LMSC-A990594

N71-35028

FINAL REPORT SUMMARY

# PAYLOAD EFFECTS ANALYSIS

June 30, 1971

National Aeronautics and Space Administration
Contract NASW-2156

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION • SUNNYVALE, CALIFORNIA

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# Section 1
# INTRODUCTION

For the past several years, the National Aeronautics and Space Administration has been studying the economic merits of new space transportation systems. Considerable reduction in space transportation costs have been projected. It has been predicted also that savings from new payloads tailored to these transportation systems are significant and may even exceed the transportation cost reductions.

To evaluate the overall economic impact of low-cost space operations and to determine the economic desirability of the Space Shuttle, NASA assembled a team of three contractors to perform an integrated study. A summary economic analysis was to be conducted by Mathematica, Inc., of Princeton, New Jersey. Aerospace Corporation was assigned to provide Mathematica with total payload/launch vehicle program costs summed from the NASA and DOD traffic models for the 1978 to 1990 time period. Lockheed Missiles & Space Company (LMSC), under the Payload Effects Study, was to provide Aerospace with detailed design, weight, and cost data on typical low-cost unmanned payloads which could be extrapolated and applied to the various missions of the traffic model. The interrelationship of the three studies is shown in Fig. 1-1.

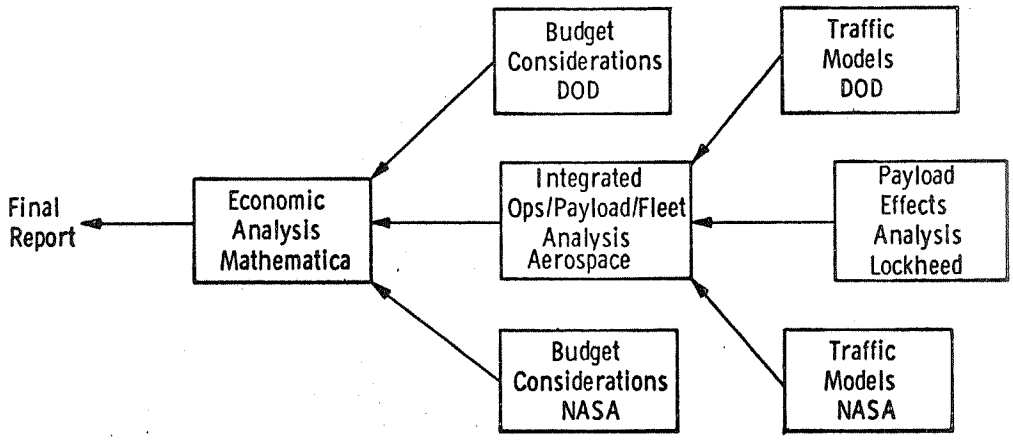



Fig. 1-1 Overall Economic Analysis Study Flow

# Section 2
# SUMMARY

This document is the Summary Final Report of the Payload Effects Study conducted by LMSC for NASA Headquarters, Office of Manned Space Flight, under Contract NAS W-2156. The data herein summarizes the Final Report, LMSC-A990556.

## 2.1 OBJECTIVES OF STUDY

LMSC's basic objective was to develop concepts for reducing cost of future NASA payloads to be used with the new space transportation systems. In executing this objective the following sub-objectives were established:

- Define design characteristics, method of operation, and costs for typical "low-cost" NASA unmanned payloads for use with new launch systems (expendable boosters and Space Shuttle).
- Derive differences in payload costs that can be anticipated as a result of introducing the new launch systems.
- Identify minimum-cost payload approaches.

## 2.2 SCOPE OF STUDY

The study was limited to NASA unmanned payloads. Because of the need for validity in the study results, only those payloads which had flown and upon which historical design and program cost data were available were considered as candidate baseline payloads.

Three payloads were selected:

- Orbiting Astronomical Observatory (OAO)

  A large, complex payload operating in low earth orbit.

- Synchronous Equatorial Orbiter (SEO)

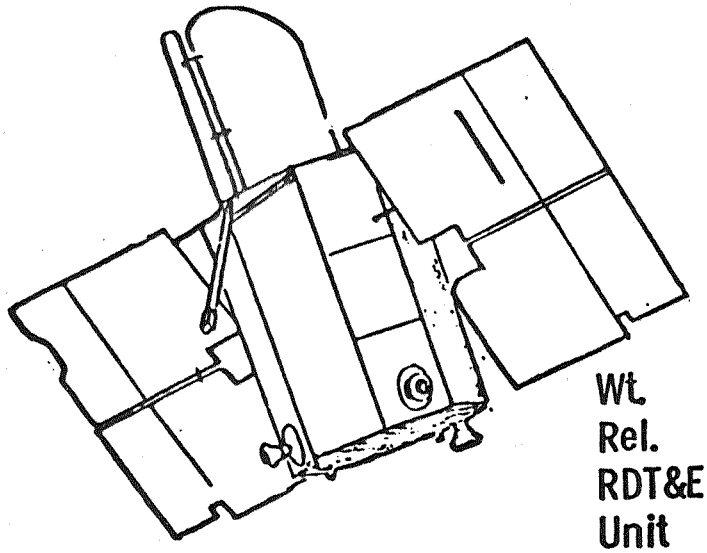
  A medium-size, semi-complex payload operating in synchronous equatorial orbit.

- Small Research Satellite (SRS)

  A small, spin-stabilized, simple payload operating in low-earth orbit.

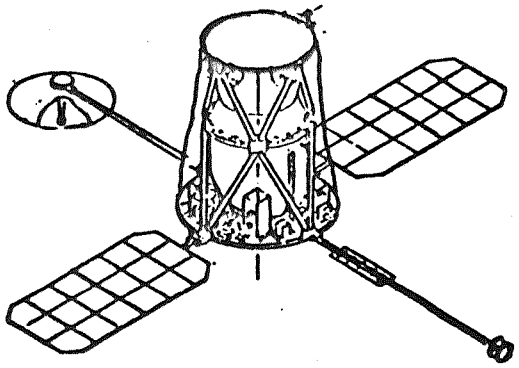
Figure 2-1 illustrates these three baseline payloads, their weights and costs.

OAO



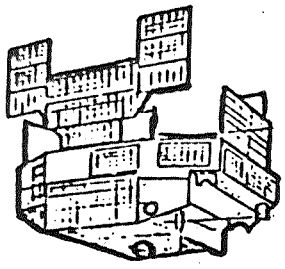
Wt. 4745 lb (2150 kg)
Rel. .609
RDT&E $ 165.41M
Unit $ 36.15M
Ops $ 11.22M

SEO



Wt. 1090 lb (495 kg)
Rel. .606
RDT&E $116.6M
Unit $13.9M
Ops $11.4M

SRS



Wt. 251 lb (114 kg)
Rel. .556
RDT&E $ 9.13M
Unit $ 1.39M
Ops $ 0.19M

Fig. 2-1 Baseline Payloads

To obtain consistency in design and costing of low-cost payloads and to cover a reasonable scope of design variants, the following groundrules were established:

- Payload Performance - of the newly-designed low-cost payloads was to be equal to the historical or "baseline" payload.
- State-of-the-Art Technology - was to be limited to 1970 technology.
- Baseline Cost Data - was to be converted to 1970 dollars.
- Payloads Variants - were to be developed for each of three launch vehicles: (1) Alternate Current Expendable, (2) Low-Cost Expendable, and (3) Space Shuttle/Tug. The matrix of launch vehicles is shown on Fig. 2-2.
- Weight and Volume Constraints - were to be minimized.

| PAYLOAD TYPE | MISSION DESTINATION | LAUNCH VEHICLE | | | |
|---|---|---|---|---|---|
| | | Baseline | Alternate Current Expendable | New Low-Cost Expendable | Reusable STS |
| SRS | 300 N.M. $82^0$ | SLV-3A/ Agena | SLV-3C/ Burner II | 3 Seg. SRM/ Titan Core II/ Agena | Shuttle |
| OAO | 400 N.M. $35^0$ | SLV-3C/ Centaur | SLV-3C/ Centaur | TIII-L2 | Shuttle |
| SEO | Syneq. 19320 N.M. | SLV-3A/ Agena | Titan IIID/ Centaur | Titan IIID/ Centaur | Shuttle/ Space Tug |
| Mars Orbiter | Mars Orbit | SLV-3C/ Centaur | Titan IIID/ Centaur | Titan IIID/ Centaur | Shuttle/ Space Tug |

Fig. 2-2 Selected Launch Vehicle/Payload Combinations

## 2.3 STUDY APPROACH

The exploration of potential payload-related cost savings involves, by necessity, a departure from established ways of payload design, development, procurement, and operation.

### 2.3.1 Initial Payload Effects Analysis

The early study effort (a) identified the characteristics of historical and current payload programs which could be changed by the introduction of new launch/transportation systems, (b) determined the type and degree of influence of the new launch systems, and (c) established the potential "cost-driver" payload effects.

2.3.1.1 Traditional Payload Design/Operations. The philosophy which has been employed for most of the historical payloads are:

- Design within limited weight and volume constraints; high-density packaging.
- Heavy emphasis on low-risk hardware; extensive reliability and qualification testing.
- High level of documentation and configuration management (traceability; because failed hardware not obtainable).
- Lengthy ground checkout of payload prior to launch; large quantities of personnel on multi-shift for ground checkout, pre-launch monitoring, ascent monitoring, data acquisition, and analysis.
- Project management decision required for commitment to launch (requires crew of specialists).

2.3.1.2 Influence of New Launch Vehicles. With the new expendable launch vehicles and the Space Shuttle, a new look can be taken at payload programs with the objective of simplification and reduced cost. The parameters listed following indicate the primary influences (separately) for new expendable and the Shuttle launch systems.

| | New Expendable | Space Shuttle |
|---|---|---|
| • Reduced transportation costs | X | X |
| • Increased weight and volume | X | X |
| • Space environment flight test | | X |
| • Softer ride (airplane-type operation) | (X) | X |
| • Payload retrieval and diagnosis | | X |
| • Orbit maintenance/refurbishment | (X) | X |
| • Checkout on orbit | | X |
| • Intact abort | | X |

Certain characteristics of flight attainable with the Shuttle can also be obtained with the planned expendables, but with some penalty to the latter: (a) the "softer ride" can be obtained with the new expendable but with more complexity and cost than has been planned (throttling engines, etc.); (b) also, orbit maintenance/refurbishment can be accomplished using expendables but at considerably increased technical development risk and cost.

2.3.1.3 Principal Cost Drivers. It was determined that there were a number of principal areas in which payload program cost savings could be derived. The primary cost-drivers listed below were pursued throughout the study.

- Volume/weight limits
- Ground/flight test philosophy
- Repair/refurbishment approach
- Acceptance of risk (reliability) and payload operating life
- Quantity and quality of parts
- Use of developed/qualified hardware (off-shelf)

### 2.3.2 Study Task Breakdown

For convenience, the study was divided into five tasks, the elements of which are shown on Fig. 2-3.

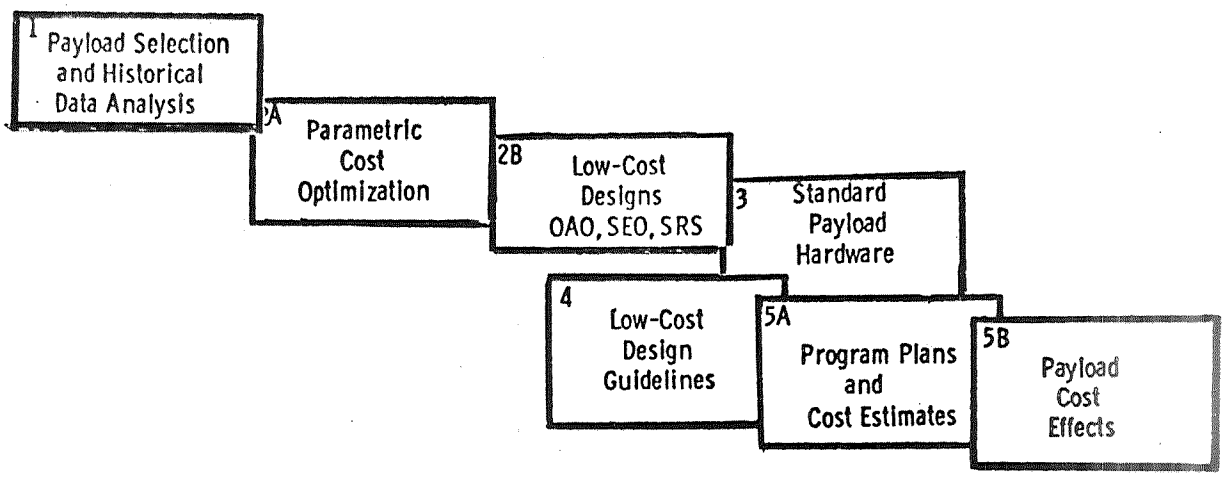



Fig. 2-3 Study Task Breakdown

## 2.4 PRINCIPAL PAYLOAD EFFECTS

The principal payload economic benefits were determined to be in three areas (discussed later in this report):

- Low-Cost Payloads

  The application of low-cost design techniques to future payload hardware will result in significant savings averaging greater than 25 percent in RDT&E, unit recurring, and operations costs.

- Refurbishment and Reuse of Payloads

  Payloads can be refurbished periodically on-orbit (or on the ground) and reused for about 35 percent of the cost of a new replacement payload.

- Standardization of Payload Hardware

  The application of standard payload subsystems or standard spacecraft to the majority of the missions in the NASA traffic model will provide savings in RDT&E costs exceeding one billion dollars.

# Section 3
# LOW-COST PAYLOADS

Using the aforelisted principal cost drivers as the base, new designs were created for the three types of payloads; OAO, SEO, and SRS. The following explains: (1) Cost and hardware breakdowns; (2) parametric cost-optimization analysis; (3) design of low-cost payloads; (4) cost estimates of low-cost payload programs, and (5) transportation system interfaces.

## 3.1 COST/HARDWARE BREAKDOWN

### 3.1.1 Cost Breakdown

Cost, weight, and reliability data were obtained on each of the baseline payloads. To assure that all cost data, both for the baseline payloads and for the to-be-designed low-cost payloads, was subdivided on a directly comparable basis, a cost breakdown structure illustrated in Fig. 3-1 was established. This cost-element listing also was utilized as a checklist during subsequent analyses of cost-reduction potential.

