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STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

FINAL REPORT

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VOLUME I
EXECUTIVE SUMMARY

United Technology Center DIVISION OF UNITED AIRCRAFT CORPORATION

CAT-28

UTC 4205-72-7

STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

FINAL REPORT

VOLUME I
EXECUTIVE SUMMARY

15 March 1972

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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

by

United Technology Center
DIVISION OF UNITED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

ABSTRACT

The study of solid rocket motors for a space shuttle booster by United Technology Center was initiated on 19 January 1972 under contract to Marshall Space Flight Center of the National Aeronautics and Space Administration. The objective was to investigate and define solid rocket motor booster stage designs; development, production and launch operations programs; and creditable, understandable costs of selected booster baseline configurations in order to furnish the National Aeronautics and Space Administration with data necessary to make decisions regarding the booster for the Space Shuttle Program.

Solid rocket motor booster stage studies were directed toward defining the basic series burn and parallel burn boosters for both the 120- and 156-in.-diameter solid rocket motors required to accommodate both the 15- by 60-ft and 14- by 45-ft payload bays. Basic vehicle characteristics were amplified by the orbiter phase B contractor teams to present a broad array of solid rocket motor stage requirements. The cost and program definition tasks were extended to reflect the requirements of the basic National Aeronautics and Space Administration mission model of 445 flights plus 3 mission model rates of 40, 20 and 10 flights per year.

During the 8 weeks of the study, documented in this report, UTC elected to define four typical baseline boosters to reflect orbiter contractor team requirements, which were the basis for program and cost definition of the total solid rocket motor booster stage costs. Definition of basic solid rocket motor cost data was pursued as necessary to fulfill the National Aeronautics and Space Administration cost estimates requirement. In addition to activities associated with solid rocket motor booster stage system definition, the technical considerations pertaining to ecology, abort, base heating and the concept of recovery and reuse of solid rocket motor components were studied. A time-phased program plan was defined for design, development, test and evaluation, production, and launch operations to provide a complete basis for cost estimation.

Detailed management, technical, and cost comparisons of the four baseline solid rocket motor configurations led to the following conclusion:

A. The solid boosters offer maximum confidence for a reliable interim booster, and all projections were based on creditable data offering the minimum technical and financial risks.

B. A 156-in.-diameter solid rocket motor booster stage should be developed for more than one-half the full mission model, and a 120-in.-diameter solid rocket motor booster stage should be developed for less than one-half the full mission model.

C. A solid rocket motor booster stage provides the Space Shuttle Program with a substantial management reserve in respect to a minimum investment for a design, development, test, and evaluation program and maximum confidence in satisfying budgetary commitments.

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ILLUSTRATIONS

TABLE

ABBREVIATIONS

AP	ammonium perchlorate
BLOW	booster liftoff weight
CDR	critical design review
DDT&E	design, development, test, and evaluation
EMI	electromagnetic interference
GLOW	gross liftoff weight
KSC	Kennedy Space Center
NASA	National Aeronautics and Space Administration
NAS/NRC	National Academy of Science/National Research Council
OLOW	orbiter liftoff weight
PBAN	polybutadiene-acrylic acid-acrylonitrile
PDR	preliminary design review
PFRT	preliminary flight rating tests
SRM	solid rocket motor
SST	supersonic transport
TT	thrust termination
UAC	United Aircraft Corporation
UTC	United Technology Center

1.0 INTRODUCTION

The study of SRM booster stages was conducted to furnish NASA with data necessary to make decisions regarding the booster for the space shuttle program.

The study was divided into manageable tasks corresponding to the study program objectives to define a SRM design; development, production, and launch support programs; and creditable, understandable costs of chosen booster baseline definitions. As design variables affecting the baseline SRM stage were identified by Phase B contractors, configuration impact upon nonrecurring and recurring costs were assessed. Study effort was applied to define recovery and reuse of SRM components for the purpose of providing comparative data.

2.0 PROGRAM OBJECTIVES

For the purpose of this study, program objectives were to be met by satisfying the following:

A. Definition of SRM designs which satisfy the performance and configuration requirements of the various vehicle/booster concepts.

B. Definition of the development, production, and launch support programs required to provide SRM booster stages at rates of 60, 40, 20 and 10 launches per year in a man-rated system.

C. Estimation of costs, including ground rules and assumptions for basis, for the defined SRM booster stages. These costs identify all hardware systems, design, development and test efforts, production efforts, and launch support operations.

3.0 GROUND RULES

The study was designed to provide hardware systems and program definition necessary to establish the estimated cost of providing SRM booster stages stated in constant calendar year 1970 dollars. Costs were developed employing representative elements of costs (i.e., labor, materials, subcontract, general and administrative, and miscellaneous) without fee. Cost estimates were prepared for total program funding and program time-phased funding requirements in consideration of the four UTC selected SRM stage configurations, using the NASA defined mission models and reflecting delta funding requirements of a basic SRM versus a complete SRM booster stage.

Actual costs of previous and current SRM development, production, and launch operations programs were utilized to the fullest extent possible.

Costs were developed and portrayed in consideration of other elements of NASA direction and SRM booster stage baseline schedule, which depicts significant milestones required to satisfy program requirements.

4.0 SRM BOOSTER STAGE SYSTEM DEFINITION

System requirements for SRM space shuttle boosters have been defined by the various Phase B orbiter contractor teams. UTC began its current SRM study by requesting basic vehicle data from these contractor teams. Booster sizes were then selected to carry out the point design and booster cost analyses. Technical integration activities were continued with the Phase B contractors to obtain more detailed SRM booster requirements, supply technical data to the contractors, complete the SRM booster-orbiter interface definition, and maintain liaison with the contractors.

Although contractor response to this request was varied, sufficient data were obtained to establish the basic sizing of the SRM boosters for the parallel burn and series burn modes. Most data received were based upon the 15- by 60-ft payload bay orbiter. Accordingly, the UTC study was oriented to define cost and design data for this vehicle. Data were obtained from a single contractor to define 14- by 45-ft payload bay orbiter booster sizing requirements.

The SRM booster stage studies were directed toward defining the basic series burn and parallel burn boosters for both the 120- and 156-in.-diameter SRMs. Cost data and design definition of the SRM boosters were directed toward total stage costs, although the basic SRM data were pursued as necessary to fulfill NASA cost requirements and to highlight apparent cost discrepancies between UTC large motor expereence and cost projections by orbiter/booster contractor teams. The cost and program definition tasks were extended to reflect the requirements of the four NASA mission models. The study variables are shown in figure 1.

All basic vehicle characteristics were amplified by the orbiter contractor teams to present a broad array of SRM stage requirements. UTC elected to define typical baseline boosters to reflect these contractor requirements.

The UTC baseline design uses the TECHROLL® seal movable nozzle on the basis of a 10% cost reduction compared to a liquid injection system and a reduction in actuation torque requirements and movement of the nozzle seal pivot point compared to the flex-seal. Thrust termination devices have been included on the basis of prior acceptance and qualification for use in abort systems on manned flight programs. Forward thrust loading has been selected on the basis of orbiter contractor preference and a relatively small weight and cost penalty within the SRM stage.

The UA 1207 seven-segment SRM is a direct derivative of the current Air Force Titan III five-segment SRM. The components of the 156-in.-diameter SRM would be scaled up from the 120-in.-diameter SRM currently in flight use. SRM characteristics involved in these applications and their derivation are presented in figure 2.

4.1 BASELINE VEHICLE DESCRIPTIONS

4.1.1 Payload Bay Orbiter (15 by 60 ft)

Basic sizing and configuration of the UTC selected baseline SRM shuttle boosters are shown in figure 3. Series burn and parallel burn configurations for the 120- and 156-in.-diameter SRMs are shown. Characteristics of the various boosters are listed in figure 4.

ITEM	SELECTED BASELINE	ALTERNATES
ORBITER PAYLOAD BAY	15 X 60 FT	14 X 45 FT
LAUNCH CONFIGURATION	PARALLEL BURN SERIES BURN	
SRM DIAMETER	120 IN. 156 IN.	
CONFIGURATION	BASIC SRM STAGE	
THRUST VECTOR CONTROL	MOVABLE NOZZLE TECHROLL® SEAL	NONE; LIQUID INJECTION
THRUST TERMINATION	WITH	WITHOUT
THRUST LOADING	FORWARD	AFT
MISSION MODEL PEAK RATE/YEAR	10, 20, 40, OR 60	

Figure 1. SRM Booster Study Variables

ITEM	UA 1205 FOR TITAN III C/D	UA 1207 TESTED	120-IN. SRM FOR SHUTTLE	156-IN. SRM FOR SHUTTLE
PROPELLANT	○	○	○	○
INSULATION		⊗	⊗	⊗
CASE SEGMENTS	○	○ (1)	○ (1)	⊗
FORWARD CLOSURE	○ (2)	⊗ (3)	⊗ (3)	⊗
IGNITER AND S/A DEVICE	○	○	○	⊗
THRUST TERMINATION SYSTEM	○ (2)	○	○	⊗
AFT CLOSURE	○	○	○	⊗
NOZZLE	○	⊗	⊗	⊗
THRUST VECTOR CONTROL	○	○	●	●
ONBOARD POWER SYSTEM	○	⊗ (4)	⊗ (4)	⊗
FLIGHT INSTRUMENTATION	○	○	○	○
SUPPORT LONGERONS	○	⊗	⊗	⊗
AFT SUPPORT	○	○	⊗	⊗
FORWARD SUPPORT	○	○	○	○

