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A DEMONSTRATIVE MODEL OF A LUNAR BASE SIMULATION ON A PERSONAL COMPUTER

by

The Large Scale Programs Institute

and

The Center for Space Research
at
The University of Texas at Austin

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ABSTRACT

This report describes the initial demonstration model of a lunar base simulation. This initial model was developed on the personal computer level to demostrate feasibilty and technique before proceeding to a larger computer-based model. Lotus "Symphony" Version 1.1 software was used to base the demonstration model on an personal computer with an MS-DOS operating system. The personal computer-based model determined the applicability of lunar base modeling techniques developed at an LSPI/NASA workshop. In addition, the PC-based demonstration model defined a modeling structure that could be employed on a larger, more comprehensive VAX-based lunar base simulation. Refinement of this personal computer model and the development of a VAX-based model is planned in near future.

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I. INTRODUCTION

The principal objective of this research is to develop a computer-based model that will enable NASA to effectively and efficiently examine the impacts of various technological advances and developments on a manned lunar base. This model should provide a graphic representation of evolution (in both time and space) of the base. The final model should detail investment, cost, and scheduling estimates for developing a lunar base, in addition to identifying key performance parameters. The model should also provide quantitative evaluations of trade studies to allow for easy analyses of the effects of alternative lunar base objectives, technologies, and elements/subsystems. The results of these analyses could then be used to develop long range plans for NASA, while near term impacts could be determined for the space station, orbital transfer vehicles, and earth-to-orbit vehicles.

An LSPI/NASA workshop in La Jolla, CA (Reference 1) defined the methodology that was to be employed in developing the lunar base simulation. The results of the workshop confirmed that the model would be both large and complex. The size of the model, along with NASA hardware capabilities, dictated that the simulation be based on a VAX or VAX equivalent computer. However, before modeling was to proceed on a large scale, a personal computer-based demonstration model was deemed appropriate as a "proof-of-concept." This report describes a first attempt at the prototype PC-based lunar base model.

The PC-based demonstration model's main function is to indicate the feasibility of employing macro-engineering techniques -developed at the LSPI/NASA workshop- to a lunar base program. Once feasibility has been determined, the demonstration model should indicate areas of the modeling structure that require refinement or complete change. This "pathfinder" model would enable designers to better define the modeling structure for the larger version of the lunar base simulation. Another equally important function of this initial model is to identify various areas that seem to violate a "reasonableness" test. The PC-based model should indicate relationships between requirements and attributes that need further study, and those which are satisfactory in their present form.

II. MODEL FORMAT

The model is intended for IBM-PC compatible computers using the Lotus "Symphony" Release 1.1 software. Utilizing the "Symphony" spreedsheet format, the simulation is screen oriented. The user need only to use the "PgDn" and "PgUp" keys to move throughout the model. However, program schedules could not be contained by one screen and thus were expanded to screens to the right. A continued screen is appropriately indicated in the upper right-hand corner of the screen by "more>>>." For user protection, a set of default input screens have been provided to allow the "lunar base designer" to change various input values, but still maintain a reference of the authors original values. The default screens appear out of the flow of the model to the right of the respective input screen.

The four different types of screens contained in the model are the information (info), input, output, and default screens. User changes may only be made to the input screens as all other screens are cell protected.

The user is required to specify desired lunar base objectives by entering an approproate value into the corresponding cell of an input screen, or to use the provided default values. The user can then "PgDn" to the desired output screen to analyze various types of data.

A flowchart of the demonstration model is shown in Figure 1 to allow the user to better understand the inter-relationships of the model. Referring to the top of the diagram, upon user selection of the top level requirements, the base population and mission support equipment is determined. The base population defines the number of habitation modules required which, along with mission support modules, determines the total mass and power requirements for housing of personnel and equipment. This mass and power requirement, coupled with that required by the initial mission equipment, contribute to the total mass and power mission requirements. The mass of the power system (type of power system selected by user) and construction equipment is added to the mission mass to yield the total mission mass. The total mission mass is incorporated with the resupply mass to determine the space transportation requirements.

Author-formulated "transforms" were used to define the relationship between desired attributes and resulting requirements. The attributes and requirements may be mission dependent, or mission independent. The general form of these transforms is:

$y = a + b(x)$ where

- x = Requirement-the product or service the item is to deliver, as specified by the user. Example: 150 MT of LO2 delivered to LEO.
- y = Attribute-the result from the consequences of fulfilling the requirement with the selected technology. Example: LO2 plant mass, MT.
- a = A constant determining the value of the attribute for the case in which the value the requirement is zero. A floor value for that attribute if the item is present at the base.
- $b(x)$ = An empirical function which will quantify an attribute given the value of the requirement and the technology selected.

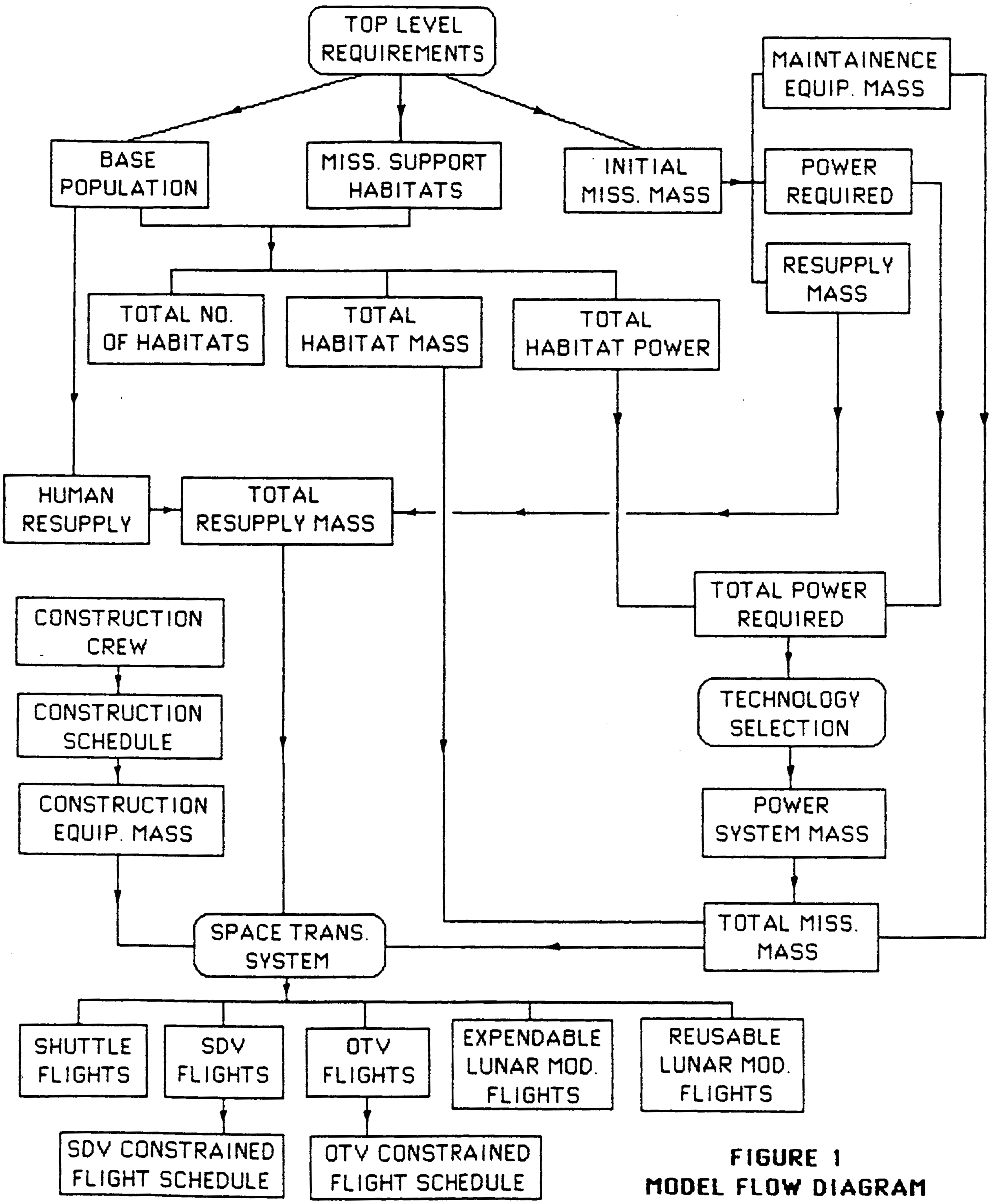

FIGURE 1
MODEL FLOW DIAGRAM

III. MODEL DESCRIPTION

As previously mentioned, the model contains four types of screens:

(1) information,
(2) input,
(3) default, and
(4) output screens (see Appendix A for model listing).

The information screens provide the user with useful insight into the purpose, use, and format of the model. First time users should consult each information screen as it appears in the general flow of the model before proceeding to the next screen of the model. Users are prohibited from making changes to the information screens by cell protection.

The input screens act as the interface between the user and the model. The modeler defines various top-level lunar base objectives such as:

(1) science capabilities,
(2) resources exported, and
(3) community size

to create a base scenario he desires. The user may wish to use the author-supplied default values, or to change the default values to obtain information on a differing scenario. Any change to an input screen destroys the specific cell reference to the default screen. To return a cell reference to its original default value, the user must "page over" to the right and determine the default value, and enter that value into the appropriate cell on the input screen.

Other areas the user is allowed to define are:

(1) the space transportation system,
(2) the lunar orbit space station, and
(3) technology selections.

Although a large list is supplied for the space transportation system, all of the vehicles are not yet interactive with the model. The launch vehicles that are available at this time are the Shuttle for personel transport, and a Shuttle Derived Vehicle (SDV) for equipment transport. Upper stages that are used in the model are:

(1) a modified Orbital Transfer Vehicle (see Appendix B),
(2) an expendable Lunar Module, and
(3) a reusable Lunar Module.

The Orbital Transfer Vehicle recently studied by NASA was considered too small for lunar base needs, thus a derivative of this vehicle was developed for this model.

Since the lunar orbit space station was deemed an integral part of the lunar base program, its characteristics were assumed (pending data to be supplied by NASA) to give the user a better overall picture of the requirements to establish a base on the Moon.

The technology selection screens allow the user to specify various types of:

(1) primary power sources,
(2) energy storage,
(3) heat rejection,
(4) thermal control, and
(5) power control.

Selection of the specific technology to be present at the lunar base must be done by manual cell reference at this time.

The default screens, located one screen to the right of the respective input screen, provide a baseline for the model user, and reflect the same information as the input screen. The default screen for the upper stages of the space transportation contains more information than the respective input screen. The upper stages default screen contains performance parameters such as the delta-v, the mass ratio, and iterated payload of the vehicles. These values were displayed for those users specifically interested in the upper stage fleet. All default screens are protected against user change.

Output screens reflect equipment, manpower, and time required to emplace the user specified base on the lunar surface. The following descriptions are some of the assumptions the authors made due to lack of contradictory data.

- All housing of equipment and personnel was assumed to be provided by LEO space station common modules modified to better accomodate the lunar environment.

- Mission resupply needs were derived from a percentage of the initial hardware mass, while human resupply was taken from a University of Houston report (Reference 2).

- The construction equipment and corresponding staff of 14 was estimated by the authors. For larger bases, the construction staff size remains the same while the construction schedule is lengthened.

- The authors also estimated the phasing of base build-up and that it would be goverened by the rate of OTV flights. Another flight schedule is produced that is dictated by the rate of SDV launches.

Output screens have cell protection to prevent user change.

There are a number of output screens that are not functional at this time. These screens were left in the model to indicate, to the user, future plans to refine and expand the demonstration model. Since this is an initial model of a very large scale future civil space program, many iterations and refinements will be necessary before the level of detail, inter-relationships, and cost/benefit forecasts can be relied upon for bugdetary estimates or actual program costing. Users are encouraged to criticize the logic, pace, element description, and transforms of the present model.

IV. TEST CASES

The initial use of the model was to perform "reasonableness tests" to determine if the indicated trend of lunar base characteristics over a range of differing requirement scenarios appeared to be sensible. The thirty-four cases run are summarized in Table 1. For this report, three preliminary sensitivity studies were performed. The science capability, lunar oxygen production, and community size were varied independently to determine specific impacts on a lunar base program. In addition, ten composite cases were reviewed. It should be noted that none of these cases were permitted the advantage of lunar-supplied resources.

