STS 86-0302-3

ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM (OSCRS)

FINAL REPORT

Volume III

PROGRAM COST ESTIMATE

(DRD-10)

Prepared for
the
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center

CONTRACT NO. NAS9-17584
CDRL DATA ITEM MA-1023T

October 1986

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OSCRS Program Manager

Rockwell International
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This report was prepared by:

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under the supervision of R. Bemis and with the assistance of the OSCRS Engineering team and Space Transportation System Division Technical Staff.

FOREWORD

This final report of the Orbital Spacecraft Consumables Resupply System (OSCRS) study was prepared by the Space Transportation Systems Division of Rockwell International for the National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas, in compliance with the requirements of Contract NAS9-17584, CDRL No. MA 1023T.

In response with the CDRL instructions, this report is submitted in three separately bound volumes:

Vol. 1. Executive Summary

Vol. 2. Study Results

Vol. 3 Program Cost Estimate

Further information concerning the contents of this report may be obtained from R. Bemis, Study Program Manager, telephone (213) 922-3805, Downey, California.

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1.0 Introduction

This cost analysis is for the design, development, qualification and production of the monopropellant and bipropellant Orbital Spacecraft Consumable Resupply System (OSCRS) tankers, their associated avionics located in the Orbiter payload bay, and the unique GSE and ASE required to support operations. Monopropellant resupply for the Gamma Ray Observatory (GRO) in calendar year 1991 is the first defined resupply mission with bipropellant resupply missions expected in the early to mid 1990's. The monopropellant program estimate also includes contractor costs associated with operations support through the first GRO resupply mission.

2.0 Cost Approach and Methodology

The monopropellant cost estimate was made using cost estimating relationships based on subsystem weights, degree of new technology or hardware, similarity to past program subsystem and classification of manned versus unmanned type of subsystems. The bipropellant cost estimate was made by engineering, based on relationships to the monopropellant tanker program.

2.1 Monopropellant Program Plan

The cost estimate is based on the program plan of STS-86-0271 for a monopropellant OSCRS. The plan has a contract go-ahead in October 1987 and a 41 month development and production plan in accordance with that depicted in Figure 2-1. This plan proposes a strong-back test article to perform functional verification of fluid, mechanical, and avionics subsystems. Thermal verification and structural loads will be certified at system level using the flight article in an integrated system test program.

2.2 Bipropellant Program Plan

The cost estimate is based on the program plan of STS-86-0300 for a bipropellant OSCRS. It assumes a contract go-ahead in October 1988 and a 41 month development and production plan in accordance with that depicted in Figure 2-2. The program assumes that the bipropellant tanker program is being performed in parallel with the monopropellant tanker program which was initiated one year earlier. Therefore, any commonalities would have been developed in the monopropellant tanker program. This plan requires that two articles will be built. The first will be a dedicated qualification article. The second is the flight article.

2.3 Design Philosophy

The cost estimate herein is based on a hybrid tanker concept which is sized for growth up to 7000 lbs. of propellant mass, either monopropellant or bipropellant, but which is developed and fabricated only to the subsystem level required to satisfy the GRO resupply. The structure is machined open grid aluminum alloy capable of holding six GRO size propellant tanks, and contains sufficient space for future (unspecified) quantities of pressurant gases and other fluids as well as space for the control avionics to support those unspecified mission requirements. The monopropellant tanker design, development, and fabrication will be of a configuration which requires the incorporation of only two GRO tanks, no pressurant resupply gases, and the associated avionics and thermal control system (Figure 2-3). The bipropellant tanker design, development, and fabrication will be of a configuration which includes 6 propellant tanks (3-oxidizer, 3-fuel), a pressurant resupply subsystem module, an ullage return module and the associated avionics and thermal subsystem (Figure 2-4).

