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SECOND PROGRESS REVIEW

STUDY ON LARGE LAUNCH VEHICLES UTILIZING SOLID PROPELLANTS

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The Boeing Company Aero-Space Division

SECOND PROGRESS REVIEW

STUDY OF LARGE LAUNCH VEHICLES UTILIZING SOLID PROPELLANTS

Contract No. NAS 8-2438
D2-13029 November 17, 1961

The Boeing Company Aero-Space Division

CP-59575

INTRODUCTION

This document is a compilation of the data presented at the Second Progress Review given to representatives of the George C. Marshall Space Flight Center, Future Projects Office, in Seattle, Washington, November 17, 1961 as required by the Contract Work Statement. The data presented is representative of the approach used in establishing vehicle preliminary designs, overall systems requirements, and development plans for the vehicles under study. Vehicle systems studied were broadly defined as follows:

Approx. Payload to 307-N.Mi. Orbit (pounds)	First Stage	Second Stage	Vehicle Identification
30,000	Solid motor segmented	1 J-2 engine	1-S1
100,000	Solid motors segmented	4 J-2 engines	3-SC4
100,000	Solid motors unitized	4 J-2 engines	3-UC4
180,000	Solid motors unitized	4 J-2 engines	4-UC4
180,000	Solid motors unitized—laterally staged	4 J-2 engines	4-UC6L
350,000	Solid motors Unitized	3 or 4 Y-1 engines One million pounds of thrust hydrogen-oxygen	N-UC4

30,000-POUND PAYLOAD VEHICLE

The 1-S1-B2 vehicle consists of a single J-2 engine with integral tankage for a second stage and a single segmented solid motor for the first stage.

The liquid second-stage tank construction consists of aluminum monocoque structure of a waffle pattern and the interstage consists of a corrugated skin reinforced at intervals with frames. The solid motor case is heat-treated steel of 200,000-psi ultimate strength.

A Freon-injection system provides the primary stability and control requirements for the first stage, except for roll, which is provided by an independent hydrogen-peroxide reaction-control system. Fins are attached to provide improved stability at first-stage burnout. Base-heat protection is provided for both stages.

30,000-POUND PAYLOAD VEHICLE

(1-S1-B2)

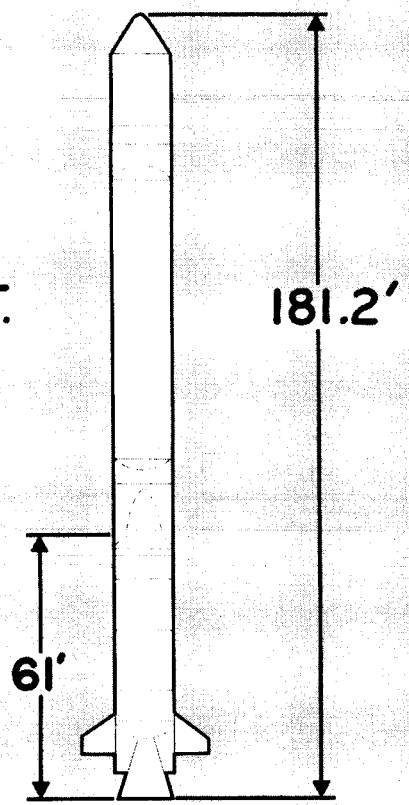
VEHICLE WT.
902,850 LBS.

2ND-STAGE WT.
191,780 LBS.

2ND-STAGE PROP. WT.
173,820 LBS

1ST-STAGE WT.
680,070 LBS

1ST-STAGE PROP. WT.
571,890 LBS.



T_2 = 200,000 LBS.
t_{b_2} = 372 SEC.
λ_2' = .906

T_1 = 1,442,572 LBS.
t_{b_1} = 86 SEC.
λ_1' = .874

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100,000-POUND PAYLOAD VEHICLE

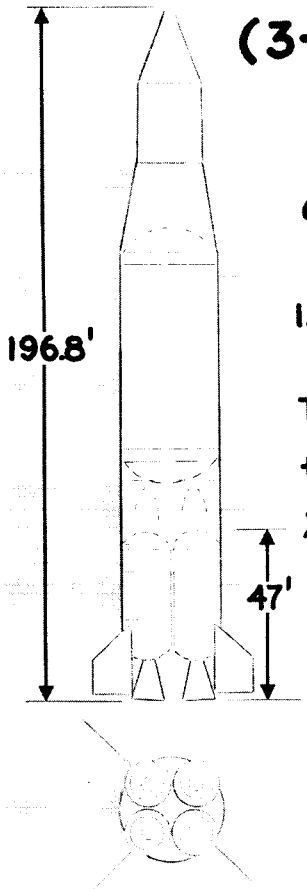
The 3-SC4-B2 vehicle consists of four J-2 engines with integral tankage for the second stage and a cluster of four segmented solid motors for the first stage.

The 3-4C4-B2 vehicle uses four unitized solid motors for the first stage. Both vehicles are otherwise identical.

The liquid second-stage tank construction consists of aluminum monocoque structure of a waffle pattern and the interstage consists of a smooth skin of semimonocoque structure reinforced at intervals with frames. The solid motor cases are steel of 200,000-psi ultimate heat-treat strength.

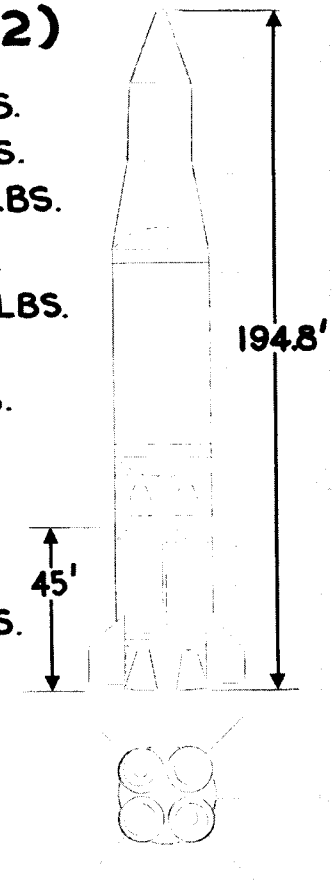
A Freon-injection system provides the primary stability and control requirements. Fins are attached to provide stability at burnout. Base-heat protection is provided for both stages.

100,000-POUND PAYLOAD VEHICLE



(3-SC4-B2)		(3-UC4-B2)
2,822,750 LBS.	VEHICLE WT.	2,766,620 LBS.
755,590 LBS.	2ND-STAGE WT.	755,590 LBS.
690,070 LBS.	2ND-STAGE PROP. WT.	690,070 LBS.
1,963,240 LBS.	1ST-STAGE WT.	1,907,110 LBS.
1,626,988 LBS.	1ST-STAGE PROP WT	1,594,630 LBS.

(3-SC4-B2)	(3-UC4-B2)
T_2 = 800,000 LBS.	T_2 = 800,000 LBS.
tb_2 = 369 SEC.	tb_2 = 369 SEC.
λ'_2 = .913	λ'_2 = .913
T_1 = 4,516,400 LBS.	T_1 = 4,426,560 LBS.
tb_1 = 87 SEC.	tb_1 = 87 SEC.
λ'_1 = .860	λ'_1 = .867



2B9789-3

180,000-POUND PAYLOAD VEHICLE

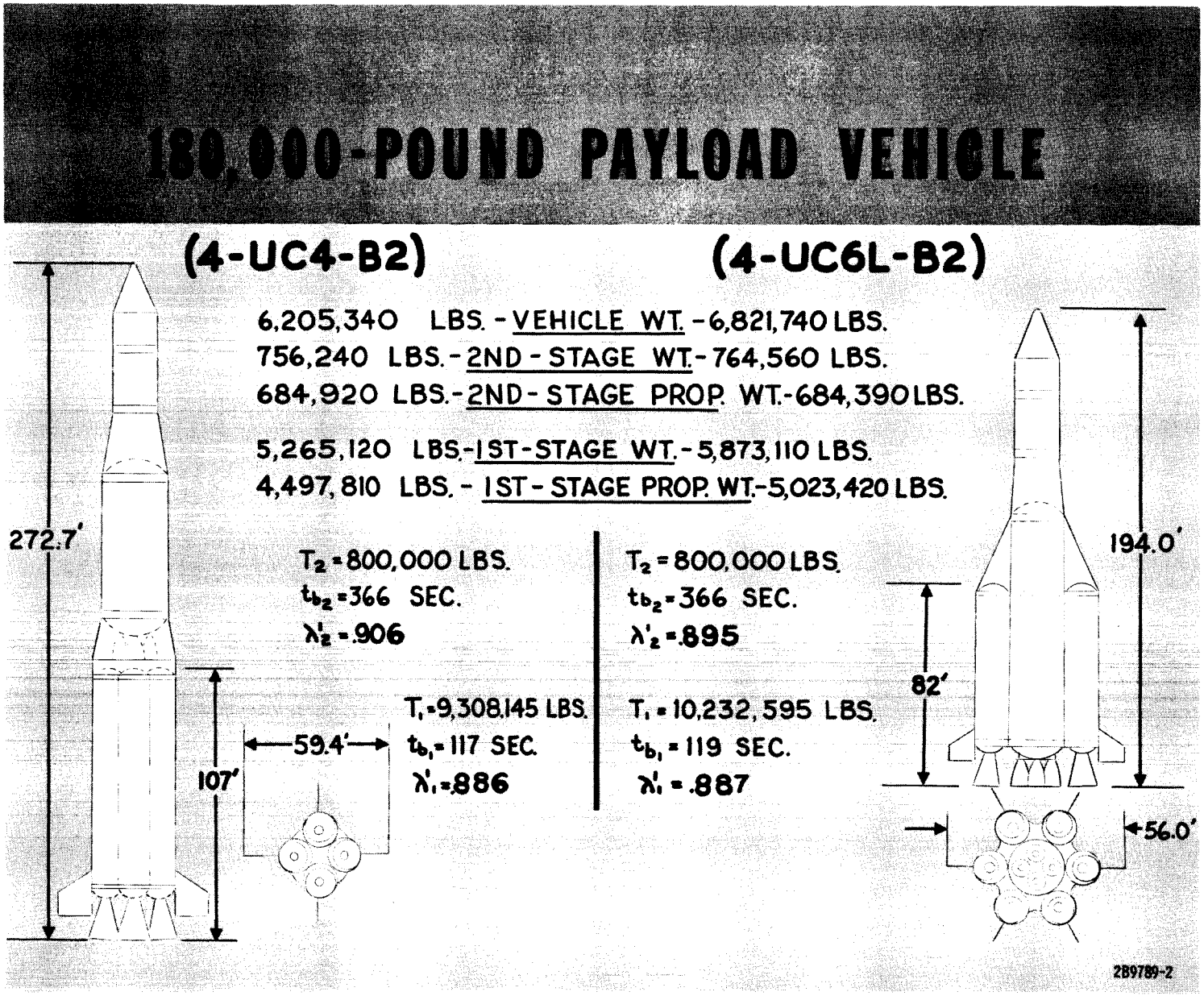
The 4-UC4-B2 vehicle consists of four J-2 engines with integral tankage for the second stage and a cluster of four unitized solid motors for the first stage.

The 4-UC6L-B2 vehicle consists of four J-2 engines with integral tankage for a second stage and six unitized solid motors laterally staged with respect to the liquid stage.

The liquid second stage tank construction for both vehicles consists of aluminum monocoque structure of a waffle pattern. The interstage for the 4-UC4-B2 vehicle consists of a smooth skin of semimonocoque structure reinforced at intervals with frames. The thrust transfer of the 4-UC6L-B2 vehicle is made at the base of the liquid stage. The top of the solid motor cases are attached to an internal ring in the liquid-stage tank. Aerodynamic fairings are provided between the tops of the two stages. The solid motor cases are of steel heat-treated to 200,000-psi ultimate strength.

A Freon-injection system provides the primary stability and control requirements of both vehicles. Fins are attached to provide neutral stability at burnout for the 4-UC4-B2 vehicle and to improve flight stability at maximum dynamic pressure for the 4-UC6L-B2 vehicle. Base-heat protection is provided for both stages of the vehicles.

Due to time limitations further work on the 4-UC6-B2 vehicles was not completed. As indicated by the structural concept initially chosen, the weight penalty resulting from the lateral arrangement was above reasonable limits. It is estimated that this condition could be improved by studying other structural arrangements and by multiple staging of the solid motors.


180,000-POUND PAYLOAD VEHICLE
(4-UC4-B2)
(4-UC6L-B2)
6,205,340 LBS. - VEHICLE WT. - 6,821,740 LBS.
756,240 LBS. - 2ND - STAGE WT. - 764,560 LBS.
684,920 LBS. - 2ND - STAGE PROP. WT. - 684,390 LBS.
5,265,120 LBS. - 1ST - STAGE WT. - 5,873,110 LBS.
4,497,810 LBS. - 1ST - STAGE PROP. WT. - 5,023,420 LBS.
272.7'
107'
59.4'
T_2 = 800,000 LBS.
t_{b_2} = 366 SEC.
λ'_2 = .906
T_1 = 9,308,145 LBS.
t_{b_1} = 117 SEC.
λ'_1 = .886
T_2 = 800,000 LBS.
t_{b_2} = 366 SEC.
λ'_2 = .895
T_1 = 10,232,595 LBS.
t_{b_1} = 119 SEC.
λ'_1 = .887
194.0'
82'
56.0'
2B9789-2

350,000-POUND PAYLOAD VEHICLE

The N-UC4-B2 vehicle consists of three Y-1 engines with integral tankage for a second stage and a cluster of four unitized solid motors for the first stage.

The liquid second-stage tank construction consists of aluminum monocoque structure of a waffle pattern and the interstage consists of a smooth skin of semimonocoque structure reinforced at intervals with frames. The solid motor cases are heat-treated steel of 200,000-psi ultimate strength.

A nitrogen-tetroxide injection system provides the primary stability and control requirements.

Base-heat protection is provided for both stages.

50,000 POUND PAYLOAD VEHICLE

N-UC4-B2

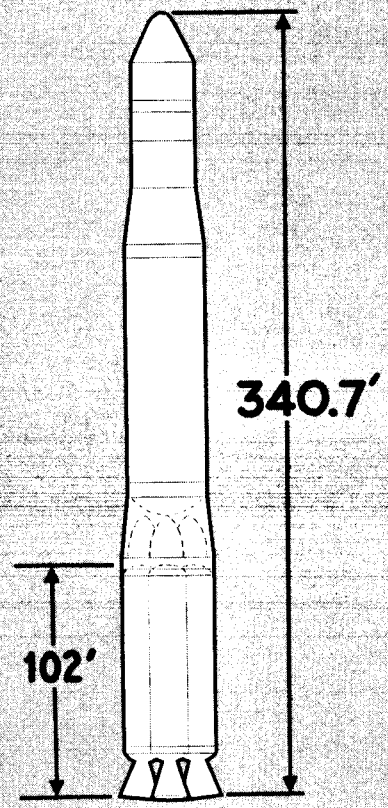
VEHICLE WT.
9,169,510 LBS.

2ND-STAGE WT.
2,109,380 LBS

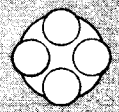
2ND-STAGE PROP. WT.
1,917,487 LBS.

1ST-STAGE WT.
6,700,730 LBS.

1ST-STAGE PROP. WT.
5,819,200 LBS.



T_2 = 3,000,000 LBS.
t_{b_2} = 273 SEC.
λ_2' = .909



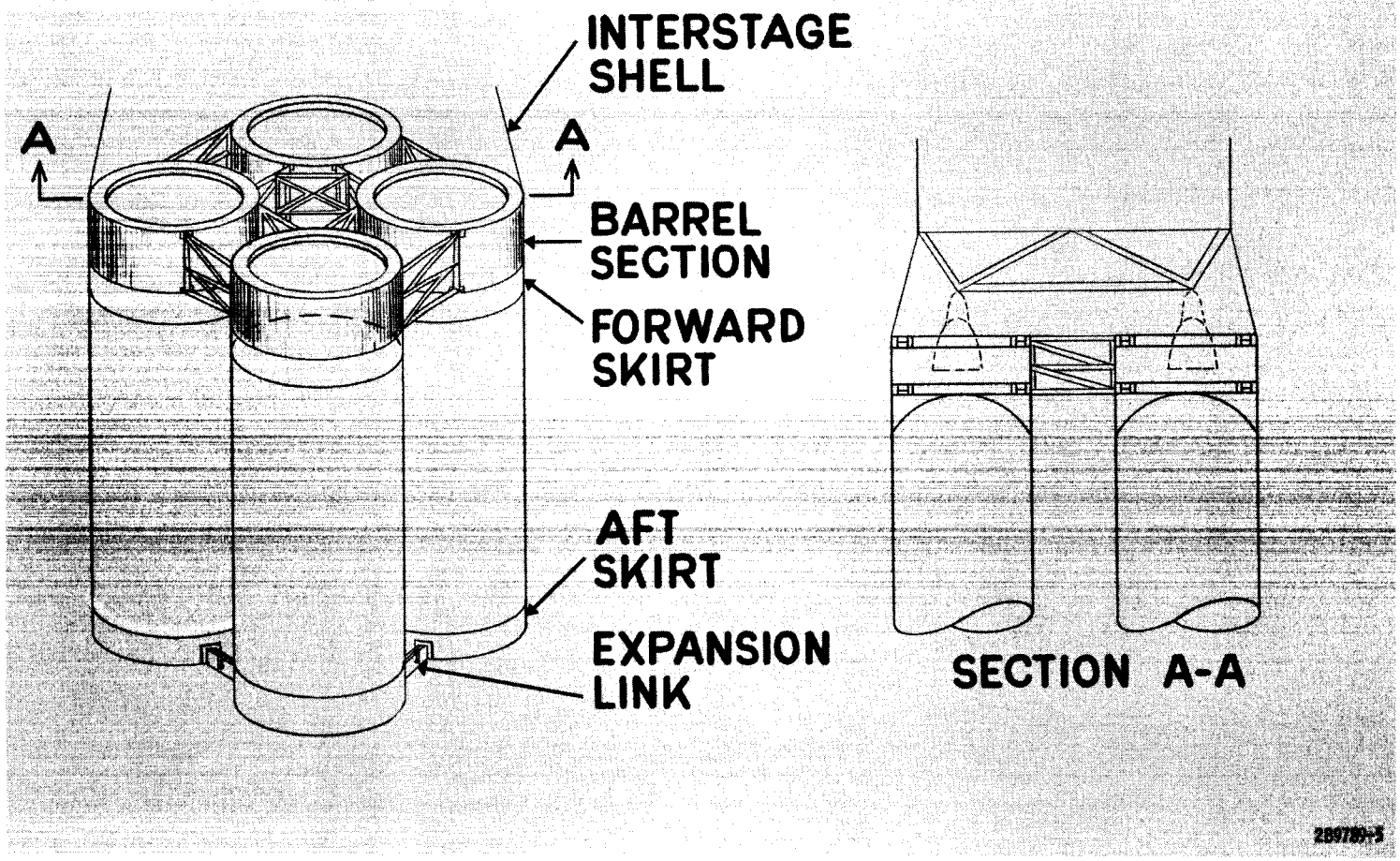
T_1 = 14,212,000 LBS.
t_{b_1} = 99 SEC.
λ_1' = .884

SOLID MOTOR CLUSTERING CONCEPT

The clustering concept used for all tandem-staged vehicles is represented on this chart. The basic principle is to provide fixity at the forward end of the clustered tanks while allowing relative expansion at the aft end. To provide end fixity and at the same time to minimize interstage length, barrel sections were attached to the upper-tank skirts enveloping the Stage-II engines. Large rings at each end of the barrel sections were tied together by truss panels to provide intertank fixity. An interstage shell was then extended from the barrel section to the Stage-II skirt. Expansion links tie the aft skirts together while allowing longitudinal tank growth.

The barrel sections are constructed of corrugated sheet. Truss panels are fabricated from tubing with mechanical fasteners at the tank-attach points.

