# CONFIGURATION EVALUATION AND CRITERIA PLAN

## VOLUME 2 - EVALUATION CRITERIA PLAN

(UPDATE)

Space Transportation Main Engine

(STME) Configuration Study

Contract NAS8-36867
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## FOREWORD

This is the updated Evaluation Criteria Plan for the Space Transportation Main Engine Configuration Study and has been prepared as part of Task 3.0 of Contract NAS8-36867 (A Prime). The work is being performed by the Aerojet TechSystems Company for the NASA - Marshall Space Flight Center.

The program objective is to identify candidate main engine configurations which enhance launch vehicle performance, operation and cost. These candidate configurations will be evaluated and the configuration(s) which provide significant advantages over existing systems will be selected for consideration for the next generation launch vehicles.

The NASA-MSFC Project Manager is Mr. J. Thompson. The ATC Program Manager is Mr. T.C. Lacefield and the ATC Study Manager is Mr. E.K. Bair.

The Evaluation Criteria Plan is Volume 2 of the Configuration Evaluation and Criteria Plan, Contract Data Requirement DR-9. Volume 1 is the System Trades Study and Design Methodology Plan, it has not required revision for the A Prime portion of the STME Configuration Study.

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## I. INTRODUCTION

The unbiased selection of the Space Transportation Main Engine (STME) configuration requires that the candidate engines be evaluated against a predetermined set of criteria which must be properly weighted to emphasize critical requirements defined prior to the actual evaluation. Since the optimum configuration is a compromise between engine and airframe design, the criteria and relative weighting of the criteria involves a team effort between ATC, MSFC and the Space Transportation Architecture Study (STAS) contractors. The evaluation and selection process, Figure 1, involves the following functions: (1) determining if a configuration can satisfy basic STME requirements (yes/no) (2) defining the evaluation criteria, (3) selecting the criteria's relative importance or weighting, (4) determining the weighting sensitivities and (5) establishing a baseline for engine evaluation. The criteria weighting and sensitivities are cost related and are based on mission model and vehicle requirements.

During Phase A of the STME study a Gas Generator Cycle engine was selected for conceptual design, with emphasis on reusability, reliability and low cost while achieving good performance. In Phase A Prime of the study emphasis will focus on expendable application of the STME while maintaining low cost and high reliability.

This update of the Configuration Evaluation and Criteria Plan reflects the desire for an expendable engine and will also consider the effect of variable production rates.

The STME/GG defined in Phase A will be used as a starting point for the A Prime study. The various configurations of this engine identified during the A Prime study, will be evaluated using the updated evaluation plan described in this document.

The basic vehicle is a two stage LOX/HC (STBE), LOX/$LH_2$ (STME) parallel burn vehicle capable of placing 150,000 lbs in low earth orbit (LEO). The mission model calls for placement of payloads in LEO starting in the 1995 to 1998 time frame. Each vehicle will utilize four STME's.

