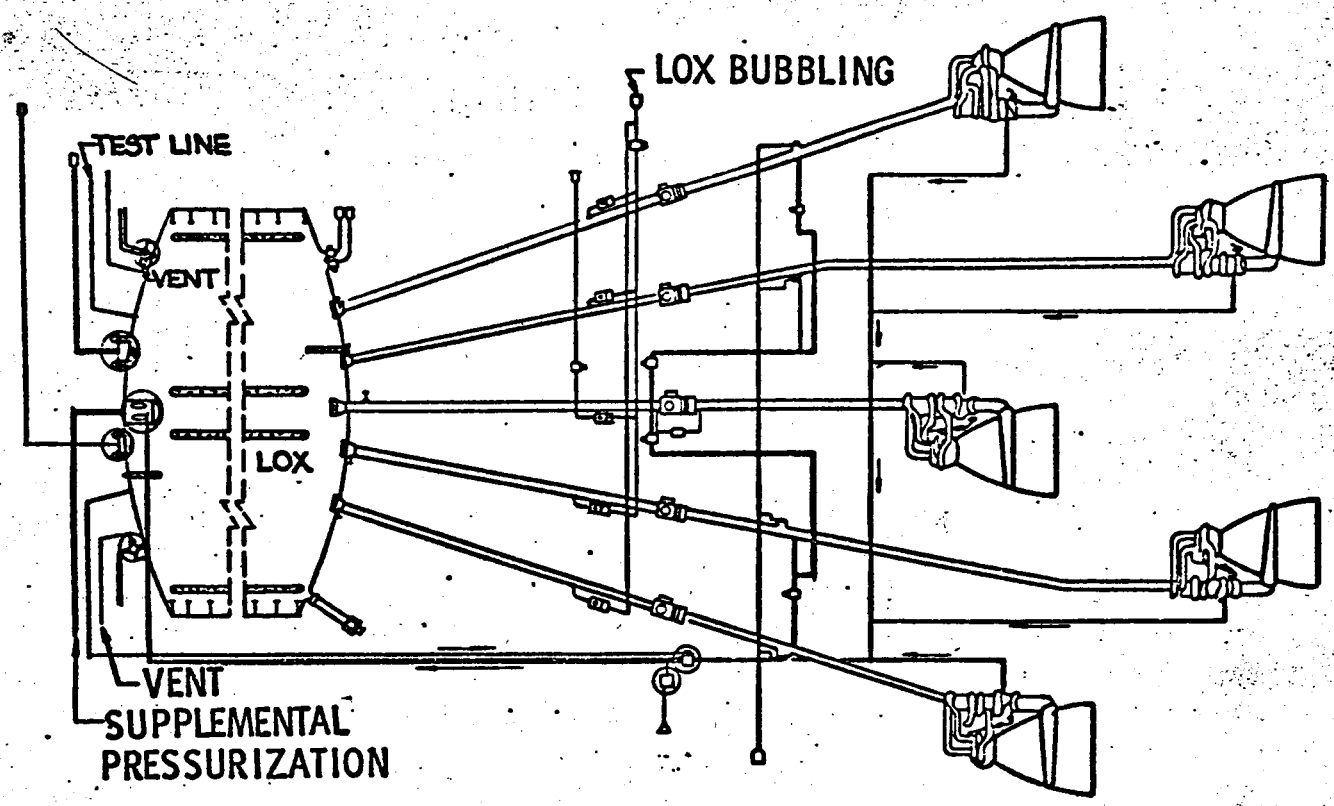
S-IC MATERIALS COMPATIBILITY

This area received a great deal of attention early in the study. One barier to feasibility (especially for early application) would have been to discover a gross incompatibility of the basic materials, processes or techniques of manufacture of the current S-IC. Published literature and direct contact with NASA and contractors formed the basis for judgement in the study.

Except for minor areas, no basic S-IC material or process incompatibility appears to exist. Tank walls, bulkheads, propellant delivery, and pressurization systems are made of materials considered at this time as FLOX compatible. The current LOX cleaning appears suitable with FLOX, provided passivation with fluorine or FLOX gas is accomplished prior to introduction of liquid FLOX.

Typical of the minor areas of incompatibility are organics such as the Teflon contained in the GOX distributor, some valves, and instrumentation points.

MATERIALS COMPATIBILITY



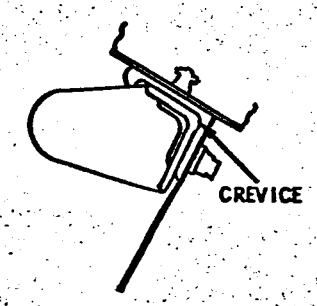
TYPICAL CONTAMINATION AREAS

Potential contamination areas were discovered during this study. Most of these areas can be avoided by proper design considerations. Minute contamination in these areas may not be considered critical provided the flow stagnation traps do not produce gaseous FLOX. There is some evidence that indicates that contamination and FLOX at cryogenic temperatures do not result in a reaction. This is substantiated by R&D tests at Boeing facilities and by some of the literature reviewed during this study. This suggests a "cold soak" with LOX may be desirable before loading FLOX. A large portion of the contamination problem areas are in the GOX pressurization system that does not use "gasified" oxidizer as a pressure source.

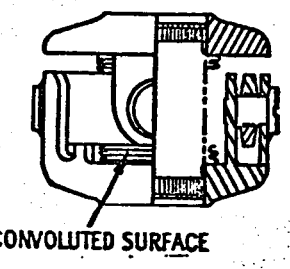
In any case, there apears to be three major avenues of approach to the contamination problem: adequate cleaning, proper design considerations, and cold soak.

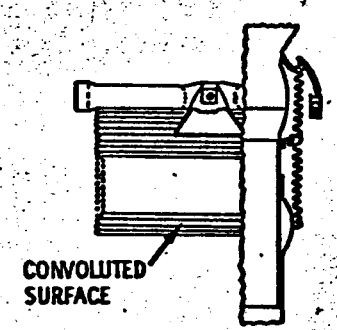
TYPICAL CONTAMINATION AREAS

ANTI-SLOSH BAFFLE CONNECTION, LOX TANK

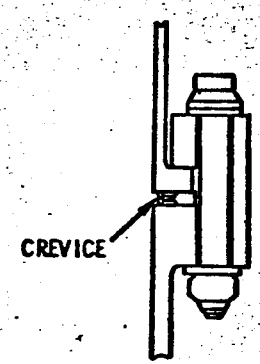


TYPICAL GIMBLE JOINT, GOX SYSTEM





TYPICAL GIMBLE JOINT, LOX SUCTION DUCT



FLANGE CONNECTION, LOX SUCTION DUCT

SUBSYSTEM EVALUATION

Outlined on this chart is a summary of the effect of FLOX on the S-IC subsystems.

The physical and thermodynamic properties of the liquid fluorine-oxygen were defined by use of available literature, analysis based on accepted theory and data obtained from a Boeing funded research contract to Stanford University - Research Institute. These properties were used to evaluate the FLOX compatibility of the following subsystems:

Propellant Delivery System - As far as is known, subsystem performance with FLOX is better than with LOX. This is true simply because the basic physical properties, i.e., density, viscosity, etc. are more favorable than LOX.

Vent System - The performance will be satisfactory, however, the system design will be influenced by GSE.

Pressurization System - The performance of this system is satisfactory as is, but due to the potential hazard of high temperature FLOX gas exposure to materials it will probably be desirable to use an alternate pressurization system.

Several alternate pressurization systems that show promise for this application are now being considered as a part of TAO-42.

SUBSYSTEM EVALUATION

- PHYSICAL & THERMODYNAMIC PROPERTIES - DEFINED
- PROPELLANT DELIVERY - PERFORMANCE OK

- VENT
  - STATIC - PERFORMANCE OK - INFLUENCED BY GSE
  - FLIGHT - PERFORMANCE OK

- PRESSURIZATION
  - STATIC - PERFORMANCE OK - INFLUENCED BY GSE
  - FLIGHT - PERFORMANCE OK - DESIRABLE TO AVOID HIGH TEMPERATURE FLOX GAS