(1) TWO ADDITIONAL SEGMENTS
(2) THRUST TERMINATION DELETED FROM PRODUCTION MODELS
(3) EXTENDED
(4) REDUNDANCY ADDED

○ SAME AS UA 1205 ⊗ SAME DESIGN AS UA 1205 ● DIFFERENT FROM UA 1205

Figure 2. SRM Characteristics

UTC-V-01541

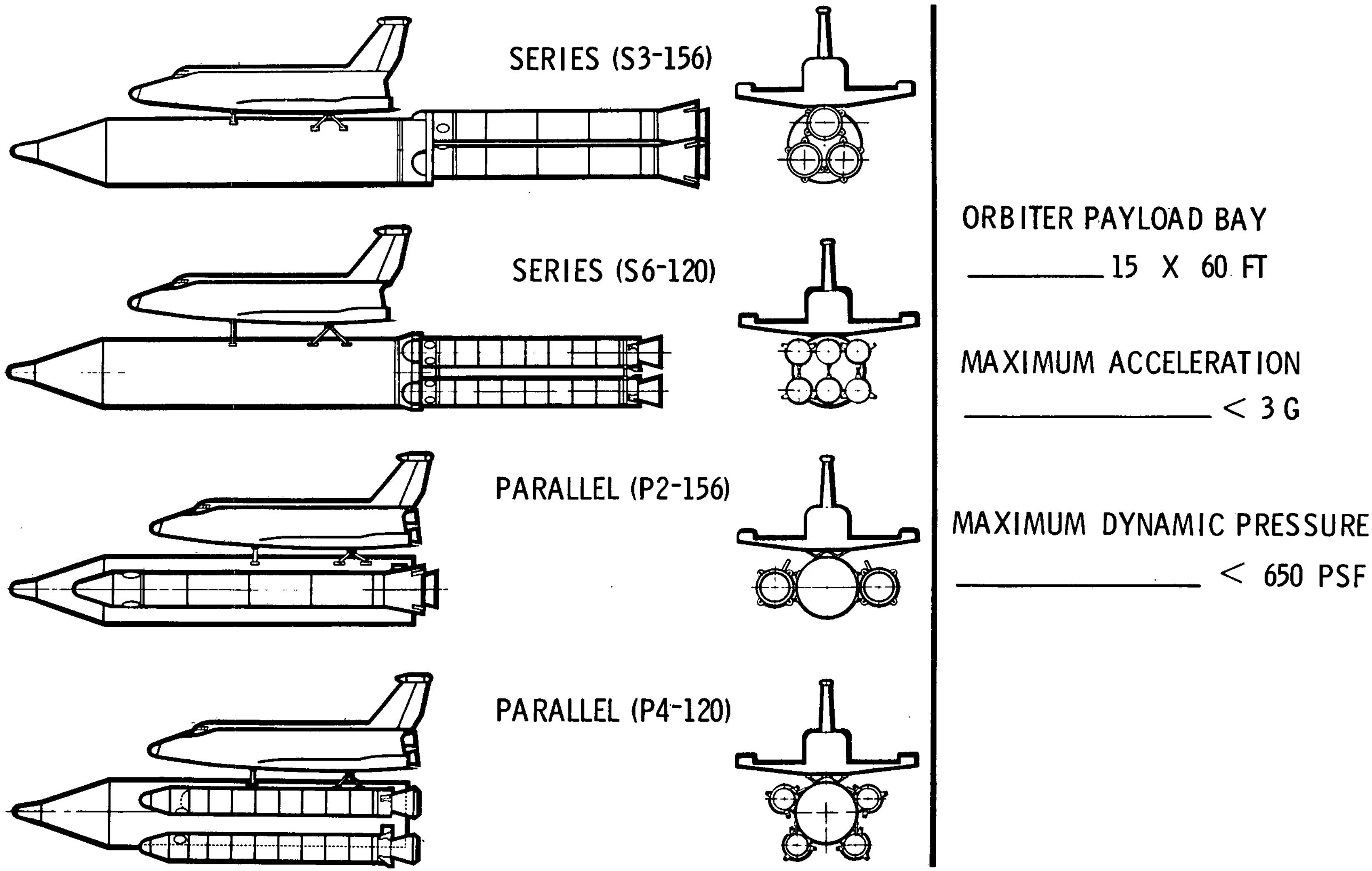

Figure 3. Baseline Launch Vehicle Configurations

UTC-V-01540

	S3-156	S6-120	P2-156	P4-120
LAUNCH CONFIGURATION	SERIES	SERIES	PARALLEL	PARALLEL
NUMBER OF SRMs	3	6	2	4
PROPELLANT WEIGHT, LB X 10^{-6}				
SRM	1.075	0.592	1.245	0.592
BOOSTER	3.225	3.552	2.489	2.368
THRUST, LB X 10^{-6}				
SRM (SEA LEVEL)	2.178	1 140	2.549	1.400
BOOSTER	6.534	6.840	5.098	5.600
ACTION TIME, SEC	141	135	137	140
STAGE MASS FRACTION	0.869	0.860	0.880	0.864
CONTROL REQUIREMENTS				
DEFLECTION, DEGREE	±12	±12	±6	±6
RATE, DEGREE/SEC	5	5	5	5
PROPELLANT	PBAN	PBAN	PBAN	PBAN
ACCELERATION, G				
LIFTOFF	1.25 TO 1.3	1.25 TO 1.3	1.25 TO 1.3	1.25 TO 1.3
FLIGHT	LESS THAN 3	LESS THAN 3	LESS THAN 3	LESS THAN 3
MAXIMUM DYNAMIC PRESSURE, PSF	LESS THAN 650	LESS THAN 650	LESS THAN 650	LESS THAN 650

Figure 4. Stage Characteristics

UTC-V-01459

The series burn configuration of three 156-in.-diameter SRMs (S3-156) is shown in more detail in figure 2-3, volume II. Three 156-in.-diameter SRMs (each SRM contains 1,080,000 lb of propellant) are grouped triangularly in a tank-end load configuration. Three identical SRM assemblies plus an interstage assembly, or HO tank adapter, make up the booster. Vehicle prelaunch support is provided by four ground support fittings at the base of each SRM. Two diametrically opposed TT ports are provided at the forward end of each SRM. The physical arrangement of the SRMs and TT ports has been selected to provide the maximum miss distance of TT debris to the orbiter.

The series burn configuration of six 120-in.-diameter SRMs (S6-120) is shown in figure 2-4, volume II. The six UA 1207 motors (each containing 592,000 lb of propellant) are arranged in a rectangular 2- by 3-ft tank-end load configuration. The booster is made up of six identical SRM assemblies plus an interstage assembly as in the 156-in.-diameter case. TT is provided at the forward end of each SRM with two ports arranged 90° apart on each motor.

The parallel burn configuration of two 156-in.-diameter SRMs (P2-156) is shown in figure 2-5, volume II. Each of the two SRMs contains 1,250,000 lb of propellant. Two identical SRM assemblies are strapped onto opposing sides of the orbiter HO tank. Precise location of the SRMs is not critical to SRM design, and the preferred location may be selected on the basis of vehicle dynamics. SRM thrust transmission to the HO tank and orbiter-HO tank ground support is provided by a structural skirt at the forward end of the SRM. Total vehicle ground support is provided by structural skirts at the aft end of the SRMs. Two diametrically opposed TT ports are provided at the forward end of each SRM. The ports are located to provide a maximum miss distance to the HO tank and orbiter while providing a laterally balanced thrust to allow abort orbit SRM ejection.

The 120-in.-diameter SRM parallel burn booster is shown in figure 2-6, volume II. The configuration of the four identical UA 1207 SRMs is similar to that of the 156-in.-diameter motors. Use of the four SRMs establishes a broader ground support base to react prelaunch wind and engine start transient overturning loads.

4.1.2 Payload Bay Orbiter (14 by 45 ft)

Vehicle sizing data were obtained to allow basic definition of candidate boosters for the 14- by 45-ft payload bay orbiter. Table I provides the basic vehicle data and indicates how the 15- by 60-ft payload booster configurations can be used to define a 14- by 45-ft payload booster. Design definition and cost data were not prepared specifically for these configurations. However, the basic 15- by 60-ft payload booster data can be applied to these boosters.

For design and cost purposes, the S2-156 series burn booster with two 156-in-diameter SRMs is identical to the P2-156 15- by 60-ft payload booster. The SRMs are attached to the HO tank in a parallel fashion, but the engines are designed to operate in a series burn mode. The ballistic design will be varied from the P2-156 in precise throat size and propellant burning rate to meet the S2-156 thrust requirements.

The S4-120 series burn configuration utilizes four identical UA 1208 SRMs with an intertank structure similar to that of the S6-120 booster. This UA 1208 is similar to the S6-120 UA 1207 with differences in an additional segment, a shorter forward closure and reduced throat size and propellant burning rate to produce the required S4-120 thrust.

The P2-156 14- by 45-ft payload booster is identical in concept to the P2-156 15- by 60-ft payload booster. The attach structure provisions are identical, and the S3-156 model SRM is utilized. Nozzle throat size and propellant burning are adjusted to provide the proper thrust characteristics.

The P3-120 SRM design is identical to that of the P4-120 with the exception of adjustments to the nozzle throat size and propellant burning to provide proper thrust tailoring.

