D5-13183-6

Final Report - Studies of Improved Saturn V Vehicles and Intermediate Payload Vehicles (P-115)

RESEARCH & TECHNOLOGY IMPLICATIONS REPORT

Prepared for
NASA - George C. Marshall Space Flight Center under Contract NAS8-20266

October 7, 1966

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STUDIES OF IMPROVED SATURN VEHICLES
AND INTERMEDIATE PAYLOAD SATURN VEHICLES (P-115)

RESEARCH & TECHNOLOGY
IMPLICATIONS REPORT
D5-13183-6

FINAL REPORT
PREPARED UNDER CONTRACT NUMBER NAS8-20266

SUBMITTED TO
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OCTOBER 7, 1966

SUBMITTED BY
SYSTEMS ANALYSIS CONTRACTOR
THE BOEING COMPANY
SPACE DIVISION
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ABSTRACT

This document reports the research and technology implications involving the Saturn vehicles studied under NASA/MSFC Contract NAS8-20266, "Studies of Improved Saturn V Vehicles and Intermediate Payload Saturn Vehicles (P-115)," from December 6, 1965, to October 7, 1966. Phase I of the study was a parametric performance and resources analysis to select one baseline configuration for each of the six vehicles. Phase II of the study included a fluid and flight mechanics study, design impact on systems, and a resources analysis for each baseline vehicle. The intermediate payload vehicle derivatives of Saturn V are a logical means of providing orbital payload capability between that of the Saturn IB and the two-stage Saturn V. The uprated vehicles are feasible configurations and logical candidates for payloads in excess of the current Saturn V capability. No major problem areas were identified for either development or production.

KEY WORDS

Contract NAS8-20266
D5-13183-6
Intermediate Saturn Vehicles
Saturn V
Research Implications
Technology Implications
Problem Areas
Uprated Saturn Vehicles

FOREWORD

This volume contains the research and technology implications resulting from a ten-month study to prepare technical and resource data on uprated payload Saturn V and intermediate payload Saturn vehicles. This study was part of a continuing effort by the National Aeronautics and Space Administration (NASA) to investigate the capability and flexibility of the Saturn V launch vehicle and to identify practical methods for diversified utilization of its payload capability. NASA Contract NAS8-20266 authorizes the work reported herein and was supervised and administered by the Marshall Space Flight Center (MSFC). S-II data were supplied by the Space & Information Division of North American Aviation. S-IVB data were supplied by the Missile & Space Systems Division of Douglas Aircraft Company. Launch system data were supplied by the Denver Division of The Martin Company. Solid motor data were supplied by United Technology Corporation. The Launch Systems Branch, Aerospace Group, Space Division of The Boeing Company, was the Systems Analysis contractor for this study.

Program documentation includes a summary volume, five volumes covering vehicle descriptions, research and technology implications report (this document), and a cost document. Individual designations are as follows:

D5-13183	Summary Document
D5-13183-1	Vehicle Description MLV-SAT-INT-20, -21
D5-13183-2	Vehicle Description MLV-SAT-V-3B
D5-13183-3	Vehicle Description MLV-SAT-V-25(S)
D5-13183-4	Vehicle Description MLV-SAT-V-4(S)B
D5-13183-5	Vehicle Description MLV-SAT-V-23(L)
D5-13183-6	Research & Technology Implications Report
D5-13183-7	First Stage Cost Plan

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1.0 INTRODUCTION

This report summarizes the technological problems involved when uprating the Saturn V payload capability or when using Saturn V stages for missions in the payload range between the current Saturn IB and Saturn V capability.

The study is part of a continuing effort by NASA to identify a spectrum of practical launch vehicles to meet future payload and mission requirements as they become defined.

The vehicles studied were combinations of existing or modified Saturn V stages; some vehicles also included boost-assist components. A primary study requirement was to make maximum use of existing Saturn technology and support equipment.

In general, the NAS8-20266 study program objectives were to:

a. Select feasible and cost effective baseline vehicles from each of several categories;

b. Prepare sufficient technical data to define vehicle environments, design, capabilities, and characteristics;

c. Define support system requirements;