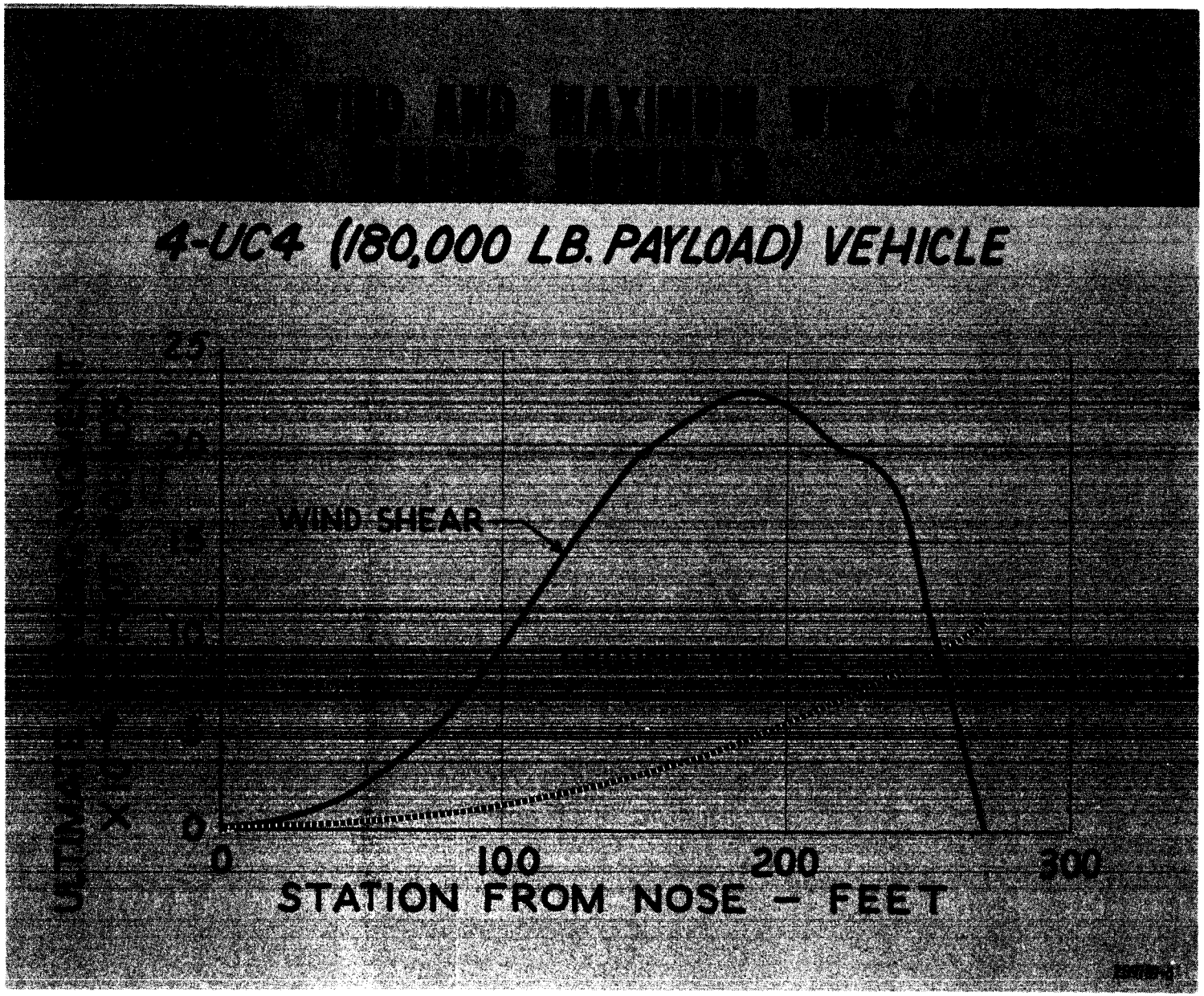
SOLID-MOTOR CLUSTERING CONCEPT



GROUND-WIND AND MAXIMUM WIND-SHEAR BENDING MOMENTS

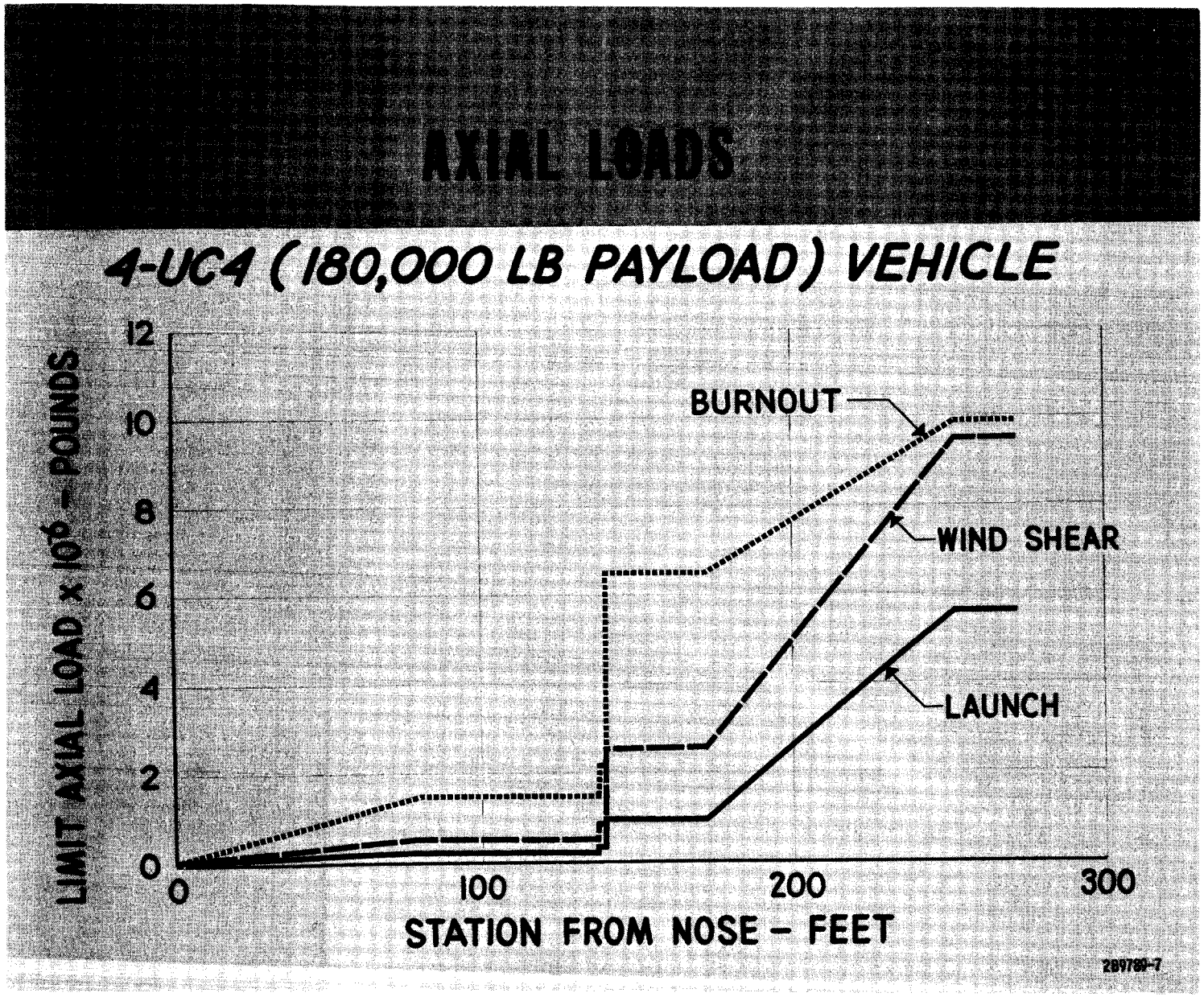
Ground-wind and maximum wind-shear bending moments for the 4-UC4 vehicle are shown. The load characteristics of this vehicle are typical of the family of vehicles studied. Wind-shear bending moments are based on a flexible vehicle analysis using the avidyne wind-shear profile plus a critically phased (1-cos) 20-fps gust. Ground-wind loads result from a 40-mph steady-state wind plus 20-mph gust at a reference point 10 feet above the ground, increasing to 134 percent of the reference value at an altitude of 120 feet. A drag coefficient of .42 and a structural magnification factor of ~~8~~ 165 percent were included.

By combining bending moments and associated axial loads, the maximum design condition for each vehicle station can be obtained. The maximum loading condition for the LH_2 and LO_2 tanks was the wind-shear loading. The interstage was designed by first-stage burnout loads. The tank intertie structure was designed by wind-shear bending moment. Vehicle-support skirts were designed by the ground wind condition.


4-UC4 (180,000 LB. PAYLOAD) VEHICLE
WIND SHEAR
2.5
2.0
1.5
1.0
0.5
0
0
100
200
300
STATION FROM NOSE – FEET

AXIAL LOADS

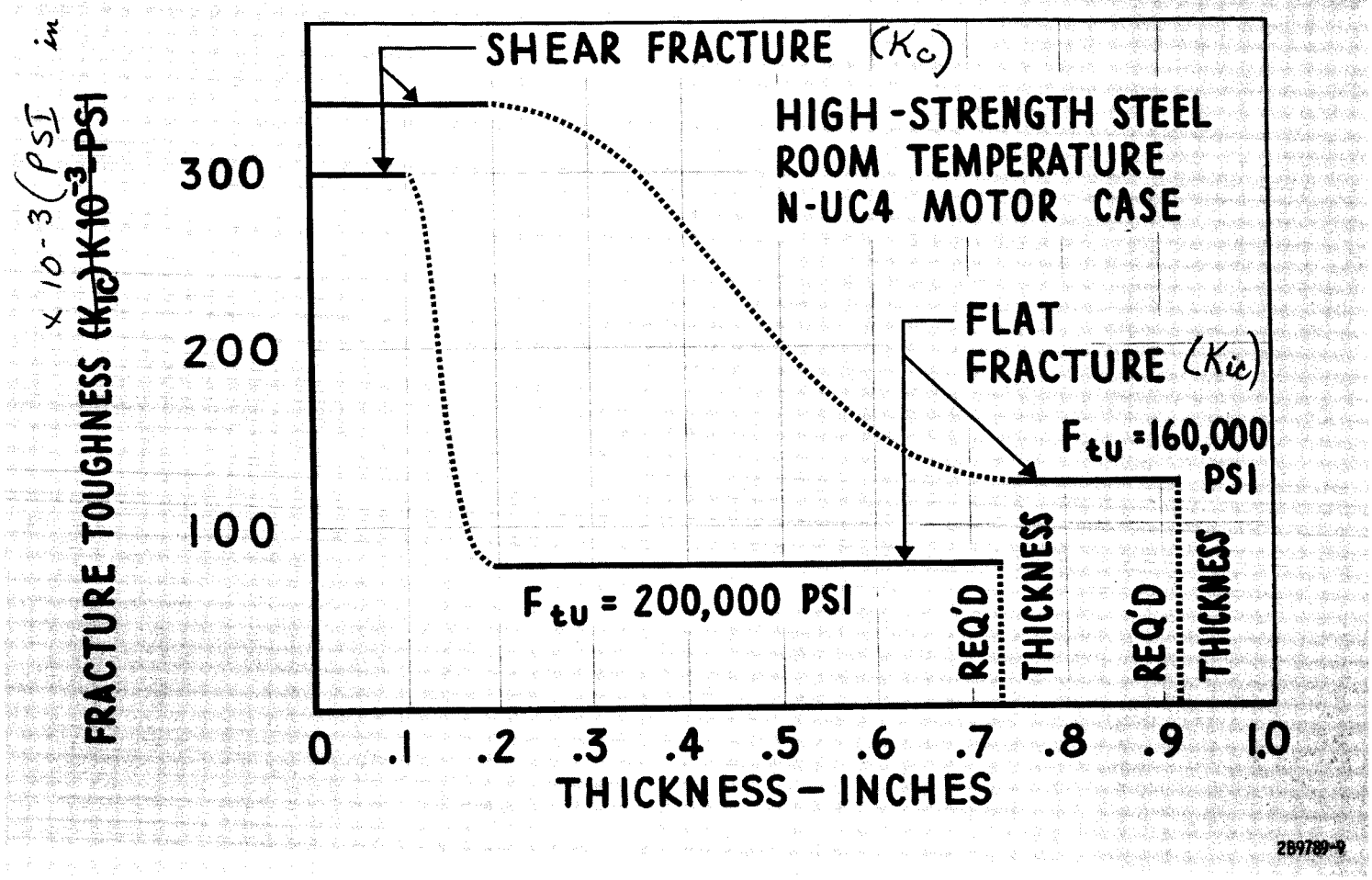
Axial load variations are shown for the 4-UC4 vehicle. Burnout loads are based on an acceleration of 6.95 g at termination of first-stage flight. At the point of maximum flight bending moment due to combined wind-shear and gust conditions, the vehicle acceleration was 2.7 g. The launch condition represents the 1-g-load distribution before liftoff.


AXIAL LOADS
4-UC4 (180,000 LB PAYLOAD) VEHICLE
LIMIT AXIAL LOAD x 10^6 - POUNDS
12
10
8
6
4
2
0
0
100
200
300
STATION FROM NOSE - FEET
BURNOUT
WIND SHEAR
LAUNCH
289789-7

FRACTURE TOUGHNESS VERSUS THICKNESS

Typical fracture-mode transition values for a high-strength steel are shown in the accompanying chart. Although data on this type of phenomenon is limited, there is sufficient information to outline the considerations necessary for the selection of a heat-treat level in high-strength steel. The important fact to be noted is that, in the efficient stress ranges, flat or "brittle" fracture modes dominate for large booster cases. The choice of stress level is therefore strongly tied to case fabrication and inspection techniques.

FRACTURE TOUGHNESS VS THICKNESS

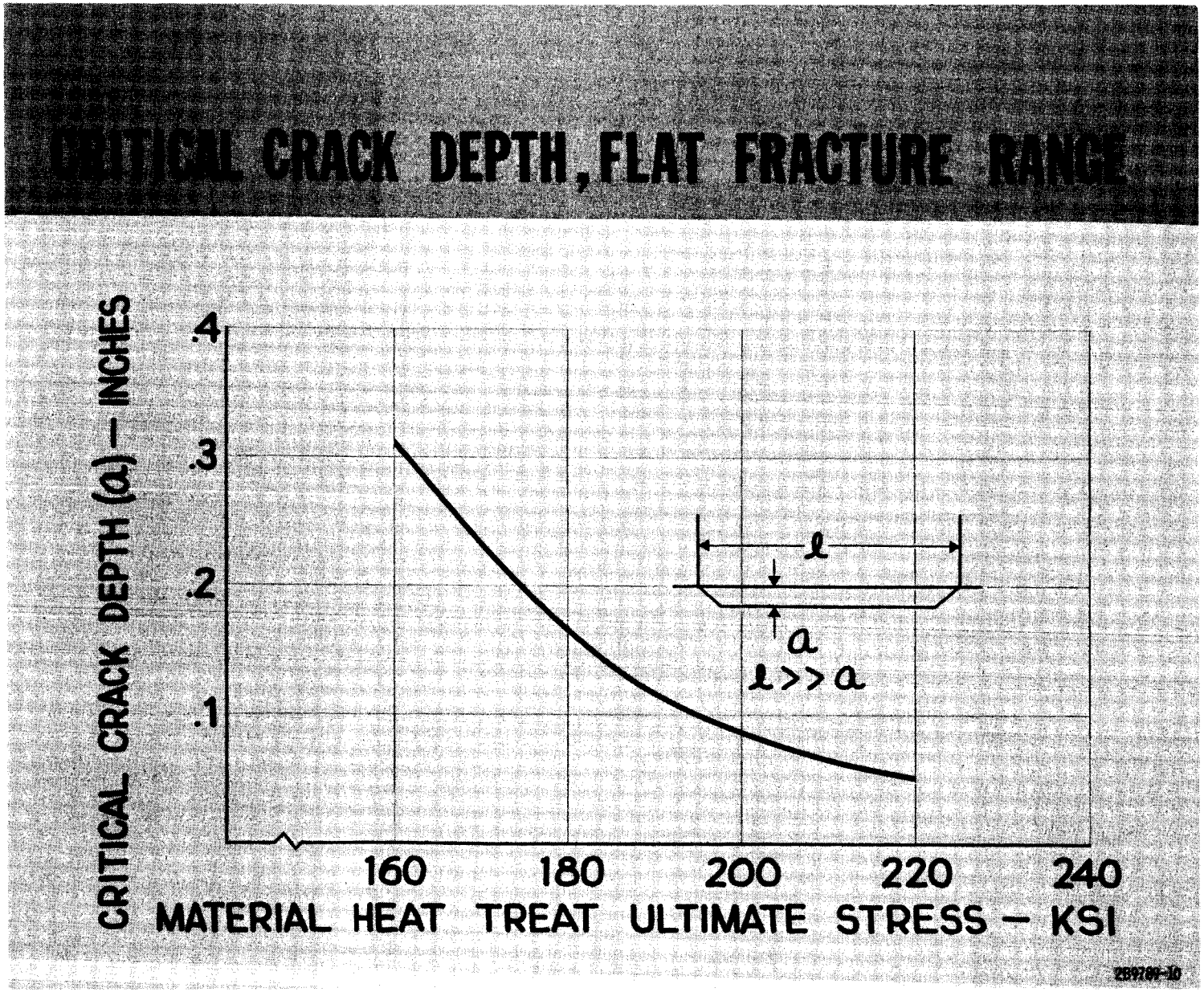


CRITICAL CRACK DEPTH AND FRACTURE RANGE

As shown here, stress risers, such as surface cracks and inclusions, must be closely controlled. The chart demonstrates the physical size of flaws that will produce case failure and their relationship to material stress level. It can be seen that, at the material working stress, a .052-inch-deep surface crack will produce failure in a 220,000-psi ultimate material and a .082-inch crack will cause failure in 200,000-psi material. The final choice of a material stress level must be an engineering judgment based on test program values for the preceding material characteristics coupled with known performance of available inspection techniques.

Based on presently available information, a stress level of 200,000-psi ultimate strength is considered compatible with reasonable inspection techniques.

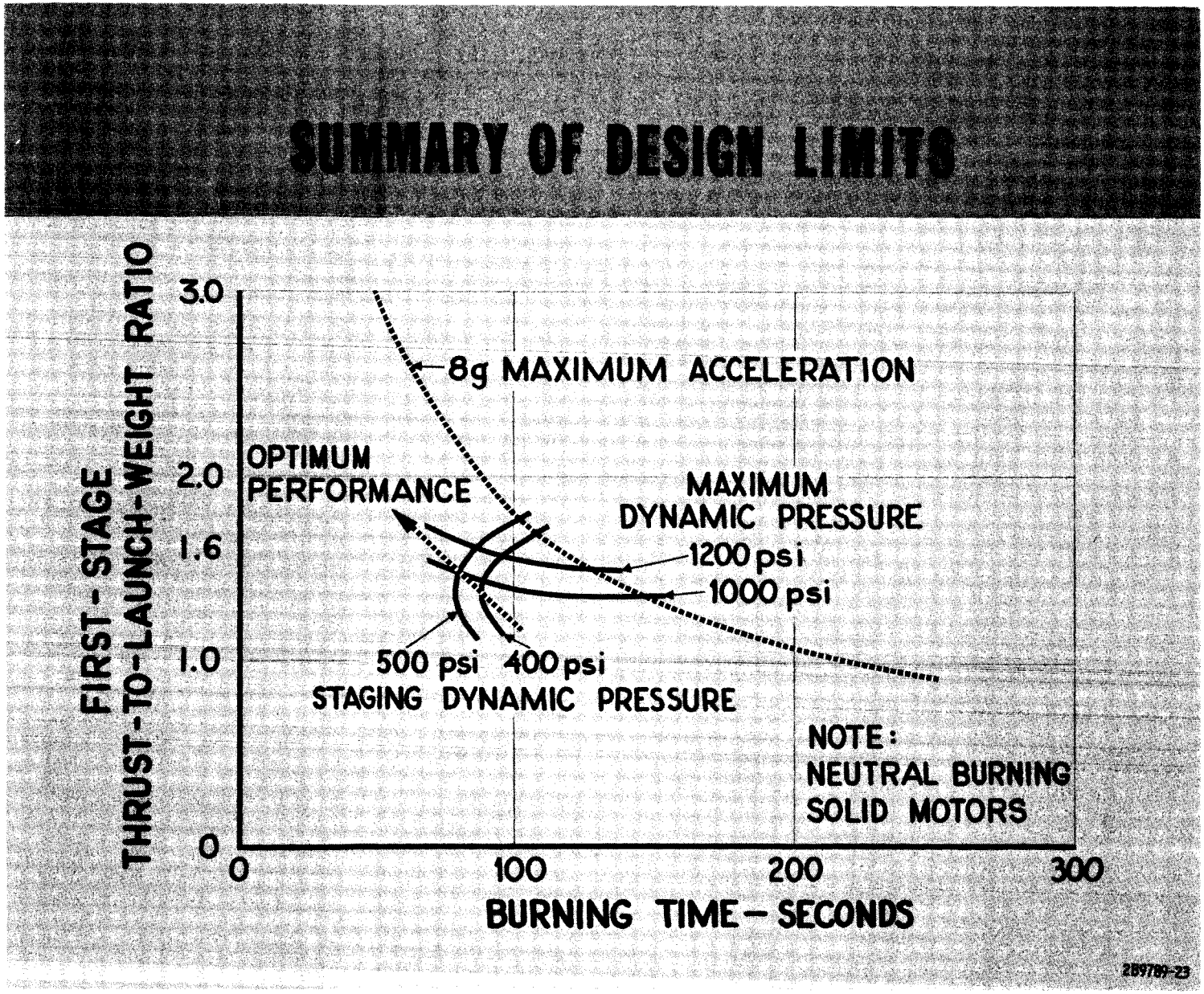
added High Strength Steel Critical Crack at Ultimate Stress divided by 1.4 factor of Safety



SUMMARY OF DESIGN LIMITS

These plots indicate the effects of dynamic pressure and acceleration limits on first-stage thrust-to-weight ratios and burn time.

It may be noted that the available design region is severely restricted by these limits.


SUMMARY OF DESIGN LIMITS
FIRST-STAGE THRUST-TO-LAUNCH-WEIGHT RATIO
3.0
2.0
1.6
1.0
0
8g MAXIMUM ACCELERATION
OPTIMUM PERFORMANCE
MAXIMUM DYNAMIC PRESSURE
1200 psi
1000 psi
500 psi
400 psi
STAGING DYNAMIC PRESSURE
NOTE:
NEUTRAL BURNING SOLID MOTORS
0
100
200
300
BURNING TIME – SECONDS
289789-23

PRELIMINARY PERFORMANCE PER J-2 ENGINE

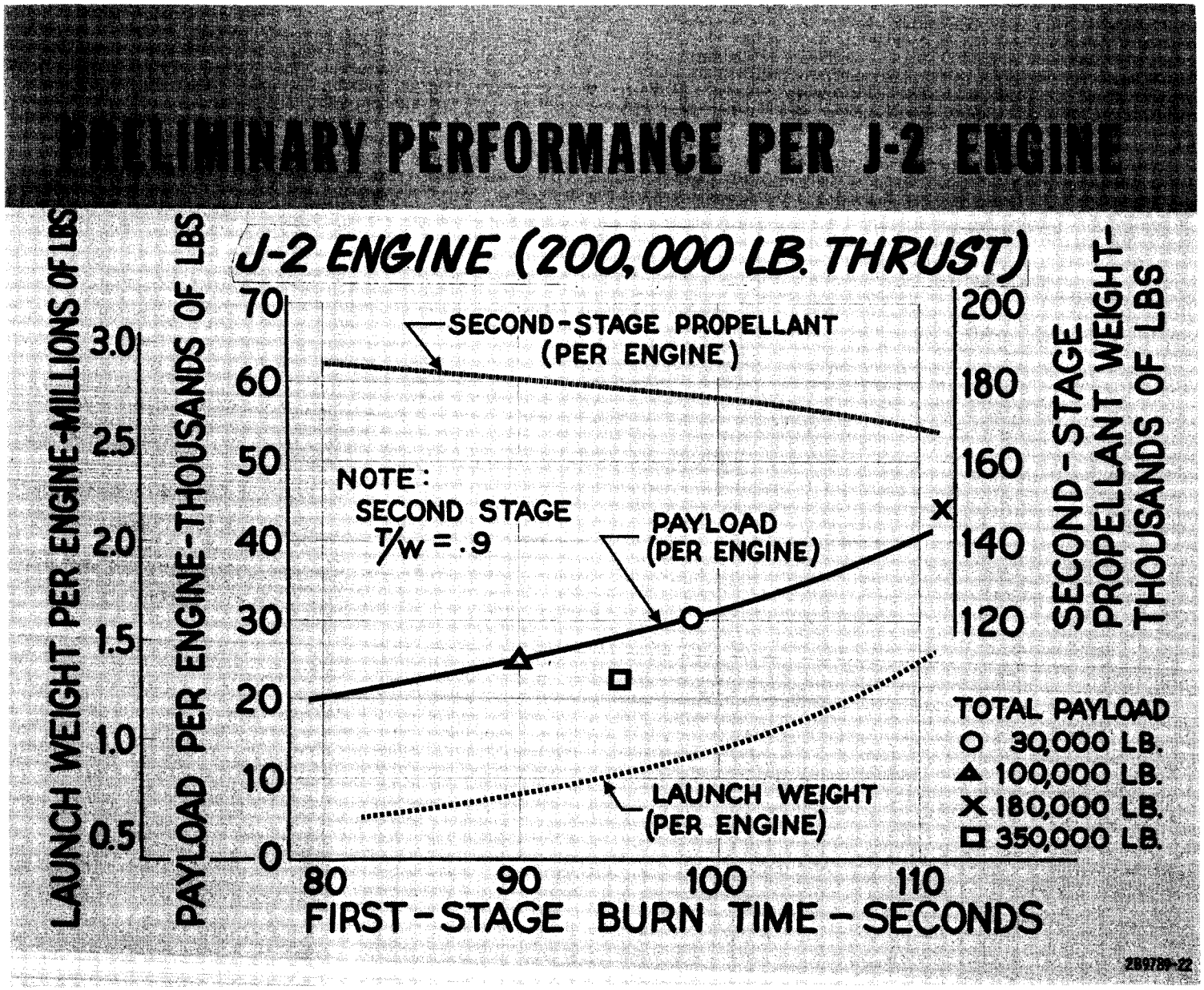
The accompanying chart shows how preliminary vehicle performance characteristics can be selected to satisfy specific payloads and numbers of upper-stage engines. The vehicles selected from this chart also satisfy the previously mentioned design limitations. The following assumptions were used for the chart: The ratio of propellant weight to stage weight (λ') for the solid stage was 0.87, and the sea-level specific impulse was 240 seconds; the liquid stage λ' was 0.92, and vacuum specific impulse was 428 seconds.

In Example 1 the payload was 30,000 pounds with one J-2 engine. It is desirable to keep the solid stage burn time less than 100 seconds; thus, a burn time of 98 seconds was selected, resulting in a launch weight of 900,000 pounds and a second-stage propellant weight of 170,000 pounds.

In Example 2 the payload was 100,000 pounds with four J-2 engines. This is equivalent to 25,000 pounds of payload for each engine.

In Example 3 the payload was 180,000 pounds with four J-2 engines, which is equivalent to 43,000 pounds of payload per engine. With such a large value of payload per engine, it is necessary to increase the burn time beyond 100 seconds to at least 112 seconds. This also results in a somewhat marginal second-stage thrust-to-weight ratio of .85.

In Example 4 the payload was 350,000 pounds with three Y-1 engines. Three Y-1 engines are equivalent in thrust to 15 J-2 engines. The required payload equivalent is 23,000 pounds per engine. Thus, burn times less than 100 seconds can be selected along with a relatively high second-stage thrust-to-weight ratio.


