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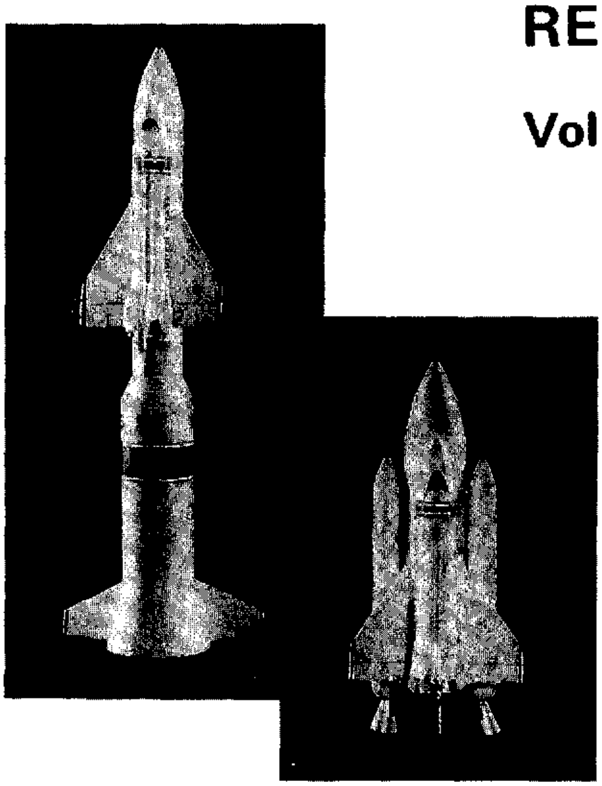
# SPACE SHUTTLE SYSTEM PROGRAM DEFINITION

## PHASE B EXTENSION FINAL REPORT

## COST AND SCHEDULE REPORT

### Volume IV



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B34-43 RP-33

15 March 1972

GRUMMAN
BOEING

# SPACE SHUTTLE SYSTEM
# PROGRAM DEFINITION

# PHASE B EXTENSION
# FINAL REPORT

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## Volume IV

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## ILLUSTRATIONS



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## Section 1

## INTRODUCTION

This document summarizes the supporting cost and schedule data for the second half of the Space Shuttle System Phase B Extension Study. The major objective for this period was to address the cost/schedule differences affecting final selection of the HO orbiter space shuttle system. The contending options under study included the following booster launch configurations:

- Series Burn Ballistic Recoverable Booster (BRB)
- Parallel Burn Ballistic Recoverable Booster (BRB)
- Series Burn Solid Rocket Motors (SRM's)
- Parallel Burn Solid Rocket Motors (SRM's).

We also examined the implications of varying payload bay sizes (15x60 and 14x45) for the orbiter, engine type (pressure vs. pump fed) for the ballistics recoverable booster, and SRM motors (120" vs 156") for the solid booster. The HO Orbiter was baselined with three 472K SSME's (Space Shuttle Main Engine) and reusable external insulation TPS for all programs. Shuttle system operational costs were determined for the standard 445 flight traffic model (maximum 60 flights per year) together with comparative data for rates of 40, 20 and 10 maximum flights per year. In addition, we considered the implications of providing orbiter pad abort, unmanned development flight testing, 380K HiPc engines in the small 14x45 payload bay orbiter, and early production phasing of the last three orbiters.

The cost/schedule estimates reported herein are in accordance with the program milestones leading to first manned orbital flight (FMOF) and with the traffic model defined in NASA Technical Directive GAC-9. These estimates were developed through the combined effort of the Grumman/Boeing team. Grumman developed cost/schedule estimates for the orbiter and its related ground support equipment. Boeing developed corresponding estimates for the booster. Estimates for flight test and operations are the result of combined Grumman/Boeing analysis. Engine costs for the SSME and F-1 engines are based on NASA guidelines and Rocketdyne data. Boeing prepared pressure-fedengine estimates based on data from Aerojet, Rocketdyne and NASA and solid rocket motor costs based on Lockheed, UTC, and Thiokol data.

This report has been organized in the following sections:

- Costing Ground Rules
- Summary Cost Comparisons
- Operational Cost Comparisons
- Other Cost Considerations
- Shuttle Program Cost/Schedule Summaries.

The second section describes the overall study groundrules used during the study. The matrix of program options is shown together with the recent update in system characteristics and design groundrules. The major assumptions employed in costing plus the attendant groundrules used for development and operations are also presented along with the baseline work breakdown structure.

Section 3 contains comparative program cost data for all the primary series and parallel burn boosters with the large (15x60) orbiter and parallel solids with the small (14x45) orbiter.

The fourth section describes additional groundrules used to determine system operational costs (i.e., out-of-pocket unamortized costs). It contains a detailed breakdown of average cost per flight of recoverable and expendable booster programs. The impact of the maximum flight rate assumption is also shown for both types of booster programs. In addition, comparative program costs are presented for initial and later years of operations.

Section 5 summarizes the results of other cost studies which examined the effect of changing some of our basic groundrules and assumptions. Specifically included are the impact of providing for an unmanned flight test, and phasing early production of the last three orbiters.

Section 6 contains a brief cost/schedule summary for each of the Space Shuttle Programs studied. These programs include the following:

- 15x60/Series/BRB (Pressure-Fed)
- 15x60/Series/BRB (Pump-Fed)
- 15x60/Series/Solids
  - 1207 and 156 SRM
- 15x60/Parallel/BRB (Pressure-Fed)

- 15x60/Parallel/Solids
  - 1207 and 156 SRM
- 14x50/Parallel/Solids
  - 1205 and 156 SRM
- 14x45/Parallel/Solids
  - 1207 and 156 SRM
- 15x60 Swing Eng/Series/BRB (Pressure-Fed)
- 15x60 (with abort rockets)/Series/BRB (Pressure-Fed).

Section 2

## COSTING GROUND RULES

During the second half of the Phase B Study Extension, the Grumman/Boeing team examined a number of system options, as directed by NASA. The study key issues (Figure 2-1) revolved around the selection of the appropriate booster (recoverable liquid or expendable solid) for the HO Orbiter together with the preferred launch arrangement (series or parallel burn). In addition we were directed to examine the implications of a smaller payload bay size orbiter (14x45 vs 15x60) and providing capability for orbiter pad abort.

- **What Are Technical & Cost Differences Between Series/BRB & Parallel SRM?**
- **How Much Weight & Cost Reduction for Smaller-Payload-Bay-Size Orbiter?**
- **What Is Booster Design & Cost Status?**
- **What Is Orbiter Design Status?**
- **How Can We Achieve Pad Abort Capability?**
- **What Are Implications of National Environmental Policy Act On Shuttle?**

*Figure 2-1 Study Key Issues*

The study matrix used to initiate this investigation (Figure 2-2) depicts 16 program options baselined with a common orbiter SSME engine. Major emphasis, however, was directed toward definition of the series burn BRB with the large (15x60) orbiter and the parallel burn solids with the small (14x45) orbiter. Since the latter configuration would show the greatest cost differential compared to the other orbiter/booster options, the remaining booster configurations associated with the small orbiter were dropped from further consideration.

The shuttle system requirements (Figure 2-3) have been updated to achieve initial performance equivalent to that previously identified with the Mk II version of a Mk I/Mk II system. Accordingly we dropped the two-phased approach for orbiter TPS and main engine development. Our current orbiter design has been baselined with SSME (472K) engines and RSI TPS.

We have used a uniform set of design ground rules for all configurations (Figure 2-4). Notably we have sized all SRM's with thrust vector control and with a capability for thrust termination.

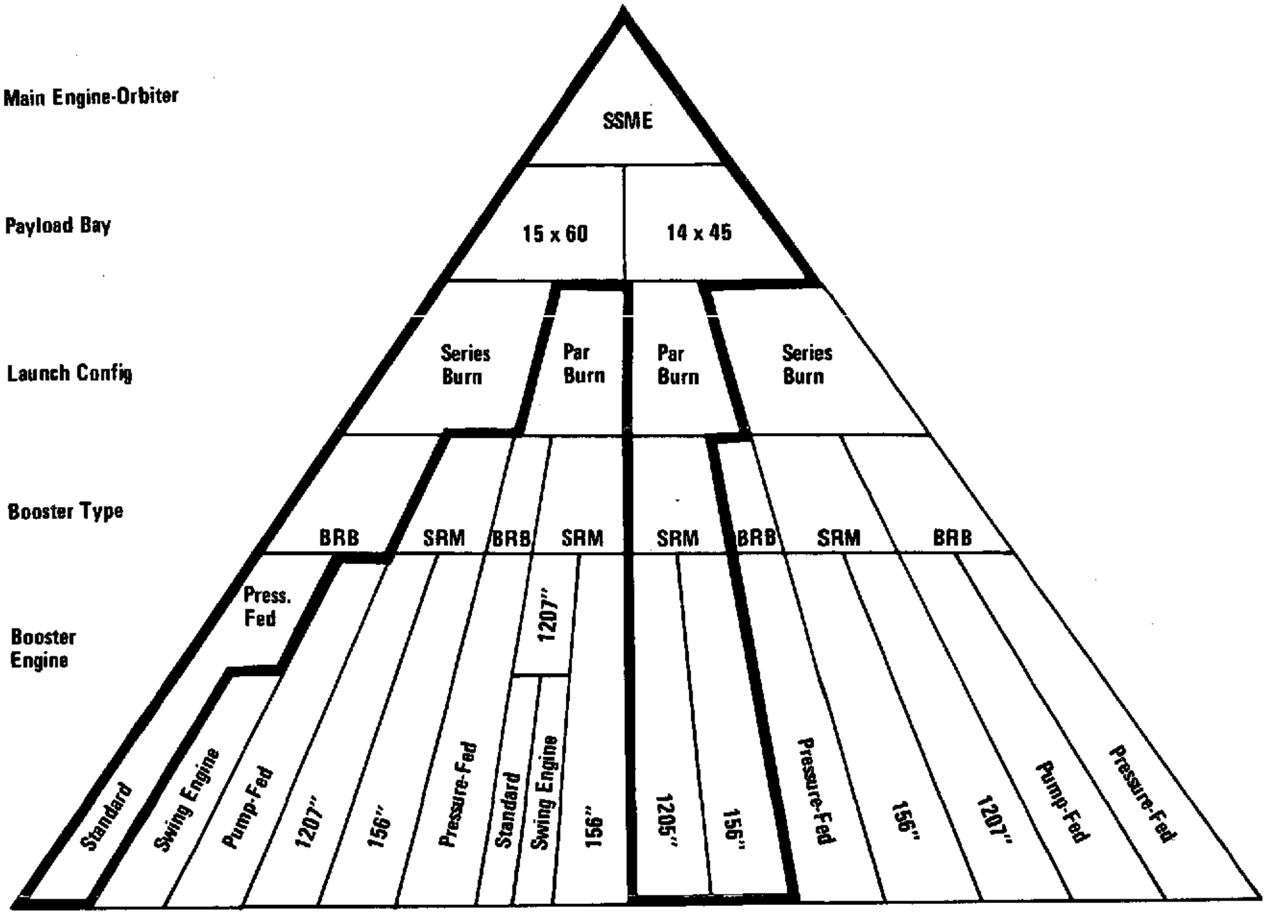



*Figure 2-2 Program Options*

| | *WAS* | | *IS NOW* | |
|---|---|---|---|---|
| | **Mk I** | **Mk II** | | |
| **Orbiter Payload** | **15 x 60** | **15 x 60** | **15 x 60** | **14 x 45** |
| **Payload Up-East/Polar/55°** | **?/25/?** | **65/40/?** | **65K/40K/25K** | **45K/?/25K** |
| **Payload Down** | **25K** | **40K** | **40K** | **25K** |
| **$V_{Stage}$, fps** | **6000 ± 1000** | **6000 ± 1000** | **>4000** | **>4000** |
| **Main Engine Type/$T_{vac}$** | **J-2S/265K** | **SSME/TBD** | **SSME/472K** | **SSME/472K** |
| **TPS** | **Ablative** | **RSI** | **RSI** | **RSI** |
| **Avionics** | **Low Cost** | **Upgraded** | **Low Cost/ Evolutionary** | **Low Cost/ Evolutionary** |
| **OMS/RCS** | **Storable** | **Storable** | **Storable** | **Storable** |
| **OMS ΔV, fps** | **650/1000** | **650/1000** | **650/1000/ 1400** | **650/1000/ 1400** |
| **Cross Range, N Mi** | **1100** | **1100** | **1100** | **1100** |
| **Abort** | **Intact (Not Pad)** | **Intact (Not Pad)** | **Intact-All Phases** | **Intact-All Phases** |

*Figure 2-3 System Characteristics*

- All SRMs Have Thrust-Termination Capability
- 1207s & 1205s to Be Used with Existing TVC, Thrust Termination, & Thrust Tailoring (Except if Max G & Max Q Constraints are Violated)
- All Booster Separation for Parallel Burn Configuration to Use Separation Rockets
- All Boosters Are Single-Stage
- All Booster $\lambda'$ Curves to Be Used for Sizing to Assume TVC
- 15 x 60 PLB Sized for Polar, 14 x 45K Sized for Due East Missions – All Payload Requirements Met
- $T/W_{LO}$ to Be 1.25, Max Q to Be at or Below 650 psf for All Configurations
- All SRM Nozzles to Be Canted to Allow Thrust Through CG at Burn-out, Including Thrust-Vectoring Capability

*Figure 2-4 Design Groundrules*

During this period we also updated our basic costing assumptions (Figure 2-5), derived from NASA Technical Directive GAC-9, to delete the Mk II program milestones. We retained the original milestones for Mk I FMOF as the new program baseline. In addition to the NASA groundrules, we have established other program ground rules (Figure 2-6) for defining comparative program costs. For example, we have baselined no unmanned development flight tests during DDT&E. We have also retained our prior definition that DDT&E terminates with FMOF. Accordingly all booster programs have been defined with only one flight vehicle (FMOF) in the development program (Figure 2-7).

| | |
|---|---|
| No. of Operational Flights | 445 |
| No. of Operational Launch Sites | 1 (KSC) |
| No. of Launches Pads | 2 |
| No. of Development Flight Test Orbiters | 2 |
| No. of Operational Orbiters | 2 + 3 = 5 |
| Major Assembly | Michoud |
| Flight Test | KSC |
| Phase C/D Go-Ahead Orbiter/Booster | June 72 |
| First Horizontal Flight Orbiter | April 76 |
| First Manned Orbital Flight | March 78 |
| Costs in 1970 Dollars | Yes |
| Contractor Effort (Less Fee) | Included |
| Primary Engine Costs | Included |
| Airbreather Engine Costs | Included |
| Government Water Recovery Facilities | Excluded |
| Government Funded Facilities | Included |
| – Launch – Refurbishment – Recovery – Flight Test | |
| Propellant Costs | Included |
| Training Costs | Included |
| Government Operations & Test | Excluded |
| Shuttle Program Management & Integration | Contractor Support |

*Figure 2-5 Key Costing Assumptions for Extended ASSC Study*

- Series Burn Interstage - Included With HO Tank
- No Unmanned Development Flights
- Vehicle Operational Life
  - Orbiter – >100 Flights
  - Series/Parallel BRB – 50 Flight
  - HO Tank – 1 Flight
  - SRM's – 1 Flight
- Main Engine Operational Life
  - SSME – 100 Flights
  - F-1 – 30 Flights
  - Pressure Fed Engine – 50 Flights
- Vehicle Production Learning Rate
  - Orbiter – 100%
  - Series/Parallel BRB – 91.5%
  - HO Tank – 90%
  - SRM's – 95%

*Figure 2-6 Additional Program Ground Rules*

| | | | 15 x 60 | | | |
|---|---|---|---|---|---|---|
| | Orbiter | Tank | Ser/Par. BRB-Press Fed | Series BRB-Pump | Ser/Par. 120 SRM | Ser/Par. 156 SRM |
| Units per Vehicle | 1 | 1 | 1/2 | 1 | 6/4 | 3/2 |
| Test Operations | | | | | | |
| Struct./Dyn/Sep Article | 1 | 3 | 1 | 1 | 1 | 1 |
| Propulsion Article | 1 | – | 1 | | 8 | 10 |
| FHF Vehicle | 1 | – | – | – | – | – |
| FMOF Vehicle | 1 | 1 | 1 | 1 | 1 | 1 |
| Flight Operations | | | | | | |
| Test Vehicle Conversion | 2 | | 1 | 1 | – | – |
| Operational Fleet, 445 Flights | 5 | 445 | 12 | 12 | 445 | 445 |

*Figure 2-7 Vehicle Allocation*

All recoverable vehicles used in development (orbiter and boosters) are also planned to be part of the basic operational fleet. Thus the two flight test orbiters plus three production orbiters comprise the five orbiter fleet. Similarly the one development booster plus 11 production boosters comprise the fleet of 12 BRB's. Expendable flight hardware, such as tanks and SRM's, are procured in accordance with the overall flight schedule.