FIGURE 2-1

O S C R S – MONOPROPELLANT TANKER
PHASE C/D PROGRAM SCHEDULE

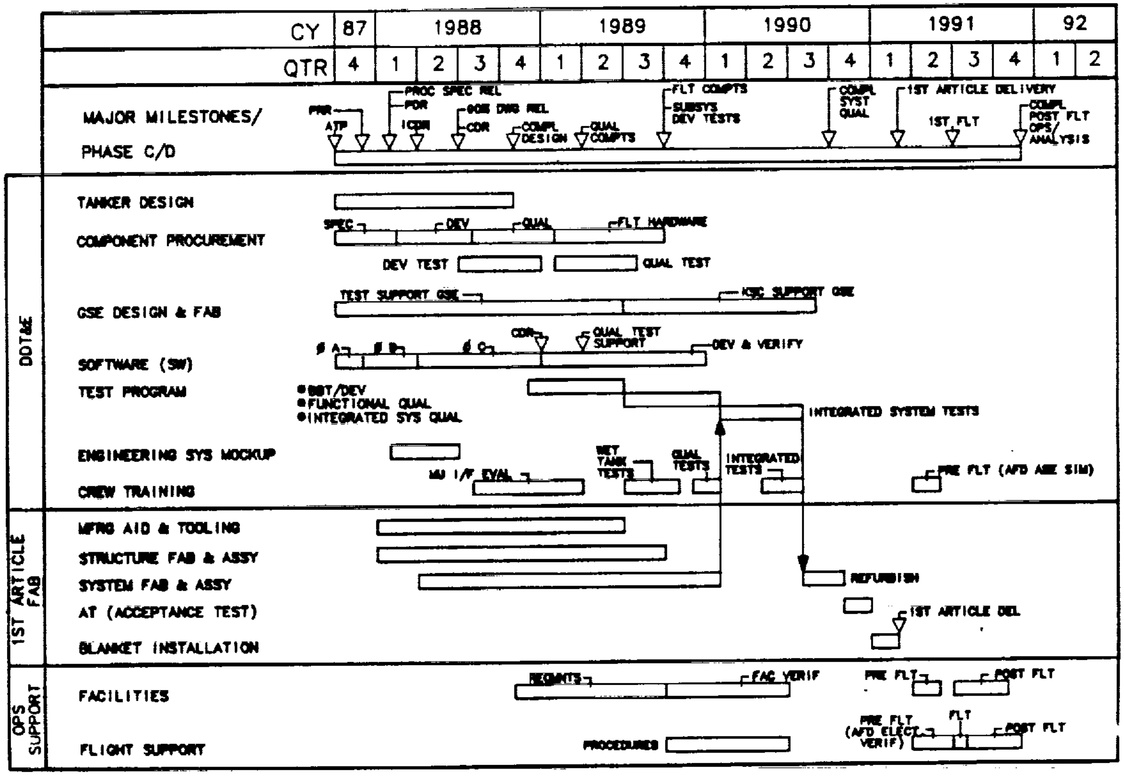
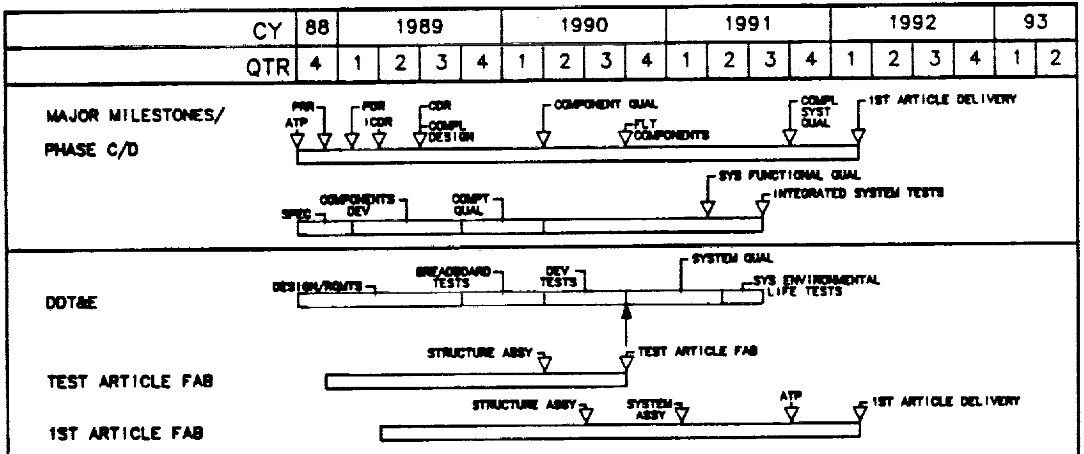


FIGURE 2-2

O S C R S – BI-PROPELLANT TANKER
PHASE C/D PROGRAM SCHEDULE



- 41 MONTH DELIVERY OF FIRST FLIGHT ARTICLE
- DEDICATED QUALIFICATION TEST ARTICLE CERTIFIES TANKER LIFE

SMK52APC

The design uses to the maximum extent possible hardware which has been qualified for Space Shuttle or other space or aero applications in that order of preference. Often the degree of qualification and production availability takes precedence over optimistic vendor low weight and costs estimates due to the uncertainties in new development, production and qualification might have on overall program cost. This is particularly true since this contract is for a single deliverable monopropellant tanker. The basic approach recommended is to design with growth in mind but to develop the first article for its intended application (GRO) only. This adds essentially no cost to the initial deliverable tanker but immensely reduces future potential costs for the expanded OSCRS mission requirements.