4.2 TECHNICAL CONSIDERATIONS

Studies were conducted in such areas as ecology in respect to pollution and acoustics, abort requirements and techniques, thrust neutralization, base heating, and SRM booster stage integration. Based on currently defined vehicle

TABLE I

STAGE CHARACTERISTICS

	S2-156	S4-120	P2-156	P3-120
OLOW	1,198,000	1,198,000	1,650,000	1,650,000
BLOW	2,820,556	2,847,876	2,446,248	2,045,113
GLOW	4,018,556	3,934,876	3,096,248	3,695,113
Launch Configuration	Series burn parallel attach	Series	Parallel	Parallel
Number of SRMs	2	4	2	3
Propellant Weight, lb x 10^{-6}				
SRM	1.250	0.620	1.080	0.592
Booster	2.50	2.480	2.160	1.776
Thrust, lb x 10^{-6}				
SRM (sea level)	2.600	1.267	1.800	1.220
Booster	5.200	5.068	3.600	3.660
Action Time	128	126	130	130
Stage Mass Fraction	0.887	0.870	0.883	0.867
Control Requirements				
Deflection, degrees	±6	±12	±6	±6
Rate, degrees/sec	5	5	5	5
Propellant	← PBAN →			
Acceleration, g				
Liftoff	← 1.25 to 1.3 →			
Flight	← Less than 3.0 →			
Maximum Dynamic Pressure, lb/ft^2	← Less than 650 →			

requirements and SRM booster stage configurations, no technical condition was identified concerning the application of SRMs for a shuttle booster. More precise definition of requirements and attendant interfaces will dictate further analyses and engineering design. The subject of ecology is included in this summary report because of the varied interests in the effects associated with SRM use rates required in support of the NASA basic mission model.

From a study of the composition of the exhaust gas of a solid propellant space booster stage in the atmosphere, it appears that most constituents are present in quantities too small by several orders of magnitude to present any problem. Because the solid propellant produces HCl, which is not present in the exhaust of most liquid engines, only the behavior of the part of the exhaust gas which can come back to earth is shown (figure 5). Following ignition, the bases initially swirl about the launch platform, mixing with the surrounding air and forming a ground cloud. After about 22 sec, the vehicle has risen so high that the exhaust gases no longer reach back to the ground cloud. Because the cloud is hot it will rise to a height of 1,330 ft (figures applicable to the Titan III-C and documented by photographic observations are shown in parentheses). The cloud then drifts downwind and grows by turbulent diffusion until at a distance of 67 miles, under adverse meteorological conditions, its edge may reach the ground again.

Based on analytical predictions for a series burn booster using six UA 1207 SRMs, the total weight of HCl emitted into the ground cloud is 139,000 lb, and the HCl concentration at first is 965 ppm. By the time the cloud has risen to its terminal altitude, the HCl concentration has dropped to 450 ppm; when the cloud touches the ground it has decreased to 3.7 ppm. The Committee on Toxicology of the National Academy of Science/National Research Council has recently set a Short Term Public Limit of 4 ppm for 10 min and a Public Emergency Limit of 7 ppm for 10 min. Neither of these limits is reached under the adverse conditions on which the calculations were based. It is of interest to note that these limits represent values at which the impact may be no more than a strong odor or, at the most, slight irritation of the mucous membranes, with no adverse health effects.

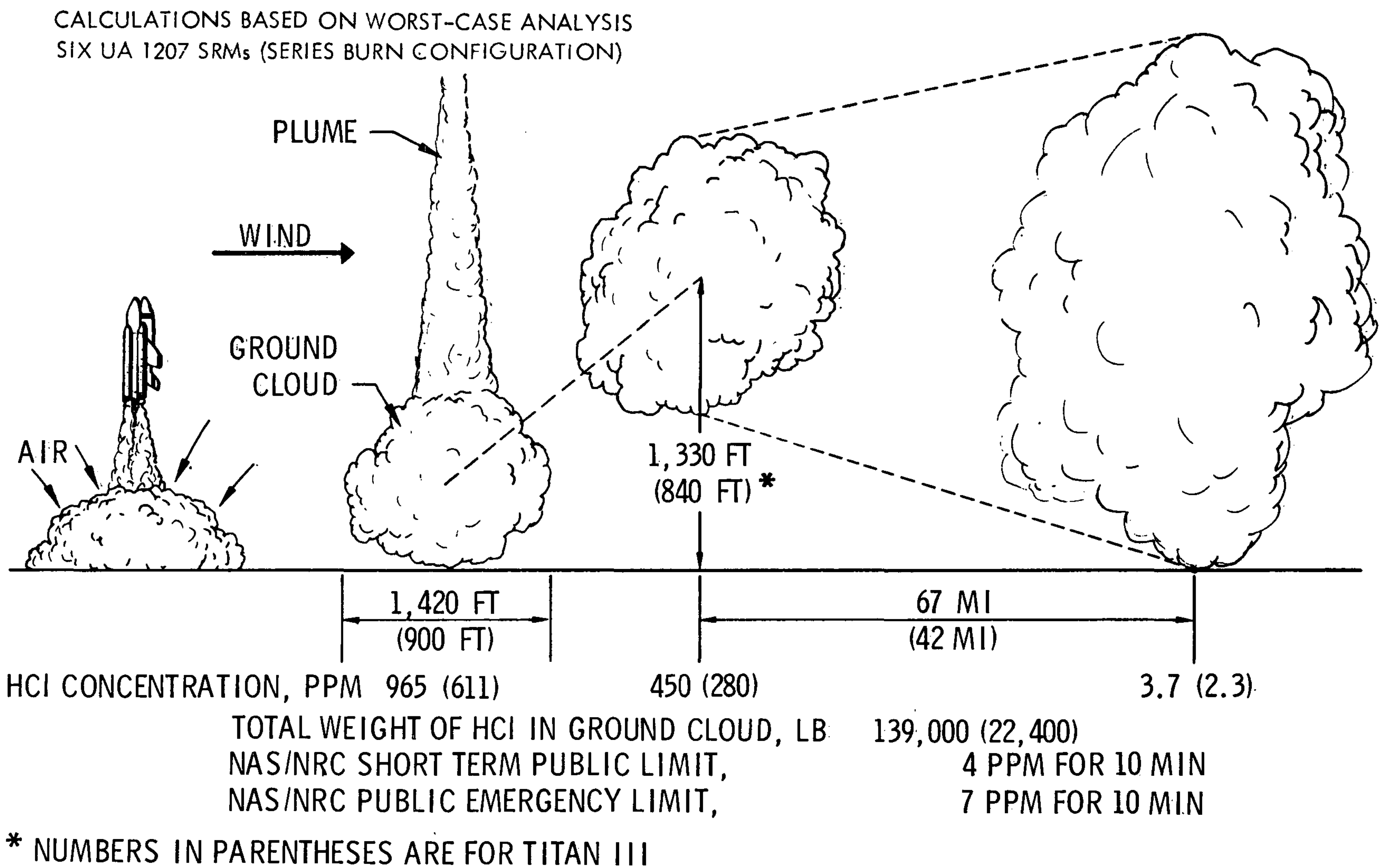

Figure 5. Calculated Maximum HCl in Space Shuttle Booster Ground Cloud

UTC-V-01471

Because the atmosphere becomes relatively thin in the stratosphere above 40,000 ft, it is of some concern whether the exhaust gas ejected by the space shuttle boosters from this altitude until burnout at 135,000 ft will be large enough to constitute a pollution problem. Because recently there have been major discussions of this problem in connection with the commerical operation of supersonic airplanes flying in the stratosphere, the quantity of material ejected at the maximum launch rate of 60 per year by a space shuttle booster using six UA 1207 SRMs was compared to that emitted by an SST fleet of 400 airplanes. It is obvious that the quantities of water, CO_2, CO, and NO ejected by the space shuttle boosters are three or more orders of magnitude smaller. Because the SSTs do not emit HCl this gas cannot be compared in the same way, but its concentration, when spread throughout this band of the stratosphere, was compared with the actual concentration of ozone in the same band. The concentration of HCl resulting from the space shuttle boosters would be one million times less than the concentration of ozone. Therefore, HCl would have no effect on the spectral absorption characteristics of the atmosphere. Particulate matter emitted by the space shuttle boosters would be less than that emitted by the SST fleet, but only by a factor of 13. However, the quantity of interstellar dust particles which pass through the atmosphere on their way to the earth's surface is one thousand times greater than that deposited by the space shuttle booster. Therefore, it is expected that pollution of the stratosphere by the space shuttle booster is not a serious problem (figure 6).

The Titan III-C launch vehicle uses two UA 1205 SRMs. Detailed acoustic measurements made on these vehicles allow a projection of noise levels to be expected within the HO tank and orbiter vehicle. The maximum noise should occur shortly after launch and diminish to a minimum about 15 sec after liftoff. Aerodynamic noise then becomes dominant, with the peak level of 150 to 158 db occurring at the time of maximum dynamic pressure (figure 7).