We used the standard 445 flight traffic model, defined in GAC-9 with 60 maximum launches per year, (Figure 2-8), to determine comparative total program costs. The launch rate buildup of the standard model was also used to define the flight schedules for the alternate models limited to lower maximum flight rates of 40, 20 and 10 launches per year.

All program costs have been accumulated in accordance with the baseline WBS, Figure 2-9. As in the past, the main base facilities required for operations are included in Flight

Test WBS since it is the initial user. The Flight Test element includes both horizontal and vertical flight testing. Program system level engineering is included under Program Management as contractor support. Conversion of all flight test orbiters and reusable boosters to an operational configuration are included in production.

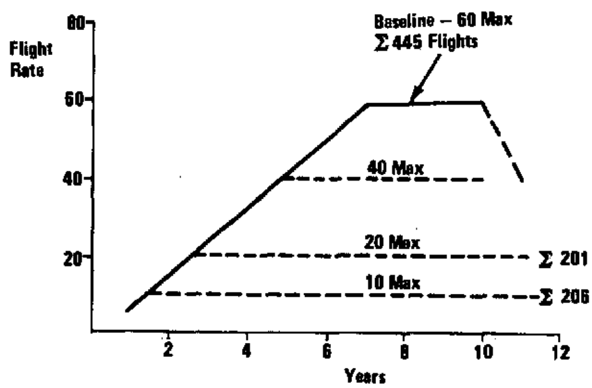



*Figure 2-8 Traffic Model*

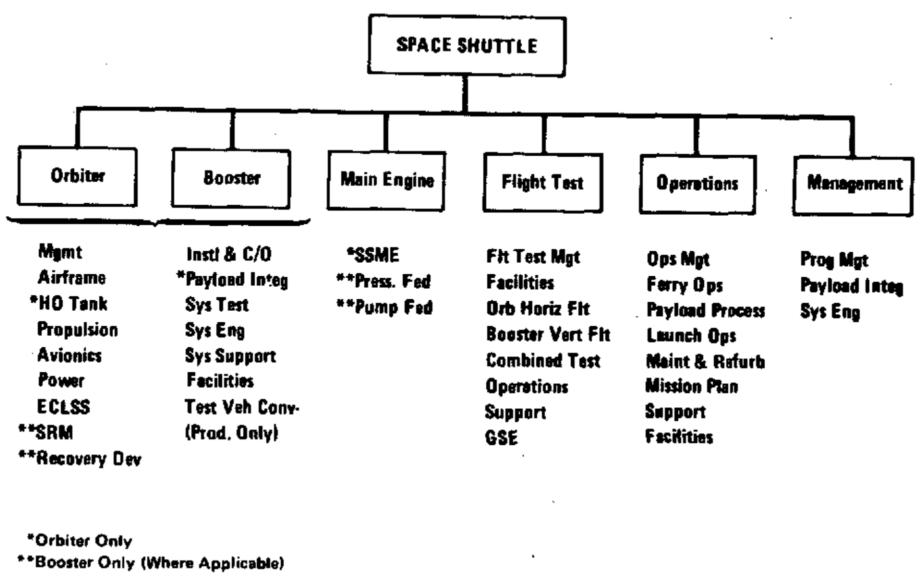



*Figure 2-9 Space Shuttle WBS*

## Section 3

## SUMMARY COST COMPARISONS

The baseline orbiter has evolved from prior shuttle system/programmatic studies focused toward reducing overall program costs. Major emphasis has been placed on lowering total development costs and associated peak funding requirements. Retaining an acceptable operational cost per flight was also considered important. The orbiter weight/cost history is shown in Figure 3-1.

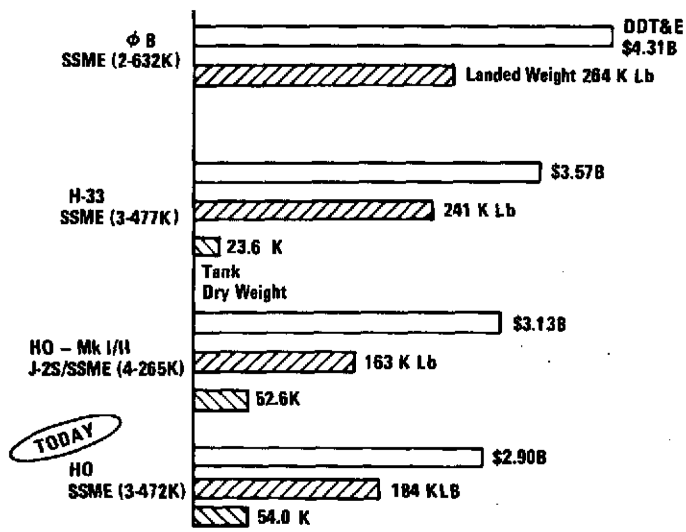



*Figure 3-1 Orbiter Weight/Cost History*

The original Phase B orbiter employed metallic TPS, internal propulsion tanks, cryogenic OMS and RCS, sophisticated avionics, and large SSME engines common with the booster. The H-33 Orbiter, which retained the same basic features, was lighter and less costly as a result of using external hydrogen tanks and smaller main engines. The HO Mk I/II 040A orbiter, however, achieved further economies by putting all the propellant in external tanks and adopting less costly current technology subsystems such as hypergolic OMS and RCS, low cost avionics, all aluminum airframe with phased external ablator/RSI TPS and a phased J-2S/SSME engine program. The Mk I development cost reported in December was \$2.38B and the total Mk I/II development cost was \$3.13B. Over \$400M of the Mk II delta cost was attributed to deferred cost for developing the SSME. The remaining difference was largely due to the cost of developing RSI TPS and Mk II avionics for later introduction in the operational fleet.

Today's baseline orbiter is an 040A derivative. It is designed to start out with a Mk II equivalent capability, namely RSI TPS, SSME engines and 40K up/down S. Polar payload. The current orbiter is somewhat heavier primarily due to the requirement for the higher landed payload (40K versus 25K). However, from a cost point of view it is less costly to achieve the same systems capability because it avoids the parallel development activities necessitated by initially operating with the Mk I ablator TPS and J-2S engine and later on phasing in new systems.

Comparative program costs are summarized in Figure 3-2 for all the program options studied. A brief cost/schedule summary is presented in Section 6 for each of these programs.

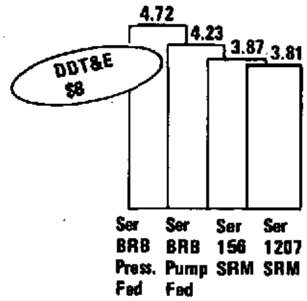
| | Ser BRB PRF | Ser BRB PUF | Ser 1207 SRM | Ser 156 SRM | Par BRB PRF | Par 1207 SRM | Par 156 SRM | Swing Eng/ Ser BRB/PRF | Par 1205 SRM | Par 156 SRM | Par 1207 SRM | Par 156 SRM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Payload Bay Size, Ft | 15 x 60 | 15 x 60 | 15 x 60 | 15 x 60 | 15 x 60 | 15 x 60 | 15 x 60 | 15 x 60 | 14 x 45 | 14 x 45 | 14 x 45 | 14 x 45 |
| SSME-Thrust, K Lb | 472 | 472 | 472 | 472 | 472 | 472 | 472 | 472 | 472 | 472 | 300 | 380 |
| No. Boosters/Vehicle | 1 | 1 | 6 | 3 | 2 | 4 | 2 | 1 | 4 | 2 | 4 | 2 |
| DDT&E | 4,720.0 | 4,226.3 | 3,813.2 | 3,869.3 | 4,636.2 | 3,823.2 | 3,852.7 | 4,920.0 | 3,766.1 | 3,809.6 | 3,724.3 | 3,760.6 |
| Production | 2,378.8 | 2,401.4 | 7,367.7 | 5,916.5 | 2,457.6 | 5,707.4 | 5,174.9 | 2539.0 | 5,037.7 | 4,503.3 | 5,591.1 | 4865.5 |
| Operations | 2,247.1 | 2,032.3 | 1,541.3 | 1,488.3 | 2,313.7 | 1,528.8 | 1,433.7 | 2,251.4 | 1,532.7 | 1,436.0 | 1,532.7 | 1,436.0 |
| Total Program-445 Flt | 9,345.9 | 8,659.9 | 12,722.2 | 11,274.1 | 9,407.5 | 11,059.4 | 10,461.3 | 9,710.4 | 10,336.5 | 9,747.9 | 10,848.1 | 10,061.3 |
| Peak Funding | 1,118.5 | 983.0 | 889.8 | 897.3 | 1,094.0 | 864.7 | 893.3 | 1,100.0 | 874.3 | 883.9 | 880.8 | 871.0 |
| Avg Cost/Flt -445 Flts | 7.07 | 8.62 | 18.46 | 14.97 | 7.381 | 14.53 | 13.10 | 7.45 | 13.10 | 11.57 | 14.30 | 12.47 |
| -201 Flts | 8.7 | 8.0 | 21.1 | 18.0 | 9.1 | 16.9 | 15.2 | 9.5 | 15.4 | 13.6 | 16.0 | 14.7 |

*Figure 3-2 Cost Summary, $M*

The number and type of boosters are the primary discriminators among these programs. The lower development costs afforded by the solid boosters is offset by the increase in production cost relative to the recoverable liquid booster programs. The average cost per flight is almost twice as high for the solids as the liquids.

Peak funding requirements generally are around $0.9B for the solids and $1.1B for the pressure fed liquids. The pump fed recoverable booster, which requires less propulsion system development with its existing F-1 engine, has a peak funding requirement of just under $1B.

By comparing all series programs (Figure 3-3) it is apparent that the solid boosters can be developed for about $900M less than the recoverable pressure fed booster. However, the solid booster systems cost more than twice as much to operate. The series pump fed booster, on the other hand, costs $500M less to develop than the pressure fed version, exhibits peak funding requirements under $1B and offers competitive operational costs.




| | | | | |
|---|---|---|---|---|
| PAF $B | 1.12 | .98 | .90 | .89 |
| Total Prog. $B | 9.35 | 8.66 | 11.27 | 12.77 |

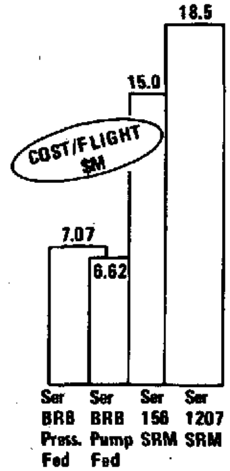
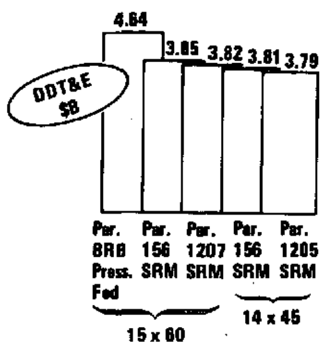



*Figure 3-3 All Series 15 x 60 Cost Comparisons — 445 Flights*

In comparing all parallel burn baseline SSME (472K) configurations, there is an apparent similar DDT&E cost relationship between solids and liquid boosters, Figure 3-4. In this case, developing solids for the small orbiter costs about $850M less than developing the parallel BRB for the large orbiter. We can save about $100M in development costs by going to the small payload bay system. The small payload bay parallel solid design does, however, reduce the system operational cost per flight from about twice the average cost per flight of the recoverable liquids to only about 1.6 times as much. The same trends are




| | | | | | |
|---|---|---|---|---|---|
| PAF $B | 1.09 | .90 | .88 | .88 | .87 |
| Total Prog $B | 9.41 | 10.46 | 11.06 | 9.75 | 10.39 |

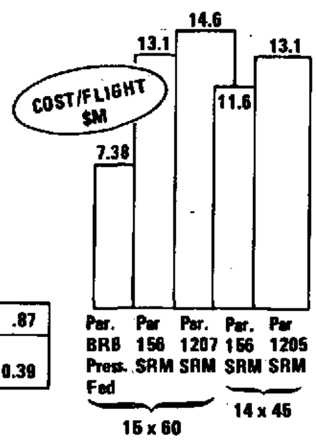
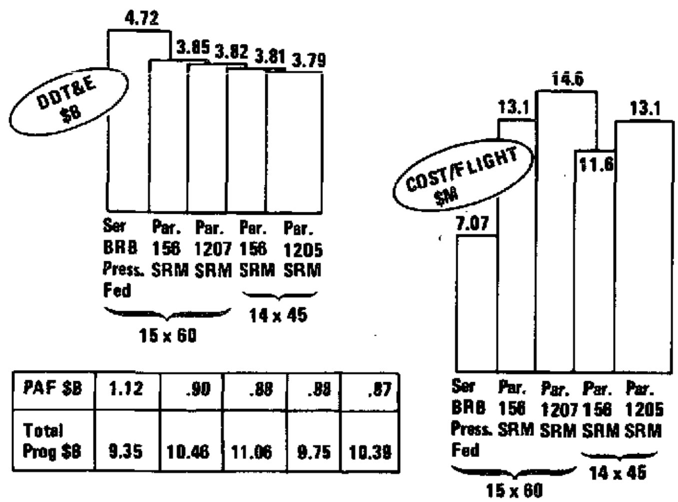



*Figure 3-4 All Parallel Burn Cost Comparisons — 445 Flights*

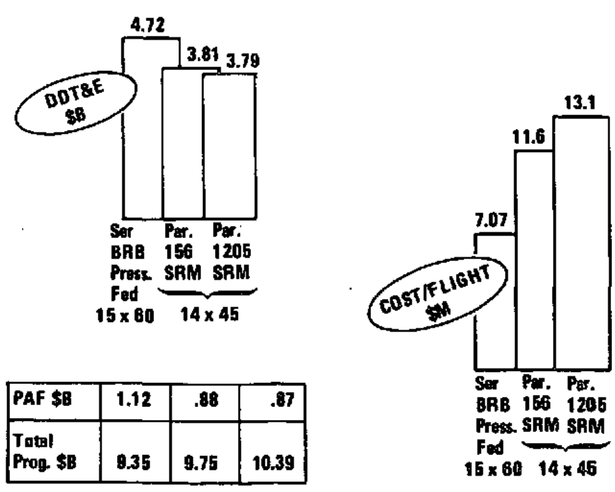
also evident when we compare the series BRB pressure-fed versus the parallel SRM programs, Figure 3-5. Again, it costs about $900M more to develop the series liquid boosters than parallel solids for the same size orbiter and about $1B more compared to the small parallel solid orbiters.




| | | | | | |
|---|---|---|---|---|---|
| PAF $B | 1.12 | .90 | .88 | .88 | .87 |
| Total Prog $B | 9.35 | 10.46 | 11.06 | 9.75 | 10.39 |

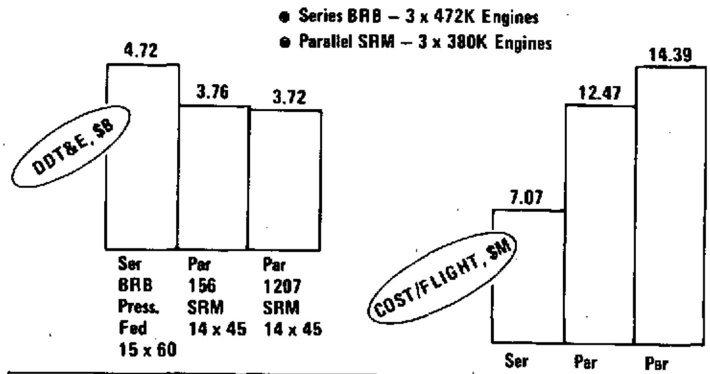
*Figure 3-5 Series BRB vs Parallel SRM Costs – 445 Flights*

We also examined the implications of using smaller SSME engines (380 K) in the 14x45 parallel burn solid programs. The results of this analysis are reflected in the comparative costs shown for the baseline 472K SSME programs and the 380K SSME program in Figure 3-6 and 3-7. While the smaller engine affords a slight decrease in total development costs it should be noted that cost per flight for the whole stack increases. The smaller




| | | | |
|---|---|---|---|
| PAF $B | 1.12 | .88 | .87 |
| Total Prog. $B | 9.35 | 9.75 | 10.39 |

*Figure 3-6 Series BRB 15 x 60 vs Parallel SRM 14 x 45*



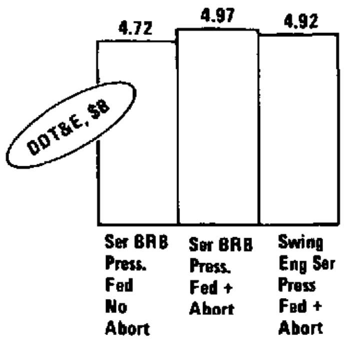

| | | | |
|---|---|---|---|
| PAF, $B | 1.12 | .87 | .86 |
| Total Prog, $B | 9.35 | 10.06 | 10.85 |

*Figure 3-7 Series/BRB 15 x 60 vs Parallel/SRM 14 x 45*

thrust/weight available with the 380K engine necessitates higher staging velocities and hence larger expendable solids. As a consequence, the small SSME system costs about $1M more to operate per flight than the equivalent baseline SSME solid booster design.

