PRINCETON
SYNERGETICS
INC.

900 STATE ROAD
PRINCETON, NJ 08540
TELEPHONE (609) 924-2020
FAX (609) 924-6942

◆ STARS ◆
The Space Transportation Architecture Risk System

Submitted to

NASA
Marshall Space Flight Center
Huntsville, Alabama

In Fulfillment of MSFC P.O. #H-27284D

April 1997

Abstract

Because of the need to perform comparisons between transportation systems that are likely to have significantly different levels of risk, both because of differing degrees of freedom in achieving desired performance levels and their different states of development and utilization, an approach has been developed for performing early comparisons of transportation architectures explicitly taking into account quantitative measures of uncertainty and resulting risk. The approach considers the uncertainty associated with the achievement of technology goals, the effect that the achieved level of technology will have on transportation system performance and the relationship between transportation system performance/capability and the ability to accommodate variations in payload mass. The consequences of system performance are developed in terms of expected values and associated standard deviations of nonrecurring, recurring and the present value of transportation system life cycle costs. Typical results are presented to illustrate the application of the methodology.

Acknowledgments

The STARS methodology was developed by Mr. Joel S. Greenberg who also authored this report. He was assisted by Mr. John Best who implemented the STARS Model and by Ms. Carole Gaelick who was responsible for the structure of the STARS input/output system. The reported work was performed under the technical direction of Dr. John Mankins, NASA Headquarters.

Approved by: ______________________

Joel S. Greenberg
President

Table of Contents

List of Figures

Introduction

In order to make informed choices with respect to investments that will lead to lower cost and internationally competitive space transportation systems it is necessary to evaluate and compare options that are in various stages of research, development and operation and therefore are faced with different levels of risk. This implies that comparisons should be based upon metrics that explicitly and quantitatively include risk related measures as well as expected value measures. In addition, since a major goal of technology programs is risk reduction, it is necessary to measure the impacts of risk reduction on future decisions and costs. This requires metrics that include measures of risk. Convenient and informative metrics include the expected value and standard deviation of the present value of space transportation system life cycle cost and expected value and standard deviation of savings resulting from a transportation system relative to a base case. This implies that each considered transportation system alternative or architecture should be described in terms of a pair of attributes {m,s} that relate to expected life cycle cost [or savings] and the variability of life cycle cost [or savings] in terms of its standard deviation, respectively.

There are a relatively large number of space transportation architectures that may be appropriate for consideration as a highly reusable space transportation system [HRST] with the potential to significantly reduce Earth to low Earth orbit transportation costs. These include various single stage to orbit [SSTO], two stage to orbit [TSTO] architectures possibly in combination with current and enhanced ELVs. Each of these architectures requires a different mix of R&D and capital investment and results in different performance, schedule and operational cost uncertainties and associated levels of risk.[1,2,3]

There are three degrees of freedom associated with the development of new architectures: performance, cost and schedule. It is not possible to fix all three but may be possible to fix two. For example, if it is desired to achieve a specified level of performance, then cost [and possibly schedule] must be considered as an uncertainty variable.[4] If cost and schedule are specified, then performance must be considered as an uncertainty variable. In order to simplify the initial analysis that explicitly and quantitatively considers risk, it is assumed that all schedules are known and that either or both performance and cost are specified with resulting development cost risk and/or performance risk.[5]

---

1 Greenberg, J.S., "Reliability, Uncertainty and Risk Analysis of Space Systems - A Methodology for Decision Making," AMS Report No. 1085, Princeton University, December 1972.

2 Greenberg, J.S., and G.A. Hazelrigg, "Methodology for Reliability-Cost-Risk analysis of Satellite Networks," Journal of Spacecraft and Rockets, Vol. 11, No. 9, September 1974.

3 Greenberg, J.S., "A Simulation Analysis of Space Operations," IAA-87-621, 38th International Astronautical Federation Congress, October 1987.

4 A variable that can only be described by a range of uncertainty and the form of the uncertainty [i.e., a probability density function] within the range.

5 A detailed analysis of risk associated with architectures that rely on the development of new technology and/or significant advances in technology requires the use of an R&D simulation

The objective is to establish both the expected value and the standard deviation of the present value of the life cycle cost associated with performing a specified mission model[6] with alternative space transportation architectures. Since Certain highly reusable space transportation (HRST) systems may not satisfy all mission requirements (for example, inclination angles), architectures may include both HRST systems and expendable launch systems. The life cycle costs include the nonrecurring cost associated with the development of the transportation architectures, capital costs associated with launch facilities and launch vehicle fleets, transportation recurring costs, payload nonrecurring costs and recurring costs (particularly as effected by the different space transportation architectures), and the relative timing of all of the costs. The payload considerations must take into account the effect of transportation margins on payload design margins and the ensuing impact on payload cost.

Because of the complexity of the analysis of space transportation architectures, it is not reasonable to seek a closed mathematical solution for the development of risk metrics. Therefore Monte Carlo simulation techniques are utilized for the development of both expected value and risk measures. The Monte Carlo techniques make possible the determination of the probability distribution of the net present value of life cycle cost and related savings associated with different space transportation architectures.

The Monte Carlo Approach

Simulation may be defined as the imitative representation of the functioning of one system or process by means of the functioning of another. The computer simulation of space transportation architectures attempts to represent the development and operation of alternative space transportation architectures as a series of logical cost incurring events that occur over an extended period of time where the occurrence and cost of an event may be dependent upon the previous events. When the characterization of events requires one or more probabilistic descriptors, the simulation process may employ Monte Carlo techniques. Monte Carlo implies performing a large number [possibly measured in hundreds to thousands] of simulations utilizing the same deterministic mathematical model and/or algorithms but randomly selecting a set of input data according to the probability density functions [uncertainty profiles] that characterize the input data set. This is illustrated in Figure 1. The uncertainty profiles frequently represent subjective judgments with respect to the range and form [within the range] of uncertainty.

---

approach such as RADSIM as described by G.A. Hazelrigg and J.S. Greenberg in "Cost Estimating for Technology Programs," IAA-91-638, 42nd Congress of the International Astronautical Federation, 1991 and PSI's report entitled "Cost Estimating for Technology Programs" submitted to NASA Hq. July 1990.

6 In the current approach the mission model is assumed to be invariant as a function of architecture. In actuality, the different architectures may result in different costs [and prices] which will effect demand for space transportation services, hence the mission model. To take this into account would require a value to be ascribed to payloads [missions] not flown because of increased cost. This is well beyond the current activity.

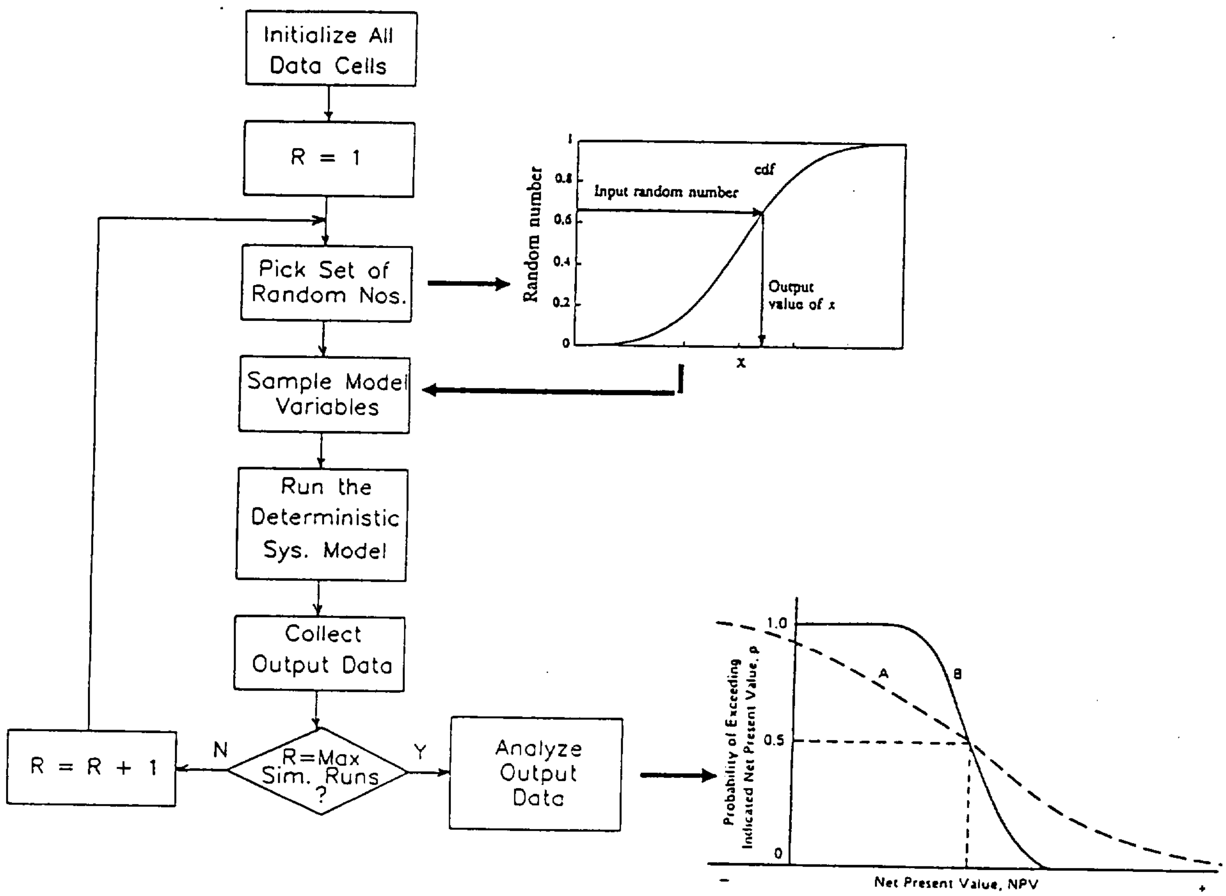


Figure 1 Monte Carlo Simulation Concept

The random sampling, according to the weighting of the probability density functions, allows a large number of different combinations of situations to be examined. The results of each of the many simulations are saved to create histograms or probability distributions of pertinent computed quantities [such as life cycle cost]. These results may be summarized in the form of expected values and standard deviations[7] with the latter being indicative of the risk or variability associated with the overall architecture as a result of uncertainty associated with the various input variables. *The mathematical model and/or algorithms serve to transform the input data uncertainty profiles into risk characterizations through the mechanism of random sampling coupled with large number of repetitions.*

As will become evident, Monte Carlo simulation is well suited for the risk analysis of space

[7] Because of the relatively large number of variables associated with the simulation of space transportation architectures, the probability distributions of the present value of life cycle cost and savings approach normality and the standard deviation [i.e., risk measure] takes on the meaning of the standard deviation of a normal distribution.

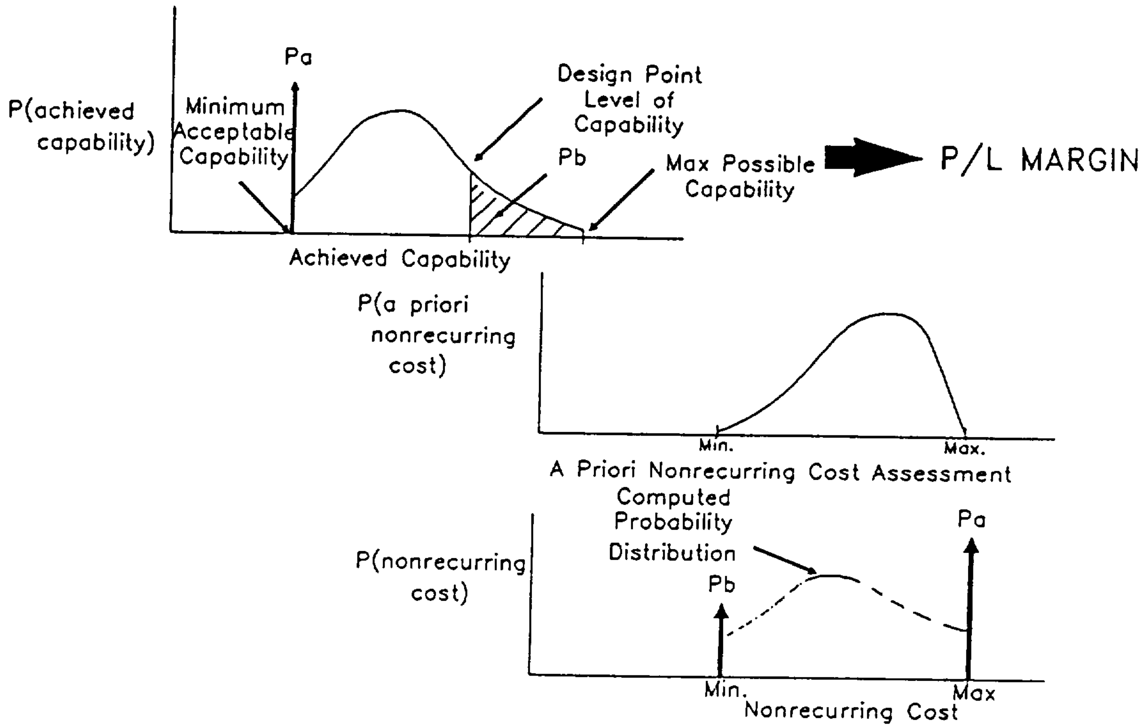


Figure 2 Development of Single Stage To Orbit Nonrecurring Cost Probability Distribution

transportation architectures. The modeling approach for performing comparisons of transportation alternatives that explicitly and quantitatively considers risk, considers generic single and two stage to orbit concepts based upon fully reusable, partially reusable and expendable systems.

Methodology

The objective is to establish the probability distribution of the present value of life cycle costs of performing a mission model over an extended period of time. The life cycle cost takes into account the nonrecurring costs, fleet and launch facility capital investments, annual transportation cost, and payload nonrecurring and recurring cost as effected by achieved transportation system capabilities. The probability distribution of life cycle cost is developed by performing a large number of Monte Carlo simulation runs wherein for each run a single value of capability, nonrecurring and other costs are established and a single present value of life cycle cost established. This is repeated a large number of times resulting in a histogram or probability density function for the present value of life cycle cost. The current methodology operates at a very high level of abstraction. In the future, detailed models can be developed that provide the level of detail necessary for replacing the high level of abstraction with more details. This is discussed further in following paragraphs. The intent is to first provide a course screen and create finer screens when found to be necessary.

In the following paragraphs the methodology is described for architectures that are based upon single and multiple stage[8] stage systems in combination with ELVs, as required to satisfy the fly-off of a mission model.

Single Stage To Orbit Architectures:

The basic approach [Figure 2] is to randomly sample a subjective assessment [provided in the form of a probability density function and referred to as an uncertainty profile] of achieved capability [for example, injected mass].[9] The random sampling of the injected mass probability density function will result in the determination of the probability that the minimum acceptable capability will not be exceeded [P_a]. However, an implied assumption is that funding will be provided so as to at least achieve the minimum acceptable level of capability. Thus, if a random sample of achieved capability is obtained that is less than the minimum acceptable level of capability, the minimum acceptable level of capability is assumed to be achieved at the maximum value of the a priori estimate of nonrecurring cost. If the random sample of achieved capability results in a level of capability greater than the design point capability, the random sample will be set equal to the design point or accepted as computed [the choice being specified as input data]. In the former case the assumption is that the "design point" will not be exceeded, i.e., funding will be adjusted accordingly. Thus there is a probability P_b that the minimum cost will be achieved (synonymous with the probability of exceeding the design point) and a probability P_a that the maximum cost will be achieved [synonymous with the probability of achieving the minimum acceptable level of capability].

If the random sample of achieved capability is less than the design point and greater than the minimum acceptable level of capability, the a priori assessment of nonrecurring cost will be randomly sampled to establish a nonrecurring cost between the specified minimum and maximum values. When this process is performed a large number of times, the nonrecurring cost probability distribution is established that takes into account the a priori assessment of nonrecurring cost uncertainty [at a specific design point] and the a priori assessment of performance or achieved capability uncertainty. Cost spreading of nonrecurring cost must be specified so that appropriate timing of annual nonrecurring cost may be established.

In addition to using the random sample of achieved level of capability to develop the nonrecurring cost probability distribution, the random sample is used to establish available payload design margins. This a posteriori payload design margin is defined as

P/L Margin = [A Priori P/L Design Margin] + [Achieved Injected Mass Capability / Design Point Injected Mass Capability] - 1

Since payload design margin is effected by the achieved level of transportation capability, and

---

[8] In the current methodology, multiple stages are limited to two [2].

[9] In the present Figures, all probability distributions are indicated as being continuous. In actuality, input data descriptors will be limited to minimum, maximum and most likely estimates and therefore result in triangular distributions.

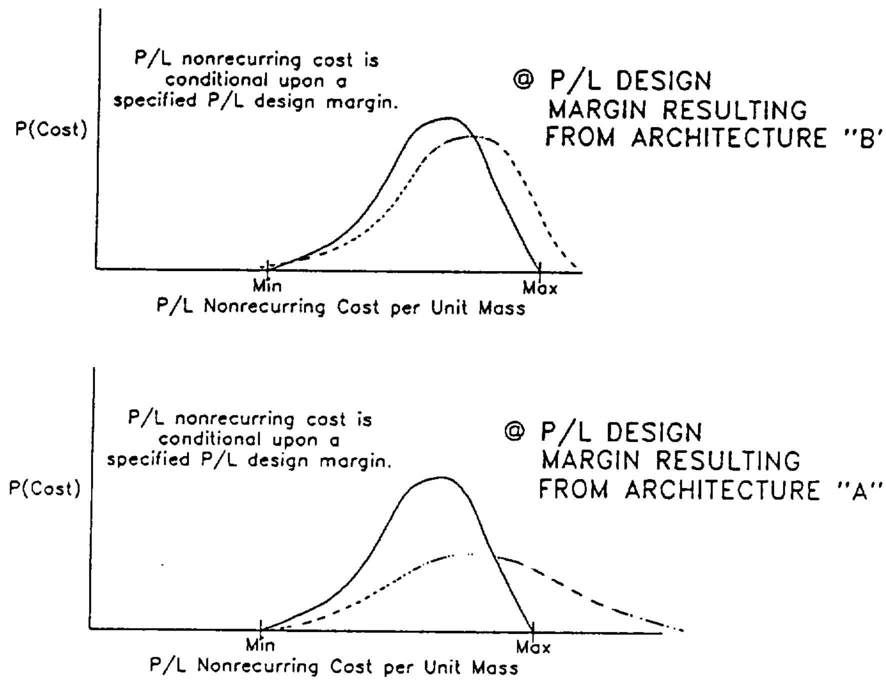


Figure 3 Subjective Assessment of P/L Nonrecurring Cost

since P/L cost is related to design margin, it is necessary to develop a relationship between P/L cost and design margin. To accomplish this subjective estimates may be provided for P/L nonrecurring cost per unit mass, as indicated in Figure 3, at a specified or a priori P/L design margin which is based upon achievement of the transportation system design point level of capability. Referring to Figure 3, it is assumed that when P/L margin decreases, then the minimum cost remains the same and the maximum [and most likely] cost increases. It is assumed that the uncertainty profile remains the same but the range of uncertainty is changed. This range change requires the estimation of a sensitivity coefficient that relates nonrecurring cost increase to decrease in P/L margin. This sensitivity coefficient of P/L design margin is described in terms of a second order polynomial. In a similar manner, when P/L margin increases, then the maximum remains the same and the minimum [and most likely] cost decreases.

