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# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY(OEPSS) DATA BOOK

## Volume VII Launch Operations Index (LOI) Design Features and Options

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Prepared by
James M. Ziese

Rocketdyne Study Managers: R. P. Pauckert/G. S. Waldrop
NASA, KSC Study Manager: R. E. Rhodes



Rockwell International
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, CA 91303

## FOREWORD

This document is part of the final report for the Operationally Efficient Propulsion System Study (OEPSS) conducted by the Rocketdyne Division of Rockwell International. Thje study was conducted under NASA contract NAS10-11568, and the NASA Study Manager was Mr. R. E. Rhodes. The Rocketdyne Program Manager was R. P. Pauckert; the Deputy Program Manager was G. Waldrop; and the Project Engineer was T. J. Harmon. The Launch Operability Index Task was completed under the guidance of Mr. J. Ziese, Rockwell International, Space Systems Division.

## ABSTRACT

A design tool or figure of merit was developed that allows the operability of a propulsion system design to be measured. This Launch Operations Index (LOI) relates Operations Efficiency to System Complexity. The Figure of Merit can be used by conceptual designers to compare different propulsion system designs based on their impact on launch operations. The LOI will improve the design process by making sure direct launch operations experience is a necessary feedback to the design process.

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## 1.0 Introduction

In view of the need for making operations an important factor in the design process, a design tool was developed during the OEPSS study that will allow the operability of the propulsion design to be measured. This design tool, called the Launch Operations Index, or LOI, is a parameter or a figure of merit which quantifies propulsion system operations. It could be used by conceptual designers to compare different propulsion system designs based on their impact on launch operations. This ensures that launch operations is a factor that is critically addressed early in the design process.

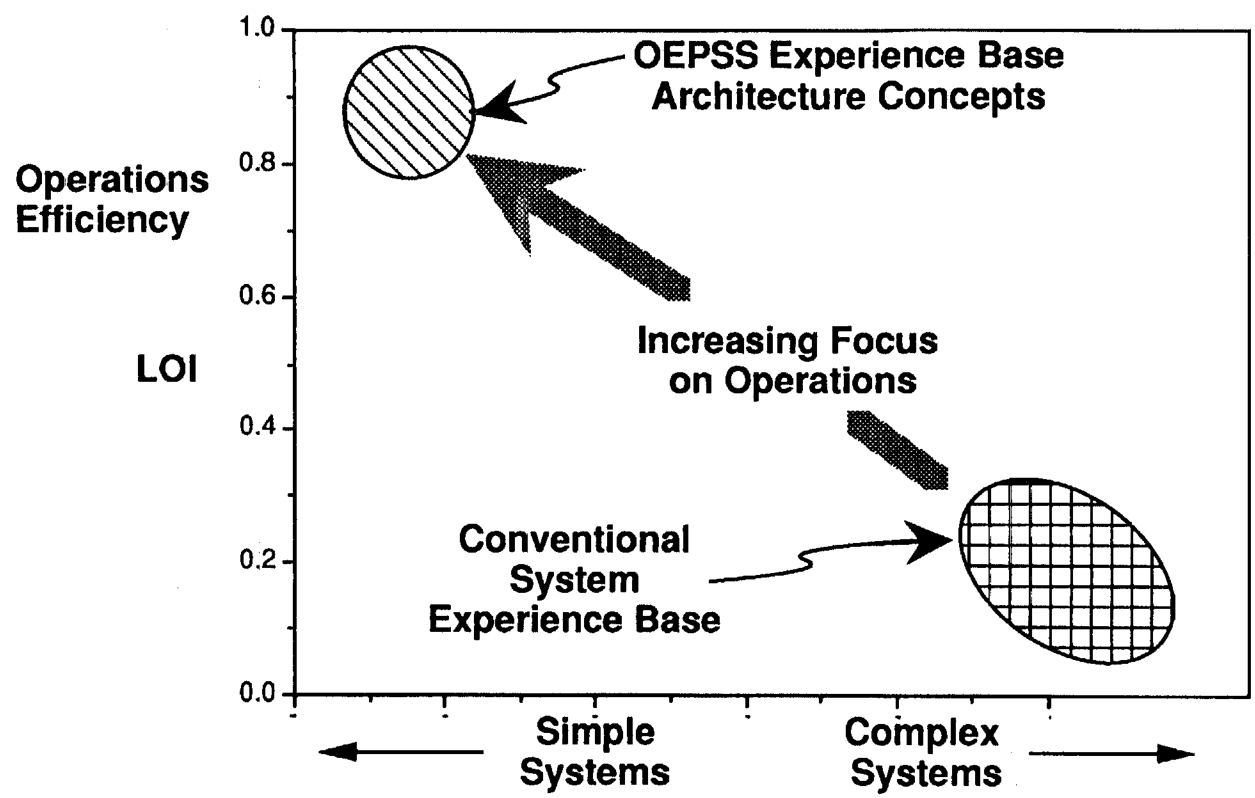
Those who must evaluate propulsion designs in program design reviews or during proposal evaluation will find the LOI a very useful parameter in their assessment of these systems. Program managers will find the LOI a means of showing a credible assessment of operability in their propulsion system designs. The LOI will improve the design process by making sure direct launch operations experience is a necessary feedback into any design process.

The Launch Operations Index is a parameter that relates "Operations Efficiency" to System Complexity." Conventional systems, for which there are many operational concerns, are complex and have correspondingly low operations efficiencies, while simple, integrated systems have high LOI's. This relationship between Operations Efficiency and System Complexity is depicted in Figure 1.