40,000- TO 135,000-FT ALTITUDE
TONS/YEAR

PRODUCT	SPACE SHUTTLE BOOSTER 60 LAUNCHES/YEAR	SST 400 PLANES IN COMMERCIAL OPERATION
WATER VAPOR	3.1×10^3	6.4×10^7
CO_2	1.3×10^3	3.7×10^7
CO	12.9×10^3	0.2×10^7
NO	—	0.2×10^7
HCl	9.6×10^3	—
PARTICULATES	14.0×10^3	180.0×10^3

$$\frac{Al_2O_3 \text{ (TONS/YEAR)}}{\text{DUST FROM SPACE (TONS/YEAR)}} \approx 0.001$$

$$\frac{\text{MEAN HCl CONCENTRATION (PPM)}}{\text{OZONE CONCENTRATION (PPM)}} \approx 1 \times 10^{-6}$$

BASED ON SIX UA 1207 SRMs (SERIES BURN CONFIGURATION)

Figure 6. Material Released into Stratosphere

UTC-V-01472

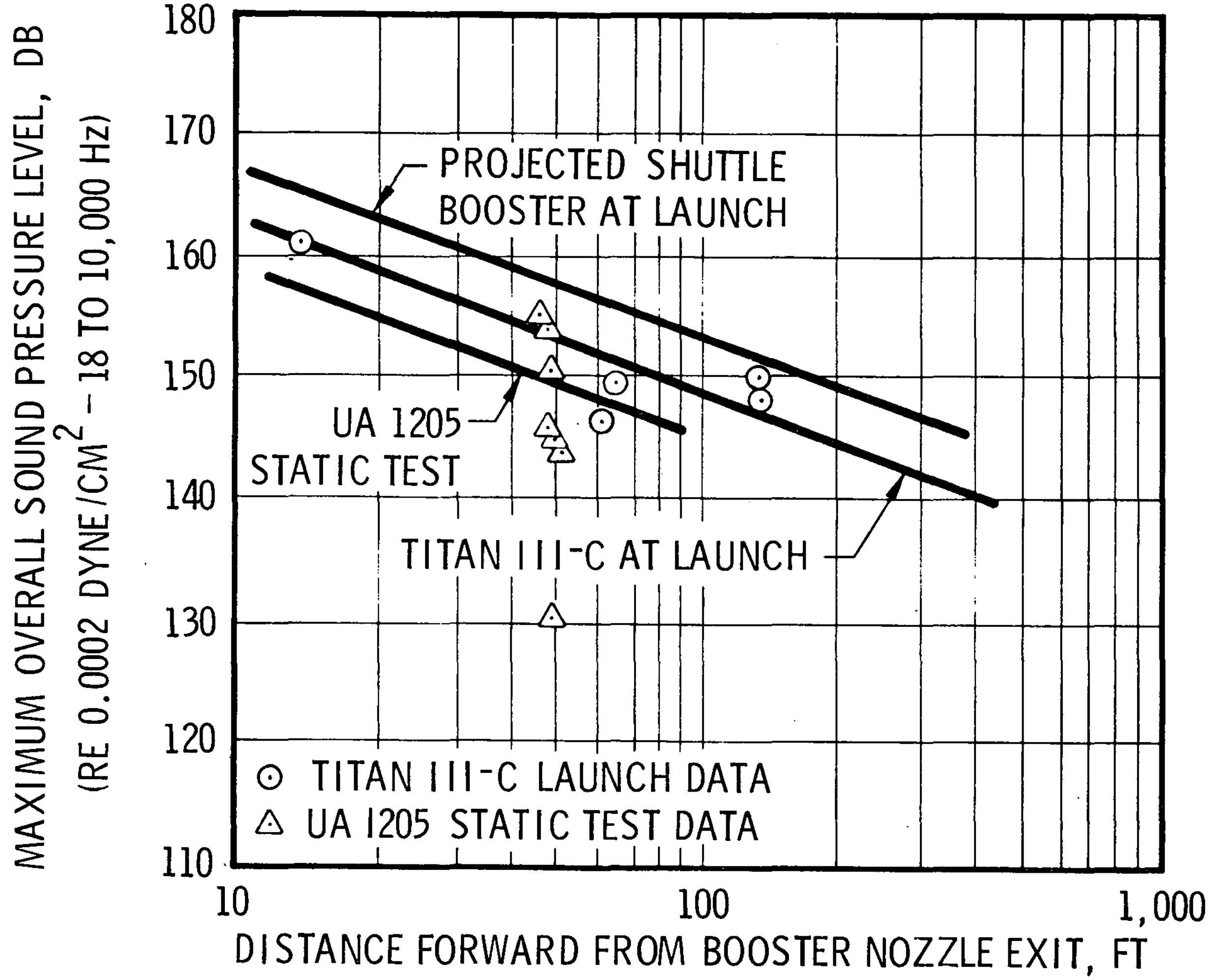

Figure 7. Projected Maximum Sound Pressure Levels

UTC-V-01544

5.0 SRM BOOSTER STAGE PROGRAM DATA

An important element of the study was definition of programs required for design, development, test, and evaluation; production capabilities and processes; and launch operations and logistic concepts. These programs were defined employing the NASA-established ground rules, assumptions, and mission models, which were the basis for the estimated booster costs furnished to NASA.

5.1 DESIGN, DEVELOPMENT, TEST, AND EVALUATION

DDT&E plans were derived from previous development experience with the 120- and 156-in.-diameter SRMs. Figure 8 portrays a representative design and development plan and a schedule time-phased to support key shuttle system milestones. The plan and schedule are applicable to both motors, except that differences will occur in long lead-time procurement items, scope of full-scale development testing, and variations in requirements for qualification testing. Figure 9 summarizes the DDT&E funding requirements for the four baseline configurations which encompass those elements of cost included in this nonrecurring cost category, such as inert motors for dynamic testing and development flight test motors. For general comparative purposes, the net DDT&E funding requirements are shown.

5.2 PRODUCTION

Production planning encompassed the support required for the recurring operational phase and was defined in terms of all SRM booster stage configurations and mission models. Other variations also were introduced per the NASA requirements and are reflected in the various cost presentations (figure 10). Figure 10 summarizes the results of reviewing required production capacities and establishing a plan to provide a production capability necessary to support the Space Shuttle Program. This can be accomplished by expanding the existing capabilities at the UTC Development Center, California, and by establishing an additional production capability at the UA facility in Florida. These requirements will be provided by use of corporate financing.

Stage structures and other inert hardware components also can be provided by expansion of existing capabilities.

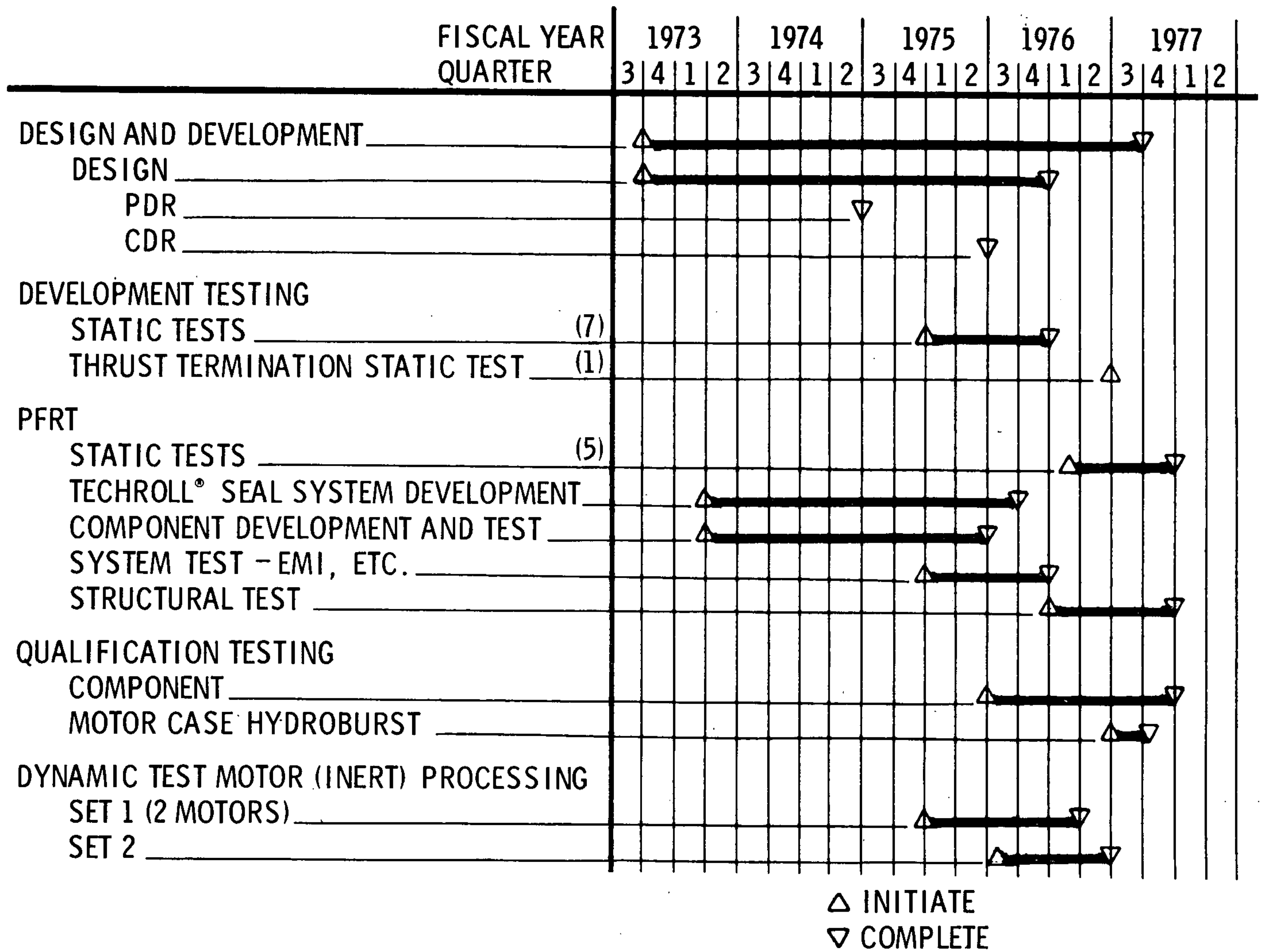

Figure 8. Design and Development

UTC-V-01477

	P4-120	P2-156	S6-120	S3-156
BASIC DEVELOPMENT	123.2	171.4	169.1	210.2
GROUND TEST HARDWARE INERT MOTORS	(14.8)	(11.9)	(24.1)	(18.7)
FLIGHT TEST HARDWARE AND OTHER PRODUCTION	(64.1)	(52.8)	(98.0)	(81.2)
LAUNCH	(11.9)	(8.7)	(13.5)	(10.7)
NET DDT&E	32.4	98.0	33.5	99.6