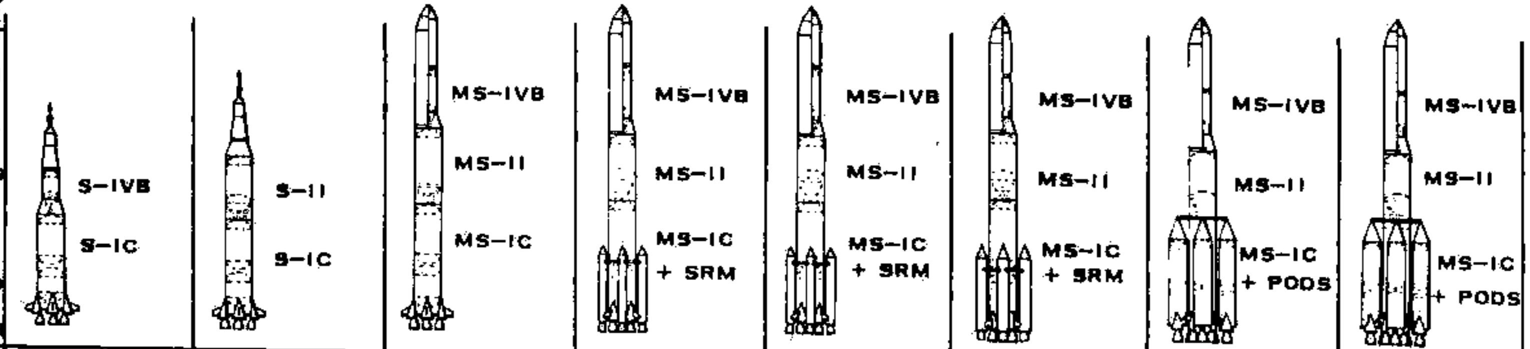
d. Determine the date that the first flight article could be available within study groundrules; and

e. Estimate cost required for implementation of the system plus production of thirty flight articles in five years.

There were two phases of study work. Phase I was a twelve-week effort in which vehicle performance and preliminary cost trade studies were conducted to select a feasible and cost effective baseline vehicle from each of five categories (shown in Figure 1-1). An additional baseline vehicle was later added from Category 4.

For each of the six baseline vehicles selected (see Figure 1-2), Phase II directed the effort to defining ground and flight environments, defining system design and resource impact for each stage and the total vehicle, and determining vehicle mission capabilities and characteristics.

GROUND RULES
MAX VEHICLE SIZE - 410 FT
MAX MS-II SIZE 1160 IN
MAX MS-IVB SIZE 350K PROPELLANT AT MR 5 :1
MAX PAYLOAD 5 LB/FT^3 (2 STG)
11 LB/FT^3 (3 STG)
STD: STANDARD
ΔL: CHANGE IN STAGE LENGTH



LAUNCH VEHICLE	INT-20	INT-21	SAT-V-3B	SAT-V-4(S)B	SAT-V-22(S)	SAT-V-25(S)	SAT-V-23(L)	SAT-V-24(L)
CATEGORY	1	2	3	4			5	
THIRD STAGE			ADVANCED ENGINE ΔL VARIABLE	STD J-2 ΔL VARIABLE	ADVANCED ENGINE ΔL VARIABLE	STD J-2 ΔL VARIABLE	STD J-2 ΔL VARIABLE	ADVANCED ENGINE ΔL VARIABLE
SECOND STAGE	STD J-2's ΔL - 0	STD J-2's ΔL - 0	ADVANCED ENGINES ΔL VARIABLE	STD J-2's ΔL VARIABLE	ADVANCED ENGINES ΔL VARIABLE	STD J-2's ΔL VARIABLE	STD J-2's ΔL VARIABLE	ADVANCED ENGINES ΔL VARIABLE
FIRST STAGE	STD F-1's ΔL - 0	STD F-1's ΔL - 0	5 X 1.8M F-1 ENGINES ΔL VARIABLE	STD F-1's ΔL VARIABLE	STD F-1's ΔL VARIABLE	STD F-1's ΔL VARIABLE	STD F-1's ΔL VARIABLE	5 X 1.8M F-1 ENGINES ΔL VARIABLE
STRAP-ON COMPONENTS				4 X 120 IN DIA SOLID MOTORS	4 X 120 IN DIA SOLID MOTORS	4 X 156 IN DIA SOLID MOTORS	4 LIQUID PODS 2 X STD F-1 ENGINES	4 LIQUID PODS 2 X 1.8M F-1 ENGINES