## 2.0 Launch Operability Index

The LOI is credible because it represents the collective experience of a wide range of propulsion interests. Initially the OEPSS team, representing NASA-KSC, Rocketdyne, and Rockwell Space Systems Division, formulated the method and assigned the ratings and weighting factors needed in calculating the operations index.

Extensive operations workshops were held at NASA-KSC, NASA-MSFC, and NASA-JSC. The workshop at JSC was also attended by representatives from Stennis Space Center, Air Force, NASA-LeRC, and NASA-MSFC. Based on inputs from these operations workshops, the LOI was further updated and refined to its present form.




LOI: A Figure of Merit Tool Relating Operations Efficiency to Complexity

**Figure 1**

LOI 2
TH/Bv 10/7/93-

## 3.0 LOI Computational Methodology

The method used in the LOI program starts with the transformation of the OEPSS operations concerns list, presented in Table 1, into a corresponding list of propulsion design features presented in Table 2. Each of the features is then assigned a weighting factor based on operations experience which represents that feature's impact on overall operability.

The weighting factor shown in parenthesis for each feature represents that feature's contribution to system complexity and potential for launch delay. As can be seen, the features with the most impact on the operations index are: number/type of propellants, degree of checkout automation, accessibility, and leakage potential.

For each of these design features, a list of candidate design options is developed. The options are arranged in order of operability and each assigned a rating from 1 to 10. A default option is selected which is typical of current systems. This default is used when a system is immature and has not yet defined an option for that design feature.

The LOI computation process is as follows: the designer or evaluator selects the option from the list which is most similar to that feature of the system being evaluated; a default is provided in case the option for that particular feature is not known and still allows the system to be evaluated; and the corresponding operability rating (OR) is used with the weighting factor (WF) to determine the score for this feature. This, combined with scores from all the other features, provides the launch operations index (LOI). Figure 2 presents an example of this LOI computation process. The numerical value for this index, similar to that for reliability or any efficiency, will range between 0 and 1.0.

## 4.0 Design Features

The listing of design features showing design options, a related operability rating and the default value for each feature is presented in Tables 3 through 23.

## Table 1. Operations Concerns List

Operations Experience Base

| No. | | No. | |
|---|---|---|---|
| 1 | Closed aft compartments | 12 | Pneumatic systems |
| 2 | Fluid system leakage | 13 | Gimbal system |
| | • External | 14 | High maintenance hardware |
| | • Internal | 15 | Ordnance Operations |
| 3 | Hydraulic system | 16 | Retractable T-O umbilical carrier plates |
| 4 | Ocean recovery/refurbishment | 17 | Propellant tank pressurization system |
| 5 | Multiple propellants | 18 | Excessive interfaces |
| 6 | Hypergolic propellants (safety) | 19 | Conditioning/geysering (LOX tank forward) |
| 7 | Accessibility | 20 | Precondition system |
| 8 | Sophisticated heat shielding | 21 | Expensive commodity usage--helium |
| 9 | Excessive components/subsystems | 22 | Lack hardware commonality |
| 10 | Lack of hardware integration | 23 | System contamination |
| 11 | Separate OMS/RCS | | |

## Table 2. Design Features List

| No. | | No. | |
|---|---|---|---|
| 1 | Compartment Configuration (8) | 11 | Fluid Ground Interface Type (5) |
| 2 | Degree Of Checkout Automation (9) | 12 | Oxidizer Tank Pressurization Systems (4) |
| 3 | Number/Type Of Propellants (10) | 12A | Fuel Tank Pressurization System (4) |
| 4 | Reusability Potential (7) | 13 | Oxidizer Preconditioning (4) |
| 5 | Auxiliary Propulsion (8) | 13A | Fuel Preconditioning (3) |
| 6 | Non-Propulsive Ordnance Systems (7) | 14 | Component/Subsystem Accessibility (9) |
| 7 | Valve Actuator Type (5) | 15 | Potential for Leakage (9) |
| 8 | Heat Shield Type (6) | 16 | Degree of Hardware Integration (7) |
| 9 | Pneumatic System (5) | 17 | Ground Support Requirements (8) |
| 10 | TVC System Type (3) | 18 | Number of Main Engines (8) |
| 10A | TVC System Power Source (4) | | |

(X) = Weighting Factor

Tables 1 & 2
TH/Bv 10/7/93

## Example LOI Calculation

| Design Feature | 1 | 2 | 3 | | | • • • • • • • | 17 | 18 |
|---|---|---|---|---|---|---|---|---|
| Weighting Factor | 8 | 9 | 10 | | | | 8 | 8 |
| Operability Rating | 5 | 6 | 3 | | | | 6 | 7 |
| WF X OR | 40 | 54 | 30 | | | | 48 | 56 |
| $\Sigma$(WF X OR) = 581 | | | | | | | | |

$$\text{LOI} = \frac{\text{CALCULATED } \Sigma(\text{WF X OR})}{\Sigma(\text{WF X MAXIMUM OR})} = \frac{581}{1340} = 0.433$$

