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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

Benefits Analysis

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a study for the National Aeronautics and Space Administration to determine Space Station needs, attributes, and architecture. The study, which emphasized mission validation by potential users, and the benefits a Space Station would provide to its users, was divided into the following three tasks:

Task 1: Mission Requirements
Task 2: Mission Implementation Concepts
Task 3: Cost and Programmatics Analysis

In Task 1, missions and potential users were identified; the degree of interest on the part of potential users was ascertained, especially for commercial missions; benefits to users were quantified; and mission requirements were defined.

In Task 2, a range of system and architectural alternatives encompassing the needs of all missions identified in Task 1 were developed. Functions, resources, support, and transportation necessary to accomplish the missions were described.

Task 3 examined the programmatic options and the impact of alternative program strategies on cost, schedule and mission accommodation.

This report, which discusses Space Station Program benefits analysis, was prepared for the National Aeronautics and Space Administration under contract NASw-3687 as part of the Task 1 activities.

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Section 1
INTRODUCTION AND SUMMARY

1.1 SCOPE AND PURPOSE OF ANALYSIS

In Task 1 of the Space Station Needs, Attributes, and Architectural Options study, MDAC assembled a baseline set of model missions. Derived from a large and extensive data base of mission descriptions, the selected set of missions has been thoroughly characterized in terms of support requirements, demands on the Space Station, operating regimes, payload properties, and statements of the mission goals and objectives. This baseline is a representative set of mission requirements covering the most likely extent of Space Station support requirements from which architectural options can be constructed and exercised by design-related activities of the study.

The results of a corollary study activity are reported in which the MDAC study team, including its subcontractors and consultants, examined the benefits which the Space Station enables in the subsequent conduct of the missions. The baseline set of 90 missions were assessed collectively and individually in terms of the economic, performance, and social benefits to be accrued and expected from the conduct thereof. An overview of the factors included in this assessment is shown in Figure 1-1. This provided an ordered set of missions that can be sequentially accommodated by a Space Station system that would increase in capability to a given budget limit. An example of the questions and issues which were addressed is shown in Figure 1-2.

1.2 RESOURCES UTILIZED IN BENEFITS ASSESSMENT

The MDAC study team includes members of the Mission Advisory Panels in the areas of commercial, operational, science and applications, and technology missions*. The panels also include individuals acting as consultants to the study or employees of study subcontractors. The advice sought from this panel

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*National security missions were not included in the assessment.

SPACE STATION ENABLING BENEFITS	SPACE STATION MISSION COST AND SUPPORT	CONSTITUENCY AND RISK FACTORS
- ECONOMIC FACTORS - SOCIAL FACTORS ● DEMOGRAPHICS ● INTERNATIONAL PARTICIPATION ● EDUCATION, CONTRIBUTION TO SCIENCE, COMMERCIAL APPLICATION	- PROGRAM IMPLEMENTATION FACTORS - INTEGRATION SUPPORT ● ORBIT ● VOLUME ● POWER ● CREW ● LOGISTICS	- INTRINSIC APPEAL & SUPPORTIVE GROUPS - TECHNICAL, SCHEDULE AND COST UNCERTAINTY - CONCEPTUAL MATURITY AND COMPETITION

Figure 1-1. Assessment of Economic, Performance and Social Benefits

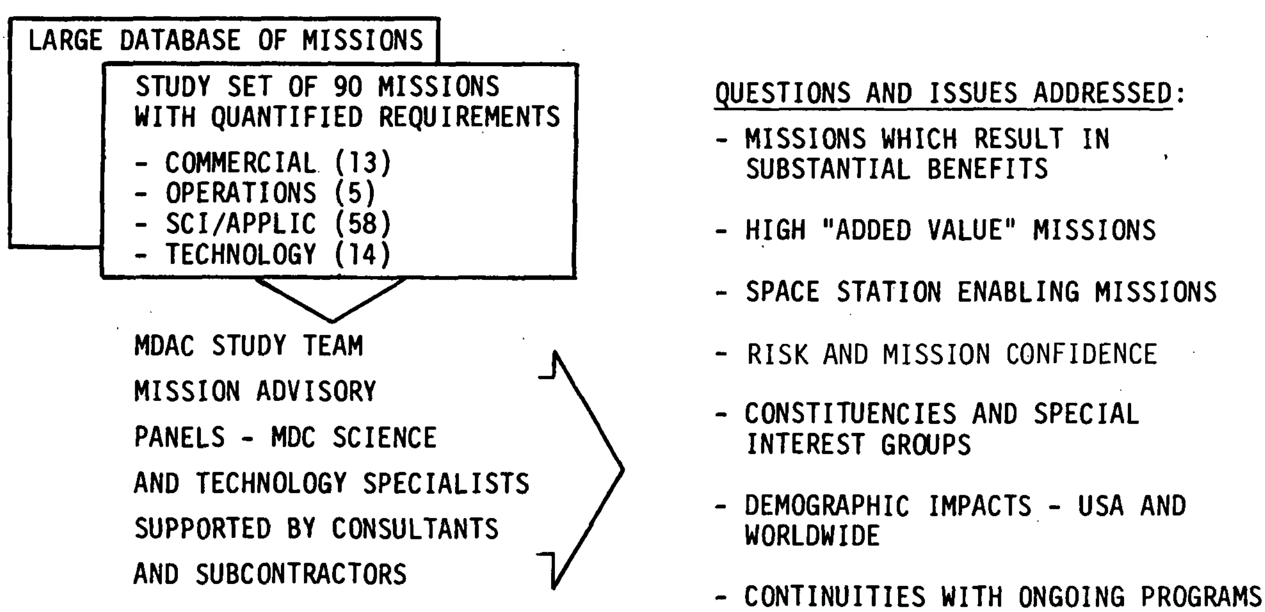

Figure 1-2. Benefits Assessment Issues

of experts in individual discipline was supplemented by MDAC's extensive Space Station/mission data base which encompasses over 20 years of directly related and applicable experience. Twelve individuals contributed directly to the benefit assessment, five of whom hold doctoral degrees. The panel collectively brought thoughts and judgments representing over 300 man-years of directly applicable expertise.

1.3 OVERVIEW OF RESULTS

The assessment method involved collecting expert judgments quantified within 34 separate parameters and factors for each of the missions. In each case, six or seven experts independently evaluated the missions and their ratings were compiled, tallied, and statistically analyzed on a mission-to-mission basis, within mission category groups, and across the entire baseline set of 90 missions.

A detailed study of the expert ratings can provide numerous possibilities in ranking and ordering the missions according to any set of criteria. For this study the criteria selected were ranking by intrinsic benefits and constituency factors, which can be labeled "mission interest" and a ranking by cost savings and confidence factors, which in turn can be labeled "mission economy". Details of the analysis and resultant ordering and rankings can be found in Section 3 of this report.

Section 2
DATA SOURCE, METHODOLOGY, AND FACTOR ASSESSED

2.1 BASELINE MISSION SET AND REQUIREMENTS PARAMETERS

The Space Station mission benefits analysis was done for the 90 missions included in the data base. The missions represent four categories of general orbital activities: (1) commercial, (2) operations, (3) science and applications, and (4) space technology development. The count of missions in each category is 13, 5, 58, and 14 respectively.

For each mission in the set, an identifying descriptive title and abbreviated code along with a brief statement of the mission goals and objectives were prepared. The mission set is listed in Table 2-1.

For each mission, 44 distinguishing parameters were collected and documented as the baseline set. These parameters were derived by the MDAC study team from NASA sources, from MDAC in-house sources, from the study team subcontractors and consultants, and from the results of ongoing study analyses, in-depth literature searches, and personal conversations with members of the discipline communities. These parameters represent the requirements for on-orbit support from the Space Station and the physical and operational characteristics of the mission payload equipment. This collection of baseline mission/payload characteristics was a primary source of information made available to the mission benefits assessment work force. A compilation of the mission set data base, including other factors derived from the benefits analysis, are included as Appendix A of this report.