In addition we evaluated the impact of adding pad abort capability to the baseline series BRB/pressure fed program as well as to a Swing Engine Series BRB/pressure-fed program. Providing pad abort involves more than simply adding a simple abort solid rocket motor system to the orbiter and accounting for the attendant design iteration affect on the airframe and HO tank. It also imposes a new design requirement on all vehicle subsystems/GSE/supporting facilities and thus adds another dimension to both hardware development and software development activities. It also necessitates another major systems development test for demonstrating overall systems adequacy. We have estimated that it will cost $250M more to develop a pad abort capability for the series BRB pressure-fed program, Figure 3-8. During the normal mission, the abort motor will be expended after it is no longer needed. Thus, there will also be an increase in operational costs ($320K per flight) due to these expended abort motors.

The swing engine orbiter system, by comparison, will provide the same capability for $50M less in total DDT&E. The swing engine feature permits a lighter and hence less costly tank design with the aft location of the $LO_2$ propellant. However, the high-cost thrust structure attached to the rear of the tank is expended during each flight which makes it more costly to operate than the comparable fixed engine design.




| | | | |
|---|---|---|---|
| PAF, $B | 1.12 | 1.18 | 1.17 |
| Total Prog, $B | 9.35 | 9.77 | 9.72 |

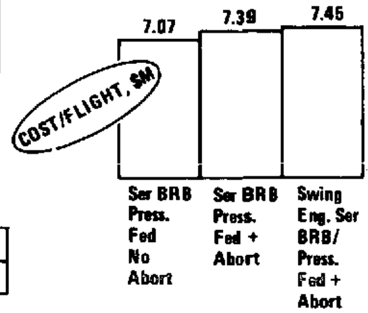



*Figure 3-8 Series BRB (15 x 60) – Abort/Swing Engine Cost Comparison*

## Section 4

## OPERATIONAL COST COMPARISONS

The system operational cost described in the previous section is simply the non-amortized out-of-pocket cost that would be charged to any user of the space shuttle system. The basic groundrules used to determine cost per flight are shown in Figure 4-1. A comparative breakdown of the basic elements included in average cost per flight is shown in Figure 4-2.

- System Operational Cost Includes
  - Expend Flight Hardware and Materials
  - Propellants
  - Operations and Support
  - Shuttle Management
- No Amortization
  - DDT&E
  - Investment – Reusable Vehicle, Engines, Facilities, and GSE
- Learning Assumptions
  - HO Tank Production – 90%
  - Solid Motor Production – 95%
  - Solid Booster Production – 88%
  - Vehicle Operations (Maintenance Repair & C/O) – 90% to 100th Flight

*Figure 4-1 Additional Ground Rules – Cost/Flight*

| | 15 x 60 Ser BRB Press. Fed | 15 x 60 Par 1207 SRM | 15 x 60 Par 156 SRM | 14 x 50 Par 1205 SRM | 14 x 45 Par 156 SRM |
|---|---|---|---|---|---|
| Expendable Tanks, $M | 2.021 | 2.116 | 2.083 | 2.114 | 2.005 |
| Expendable Boosters | – | 8.530 | 7.387 | 7.150 | 6.008 |
| Orbiter Refurbishment Material | 1.140 | 1.140 | 1.140 | 1.140 | 1.140 |
| Booster Refurbishment Material | .803 | .002 | .002 | .002 | .002 |
| Facilities/GSE Refurbishment Material | .265 | .265 | .265 | .265 | .265 |
| Propellants | .389 | .214 | .214 | .214 | .214 |
| Operations and Support | 2.114 | 1.600 | 1.385 | 1.600 | 1.385 |
| Shuttle Management | .337 | .693 | .623 | .624 | .550 |
| Cost/Flight, $M | 7.069 | 14.560 | 13.099 | 13.109 | 11.569 |

*Figure 4-2 Average Cost/Flight – Standard Model 445 Flights*

The average cost per flight is derived from the total cost of each element divided by the total number of flights. However, if the effects of learning are considered, the initial flights will be more costly than the later flights. The basic learning assumptions used for the production of tanks, solid motors, and booster stages are noted in Figure 4-1. The effects of learning at the launch site during vehicle operations associated with maintenance, repair, and checkout have also been considered.

Figure 4-3 illustrates the anticipated variation of cost per flight over the duration of the program. In the case of series BRB programs, only the learning effects due to tank production and vehicle operations impacts the cost. For the standard 445 flight (maximum 60 flights per year) traffic model, the cost per flight varies from $16M per launch for the first six launches to $6.4M per launch in the tenth year of operations. The average cost per flight ($7.07M) is not achieved until the sixth year of operations. At the lower traffic rates, constraints on minimum launch operation crews override any practical learning beyond the first few years. Hence the predominant effect lies in tank production. Comparative tenth year operation costs for the lower maximum flight rates of 40, 20, and 10 per year are $6.8M, $8.1M, and $9.8M respectively.

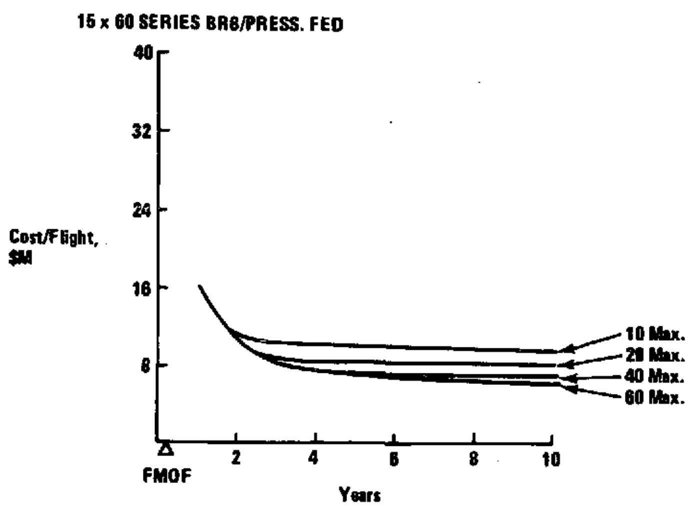



*Figure 4-3 Operational Cost Sensitivity, 15 x 60 Series BRB/Pressure-fed*

When the effects of production learning associated with solid boosters are added to the combined learning on tank production and vehicle operations a similar relationship is obtained for the small parallel solid program (Figure 4-4). The initial cost per flight varies from $25M for the first six launches to $11.9M in the tenth year of the 60 flight rate program. The average cost per flight of $13.1M is also not achieved until the sixth year of operations. Comparative operations costs in the tenth year for lower maximum flight rates of 20 and 10 per year are $13.7M and $17.2M respectively.

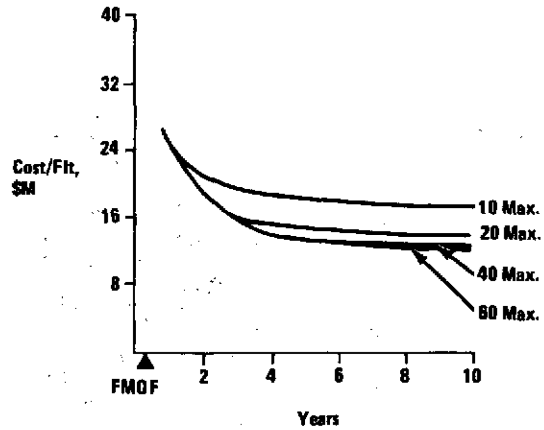



*Figure 4-4 Operational Cost Sensitivity, 14 x 45 Parallel 1205 SRM*

During the initial years of operations the shuttle will be competing with other programs for its share of the available pay loads. Accordingly, the initial operational cost will be of immediate concern to any potential users. Figure 4-5 illustrates the wide variation in operational costs between the recoverable liquid systems and the expendable solids. During the second year of operations the pump-fed booster will run at about \$9.2M per launch and the small 1205 parallel solid program at about \$16.9M per launch.

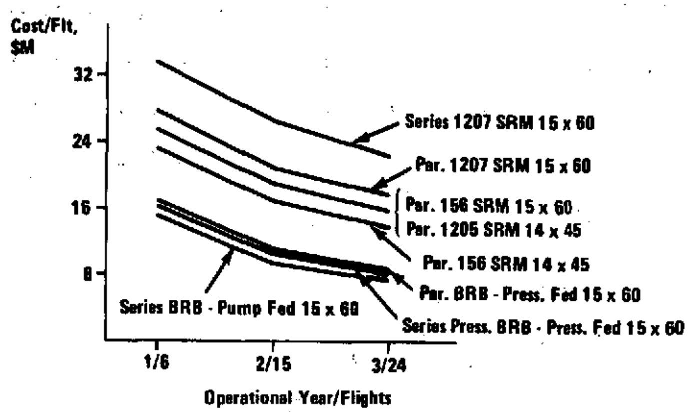



*Figure 4-5 System Operational Costs Early Years*

Later on, the system operation cost will vary in accordance with the maximum annual flight rate. Comparative operational costs are shown in Figure 4-6 for the sixth and tenth year of operations. The cost/flight relationships between recoverable liquids and expendable solids are, however, the same as during the early years of the program.

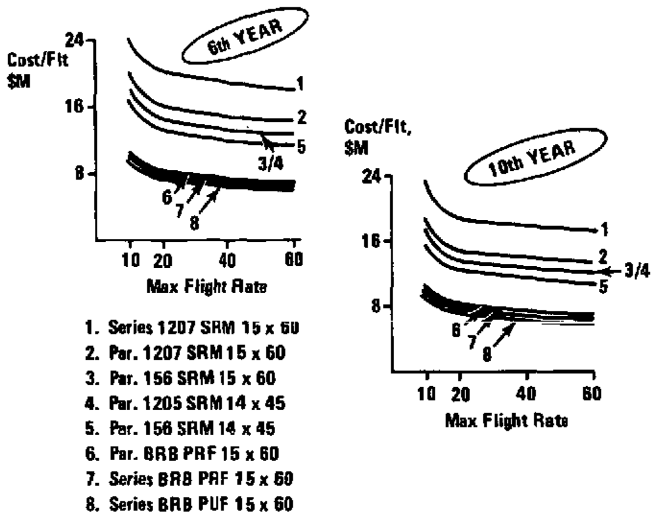



*Figure 4-6 System Operational Cost Comparison*

Another way to look at the implications of the traffic model is to consider total program costs after an equivalent period of operation. In Figure 4-7 it was assumed that the entire fleet of recoverable vehicles (i. e., five orbiters and 12 BRB) would be procured as planned. Only the expendable hardware (tanks and solid boosters) were considered to vary with the vehicle operations and the corresponding traffic model. It should be noted that the pressure-fed becomes the most costly at the lowest flight rate, but the pump-fed retains its standing with decreasing traffic. When these costs vs total flights are plotted (Figure 4-8) it appears that the cross over in total program costs between recoverable liquid boosters and expendable solids lies between 100 and 200 total flights. Thus, if it is anticipated that total program traffic will exceed 200 flights, the liquids are lower cost options.

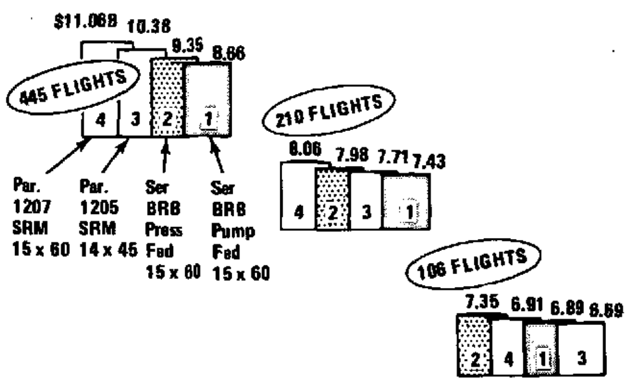



*Figure 4-7 Total Program Traffic/Cost Comparison*

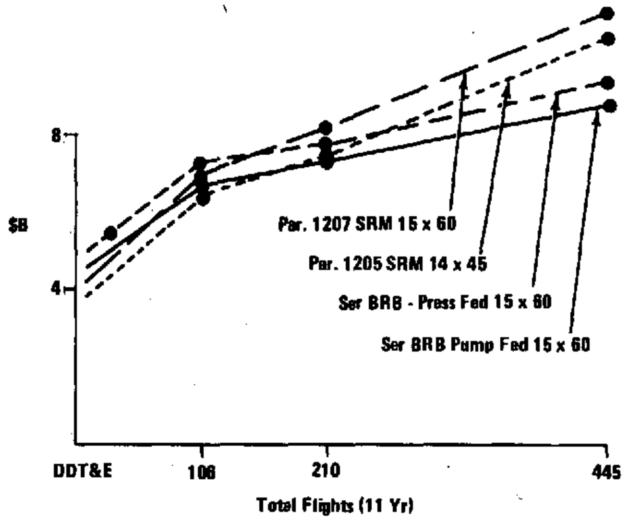



*Figure 4-8 Total Program Traffic/Cost Comparison*

## Section 5

## OTHER COST CONSIDERATIONS

Throughout the study we have conducted numerous trade studies ranging from the major system and programmatic issues addressed in this report to more limited optimization studies within the vehicle subsystems. The impact on program cost is a primary factor in all of our studies. The results of our vehicle design/cost studies are discussed in the final technical report and will not be covered herein. Initial results of two major programmatic issues, related to the impact of providing an unmanned flight test, and phasing early production of the last three orbiters, are discussed below.

### 5.1 UNMANNED FLIGHT TEST

Our current baseline does not include any provision for unmanned development flight testing. As we see it, the issue lies in determining whether it is necessary to man-rate the entire launch configuration (i.e., orbiter and booster) prior to FMOF, whether partial man-rating limited to the booster is adequate, or whether we can gain the necessary confidence from the results of the ground test program to avoid the added expense and risks associated with an unmanned orbiter/booster flight. The orbiter, of course, provides over 3/4 of the total velocity necessary to achieve orbit. It also has a much tighter development schedule than the booster. Our studies have shown (Figure 5-1) that implementing a full-up unmanned launch will delay FMOF by at least six months. This assumes that we limit the development program to two flight-test orbiters. Adding a third orbiter might ease the schedule delay but only at the expense of added peak funding. We have estimated that a six month delay plus

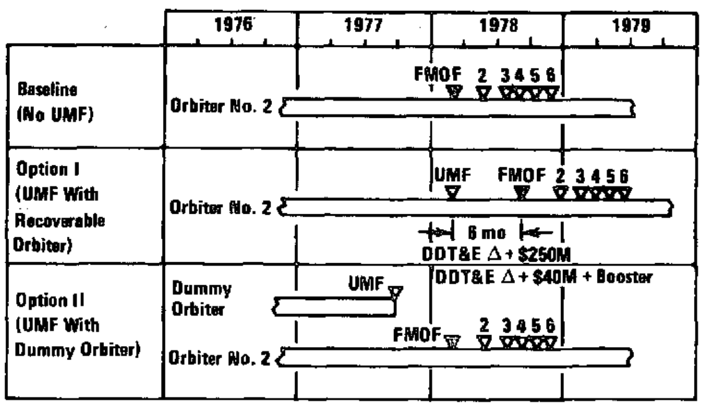



*Figure 5-1 Implications of Unmanned Flight (UMF)*

the extra systems and additional software activity necessary to support this type of flight will increase the total development cost by approximately $250M. Most of this cost will be incurred during the peak funding years.

The second option, limited to man-rating the booster only, is less costly, but, we feel, also of questionable value. If the system must be man-rated with an unmanned flight, we believe it should be the entire launch configuration. This, however, imposes an added cost and schedule risk associated with the problems of successfully recovering an unmanned system from its first flight. Further studies will be required to resolve this issue.