PRELIMINARY PERFORMANCE PER J-2 ENGINE
J-2 ENGINE (200,000 LB. THRUST)
LAUNCH WEIGHT PER ENGINE-MILLIONS OF LBS
3.0
2.5
2.0
1.5
1.0
0.5
PAYLOAD PER ENGINE-THOUSANDS OF LBS
70
60
50
40
30
20
10
0
SECOND-STAGE PROPELLANT (PER ENGINE)
NOTE:
SECOND STAGE
T/W = .9
PAYLOAD (PER ENGINE)
LAUNCH WEIGHT (PER ENGINE)
200
180
160
140
120
SECOND-STAGE PROPELLANT WEIGHT-THOUSANDS OF LBS
TOTAL PAYLOAD
30,000 LB.
100,000 LB.
180,000 LB.
350,000 LB.
80
90
100
110
FIRST-STAGE BURN TIME-SECONDS
289789-22

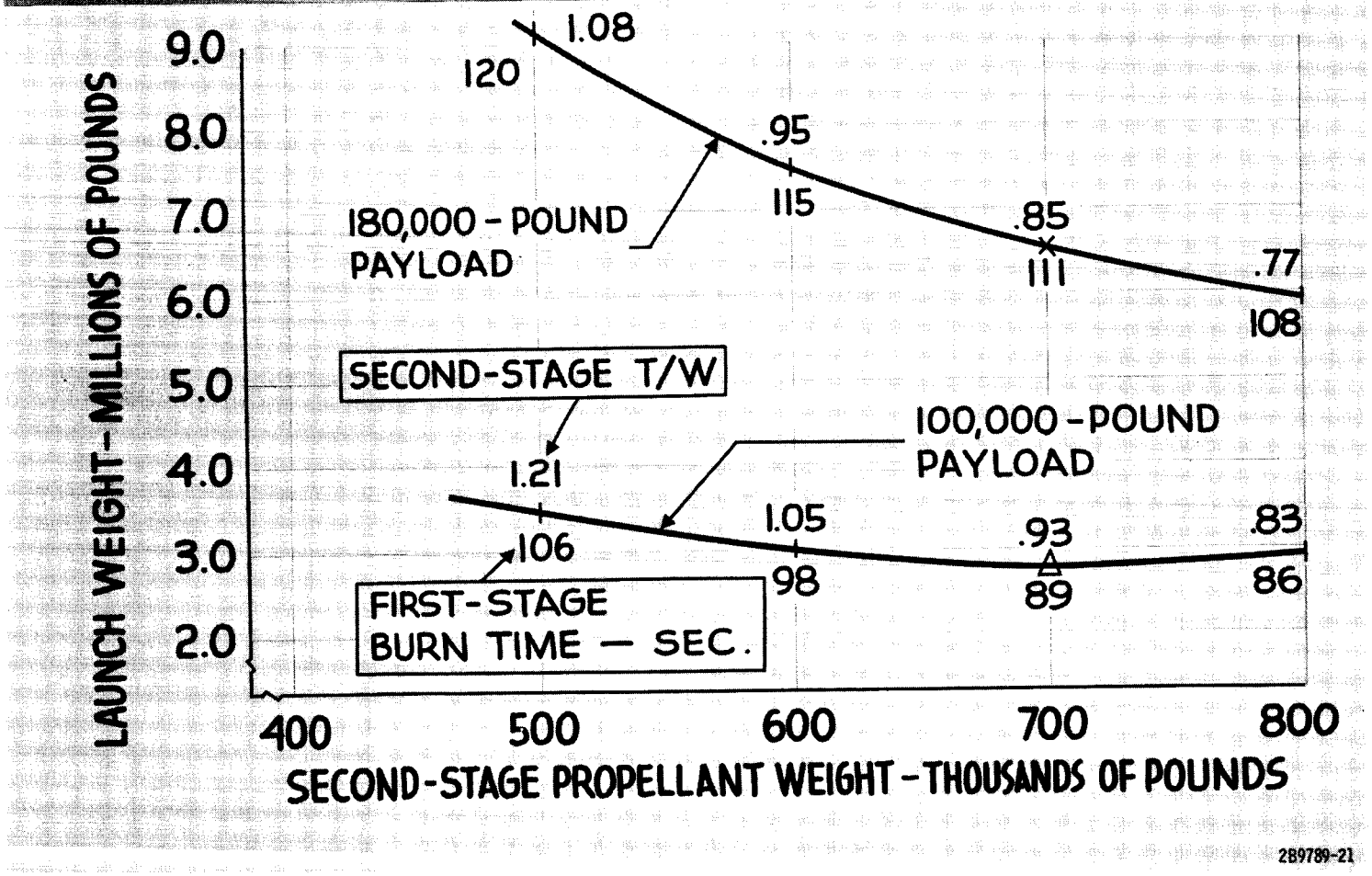
PRELIMINARY VEHICLE SELECTION

The previous chart (performance per J-2 engine) modified for upper-stage thrust-to-weight ratio and λ' was then used to determine vehicle preliminary performance in terms of launch weight and second-stage propellant. The preliminary vehicle selected for the 100,000- and 180,000-pound payloads are indicated on the chart.

The launch weight for the 180,000-pound payload vehicle could not be minimized because of the extremely low second-stage thrust-to-weight ratio required.

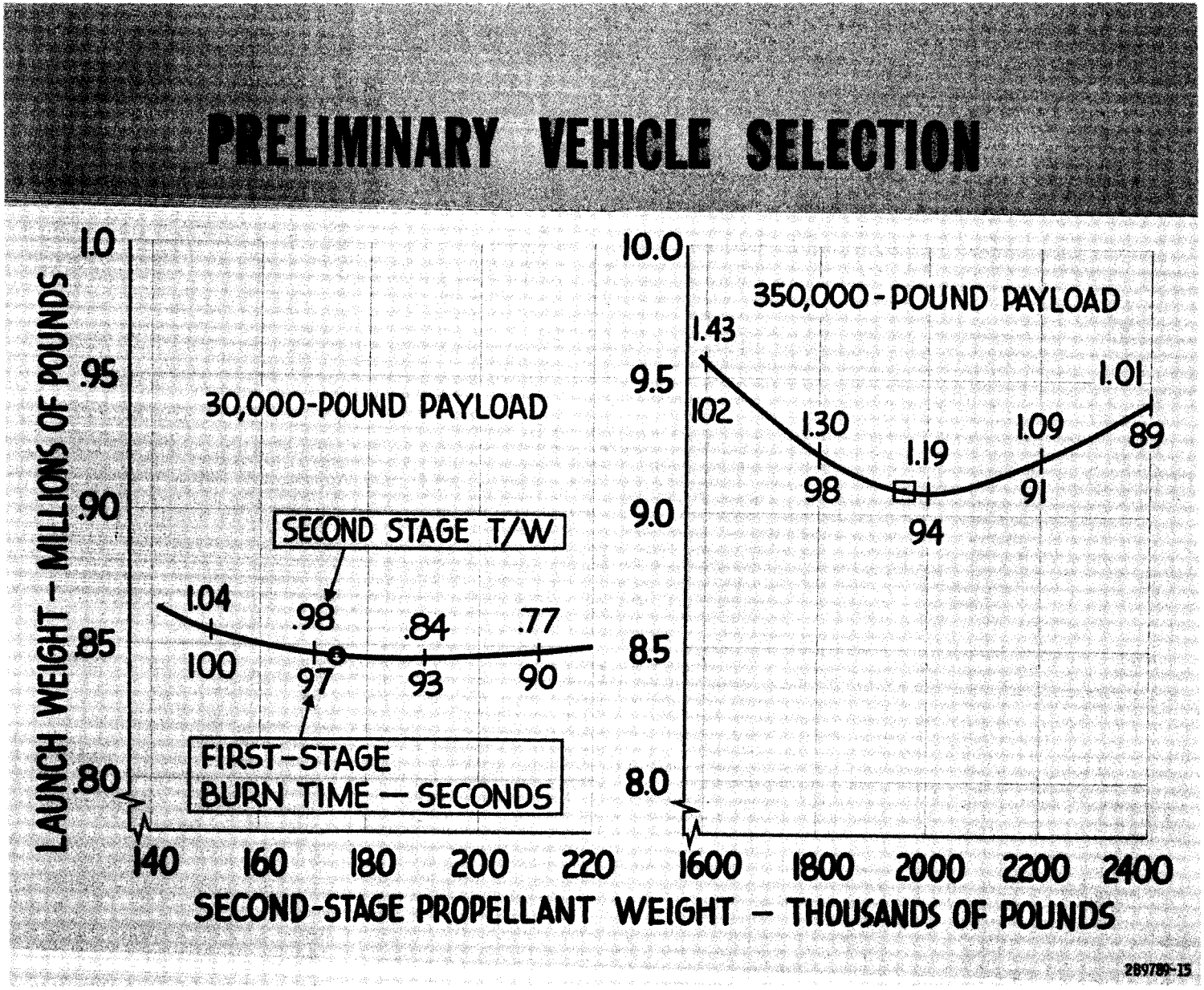
Vehicle definitions specified for this phase of the study defined the ratio of payload to second-stage thrust for each type of vehicle, and it is this ratio that significantly influences the performance characteristics of each.

PRELIMINARY VEHICLE SELECTION



PRELIMINARY VEHICLE SELECTION

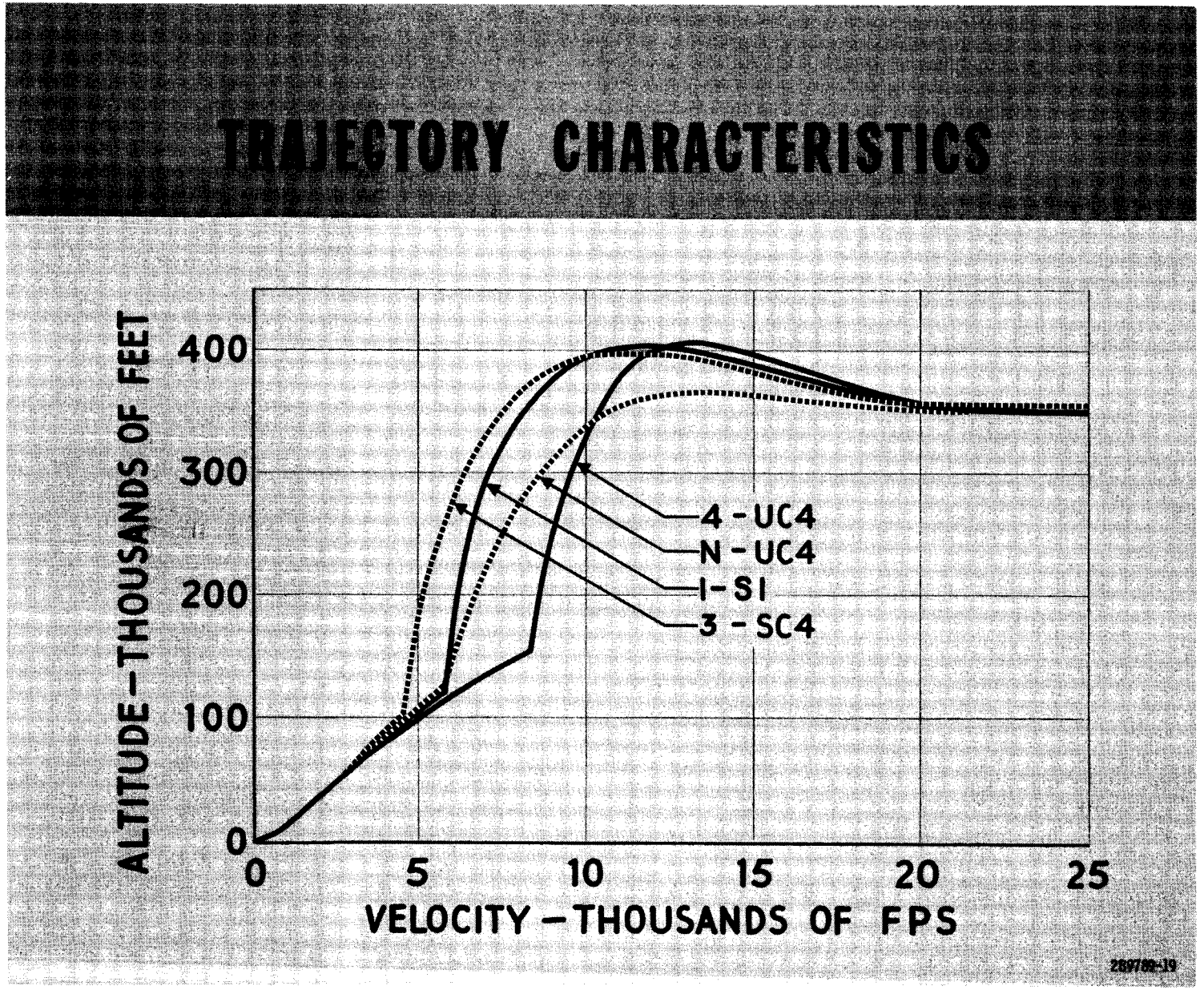
The thrust-to-weight ratio and related first-stage burn times are shown for the 30,000- and 350,000-pound payload vehicles.


PRELIMINARY VEHICLE SELECTION
LAUNCH WEIGHT – MILLIONS OF POUNDS
1.0
.95
.90
.85
.80
30,000-POUND PAYLOAD
SECOND STAGE T/W
1.04
.98
.84
.77
100
97
93
90
FIRST-STAGE
BURN TIME — SECONDS
140
160
180
200
220
10.0
9.5
9.0
8.5
8.0
350,000-POUND PAYLOAD
1.43
1.01
102
1.30
1.19
1.09
89
98
94
91
1600
1800
2000
2200
2400
SECOND-STAGE PROPELLANT WEIGHT – THOUSANDS OF POUNDS
289789-13

TRAJECTORY CHARACTERISTICS

The altitude-velocity trajectory characteristics are indicated for the four selected vehicles.

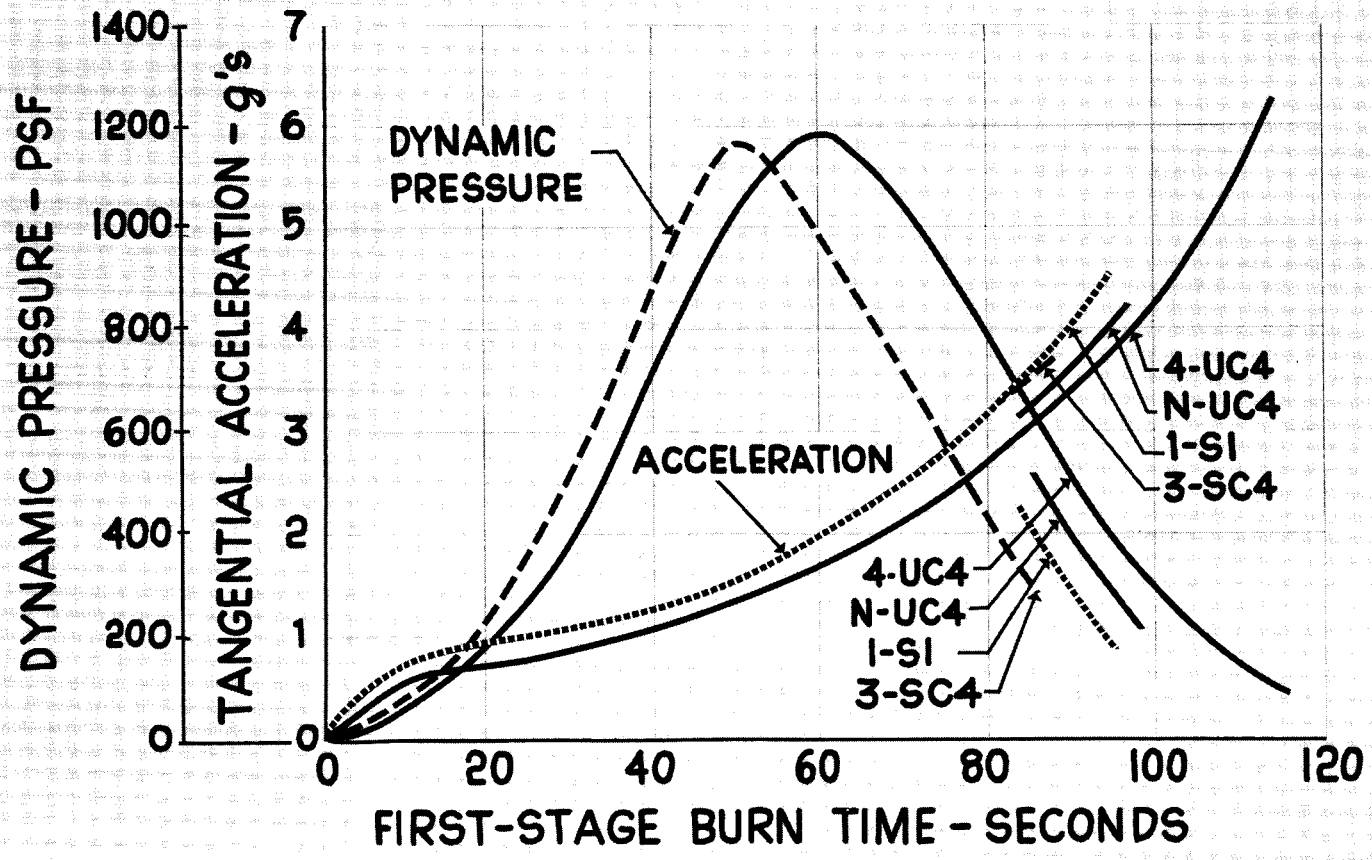
The drop-off in maximum altitude prior to second-stage burnout is characteristic of low second-stage thrust-to-weight ratios.


TRAJECTORY CHARACTERISTICS
ALTITUDE – THOUSANDS OF FEET
400
300
200
100
0
0
5
10
15
20
25
VELOCITY – THOUSANDS OF FPS
4 - UC4
N - UC4
I - SI
3 - SC4

TRAJECTORY CHARACTERISTICS

The maximum dynamic limits of 1200 psf and accelerations of 8 g were not exceeded by the vehicles configurated. Slight variations in trajectories were required to meet the maximum dynamic pressure limit of 1200 psf. In the case of the 4-UC4 and N-UC4 vehicles, it was necessary to reduce the launch thrust-to-weight ratio values to 1.5 and 1.55, respectively. Increased first-stage burn time generally reduces staging dynamic pressure but tends to increase maximum dynamic-pressure values.

TRAJECTORY CHARACTERISTICS

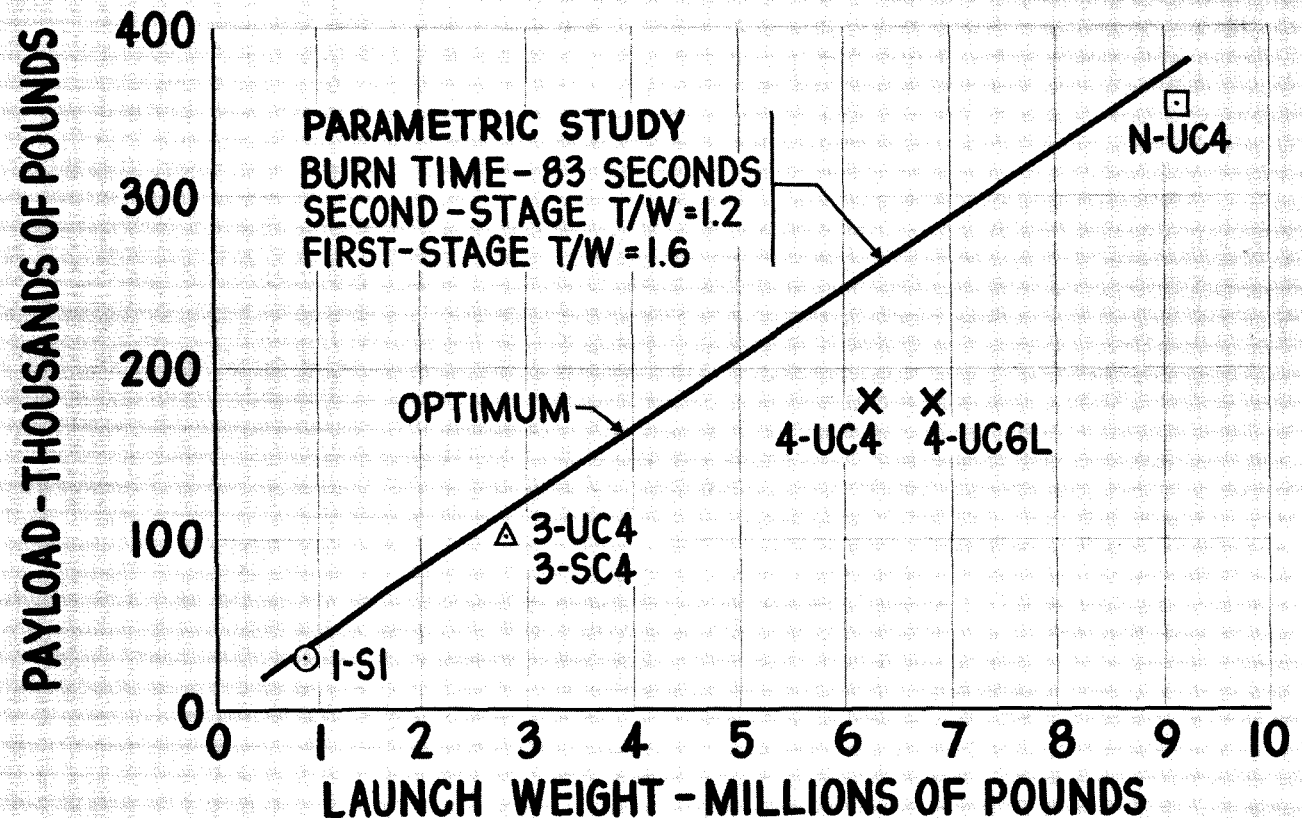


2B9789-14

PERFORMANCE COMPARISON OF FINAL VEHICLES SELECTED

The payloads and launch weights of the final vehicles are compared to the parametric studies performed in Phase I. The 1-S1 vehicle has about 20-percent increase in launch weight over that of the optimum values obtained from the parametric studies. This is mainly due to the lower second-stage thrust-to-weight ratio and allowances for thrust-vector-control (TVC) fluid. The 3-UC4 vehicle has about 16-percent increase in launch weight over that of the parametric study, likewise due to the second-stage thrust-to-weight ratio being on the low side (and TVC fluid). The 4-UC4 vehicle has about 50-percent increase in launch weight over the parametric study, which is due to not only the low second-stage thrust-to-weight ratio but the long first-stage burn time as well. The N-UC4 vehicle compares favorably to the parametric study, with only an 8-percent increase in launch weight relative to the optimum value.

PERFORMANCE COMPARISON OF FINAL SELECTED VEHICLES

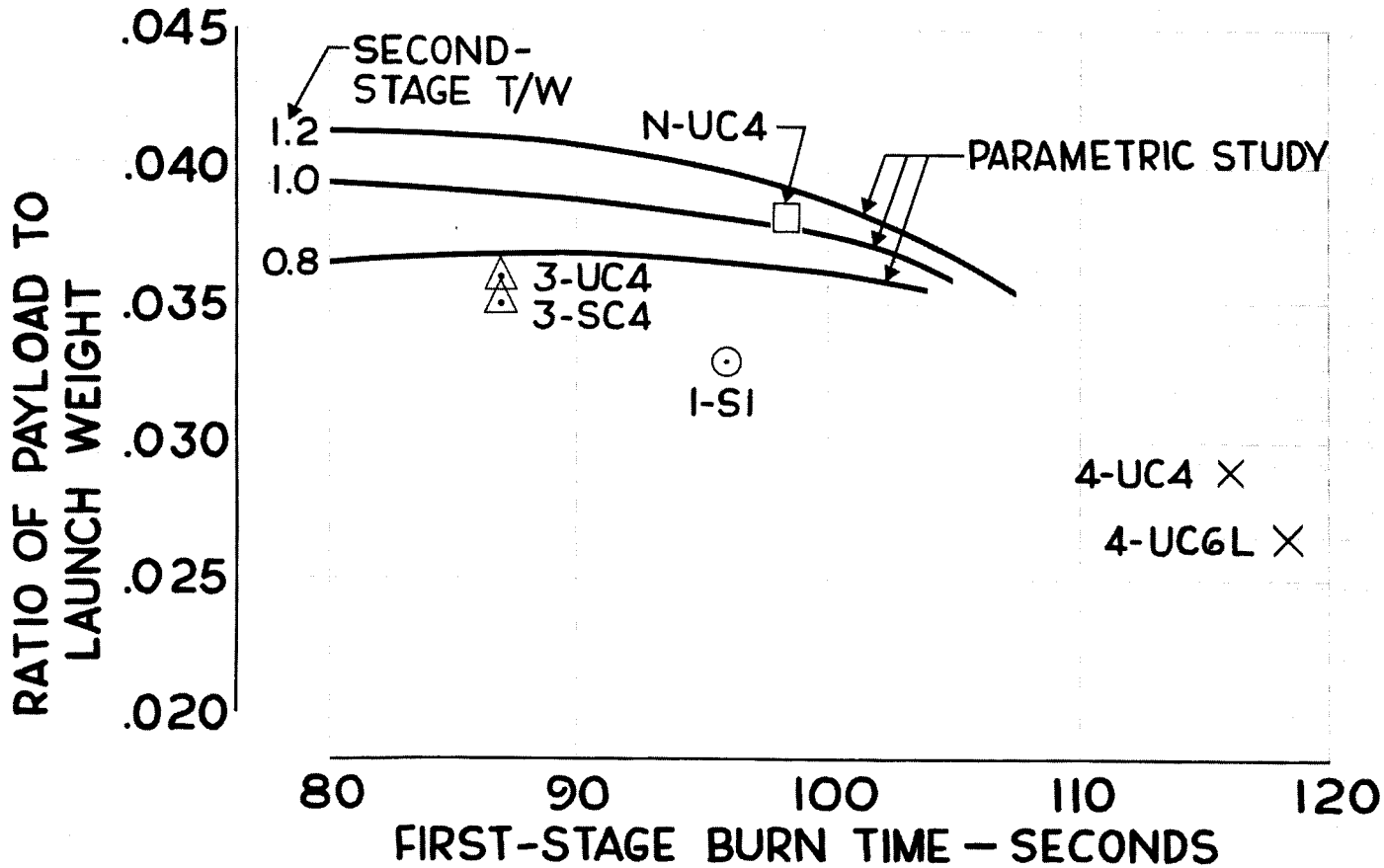


2B9789-18

PERFORMANCE COMPARISON OF FINAL VEHICLES SELECTED

As a supplement to the preceding chart, these plots demonstrate the payload to launch-weight efficiency of the vehicles studied.