Single Stage To Orbit fleet capital investment,[10] launch facility investment, transportation system delivery cost per unit mass and payload recurring cost per unit mass are also established using random sampling of specified ranges of uncertainty and weighted by a triangular probability distribution based upon the specification of maximum, minimum, and most likely values. Since there may not be a one for one correspondence between the number of satellites developed and satellites flown, an estimate is required of the ratio of satellites flown to satellites developed. Finally, an estimate of delivered payload mass [at the a priori design margin] is required as a

[10] No consideration has been given to the establishment of fleet size and the associated implications of reliability, resiliency and system operability.

function of time. To maintain flexibility for comparison purposes, allowance is made for the use of ELVs during transition to the reusable system and for those payloads that for one reason or another, will likely be launched by ELVs. Thus when comparing architectures, the annual payload mass delivered to LEO is maintained as constant across the architectures.

As a result, annual cost can be established as:

Annual Cost(I,R) = Nonrecurring Transportation System Cost(I,R) + Fleet Capital Investment(I,R) + Launch Facility Capital Invest(I,R) + [RLV Transport. Sys. Cost per Unit Mass(R) + K * Payload Nonrecurring Cost per Unit Mass(I,R) + Payload Recurring Cost per Unit Mass(I,R)] * [Payload Delivered Mass(I) * F(I)] + [ELV Transportation System Cost per Unit Mass(R) + K * Payload Nonrecurring Cost per Unit Mass(I,R) + Payload Recurring Cost per Unit Mass(R)] * [Payload Delivered Mass(I) * (1 - F(I))]

where K is the ratio of satellites developed to satellites flown [or stated another way, the reciprocal of the average number of P/Ls per mission], I is an index that refers to time [i.e., years], R is the Monte Carlo run index and F(I) is the fraction of payload mass placed into orbit on a reusable launch vehicle. Thus each variable containing an R index will be dimensioned according to the specified number of simulation runs to be performed. The present value of life cycle costs, PVLCC, is

$$PVLCC(R) = \sum_{I} [\text{Annual Cost}(I,R)] / [1 + d]^{I}$$

where d is the discount rate. The expected value (m) and standard deviation (σ) of the distribution of PVLCC are given by

$$m = [\sum_{R} PVLCC(R)] / MAXR$$

$$\sigma = [\{\sum_{R} PVLCC(R)^2\} / MAXR - m^2]^{0.5}$$

where MAXR is the number of Monte Carlo runs performed.

To establish the expected value and standard deviation (i.e., risk) of a single stage to orbit architecture, the following types of data are required:[11]

- Design point and minimum acceptable injected [into LEO] mass capability.
- Minimum, maximum and most likely achievable injected mass [into LEO] capability.
- A priori minimum, maximum and most likely Single Stage To Orbit nonrecurring cost.
- A priori minimum, maximum and most likely Single Stage To Orbit LEO delivery cost per unit payload mass.
- A priori minimum, maximum and most likely Single Stage To Orbit capital cost per vehicle.
- A priori minimum, maximum and most likely launch complex investment.
- Number of vehicles in the Single Stage To Orbit fleet.

---

11 Specific data requirements are presented in the following pages.

In addition, data must be provided for the following types of variables that may be reasonably assumed to be independent of transportation system architecture:

- Minimum, maximum and most likely payload nonrecurring cost per unit mass at the nominal payload design margin with the design point injected mass capability.
- Sensitivity of payload nonrecurring cost to decreasing payload design margin.
- Minimum, maximum and most likely payload recurring cost per unit mass at the nominal payload design margin with the design point injected mass capability.
- Sensitivity of payload recurring cost to decreasing payload design margin.
- Nominal payload design margin.
- Average number of payloads launched per mission.
- Annual payload mass delivered to LEO at nominal payload design margin.

Finally, cost spreading functions need to be specified to establish reasonable timing of expenditures for present value computations.

Two Stage To Orbit Architectures:

A two stage to orbit system is presumed to consist of an upper stage having both performance and cost uncertainty that are conditional upon the performance achieved by the lower stage. The general approach for considering the effect of the first-stage upon the TSTO second-stage nonrecurring costs is illustrated in Figure 4. It is also presumed that both the performance and cost of each stage must be described, a priori, in terms of probability distributions as in the case of the Single Stage To Orbit. The major difference between the TSTO and SSTO analyses is that the a priori probability distribution of second- stage performance is specified given the first- stage design point. The analysis proceeds (using Monte Carlo simulation techniques) by randomly sampling the first-stage achieved capability probability distribution. If the sample results in a capability less than the minimum acceptable value, the maximum nonrecurring cost is utilized; otherwise the a priori probability distribution of nonrecurring cost is sampled. When this process is repeated a large number of times, the a posteriori probability distribution of cost is established with the maximum cost occurring with a probability P_{a1}. The second-stage a priori probability distribution of capability is also randomly sampled with a new level of capability being established based upon the sampled capabilities of both stages. This implies that a functional relationship exists between first- and second-stage performance.

The a posteriori probability distributions of second-stage performance and nonrecurring cost are established by setting the achieved capability to the minimum acceptable value and the cost to the maximum value when the random sample of capability is less than the minimum acceptable capability level. Similarly, if the capability [as adjusted to reflect the first-stage capability] exceeds design point, the a posteriori capability is set equal to the design point and the cost is set equal to the minimum of the range of costs. If the random sample is between these two extremes then the probability distribution of capability and cost are sampled. This results in the a posteriori nonrecurring cost distributions as indicated in Figure 4 with the indicated probabilities P_{a2} and P_{b2}. In addition to using the random sample of achieved level of capability to develop the nonrecurring cost probability distribution, the random sample is used to establish available payload design margins. The P/L design margins take into account the capability established for both stages and are used to modify the a priori P/L nonrecurring cost per unit mass estimates.

As for the SSTO case, TSTO fleet capital investment, launch facility investment, transportation system delivery cost per unit mass and payload recurring cost per unit mass are also established. Since there may not be a one for one correspondence between the number of satellites developed

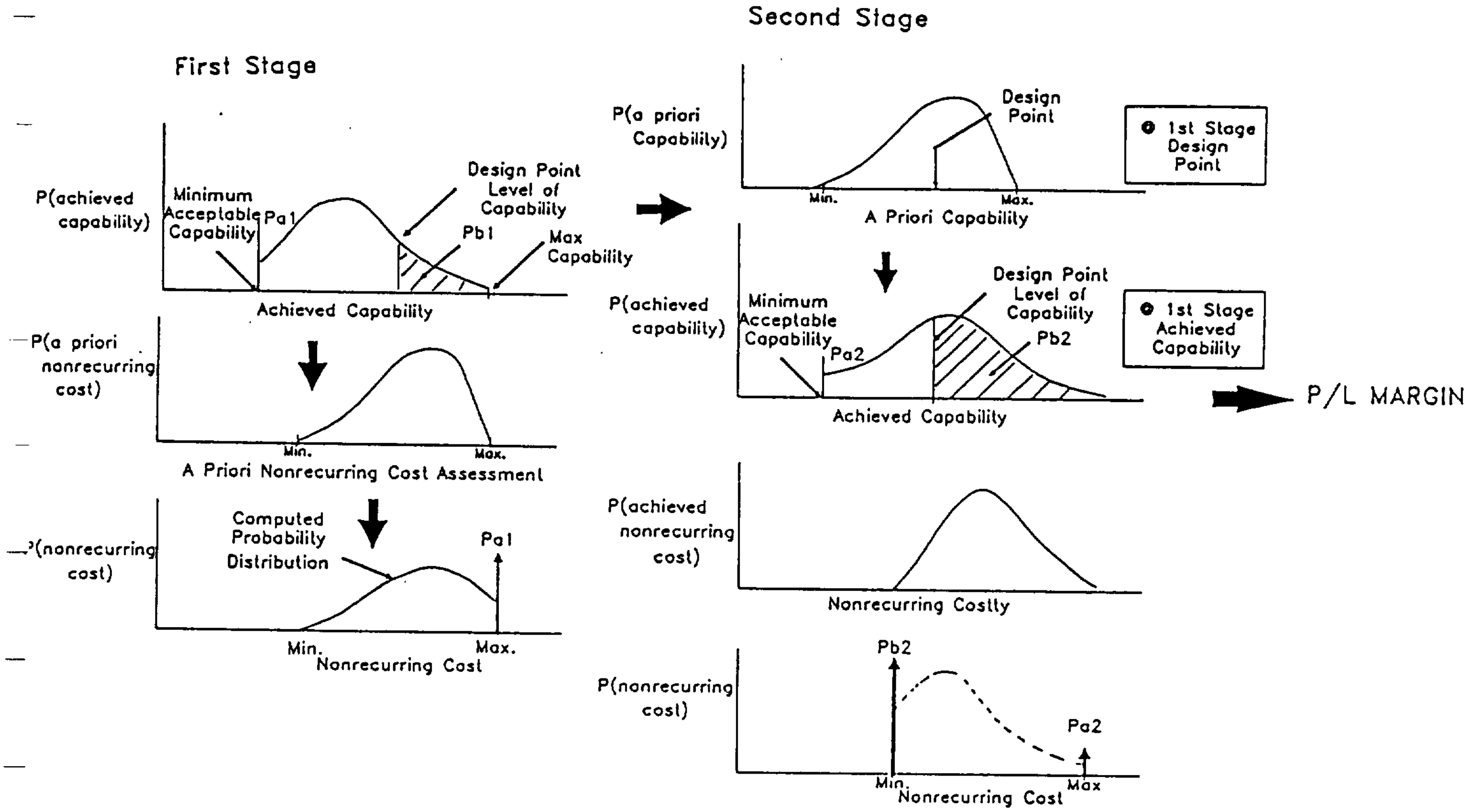


Figure 4 Development of Two Stage To Orbit Nonrecurring Cost Probability Distribution

and satellites flown, an estimate is required of the ratio of satellites flown to satellites developed. Finally, an estimate of delivered payload mass [at the a priori design margin] is required as a function of time. Allowances may be required for first-stage reliability/reusability.

As a result, annual cost is established as described for the SSTO. The SSTO and TSTO life cycle costs as computed by the above process are comparable since they include both the expected value and risk dimensions. Differences are reflected in the computed a posteriori probability distributions which then result in different expected values and risk.

The Two Stage To Orbit analysis requires the specification of at least the following key data items:

- First-stage design point and minimum acceptable level of capability.
- First-stage minimum, maximum and most likely achievable capability.
- First-stage a priori minimum, maximum and most likely nonrecurring cost.
- Second-stage design point and minimum acceptable level of capability.
- Second-stage minimum, maximum and most likely achievable capability at the first-stage design point.
- Second-stage a priori minimum, maximum and most likely nonrecurring cost.

- Functional relationship between first- and second-stage capabilities.
- A priori minimum, maximum and most likely Two Stage To Orbit LEO delivery cost per unit payload mass.
- A priori minimum, maximum and most likely Two Stage To Orbit capital cost per vehicle.
- A priori minimum, maximum and most likely launch complex investment.
- Number of vehicles in the Two Stage To Orbit fleet.

In addition, the same data must be provided as for the Single Stage To Orbit for the variables that may be reasonably assumed to be independent of transportation system architecture and cost spreading functions need to be specified to establish reasonable timing of expenditures for present value computations.

A Typical HRST Architecture:

The following discussion is presented to clarify and expand upon the use of the STARS Model. The discussion uses a Maglev architecture as a typical example of an HRST architecture. The data utilized and the results obtained are presented for illustrative purposes only and should not be taken as a definitive analysis and/or evaluation of a Maglev Architecture.

"Maglev Architecture" refers to an Earth to orbit [ETO] launch concept that employs a catapult that uses superconducting maglev to achieve dramatically augmented payload capacity in ETO transportation systems, while reducing mission costs.[12,13] Unlike other "gun" concepts, the Maglev architecture does not require extremely high accelerations, does not involve radical changes in payload [i.e., spacecraft] design or components, and does not require very high launch rates to achieve economical operations.

Maglev is straightforward in its conception. The payload capacity of a wide range of vehicles – but especially SSTO vehicles – can be significantly increased with the provision of a relatively small 'assist' during the first minute of the launch to LEO by means of a ground-based catapult system. Maglev provides this assist via an advanced, high-speed maglev guideway and carrier vehicle[s]. The system – depicted in Figure 5 – consists of the following major elements:

- A highly robust structural support system [to altitude], typically a tunnel inside a mountain [acceleration phase, having a length of several miles], and an external guideway support system on the mountain [deceleration phase, also having a length of several miles].

  A long maglev guideway, including the accelerator system and the carrier decelerator. Typically, the accelerator system will be enclosed in a tunnel [or pressurized tube] which will be filled with a gas at partial pressure – i.e., Helium – with a low density and a high speed of sound.

- A local power supply system, such as a superconducting magnetic energy storage system, which may be charged from the local power grid and then discharged during a launch sequence. Other options exist [such as using a battery of gas turbines for direct power

---

12 Mankins, J.C, "Maglifter: An Advanced Concept for Reducing the Cost of Earth-to-Orbit Transportation," a NASA White Paper, December 5, 1993.

13 Mankins, J.C., "The Maglifter: An Advanced Concept Using Electro-Magnetic Propulsion in Reducing the Cost of Space Launch," AIAA 94-2726, 30th Joint Propulsion Conference, June 1994.

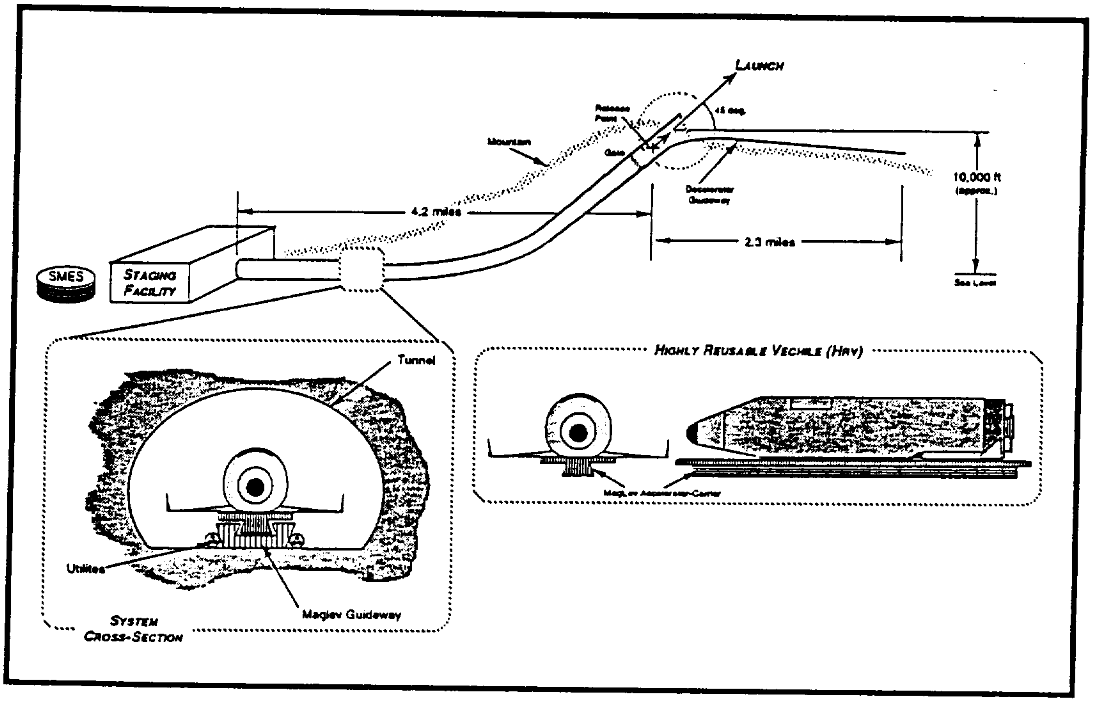


Figure 5 A Typical Maglev Concept [Source: Mankins, December 1993]

generation during launch]. The final choice would be based on the results of studies of life cycle costs, R&D investment values, etc.

- A set of fully reusable maglev 'accelerator-carriers" which provide the initial acceleration for the vehicles to be launched. These carriers, which may need to be 'ganged' for launching larger vehicles, would accommodate 'cradles' capable of structural support to vehicles during acceleration as well as rapid, controlled release at the appropriate point in the catapult sequence. They would also provide any needed support for vehicles during the launch sequence [approximately 1 minute in duration].

- A Launch/Exit system which will provide a managed transition from the environment inside the tunnel and on the guideway to free flight in the external environment. Active control of both the vehicle and the accelerator-carrier will be required during the transition.

- A Staging Facility, including maglev carrier staging, vehicle-carrier integration, launch vehicle staging [specific to vehicles and payloads], servicing and maintenance facilities, and an operations control center.

Typically, the vehicle launch would emerge from the Maglev system at an altitude of approximately 10,000 feet, at velocities of about 600 mph. At exit from the launch system, the angle of the velocity vector of the center of gravity of the vehicle would be approximately 45 degrees [measured from the local horizontal]. The maximum acceleration during the acceleration phase of launch would be approximately 3 gravities. All of these parameters are subject to variation through design trades and analyses currently underway.

ARCHITECTURE SUMMARY

Architecture Description:	Argus with Maglifter		
	Typical Example: Georgia Tech - AE		
Reference Number:	1003	Date:	4/11/97
Start of HRV Operations:	2010		
Can Exceed Design Point:			
Stage 1	1		
Stage 2	1		

	Expected	Std. Dev.	
Trans. Sys. Nonrec. Cost	5,416	1661	(M$)
HRV Unit Cost	704	242	(M$)
HRV Fleet Investment	2,112	725	(M$)
Infrastructure Investment	2,333	522	(M$)
Launch Cost/Unit PL Mass	5	0.00	(K$/kg)
PL Nonrec. Cost/Unit Mass	42	3.97	(K$/kg)
PL Rec. Cost/Unit Mass	20	1.21	(K$/kg)
PL Design Margin	5	4.23	(%)
Infinite Horizon Discounting	N		
Present Value of Oper. Sys. LCC	394661	11784	(M$)
Present Value of Tech. Prog.			(M$)

Figure 6 Architecture Summary Information

A typical set of assumptions[14] describing a Maglev architecture are presented in the Appendix in the form of data for the STARS Model. Associated with this data are the computed results in terms of annual and life cycle costs.

STARS developed results are presented in a series of reports as illustrated in Figures 6 through 9 [based upon the data provided in the Appendix].. Figure 6 presents information that provides an overview of the architecture being analyzed. All computed results include both expected and standard deviation values. Of particular importance are the present value expected value and standard deviation data that provides the basic information for the comparison of alternative architectures. The "Infinite Horizon Discounting?" response indicates whether infinite horizon discounting is considered or discounting within the specified life cycle cost time frame [finite] is considered. Figure 7 provides an annual cost summary of the considered architecture. Figure 7 indicates the annual nonrecurring and recurring costs. The nonrecurring cost includes HRV stage 1, HRV stage 2, infrastructure, HRV payload, ELV payload [when ELV flights are required in conjunction with HRV flights to place the mission model payloads into orbit], HRV fleet investment, HRV fleet replacement, and research and technology costs. The recurring cost includes HRV launch operations, ELV launch operations, and HRV and ELV payload recurring costs. Figure 8 presents the architecture annual costs in graphic form with expected nonrecurring, recurring and total costs illustrated as a function of time. Figure 9 summarizes the architecture nonrecurring, recurring and total cost on a cumulative basis.