Runs 1 through 6 examined the impact of the magnitude of the science mission upon a lunar base. The complement of scientists were varied from zero to eight persons. The "bare bones" lunar base was assumed to have a crew size of seven persons. They required a lunar base aggregating 220 MT which, in turn, required 3.8 months for the construction crew to assemble on the lunar surface. Three expendable lunar modules were consumed, and 30 OTV flights were required to emplace the base on the Moon's surface. This included the placement of the Lunar Orbit Space Station. Sixty-two flights of an SDV and three flights of the Shuttle were needed to fufill mission requirements. The total program duration was 7.6 years, of which 0.5 years were devoted flight operations.

The base supporting eight scientists had a total base complement of 17 persons which needed 12 LEO space station "common modules" for base support. The resulting base had an aggregate mass of 502 MT, with seven months indicated as the surface construction interval. Four expendable lunar modules were expended, while 47 OTV, 96 SDV, and four Shuttle were required to provide flight operation support. In all "science only" cases, the base power supply size was less than 100 Kw.

A series of lunar bases providing only lunar oxygen were next examined. The size of the production output of the 02 plant was varied from 25 MT/month to 300 MT/month. A "reference" case of 1000 MT/year of 02 producted was supplied by Dr. Chris Knudsen of Carbotech. The smallest of these lunar 02 bases required a staff of 10, 300 Kw of power and amassed 478 MT. Ninety SDV flights were required.

The largest base in this series had a mass of 2530 MT, a 2.8 Mw power supply and required 313 SDV flights. The crew size remained at 10 persons, as no scaling of plant operators to size of plant are now available. With the automation likely in the time frame of a lunar base, this could later be found to be an accurate assessment.

The final "sensitivity study" was done for bases which simply support people, or a "community." The community size was varied from five to 500 persons. The smallest base of 377 MT required 76 SDV flights and had a total crew size of 13 persons.

The largest base reviewed had a total population of 632 persons, needed 288 of the LEO Space Station "common modules" and required a 1.5Mw power source. Base mass was 15,417 MT and required over 10 years to construct. Seventy-six expendable lunar modules were consumed, while 735 OTV, 81 shuttle, and 1521 SDV missions were flown.

Large composite function bases were the final cases run. The largest of these bases accomodated 33 scientists, exported 02, Silicon, Glasses and 1000 MT of raw regolith shielding per month. One hundred persons not occupied in these tasks were also accomodated. This base had a total complement of 188 persons, required 81 "common modules," a 1.7 Mw power source, and aggregated 5118 MT. Over four years were required for construction. Twenty-three expendable lunar modules were used along with 284 OTV missions. Twenty-five shuttle flights, and 579 SDV flights provided earth launch services. Total program duration, from ATP to IOC was 12.6 years, with 5.2 years of maximum rate flight operations.

As no cost data are yet provided, no assessment of the economic factors were exposed by these test cases. The results did not appear to be totally implausible upon first examination, therefore it was concluded that the model works within its known limitations. Refinement is clearly necessary, but the "linkages" needed seem to manifest themselves appropriately.

V. FUTURE WORK

Obviously, this initial model is not in final form. Refinements and changes initiated by the authors and users will continue until confidence in the model's accuracy and completeness is established. Currently, the authors plan to incorporate NASA Cost Estimating Relationships (Appendix C) and Work Breakdown Structure (Appendix D) to the next iteration of the demonstration model. Also, values and dependencies of the key parameters of areas such as the LEO space station and program emphasis should be addressed in the future prototype model. However, care must be taken not to spend a prohibitively large amount of time on the PC-based model which delays work on the more comprehensive VAX-based model.

The value of the follow-on work to the demonstration model depends as much on NASA and its contractors inputs of data and suggestions as it does upon the efforts of the authors. More accurate transforms are needed in all of the model "modules" to make the simulation as realistic as possible. The authors look forward to your assistance.

Table 1 - Summary of Test Cases

Test Case / Base Attribute	"Bare Bones"	1 Surf Sci	1 sur & 1 phy sci	1 sur, 1 phy, & 1 astr sci	1 sur,1 phy, 1 astr, & 1 other
Population	7	8	9	10	12
Number of Habitats	7	8	9	10	10
Pwr Plnt Size (Mw)	<0.1	<0.1	<0.1	<0.1	<0.1
Base Mass (MT)	220	266	314	373	382
Cnstrctn Intrvl (mo)	3.8	4.3	4.8	5.4	5.6
Expendable LM's	3	3	3	3	3
OTV Flights	30	32	35	38	39
Shuttle Flights	3	3	3	3	3
SDV Flights	62	67	73	79	81
Total Time (yrs)	7.6	7.6	7.7	7.8	7.8
Flgt Ops Time (yrs)	0.5	0.6	0.6	0.7	0.7

Test Case / Base Attribute	8 sci, 2 ea dis	02 Prod 25 MT/mo	02 Prod 50 MT/mo	02 Prod 75 MT/mo	02 Prod 83 MT/mo
Population	17	10	10	10	10
Number of Habitats	12	9	9	9	9
Pwr Plnt Size (Mw)	0.1	0.3	0.5	0.7	0.8
Base Mass (MT)	502	478	665	851	914
Cnstrctn Intrvl (mo)	7.0	6.7	8.9	11.1	11.9
Expendable LM's	4	3	4	4	4
OTV Flights	47	44	54	65	68
Shuttle Flights	4	3	3	3	3
SDV Flights	96	90	110	130	137
Total Time (yrs)	7.9	7.9	8.1	8.3	8.3
Flgt Ops Time (yrs)	0.9	0.8	1.0	1.2	1.2

Table 1 (continued)

Base Attribute / Test Case	02 Prod 100 MT/mo	02 Prod 150 MT/mo	02 Prod 200 MT/mo	02 Prod 300 MT/mo	Com only 5 per
Population	10	10	10	10	13
No. of Habitats	9	9	9	9	10
Pwr Plnt Size (Mw)	1.0	1.4	1.9	2.8	<0.1
Base Mass (MT)	1038	1411	1784	2530	377
Cnstrtn Intrvl (mo)	13.3	17.8	22.4	31.4	5.0
Expendable LM's	4	5	5	7	3
OTV Flights	75	96	117	159	37
Shuttle Flights	3	3	3	3	4
SDV Flights	150	191	231	313	76
Total Time (yrs)	8.4	8.8	9.2	10.0	7.7
Flgt Ops Time (yrs)	1.4	1.7	2.1	2.9	0.7

Base Attribute / Test Case	Com only 10 per	Com only 20 per	Com only 40 per	Com only 60 per	Com only 80 per
Population	19	32	57	82	107
No. of Habitats	13	18	30	41	52
Pwr Plnt Size (Mw)	0.1	0.1	0.2	0.2	0.3
Base Mass (MT)	539	820	1453	2053	2653
Cnstrtn Intrvl (mo)	6.2	8.4	13.5	18.3	23.2
Expendable LM's	4	5	9	11	14
OTV Flights	44	56	86	113	141
Shuttle Flights	4	6	9	12	15
SDV Flights	91	117	177	234	292
Total Time (yrs)	7.9	8.1	8.7	9.3	9.8
Flgt Ops Time (yrs)	0.8	1.0	1.6	2.1	2.6

Table 1 (continued)

Test Case / Base Attribute	Com only 100 per	Com only 150 per	Com only 200 per	Com only 500 per	02 - 83 Al - 50 Com - 8
Population	132	194	257	632	24
No. of Habitats	63	92	120	288	14
Pwr Plnt Size (Mw)	0.3	0.5	0.6	1.5	1.1
Base Mass (MT)	3252	4805	6319	15417	1296
Cnstrctn Intrvl (mo)	28.0	40.7	53.0	127.1	15.5
Expendable LM's	17	25	32	76	6
OTV Flights	169	241	312	735	88
Shuttle Flights	18	26	34	81	5
SDV Flights	350	499	645	1521	177
Total Time (yrs)	10.4	11.8	13.2	21.6	8.7
Flgt Ops Time (yrs)	3.1	4.4	5.7	13.4	1.6

Test Case / Base Attribute	02 - 83 Si - 50 Gl - 50 Com - 8	02 - 83 Si - 50 Gl - 50 Shl -100 Com - 8	02 - 83 Si - 50 Gl - 50 Shl -200 Com - 8	02 - 83 Si - 50 Gl - 50 Shl -300 Com - 8	02 - 83 Si - 50 Gl - 50 Shl -400 Com - 8
Population	28	32	32	32	32
No. of Habitats	16	17	17	17	17
Pwr Plnt Size (Mw)	1.2	1.2	1.2	1.2	1.2
Base Mass (MT)	1393	1439	1451	1463	1476
Cnstrctn Intrvl (mo)	16.6	17.2	17.3	17.5	17.6
Expendable LM's	6	7	7	7	7
OTV Flights	94	97	98	98	99
Shuttle Flights	5	6	6	6	6
SDV Flights	189	196	197	198	200
Total Time (yrs)	8.8	8.9	8.9	8.9	8.9
Flgt OPs Time (yrs)	1.7	1.8	1.8	1.8	1.8

Table 1 (continued)

Test Cases / Base Attributes	O2 - 83 Si - 50 Gl - 50 Shl -500 Com - 8	O2 - 83 Si - 50 Gl - 50 Shl-1000 Com - 8	O2 - 83 Si - 50 Gl - 50 Shl-1000 Com - 8 Sci - 33	O2 - 83 Si - 50 Gl - 50 Shl-1000 Com -100 Sci - 33
Population	32	32	73	188
No. of Habitats	17	17	30	81
Pwr Plnt Size (Mw)	1.2	1.3	1.5	1.7
Base Mass (MT)	1488	1549	2346	5118
Cnstrctn Intrvl (mo)	17.8	18.6	28.7	51.3
Expendable LM's	7	7	10	23
OTV Flights	100	103	155	284
Shuttle Flights	6	6	11	25
SDV Flights	201	208	312	579
Total Time (yrs)	8.9	9.0	10.0	12.6
Flgt Ops Time (yrs)	1.8	1.9	2.8	5.2

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APPENDIX A

MODEL LISTING

(Listed by screen, as it appears in the model)

WELCOME TO
the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

LUNAR BASE MODELLING PROGRAM
RELEASE 1.0
MARCH 15, 1986

developed under NASA Grant NAG 9-116
by
THE CENTER FOR SPACE RESEARCH, THE UNIVERSITY OF TEXAS AT AUSTIN
and
THE LARGE SCALE PROGRAMS INSTITUTE, AUSTIN, TEXAS
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(please press "page down" key to continue)

PREFACE

Screen i
(Info)

This document is the current version of a long-term effort to develop a comprehensive computer simulation of a permanent Free World inhabited base on the surface of Earth's moon. Such a base is considered by many in the aerospace advanced systems community as a natural follow-on to the present United States Low Earth Orbit Space Station program. The feasibilty of a lunar base can be enhanced if key technology areas that have a direct effect on lunar base emplacement and operation are identified. This simulation is devoted to the task of identifying those specific areas, when developed, capable of making a lunar base a reality.

As this is a progress report, rather than a completed model, numerous important facets of the Lunar Base program are not yet addressed. Notably, no program cost data are provided because such data produced by the model in its present, immature form could be misleading and irresponsible. Consequently, only "place-holder" screens are provided for the period beyond completion of the mature base and initial presence of the full complement of inhabitants. Therefore, no "mass payback" or "cost/benefit" ratios are calculated by this prototype model.

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ACKNOWLEDGEMENTS

Screen ii
(Info)

This effort was supported by NASA Grant NAG 9-116 from the NASA Lyndon B. Johnson Space Center. The technical monitor, Mr. Barney Roberts, offered laudable technical counsel and needed encouragement during the work on this preliminary model. Significant input data and assistance were provided by Mr. Humboldt Mandell and Mr. Kyle Fairchild of NASA-JSC and Mr. John Butler and Mr. Eugene Austin of NASA- MSFC. Many others also made contributions, including valuable assistance from Mr. Stan Sadin of NASA Hq. and Mr. Bill Stump of Eagle Engineering, Inc., who works in parallel with the team in Austin in examining the overall program. Dr. Chris Knudsen provided the lunar oxygen plant transforms.

Drs. Hans Mark and George Kozmetsky of the Large Scale Programs Institute of the University of Texas and Dr. Byron Tapley, Director of the Center for Space Research of the University of Texas at Austin, provided continuous support, counsel, and assistance.

PURPOSE

Screen iii
(Info)

The purpose of this demonstration model is to permit quick assessment of the influence of changes in top-level requirements, available space infrastructure and technologies upon the characteristics, size, mass, and costs of a permanently inhabited base on the surface of Earth's moon. The model also provides a description of the mission operations needed to establish and maintain the selected Lunar Base scenario. This prototype is a preliminary "proof-of-concept model being used as a "pathfinder" for a larger model planned for the near future.