PERFORMANCE COMPARISON OF FINAL SELECTED VEHICLES



2B9789-16

MOTOR CONCEPT

This study has afforded an opportunity to examine two basic solid-propellant motor design concepts for one-piece (monolithic) motors and segmented motors. As shown here, they have been compared for the 100,000-pound payload vehicle.

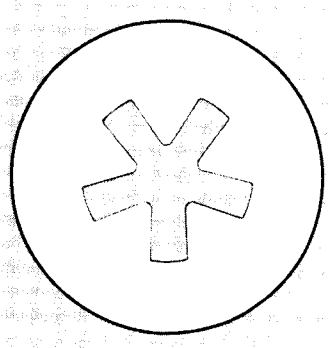
Typical sections through the propellant grain are shown, together with pertinent design information. The unitized section on the left is a Thiokol design developed for a solid-propellant NOVA motor. The section on the right is a circular-ported internal and end-burning cylindrical segment now being proposed generally by the industry.

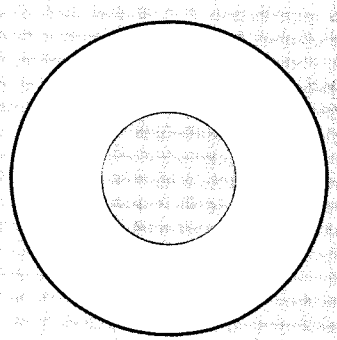
Performance characteristics of the two motors are similar. The weight of the joints and insulation of the segmented motor results in a slightly lower motor mass fraction than the unitized motor. The circular port of the segmented grain gives rise to less stress concentration for an equivalent cross-sectional loading, and the transverse cuts relieve axial stresses and provide good grain inspection points prior to motor assembly.

MOTOR CONCEPT

PRELIMINARY COMPARATIVE DESIGNS

3-UC4	CONFIGURATION	3-SC4
1,106,640	THRUST (LB.)	1,129,100
398,655	$W_{PROPELLANT}$ (LB.)	406,748
436,995	W_{MOTOR} (LB.)	453,413
0.912	W_P/W_M (NO TVC)	0.897
160	GRAIN O.D. (IN. NOM.)	160
35.2	WEB THICKNESS (IN.)	48
0.83	VOLUMETRIC LOADING	0.83





FOR BOTH MOTORS: $\bar{P}_C$ = 800 PSIA ϵ = 8

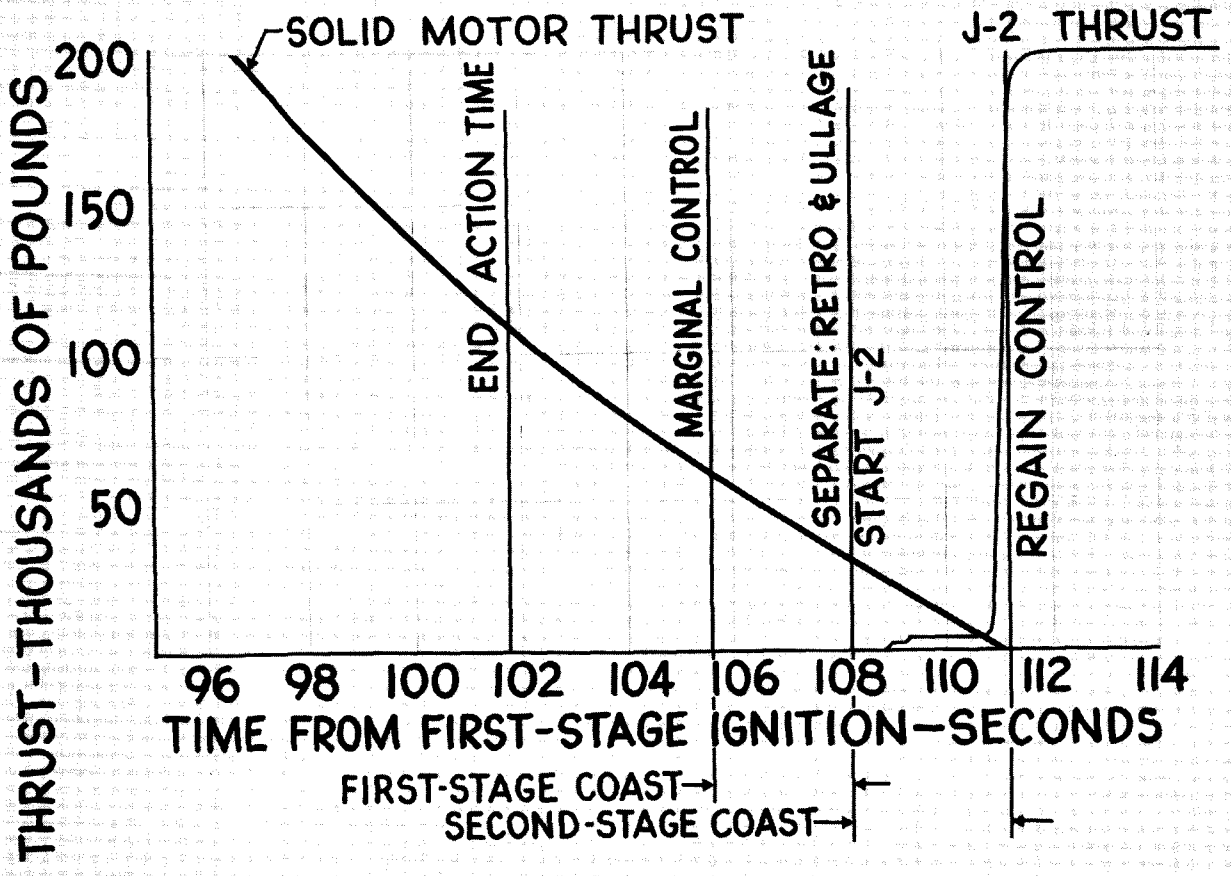
T/W_{VL} = 1.6 t_B (ref.) = 87.08 SEC.

2B9789-45

STAGING SEQUENCE

A study is in progress to define the sequence of staging events. Assuming a typical unitized motor thrust tail-off trace and vehicle control requirement, and the second-stage start transient, it is possible to define times at which separation and second-stage start should occur. In this plot, it is assumed that separation is accomplished with a retrosystem capable of decelerating the booster at 1/2 g. The J-2 is started as soon as a separation of several feet is assured. Effective first- and second-stage coast periods are defined as those intervals when available control forces are less than those required to maintain zero angle of attack. On the basis of this plot, it is apparent that with the type of solid-motor thrust tail-off assumed, several seconds are involved in staging, and near-neutral vehicle stability is required to prevent excessive build-up of angle of attack.

STAGING SEQUENCE



2B9789-36

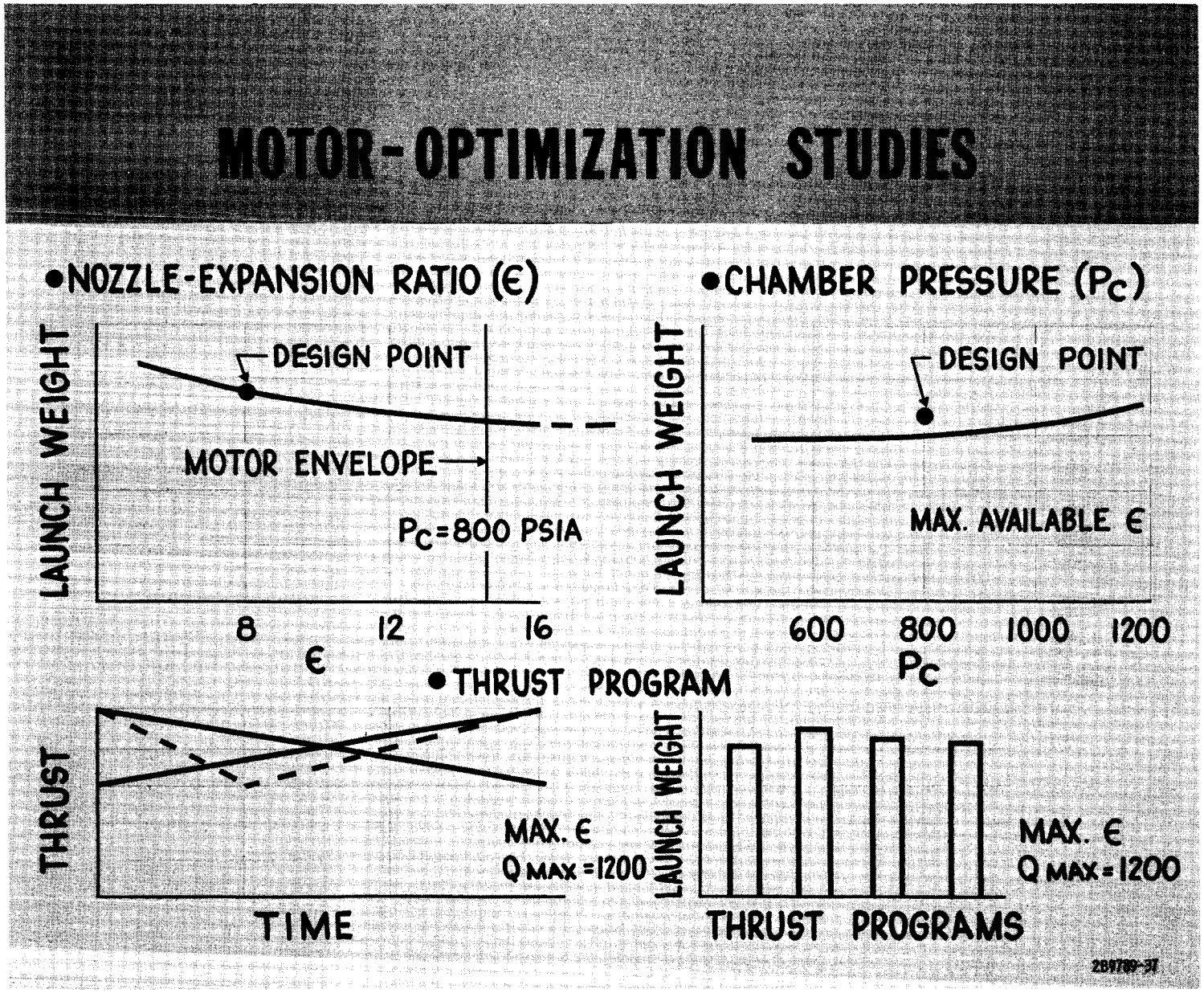
MOTOR OPTIMIZATION STUDIES

A series of studies have been undertaken to define near-optimum solid-propellant motor performance characteristics for the vehicles of this study.

In the first, the effect of varying nozzle expansion ratio at a reference chamber pressure has been investigated. It has been found that motor performance improves with increasing expansion ratio—out to and beyond the motor diameter envelope. Fifteen-degree conical half-angle nozzles, canted at five degrees to alleviate the thrust-vector requirement during uneven burnout of a clustered stage, were assumed.

Using the maximum available expansion ratio, vehicle launch weight is being determined as a function of chamber pressure. With preliminary weight data, launch weight appears to be minimum at a chamber pressure of about 600 psia.

A study is now in progress to learn the effect of thrust program on motor-impulse-to-weight ratio and vehicle launch weight. Simplified progressive, regressive, and saddle thrust-time traces have been assumed. Data on the relative effects of these programs, compared to the rectangular trace, will be available for the final study report.


MOTOR-OPTIMIZATION STUDIES
•NOZZLE-EXPANSION RATIO (ϵ)
LAUNCH WEIGHT
DESIGN POINT
MOTOR ENVELOPE
Pc=800 PSIA
8
12
16
ϵ
•CHAMBER PRESSURE (Pc)
LAUNCH WEIGHT
DESIGN POINT
MAX. AVAILABLE ϵ
600
800
1000
1200
Pc
•THRUST PROGRAM
THRUST
MAX. ϵ
Q MAX =1200
TIME
LAUNCH WEIGHT
MAX. ϵ
Q MAX = 1200
THRUST PROGRAMS
289789-37

THRUST TERMINATION

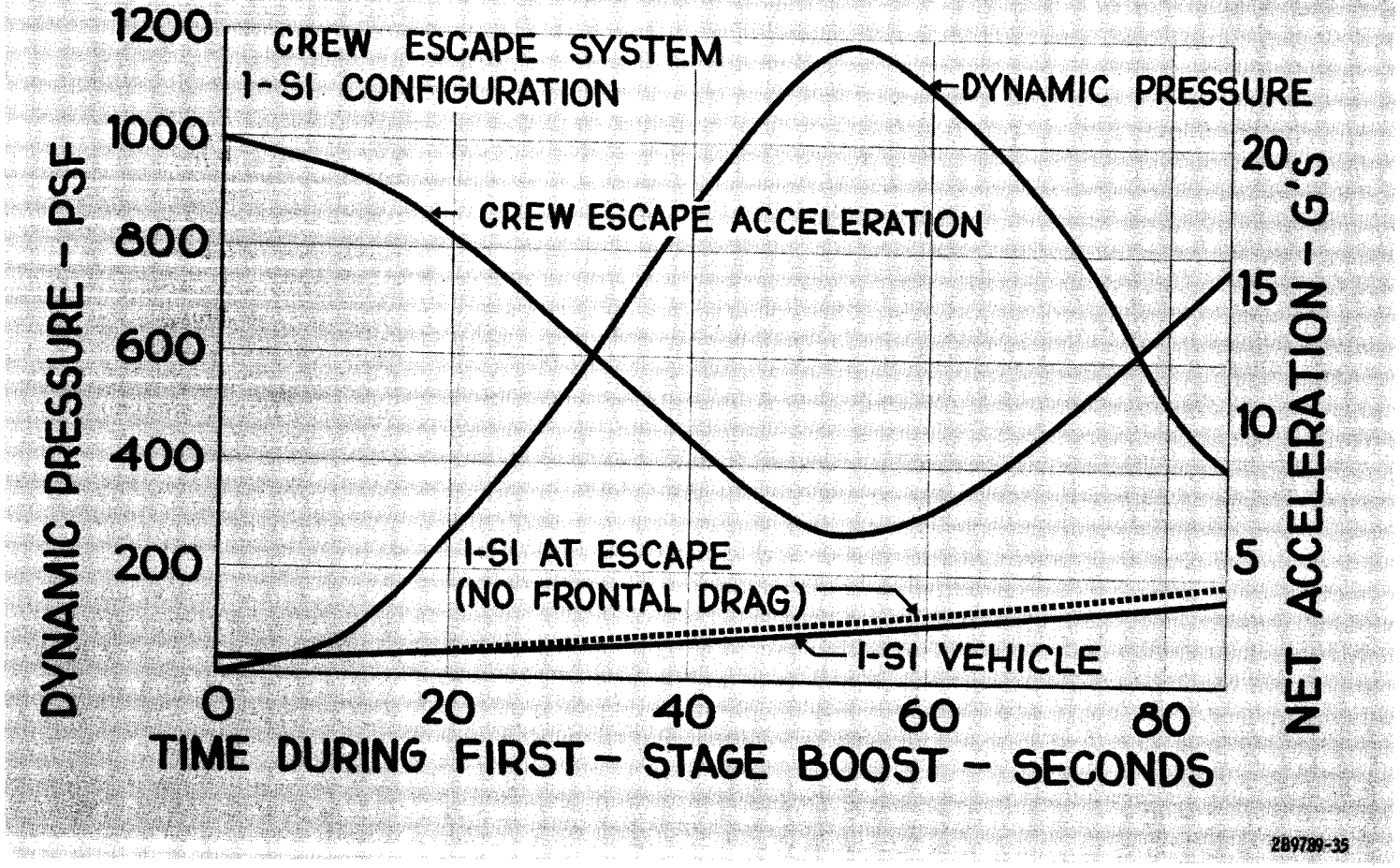
A fundamental question in the use of solid-propellant motors in large space boosters is that of crew and range safety. An impending catastrophic failure of the first stage must be sensed, and acted upon. To destroy the solid stage with the crew capsule still attached is an unacceptable risk of human life; provision must be made for crew escape. It must be determined if a crew capsule accelerating within human tolerance can separate from the booster vehicle.

This is a plot of the initial net acceleration of an Apollo-type escape capsule and the 1-S1 boost vehicle, as functions of the time during first-stage boost at which escape is initiated. The escape capsule is capable of the least net acceleration at high dynamic pressure, where it feels the highest drag. The booster will accelerate slightly faster when relieved of the escape capsule.

A measure of the thrust-termination requirement is the minimum net acceleration between the escape capsule and the booster. It is assumed that the 1-S1 booster is at full thrust, and the escape capsule W/C_DA is 90. Then the minimum net initial acceleration of the escape capsule away from the booster is about 3.5 g's, or about 110 feet in the first second. It can be concluded on the basis of these assumptions that thrust termination is not necessary for the first stage.

This matter should be re-examined as escape capsule and booster detailed design data become available.

THRUST TERMINATION



STABILITY AND CONTROL CHARACTERISTICS

Stability and control characteristics for the critical phases of boost have been computed. First-stage fins are employed to meet a crew-escape stability criterion of time-to-double amplitude of 2 seconds at maximum dynamic pressure. The estimated maximum thrust-vector-control deflections are low for this stability level. At first-stage burnout, vehicle attitude excursions are kept low by aiming the thrust vector through the center of gravity and having low uncontrolled aerodynamic divergence rates. Reasonable second-stage coast times can be obtained for burnout dynamic pressures below 200 psf.

STABILITY AND CONTROL CHARACTERISTICS

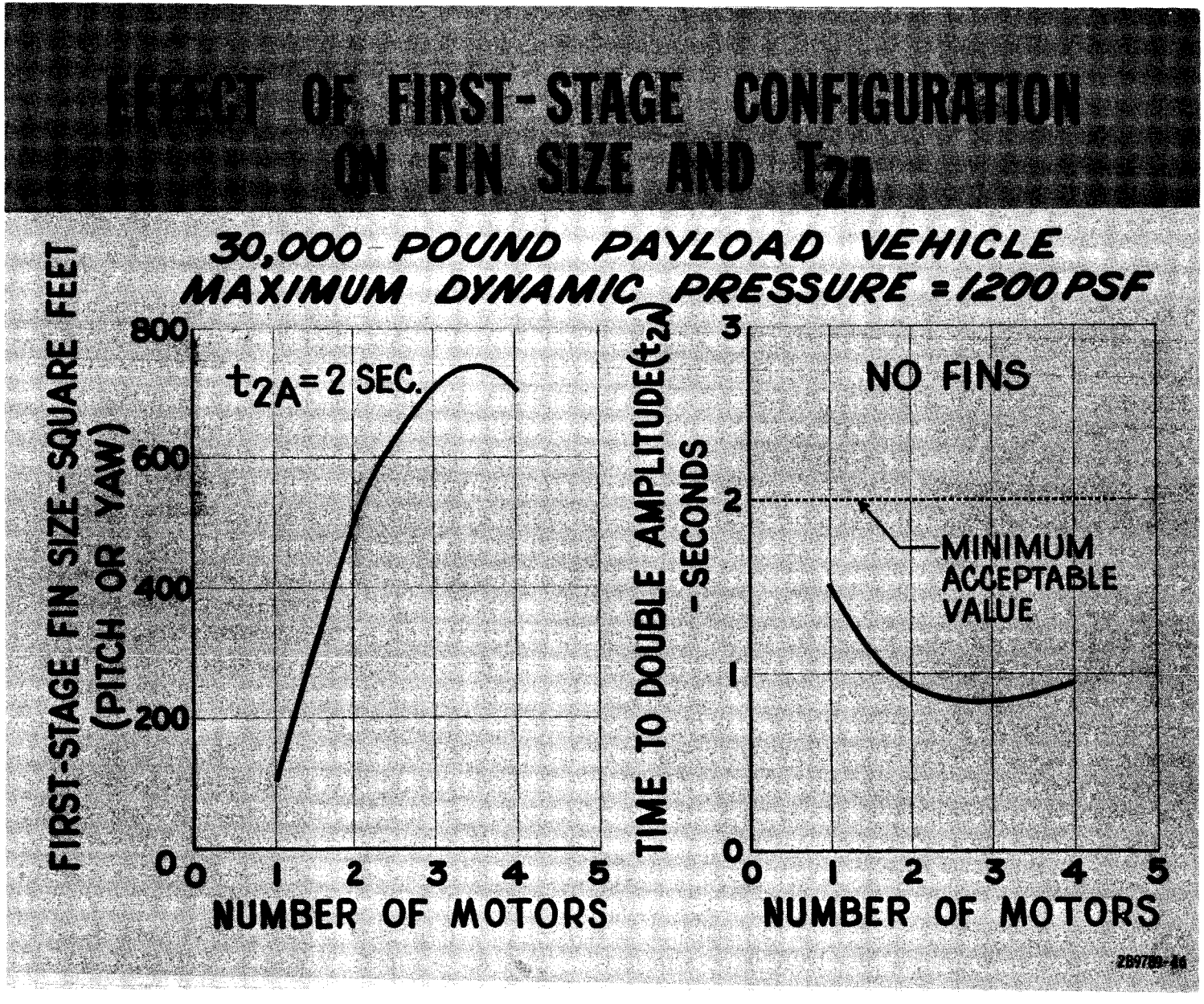
VEHICLE	1-S1	3-SC4 3-UC4	4-UC4	4-UC6L	N-UC4
MAX q = 1200 PSF, M=2					
NO FINS					
t_{2A}, TIME TO DOUBLE AMPLITUDE, SEC.	1.6	1.6	1.7	1.7	3.4
FINS ON FIRST STAGE					
FIN SIZE, FT^2 (PITCH ONLY)	100(1)	450(1)	350(1)	300(1)	0
t_{2A}, TIME TO DOUBLE AMPLITUDE, SEC.	2.0	2.0	2.0	2.0	3.4
$\delta(\alpha = 6°)$, DEGREES	1.4	1.2	1.2	.9	1.0
FIRST-STAGE BURNOUT					
q, PSF	175	257	92	105	203
t_{2A}, TIME TO DOUBLE AMPLITUDE, SEC.	4.3	3.2	7.8	∞	5.8
SECOND-STAGE STARTBURN					
q, PSF	100	150	60	75	135
t_{2A}, TIME TO DOUBLE AMPLITUDE, SEC.	3.4	2.4	3.7	12.6	8.5