FIGURE 1-1 PHASE I LAUNCH VEHICLE CANDIDATES

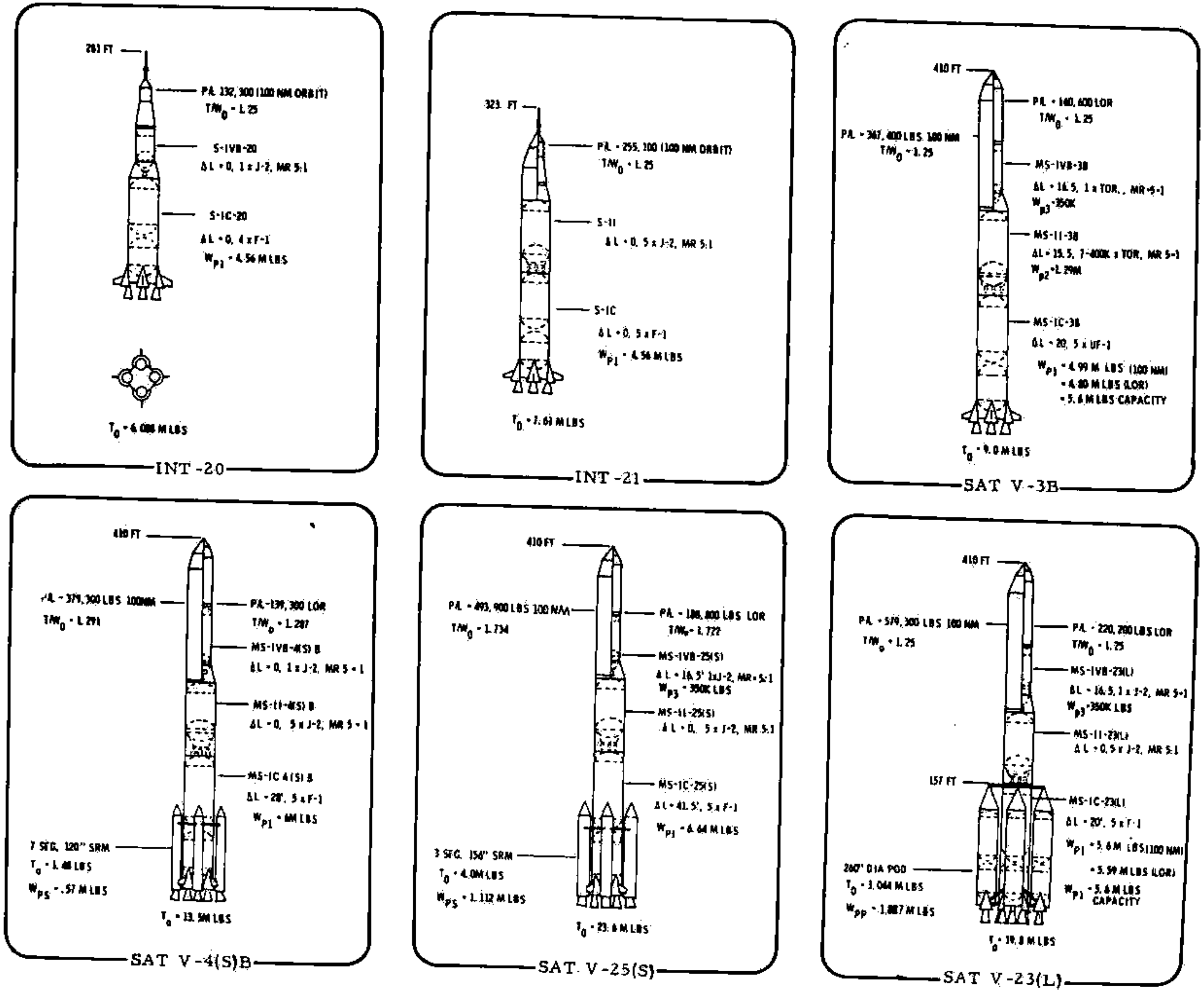


FIGURE 1-2 SELECTED BASELINE LAUNCH VEHICLES FOR PHASE II STUDY EFFORT

The launch vehicles in Categories 1 and 2 are Saturn V stage combinations for missions in the payload range between the current Saturn IB and Saturn V payload capability. The launch vehicles in Categories 3, 4, and 5 are advanced Saturn V configurations with payload capabilities beyond that of the existing Saturn V.

The five categories of vehicles are as follows:

Category 1 (MLV-SAT-INT-20) during Phase I was a family of two-stage launch vehicle candidates with standard size S-IC and S-IVB stages using standard F-1 engines (three, four, and five) and a standard J-2 engine. A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort.

Category 2 (MLV-SAT-INT-21) during Phase I was a family of two-stage launch vehicle candidates with standard size S-IC and S-II stages using standard F-1 engines (three, four, and five) and J-2 engines (three, four, and five). A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort.

Category 3 (MLV-SAT-V-3B) during Phase I was a family of two- and three-stage launch vehicle candidates with modified Saturn V stages using various types, numbers, and thrust levels of advanced engines in the upper stages and uprated F-1 engines in the modified S-IC stage. A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort.

Category 4 included modified Saturn V launch vehicles with strap-on solid motor boost-assist components. Three families of vehicles were studies as follows:

a. MLV-SAT-V-4(S)B during Phase I was a family of two- and three-stage launch vehicles with modified Saturn V stages, standard F-1 and J-2 engines with strap-on 120-inch diameter (five, six, and seven segmented) solid motors. A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort.

b. MLV-SAT-V-22(S) during Phase I was a family of two- and three-stage launch vehicles with modified Saturn V stages using various types, numbers, and thrust levels of advanced engines in the upper stages, a modified S-IC stage with standard F-1 engines in the first-stage, and strap-on 120-inch diameter (five, six, and seven segmented) solid motors. No launch vehicle in this family was studied beyond Phase I.

c. MLV-SAT-V-25(S) during Phase I was a family of two- and three-stage launch vehicles with modified Saturn V stages, standard F-1 and J-2 engines, and strap-on 156-inch diameter (two, three, and four segmented) solid motors. A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort.