Examples of the types of support requirements and characteristics data for each mission residing in the compiled data base include (1) status of the mission concept in terms of mission time period and operational readiness of the mission hardware; (2) orbital parameters required, desired, or tolerated; (3) space platform support (i.e., manned space station, unmanned platform, satellite service platform); (4) manpower requirements in direct support of

Table 2-1
BASELINE MISSION SET DESCRIPTIONS

CODE	NAME	OBJECTIVE/DESCRIPTION
CIR001	MATERIALS RESEARCH FACILITY	Manned pressurized module & associated pallet containing laboratory apparatus (furnaces, separation devices, etc.) for industrial sponsored R&D.
CMP001	ELECTROPHORETIC PRODUCTION	Man-tended commercial electrophoretic processing facility including off-line analytic & testing equipment for biologicals and provisions for live organism test specimens.
CMP002	SILICON RIBBON MANUFACTURE	Dedicated facility containing processing equipment & support systems for the production of silicon crystal in ribbon form.
CMP003	ELECTRONIC CIRCUIT ELEMENTS	Dedicated facility containing an electron beam etcher, scanning microscope, control/display consoles, & support equipment for manufacture of frequency sensing elements & delay lines for electronic circuits.
CMP004	MATERIAL MELT/REFORM	Facilty for containerless melting & refreezing of products such as Tungsten, homogenous alloys & precious metals.
CMP005	ORIENTED MIXTURES	Facility for developing & producing oriented mixtures including metal-fiber composites, fibrous gels, pore size films, emulsion polymers.
CMP006	DIRECTIONAL CRYSTAL GROWTH	Facility for directional crystal growth including such products as uniform indium-antimonide crystals & unique single crystals.
CMP007	HIGH STRENGTH PLASTICS	Facility for utilizing attributes of space for rapid heating & cooling in the production of such products as stress plastics of high strength fibers.

Table 2-1

BASELINE MISSION SET DESCRIPTIONS

(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
CMP008	SEPARATIONS LABORATORY	Facility capability for production of products requiring unidirectional processing including composite materials & protein purification as in immunoglobulias & cellular or protein fractionation as in AHF.
CMP009	TOXIC WASTE MONITORING	Facility for commercial applications of earth observations including monitoring of toxic waste emissions as well as resource assessment, site monitoring, land use, weather forecasting, etc.
CMP010	BIOMATERIALS PROCESSING	Facility to provide/develop products for energy production including solar furnaces, concentrated controlled reactors, metal liners, & biomass for energy production.
CMP011	MEDICAL FACILITY	Research laboratory for utilization of weightlessness in developing techniques for biomedical procedures including organ transplants, burn treatments, directed cell growth, etc.
CMP012	GALLIUM ARSENIDE PRODUCTION FACILITY	EVA resupplied & maintained facility containing furnaces & other processing equipment & support systems for the production of high quality gallium arsenide crystals.
OAI001	STRUCTURAL ASSEMBLY & TEST	Provide the resources required to support construction, alignment & checkout of large space structures.
OSR001	SATELLITE SERVING OPERATIONS	Repair, replenish, reconfigure & checkout ORUs that have been removed from berthed and/or free-flying scientific & commercial SATs.
OTR001	TMS OPERATIONS	Provide a 28.5° base for operating the TMS in its role of place/retrieve free flyers. Includes, Maint., replenish, repair, c/o, launch control, pld mate.

Table 2-1
BASELINE MISSION SET DESCRIPTIONS
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
OTR002	TMS OPERATIONS	Provide a 57° base for operating the TMS in its role of place/retrieve free flyers. Includes maint., replenish, repair, c/o, launch control, pld mate.
OTR004	OTV OPERATIONS	Provide a 28.5° base for operating the OTV in its role of place/retrieve free flyers. Includes maint., replenish, repair, c/o, launch, control, pld mate.
SAS001	ADVANCED SOLAR OBSERVATORY/ SOLAR OPTICAL TELESCOPE	High resolution observation of sun. Spacelab Derivative Mission. Grows from visible to full spectrum (Near IR through hard X-ray.)
SAS002	SHUTTLE INFRARED TELESCOPE FACILITY	Astronomical telescope. Near-to-Far IR spectroscopy. Cryo-cooled structure sensitive down to 3°K background radiation.
SAS003	STARLAB	Spacelab visible through UV telescope, 1 m class. Astronomical observations. Multiple, changeable, focal plane instruments.
SAS004	ELEMENTAL COMPOSITION AND ENERGY SPECTRA OF COSMIC RAY NUCLEI	Spacelab cosmic ray composition and spectra measurements at energies up to and beyond 1 TEV for more abundant isotopes.
SAS005	SOLAR SOFT-X-RAY TELESCOPE	Spacelab telescope to be integrated into ASO (SAS001). 0.8 m optics with spectral range from 0.185 to 10 nm.
SAS006	EXTRA LARGE LONG DURATION EXPOSURE FACILITY	Very large area, passive, plastic cosmic ray detector. Searching for rare nuclei and exotic particles (e.g., magnetic monopoles).
SAS007	TRANSITION RADIATION AND IONIZATION CALORIMETER	Spacelab facility observing electrons, protons, and helium nuclei up to 100 Tev.
SAS008	X-RAY OBSERVATORY	Broad Bandwidth, Astronomical Observatory for X-ray Imaging, Spectroscopy, Polarity, and Background Measurement. Late 1990's Technology.

Table 2-1
BASELINE MISSION SET DESCRIPTIONS

(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SAS009	SPACE TELESCOPE	Astronomical Observatory. Dedicated Satellite. Near IR through UV Imaging and Spectroscopy. 2.4 m Optics with Multiple Focal Plane Instruments.
SAS010	HIGH RESOLUTION X AND γ RAY SPECTROMETER	High Resolution X and γ Ray Spectrometry (100 KeV to 10 MeV). Gallactic Nucleosynthesis.
SAS011	X-RAY TIMING EXPLORER	Dedicated Explorer Satellite. Observes Temporal Variation of X-Ray Emitting Celestial Objects. 1989 Launch with Shuttle Retrieval after 2 years. Reflight for continued observation desirable.
SAS012	SOLAR INTERIOR DYNAMICS MISSION	Dedicated Satellite. Solar Observation, including Magnetic Field, Coronal temperature and Structure, Solar surface, solar spectrum. On-orbit service contemplated to extend life.
SAS013	ADVANCED X-RAY ASTROPHYSICS FACILITY	Dedicated Satellite, Mature X-Ray Observatory. Advanced State-of-the-Art Optics, Detectors, etc., for High Resolution Imaging, Spectroscopy and Polarity.
SAS014	HIGH THROUGHPUT MISSION - (LARGE AREA MODULAR ARRAY OF REFLECTORS)	Multiple reflector X-ray observatory for detecting very faint X-ray sources and rapid variation of stronger sources. Spacelab derivative, modular construction.
SAS015	VERY LONG BASELINE INTERFEROMETRY	Orbiting 15-60 m Radio Telescope. Spacelab Development. Use in conjunction with ground stations for radio frequency interferometry.
SAS016	LARGE DEPLOYABLE REFLECTOR	Large (10 to 20 m), ambient, IR observatory. Near IR to microwave spectral range. High resolution study of star formation and observation of faint IR sources.
SAS017	GAMMA RAY OBSERVATORY	Dedicated satellite observation of Celestial Gamma Ray sources. Imaging, Spectroscopy, and Transient Burst Detection.