Figure 2

Table 3

## Design Feature #1 -- Compartment Configuration

| Operability Rating | Design Options |
|---|---|
| 10 | Completely open -- no compartments or traps |
| 9 | Completely open before flight -- single simple cover added for launch |
| 8 | Completely open before flight -- multiple simple covers added for launch |
| 7 | Open but small trap area |
| 6 | Open but multiple or large trap areas |
| 5 | Open except few small closed compartments |
| 4 | Open except many or large closed compartments |
| 3* | Completely closed compartment -- access through large easily utilized doors |
| 2 | Completely closed compartment -- access through multiple small hatches |
| 1 | Completely closed compartment -- access through single small hatch |

*Default for this feature = 3 (reflects current typical configuration)

LOI2 THUBv 10/7/93

Table 4

## Design Feature #2 - Checkout Automation

| <u>Operability Rating</u> | <u>Feature Option</u> |
|---|---|
| 10 | No using site checkout required |
| 9 | Totally automated - single command required for complete checkout |
| 8.5 | Totally automated except multiple manual commands required for complete checkout |
| 5 | Functional checks of all active components automated - most leak checks automated |
| 4 | Functional checks of all active components automated - some leak checks automated |
| 2 | Functional checks of all active components automated - leak checks performed manually |
| 1.5* | Functional checks of some active components automated - leak checks performed manually |
| 1 | No automation - all checkout performed manually |

* Default for this feature = 1.5

LOI2 THUBv 10/7/93

Table 5

## Design Feature #3 - Number/Type of Propellants

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Prepackaged, sealed propellants - no GSE |
| 9.5 | Single, ambient temperature, non-toxic propellant |
| 6.5 | LH2 |
| 6 | Multiple non-toxic, non-hazardous propellants |
| 5 | LO2 with hydrocarbon fuel |
| 4 | LH2, LO2 |
| 1.7 | LO2, LH2, and hydrazine mono-propellants |
| 1.5* | LO2, LH2, and hypergolic bi-propellants |
| 1.2 | LO2, LH2, hypergolic bi-propellants, and hydrocarbons |
| 0.5 | Extremely hazardous/toxic propellants (e.g.; fluorine, flox, pyrophorics, etc.) |

* Default for this feature = 1.5

LOI 3-9
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Table 6

## Design Feature #4 - Reusability Potential

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Expendable - no recovery |
| 8 | Horizontal land (soft landing), powered |
| 7 | Horizontal land (soft landing), non-powered |
| 1 | Ocean recovery with complete exposure protection |
| 0.5 | Ocean recovery with no exposure protection |

* Default for this feature = 10

LOI 3-10
TH/Bv-10/8/93

Table 7

## Design Feature #5 - Auxiliary Propulsion

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No auxiliary propulsion |
| 9 | Auxiliary propulsion prepackaged & sealed |
| 8.5 | Single auxiliary propulsion system using main engine propellants from same tanks |
| 8 | Multiple auxiliary propulsion systems using main engine propellants from same tanks |
| 5 | Single auxiliary propulsion system using main engine type propellants loaded or charged separately from me propellants |
| 4.5 | Multiple auxiliary propulsion system using main engine type propellants loaded or charged separately from me propellants |
| 2 | Single auxiliary propulsion system using a toxic or hazardous propellant |
| 1.5* | Multiple auxiliary propulsion systems using a common toxic or hazardous propellant |
| 1 | Multiple auxiliary propulsion systems, each with different type toxic propellants |

* Default for this feature = 1.5

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TH/Bv-10/8/93

Table 8

## Design Feature #6 - Non-propulsive Ordnance Systems

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No ordnance |
| 9 | Pre-installed benign ignition (e.g.: laser) |
| 8 | Pre-installed electrical ignition |
| 6 | Launch site installation - clearing of personnel not required |
| 4 | Single launch site installation operation - clearing of personnel required |
| 1 | Multiple launch site installation operations - clearing of personnel required |

* Default for this feature = 1

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Table 9

## Design Feature #7 - Valve Actuator Type

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No actuators |
| 8 | All EMA |
| 7.5 | All EHA |
| 5 | Pneumatic |
| 4.5 | EMA with pneumatic back-up |
| 3 | Distributed hydraulics |
| 2* | Distributed hydraulics with pneumatic back-up |

* Default for this feature = 2

LOI 3- 13
TH/Bv-10/8/93

Table 10

## Design Feature #8 - Heatshield Type

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No heatshield |
| 7 | Gimbal plane heatshield + engine blankets |
| 6.5 | Spray on foam heatshield |
| 6 | Gimbal plane & engine blankets |
| 7 | Local shielding of critical components |
| 2* | Aft heatshield with dynamic seal to accommodate engine gimballing |

* Default for this feature = 2

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Table 11

## Design Feature #9 - Pneumatic System

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No pneumatic system |
| 8 | Pre-packaged system - no GSE |
| 7 | Single ground only purge. ground supplied & controlled. |
| 6.5 | Multiple ground only purges. ground supplied & controlled. |
| 5 | Multiple ground only purges. vehicle provides on-off control. |
| 4 | Multiple ground only purges. vehicle provides regulation & distribution. |
| 3 | Simple storage & distribution provides few flight purges. |
| 2.5 | Simple storage, distribution, & regulation provides few flight purges. |
| 2* | Storage, distribution, & regulation for multiple flight purges or simple valve pneumatic control system. |
| 1.5 | Pneumatic storage, regulation & distribution. multiple ground & flight purges. some pneumatic valve control |
| 1 | Complex pneumatic storage, regulation & distribution. multiple ground & flight purges. extensive pneumatic valve control system |