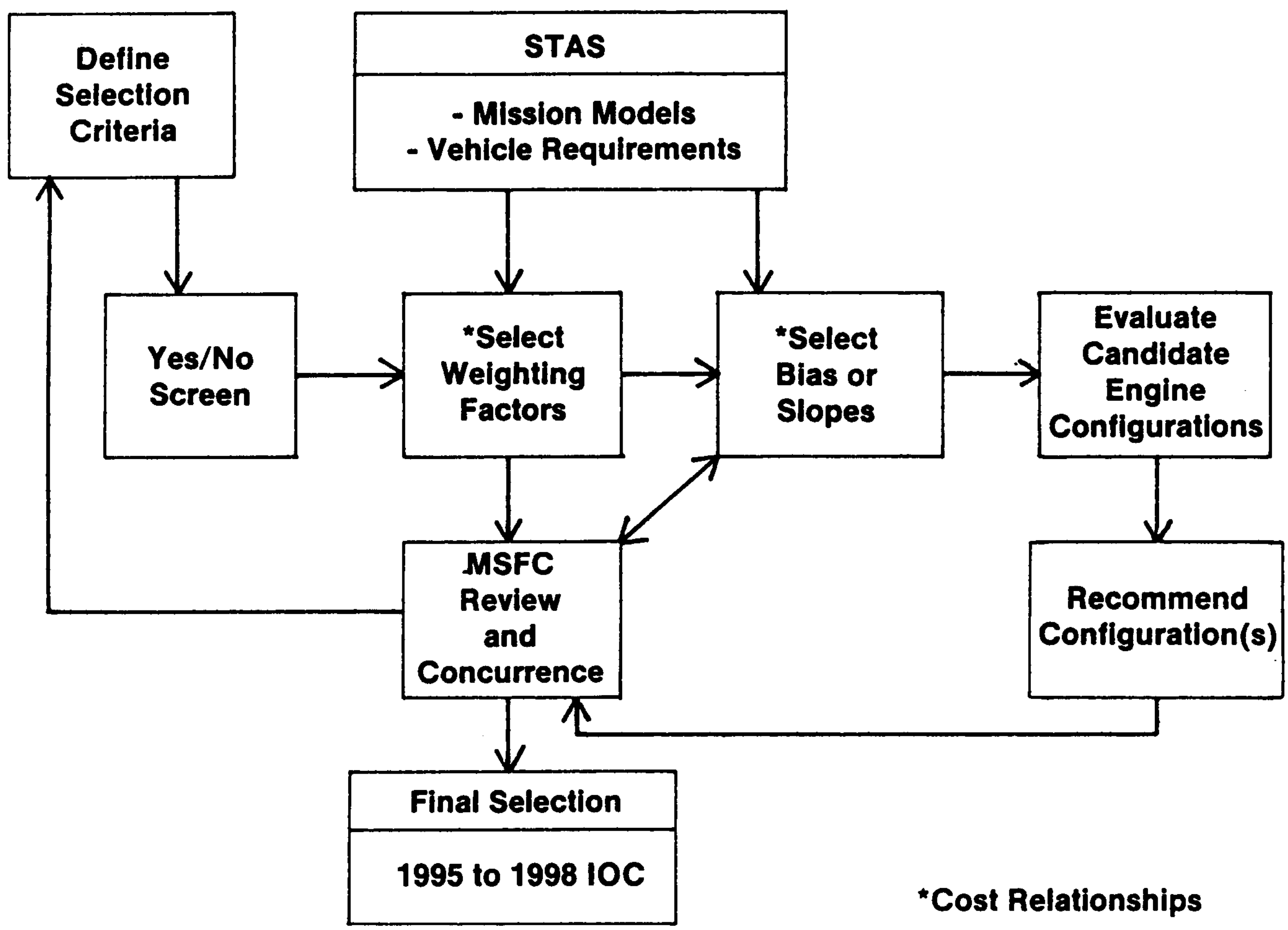



Figure 1. Configuration Evaluation and Selection Plan

I, Introduction (cont.)

The STME has a normal power level (NPL) thrust of 435K lbf (vacuum) and an emergency power level (EPL) thrust 580K lbf (vacuum). The mission burn time is 520 seconds with a sea level ignition.

## II. EVALUATION CRITERIA

The evaluation criteria define the significant functions that are required to properly evaluate an engine system. These criteria include all the significant items covered by the STAS studies in the architecture evaluation as well as items considered significant by ATC. The criteria must allow evaluation from both an engine and vehicle system point of view for proper integration into a complete system.

### A. YES/NO SCREEN EVALUATION

Initially, the engine concept must pass an evaluation relative to "yes/no" type criteria. A concept had to judged as a "yes" in all areas in order to be given further consideration. These criteria are:

Safety
Maximum Envelope
Gimballing Capability
Sea Level and Altitude Start Capability
Single or Multi Engine Application
Expendable or Reusable (Expendable for A Prime)
Throttling Capability
One Hundred Mission Capability (Expendable for A Prime)
IOC Compatibility

Stage Combustion and Gas Generator Cycle STME's passed this part of the evaluation and were then assessed on a quantitative basis during Phase A.

### B. QUANTITATIVE (COST BASED) SCREEN EVALUATION

The quantitative criteria screen evaluation for the A Prime configurations, is based on cost and is divided into the following five categories: categories: (1) Performance and weight, (2) Development, (3) Production, (4) Facilities, and (5) Operation and Support, see Table I. The original evaluation criteria included "availability" but since all configuration to be considered in the A Prime Phase will have the same availability this criteria was deleted.

TABLE I

QUANTITATIVE EVALUATION CRITERIA

| Category | Criteria | Subcriteria |
| --- | --- | --- |
| Performance and Weight | Isp<br>Weight | |
| Development | Development Time and Risk, Reliability and Safety | |
| Production | | |
| Facilities | Development | Component<br>Engine |
| | Launch/GSE | |
| Operation & Support | Installation & Checkout Launch Support | |

## Performance and Weight

The performance and weight category includes specific impulse and engine weight. The specific impulse represents a major factor in engine cost and complexity and vehicle system design. The engine propellant, efficiency, cycle, mixture ratio and chamber pressure are the primary factors in determining specific impulse.

Engine weight is dependent on thrust and chamber pressure requirements. The weight is not a totally dominant factor in vehicle design and the airframe contractors are willing to sacrifice some engine weight to enhance operations, reliability and life while reducing costs.

## Development (DDT&E)

The development category includes the factors that determine the DDT&E costs for developing an engine system and include manpower, hardware and testing. Engine cycle, thrust level, chamber pressure, propellant selection and life are important factors in determining development costs. Additionally, technology availability and development risk must be considered in this category. Reliability and safety features are incorporated during the design phase and verified during development.

## Production

The production category includes the factors that determine the production cost of an engine system. Component weight and complexity relationships are used to determine their unit cost. These costs are summed and an assembly cost added to yield the overall engine cost. Variable production rates are considered through the use of learning curve relationships which consider the type of hardware being produced as well as the quantities.

Facilities

The facilities category determines the development and launch/ground support requirements for the engine development, acceptance and use. The development facilities are dependent on engine cycle propellants and chamber pressure. The launch and ground support criteria is dependent on propellant selections and engine cycle.

Operation and Support

The operation and support category includes the criteria involved with defining the operations cost of an engine. For an expendable application this includes installation, checkout and launch support.

## III. "YES/NO" EVALUATION CRITERIA

As discussed in Section II, the initial engine evaluation was a "yes/no" screening which required that a concept pass every element in the criteria to be considered further. All configuration considered in Phase A Prime have passed these criteria since they will be derived from the gas generator cycle engine selected in Phase A.

## IV. QUANTITATIVE CRITERIA WEIGHTING

The mission model assumed for use in developing the quantitative evaluation criteria will account for a variable fleet size. The first mission occurs between 1995 and 1998. For the upper stage, four engines are assumed with a burn time totaling 520 seconds for each mission.

For use in the evaluations, it was assumed that combined capability of existing NSTL and other (new or existing) facilities would be in place and operation in time to support the STME development, qualification and production acceptance test schedule demands.