14 Bases upon data provided by Dr. John Olds, Georgia Institute of Technology.

ARCHITECTURE ANNUAL COST (M$)

Architecture Description: Argus with Maglifter

Typical Example: Georgia Tech - AE

Reference Number: 1003 | Date: 4/11/97

Start of HRV Operations: 2010

Year	2009	2010	2011	2012	2013	2014
HRV Stage 1	39	0	0	0	0	0
HRV Stage 2	463	231	0	0	0	0
Infrastructure	0	0	0	0	0	0
HRV Payloads	0	0	3,723	10,110	19,642	22,258
ELV Payloads	15,651	17,203	14,553	10,015	2,229	1,160
Fleet Investment	422	211	0	0	0	0
Fleet Replacement	0	0	106	106	106	106
Technology Program	0	0	0	0	0	0
Total Nonrecurring Cost	16,575	17,645	18,382	20,230	21,977	23,523
* Std. Deviation *	1673	1832	1655	1354	1886	2061
HRV Launch Ops.	0	0	79	214	416	472
ELV Launch Ops.	5,670	6,124	5,262	3,572	771	414
HRV Payloads	0	0	5,212	14,154	27,499	31,161
ELV Payloads	22,326	24,112	20,718	14,065	3,036	1,630
Total Recurring Cost	27,996	30,235	31,271	32,006	31,723	33,677
* Std. Deviation *	1390	1501	1303	1179	1679	1902
Total Annual Cost	44,571	47,881	49,653	52,236	53,699	57,200
* Std. Deviation *	2175	2368	2106	1796	2525	2805

Figure 7 Architecture Annual Cost Summary

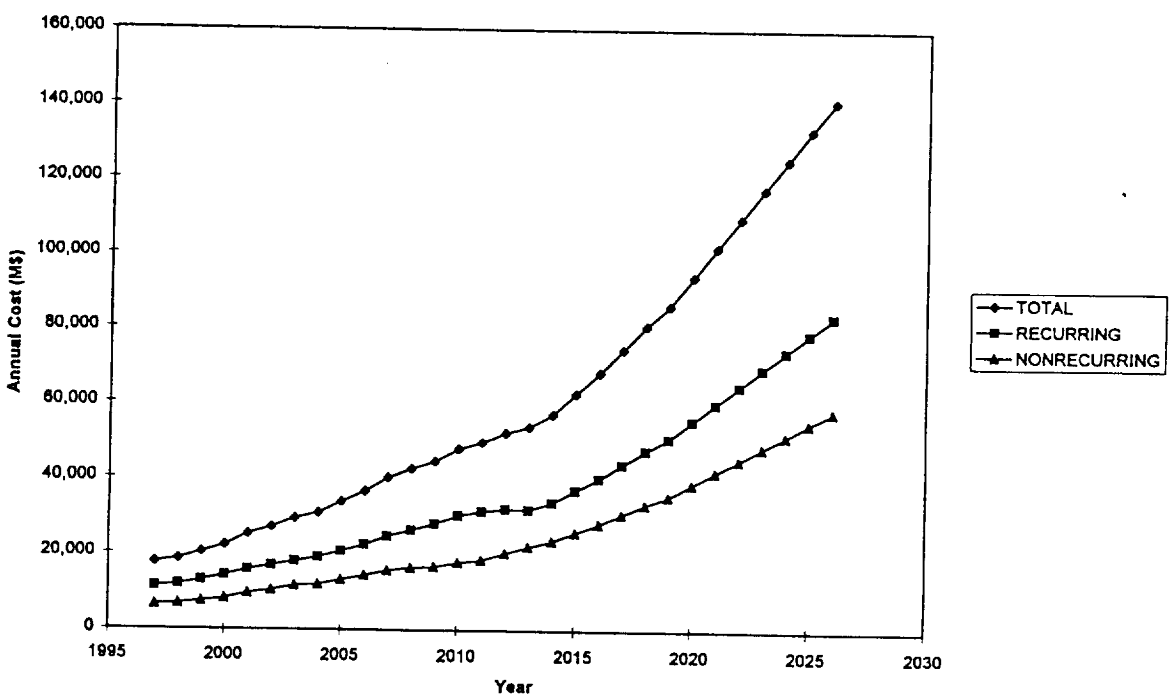


Figure 8 Graphical Representation of Architecture Annual Cost

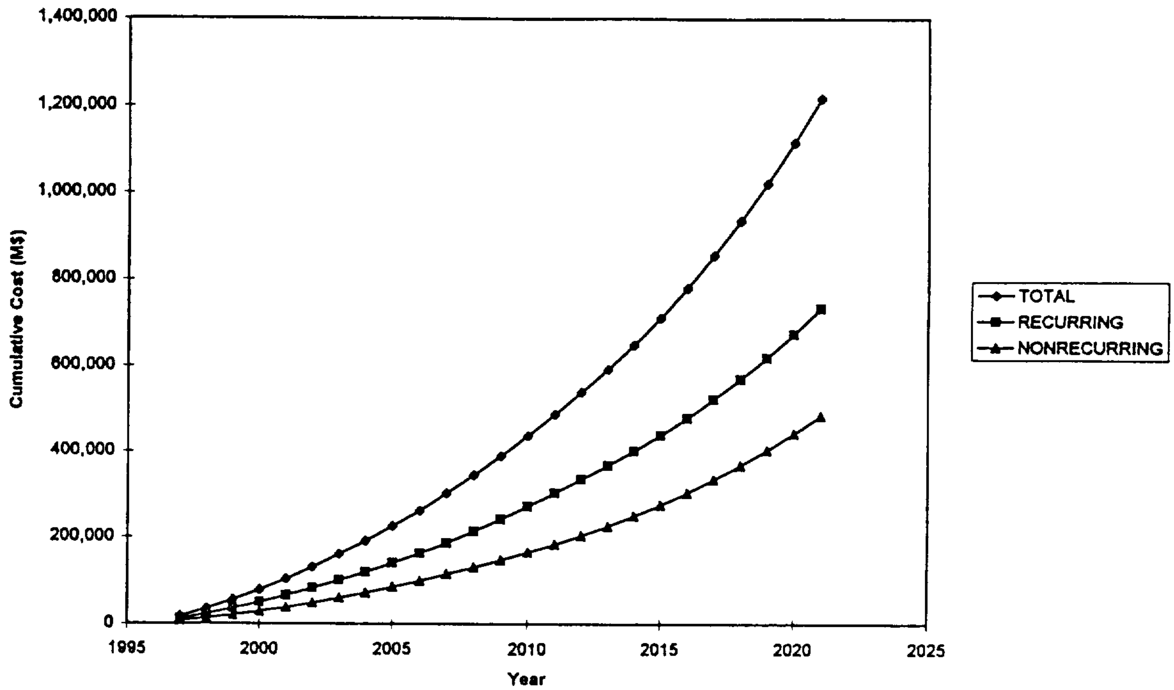


Figure 9 Graphical Representation of Architecture Cumulative Cost

ARCHITECTURE SUMMARY

Architecture Description: Argus with Maglifter
Typical Example: Georgia Tech - AE

Reference Number: 1003 Date: 4/11/97

Start of HRV Operations: 2010

Can Exceed Design Point:
Stage 1: 1
Stage 2: 1

	Expected	Std. Dev.	
Trans. Sys. Nonrec. Cost	5,416	1661	(M$)
HRV Unit Cost	704	242	(M$)
HRV Fleet Investment	2,112	725	(M$)
Infrastructure Investment	2,333	522	(M$)
Launch Cost/Unit PL Mass	5	0.00	(K$/kg)
PL Nonrec. Cost/Unit Mass	0	0.00	(K$/kg)
PL Rec. Cost/Unit Mass	0	0.00	(K$/kg)
PL Design Margin	5	4.23	(%)
Infinite Horizon Discounting	N		
Present Value of Oper. Sys. LCC	36325	777	(M$)
Present Value of Tech. Prog.			(M$)

Figure 10 Architecture Summary Information with Payload Related Costs Eliminated

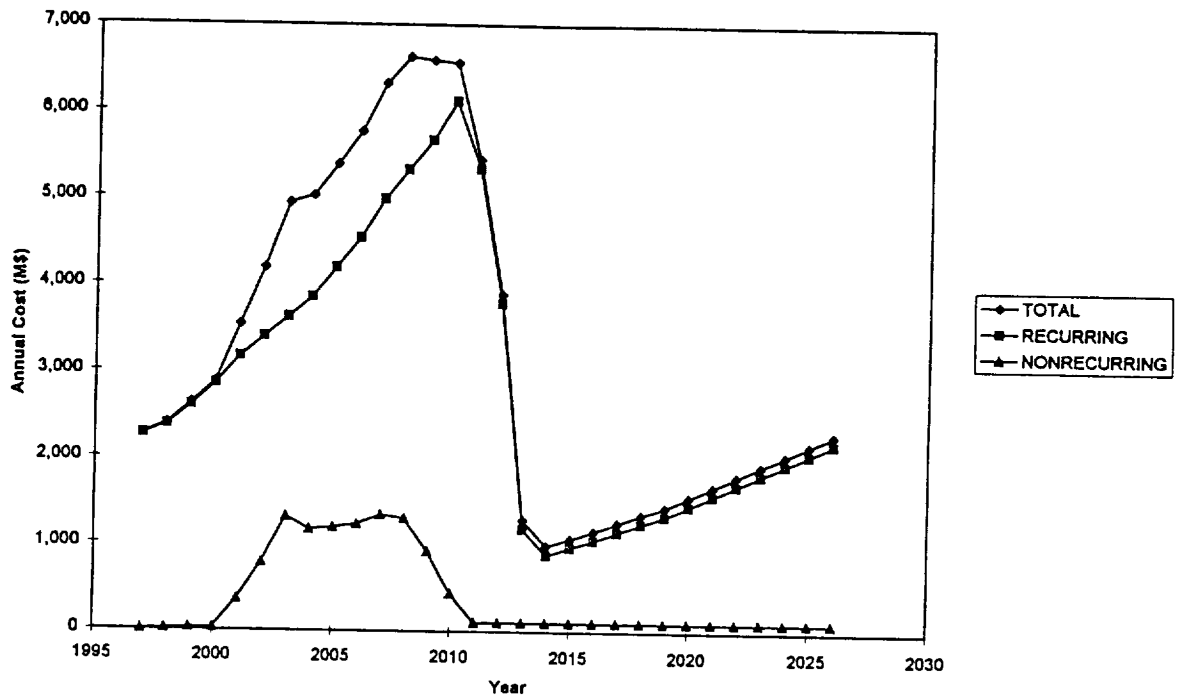


Figure 11 Graphical Representation of Architecture Annual Cost with Payload Related Costs Eliminated

The dominance of payload related costs can be observed by setting the payload recurring and nonrecurring costs per unit mass to zero. Obtained results are illustrated in Figures 10 and 11 and indicate only transportation related costs.

Comparison of Architectures:

The economic comparison of advanced space transportation architectures involves establishing cash flow patterns that occur over many years; thus, it is desired to present the results of analyses in terms of the present value of costs. The present value [previously indicated as PVLCC(R)] takes into account the magnitude and the timing of cash flow patterns, was previously discussed and defined as the summation of future annual costs discounted to the present. Also as previously described, the annual costs entering into the present value computation are not deterministic quantities because of the uncertainties in predicting level of achieved performance, and recurring and nonrecurring costs. Thus the present value of costs must also be characterized by a probability distribution which can be summarized in terms of its expected value, m, and standard deviation, σ, with the latter indicating the risk dimension.

Since the present value of life cycle cost of each transportation architecture is characterized by both an expected value and a standard deviation [i.e., the risk dimension], a tradeoff between expected cost and risk must be made to select a best or most desired alternative. This is illustrated in Figure 12 where all of the points in the m-σ space represent alternatives that will result in satisfying a specified mission model. Indicated are alternatives 1 and 2 having the same level of risk (i.e., $\sigma_1 = \sigma_2$), but the expected present value of cost of alternative 1 is greater than

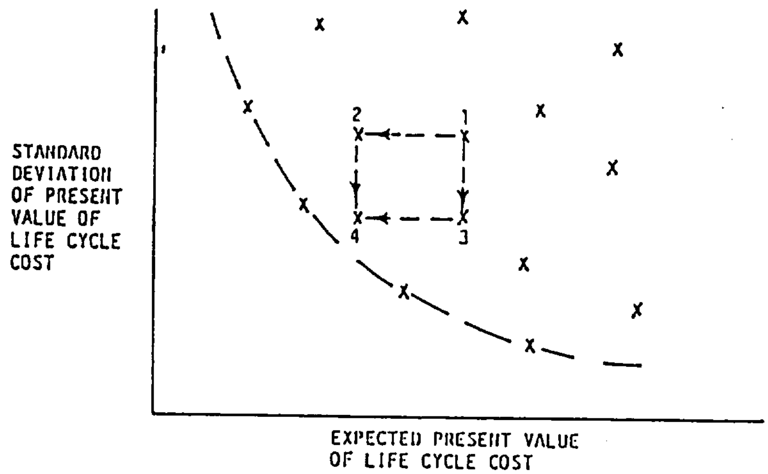


Figure 12 General Problem of Decision Making Under Uncertainty

that of alternative 2. Therefore, alternative 2 is preferable to alternative 1. In a similar manner, it can be argued that alternative 4 is preferable to alternative 3. Also in a similar manner, alternative 3 is preferable to alternative 1 since both have the same expected present value of cost, but alternative 1 is riskier. This process can be continued with all alternatives being considered. In the limit, it can be seen that a frontier of "best" alternatives can be established. Each of the points or alternatives represented by the frontier are different in the respect that the risk and expected present value are different. The class of best alternatives has thus been obtained and the "best" alternative can be selected based on the decision maker's risk judgment. That is, the decision maker must decide what the tradeoff is between a reduction in expected present value of cost and an accompanying increase in risk.

The analysis and the determination of expected present value and risk makes it possible to identify and then focus attention on those alternatives that appear to be most attractive [i.e., lie on or are close to the frontier of best alternatives]. In accomplishing this it is necessary to compare alternatives on a common basis. To achieve this common basis a demand scenario [i.e., mass delivered to orbit as a function of time] has been assumed. However, demand will most likely be related to transportation price [so far only cost has been considered] and architectures having significantly different costs [and prices] will ultimately have to be considered as well as their effect on payload demand through price elasticity considerations. All is not lost, however. Since architectures that are not significantly different in cost are likely to be compared, utilizing the same demand scenario may still give reasonably comparative results. In addition, utilizing a common demand scenario is likely to overstate the cost differences between architectures without changing the order of desirability. In any event, to totally avoid this problem would require the development of a pricing and demand component for STARS and the consideration of metrics other than present value of life cycle costs.

Suggestions for a More Robust STARS Capability

The present STARS Methodology results in the estimation of the expected value and standard deviation of the present value of life cycle cost. The implication is that informed choices can be made with respect to identifying preferred architectures using cost based metrics. The decision problem and process becomes more complex when private sector involvement in the architecture is required and decisions go beyond the theoretical identification of the best alternative. For example, the present value of the amount spent by government on a technology program must be equal to or less than the present value of the savings that are likely to result for the government. The savings are clearly related to the price that the government must pay for the resulting private sector provided transportation services.

When government owns and operates the transportation system, price and cost are the same. However, if the private sector own and operates the resulting transportation system [as is today's goal], government cost and resulting savings will be based upon private sector business decisions. These decisions ultimately result in a pricing policy that provides an adequate rate or return on investment to offset risk perceptions. Thus, decisions relating to the development and funding of a technology program must consider both the public and private sectors' roles with the architectures.

To bring private sector concerns into the analysis requires that the STARS Model be modified so as to capture the essence of the role of the private sector and related investment decisions. This implies the development of a business planning model as an integral part of STARS with particular attention paid to pricing policies and market segmented demand elasticities. A number of pricing policies should be addressed: for example, pricing to maximize profit but with prices constrained by competitive pricing, and two-tier pricing [a government price for a specified duration or total delivered mass with commercial pricing to maximize profits].

The modeling challenge is to work at a reasonable level of abstraction without getting bogged down in the minutia of business financial analysis.

Summary

A methodology for performing comparisons of transportation architectures that explicitly and quantitatively considers risk has been developed including the appropriate software for operation in Excel within the Windows environment. The methodology, developed for comparisons between architectures that are based upon Single and Two Stage To Orbit concepts, and is applicable to a broad range of transportation architectures, takes into account the uncertainty with respect to achievement of technology goals, the effect that the achieved level of technology will have on transportation system performance and the relationship between transportation system performance capability and the ability to accommodate variations in payload mass. The consequences of system performance are developed in terms of nonrecurring, recurring and the present value of transportation system life cycle costs. Transportation system impacts on payload costs are also taken into account in the development of life cycle costs. *The results are in a form that will allow future space transportation system options to be compared explicitly taking into account expected present value of transportation system life cycle cost and the associated level of risk* as indicated by the standard deviation of the present value of life cycle costs.

The current system presumes that informed choices can be made with respect to identifying preferred architectures using cost based metrics. Cost-based metrics are well suited to government operations aimed at cost minimization [within a given set of objectives]. However, when commercial operations become an important part of the architecture being considered, other metrics need to be considered that more adequately reflect private sector concerns. These metrics relate to business financial performance and include profit and ROI concerns. Since financial performance depends upon both revenue and cost it is recommended that the STARS Model be modified to include pricing alternatives and demand [by market segment] elasticities. Pricing decisions based upon business financial viability may not lead to the same government cost savings that are indicated through a life cycle cost analysis and cost-based metrics.

Appendix

The STARS Mathematical Model

Data Requirements (Definition of Input Variables)

The following is the set of input variables that are used in the STARS Model. These variables are defined below and are organized for data entry into a series of user friendly input data screens in EXCEL.

APLMARG	A priori payload design margin. (%)
APLMASS(I)	Annual payload mass delivered to low Earth orbit. (kg/yr)
CSHRVFI(N)	Percent (%) of fleet investment spent in year N. Cost spreading is backward in time with N=1 being the year of completion of fleet investment (CYFI).
CSHRVS1(N)	Percent (%) of Stage 1 nonrecurring cost spent in year N. Cost spreading is backward in time with N=1 being the year of start of HRV operations (CYSO).
CSHRVS2(N)	Percent (%) of Stage 2 nonrecurring cost spent in year N. Cost spreading is backward in time with N=1 being the year of start of HRV operations (CYSO).
CSIF(N)	Percent (%) of infrastructure investment spent in year N. Cost spreading is backward in time with N=1 being the year of completion of the infrastructure investment (CYLF).
CSTP(I)	Percent (%) of technology program cost spent in year I starting in the year of the start of the analysis.
CY	Calendar year (for example, 1996) of start of analysis. The annual time index, I, is equal to "1" at calendar year CY.
CYFI	Calendar year of completion of HRV fleet acquisition.
CYLF	Calendar year of completion of launch infrastructure.
CYSO	Calendar year (for example, 2005) of start of HRV operations.
DR	Discount rate (%) used in computation of present value of life cycle cost.
FIMLHRV	Most likely cost (price) of an HRV incorporated into the HRV fleet. (M$)
FIMNHRV	Minimum possible cost (price) of an HRV incorporated into the HRV fleet. (M$)
FIMXHRV	Maximum possible cost (price) of an HRV incorporated into the HRV fleet. (M$)
FLTRP	Percentage (%) of HRV fleet cost spent per year for replacements.

IHD	When IHD = "yes," infinite horizon discounting will be included and when IHD ≠ "yes," infinite horizon discounting will not be included.
LFML	Most likely launch infrastructure investment. (M$)
LFMN	Minimum possible launch infrastructure investment. (M$)
LFMX	Maximum possible launch infrastructure investment. (M$)
MAXR	Number of Monte Carlo simulation runs to be performed.
MAXYRS	Maximum number of years to be considered in the analysis.
MLTPC	Most likely technology program cost (M$).
MNTPC	Minimum technology program cost (M$).
MXNRCH	Maximum possible reduction in nonrecurring cost due to increase in P/L margin. (% reduction in cost)
MXRCCH	Maximum possible reduction in recurring cost due to increase in P/L margin. (% reduction in cost)
MXTPC	Maximum technology program cost (M$).
NOHRV	Number of HRVs purchased for the fleet.
PLMLNRC	Most likely P/L nonrecurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLMNNRC	Minimum possible P/L nonrecurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLMLRC	Most likely P/L recurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLMNRC	Minimum possible P/L recurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLMXNRC	Maximum possible P/L nonrecurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLMXRC	Maximum possible P/L recurring cost per unit mass at the nominal P/L design margin. (K$/kg)
PLPM	Average number of payloads launched per mission.
PLSENNRC	Sensitivity of P/L nonrecurring cost to increasing payload design margin. (% decrease in cost/% increase in margin)
PLSENRC	Sensitivity of P/L recurring cost to increasing payload design margin. (%

decrease in cost/% increase in margin)

PPL(I) Percent of payload mass delivered by ELVs as a function of time. (%/yr)

S1ALC HRV Stage 1 minimum acceptable level of capability relative to nominal design point. (% of design point capability)

S1DEC Decision to allow a Stage 1 capability to exceed the design point level of capability (1 = can exceed, 0 = cannot exceed).