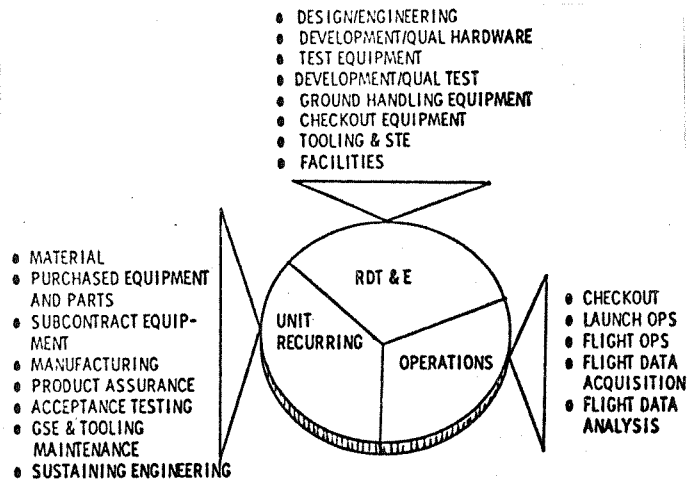



Fig. 3-1 Cost Breakdown for Visibility of Payload Effects

### 3.1.2 Hardware Breakdown

To assure similar uniformity in hardware breakdown, a typical payload assembly breakdown was established. The eight subsystems are shown in Fig. 3-2. For purposes of weight, reliability, and cost tradeoffs, the experiment package was considered a subsystem and integral with the payload.

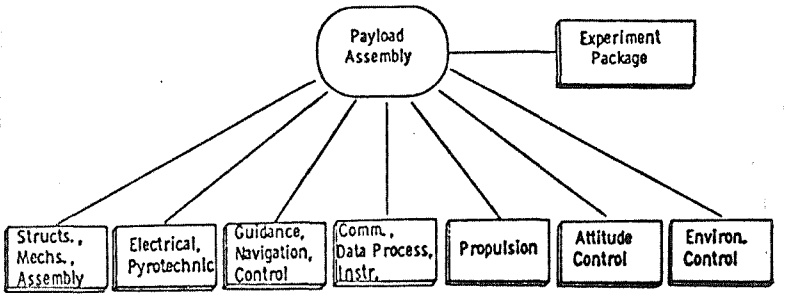



Fig. 3-2 Subsystem Breakdown for Hardware Consistency

### 3.1.3 Apportionment of Cost, Weight, Reliability

Baseline data, as received, was not in all cases segregated into the aforementioned cost element and hardware breakdowns. Apportionment was therefore done, using best engineering judgment and the available data, to allocate costs, weights, and reliabilities to the individual subsystems.

### 3.1.4 Preliminary Analysis of Payload Effects

To obtain a "feel" for the type and magnitude of cost savings potential, the cost reduction areas were matrix-plotted against the cost category affected. Figure 3-3 shows a summary of this analytical approach. In this manner, a determination was made of primary-emphasis areas for cost reduction and there was developed early an indication what savings could be derived for the Shuttle-launched versus the expendable-launched payloads.

| COST REDUCTION AREA | Launch Applicability | RDT&E | | | | | | | | | UNIT PRODUCTION | | | | | OPERATIONS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Program Mgt. | Payload Integr. | Devel/Des. Engr | Devel/Qual Hdwe | Devel/Qual Test | Test Equipment | Tooling | Checkout Equip. | Facilities | Matl./Parts | Purch. Equip. | Manufacturing | Product Assur. | Accep. Test | Checkout | Launch Ops | Flight Ops | Flt Data Acq/Anal |
| SIMPLIFIED CONTRACT/DOCUMENT REQUIREMENTS | E/S | X | X | X | | X | | | | | X | X | X | X | X | | | | |
| SIMPLIFIED CONFIGURATION MANAGEMENT (TRACEABILITY) | S | X | X | X | | X | | | | | X | X | X | X | X | | | | |
| USE OF PROVEN TECHNOLOGY-OFF SHELF | E/S | | | X | | X | | | | | | | | | X | | | | X |
| USE OF LOW-COST MATERIALS | E/S | | | | X | X | | X | | | X | | X | X | X | | | | |
| DECREASE STRESS LEVEL ON PARTS | E/S | | | | X | X | | | | | X | X | | | X | X | | | |
| USE LOWER-QUALITY PARTS | S | | | X | X | X | | X | | X | X | X | X | X | X | X | | | |
| INCREASE STRUCTURE SAFETY MARGIN | E/S | | | X | X | X | X | X | | X | X | X | X | X | X | X | | | |
| USE LOWER RELIABILITY GOALS (W/MAINTENANCE) | S | | | X | X | X | X | | X | | X | X | | X | X | X | | | |
| INCREASE VOLUME OF PACKAGES | E/S | | | X | | | | X | | | | X | X | X | | | | | |
| INCREASE HARDWARE WEIGHT ALLOWANCE | E/S | | | X | X | | | X | | | X | X | X | X | | | | | |
| SIMPLIFY/MODULARIZE HARDWARE | E/S | | | X | X | X | X | | X | | X | X | X | X | X | X | | | X |
| SIMPLIFY/REDUCE GROUND TESTING | S | X | X | X | X | X | X | | | X | | | | | | | | | |
| USE ORBIT MAINTENANCE/REFURBISHMENT AND REUSE | S | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| EMPLOY HARDWARE UPDATE (VS NEW HARDWARE) | S | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| USE PRE-DEPLOYMENT ORBIT CHECKOUT | S | | | X | X | X | X | | X | X | X | X | | X | X | X | | X | X |

E = Expendable
S = Shuttle

Fig. 3-3 Potential Cost Reduction Areas

## 3.2 PARAMETRIC ANALYSIS FOR INTERIM REPORT

The early need date for preliminary cost data on payload effects (December 1970) necessitated initiation of a parametric payload cost-optimization analysis prior to establishment of point designs for typical low-cost payloads. The baseline payload data analysis, the computerized optimization analysis, and principal results are summarized below.

### 3.2.1 Computerized Cost-Optimization Analysis

An existing LMSC computer program was modified to: (1) accept a fairly large quantity of input data on payload, launch vehicle, and mission parameters,

(2) perform a program-cost minimization calculation; and (3) re-apportion weight, reliability, and cost to each of the optimized-payload subsystems. A schematic representation of this analysis technique is shown in Fig. 3-4.

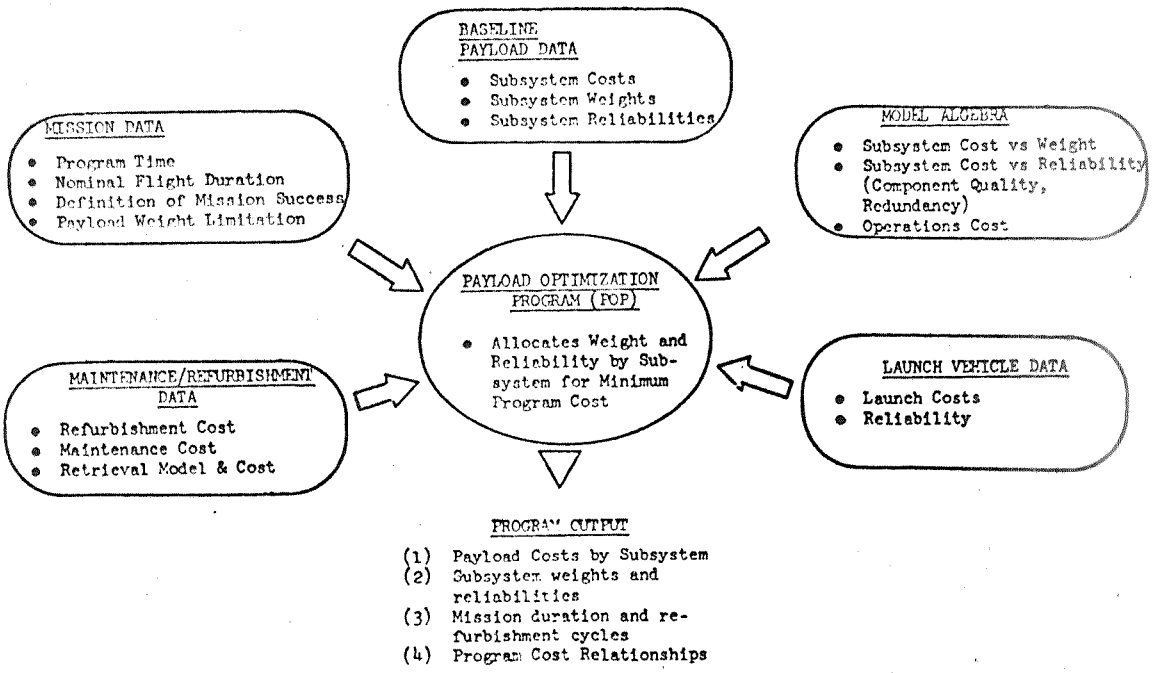



Fig. 3-4 Cost Optimization Analysis for Payload Programs

One of the principal features of this cost-optimization was the use of a multi-dimensional CER (cost estimating relationship) concept which combined and traded-off the parameters of cost, weight, and reliability (including both component reliability elements) for a constant-performance subsystem.

### 3.2.2 Interim Report Data

Preliminary data based on the parametric analysis was supplied to NASA and to Aerospace Corporation in the LMSC "Interim Report - Payload Effects Analysis", LMSC-A983808, dtd 22 December 1970. These data included those items listed following:

- Baseline payload cost data by subsystem
- Baseline payload weight, and reliability data by subsystem
- Low-cost payload target costs (OAO, SEO, SRS) by subsystem and by cost category
- Low-cost payload weight, volume, and reliability characteristics
- Parametric payload effects on program costs
- Refurbishment cycle time and cost
- Mission duration and payload life requirements
- Reliability and weight sensitivity

## 3.3 DESIGN OF LOW-COST PAYLOADS

### 3.3.1 Initial Instructions and Groundrules for Low-Cost Design

As a first step, the complete set of baseline design data for each payload was thoroughly reviewed to understand the relative complexity of each subsystem, the parts and components used, and the type and amount of testing which had been performed. The payload subsystem characteristics were then evaluated relevant to the potential for cost reduction.

Instructions were then given to the designers to: (1) familiarize them with the results of the parametric cost-optimization analysis; (2) explain basic low-cost design approaches; and (3) illustrate the effect of various design approaches upon program costs. The principal instructions were:

- Review parametric target costs and consider relationships and cost effects of weight, reliability, and refurbishment

- Repetitive review of payload design effects upon primary cost-driver elements
- RDT&E cost reductions preferred over unit cost reduction
- Use proven technology and qualified off-shelf hardware
- Minimize development/qualification testing
- Reduce types and quantity of different components
- Provide maximum accessibility
- Provide for growth and updating

The following design groundrules were established:

- Volume and Weight - Minimum constraints
- Performance - Configuration, functions, and hardware may be altered to obtain cost reduction; however, overall performance capability must be retained.
- Overdesign - Use high structural safety factors and reduce parts/component stress levels.
- Modularization - Equipment to be modularized to facilitate on-orbit replacement and refurbishment/reuse
- Hardware Complexity - Reduce without affecting overall payload reliability.
- Materiel - Use inexpensive materials, off-shelf components.

For the Shuttle-launched payloads, a design premise was developed that distinguished "man-safety" from "man-rating". In agreement with the Technical Monitoring Team, it was determined that the man-safety requirements as listed following should apply.

- Man-rating of payloads (not required)

  Failure of payload hardware usually does not contribute directly to safety of flight. It need not be man-rated. Example: complete failure of payload electrical subsystem has no effect on Shuttle safety of flight.

- Man-safety

  All payload hardware elements, failure or malfunction of which may damage the Shuttle or injure personnel, must be designed to prevent the failure or to restrain the effects within the payload:

  - Use higher safety factors and overdesign
  - For fluid systems, design tankage to withstand overpressures even if relief valves fail
  - Provide blast shields for explosive devices
  - Provide deactivation when crew is near payload

### 3.3.2 Modular Design of Low-Cost Payloads

Because of the prime importance of modular design to allow in-orbit replacement of payload equipment for repair or refurbishment, explicit requirements were established for the OAO and SEO.

A summarization of the modularization requirements include:

(1) Divide payload subsystems into minimum quantity of modules consistent with:

- Maximum weight/size which can be readily installed or removed by space crew
- Maximum cost of a single module which is economical for spares replacement

(2) Segregate components which have high probability of replacement from those which have higher predicted life.

(3) Establish operating tolerances on individual modules so that module replacement will not require payload recalibration.

(4) Provide simple functional and mechanical interfaces between modules.

(5) Provide for easy access to and removal/installation of modules without need for special tools.

The modular design was actually implemented on the OAO and the SEO; the latter is schematically illustrated in Fig. 3-5. It may be noted that some

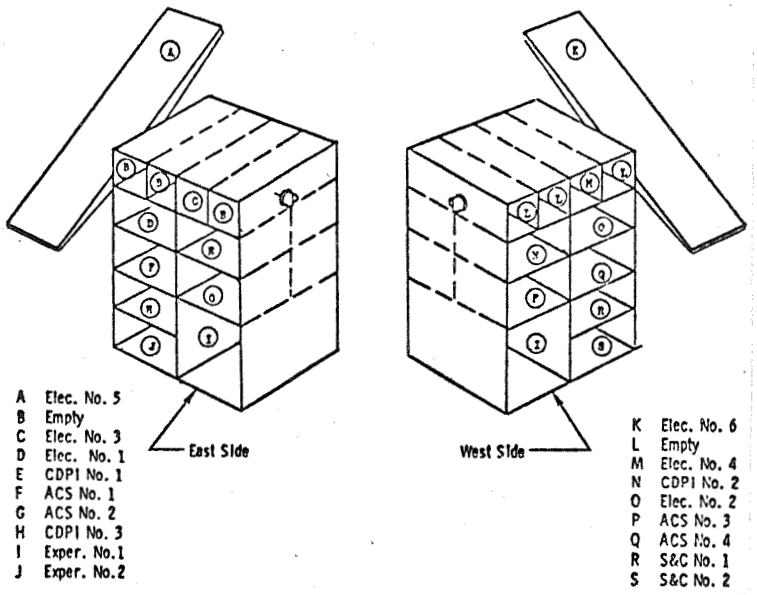



Fig. 3-5 SEO Module Location & Arrangement

compartments have been left empty to accommodate future growth and/or update. Figure 3-6 illustrates the four different modules of the electrical power subsystem for the low-cost SEO. In most cases, the modules of the various subsystem are a common size, approximately 14 x 24 x 30 in. (36 x 61 x 76 cm). The module approach accrues cost savings in manufacturing assembly and testing as well as providing ease of equipment replacement and refurbishment.