The quantitative criteria weighting represents the relative importance of the defined categories and criteria used to evaluate an engine system. The STAS contractors recommend costing the criteria categories to establish their relative importance, and this is the procedure which will be used. The cost values for each category are shown in Table II and were estimated, using cost relationships developed in Phase A. The relative weighting of each category is a function of the number of missions anticipated and Table II reflects this relationship for some selected mission quantities. During the actual evaluation the baseline weighting values will be determined using the percentage relationships shown in Figure 2, depending on the number of missions selected.

The performance and weight criteria are based on the effect of Isp and engine weight. The performance and weight cost is determined based on the potential loss of revenue due to a lower performing engine (-10 sec max) and the impact of added engine weight (1600 lbs, max, total). Because of added propellant or engine weight, a corresponding payload loss is incurred with an attendant loss in revenue. This is applied across the entire mission model.

The DDT&E baseline cost is $\$1.5 \times 10^9$ based on Phase A results and the unit cost (first) is set at $\$17 \times 10^6$. A learning factor is applied to the quantities required to support the missions. Figure 3 shows the learning curve relationship; a.9 learning curve was used.

TABLE II

*CATEGORY COST AND WEIGHTING

| Category | 10 Mission | | 100 Missions | | 400 Missions | |
|---|---|---|---|---|---|---|
| | Value/Mission | Weighting Value | Value/Mission | Weighting Value | Value/Mission | Weighting Value |
| Performance and Weight | $\$5.55 \times 10^6$ | 2.5% | $\$5.55 \times 10^6$ | 10.0% | $\$5.55 \times 10^6$ | 15.5% |
| Development | $\$150 \times 10^6$ | 67.8% | $\$15 \times 10^6$ | 27.1% | $\$3.75 \times 10^6$ | 10.5% |
| Production | $\$45.56 \times 10^6$ | 20.6% | $\$32.6 \times 10^6$ | 59.0% | $\$25.8 \times 10^6$ | 72.2% |
| Facilities | $\$20 \times 10^6$ | 9.0% | $\$2 \times 10^6$ | 3.65% | $.5 x 10% | 1.4% |
| Operations | $\$.14 \times 10^6$ | .1% | $\$.14 \times 10^6$ | .25% | $\$.14 \times 10^6$ | .4% |
| Total | $\$221.25 \times 10^6$ | 100% | $\$55.29 \times 10^6$ | 100% | $\$35.72 \times 10^6$ | 100% |

*Category Costs form a basis from which to evaluate and judge the various engine configurations, for the number of missions being considered.

