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PROJECT APOLLO

A Feasibility Study of an Advanced
Manned Spacecraft and System

FINAL REPORT

VOLUME IV. ON-BOARD PROPULSION

Book 1 — Text and Appendix P-C

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Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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May 15, 1961

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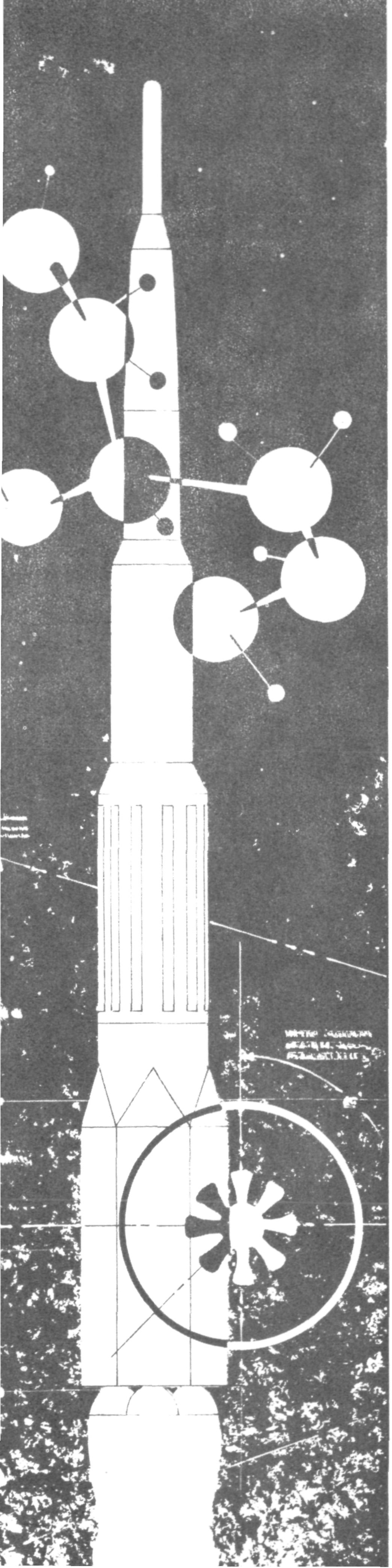

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15 March 1961

REPORT NO. SR-60514-5

Project Apollo

ONE DESIGN APPROACH TO A COMBINED SOLID AND LIQUID PROPELLANT PROPULSION SYSTEM

Aerojet-General® CORPORATION
SOLID ROCKET PLANT • SACRAMENTO, CALIFORNIA

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I. INTRODUCTION

For the maneuver requirements of the Apollo spacecraft on a lunar orbit mission, several integrated solid and liquid propellant systems are being studied by the Aerojet-General Corporation. One approach to such integrated propulsion systems is described in this report as an example. The system described uses solid-propellant rockets for launch-abort escape and lunar-orbit injection and exit, storable liquid propellants are used for midcourse guidance and attitude control. Further data concerning storable and cryogenic liquid-propellant systems for the lunar orbit maneuvers are being prepared. Although solid propellant motors do not have as high a specific impulse as the high-energy cryogenic liquid propellant systems, they do offer some interesting features with respect to reliability (crew safety and mission completion), utmost compactness, and simplicity.

II PROPULSION SUBSYSTEMS

The on-board propulsion system consists of the following subsystems:

A. LAUNCH-ABORT ESCAPE

A means of fast separation of the crew module from the booster rocket is provided in case of a malfunction or irregularity during the first-stage and early second-stage operation. After passing successfully through these critical phases, the escape motor is jettisoned Since the escape motor is not carried up to escape velocity, it only partially counts as payload for the booster rocket

B. ATTITUDE CONTROL

The vehicle is oriented with respect to space-fixed coordinates

II. Propulsion Subsystem (cont)

C. MIDCOURSE CONTROL

Impulses are produced as required to correct the trajectory during transit from earth to the vicinity of the moon and on the way back to earth.

D. ORBIT INJECTION

The injection propulsion produces the required velocity decrement to achieve a lunar orbit.

E. ORBIT EXIT

The orbiting spacecraft is provided with the velocity increment necessary to leave the lunar orbit and return to earth.

The most critical phase of the lunar orbit mission is the exit phase (subsystem E). A failure to achieve the required impulse is equivalent to a loss of the crew and the vehicle.

Also mandatory is the reliable performance of the midcourse control system for a safe mission completion or emergency return.

The injection phase (subsystem D) is considered to be less critical. A failure to produce the desired velocity decrement results in over-shooting and means that the lunar orbit mission has to be abandoned Using the orbit-exit propulsion, completely or partially, allows transforming the planned trajectory into a circumlunar one with a delayed, but probably safe, return to earth.