S1MLLC Most likely Stage 1 level of capability relative to nominal design point. (percent of design point capability)

S1MNLC HRV Stage 1 minimum achievable level of capability relative to nominal design point. (% of design point capability)

S1MLNRC Most likely Stage 1 nonrecurring cost. (M$)

S1MNNRC Stage 1 minimum possible a priori nonrecurring cost. (M$)

S1MXLC HRV Stage 1 maximum achievable level of capability relative to nominal design point. (% of design point capability)

S1MXNRC Stage 1 maximum possible a priori nonrecurring cost. (M$)

S2ALC HRV Stage 2 minimum acceptable level of capability relative to nominal design point. (% of design point capability)

S2DEC Decision to allow a Stage 2 capability to exceed the design point level of capability (1 = can exceed, 0 = cannot exceed).

S2MLLC Most likely Stage 2 level of capability relative to nominal design point. (% of design point capability)

S2MNLC HRV Stage 2 minimum achievable level of capability relative to nominal design point. (% of design point capability)

S2MLNRC Most likely Stage 2 nonrecurring cost. (M$)

S2MNNRC Stage 2 minimum possible a priori nonrecurring cost. (M$)

S2MXLC HRV Stage 2 maximum achievable level of capability relative to nominal design point. (% of design point capability)

S2MXNRC Stage 2 maximum possible a priori nonrecurring cost. (M$)

S2S1A Percent change in Stage 2 capability per percent change in Stage 1 capability (at Stage 1 and Stage 2 design points).

S2S1B Percent change in Stage 2 capability per percent change squared in Stage 1 capability (at Stage 1 and Stage 2 design points).

TCMLELV	Most likely ELV transportation cost per unit payload mass. (K$/kg)
TCMNELV	Minimum possible ELV transportation cost per unit payload mass. (K$/kg)
TCMLHRV	Most likely HRV transportation cost per unit payload mass. (K$/kg)
TCMNHRV	Minimum possible HRV transportation cost per unit payload mass (operating cost does not consider purchase or replacement of fleet). (K$/kg)
TCMXELV	Maximum possible ELV transportation cost per unit payload mass. (K$/kg)
TCMXHRV	Maximum possible HRV transportation cost per unit payload mass (operating cost does not consider purchase or replacement of fleet). (K$/kg)

The STARS Mathematical Model:

The details of the STARS mathematical model are described in the following pages. this description takes the form of an overall functional flow chart together with a set of mathematical relationships. The mathematical relationships are cross-referenced to the flow chart through the numbering that appears in the brackets ([ ]) associated with the blocks indicated in the flow chart.

In the mathematical relationships, *italics* are used to indicate input variables (i.e., input data is provided) and roman characters are used to refer to computed quantities. All input variables and computed quantities have mnemonic names (for example, *S2MLLC* indicates "stage 2 most likely level of capability").

[1] **Determination of Stage 1 Level of Capability:** **(%)**
S1CAP(R) **$1 \leq R \leq$ *MAXR***

Generate Random Number, RN

Using random sampling algorithm establish value of S1CAP(R)

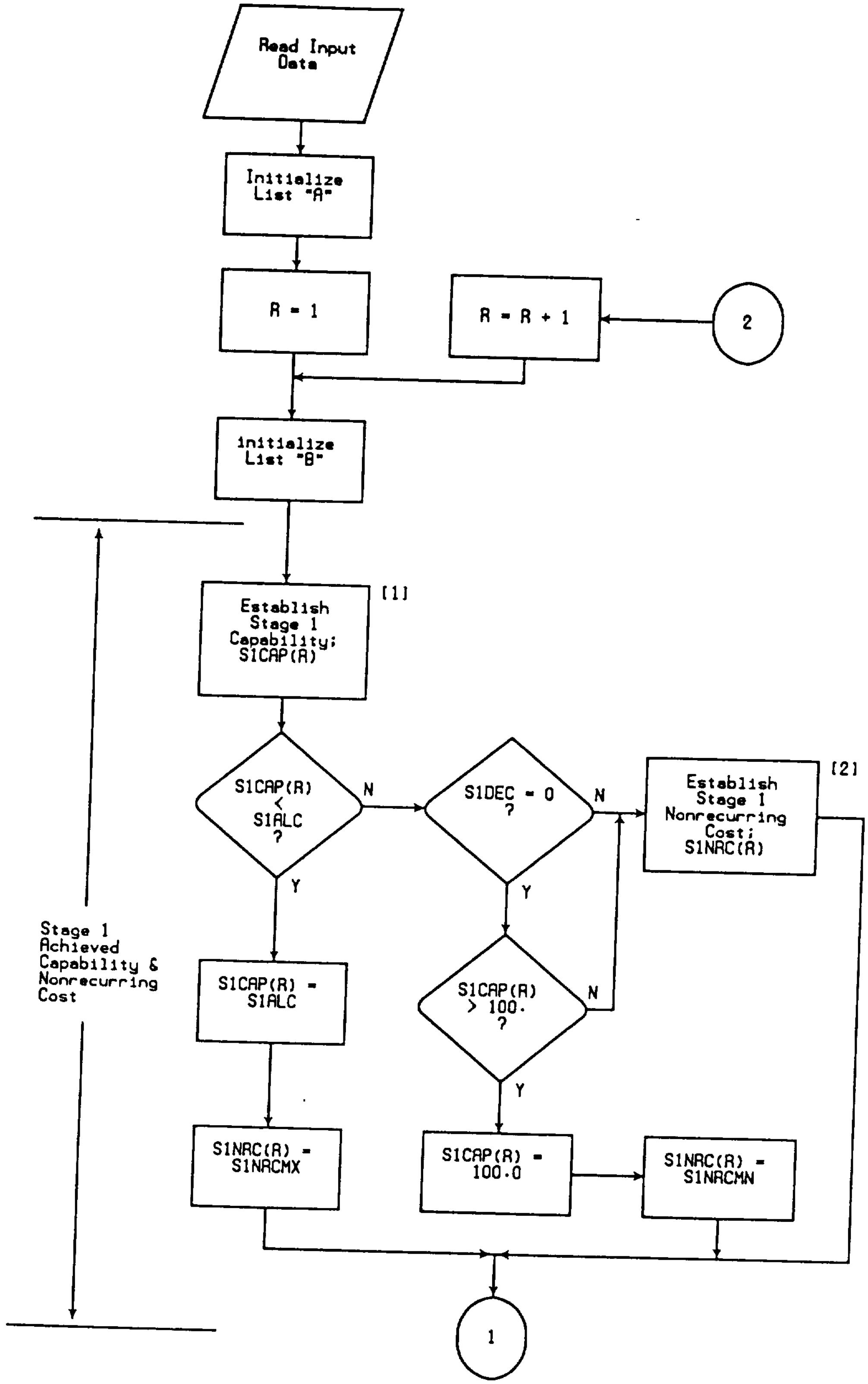
[S1MXLC; S1MNLC; S1MLLC] ==> S1CAP(R)

[2] **Determination of Stage 1 Nonrecurring Cost:** **(M$)**
S1NRC(R) **$1 \leq R \leq$ *MAXR***

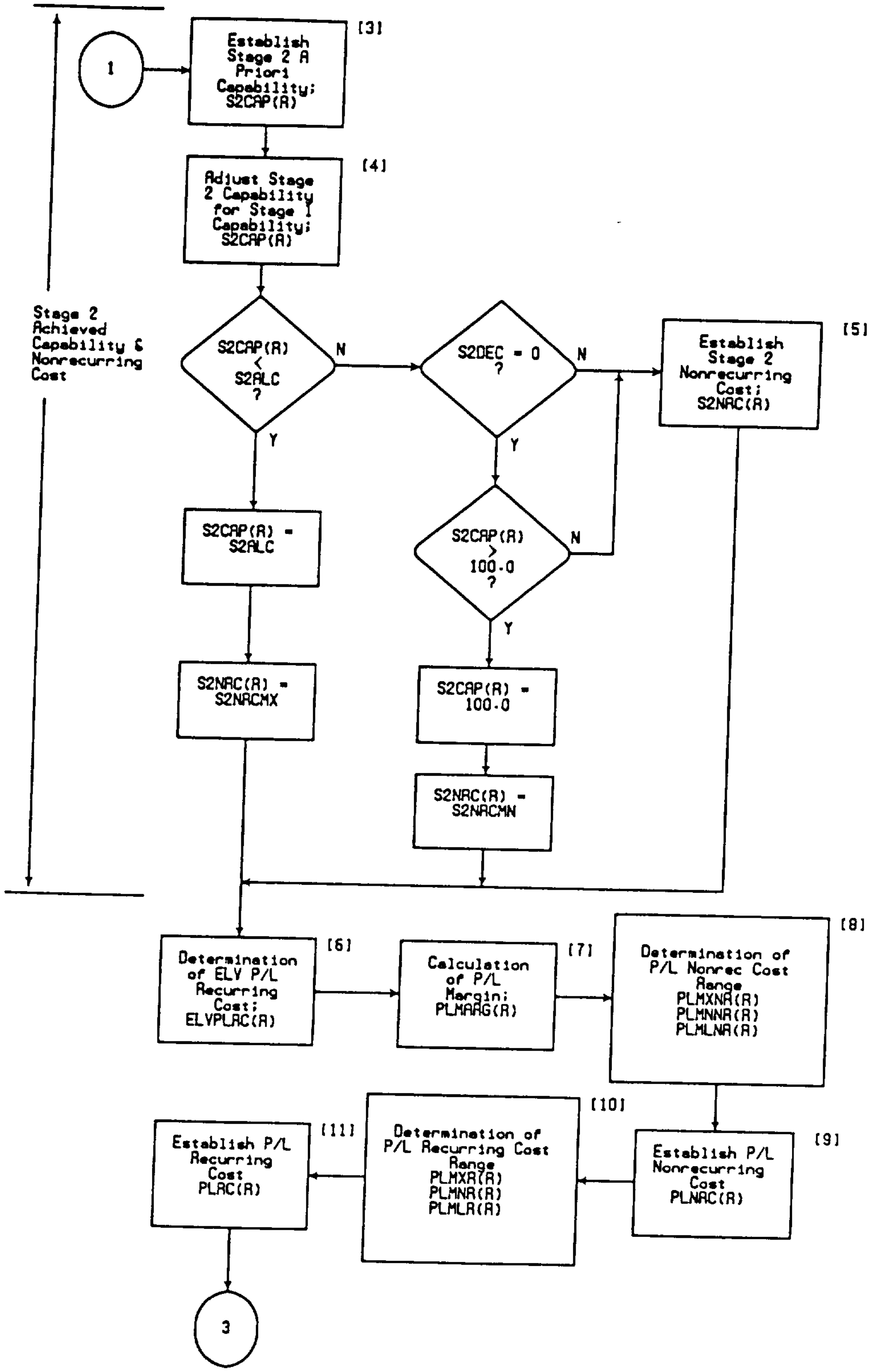
Generate Random Number, RN

Using random sampling algorithm establish value of S1NRC(R)

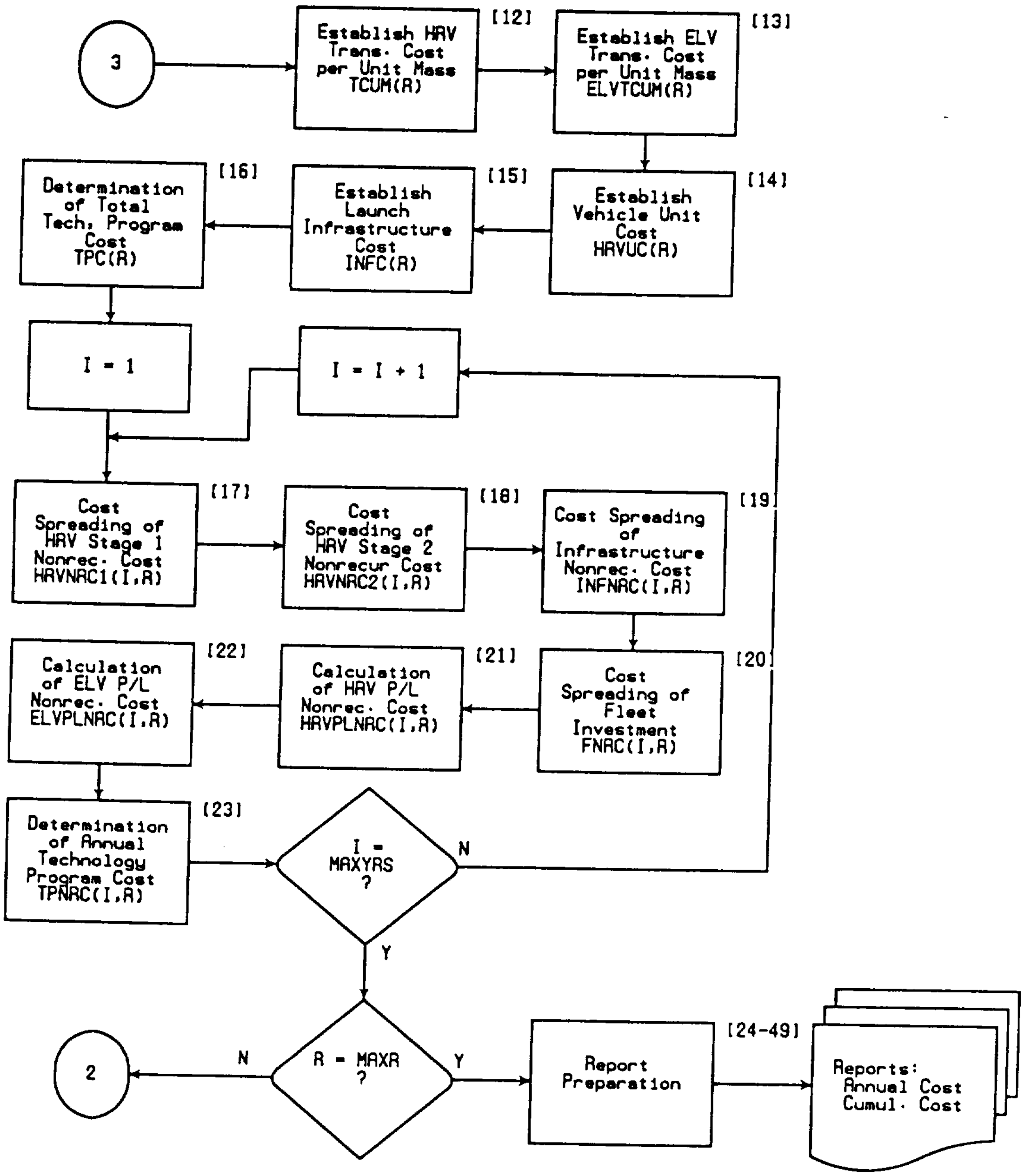
[S1MXNRC; S1MNNRC; S1MLNRC] ==> S1NRC(R)



STARS Functional Flow Diagram



STARS Functional Flow Diagram (Continued)



STARS Functional Flow Diagram (Continued)

[3] Determination of Stage 2 A Priori Level of Capability: **(M$)**
S2CAP(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of S2CAP(R)

[S2MXLC; S2MNLC; S2MLLC] ==> S2CAP(R)

[4] Adjustment of A Priori Stage 2 Capability to Account for Achieved Stage 1 Capability: **(%)**
S2CAP(R) **$1 \leq R \leq MAXR$**

$$S2CAP(R) = S2S1A * [S1CAP(R) - 100.0]$$

$$+ K1 * S2S1B * [S1CAP(R) - 100.0]^2 + S2CAP(R)$$

<u>If</u> S1CAP(R) ³ 100.0
<u>Then</u>
K1 = 1.0

<u>If</u> S1CAP(R) < 100.0
<u>Then</u>
K1 = - 1.0

[5] Determination of Stage 2 Nonrecurring Cost: **(M$)**
S2NRC(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of S2NRC(R)

[S2MXNRC; S2MNNRC; S2MLNRC] ==> S2NRC(R)

[6] Determination of ELV Payload Recurring Cost per Unit Mass: **(K$/kg)**
ELVPLRC(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of ELVPLRC(R)

[PLMXRC; PLMNRC; PLMLRC] ==> ELVPLRC(R)

[7] **Calculation of P/L Design Margins:** **(%)**
PLMARG(R) **$1 \leq R \leq MAXR$**

PLMARG(R) = *APLMARG* + [S2CAP(R) - 100.0]

<u>If</u> PLMARG(R) < 0.0
<u>Then</u>
PLMARG(R) = 0.0

[8] **Determination of Range of Uncertainty of P/L Nonrecurring Cost per Unit of P/L Mass:** **(K$/kg)**
PLMXNR(R); PLMNNR(R); PLMLNR(R) **$1 \leq R \leq MAXR$**

<u>If</u> PLMARG(R) ≤ *APLMARG*
<u>Then</u>
PLMNNR(R) = *PLMNNRC*
PLMXNR(R) = *PLMXNRC* * {1.0 + *PLSENNRC* * [PLMARG(R) - *APLMARG*] * 0.0001}
PLMLNR(R) = *PLMLNRC* * {1.0 + *PLSENNRC* * [PLMARG(R) - *APLMARG*] * 0.0001}

<u>If</u> PLMARG(R) > *APLMARG*
<u>Then</u>
PLMNNR(R) = *PLMNNRC* * {1.0 + *PLSENNRC* * [PLMARG(R) - *APLMARG*] * 0.0001}
PLMXNR(R) = *PLMXNRC*
PLMLNR(R) = *PLMLNRC* * {1.0 + *PLSENNRC* * [PLMARG(R) - *APLMARG*] * 0.0001}

<u>If</u> PLMLNR(R) < *MXNRCH* * *PLMLNRC* * 0.01
<u>Then</u>
PLMLNR(R) = *MXNRCH* * *PLMLNRC* * 0.01

<u>If</u> PLMNNR(R) < *MXNRCH* * *PLMLNRC* * 0.01
<u>Then</u>
PLMNNR(R) = *MXNRCH* * *PLMNNRC* * 0.01

[9] **Determination of P/L Nonrecurring Cost per Unit Mass:** **(K$/kg)**
PLNRC(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of PLNRC(R)

[PLMXNR(R); PLMNNR(R); PLMLNR(R)] ==> PLNRC(R)

[10] Determination of Range of Uncertainty of P/L Recurring Cost per Unit of P/L Mass: **(K$/kg)**
PLMXR(R); PLMNR(R); PLMLR(R) **$1 \leq R \leq MAXR$**

<u>If</u> PLMARG(R) $\leq$ *APLMARG*
<u>Then</u>
PLMNR(R) = *PLMNRC*
PLMXR(R) = *PLMXRC* * {1.0 + *PLSENRC* * [PLMARG(R) - *APLMARG*] * 0.0001}
PLMLR(R) = *PLMLRC* * {1.0 + *PLSENRC* * [PLMARG(R) - *APLMARG*] * 0.0001}

<u>If</u> PLMARG(R) > *APLMARG*
<u>Then</u>
PLMNR(R) = *PLMNRC* * {1.0 + *PLSENRC* * [PLMARG(R) - *APLMARG*] * 0.0001}
PLMXR(R) = *PLMXRC*
PLMLR(R) = *PLMLRC* * {1.0 + *PLSENRC* * [PLMARG(R) - *APLMARG*] * 0.0001}