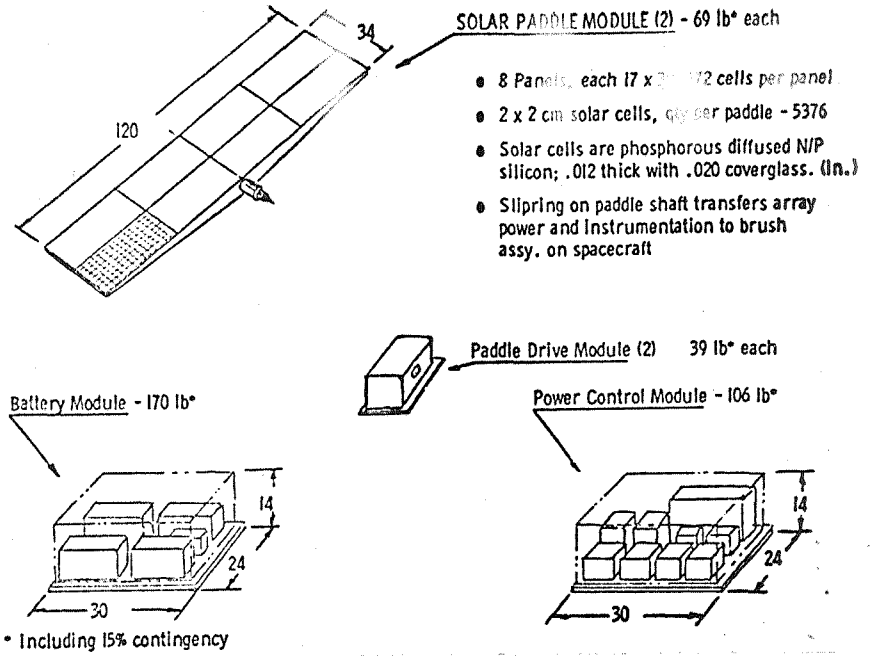



Fig. 3-6 Low-Cost SEO Electrical Subsystem Modules

### 3.3.3 Parts and Component Reliability

It was recognized early in the study that reduction in payload part/component quality might be compatible with the orbit revisit capability of the Shuttle for repair or refurbishment of the payloads. Investigations were made into relative hardware costs for various quality grades and the practicability of using the lower-cost parts on future payloads. The mission model requirements covering the Space Shuttle operational time period indicated a need for high-reliability parts and components. Therefore, the lower-cost (MIL-Spec and aircraft) parts were not pursued to their final potential. This area should

be studied in more depth as mission equipment and spacecraft subsystems become better defined.

Preliminary analysis revealed that use of aircraft-quality parts was feasible only for very short mission durations, on the order of 4 months; the critical part characteristic was parametric drift. Also, use of MIL-Spec parts was proved feasible for use on payloads with design operating life up to 9 months. It is possible, with the short-time revisit cycles anticipated with the Shuttle, that application of lower-quality parts would be operationally and economically feasible.

Specifically, with the short-duration sortie missions planned with the Shuttle, the use of aircraft parts might show significant benefits. Further study should be undertaken of this low-cost part application as the sortie mission hardware requirements are firmed-up.

### 3.3.4 Low-Cost Subsystem and Payload Designs

Each subsystem of the three candidate payloads, OAO, SEO and SRS, was analyzed as to functional efficiency and general cost-effectiveness of the hardware. Low-cost design methodology was applied and a substitute low-cost subsystem was developed. The design outputs included:

- Parts lists with weight breakdown
- Block diagram and functional description of subsystem
- Dimensions and alignment/calibration requirements
- Special test requirements
- Approximate component costs (where known)
- Special capabilities in ground and flight operations
- Special interface requirements with launch vehicle

These data were documented in a number of LMSC engineering memoranda which were provided to NASA agencies and Aerospace Corporation for information and comment.

3.3.4.1 Low-Cost Subsystem Characteristics. A summary listing of the principal cost-reduction features of the low-cost subsystems is shown in Fig. 3-7.

STRUCTURES & MECHANISMS

- Low-cost materials, manufacturing processes
- Simple structure, high safety factors (3 or more)
- Maximum-allowable dimensional tolerances
- Eliminate extension mechanisms where possible

AVIONICS

- Increase on-board data processing capability (computer)
- Utilize Shuttle GNC capability for initial orbit positioning
- Design modules, components to allow replacement without recalibration
- Reduce packaging density
- Standardize hardware elements (circuits, PCBs, etc.)

EXPERIMENTS

- Standardized and versatile interface with payload
- Design for fixed-mounting and ground alignment where possible
- Mechanisms to be self-supporting in 1-g field

ELECTRICAL

- Ruggedized simple sheet metal structure for solar array structure
- Fixed solar arrays - eliminate folding where possible
- Large-size, 97.5% yield solar cells
- Design for long-time degradation to reduce average refurbishment cost

Fig. 3-7 Principal Contributors to Subsystem Cost Reduction

Special attention was devoted to investigating methods for cost-reduction in electronic assemblies. After review of historical design, manufacturing, and product assurance at LMSC on a large variety of electronic flight hardware, basic low-cost design principles were established; Fig. 3-8 is a summary listing of these.

- STANDARDIZE BOX AND PCB SIZES AND CONNECTORS WHERE POSSIBLE
- STANDARDIZE CIRCUITRY ELEMENTS
- DECREASE CIRCUIT DENSITY OF PARTS - REDUCTION FROM 75% TO 30% ALLOWS ABOUT 35% SAVING IN MANUFACTURING/INSPECTION LABOR
- DESIGN THE BREADBOARD UNIT AS A PRODUCTION PROTOTYPE - USE PRODUCTION PROCESSES FOR FABRICATION OF BREADBOARD
- INCREASE CONDUCTOR SPACING; PROVIDE "BLANK" SPACE ON PCBs
- USE CONFORMAL COATING IN LIEU OF HARD POTTING TO ALLOW REPAIRS
- USE PCBs IN LIEU OF CORDWOOD MODULES - ALLOWS REDUCTION UP TO 50% OF TROUBLE-SHOOTING AND INSPECTION LABOR

Fig. 3-8 Design of Low-Cost Electronic Boxes

3.3.4.2 Low-Cost Payload Configurations. A structural design has been developed for each payload, with external configuration being determined by the volumetric need for equipment module mounting. The general configurations of the low-cost OAO and SEO payloads are illustrated in Figs. 3-9 and 3-10.

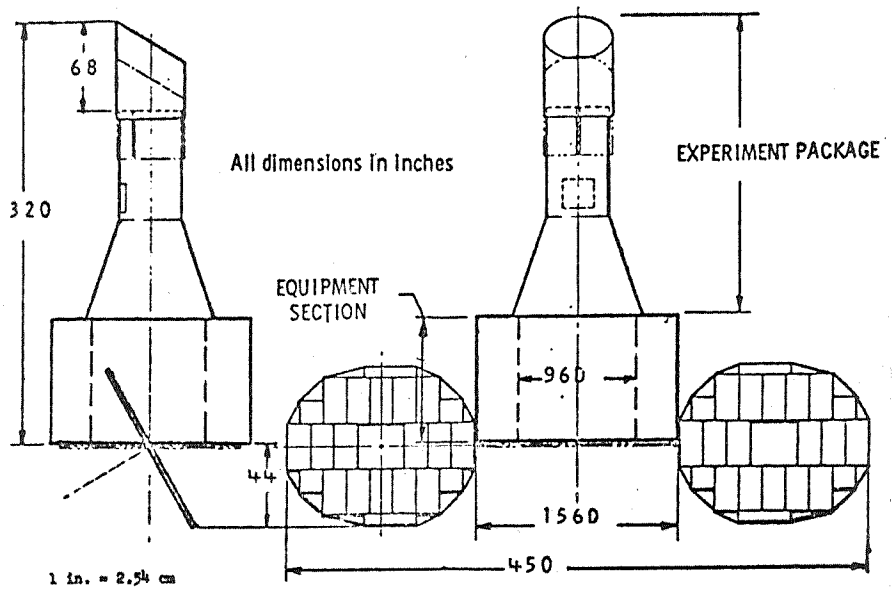



Fig. 3-9 Low-Cost OAO Configuration

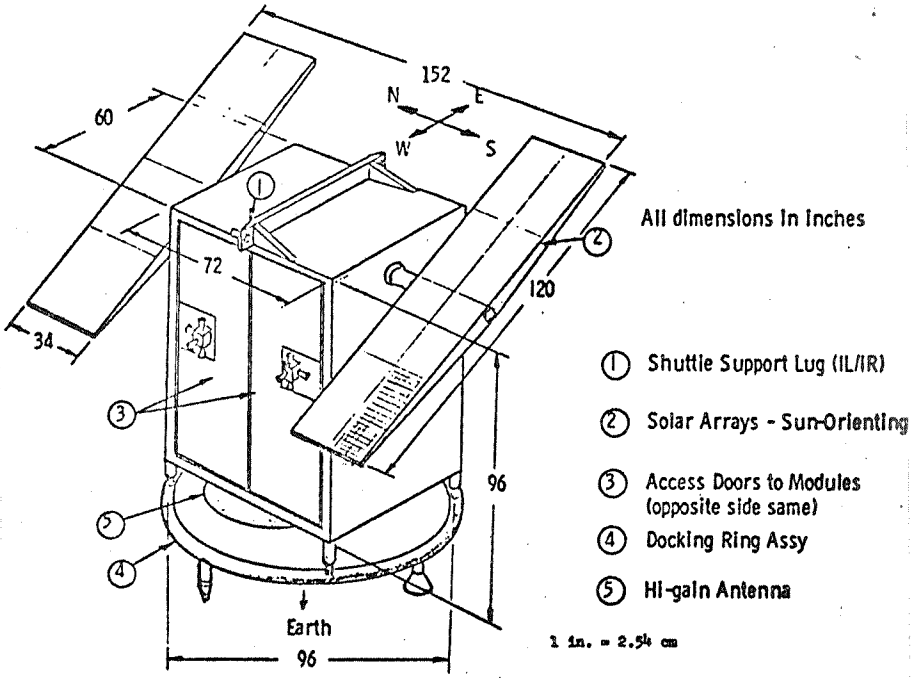



Fig. 3-10 Low-Cost SEO Configuration

The low-cost SRS is shown in Fig. 3-11.

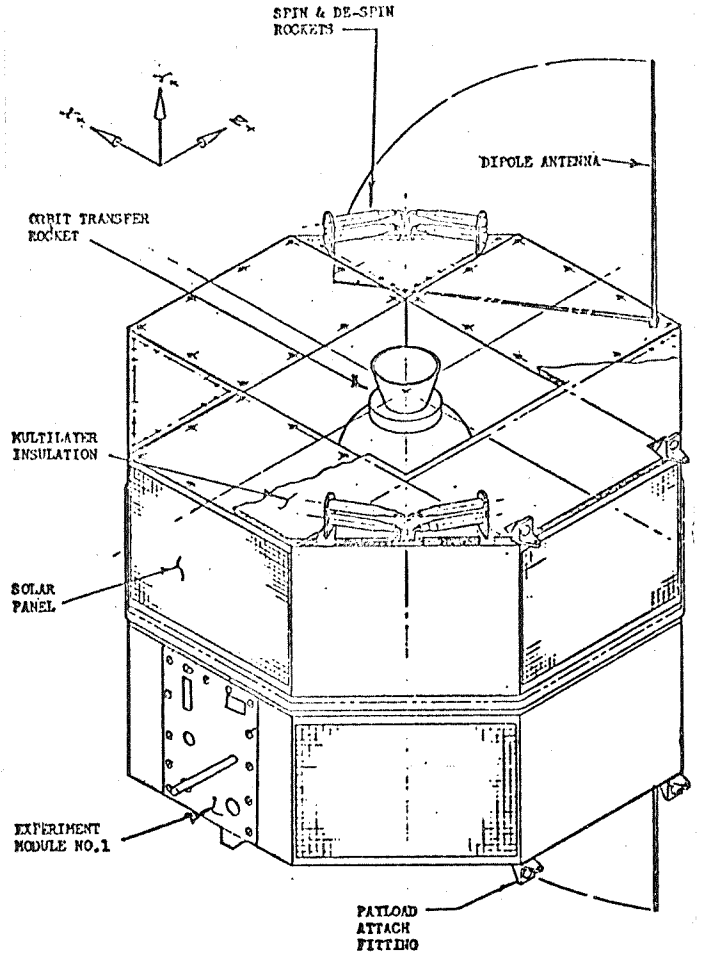



Fig. 3-11 Low-Cost SRS Configuration

3.3.4.3 Weights of Low-Cost Payloads. Weight statements were prepared for the OAO, SEO, and SRS. Data on Fig. 3-12 compares the baseline with the low-cost versions.

| | WEIGHT (INCL. EXPENDABLES) | | |
|---|---|---|---|
| | BASELINE PAYLOAD | LOW-COST PAYLOAD | RATIO |
| OAO | 4877 lb | 7903 lb | 1.62 |
| SEO | 1151 lb | 3127 lb | 2.72 |
| SRS | 317 lb | 697 lb | 2.20 |

Refurbishment Factors

OAO (1 Year Cycle) - .325
SEO (2 Year Cycle) - .390

Fig. 3-12 Weight Ratios - Shuttle-Launched Payloads

## 3.4 PLANS AND COST ESTIMATES

To provide the basis for estimating the costs of developing, manufacturing and operating the low cost payloads, program plans were prepared for each of the three payloads. Using these plans and the low-cost payload design data bottom-up cost estimates were made. Following is a summary of the highlights of the planning and costing effort.