Category 5 included modified Saturn V launch vehicles with strap-on boost-assist liquid propellant pods. Two families of vehicles were studied as follows:

a. MLV-SAT-V-23(L) during Phase I was a family of two- and three-stage launch vehicles with modified Saturn V stages, standard F-1 and J-2 engines, and four strap-on liquid propellant pods, each using two standard F-1 engines. A single baseline launch vehicle (Figure 1-2) was selected for the Phase II study effort..

b. MLV-SAT-V-24(L) during Phase I was a family of two- and three-stage launch vehicles with modified Saturn V stages using various types, numbers, and thrust levels of advanced engines in the upper stages, a modified S-IC stage with uprated F-1 engines, and four liquid propellant pods each containing two uprated F-1 engines. No launch vehicles in this family were studied beyond Phase I.

2.0 STUDY RESULTS

The six baseline vehicles studied under the contract are logical configurations and candidates for payloads ranging from 78,000 pounds to 579,000 pounds to a 100 N.M. Earth orbit.

All eight configurations of the intermediate launch vehicles studied during the trade study phase are feasible using existing Saturn V stages with minimum modification. These vehicles have payload capabilities ranging from 78,000 pounds to 255,000 pounds and provide a family of flexible and cost effective launch vehicles which are available within the normal lead time required for the stage elements (2 years).

The four uprated baseline vehicles are feasible configurations and logical candidates for payloads in excess of the current Saturn V capability. No major problem areas for development, production, or flight environmental characteristics were identified. The increased payload capability and improved cost effectiveness over that of the existing Saturn V could be used to reduce overall mission costs. For some missions, increased payload capability can be used to simplify the mission mode and thus result in less complex payload designs and fewer components. For example, a direct lunar shot for Apollo-type missions could greatly reduce the costs of the payload package from those costs required for the current LOR hardware by the elimination of the lunar rendezvous.

Explanation of the technical and resource data on this contract is summarized and reported in detail in the following documentation:

D5-13183	Summary Document
D5-13183-1	Vehicle Description MLV-SAT-INT-20, -21
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D5-13183-7	First Stage Cost Plan

3.0 AERONAUTICS TECHNOLOGICAL IMPLICATIONS

3.1 AERODYNAMIC STATIC STABILITY

3.1.1 Problem Definition

The uprated Saturn V launch vehicles are aerodynamically unstable during boost flight. The amount of aerodynamic instability is one of the major factors that determines the thrust vector control requirement. The uprated launch vehicles that use boost assist components are difficult to analyze because of the complex flow fields about the core vehicle and the strap-on solid motors or liquid propellant pods. Estimates of the total normal force contribution to the core vehicle are difficult to make because of the carryover from the strap-on to the core vehicle and the carryover from the core vehicle to the strap-ons. The effect of the gap between the core vehicle and the strap-on and the effect of the strap-on on fin or engine shroud effectiveness are also difficult to determine. The lack of experimental data and the inability of the various theoretical methods to analyze these complex vehicles add to the difficulties.

3.1.2 Solution Approach

It is recommended that wind tunnel tests be conducted on a Saturn V uprated configuration that uses solid strap-on motors for boost assist to determine the effect of the strap-on motors on the vehicle aerodynamic coefficients. The tests should determine the increment in the aerodynamic coefficients so that the results can be applied to other vehicles with a minimum of effort.

Typical wind tunnel data would have a variety of uses if it followed the form shown on Figure 3-1.

3.2 WIND SPEED ENVELOPE FOR LAUNCH TOWER CLEARANCE STUDIES

3.2.1 Problem Definition

In the definition of launch tower clearance, the 99 percentile ground wind speed envelope is used. This wind speed envelope is the result of a statistical analysis of ground winds measured over a number of years in a clear field at Patrick Air Force Base at various altitudes and correlated with the power law $U = U_1 (Z/Z_1)^P$ A wind speed envelope determine in this manner could be different from what a Saturn V type launch vehicle experiences because of large protuberances around the launch vehicle. The schematic in Figure 3-2 illustrates the problem.