A single (for monopropellant, growth, and bipropellant tankers) but very versatile structure concept (machined open grid) was selected over an apparently lighter but more complex composite tubular structure. The latter structure is less flexible in terms of growth potential, and has little if any weight advantage when looked at as a total system due to its more complex component mounting characteristics.

Many off-the-shelf avionic and fluid system components are used in lieu of new designs which vendors claim cost and weigh less. This approach is taken because historically new component development and qualification have significantly increased both cost and weight of the final products. Costs can be inflated many times over original estimates while schedules are put in jeopardy. This approach seems to be appropriate since the contract is for a single tanker only. New technology can be taken advantage of with the growth of the tanker beyond the GRO resupply requirements.

2.4 Testing Philosophy

The basic test philosophy is to certify the OSCRS at the highest possible level. The approach shown in Figure 2-1 & Figure 2-2 is to conduct integrated fluid, avionic and thermal control tests at the combined subsystem level and then to integrate these subsystems into the structures to verify the thermal, and static and dynamic load attributes of the total system. An extension of the certification process includes sending the tanker assembly to KSC to verify the GSE and facility interfaces at the integrated system level.

2.5 Ground Rules and Assumptions

2.5.1 Monopropellant OSCRS Configuration

The monopropellant OSCRS tanker configuration (Figure 2-3) defined in STS 86-0268 is the basis for the section 3.1 cost estimate. The basic structure is designed for growth, up to 7000 lbs of monopropellant or bipropellants, pressurants or other fluids, and the associated control avionics and contractor flight and facilities support costs through the first flight. The system will be designed, developed, qualified and produced to meet the GRO resupply requirements. These requirements can be satisfied with two GRO propellant tanks and no pressurant resupply. The fluid transfer system is a pump fed blowdown system which utilizes an auxiliary ullage tank to provide adequate pump head pressure. The thermal control system uses radiant panel heaters, and a multi-layer insulation which encapuates the tanker structure.

FIGURE 2-3

Basic OSCRS Tanker Concept Configured For GRO Resupply Mission

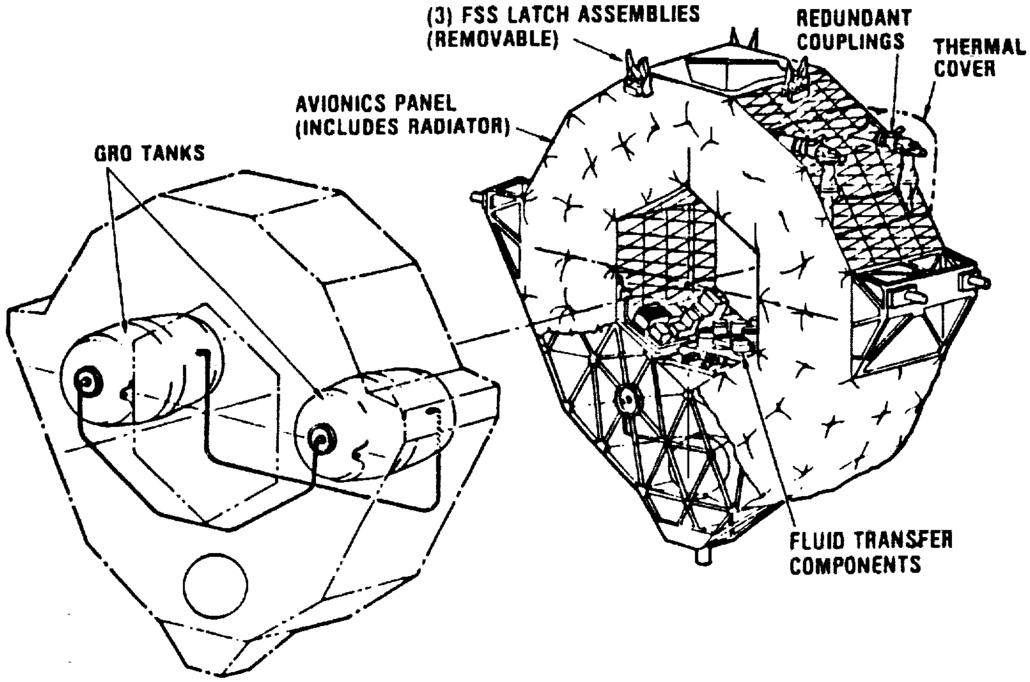
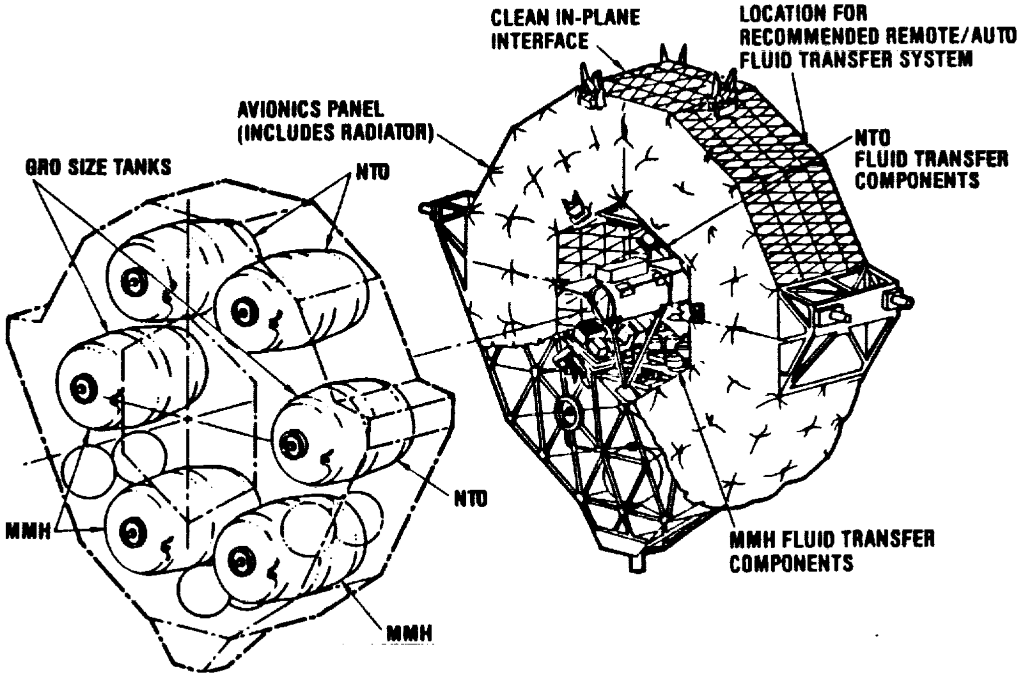