The space transportation vehicles required to emplace and sustain the lunar facilities will be characterized external to this model and only the resultant vehicle characteristics essential to this model will be employed in the internal calculations. All required vehicles must be specified in the "input" section of the model. Development, fleet acquisition, and launch/landing facilities costs must be manually added to the cost outputs if needed. Only vehicle flights and "user charges" are accumulated within this model.

INSTRUCTIONS FOR USE Screen iv (Info)

This model is intended for IBM-PC-compatible computers using Lotus "Symphony" release 1.1 software. The minimum memory required is 512K while 640K is recommended. An 8086 or 82086 CPU will allow more rapid recomputation of a model run. To be more useful,it is screen, not page, oriented. Go to Cell A161 to begin inputs, then A1061 for summary model run outputs. Cell protection is provided for default, info, and output screens. However, the standard "backup" procedures should be followed prior to alterations of cell contents by producing a duplicate diskette kept out of daily use. Should this fail, please return your diskette to LSPI for re-recording of the original (or then-current update) template diskette.

If hardcopy is desired, set pitch to 12, margins to L10 & R125. Four printing passes are necessary to obtain the entire model. "Source" settings are A1..I1060, J161..Q340, S221..Z240 and J761..Q860, respectively. The final instruction is to recognize this as a working tool and to provide criticism or suggestions for improvement to the originator, as the work continues and this model is truly a community effort. Your help is needed.

MODEL OUTPUT FORMAT

Screen v
(Info)

This model will later use a prelimary Work Breakdown Structure (WBS) in accordance with NHB 9501.2B, "Procedures for Contractor Reporting of Correlated Cost and Performance Data", February 1985. The model will produce tabular reports which are based upon the NASA Form 933 series as required by NMI 9501.1, plus textual reporting as needed for lucidity.

Obviously, since this is an initial model of a large scale future civil space program, many iterations and refinements will be necessary before the level of detail, inter-relationships, and cost/benefit forecasts can be relied upon for budgetary estimates or actual program costing. It is considered important, however, that the work begin with the recognition of the NASA procedures for generating real program cost forecasts and reports, and to conform, insofar as practicable, to these NASA policies and procedures in constructing, using and interpretating results from the use of this Lunar Base Model. Users are encouraged to criticize the logic, pace, element descriptions, and transforms to assist in its improvement. Please offer your suggestions to NASA JSC or to LSPI, Austin, Texas.

LIMITATIONS

Screen vi
(Info)

Each input parameter will have an "applicable range" indicated. The model output has been reviewed only within these limits and results are unpredictable outside these boundaries. It is therefore recommended that the user provide values of each input parameter within the applicable range. (range feature not present in this prototype model)

This model specifies the technology levels employed by "transform algorithms" internal to the model. These transforms utilize the "figures of merit" for the circa 2000 technologies selected by the user. Transforms are displayed in the screen upper LH corner for the cell selected by the cursor and can be altered by the user by editing the algorithm contained in that cell. The final printout may display the algorithm of each transform on the report printout of the final run. Figures of merit are based upon results of the August, 1985 La Jolla Conference, supplemented by the documents listed in the bibliography. These are the best forecasts of the state-of-the-art available to the authors at the time this prototype model was prepared.

INPUT SCREENS

Screen vii
(Info)

The following screens are designated for input of the various elements required to define the lunar base. The following input areas must be defined by the user to initiate each run of the model:

I. Top Level Requirements
   a. Science Objectives
   b. Resources Export
   c. Lunar Community

NOTE: The follow-on model will permit entry of a range of values for each reqm't.

II. Space Transportation System
   a. Launch Vehicles
   b. Upper Stages
III. Low Earth Orbit Space Station (not functional in this model)
VI. Lunar Orbit Space Station
V. Programmatic Selections (not functional in this model)
   a. Emphasis
   b. Fiscal and Fleet Size Constraints
VI. Technology Selections

LUNAR BASE TOP LEVEL REQUIREMENTS — Screen 1 (Input)

(do NOT enter "zeros" as input values)

SCIENCE:	reference parameter	value, mature base (per)	Mission Equip. mass (MT/per)	Resupply Required Miss. Eq. (MT/per/yr)	Spec.Pwr. (Kw/per)
Astronomy	persons	1	20	0.500	1.5
Physics	persons	1	10	2.000	15
Surface	persons	2	7	1.500	2
Other	persons	1	8	1.500	2

RESOURCES EXPORT:	* -(ref:Knudsen, Feb 1986)		Requirements of Production			
		Output (MT/mo.)	Equipmnt (MT/MT/mo)	Consumbls (MT/MT)	Energy (KwHr/MT)	Power (Kw/MT/mo)
Oxygen*	shipments	83.33	4.80	0.013	27000	32.00
Hydrogen	shipments		0.00	0.000	0	0.00
Silicon	shipments		0.75	0.035	18000	25.00
Aluminum	shipments		0.00	0.000	0	0.00
Iron/Steel	shipments		0.00	0.000	0	0.00

LUNAR BASE TOP LEVEL REQUIREMENTS (cont) Screen 2 (Input)

RESOURCES EXPORT (cont):	reference parameter	value, mature base (MT/mo)	Mission Equip. mass (MT/MT/mo)	Resupply Required Miss. Eq. (MT/MT)	Energy (KwHr/MT)	Power (Kw/MT/mo)
Glasses	shipments	50	0.25	0.015	2500	3.47
Shielding	shipments	150	0.10	0.006	200	0.28
Mfgr. Prod.	shipments		0.00	0.000	0	0.00
Foodstuffs	shipments		0.00	0.000	0	0.00
Water	shipments		0.00	0.000	0	0.00

COMMUNITY		value, mature base (per)	Equipment Mass (MT/per)	Extra Resupply (MT/per)	Extra Energy (KwHr/per)
Additional People	, persons	8	10.00	0.050	0

SPACE TRANSPORTATION SYSTEM Screen 3 (Input)

The model assumes that a fleet of launch vehicles and upper stages were developed for other space programs and are available for use in establishing and maintaining a lunar base by payment of a fixed "user charge" for each flight. Characteristics of this space transportation system are tabulated below and will be used for this version of the luna base model until new values are determined for the following parameters.

LAUNCH VEHICLES:

LAUNCH VEHICLE	USER CHARGE $Mill/Flt	PAYLOAD Metric tons	ALTITUDE DECREMENT MT/Km.	PASSENGERS (max) no.
Shuttle	$59.0	29.50	0.075	8
Shutt.II	$61.3 (prelim)	35	0.04	16
TransAtmo	$35.0 (prelim)	5	0.03	2
SDV	$88.5	66.4	0.05	0
HLLV	$59.0	147.5	0.12	0

UPPER STAGES: Screen 4 (Input)

VEHICLE	USER CHARGE $Mill/Flt	USABLE PROPELL. Metric tons	INERT MASS	Isp DELIV. Seconds	AEROBRAKE MASS %	LNDG GR MASS %	CREW MOD MASS MT
IUS - 1	$15.0	9	1	298	none	none	none
IUS - 2	$35.0	3	2	301	none	none	none
CentaurG'	$65.0	22	3	446	none	none	none
OTV-I	$45.0	40	6	475	15	none	3
OTV-II	$40.0	40	5	500	12	none	5
EOTV-I	TBD	TBD	TBD	2000	none	none	none
EOTV-II	TBD	TBD	TBD	3000	none	none	none
Railgun OTV	TBD	TBD	TBD	10000	none	none	none
LM-exp	$100.0	40	6	475	none	5%	none
LM-I reu	$50.0	40	5	475	none	5%	7
LM-II reu	$25.0	40	5	475	none	3%	5
2St OTVII	$55.0	80	11	475	TBD	TBD	TBD

(to continue press "PgDn", for Upper Stage Performance- see right)

LOW EARTH ORBIT SPACE STATION — 28.5 deg inclination orbit — Screen 5 (Input)

NOTE: Need NASA input on Space Station

	MIN	MAX	NOTES
Operational Altitude, Km.	315	325	maintain within 10 Km.
O+H Propellant on-hand, MT	100	250	available for purchase
Transient crew accom., no.	2	10	not incl. crew rotatation
STS docking ports, no.	1	3	not incl. S/S resupply
SDV/HLLV docking ports	0	2	
OTV Sortie capab., no./mo.	2	10	paced by maintenance facil.
OMV Sorties, no./mo.	5	25	paced by no. of OMV's

USER CHARGES	$Millions
STS/SDV docking/turnaround	0
OMV dispatch/control, mission	0
OTV dispatch/control, mission	0
Warehousing, MT-month	0
HO propellant, MT, FOB S/S	0
Subsisentance, person day	0
Lunar Mission Support, mo.	0

NOTE:
To be provided by NASA-JSC for follow-on model.

LOW LUNAR ORBIT SPACE STATION
Equatorial, 100 KM Orbit

Screen 6
(Input)

It is assumed, for this model, that a low lunar orbit space station is provided as an integral part of the lunar base program. The station wil act as a forward staging base for the personnel and material destined for the lunar surface. The assumed characteristics, pending NASA data, are:

FEATURE	SIZE	UNITS	MASS (MT)	NOTES
Habitation for personnel:	12	persons	80.4	3 LEOSS CM
Command/Communications Center		each	26.8	1 LEOSS CM
Solar Electric Power Supply	15	kW	0.3	
Radiator heat rejection	15	kW	0.2	
Truss structure storage			10.0	Estimated
Propellant storage system	80	MT, wet	106.7	2 OTV loads
Contingency	0.15	capacity	33.6	capacity
Total:			257.9	

PROGRAMMATIC INPUT SELECTIONS
—to be employed in follow-on model—

Screen 7
(Input)

These selections will determine the sequence in which capabilities will be constructed on the lunar surface and the iteration of program pace (schedule) and content in response to specified constraints, if any.

A. Emphasis ________Science ________Resources________Community
(insert 0,1,2 or 3)

B. Fiscal Constraints

________Runout Costs ($Billions)

________Peak Year Funding ($Billions/yr.)

C. Fleet Size Constraints upon Lunar Base Program

Shuttle launches per year ________(number)
SDV launches per year ________(number)
HLLV launches per year ________(number)
OTV launches per year ________(number)
Lunar Landings per year ________(number)

TECHNOLOGY SELECTIONS
(select one from ea. category)

Screen 8
(Input)

PRIMARY POWER SOURCES (enter "1" if present)		Specific Mass (KG/Kw)	Unit Size (Kw)	Spec. Cost ($/Kw)	Fuel Cons. (KG/KwHr)	Oper. Life, (yrs)
________	Chem. Fuel Cells	7.7	175	10000	0.36	
________	Solar PV-I	5.6	250	100000	0.00	
________	Solar PV-II	4.0	250	90000	0.00	
						Conv.Eff.%
________	Solar Dynamic-I					
________	Solar Dynamic-II					
________	Nuclear RTG	125.0	100			10.5%
1	Nuc.Reactor-I	33.3	100			12.0%
________	Nuc.Reactor-II	20.0	100			12.0%
________	Other					

— This prototype model uses manual cell reference ONLY —

TECHNOLOGY SELECTIONS (cont)
(select one from ea. category)

Screen 9
(Input)

ENERGY STORAGE	Specific Mass	Specific Cost	Unit Size	Consum. Losses	Life
	(KG/KwHr)	($/KwHr)	(M3/KwHr)	(KG/KH/yr)	(yrs)
________SOA Batt.	22.22				15
1 Adv Batt.	9.09	0	0	0	10
________Regen F/C					
________Mechanicl					
________Thermal					
HEAT REJECTION	(KG/Kw)	($/Kw)	(M2/Kw)	(KG/Kw/yr)	(yrs)
1 Radiator	11.11	0.00	1.43	0.00	TBD
________Droplet					
________Soil					
THERMAL CONTROL					
1 Pumped	4	(prelim)			
POWER CONTROL					
1	11.76				

OUTPUT SCREENS

Screen 10
(Info)

The following screens show the results of applying various "transforms" to the user's input selections. The results include such information as:

1. Habitation Requirements
2. Resupply Mission Requirements
3. Power Requirements
4. Delivery Manifest Summary
5. Construction Requirements
6. Base Delivery and Construction Schedule
7. Transportation Requirements
8. Master Program Schedule (not available in this model)
9. Flight Schedule
10. Cost Estimates (not available in this model)
11. Science and Resources Return (not available in this model)

--- Do NOT make entries on Output/Transform Screens ---

THE FORMAT AND USE OF "TRANSFORMS" Screen 11 (Info)

The relationships between a stated "requirement" and the resulting system or subsystem characteristic ("attribute") are, for the purpose of this model, known as "transforms". The general form of these transforms is:

$y = a + b(x)$,

- y = attribute, may be a reqmnt. for other items
- a = a constant, can be "0"
- b(x) = may a simple linear relationship, or a non-linear function to denote relationships such as cost estimation.
- x = the requirement value, selected by the user or defined by another transform.