## 5.2 PHASING PRODUCTION ORBITERS

At our mid term report we scheduled the fabrication of the three production orbiters to be compatible with the delay imposed by the program milestone for Mk II FMOF. As a consequence, we had a production gap of over four years between the start of the second vehicle required for development flight testing and the third vehicle required to support additional launches and initiate Mk II operations. Deferring manufacture of production vehicles not required to meet FMOF was originally identified as one of the fundamental approaches for reducing peak funding. Since the latest design groundrules start out with an equivalent Mk II systems capability at FMOF, the previous production delay is no longer warranted. However, the concern for scheduling these vehicles to minimize the impact on peak funding still exists. Our studies to date have shown that the procurement of long lead items starts approximately 18 months before the onset of vehicle subassembly fabrication. For example, if initial manufacture of the third vehicle were delayed 13 months to coincide with the completion of vehicle No. 2, $30M would be added to the peak funding year. Figure 5-2 shows how the impact on peak funding diminishes with further production

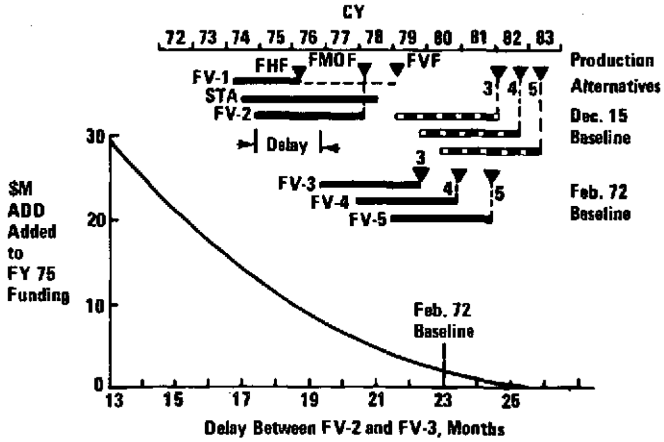



*Figure 5-2 Impact of Production Delay on Peak Funding (Fiscal '75)*

delay. For our final report we baselined a 23-month production delay to minimize the impact on FY75 funding. However, this schedule is not an optimal solution for either retaining the production crews in place nor deriving any practical benefits through normal production learning. Further studies on other production cycles will be required to select the optimal baseline schedule.

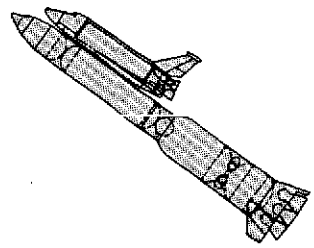
Section 6

# SHUTTLE PROGRAM - COST/SCHEDULE SUMMARIES

This section contains a brief cost/schedule data package for each of the shuttle programs studied. Within each data package we have included a generic capsule summary of each program, a generic program schedule, system launch configuration, summary cost breakdown, and a summary funding schedule. The program data packages have been grouped in the following sequence:

- 15x60 Orbiter/Series/Pressure-Fed BRB
- 15x60 Orbiter/Series/Pump-Fed BRB
- 15x60 Orbiter/Series/Solids
  - 1207 and 156 SRM
- 15x60 Orbiter/Parallel/Pressure-Fed BRB
- Parallel/Solids
  - 15x60 Orbiter/1207 and 156 SRM
  - 14x50, 472K SSME's Orbiter/1205 and 156 SRM
  - 14x45, 380K SSME's Orbiter/1207 and 156 SRM
- 15x60 Swing Engine Orbiter/Series/Pressure-Fed BRB
- 15x60 Orbiter With Abort Rockets/Parallel/Pressure-Fed BRB.

## 6.1 SUMMARY - 15x60 ORBITER/SERIES/PRESSURE-FED BRB



This program is defined with concurrent program go-ahead date of 6/1/72 for orbiter and booster. It supports the First Horizontal Flight (FHF) date of 4/1/76 and First Manned Orbital Flight (FMOF) date of 3/1/78. The main engine development programs for the orbiter (SSME) and the booster (pressure-fed engine) are also planned to support the FMOF milestone.

Preliminary design review of the HO Orbiter is scheduled for Dec. 1973, 18 months after ATP, and Critical Design Review (CDR) early in CY 1975. To attain the early FHF, the horizontal flight test orbiter, FV-1, will be manufactured first, followed by the structural test article (STA) and the FMOF orbiter, FV-2. A heavweight propulsion test article (PTA) will be utilized for the main propulsion testing. Manufacture of the third orbiter, FV-3, will be started 23 months after the start of the second orbiter with the manufacture of structural spares helping to fill the production gap of 10 months. The two subsequent vehicles will be started at 13-month intervals.

The Series/Pressure-Fed BRB is planned to have a development program similar to the orbiter. Major ground testing will be conducted utilizing a structural test article and a propulsion test article. The first flight vehicle will be used for FMOF, and 11 additional boosters are planned to support operations. During the 445 flight program normal attrition is expected to account for half the fleet.

The costs reflect the modification/construction/activation of supporting facilities as follows:

- Michoud Assembly Facility (MAF) for orbiter and booster final assembly starting in 1974
- Use of existing Seal Beach Facility for initial HO tank production. A new facility would be constructed to support the higher flight rate requirements in the 1980's. Transportation cost reduction may be realized by using Michoud for tank manufacturing, assembly and checkout
- Mississippi Test Facility (MTF) for orbiter and booster main propulsion testing starting in 1975
- KSC Airfield for horizontal flight tests starting in 1976
- MSFC Dynamic Test Rig for orbiter/booster modal survey starting in 1977
- KSC VAB and LUT modifications for orbiter/booster mating, integration and launch operations starting in 1977.

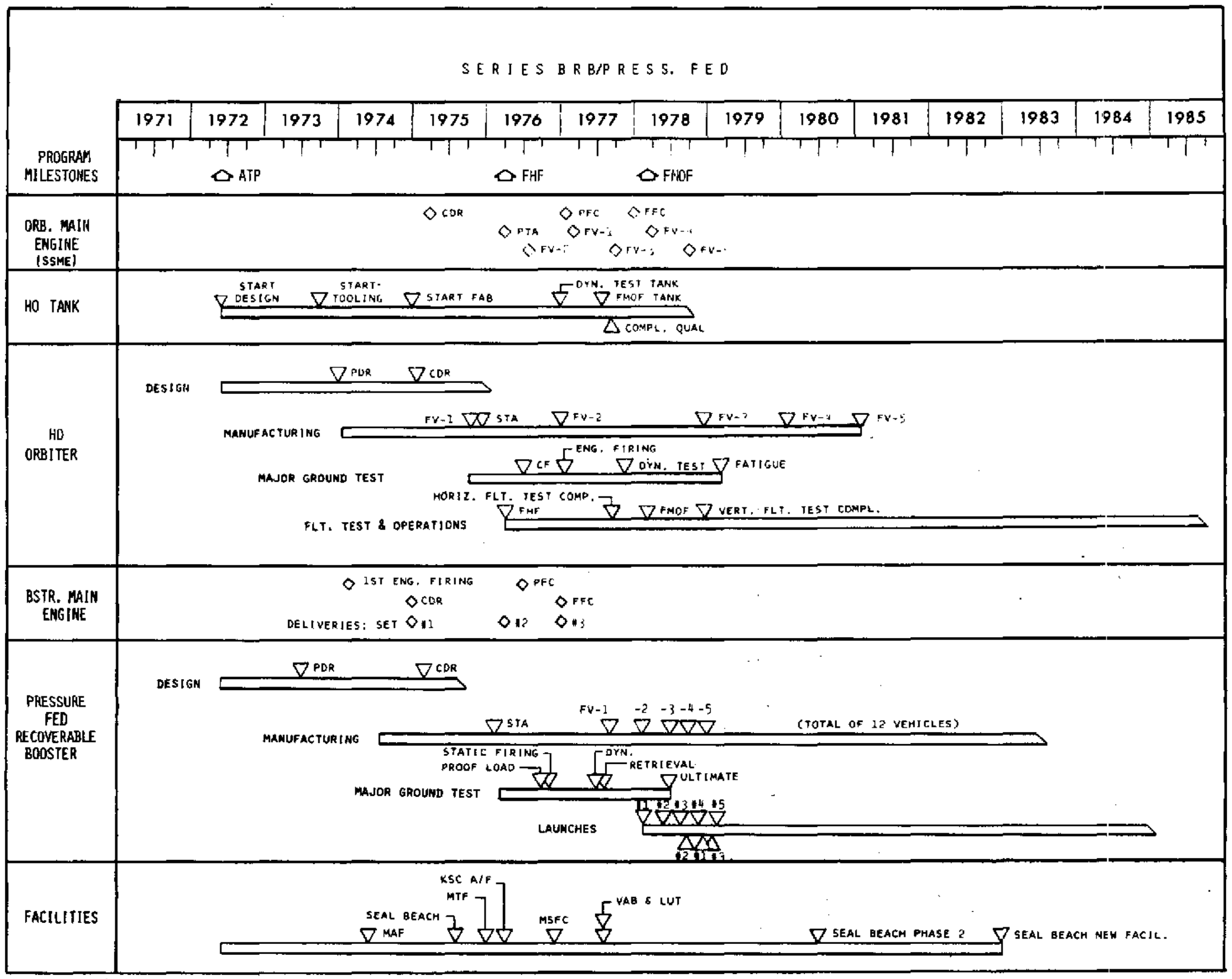



*Figure 6-1 15 x 60 Orbiter/Series/Press. Fed BRB Program Schedule*

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 6.396 |
| BLOW, M Lb | 5.118 |
| HO Tank Liftoff Weight, M Lb | 1.034 |
| Orbiter Injected Weight, K Lb | 244 |
| Total Inert Weight, M Lb | 1.158 |
| $V_{Stage}$, fps | 4879 |

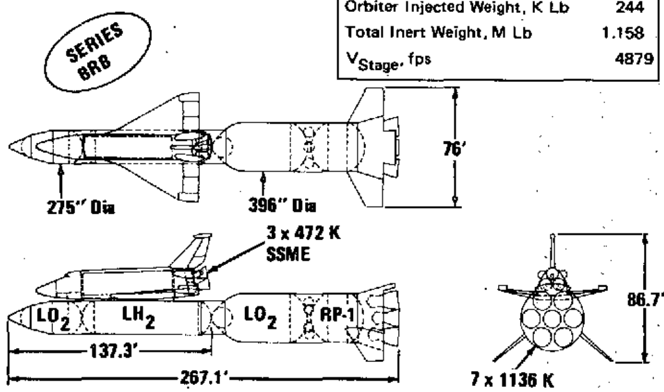
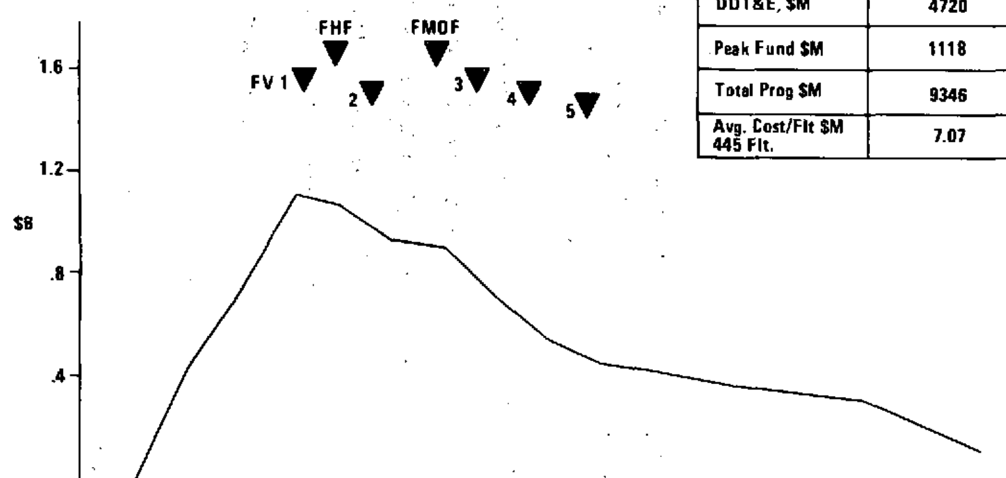



*Figure 6-2 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2203.0 | 579.7 | – | 2782.7 |
| HO Tank | 263.3 | 899.3 | – | 1162.6 |
| Booster | 946.7 | 565.4 | – | 1512.1 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster/Press. Fed | 142.6 | 52.8 | – | 195.4 |
| Flight Test-Orbiter | 402.8 | 1.3 | – | 404.1 |
| Flight Test-Booster | 121.6 | – | – | 121.6 |
| Operations | – | – | 2149.4 | 2149.4 |
| Shuttle Management | 205.0 | 103.3 | 97.7 | 406.0 |
| Total Program | 4720.0 | 2378.8 | 2247.1 | 9345.9 |

*Figure 6-3 15 x 60 Orbiter/Series/Pressure-Fed BRB Program Cost Summary (445 Flights), $M*

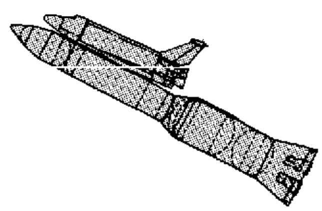
| | |
|---|---|
| DDT&E, $M | 4720 |
| Peak Fund $M | 1118 |
| Total Prog $M | 9346 |
| Avg. Cost/Flt $M 445 Flt. | 7.07 |




| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .46 | .76 | 1.118 | 1.012 | .45 | .91 | .72 | .56 | .47 | .43 | .39 | .37 | .34 | .32 | .28 | .14 |

*Figure 6-4 15 x 60 Orbiter/Series/Pressure-Fed BRB Program Costs*

## 6.2 SUMMARY-15x60 ORBITER/SERIES/PUMP FED BRB



This program is defined with the same program milestones as the Series/Pressure-Fed BRB Program. The orbiter development and SSME development programs are also the same.

The Series/Pump-Fed BRB Development Program, however, does not require the same engine/vehicle integration activity since it will be using existing F-1 engines. As the pump-fed propulsion technology is well in hand, there are no plans for the usual main propulsion test. As in the previous program, the first flight vehicle will be used for FMOF, and 11 additional boosters are planned to support the 445 flight operations.

Facility utilization is also the same except that MTF is only planned for the orbiter main propulsion tests.