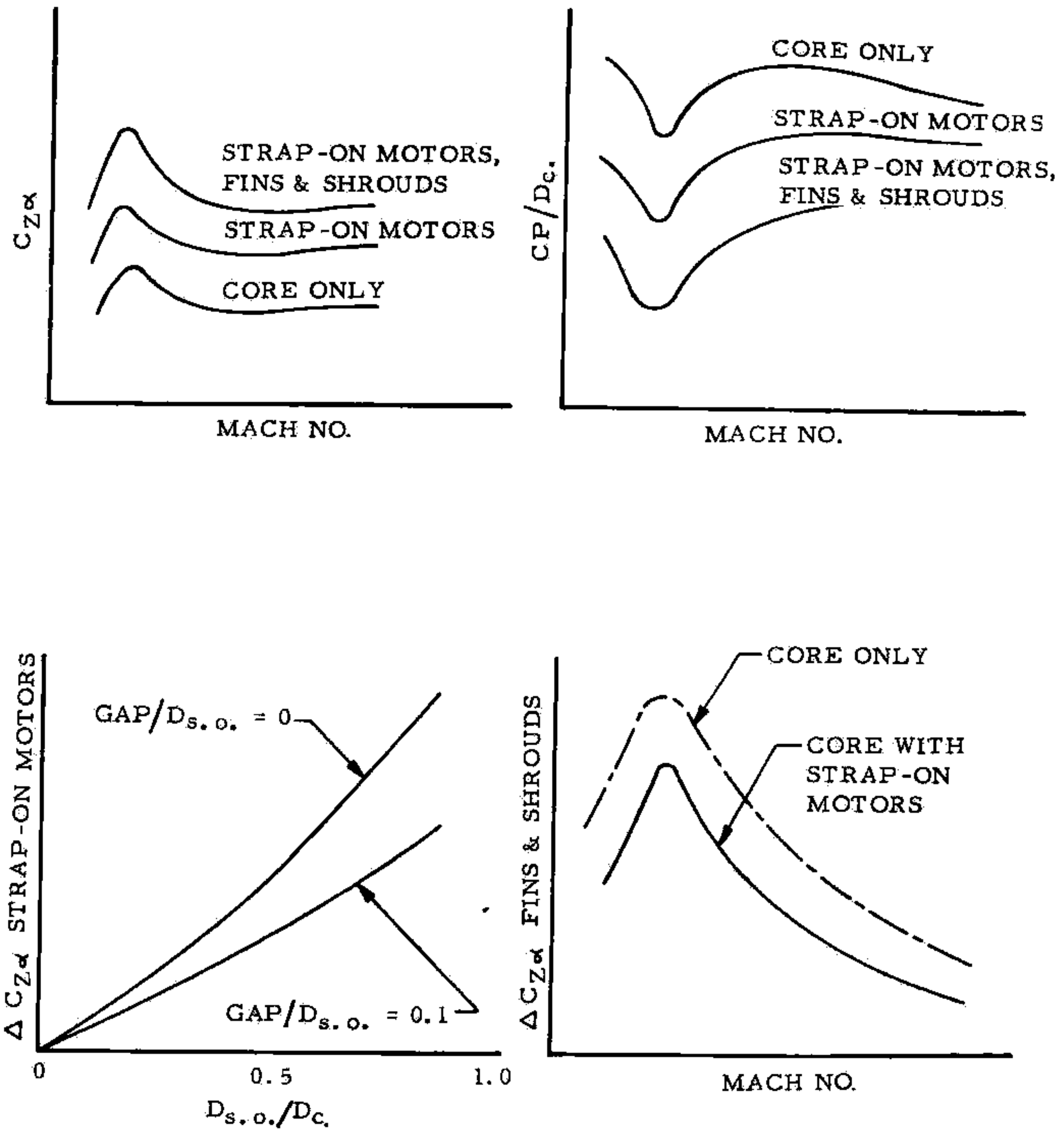

FIGURE 3-1 TYPICAL AERODYNAMIC DATA

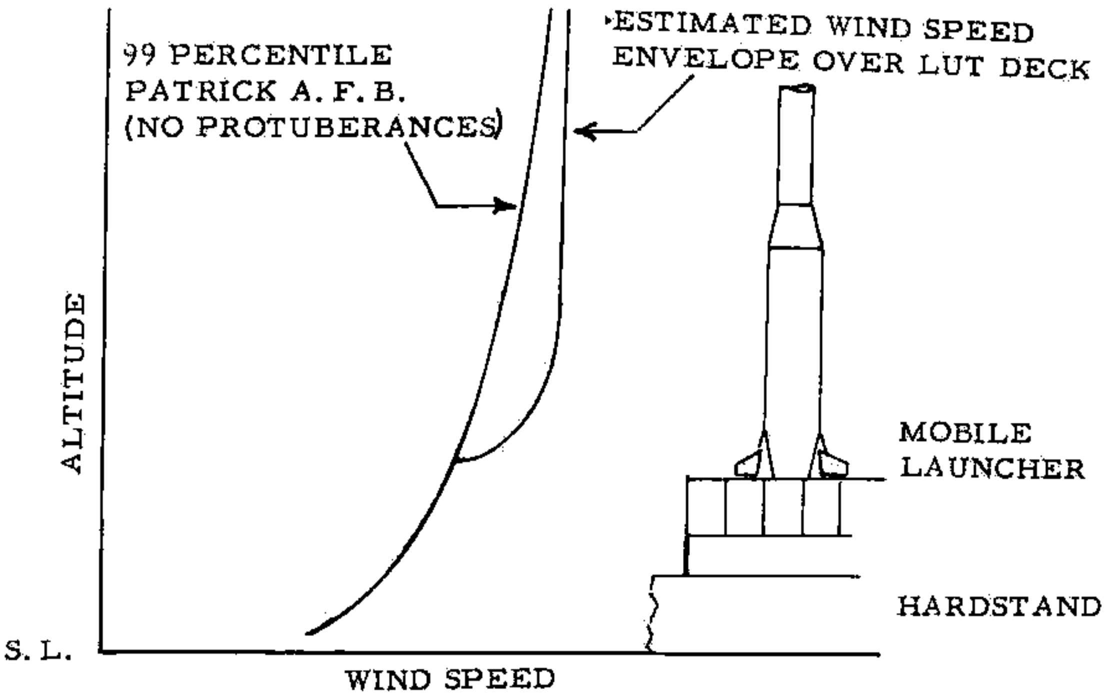

FIGURE 3-2 TYPICAL GROUND WIND SPEED ENVELOPE

Differences between a wind speed envelope determined in a clear field and that experienced by a Saturn V launch vehicle will result in differences in the aerodynamic disturbing moment on the vehicle which would affect the liftoff trajectory .

3 2 2 Solution Approach

Theoretical estimates of the induced wind velocity should be made using the Schwarz Christoffel theorm or other complex transformations to update the wind speed envelope. These theoretical estimates of the induced velocity over the hardstand and the mobile launcher can be used to determine, more accurately, the wind speed envelope that the launch vehicle will experience and to correlate the experimental wind speed data that is now being obtained on the mobile launcher.

4.0 ELECTRONICS AND CONTROL TECHNOLOGICAL IMPLICATIONS

4.1 LAUNCH TOWER CLEARANCE

4.1.1 Problem Definition

Large launch vehicles of the nature of those considered in this study experience high horizontal translations during lift-off when subjected to design winds and biased with off nominal design and construction parameters. Large drift distances and the resulting probability of tower collision can require extensive modification to existing launch pad facilities.

4.1.2 Solution Approach

Investigate the effect of distributed aerodynamics on vehicle lift-off trajectory and extend the study of lift-off dynamics to include representation of restrained release and malfunction conditions (engine loss). Parameterize rigid body control system feedback loops to minimize drift distance while remaining within attitude (guidance) constraints. A six degree of freedom digital simulation should be used to conduct these studies.

4.2 EFFECT OF CONTROL MODES ON VEHICLE LOADS

4.2.1 Problem Definition

The effect of alternate control modes on gimbal requirements was examined during the course of these studies. These results showed that the effect of varying control modes on gimbal displacement was negligible, and that one control system could not be recommended over another on the basis of reduced TVC requirements. This result does not preclude, however, the possible advantage of one control system over another in the area of reducing bending