Values of the constants and exponents in b(x) are determined empiricall from NASA "technology forecasts" and other sources. They are, in general, not to be altered by the user of the model except for "sensitivity study" applications of the model. Changes are possible by editing cell contents. This results in permanent user-induced changes to this volume of the model

THE FORMAT AND USE OF "TRANSFORMS" (cont) Screen 12 (Info)

x = requirement, the product or service the item is to deliver, as specified by a user. Example: 150 MT of LO2 delivered to LEO.

y = attribute (mass, elec. power req'd, fuel req'd, data rate, etc.) resulting from the consequences of fulfilling the requirement with the selected technology. Example: LO2 plant mass, MT.

a = a constant determining the value of the attribute for the case in which the value of the requirement is zero, e.g., a floor value for that attribute if the item is present in the base.

b(x) = an empirical function which will quantify an attribute given the value of the requirement and the technology selected. May be, alone, an adequate transform for defining many attributes.

BASE SHOPS/LABS/OFFICES TRANSFORM CALCULATION Screen 13 (Info)

More elaborate means of determining the requirements for housing of people and operational functions is needed in the next version of this model. For the present, it is assumed that all pressurized housing is comprised of LEO space station "common modules" modified to better accomodate the lunar environment and the operational functions of the lunar surface base. In the absence of more accurate transforms, it is also assumed that 4 persons can occupy the common module for a full 12 month tour of duty and that the base functions require that a command and communications center, a small warehouse for pressurized storage, a common eating/meeting place and a clinic be provided. This would require 2 complete modules and ancilliary items.

Similarly, although the "office" functions for the science and resource production of the base have not yet been assessed, it is assumed that each activity can be accomodated within 50% of a module. As the mission activities become better defined, this estimate will be refined.

BASE COMPLEMENT TRANSFORM CALCULATION Screen 14 (Output)

Core Operating Staff:	It is assummed that the lunar base staff,for th base to function without output of resources or science, will be 5 persons (one for each of 2 shifts and 3 for the 1st shift of operations).
Base Staff Support:	It is assumed that 0.25 per. staff increase is required to assist each non-core staff perso including maintenance of pwrplnt, opns., etc.
Resources Support:	Although highly automated, it is assumed that each resource shipped will require 3 persons fo 150 MT/yr. prod. plus 0.5 person for each added increment of 50 MT/yr. (Future model addition)
Total Base Complement: RESULT:	For this run of the model, the total population of the mature lunar base is 33 persons.

BASE HABITAT TRANSFORM CALCULATION Screen 15 (Output)

No. of Habitats:	It is estimated 4 persons can occupy each standard habitat of STS size (4.3M D X 13.5M L).
RESULT	For this run of the model, 9 standard habitat modules are required for housing the mature base crew.
Habitat Mass:	Each habitat, with its self-contained ECLSS, tunnels & heat rejection, is estimated to have a dry mass of 26.8 MT and will require an initial inventory of consumables of 5 MT.(water, food, clothing) For this run of the model, total housing habitat mass
RESULT	delivered for the base is: 286.1 MT.
Habit Pwr/Energy:	Each habitat will require a peak power level of 4.5 KW and an average annual electrical energy supply of 15779 KWHr at an average duty cycle of 40% . Total base housing power & energy are:
RESULT	40.5 KW and 142009 KwHr/yr, respectfully.

BASE SHOPS/LABS/OFFICES TRANSFORM CALCULATION Screen 16 (Output)

No. of Habitats: Estimates are that 2 modules are needed for non-housing purposes of the base and 0.5 module fo
RESULT each activity. Therefore, 10 standard habitat modules are required for mission-related purposes.

Habitat Mass: Each mission habitat, with its self-contained ECLSS and heat rejection, is estimated to have an empty mass of 26.8 MT and will require an inventory of equip. & consumables of 8.5 MT.(std equip, reagents, etc) For this run of the model, total mission habitat mass
RESULT delivered to the base is: 352.9 MT.

Habit Pwr/Energy: Each mission habitat will require a peak power level of 6 KW and an average annual electrical energy
RESULTS supply of 36817 KWHr at an average duty cycle of 70%. Base mission habitats power & energy are: 60 KW and 368172 KwHr/yr, respectfully.

RESUPPLY REQUIREMENTS OF MATURE BASE

		(KG/MYE)	(MT/yr)	Screen 17 (Output) NOTES
Human Needs for:	33 persons			
Food (dry)		234	8	per Larry
Water		1174	39	Bell, UofH
Oxygen		294	10	Draft of
Clothing Allowance	(estim.)	150	5	Dec. 8, '8
Personal items	(estim.)	183	6	0.5 Kg/manday
Other	(estim.)	102	3	5.0% of totals
Subtotal:		2136	70	33 person bas
Mission Needs (Science & Resources, less transport)				
Equipment, new			73	15.0% per year
Parts & Supplies			67	5.0% per year
Water	50.0% resupply stores		16	10.0% loss/yr.
Hydrogen, assume	25.0% resupply stores		13	10.0% loss/yr.
Other consumable	25.0% resupply stores		13	10.0% loss/yr.
Subtotal:			182	
Total re-supply / year, no lunar O2:			253	4.8 LM2/year

BASE DELIVERY/CONSTRUCTION CONSUMABLES — Screen 18

HUMAN NEEDS — (Output)

According to Dr. Larry Bell, et al, of the University of Houston "Lunar Base Study Group" Working Draft of Dec. 8, 1985, humans need:

Item	KG/day Mat'l.	Packaging` Mat'l., %	KG/mo total	notes
Dry Food:	0.641	25%	24.04	Larry Bell
Water (free)	2.845	20%	102.42	Larry Bell
Metabolic Wat.(Ox)	0.371	20%	13.36	Larry Bell
Oxygen	0.806	100%	48.36	Larry Bell
Clothing	0.411	10%	13.56	estimated here
Personal items	0.500	10%	16.50	estimated here
Other	0.279	10%	9.20	estimated here
Total:	5.85		227.43	Bell + here

Construction crew size and time interval are derived on Screen 26.
A crew of 14 requires supplies of 3184 KG per month.
Therefore, for a construction interval of 11.5 months, 36.6 Metric Tons of human needs consumables are required.

MATURE LUNAR BASE MASS/POWER SUMMARY

Screen 19
(Output)

Area		Initial Mass (MT)	Hardware Resupply (MT/yr)	Power (Kw)	Energy (KwHr/yr)
Total Base Housing & Mission Modules		639.0	9.6	101	5.10E+05
Central Pwrplnt @	0.97 MWe	32.5	0.5		
Pwr Control Sys @	0.97 MWe	82.8	1.2	(seems too high)	
Central Radtr @	8.93 MWt peak	99.2	1.5		
Thrml Contrl Sys @	8.93 MWt peak	35.7	(Check estimate w/ Stan Sadin		
Operations Equipment	TBD				
Transportation Equipment	TBD				
Science Equipment		52	7.0	22.5	1.04E+05
Resources Equipment		427.5	2.7	823.1	7.22E+06
Community Equipment		80.0	0.4	0.0	0.00E+00
Maintenance Equipment @	3%	43.5	1.3		
Totals:		1492	24	946	7.83E+06

BASE DELIVERY MANIFEST SUMMARY Screen 20
LUNAR SURFACE OPERATIONS (Output)

The LM load factor of 85% accounts for packing material, payloa shrouds or fairings, and equipment to accomodate transfer of the payload t the lunar surface conveyances, and loss of useful payload due to equipment unit sizes or masses. The follow-on model should approach each lunar module landing as a discrete mission and use mission planning software modules to manifest payload. LM exp vehicle mass is: 46 MT and maximum payload to the lunar surface is: 61.8 MT, gross.

Additionally, a base construction subroutine is needed for the future lunar base computer simulation to more carefully time-phase the arrival of personnel and equipment to accomplish the base construction tasks.

Finally, a lunar base ground operations subroutine is needed to more thoroughly address the vehicle landing, offloading, turn-around and preparations for ascent flight to lunar orbit. Also, a similar operations routine for the low earth orbit and lunar orbit (or libration point) space station activities should be developed for incorporation into the model.

BASE DELIVERY MANIFEST SUMMARY
LUNAR FERRY OPERATIONS

Screen 21
(Output)

The LM-II vehicle is flown in a re-usable mode, once personnel are on the lunar surface, for cargo as well as personnel delivery. This LM-II vehicle has all-up mass of 52.6 MT and a cargo payload of 59.6 while carrying a crew module housing 6 persons. The load factor wil be improved to 90% , yielding a net cargo of 53.7 MT,includi the propellants needed to return the LM-II to Lunar Orbit. During the bas construction and initial operations intervals, this propellant will be delivered from Earth, thus launch and ferry to LO of 112.3 MT is required to deliver a net cargo of 46.1 MT, not including 7.5 of ascent propellant needed. These data will be refined in the follow-on effort, including re-sizing of all vehicles. Thus OTV/LM II = 2.38

Due to the extreme demands for LEO to LO ferry during the buildup of the lunar base, there is strong motivation for early production of luna oxygen. Re-phasing of the buildup schedule will be done in the follow-on model development to achieve the savings available with this strategy.

BASE DELIVERY MANIFEST SUMMARY

Screen 22 (Output)

Area		LS Base Mass (MT)	Exp LM Landings to estab (refine)	Hardware Resupply (MT/yr)	Reusable L Resupply (Flts/yr)
Total Base Housing +Mission Habitats		639.0	10.3	9.6	
Central Powerplant	0.97 MW output	32.5	0.5	0.5	
Power Control Sys.	0.97 MW output	82.8	1.3	1.2	
Central Radiator	8.93 MW peak	99.2	1.6	1.5	
Thermal Control Sy	8.93 MW peak	35.7	0.6	Chk est. w/ S. Sadin	
Operations Equipment	TBD	0.0	0.0	0.0	
Transportation Equipment	TBD	0.0	0.0	0.0	
Science Equipment		52.0	0.8	7.0	
Resources Equipment		427.5	6.9	2.7	
Community Equipment		80.0	1.3	0.4	
Maintenance Equipment @	3.00%	43.5	0.7	1.3	
Totals @	85%load fact	1492	28	24	0.5

MISSION EQUIPMENT TRANSFORM CALCULATION

Screen 23 (Output)

Area	Activity	Size of Activity	Initial Mass(MT)	Resupply (MT/yr)	Power (Kw)	Energy (KwHr/yr)
Science	Astronomy, persons	1	20	0.5	1.5	3.29E+03
Facil.	Physics , persons	1	10	2	15	6.57E+04
	Surface , persons	2	14	3	4	2.63E+04
	Other , persons	1	8	1.5	2	8.77E+03
Resource	Oxygen , MT/mo.	83.33	400	1.08	770	6.75E+06
Facil.	Hydrogen , MT/mo.	0	0	0	0	0.00E+00
	Silicon , MT/mo.	0	0	0	0	0.00E+00
	Aluminum , MT/mo.	0	0	0	0	0.00E+00
	Iron/Steel, MT/mo.	0	0	0	0	0.00E+00
	Glasses , MT/mo.	50	12.5	0.75	43	3.75E+05
	Shielding, MT/mo.	150	15	0.9	10	9.00E+04
	Mfgr. Prod, MT/mo.	0	0	0	0	0.00E+00
	Foodstuffs, MT/mo.	0	0	0	0	0.00E+00
	Water , MT/mo.	0	0	0	0	0.00E+00

MISSION EQUIPMENT TRANSFORM CALCULATION (cont) Screen 24 (Output)

Area	Activity	Number	Initial Mass(MT)	Resupply (MT/yr)	Power (Kw)	Energy (KwHr/yr)
Commun.	Additional People	8	80	0.4		
	Extra Energy used	0			0.0	0.00E+00
	Transport-surface	0				
	Transport-LEO	0				
Total Mission Equipment			487.5	10.1	846	7.32E+06

BASE DELIVERY - OTV FLIGHTS FROM LEO Screen 25 (Output)

Through the construction phase, the demands upon the LEO space statio will be severely taxing to accomodate the traffic of vehicles and goods. This screen updates an approximation of the demands based on earlier work, EEI Report 83-63, "Lunar Oxygen Impact Upon STS Effectiveness," May 1983. Here, a single stage 5.1 MT OTV, consuming 73.4 MT of hydrogen/oxygen propellants, can deliver to lunar orbit a payload of 42 metric tons. It is assumed that the life of an OTV is 25 missions, thus requiring an OTV replacement allowance of 0.20 MT and an assumed OTV spares allowance of 2.0% of total inert mass Therefore, each metric ton delivered to the lunar orbit space station requires 0.024 OTV user charges to be spent and 1.75 MT to be launched from Earth (until lunar oxygen is available) at a SDV load factor of 92% to account for manifesting, P/L shroud, etc.