* Default for this feature = 2

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Table 12

## Design Feature #10 - TVC System Type

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Differential throttling - fixed main engine nozzles |
| 7.5 | Auxiliary thrusters - all engine nozzles fixed |
| 7 | Vanes |
| 6 | Fluid injection - fixed main engine nozzles |
| 5.5 | Main engine nozzles fixed - auxiliary thrusters gimballed |
| 4 | Main engines hinged |
| 3* | Main engines gimballed |

* Default for this feature = 3

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Table 13

## Design Feature #10A - TVC System Power Source

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | None required |
| 8 | Engine power take off (EPTO) directly powers electric TVC |
| 7.5 | Batteries directly power electric TVC |
| 7 | EPTO directly provides hydraulic power |
| 6 | EPTO powered electric APU provides hydraulic power |
| 5 | Hydrazine APU provides electric power |
| 4 | Battery powered electric APU provides hydraulic power |
| 3 | Bi-propellant APU provides electric power |
| 2* | Hydrazine APU provides hydraulic power |
| 1 | Bi-propellant APU provides hydraulic power |

* Default for this feature = 2

LOI 3-17
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Table 14

## Design Feature #11 - Fluid Ground Interface Type

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Fluids only - expendable, rise off connections located on base of vehicle, zero external leakage design |
| 6 | Multi-fluid - expendable, rise off connections located on base of vehicle |
| 5 | Expendable mast |
| 4 | Multi-fluid - pull away connections located at vehicle base and other conventional vehicle / ground interface points requiring QD protection |
| 2* | Multi-fluid - retract at commit, connections located at conventional vehicle / ground interface points, requiring tail service mast infrastructure, towers and swing arm infrastructure, and reusable, sophisticated QD configuration requiring extensive maintenance / refurbishment |

* Default for this feature = 2

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Table 15

## Design Feature #12 - Oxidizer Tank Press Systems

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | None |
| 9 | Tank self pressurized |
| 6 | Autogenous - fixed orifice control |
| 5.5 | Ambient helium - fixed orifice control |
| 5 | Autogenous - open loop control valve |
| 4 | Ambient helium - closed loop flow control valve |
| 3* | Autogenous - closed loop flow control valve |
| 1 | Cold helium, heat exchanger - fixed orifice control |
| 0.5 | Cold helium, heat exchanger - closed loop flow control valve |

* Default for this feature = 3

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Table 16

## Design Feature #12A - Fuel Tank Press Systems

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | None |
| 9 | Tank self pressurized |
| 6 | Autogenous - fixed orifice control |
| 5.5 | Ambient helium - fixed orifice control |
| 5 | Autogenous - open loop control valve |
| 4 | Ambient helium - closed loop flow control valve |
| 3* | Autogenous - closed loop flow control valve |
| 1 | Cold helium, heat exchanger - fixed orifice control |
| 0.5 | Cold helium, heat exchanger - closed loop flow control valve |

* Default for this feature = 3

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Table 17

## Design Feature #13 - Oxidizer Preconditioning

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No preconditioning required |
| 9 | Preconditioning through natural convection |
| 8.7 | Preconditioning through engine external passive bleed/leakage overboard |
| 8 | Preconditioning by helium injection |
| 4 | Preconditioning by passive feed line bleeds to tanks |
| 3 | Preconditioning by passive feed line bleeds to ground |
| 2 | Ground pumps required for preconditioning |
| 1* | Flight pumps required for preconditioning |

* Default for this feature = 1

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Table 18

## Design Feature #13 A- Fuel Preconditioning

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No preconditioning required |
| 9 | Preconditioning through natural convection |
| 8.7 | Preconditioning through engine external passive bleed/leakage overboard |
| 8 | Preconditioning by helium injection |
| 4 | Preconditioning by passive feed line bleeds to tanks |
| 3 | Preconditioning by passive feed line bleeds to ground |
| 2 | Ground pumps required for preconditioning |
| 1* | Flight pumps required for preconditioning |

* Default for this feature = 1

LOI 3- 22
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Table 19

## Design Feature #14 - Component/Subsystem Accessibility

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Each component & subsystem completely accessible without removal of any other parts or use of any support equipment (stands, platforms, etc.) |
| 7 | Each component & subsystem completely accessible without removal of any other . Support equipment required for access to some items. |
| 5 | Access to some components or subsystems requires removal of panels. Each component & subsystem completely accessible without removal of any other . Limited support equipment required. |
| 3* | Access to some components or subsystems requires removal of panels. Access to some LRU's requires removal of other hardware. Support equipment required for access to some items. |
| 2 | Access to most components or subsystems requires removal of panels. Access to some LRU's requires removal of other hardware. Support equipment required for access to some items. |
| 0.5 | Access to any component or subsystem requires removal of structural panels. access to many LRU's requires removal of other hardware. Extensive support equipment must be used. |

* Default for this feature = 3

LOI 3- 23
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Table 20

## Design Feature #15 - Fluid System Leakage Potential

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Hermetic sealing of all fluid systems |
| 7 | Few static seals only used in fluid systems. |
| 5 | Many static seals only used in fluid systems. |
| 3* | Extensive use of static seals in all fluid systems. few dynamic seals used. |
| 1 | Extensive use of static & dynamic seals in all fluid systems |

* Default for this feature = 3

LOI 3- 24
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Table 21

## Design Feature #16 - Hardware Integration

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Fully integrated - essentially a single subsystem |
| 7 | Physical integration of major subsystems - common requirements where possible |
| 5 | Modular, self contained subsystems |
| 3* | Little physical integration - some common subsystem requirements |
| 1 | No integration - each subsystem has differing requirements |