Table 2-1
BASELINE MISSION SET DESCRIPTIONS
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SAS018	HIGH ENERGY ISOTOPE EXPERIMENT	Spacelab Derivative. Cosmic Ray Observatory for particles above 1 GeV.
SAS019	SOLAR CORONAL DYNAMICS MISSION	Studies of the solar corona and its Dynamics, especially the mechanisms for coronal heating. Dedicated satellite or ASQ.
SAS020	COSMIC RAY OBSERVATORY	Advanced, Full Range Observatory for Cosmic Rays. May integrate Spacelab Derivative Equipment.
SCM001	REMOTE SENSING AND RFI MEASUREMENTS	25 to 55 m Antenna with Passive Detection in the 600-10,000 MHz and RF. Observes use of communications channels and power density in orbit.
SCM002	ORBITING STANDARDS PACKAGE	Antennas, Receivers, and Transmitters in the UHF to Ku bands to characterize and calibrate satellite communications.
SCM003	COMMUNICATIONS RESEARCH FACILITY	Manned Laboratory for Communications Equipment Development, Test Characterization and Propagation Measurements.
SEE001	OCEAN PAYLOAD	Multi Instrument Package to determine ocean circulation, heat content, and heat flux. Research on Effects of Oceans on Atmosphere and climate, ocean productivity and food chain.
SEE002	ATMOSPHERIC COMPOSITION	Multi Instrument Package to Measure Atmospheric Species, Sources, Sinks Diuernal Variations and Migration in the lower 30 km.
SEE003	UPPER ATMOSPHERIC RESEARCH SATELLITE	Study of Radiation, Chemistry, and Dynamics of the Upper Atmosphere. Dedicated Satellites with on-orbit service potential.
SEE004	SPACE PLASMA PHYSICS PAYLOAD	Interactive Experimental Study of Near Earth Plasma and its Interactions with the Sun and Atmosphere. Spacelab Derivative Hardware.

Table 2-1
BASELINE MISSION SET DESCRIPTIONS
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SEE005	ZERO G CLOUD PHYSICS	Spacelab Derivative, Manned Orbital Laboratory for Study of Atmospheric Microscale Processes such as Cloud Formation and Development.
SEE006	METEOROLOGICAL RESEARCH PACKAGE	Manned Orbital Laboratory for Development and Testing of Meteorological Instruments and Research on Weather and Climate.
SEE007	ATMOSPHERIC DYNAMICS AND RADIATION	Spacelab Derivative, Multi-instrument Package to Measure Temperature, Water Vapor, Liquid Water, Precipitation, and Wind Profiles to Monitor and Model Atmospheric Dynamics.
SEE008	OPERATIONAL CIVIL METEOROLOGICAL STATION	Operational Civil Meteorology Measurements, On-Orbit Instrument Service & Repair.
SEP001	SYNTHETIC APERTURE RADAR	Spacelab Derivative Radar for Developing Basic Data and Monitoring changes in Land Vegetative Cover, Hydrological Cycle, Water Resources, and Geological Resources.
SEP002	MULTISPECTRAL LINEAR ARRAY	Thermal IR to Visible, Multi-Channel Spectrometer for Vegetative Cover, Hydrological Cycle, Water Resources and Geological Studies.
SEP003	MAGNETIC FIELD MAPPER	Refined Measurements of Near Earth Magnetic Field and Variability
SEP004	PASSIVE MICROWAVE RADIOMETER	Medium to Large, Passive Antenna Imaging Microwave Emissions in up to 10 Rands from 1.4 to 94 GHz to Develop Snow and Water Inventory, Hydrological Cycle, Meteorology, Polar Ice, and Ship Routing Data.
SEP005	LARGE FORMAT CAMERA	High Resolution IR to Visible Photography of Earth's Surface. Spacelab Developed Hardware.

Table 2-1
BASELINE MISSION SET DESCRIPTION
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SEP006	IMAGING SPECTROMETER	Near IR through Visible, High Resolution Spectroscopy of the Earth's Surface for Vegetative, Hydrological, and Geological Studies up to 128 channels. Spaclab developed instrument.
SEP007	LUMINESCENCE DETECTOR	Detection of Natural Luminescence of the Earth's Surface to Identify Surface Rock and Soil Composition.
SEP008	SPACE BASED LASER RANGING	Monitoring of Crustal Dynamics by Laser Ranging to Ground Based Corner Reflectors.
SEP009	LANDSAT D-D'	Dedicated Satellite Providing Earth Research Data. Multispectral Scanner and Thermatic Mapper. On Orbit Service and Retrieval Refurbishment/Relaunch Planned to Extend Life.
SEP010	RADAR ALTIMETER	Use in Conjunction with Other Instruments for Vegetative Inventory Monitoring.
SEP011	ACTIVE FLUORESCENCE SPECTROMETER	Laser Activated Fluorescence Study to Determine the Composition of the Earth's Surface.
SEP012	PLANETORY SPECTROSCOPY TELESCOPE	Near IR to UV, 1M Class Telescope for Spectroscopy Studies of Solar System Objects from Earth's Surface can use Spacelab.
SEP013	INFRARED SPECTROSCOPY TELESCOPE	Thermal to Near IR Spectroscopy Studies of Planetary Atmosphere. 1 M Optics, Diffraction Limited can use SIRTF, with modifications.
SEP014	FAR INFRARED AND SUBMILLIMETER SPECTROSCOPY AND RADIOMETRY	Large (10-20m) Ambient IR to sub-millimeter Spectroscopy of Planetary Atmospheres, Comets and Other Solar System Objects. Can use LOR.
SEP015	EXTRA SOLAR SYSTEM DETECTION	1M Visible Spectrum Optics with Scanning Ronchi Ruling to Detect Motion of Nearby Stars Indicating the Presence of Planetary Systems. Can Use Spacelab.

Table 2-1
BASELINE MISSION SET DESCRIPTION
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SEP016	PLANETARY PHYSICAL PROCESSES LABORATORY	Spacelab Derivative, Orbital Laboratory for Study of Planetary Geological Processes and Effects of Space Environment on Materials.
SLS001	PRIMATE EXPERIMENTAL FACILITY	Manned Laboratory for Study of Space Environment Effects. Bone and Muscle Loss, Electrolyte Changes, Cardiovascular and Vestibular Systems. Spacelab Derivative Hardware.
SLS002	PLANT BIOLOGY/LIFE CYCLE FACILITY	Manned Laboratory for Studies of Plant Biology and Life Support Systems Using Plants. Spacelab Derivative.
SLS003	RODENT EXPERIMENT FACILITY	Manned Laboratory for Experiments on Animal Development, Reproduction, Bone and Muscle Loss, Fluid and Electrolyte Loss, Vestibular and Metabolic Processes, and Radiation Biology. Spacelab Derivative.
SLS004	ORBITING QUARANTINE FACILITY	Facility for Isolating Extra Terrestrial Materials for Analysis and Study on Orbit.
SLS005	EXPERIMENTAL MEDICAL TREATMENT FACILITY	Manned Facility for Development of Emergency and Minor Medical Treatment Procedures.
SLS006	HUMAN EXPERIMENT FACILITY	Spacelab Derivative Facility for Study of Effects of Space Environment on Man. Bone and Muscle Loss, Hematology and Immunology, Cardiovascular and Vestibular Studies.
SMP001	MATERIALS PROCESSING LABORATORY	Manned Laboratory for Materials Processing Research and Development. Production of R&D Quantities of Spherical Materials.
SMP002	MATERIALS EXPERIMENT CARRIER	Production Unit for Solidification and Capital Growth Processes. Magazine Fed with Multiple Samples Processed in Series. R&D/Clinical Small Production Quantities.

Table 2-1
BASELINE MISSION SET DESCRIPTION
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
SMP003	MATERIALS EXPERIMENT ASSEMBLY	Preproduction Facility to Demonstrate Materials Processing Methods Prior to Commercial Scale Production.
SMP004	WAKE SHIELD EXPERIMENT	Measurement of Composition and Flux of Molecules Into Wake Shield and Level of Vacuum Achievable.
SMP005	ULTRAVACUUM FACILITY	Materials Processing Facility Using Wake Shield for Ultra Vacuum and Levitation Methods to Produce Extremely Pure Materials.
TFM001	LASER COMMUNICATIONS & TRACKING DEVELOPMENT	Develop technology to support a Space Station Communications System.
TGN001	LARGE SPACE STRUCTURE CONTROL EXPERIMENT	To validate LSS dynamic modeling, dynamic characteristics identification techniques, sensing and actuating hardware, pointing performance, and control algorithms.
TGN002	ZERO G ANTENNA RANGE	Expedite development of large space antennas by providing capability for performance evaluation (radiation pattern measurement).
TGN003	MATERIALS & COATINGS TECHNOLOGY	To provide a technology data base for production of structural and insulating materials and absorbing surface coatings capable of sustained performance in the space environment.
TGN004	TETHER DYNAMICS	To provide a data base for deployment operation, and retrieval of long tethers and the use of electrodynamic forces for thrust and drag control.
TGN005	LARGE STRUCTURE CONSTRUCTION	To develop and verify the designs and techniques for constructing large structures in space.
TGN006	FLUID STORE & MANAGEMENT	To develop technology for the transfer and long term storage of cryogenic liquids in space, including, acquisition, venting, active and passive refrigeration, insulation concepts, pumped and pressure transfer.