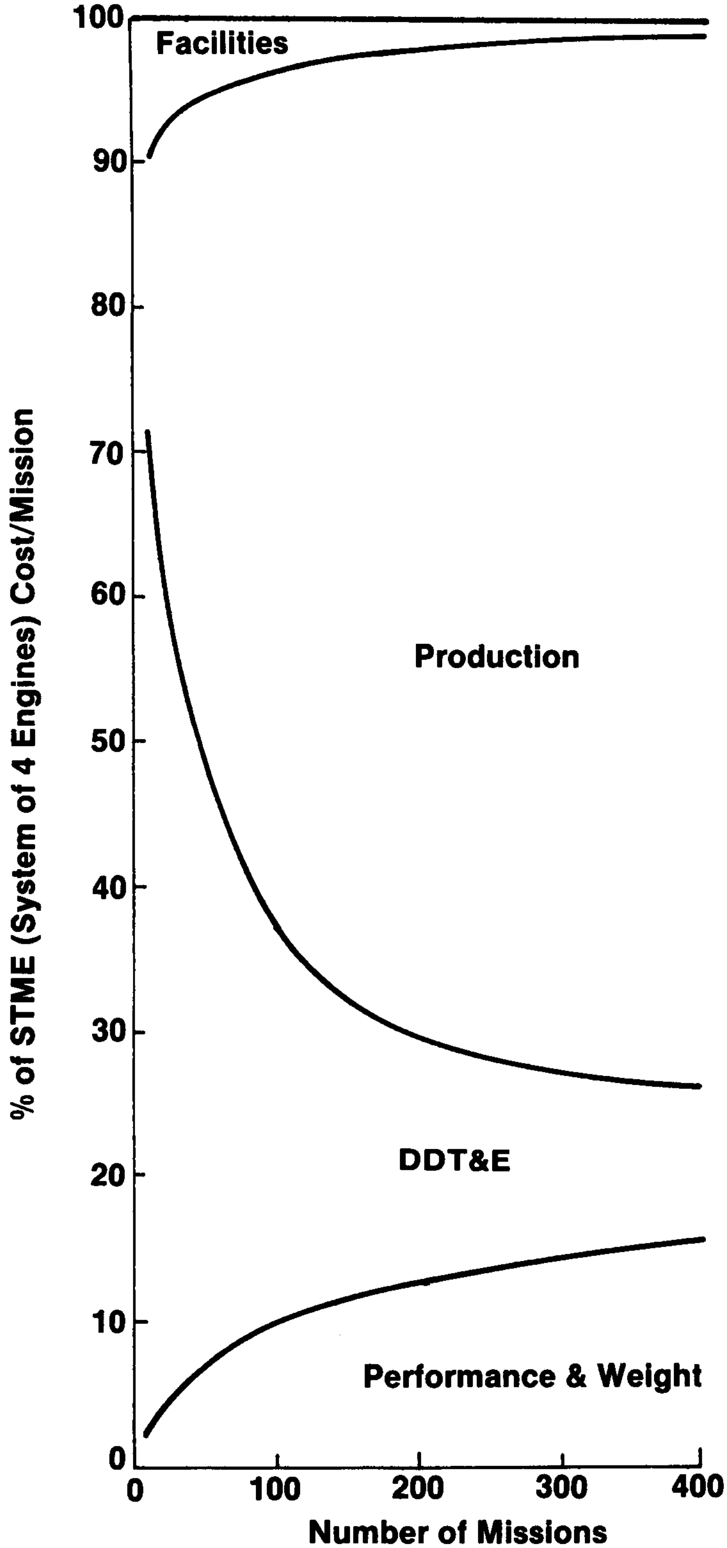
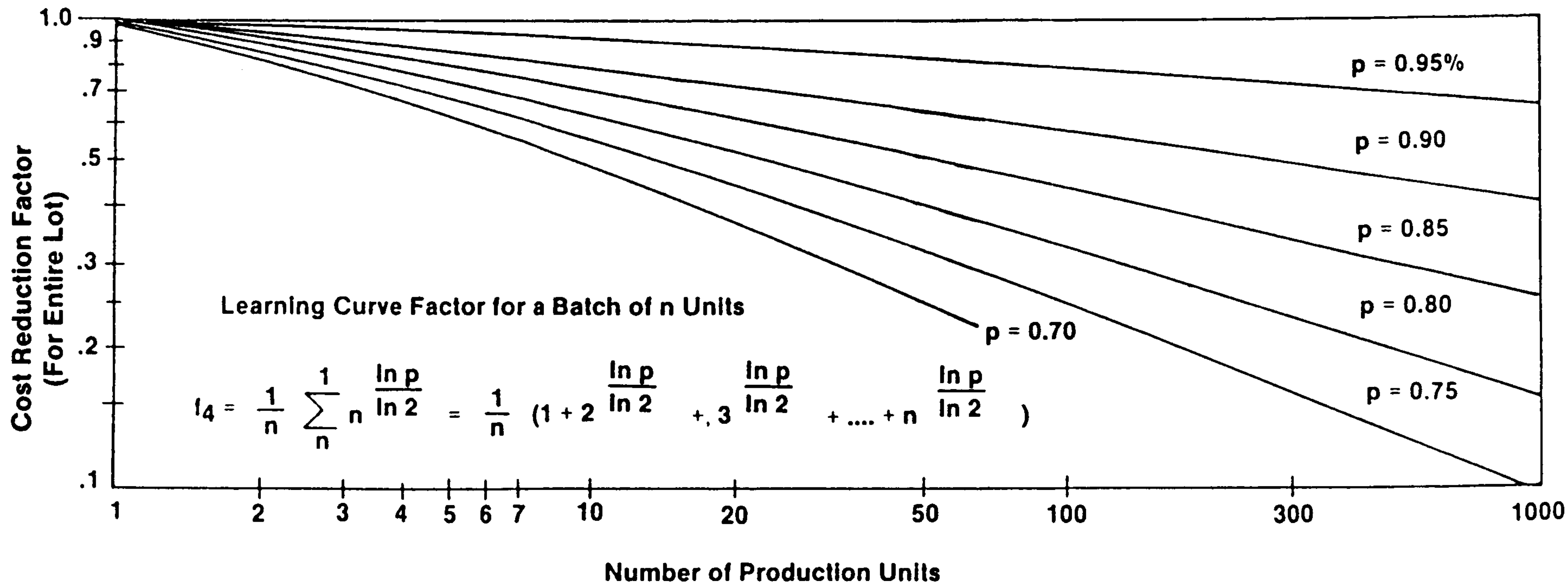



Figure 2. Category Cost Relationships vs. Number of Missions

P = Learning Curve Factor




Ref: Cost Model for Space Transportation Systems
Development, Fabrication and Operations;
MBS: TN RX1-328B; 1983 Edition; D.E. Koelle

**Figure 3. Learning Curve**

The operations and support evaluation criteria are based upon an estimated installation and checkout time of 500 hours per engine. The facility costs were estimated assuming the construction of five engine test stands, an engine component test facility for pump, chamber and GC/preburner development and GSE requirements.

After developing a cost for each category as discussed above, a percentage of the total cost was assigned to each category. The individual category costs and weighting are shown on Table II. The evaluation format used (for a fixed number of missions) is shown in Figure 4.

Once the criteria weight is determined, for a given number of missions, it is then used as a basis for assessing the impact of the various engine concept features. The actual score achieved by a concept is arrived at using the baseline value for that category and adjusting it based on the actual value of that particular concept feature.

As an example the value of performance, Isp, is derived from the estimated dollar value of a 10 second swing in performance; from 450 to 440 seconds. At 450 seconds the candidate would receive the full value of the weighting value; as the performance diminishes towards 440 seconds the value would approach zero; ie actual value is equal to the weighting value times the quantity of the actual Isp minus 440 divided by 10.

$$\text{Actual Value} = \text{Weighting Value} \left(\frac{\text{Actual Isp} - 440}{10}\right)$$

The scoring system is set-up to be open ended and allows for scores which may exceed the weighting value or are negative in value.

## For XX Mission

| Evaluation Criteria | Weighting Value (W.V.) | Engine Concepts | | | |
|---|---|---|---|---|---|
| | | | | | |
| Performance and Weights | W.V. P&W | | | | |
| Development | W.V. DDT&E | | | | |
| Production | W.V. PROD. | | | | |
| Facilities | W.V. FAC. | | | | |
| Operations | W.V. OPS. | | | | |
| TOTAL | 100 | | | | |

Figure 4. Engine Concept Evaluation Format

IV, Quantitative Criteria Weighting (cont.)