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OPERATIONAL FACTORS

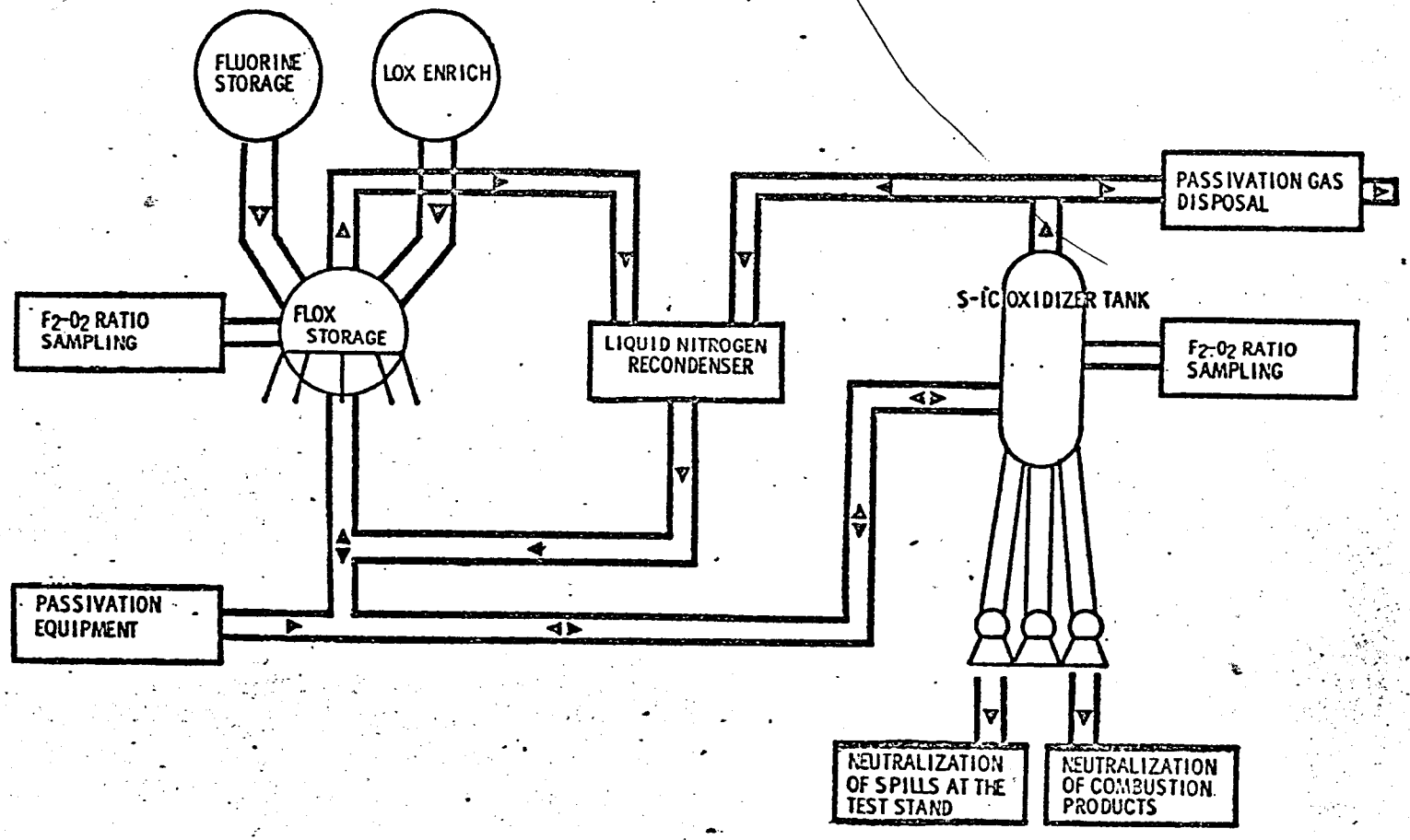
GENERAL FLOW DIAGRAM FOR FLOX USAGE

Shown on this chart is the additional equipment believed necessary to initiate large scale FLOX operation at the launch area. An exception is that the present LOX storage tank can probably be used for the LOX enrichment supply.

The liquid nitrogen recondenser would be one of the major items in the system. (A more detailed schematic of the recondenser is shown in the back-up section of this document.) The purpose of the recondenser is to prevent toxic gas from escaping to the atmosphere during fill and hold periods. Also since fluorine preferentially boils off from FLOX, the recondenser will assure that fluorine concentration in the tank is held to constant value.

The passivation equipment will pass low pressure fluorine-gas into the oxidizer tank and delivery ducts to clean contaminants and to establish fluoride film on certain materials, thus reducing the possibility of any reaction when the FLOX is loaded.

GENERAL FLOW DIAGRAM FOR FLOX USAGE



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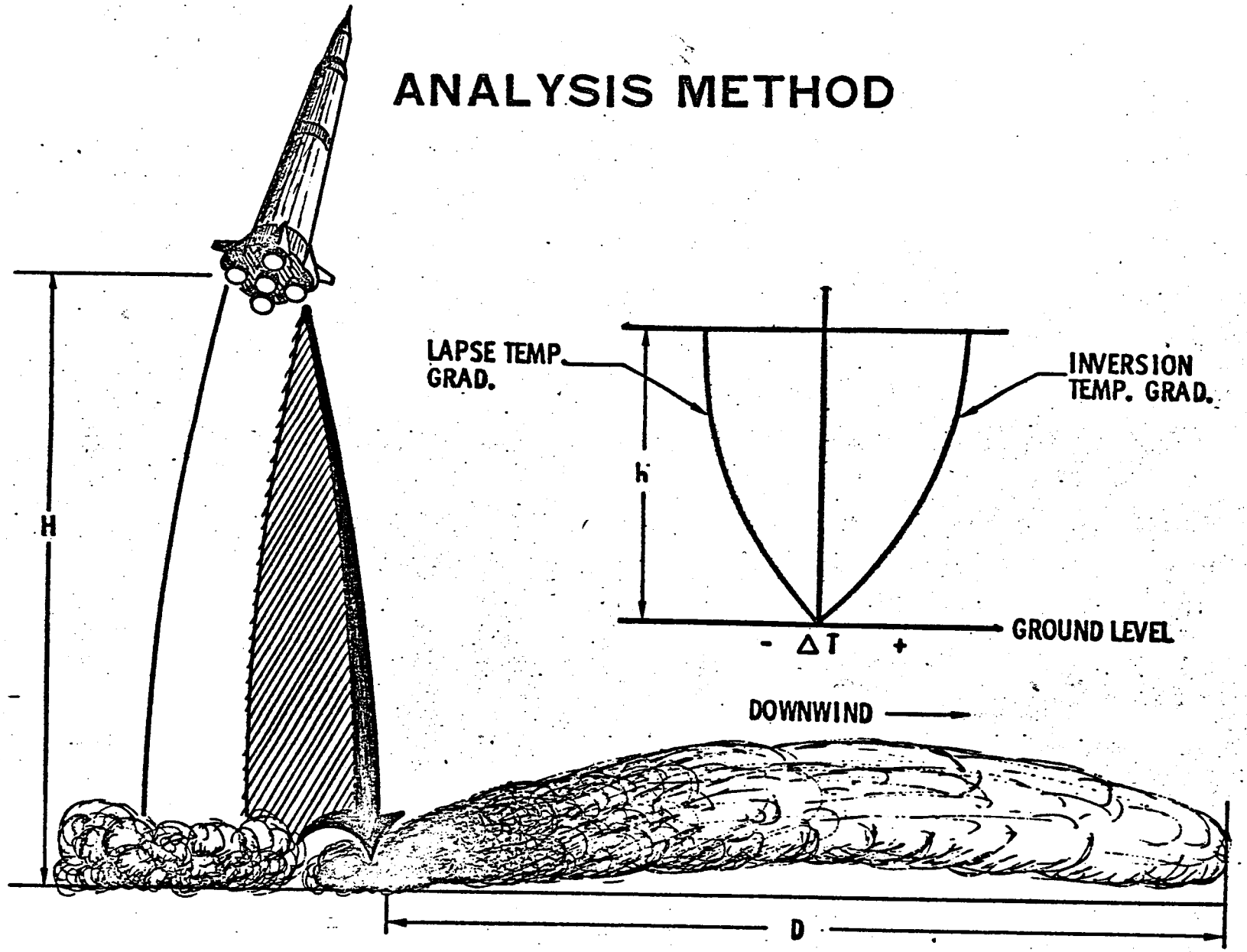
TOXIC CLOUD ANALYSIS

TOXIC CLOUD ANALYSIS TECHNIQUE

The analysis technique used in estimating the concentration of HF downwind of a normal launch is illustrated on this chart. A simplifying assumption was used in the analysis, that is, all the exhaust gas released from engine ignition to a selected altitude, was assumed to have been released as a ground-level point source. Sutton's diffusion equation was used for the point source evaluation by applying data from "Army Chemical Corps ORG Study No. 17," 1 May 1958.

This analysis is not intended to quantitively define the time periods of safe launch, but is intended to supply an answer to the general feasibility of launching the S-IC with FLOX. As shown on the following charts, the conclusion from the study is that feasibility is probable.

ANALYSIS METHOD



TOXIC CLOUD STUDIES

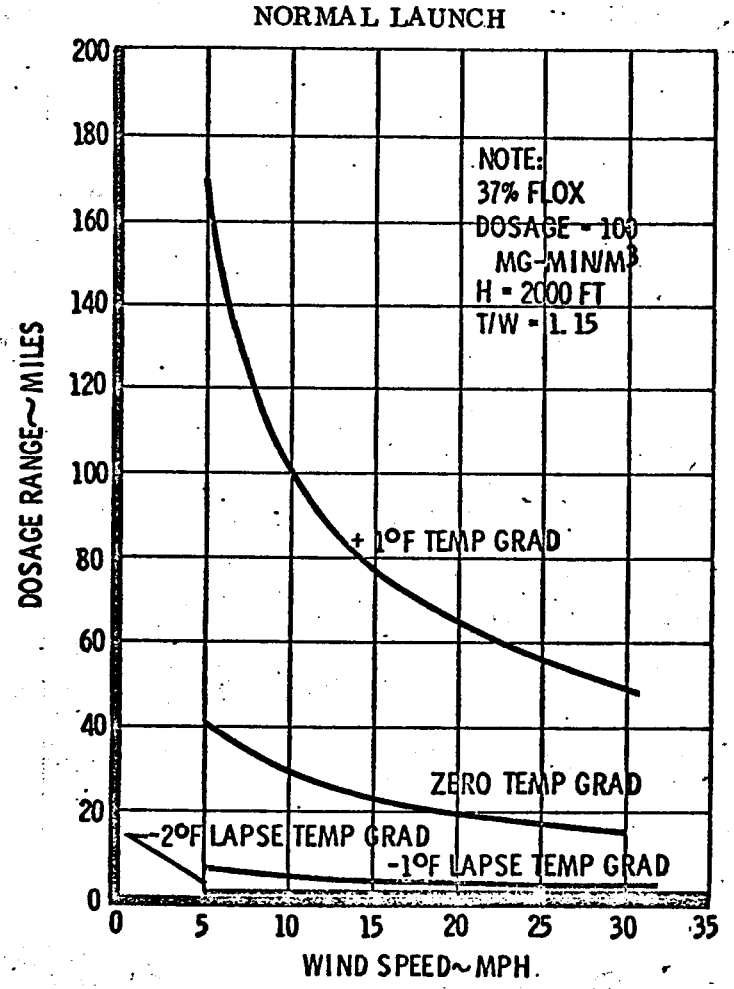
The two plots on the opposite page indicate that the atmospheric conditions probably will control the times when a FLOX Saturn V launch can occur.