The refinement of this model should carefully assess the traffic flow and consequent capabilities needed at the LEO space station, as "design drivers" of importance to the growth space station are inevitable. Also, an update is needed of OTV propellant, inert mass, payload and maintenance

BASE CONSTRUCTION EQUIPMENT & STAFF REQUIREMENTS Screen 26 (Output)

Construction Equipment Required:	(prelim)	Mass (MT)	Notes
2 10T Mobile Cranes	8 metric tons =	16	20M boom
2 Tractors @	5 metric tons =	10	multi-use
3 Lo-boy Trlrs @	2 metric tons =	6	4.5M d x 1
6 Bucket/etc. kits @	2 metric tons =	12	for tracto
5 Tool kits @	1 metric tons =	5	power+hand
2 Sets scaffolding @	1 metric tons =	2	
20 Items Subtotal of Construction Equipment:		51	MT
= 1.0 Exp LM flts.			

Construction Staff Required:	Prdtvty (MT/mnwk)	Cnstrctn Intrvl(wks)	
2 Construction Engineers @	15	50	(prelim)
4 Riggers/Mechanical Techs @	8	47	(prelim)
2 Electricians/Electronics @	15	50	(prelim)
2 Pipe/Instrument Fitters @	18	41	(prelim)
4 Operating Engineers @	10	37	(prelim)

14 Person crew constructs the lunar base in: 50 weeks

BASE DELIVERY/CONSTRUCTION SCHEDULE — Screen 27 (Output)

Large OTV Payload: 42 MT, flts./wk. = 1

Pre-placmnt Phase: 23.6 weeks (based upon max. OTV flt. rate - needs new look)	% delivered	LEO-LO OTV Flts.	Expendible LM flts.
A. Establish Lunar Orbit Station	100%	6.1	0.0
B. Stock & Staff LO Station	100%	1.0	0.0
C. Deliver Construction Equipment	100%	1.2	1.0
D. Deliver Central Powerplant	25%	0.2	0.2
E. Deliver Pwr Cntrls & Radiators	25%	1.1	0.9
F. Deliver Thermal Control System	25%	0.2	0.2
G. Deliver Habitats	40%	6.1	4.9
H. Deliver Exp Lunar Modules	7 each	7.7	0
Subtotal:		23.6	7.0

Constr Crew Deliv: 5.5 weeks	% delivered No. or MT	LEO-LO OTV Flts.	Reusable LM-II flt
A. Dedicated cnstrctn crew flt.	14 persons	2.3	2.3
B. Deliver life support expendbls	36.6 MT	1.9	0.8
C. Deliver Lunar Module II stages + crew modules		2.7	
Subtotal:		5.5	2.3

BASE DELIVERY/CONSTRUCTION SCHEDULE (cont) Screen 28 (Output)

		% delivered	OTV Flts.	LM-II flt
Initialzatn Phase:	16.4 weeks			
A.	Deliver Central Powerplant	25%		0.2
B.	Deliver Power Controls & Rad	25%		1.0
C.	Deliver Thermal Control System	25%		0.2
D.	Deliver Habitats	40%		5.5
	Subtotal:		16.4	6.9
Pwrplnt Erct Phase	3.2 weeks			
A.	Deliver Central Powerplant	25%		0.2
B.	Deliver Power Controls & Rad	25%		1.0
C.	Deliver Thermal Control System	25%		0.2
	Subtotal:		3.2	1.4
Base Erectn Ph I:	9.8 weeks			
A.	Deliver Central Powerplant	25%		0.2
B.	Deliver Power Controls & Rad	25%		1.0
C.	Deliver Thermal Control System	25%		0.2
D.	Deliver Habitats	20%		2.8
	Subtotal:		9.8	4.1

BASE DELIVERY/CONSTRUCTION SCHEDULE (cont) Screen 29 (Output)

Base Erectn Ph II:	28.4 weeks	% delivered	OTV Flts.	LM-II flt
D. Deliver Science Mission Equipmen		100%		1.1
E. Deliver Resource Production Equi		100%		9.3
F. Deliver Contigency Constr. Equip		100%		0.1
G. Deliver Construction Troubleshoo		100%		1.0
H. Deliver additional life support		100%		0.4
	Subtotal:		28	11.9
Base C/O Phase:	9.1 weeks			
A. Deliver checkout equipment & sup		100%		1.0
B. Checkout, deliver replacement units for failed items (10%)				2.8
	Subtotal:		9	3.8
Crew Change Phase:	5.5 weeks			
A. Deliver Lunar Base crew compleme		100%	6	5.5
B. Recover construction & c/o crews		100%		0.0
	Subtotal:		6	5.5
	weeks	months	OTV Flts.	LM flts.
Total Construction	78 , or	18.0	102	43

```
          EARTH LAUNCHES TO SUPPORT LUNAR BASE ESTABLISHMENT     Screen 30
                                                                 (Output)
Each STS delivers      29.5 MT for      $29.5 millions and up to        8
Each SDV delivers      66.4 MT for      $66.4 millions             \passenger
Each OTV requires      73.4 MT propellant and      0.4 MT spares and incurs
   a use charge of     $1.8 millions per flight plus propellant, etc. del.
   charges for         73.8 MT per use, until lunar O2 is available.

     As a simpler transform, each metric ton launched from the LEO S/S to
the lunar orbit requires        1.75 MT to be launched from Earth, includin
reusable OTV spares and an allowance for OTV replacement.
Therefore, each OTV flight requires      1.89 SDV Flights.

     The total lunar base placement,including the complement of        33
persons,requires a total of      102 OTV flights, delivering          4269
metric tons to lunar orbit, requiring the launch of        193 SDV's.
       7 expendable LM vehicles and        4.1 large reusable OTV's are
expended in the operation as well as       1.4 LM-II vehicles before
init. operation of the base     23.5 mos. after initial deployment from LEO
```

BASE DELIVERY/CONSTRUCTION FLIGHT SCHEDULE   Screen 31

Based on SDV capacity of   2 flts./wk....more>>>   (Output)

	RD&D	Sys Fab	Grnd C/O	to LEO	Pre-place	CoCr Del
Serial Time, weeks	208	104	52	6	22	5
ETO - Number of Flights within Program Phase						
Shuttle						2
Shutt.II						
TransAtmo						
SDV				13	45	11
HLLV						
SPACE - Number of Flights witin Program Phase						
OTV-I						
OTV-II					24	6
LM-exp					7	
LM-I reusable						2
LM-II reusable						
2St OTVII						
Total Flt. Oper.	0	0	0	13	75	20
Rate- Flt Opns/yr	0	0	0	104	175	202

BASE DELIVERY/CONSTRUCTION FLIGHT SCHEDULE (cont)

No. of flights within Program Phase

Screen 31
(Output)

PP Erect	Base EI	Base EII	Checkout	Crew Cha	PrepOp	Opn B/U	Totals
3	9	27	9	5			467
						months =	107.8
				4			6
							0
							0
6	19	54	17	10	0	0	205
							0
							0
							0
3	10	28	9	6			102
							7
1	4	12	4	6			36
							0
							0
11	33	94	30	25	0	0	356
182	182	182	182	254	ERR	ERR	

LUNAR BASE DESIGN, DEVELOPMENT, TEST, & EVALUATION COSTS — Screen 32 (Output)

	Costs, $ Millions, 1986 $ Developmt	Test	Evaluatn	Totals
Earth Launch Fleet Mods				
Upper Stage Fleet Mods				
LEO Space Station Upgrading				
Lunar Orbit Space Station				
Expendable Lunar Modules				
Reusable LM-1's				
Reusable LM-2's	TO BE SUPPLIED IN FOLLOW-ON MODEL			
Lunar Base Habitats				
Lunar Base Powerplant				
Lunar Base Heat Rejection				
Lunar Surface Transport operations				
Science Mission Equipment				
Resource Production Plants				
System Test				
Totals:				

LUNAR BASE SYSTEM ACQUISITION & CHECKOUT COSTS — Screen 33 (Output)

	Costs, $ Millions, 1986 $			
	Hardware	Software	Operations	Totals
Earth Launch Fleet Mods				
Upper Stage Fleet Mods				
LEO Space Station Upgrading				
Lunar Orbit Space Station				
Expendable Lunar Modules				
Reusable LM-1's				
Reusable LM-2's	TO BE SUPPLIED IN FOLLOW-ON MODEL			
Lunar Base Habitats				
Lunar Base Powerplant & Controls				
Lunar Base Heat Rejection				
Lunar Surface Transport operations				
Science Mission Equipment				
Resource Production Plants				
System Test				
Totals:				

```
          LUNAR BASE DELIVERY/CONSTRUCTION COSTS TIMELINE       Screen 34
        Costs, $Millions '86$      Calendar Year...more>>>      (Output)
Task                  |   1   |   2   |   3   |   4   |   5     |   6

ATP                   +
Lunar Base DDT&E        +++++++++++++++++++++++++++++++++++++
System Acquisition                          ++++++++++++++++++ +++++++++
System Ground C/O                                              +++++++++
Marshall @ LEO S/S
Pre-placmnt Phase:
Crew Delvry Phase:
Initialzatn Phase:-- NOTE: ILLUSTRATIVE ONLY, NOT YET INTERACTIVE --
Pwrplnt Erct Phase:
Base Erectn Phase:
Base C/O Phase:
Crew Change Phase:
Prepare Operations
Initial Capability
Operations Buildup
```

```
         LUNAR BASE DELIVERY/CONSTRUCTION COSTS TIMELINE(cont) Screen 34
                  Costs, $Millions '86$      Calendar Year     (Output)
|    8    |    9    |   10    |   11    |   12    |   13    |   14    |Totals



+++++
++++++++++++++++++++++
         ++++
         ++++++++
                  ++++++++++++++++++
                           +++++++++
                                    +++++
                                        +++
                                           ++++++++
                                                    +
                                                      +++++++++
```

LUNAR BASE DELIVERY/CONSTRUCTION COSTS -BY ELEMENT Screen 35

Costs, $Millions '86$ Calendar Year...more>>> (Output)

Cost Element	1	2	3	4	5	6
Launch Services						
LEO S/S Services						
OTV Services						
Lunar Orbit S/S						
Lunar Modules						
Habitats						
Powerplant, etc.		TO BE SUPPLIED IN FOLLOW-ON MODEL				
Scientific Equip.						
Resources Equip.						
Community Equip						
Construction, all						
Crew & Support						
Ground Support						
Re-supply						
Total	0	0	0	0	0	0

LUNAR BASE DELIVERY/CONSTRUCTION COSTS -BY ELEMENT Screen 35
Costs, $Millions '86$ Calendar Year (Output)

8	9	10	11	12	13	14	Totals
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
							0
0	0	0	0	0	0	0	0

LUNAR BASE REQUIREMENTS DURING OPERATIONAL BUILDUP — Screen 36 (Output)

WBS Element	Year after IOC 1	2	3	4	5	Totals
Resupply req'd, MT						
Crew Rotation, no.						
SDV Flts						
STS Flts						
2St OTV Ferry Flts						
LM- exp Flts.						
LM-1 Reusable Flts	TO BE SUPPLIED IN FOLLOW-ON MODEL					
LM-2 Reusable Flts						
LEO S/S Use Units						
LO S/S Use Units						
Earth Support, MYE						

BASE OPERATIONS COSTS DURING START-UP OF OPERATIONS Screen 37 (Output)

WBS Element	Year after IOC 1	2	3	4	5	Totals
Resupply req'd, $						
Crew Rotation, $						
SDV Flts user chrg						
STS Flts user chrg						
2St OTV Ferry chrg						
LM- exp Flts costs						
LM-1 Reusable chrg	TO BE SUPPLIED IN FOLLOW-ON MODEL					
LM-2 Reusable chrg						
LEO S/S Use Charge						
LO S/S Use Charge						
Earth Support, $						
Opertns & Mgmt., $						
Other Costs						
Contingency Fund						
Totals						

TYPICAL FULL SCALE OPERATIONS YEARLY PERFORMANCE

Screen 38
(Output)

SCIENCE DELIVERED, MM/yr.
Astronomy
Physics
Surface
Other
RESOURCES DELIVERED, MT/yr.
Oxygen
Hydrogen
Silicon
Aluminum
Iron/Steel
Glasses
Shielding
Mfgr. Prod.
Foodstuffs
Water

TO BE SUPPLIED IN FOLLOW-ON MODEL

TYPICAL FULL SCALE OPERATIONS ANNUAL REQUIREMENTS
(typical of 20 years of full scale operations)

Screen 39
(Output)

WBS Element	Chargeable to SCIENCE	RESOURCES	OTHER	TOTALS
Resupply req'd, MT				
Crew Rotation, no.				
SDV Flts				
STS Flts				
2St OTV Ferry Flts				
LM- exp Flts.	TO BE SUPPLIED IN FOLLOW-ON MODEL			
LM-1 Reusable Flts				
LM-2 Reusable Flts				
LEO S/S Use Units				
LO S/S Use Units				
Earth Support, MYE				

TYPICAL FULL SCALE OPERATIONS ANNUAL COSTS

Screen 40
(Output)

WBS Element	Chargeable to SCIENCE	RESOURCES	OTHER	TOTALS
Resupply req'd, MT				
Crew Rotation, no.				
SDV Flts				
STS Flts				
2St OTV Ferry Flts				
LM- exp Flts.	TO BE SUPPLIED IN FOLLOW-ON MODEL			
LM-1 Reusable Flts				
LM-2 Reusable Flts				
LEO S/S Use Units				
LO S/S Use Units				
Earth Support, MYE				
Total Costs				
Figure of Merit				

	SCIENCE & RESOURCE RETURNS			Screen 41	(Output)
Benefit	Benefits, $Millions '86$		Calendar	Yr. after	IOC more>
SCIENCE, MYe	1	2	3	4	5	6
Astronomy						
Physics						
Surface						
Other						
RESOURCES SUPPLIED, MT						
Oxygen						
Hydrogen						
Silicon	TO BE SUPPLIED IN FOLLOW-ON MODEL					
Aluminum						
Iron/Steel						
Glasses						
Shielding						
Mfgr. Prod.						
Foodstuffs						
Water						
COMMUNITY, No.						