<u>If</u> PLMLR(R) < *MXRCCH* * *PLMLRC* * 0.01
<u>Then</u>
PLMLR(R) = *MXRCCH* * *PLMLRC* * 0.01

<u>If</u> PLMNR(R) < *MXRCCH* * *PLMLRC* * 0.01
<u>Then</u>
PLMNR(R) = *MXRCCH* * *PLMNRC* * 0.01

[11] Determination of P/L Recurring Cost per Unit Mass: **(K$/kg)**
PLRC(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of PLRC(R)

[PLMXR(R); PLMNR(R); PLMLR(R)] ==> PLRC(R)

[12] Determination of HRV Transportation Cost per Unit Mass: **(K$/kg)**
TCUM(R) **$1 \leq R \leq MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of TCUM(R)

[TCMXHRV; TCMNHRV; TCMLHRV] ==> TCUM(R)

[13] Determination of ELV Transportation Cost per Unit Mass: ELVTCUM(R) **(K$/kg)** **$1 \le R \le MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of ELVTCUM(R)

[TCMXELV; TCMNELV; TCMLELV] ==> ELVTCUM(R)

[14] Establish HRV Unit Cost (Purchase Price for Inclusion Into HRV Fleet: HRVUC(R) **(M$/unit)** **$1 \le R \le MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of HRVUC(R)

[FIMXHRV; FIMNHRV; FIMLHRV] ==> HRVUC(R)

[15] Establish Launch Infrastructure Cost: INFC(R) **(M$)** **$1 \le R \le MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of INFC(R)

[LFMX; LFMN; LFML] ==> INFC(R)

[16] Determination of Total Technology Program Cost: TPC(R) **(M$)** **$1 \le R \le MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of TPC(R)

[MXTPC; MNTPC; MLTPC] ==> TPC(R)

[17] Cost Spreading of HRV Stage 1 Nonrecurring Cost: HRVNRC1(I,R) **(M$)** **$1 \le R \le MAXR$** **$1 \le N \le 10$**

When $I = CYSO - CY - 10 + N$ and $I \ge 1$

Then

HRVNRC1(I,R) = *CSHRVS1(N)* * 0.01 * S1NRC(R)

[18] Cost Spreading of HRV Stage 2 Nonrecurring Cost: HRVNRC2(I,R) — **(M\$)** — **$1 \le R \le MAXR$**, **$1 \le N \le 10$**

<u>When</u> $I = CYSO - CY - 10 + N$ <u>and</u> $I \ge 1$

<u>Then</u>

$$HRVNRC2(I,R) = CSHRVS2(N) * 0.01 * S2NRC(R)$$

[19] Cost Spreading of Infrastructure Expenditures: INFNRC(I,R) — **(M\$)** — **$1 \le R \le MAXR$**, **$1 \le N \le 10$**

<u>When</u> $I = CYLF - CY - 10 + N$ <u>and</u> $I \ge 1$

<u>Then</u>

$$INFNRC(I,R) = CSIF(N) * 0.01 * INFC(R)$$

[20] Cost Spreading of Fleet Investment: FNRC(I,R) — **(M\$)** — **$1 \le R \le MAXR$**, **$1 \le N \le 10$**

<u>When</u> $I = CYFI - CY - 10 + N$ <u>and</u> $I \ge 1$

<u>Then</u>

$$FNRC(I,R) = CSHRVFI(N) * 0.01 * HRVUC(R) * NOHRV$$

[21] Determination of annual HRV Payload Nonrecurring Cost: HRVPLNRC(I,R) — **(M\$)** — **$1 \le R \le MAXR$**

$$HRVPLNRC(I,R) = PLNRC(R) * APLMASS(I) * 0.001 * [100 - PPL(I)] * 0.01 / PLPM$$

[22] Determination of Annual ELV Payload Nonrecurring Cost: ELVPLNRC(I,R) — **(M\$)** — **$1 \le R \le MAXR$**

Generate Random Number, RN

Using random sampling algorithm establish value of EXPLNRC(R)

[PLMXNRC; PLMNNRC; PLMLNRC] ==> EXPLNRC(R)

$$ELVPLNRC(I,R) = EXPLNRC(R) * APLMASS(I) * 0.001 * PPL(I) * 0.01 / PLPM$$

[23] Determination of Annual Research & Technology Program Cost: TPNRC(I,R) — **(M\$)** — **$1 \le R \le MAXR$**

$$TPNRC(I,R) = 0.01 * CSTP(I) * TPC(R)$$

[24] Determination of Expected Value and Standard Deviation of Transportation System Nonrecurring Cost: (M$)

$$ETSNRC = \{ \sum_{R=1}^{MAXR} [S1NRC(R) + S2NRC(R)] \} / MAXR$$

$$SDTSNRC = \{\{ \sum_{R=1}^{MAXR} [S1NRC(R) + S2NRC(R)]^2 \} / MAXR - [ETSNRC]^2 \}^{0.5}$$

[25] Determination of Expected Value and Standard Deviation of HRV Unit Cost: (M$)

$$EHRVUC = \{ \sum_{R=1}^{MAXR} HRVUC(R) \} / MAXR$$

$$SDHRVUC = \{\{ \sum_{R=1}^{MAXR} [HRVUC(R)]^2 \} / MAXR - [ELVUC]^2 \}^{0.5}$$

[26] Determination of Expected Value and Standard Deviation of HRV Fleet Investment: (M$)

$$EHRVFC = NOHRV * EHRVUC$$

$$SDHRVFC = NOHRV * SDHRVUC$$

[27] Determination of Expected Value and Standard Deviation of Infrastructure Investment: (M$)

$$EINFC = \{ \sum_{R=1}^{MAXR} INFC(R) \} / MAXR$$

$$SDINFC = \{\{ \sum_{R=1}^{MAXR} [INFC(R)]^2 \} / MAXR - [EINFC]^2 \}^{0.5}$$

[28] Determination of Expected Value and Standard Deviation of Launch Cost per Unit Payload Mass: (K$/kg)

$$ELCUM = \{ \sum_{R=1}^{MAXR} TCUM(R) \} / MAXR$$

$$SDLCUM = \{\{ \sum_{R=1}^{MAXR} [TCUM(R)]^2 \} / MAXR - [ELCUM]^2 \}^{0.5}$$

[29] Determination of Expected Value and Standard Deviation of Payload Nonrecurring Cost per Unit Payload Mass: (K$/kg)

$$\mathrm{EPLNRC} = \{ \sum_{R=1}^{MAXR} \mathrm{PLNRC(R)}\} / MAXR$$

$$\mathrm{SDPLNRC} = \{\{ \sum_{R=1}^{MAXR} [\mathrm{PLNRC(R)}]^2\} / MAXR - [\mathrm{EPLNRC}]^2 \}^{0.5}$$

[30] Determination of Expected Value and Standard Deviation of Payload Recurring Cost per Unit Payload Mass: (K$/kg)

$$\mathrm{EPLRC} = \{ \sum_{R=1}^{MAXR} \mathrm{PLRC(R)}\} / MAXR$$

$$\mathrm{SDPLRC} = \{\{ \sum_{R=1}^{MAXR} [\mathrm{PLRC(R)}]^2\} / MAXR - [\mathrm{EPLRC}]^2 \}^{0.5}$$

[31] Determination of Expected Value and Standard Deviation of Payload Design Margin: (%)

$$\mathrm{EPLDM} = \{ \sum_{R=1}^{MAXR} \mathrm{PLMARG(R)}\} / MAXR$$

$$\mathrm{SDPLDM} = \{\{ \sum_{R=1}^{MAXR} [\mathrm{PLMARG(R)}]^2\} / MAXR - [\mathrm{EPLDM}]^2 \}^{0.5}$$

[32] Determination of Expected Value and Standard Deviation of Present Value of Operational System Life Cycle Cost: (M$)

If $I \le CYSO - CY + 1$
Then
$\mathrm{AFRNRC(I,R)} = 0$

If $I > CYSO - CY + 1$
Then
$\mathrm{AFRNRC(I,R)} = 0.01 * FLTRP * NOHRV * \mathrm{HRVUC(R)}$

$$\begin{aligned}\mathrm{TACA(I,R)} = \{&\mathrm{HRVNRC1(I,R)} + \mathrm{HRVNRC2(I,R)} + \mathrm{INFNRC(I,R)} + \mathrm{HRVPLNRC(I,R)} \\ &+ \mathrm{ELVPLNRC(I,R)} + \mathrm{FNRC(IR)} + \mathrm{AFRNRC(I,R)}\} + \{[\mathrm{TCUM(R)} \\ &+ \mathrm{PLRC(R)}] * 0.001 * APLMASS(I) * [1 - 0.01 * PPL(I)] \\ &+ [\mathrm{ELVTCUM(R)} + \mathrm{ELVPLRC(R)}] * 0.001 * APLMASS(I) * 0.01 \\ &* PPL(I)\}\end{aligned}$$

When *IHD* ≠ "yes"
Then

$$EPVC = \{ \sum_{R=1}^{MAXR} \sum_{I=1}^{MAXYRS} TACA(I,R) / [1 + .01 * DR]^{I-1} \} \} / MAXR$$

$$SDPVC = \{\{ \sum_{R=1}^{MAXR} \{ \sum_{I=1}^{MAXYRS} TACA(I,R) / [1 + .01 * DR]^{I-1} \}^2 \} / MAXR - [EPVC]^2 \}^{0.5}$$

When *IHD* = "yes"
Then

$$EPVC = \{ \sum_{R=1}^{MAXR} \{ \sum_{I=1}^{MAXYRS} TACA(I,R) / [1 + .01 * DR]^{I-1} \} + TACA(I{=}MAXYRS,R) / [.01 * DR] * [1 + .01 * DR]^{MAXYRS} \} / MAXR$$

$$SDPVC = \{\{ \sum_{R=1}^{MAXR} \{ \sum_{I=1}^{MAXYRS} TACA(I,R) / [1 + .01 * DR]^{I-1} \} + TACA(I{=}MAXYRS,R) / [.01 * DR] * [1 + .01 * DR]^{MAXYRS} \}^2 \} / MAXR - [EPVC]^2 \}^{0.5}$$

[33] Determination of HRV Stage 1 Expected Annual Nonrecurring Cost: HRVS1NC(I) **(M$)**

$$HRVS1NC(I) = \{ \sum_{R=1}^{MAXR} HRVNRC1(I,R)\} / MAXR$$

[34] Determination of HRV Stage 2 Expected Annual Nonrecurring Cost: HRVS2NC(I) **(M$)**

$$HRVS2NC(I) = \{ \sum_{R=1}^{MAXR} HRVNRC2(I,R)\} / MAXR$$

[35] **Determination of Infrastructure Expected Annual Nonrecurring Cost: INFNC(I)** **(M$)**

$$\mathrm{INFNC(I)} = \{ \sum_{R=1}^{MAXR} \mathrm{INFNRC(I,R)} \} / MAXR$$

[36] **Determination of HRV Payloads Expected Annual Nonrecurring Cost: HRVPLNC(I)** **(M$)**

$$\mathrm{HRVPLNC(I)} = \{ \sum_{R=1}^{MAXR} \mathrm{HRVPLNRC(I,R)} \} / MAXR$$

[37] **Determination of ELV Payloads Expected Annual Nonrecurring Cost: ELVPLNC(I)** **(M$)**

$$\mathrm{ELVPLNC(I)} = \{ \sum_{R=1}^{MAXR} \mathrm{ELVPLNRC(I,R)} \} / MAXR$$

[38] **Determination of Fleet Investment Expected Annual Nonrecurring Cost: HRVFNC(I)** **(M$)**

$$\mathrm{HRVFNC(I)} = \{ \sum_{R=1}^{MAXR} \mathrm{FNRC(I,R)} \} / MAXR$$

[39] **Determination of Fleet Replacement Expected Annual Nonrecurring Cost: HRVRNC(I)** **(M$)**

<u>If</u> $\mathrm{I} \leq CYSO - CY + 1$
<u>Then</u>
HRVRNC(I) = 0

<u>If</u> $\mathrm{I} > CYSO - CY + 1$
<u>Then</u>
$\mathrm{HRVRNC(I)} = 0.01 * FLTRP * \mathrm{EHRVFC}$

[40] Determination of Technology Program Expected Annual Nonrecurring Cost: (M$)
TPNC(I)

$$TPNC(I) = \{ \sum_{R=1}^{MAXR} TPNRC(I,R)\} / MAXR$$

[41] Determination of HRV Expected Annual Launch Operations Recurring Cost: (M$)
HRVRC(I)

$$HRVRC(I) = \{ \sum_{R=1}^{MAXR} TCUM(R)\} * 0.001 * APLMASS(I) * [1 - 0.01 * PPL(I)] / MAXR$$

[42] Determination of ELV Expected Annual Launch Operations Recurring Cost: (M$)
ELVRC(I)

$$ELVRC(I) = \{ \sum_{R=1}^{MAXR} ELVTCUM(R)\} * 0.001 * APLMASS(I) * .01 * PPL(I) / MAXR$$

[43] Determination of HRV Payload Expected Annual Recurring Cost: (M$)
HRVPLC(I)

$$HRVPLC(I) = \{ \sum_{R=1}^{MAXR} PLRC(R)\} * 0.001 * APLMASS(I) * [1 - 0.01 * PPL(I)] / MAXR$$

[44] Determination of ELV Payload Expected Annual Recurring Cost: (M$)
ELVPLC(I)

$$ELVPLC(I) = \{ \sum_{R=1}^{MAXR} ELVPLRC(R)\} * 0.001 * APLMASS(I) * .01 * PPL(I) / MAXR$$

[45] Calculation of Total Expected Annual Nonrecurring Cost, Total Expected Annual Recurring Cost, and Total Expected Annual Cost: (M$)
TNRC(I); TRC(I); ETAC(I)

$$TNRC(I) = HRVS1NC(I) + HRVS2NC(I) + INFNC(I) + HRVPLNC(I) + ELVPLNC(I) + HRVFNC(I) + HRVRNC(I) + TPNC(I)$$

$$TRC(I) = HRVRC(I) + ELVRC(I) + HRVPLC(I) + ELVPLC(I)$$

$$ETAC(I) = TNRC(I) + TRC(I)$$

[46] Calculation of Total Expected Cumulative Nonrecurring Cost, Total Expected Cumulative Recurring Cost, and Total Expected Cumulative Cost: (M$)
CTNRC(I); CTRC(I); CETAC(I)

$$CTNRC(I) = \sum_{A=1}^{I} TNRC(A)$$

$$CTRC(I) = \sum_{A=1}^{I} TRC(A)$$

$$CETAC(I) = CTNRC(I) + CTRC(I)$$

[47] Calculation of Standard Deviation of Total Nonrecurring Cost: (M$)
SDNRC(I)

$$SDNRC(I) = \{\{ \sum_{R=1}^{\mathit{MAXR}} [HRVNRC1(I,R) + HRVNRC2(I,R) + INFNRC(I,R) + HRVPLNRC(I,R) + ELVPLNRC(I,R) + FNRC(I,R) + AFRNRC(I,R) + TPNRC(I,R)]^2 \} / MAXR - [TNRC(I)]^2 \}^{0.5}$$

[48] Calculation of Standard Deviation of Total Recurring Cost: (M$)
SDRC(I)

$$SDRC(I) = \{\{ \sum_{R=1}^{\mathit{MAXR}} [TCUM(R) * 0.001 * \mathit{APLMASS(I)} * [1 - 0.01 * \mathit{PPL(I)}] + ELVTCUM(R) * 0.001 * \mathit{APLMASS(I)} * .01 * \mathit{PPL(I)} + PLRC(R) * 0.001 * \mathit{APLMASS(I)} * [1 - 0.01] * \mathit{PPL(I)} + ELVPLRC(R) * 0.001 * \mathit{APLMASS(I)} * .01 * \mathit{PPL(I)}]^2 \} / MAXR - [TRC(I)]^2 \}^{0.5}$$

[49] Calculation of Standard Deviation of Total Annual Cost: (M$)
SDTAC(I)

$$SDTAC(I) = \{[SDNRC(I)]^2 + [SDRC(I)]^2 \}^{0.5}$$

LIST "B"

HRVNRC1(I,R) = 0	for $1 \le I \le MAXYRS$
HRVNRC2(I,R) = 0	for $1 \le I \le MAXYRS$
INFNRC(I,R) = 0	for $1 \le I \le MAXYRS$
FNRC(I,R) = 0	for $1 \le I \le MAXYRS$
TPNRC(I,R) = 0	for $1 \le I \le MAXYRS$

Getting Started with the STARS Model:

The Space Transportation Architecture Risk System (STARS) Model currently operates on an IBM compatible computer with a 486 processor, 8 megabytes of Random Access Memory and Excel for Windows Version 5.0C. The Model is completely contained within a Microsoft Excel workbook.

To commence using the program, the user should copy the file (STARS1.XLS) to the hard drive of the computer either to the root directory or to any directory that the user chooses for the Model. The user simply activates Excel and opens the file (STARS1.XLS). From this point the user will be guided by custom made menus and buttons.

Upon entering the system a Welcome Screen will appear (Figure A.1). This screen allows for immediate exit or continuation (by clicking on the appropriate button). Clicking on "continue" brings up the Main Menu Screen (Figure A.2). The Main Menu Screen allows input data to be provided to the Model (clicking on "Input Data"), computations to be performed (clicking on "Analysis" which causes the STARS Monte Carlo Simulation Model to perform all of the calculations) and computed results provided to the reports, viewing of the computed results (clicking on "Results"), printing of all of the input data or of all of the computed results (clicking on "Print"), and saving all of the computed results and/or exiting the system (clicking on "Save/Exit"). Each of the main menu topics (with the exception of "Analysis") results in the display of a pull down menu which in turn leads to specific screens being displayed. Each of these screens and related functions are described in the following paragraphs via an example.

An Application Example:

The application example is described by presenting the set of input data screens and computed results as displayed in the results screens. Each of the input data screens allows the user to enter data, move to the next screen, print the specific input data screen which is in view, returning to the Main Menu Screen, and clicking on the "Help" button in order to view a help screen that provides definitions and clarifications of the input data requirements. In the following paragraphs, each of the screens is presented and briefly described. The descriptions are augmented by the inclusion of the Help screens with their definitions and clarifications.

The following example is based upon a hypothetical architecture having the basic structure of Maglifter,[15] a magnetic acceleration boost assist system for placing payloads into low Earth orbit. It is assumed that this system will require expendable launch vehicles to place payloads into inclination angle orbits not efficiently handled by Maglifter. The described architecture includes

[15] Mankins, J.C., "The Maglifter: An Advanced Concept Using electromagnetic Propulsion in Reducing the Cost of Space Launch," 30th Joint Propulsion Conference, June 1994.

an R&T program, construction and maintenance of a fleet of vehicles that will be launched via the magnetic acceleration system, the development of necessary infrastructure elements, and the provision and use of expendable launch vehicles as required. *It must be cautioned that the data utilized in the example is totally fictional and is presented only to demonstrate the STARS system and methodology. No conclusions should be drawn from the presented results relative to architecture cost, risk and overall desirability.*

Input Data/Global: The input data screen (Figure A.3) allows for the provision of a brief description of the architecture being considered and the specification of a reference number. This reference number and the computer generated date will appear on all screens and reports produced for the considered architecture. In addition, the discount rate and the type of discounting that will be used for the present value of cost computations is specified. Finally, the duration or time frame of the analysis and the number of Monte Carlo runs to be performed must be specified.