### 3.4.1 Planning Approach

Program plans were prepared covering development, qualification, manufacturing, and operations of the low-cost payloads. The basic guidelines used were:

- Comparability to baseline retained
  - Flight-article quantity same as baseline
  - Equipment and software development comparable to baseline program
- NASA phased project planning approach

  OAO - $4\frac{1}{2}$ Year Program - Phase B to launch

  SEO - $3\frac{1}{2}$ Year Program - Phase B to launch - combined Phase C/D
- Current NASA/DOD program management approaches
  - MIL-STD-499
  - NHB 5300.4 (1A) and 1B)
- GFE Assumed
  - Launch vehicle, fairings, and adapters, launch services control center, NASCOM, STADAN, operational computer
- Similar spacecraft design for either Shuttle or expendable

### 3.4.2 Cost Estimates - Low-Cost Payloads

Cost estimates were made on each low-cost payload program. The basic approach used is summarized following:

- Bottom-up costing - using 1970 rates - includes labor, overhead, and G&A (no prime contractor fee)
- Engineering, Manufacturing, Test, and Operations cost estimates based on Program Plan
- Typical Program Management and Quality Assurance percentages applied
- Allowances included for:
  - Rework and scrappage
  - Engineering changes
  - Spares and Logistic Support
  - Tooling, GSE, and STE Maintenance
  - Computer Hours
- All cost spreads by subsystem and by year

Costs were derived at component and subsystem level and summed to obtain totals of RDT&E, Unit, and Operations. This was done separately for the expendable-launched and the Shuttle-launched programs. Typical payload cost totals are shown in Fig. 3-13.

A comparison of the RDT&E, unit, and operations cost for each Shuttle-launched low-cost payload is shown on Fig. 3-14; the baseline costs are shown for comparison. The OAO figures for designs with and without a computer are shown. (Paragraph 3.4.4 explains the computer significance.)

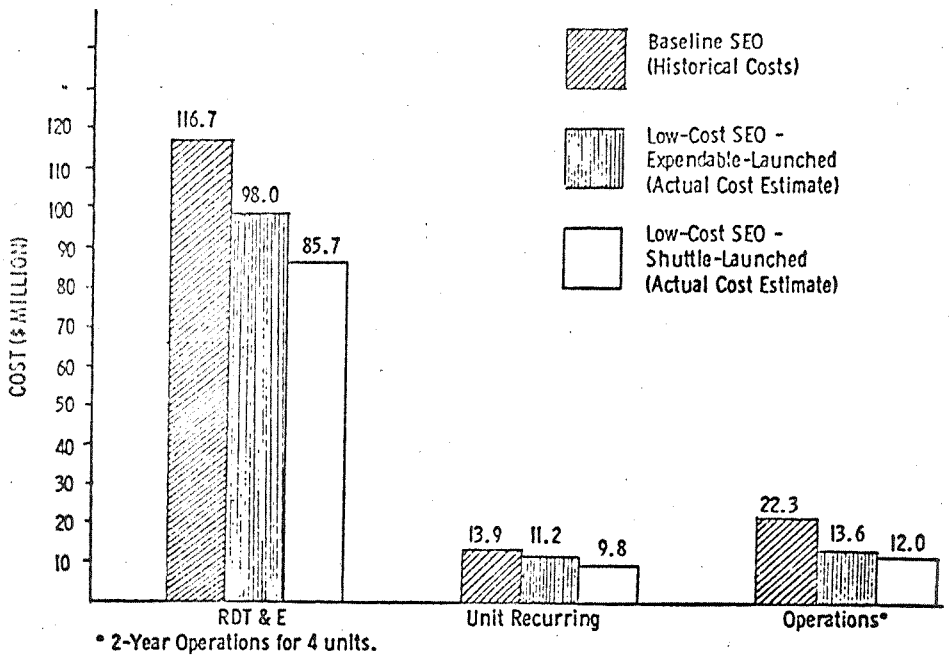



Fig. 3-13 SEO Cost Comparison (Sample)

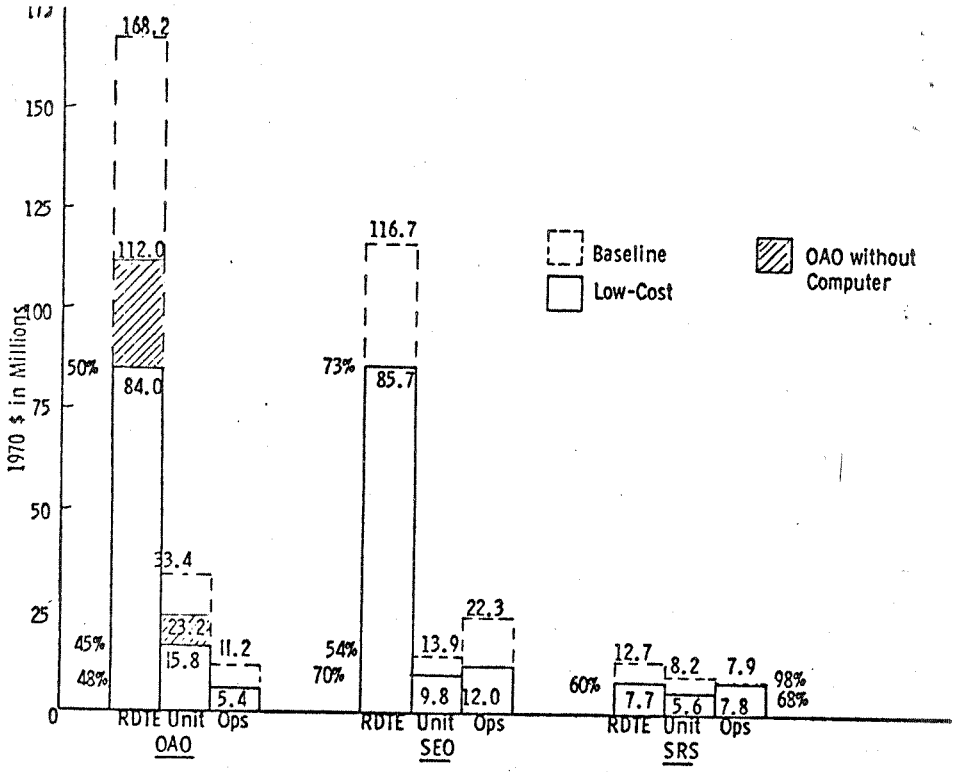



Fig. 3-14 Cost Comparison - Low-Cost Designs (Shuttle-Launched)

Costs to the subsystem level were provided to Aerospace Corporation for application of cost-reduction ratios to the various payloads in the traffic model. A typical set of subsystem cost data for a low-cost payload is shown on Fig. 3-15.

| | RDT&E | | UNIT | | OPS*** | |
|---|---|---|---|---|---|---|
| | Low Cost* | Ratio** | Low Cost | Ratio** | Low Cost* | Ratio** |
| Experiment | $37.5 | 80% | $ 1.9 | 76% | $ 4.6 | 49% |
| Struct. & Mech. | 6.0 | 87 | 0.6 | 50 | 0.6 | 75 |
| Electrical | 10.2 | 82 | 1.7 | 90 | 1.5 | 79 |
| Stabilization & Control | 9.6 | 60 | 1.9 | 58 | 1.8 | 72 |
| Attitude Control | 3.4 | 85 | 0.6 | 100 | 0.5 | 100 |
| CDPI | 17.8 | 69 | 2.8 | 72 | 2.6 | 60 |
| Environmental Control | 0.8 | (160) | 0.1 | 100 | 0.1 | 100 |

* $ Million
** Ratio of low-cost subsystem cost to baseline cost
*** Two-year ops for 4 payloads

Fig. 3-15 Typical Low-Cost Subsystem Cost Breakdown (SEO)

The percentage saving (as compared to the baseline) for each payload type was determined. The summary comparison is shown on Fig. 3-16. The savings noted do not include launch system nor payload refurbishment.

| | OAO | | SEO | | SRS | |
|---|---|---|---|---|---|---|
| | LCE | SS | LCE | SS | LCE | SS |
| RDTE | 47% | 50% | 16% | 26% | 14% | 39% |
| Unit (Average) | 43% | 52% | 19% | 29% | 15% | 32% |
| Operations (Average) | 40% | 52% | 39% | 46% | - | 1% |

* Saving ratio to revised baseline cost.

Fig. 3-16 Summary of Payload Effects Saving* (Excluding savings from launch system and payload refurbishment)

The addition of refurbishment savings and launch vehicle costs to the payload cost summations provides an interesting comparison of total program costs between (1) baseline payload, expendable-launched; (2) low-cost payload, low-cost expendable-launched; and (3) low-cost refurbished payload, Shuttle-launched. Figure 3-17 shows the relationships for a 6-year program with an OAO-type payload.

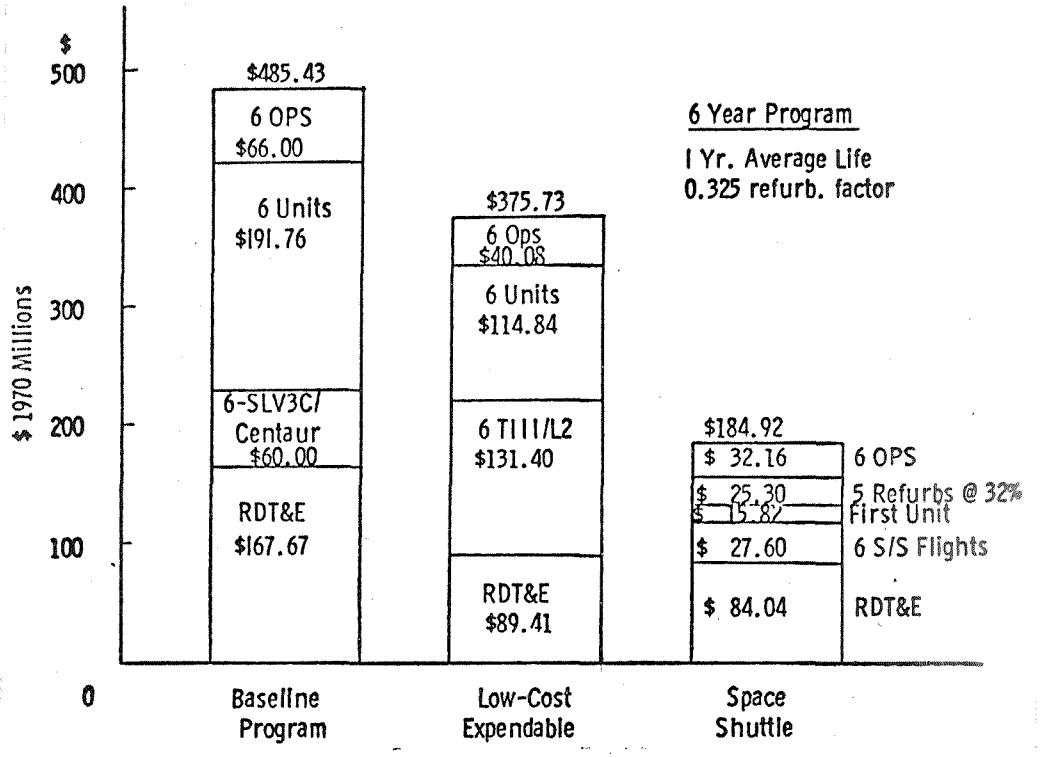



Fig. 3-17 OAO Total Program Cost Comparison

Similar summaries have been made for a 10-Year SEO-type payload program. Although these examples represent only two single programs, similar cost-reductions can be applied to many of the missions included in the traffic model for the 1978 to 1990 period. Total program savings approaching 50 percent are feasible utilizing low-cost payloads with refurbishment and reuse.

### 3.4.3 Recosting of Baseline OAO, SEO

Because of the desire to have a "calibration" of the LMSC estimates so that true delta-cost values could be derived between the low-cost payloads and the historical baseline, it was requested by NASA/HQ that LMSC estimate the costs of the baseline OAO and SEO payload programs: (1) using the same estimating methods employed on the low-cost payloads; but (2) using all the program approach and hardware of the baseline programs.

Recosting of the baseline OAO and SEO programs was accomplished. The results are summarized in Fig. 3-18. There are some significant differences at the subsystem level but the total program costs are very nearly the same. It was thereafter assumed that the LMSC estimating methodology employed sufficient realism and conservatism so that the low-cost payload estimates could be used without multiplying by a "growth" factor.

| | SEO | | | | OAO | | | |
|---|---|---|---|---|---|---|---|---|
| | RDT&E | Avg. Unit | Ops. | Total* | RDT&E | Avg. Unit | Ops. | Total |
| Historical Actual | $117 | $ 14 | $ 22 | $ 209 | $ 166 | $ 36 | $ 11 | $ 213 |
| LMSC Estimate | $121 | $ 13 | $ 17 | $ 203 | $ 168 | $ 32 | $ 11 | $ 211 |

* Includes 5 Units.

Fig. 3-18 Historical vs Recosted Baseline Programs ($ Million)

### 3.4.4 Technology vs Payload Effects

As mentioned early in this report, a baseline requirement of the study was to use 1970 technology where possible to obtain a cost reduction. In general, technology did not influence the low-cost design approach in a cost-significant manner. The principal exception was in the OAO, where a 1970 state-of-the-art general-purpose computer was substituted for a fairly large quantity of electronic assemblies in the Stabilization & Control and CDPI subsystems. This type of fairly low-cost, reliable computer was not available for spacecraft application in the early 1960's (during the OAO development). The use of this computer accounted for a large percentage of the RDT&E and unit cost savings in the low-cost OAO. A separate cost-allocation analysis was performed, including recosting of the low-cost OAO without the computer substitution. The resulting costs indicated that the computer substitution accounted for about 35 percent of the total program savings on the OAO (33.6 percent of the RDT&E savings; 39.5 percent of the unit savings). The "without-computer" low-cost OAO provided about a 33 percent reduction in baseline RDT&E and unit cost when compared with the "with-computer" reduction of 50 percent. Figure 3-19 illustrates graphically the major contributors to the cost reduction.