III. SELECTION OF SUBSYSTEMS

The emphasis of highest possible reliability in subsystems C and E is reflected in the selection of redundant systems.

The requirements for the escape system, high thrust level and short duration, are best met with solid propellant motors.

Attitude control requires many small and unpredictable pulses and is best accomplished by a hypergolic liquid-propellant system with start-stop capability.

The midcourse control system also may require many pulses at different thrust levels. This requirement of flexibility favors the use of a hypergolic liquid propellant system. Reliability may be achieved by the use of dual thrust chambers and dual sets of fluid controls to provide a redundant subsystem.

The orbit injection system has to deliver a high impulse to a predetermined maximum value in a relatively short time. A solid propellant motor with highly accurate total impulse control by thrust reversal achieves this. The solid propellant rocket has the further advantage of simplicity and, therefore, inherent reliability Storability in the space environment without special provisions, good performance, and compactness are also inherent qualities of the solid-propellant motors.

A highly reliable orbit exit propulsion can be attained by splitting the total amount of propellant into several highly reliable solid propellant motors. One additional redundant motor can replace any one of the other motors, thus keeping the potential total impulse at the necessary level. Also, the weight penalty for redundancy is thus kept at a fraction of the total system weight. The redundant motor can be a solid propellant motor or the midcourse-propulsion liquid-propellant system. The integrated solid-liquid configuration is shown in Figure 1

IV. SYSTEM DESCRIPTION

The spacecraft and the selected subsystems are shown in a schematic drawing in Figure 1. To show the application of an integrated propulsion system, a vehicle configuration was assumed which only reflects the basic Apollo idea: command module, mission module, and propulsion module.

The attitude control system consists of eight thrust chambers with possibly eight additional ones as redundancy. Each chamber develops 10 lb of thrust. The attitude control system is not shown in Figure 1; however, the pressurization and tank system are integrated in the midcourse subsystem. The total impulse is 60,000 pound-seconds.

The escape motor is connected to the command module by means of a Mercury-type tower structure.

In form of two half-rings, the mission module is located around the command module.

In the case of a launch abort, the mission module and the fairing are separated and jettisoned sideways, and the propulsion module remains on top of the launch vehicle. The command module is now free and can be rapidly lifted by the escape motor to a safe altitude to deploy the descent mechanism. With a command module weight of approximately 7000 lb, the 1KS-130,000 motor shown can achieve an altitude of 300 ft in the first second, and the module will coast to an apogee altitude of 4000 ft within 15 sec. The maximum acceleration is 18 g. These values are only approximate, since the performance depends very much on the drag of the capsule.

IV, System Description (cont.)

In the case of a launch abort at maximum dynamic pressure conditions (approximately 35,000 ft), the escape motor develops a thrust of 140,000 lb and can achieve a separation of the capsule from the booster of approximately 100 feet in 1 second

An alternative motor design with a forward nozzle arrangement may shorten the tower structure. A detailed description of the escape motor is presented in Aerojet-General Report No SR-60514-2A.

The single motor for orbit injection propulsion is located at the centerline of the vehicle. A fiber-glass chamber and a fixed light-weight nozzle are used to achieve a high mass fraction. To compensate for initial thrust misalignment, shifts in location of the vehicle center of gravity, and shifts in thrust vector during burning, provisions are made to vector the motor The motor is mounted on three ball-nut screw-jack actuators which allow a 1.5-degree inclination of its axis in all directions

This orbit-injection motor is equipped with a thrust-reversal device to terminate the thrust at the moment the desired velocity increment is achieved or to terminate the thrust immediately after an improper firing The thrust termination is achieved within 1 to 3 milliseconds after command. At the moment of thrust reversal, the motor is disconnected from the spacecraft by explosive bolts and jettisoned.

The exit propulsion system shown in Figure 1 consists of 10 motors placed around the injection motor. The motors have fixed nozzles, are rigidly mounted, and are adjusted in such a way that the thrust vectors intersect in one point on the vehicle axis.

IV System Description (cont.)

Since the exit propulsion motors are of the type to achieve high thrust and short duration, they are not fired simultaneously The firing schedule provides for firing the first six motors simultaneously, thrust termination, explosive disconnect, and jettisoning of the six motor casings Then, in the second pulse, the remaining four motors are fired, thrust is terminated after the desired velocity increment is achieved, and the motors are jettisoned.