Figure 9. DDT&E Cost Breakdown
1970 Dollars in Millions

UTC-V-01551

- UTC MANUFACTURING AND TEST CENTER

  PRESENT CAPACITY ——— 36 MILLION POUNDS OF PROPELLANT/YEAR
  EXPAND TO ——— 72 MILLION POUNDS OF PROPELLANT/YEAR (20 FLIGHTS/YEAR)

- FLORIDA PRODUCTION FACILITY (WEST PALM BEACH)

  PRODUCTION CAPACITY ——— 140 MILLION POUNDS OF PROPELLANT/YEAR (40 FLIGHTS/YEAR)

- STRUCTURE PRODUCTION CAPACITY

  CURRENT UTC ——— 12 SETS/YEAR
  EXPAND TO ——— 20 SETS/YEAR
  FLORIDA CAPACITY ——— 40 SETS/YEAR

- CORPORATE INVESTMENT

- EXISTING INDUSTRIAL BASE

Figure 10. Production Plan

UTC-V-01481

Maximum use of the subcontractors and vendors currently qualified for the Titan III Program has been considered. Production can be expanded as necessary to support selected mission models.

With the exception of AP, production capacities exist to support the annual peak requirements for propellant raw materials presently defined. Current capacities for AP are in the range of 35 to 50 million pounds per year. Because of the limited commercial use for this product and an estimated production facility expansion cost of $15 to $25 million, a Government industrial facility will be required to support this significant production requirement.

Element	Annual Peak Requirement, lb
Aluminum powder	36 million
AP	150 million
Epoxy resin (DER 332)	7 million
PBAN Polymer	25 million
Other materials	As required

5.3 OPERATIONS

Operations planning incorporated previously discussed ground rules, assumptions, and mission models in addition to assuming all flights were from KSC per the NASA instructions. The concepts defined the transportation, logistics, material handling and launch base activities necessary to successfully implement a factory-through-launch plan for a man-rated SRM booster stage. This concept and the ground systems required were derived from significant Titan III experience gained from launch operations from both the East and West Coasts. This ground system has been demonstrated completely and is capable of accommodating the space shuttle booster system. Figure 11 identifies launch site functions in the three major categories of SRM operations required for flight. Within each category, discrete operations are identified which form the basis for establishing facilities, ground support equipment, manpower, and associated requirements.

RECEIVE AND INSPECT	ASSEMBLE AND TEST	INTEGRATED OPERATIONS
TRAIN TURNAROUND	BOOSTER STAGE ASSEMBLY	ORBITER MATE
COMPONENT STORAGE	BOOSTER STAGE TEST	VEHICLE TEST
END SECTION ASSEMBLY	BATTERY INSTALLATION	ORDNANCE INSTALLATION
BOOSTER SUPPORT	BOOSTER STAGE ACCEPTANCE	MOVE TO LAUNCH PAD
		PRELAUNCH PREPARATION

Figure 11. SRM Booster Stage Launch Site Functions

UTC-V-01478

The three functional categories relate to the following SRM activities: (1) receipt, inspection, and subassembly required to initiate SRM booster stage assembly on the launch platform, and recycle and turnaround operations associated with transportation and transportation ground support equipment; (2) assembly, checkout, and acceptance of the SRM booster stage, integration with the orbiter propellant tank and the orbiter, and integrated system testing required prior to transfer to the launch area; and (3) launch pad final preparations, prelaunch functional checkout operations, and launch support.

Launch site manpower requirements are a function of the booster configuration, mission model, and definition of the ground support system, as presented in figure 12.

6.0 RECOVERY AND REUSE

Recovery and reuse of SRMs received considerable emphasis during this study. Although SRM recovery was studied in some detail by UTC in the early 1960s for application with the space shuttle system, a complete update and review was done. The results of the current UTC recovery and reuse study are summarized in figure 13.

The launch cost savings which accrue to the program by recycling 7, 14, 21, and 100 times represents a very significant savings. In each of the NASA mission models, a savings of approximately 25% to 35% of the total SRM fabrication cost can be realized by recycling. These savings (figure 14) represent worst-case conditions for recovery and refurbishment and include attrition rates of 16% to 25% for recovered hardware for 7 reuses and up to 42% for 100 reuses. The cost analysis was based on recovering only major components of the SRM with no redesign required, except for incorporation of the parachute recovery system into the nose section of the SRM.

It is of importance to recognize that if the results of subsequent studies on recovery of SRMs reveal that recovery and reuse of SRM components is not feasible, the maximum financial risk will remain limited to the expendable SRM costs as indicated.

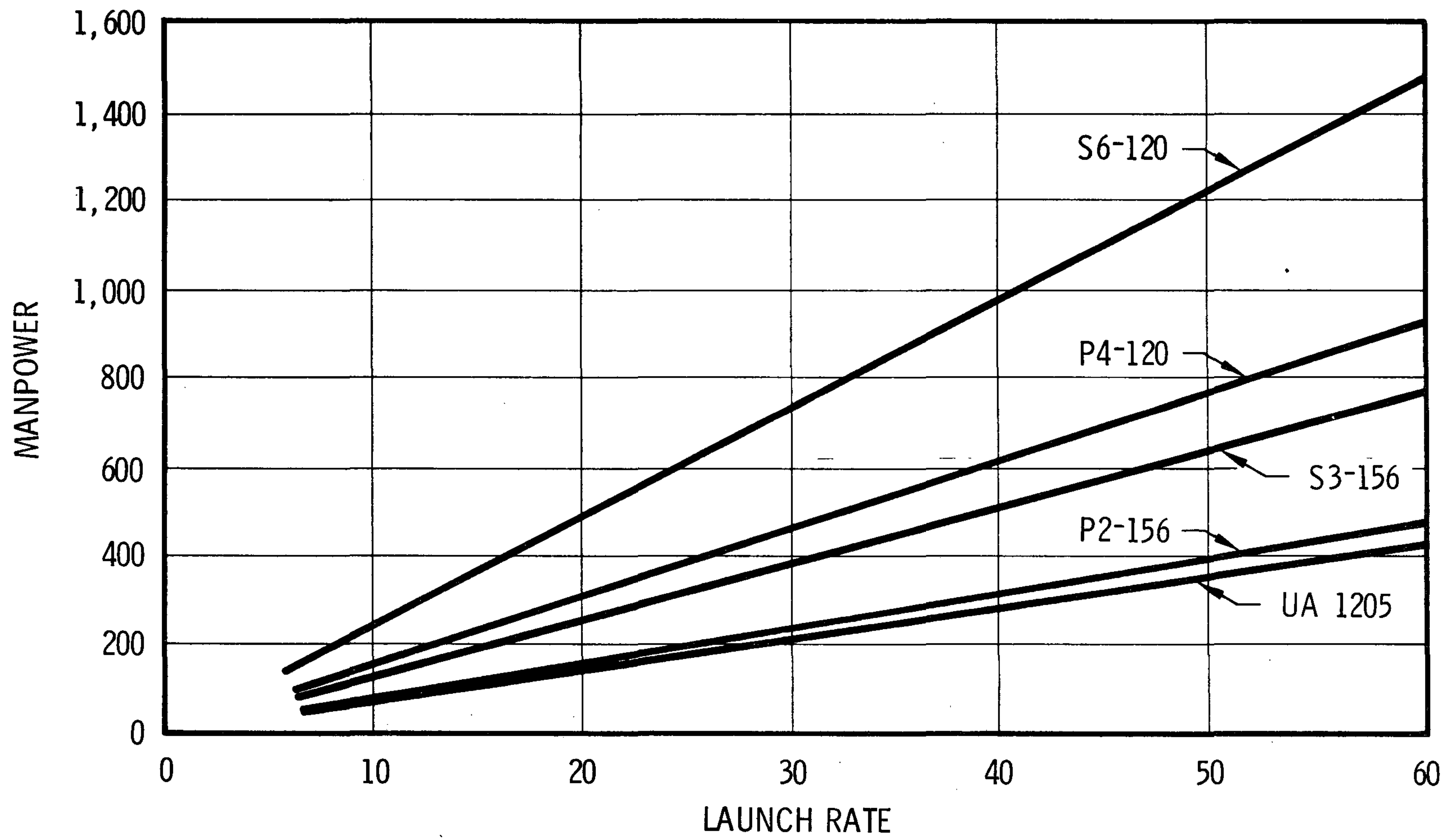

Figure 12. Flight Operations Manpower Production Flights

UTC-V-01484

- MODULAR CONSTRUCTION
    - SIMPLIFIES REFURBISHMENT OPERATIONS
    - LOCALIZES ACCIDENTAL DAMAGE – GREATLY REDUCES FINANCIAL RISK
- RECOVERED SRM STAGE IS LIGHT – SIMPLIFIES OPERATIONS
    - 120-IN. 85,000 LB
    - 156-IN. 140,000 LB
- SIMPLE, RUGGED CONSTRUCTION REDUCES DAMAGE HAZARD
    - HEAVY WALL
    - SMALL DIAMETER (10 TO 13 FT)
    - NEGLIGIBLE INTERNAL SENSITIVE COMPONENTS
- MOTOR COOL ON WATER ENTRY – ONLY HOT PART IS NOZZLE THROAT, WHICH IS REFURBISHED
- LOW ENTRY VELOCITY WITH 120-IN.-DIAMETER SRM ACHIEVED WITH CURRENTLY AVAILABLE PARACHUTE RECOVERY PACKAGE
- NO ROTATING MACHINERY OR CRYOGENIC PLUMBING
- **COSTS NOT CRITICALLY DEPENDENT ON FULL RECOVERY**