Performance

The weighting for the performance criteria is based on the impact the variation in performance will have on payload delivery capability. (In this case, a total performance variation of 10 seconds of Isp was assumed). Using a modified $\Delta V$ requirement, which accounts for gravity, drag and thrust losses, and an assumed lift-off thrust to weight ratio of 1.3, the propellant difference imposed by the 10 second performance variations was determined. This was converted to equivalent payload assuming a $500/lb to LEO delivery cost.

The cost effect of engine weight was based on a potential total engine weight variance of 1600 lbs, for all four engines. This was then equated to loss of payload.

Within this category the value of performance accounts for 84% of the total weighting value while the weight impact is 16%. The performance evaluation criteria is graphically shown in Figure 5.

Development

The weighting for the development criteria is based on the DDT&E cost determined in the Phase A effort which was $1.5B. This figure is approximately evenly divided between engineering support, development hardware and development testing.

The testing assumes that their are 1000 tests costing $500,000 each. The attendant reliability associated with the 1000 tests is .99. Figure 6 shows the relationship between reliability and the number of development tests required. If the desired reliability can be achieved in fewer tests then the DDT&E may be reduced; yielding an improved score in this category. The scoring system also allows for variations in reliability requirements.

| Evaluation Criteria | | Weighting Value |
|---|---|---|
| Performance and Weight | Isp | 84% of W.V. (P&W) |
| | Weight | 16% of W.V. (P&W) |

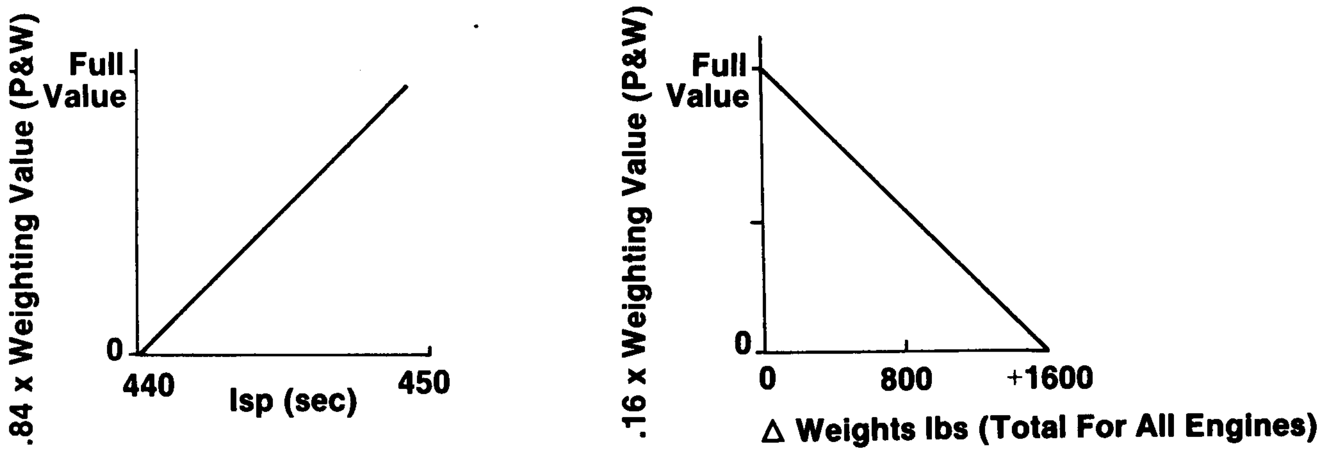
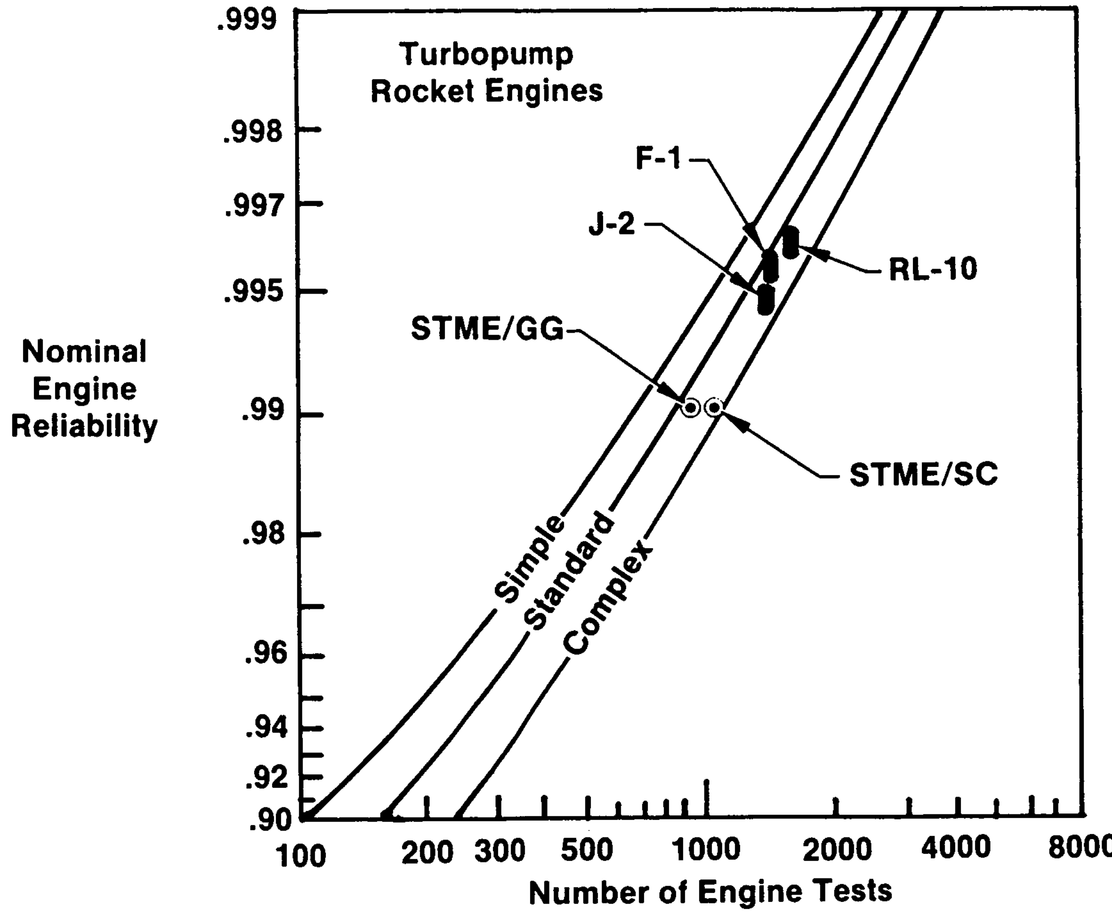