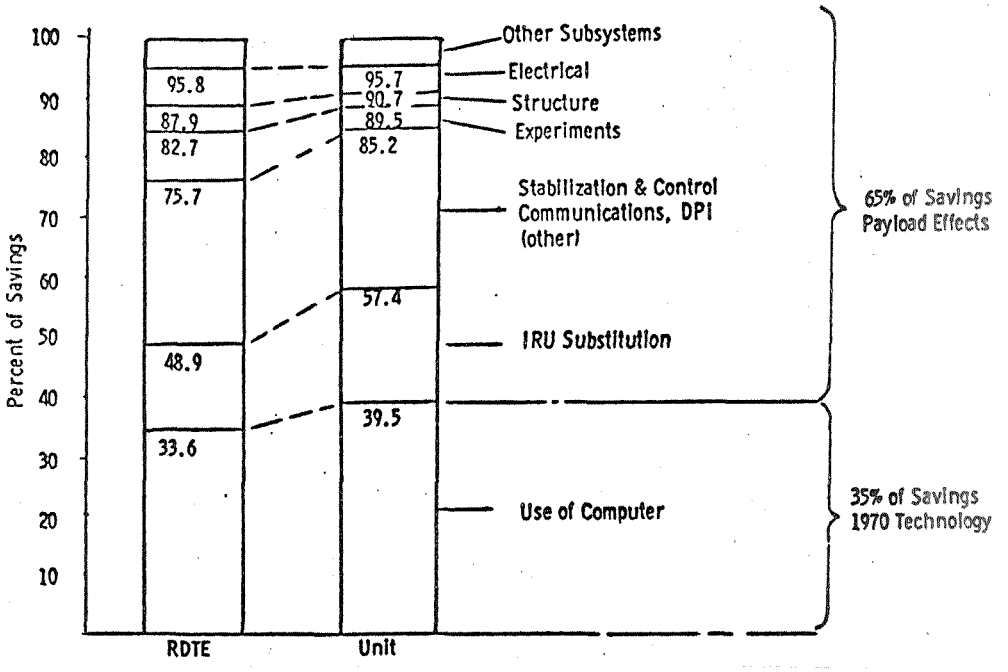



Fig. 3-19 Technology vs Payload Effects

## 3.5 IMPACT OF LOW-COST PAYLOADS ON TRANSPORTATION SYSTEM AND PROGRAM COSTS

Because of the strong dependence of the Shuttle-launched low-cost payloads upon the implementation of payload-compatible interfaces, it was determined necessary to verify that the LMSC-proposed interfaces with the Shuttle system were feasible and practicable. Conceptual designs were therefore created for: (1) a payload deployment/retrieval gear and, (2) a payload checkout set for on-orbit use with the Shuttle.

The study results are discussed following.

### 3.5.1 Payload/Shuttle Interfaces

In obtaining the maximum cost benefit from the low-cost payloads, it seemed desirable to adapt the payloads and the supporting Shuttle systems to "a launch base on orbit". In this manner, the failures experienced in launch/ascent could be repaired on orbit prior to payload deployment from the Shuttle. This concept required: (1) the use of on-orbit checkout by Shuttle-carried payload checkout equipment and, (2) the design of payloads to allow easy repair, refurbishment, and reuse, it was necessary to provide an installation which could be employed for these operations with various payloads. The elements of the payload support equipment and interfaces are listed on Fig. 3-20. These interfaces have been investigated, preliminary requirements established, and payload compatibility with the Shuttle has been verified.

### 3.5.2 Payload Support, Deployment, and Retrieval

A universal-usage deployment/retrieval gear was conceptually designed. The principal hardware elements are bi-stem extendable booms, smaller sizes of which have been successfully used on previous spacecraft applications. These booms, installed as a single unit, in pairs, or as a set of four, can extend or retract a payload from its base mounting position in the Shuttle cargo bay.

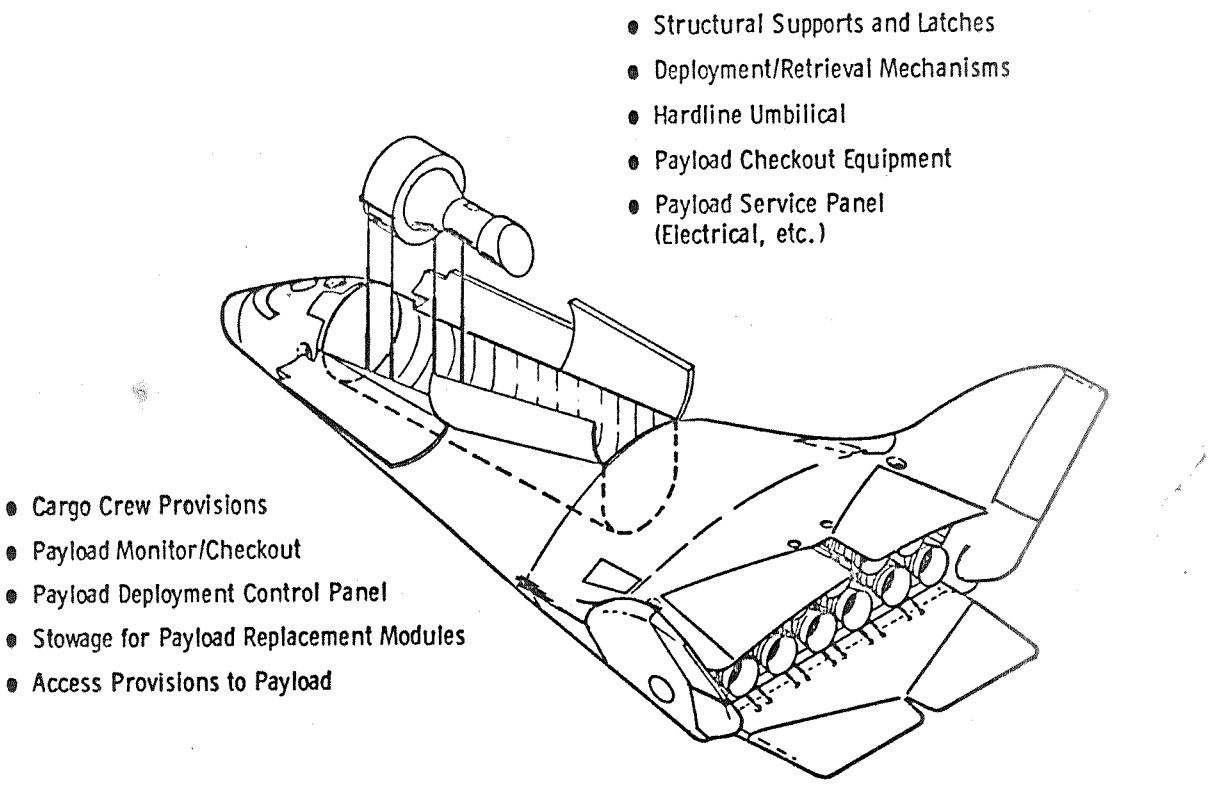



Fig. 3-20 Shuttle Interfaces with Low-Cost Payloads

which have been successfully used on previous spacecraft applications. These booms, installed as a single unit, in pairs, or as a set of four, can extend or retract a payload from its base mounting position in the Shuttle cargo bay.

A scale drawing of the installation of the SEO/Tug in the Shuttle is shown on Fig. 3-21. The booms operating in zero-g are stiff enough to sustain the bending loads applied by minor maneuvering of the Shuttle even with booms extended. The booms can sustain reasonable loads even in 1-g load field and can be readily tested on the ground with simulated weights attached. Positioning for retrieval engagement can be accomplished by vernier control of the Tug, by use of telefactor robot, by separate "grappling" mechanism deployed from the Shuttle, and/or by use of crew in EVA with strap-on thruster devices.

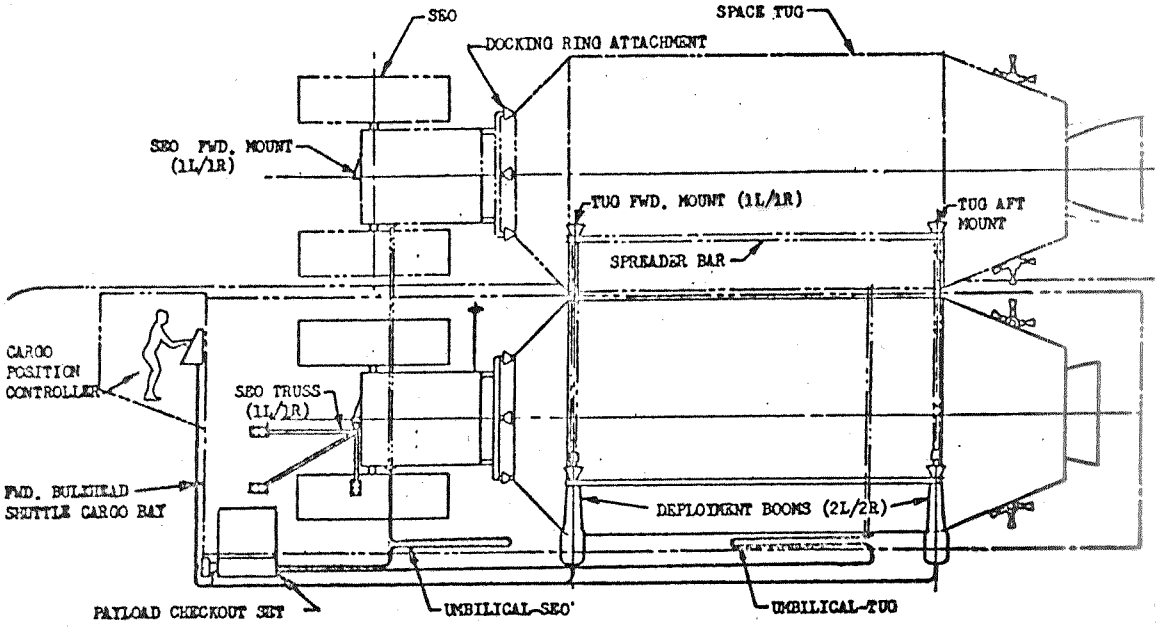



Fig. 3-21 Shuttle Installation of SEO and Space Tug

3.5.3 On-Orbit and Standardized Checkout

On-orbit checkout of payloads provide specific advantages:

- Greatly increases probability of successful mission by allowing elimination of launch/ascent failure contribution
- Allows lower payload design reliability and concomitant reduced cost
- Allows payload - cognizant personnel to perform first-hand observation of payload operating in orbit environment
- Makes feasible on-orbit module replacement and re-checkout for repair or refurbishment

A phased-checkout approach was developed so that payloads could be exposed to a series of verifications, using the same checkout set. The seven phases of test/checkout proposed are shown on Fig. 3-22.

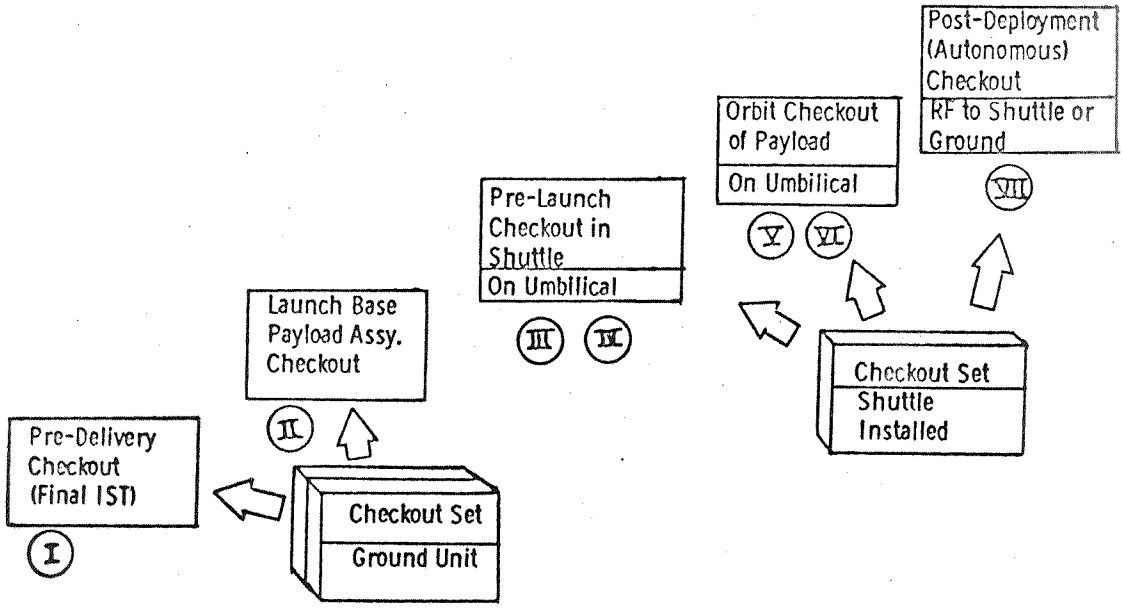



Fig. 3-22 Phased Test & Checkout Approach

Phase I is accomplished at the payload production plant and Phase II is accomplished at the launch base prior to mating of the payload into the Shuttle. Phases III through VII are conducted with payload mounted in the Shuttle and using a Shuttle-carried payload checkout set. Considerable analysis of this concept has been done and detail checkout lists have been created for the OAO, equivalent to the historical ground checkout requirements for the OAO-3 payload (reference data supplied by NASA/GSFC). It has been determined that the concept is feasible and desirable. Further, actual concept design of a Shuttle-carried checkout set has been developed and weight, volume, and cost estimates made.

An extension of the payload checkout set, standardized checkout equipment, has also been investigated and also determined to be feasible.

# Section 4
# REPAIR, REFURBISHMENT, REUSE OF PAYLOADS

The single most important cost driver in the unmanned payload cost-reduction effort is the repair, refurbishment, and reuse of payloads. A methodology was therefore developed to validate the feasibility and quantitative cost data were derived for repair/refurbishment which could be used for application to the total traffic model by Aerospace Corporation and Mathematica. A brief resume is provided following.

## 4.1 INVESTIGATION OF HARDWARE AND OPERATIONAL FACTORS

A number of factors were considered during establishment of the proposed payload repair/refurbishment approaches; they are:

- Deactivation and attitude stabilization of payload
- EVA vs remote manipulators
- Manned and unmanned Space Tug operations with the Shuttle
- Recalibration of payload after module replacement
- Ground-base response time
- Turn around time for ground refurbishment
- On-orbit re-checkout after maintenance/refurbishment
- Payload wearout/reliability vs refurbishment cycle

These were analyzed and concepts and approaches derived in each area to verify the feasibility and establish a basic technique or method of hardware implementation.