loads. Limited studies showed differences in maximum bending responses of 12 percent and 5 percent respectively for the MLV-Saturn V-3B and the MLV-Saturn V-4(S)B vehicles when comparing an attitude-attitude rate control system to attitude-attitude rate with angle of attack feedback. These results were obtained without optimizing control gains for load relief and using synthetic wind representations.

The amount of load reduction available by control systems optimization is a function of control mode, vehicle configuration, and the nature of the wind forcing input. These effects should be assessed to provide information upon which selections of optimum control systems for the uprated Saturn family of vehicles may be based.

4.2.2 Solution Approach

A comprehensive study is indicated using candidate control systems with gains optimized for load relief. In order to determine the relative effect of varying vehicle configuration, it is suggested that the family of uprated and intermediate Saturn V vehicles in its entirety be examined. Selected vehicles among these should be examined using both synthetic and real wind representations which are consistent with each other. A number of measured (Jimsphere) profiles of varying severity would be selected and consistent synthetic profiles having the same peak wind magnitude at the same altitude would be constructed. Wind shear of the synthetic profiles would be adjusted to give the same peak bending response using nominal attitude-attitude rate control before control systems optimizations for load relief are begun. Stability analyses using the elastic properties of the vehicles and varying sensor placement to assure practicability of the control gains selections and optimizations would be required.

The feasibility of employing multiple sensors and weighted control systems feedbacks to limit vehicle elastic bending response should be examined.

4.3 RANGE/VEHICLE COMMUNICATION INTERFERENCE

4.3.1 RF Interference From Added Strap-On Structure

4.3.1.1 Problem Definition

The addition of strap-on boosters, either liquid or solid, may place the structure of the booster in a position that interferes with antenna look angles from the vehicle to the ground station. Each antenna on the Saturn V stages should be considered to determine if structure obscures line of sight to any ground station.