If one of the six motors or one of the four motors fails to ignite, one of the redundant liquid-propellant midcourse engines is lighted and aligned so that the resultant thrust vector points through the center of gravity of the spacecraft. Therefore, no turning moment exists. With the attitude control, the vector is brought into flight direction. If one midcourse engine fails to light, the other engine would automatically start and replace it.

The location of the two gimbaled thrust chambers is also shown in Figure 1, along with tanks for fuel and oxidizer and for the pressurization helium of this dual-purpose liquid midcourse propulsion subsystem. A more detailed description, system diagrams, and reliability analysis, are presented in Aerojet-General Report LRP-PDR 61-5, "General Mechanization Scheme and Reliability Analysis for Project Apollo," dated 27 January 1961.

V. WEIGHT AND PERFORMANCE

For this study, a vehicle weight of 7000 lb without propulsion was assumed A velocity increment of 250 ft/sec for midcourse correction for each way and a velocity increment of 3150 ft/sec for the injection and exit maneuver were also assumed.

The tables presented at the end of this report show preliminary data pertaining to the Apollo vehicle, in general, and propulsion systems. A weight tabulation for significant points on the trajectory is shown in Table 1. Performance and weight data for the launch-abort escape motor are shown in

V, Weight and Performance (cont.)

Table 2. For the midcourse-guidance liquid propellant system, data are shown in Table 3 to supplement references in the text of this report. Data concerning the solid propellant motors used for orbit injection and exit are presented in Tables 4 and 5, respectively.

Table 1

WEIGHT OF APOLLO VEHICLE AT SIGNIFICANT POINTS IN TRAJECTORY

At:	Vehicle wt lb	Component wt lb	Component Burned-Out or Jettisoned
Launch	16,599		
		765	Escape Motor
Escape velocity	15,834		
		344	Midcourse propellant, earth to moon
		120	Attitude control propellant, earth to moon
Lunar orbit injection	15,370		
		4438	Injection motor
Lunar orbit	10,932		
		3297	Exit propulsion system (10 motors)
Lunar orbit exit	7635		
		250	Redundant exit engine propellant
		175	Midcourse propellant, moon to earth
		70	Attitude control propellant, moon to earth
		100	Midcourse propulsion system hardware
		40	Attitude control hardware
Re-entry	7000		

Table 1 (cont.)

WEIGHT OF APOLLO VEHICLE AT SIGNIFICANT POINTS IN TRAJECTORY

Assumptions.

$I_{s\ (solid)}$ = 305 lbf-sec/lbm, vacuum, ϵ= 30:1 (lunar orbit and exit motors)

$I_{s\ (liquid)}$ = 320 lbf-sec/lbm, vacuum, ϵ= 40:1

Mass fraction: Injection motor = 0.95
Exit propulsion system (10 motors) = 0.91

Velocity increment: Midcourse (each way) = 250 fps
Orbit injection = 3150 fps
Orbit exit = 3150 fps

Total impulse of attitude control = 60,000 lb-sec

Table 2

LAUNCH-ABORT PROPULSION SYSTEM

IKS-130,000
SINGLE SOLID ROCKET MOTOR, THREE CANTED NOZZLES

Total weight = 747 lb

Expansion ratio (ϵ) = 18:1

Chamber material - Nickel-steel

I_s at altitude (35,000 ft) = 276 lbf-sec/lbm

I_s at sea level = 250 lbf-sec/lbm

Thrust at maximum acceleration (35,000 ft) = 140,000 lb

Thrust at sea level = 127,000 lb

Mass fraction = 0.762

Chamber pressure = 1100 psi

Burning time = 1 sec

Propellant Properties

ANP-2913 CD: 68% NH_4ClO_4 16% Al
0.3% Ballistic additive
15.7 wt% Polyurethane Binder

I_s at 1000 psi (sea level) = 247 lbf-sec/lbm, measured

Burning rate = 0.7 in./sec at 1000 psi

T_c = 5740°F

Density = 0.064 lb/cu in.

Table 3

MIDCOURSE CONTROL SYSTEM

Liquid: Pressure Feed System with Dual Thrust Chambers and Controls

Propellant: N_2O_4 and 0.5 N_2H_4 + 0.5 UDMH Misture Ratio MR 2.1:1

I_s = 320 lbf-sec/lbm

Expansion ratio = 40:1

Throat diameter = 3.2 in.

Exit cone diameter = 20 in.

Over-all length of thrust chamber = 35 in.