Figure 13. Recovery of Solids

UTC-V-01564

COSTS OF RECOVERY INCLUDE

- PARACHUTE SYSTEM
- NOZZLE SHOCK ABSORBER
- RECOVERY SHIP AND CREW
- TRANSPORTATION
- HANDLING
- PACKAGING
- CLEANUP
- INSPECTION
- NONDESTRUCTIVE TESTING
- REFURBISHMENT

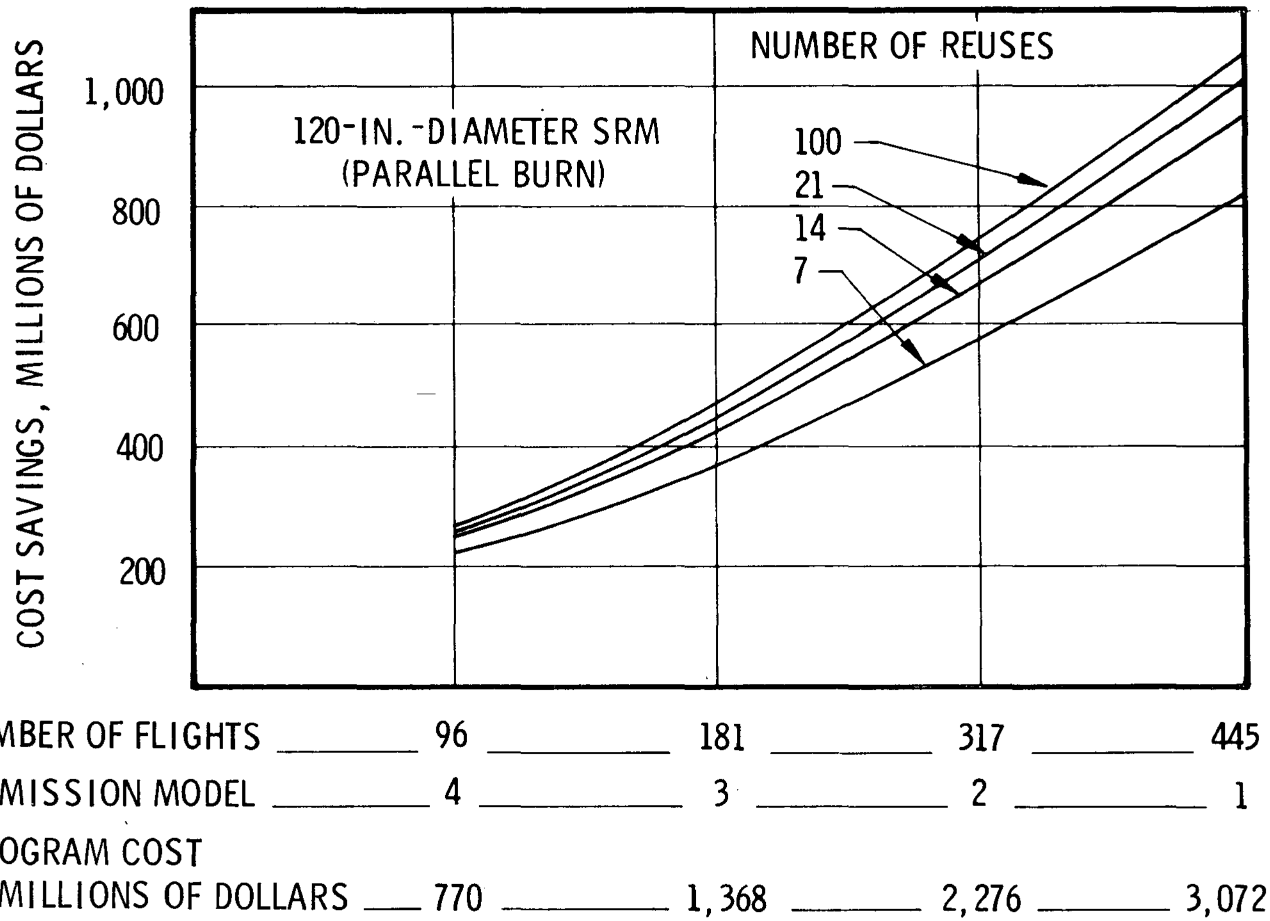

Figure 14. Program Savings Based on Recovery and Reuse

UTC-V-01561

7.0 ESTIMATION OF COSTS

Estimation was a significant objective of this study. Information from previous and current development and production programs were used with the SRM system definition and program planning from this study, to accumulate creditable and understandable cost data. The cost data then were portrayed in the formats and cost elements established by the NASA direction. In addition, various cost data presentations were established to assist NASA in their determinations. Figure 15 presents the SRM program schedule used for cost extimation.

The SRM booster stage cost summary presented in figure 16 is the result of UTC's cost estimations based on the defined baseline configurations and programs and the variations due to mission models with and without recovery. A time-phased annual funding requirement for a mission model of 10 launches per year is shown in figure 17.

Although this study involved SRM booster stage requirements for the 14- by 45-ft payload bay orbiter as a secondary effort, a program cost summary for three candidate SRM booster configurations was prepared and is presented in figure 18.

To provide further cost parameters for use by NASA, figures 19 and 20 are presented. Figure 19 provides information useful in analyzing recovery savings, production funding, and vendor recurring funding requirements. Figure 20 presents information reflecting recurring costs of the varous mission models of the four baseline configurations and showing the delta cost impact of SRM recovery and reuse.

Figure 21 presents information significant to the impact of funding requirements as a function of launch rate based on the four mission models examined. These costs are in millions of dollars and assume no recovery or reuse.