The structure of the strap-on booster also may modify the antenna radiation patterns. The booster structure acts as reflectors which will modify the radiation characteristics of each antenna.

4.3.1.2 Solution Approach

Antenna radiation pattern tests should be conducted on an antenna range using models of the vehicles with strap-on boosters. These tests should be performed for all of the antenna systems on every stage. A complete description of an antenna's radiation field as it exists in space about the vehicle should be plotted. The tests and plotting of data should be conducted to the same groundrules as the data presented in Boeing Document D5-15526-1, May 16, 1966, title: "Saturn V Antenna Systems AS-501," conducted for contract NAS8-5608.

4.3.1.2 Solution Approach (Continued)

It may be necessary to relocate the antennas by moving them outward, forward, or to a different angular position to improve the radiation pattern and/or look angle. It may also be necessary to change the design of the antenna systems to improve the radiation pattern.

4.3.2 RF Interference From Modified Exhaust Plume

4.3.2.1 Problem Definition

The uprated vehicles have enlarged exhaust plumes due to increased mass flow. The solid strap-on motors also add different exhaust products, including metal particles, which increase the degradation of the RF system.

4.3.2.2 Solution Approach

The communication data recorded from Titan III flights should be evaluated to determine RF interference through the exhaust plume of combined liquid engines and solid rocket motors. This data should be correlated to data from Saturn I flights and other sources of RF interference data through exhaust plumes. This evaluation should consider the RF interference as a function of antenna look angle, using the look angle curves in Section 5.2.7 of documents D5-13183-3, -4, and -5.

4.3.3 Modified Antenna System

4.3.3.1 Problem Definition

The improvement study indicated a requirement to place a redundant set of MS-IC antennas on the strap-on boosters which would be used prior to staging of the strap-on boosters. The strap-on boosters have RF systems independent of the Saturn V, but require combination of the four booster RF circuits on the MS-IC and redistribution to antennas on the strap-ons. The longer circuit paths and added switching from the transmitters to the antennas may produce increased RF degradation as well as presenting hardware problems for the proposed system.

4.3.3.2 Solution Approach

The modified antenna systems proposed (in Sections 6.1.4 of documents D5-13183-3, -4, and -5) for use with the strap-on boosters should be evaluated analytically, and then tested with a systems breadboard using S-IC components.

4.3.3.2 Solution Approach (Continued)

The results of this investigation would be to determine areas of RF systems adequacy, recommend changes to the Saturn V systems, and define further testing required. It is necessary to investigate the RF systems for the upper stages as well as the MS-IC to assure adequare communication for the vehicle.

5.0 MATERIALS AND STRUCTURES TECHNOLOGICAL IMPLICATIONS

5.1 STABILITY CRITICAL STIFFENED CYLINDRICAL SHELL DESIGN

5.1.1 Problem Definition

Since the original design of the Saturn V vehicle, several methods of analyses have been developed to more accurately predict the load-carrying capability of stability-critical axially compressed stiffened cylinders. However, none of these methods have been proved reliable for all stiffened cylinder configurations applicable to the Saturn V vehicle. One of these methods, developed by Boeing, (Ref. D5-13272) considers all three possible modes of instability failures and has been partially verified with results from the S-IC corrugated intertank test program and from various test data in the literature. This method is currently being extended to account for the increase in load-carrying capability due to pressure stabilization.

5.1.2 Solution Approach

1. Verify by test and analyses the validity and range of application of the available analytical procedures including the method developed by Boeing.

2. Compare results of the various methods.

3. Use the best of these methods for each type of stiffened cylinder applicable to the Saturn V vehicle and re-evaluate the various uprated Saturn V vehicles for possible weight savings and increased reliability.

5.2 PAYLOAD ENVELOPE WIND SENSITIVITY

5.2.1 Problem Definition

The intermediate vehicles INT-20 and INT-21 were studied using the Apollo payload shape and were shown to have adequate strength without modification using current Saturn wind criteria. Due to the limited volume of the Apollo envelope, and larger payload weights afforded by these vehicles for orbital missions, payload densities are relatively high. Actually these vehicles have considerably more versatility for carrying payloads of higher volume and lower density during extensive periods of the year. This versatility is available from two sources: (1) using reduced factors of safety for un-manned missions, and (2) from reduced wind magnitudes which exist during periods of the year for which launches may be planned.

5.2.2 Solution Approach

In order to define the versatility which exists in this respect, it is suggested that comprehensive analyses be performed using a family of payload shapes and sizes and winds of varying magnitude as defined by MSFC criteria for each month of the year. Payload length limits would be established for each month of the year as a function of peak wind speed for manned and un-manned factors of safety within the structural capability of these vehicles. From these data estimates of launch availability versus month of the year may be obtained for payloads of varying size on a probabilistic basis. Such information is very desirable for planning purposes.