Table 2-1
BASELINE MISSION SET DESCRIPTION
(Continued)

CODE	NAME	OBJECTIVE/DESCRIPTION
TGN007	LIQUID DROPLET RADIATOR	Demonstration of a droplet radiator concept under space conditions. Determine performance, constraints, contamination effects.
TGN008	ECLS WATER RECOVERY	Demonstrate satisfactory long term performance and reliability of a waste water recovery system under space conditions.
TGN009	ECLS OXYGEN RECOVERY	Demonstrate satisfactory long term performance and reliability of an oxygen recovery system under space conditions.
TOP001	SATELLITE SERVICING TECHNOLOGY	To develop satellite servicing technology for free flying spacecraft/satellites at an on-orbit support facility.
TOP002	OTV SERVICE TECHNOLOGY	To develop the technology required to maintain an orbit transfer vehicle on-orbit between flights.
TOP003	CREW/MANIPULATOR CONTROL	Determine characteristics of control technology applied to teleoperators. Develop data base for comparing crew EVA capabilities versus teleoperators.
TOP004	MAN'S ROLE EVALUATION	Provide on-orbit evaluation data to support optimization of man's role in spacecraft operations.

the mission; (5) mass and volume properties of the mission payload equipment; (6) data retrieval and payload logistics requirements; and (7) onboard electrical power and energy requirements.

2.2 ASSESSMENT METHODOLOGY AND FACTORS CONSIDERED IN MISSION EVALUATION

An objective of the mission benefits assessment has been to examine and evaluate each mission in set in terms of its overall value and potential contribution and to develop a basis of comparison of individual missions and groups of missions with each other (ranking). This evaluation has been able to identify the missions that are strong candidates for the initial Space

Station payloads and to place the missions in rank order based upon chosen relative measure of merit criteria.

As a first step in the evaluation, a number of individual rating parameters were examined. The parameters which were finally selected had in common several attributes: (1) they could be applied in a consistent manner to each mission in the set, (2) they could be applied by each rater in the assessment process by relying on a common understanding of their application, (3) they could be quantified either on a well-defined five-point scale or on a simple yes/no basis, (4) they were relatively independent of one another, (5) they covered the extent and range of potential benefit categories, and (6) they excluded the potential of introducing strong biases into the analysis stemming either from the individual rater's personal view of the mission or from outside influences such as current political points of view or opinions concerning the national mood. A total of 34 factors to be assessed for each mission was identified and defined, and a worksheet was prepared. A sample of the four-page worksheet is shown in Figure 2-1.

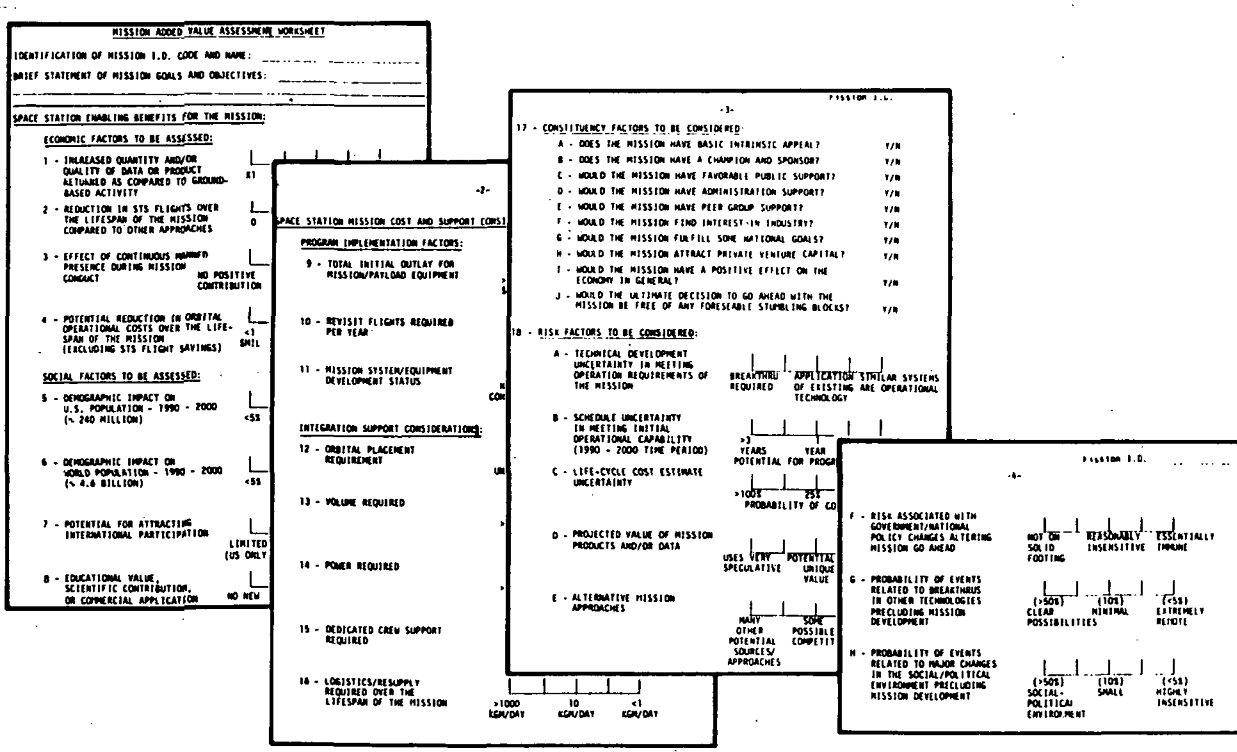

Figure 2-1. Mission Worksheet

For the mission set, 12 members of MDAC's Space Station Mission Advisory Panel independently evaluated and assessed the missions entering their individual evaluations on the data sheets. In each case, the individual raters were assigned to assess the missions in which they were both expert in the mission area and in the related manned Space Station functional operations. Figure 2-2 summarizes the individual decisions which were amassed by the activity.

88 MISSIONS • 31 REQUIREMENTS PARAMETERS
34 FACTORS ASSESSED • 12 RATING SPECIALISTS

∇

19652
INDIVIDUAL DECISIONS AND ASSESSMENT
DATA ITEMS QUANTIFIED

∇

90 MISSIONS • 6 DATA GROUPS • 6 ELEMENTARY STATISTICS

∇

3240
STATISTICAL ITEMS

∇

REDUCTION AND MANIPULATIONS OF STATISTICAL DATA BASE

- RANKING AND ORDERINGS
- EXTRACTIONS AND SORTINGS
- SENSITIVITY STUDIES
- SCORING WITHIN AND BETWEEN GROUPS
- CORRELATION AND REGRESSION
- FACTOR ANALYSIS

Figure 2-2. Mission Benefits Assessment Analysis

After the raters had completed their individual evaluation, the worksheets were gathered into sets for each mission and initially segregated by mission category. The individual ratings were summarized and the summary data collected as follows: A Space Station enabling benefit-score was tabulated comprising a simple arithmetic sum of the first eight factors. A cost and savings score was summed in a similar fashion using factors 9 through 16. A constituency score was computed by adding the number of "yes" decisions for the ten factors under item 17. A risk (or confidence) score was computed from a tabulation of the eight factors listed under item 18 on the worksheet. The format of the loadsheet which was used to tabulate the raters' scoring summaries is shown in Figure 2-3.

Factors Assessed	Factor Scores by Rater						
	A	B	C	D	E	F	G
1 – Space Station Enabling Benefits							
2 – Mission Cost and Support Savings							
3 – Mission Constituencies							
4 – Mission Risk and Confidence Considerations							

Figure 2-3. Mission Summary Data Loadsheet Format

2.3 MECHANIZED DATA BASE REDUCTION

For each of the 90 missions, the rating score summaries were entered into the McAUTO Cyber System memory bank, of which the MDAC Space Station Study is a user. These mission scores were then analyzed by the study team to easily derive elementary statistics and correlational analysis in a most efficient manner. For example, for each of the four summary factors as shown on the loadsheet, the arithmetic mean, the standard deviation of the means, the standard error, maximum, minimum, and range was computed. The study of these statistics on an individual mission-by-mission basis is useful in understanding the agreement among the raters in their assesesment of the missions.