FIGURE 2-4

OSCRS Bipropellant Tanker Concept



The avionics is comprised of components located on the Orbiter aft flight deck (AFD) or on the tanker in the payload bay. The AFD avionics provides the controls and displays. The tanker dedicated avionics include the control and data processing, power and control, data acquisition/signal conditioning functions for the OSCRS. The tanks and all support equipment are modular mounted so that they may be easily installed or removed to satisfy varying resupply mission scenarios. Operation costs are based on the performance of a single resupply mission to service the GRO. The costs include preflight EVA training of the crew for GRO, support of the preflight checkout of the tanker and associated avionics, mission support, post mission checkout and restoration as required, and data analysis of the resupply mission.

2.5.2 Bipropellant OSCRS Configuration

The bipropellant OSCRS tanker configuration (Figure 2-4) defined in STS 86-0299 is the basis for the section 3.2 cost estimate. The primary structure is designed for up to 7000 lbs of bipropellants, pressurants or other fluids, and the associated control avionics. The fluid transfer system contains a pump fed blowdown system which utilizes auxiliary ullage tanks to provide adequate inlet pump pressure. Six propellant tanks (3 oxidizer, 3 fuel) will provide storage space for the 7000 lbs of propellant. The fluid transfer system also contains a pressurant resupply subsystem and an ullage disposal subsystem. The tanks and all support equipment are modular mounted so that they may be easily installed or removed to satisfy varying resupply mission scenarios. The thermal control and avionics subsystems are essentially identical to the monopropellant tanker except for added power control assemblies to control the additional fluid subsystems.

2.5.3 Monopropellant Methods/Methodology/Assumptions

2.5.3.1 Cost Estimating Methods.

A number of methods can be used to estimate the OSCRS program costs. They include:

(1) Analogy. This method involves reasoning by analogy with one or more completed projects to relate their actual costs to an estimate of the cost of the similar new project.

(2) Expert Judgement. This method involves consulting one or more experts (such as subcontractors).

(3) Algorithmic Models. These methods provide one or more algorithms which produce a hardware or software cost estimate as a function of a number of variables which are considered to be the major cost drivers. RCA PRICE is an example of an algorithmic model.

Estimation by analogy involves reasoning by analogy with one or more completed projects to relate their actual costs to an estimate of the cost of a similar new project. Estimating by analogy can be done either at the total project level or at a subsystem level. The total project level has the advantage that all components of the system cost will be considered (such as including the costs of integrating the subsystems), while the subsystem level has the advantage of providing a more detailed assessment of the similarities and differences between the new project and the completed projects.