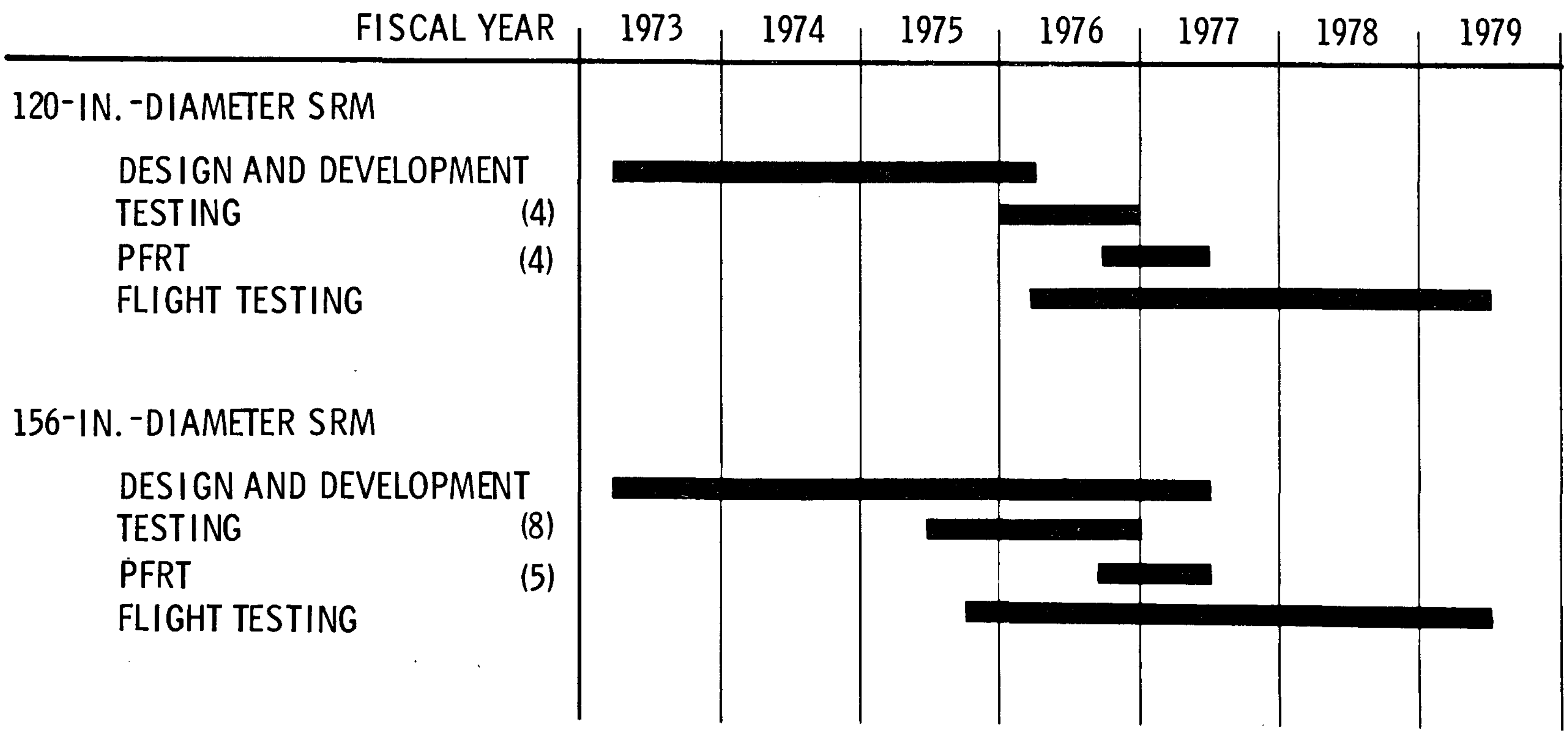

Figure 15. SRM Program Schedule

UTC-V-01549

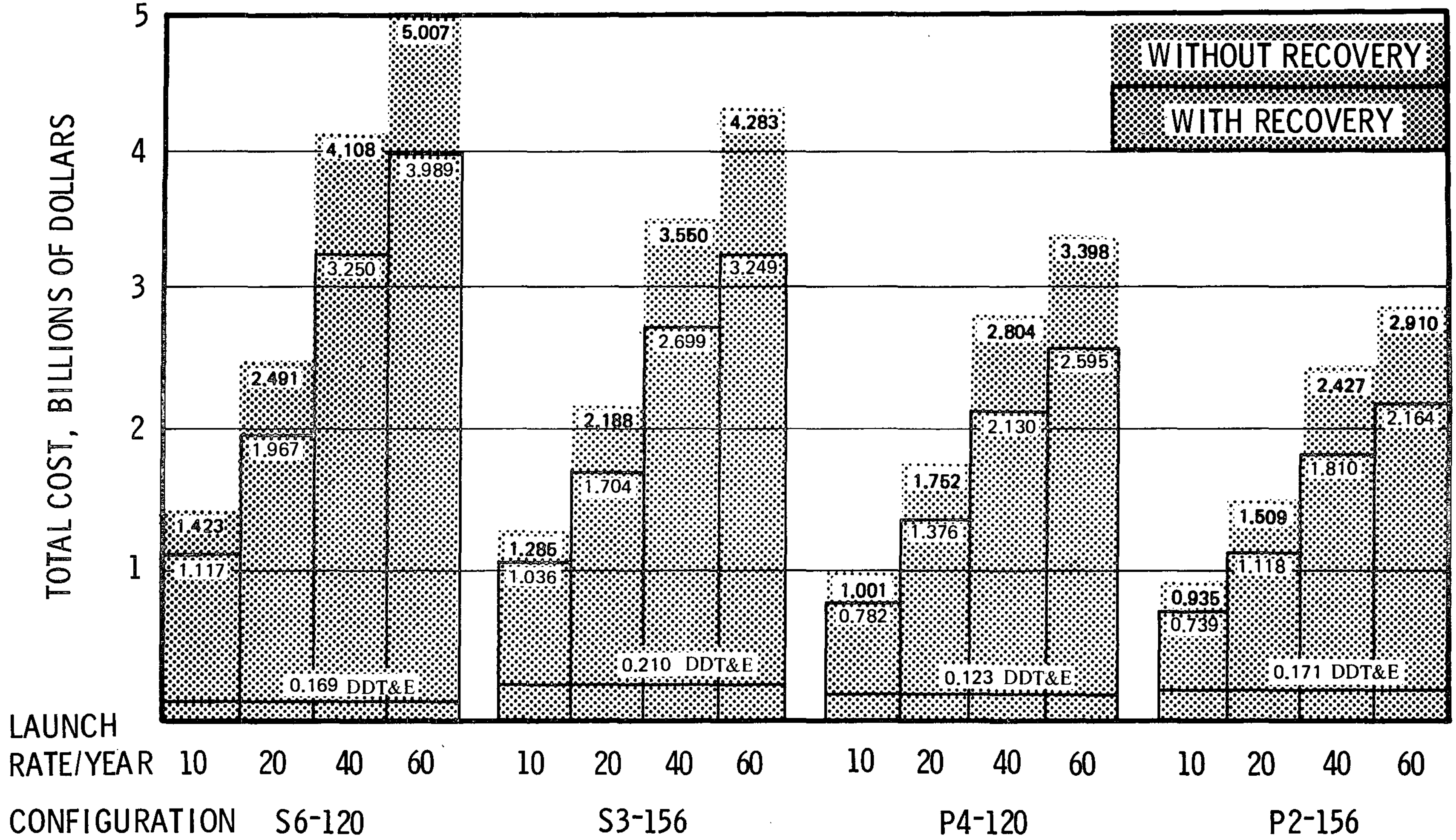

Figure 16. Program Cost Summary, SRM Booster Stage

UTC-V-01554

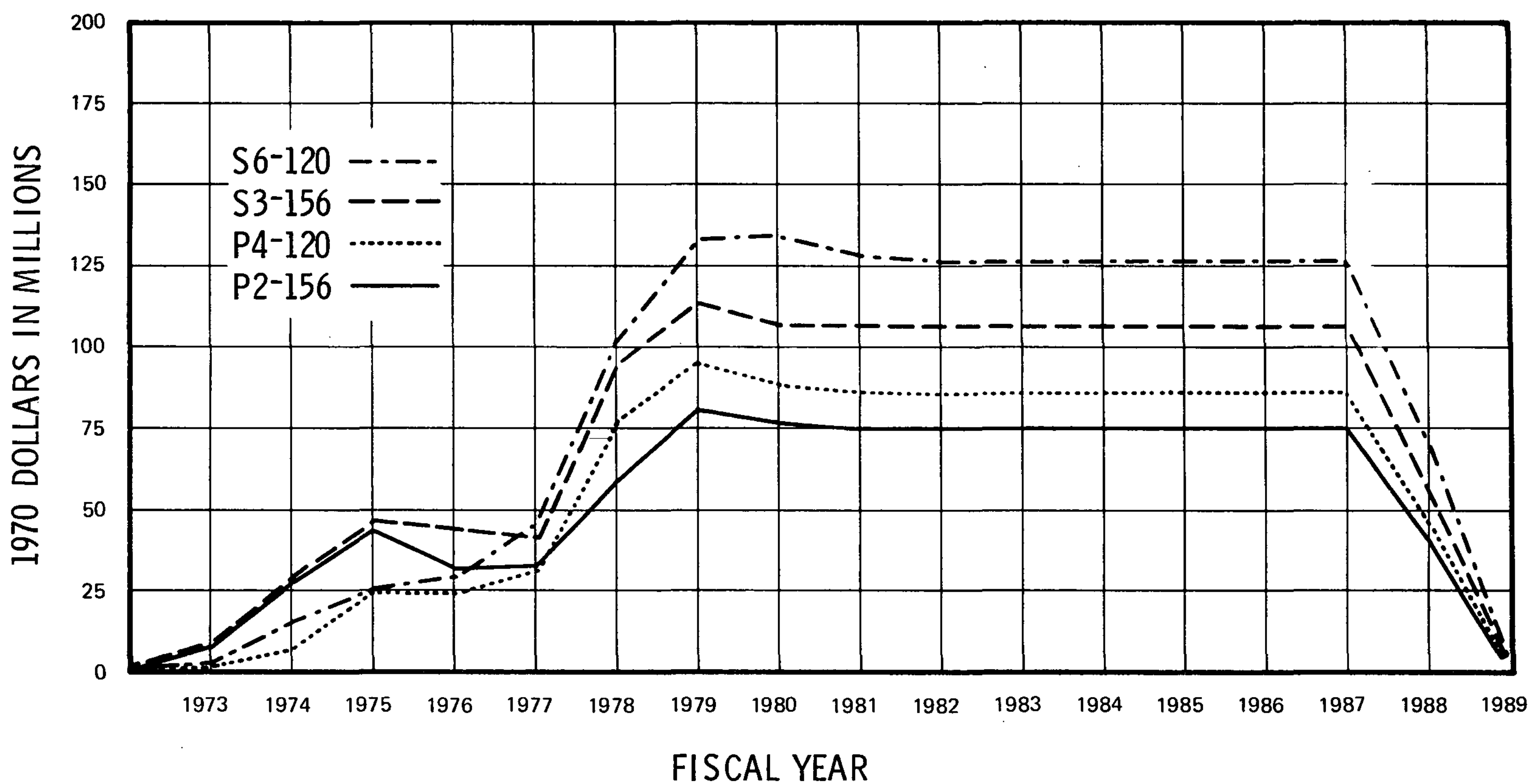

Figure 17. Annual Funding Requirement
10 Launches/Year

UTC-V-01552

CONFIGURATIONS	COST, MILLIONS OF DOLLARS			
	DDT&E NONRECURRING	PRODUCTION (INVESTMENT) RECURRING	OPERATIONS RECURRING	TOTAL PROGRAM
P3-120				
20 LAUNCHES/YEAR	108.120	950.653	105.531	1,164.334
60 LAUNCHES/YEAR	108.120	2,273.528	182.725	2,564.373
S2-156				
20 LAUNCHES/YEAR	183.616	1,342.349	109.968	1,635.933
60 LAUNCHES/YEAR	183.616	2,598.931	178.735	2,961.282
S4-120				
20 LAUNCHES/YEAR	131.982	1,555.552	140.707	1,828.241
60 LAUNCHES/YEAR	131.982	3,190.178	244.864	3,567.024