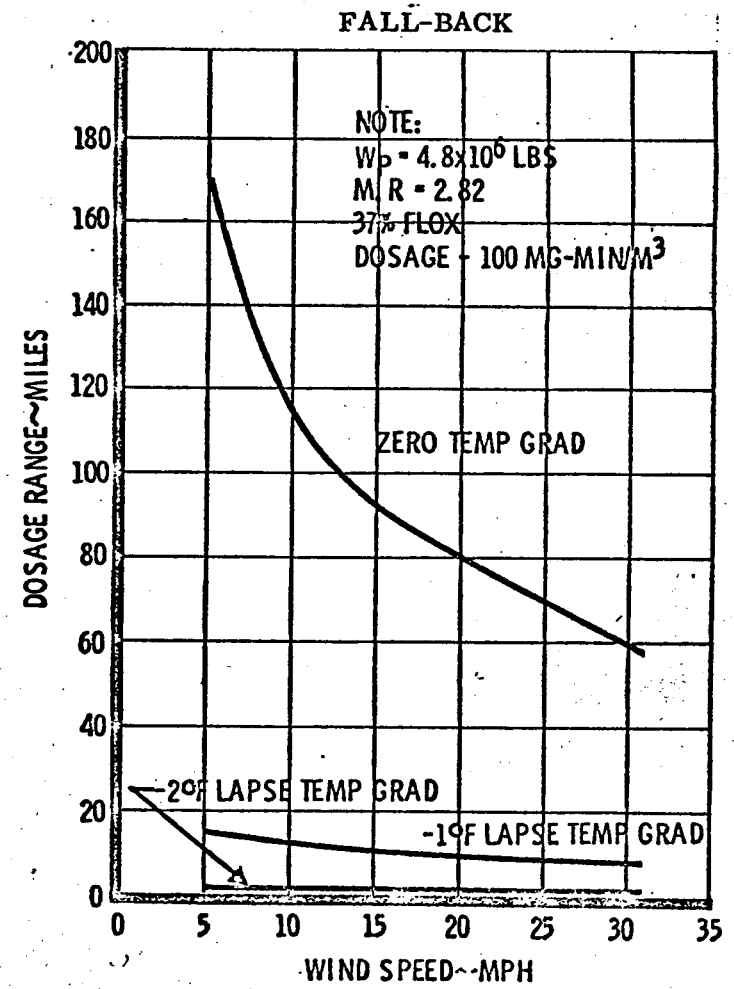
The "Normal Launch" (L.H. plot) was analyzed using the conditions as noted on the curve. It was further assumed that all the fluorine reacts to form hydrogen fluoride (HF) during the combustion process in the engine. The primary variables are downwind dosage range, wind velocity, and temperature gradient. The temperature gradient is the difference between the temperature at 0.5 and 5 meters. The dosage quantity was arbitrarily selected early in the study at 100 milligram-minutes per cubic meter, i.e., 88 parts per million-minutes. This quantity is approximately 50 % of the level stipulated as tolerable for uncontrolled (off site) population by the American Conference of Governmental Hygienists. Theoretically "on-site" controlled population could tolerate a dosage approximately 16 times greater than the value used in the study analysis.

The "Fall-Back" or catastrophic failure (R.H. curve) was considered with the assumptions as noted. It again was assumed that all fluorine reacted to form hydrogen fluoride. Since FLOX is hypergolic with nearly all fuels, this seems reasonable. The temperature gradient is as defined for the "Normal Launch."

Preliminary information indicates that -1°F temperature gradient and 10 mph wind does occur in the MILA area, however, a statistical analysis of S-IC FLOX operation has not been made. These data suggest general feasibility, but also indicate the necessity for further study and in particular, point to the need for an examination of the meteorological instrumentation and analysis (computer) system that would be used for judging the suitability of launch at any given time period.

TOXIC CLOUD STUDIES





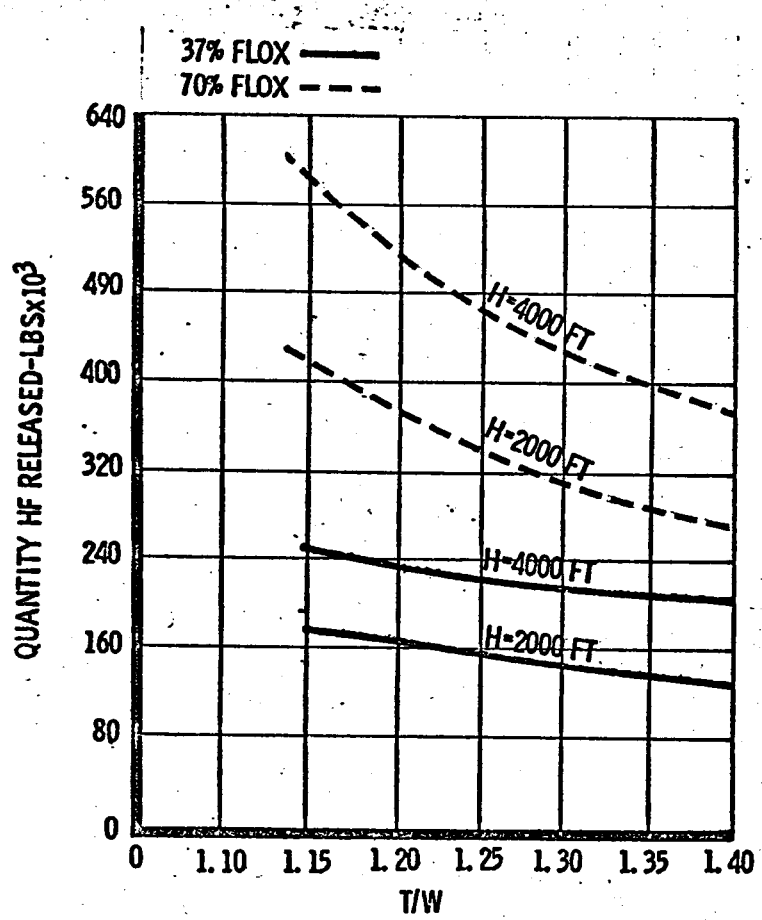
LAUNCH ANALYSIS

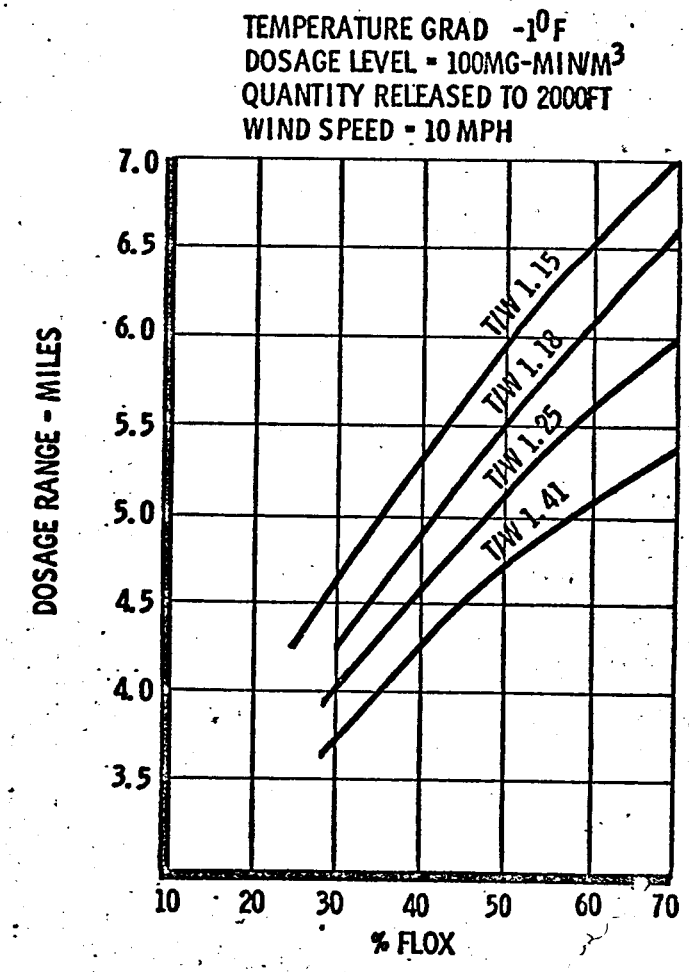
The two plots on the chart (opposite page) show the effect of two other variables relative to the toxicity picture. These are thrust to weight at launch and the percent FLOX in the S-IC tanks.