The main strength of estimation by analogy is that the estimate is based on actual experience on a similar project. This experience can be used to determine specific differences from the new project, and their likely cost impact. The main weakness of estimation by analogy is that it is not clear to what degree the previous project is actually representative of the constraints, techniques, personal, and functions to be performed by the new project or in the construction of the new project.

Estimation by analogy was one approach examined by Rockwell, Seal Beach Satellite Division. The analyst used the P80-1 satellite program in the analogy. The total OSCRS system costs were comparable $64.6 million and $62.2 million for the P80-1 analogy and RCA Price H & S estimate. At the subsystem level the analogy approach broke down because of the difficulty of removing or adding differences between the subsystems.

Expert judgement techniques (also known as grassrooting) involves consulting with one or more experts, who use their experience and understanding of the proposed project to estimate costs of components or subsystems. On the positive side, an expert's judgement is able to factor in the differences between past experiences and the new techniques, architectures, or applications involved in the new project. On the weak side, expert judgment is no better than the expertise and objectivity of the estimator, who may be biased, optimistic, or unfamiliar with key aspects of the project.

Expert judgement techniques can vary from subcontractor cost estimates (where the same information is transmitted to each vendor and the returned inputs compared) to a in-house price determination meeting. Vendor inputs on qualified components tend to agree within a 25% range on such components as isolation valves, filters, orifices, and test ports; but on new components, such as a pump, the costs vary by a factor of 2 or more. In general, most vendor cost estimates tend to be about 50% or less than the recurring costs of shuttle qualified components.

The technique of expert judgement tends to present results that are no better than the participants. The results tend to be low due to optimistic biases, incomplete recall of the total cost factors, and a desire to win or please. The only way that this approach can be used for a complete system cost estimate is to obtain estimates from several experts for each subsystem and then present the results to the experts for a second iteration. This is almost impossible for a complete OSCRS system, due to time and cost constraints therefore the results of the expert judgement technique were used for comparison purposes only.

Algorithmic models provide one or more mathematical algorithms which produce a cost estimate as a function of a number of variables considered to be the major cost drivers. The most common forms of algorithms to be used for cost estimation include linear, multiplicative, analytic, and tabular models. Composite models incorporate a combination of the above mentioned models. Thus composite models have the advantage of using the most appropriate functional form for each component of the cost estimate.

The main difficulties with algorithmic models are that they are more complicated to learn and they require more data and effort to calibrate and validate. The RCA PRICE H & S models are composite models.

Compared to other cost estimation methods, algorithmic models have a number of strengths. They are objective, and not influenced by such factors as a desire to win, desire to please, or distaste for the project. They are repeatable; you can ask them the same question a month later and get the same answer. They are efficient and able to support a family of estimates or a sensitivity analysis, and they are objectively calibrated to previous experience.

On the other hand, algorithmic models have several weaknesses. Since they are calibrated to previous projects, it is always an open question to what extent these projects are representative of future projects using new techniques and dealing with new application areas. They are unable to deal with exceptional conditions, particularly exceptional personnel, exceptional project teamwork, or exceptional matches (mismatches?) between the project personnel and the job to be done. And, like any model, there is no way the model can compensate for poor sizing inputs and inaccurate cost driver ratings.

Using the RCA PRICE H & S model two runs were completed to compare price estimates of a manned tanker and a unmanned tanker (except the fluid system). A total cost reduction of $14.7 million is realized by assuming that the OSCRS is uninhabited because the structure, mechanical, thermal, and avionics subsystems are relatively benign. The fluid subsystem is potentially hazardous and must be interfaced by the crew and was therefore treated as a manned subsystem.

2.5.3.2 Methodology/Assumptions

The methodology used for the monopropellant tanker was an all-parametric estimating approach (RCA PRICE H & S model). This approach proceeds directly from a technical and programmatic definition of the OSCRS system to the estimated costs by way of a mix of parametric cost-prediction models and relationships. Starting point for the cost analysis involves OSCRS system definition documentation. This documentation includes the following:

OSCRS Phase C/D Program Plan.

Component-level design data summaries by subsystem. These summaries present unit weights, quantities, component identification, and qualification status.

Additional hardware design data, such as sketches, and software descriptors.

All hardware and software costs were estimated using the RCA PRICE models. The data from the RCA PRICE models was generated by ECON, Inc. for the construction of OSCRS by the general aerospace industry. PRICE is a family of general case cost-prediction models. The term 'general case' means that the models are, in fact, a simulation of the forces that drive cost (e.g., size, complexity, schedule) and are not based on specific, historically-derived cost estimating relationships. Special-case models are used to estimate costs for narrow product lines. A general-case model can estimate the cost of any product, providing the model is given a technical and programmatic description of the product, and provided that the model variables have been calibrated to that product.