Chamber pressure = 134 psi

Weight of thrust chambers, control module, and tanks ≈ 75 lb

Thrust, each engine = 1500 lb

Table 4

ORBIT INJECTION MOTOR

Single Solid Rocket Motor, One Fixed Nozzle

Total weight =	4360 lb
Propellant weight =	4142 lb
Inert weight =	218 lb
Mass fraction =	0.95
Thrust =	31,500 lb
Burning time =	40 sec
$I_{s(vac)}$ (ϵ= 30:1) =	305 lbf-sec/lbm
Chamber pressure =	500 psi
Chamber material =	Glass-fiber-resin composite

Propellant Properties

Propellant with Beryllium Additive:	49.4 wt% NH_4ClO_4
	13% Be
	37.6% Nitropolyurethane binder

I_s at 1000 psi (sea level) = 264 lbf-sec/lbm, expected measured

T_c = 6000°F

Density = 0.061 lb/cu in.

Table 5

ORBIT EXIT PROPULSION SYSTEM

Ten Solid Rocket Motors, Each With a Single Fixed Nozzle

Total weight (each motor) = 324 lb

Propellant weight = 295 lb

Inert weight = 29 lb

Mass fraction = 0.91

Thrust = 3600 lb

Burning time = 24 sec

$I_{s(vac)}$ (ϵ= 30:1) = 305 lbf-sec/lbm

Chamber pressure = 500 psi

Chamber material = Glass-fiber-resin composite

Propellant. Same as in Table 4

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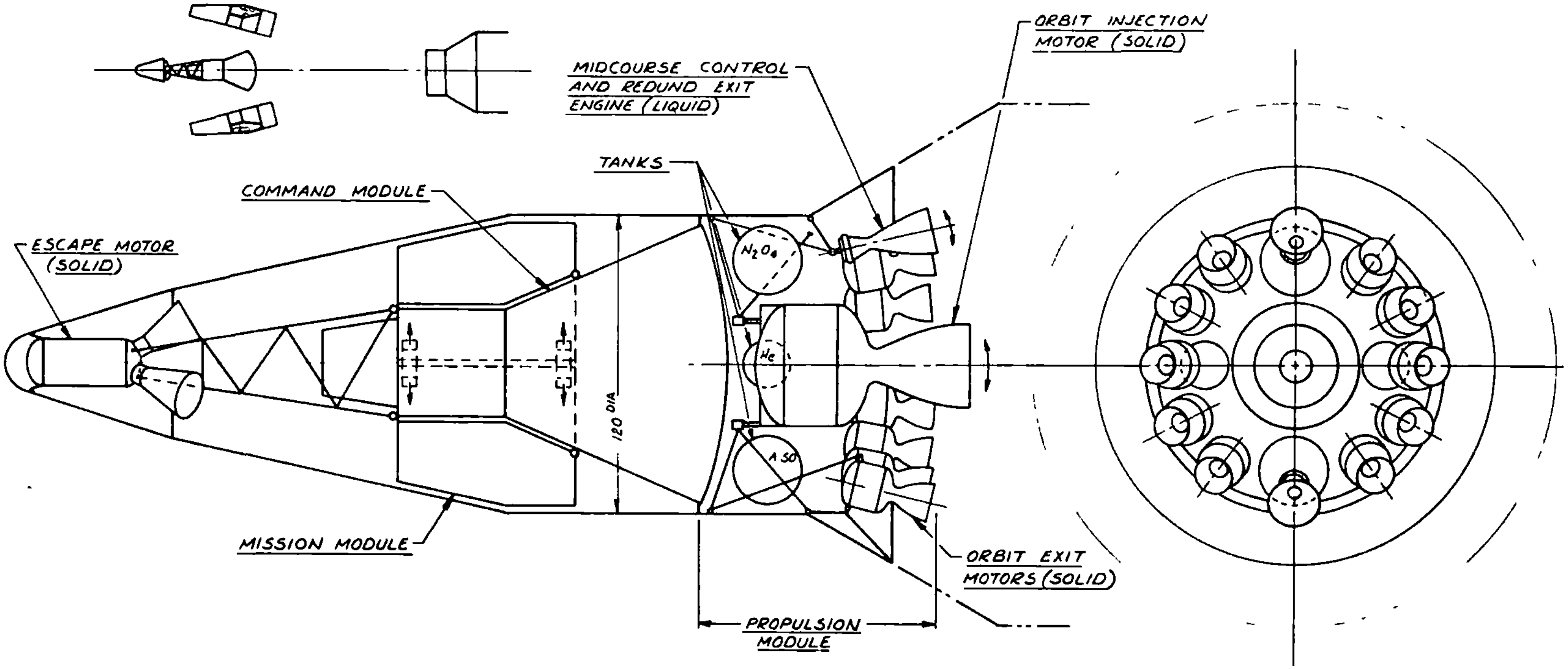
Figure 1



Apollo Solid-Liquid Propulsion System

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