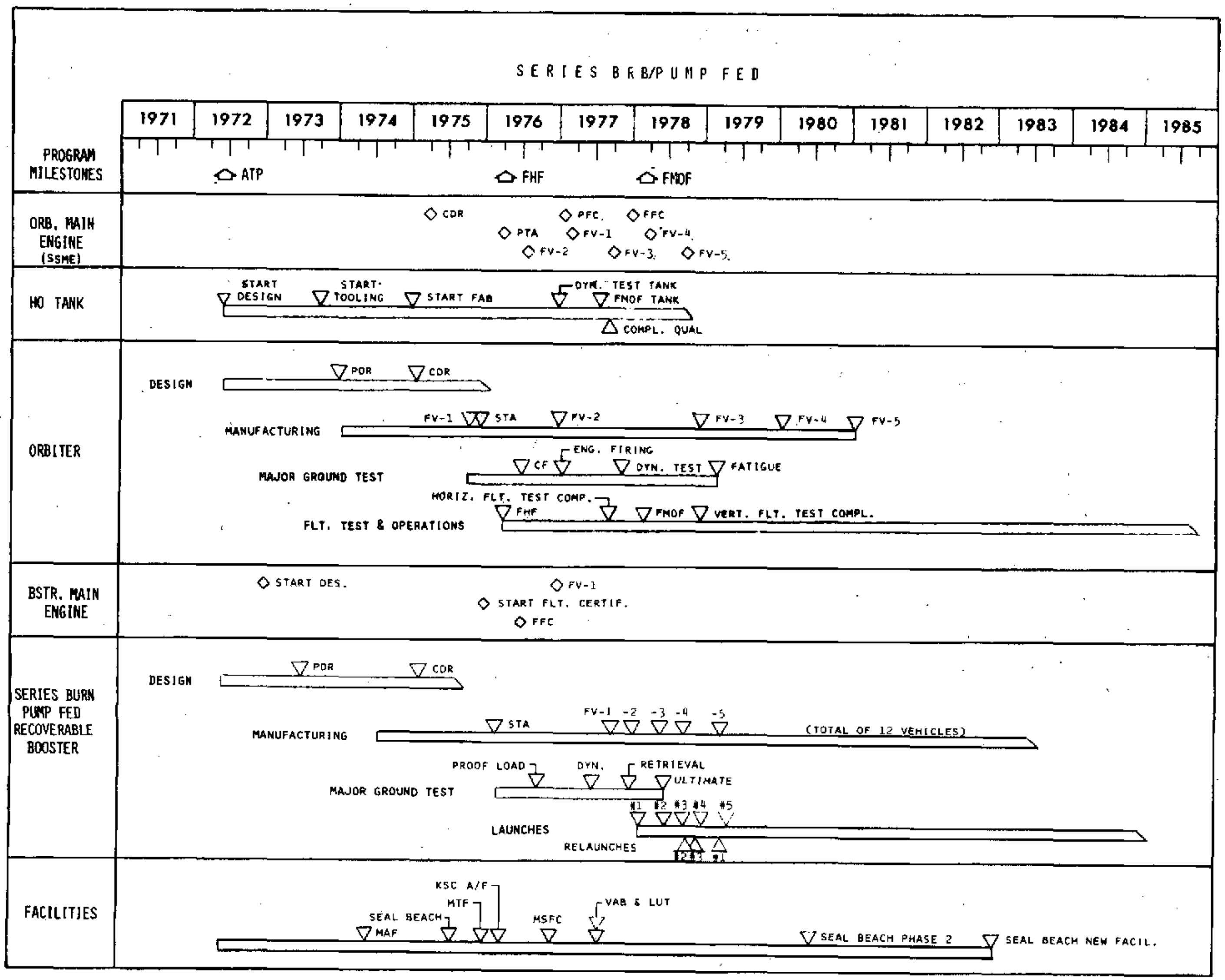



*Figure 6-5 15 x 60 Orbiter/Series/Pump-Fed BRB Program Schedule*

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 4.898 |
| BLOW, M Lb | 3.616 |
| HO Tank Liftoff Weight, M Lb | 1.034 |
| Orbiter Injected Weight K Lb | 248 |
| Total Inert Weight, K Lb | 736 |
| $V_{Stage}$, fps | 5208 |

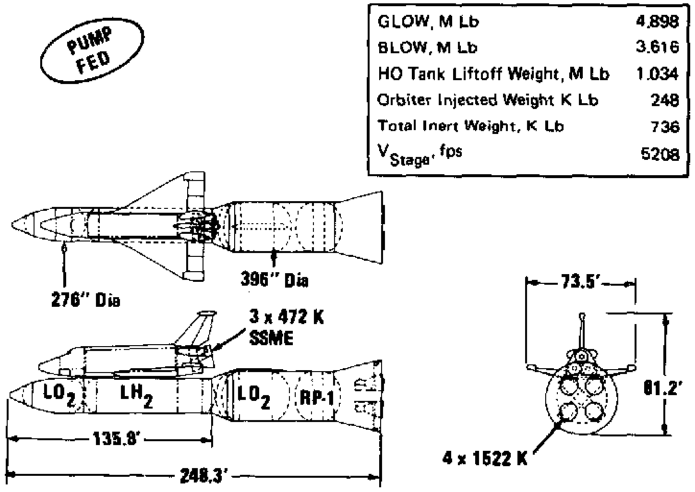
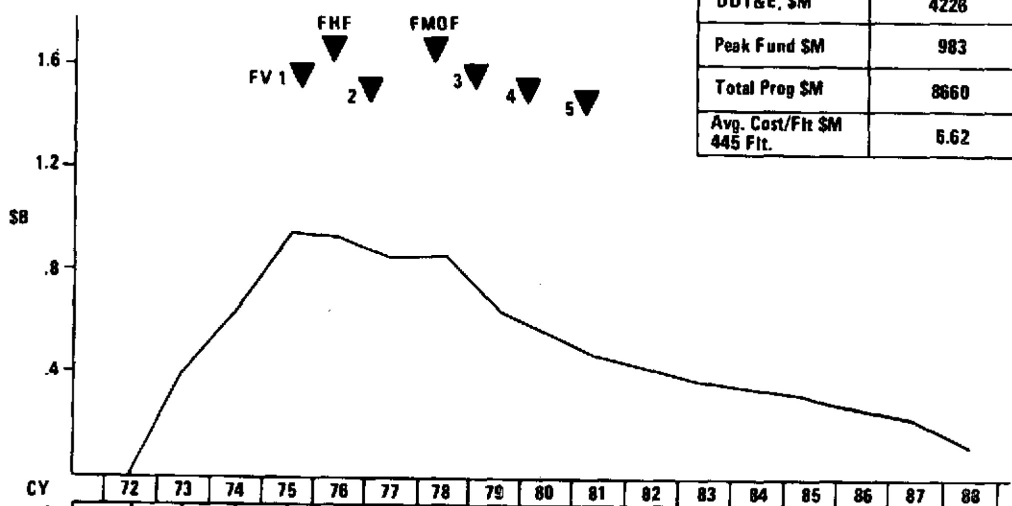



*Figure 6-6 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2203.0 | 579.7 | – | 2782.7 |
| HO Tank | 237.5 | 832.8 | – | 1070.3 |
| Booster | 591.3 | 499.1 | – | 1090.4 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster/F-1 | 68.0 | 197.0 | – | 265.0 |
| Flight Test-Orbiter | 397.6 | 1.3 | – | 398.9 |
| Flight Test-Booster | 96.7 | – | – | 96.7 |
| Operations | – | – | 1937.9 | 1937.9 |
| Shuttle Management | 197.2 | 114.5 | 94.3 | 406.0 |
| Total Program | 4226.3 | 2401.4 | 2032.2 | 8659.9 |

*Figure 6-7 15 x 60 Orbiter/Series/Pump-Fed BRB Program Cost Summary (445 Flights), $M*

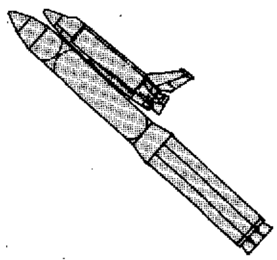
| | |
|---|---|
| DDT&E, $M | 4226 |
| Peak Fund $M | 983 |
| Total Prog $M | 8660 |
| Avg. Cost/Flt $M 445 Flt. | 6.62 |

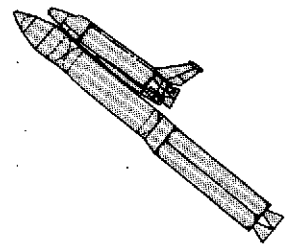



| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $B | .04 | .43 | .684 | .983 | .954 | .88 | .88 | .67 | .59 | .47 | .40 | .36 | .33 | .31 | .27 | .22 | .13 |

*Figure 6-8 15 x 60 Orbiter/Series/Pump-Fed BRB Program Costs*

## 6.3 SUMMARY-15x60 ORBITER/SERIES/1207 (or 156") SRM'S





These programs are defined with the same program milestones as the Series/Pressure-Fed BRB Program. The orbiter development and SSME development programs are also the same.

Development of 6-1207 SRM cluster will be more complex than the 3-156" SRM cluster. However the Titan 1205/1207 motor development will be more directly applicable to the series solid booster than the limited 156" motor development program. A structural test article will be used for static and dynamic testing of the SRM booster. The propulsion system testing, however, will be conducted at the motor contractors facility. A total of 445 sets of boosters will be manufactured for the ten-year program.

Facilities utilization is similar to the Series/Pressure-Fed BRB with added requirement of constructing a solid motor integration building (SMIB) at KSC. This facility will be used for assembly of the SRM's and mating of the booster with the HO tank/orbiter.

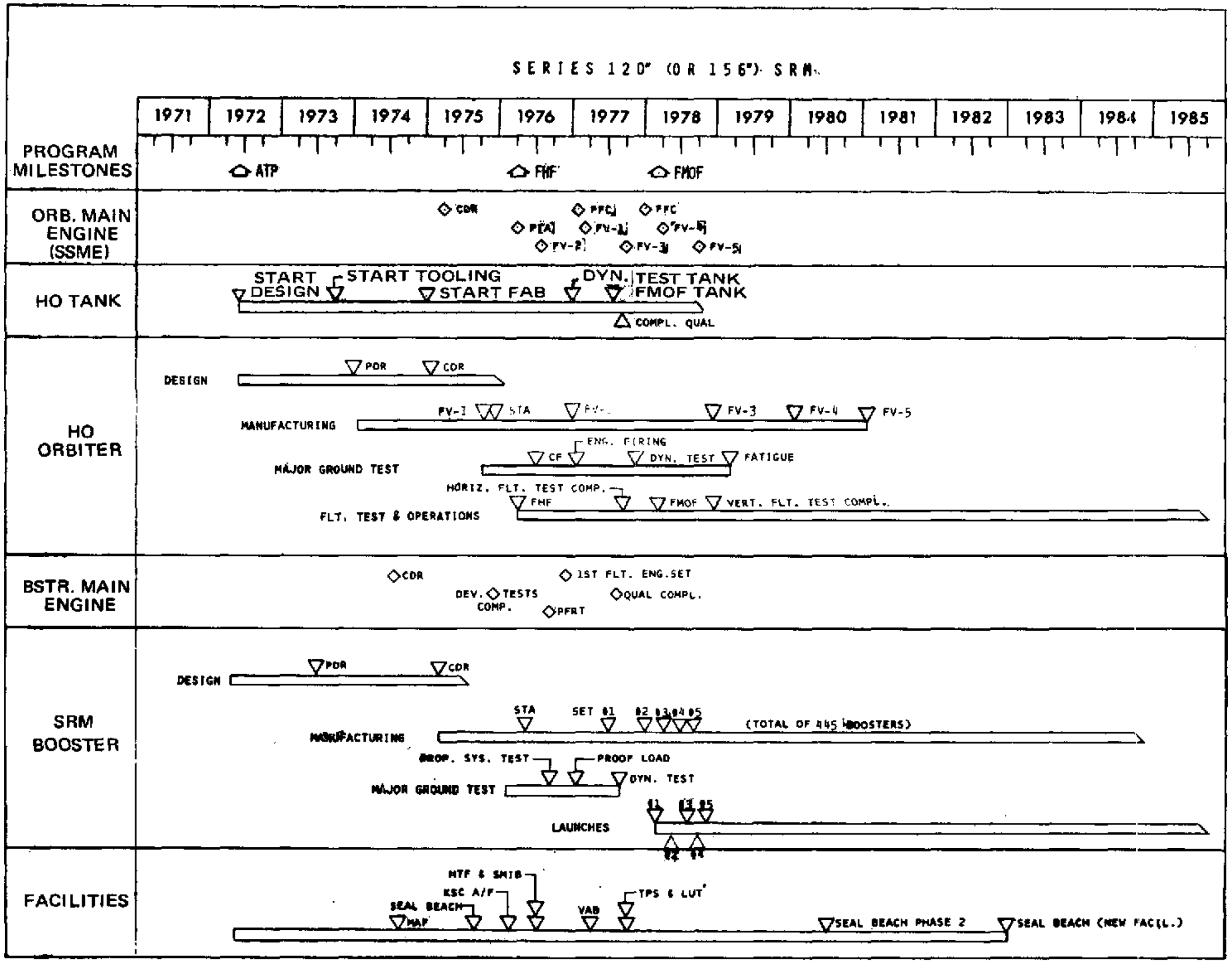



*Figure 6-9 15 x 60 Orbiter/Series/120" (or 156") SRM Program Schedule*

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 5.363 |
| BLOW, M Lb | 4.202 |
| HO Tank Liftoff Weight, K Lb | 917 |
| Orbiter Injected Weight, K Lb | 244 |
| Total Inert Weight, K Lb | 769 |
| $V_{Stage}$, fps | 5615 |

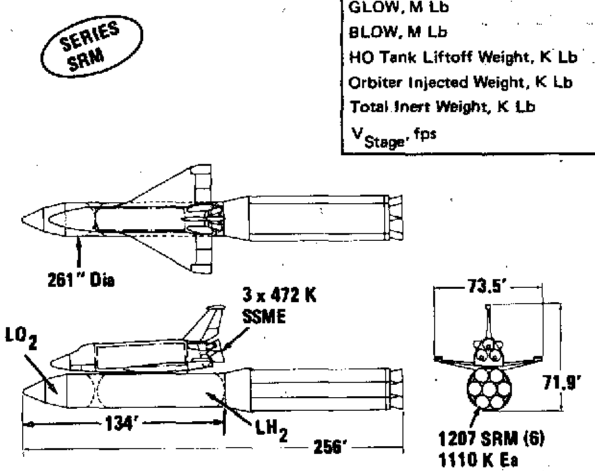
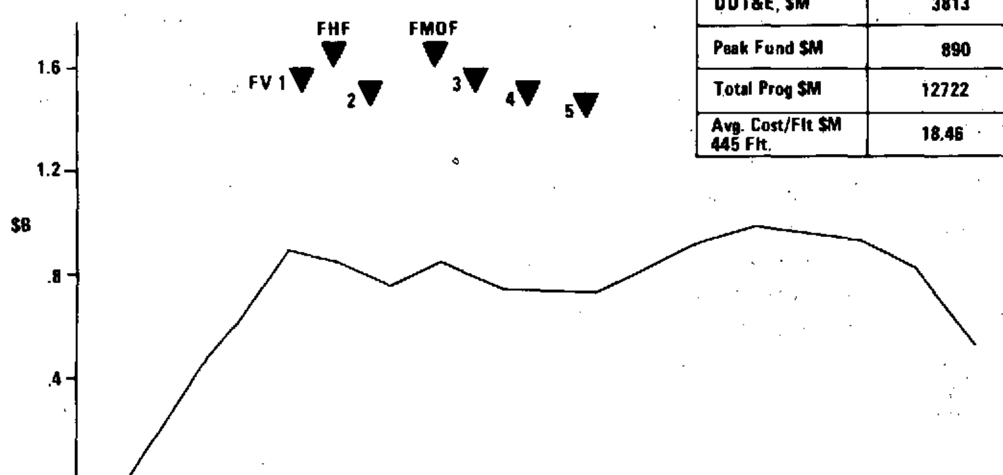



Figure 6-10 Launch Configuration

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2203.0 | 579.5 | – | 2782.7 |
| HO Tank | 245.3 | 853.2 | – | 1098.5 |
| Booster, 6-1207 SRM | 258.0 | 5521.4 | – | 5779.4 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster | | | | |
| Flight Test-Orbiter | 416.5 | 1.3 | – | 417.8 |
| Flight Test-Booster | 133.7 | – | – | 133.7 |
| Operations | – | – | 1492.1 | 1492.1 |
| Shuttle Management | 121.7 | 235.1 | 49.2 | 406.0 |
| Total Program | 3813.2 | 7367.7 | 1541.3 | 12,722.2 |

Figure 6-11 15 x 60 Orbiter/Series/1207 SRM Program Cost Summary (445 Flights), $M




| | |
|---|---|
| DDT&E, $M | 3813 |
| Peak Fund $M | 890 |
| Total Prog $M | 12722 |
| Avg. Cost/Flt $M 445 Flt. | 18.46 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .39 | .618 | .890 | .853 | .78 | .85 | .78 | .76 | .73 | .82 | .92 | .98 | .96 | .92 | .82 | .52 |

Figure 6-12 15 x 60 Orbiter/Series/1207 SRM Program Costs

SERIES SRM

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 4.989 |
| BLOW, M Lb | 3.794 |
| HO Tank Liftoff Weight, K Lb | 951 |
| Orbiter Injected Weight, K Lb | 244 |
| Total Inert Weight, K Lb | 669 |
| $V_{Stage}$, fps | 5367 |

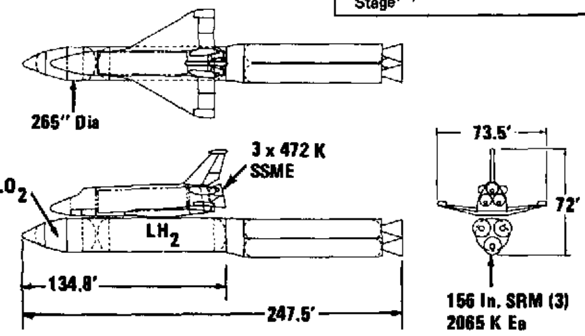



*Figure 6-13 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2203.0 | 579.7 | – | 2782.7 |
| HO Tank | 250.8 | 867.0 | – | 1117.8 |
| Booster, 3-156 SRM | 273.9 | 4086.5 | – | 4360.4 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster | – | – | – | – |
| Flight Test-Orbiter | 414.6 | 1.3 | – | 415.9 |
| Flight Test-Booster | 146.0 | – | – | 146.0 |
| Operations | – | – | 1433.3 | 1433.3 |
| Shuttle Management | 146.0 | 204.0 | 56.0 | 406.0 |
| Total Program | 3869.3 | 5915.5 | 1489.3 | 11,274.1 |