PRICE 'H' (hardware) was used to estimate OSCRS flight hardware development and production costs. PRICE 'S' (software) was used to estimate OSCRS flight and ground software development costs. For both models the deepest available level of system definition was the basis for estimating costs; integration costs were modeled at higher levels of indenture as required to simulate OSCRS program behavior.

The following assumptions were used in the cost estimate

(1) Cost are expressed in U.S. dollars measured as of January 1, 1986 economic conditions.

(2) Costs are for contractor activities only. No Government research and program management (R&PM) costs or other wraparound loadings (i.e., contractor fee) are included.

(3) Dedicated test hardware exists at component and subsystem levels only. A single complete system-level OSCRS flight article is built and its costs are charged to production; this protoflight article also serves as a system-level test article as required.

(4) Since the OSCRS is uninhabited and the structure, mechanical, thermal, and avionics subsystems are relatively benign, these subsystems were defined as unmanned.

(5) Because the fluid system is potentially hazardous and must be interfaced by the crew, it was defined as a manned subsystem.

2.5.4 Bipropellant Methodology/Assumptions

The results of the monopropellant tanker study using the above techniques were used to determine a preliminary cost estimate of the bipropellant tanker. Using the monopropellant tanker cost estimate a number of assumptions were made (Table 2-1) to determine the bipropellant DDT&E and first production unit cost.

Table 2-1

Bipropellant Tanker DDT&E and 1st Unit Preliminary Cost Estimate Assumptions

1) All costs are based on ECON's cost analysis of OSCRS monopropellant tanker system in 1986 dollars.

2) DDT&E costs are based on the following assumptions:

   a) The monopropellant tanker is being constructed in parallel with the bipropellant tanker.
   b) The same structure is used for the monopropellant and bipropellant Bi cost = Mono cost x 1.3
   (mono cost = 1st unit production costs)
   c) Mechanism is assumed to be an automated docking and latching umbilical requiring 5 people for 3 years.
   d) Fluid costs are (0.7 (fuel) + 1.1 (oxidizer)) times mono cost plus 1M for oxidizer tank DDT&E
   plus two times a grass root cost for the pressurant DDT&E.
   e) Thermal costs are mono cost x 1.5 (for growth)
   f) Avionics costs are (mono cost x 0.2) plus 4 PCAs
   g) ASE costs are (mono DDT&E costs x .15)
   h) GSE costs are ((mono costs - Avionics)) times (.4 (oxidizer) plus .5 (pressurant)).
   i) Software costs mono DDT&E times 0.15 (for bipropellant unique features)
   j) System Engineering cost used the same factor (6.0%) as ECON
   k) Program Management cost used the same factor (24.0%) as ECON
   l) IACO costs are mono costs time (0.4 (oxidizer) + 0.5 (pressurant))

3) Production of 1st unit cost are as follows:

   a) Structure and Mechanism costs are the same as for the monopropellant production unit.
   b) Thermal costs = mono costs times 1.2
   (mono costs = 1st production unit costs).
   c) Fluid costs equal mono costs time (1.0 (fuel) + 1.1 (oxidizer)) plus 1.5 times the grass root pressurant component costs.
   d) Avionics cost equal mono cost plus the cost of 4 PCA.
   e) Program Management cost used the same factor (19.0%) as ECON.
   f) IACO costs are mono cost times (1.0 (fuel) + 1.0 (oxidizer) + 0.5 (pressurant))

3.0 Cost Summary

3.1 Monopropellant Program Costs

The estimated DDT&E and Production costs for the first deliverable system is shown in Table 3-1. The cost to develop the subsystems through subcontractor development and in-house breadboard tests is $22.3 million. Integration assembly, and checkout -(IACO) costs for the DDT&E portion of the tanker is $4.9 million at the system level. The GSE development and production is estimated at $5.8 million and the software development is estimated at $5.2 million. The total DDT&E cost with system engineering and system and program management is $45.1 million.

The cost estimate of the first production unit (T_1) is $17.1 million. Estimated costs of the first on-orbit resupply operation is $1.0 million and includes EVA training costs, contractor flight and facilities support. Percentage breakdown of the monopropellant tanker is presented in Figure 3-1.