Figure 5. Performance and Weight Criteria Evaluation




Ref: "Transcost", TN-RX1-328B, MBB, D.E. Koelle

*Number of Tests = $62.5\ (1-R)^{-.6020}$

Note: For Every Additional "9" the Number of Test Increases by a Factor of 4.

For R = .99: STME/SC Requires 1050 Tests
STME/GG Requires 950 Tests

- Reliability is Achieved through Development Testing

**Figure 6. Reliability as a Function of Development Test Quantity**

The hardware costs are based on development engines costing $20M each (includes development features, special instrumentation, etc.). If the hardware cost changes then the score is adjusted to reflect the effect.

The scoring relationship is similar to that use in the Phase A evaluation in that a DDT&E cost of $1.5B will receive a score of zero. A lower DDT&E cost will result in a positive score and a higher cost in a negative value.

$$\text{Actual Value} = \text{Weighting Value}\left(\frac{\$1.5B - \text{Actual DDT\&E }\$}{\$1.5B}\right)$$

This relationship is shown graphically in Figure 7.

<u>Production</u>

A first (production) baseline cost of $17M per engine assembly will be used in this part of the evaluation. This value was developed in Phase A using the component cost, weight and complexity relationships shown in Figure 8. Here predicted component weights (from power balance program or by actual weights calculations) are used in conjunction with relative complexity factors to determine a cost per pound and subsequently the actual component cost.

The component costs are summed and an assembly cost added to arrive at the total engine cost.

As the quantities change the unit cost is adjusted by a learning curve as shown in Figure 3. For aerospace hardware a learning curve factor of .9 is assumed.

The unit cost is multiplied by the quantity required to arrive at a production cost.