* Default for this feature = 3

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Table 22

## Design Feature #17 - Ground Support Requirements

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | No ground support equipment required |
| 7 | Only simple standard tools and equipment required for ground support |
| 5 | Complex equipment required but all common usage with little maintenance needed |
| 3* | Some specially development equipment equipment needed with significant maintenance required |
| 1 | Complex specially developed equipment needed with extensive maintenance requirements |

* Default for this feature = 3

LOI 3- 26
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Table 23

## Design Feature #18 - Number of Main Engines

| OPERABILITY RATING | FEATURE OPTION |
|---|---|
| 10 | Single main engine |
| 7 | Two main engines |
| 5* | Three main engines |
| 3 | Four main engines |
| 1 | Five or more main engines |

* Default for this feature = 3

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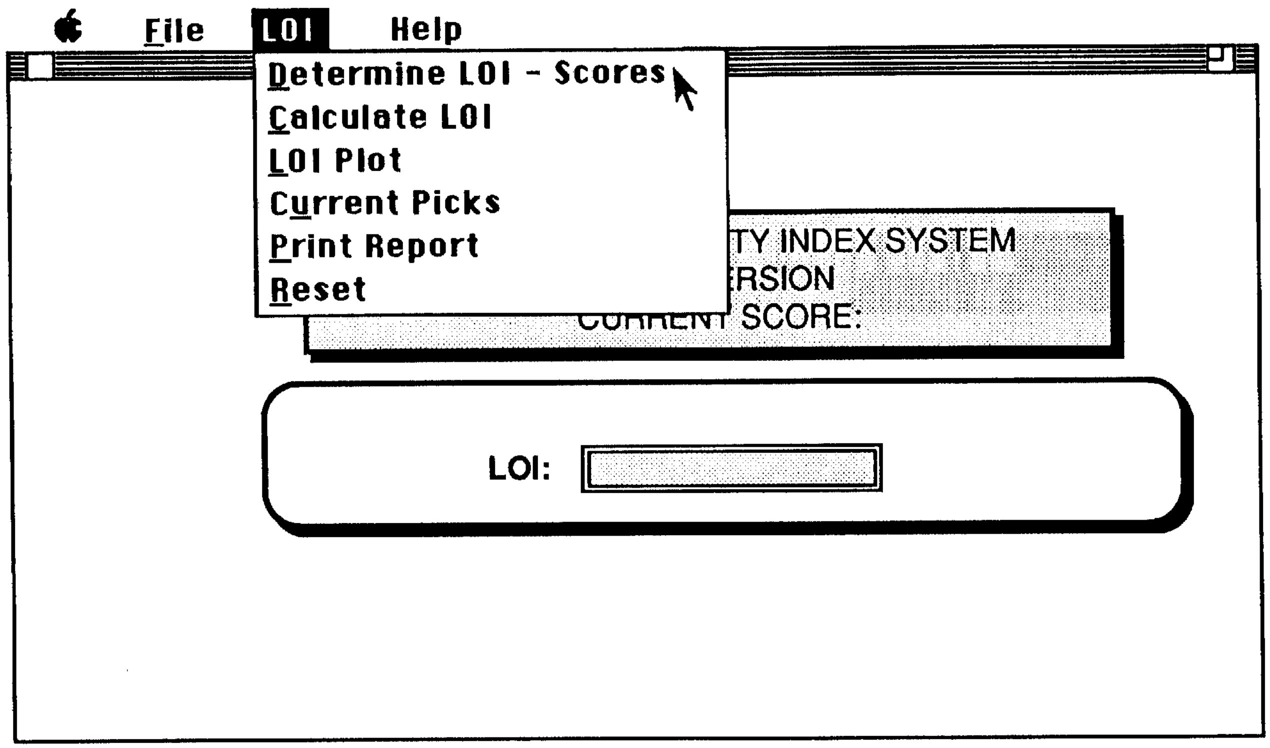
## 5.0 Prototype LOI Program