The plot on the left indicates the amount of HF (hydrogen fluoride) released as a function of thrust/weight, from engine ignition to 2000 or 4000 feet altitude for 37 and 70 percent FLOX. It has been assumed in the toxic cloud analysis that HF released above 2000 feet would not produce any adverse effects at ground level. As mentioned on the previous chart, the quantity released to 2000 feet is considered as a point source at ground level.

From the assumptions noted, the dosage range as a function of % FLOX is presented in the right-hand plot. This plot indicates that a normal launch can be executed with 70% FLOX and 1.15 T/W with a dosage range of only 7 miles.

LAUNCH ANALYSIS

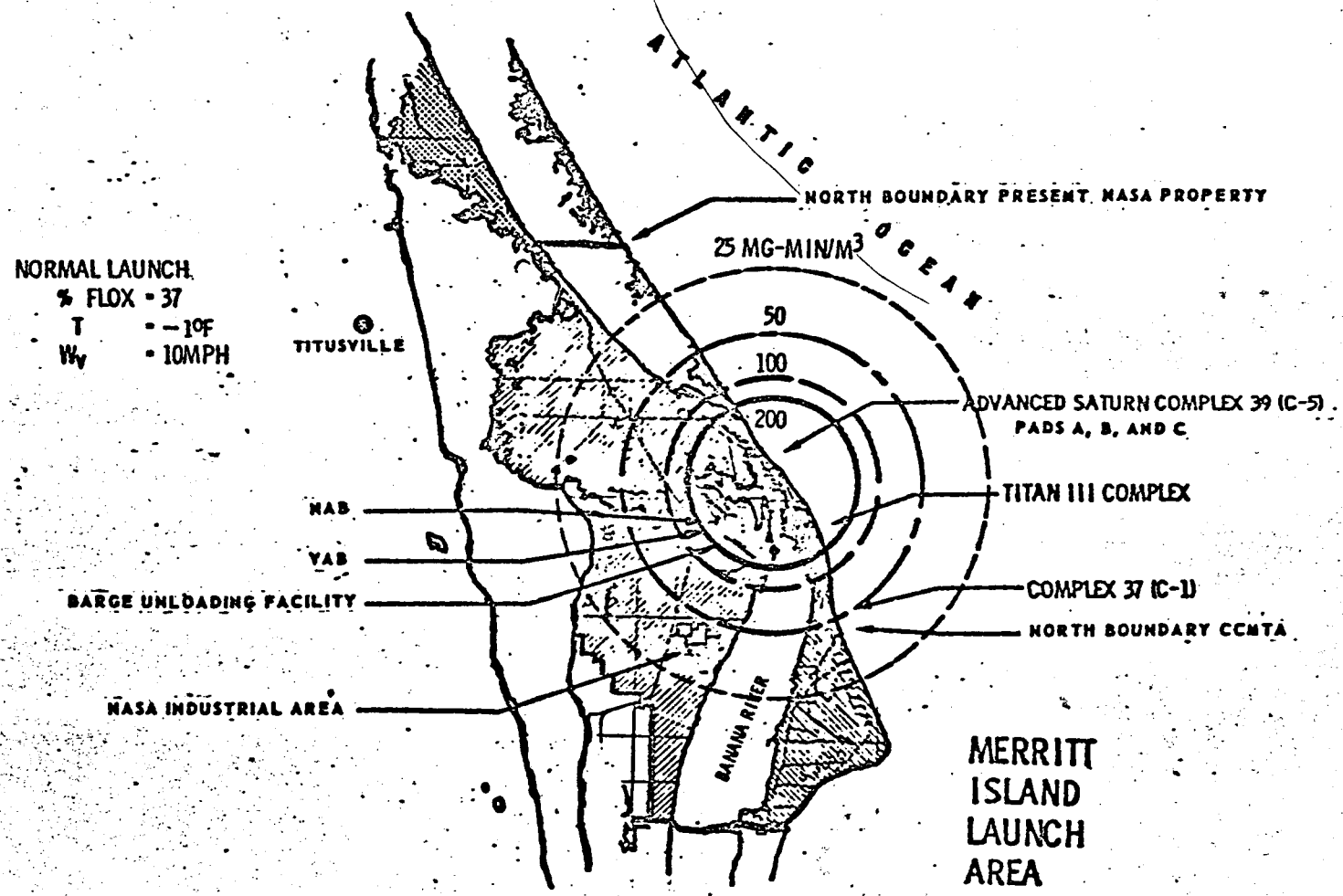




HYDROGEN FLUORIDE CONCENTRATIONS

The next two charts show the expected dosage ranges associated with a normal MILA launch of a Saturn V with FLOX in the S-IC. The weather conditions and % FLOX are as noted on each chart. The rings indicated on the map are the downwind distances associated with each dosage level. Neither FLOX vehicle shown imposes any restrictions on wind direction for a normal launch. The NASA property boundary encompasses all areas that would be considered hazardous.

HYDROGEN FLUORIDE CONCENTRATIONS



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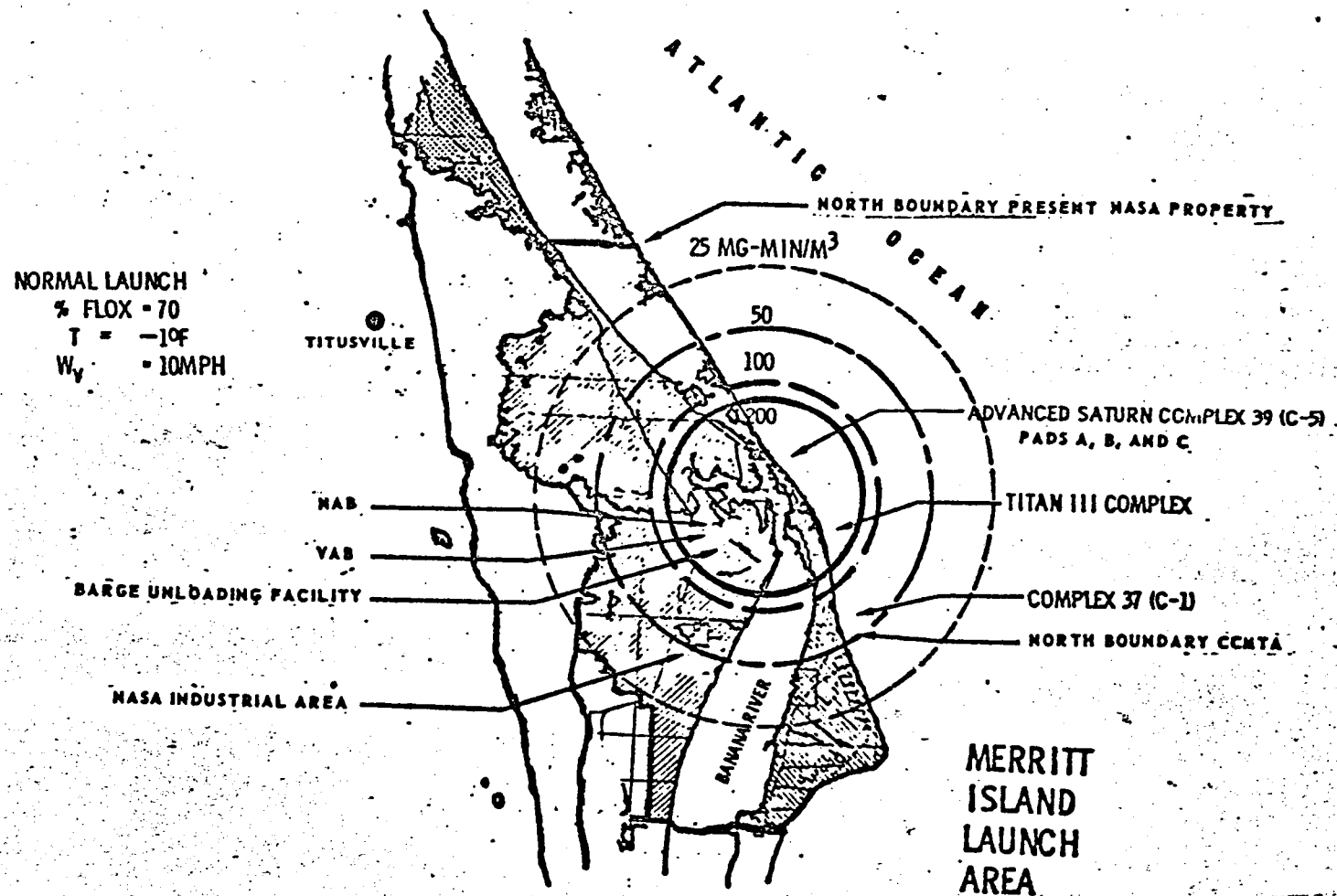
HYDROGEN FLUORIDE CONCENTRATIONS



FLOX OPERATIONAL FACTORS SUMMARY

Launch Area - New or modified facilities and GSE will be required, however, no new technology appears necessary. The FLOX transfer/handling equipment may require special design considerations such as nitrogen jacketed transfer lines, sampling equipment, passivation equipment, etc. The proposed vent gas recondenser will require considerable analysis relative to its "match" with the stage and FLOX storage system. Regardless of the results of the toxic cloud analysis, final definition of time restrictions on launch will probably be determined by constantly measuring weather conditions at various distances from the launch area. These weather data can be fed into a computer programmed to indicate "go" or "no go" based on the existing and predicted weather conditions.