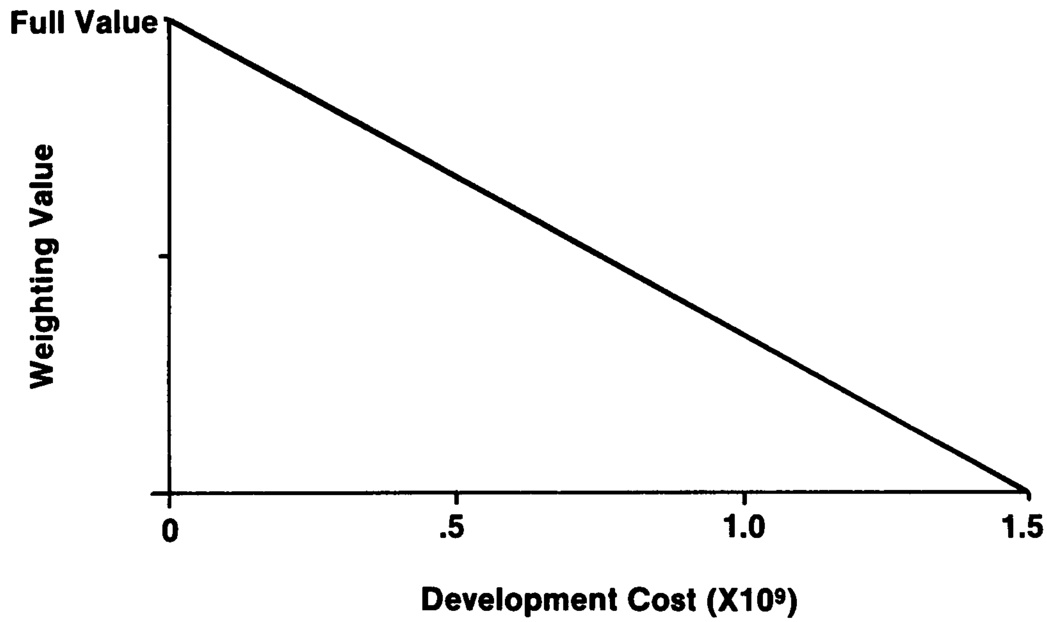



Figure 7. Development Evaluation

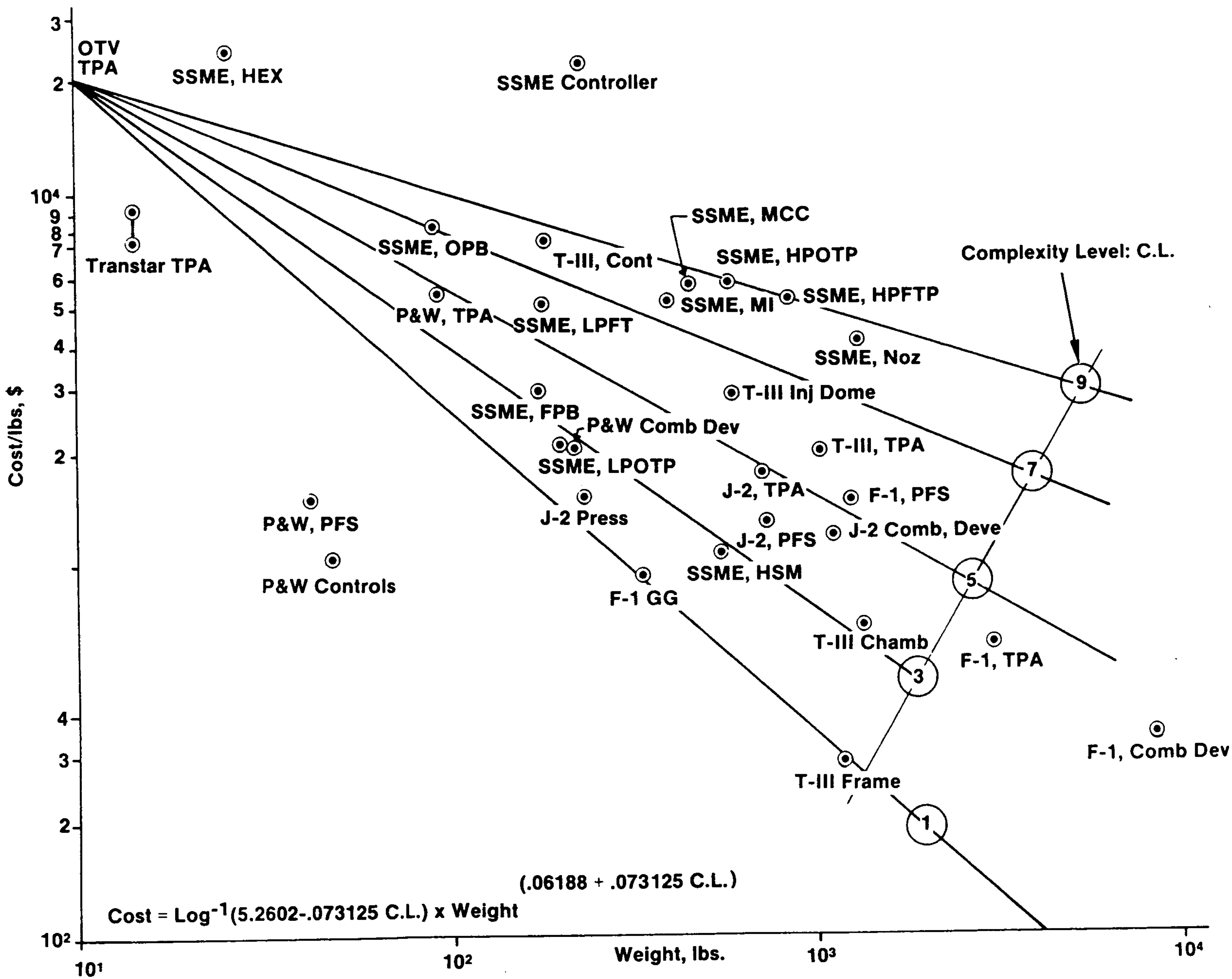



**Figure 8. Component Cost Relationships**

The value of the criteria weighting factor is equal to the weighting factor (for the quantities envisioned) times the basic unit cost ($17M x L.C.F.) minus the estimated cost divided by the basic unit cost.

$$\text{Actual Value} = \text{Weighting Value}\left(\frac{\text{Basic Unit Cost - Actual Unit Cost}}{\text{Basic Unit Cost}}\right).$$

Figure 9 shows this relationship.

## Operation

For the expendable STME the baseline operations and support are equated to a cost of 500 hours per engine at a rate of $70/hr. As the time required or hourly rate change the value changes and the weighting value (for the quantity of engine being examined) can be determined. Actual Value = Weighting Value $\left(\frac{\text{Base Cost-Actual Cost}}{\text{Base Cost}}\right)$. The relationship is as seen in Figure 10.

## Facilities

The weighting for the facility category is based on the cost of the new facilities involved with the development and launch support of the STME. These costs are estimated to be approximately $200 million which would yield weighting factors which are related to engine quantities, as shown in Table II and Figure 1.

The estimated facilities cost for a particular design are assigned weighting value scores in a manner similar to those previously discussed. Actual Value = Weighting Value $\left(\frac{\$200\text{ M - Actual Cost}}{\$\ 200\text{M}}\right)$. Figure 11 shows this relationship.