(1) = FINS SIZED FOR MAXIMUM q TIME TO DOUBLE AMPLITUDE = 2 SECONDS

2B9789-32

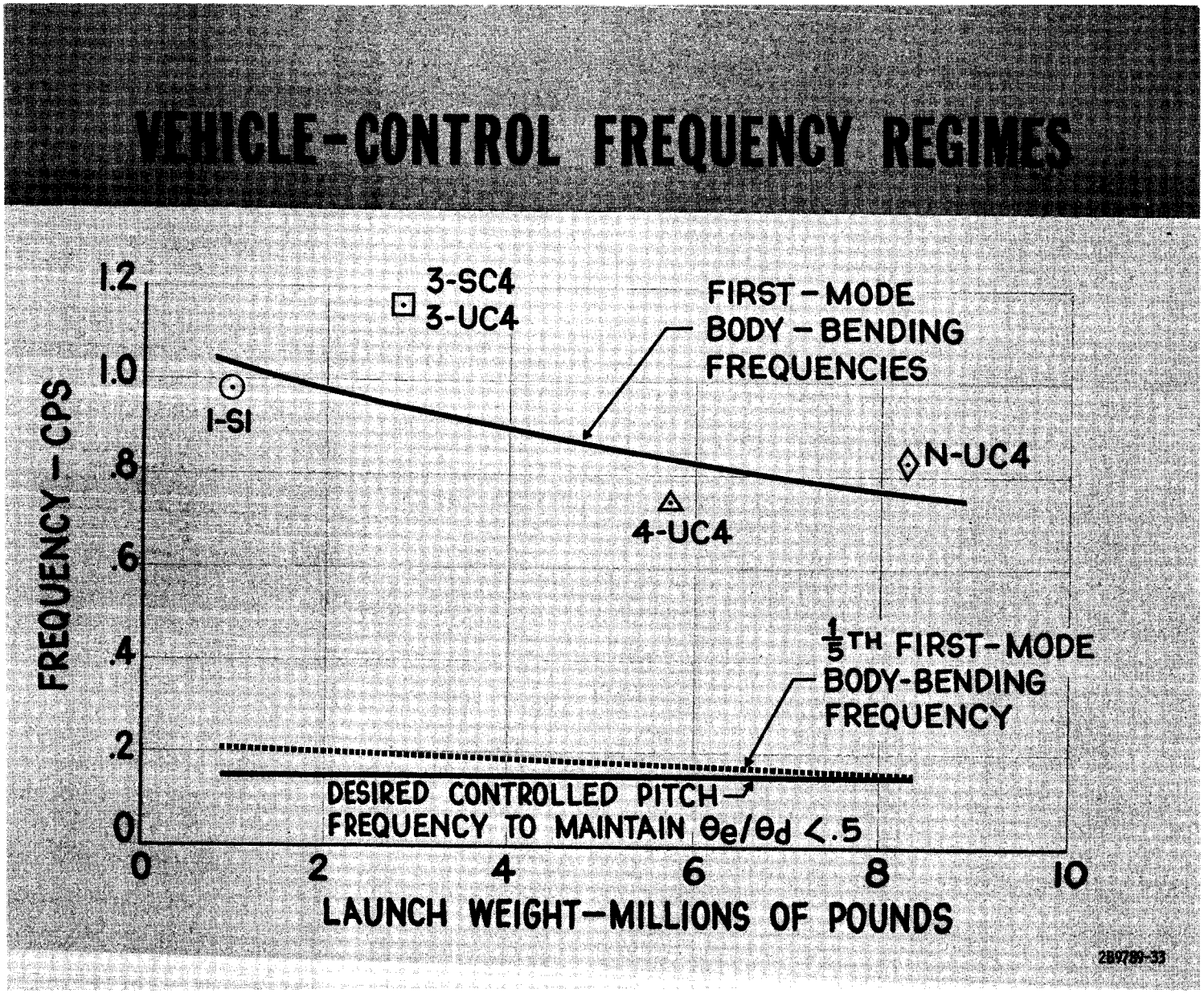
EFFECT OF FIRST-STAGE CONFIGURATION ON FIN SIZE AND TIME TO DOUBLE AMPLITUDE (t_2A)

The effect of clustering upon vehicle stability was investigated for the 30,000-pound payload vehicle at maximum dynamic pressure. Increasing the number of first-stage motors in a cluster increased vehicle instability through a combination of rearward shift in center of gravity, increased normal force, and lowered inertia. Consequently, the single-motor configuration required the least fin area to achieve the stability criterion of time-to-double amplitude of 2 seconds.


EFFECT OF FIRST-STAGE CONFIGURATION ON FIN SIZE AND T_{2A}
30,000 POUND PAYLOAD VEHICLE
MAXIMUM DYNAMIC PRESSURE = 1200 PSF
FIRST-STAGE FIN SIZE-SQUARE FEET (PITCH OR YAW)
800
600
400
200
0
t_{2A} = 2 SEC.
0 1 2 3 4 5
NUMBER OF MOTORS
TIME TO DOUBLE AMPLITUDE (t_{2A}) -SECONDS
3
2
1
0
NO FINS
MINIMUM ACCEPTABLE VALUE
0 1 2 3 4 5
NUMBER OF MOTORS

VEHICLE-CONTROL FREQUENCY REQUIREMENTS

Calculations of first-mode body-bending frequencies for the present configuration are on the order of 1 cps compared to 2 cps in the Phase-I study. Since this new frequency is only five times the estimated controlled pitch frequency, additional study is required to define the available margin of controlled pitch frequency between the upper limit dictated by structural coupling and the lower limit dictated by satisfactory vehicle response.

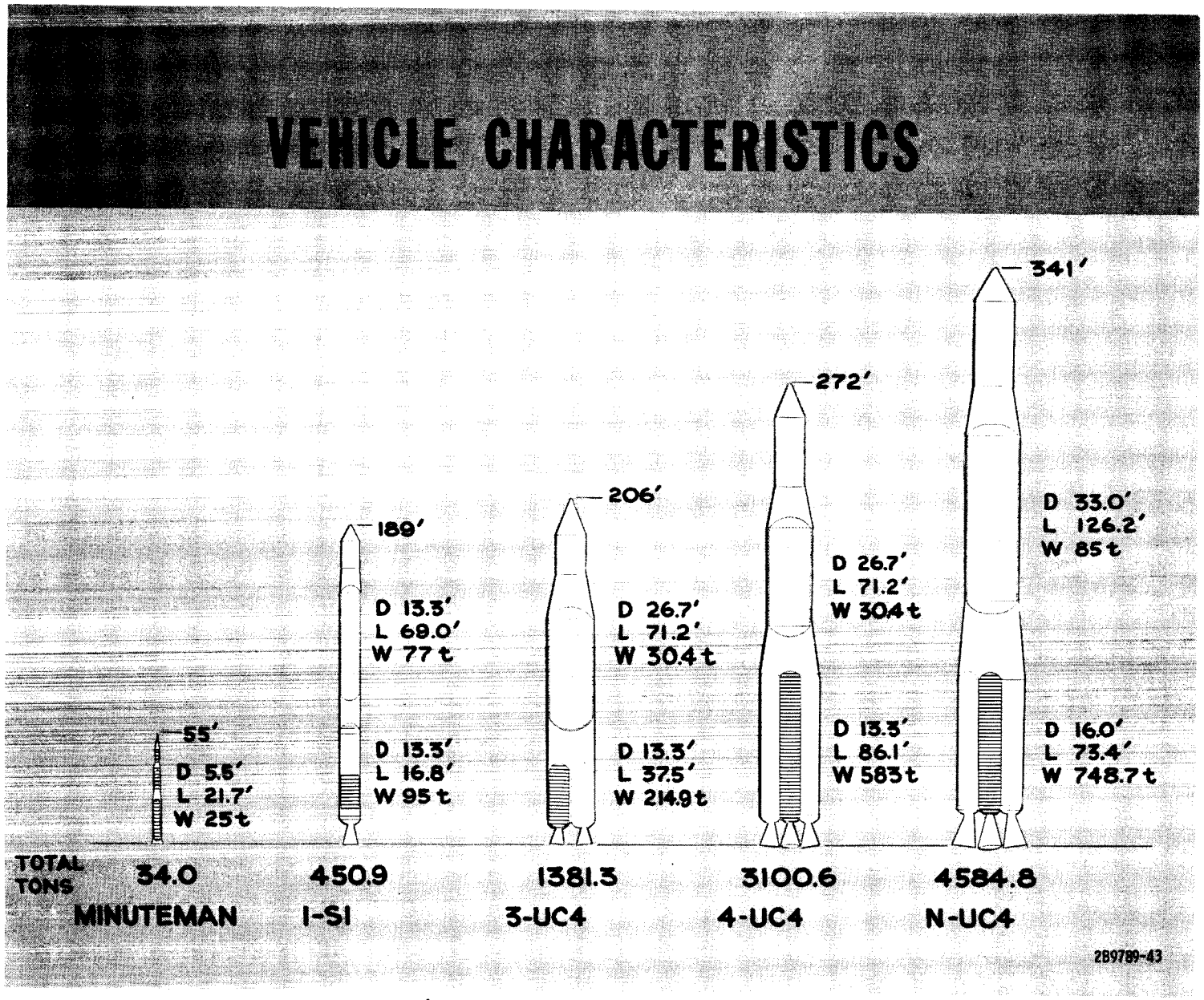

VEHICLE-CONTROL FREQUENCY REGIMES
FREQUENCY – CPS
1.2
1.0
.8
.6
.4
.2
0
3-SC4
3-UC4
1-S1
FIRST-MODE BODY-BENDING FREQUENCIES
N-UC4
4-UC4
1/5TH FIRST-MODE BODY-BENDING FREQUENCY
DESIRED CONTROLLED PITCH FREQUENCY TO MAINTAIN θe/θd < .5
0
2
4
6
8
10
LAUNCH WEIGHT–MILLIONS OF POUNDS
289789-33

VEHICLE CHARACTERISTICS

The ground support system is defined by vehicle configuration. The vehicle characteristics that determine ground support design are the overall weight and height of the launch vehicle; the diameter, length, and weight of solid motors; the diameter, length, and weight of motor cases; and the number of these components making up the launch vehicle.

By comparison with the size and weight of the Minuteman first stage, the first-stage assemblies of vehicles under consideration are up to four times longer, six times greater in diameter, from 4 to 30 times heavier, and include many more components such as motor segments and clustered motor assemblies. The smallest second-stage liquid motor case is longer and almost 2 1/2 times the diameter of the entire Minuteman missile. The overall height of these vehicles is from three to six times the height of Minuteman. The solid propellant required for the first stage of single vehicles varies from 12 to 124 times that required by a first-stage Minuteman motor.

For such sizes and weights, it has become evident that a new approach to the manufacture, transportation, assembly, testing, safety, and quality control of such vehicles must be considered. Of primary consideration is the capacity of industry to produce materials and components, the location of this industrial capacity relative to the assembly and launch complex, and the proposed production schedules.

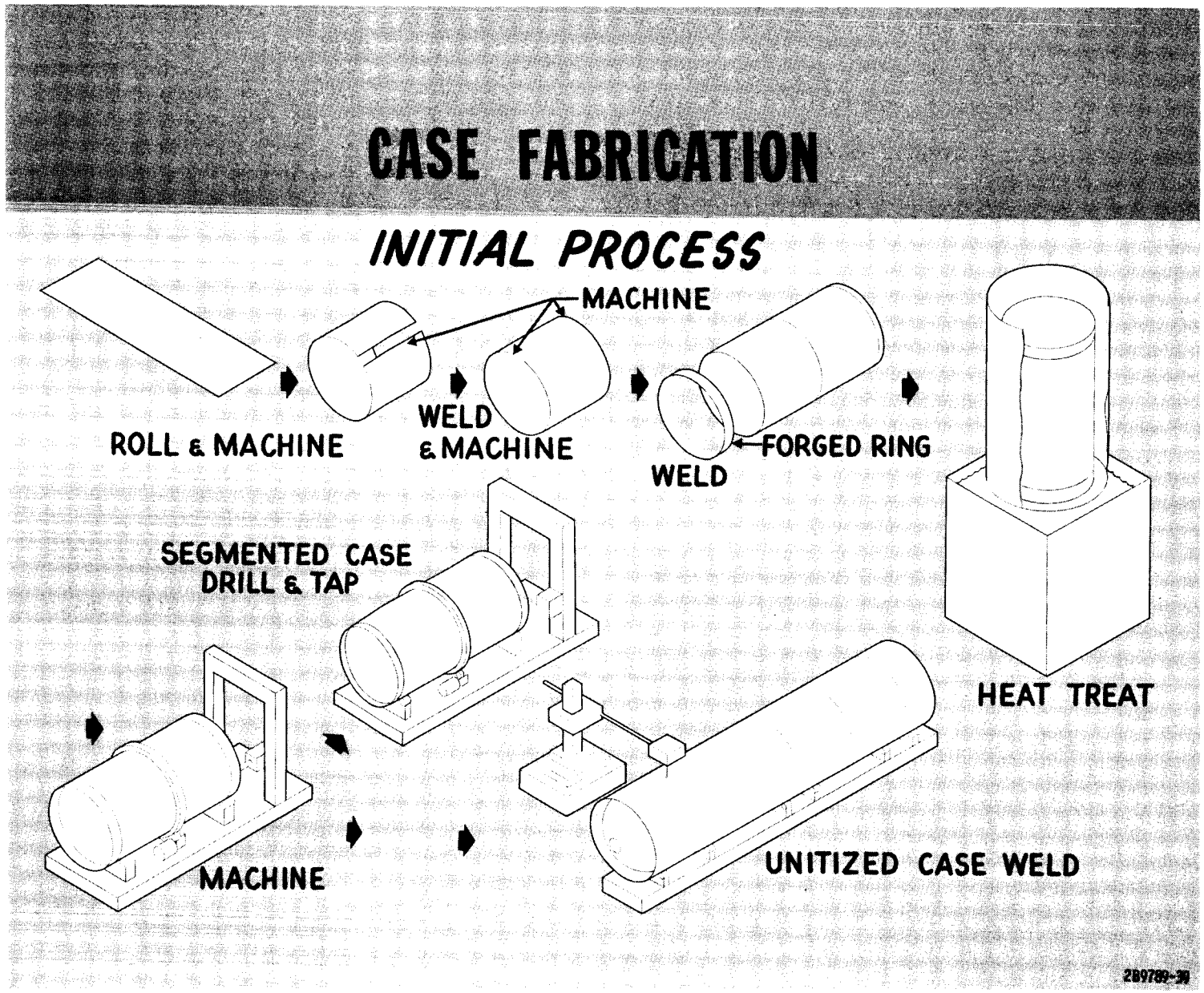

VEHICLE CHARACTERISTICS
55'
D 5.5'
L 21.7'
W 25t
189'
D 13.3'
L 69.0'
W 77 t
D 13.3'
L 16.8'
W 95 t
206'
D 26.7'
L 71.2'
W 30.4 t
D 13.3'
L 37.5'
W 214.9t
272'
D 26.7'
L 71.2'
W 30.4 t
D 13.3'
L 86.1'
W 583t
341'
D 33.0'
L 126.2'
W 85 t
D 16.0'
L 73.4'
W 748.7 t
TOTAL TONS
34.0
450.9
1381.3
3100.6
4584.8
MINUTEMAN
I-S1
3-UC4
4-UC4
N-UC4
2B9789-43

MOTOR CASE FABRICATION

One major manufacturing consideration is the production of solid-propellant motors — segmented and unitized. Although industry is not now geared for production in the sizes and quantities required for the vehicles under study, there is considerable experience in fabricating motor cases and in preparing, casting, and curing propellants. Only slight facility modification is required to produce the larger motor cases, provided the unitized cases are formed in sections and welded together as depicted on the page below. There are some new and modern facilities available for propellant mixing. Also, there are organizations well trained in management and in the technical skills of handling, controlling, and testing motor cases and propellants.

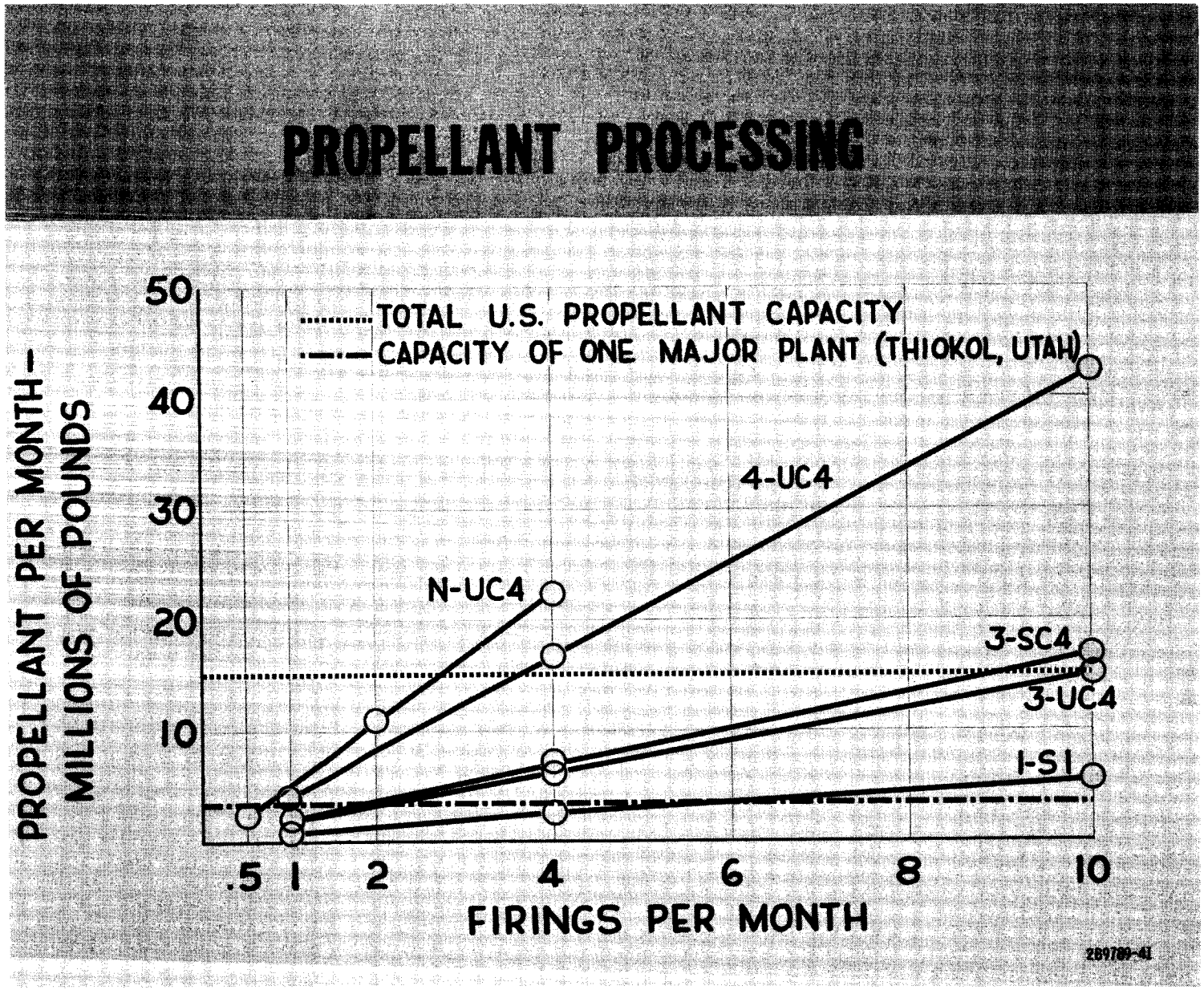
Laboratory specimens of 3/4-inch-thick plates of 4330 steel, heat-treated to 225-psi ultimate tensile strength, have recently been conventionally welded and locally heat-treated with a joint efficiency of 98.2 percent. This process can be developed to production status. Localized heat treat after welding will eliminate the requirement for thickened edges to compensate for loss of strength in the non-heat-treated weld joints.

Spin-forge machines, capable of forging 16-foot-diameter cylinders and end closures for steel billets, should be available in 2 to 3 years. This will permit forming of end closures and cylindrical sections, including heavy cross-sectional areas for machining, joint rings and igniter or nozzle-attach rings from single billets. Longitudinal joints can be eliminated. An immediate reduction in fabrication tools, processes, and flow time will result; plus an increase in the reliability-confidence level.


CASE FABRICATION
INITIAL PROCESS
MACHINE
ROLL & MACHINE
WELD
& MACHINE
FORGED RING
WELD
HEAT TREAT
SEGMENTED CASE
DRILL & TAP
MACHINE
UNITIZED CASE WELD
289789-30

PROPELLANT PROCESSING

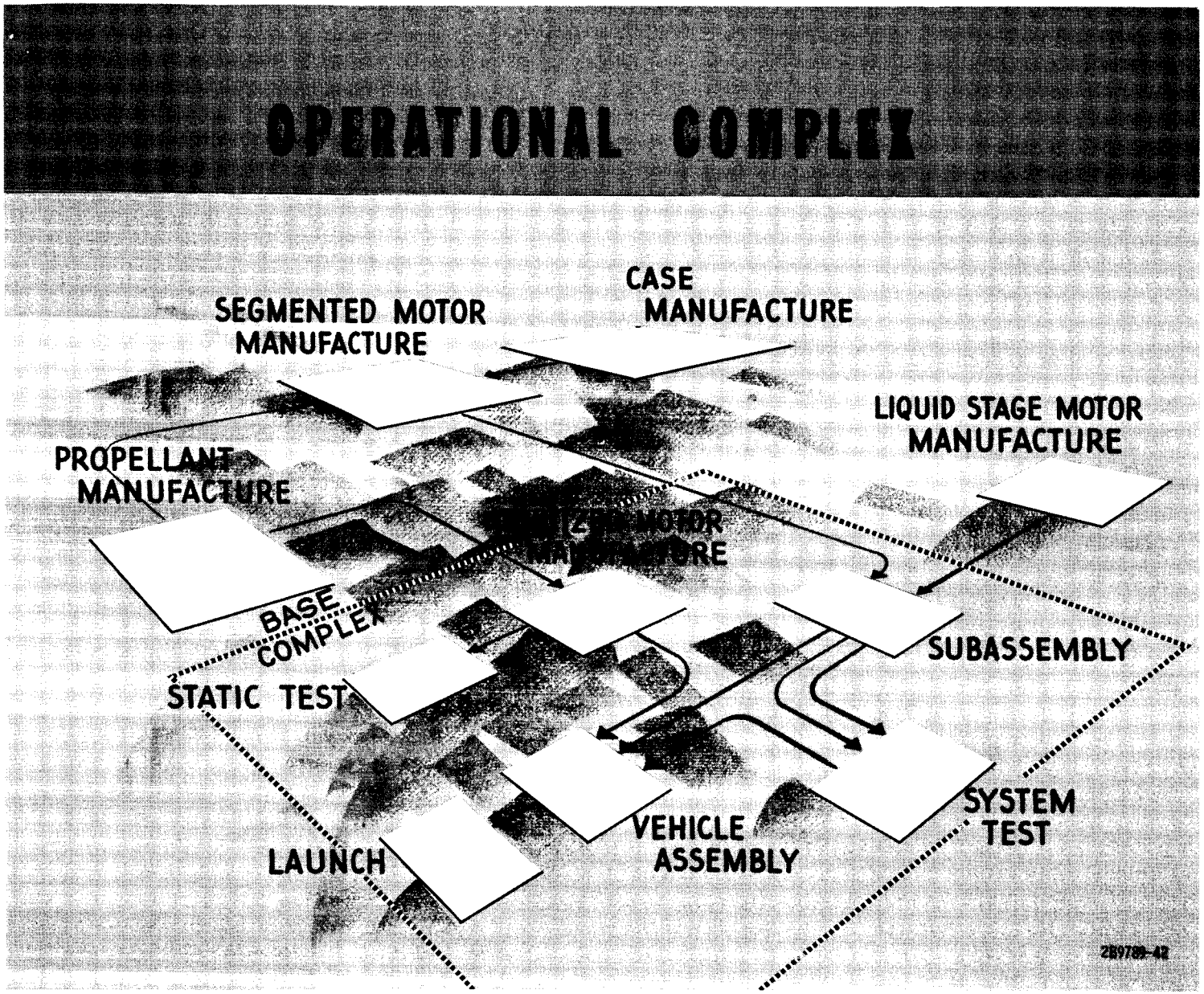
The graph below compares the propellant-processing capacity required to sustain the launch rates of vehicles under study with the total capacity available today. In addition to the requirements of the program under study, the demands of all other solid-propellant motor programs will have to be satisfied. Therefore, the present processing capacity would allow only for the developmental program for each vehicle, the production program for the small vehicle, and the low production rates for the larger vehicles. New facilities will be required to support this program.