Input Data/Arch. Timing: Timing, in calendar years is provided (Figures A.4a and A.4b) indicating the start of the analysis, the completion of the infrastructure, completion of fleet acquisition and the start of HRV operations. These times then appear on other screens to establish the reference points for the provision of data such as cost spreading (relative to infrastructure completion, start of operations, etc.). The total annual payload mass delivered to low Earth orbit and the percentage of this delivered by ELVs (i.e., transportation system other than the HRV) must be specified.

Input Data/HRV-Stage 1: The anticipated HRV Stage 1 level of capability is specified (Figure A.5) relative to the nominal design point capability and is expressed as a percentage of the design point capability. The anticipated level of capability is considered as an uncertainty variable requiring the specification of maximum, most likely and minimum values. The associated nonrecurring cost is also specified as an uncertainty variable. In addition, the HRV Stage 1 minimum acceptable level of capability relative to the nominal design point is also specified. A level of capability below that specified is not allowed; i.e., when the random sampling leads to a value below the minimum acceptable level then the minimum acceptable level will be used and the maximum nonrecurring cost will be utilized.

Input Data/HRV-Stage 2: The anticipated HRV Stage 2 level of capability is specified (Figure A.6) relative to the nominal design point capability and is expressed as a percentage of the design point capability. The anticipated level of capability is considered as an uncertainty variable requiring the specification of maximum, most likely and minimum values. The associated nonrecurring cost is also specified as an uncertainty variable. In addition, the HRV Stage 2 minimum acceptable level of capability relative to the nominal design point is also specified. A level of capability below that specified is not allowed; i.e., when the random sampling leads to a value below the minimum acceptable level then the minimum acceptable level will be used and the maximum nonrecurring cost will be utilized.

Input Data/HRV-General: Options may be selected (Figure A.7) concerning whether or not stage capabilities will be allowed to exceed design point values. The relationship between Stage 2 capability and Stage 1 capability is specified. Also specified is the percentage of nonrecurring cost that is incurred each year (i.e., cost spreading).

Input Data/Payload: The payload related data is entered via the payload data screen (Figure A.8) and includes the payload nonrecurring and recurring cost per unit mass at the nominal payload design margin, Both of these variables are considered as uncertainty variables. Sensitivity of payload nonrecurring and recurring cost to increases in design margin and the

Sensitivity of payload nonrecurring and recurring cost to increases in design margin and the maximum possible reduction in payload cost due to increases in payload margin are also specified. In addition, the a priori payload design margin and the average number of payloads per mission are specified.

Input Data/Fleet: The Input Data/Fleet Screen (Figure A.9) allows the number of HRVs in the fleet and the average annual replacement cost (of the fleet) to be specified. In addition, the cost or price of an HRV incorporated into the HRV fleet is specified (as an uncertainty variable) as is the cost spreading to be associated with the procurement of an HRV.

Input Data/Infrastructure: The Input Data/Infrastructure Screen (Figure A.10) allows the launch infrastructure investment to be specified (as an uncertainty variable) together with its cost spreading function.

Input Data/Trans. Cost: The Input Data/Operations Transportation Cost Screen (Figure A.11) provides the means for specifying both the anticipated HRV and ELV transportation cost per unit payload mass. These variables are treated as uncertainty variables.

Input Data/R&T Program: The Input Data/R&T Program Screen provides the means for specifying the overall research and technology program cost and its associated cost spreading function. The R&T program cost is treated as an uncertainty variable.

Architecture Summary: The Architecture Summary (Figure A.13) indicates the previously stated architecture description and reference number and computer established date (this information is also provided on all of the other output reports). The objective of the Summary is to present an overview of the obtained results and key decisions in the setting of the structure of the analysis (i.e., the time of the start of HRV operations, whether or not performance for stages 1 and 2 can exceed specified design points, and whether or not infinite horizon discounting has been utilized).

Calculated expected values and associated standard deviations are presented for transportation system nonrecurring cost, HRV unit cost, HRV fleet investment, infrastructure investment, launch cost per unit payload mass, payload nonrecurring cost per unit mass, payload recurring cost per unit mass and payload design margin. Also indicated are the expected value and standard deviation of the present value of operational system life cycle cost and the present value of the technology program.

Architecture Annual Cost (Table): The Architecture Annual Cost Table (Figure A.14) presents the expected values of the components of the total nonrecurring cost (i.e., HRV Stage 1, HRV Stage 2, infrastructure, HRV payloads, ELV payloads, fleet investment, fleet replacement and technology program) and the expected value and standard deviation of the total nonrecurring cost. Similarly, the expected values of the components of total recurring cost (i.e., HRV launch operations, ELV launch operations, HRV payloads and ELV payloads) and the expected value and standard deviation of total recurring cost are presented. Expected values and standard deviations of total annual costs are also indicated. The results are continued on a number of screens and can be observed by clicking on "Continue."

Architecture Annual Cost (Graph): The architecture annual cost results are summarized in graphical form (Figure A.15). A graph of the major components of architecture annual cost is presented. Indicated are the expected values of recurring, nonrecurring and total annual cost as a function of time.

Architecture Cumulative Cost (Graph): The architecture cumulative cost graph (Figure A.16) indicates the cumulative expected recurring, nonrecurring and total cost as a function of time. The cumulative costs indicate the cost from the first year of the program through each of the indicated years.

Print: Clicking on the Print function results in the print pull-down menu. There is a print function associated with each screen that allows the individual screens to be printed upon request. The Main Menu print function allows all of the input to be printed via a single command (i.e., clicking on "Input data") or all of the results to be printed via a single command (i.e., clicking on "Results").

Save/Exit: Clicking on the Save/Exit function results in the display of a pull-down menu wherein three options are presented. Clicking on "Save Continue" results in the current file being saved with the analysis allowed to continue. Clicking on "Save Exit" allows the current file to be saved and exit from the analysis. Clicking on "No Save Exit" results in an immediate exit from the system.

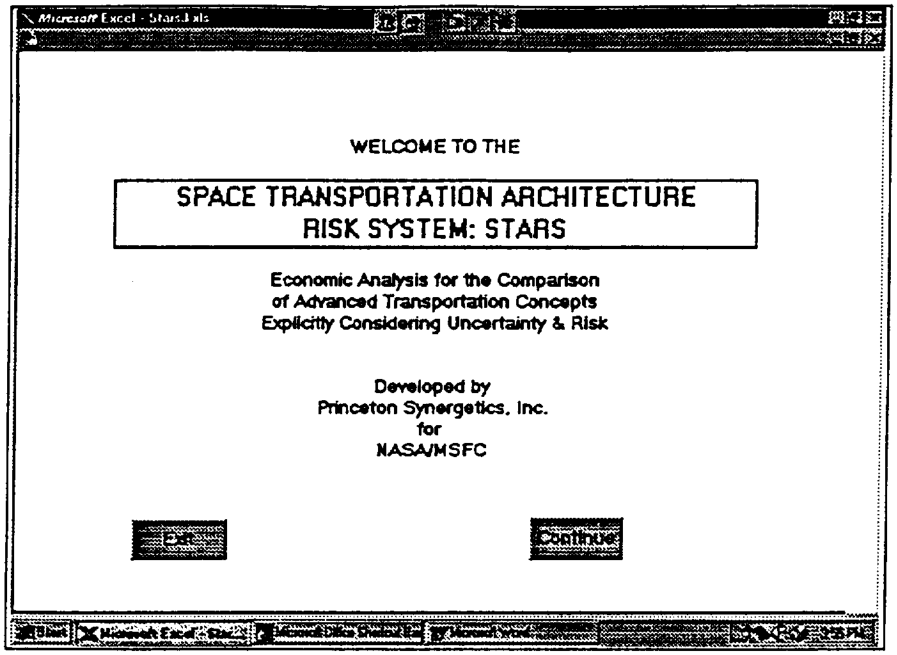


Figure A.1 STARS Welcome Screen

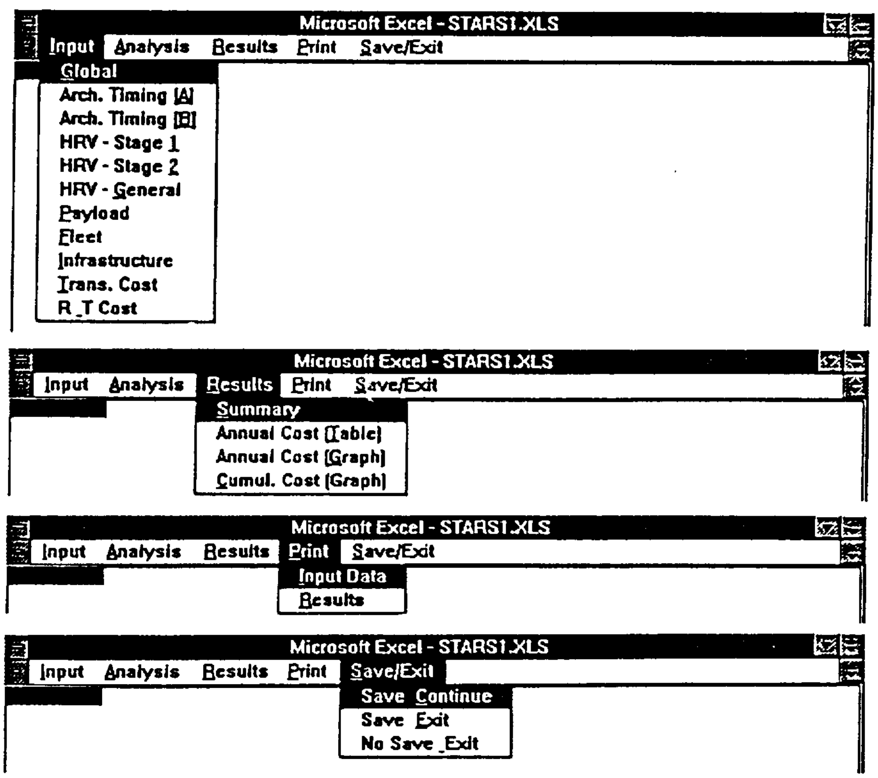
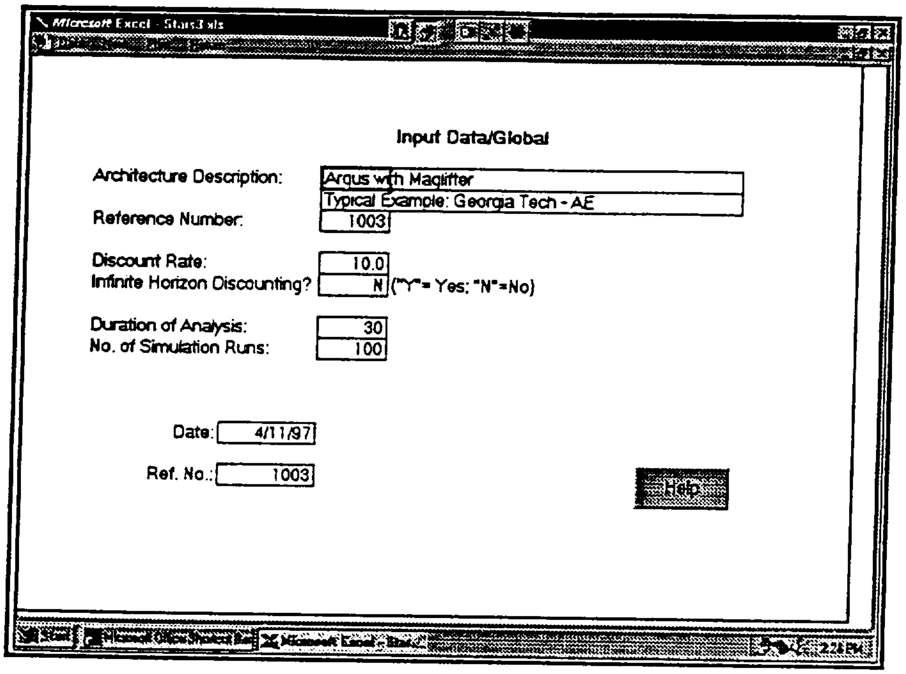


Figure A.2 STARS Main Menu Screen



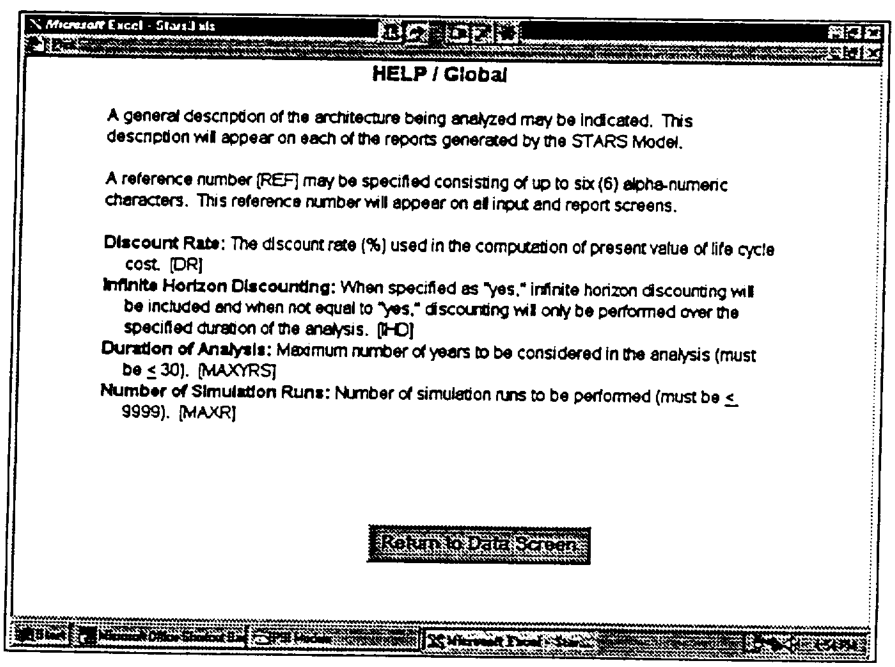


Figure A.3 Input Data/Global

Microsoft Excel - Stars3.xls

Input Data/Architecture Timing [A]

Calendar Years:

Start of Analysis	1997
Completion of Infrastructure	2005
Completion of Fleet Acquisition	2010
Start of HRV Operations	2010

P/L Mass Delivered to LEO (kg/yr)

1997	1998	1999	2000	2001	2002
453,600	476,280	521,640	571,536	635,040	680,400
2003	2004	2006	2006	2007	2008
725,760	771,120	839,160	907,200	997,920	1,065,960
2009	2010	2011	2012	2013	2014
1,134,000	1,224,720	1,315,440	1,428,840	1,542,240	1,655,640
2015	2016	2017	2018	2019	2020
1,814,400	1,973,160	2,154,600	2,336,040	2,494,800	2,721,600
2021	2022	2023	2024	2025	2026
2,948,400	3,175,200	3,402,000	3,628,800	3,855,600	4,082,400

Date: 4/11/97

Reference Number: 1003

Help

Microsoft Excel - Stars3.xls

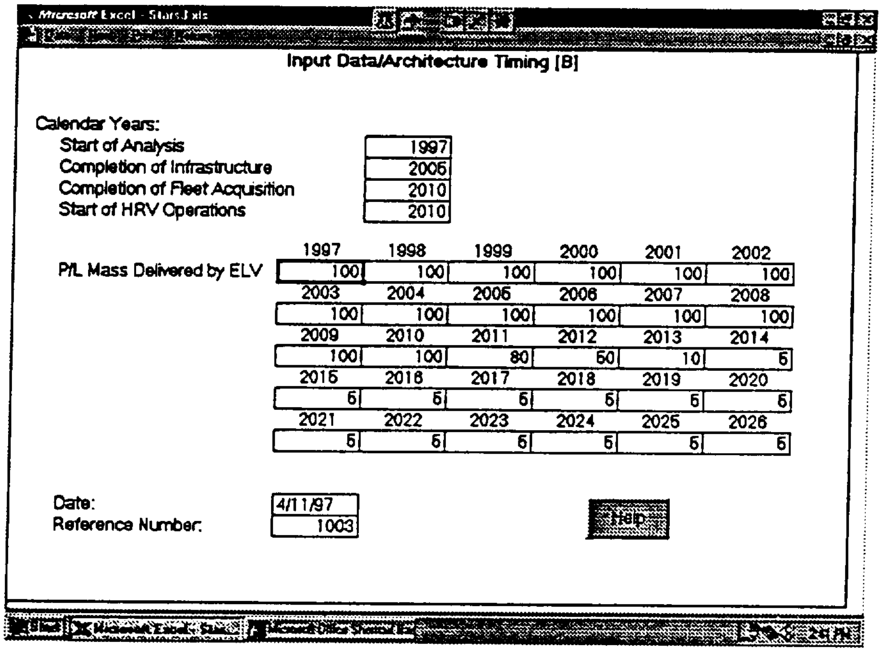
HELP / Architecture Timing [A]

The general timing of the overall analysis is established by specifying the calendar years (for example, 1995) associated with the start of the analysis [CY], the completion of the infrastructure [CYLF], the completion of fleet (HRV) acquisition [CYFI], and the start of HRV operations [CYSO]. This information is used for cost spreading and appears on a number of following screens.

P/L Mass Delivered to LEO: Annual payload mass (kg) delivered to low Earth orbit. This information is to be specified from the start of the analysis calendar year through the indicated years. [APLMASS(I)] It is important to place "N/A" in all cells prior to the year of "Start of HRV Operations."

Return to Data Screen

Figure A.4a Input Data/Architecture Timing (Delivered Mass to LEO)



Input Data/Architecture Timing [B]

Calendar Years:

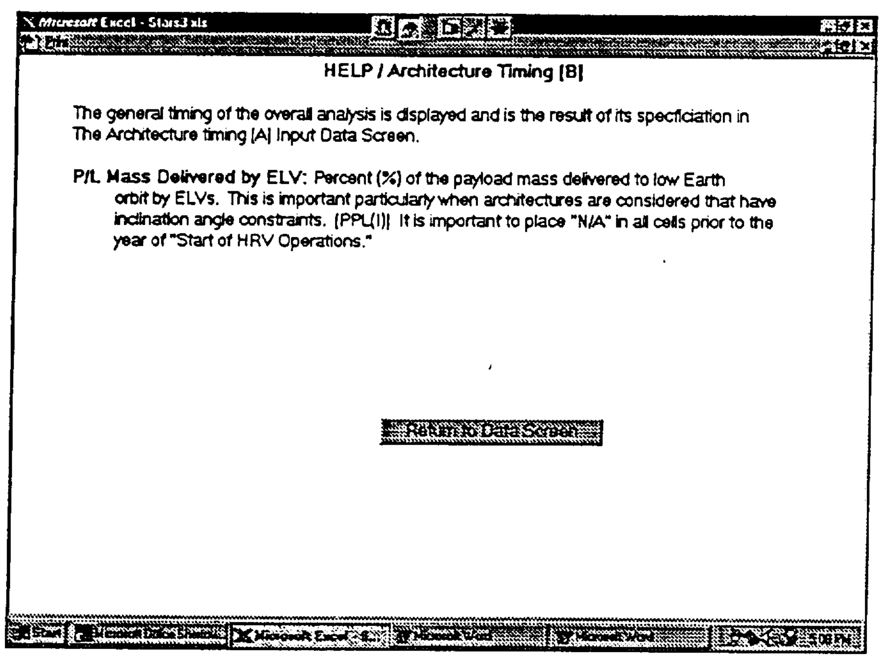
Start of Analysis	1997
Completion of Infrastructure	2005
Completion of Fleet Acquisition	2010
Start of HRV Operations	2010

P/L Mass Delivered by ELV

1997	1998	1999	2000	2001	2002
100	100	100	100	100	100
2003	2004	2005	2006	2007	2008
100	100	100	100	100	100
2009	2010	2011	2012	2013	2014
100	100	80	50	10	5
2015	2016	2017	2018	2019	2020
5	5	5	5	5	5
2021	2022	2023	2024	2025	2026
5	5	5	5	5	5

Date: 4/11/97
Reference Number: 1003

Help



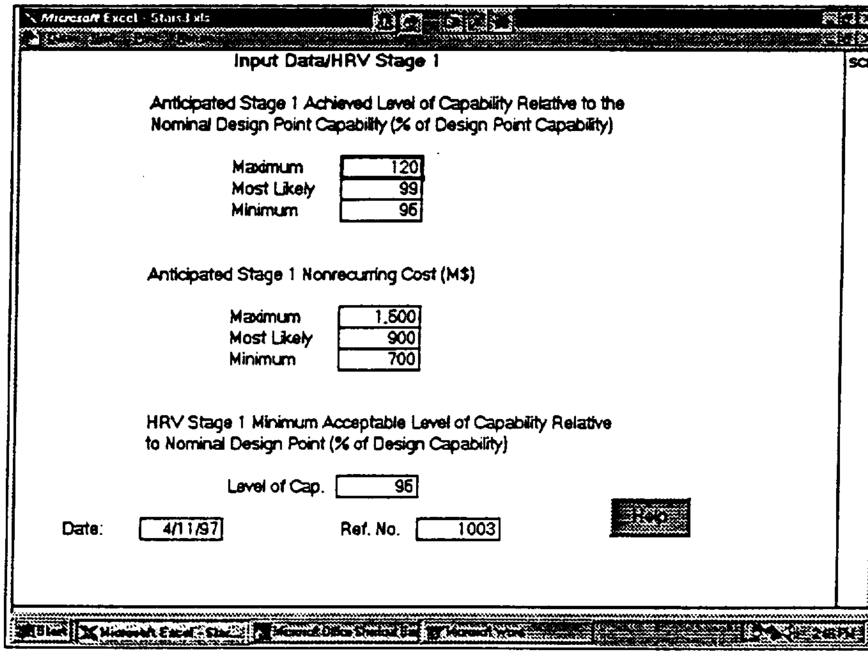
HELP / Architecture Timing [B]

The general timing of the overall analysis is displayed and is the result of its specficiation in The Architecture timing [A] Input Data Screen.