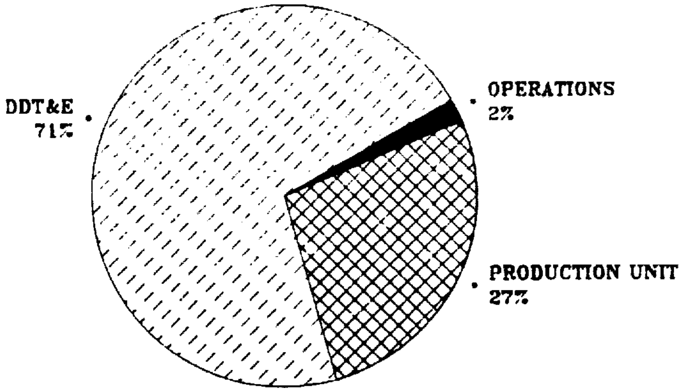
3.2 Bipropellant Program Costs

The estimated DDT&E and Production costs for the first deliverable system is shown in Table 3-2. The cost to develop the subsystems through subcontractor development, tanker certification, hardware costs, and in house breadboard is $19.1 million. Manufacturing (installation, assembly, and checkout - IACO) cost for the DDT&E tanker is $4.4 million at the system level. The GSE development production is estimated at $2.6 million and the software development is estimated at $0.8 million. The total DDT&E cost with System Engineering and Program Management is $32.7 million. The cost estimate of the first production unit (T_1) is $30.1 million. Percentage breakdown of the monopropellant tanker is presented in Figure 3-2.

FIGURE 3-1

PHASE C/D MONOPROPELLANT OSCRS PROGRAM COSTS

TOTAL PHASE C/D COSTS = $63.2 M

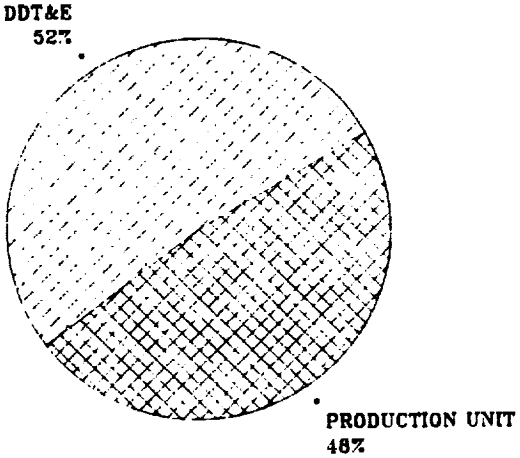


IN 1986 DOLLARS

FIGURE 3-2

PHASE C/D BIPROPELLANT OSCRS PROGRAM COSTS

TOTAL PHASE C/D COSTS = $ 62.8 M



IN 1986 DOLLARS

Table 3-1

Monopropellant Tanker DDT&E and Production Preliminary Cost Estimate (1986 $ Million)

	DDT&E $ Million	T_1 $ Million
Structures	4.1	0.9
Mechanisms	0.4	1.2
Thermal	1.6	0.3
Fluid	8.0	3.7
Avionics	7.2	7.1
ASE	1.1	0.3
Subtotal	22.3	13.5
GSE	5.8	0.0
Software	5.2	0.0
System Engineering	1.4	0.0
System & Program Management	5.5	2.5
IACO, System Level	4.9	1.1
Total	$45.1 M	$17.1 M

Table 3-2

Bipropellant Tanker DDT&E and Production Preliminary Cost Estimate (1986 $ Million)

	DDT&E $ Million	T_1 $ Million
Structures	1.2	0.9
Mechanisms	1.5	1.2
Thermal	0.5	0.4
Fluid	10.9	9.7
Avionics	4.8	10.5
ASE	0.2	0.3
Subtotal	19.1	23.0
GSE	2.6	0.0
Software	0.8	0.0
System Engineering	1.2	0.0
System & Program Management	4.6	4.4
IACO, System Level	4.4	2.7
Total	$32.7 M	$30.1 M

4.0 Cost Estimate by WBS

4.1 Monopropellant Cost Estimate

The cost at WBS level 3 is estimated as follows:

1.1	DDT& E	$45.1 million
1.2	Production	$17.1 million
1.3	Operations	$1.0 million

4.2 Bipropellant Cost Estimate

The cost at WBS level 3 is estimated as follows:

2.1	DDT&E	$32.7 million
2.2	Production	$30.1 million

5.0 Program Funding

5.1 Monopropellant Program Funding

The DDT&E, production, and operation cost estimates of Section 3.0 have been time phased to the program plan. The funding distribution for each government fiscal year (GFY) is presented in Table 5-1 and Figure 5-1.

Table 5-1

Estimated Monopropellant OSCRS DDT&E, Production, and Operations Funding by GFY ($ Million)

	1988	1989	1990	1991	Total
DDT&E	18.0	19.0	8.1	0.0	45.1
Production	4.5	7.0	5.0	0.6	17.1
Operation	0.3	0.1	0.2	0.4	1.0
Total	22.8	26.1	13.3	1.0	63.2

5.2 Bipropellant Program Funding

The DDT&E and production cost estimates of section 3.0 was time phased to the program plan. The funding distribution for each government fiscal year is presented in Table 5-2 and Figure 5-2.