PROPELLANT PROCESSING
TOTAL U.S. PROPELLANT CAPACITY
CAPACITY OF ONE MAJOR PLANT (THIOKOL, UTAH)
PROPELLANT PER MONTH—
MILLIONS OF POUNDS
50
40
30
20
10
4-UC4
N-UC4
3-SC4
3-UC4
1-S1
.5
1
2
4
6
8
10
FIRINGS PER MONTH
2B9709-4I

OPERATIONAL COMPLEX

In establishing an operational complex, the factors of time, cost, transportation, and handling, which are fundamental in determining the merits of the total program, were studied. The location of existing and planned plants for manufacturing motor cases, for preparing and mixing propellants, and for casting and curing solid segments or motors sets up a widespread pattern of transportation across the entire United States. By pushing all limits, the transportation pattern at best would be composed of long distances, combinations of modes, special handling, special routes, and numerous transfer terminals. Also, the hazards of transporting explosives, physical damage to the case or grain, and environmental change are items of concern in long-distance transportation and contribute to high costs.

An operational complex was devised that minimizes time, cost, and problems of transportation and handling. In this plan, motor production, vehicle assembly, and launch have been integrated into a single base complex. Within this integrated base, an assembly-line base concept was developed. In support of the assembly-line concept, a waterborne system of transportation was developed.


OPERATIONAL COMPLEX
SEGMENTED MOTOR MANUFACTURE
CASE MANUFACTURE
LIQUID STAGE MOTOR MANUFACTURE
PROPELLANT MANUFACTURE
BASE COMPLEX
SUBASSEMBLY
STATIC TEST
SYSTEM TEST
VEHICLE ASSEMBLY
LAUNCH
289789-42

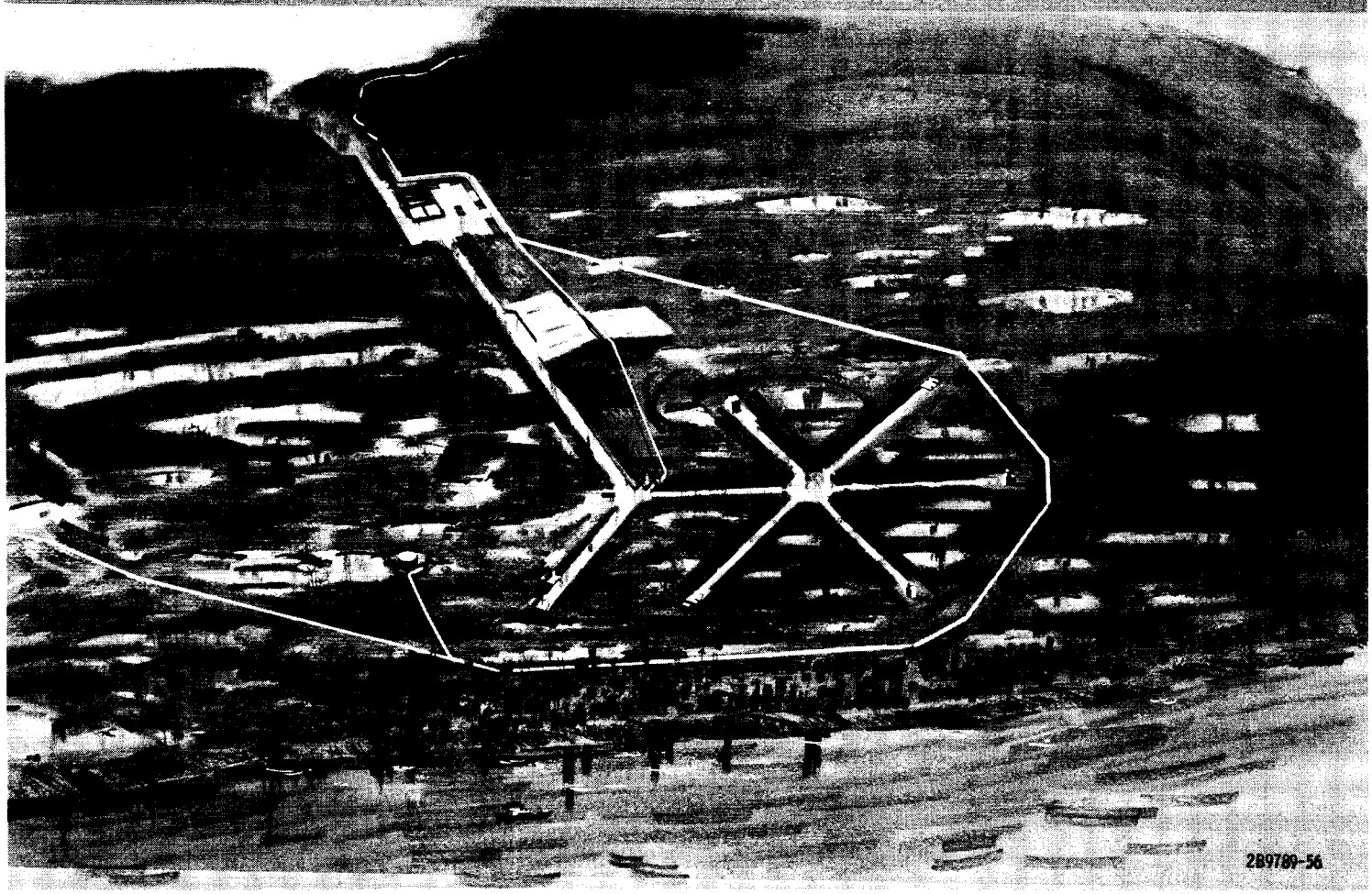
OPERATIONAL CONCEPT

The single, integrated base complex minimizes the hazards of long-distance transportation, reduces the number of production facilities needed and provides for product uniformity and quality control, and allows for construction of new facilities, as required, in the most effective location.

The assembly-line concept has several advantages: It makes maximum continuous use of facilities, provides for major vehicle-replacement units to ensure uninterrupted launch rates, and minimizes land requirements.

The waterborne concept imposes no restrictions on the requirements of this study. The specific advantages with this concept are: Heavy loads can be moved in the simplest and easiest manner; development time and cost are minimized, because the need for roads, rails, foundations, and mechanical equipment is considerably lessened; low-cost canals and transportation equipment can be used; the stability of floating equipment can be combined with the stability of liquid-solid vehicles before final fueling; and this base system concept is adaptable to potential base sites.

OPERATIONAL CONCEPT

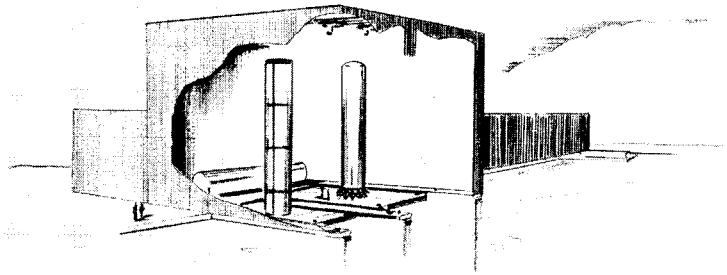


MOTOR PRODUCTION FACILITIES

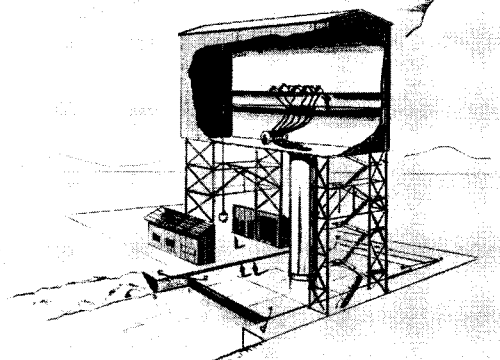
The solid motor cases, propellant raw materials, nozzles, subsystems, interstage structures, liquid cases, and payload are received at an integrated base, either by barge or rail. A solid motor case is prepared and lifted by bridge crane into a vertical position, open end up, and is placed on a barge in a supporting ring. An environmental container is placed around the case. The barge with the motor case is floated out of the loading building and along a canal to a propellant-casting facility adjacent to a mixing plant, where the propellant is poured into the case from overhead nozzles. The motor, still on the barge and at a controlled temperature inside the container, is floated along to a curing dock, where it remains until cured and cooled. The cured motor is then moved into an inspection building where the mandrel is removed, the container removed, and the motor is upended by means of a portable trunnion-mounted strongback. A radiographic inspection of the motor is made in a shielded building. The motor is finally trimmed, ready for assembly.

MOTOR PRODUCTION FACILITIES

PROPELLANT CASTING, CURING & INSPECTION

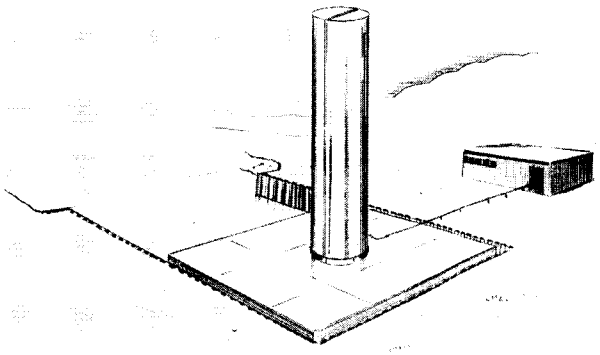


CASE LOADING

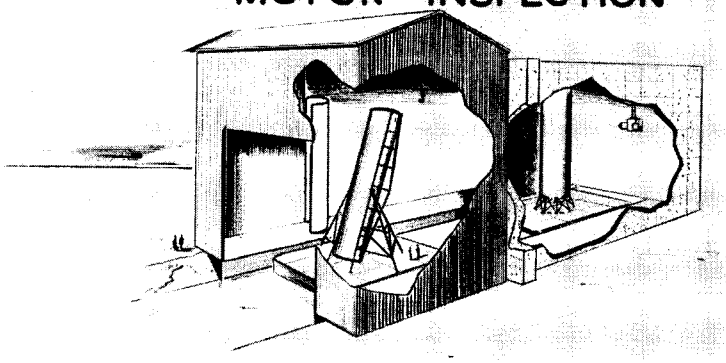


PROPELLANT CASTING

PROPELLANT CURING



MOTOR INSPECTION



2B9789-51

VEHICLE ASSEMBLY COMPLEX

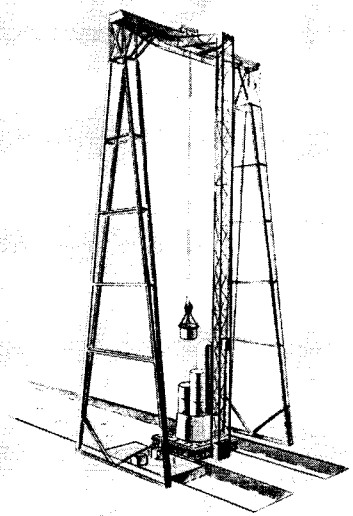
The vehicle is assembled at two separate sites; the first-stage assembly area and the final assembly area separated by suitable quantity-distance. The two functions are separate because of the difference in the tasks and the equipment necessary to accomplish them.

For vehicles made up of unitized solid motors in the first-stage clusters, the task at first-stage assembly area is to lift motors and structures weighing up to 750 tons from delivery barges on to an assembly pad. A heavy-duty, rigid-frame crane structure is mounted on two barges and acts as a simple bridge crane for movement in one direction. Movement in the other direction is accomplished by repositioning the barges.

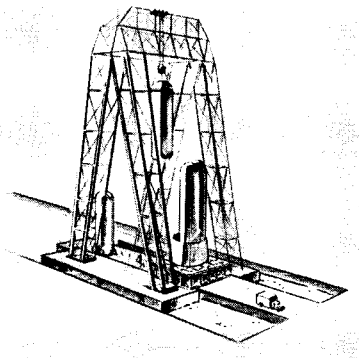
The task at the final-assembly area is to stack the upper stage and payload onto the first stage. This requires a lift of 350 feet for loads up to 100 tons. A crane span is required to move the components from the barges to the centerline of the assembly. The access to upper levels is provided by an elevator tower mounted on shore and attached to the center of the crane structure. Movable catwalks extend from the tower to the interstage levels of the vehicle. Lightweight catwalks are hung from the vehicle structure where needed for assembly and service.

For vehicles made up of segmented solid motors in the first stage, the weights are so much less that the heavy crane is unnecessary. All tasks could be accomplished with facilities used in the final assembly area.

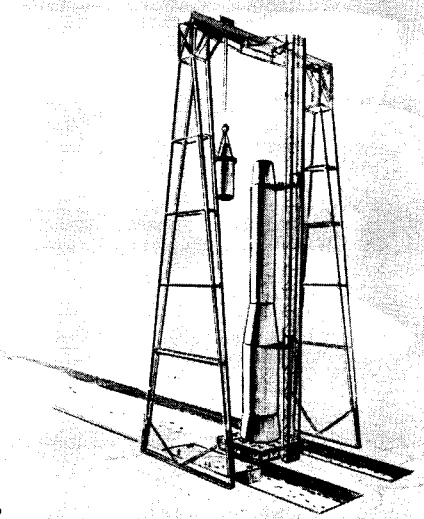
VEHICLE ASSEMBLY COMPLEX



1ST-STAGE ASSEMBLY
SEGMENTED MOTORS



1ST-STAGE ASSEMBLY
UNITIZED MOTORS



FINAL ASSEMBLY

2B9789-50

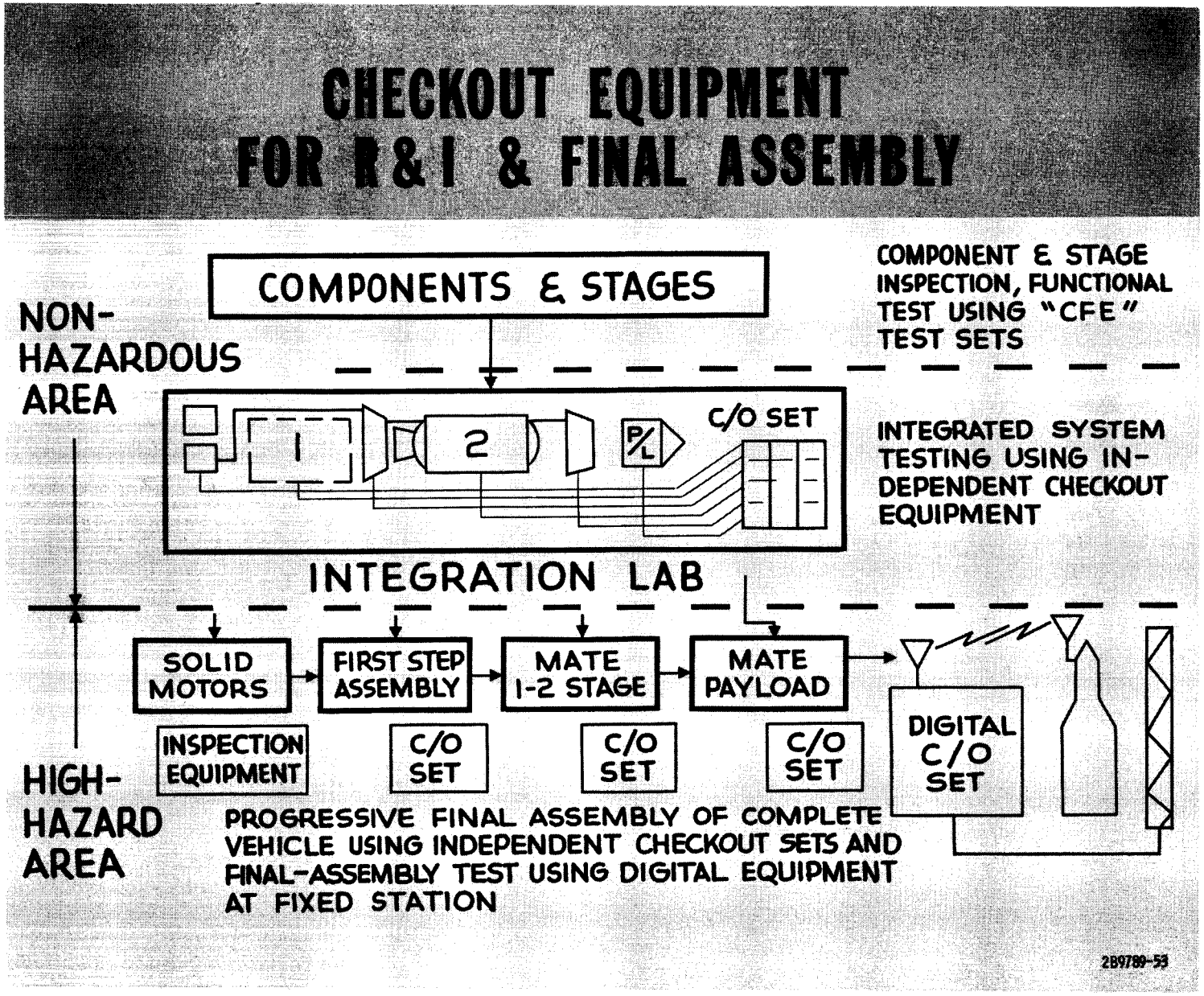
CHECKOUT EQUIPMENT

As stages and components are received, they are inspected for shipping damage and are functionally tested to assure compliance with engineering specifications. The test equipment will be that furnished by the individual stage manufacturer. The equipment will be either manual or automatic, depending on the complexity of the testing.

In the integration laboratory, the various stages are assembled in a vehicle mockup to prove the compatibility of the individual stages in a vehicle. Adjustments may be made at this time in the stage assemblies to ensure optimum vehicle performance. Automatic programing and checkout equipment will be used to provide rapid, accurate, and repeatable testing.

As the stages are assembled into a vehicle, the integrity of the assembly and mating process will be verified by small manual, general-purpose, checkout sets.

Before leaving the assembly area, the vehicle will receive a complete system checkout including flight simulation and operation of all telemeter channels. Due to the number of tests to be made and the mass of test results to be evaluated, an automatic digital computer will be used to program and evaluate these tests. This operation will be conducted at the intravehicle checkout facility, which is a pad location between the final-assembly area and the launch area.

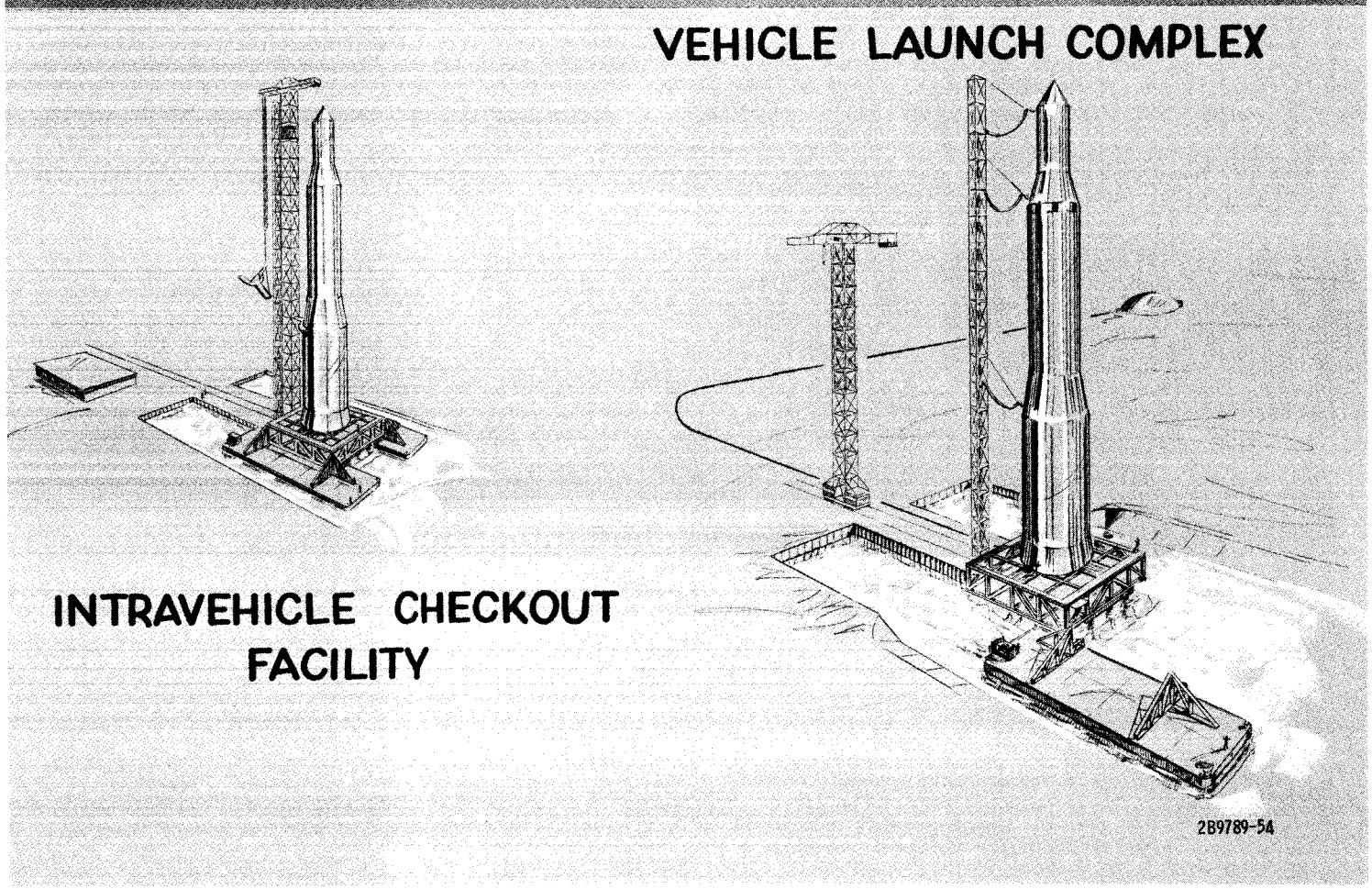

CHECKOUT EQUIPMENT
FOR R&I & FINAL ASSEMBLY
COMPONENTS & STAGES
COMPONENT & STAGE INSPECTION, FUNCTIONAL TEST USING "CFE" TEST SETS
NON-HAZARDOUS AREA
1
2
P/L
C/O SET
INTEGRATED SYSTEM TESTING USING IN-DEPENDENT CHECKOUT EQUIPMENT
INTEGRATION LAB
SOLID MOTORS
FIRST STEP ASSEMBLY
MATE 1-2 STAGE
MATE PAYLOAD
INSPECTION EQUIPMENT
C/O SET
C/O SET
C/O SET
DIGITAL C/O SET
HIGH-HAZARD AREA
PROGRESSIVE FINAL ASSEMBLY OF COMPLETE VEHICLE USING INDEPENDENT CHECKOUT SETS AND FINAL-ASSEMBLY TEST USING DIGITAL EQUIPMENT AT FIXED STATION
2B9789-53

VEHICLE LAUNCH COMPLEX

The complete vehicle checkout is accomplished at a separate location for high launch rates. For lesser rates, the checkout function is conducted either at the final-assembly area or at the launch site.