Static Test - Mississippi Test. Production test on the FLOX vehicles may cause some severe problems, therefore, it is proposed that a possible FLOX substitute (ie LOX) be employed for the production test at MTO.

Development Test - The development testing required for a FLOX S-IC are at the present time undefined.

FLOX OPERATIONAL FACTORS SUMMARY

○ LAUNCH AREA	
NEW MOD FACILITIES-GSE FLOX TRANSFER/HANDLING FLOX LAUNCH (TOXICITY)	NO NEW TECHNOLOGY DESIGN CONSIDERATIONS TIME RESTRICTIONS
○ STATIC TEST	
MTF-PRODUCTION TEST	POSSIBLE LOX SUBSTITUTE
○ DEVELOPMENT TEST	UNDEFINED

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RECOMMENDATIONS FOR FOLLOW-ON STUDIES

FLOX OPERATIONAL FACTORS

This chart outlines the FLOX operational factors that are recommended for follow-on studies.

General Technology - The toxicity tolerance limits should be defined. Coordination with NASA Safety Division, National Academy of Sciences and other authorities are recommended.

The toxic cloud behavior should be determined by application of contemporary toxic cloud analysis techniques to the unique situation resulting from rocket operation during hold down and launch.

Definition of design conditions are recommended. This should include back-up equipment for safety considerations, maximum spill rates, burn-off ponds, etc.

It is proposed that during these follow-on studies, the test requirements for the FLOX vehicle and associated equipment be determined.

Launch Area - The probable allowable launch periods can be determined by use of available area weather data. Identification should be made of FLOX handling and storage systems that will be required for the launch and test area.

Development requirements, such as the liquid nitrogen recondenser, passivation equipment, neutralization system, etc. need definition. Conceptual designs are necessary of a weather monitoring system and a computer data link to continuously define conditions in the downwind direction as a function of vehicle thrust to weight, percent FLOX, and weather conditions.

Production Test - The probable favorable test periods can be determined by use of available area weather data.

A study should be conducted to determine if LOX substitution for production test in lieu of FLOX is acceptable.

The FLOX handling, transport and storage equipment required for FLOX production test and the development program requirements require definition.

FLOX OPERATIONAL FACTORS

STUDY RECOMMENDATIONS

- GENERAL TECHNOLOGY

  TOXICITY DESIGN LIMITS
  TOXIC CLOUD BEHAVIOR
  DEFINE DESIGN CONDITIONS
  TEST REQUIREMENTS

- LAUNCH AREA

  PROBABILITY-LAUNCH PERIODS
  FLOX HANDLING SYSTEMS & STORAGE
  DEVELOPMENT REQUIREMENTS
  FEASIBILITY OF LAUNCH

- PRODUCTION TEST

  PROBABILITY-FIRING PERIODS
  FLOX VS LOX OPERATION
  FLOX HANDLING-TRANSPORT-STORAGE
  DEVELOPMENT REQUIREMENTS

FLOX VEHICLE DESIGN AND RESOURCES STUDY

Outlined on this chart are vehicle and resource studies that are recommended for accomplishment.

Saturn V Performance - Under this phase of study, logical vehicles should be defined to determine the extent of changes required. Vehicle optimization studies should be accomplished.

Preliminary Design - Preliminary design of the select configurations should be accomplished by use of data generated under "Logical FLOX Vehicles."

The basic vehicle materials should be tested for FLOX compatibility and sensitivity early in this follow-on program.

Preliminary design or modification of existing systems/subsystems should be accomplished and changes defined.

Resources Analysis - From all the supporting study data, a resources analysis should be accomplished. The development, timing and cost could then be determined for a logical FLOX vehicle(s), and a logical implementation plan recommended.

FLOX-VEHICLE DESIGN & RESOURCE STUDY RECOMMENDATIONS

- SATURN V PERFORMANCE

  LOGICAL FLOX VEHICLES

- PRELIMINARY DESIGN

  SELECTED CONFIGURATIONS
  CRITICAL MATERIALS TEST
  SYSTEM - SUBSYSTEM DESIGN

- RESOURCE ANALYSIS

  DEVELOPMENT
  PRODUCTION
  FACILITIES
  SCHEDULE-COST

- IMPLEMENTATION PLAN

CONCLUSIONS - FLOX PROGRAM

Outlined on the opposite page are the important results of this study.

Performance - Preliminary estimates of possible payload increases range up to a maximum of sixty-five percent. This is within the present S-IC envelope and moderate modifications to the F-1 engine.

Vehicle Design - Implementation of FLOX on the S-IC will require minor material changes, redesign of some items to minimize contamination traps and possible and alternate pressurization system.

Structural modifications are generally defined as noted on the chart.

F-1 Engine - The changes to the engine for a twenty percent payload increase will be mainly material changes for FLOX compatibility. Payload increases from twenty percent to sixty-five percent requires cooling modification within the engine main chamber.

Operations - The FLOX S-IC will require additional or modified facilities and GSE. The development testing for the FLOX vehicle is undefined at the present time. Production testing appears to be feasible. Using LOX as a substitute for FLOX may prove desirable.

The launch feasibility appears good for the MILA area, however, launch window restrictions are anticipated.

CONCLUSIONS - FLOX PROGRAM

PERFORMANCE - PL INCR 65% @ 70% FLOX

VEHICLE DESIGN - MINOR MATERIALS CHANGES
- MINIMIZE CONTAMINATION TRAPS
- POSSIBLE ALT PRESS SYSTEM
- STRUCTURAL MODIFICATIONS
  - UP TO 15% ΔPL - MIN CHANGE
  - UP TO 50% ΔPL - EXIST. TANKS
  - UP TO 65% ΔPL - OPT. BULKHEAD LOC.

F-1 ENGINE - 20% PL INCR. - NO CHANGE
- 20% TO 65% - COOLING MOD.

OPERATIONS - SUBSTANTIAL FACILITIES REQD
- VEHICLE - GSE DESIGN INTEG REQD
- DEVELOPMENT TESTING - UNDEF
- PRODUCTION TEST - FEAS. PROBABLE
- LAUNCH FEAS. PROBABLE

RECOMMENDATIONS - FLOX PROGRAM

It is recommended that a follow-on FLOX program be implemented in the near future. It is apparent that use of high propellants in the space program is an essential step, and the most promising one at the present time is FLOX. The areas that need further study are outlined on the opposite page. They are: Toxicity Analysis, Engine Performance Confirmation, Operational Factors, Evaluation and Vehicles Design & Resources Analysis.

RECOMMENDATIONS - FLOX PROGRAM

IMPLEMENT FOLLOW-ON PROGRAM

- TOXICITY ANALYSIS
- ENGINE PERFORMANCE
- OPERATIONAL FACTORS - DEV. PLAN
  - -GSE DESIGN
  - -LAUNCH ANALYSIS
- VEHICLE DESIGN - RESOURCE ANALYSIS

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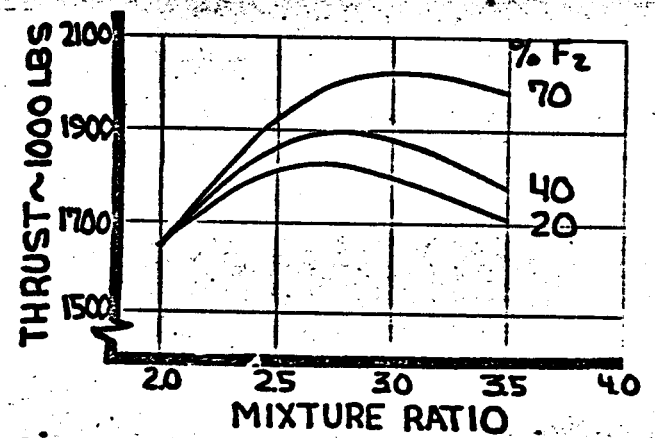
BACKUP DATA