5.3 FLIGHT LOADS PROBABILITY

5.3.1 Problem Definition

Generally speaking synthetic wind representations which have been developed from statistical analysis of measured wind data do not produce loads responses with the same probability, i.e., there is no direct correlation between the probabilities of peak wind speed, wind shear, altitude, and direction, and load exceedance probability. Currently there are insufficient data upon which to base computation of the combined probability of all wind parameters so that even synthetic criteria must still be selected through exercise of sound engineering judgments. Obviously conservatism is a desirable consideration in this case. There are sufficient measured winds, however, to approach the problem from the direct load exceedance standpoint. Improved wind measurement systems are producing higher resolution profiles. It should be possible to use these data coupled with other measured wind information to compute load exceedance probability from statistical samples of measured profiles. This approach would reduce the need for conservatism associated with engineering judgments which have been required in the past in the development of synthetic profiles.

5.3.2 Solution Approach

Up to this time such solutions have not been practicable due to the limited wind information available, extensive computer times required to obtain solutions for adequate statistical samples of measured profiles, limited accuracy of the profiles themselves, and absence of correlations between mean wind and random turbulence responses. As a result, no methods have been tailored to this purpose which encompass the complete solution.

In order to obtain loads of known exceedance probability the following is required:

5.3.2 Solution Approach (Continued)

1. Development of high speed digital or analog simulations to obtain probability distributions of loads responses to statistical samples of mean winds.

2. Utilization of Jimsphere data to obtain power spectral densities of random turbulence and associated mean wind profiles.

3. Statistical ordering of vehicle responses to mean winds and random turbulence and correlation of these responses using vehicle responses to total wind profiles (Jimsphere).

The result would be bending load probability distributions for desired launch periods as functions of launch azimuth for critical vehicle stations for all times during boost. Such information would be very valuable to assist in the selection of design criteria for the advanced Saturn family of vehicles. In addition, correlations of these results could be made with synthetic profiles developed through statistical analysis of the winds themselves. This would provide consistent synthetic criteria for use in design studies and the relationships between primary wind statistical parameters and the statistical properties of vehicle responses.

5.4 GROUND WIND LOADS

5.4.1 Problem Definition

Computation of the ground winds loads response for large launch vehicles is one of the most problematic areas faced in the course of vehicle design. Limited knowledge of wind forcing functions and the coupled elastic response to random vortex shedding has historically required wind tunnel verification or total reliance on wind tunnel results. Vehicle size has progressed to the point where limited knowledge of scaling relationships seriously hinders application of wind tunnel results. Considerable time and effort is being spent on the current Saturn V program to learn more about this problem area including full scale ground winds testing using the AS-500F vehicle. An effort should be made to assemble all available knowledge from this and other sources and to extrapolate the results to the larger uprated configurations. In addition, wind tunnel tests of uprated Saturn configurations will be required.

5.4.2 Solution Approach

Apply these results to the larger uprated Saturn configurations and obtain revised ground wind loadings for design purposes.

5.4.2 Solution Approach (Continued)

1. Plan and conduct wind tunnel tests to establish ground wind load responses of uprated configurations.

2. Utilize this information and current Saturn V analysis and test results to extend analyses methods to include the larger uprated vehicles.

3. Revise ground wind loads for design purposes based on these results.

6.0 LOW COST LIQUID PROPELLANT POD

Large pressure fed liquid engine systems for boost-assist and for booster application are feasible, and approach the simple systems and structures of solid rocket motors.

6.1 PROBLEM DEFINITION

The use of liquid propellant pods for boost-assist on the MLV-SAT V-23(L) configuration provided a flexible method for vehicle uprating. However, the pod design was based on S-IC technology and concepts which result in higher costs than for solid motors.

The use of a pressure fed engine(s) and monocoque propellant tank structure can make the pods competitive with solid motors on a cost basis. The liquid propellants are cheaper than solid propellants, and transportation and handling of the dry stage is easier. The specific impulse of the liquid pod is better than the solid motors which provides a performance advantage.

6.2 SOLUTION APPROACH

The feasibility of a simplified liquid pod design which will be cost-competitive with solid motors should be determined. The design should be optimized from a cost and reliability standpoint, with lesser emphasis on performance.

Evaluation of pod components and systems to define performance characteristics and cost would lend not only to understanding the specific reasons for cost differences, but also to identify means of optimizing cost effectiveness. The potential of incorporating the following into the pod design should receive attention:

a. Simplified engine - eliminate turbopump (pressure-fed) - minimum valves and controls.

b. Simplified pressurization system - minimum complexity and components, and simple controls.

c. Simplified propellant tankage (monocoque structure) and thrust structure, made of inexpensive materials and fabrication techniques, requiring minimum inspection and testing.

d. Storable propellants and pressurization gases, packaged, and sealed.

These analyses of a low-cost pod should be compared in size and cost-effectiveness to the cryogenic pump-fed pod and solid motors used in the studies under NAS8-20266.