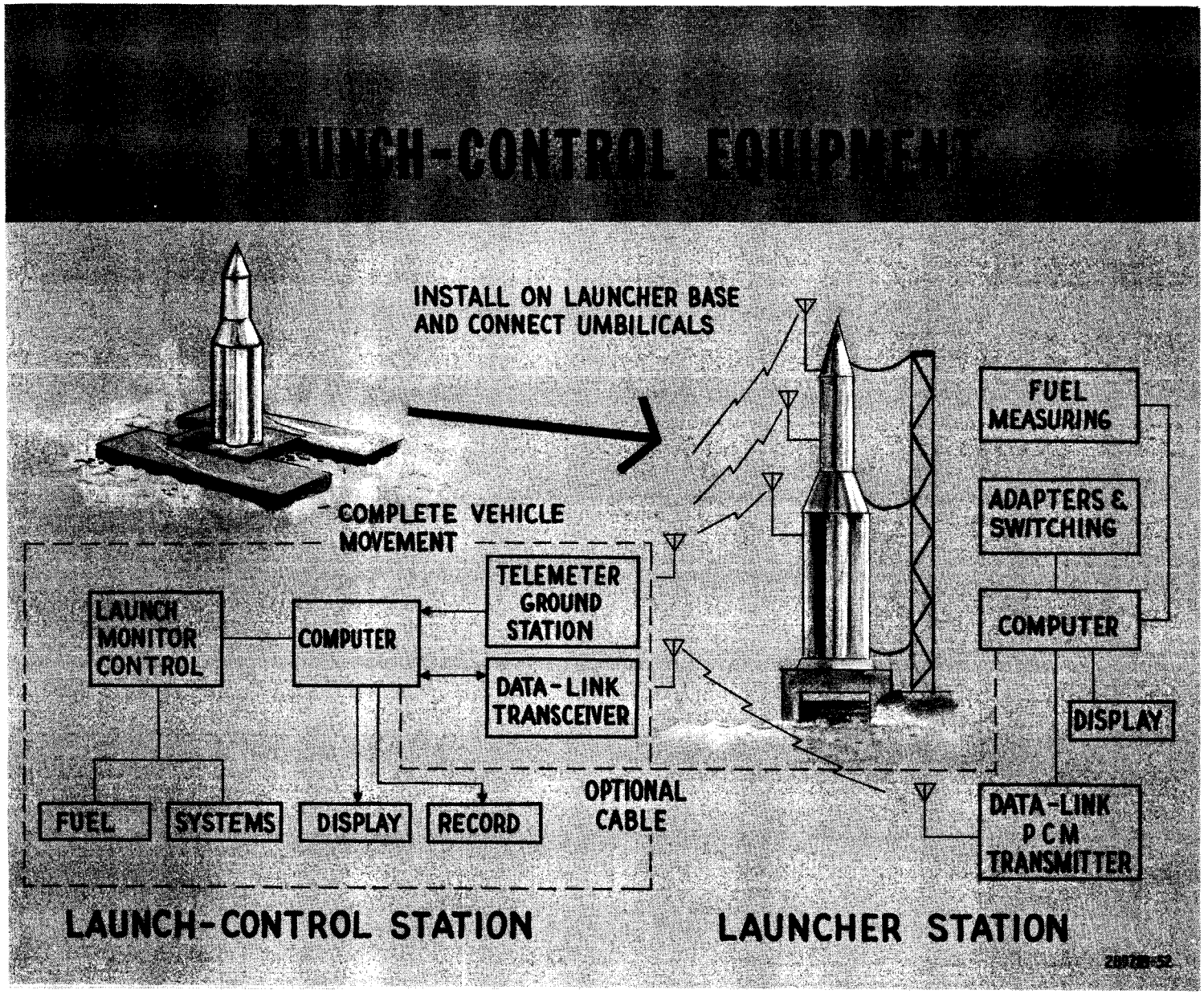
The completely tested vehicle is moved by waterborne equipment to the launch site where final countdown procedure is conducted, including fueling of the liquid stages, installation of initiators, and final preparation of the payload. The telescoping service tower is moved back from the pad before launch. The umbilical tower remains during launch and is considered expendable.

VEHICLE LAUNCH COMPLEX



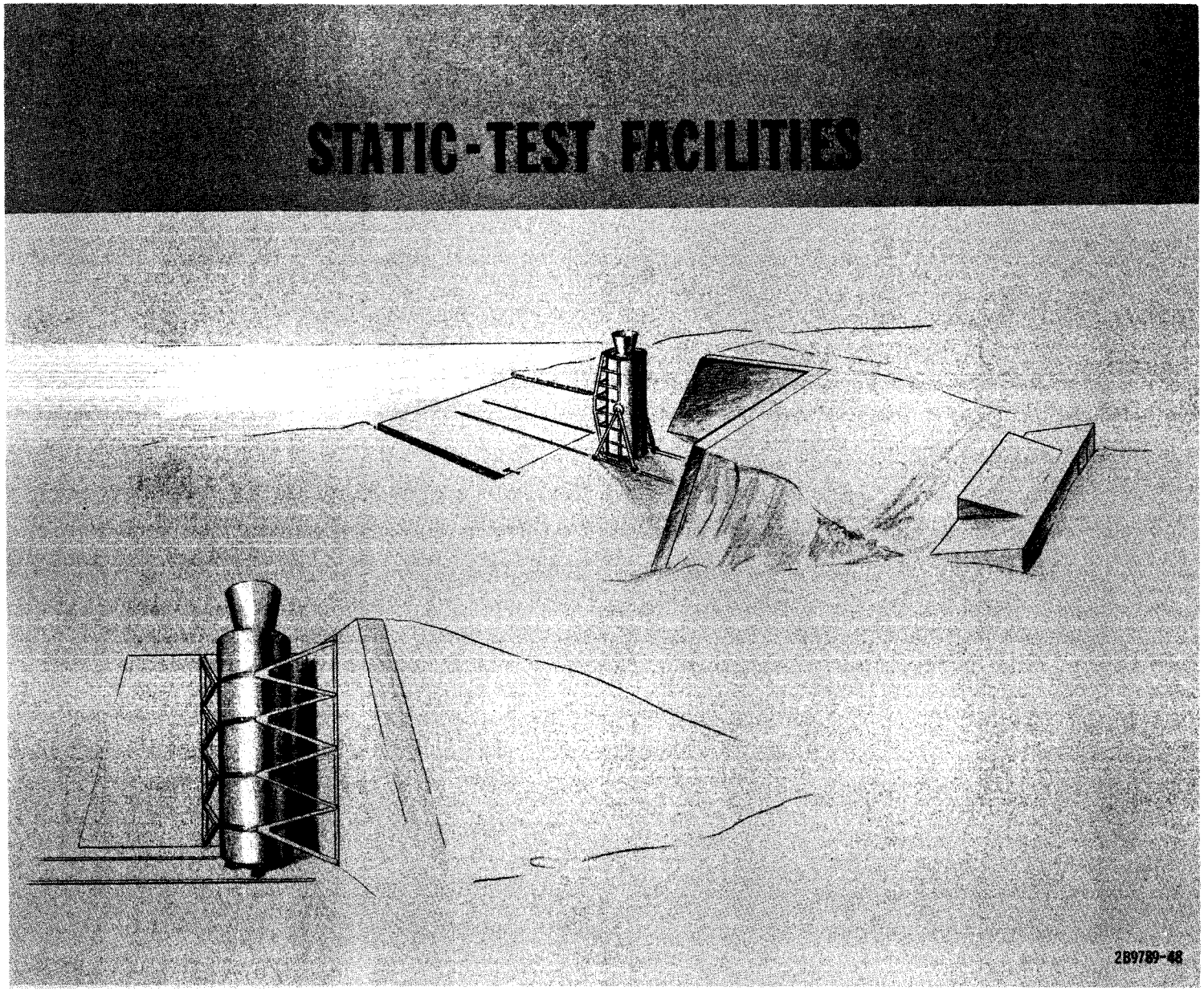
LAUNCH-CONTROL EQUIPMENT

The launch control and final checkout should be integrated into one test complex. Vehicle parameters will be measured and evaluated by a digital computer at the launch site. This computer would be slaved to a computer in the launch blockhouse. Telemeter response will be evaluated by the control computer. All this information will be recorded, and selected data will be available to the launch director at the launch monitor console.


LAUNCH-CONTROL EQUIPMENT
INSTALL ON LAUNCHER BASE AND CONNECT UMBILICALS
COMPLETE VEHICLE MOVEMENT
LAUNCH MONITOR CONTROL
COMPUTER
TELEMETER GROUND STATION
DATA-LINK TRANSCEIVER
FUEL
SYSTEMS
DISPLAY
RECORD
OPTIONAL CABLE
FUEL MEASURING
ADAPTERS & SWITCHING
COMPUTER
DISPLAY
DATA-LINK PCM TRANSMITTER
LAUNCH-CONTROL STATION
LAUNCHER STATION

STATIC-TEST FACILITY

A completed motor to be static tested remains on the production barge. A mobile strongback is attached to the motor. This assembly is moved on the canal to a shore based test facility where the motor is rolled ashore into a test fixture, which is revetted and where it can be observed from a blockhouse. The motor thrust is vertically upward, which simplifies the thrust resistance and minimizes the acoustical hazard. Thrust-vector-control testing can also be accomplished simultaneously in this type of vertical stand.


STATIC-TEST FACILITIES
2B9789-48

FIRST-UNIT RELIABILITY PREDICTIONS

This chart indicates the first-unit vehicle reliabilities that may be predicted on the basis of historical failure results. These values were obtained by analyzing the histories of currently operating systems in the detail necessary for application to the specific vehicles under study. Projected improvement factors for gains in such items as design know-how, manufacturing processes, and quality control have not been included.

It may be noted that historical data indicates that neither motor length nor burning time significantly affect the reliability of the solid-propellant motors. Accordingly, a number of the first-stage configurations were given the same values.

It should be concluded here that since thrust-vectoring systems, other controls, and instrumentation are weakest links in reliability, they must receive particular emphasis in the development program.

FIRST UNIT RELIABILITY PREDICTIONS

BASED ON HISTORICAL DATA

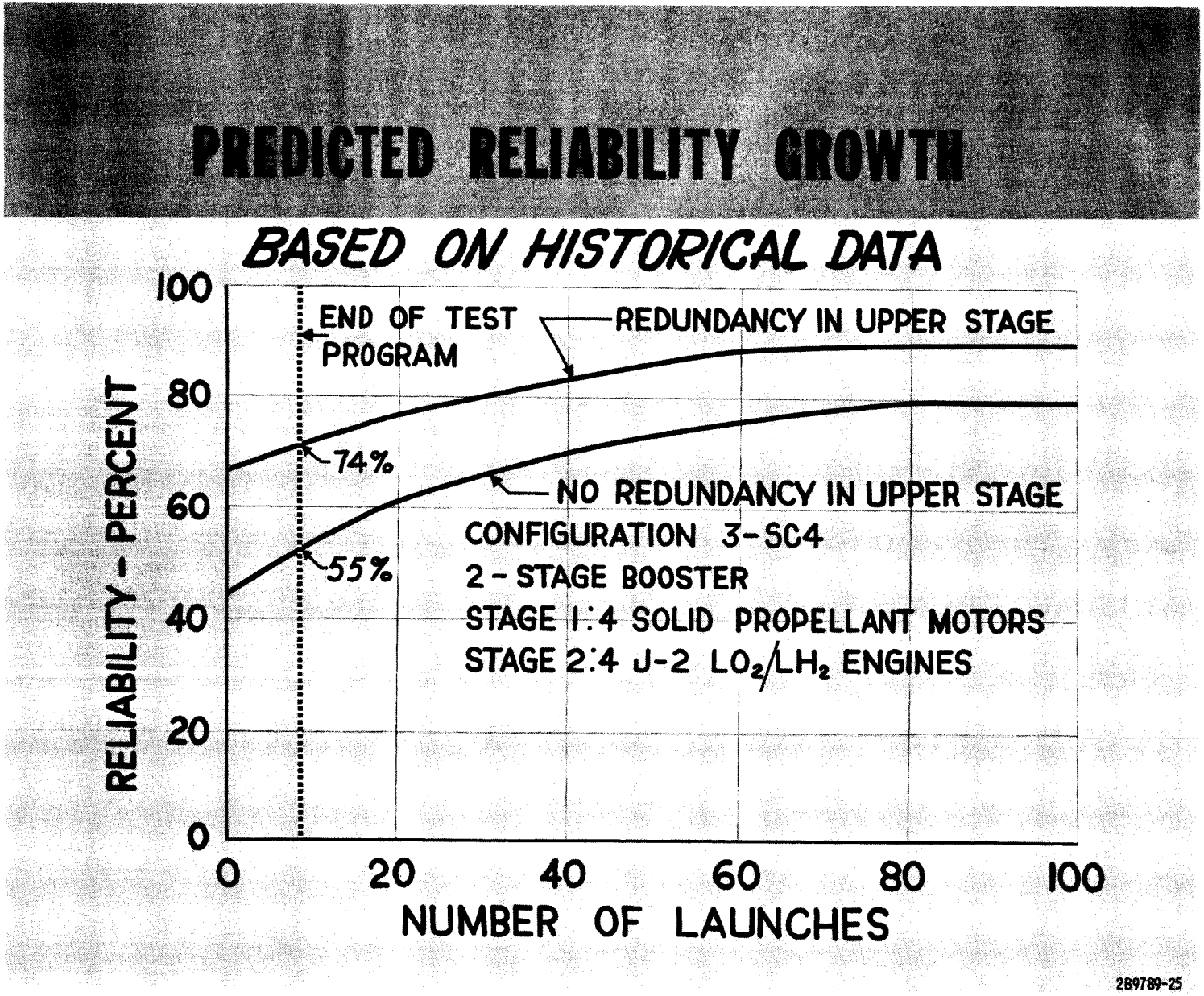
FIRST STAGE	I-SI	4-UC4 3-UC4 3-SC4		N-UC4	
PROPULSION (IGNITION, ETC.)	0.980	0.961		0.961	
TVC & CONTROLS	0.965	0.913		0.913	
STRUCTURE	0.995	0.995		0.995	
HUMAN FACTOR	0.999	0.999		0.999	
STAGE TOTAL	0.940	0.872		0.872	
SECOND STAGE					
PROPULSION, PROP. FEED, ETC.	0.889	0.715	0.909*	0.760	0.874***
TVC, CONTROLS & INST.	0.919	0.759	0.902**	0.808	0.887****
STRUCTURE	0.993	0.993	0.993	0.993	0.993
HUMAN FACTOR	0.985	0.985	0.985	0.985	0.985
STAGE TOTAL	0.799	0.531	0.802	0.601	0.758
TOTAL VEHICLE SYSTEM	0.751	0.463	0.699	0.524	0.661

* ENGINE-OUT CAPABILITY (10% CATASTROPHIC FAILURES)
** ONE THRUST-VECTOR-CONTROL REDUNDANT
*** REDUNDANT VALVES, ETC.
**** REDUNDANT SERVOACTUATORS, ETC.

2B9789-30

PREDICTED RELIABILITY GROWTH

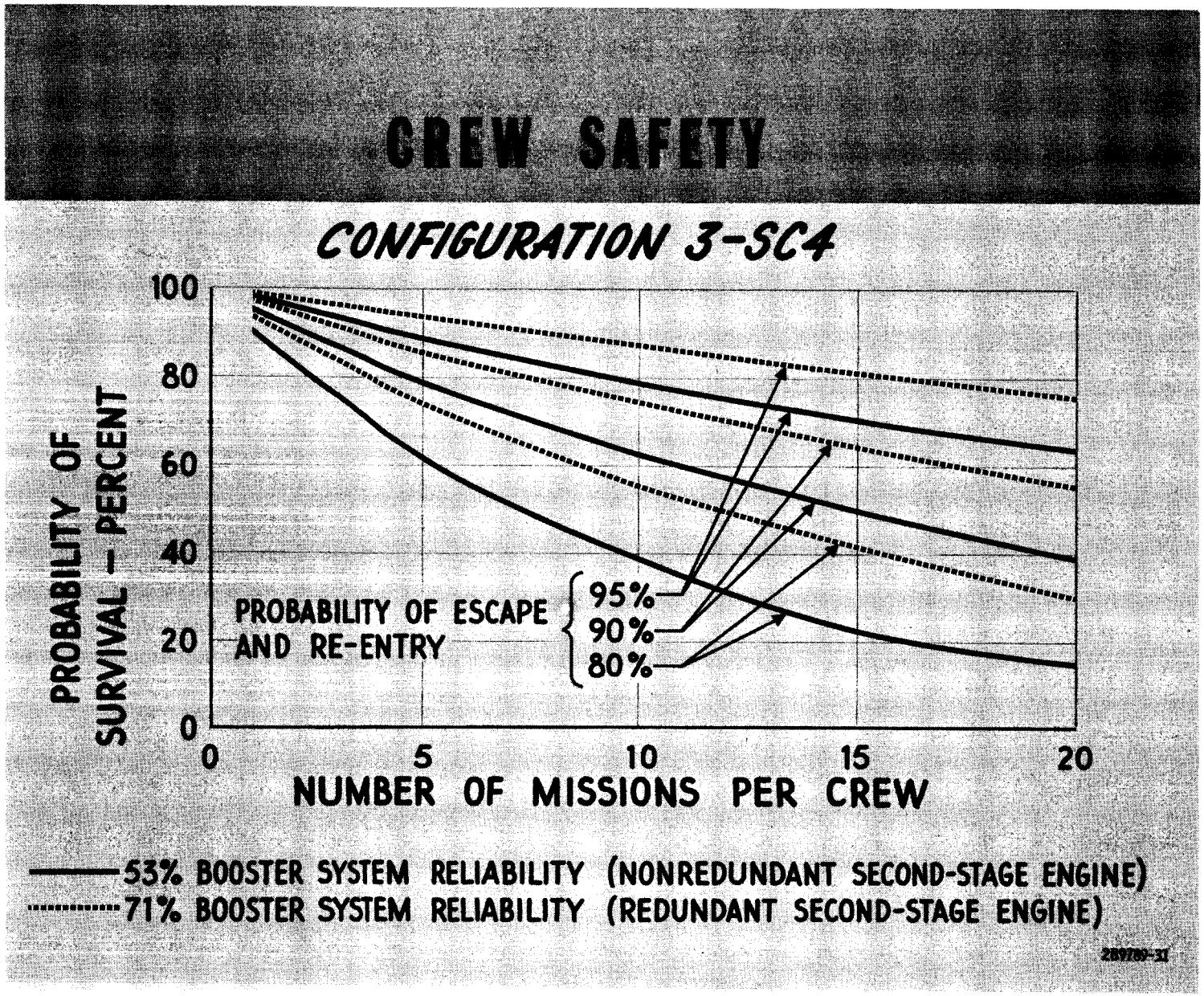
Beginning with first-unit reliability predictions shown in the previous chart, and applying the historical rate of reliability improvement as a function of the number of vehicles launched, these curves reflect the ultimate expected reliability of the 3-SC4 vehicle. The point may be made here that it takes a prohibitively large number of launches to substantially improve the reliability of a specific design. The problem can be approached more realistically by using design concepts that are initially adequate for the task at hand. Test launchings then become acts of demonstration and/or determining the fundamental adequacy of designs and manufacturing methods.


PREDICTED RELIABILITY GROWTH
BASED ON HISTORICAL DATA
END OF TEST PROGRAM
REDUNDANCY IN UPPER STAGE
74%
NO REDUNDANCY IN UPPER STAGE
55%
CONFIGURATION 3-SC4
2-STAGE BOOSTER
STAGE 1: 4 SOLID PROPELLANT MOTORS
STAGE 2: 4 J-2 LO2/LH2 ENGINES
RELIABILITY - PERCENT
100
80
60
40
20
0
0
20
40
60
80
100
NUMBER OF LAUNCHES
2B9789-25

CREW SAFETY

These curves indicate the probability that a crew would survive a specific number of missions on the 3-SC4 vehicle when escape and re-entry system reliabilities are 80, 90, and 95 percent. This probability was computed using vehicle reliabilities of 55 and 74 percent, as shown for the tenth launching on the preceding chart.

It may be noted that for the nonredundant upper-stage vehicle, and assuming 90-percent escape and re-entry reliability, the crew will have a 98-percent chance of surviving if the tenth launch is used for the first manned flight.


CREW SAFETY
CONFIGURATION 3-SC4
PROBABILITY OF SURVIVAL – PERCENT
100
80
60
40
20
0
0
5
10
15
20
NUMBER OF MISSIONS PER CREW
PROBABILITY OF ESCAPE AND RE-ENTRY
95%
90%
80%
53% BOOSTER SYSTEM RELIABILITY (NONREDUNDANT SECOND-STAGE ENGINE)
71% BOOSTER SYSTEM RELIABILITY (REDUNDANT SECOND-STAGE ENGINE)
289789-31

FLIGHT-TEST PROGRAM

The requirement for man-rating dictated an "all up" test configuration from the start, since it is necessary to attain a high probability of escape. Also, development considerations favor early testing of upper stages. The predicted reliability growth of the configurations studied will not greatly improve over the test period. This indicates that, with one exception, any cost advantage gained by starting with dummy upper stages would be small. Since two of the escape tests are planned specifically to occur during first-stage burning, the second stages to be used for these tests need not be complete. The desirability of constructing suitable dummy second stages should be considered.

The approach used was to program tests of all three systems using the minimum number of tests to produce acceptable confidence in each system, i.e., four successful booster tests, four re-entry tests, and five escape tests.

At the least, 9 flights will be required, since re-entry tests can be obtained after successful completion of the boost phase, and escape tests will require separate flights. Two escape tests are considered mandatory and are scheduled separately: escape at maximum dynamic pressure and escape at maximum first-stage acceleration. Other escape tests will be performed with the booster tests.

The number of tests programed for each configuration studied was obtained by dividing the number of required successful tests (four-booster plus two escape) by the predicted initial reliability, and adding, where necessary, the number required if the initial vehicle reliability is more than .67, and more are required if that reliability is lower.

Referring to the preceding chart on first-unit reliability predictions, the more optimistic reliability values were used because it is believed the configurations under study must be redesigned as required to approach these values.

FLIGHT-TEST PROGRAM

TEST SEQUENCE	TOTAL FLIGHTS PROGRAMED
REDUCED DYNAMIC PRESSURE	1
DESIGN MISSION	2
MAXIMUM HEATING & LOADS-PROOF TEST	2
MAXIMUM WIND SHEAR -PROOF TEST	2
ESCAPE AT MAXIMUM DYNAMIC PRESSURE -PROOF TEST	1
ESCAPE AT MAXIMUM FIRST-STAGE ACCELERATION -PROOF TEST	1
	9

MANNED MISSIONS-TELEMETRY FOR *ALL* REMAINING FLIGHTS

289789-2A

PHASING SUMMARY

The phasing summary is a comparative analysis of each configuration and shows the main events necessary to arrive at the times shown. Configuration phasing was developed by evaluating each program task: Identify critical and controlling elements of each task; and assess the time, effort, and complexity interrelationships of these elements for an optimum sequence of activities. It is assumed that payload and second stages would be available when required.

PROGRAMING APPROACH

It is assumed that, before R&D contract go-ahead, a preliminary vehicle definition will be established by a preliminary design contractor, an in-house effort by the using agency, or the initial effort of a system manager or prime contractor. This will allow: Motor manufacturer selection at go-ahead, and a motor design complete at 12 months; establishment of GSE operating plans consisting of general requirements and preliminary design specifications; and early site selection and acquisition of new facilities, when required.

1. Segmented Booster Configurations

   a. 1-S1—Existing manufacturing and propellant processing facilities will be used to develop segmented motors, which allows the static test and PFRT programs to begin earlier for the unitized motors. Because of the advance of segmented motor development, only a short redesign period is required, thus making segmented motors a noncritical item. Due to the size and complexity of the overall vehicle and its launch complex, the availability of the electric and electronic GSE is critical.

   b. 3-SC4—The phasing for this configuration is the same as 1-S1 except that the availability of the first flight airframe becomes critical along with the GSE due to a later final drawing release date. This is predicated on the requirement for clustering the motors and on the increase in size.

   c. The first launch of the 1-S1 and 3-SC4 varies because of the longer period required for system integration, and assembly and checkout.