## 4.2 MODES FOR ON-ORBIT REPAIR/REFURBISHMENT

Some of the possible modes of accomplishing in-orbit repair/refurbishment are conceptually pictured in Fig. 4-1. Although the pressurized IVA (shirt sleeve) mode was initially desired by NASA in the early Shuttle design phase, it has been removed as a mandatory requirement in favor of EVA or non-pressurized IVA modes for crew direct access to payloads in combination with automated payload handling devices. An automated module replacement device could be readily substituted for the robot mode pictured; NASA/GSFC has done preliminary work on such a device for use with the Large Stellar Telescope.

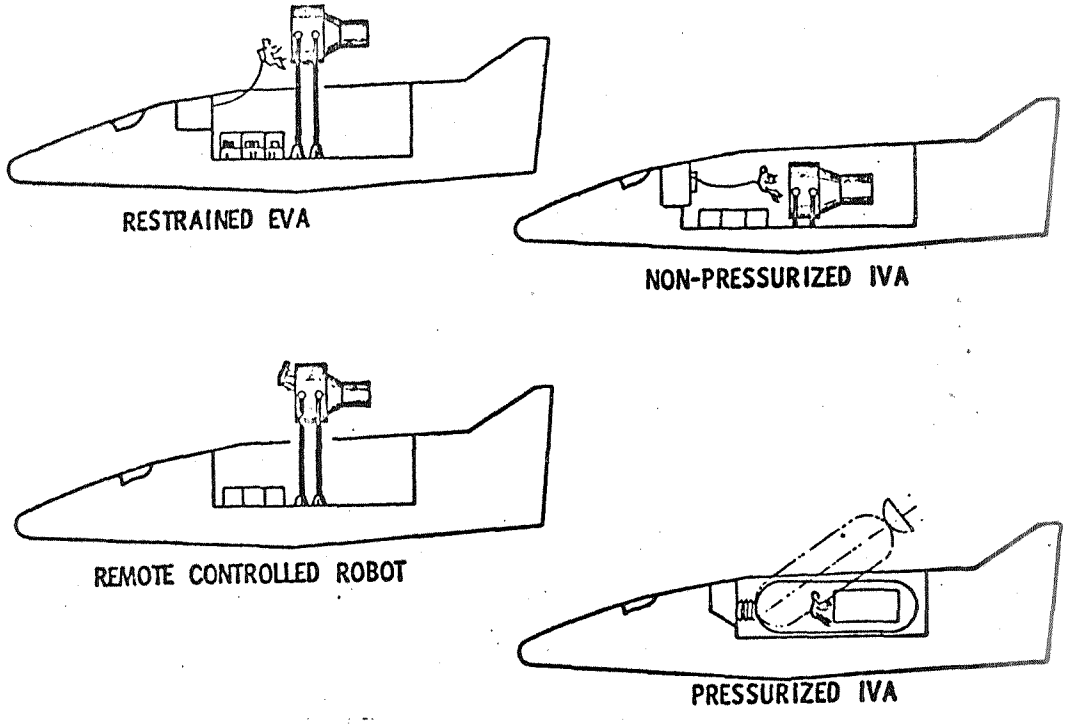



Fig. 4-1 In-Orbit Maintenance/Refurbishment Concepts

In each of the modes, the actual repair or refurbishment would consist of replacing equipment modules in the payload with replacement modules carried to orbit by the Shuttle.

## 4.3 BASIC CONCEPT FOR PAYLOAD REPAIR/REFURBISHMENT

The four elements involved in repair and refurbishment of payloads are listed following; examples used are the OAO and SEO-type payloads:

(1) Repair on Orbit

- Carry as spares on initial launch 10 different modules (total wt. 2093 lb) - OAO
  11 different modules (total wt. 1423 lb) - SEO
- Checkout of payload on orbit
- Replace any module which has failed or degraded in launch/ascent
- Return failed module for ground refurbishment

(2) Refurbishment of Payload

- Periodically replace the orbiting payload with a refurbished (at nom. 1-yr. interval for OAO; at 2-yr. intervals for SEO)
- Retrieve the "used" payload from orbit with Shuttle or Tug/Shuttle and return to earth.
- Remove used/failed modules from space frame - install new/refurbished modules
- Perform system-level payload checkout

(3) Refurbishment of Modules

- Install new (or refurbished) components into module
- Test module in spacecraft simulator, using standard checkout set

(4) Refurbishment of Components

## 4.4 COST SAVINGS WITH PAYLOAD REFURBISHMENT

### 4.4.1 Program Cost Savings

The savings attainable with the proposed refurbishment at the payload, module, and component level are extremely significant.

Figure 4-2 is a tabulation of results obtained from the OAO and SEO refurbishment analyses. At the payload system level, the refurbishment approach provides a 39 percent saving for an OAO 6-year program and a 41 percent saving for a 10-year SEO program (compared with a low-cost expendable-launched low-cost payload). When the launch and operations costs are made part of the total, the savings increase to 50 percent for both the OAO and SEO programs.

| COST ELEMENT | OAO (6-Year Program)* | | SEO (10-Year Program) | |
|---|---|---|---|---|
| | Expendable-Launched | Shuttle-Launched | Expendable-Launched | Shuttle-Launched |
| Non-Recurring | $ 89.41 M | $ 84.03 M | $ 97.99 M | $ 85.70 M |
| Unit Cost - Delivered Payloads | 114.84 | 15.81 | 234.56 | 49.15 |
| Average Refurb. Ratio | - | .325/1 yr. | - | .390/2 yrs. |
| Payload Module/Component Refurb | - | 25.29 | - | 60.88 |
| Payload Totals | (204.25) | [125.13] | (332.55) | [195.73] |
| Launch Costs | 108.00 | 18.00 | 318.00 | 102.00 |
| Operations Cost | 40.02 | 31.05 | 67.80 | 59.75 |
| Total Program Cost | $ (352.27) M | $ [174.18] M | $ (718.35) M | $ [357.48] M |
| Program Savings ⟶ | $ 178.1 M | | $ 360.9 M | |

* Refurbishment performed at 1-yr. cycle intervals
** Refurbishment performed at 2-yr. cycle intervals

Fig. 4-2 Savings with Payload Refurbishment

## 4.4.2 Refurbishment Cost Ratios

Summary calculations were made of the cost of a refurbished OAO or SEO. The "average" refurbished OAO would cost 32.5 percent of the unit recurring cost of a new OAO, with refurbishment performed on a one-year time cycle. The average refurbished SEO would cost 39 percent of a new SEO, with refurbishment performed on a two-year time cycle. These ratios were supplied to Aerospace Corp. for application across the various missions included in the traffic model.

## 4.5 ANALYSIS OF MODULE & COMPONENT REFURBISHMENT

A hardware analysis was made of the various subsystem equipment of the low-cost OAO and SEO payloads to determine the degree to which replacement parts and components could be readily installed during a refurbishment. Cost estimates were made of replacement parts, assembly/disassembly, and QA/testing required to sustain the refurbishment operation. Figure 4-3 is a sample summary sheet of the cost estimating effort. It shows the derivation of module refurbishment costs as compared to the costs of new replacement modules.

| | Repl. Parts | Eng. Sup. 5% | Comp Disassy Assy | Module Disassy Assy | Comp. QA & Test | Module QA & Test (80%) | Total Refurb Cost | % of New Cost |
|---|---|---|---|---|---|---|---|---|
| Electrical - Battery No. 1 | .047 | .006 | .001 | .002 | .001 | .060 | .117 | 63 |
| Power Cont. No.2 | .124 | .012 | .011 | .006 | .011 | .100 | .264 | 66 |
| (ea) Paddle Dr. No.3,4 | .012 | .006 | .001 | .003 | .001 | .032 | .055 | 46 |
| (ea) Solar Paddle No5,6 | - | - | - | - | - | - | - | 100 |
| CDPI - Data Handling, (ea) No. 1, 2 | .280 | .014 | .012 | .003 | .008 | .056 | .373 | 56 |
| Commun. No.3 | .336 | .012 | .006 | .002 | .007 | .080 | .443 | 50 |
| S&C - Flight Cont. No.1 | .453 | .025 | .009 | .006 | .015 | .108 | .616 | 55 |
| Momentum No. 2 | .129 | .020 | .010 | .006 | .005 | .072 | .242 | 48 |
| Attitude Control (ea) No. 1,2,3,4 | .007 | .003 | .010 | .003 | .005 | .032 | .060 | 43 |
| Exper. - Photo No. 1 | .124 | .080 | .016 | .016 | .013 | .252 | .501 | 39 |
| TV Camera No.2 | - | - | - | - | - | - | - | 100 |

Fig. 4-3 Cost of Module/Component Refurbishment - SEO

## 4.6 IMPLEMENTATION OF REFURBISHMENT CONCEPT

The refurbishment concept and the special-designed payload hardware will require well-planned supporting elements. Principal areas are:

- Field Repair Depot - Establish one or more facilities to provide repair and refurbishment support for payloads. Could be located at the Shuttle launch site.

- Replacement Parts (Spares) - All replacement parts, components and modules are to be procured concurrently with the deliverable payloads. Quantities to be based upon logistic analyses of anticipated repair and refurbishment.

- Refurbishment Technique - All payload hardware will be designed to allow simplified hardware replacement and re-test. A Refurbishment Instruction Manual will be delivered by contractor concurrent with payload initial delivery.

- Personnel - NASA technicians trained in payload subsystem specialty areas to perform the refurbishment.

- Final Checkout of Modules - The refurbished modules will be verified functionally and mechanically using a payload checkout set and a payload simulator (duplicate of ground support equipment supplied to launch base for payload checkout.

# Section 5
# STANDARD SPACECRAFT AND SUBSYSTEMS

Standardization of space hardware was investigated during Task 3 of the study to: (1) ascertain its technical feasibility and, (2) evaluate its economic desirability. A lowered emphasis on weight and volume constraints, avoiding the need for program peculiar optimized designs, makes standardization more attractive than previously.

## 5.1 FEASIBILITY OF A STANDARD SPACECRAFT

### 5.1.1 Mission Model Analysis

In analysis of the NASA Mission Model, a large percentage (86 percent) of payload programs were potentially suitable for some combination of experiments onto one or more spacecraft. Further analysis revealed that unmanned missions also could be grouped by orbit and general scientific objective. Two examples of this are shown in Fig. 5-1 for low-altitude/28.5 deg orbits and for polar/sun-synchronous orbits.

LOW ALTITUDE - 28.5°

| Mission | Alt. (N.M.) | Exper. Weight (lb) | Qty. S/C | Exper. Power | Point. Accur. | Start Year | Program Duration |
|---|---|---|---|---|---|---|---|
| Large Stellar Telescope | 350 | 8270 | 1 | 1.5 KW | 10 sec | 1980 | 11 yr. |
| Large Stellar Observatory | 350 | 7520 | 1 | 1.0 KW | 1 deg | 1982 | 9 yr. |
| HEAO | 230 | 12500 | 2 | 265 W | 5 sec | 1979 | 12 yr. |
| Large Radio Observatory | 350 | 10000 | 1 | 2.0 KW | 10 sec | 1984 | 7 yr. |
| Astronomy Explorers | 270 | 250 | 15 | 50 W | 3 deg | 1978 | 13 yr. |

POLAR - SUN SYNCHRONOUS

| Mission | Alt. (N.M.) | Exper. Weight(lb) | Qty. S/C | Exper. Power | Point. Accur. | Start Year | Program Duration |
|---|---|---|---|---|---|---|---|
| Polar EOS | 500 | 870 | 12 | 400 W | 4 min | 1980 | 13 yr. |
| Earth Physics | 400 | 150 | 7 | 150 W | 10 sec | 1980 | 13 yr. |
| Polar ERS | 500 | 850 | 28 | 400 W | 4 min | 1978 | 13 yr. |
| TIROS | 700 | 245 | 14 | 100 W | 3 deg | 1978 | 13 yr. |

Fig. 5-1 Common Low-Earth Orbits and Spacecraft Requirements

### 5.1.2 Preliminary Version of Standard Spacecraft

A preliminary analysis of the spacecraft support for the various candidate missions revealed that a single spacecraft with quite broad subsystem capability could accommodate the majority of all missions. The characteristics of this hypothetical standard spacecraft are listed in Fig. 5-2. Combining these preliminary conclusions with data from previous LMSC effort on design and manufacture of standard spacecraft elements, it was determined that the standard spacecraft was indeed technically feasible.

**STANDARD SPACECRAFT WITH SUBSYSTEM CAPABILITY TO MEET FOLLOWING REQUIREMENTS WILL ACCOMMODATE THE MAJORITY OF ALL MISSIONS:**

| | |
|---|---|
| GNC | Earth or Inertial orientation<br>1/4° attitude reference with option for 10 arc sec<br>Stabilization by reaction wheels and/or mass expulsion |
| TT&C | Wide-band data link with up to 1 megabit capability<br>Choice of transmission powers up to 50 watts<br>Data recording capability up to 1 MHz |
| Electrical | Modular capability from 350 to 1050 watts average power,<br>± 28 VDC regulated or unregulated, 115 VAC,<br>1, 2 or 3-Phase |
| Environmental Control | Provided for standard spacecraft exclusive of experiment subsystem, for earth orbit or equivalent |

Fig. 5-2 Standard Spacecraft for Unmanned Missions

### 5.1.3 Basic Approach to Design of Standard Spacecraft Hardware

Basic conclusions, involving preliminary economic considerations, and relevant to the approach to standard spacecraft were also developed.

- Rather than a single all-coverage spacecraft to accommodate all missions, there may be a small group of standard spacecraft.
- Even though a standard spacecraft were developed, there may be certain space missions which can be more economically supported by specialized designs.
- The real foundation for a standard spacecraft appears to be the development of standard subsystems and/or modules thereof.