P/L Mass Delivered by ELV: Percent (%) of the payload mass delivered to low Earth orbit by ELVs. This is important particularly when architectures are considered that have inclination angle constraints. [PPL(I)] It is important to place "N/A" in all cells prior to the year of "Start of HRV Operations."

Return to Data Screen

Figure A.4b Input Data/Architecture Timing (% Mass by ELV)



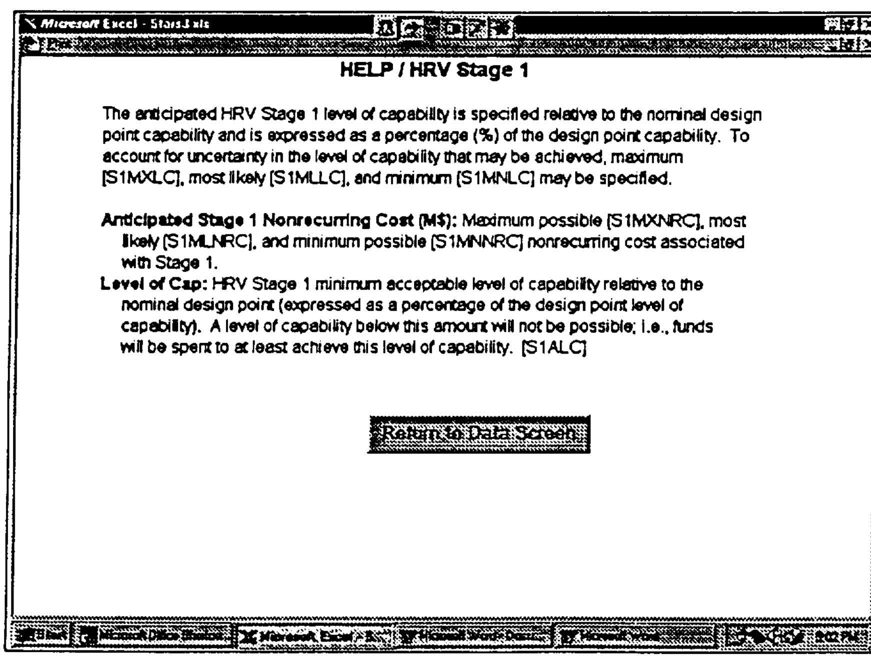
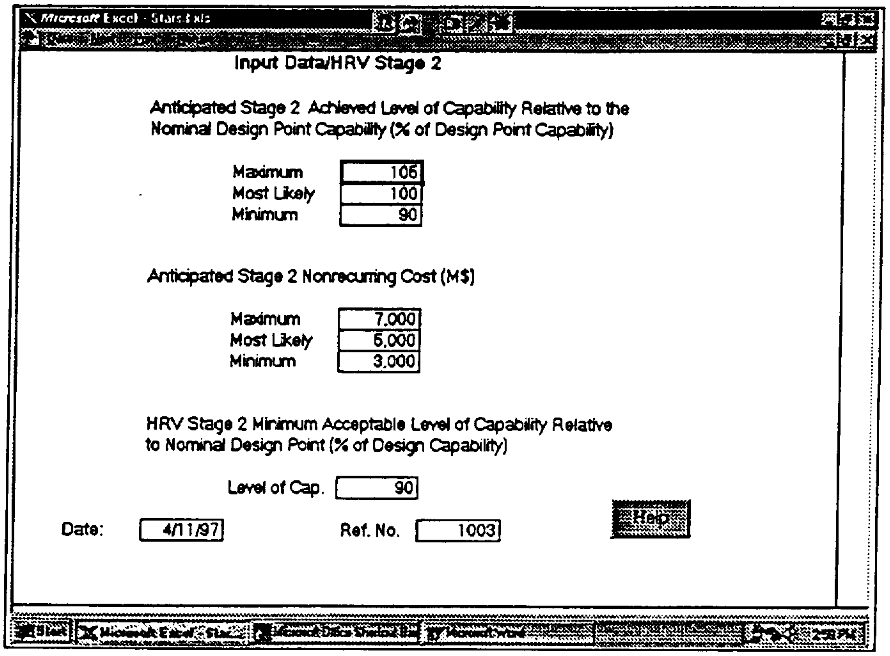


Figure A.5 Input Data/HRV Stage 1



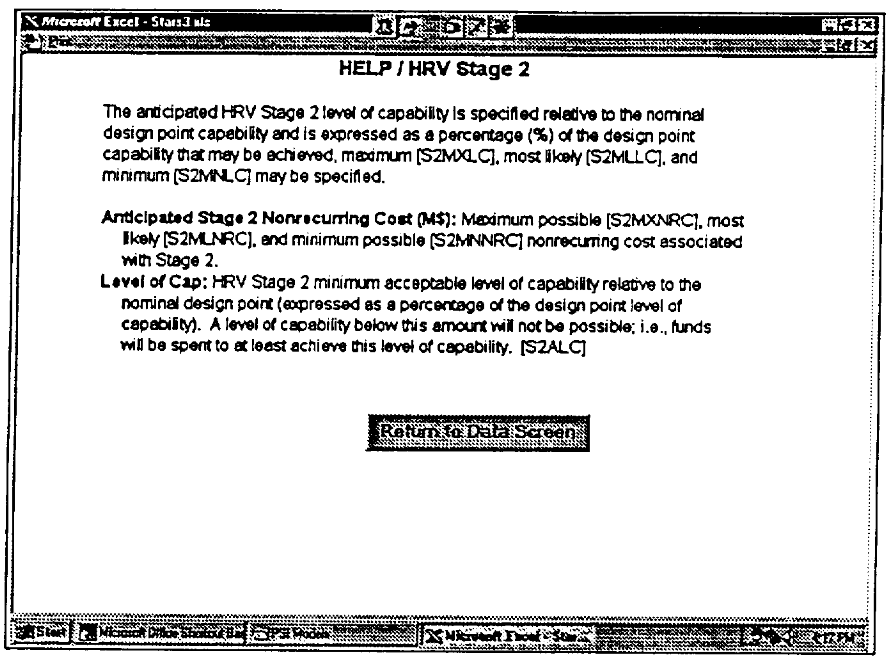
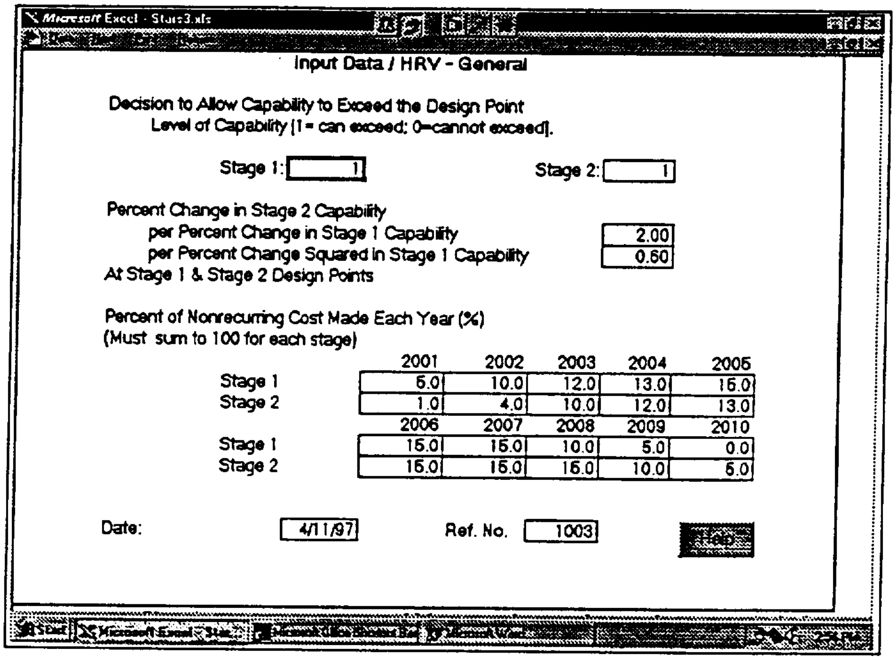


Figure A.6 Input Data/HRV Stage 2



Input Data / HRV - General

Decision to Allow Capability to Exceed the Design Point
Level of Capability [1 = can exceed; 0=cannot exceed].

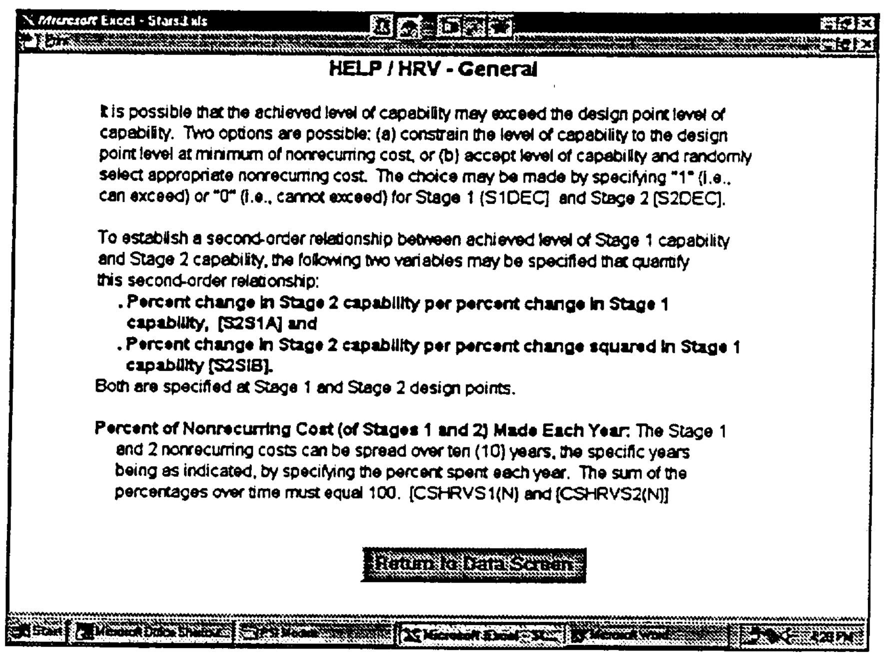
Stage 1: 1 Stage 2: 1

Percent Change in Stage 2 Capability
per Percent Change in Stage 1 Capability 2.00
per Percent Change Squared in Stage 1 Capability 0.60
At Stage 1 & Stage 2 Design Points

Percent of Nonrecurring Cost Made Each Year (%)
(Must sum to 100 for each stage)

	2001	2002	2003	2004	2005
Stage 1	5.0	10.0	12.0	13.0	16.0
Stage 2	1.0	4.0	10.0	12.0	13.0
	2006	2007	2008	2009	2010
Stage 1	15.0	15.0	10.0	5.0	0.0
Stage 2	15.0	15.0	15.0	10.0	5.0

Date: 4/11/97 Ref. No. 1003



HELP / HRV - General

It is possible that the achieved level of capability may exceed the design point level of capability. Two options are possible: (a) constrain the level of capability to the design point level at minimum of nonrecurring cost, or (b) accept level of capability and randomly select appropriate nonrecurring cost. The choice may be made by specifying "1" (i.e., can exceed) or "0" (i.e., cannot exceed) for Stage 1 [S1DEC] and Stage 2 [S2DEC].

To establish a second-order relationship between achieved level of Stage 1 capability and Stage 2 capability, the following two variables may be specified that quantify this second-order relationship:

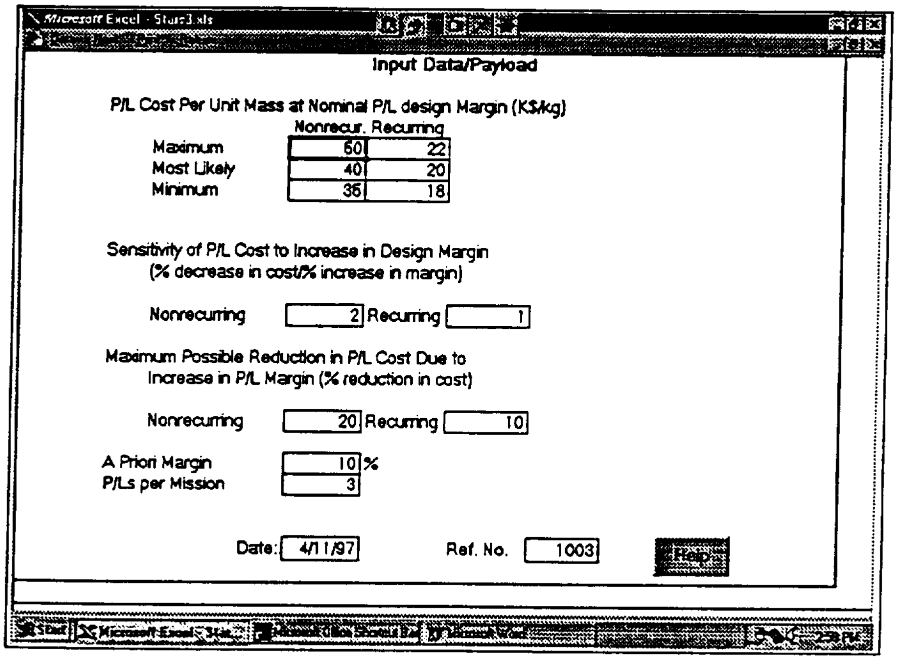
- **Percent change in Stage 2 capability per percent change in Stage 1 capability, [S2S1A] and**
- **Percent change in Stage 2 capability per percent change squared in Stage 1 capability [S2S1B].**

Both are specified at Stage 1 and Stage 2 design points.

Percent of Nonrecurring Cost (of Stages 1 and 2) Made Each Year: The Stage 1 and 2 nonrecurring costs can be spread over ten (10) years, the specific years being as indicated, by specifying the percent spent each year. The sum of the percentages over time must equal 100. [CSHRVS1(N) and [CSHRVS2(N)]

Return to Data Screen

Figure A.7 Input Data/HRV - General



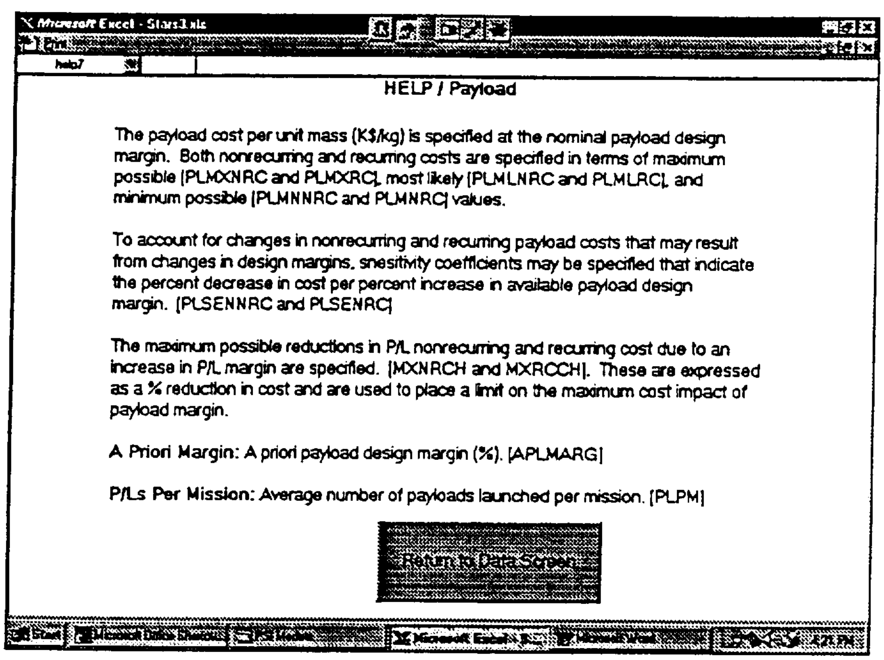
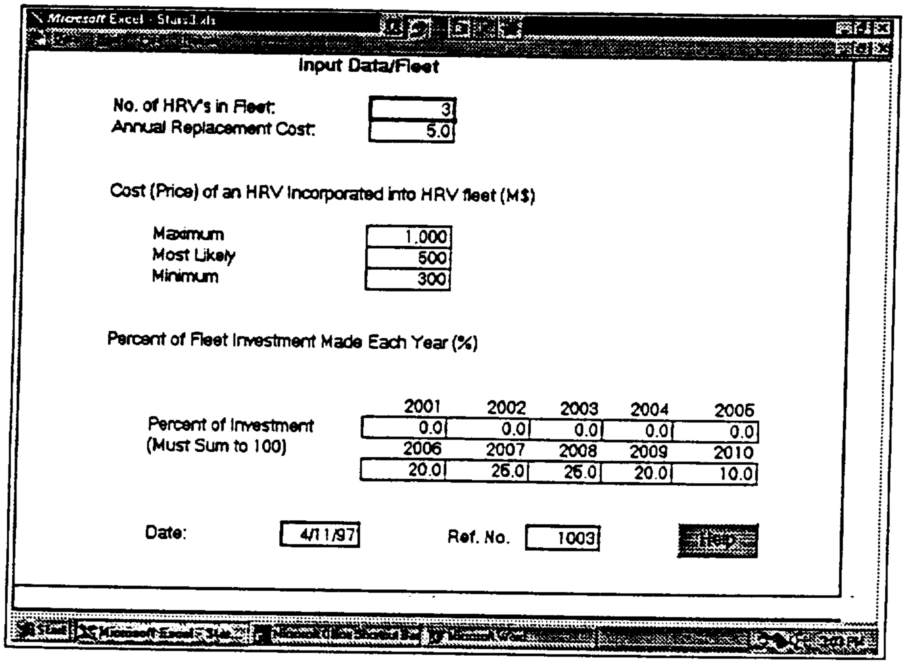