One of the compelling reasons for codifying the rating summaries in the computer data bank has been to permit comparisons of the statistical characteristics of the rating scores for each mission and across missions within one of the four major categories (commercial, operations, science/applications, technology) and across the entire set of 90 missions.

Another value of the codifications is the linking of the rating statistics to the mission requirements data set. By this means, the errors attendant with routine calculation are avoided as are the problems of large-scale manipulations of the entire data base. Typical manipulations include sorting the mission set on selected criteria and computation of combinations of statistics that have been selected for study.

Section 3
DISCUSSION OF DATA AND RESULTS OF THE ANALYSIS

3.1 STATISTICS OF MISSION SET

Previously, it was stated that the rater's scores for each mission had been collected, grouped into four factors (benefits, savings, constituency, risk), and statistically averaged across the several rating experts for each mission. In each case, the higher numeric scores represent the higher characteristics attribute of a given mission. These statistics are presented in Table 3-1.

Table 3-1. Summary Statistics of the Mission Data Set

I.D. No.	Short Title	Factors 1	2	3	4
	Commercial				
CIR001	MATERIALS RES FAC	23	21	7	27
CMP001	ELECTROPHORETIC PRO	29	21	9	30
CMP002	SILICON RIBBON MAN	22	22	7	22
CMP003	ELECTRONIC CIR ELEM	19	24	6	22
CMP004	MATERIAL MELT/REFORM	22	20	7	23
CMP005	ORIENTED MIXTURES	22	22	7	22
CMP006	DIR XTAL GROWTH	21	24	7	22
CMP007	HI STRENGTH PLASTICS	22	22	7	23
CMP008	SEPARATIONS LAB	23	18	8	25
CMP009	TOXIC WASTE MONITER	21	29	7	25
CMP010	BIO PROCESSING	20	24	7	23
CMP011	MEDICAL FACILITY	19	18	6	21
CMP012	GA AS FACILITY	20	22	6	23
	Operations				
OAI001	STRUCT ASSY & TEST	23	19	5	22
OSR001	SAT SERV OPS	21	23	6	24
OTR001	TMS OPS	20	24	6	24
OTR002	TMS OPS	20	23	5	24
OTR004	OTV OPS	22	22	5	20
	Science/Applications				
SAS001	SOLAR OPT TELE(ASO)	24	24	6	26
SAS002	SIRTF	23	25	5	24
SAS003	STARLAB	23	24	5	24
SAS004	COMP SPEC COSRAY NUC	20	29	5	25
SAS005	SOL SOFT XRAY TS	22	28	5	23
SAS006	LONG DUR EXP	21	28	3	21
SAS007	TRANS RAD ION.CAL.	19	30	3	21
SAS008	XRAY OBSER	20	28	4	22
SAS009	SPACE TELESC	24	24	6	28
SAS010	HIRES X&G-RAY SPEC	20	28	3	21
SAS011	XRAY TIMING EXPL	19	30	5	23
SAS012	SOLAR INT DYNAMICS	19	27	4	23
SAS013	ADV XRAY ASTROFAC	23	25	5	22
SAS014	LAMAR(HTM)	22	24	4	21
SAS015	VLBI	19	28	5	23
SAS016	LRG DELP REFL	22	25	4	21
SAS017	GAMMA RAY OBS	21	24	6	24
SAS018	HIGH ENER ISO EXP	18	28	3	21
SAS019	SOLAR COR DYN	18	30	4	21
SAS020	COSMIC RAY OBS	22	26	4	22
SCM001	REMOTE SENSING RFI	18	28	4	21
SCM002	ORB STANDARDS PACK	17	32	5	23
SCM003	COMM RESEARCH FAC	18	23	4	20
SEE001	OCEAN PAYLOAD	28	23	7	24
SEE002	ATMOS COMP	21	25	5	21
	Science/Applications				
SEE003	UPPER ATMOS RES	20	25	5	23
SEE004	SPACE PLASMA PHYSICS	20	25	4	22
SEE005	ZERO G CLOUD PHYSICS	26	28	5	23
SEE006	METEOROLOGICAL PL	24	25	5	20
SEE007	ATM DYNAMICS&RAD	25	25	5	22
SEE008	OP CIVIL MET	22	26	5	24
SEP001	SAR	26	25	6	25
SEP002	MULTISPECT LIN ARRAY	24	29	5	23
SEP003	MAG FIELD MAPPER	17	30	3	24
SEP004	PASS MICROWAVE RAD	22	29	5	22
SEP005	LARGE FORMAT CAMERA	24	30	6	26
SEP006	IMAGE SPECTROMETER	20	29	5	22
SEP007	LUMINESCENCE DET	18	32	4	20
SEP008	LASER RANGING	17	33	4	24
SEP009	LANDSAT D-D'	21	27	6	24
SEP010	RADAR ALT	20	30	4	23
SEP011	ACT FLUOR SPECT	17	27	3	19
SEP012	PLAN SPECT TELE	21	25	4	21
SEP013	IR SPECT	20	27	4	21
SEP014	FAR IR SPECT	20	25	4	20
SEP015	EXTRA SS DET	20	26	4	19
SEP016	PLANETARY PROC LAB	21	24	3	18
SLS001	PRIMATE EXP FAC	22	26	4	25
SLS002	PLANT BIO/LS FACIL	23	27	5	23
SLS003	RODENT EXP FACIL	23	26	4	25
SLS004	ORB QUARANTINE	16	26	3	20
SLS005	EXP MED TREAT FAC	18	27	3	23
SLS006	HUMAN EXP FAC	24	28	4	27
SMP001	MATERIALS PROC LAB	26	22	7	25
SMP002	MATERIALS EXP CARR	25	23	7	25
SMP003	MATERIALS EXP ASS	23	27	7	24
SMP004	WAKE SHIELD EXP	16	33	3	24
SMP005	ULTRAVACUUM FAC	18	31	3	24
	Technology				
TFM001	LASER COMM&TRACK DEV	14	28	4	23
TGN001	LSS CONTR EXP	18	28	4	24
TGN002	ZERO G ANT RANGE	21	25	5	25
TGN003	MATERIALS&COAT TECH	15	32	4	26
TGN004	TETHER DYNAMICS	18	31	4	24
TGN005	LRG STRUCT CONSTR	21	23	5	24
TGN006	FLUID STORE&MANAG	17	28	4	24
TGN007	LIQUID DROPLET RAD	15	32	4	23
TGN008	ECLS WATER REC	14	33	5	25
TGN009	ELCS OXY REC	18	29	5	22
TOP001	SATELL SERV TECH	19	26	5	25
TOP002	OTV SERVICE TECH	18	26	5	23
TOP003	CREW/MANIP CONT	18	29	4	23
TOP004	MAN ROLE EVAL	22	30	5	26

Another statistic which was computed for the mission set was the Pearson product moment coefficient of correlation for each of the four grouped factors with one another. A matrix listing of these statistics is as follows:

	F_1	F_2	F_3	F_4
F_1 - Benefits	1.00	-0.536	0.576	0.296
F_2 - Savings	-0.536	1.00	-0.572	0.023
F_3 - Constituency	0.576	-0.572	1.00	0.462
F_4 - Risk (confidence)	0.296	0.023	0.462	1.00

A study of the correlation matrix shows that the benefits factor (F_1) and the constituencies factor (F_2) have a relatively small (0.576) yet positive correlation with each other while the savings (F_2) and risk (F_3) factors are negative (-0.536) and quite small (0.296), respectively. From this observation, adding to the consideration of the fact that the correlations of the savings factor (F_2) were either negative with the benefits factor (-0.536) and the constituency factor (-0.572) or very low with the risk factor (0.023), two additional and combined factors were formed by multiplying two factors together which on the basis of the correlations statistics, would seem to belong together. Multiplying the benefits factor (F_1) and the constituency factor (F_3) together formed a new and composite factor labeled BENCONS. Similarly, the savings factor and the risk factor were combined forming a factor labeled COSTRISK. These two composite factors were to prove useful in ordering and ranking the missions according to certain of their statistical analyzed assessment factors.