## 5.2 STANDARD SUBSYSTEMS

The basic concept of standard subsystems was developed by (1) listing separately all of the mission requirements by spacecraft subsystem and (2) consolidating these requirements into a minimum quantity of variants to cover the missions. The subsystem characteristics for these variants, some of which can be built up by using multiples of a single module (such as for the electrical subsystem), are shown on Fig. 5-3. These variants were applied to the NASA Mission Model and the total number of applications determined by quantity of missions and quantity of spacecraft required per mission. A sample sheet of this application analysis is shown as Fig. 5-4. These data were transferred to the economic analysis totals for standard subsystems.

| SUB-SYSTEM TYPE | ELECTRICAL (BATTERY & SOLAR ARRAY) | GUIDANCE, NAVIG., STABILIZATION, CONTROL | TELEMETRY (S/C DATA & COMMAND) | COMMUNICATION-(EXPERIMENT DATA) S-BAND* |
|---|---|---|---|---|
| A | • 350 W<br>• Sun-Orient. Solar Array | • Stellar/Solar Ref.<br>• 10 arc sec<br>• Inertial Platform | • 8 - 33 BPS<br>• 50 W XMTR (TP)<br>• Omni Ant. | • $10^3$ - $10^4$ BPS<br>• 50W XMTR (TP)<br>• 10-30 Hi-Gain Tracking Antenna |
| B | • 700 W<br>• Sun. Or. S/A | • Stellar/Solar Ref.<br>• 15 arc min.<br>• Inertial Platform | • $10^4$ BPS<br>• 2 W XMTR (SEO)<br>• Omni Antenna | • 2x $10^6$ BPS<br>• 2 W XMTR (SEO)<br>• 3 Ft. Fixed Hi-Gain Antenna |
| C | • 1050 W<br>• Sun. Or. S/A | • Earth Reference<br>• 15 arc min<br>• Inertial Platform | • $10^5$ BPS<br>• 2W XMTR (LEO)<br>• Omni Antenna | • $10^7$ BPS<br>• 2 W XMTR (SEO)<br>• 6 ft. Hi-Gain Tracking Antenna |
| D | • 100 W<br>• Body-Mounted Spinning Array | • Spin Stabilized<br>• Axis Orientation Control | | • 2 x $10^7$ BPS (LEO)<br>• 2W XMTR (Spin)<br>• Toroidal Antenna |
| E | | • Earth Ref. & Star Tracker<br>• 4 arc min<br>• Inertial Platform | | • $10^6$ BPS<br>• 2 W XMTR (LEO)<br>• Omni Antenna |

* 30 ft. dia. ground receiver antenna, except for interplanetary which uses 210 ft antenna.

Fig. 5-3 Standard Subsystem Types and Characteristics

| MISSION NAME | NO. | ORBIT ALTITUDE | ORBIT INCL. | NO. OF SPACE-CRAFT | STANDARD SUBSYSTEM TYPE/QTY GNSC | COMM | T/M | ELECT | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | NASA EARTH OBSERVATION | | | | | | |
| Polar EOS | 21 | 500/500 | SS | 12 | E 12 | E 12 | C 12 | B 12 | |
| Sync EOS | 22 | Sync | 0° | 6 | E 6 | C 6 | B 6 | B 6 | |
| Earth Physics | 23 | 400/400 | 90° | 7 | E 7 | C 7 | C 7 | A 7 | |
| Sync Met | 24 | Sync | 0° | 2 | C 2 | C 2 | B 2 | A 2 | |
| Tiros | 25 | 700/700 | SS | 3 | C 3 | B 3 | C 3 | A 3 | |
| Polar ERS | 26 | 500/500 | SS | 6 | E 6 | E 6 | C 6 | B 6 | |
| Sync ERS | 27 | Sync | 0° | 7 | E 7 | C 7 | B 7 | B 7 | |
| | | | NASA COMMUNICATION/NAVIGATION | | | | | | |
| ATS | 28 | Sync | 0° | 7 | E 7 | C 7 | B 7 | -- | 8 kw |
| Small ATS Sync | 29 | Sync | 0° | 12 | C 12 | C 12 | B 12 | B 12 | |
| Low | 30 | 3000/300 | 90° | 12 | C 12 | E 12 | C 12 | B 12 | |
| Co-Op ATS Sync | 31 | Sync | 0° | 2 | C 2 | C 2 | B 2 | B 2 | |
| Low | 32 | 3000/300 | 90° | 2 | C 2 | E 2 | C 2 | B 2 | |
| Medical Net | 33 | Sync | 0° | 2 | C 2 | Comm. part of P/L | B 2 | C 2 | |
| Educ. Broadcast | 34 | Sync | 0° | 2 | C 2 | | B 2 | -- | 2 kw |
| Follow-on Sys.Demo. | 35 | Sync | 0° | 20 | C 20 | | B 20 | C 20 | |
| Tracking/Data Relay | 36 | Sync | 0° | 10 | C 10 | C 10 | B 10 | B 10 | |
| Planetary Relay | 37 | Sync | 0° | 9 | C 9 | C 9 | B 9 | A 9 | |

Fig. 5-4 Applicability of Standard Subsystem Options to Missions (Sample)

## 5.3 STANDARD SPACECRAFT DESIGN

A typical set of subsystem variants were selected which could accommodate a reasonably large quantity of missions. Subsystem modules were concepted and developed into a set of "standard" modules; one of these is shown in Fig. 5-5. These modules were then arranged into an overall spacecraft configuration which is illustrated on Fig. 5-6. Each module, as with the previously-described low-cost payloads, is readily replaceable in orbit by a Shuttle crew member or by automated module handling devices. The standard spacecraft design effort was accomplished to the depth required to verify that the concepts were feasible and could be implemented in an actual hardware program. The eventual standard spacecraft may be different in actual configuration from the typical one developed; however, the basic characteristics to provide compatibility with the Shuttle system and to allow on-orbit checkout, repair, refurbishment, and equipment and experiment update must be maintained.

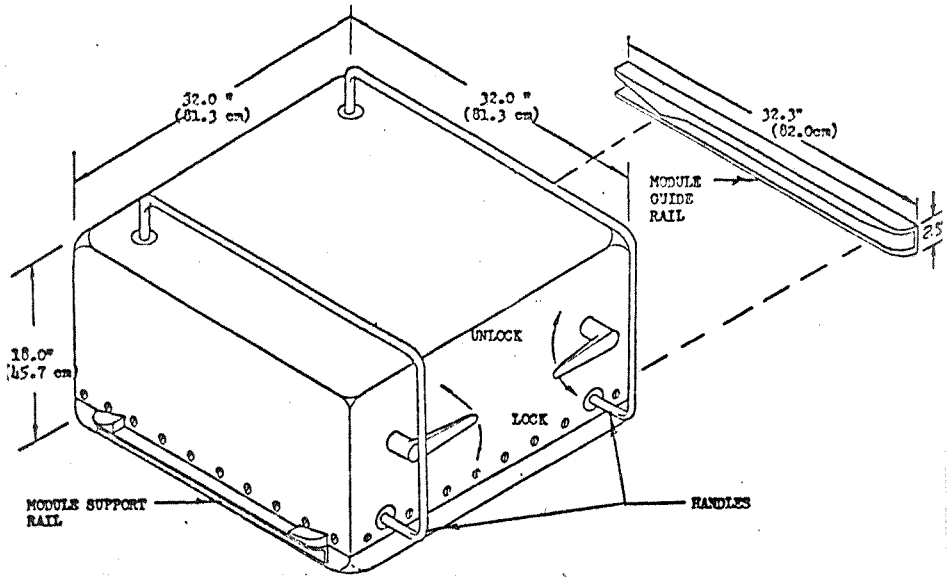



Fig. 5-5 Typical Standard Spacecraft Module

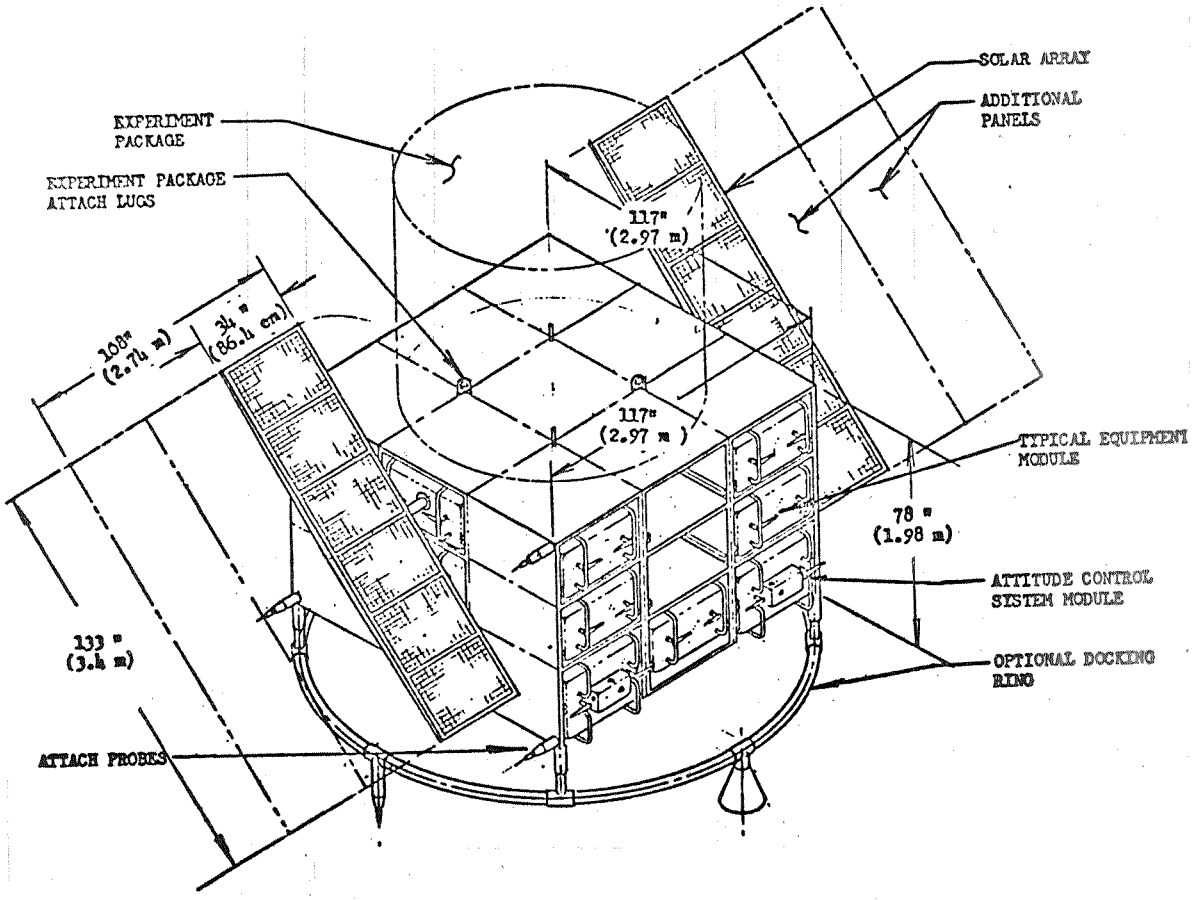



Fig. 5-6 Standard Spacecraft General Configuration

## 5.4 POTENTIAL SAVINGS WITH STANDARD SPACECRAFT HARDWARE

Two economic analyses were performed: (1) determination of the savings accruing from the use of standard subsystems applied throughout the NASA Mission Model, and (2) determination of overall savings resulting from the use of a typical standard spacecraft (itself comprising standard subsystem elements) for a majority of the missions in the Mission Model. The primary cost saving of course is in the sharing of hardware development costs by a number of payload programs rather than having a separate project-peculiar development for each program.

### 5.4.1 Standard Subsystem Cost Savings

The results of a typical sub-analysis on a standard electrical power subsystem applied to varying quantities of programs and spacecraft are tabulated on Fig. 5-7. Modular-design subsystems were used as the cost base. A 300-watt capacity subsystem could be applied to 17 payload programs comprising 52 spacecraft and result in a saving of $60.2 million. Increasing the subsystem capacity to 600 watts would "capture" 30 missions and 165 spacecraft and provide savings of $133 million. Using an approach where a modular subsystem could provide 300, 600, or 1200 watt capacity (modules selected as needed to fit the particular program requirement); the savings could be further increased to $231 million, covering 45 programs and 264 spacecraft.

| SUBSYSTEM TYPE | MODULE CAPACITY (WATTS) | TRAFFIC CAPTURED | | POTENTIAL SAVINGS ($M) |
|---|---|---|---|---|
| | | NO. OF PROGRAMS | NO. OF SPACECRAFT | |
| SINGLE MODULE | 300 | 17 | 52 | 60.6 |
| | 600 | 30 | 165 | 133.0 |
| MULTI-MODULE | 600/1200 | 40 | 218 | 210.4 |
| | 300/600/1200 | 45 | 264 | 231.4 |

Fig. 5-7 Savings Potential - Standard Electrical Subsystem

The economic impact in RDT&E of applying standard subsystems to 53 missions of the Mission Model is shown in Fig. 5-8. Additional savings of $2262 million are indicated, as compared to the development of low-cost subsystems specially designed and developed for each of the 53 missions. This saving could be reduced somewhat by the higher average unit cost of the standard subsystems (because of capability "overkill" when compared to the project-peculiar subsystem.

| | | | RDT&E ($ Million) | | |
|---|---|---|---|---|---|
| Subsystem | Option | Qty. Programs | Program Peculiar | | Std. Total |
| | | | Per Program | Cumulative Total | |
| CDPI | A | 13 | $ 38.0 | $ 494 | - |
| | B | 4 | 18.0 | 72 | - |
| | C | 12 | 18.0 | 216 | - |
| | D | 3 | 5.5 | 17 | - |
| | E | 12 | 15.5 | 186 | - |
| | COMSAT | 8 | 6.5 | 52 | - |
| | Total | 52 | - | $ 1037 | $ 58 |
| GNSC | A | 9 | 27.0 | $ 243 | - |
| | B | 13 | 9.5 | 124 | - |
| | C | 8 | 9.5 | 171 | - |
| | D | 5 | 1.3 | 7 | - |
| | E | 8 | 27.0 | 216 | - |
| | Total | 53 | - | $ 761 | $ 32 |
| EPS | A | 16 | 10.6 | $ 169 | - |
| | B | 14 | 14.4 | 202 | - |
| | C | 6 | 17.4 | 104 | - |
| | D | 4 | 6.7 | 27 | - |
| | Total | 40 | - | $ 502 | $ 24 |
| ACS | A | 17 | 1.0 | $ 17 | - |
| | B | 31 | 2.0 | 62 | - |
| | Total | 48 | - | $ 79 | $ 3 |
| | | | GROSS TOTALS | $ 2379 | $ 117 |