*Figure 6-14 15 x 60 Orbiter/Series/156" SRM Program Cost Summary (445 Flights), $M*

| | |
|---|---|
| DDT&E, $M | 3869 |
| Peak Fund $M | 897 |
| Total Prog $M | 11274 |
| Avg. Cost/Flt $M 445 Flt. | 14.97 |

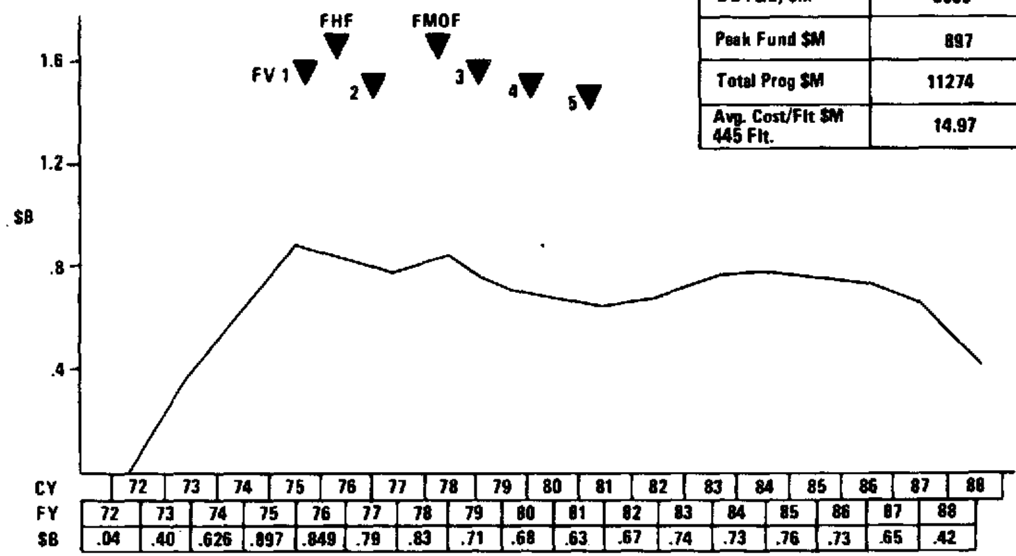
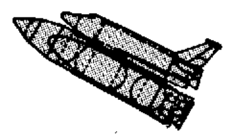



*Figure 6-15 15 x 60 Orbiter/Series/156" SRM Program Costs*

## 6.4 SUMMARY-15x60 ORBITER/PARALLEL/PRESSURE-FED BRB



This program is also defined with the same program milestones as the Series/Pressure-Fed BRB Program. Development requirements for the orbiter/booster/SSME/pressure-fed engine programs are the same. However, since the orbiter operates in parallel with two BRB's attached to the HO tank, twice as many boosters will be required. That is, a total of 24 boosters (or 12 sets) will be manufactured to support the 445 flight program.

Similar supporting facility requirements are also planned.

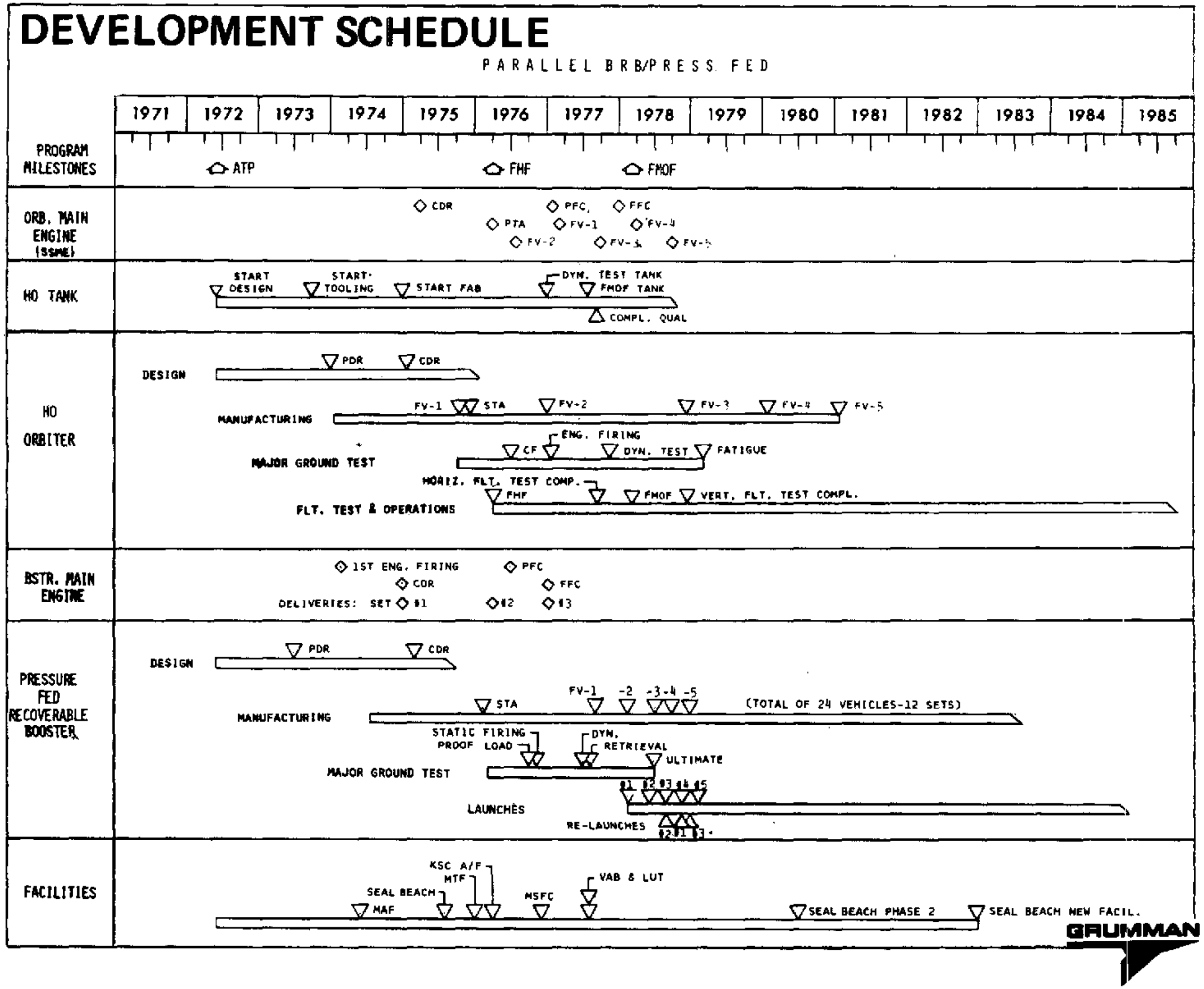
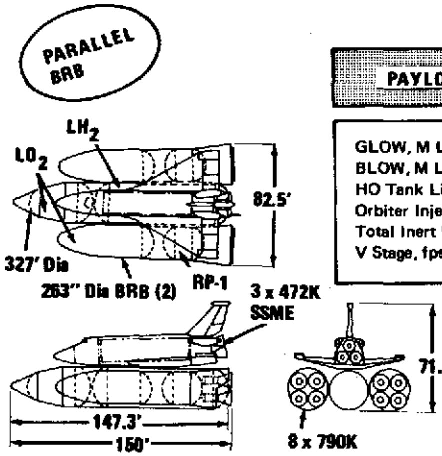



*Figure 6-16 15 x 60 Orbiter/Parallel/Pressure-Fed BRB Program Schedule*



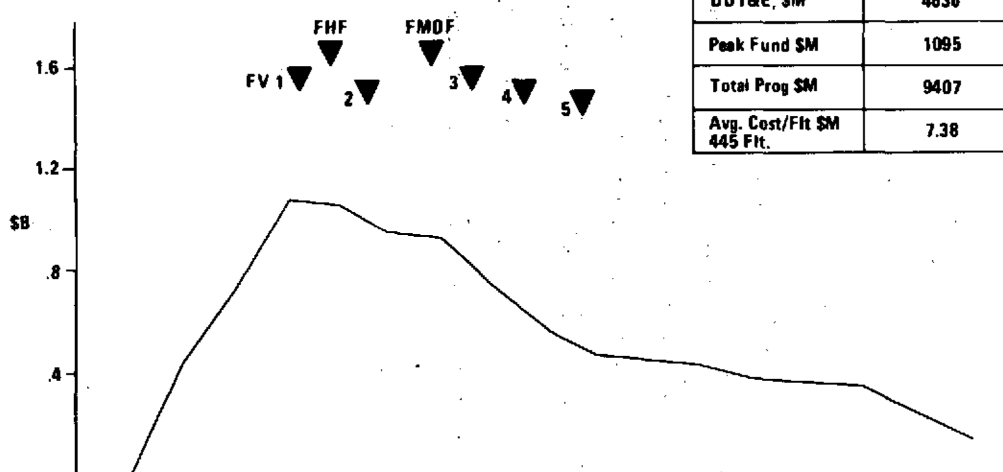

**PAYLOAD BAY SIZE 15 x 60**

| | |
|---|---|
| GLOW, M Lb | 5.969 |
| BLOW, M Lb | 4.204 |
| HO Tank Liftoff Weight, M Lb | 1.519 |
| Orbiter Injected Weight, K Lb | 246 |
| Total Inert Weight, M Lb | 1.039 |
| V Stage, fps | 5373 |

*Figure 6-17 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2207.0 | 581.1 | – | 2788.1 |
| HO Tank | 291.7 | 970.4 | – | 1262.1 |
| Booster | 865.3 | 575.9 | – | 1441.2 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster/Press. Fed | 120.7 | 45.8 | – | 166.5 |
| Flight Test-Orbiter | 403.6 | 1.3 | – | 404.9 |
| Flight Test-Booster | 112.8 | – | – | 112.8 |
| Operations | – | – | 2213.9 | 2213.9 |
| Shuttle Management | 200.1 | 106.1 | 99.8 | 406.0 |
| Total Program | 4636.2 | 2457.6 | 2313.7 | 9407.5 |

*Figure 6-18 15 x 60 Orbiter/Parallel/Pressure-Fed BRB Program Cost Summary (445 Flights), $M*




| | |
|---|---|
| DDT&E, $M | 4636 |
| Peak Fund $M | 1095 |
| Total Prog $M | 9407 |
| Avg. Cost/Flt $M 445 Flt. | 7.38 |

| CY | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | |
| $B | .04 | .45 | .743 | 1.095 | 1.082 | .94 | .92 | .74 | .58 | .48 | .45 | .42 | .39 | .35 | .34 | .25 | .15 | |

*Figure 6-19 15 x 60 Orbiter/Parallel/Pressure-Fed BRB Program Costs*

## 6.5 SUMMARY-PARALLEL SOLIDS (120" or 156")

The parallel solid programs for the large 15x60 orbiter and smaller (14x50/472K-SSME and 14x45/380K-SSME) orbiters are also defined with the same program milestones as the Series/Pressure-Fed BRB Program. The orbiter/SSME development programs are also planned the same. The parallel solid boosters are planned similar to the series solid boosters and will require 445 sets of boosters to support the operations program.

Extensive modification of the Launch Umbilical Tower (LUT) is required in order to provide for liftoff of the parallel burn configuration.

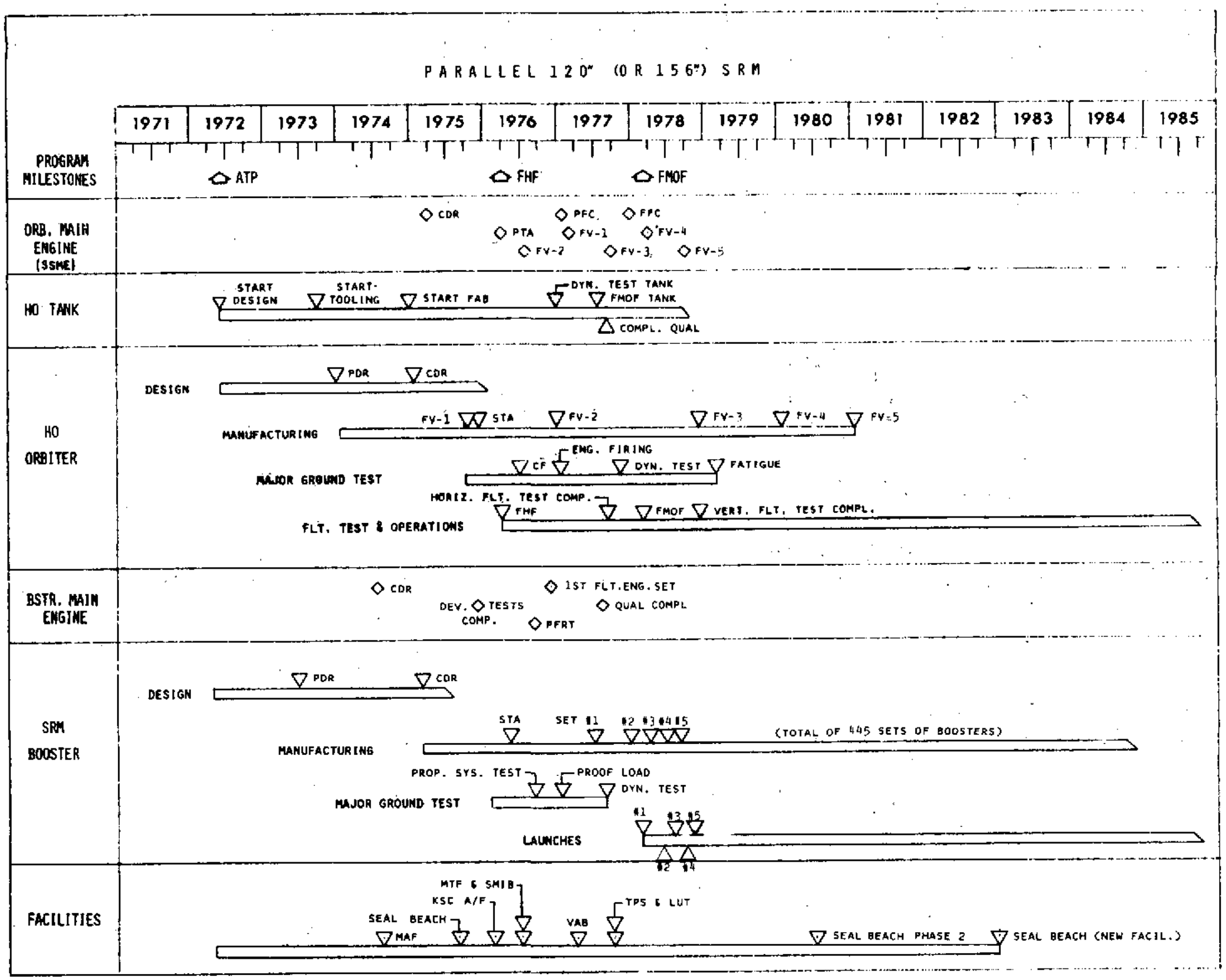
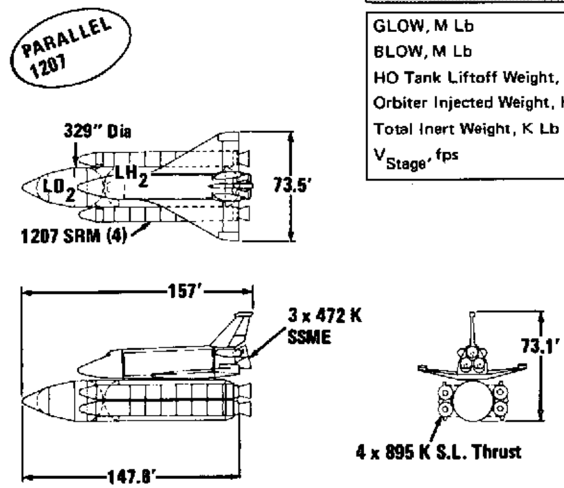