3.2 MISSION COMPARISONS, ORDERINGS, AND RATINGS

Prior discussion has been on the statistical methods employed to reduce the raters' scores for each factor for each of the missions of the mission set. A recapitulation of that process, including numerical ordering of the missions by selected statistical factors, is shown in Figure 3-1. The figure shows at (1) in the upper left-hand corner that the missions were sorted in order of increasing value of the two combined assessment factors BENCONS and SAVERISK. The mission distribution of these two factors is shown in Figure 3-2. As mentioned each parameter is scaled such that increasing value is up and to the right thus the highest value missions are located there. The

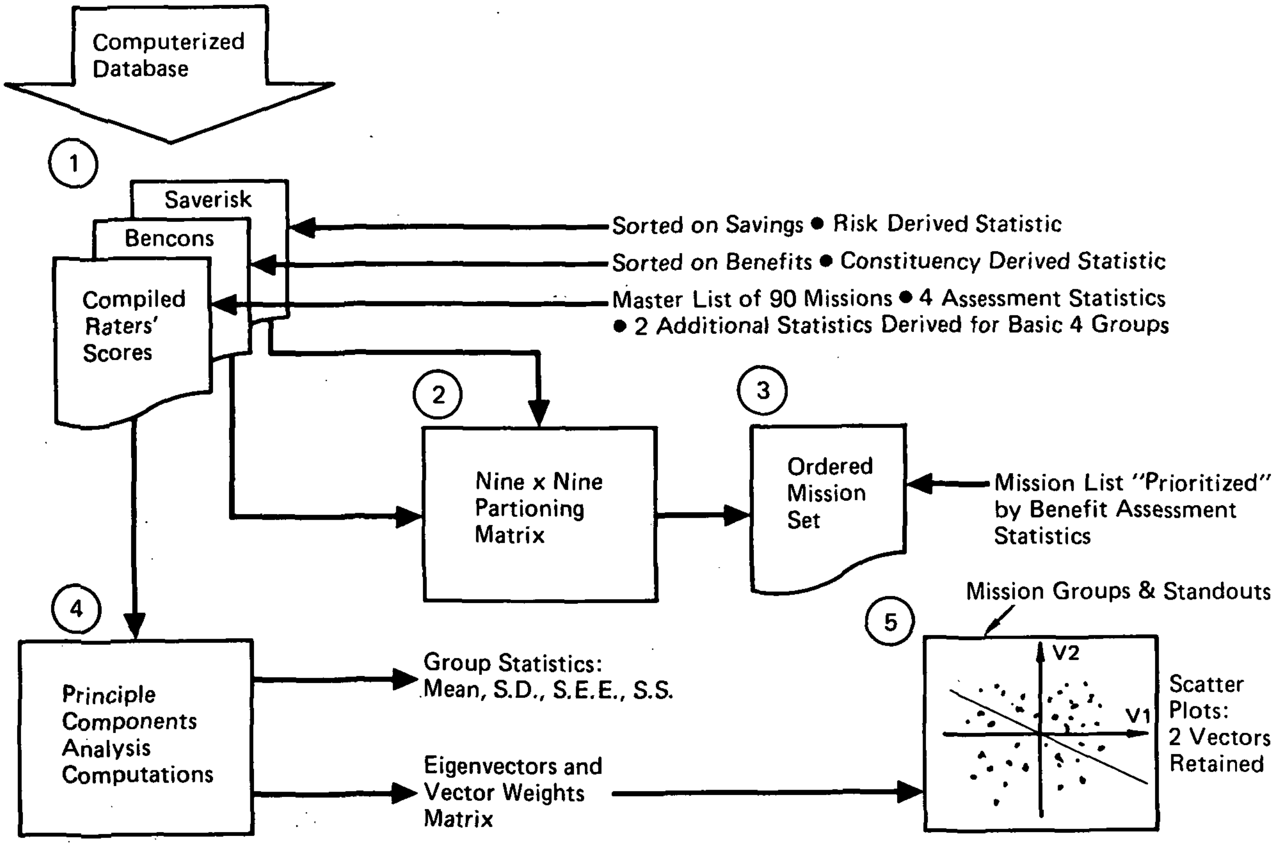

Figure 3-1. Manipulation of Computerized Database

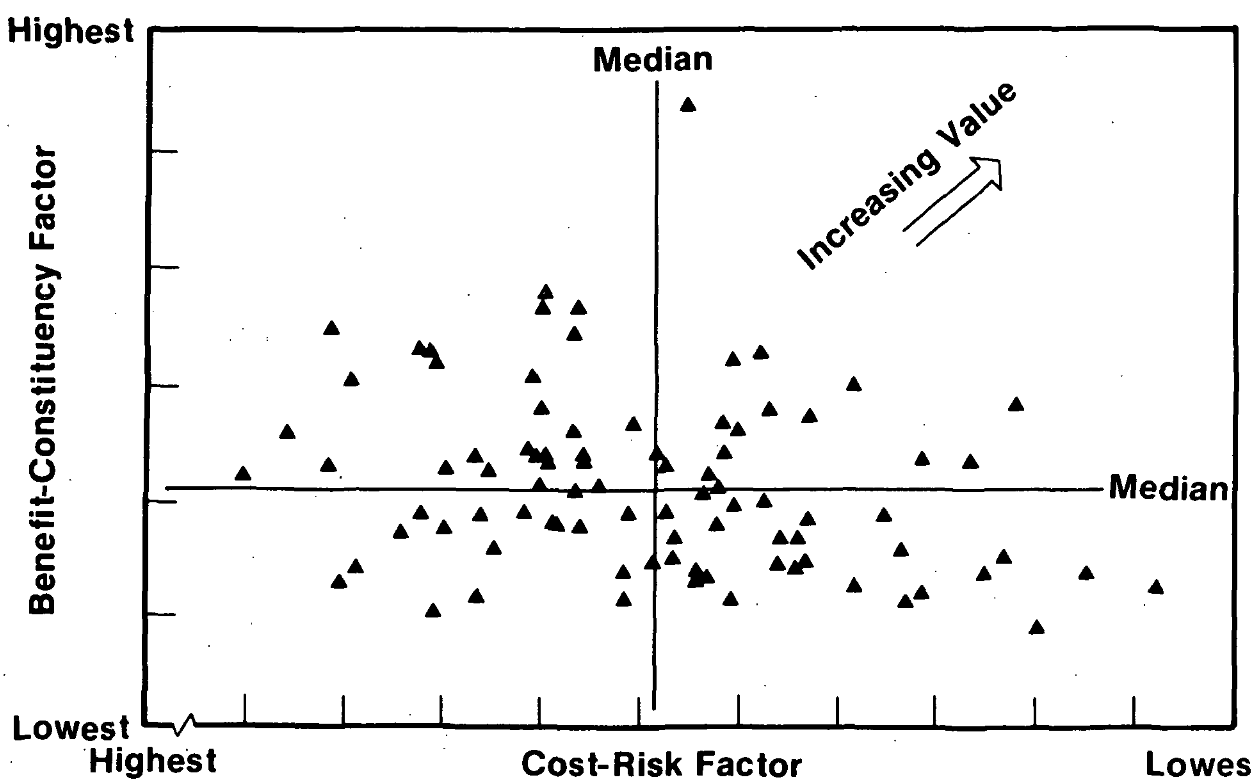

Figure 3-2. Mission Value Distribution

distribtion is seen to be slightly correlated, the correlation coefficient between the factors is calculated as -0.24. This low value suggests a common variance of only 6%, thus both factors would be meaningfully used in mission prioritization. Since there were 90 missions in the set, it was convenient to portion the list in "ninth-file" groups of ten missions each. These groups were then cross-plotted; the BENCONS groups versus the SAVERISK groups as shown at (2) in the figure. The resultant portioning matrix is shown as Figure 3-3.