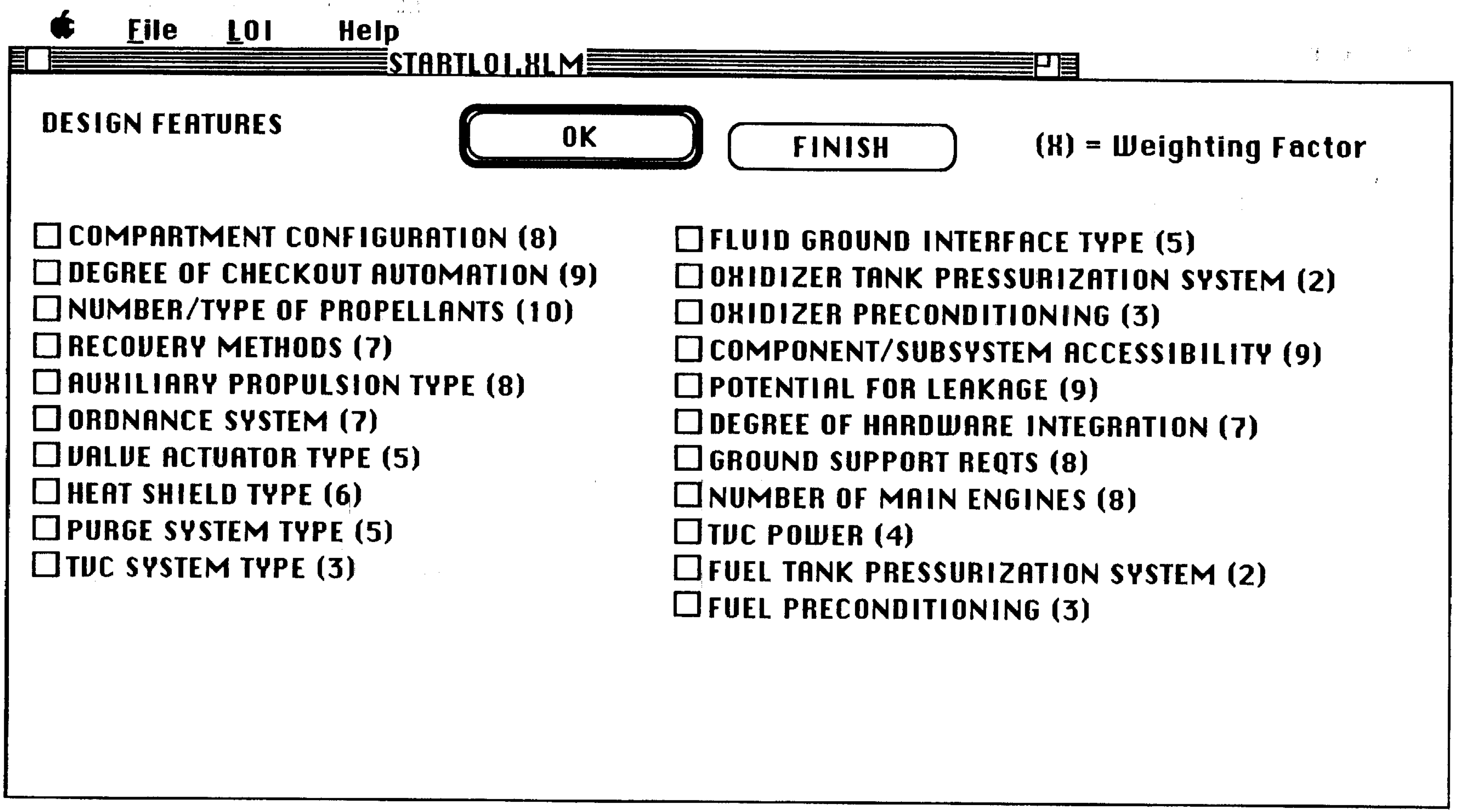
A prototype LOI Program was developed to calculate the Launch Operability Index of propulsion system designs. The LOI is based on the OEPSS program concerns list with additional inputs received from workshops at JSC, MSFC and KSC. The prototype program is available for both IBM compatible and Macintosh computers. Examples of running the program and program output are presented in Figures 3 through 7.




The prototype LOI is Exel based, with both Macintosh and IBM compatible versions available. Opening the **STARTLOI.XLM** file results in the window shown here. Selecting the **LOI** menu provide the options shown.

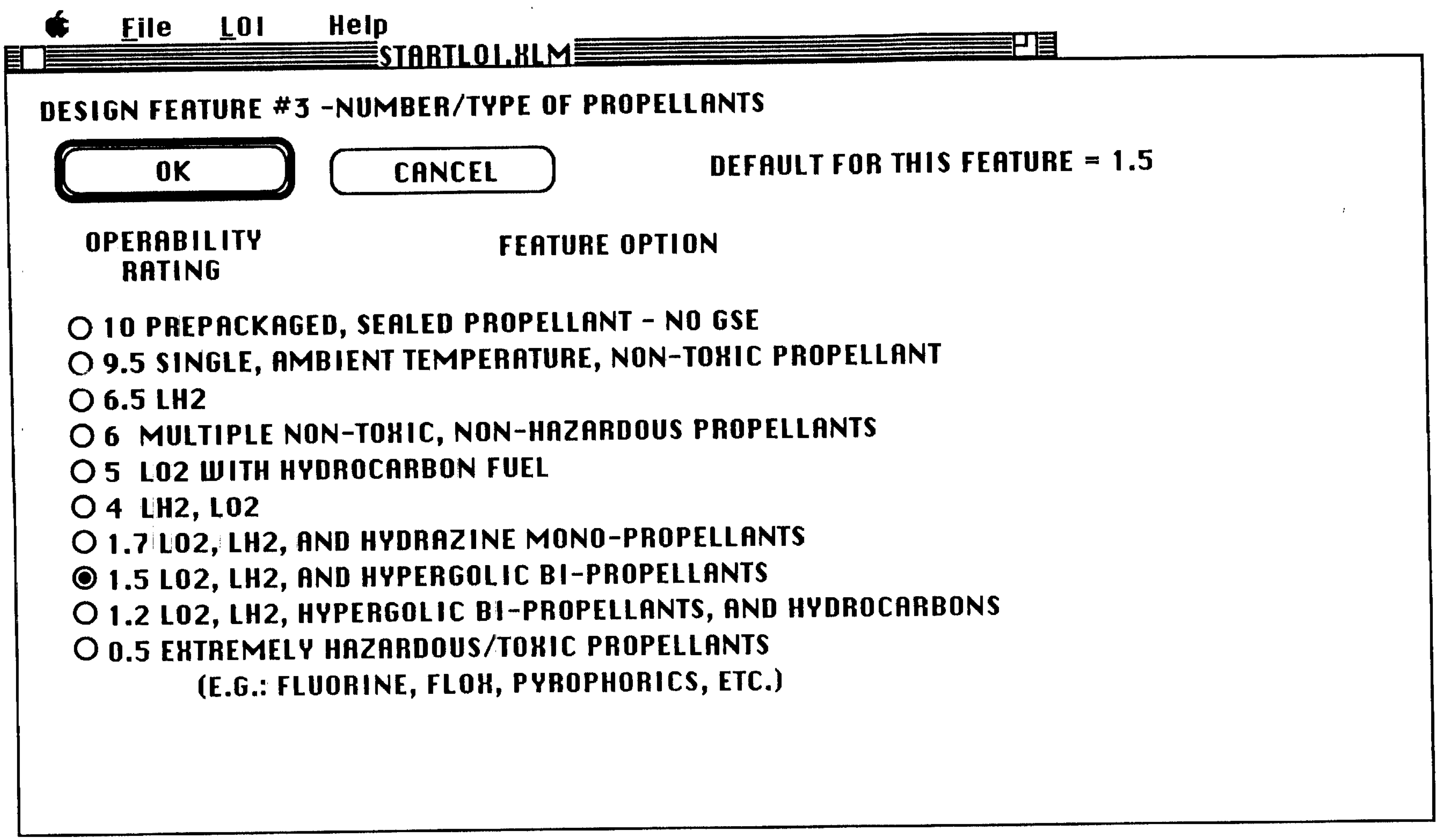
When evaluating a system, the first step is to select **Determine LOI - Scores.**