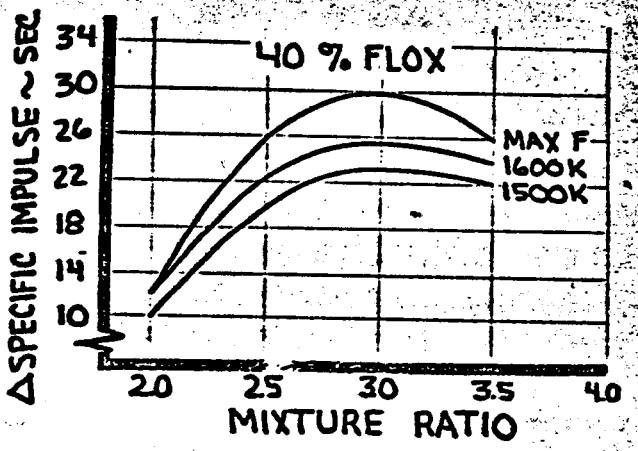
PERFORMANCE SUMMARY

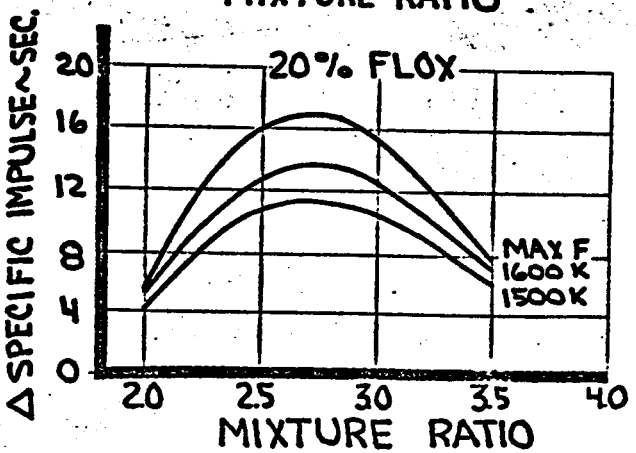
FLOX S-IC

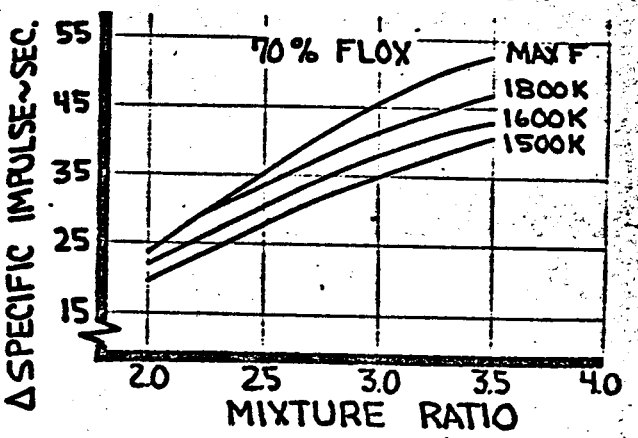
	THRUST	ΔI_{SP}	% FLOX	M.R.	L. WT.	W_P	% FUEL OFF-LOAD	T/W	W-% F-1	THEORETICAL ΔPL	CORRECTED ΔPL
1. EXISTING ENG & STAGE (OXIDIZER OFF-LOAD)	1522K	21	30	2.81	6.23M	4.50M	22.4	1.22	92	——	10,000
2. EXISTING ENG (FULL OXIDIZER)	1522K	24	37	2.81	6.52M	4.75M	16.0	1.17	92	17,000	14,000
3. EXISTING 1625K ENG (FULL OXIDIZER)	1625K	22	38	2.54	6.70M	4.80M	6.5	1.21	98	20,300	17,000
4. MOD. F-1 COOLING (FULL OXID) (EXIST TANKS-NOM. THRUST)	1800K	54	70	3.45	6.80M	4.99M	28.8	1.32	100	54,700	45,000
5. MOD. F-1 COOLING (FULL OXID) (EXIST TANKS-MAX THRUST)	2015K	52	70	3.25	6.88M	5.06M	21.5	1.46	113	65,600	54,000
6. MOD. F-1 COOLING OPT. BULKHEADS (NOM. THRUST)	1800K	54	70	3.35	7.21M	5.40M	0	1.25	100	61,500	51,000
7. MOD. F-1 COOLING OPT. BULKHEADS (MAX THRUST)	1985K	54	70	3.50	7.23M	5.41M	0	1.37	110	74,000	62,000