SCIENCE & RESOURCE RETURNS Screen 41

Benefit	Benefits, $Millions '86$	Calendar Yr. after IOC					
8	9	10	11	12	13	14	Totals

LUNAR BASE TOTAL PROGRAM SUMMARY Screen 42 (Output)

	Value	Units
Population of Lunar Surface Base, incl. LO S/S	33	persons
Science Manyears on Lunar Surface		person yea
Oxygen delivered to space users		MT, total
Hydrogen delivered to space users		MT, total
Silicon delivered to space users		MT, total
Aluminum delivered to space users		MT, total
Iron/Steel delivered to space users		MT, total
Glasses delivered to space users		MT, total
Shielding delivered to space users		MT, total
Mfgr. Products delivered to space users		MT, total
Foodstuffs delivered to space users		MT, total
Water delivered to space users		MT, total
TO BE SUPPLIED IN FOLLOW-ON MODEL		
Development Costs		$, Billion
System Acquisition & Placement Costs		$, Billion
Operations costs		$, Billion
Total Program Costs	0	$, Billion

COST/BENEFITS ANALYSIS
TO BE SUPPLIED IN FOLLOW-ON MODEL

Screen 43
(Output)

	value	units
Development Interval		years
Placement Interval		years
Buildup Interval		years
Operational Interval	20	years
Total Program Duration	20	years
Net Present Value of Program Costs, '86 $		$, Billion
Net Present Value of Resources Provided to Space		$, Billion
Net Present Value of Science Conducted		$, Billion
Net Present Value of Space Operations Support		$, Billion
Net Present Value of Commercial Applications		$, Billion
Net Present Value to National Security		$, Billion
Net Costs (Benefits) to taxpayer, total program	0	$, Billion
Net Costs (Benefits) to taxpayer, per year	0	$, Billion
Benefits/Costs Ratio	ERR	dimensionl

Synopsis of Run No________ 01:08 AM 01-Jan-80

INPUT:	
Science (persons)	
Astronomy	1
Physics	1
Surface	2
Other	1
Resources Export (MT/mo)	
Oxygen	83.33
Hydrogen	0
Silicon	0
Aluminum	0
Iron/Steel	0
Glasses	50
Shielding	150
Mfgr. Products	0
Foodstuffs	0
Water	0
Community-person	8

OUTPUT:	Screen 44 (Output)
Total Base Population:	34
No. of Habitable Modules:	20
Powerplant rating, Megawatt	0.9
Mass of Base, Metric Tons:	1492
Size of Construction Crew:	14
Construction Interval, mos.	18.0
No. of Expendable LM's:	7
OTV Flights:	102
Shuttle Flights:	6
SDV Flights:	205
Max. OTV flts/wk. (an input)	1
Max. SDV flts/wk. (an input)	2
Time, total, years, SDV cons	9.0
Time, flight operations, years, SDV Constrains pace:	1.9
Time, flight operations, years, OTV Constrains pace:	1.5

OUTPUT MENU LISTING

Bill of Materials of lunar surface facil. & stores
Total LV Flights, no., type, fleet size increase
Total OTV Flts, no., type, fleet size increase
Total LMexp Flts, no. used
Total LM flts, no., type, fleet size
Launch Transportation Cost, $B
Orbit Transport Cost, $B
Landing/Launch Transport Cost, $B
Equipment Required, MT
Equipment Cost, $B
Commodities Consumed, 1000's MT, type, total
Commodities Exported, 1000's MT, type, total
Buildup Phase Timeline, events, time spans
Buildup Phase Cost, $B
Operational Phase Cost, $B
Export Sales Value, $B, by type, total
Science Conducted, Manyears

Screen x
(Output)
Commodity Production
Product Production
Operational MPR
Total MPR, 25 yrs. o
Total Cost
NPV Exports
NPV Costs-1
NPV Costs-2
NPV Costs-3
NPV Costs-4
B/C-1
B/C-2
B/C-3
B/C-4

OUTPUT MENU LISTING (con't.)

Screen x+1
(Output)

Time-phased Plots (per year of construction and operational phases)
  Lunar Base Mass, by WBS major element, total
  LSB Population, by type: base staff, science, resources, other, total
  LV Flights, by type, total user charges, total mass launched from earth
  OTV Flights, by type, user charges, propellants required from LEO & LLO
  LM Flights, by type, user charges, propellants consumed from LLO and LS
  Lunar Surface Production, by type, totals
  Imports, not including vehicles, propellants or people
  Exports - by type, total commodities/products arriving at LEO station
  Sales by Commodity & Product, total
  Science MM, by type, total
  Costs by WBS major element, total
  Sunk Capital, $B

LUNAR BASE TOP LEVEL REQUIREMENTS

Screen 1D (Default)

SCIENCE:	reference parameter	value, mature base (per)	Mission Equip. mass (MT/per)	Resupply Required Miss. Eq. (MT/per/yr)	Spec.Pwr. (Kw/per)
Astronomy	no.person	1	20	0.500	1.5
Physics	no.person	1	10	2.000	15
Surface	no.person	2	7	1.500	2
Other	no.person	1	8	1.500	2

			Requirements of Production			
RESOURCES EXPORT: * -(ref:Knudsen, Feb. '86)		Output (MT/mo.)	Equipmnt (MT/MT/mo)	Consumbls (MT/MT)	Energy (KwHr/MT)	Power (Kw/MT/mo)
Oxygen*	shipments	83.33	4.80	0.013	27000	32.00
Hydrogen	shipments					
Silicon	shipments		0.75	0.035	18000	25.00
Aluminum	shipments					
Iron/Steel	shipments					

LUNAR BASE TOP LEVEL REQUIREMENTS (cont) Screen 2D (Default)

RESOURCES EXPORT (cont):	reference parameter	value, mature base (MT/mo)	Mission Equip. mass (MT/MT/mo)	Resupply Required Miss. Eq. (MT/MT)	Energy (KwHr/MT)	Power (Kw/MT/mo)
			Preliminary Estimates - refine!			
Glasses	shipments		0.25	0.015	2500	3.47
Shielding	shipments		0.10	0.006	200	0.28
Mfgr. Prod.	shipments					
Foodstuffs	shipments					
Water	shipments					

COMMUNITY		value, mature base (per)	Equipment Mass (MT/per)	Extra Resupply (MT/per)	Extra Energy (KwHr/per)
Additional People	no.person	4	10.00	0.050	

SPACE TRANSPORTTATION SYSTEM

Screen 3D
(Default)

Values taken from NASA OAST "Space Systems Technology Model", Executive Summary, June, 1985, 6th Edition, page 1-108, except as noted by "*".

DEFAULT VALUES (cells to be protected)

VEHICLE	USER CHARGE $Mill/Flt	PAYLOAD Metric tons	Altitude* Decrement MT/Km.	PASSENGERS (max)* no.
Shuttle	59	29.50	0.075	8
Shutt.II	61.3	35	0.04	16
TransAtmo	35 *	5	0.03	2
SDV	88.5	66.4	0.05	0
HLLV	59	147.5	0.12	0

UPPER STAGES (more >>>>> Screen 4D (Default)

VEHICLE	USER CHARGE $Mill/Flt	USABLE PROPELL. Metric tons	INERT MASS	Isp deliv. Seconds	Aerobrake mass %	Lndg. Gr mass MT	Crew Mod mass MT	Tot DV M/sec.
IUS - 1	15	9.43	0.93	298	none	none	none	2530
IUS - 2	35	2.72	1.70	301	none	none	none	1768
CentaurG'	65	21.77	3.25	446	none	none	none	4299
OTV-I	45	40.00	5.98	475	15	none	3.40	4299
OTV-II	40	40.00	5.38	500	12	none	4.54	4299
EOTV-I	TBD	TBD	TBD	2000	none	none	none	
EOTV-II	TBD	TBD	TBD	3000	none	none	none	
RGOTV	TBD	TBD	TBD	10000	none	none	none	
LM-exp	100	40.00	5.98	475	none	5%	none	2073
LM-I reu	50	40.00	5.38	475	none	5%	6.80	2073
LM-II reu	25	40.00	4.84	475	none	3%	4.54	2073
2St OTVII	55	80.00	10.65	475	TBD	TBD	TBD	

UPPER STAGES

Screen 4D (continued

MR	Wp/(MR-1) = PL +Wi MT	Payload MT	Iterated Payload MT	Mission
2.38	6.8	5.9		exp GTO
1.82	3.3	1.6		exp GEO
2.67	13.0	9.8		exp GEO
2.52	26.3	20.4		exp GEO
2.40	28.5	23.1		exp GEO
1.00	ERR	ERR		
1.00	ERR	ERR		
1.00	ERR	ERR		
1.56	71.3	65.3	61.8	LunarLndg
1.56	71.3	65.9	55.2	M.Lunar Del.
1.56	71.3	66.5	59.6	M.Lunar Del.
1.00	ERR	ERR		Lun Ferry

LOW EARTH ORBIT SPACE STATION 28.5 deg inclination orbit			Screen 5D (Default)
	MIN	MAX	NOTES
Operational Altitude, Km.	315	325	maintain within 10 Km.
O/H Propellant on-hand, MT	100	250	available for purchase
Transient crew accom., no.	2	10	not incl. crew rotatation
STS docking ports, no.	1	3	not incl. S/S resupply
SDV/HLLV docking ports	0	2	
OTV Sortie capab., no./mo.	2	10	paced by maintenance fac.
OMV Sorties, no./mo.	5	25	paced by no. of OMV's

USER CHARGES	$Millions
STS/SDV docking/turnaround	
OMV dispatch/control, mission	
OTV dispatch/control, mission	
Warehousing, MT-month	
HO propellant, MT, FOB S/S	
Subsisentance, person day	
Lunar Mission Support, mo.	

LOW LUNAR ORBIT SPACE STATION
Equatorial, 100 KM Orbit

Screen 6D
(Default)

It is assumed, for this model, that a low lunar orbit space station is provided as an integral part of the lunar base program. The station will act as a forward staging base for the personnel and material destined for the lunar surface. The assumed characteristics include:

FEATURE	SIZE	UNITS	MASS (MT)	NOTES
Habitation for personnel:	12	persons	80.4	3 LEOSS CM
Command/Communications Center		each	26.8	1 LEOSS CM
Solar Electric Power Supply	15	kW	0.3	
Radiator heat rejection	15	kW	0.2	
Truss structure storage			10.0	Estimated
Propellant storage system	80	MT, wet	106.7	2 OTV loads
Contingency	15%		33.6	
Total:			257.9	

PROGRAMMATIC INPUT SELECTIONS (to be employed in follow-on model)

Screen 7D (Default)

These selections will determine the sequence in which capabilities will be constructed on the lunar surface and the iteration of program pace (schedule) and content in response to specified constraints, if any.