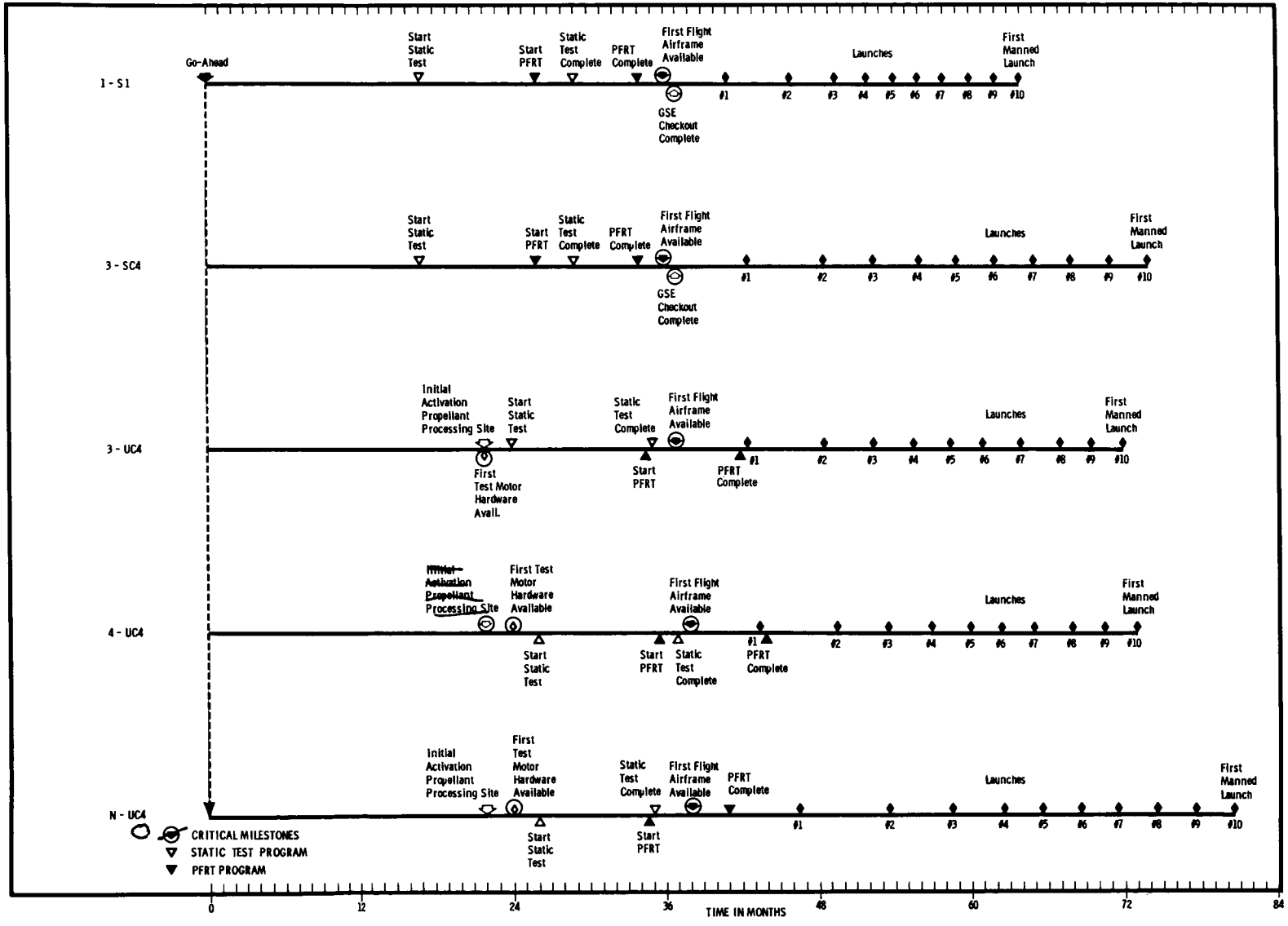
2. Unitized Booster Configurations (3-UC4, 4-UC4, N-UC4)

   a. Existing manufacturing facilities will be used but a new propellant processing site is required. It can be developed 18 months after go-ahead and is not a critical item.

   b. The unitized motor development will start at go-ahead and will be a critical item on all unitized configurations as will the availability of first flight airframe hardware.

   c. The launches vary due to the time required for integration, assembly and checkout.

PHASING SUMMARY

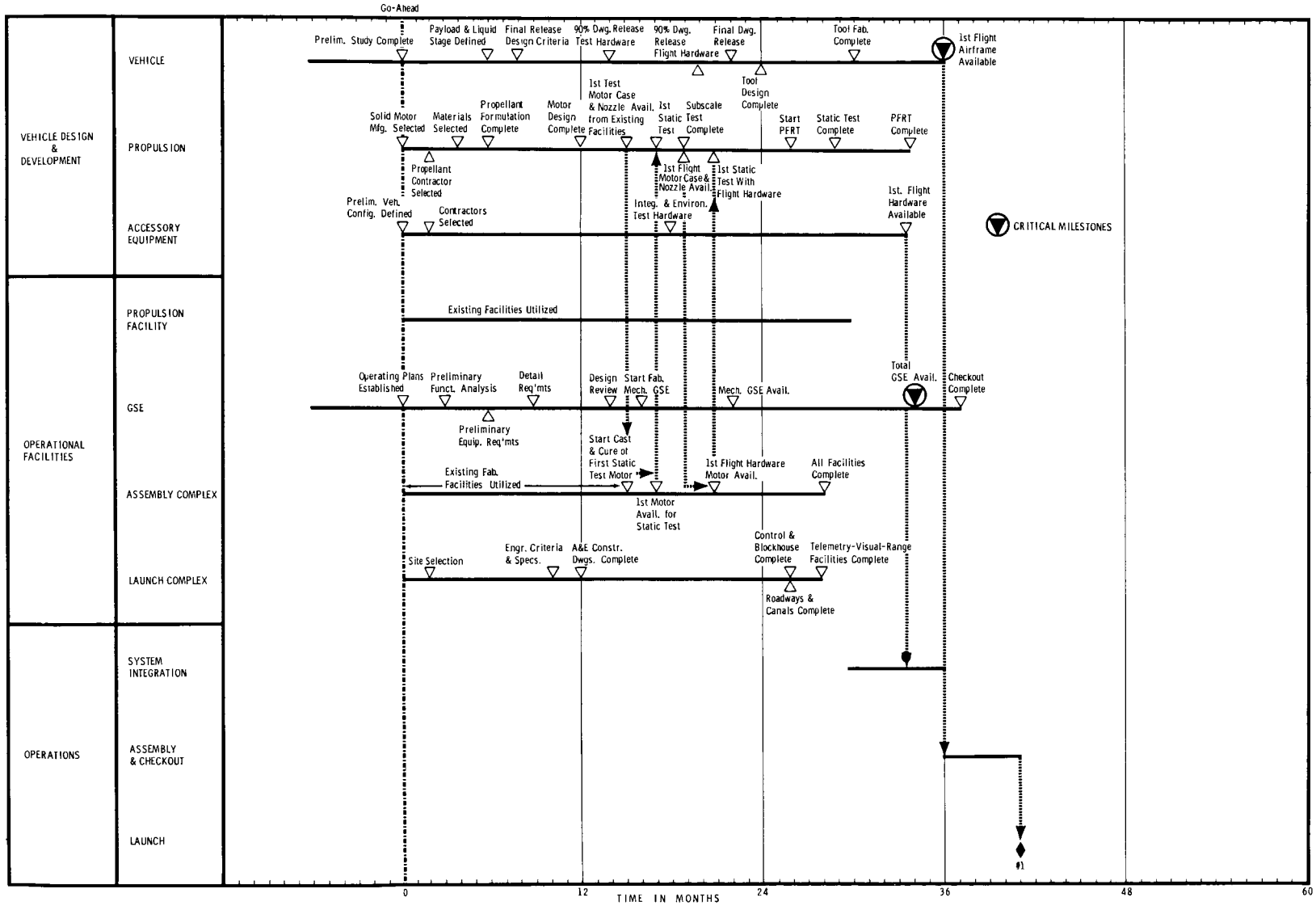


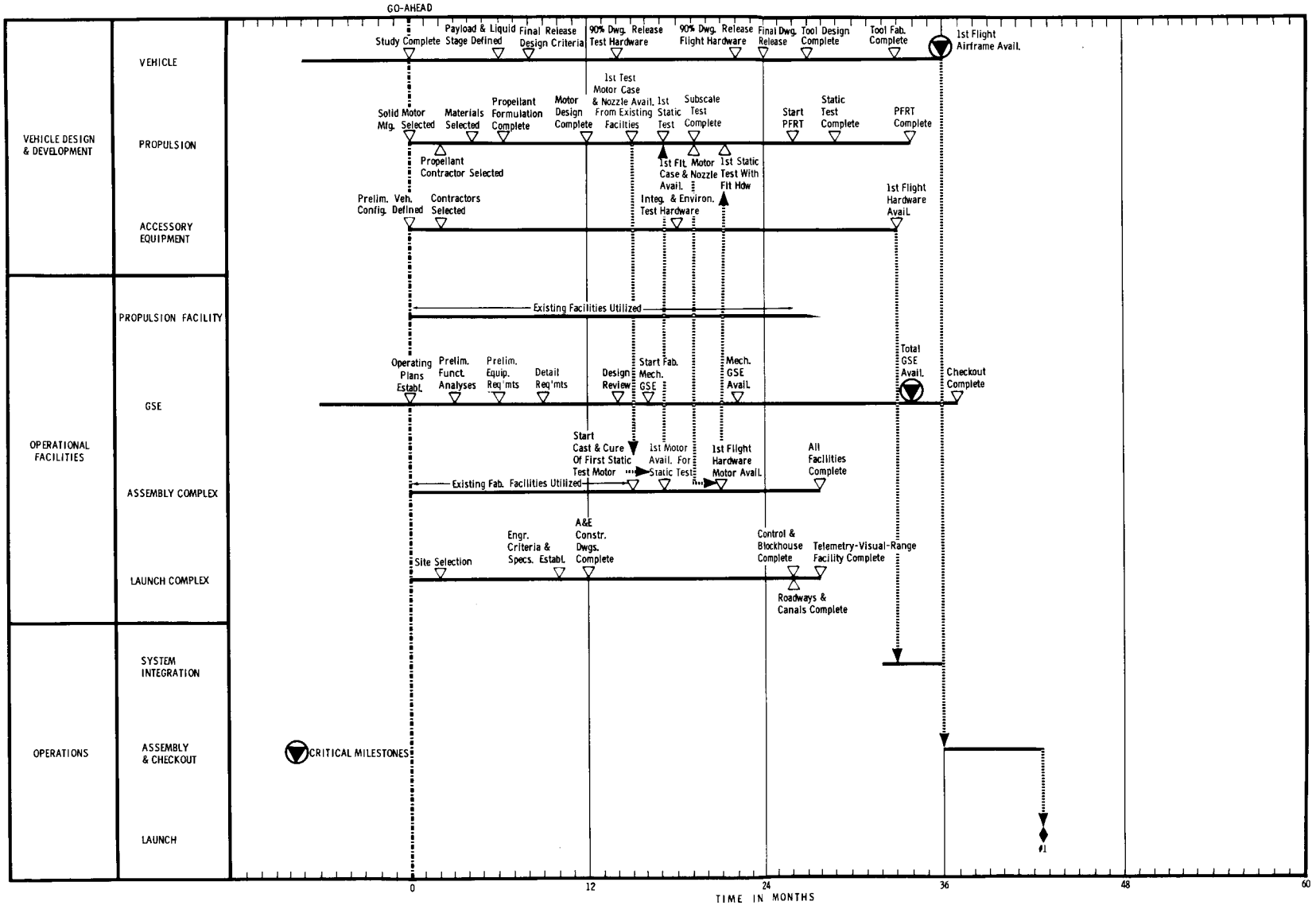
PROGRAM PHASING

The following set of program phasing charts indicates the development time for the family of vehicles studied. Development prior to initial launch will require from ~~42 1/2~~ 41 to ~~48~~ 46 1/2 months. The schedules show the phasing of the major areas of work to accomplish this from an arbitrary time zero; however, a pre-go-ahead period for vehicle design and ground support equipment is required.

The schedules reflect what is required to accomplish the complete development of the vehicle; it is assumed that both the payload and the liquid stages will be available as required. No detail is shown for development of these items but consideration has been given to their effect on system integration testing, assembly, and prelaunch time requirements. Critical items for each program are emphasized by encircling the normal milestones.

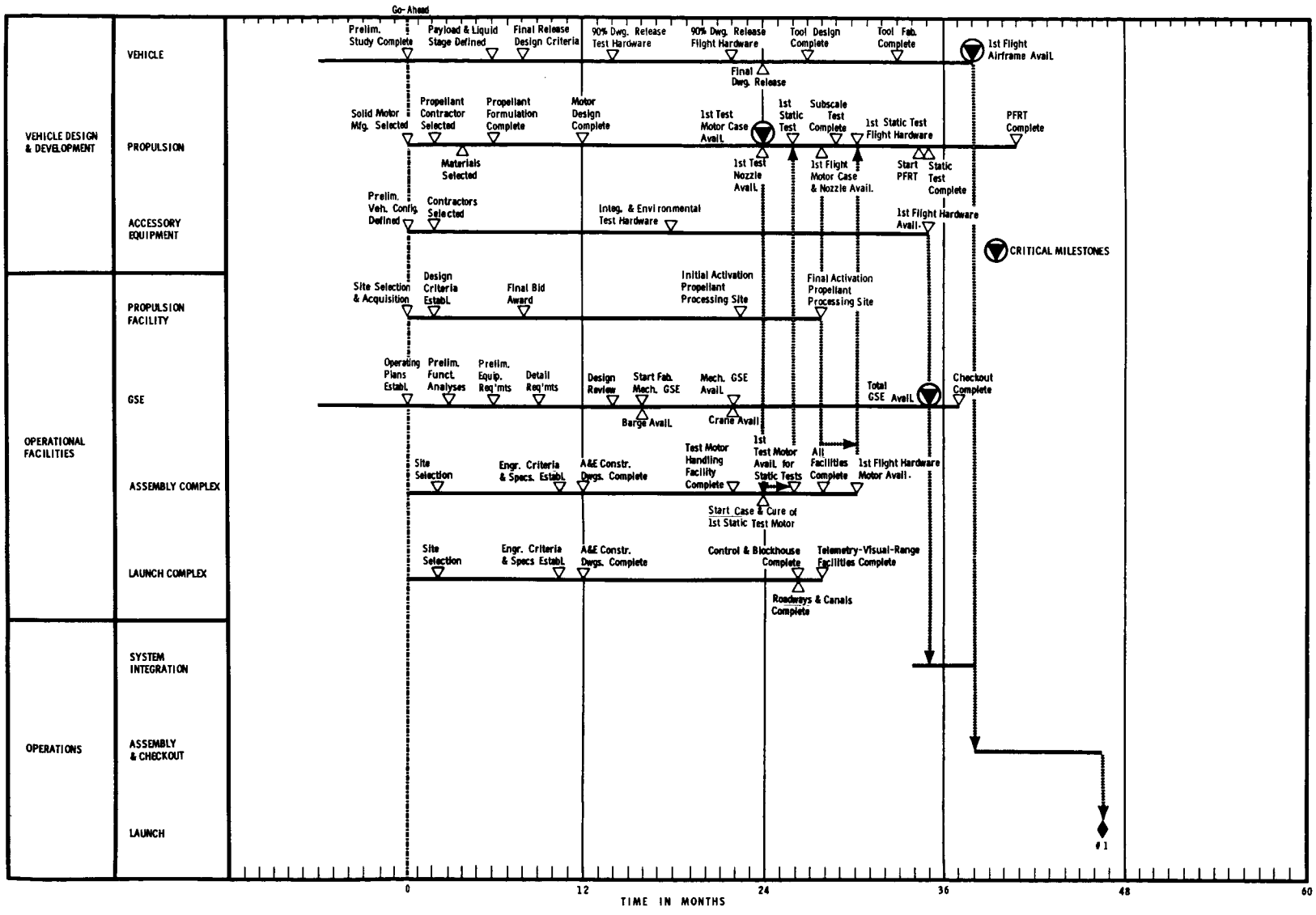
PROGRAM PHASING
Vehicle Configuration 1-S1

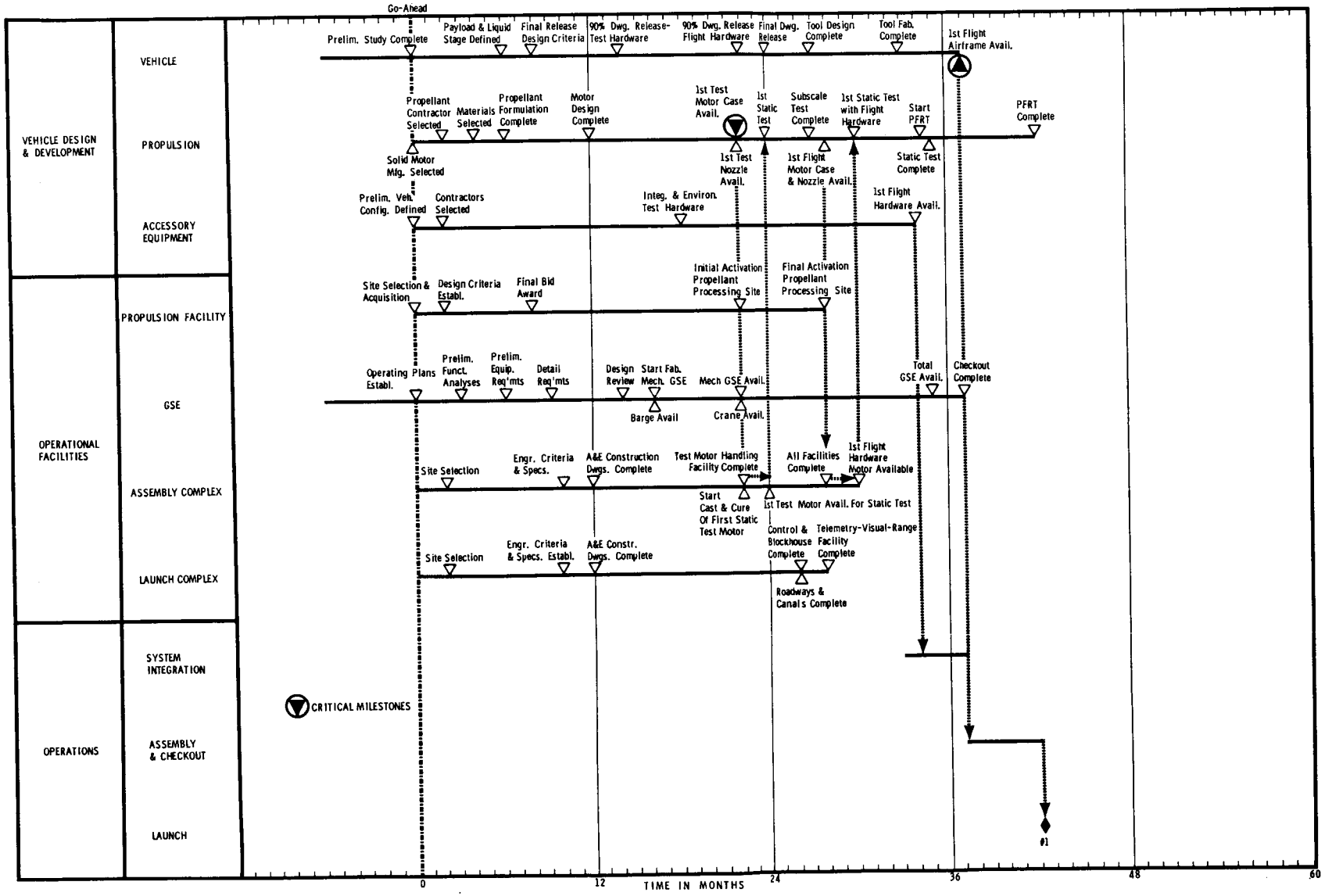




PROGRAM PHASING
Vehicle Configuration 3-SC4

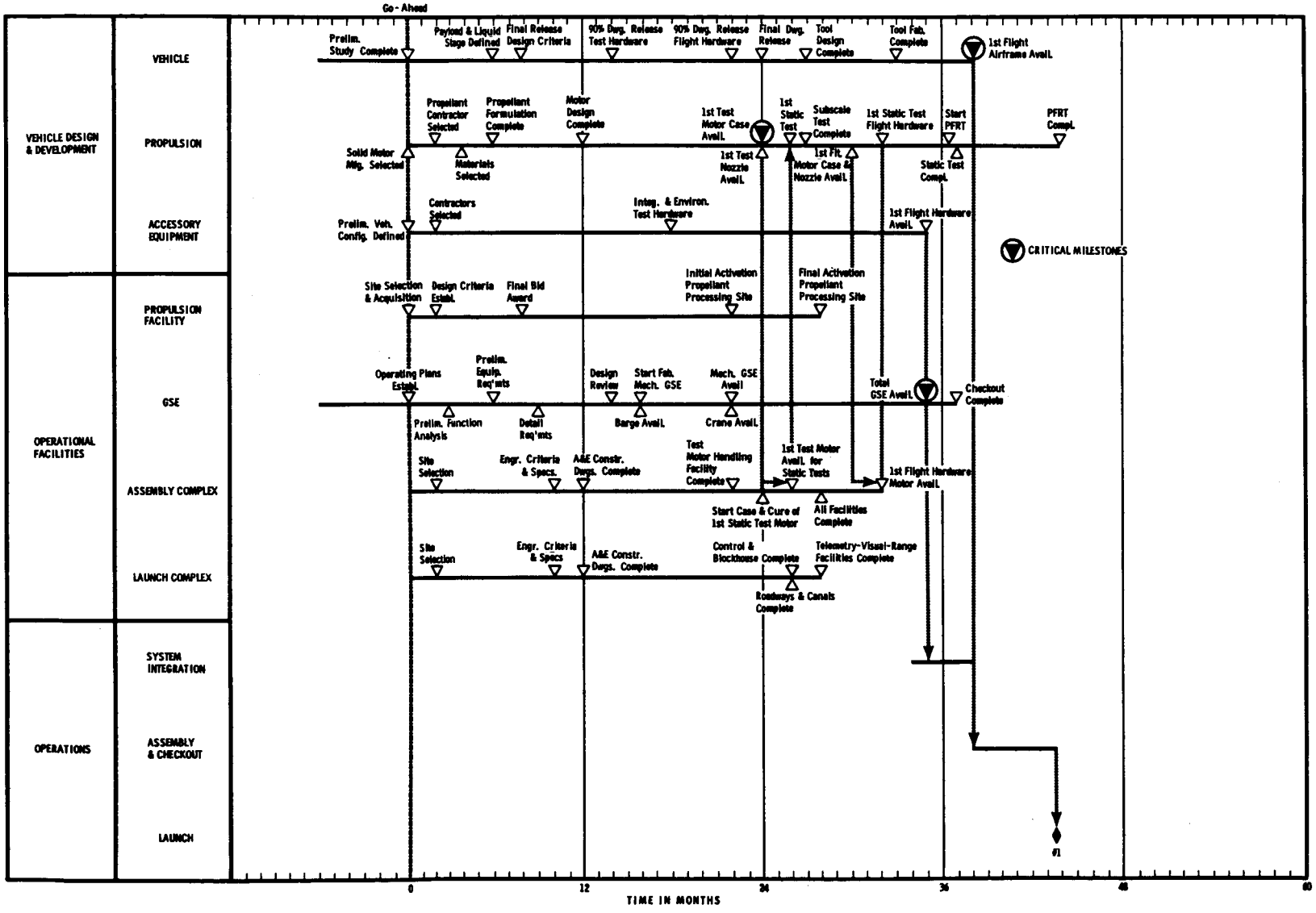
PROGRAM PHASING
Vehicle Configuration ~~3-UC4~~ N-UC 4





PROGRAM PHASING
Vehicle Configuration ~~4-UC4~~ 3-UC4

PROGRAM PHASING
Vehicle Configuration ~~N-UC4~~ 4-UC4



SUMMARY

- SOLID PROPELLANT STAGE RELIABILITY CAN BE HIGHER THAN FOR LIQUIDS
- INTEGRATED AIRFRAME AND GSE PACING IN DEVELOPMENT (MOTOR DEVELOPMENT AHEAD OF OTHER VEHICLE SUBSYSTEMS)
- NO IMMEDIATE ADVANTAGE EVIDENT FOR UNITIZED DESIGNS (SEGMENTED MOTORS AVAILABLE MUCH SOONER)
- SECOND-STAGE RELIABILITIES MUST BE IMPROVED FOR VEHICLES STUDIED
- ON-SITE PROPELLANT MIXING & OFF-PAD VEHICLE ASSY. MOST DESIRABLE

2B9789-63

RECOMMENDATIONS

- SELECT A SPECIFIC VEHICLE CONFIGURATION AND PERFORM THE FOLLOWING :

  DETAIL ANALYSIS TO ESTABLISH CONTROL SYSTEM REQUIREMENTS

  ANALYZE FEASIBLE THRUST-VECTOR CONTROL SYSTEMS AND RECOMMEND SELECTION

  DETERMINE OPTIMUM CLUSTER STRUCTURE METHOD

- PERFORM COST ANALYSIS OF C-1, C-3, C-4 AND NOVA LIQUID PROPELLANT VEHICLES ON BASES DIRECTLY COMPARABLE WITH PRESENT STUDY

2B9789-64