Fig. 5-8 Economic Impact of Application of Standard Subsystems

In Fig. 5-9, there is shown the economic results of applying a single standard spacecraft to selected missions of the Mission Model. The cost savings accrue because a single-spacecraft development is substituted for the development of a large quantity of special spacecraft. The savings of $355 million on the 15-mission application indicates a better choice than the $161 million savings on the 23-mission application. The difference occurs as a result of minus-savings in unit cost accruing from higher "overkill" on the program-peculiar requirements. Follow-on analysis is required in this area to optimize the economic benefits by tailoring the standard subsystems.

| Mission Coverage | Subsystem | Sub-System Option | RDT&E ($ Million) | | Unit ($ Million) | | Standard Spacecraft Savings ($ Million) |
|---|---|---|---|---|---|---|---|
| | | | Program-Peculiar | Standard Spacecraft | Program-Peculiar | Standard Spacecraft | |
| 15 Missions 151 Spacecraft | CDPI | C | 211.5 | 18.0 | 307.4 | 422.8 | |
| | GNSC | C | 76 | 9.5 | 280.9 | 280.8 | |
| | EPS | C | 212.8 | 17.4 | 282.7 | 350.3 | |
| | ACS | B | 29 | 2 | 39.1 | 39.3 | |
| | Struct. | - | 61 | 5.3 | 65.1 | 90.6 | |
| | ECS | - | 22.0 | 1.8 | 25.1 | 30.2 | |
| | Totals | | 612.3 | 54.0 | 1000.3 | 1214.0 | 344.6 |
| 23 Missions 219 Spacecraft | CDPI | C | 327.50 | 18.0 | 479.0 | 613.2 | |
| | GNSC | E | 157 | 27 | 598.5 | 1022.7 | |
| | EPS | C | 309.8 | 17.4 | 416.1 | 508.1 | |
| | ACS | B | 39 | 2 | 56.4 | 56.9 | |
| | Struct. | - | 102.4 | 7.3 | 113.1 | 175.2 | |
| | ECS | - | 35.8 | 3.0 | 43.0 | 65.7 | |
| | Totals | | 971.5 | 74.7 | 1706.1 | 2441.9 | 161.0 |

Fig. 5-9 Economic Impact of Application of Typical Standard Spacecraft

### 5.4.3 Overall Impact of Payload Hardware Standardization

Preliminary LMSC economic analyses indicate a rather dramatic effect resulting from application of standard subsystems to the majority of payloads in the 1978-1990 traffic model. These savings are additive to those accruing from application of low-cost payloads; the RDT&E and Unit costs of the low-cost payloads were used as a base for extrapolation of the standardization savings. Figure 5-10 illustrates graphically that the peak annual funding level for the national space program can be lowered by about $1 Billion during the critical Shuttle development period.

With proper pre-planning and technical coordination, the standard subsystems could be refurbished after use on one program and reused on a later program. This would afford even greater savings (in the unit recurring cost area).

In summary, the economic benefits with use of standard spacecraft and/or standard subsystems are quite large and there is no question of the technical feasibility.

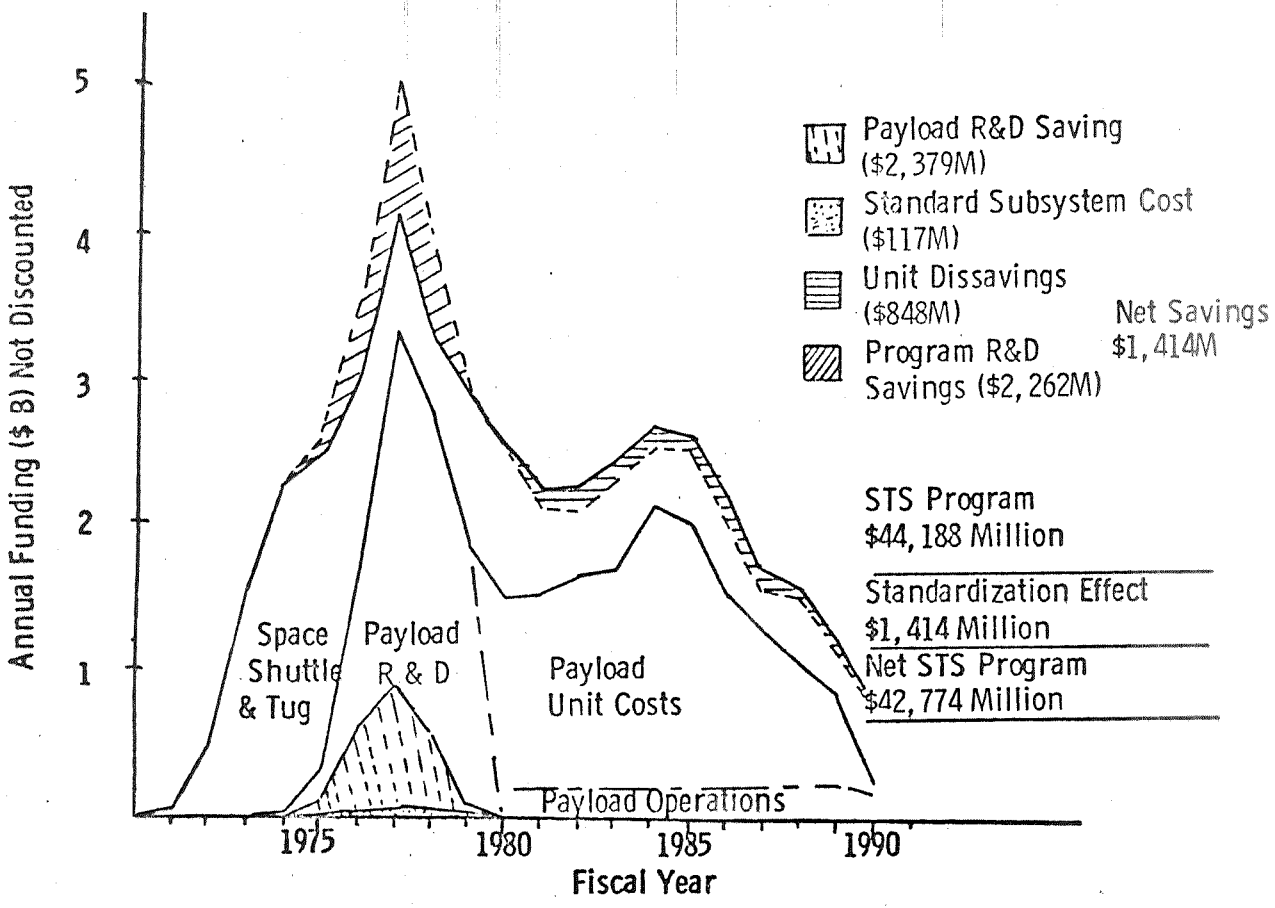



Fig. 5-10 Standardization Impact on Total Space Program Funding

# Section 6
# DESIGN GUIDELINES FOR FUTURE PAYLOAD DESIGN

Task 4 of the study was devoted to preparation of a Design Handbook for payload designers. The data developed will be issued as a separate contract end-item document, LMSC-A990558. A brief summary of data in the Handbook, which provides guidelines for design of low-cost payloads to be used with the Shuttle system, is provided here.

## 6.1 SYSTEM ENGINEERING APPROACHES

Many of the basic requirements which frequently force the designer into a high-cost design are originated at the system engineering level. The following are principles which should be employed by the system engineer:

- Specify minimum-mandatory design and performance requirements
- Specify only mandatory minimum requirements for purchased equipment
- Specific minimum development and qualification testing consistent with hardware reliability requirements
- Tradeoff payload reliability vs on-orbit repair/refurbishment cycles to obtain cost-optimized hardware requirements
- Tradeoff experiment vs spacecraft requirements and establish interface which will allow payload cost optimization
- Tradeoff payload vs ground support equipment and space operations to establish program cost-optimized requirements

## 6.2 GENERAL PAYLOAD DESIGN GUIDELINES

A large variety of "do" and "don't" recommendations are included in the Handbook. Specific examples resulting from the detailed design data on the low-cost payloads are included and explanation is offered as to the cost-effect of selecting comparative design approaches. These guidelines include, among others:

- Design to satisfy mission life and functional requirements - do not overdesign unless there is a cost benefit
- Use qualified off-shelf components where possible
- Apply parts/components for low-stress level operation to obtain added assurance and reduce wearout
- Provide minimum-density installation of equipment to allow easy assembly/removal
- Modularize equipment to allow bench assembly and testing, minimum installation and spacecraft testing, and module replacement
- Provide minimum-density packaging of parts within components and extra volume for growth or modification
- Design for minimum functional complexity
- Design to obtain maximum cost benefit from use of on-orbit checkout and repair/refurbishment

# Section 7
# RESULTS, CONCLUSIONS AND RECOMMENDATIONS

## 7.1 APPLICATION OF LOW-COST PAYLOAD DESIGN

It has been determined by actual preliminary design, preparation of program plans, and costing that payload program savings in the vicinity of 25 percent to 30 percent of the historical baseline can be obtained by implementation of low-cost design techniques.

## 7.2 IMPACT OF PAYLOAD REFURBISHMENT

By using the Shuttle to perform revisit and support refurbishment and reuse of low-cost payloads, total mission savings on the order of 50 percent can be realized (compared with low-cost expendable payloads launched by low-cost expendable launch vehicles). Summary figures illustrating this saving are shown on Fig. 7-1 for SEO-type and OAO-type missions.

| | 10-Year SEO Program | | 6-Year OAO Program | |
|---|---|---|---|---|
| | Low-Cost Expendable Supported | Shuttle/ Tug Supported | Low-Cost Expendable Supported | Shuttle/ Tug Supported |
| Payload Systems Cost | $ 400M | $ 255M | $ 244M | $ 156M |
| Launch/Revisit Cost | 318 | 102 | 108 | 18 |
| Total | $ 718M | $ 357M | $ 352M | $ 174M |
| Savings | $ 361M (50%) | | $ 178M (50% | |

Fig. 7-1 Savings with Refurbishment on Low-Cost Payloads

## 7.3 COST EFFECTS OF NASA POLICY

At the request of NASA/HQ, a brief survey was made of NASA operational policies as they might affect implementation of low-cost payloads. The items listed on Fig. 7-2 were provided.. The cost of these policy changes has not been quantified; rather, they were intended only as a broad-spectrum "beginning" list. It is assumed that NASA will implement whatever follow-on analysis they determine to be appropriate.

| POLICY CHANGE | REASON AND/OR EFFECT |
|---|---|
| • Reduce degree of configuration management (hardware traceability) | • Failures can be determined by actual inspection of retrieved hardware |
| • Utilize standard subsystems and checkout equipment (in lieu of project peculiar) | • Large savings in RDT&E costs. Allows reduction also in training and operations costs. |
| • Reduce amount of contract documentation | • Changes possible in NASA procurement documents. |
| • Reduce reliability and QA requirements and reduce acceptance tests<br>• Use lower-grade (perhaps aircraft quality) hardware | • Ability for in-orbit checkout and repair allows higher risk on payload hardware |
| • Shorten program time (spacecraft and experiments) | • Flight-testing hardware on Shuttle sortie missions (flying lab) allows shortening of devel/qual. test. |
| • Increased autonomy of payload/Shuttle flight operations | • Allows reduction of ground support facilities and personnel. |
| • Standardize missions and consolidate experiment objectives (orbit inclination, altitudes, etc.) | • Allows reduction in variety of spacecraft and multi-payload launch and revisit for Shuttle. |

Fig. 7-2 NASA Policy Issues Affecting Program Costs (for Shuttle-Launched Payloads)

## 7.4 STUDY CONCLUSIONS

The following basic conclusions have been derived from the study:

- The Payload Effects Study has confirmed that significant cost benefits accrue from new payloads designed to low-cost criteria:
  - Reduced weight/volume constraints
  - Modularization and repair/refurbishment/reuse
  - Relaxed reliability requirements with higher risk (Shuttle only)
- Additional significant savings, primarily in RDT&E, are possible with standardization of payload subsystems and/or with use of standard spacecraft
- The savings developed in this study for low-cost payloads are conservative; as Shuttle flight experience is gained, additional cost savings are forecast.
- Some of the payload savings can be implemented prior to the Shuttle era on current expendables
- With planned NASA budget limits, it is important to continue vigorous pursuit of payload cost reduction in order to provide the $ savings which will make the Shuttle itself a reality.

## 7.5 RECOMMENDATIONS

Although the cost savings represented by the low-cost payload designs, and refurbishment thereof, are quite significant, there are further important cost-reductions attainable in the national space program. The areas recommended for further action are tabulated in Fig. 7-3.

| RECOMMENDED APPROACH | COST REDUCTION EFFECTS |
|---|---|
| • Standardize unmanned payload subsystems<br>• Standardize experiment interfaces<br>• Utilize minimum quantity of multi-mission standard spacecraft<br>• Standardize unmanned payload checkout equipment - for ground and in-orbit usage | • Large savings in RDT&E<br>• Allows standard refurbishment depots and lower refurbishment costs<br>• Allows reduced-cost training of field crews in standard approaches to payload hardware repair, refurbishment, checkout<br>• Allows simplification of Shuttle interfaces with payloads and standardization of cargo crew operations procedures<br>• Allows simplification of ground support facilities and uniformity of support personnel across many projects |
| • Apply low-cost design approaches to other payloads: Space Tug, manned payloads, lunar mission hardware, etc. | • Dollars saved on unmanned payloads can be applied to enlarging the total space exploration capability (e.g., inclusion of lunar programs). Further similar savings can be obtained from other space payloads. |
| • Apply new technology only after thorough cost-effectiveness tradeoff assumes lower program costs | • Reduced risk (and cost) in new programs schedules and assurance that cost-optimized hardware is adopted |
| • Implement analyses to cost-optimize the combined effects of payload subsystem reliability and operating life vs launch ascent effects vs orbit repair and refurbishment | • Provides minimum-cost payload<br>• Provides guide for detail provisioning of spare modules, components, and parts for each payload (procured with payload)<br>• Establishes base for payload field repair/refurbishment depot implementation |
| • Conduct more detailed analyses of repair and refurbishment of typical unmanned payloads and extend to other types of payloads | • Refurbishment of payloads is the single largest cost-driver and any further reduction in refurb-to-new cost ratio can be multiplied by large quantities of payloads in the overall Mission Model. |

Fig. 7-3 Additional Considerations for Cost Reduction