A. Emphasis ________Science ________Resources ________Community
(insert 0,1,2 or 3)

B. Fiscal Constraints
________Runout Costs ($Billions) ________Peak Year Funding ($Billions/yr.)

C. Fleet Size Constraints upon Lunar Base Program
Shuttle launches per year ________(number)
SDV launches per year ________(number)
HLLV launches per year ________(number)
OTV launches per year ________(number)
Lunar Landings per year ________(number)

TECHNOLOGY SELECTIONS
(select one from ea. category)

Screen 8D
(Default)

(enter "1" if present in lunar base)

	Primary Power Sources	Specific Mass Kg/Kw	Unit Size Kw	Spec. Cost $/Kw	Fuel Cons. KG/KwHr	Oper. Life, years
________	Chem. Fuel Cells	7.7	175	10000	0.36	
________	Solar PV-I	5.6	250	100000	0	
________	Solar PV-II	4.0	250	90000	0	
						Conv.Eff.%
________	Solar Dynamic-I					
________	Solar Dynamic-II					
________	Nuclear RTG	125.0	100			10.5%
1	Nuc.Reactor-I	33.3	100			12%
________	Nuc.Reactor-II	20.0	100			12%
________	Other					

TECHNOLOGY SELECTIONS
(select one from ea. category)

Screen 9D
(Default)

Energy Storage	Specific Mass	Specific Cost	Unit Size	Consum. Losses	Life
	Kg/KwHr	$/KwHr	M3/KwHr	KG/KH/Y	Years
________ SOA Batt.	22.22				15.00 Sec. cells
________ Adv Batt.	9.09				10.00 Sec. cells
________ Regen F/C					
________ Mechanicl					
________ Thermal					
Heat Rejection	Kg/Kw	$/Kw	M2/Kw	KG/Kw/Y	Years
________ Radiator	11.11		1.43		TBD
________ Droplet					
________ Soil					

Thermal Control System (Q. Does NASA SSTM, p 1-119 refer to this system?)

1	4

Power Control

1	11.76

LUNAR BASE HABITATION MODULE MASS ESTIMATION Screen 15 (Default)

NASA JSC Memo EZ-85-38 provides mass property estimates for the LEO Space Station. Relevant data from this memorandum are:

Module	Mass, Kg.	Mass, less Equipment (est
Laboratory 1	32,581	16,000
Habitation 1	16,238	16,238
Laboratory 2	19,283	16,000
Habitation 2	15,765	15,765
Logistics	17,145	17,145
Nodes (6)	15,005	15,005
Tunnels (3)	3,927	3,927
Airlocks (2)	7,072	7,072
Totals:	127,016	107,152

The LEO S/S Laboratory modules include equipment book-kept separately fo this lunar base model, but the lunar base will require support modules similar to the LEO S/S. An "average" LSB module mass is thus: 26,788

APPENDIX B

ORBITAL TRANSFER VEHICLE ANALYSIS

OTV PERFORMANCE INPUT DATA — Screen 1

OTV SIZING

References: Martin-Marietta Report MCR-85-2601, "Orbital Transfer Vehicle Concept Definition and System Analysis Study", 22 August, 1985
Eagle Engineering Report 8363, May 1983, Appendix A

OTV Concept: The MMC study defined a "growth" cryogenic OTV to meet post-space station needs, including dual 36.7 MT propellant capacity stages to deliver the 6.8 to 36.3 MT lunar payloads, utilizing:

a. STS ET "Aft Cargo Carrier" initial delivery to LEO
b. Dual 33.3 KN thrust cryogenic "Advanced Space Engines"
c. Aerobraking for Earth return via a 867 KG rigid aerobrake

Derivations: Since MMC provided an inert mass, less aerobrake, of 2.47 MT for the 24.9 MT Wp stage, and a scaling law for inert mass, (p23,Vol II,Bk 1),conservative inert mass of larger stages may be estimated:

Prop. Cap., MT	24.94	36.73	49.89	61.68	73.47
Inert Mass, MT	2.69	3.09	3.51	3.88	4.23
Mass fraction	0.90	0.92	0.93	0.94	0.95

Conclusion: Since cost per flight will favor a single, larger vehicle, the largest vehicle above will be used for performance estimation.

OTV PERFORMANCE INPUT DATA (con't.) Screen 2

DELIVERIES TO LUNAR ORBIT

As the large OTV will be required to eventually deliver large H2 payloads to LO and return a crew cabin,it will be assumed that this large stage will be flown w/TPS for LO stockpiling, returning empty, and that the 0.868 MT aerobrake will suffice for empty return missions. The mass is 5.10 MT, with a delivered Isp of 475 sec. The delivery performance, using velocity increments from Appendix A, EEI8363, May 1983, w/ 3/4 % FPR, is:

	Final	D-V,mps	MR	TotalWp	P/L, MT	Initial
Inbound:	5.10	1102	1.2672	1.36	0	6.47
Outbound:	21.47	4297	2.5148	32.52	15	52.62
	26.47	4297	2.5148	40.09	20	65.19
	31.47	4297	2.5148	47.66	25	77.76
	36.47	4297	2.5148	55.24	30	90.34
	41.47	4297	2.5148	62.81	35	102.91
	46.47	4297	2.5148	70.39	40	115.49
	47.47	4297	2.5148	71.90	41	118.00
Full Wp >	48.47	4297	2.5148	73.42	42	120.51

Thus, an OTV requiring 73.4 MT prop., delivers (in MT): 42

OTV PERFORMANCE INPUT DATA (con't.) Screen 3

DELIVERIES FROM LUNAR ORBIT TO LEO S/S

The MMC August, 1985 estimate for the OTV TPS is 9.5% of mass entered (less aerobrake mass). OTV performance for return missions with TPS delivery outbound and lunar orbit servicing may now be estimated.

Payload	EntryMass	TPS mass	Tot mass	Wp in	H2 in	H2+tank	+TPS
0.00	4.23	0.40	4.63	1.24	0.18	0.24	0.64
25.00	29.23	2.78	32.01	8.55	1.22	1.63	4.41
50.00	54.23	5.15	59.38	15.87	2.27	3.02	8.17
75.00	79.23	7.53	86.76	23.18	3.31	4.42	11.94
100.00	104.23	9.90	114.13	30.50	4.36	5.81	15.71
125.00	129.23	12.28	141.51	37.81	5.40	7.20	19.48
150.00	154.23	14.65	168.88	45.13	6.45	8.60	23.25
175.00	179.23	17.03	196.26	52.44	7.49	9.99	27.02
200.00	204.23	19.40	223.63	59.75	8.54	11.38	30.78
225.00	229.23	21.78	251.01	67.07	9.58	12.78	34.55
247.00	251.23	23.87	275.10	73.51	10.50	14.00	37.87

For a full OTV, the TPS mass is 23.9 MT, (partly lunar-derived?).

Thus, an OTV requiring 73.5 MT Wp returns 247.0 MT P/L.

APPENDIX C

ITEMIZED TEST CASE LISTING

	Run No. 1		09:50 PM 05-Mar-86
INPUT:	SYNOPSIS OF CURRENT MODEL RUN	OUTPUT:	Screen 44
Science (persons)		Total Base Population:	7
Astronomy	0	No. of Habitable Modules:	7
Physics	0	Powerplant rating, Megawatt	0.0
Surface	0	Mass of Base, Metric Tons:	220
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	3.8
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	30
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	62
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.6
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.5
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.3

Run No. 2 09:51 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	8
Astronomy	0	No. of Habitable Modules:	8
Physics	0	Powerplant rating, Megawatt	0.0
Surface	1	Mass of Base, Metric Tons:	266
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	4.3
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	32
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	67
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.6
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.6
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.4

Run No. 3 09:51 PM 05-Mar-86

INPUT:		SYNOPSIS OF CURRENT MODEL RUN OUTPUT:	Screen 44
Science (persons)		Total Base Population:	9
Astronomy	0	No. of Habitable Modules:	9
Physics	1	Powerplant rating, Megawatt	0.1
Surface	1	Mass of Base, Metric Tons:	314
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	4.8
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	35
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	73
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.7
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.6
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.4

Run No. 4 09:51 PM 05-Mar-86

SYNOPSIS OF CURRENT MODEL RUN

INPUT:		OUTPUT:	Screen 44
Science (persons)		Total Base Population:	10
Astronomy	1	No. of Habitable Modules:	10
Physics	1	Powerplant rating, Megawatt	0.1
Surface	1	Mass of Base, Metric Tons:	373
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	5.4
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	38
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	79
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.7
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.4

Run No. 5 09:52 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	12
Astronomy	1	No. of Habitable Modules:	10
Physics	1	Powerplant rating, Megawatt	0.1
Surface	1	Mass of Base, Metric Tons:	382
Other	1	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	5.6
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	39
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	81
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.7
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.5

Run No. 6 09:52 PM 05-Mar-86

INPUT:		SYNOPSIS OF CURRENT MODEL RUN OUTPUT:	Screen 44
Science (persons)		Total Base Population:	17
Astronomy	2	No. of Habitable Modules:	12
Physics	2	Powerplant rating, Megawatt	0.1
Surface	2	Mass of Base, Metric Tons:	502
Other	2	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	7.0
Oxygen	0.00	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	47
Silicon	0	Shuttle Flights:	4
Aluminum	0	SDV Flights:	96
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.9
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.6

Run No. 7 09:52 PM 05-Mar-86

INPUT:	SYNOPSIS OF CURRENT MODEL RUN	OUTPUT:	Screen 44
Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	0.3
Surface	0	Mass of Base, Metric Tons:	478
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	6.7
Oxygen	25.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	44
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	90
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.8
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.6

Run No. 8 09:53 PM 05-Mar-86

INPUT:		SYNOPSIS OF CURRENT MODEL RUN OUTPUT:	Screen 44
Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	0.5
Surface	0	Mass of Base, Metric Tons:	665
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	8.9
Oxygen	50.00	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	54
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	110
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.1
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.0
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.7

C-2

Run No. 9 09:53 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	0.7
Surface	0	Mass of Base, Metric Tons:	851
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	11.1
Oxygen	75.00	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	65
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	130
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.3
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.2
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	0.9

Run No. 10 09:53 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	1.0
Surface	0	Mass of Base, Metric Tons:	1038
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	13.3
Oxygen	100.00	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	75
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	150
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.4
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.4
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	1.1

Run No. 11 09:53 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	1.4
Surface	0	Mass of Base, Metric Tons:	1411
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.8
Oxygen	150.00	No. of Expendable LM's:	5
Hydrogen	0	OTV Flights:	96
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	191
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.7
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	1.5

Run No. 12 09:54 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	1.9
Surface	0	Mass of Base, Metric Tons:	1784
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	22.4
Oxygen	200.00	No. of Expendable LM's:	5
Hydrogen	0	OTV Flights:	117
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	231
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	9.2
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	2.1
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	1.9

Run No. 13 09:54 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	2.8
Surface	0	Mass of Base, Metric Tons:	2530
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	31.4
Oxygen	300.00	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	159
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	313
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	10.0
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	2.9
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	2.6

Run No. 14 09:54 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	10
Astronomy	0	No. of Habitable Modules:	9
Physics	0	Powerplant rating, Megawatt	0.8
Surface	0	Mass of Base, Metric Tons:	914
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	11.9
Oxygen	83.33	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	68
Silicon	0	Shuttle Flights:	3
Aluminum	0	SDV Flights:	137
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.3
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.2
Water	0	Time, flight operations, years,	
Community-person	0	OTV Constrains pace:	1.0

Run No. 15 09:55 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	13
Astronomy	0	No. of Habitable Modules:	10
Physics	0	Powerplant rating, Megawatt	0.0
Surface	0	Mass of Base, Metric Tons:	377
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	5.0
Oxygen	0.00	No. of Expendable LM's:	3
Hydrogen	0	OTV Flights:	37
Silicon	0	Shuttle Flights:	4
Aluminum	0	SDV Flights:	76
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.7
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.7
Water	0	Time, flight operations, years,	
Community-person	5	OTV Constrains pace:	0.4

Run No. 16 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	19
Astronomy	0	No. of Habitable Modules:	13
Physics	0	Powerplant rating, Megawatt	0.1
Surface	0	Mass of Base, Metric Tons:	539
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	6.2
Oxygen	0.00	No. of Expendable LM's:	4
Hydrogen	0	OTV Flights:	44
Silicon	0	Shuttle Flights:	4
Aluminum	0	SDV Flights:	91
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	7.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	0.8
Water	0	Time, flight operations, years,	
Community-person	10	OTV Constrains pace:	0.5

Run No. 17 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	18
Physics	0	Powerplant rating, Megawatt	0.1
Surface	0	Mass of Base, Metric Tons:	820
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	8.4
Oxygen	0.00	No. of Expendable LM's:	5
Hydrogen	0	OTV Flights:	56
Silicon	0	Shuttle Flights:	6
Aluminum	0	SDV Flights:	117
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.1
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.0
Water	0	Time, flight operations, years,	
Community-person	20	OTV Constrains pace:	0.7