Figure A.8 Input Data/Payload



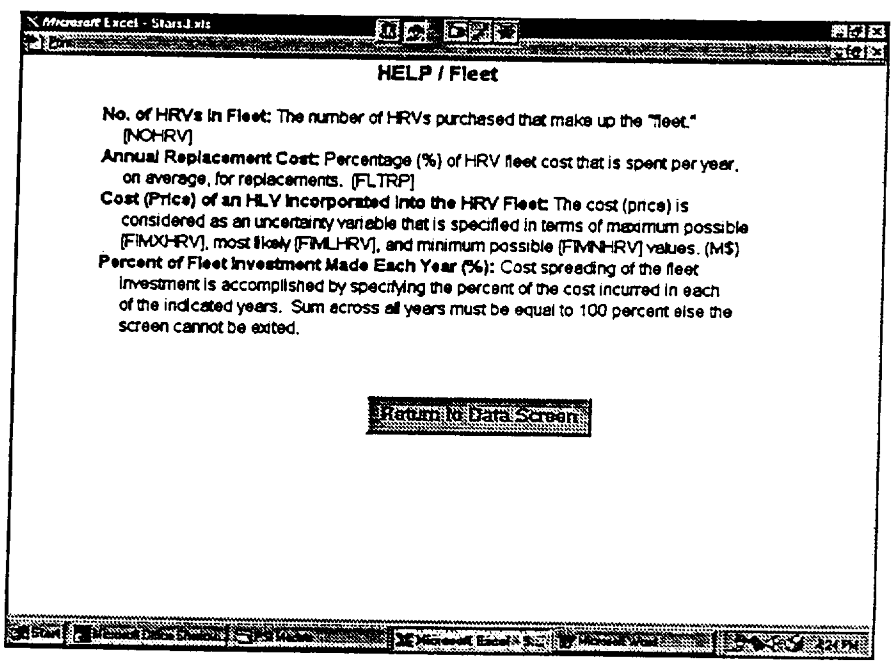
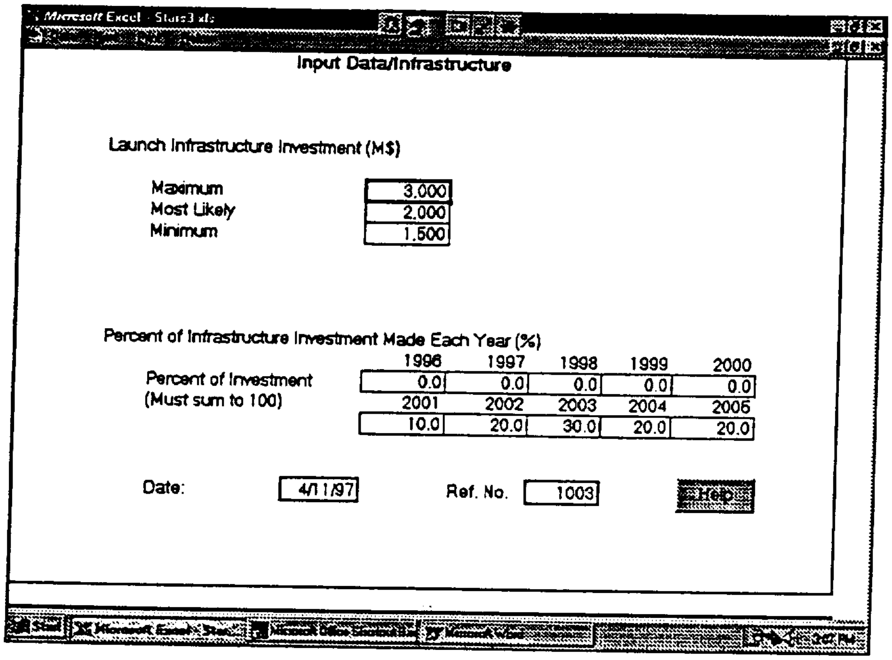


Figure A.9 Input Data/Fleet



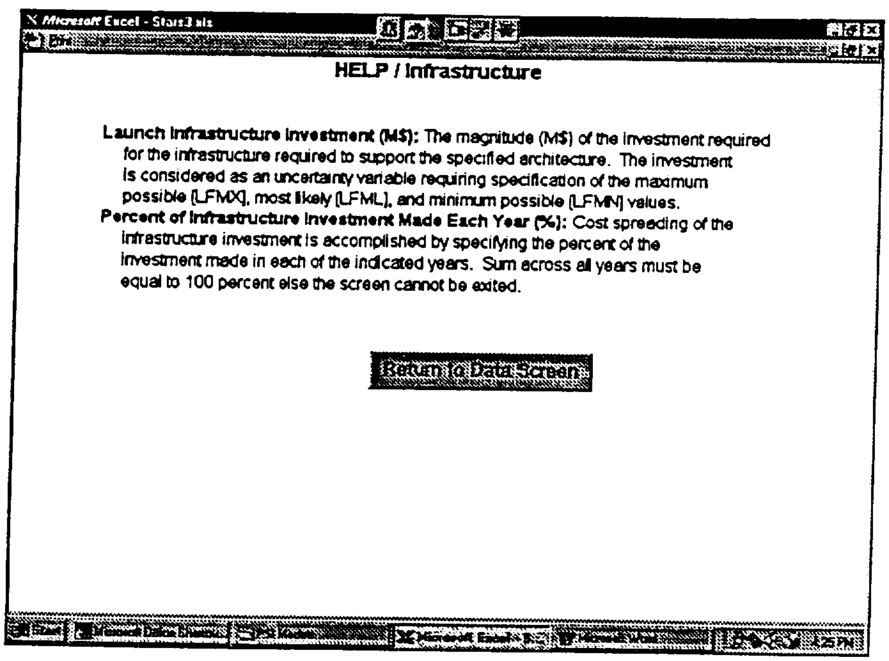
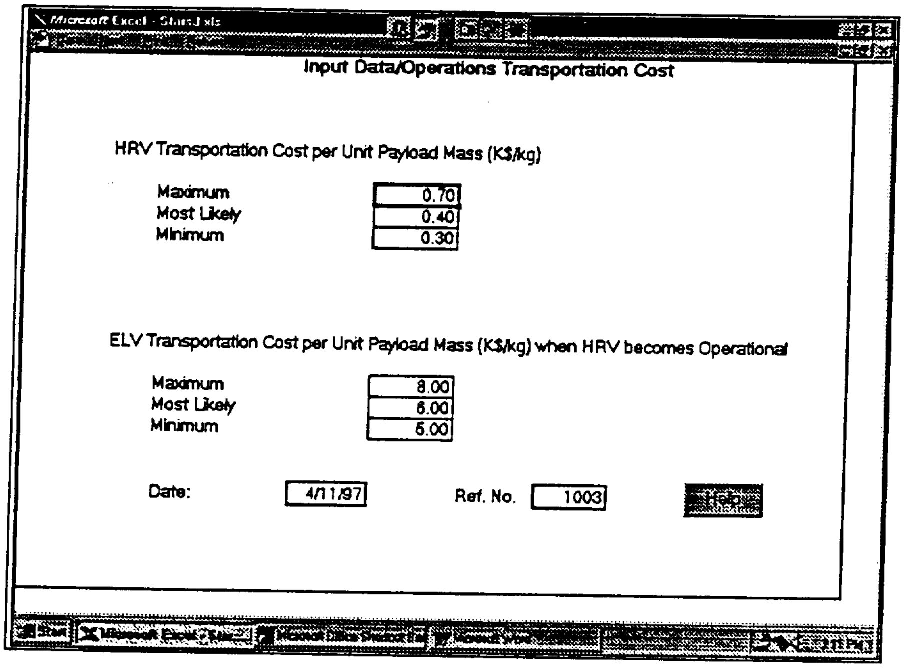


Figure A.10 Input Data/Infrastructure



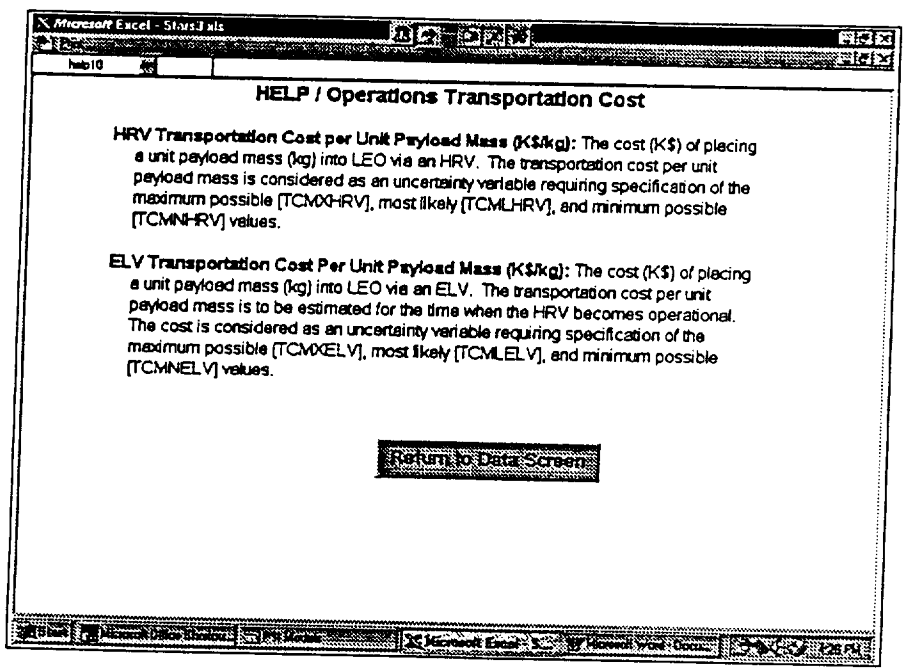
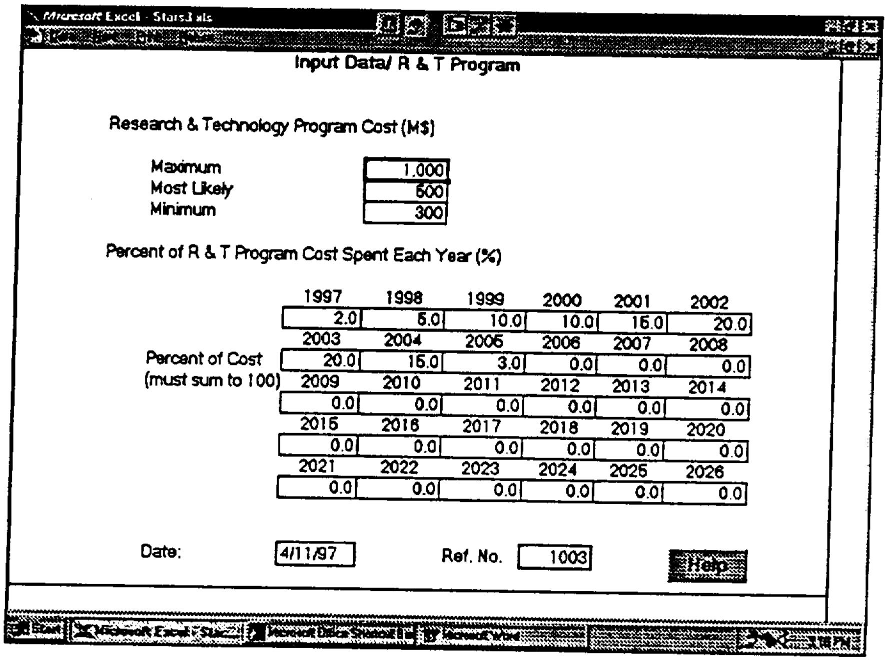


Figure A.11 Input Data/Operations Transportation Cost



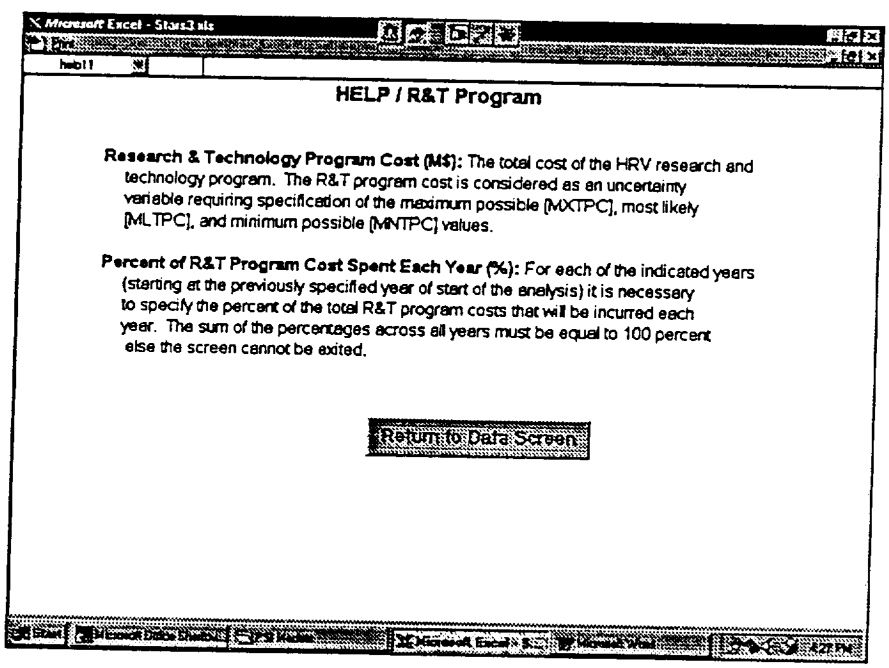


Figure A.12 Input Data/R&T Program Cost

Microsoft Excel - Stars3.xls

ARCHITECTURE SUMMARY

Architecture Description: Argus with Maglifter

Typical Example: Georgia Tech - AE

Reference Number: 1003 Date: 4/11/97

Start of HRV Operations: 2010

Can Exceed Design Point:

Stage 1: 1

Stage 2: 1

	Expected	Std. Dev.	
Trans. Sys. Nonrec. Cost	6,416	1661	(M$)
HRV Unit Cost	704	242	(M$)
HRV Fleet Investment	2,112	726	(M$)
Infrastructure Investment	2,333	522	(M$)
Launch Cost/Unit PL Mass	5	0.00	(K$/kg)
PL Nonrec. Cost/Unit Mass	42	3.97	(K$/kg)
PL Rec. Cost/Unit Mass	20	1.21	(K$/kg)
PL Design Margin	5	4.23	(%)
Infinite Horizon Discounting	N		
Present Value of Oper. Sys. LCC	394661	11784	(M$)
Present Value of Tech. Prog.			(M$)

Figure A.13 Architecture Summary

Microsoft Excel - Stars3.xls

ARCHITECTURE ANNUAL COST (M$)

Architecture Description: Argus with Maglifter

Typical Example: Georgia Tech - AE

Reference Number: 1003 Date: 4/11/97

Start of HRV Operations: 2010

Year	2009	2010	2011	2012	2013	2014
HRV Stage 1	39	0	0	0	0	0
HRV Stage 2	463	231	0	0	0	0
Infrastructure	0	0	0	0	0	0
HRV Payloads	0	0	3,723	10,110	19,642	22,258
ELV Payloads	16,651	17,203	14,553	10,015	2,229	1,160
Fleet Investment	422	211	0	0	0	0
Fleet Replacement	0	0	106	106	106	106
Technology Program	0	0	0	0	0	0
Total Nonrecurring Cost	16,576	17,646	18,382	20,230	21,977	23,523
* Std. Deviation *	1673	1832	1655	1354	1886	2061
HRV Launch Ops.	0	0	79	214	416	472
ELV Launch Ops.	5,670	6,124	5,262	3,572	771	414
HRV Payloads	0	0	5,212	14,154	27,499	31,161
ELV Payloads	22,326	24,112	20,718	14,065	3,036	1,630
Total Recurring Cost	27,996	30,235	31,271	32,006	31,723	33,677
* Std. Deviation *	1390	1601	1303	1179	1679	1902
Total Annual Cost	44,571	47,881	49,653	52,238	53,699	57,200
* Std. Deviation *	2176	2368	2106	1796	2526	2806

Figure A.14 Architecture Annual Cost (Table)

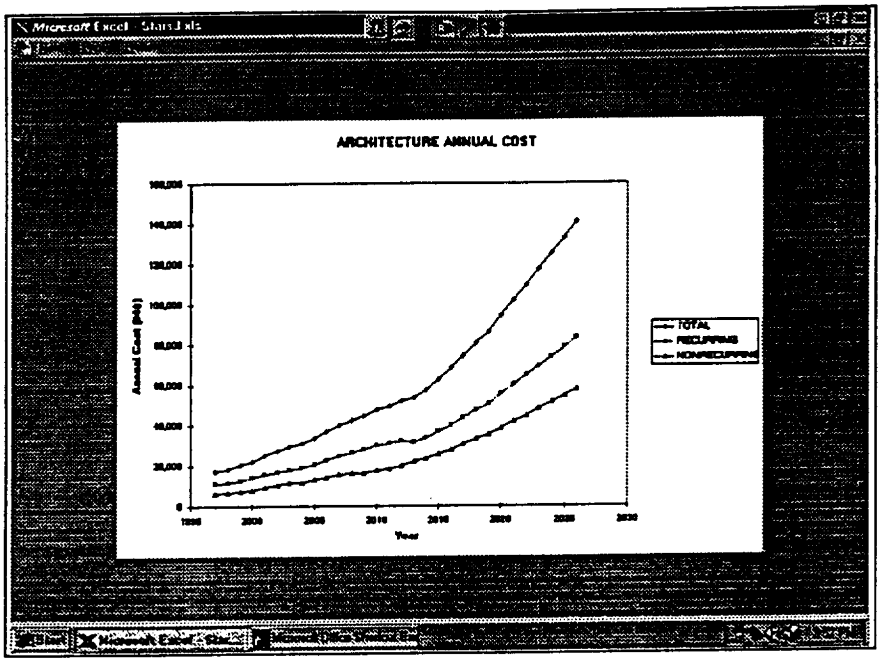


Figure A.15 Architecture Annual Cost (Graph)

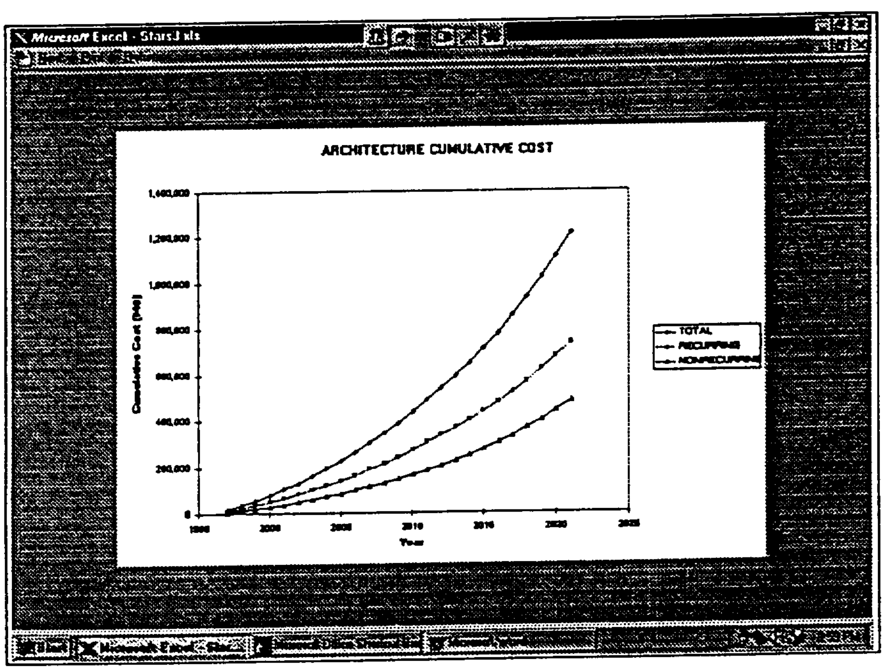


Figure A.16 Architecture Cumulative Cost (Graph)