The matrix is portioned into nine rows and nine columns. The columns of the matrix, from left to right, represent increasing scores as shown by the BENCONS factor, each of the nine columns, as numbers across the top of the matrix, containing 10 missions. Similarly, the nine rows of the matrix represent the SAVERISK assessment factor grouping in ascending order reading bottom to top.

The nine-by-nine portioning of the matrix in 81 cells is shown in Figure 3-3. In the upper right cell, labeled "18" would be found the missions constituting those missions which ranked in the highest ninth-file of both portioned factors. The lower left-hand cell, labeled "2", would represent those missions ranked in the lowest ninth-file for both factors. All the other cells of the matrix are identified by a label that is merely the sum of the ordered ninth-file numbers at any particular intersection. Table 3-2 lists the missions by their identifying codes which appear in the various cells of the matrix. This listing corresponds to (3) on Figure 3-1. For the set of 90 missions taken as a whole, the group statistics were computed and a principal components solution of the mission set computed as shown in (4) in Figure 3-1. The results of these computations, some of which appear in Section 3.1, are presented in Table 3-3.

By way of introduction to the principal components analysis, which is also shown as Factor Analysis, this multivariate technique examines the intercorrelations within a set of variables to determine whether the variance might be adequately explained by a smaller number of factors*. For our treatment in the study, each of the 90 missions was considered an "observation" with the values of four variables for the case in point

*Harman, Harry H., Modern Factor Analysis, University of Chicago Free Press, 1960.

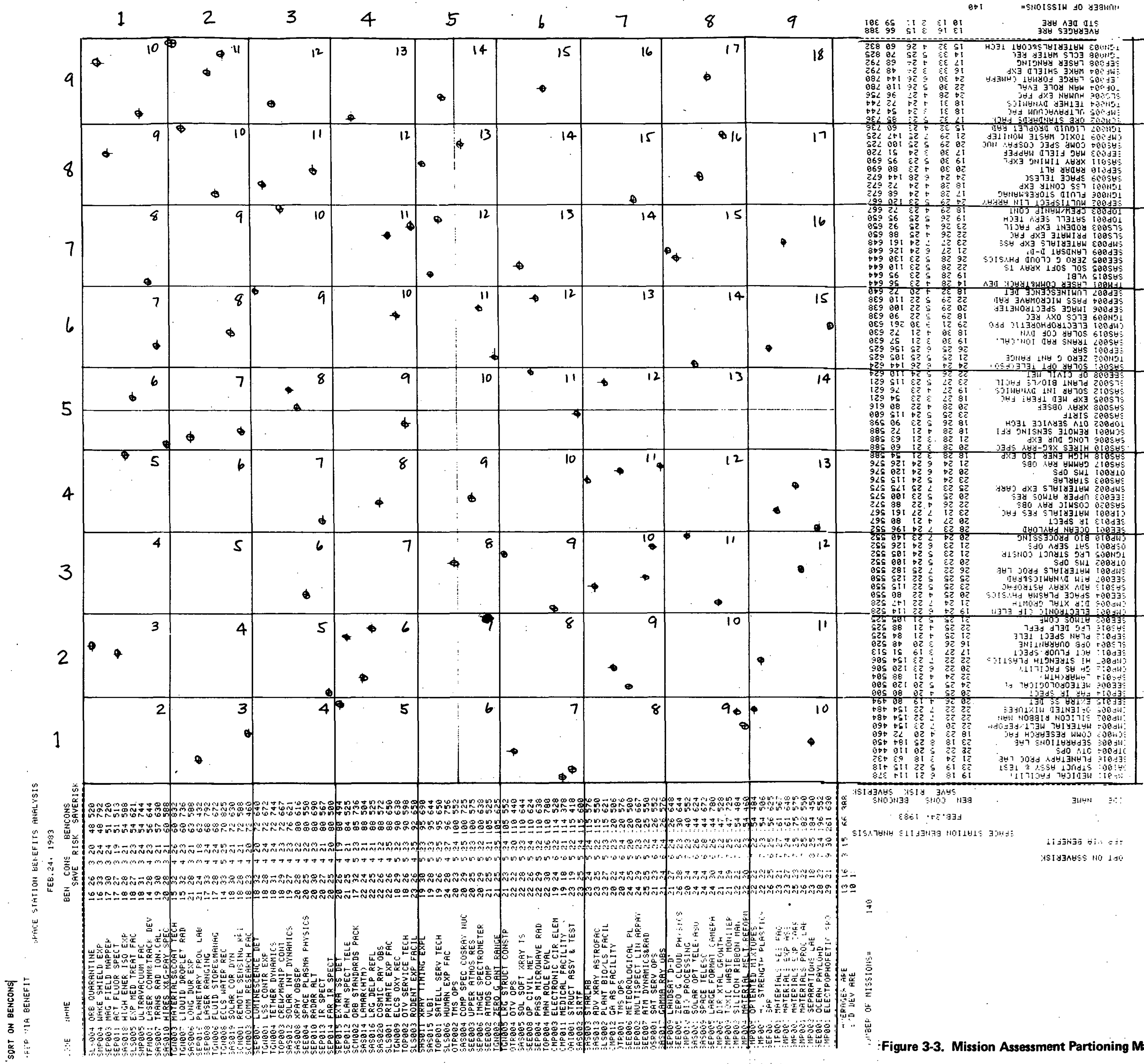

Figure 3-3. Mission Assessment Partioning Matrix

Table 3-2. Mission Partitioning Matrix Scores

N-Tile Number	Mission I.D. Code	N-Tile Number	Mission I.D. Code	N-Tile Number	Mission I.D. Code
18	None	13	SAS011	11	SAS017
17	SEP005		SCM002		SEE008
16	CMP009		SEE001		SEP006
	SAS009		SMP002		SEP008
	SMP003	12	SAS015		SEP010
15	CMP001		SEP004		SLS001
	SEE005		SLS002		SLS003
	SEP001		SMP001		TGN001
	SEP002		TGN004		TGN002
	SEP009		TOP001		TGN003
	TOP004	11	CMP006		TGN008
14	SAS001		CMP007	10	CMP005
	SLS006		CMP010		CMP008
13	CIR001		OTR001		OSR001
	SAS004		SAS002		SAS013
	SAS005		SAS003		SEE007
10	SMP004	8	OTR002	6	SAS014
	SMP005		SAS008		SAS016
	TGN006		SAS012		SEE004
	TGN009		SAS019		SEP012
	TOP003		SAS020		SLS005
9	CMP002		SEP003	5	SAS018
	CMP003		TFM001		SEP014
	CMP004	7	CMP011		SEP015
	CMP012		OA1001	4	None
	SEE003		OTR004	3	SCM003
	SEE006		SAS006		SEP011
	SEP007		SAS007		SEP016
	TGN005		SCM001		SLS004
	TOP002		SEE002	2	None
			SEP013		
		6	SAS010		

represented the benefits, savings, constituency, and risk group statistics computed for each mission as previously described. The elementary statistics for each of the four variables are listed in Table 3-3. The correlation matrix also listed in the table represents the Pearson product moment coefficient of correlation calculation of the four variables among themselves. The correlation matrix transformed into the characteristics polynomial of the matrix and these equations solved for their latent roots (eigenvalues) and latent vectors (eigenvectors). The eigenvalues are listed

Table 3-3. Mission Set Group Statistics and Principle Components Solution

Elementary Statistics

Variable	Mean	Std Dev	Std Err	
1	20.63	2.92	.30	Benefits
2	26.24	3.40	.36	Savings
3	4.933	1.31	.1	Constituencies
4	23.08	2.40	.21	Risk

Variable	Max	Min	Range
1	29.00	14.00	15.00
2	33.00	18.00	15.00
3	9.000	3.000	6.00
4	30.00	18.00	12.00

Correlation Matrix

1.00	−.536	.575	.295
−.536	1.00	−.571	.0230
.575	−.571	1.00	.461
.295	.0230	.461	1.00

Vector	Eigenvalue	Cumulative Proportions of Eigenvalues
1	2.273	5.68
2	1.032	.826 ← Threshold Selected
3	.4424	.937
4	.2510	.999

Vector Weights Matrix

1	2	
.828	−.099	Benefits
−.738	.567	Savings
.888	.093	Constituencies
.501	.831	Risk

Percentages

.687	.0992
.545	.322
.789	.0087
.252	.692

Inverse of Vector Weights Matrix

1	2	3	4
.364	−.324	.390	.221
−.0955	.549	.0905	.805

in the table along with the vector weighting coefficients for each of the four variables.