Figure 18. SRM Booster Stage Program Cost Summary Orbiter with 14- x 45-ft Payload Bay

UTC-V-01556

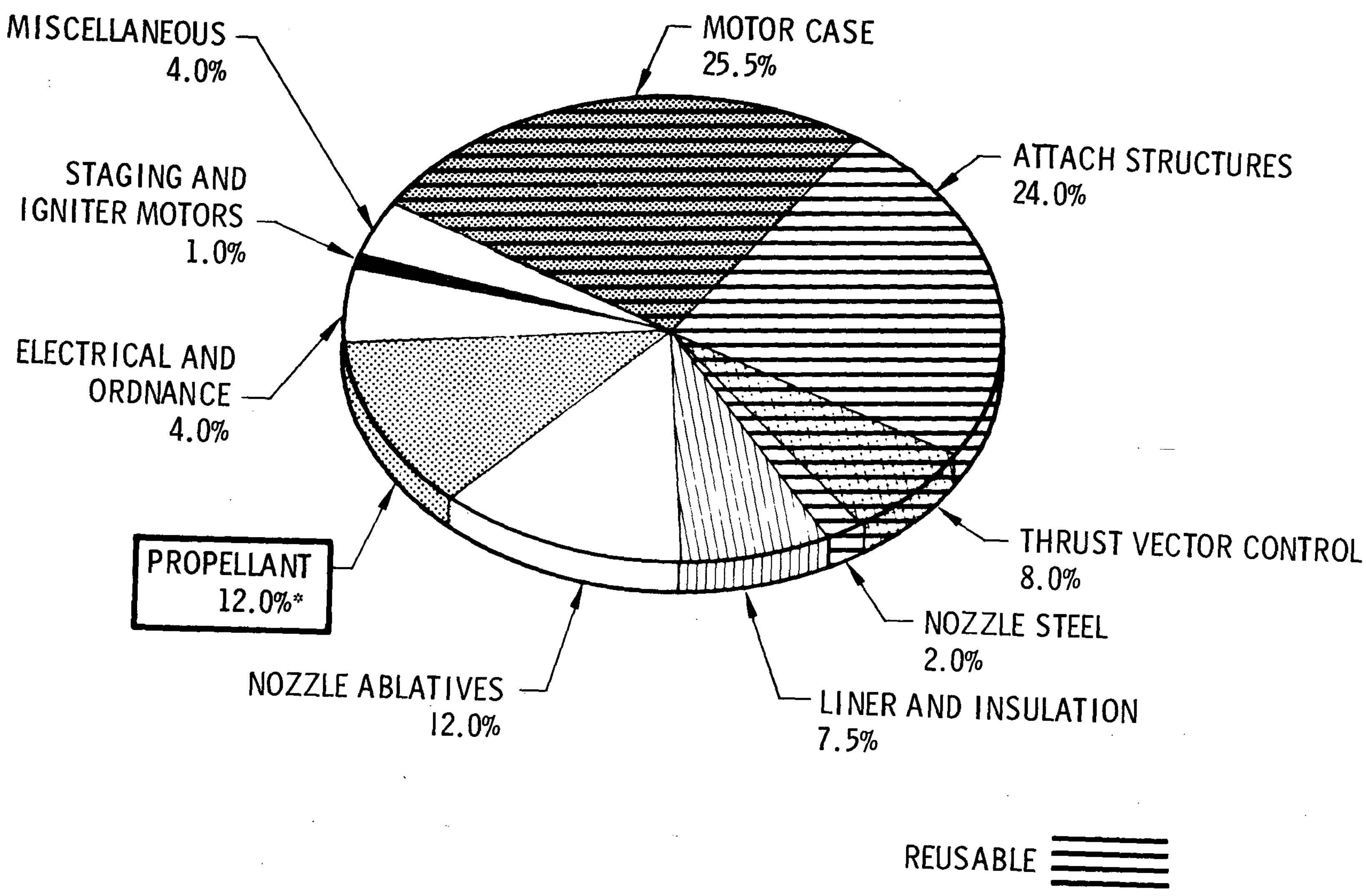

Figure 19. Typical SRM Hardware Cost Percentages

UTC-V-01547

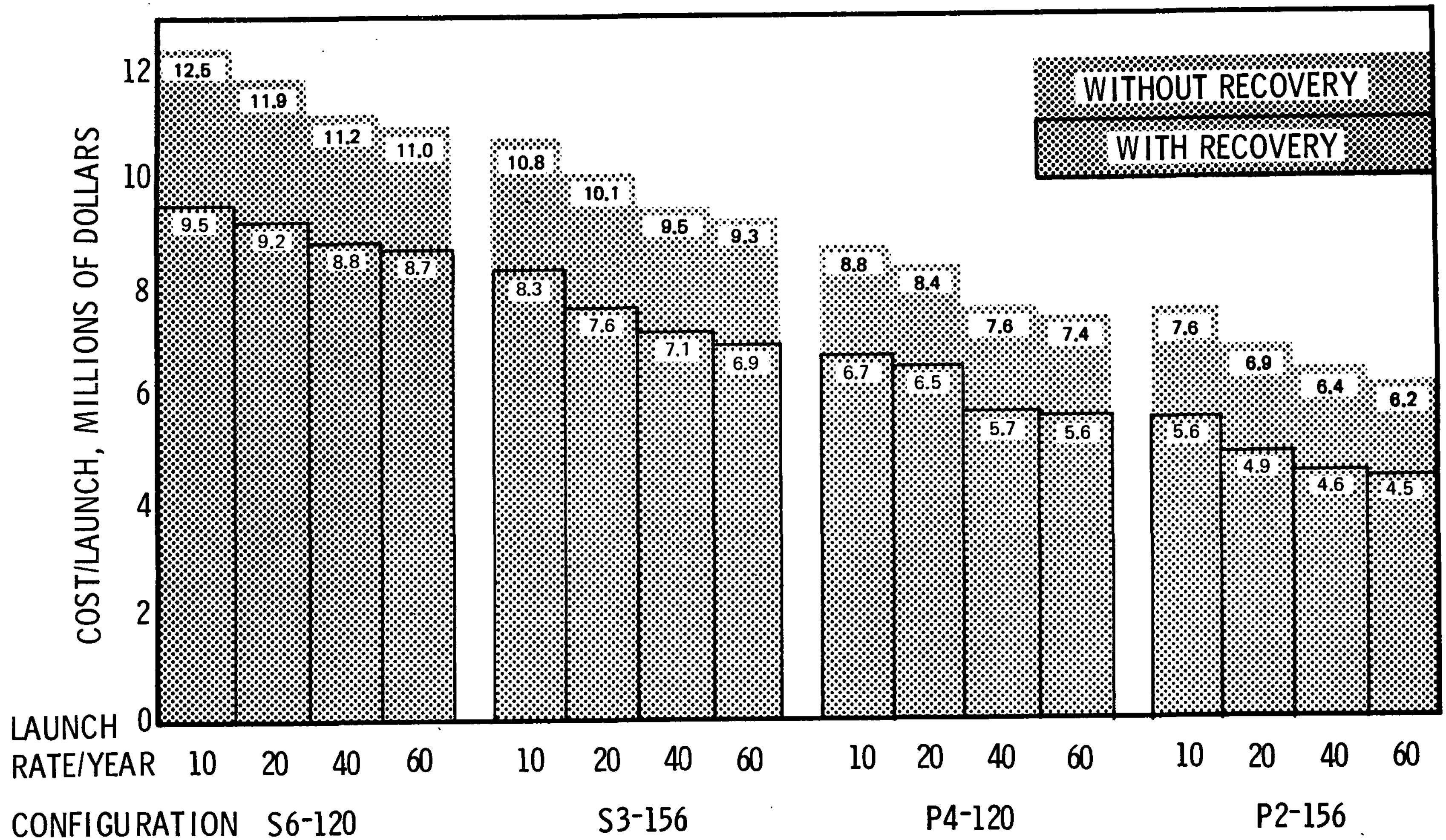

Figure 20. SRM Booster Stage Recurring Costs/Launch

UTC-V-01555

FLIGHTS/YEAR	S6-120	S3-156	P4-120	P2-156
10	2.08	3.64	2.20	3.80
20	1.98	3.37	2.10	3.45
40	1.87	3.18	1.90	3.20
60	1.83	3.10	1.85	3.10

Figure 21. Average Cost per SRM
Configured as Stage

8.0 CONCLUSIONS AND RECOMMENDATIONS

The UTC study of SRMs for a space shuttle booster investigated and defined four SRM booster stage designs; established concepts and plans for development, production, and launch operations programs; and determined creditable, understandable costs for the selected baseline booster configurations.

The detailed management, technical, and cost comparison of these study results leads to the conclusion that:

A. The solid boosters offer maximum confidence for a reliable interim booster; all projections were based on creditable data offering maximum technical and financial risk.

B. A 156-in.-diameter SRM booster stage should be developed for flights in excess of one-half the full mission model, and a 120-in.-diameter SRM booster stage should be developed for less than one-half of the full mission model.

C. An SRM booster stage for the Space Shuttle Program requires a minimum investment in a DDT&E program and yields maximum confidence in satisfying known budgetary restraints.

It is recommended that the results of this study be accepted as the basis for a decision to select the SRM booster stage for the space shuttle system.

It is further recommended that near-term design, development, test and evaluation projects be implemented for SRM recovery and reuse technology, thrust vector control development and test, and for advancement of the manufacturing industries' state of the art.