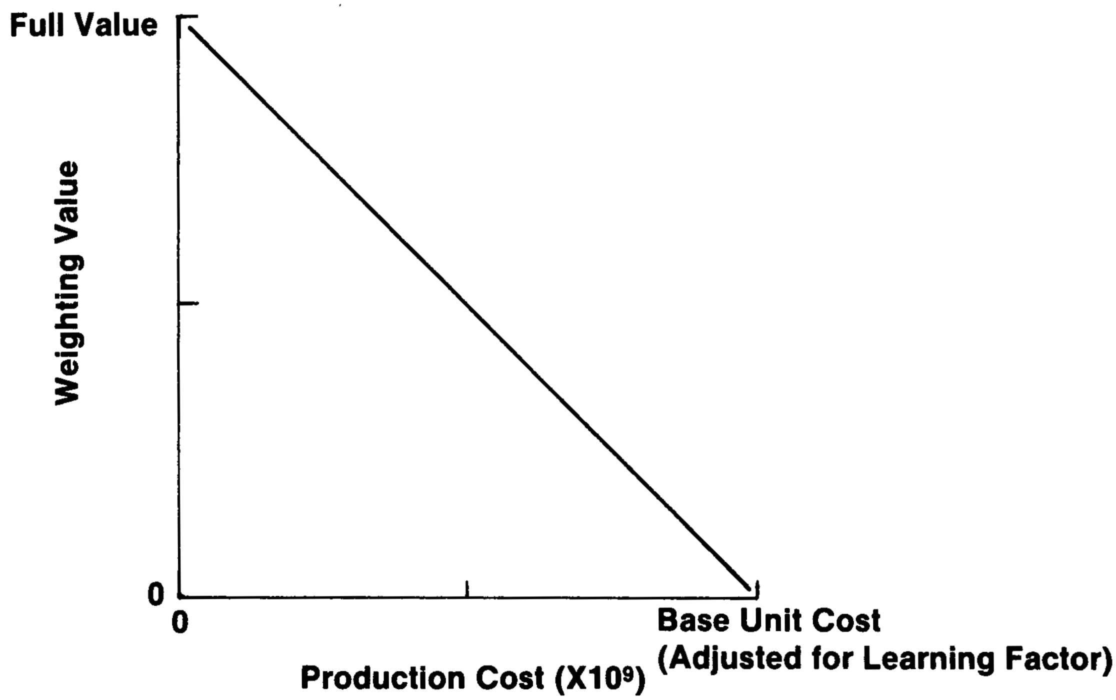



Figure 9. Production Criteria Evaluation

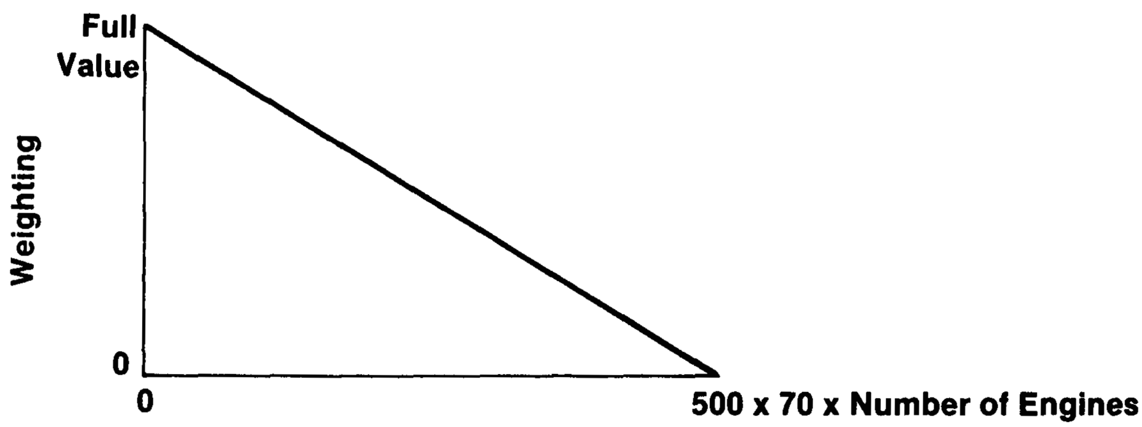



Figure 10. Operations Criteria Evaluation

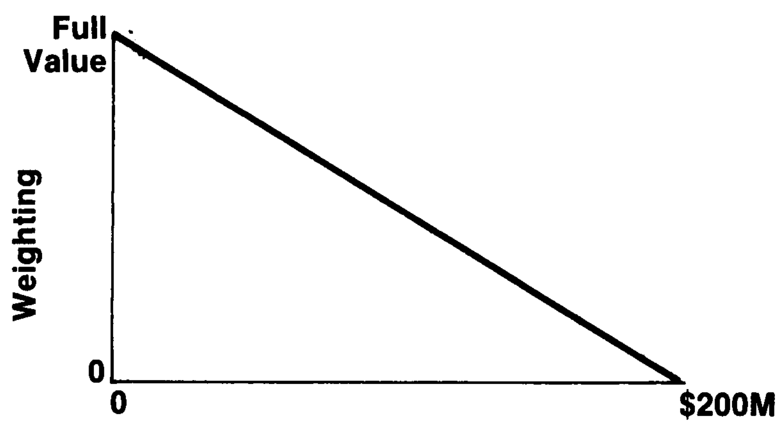



Figure 11. Facilities Criteria Evaluation

## V. BASELINE ENGINE

The engine scores are determined by the addition of the weighting values for each criteria, which totals 100 points for the baseline. The engine design which provides the highest performance for the lowest price with the lowest operation and support costs represents the optimum choice on a life cycle cost basis. Rating the engines against the maximum value for a given category results in obtaining a clear perspective on the relative strengths and weaknesses of a given candidate configuration.

Judging an engine based on its score for a given criteria, while varying the number of engines, is not valid because the category weighting values change as the number of engines change . However an assessment based on the total for all criteria categories is valid since the assessment is based on a total maximum score of 100 for all cases, independent of the number of engines involved.