**Figure 3. Prototype LOI Program Opening Screen**



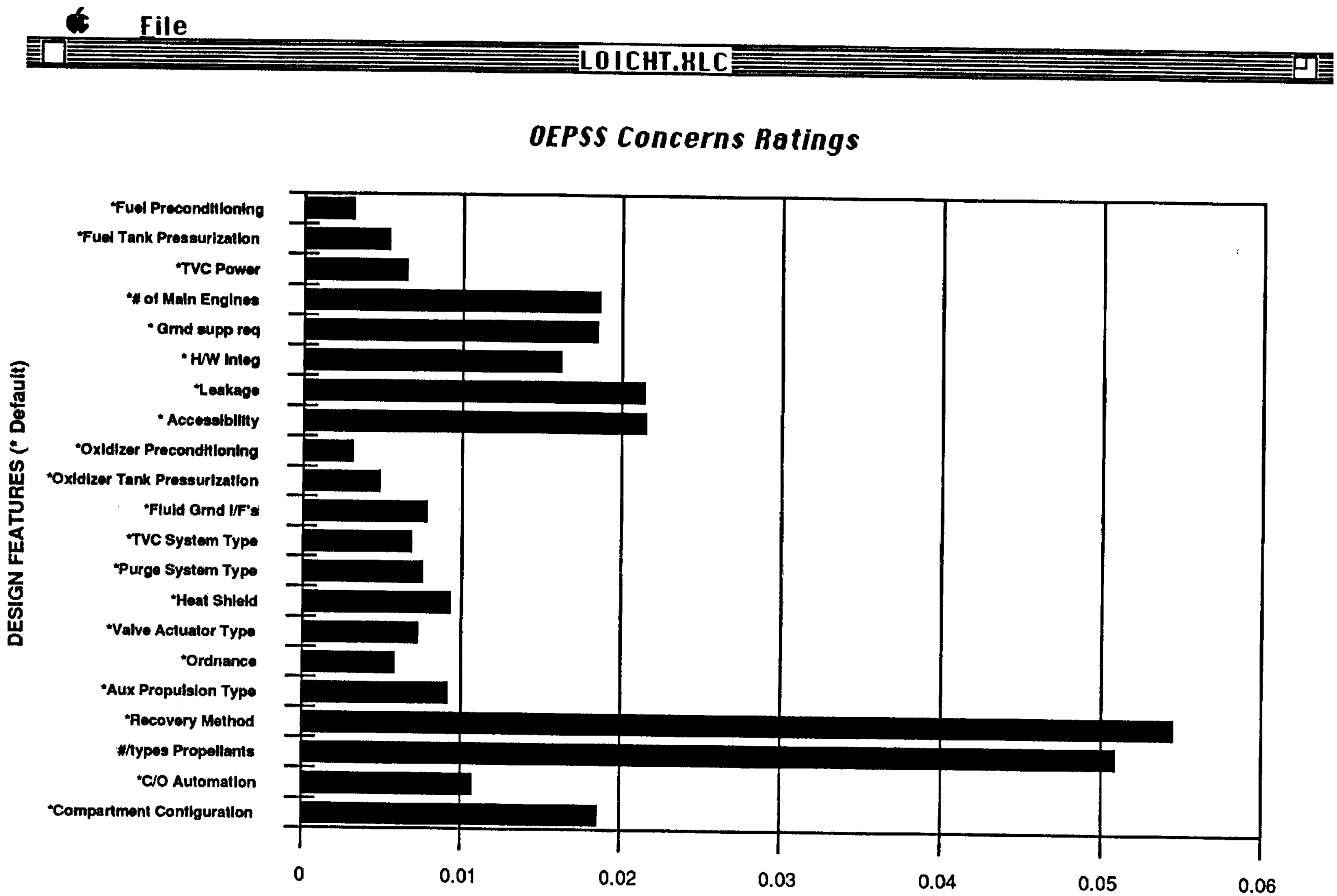

When the select **Determine LOI - Scores** option is selected this window appears. The user then selects any or all of the design features for scoring and then selects the **OK** button. Those not selected will utilize the default values in calculating the total LOI score.