*Figure 6-20 15 x 60 Orbiter/Parallel 120" (or 156") SRM Program Schedule*



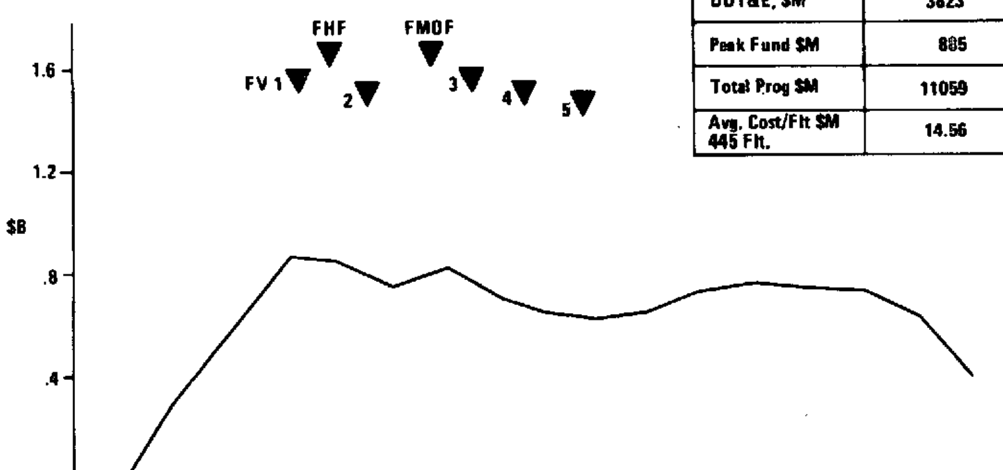

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 4.580 |
| BLOW, M Lb | 2.788 |
| HO Tank Liftoff Weight, M Lb | 1.546 |
| Orbiter Injected Weight, K Lb | 246 |
| Total Inert Weight, K Lb | 598 |
| $V_{Stage}$, fps | 5067 |

*Figure 6-21 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2207.0 | 581.1 | – | 2788.1 |
| HO Tank | 280.2 | 941.6 | – | 1221.8 |
| Booster, 4-1207 SRM | 215.3 | 3797.4 | – | 4012.7 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster | | | | |
| Flight Test-Orbiter | 414.6 | 1.3 | – | 415.9 |
| Flight Test-Booster | 130.1 | – | – | 130.1 |
| Operations | – | – | 1472.8 | 1472.8 |
| Shuttle Management | 141.0 | 209.0 | 56.0 | 406.0 |
| Total Program | 3823.2 | 5707.4 | 1528.8 | 11,059.4 |

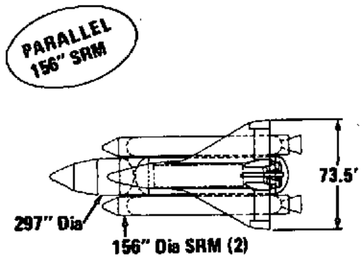
*Figure 6-22 15 x 60 Orbiter/Parallel/1207 SRM Program Cost Summary (445 Flights), $M*

| | |
|---|---|
| DDT&E, $M | 3823 |
| Peak Fund $M | 885 |
| Total Prog $M | 11059 |
| Avg. Cost/Flt $M 445 Flt. | 14.56 |




| CY | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | |
| $B | .04 | .39 | .615 | .888 | .849 | .78 | .83 | .71 | .66 | .62 | .66 | .73 | .77 | .75 | .72 | .64 | .40 | |

*Figure 6-23 15 x 60 Orbiter/Parallel/1207 SRM Program Costs*




| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 4.553 |
| BLOW, M Lb | 2.864 |
| HO Tank Liftoff Weight, M Lb | 1.453 |
| Orbiter Injected Weight, K Lb | 246 |
| Total Inert Weight, K Lb | 568 |
| $V_{Stage}$, fps | 5895 |

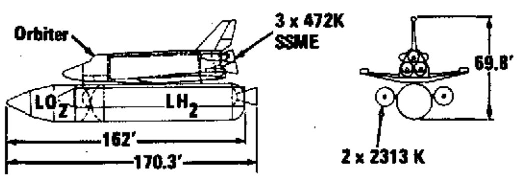
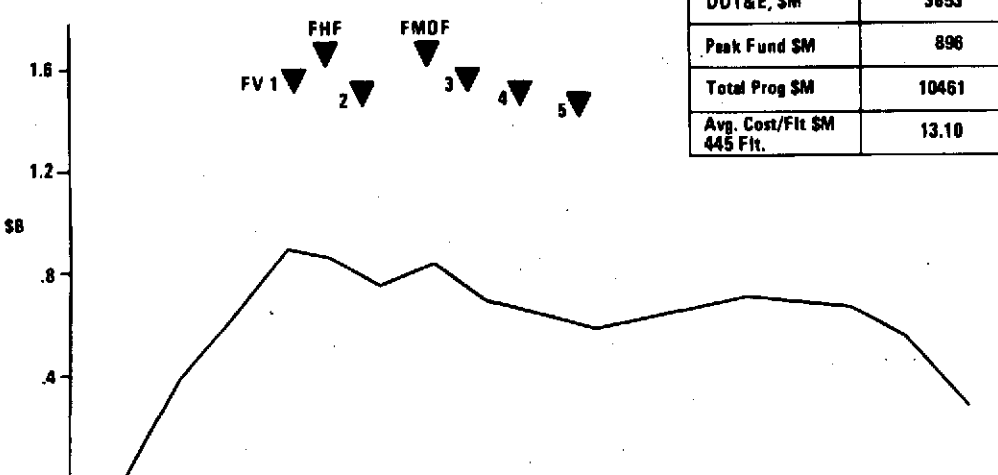



*Figure 6-24 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2207.0 | 581.1 | – | 2788.1 |
| HO Tank | 272.6 | 927.0 | – | 1199.6 |
| Booster, 2-156" SRM | 244.3 | 3287.7 | – | 3532.0 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster | | | | – |
| Flight Test-Orbiter | 414.5 | 1.3 | – | 415.8 |
| Flight Test-Booster | 129.8 | – | – | 129.8 |
| Operations | – | – | 1378.0 | 1378.0 |
| Shuttle Management | 149.5 | 200.8 | 55.7 | 406.0 |
| Total Program | 3852.7 | 5174.9 | 1433.7 | 10,461.3 |

*Figure 6-25 15 x 60 Orbiter/Parallel/156" SRM Program Cost Summary (445 Flights), $M*

| | |
|---|---|
| DDT&E, $M | 3853 |
| Peak Fund $M | 896 |
| Total Prog $M | 10461 |
| Avg. Cost/Flt $M 445 Flt. | 13.10 |

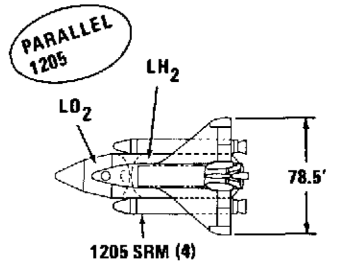



| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .40 | .626 | .896 | .853 | .78 | .84 | .68 | .64 | .59 | .62 | .68 | .70 | .67 | .64 | .54 | .27 |

*Figure 6-26 15 x 60 Orbiter/Parallel/156" SRM Program Costs*



GRUMMAN




| PAYLOAD BAY SIZE 14 x 45 | |
|---|---|
| GLOW, M Lb | 3.738 |
| BLOW, M Lb | 2.032 |
| HO Tank Liftoff Weight, M Lb | 1.495 |
| Orbiter Injected Weight, K Lb | 211 |
| Total Inert Weight, K Lb | 513 |
| $V_{Stage}$, fps | 4045 |

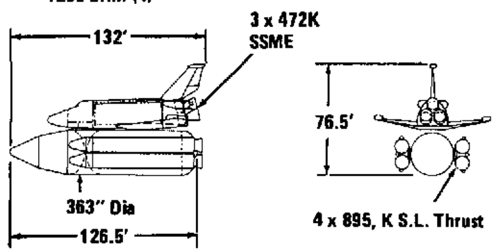
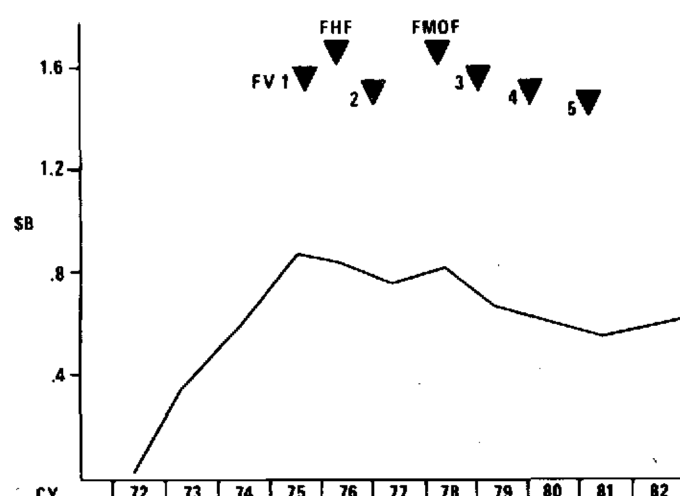



*Figure 6-27 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2182.4 | 570.2 | -- | 2752.6 |
| HO Tank | 279.7 | 940.6 | -- | 1220.3 |
| Booster, 4-1205 SRM | 196.3 | 3180.5 | -- | 3376.8 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | -- | 612.0 |
| Main Engine-Booster | | | | |
| Flight Test-Orbiter | 414.6 | 1.3 | -- | 415.9 |
| Flight Test-Booster | 130.1 | – | -- | 130.1 |
| Operations | – | – | 1472.8 | 1472.8 |
| Shuttle Management | 148.0 | 198.1 | 59.9 | 406.0 |
| Total Program | 3786.1 | 5067.7 | 1532.7 | 10,386.5 |

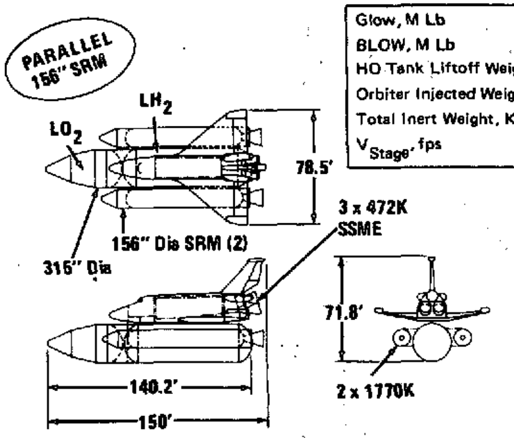
*Figure 6-28 14 x 50 Orbiter/Parallel/1205 SRM (472K/SSME) Program Cost Summary (445 Flights), $M*




| | |
|---|---|
| DDT&E, $M | 3786 |
| Peak Fund $M | 874 |
| Total Prog $M | 10386 |
| Avg. Cost/Flt $M 445 Flt. | 13.10 |

| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .39 | .606 | .874 | .847 | .77 | .81 | .67 | .62 | .57 | .60 | .66 | .69 | .67 | .64 | .57 | .36 |

*Figure 6-29 14 x 50 Orbiter/Parallel/1205 SRM (472K/SSME) Program Costs*




**PAYLOAD BAY SIZE 14 x 45**

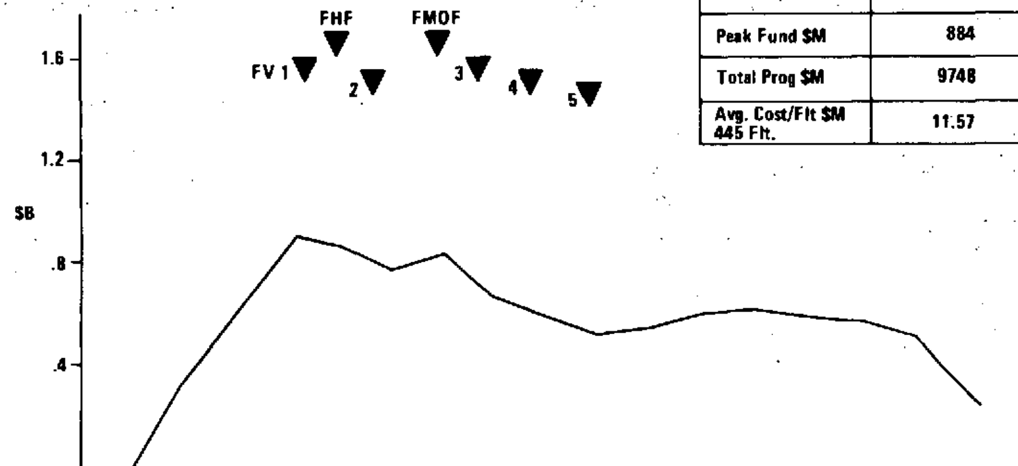
| | |
|---|---|
| Glow, M Lb | 3.705 |
| BLOW, M Lb | 2.144 |
| HO Tank Liftoff Weight, M Lb | 1.350 |
| Orbiter Injected Weight, K Lb | 211 |
| Total Inert Weight, K Lb | 476 |
| $V_{Stage}$, fps | 5,399 |

*Figure 6-30 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2182.4 | 570.2 | – | 2752.6 |
| HO Tank | 260.5 | 892.2 | – | 1152.7 |
| Booster, 2-156" SRM | 227.4 | 2673.6 | – | 2901.0 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster | – | – | – | – |
| Flight Test-Orbiter | 414.5 | 1.3 | – | 415.8 |
| Flight Test-Booster | 129.8 | – | – | 129.8 |
| Operations | – | – | 1378.0 | 1378.0 |
| Shuttle Management | 160.0 | 189.0 | 57.0 | 406.0 |
| Total Program | 3809.6 | 4503.3 | 1435.0 | 9747.9 |

*Figure 6-31 14 x 50 Orbiter/Parallel/156" SRM (472K/SSME) Program Cost Summary (445 Flights), $M*

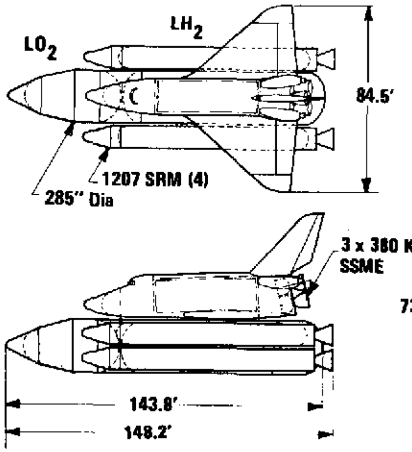
| | |
|---|---|
| DDT&E, $M | 3810 |
| Peak Fund $M | 884 |
| Total Prog $M | 9748 |
| Avg. Cost/Flt $M 445 Flt. | 11.57 |




| CY | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | |
| $B | .04 | .89 | .615 | .884 | .842 | .77 | .81 | .65 | .59 | .53 | .55 | .60 | .61 | .58 | .56 | .48 | .24 | |

*Figure 6-32 14 x 50 Orbiter/Parallel/156" SRM (472K/SSME) Program Costs*

| PAYLOAD BAY SIZE 14 x 45 | | |
|---|---|---|
| Orbiter Engines | 3 x 472 | 3 x 380 |
| SRM Diameter, In. | 120 | 120 |
| GLOW, M Lb | 3.738 | 4.163 |
| BLOW, M Lb | 2.032 | 2.789 |
| HO Tank Liftoff Weight, M Lb | 1.495 | 1.170 |
| Orbiter Injected Weight, K Lb | 211 | 203.2 |
| Total Inert Weight, K Lb | 513 | 561 |
| $V_{Stage}$, fps | 4045 | 6238 |



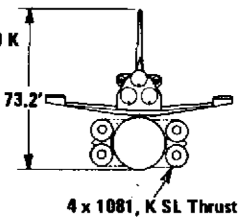
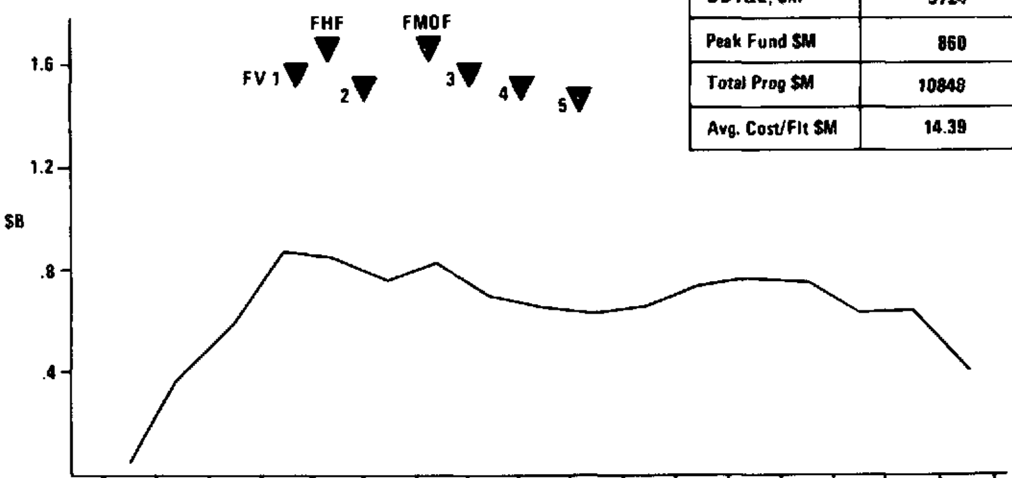