ROCKETDYNE DATA

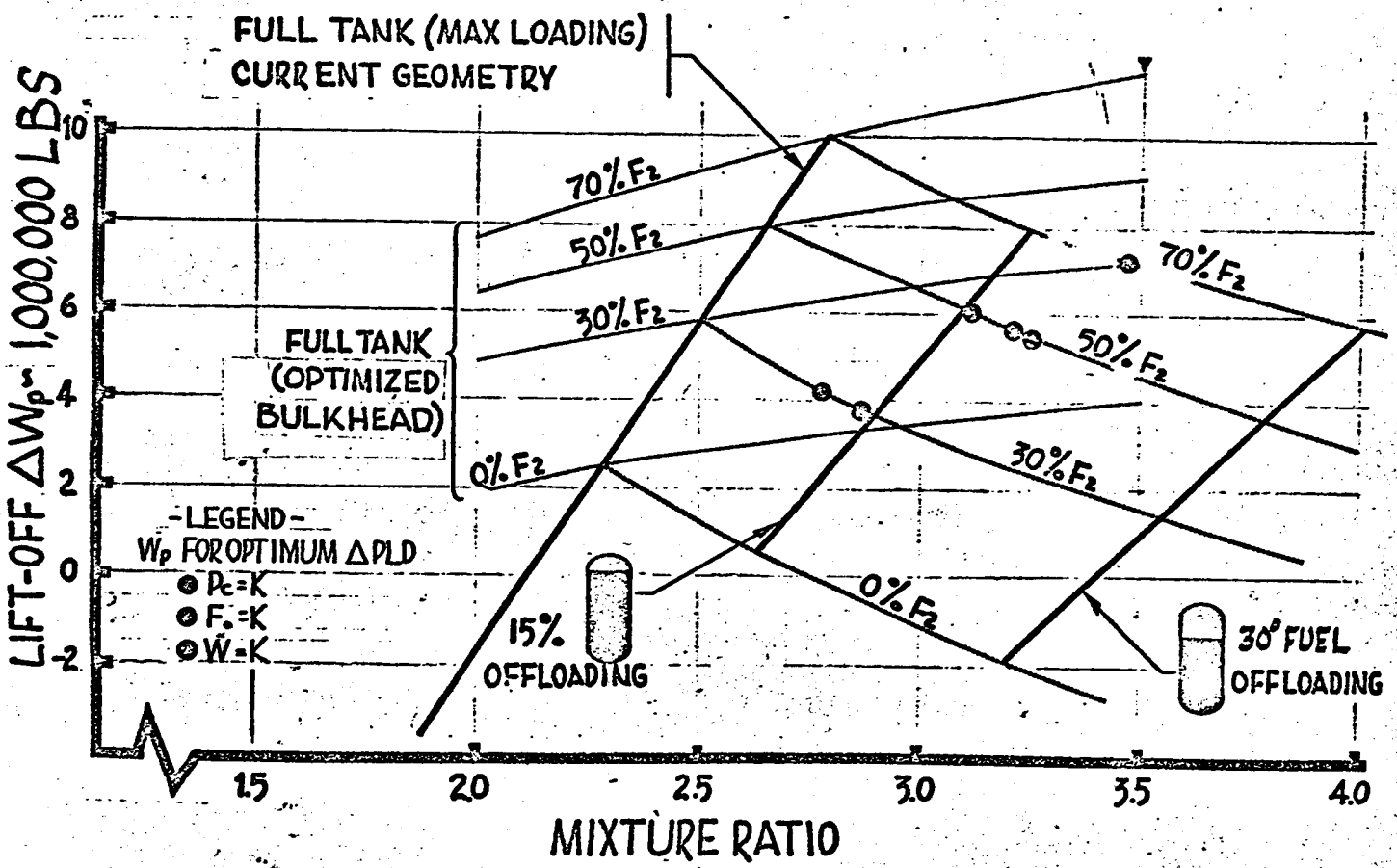






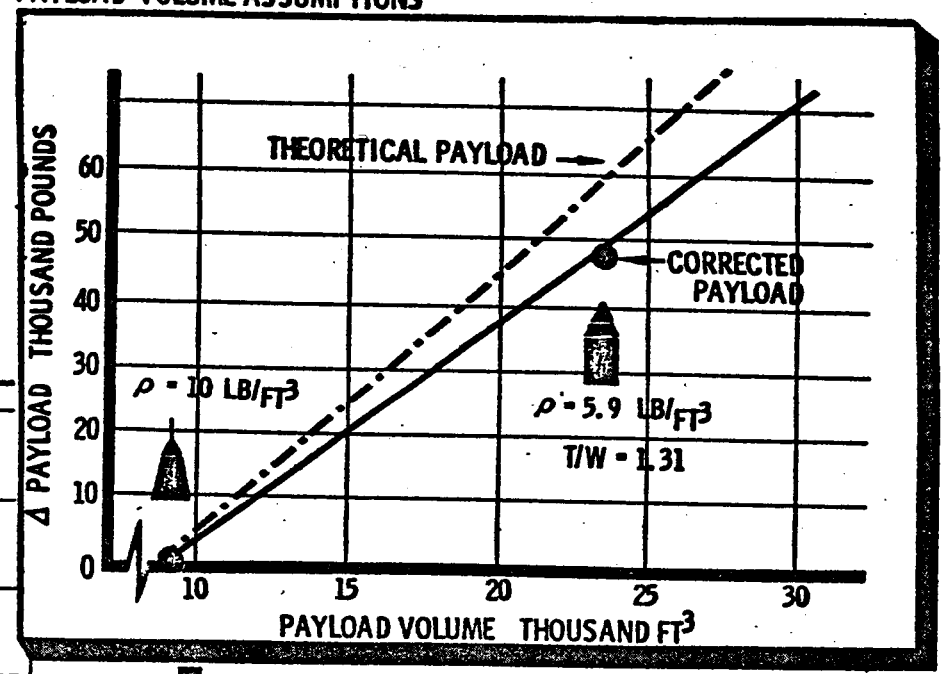


FLOX LOADING STUDY

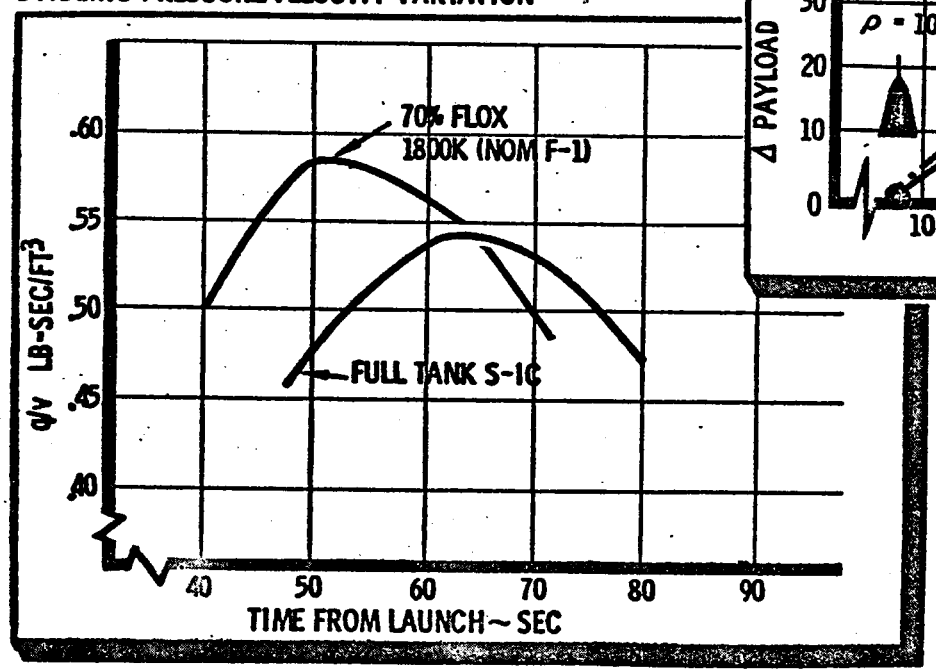


STRUCTURAL WEIGHT EFFECTS

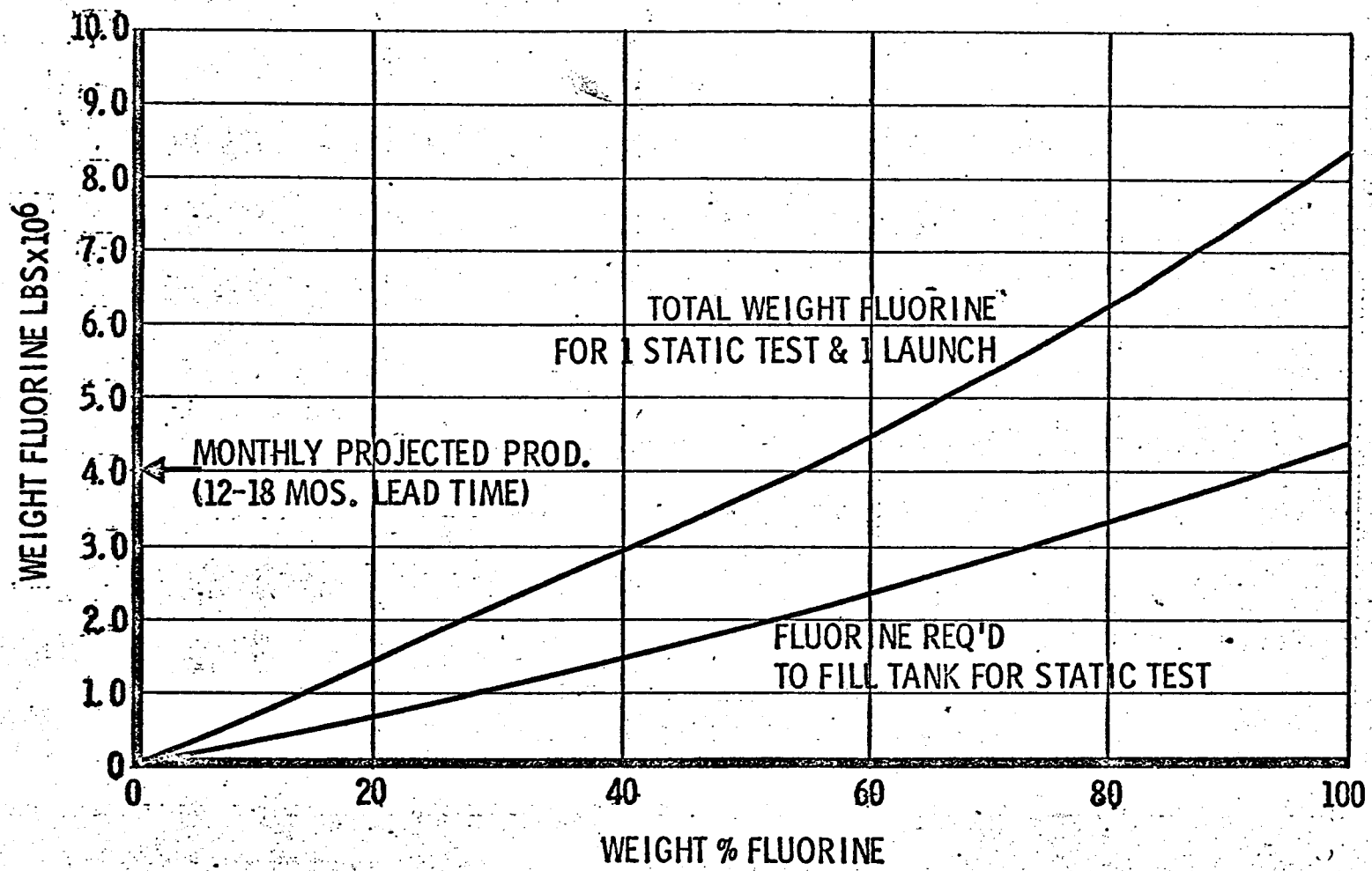
PAYLOAD-VOLUME ASSUMPTIONS



DYNAMIC PRESSURE/VELOCITY VARIATION



FLUORINE QUANTITY REQUIREMENTS



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TOXIC PROPELLANT EXPOSURE LIMITS

COMPARISON OF FLUORINE*, HYDROGEN FLUORIDE,* NITROGEN TETROXIDE (DIOXIDE)** AND UDMH **

MINUTES EXPOSED	CONCENTRATION IN AIR (PPM)				POPULATION CATEGORY	EXPECTED EFFECTS ON HUMANS (F_2, HF)
	F_2	HF	NO_2	UDMH		
5	5	30	35	50	UNCONTROLLED OFF-SITE	NO SENSORY DISCOMFORT; DETECTABLE BY ODOR
15	3	15	25	35		
30	2	10	20	20		
60	1	8	10	10		
5	25	300	SAME AS ABOVE	SAME AS ABOVE	CONTROLLED ON-SITE	MILD TO MODERATE SENSORY DISCOMFORT; DETECTABLE BY ODOR
15	15	150				
30	10	100				
60	5	50				
480 (8 HR) (THRESHOLD OR MAC)	0.1	3	5	~0.5	ON-SITE	NO DISCOMFORT; DETECTABLE BY ODOR