**Figure 4. Determine LOI Scores Screen**



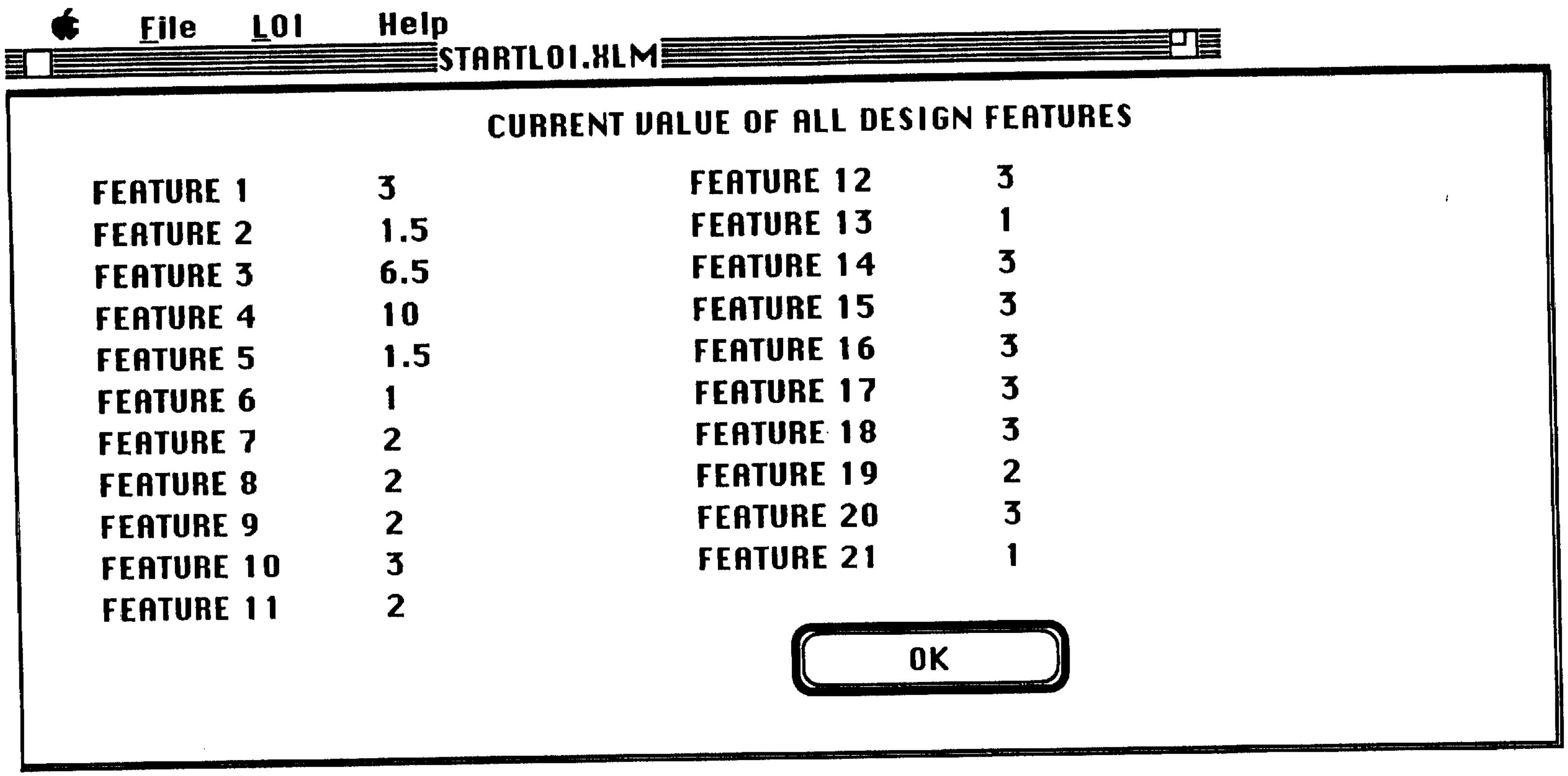

The user is then presented with window for each design feature previously selected for scoring. He then selects the feature option most closely resembling that of the system being evaluated. For example, if the system uses LO2, LH2, and hypergolic bi-propellants, the button adjacent to that option is selected and a rating of **1.5** is provided for the LOI calculation. The **OK** button is then selected and the next design feature chart is presented. When all the desired design feature options have been defined the window from the preceding page reappears. The user may select additional design features for scoring or may select **FINISH** indicating no further input data. The program then calculates the LOI score and displays it in the first window.

**Figure 5. Sample Design Feature Screen**




Selecting **LOI Plot** from the **LOI** Menu in the first window opens the above chart. This shows how each feature combined with its weighting factor contributes to the calculated operability rating. The asterisk by the feature name indicates the default was used in the calculation.

**Figure 6. LOI Design Feature Contribution to LOI Rating Screen**




Selecting **Current Picks** from the **LOI** Menu in the first window opens the above chart. This shows the current score for each feature.

**Figure 7. Design Feature Operability Rating Screen**

# REPORT DOCUMENTATION PAGE

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Rocketdyne Division
Rockwell International Corporation
6633 Canoga Avenue
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* Block 4 Con't: Vol X, Air Augmented Rocket Afterburning; OEPSS Final Briefing/Report; OEPSS Video Script with Video

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