*Figure 6-33 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2165.5 | 563.3 | – | 2728.8 |
| HO Tank | 250.8 | 867.0 | – | 1117.8 |
| Booster, 4-1207 SRM | 215.3 | 3797.4 | – | 4012.7 |
| Main Engine-Orbiter/SSME | 400.0 | 164.0 | – | 564.0 |
| Main Engine-Booster | – | – | – | – |
| Flight Test-Orbiter | 414.6 | 1.3 | – | 415.9 |
| Flight Test-Booster | 130.1 | – | – | 130.1 |
| Operations | – | – | 1472.8 | 1472.8 |
| Shuttle Management | 148.0 | 198.1 | 59.9 | 406.0 |
| Total Program | 3724.3 | 5591.1 | 1532.7 | 10,848.1 |

*Figure 6-34 14 x 45 Orbiter/Parallel/1207 SRM (380K/SSME) Program Cost Summary (445 Flights), $M*

| | |
|---|---|
| DDT&E, $M | 3724 |
| Peak Fund $M | 860 |
| Total Prog $M | 10848 |
| Avg. Cost/Flt $M | 14.39 |




| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .39 | .599 | .860 | .827 | .76 | .81 | .70 | .66 | .61 | .65 | .72 | .76 | .74 | .71 | .63 | .40 |

*Figure 6-35 14 x 45 Orbiter/Parallel/1207 SRM (380K/SSME) Program Costs*

| PAYLOAD BAY SIZE 14 x 45 | | |
|---|---|---|
| Orbiter Engines | 3 x 472 | 3 x 380 |
| SRM Diameter, In | 156 | 156 |
| GLOW, M Lb | 3.705 | 3.953 |
| BLOW, M Lb | 2.144 | 2.569 |
| HO Tank Liftoff Weight, M Lb | 1.350 | 1.181 |
| Orbiter Injected Weight, K Lb | 211 | 203 |
| Total Inert Weight, K Lb | 476 | 504 |
| $V_{Stage}$, fps | 5399 | 6176 |

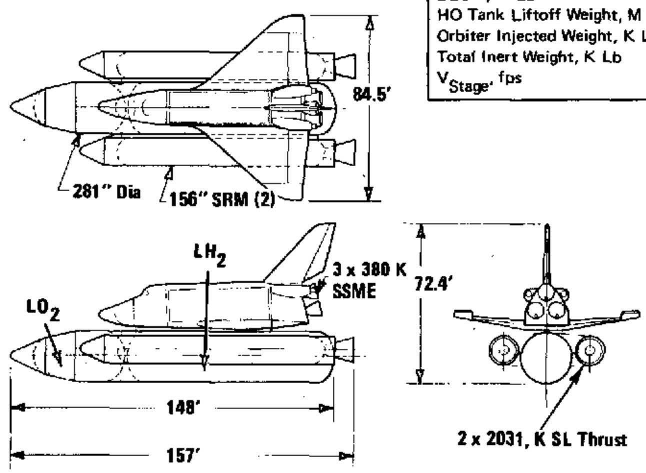
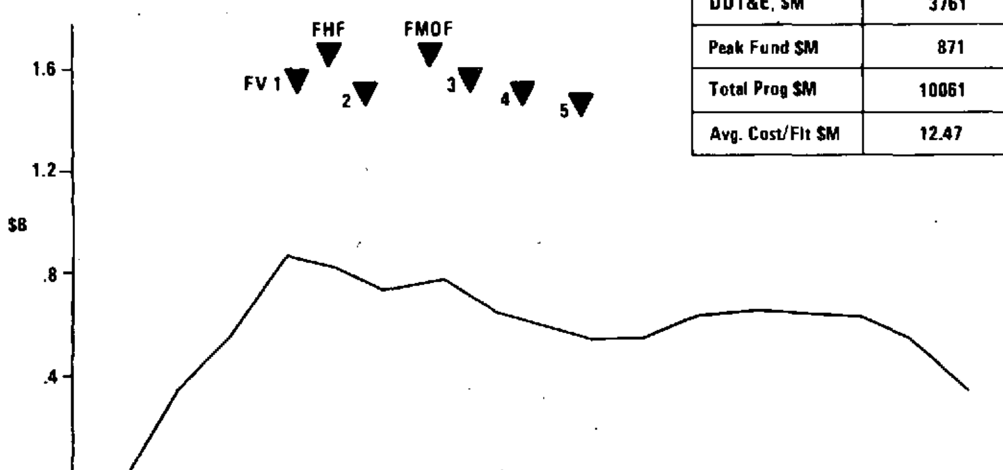



*Figure 6-36 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2165.5 | 563.3 | – | 2728.8 |
| HO Tank | 251.0 | 867.9 | – | 1118.9 |
| Booster, 2-156" SRM | 240.0 | 3080.0 | – | 3320.0 |
| Main Engine-Orbiter/SSME | 400.0 | 164.0 | – | 564.0 |
| Main Engine-Booster | – | – | – | – |
| Flight Test-Orbiter | 414.5 | 1.3 | – | 415.8 |
| Flight Test-Booster | 129.8 | – | – | 129.8 |
| Operations | – | – | 1378.0 | 1378.0 |
| Shuttle Management | 160.0 | 189.0 | 57.0 | 406.0 |
| Total Program | 3760.8 | 4865.5 | 1435.0 | 10061.3 |

*Figure 6-37 14 x 45 Orbiter/Parallel/156" SRM (380K/SSME) Program Cost Summary (445 Flights), $M*

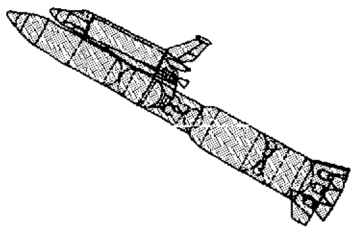
| | |
|---|---|
| DDT&E, $M | 3761 |
| Peak Fund $M | 871 |
| Total Prog $M | 10061 |
| Avg. Cost/Flt $M | 12.47 |




| CY | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | |
| $B | .04 | .38 | .592 | .871 | .808 | .74 | .79 | .66 | .60 | .55 | .57 | .64 | .67 | .65 | .62 | .55 | .35 | |

*Figure 6-38 14 x 45 Orbiter/Parallel/156" SRM (380K/SSME) Program Costs*

## 6.6 SUMMARY-15x60 SWING ENGINE ORBITER/SERIES/PRESSURE-FED BRB PROGRAM



As in the prior programs, this program is also defined with the same program milestones as the baseline Series/Pressure-Fed BRB Program. The booster and pressure-fed engine development programs are planned the same. Except for the need to develop integral SSME/hydraulic pumps the SSME program is also the same. The orbiter development program is also similar except that it is planned with a flight weight rather than heavy weight propulsion test article and has additional development activity associated with the swing engine mechanism and the abort motor system. A major subsystem/GSE hardware and software development activity is anticipated due to the pad abort capability. In addition a major systems test (TBD) is planned to demonstrate overall systems abort capability. As the abort motor is expended during each flight, when it is no longer needed, 445 sets of motors will be required for operations. Except for the requirements imposed by the abort motor, supporting facility requirements are also expected to be the same as the baseline Series/Pressure-Fed BRB Program.

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 6.353 |
| BLOW, M Lb | 5.020 |
| HO Tank Liftoff Weight M Lb | 1.051 |
| Orbiter Injected Weight, K Lb | 210 |
| Total Inert Weight M Lb | 1.13 |
| $V_{Stage}$, fps | 4743 |

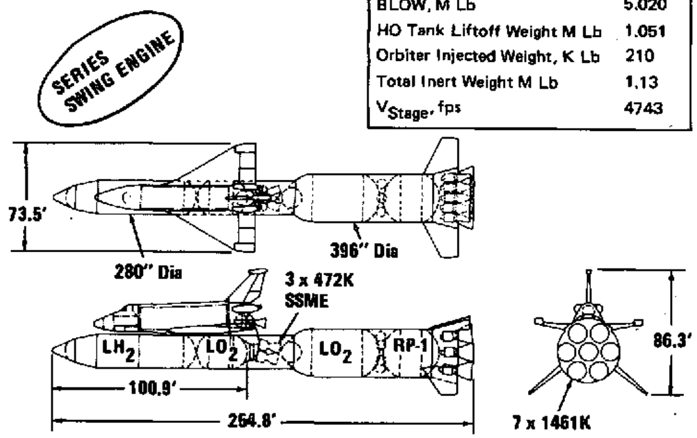
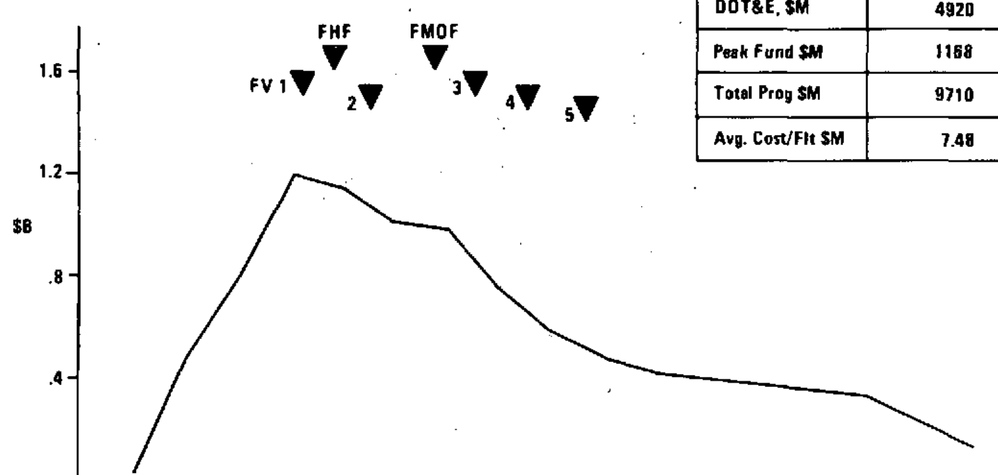



Figure 6-39 Launch Configuration

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2399.4 | 711.4 | – | 3110.8 |
| HO Tank | 240.9 | 928.1 | – | 1169.0 |
| Booster | 946.7 | 565.4 | – | 1512.1 |
| Main Engine-Orbiter/SSME | 445.0 | 177.0 | – | 622.0 |
| Main Engine-Booster/Press. Fed | 142.6 | 52.8 | – | 195.4 |
| Flight Test-Orbiter | 412.8 | 1.3 | – | 414.1 |
| Flight Test-Booster | 121.6 | – | – | 121.6 |
| Operations | – | – | 2149.4 | 2149.4 |
| Shuttle Management | 211.0 | 103.0 | 102.0 | 416.0 |
| Total Program | 4920.0 | 2539.0 | 2251.4 | 9710.4 |

Figure 6-40 15 x 60 Swing Engine Orbiter/Series/Pressure-Fed BRB Program Cost Summary (445 Flights), $M

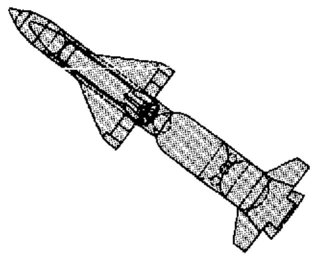
| | |
|---|---|
| DDT&E, $M | 4920 |
| Peak Fund $M | 1168 |
| Total Prog $M | 9710 |
| Avg. Cost/Flt $M | 7.48 |




| CY | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | |
| $B | .04 | .50 | .807 | 1.168 | 1.145 | 1.03 | .96 | .74 | .59 | .48 | .43 | .40 | .38 | .34 | .32 | .23 | .15 | |

Figure 6-41 15 x 60 Swing Engine Orbiter/Series/Pressure-Fed BRB Program Costs

## 6.7 SUMMARY-15x60 ORBITER WITH ABORT ROCKETS/SERIES/PRESSURE-FED BRB PROGRAM



This program is defined with the same milestones as the Series/Pressure-Fed BRB Program. The orbiter development and SSME development programs are also the same. Additional development activity associated with the abort rockets will be required concurrent with orbiter development. Pad abort capability will also require additional development costs in orbiter system level development, test, integration, installation, assembly and checkout as in the Swing Engine Program. Since the abort motors are jettisoned at staging on flights where abort is not required, 445 sets of abort motors will be required for operations. Facilities requirements will be as in the Swing Engine Program.

| PAYLOAD BAY SIZE 15 x 60 | |
|---|---|
| GLOW, M Lb | 6.572 |
| BLOW, M Lb | 5.281 |
| HO Tank Liftoff Weight, M Lb | 1.045 |
| Orbiter Injected Weight, K Lb | 246 |
| Total Inert Weight, M Lb | 1.185 |

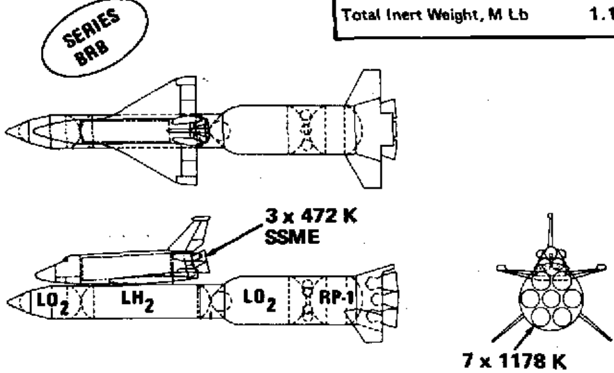
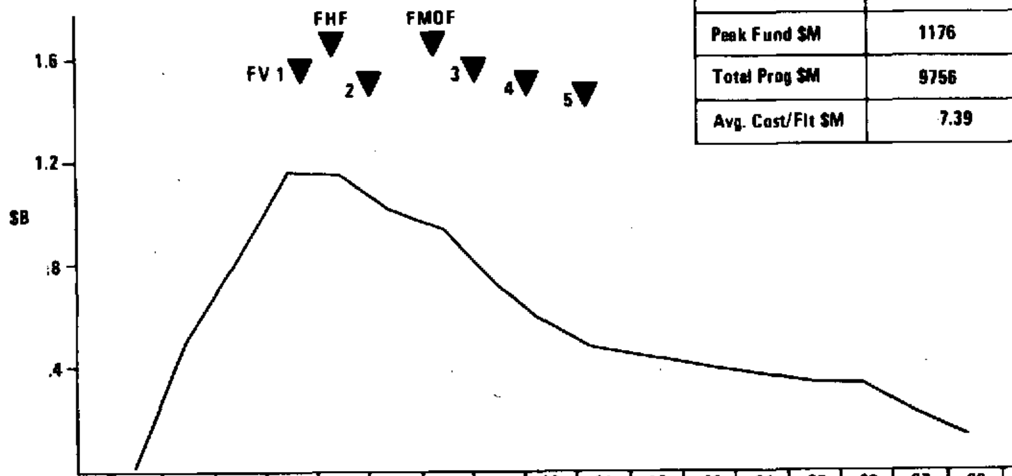



*Figure 6-42 Launch Configuration*

| | DDT&E | Production | Operations | Total |
|---|---|---|---|---|
| Orbiter | 2425.6 | 706.9 | – | 3132.5 |
| HO Tank | 265.7 | 906.3 | – | 1172.0 |
| Booster | 958.6 | 584.4 | – | 1543.0 |
| Main Engine-Orbiter/SSME | 435.0 | 177.0 | – | 612.0 |
| Main Engine-Booster/Press. Fed | 145.7 | 59.8 | – | 205.5 |
| Flight Test-Orbiter | 402.8 | 1.3 | – | 404.1 |
| Flight Test-Booster | 121.6 | – | – | 121.6 |
| Operations | – | – | 2149.3 | 2149.3 |
| Shuttle Management | 215.0 | 103.3 | 97.7 | 416.0 |
| Total Program | 4970.0 | 2539.0 | 2247.0 | 9756.0 |

*Figure 6-43 15 x 60 Orbiter With Abort Rockets/Series/Pressure-Fed BRB Program Cost Summary (445 Flights), $M*

| | |
|---|---|
| DDT&E, $M | 4970 |
| Peak Fund $M | 1176 |
| Total Prog $M | 9756 |
| Avg. Cost/Flt $M | 7.39 |




| CY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 |
| $B | .04 | .51 | .822 | 1.176 | 1.158 | 1.02 | .96 | .75 | .59 | .48 | .43 | .40 | .37 | .34 | .32 | .23 | .14 |

*Figure 6-44 15 x 60 Orbiter With Abort Rockets/Series/Pressure-Fed BRB Program Costs*