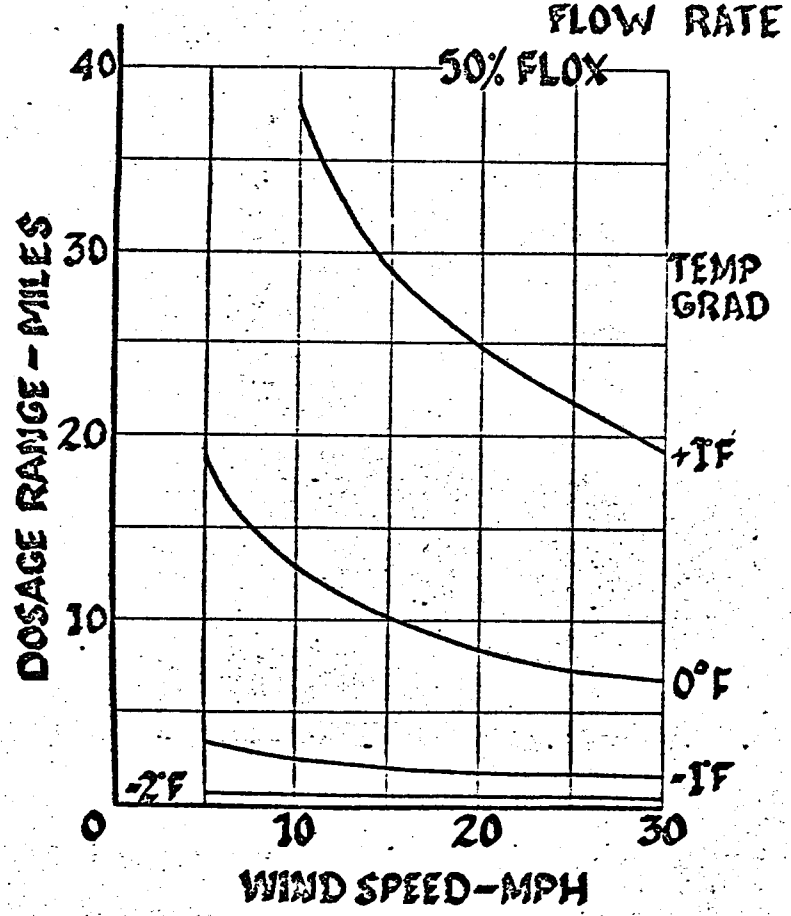
* RECOMMENDED BY AMERICAN CONFERENCE OF GOVERNMENT INDUSTRIAL HYGIENISTS

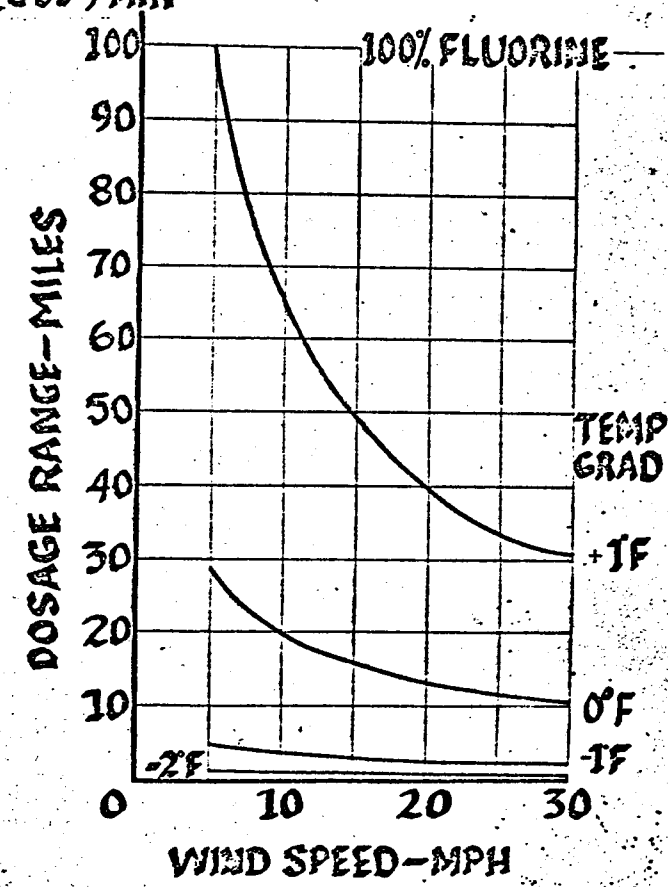
** FROM AIR FORCE T. O. 00-80 BB-2 AND -3, 18 JULY 1961

ROCKETDYNE

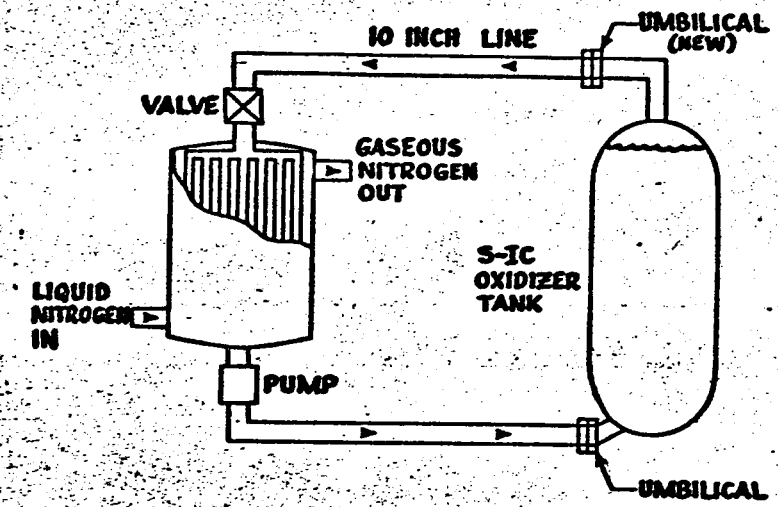
TRANSFER LINE RUPTURE

COLD SPILL
DOSAGE 100 MG-MIN/M³
FLOW RATE 94000 #/MIN

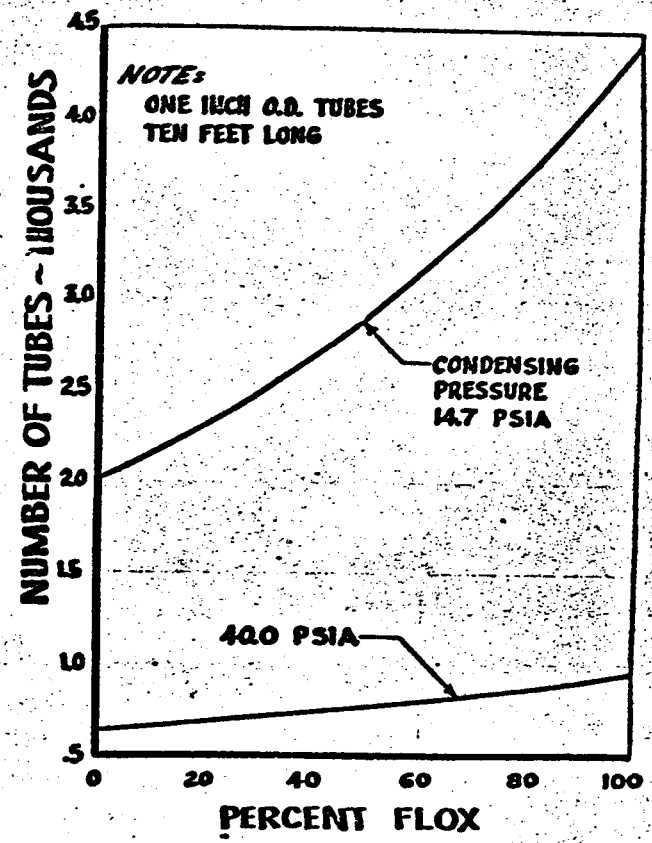




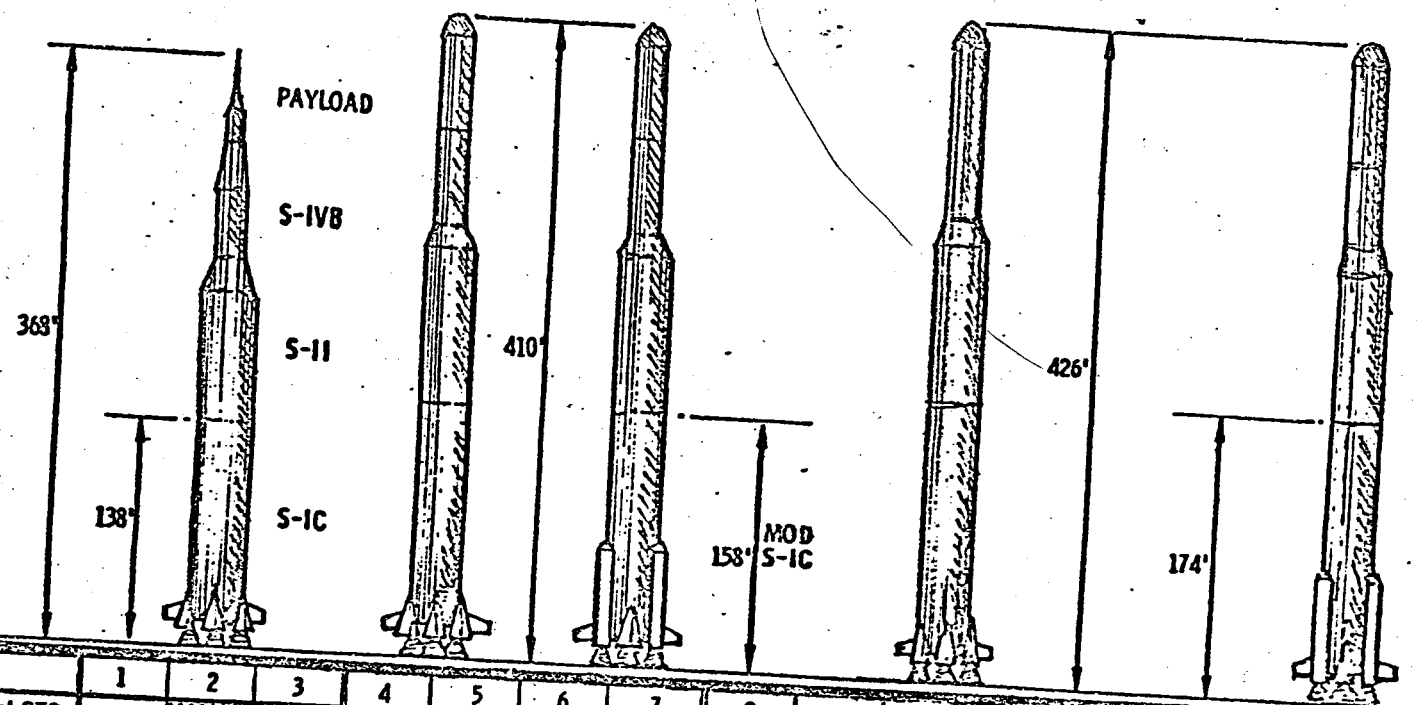
VENT SYSTEM RECONDENSER DESIGN CONCEPT



SYSTEM SCHEMATIC



SATURN V GROWTH CONCEPTS



MODIFICATION		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
STRAP-ON SOLIDS	MM-1st STG		■													
	120" DIA															
EXT S-IC L	20'						■	■								
	36'				■	■	■	■					■	■	■	■
ENGINE UPRATING	F-1								■	■	■	■	■	■	■	■
	RE-315				■	■	■	■	■	■	■	■	■	■	■	■
	J-2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
11.0 M THRUST BOOSTER																
FLOX - 70% (1800K NOM)				■		■		■		■	■	■			■	■
15.5' S-II, 12' S-IVB					■	■	■	■	■	■	■	■	■	■	■	■
WEIGHT 10^5		6.0	6.5	6.8	7.2	8.6	9.8	10.6	7.8	9.4	9.0	9.7	10.9	11.6	10.9	11.7
PAYLOAD 10^5 (ORBITAL)		2.5	2.63	3.5	3.2	4.5	3.6	5.0	3.4	4.3	3.9	5.2	3.8	5.2	5.4	5.8