Table 5-2

Estimated Bipropellant OSCRS DDT&E and Production Funding by GFY ($ Million)

	1989	1990	1991	1992	Total
DDT&E	13.0	14.3	5.4	0.0	32.7
Production	3.0	8.1	15.0	4.0	30.1
Total	16.0	22.4	20.4	4.0	62.8

FIGURE 5-1

EXPENDITURE PROFILE

FOR OSCRS

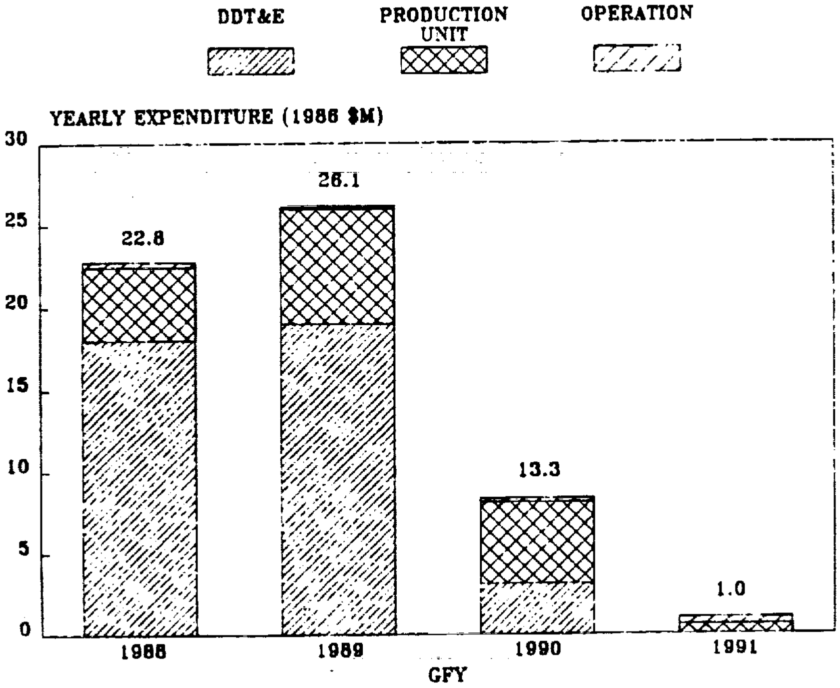
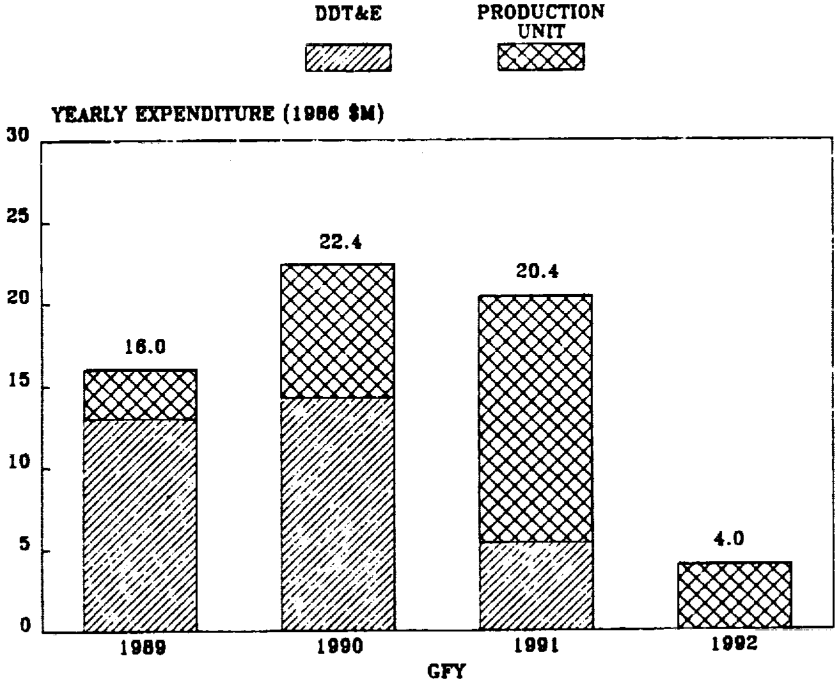


FIGURE 5-2

EXPENDITURE PROFILE

FOR BIPROPELLANT TANKER



5.3 Total Program Funding

A combined funding distribution for the monopropellant and bipropellant tanker is presented in Figure 5-3 for each government fiscal year.

FIGURE 5-3

EXPENDITURE PROFILE

FOR A MONO & BIPROPELLANT TANKER