Run No. 18 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT:		OUTPUT:	
Science (persons)		Total Base Population:	57
Astronomy	0	No. of Habitable Modules:	30
Physics	0	Powerplant rating, Megawatt	0.2
Surface	0	Mass of Base, Metric Tons:	1453
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	13.5
Oxygen	0.00	No. of Expendable LM's:	9
Hydrogen	0	OTV Flights:	86
Silicon	0	Shuttle Flights:	9
Aluminum	0	SDV Flights:	177
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.7
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.6
Water	0	Time, flight operations, years,	
Community-person	40	OTV Constrains pace:	1.1

Run No. 19 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	82
Astronomy	0	No. of Habitable Modules:	41
Physics	0	Powerplant rating, Megawatt	0.2
Surface	0	Mass of Base, Metric Tons:	2053
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	18.3
Oxygen	0.00	No. of Expendable LM's:	11
Hydrogen	0	OTV Flights:	113
Silicon	0	Shuttle Flights:	12
Aluminum	0	SDV Flights:	234
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	9.3
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	2.1
Water	0	Time, flight operations, years,	
Community-person	60	OTV Constrains pace:	1.5

Run No. 20 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	107
Astronomy	0	No. of Habitable Modules:	52
Physics	0	Powerplant rating, Megawatt	0.3
Surface	0	Mass of Base, Metric Tons:	2653
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	23.2
Oxygen	0.00	No. of Expendable LM's:	14
Hydrogen	0	OTV Flights:	141
Silicon	0	Shuttle Flights:	15
Aluminum	0	SDV Flights:	292
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	9.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	2.6
Water	0	Time, flight operations, years,	
Community-person	80	OTV Constrains pace:	1.9

Run No. 21 09:56 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	132
Astronomy	0	No. of Habitable Modules:	63
Physics	0	Powerplant rating, Megawatt	0.3
Surface	0	Mass of Base, Metric Tons:	3252
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	28.0
Oxygen	0.00	No. of Expendable LM's:	17
Hydrogen	0	OTV Flights:	169
Silicon	0	Shuttle Flights:	18
Aluminum	0	SDV Flights:	350
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	10.4
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	3.1
Water	0	Time, flight operations, years,	
Community-person	100	OTV Constrains pace:	2.3

Run No. 22 09:57 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	194
Astronomy	0	No. of Habitable Modules:	92
Physics	0	Powerplant rating, Megawatt	0.5
Surface	0	Mass of Base, Metric Tons:	4805
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	40.7
Oxygen	0.00	No. of Expendable LM's:	25
Hydrogen	0	OTV Flights:	241
Silicon	0	Shuttle Flights:	26
Aluminum	0	SDV Flights:	499
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	11.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	4.4
Water	0	Time, flight operations, years,	
Community-person	150	OTV Constrains pace:	3.4

Run No. 23 09:57 PM 05-Mar-86

INPUT:	SYNOPSIS OF CURRENT MODEL RUN	OUTPUT:	Screen 44
Science (persons)		Total Base Population:	257
Astronomy	0	No. of Habitable Modules:	120
Physics	0	Powerplant rating, Megawatt	0.6
Surface	0	Mass of Base, Metric Tons:	6319
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	53.0
Oxygen	0.00	No. of Expendable LM's:	32
Hydrogen	0	OTV Flights:	312
Silicon	0	Shuttle Flights:	34
Aluminum	0	SDV Flights:	645
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	13.2
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	5.7
Water	0	Time, flight operations, years,	
Community-person	200	OTV Constrains pace:	4.4

Run No. 24 09:57 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	632
Astronomy	0	No. of Habitable Modules:	288
Physics	0	Powerplant rating, Megawatt	1.5
Surface	0	Mass of Base, Metric Tons:	15417
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	127.1
Oxygen	0.00	No. of Expendable LM's:	76
Hydrogen	0	OTV Flights:	735
Silicon	0	Shuttle Flights:	81
Aluminum	0	SDV Flights:	1521
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	21.6
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	13.4
Water	0	Time, flight operations, years,	
Community-person	500	OTV Constrains pace:	10.6

Run No. 25 09:58 PM 05-Mar-86

INPUT:		SYNOPSIS OF CURRENT MODEL RUN OUTPUT:	Screen 44
Science (persons)		Total Base Population:	24
Astronomy	0	No. of Habitable Modules:	14
Physics	0	Powerplant rating, Megawatt	1.1
Surface	0	Mass of Base, Metric Tons:	1296
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	15.5
Oxygen	83.33	No. of Expendable LM's:	6
Hydrogen	0	OTV Flights:	88
Silicon	50	Shuttle Flights:	5
Aluminum	0	SDV Flights:	177
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	0	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.7
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.6
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.3

Run No. 26 09:58 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	28
Astronomy	0	No. of Habitable Modules:	16
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1393
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	16.6
Oxygen	83.33	No. of Expendable LM's:	6
Hydrogen	0	OTV Flights:	94
Silicon	50	Shuttle Flights:	5
Aluminum	0	SDV Flights:	189
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	0	Time, total, years, SDV cons	8.8
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.7
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.4

Run No. 27 09:59 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1439
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.2
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	97
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	196
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	100	Time, total, years, SDV cons	8.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.4

Run No. 28 09:59 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1451
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.3
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	98
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	197
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	200	Time, total, years, SDV cons	8.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.4

Run No. 29 09:59 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT		OUTPUT	
Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1463
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.5
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	98
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	198
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	300	Time, total, years, SDV cons	8.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.5

Run No. 30			09:59 PM 05-Mar-86
INPUT: SYNOPSIS OF CURRENT MODEL RUN		OUTPUT:	Screen 44
Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1476
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.6
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	99
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	200
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	400	Time, total, years, SDV cons	8.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.5

Run No. 31 09:59 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.2
Surface	0	Mass of Base, Metric Tons:	1488
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	17.8
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	100
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	201
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	500	Time, total, years, SDV cons	8.9
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.5

Run No. 32 09:59 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT:		OUTPUT:	
Science (persons)		Total Base Population:	32
Astronomy	0	No. of Habitable Modules:	17
Physics	0	Powerplant rating, Megawatt	1.3
Surface	0	Mass of Base, Metric Tons:	1549
Other	0	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	18.6
Oxygen	83.33	No. of Expendable LM's:	7
Hydrogen	0	OTV Flights:	103
Silicon	50	Shuttle Flights:	6
Aluminum	0	SDV Flights:	208
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	1000	Time, total, years, SDV cons	9.0
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	1.9
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	1.5

Run No. 33 10:00 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

Science (persons)		Total Base Population:	73
Astronomy	3	No. of Habitable Modules:	30
Physics	6	Powerplant rating, Megawatt	1.5
Surface	12	Mass of Base, Metric Tons:	2346
Other	12	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	28.7
Oxygen	83.33	No. of Expendable LM's:	10
Hydrogen	0	OTV Flights:	155
Silicon	50	Shuttle Flights:	11
Aluminum	0	SDV Flights:	312
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	1000	Time, total, years, SDV cons	10.0
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	2.8
Water	0	Time, flight operations, years,	
Community-person	8	OTV Constrains pace:	2.4

Run No. 34 10:01 PM 05-Mar-86

INPUT: SYNOPSIS OF CURRENT MODEL RUN OUTPUT: Screen 44

INPUT:		OUTPUT:	
Science (persons)		Total Base Population:	188
Astronomy	3	No. of Habitable Modules:	81
Physics	6	Powerplant rating, Megawatt	1.7
Surface	12	Mass of Base, Metric Tons:	5118
Other	12	Size of Construction Crew:	14
Resources Export (MT/mo)		Construction Interval, mos.	51.3
Oxygen	83.33	No. of Expendable LM's:	23
Hydrogen	0	OTV Flights:	284
Silicon	50	Shuttle Flights:	25
Aluminum	0	SDV Flights:	579
Iron/Steel	0	Max. OTV flts/wk. (an input)	1
Glasses	50	Max. SDV flts/wk. (an input)	2
Shielding	1000	Time, total, years, SDV cons	12.6
Mfgr. Products	0	Time, flight operations, years,	
Foodstuffs	0	SDV Constrains pace:	5.2
Water	0	Time, flight operations, years,	
Community-person	100	OTV Constrains pace:	4.3

APPENDIX D

NASA SPACE STATION COST ESTIMATING RELATIONS

NASA SPACE STATION COST ESTIMATING RELATIONSHIPS

Subsystem Element	Costs, \$ Millions, 1982 \$ Design&Development	Flight Hardware
1. Pressurized Structures	$y = .7018WT^{.5488}$	$y = .1027WT^{.6265}$
2. Secondary Structures	$y = .2889WT^{.6386}$	$y = .0034WT^{.9724}$
3. Mechanisms	$y = .8656WT^{.4265}$	$y = .0311WT^{.7034}$
4. Tanks	$y = .0811WT^{.7177}$	$y = .0407WT^{.5803}$
5. Thermal Control	$y = .8630WT^{.5}$	$y = .1151WT^{.7}$
6. Attitude Control	$y = 6.5468WT^{.5995}$	$y = .7061WT^{.7}$
7. Reaction Control	$y = .1322WT^{.6995}$	$y = .0025WT^{1.323}$
8. Power - Excluding Solar Array	$y = 1.614WT^{.6548}$	$y = .0035WT^{1.064}$
9. Solar Arrays	$y = 7.652PW^{.3974}$	$y = 4.058PW^{.6743}$
10. Environmental Control & Life S	$y = .2838WT^{.7155}$	$y = .2652WT^{.6665}$
11. Crew Accomodations	$y = .6488WT^{.4663}$	$y = .1975WT^{.4801}$
12. Command & Data Handling	$y = .0852WT^{.9328}$	$y = .0659WT^{.7785}$
13. Displays & Controls	$y = 2.172WT^{.5}$	$y = .0663WT^{.9004}$
14. Instrumentation	$y = 2.982WT^{.5}$	$y = .0662WT^{.7}$
15. Communications	$y = 5.701WT^{.5}$	$y = .2904WT^{.7}$

System Level Elements	Costs, \$ Millions, 1982 \$ Design&Development	Flight Hardware
1. Systems Test Hardware	$y = 1.362BC^{.9947}$	0
2. Integration, Assembly & C/O	$y = .0891BC^{.9916}$	$y = .4638BC^{.7406}$
3. Systems Test Operations	$y = .2022BC^{1.058}$	0
4. Ground Support Equipment	$y = .7691BC^{.8105}$	0
5. Systems Engineering & Integr.	$y = 7.276BC^{.4514}$	$y = .5414BC^{.7214}$
6. Program Management	$y = .9801BC^{.6546}$	$y = .0468BC^{1.047}$

Legend: BC = Base Cost (1982 \$M) = Summation of Subsystem Elements Costs
WT: Weight (lbs.)
PW = Power (kW)

Cost Estimating Procedure: (note: apply escalation factors to FY'82 costs)

a. Determine mass of all subsystem elements, per 15 items of Sc 26A
b. Determine cost of each subsystem element D&D and Flt Hardware
c. Sum element costs to derive BC for each cost category: D&D, FH
d. Using "learning curve" and size of fleet, determine fleet cost.
e. Compute and add "systems level" cost elements for program cost.

APPENDIX E

STANADARD INDUSTRIAL CLASSIFICATION OF LUNAR INDUSTRIES

STANDARD INDUSTRIAL CLASSIFICATION OF LUNAR INDUSTRIES

Use of a four digit Codes for prospective ventures (incomplete)

Ref:"Standard Industrial Classification Manual", GPO 041-001-0066-6, 1972

Industry Number	Title	Industry Number	Title
		22XX	Textile Mill Products
182	Food crops grown under cover	2813	Industrial Gases
219	General Livestock	2819	Inorganic Chemicals
279	Fish farms	2899	Chemical Preparations
1011	Iron Ores	3211	Flat Glass
1051	Aluminum Ores	3231	Glass Products
1081	Metal Mining Services	3241	Cement, Hydraulic
1099	Titanium, etc. mining	325X	Structural Clay Products
1429	Crushed & Broken Stone	33XX	Primary Metals Industries
1459	Ceramic & Refractory Minerals	34XX	Fabricated Metal Products
1499	Miscellaneous Nonmetallic Minerals	3674	Semiconductors
1541	General Building Contractors	3832	Optical Instruments & Lense
1629	Heavy Construction	4XXX	Transport, Comm & Utilities
1799	Special Trade Contractors	6XXX	Finance, Insur & Real Est
20XX	Food & Kindred Products	9661	Space Research & Technology