When the individual values of the four mission assessment variables are multiplied by the vector weighting coefficients and then summed, a number is produced for each vector corresponding to the transformation from the real matrix values to the characteristic equations of the matrix. Since about 83% of the variance can be accounted for in using the first two eigenvectors, the characteristics of the mission set can be described in only these two vectors. The vector scores for each mission are depicted in the scatter plot shown in Figures 3-2 and 3-3 [labeled (5) on Figure 3-1].

Returning to the vector weights matrix listed in Table 3-3, it is seen that the first vector displays high weights in the benefits and constituencies variables 1 and 3, a relatively large but negative weight in the savings variable 2, and a modest weight in the risk variable. The second vector, on the other hand, shows low weights in variables 1 and 3 and modest to high weights in the other variables of savings and risk. Since higher relative scores in benefits and constituencies would suggest keener interest in a particular mission, and since higher scores in saving and risk (recalling that larger values of the risk parameter corresponds to higher confidence in the programmatics of the mission) would suggest higher confidence and savings potential of a selected mission, then the vectors can be thought as representing the "Appeal" of the mission in the first case and the "Economy" of the mission in the second. The axes of the vectors in Figure 3-4 have been so labeled.

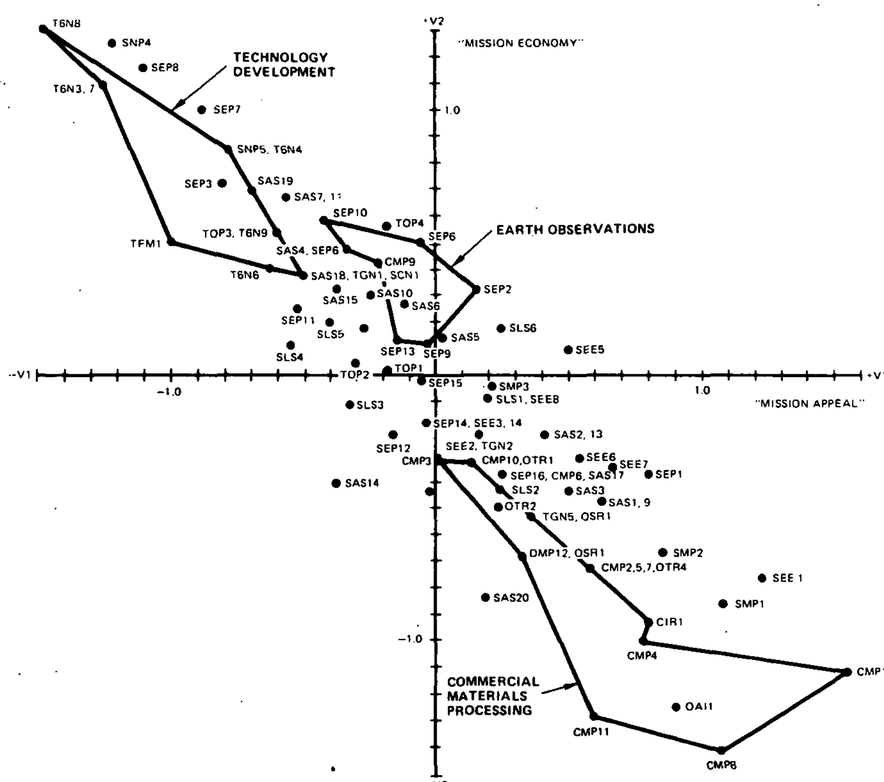

Figure 3-4.

3.3 MISSION PRIORITY GROUPS

All the missions in the data base were allocated into priority groups based upon their matrix scores of Table 3-2 and augmented by later added factors. These factors included recently received NASA planning documents, NASA criteria (Science and Applications) of the relative benefit scores, mission predecessor-successor relationships (i.e., some missions are necessary precursors to others), and legacy missions from prior programs. These factors were incorporated by adjusting the relative mission scores or priority positions. The resulting four mission priority groups are shown in Figure 3-5. It should be noted that the intent of these priority groups is to provide a systematic mechanism for sequentially imposing increased requirement on the space station architecture until the architecture size or the budget required exceeds the availability. In so doing the most promising, highest value missions (Priority Group 1) were first accommodated followed sequentially by the other groups (Priority Group 2, etc.). These relative mission values or priorities were thus determined as a mechanism for determining Space Station architecture rather than as a means to promote one mission over the other. The culling process used throughout the study (i.e., from 100's of missions down to these 88) resulted in a viable set that are all valuable missions for a Space Station. The Space Station architecture was constructed to be responsive to the needs of all the missions but not sized for their simultaneous accommodation.

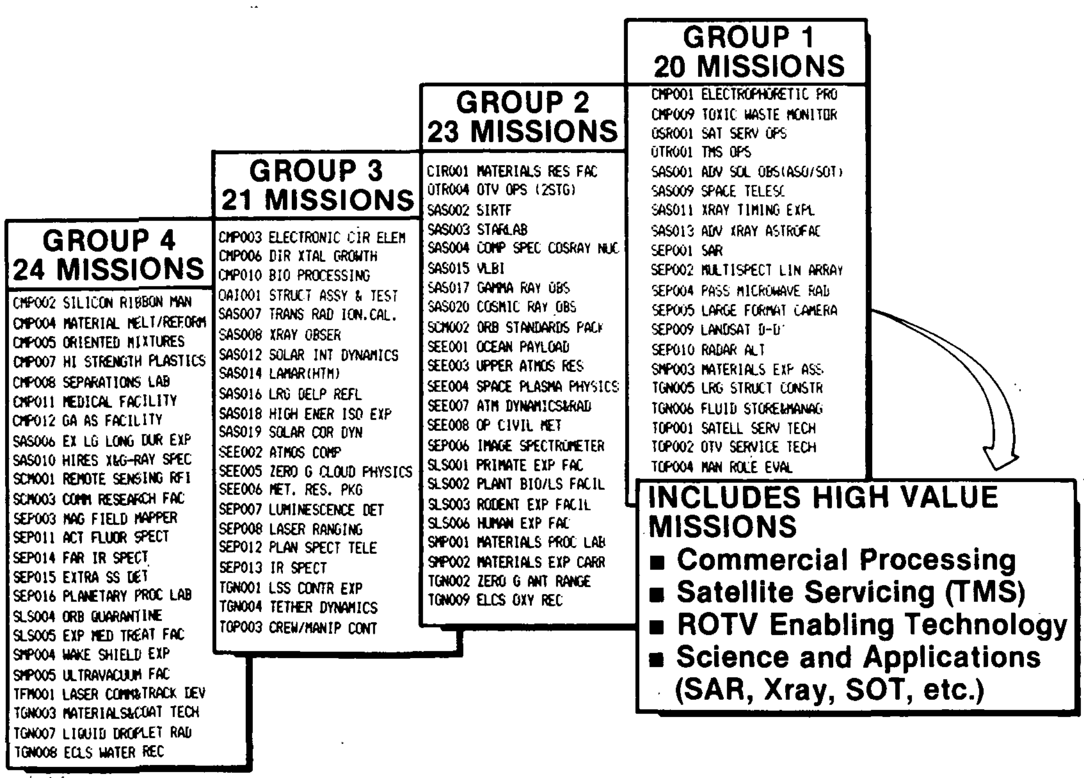

Figure 3-5. Prioritized Mission Model

Economy and architecture capabilities limited a typical program to accommodate by 1997 all of the Priority Group 1 missions, all but 2 of Group 2, all of Group 3, and 5 of the 24 in Group 4. Those remaining would be accommodated after 1997 or by increasing the capacity of the Space Station and the size of the available budget.

It should be noted that all the mission categories are represented in all four of the priority groups.

Section 4
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Those activities that determined the relative benefits attributable to the Space Station mission set have proven successful in ordering the mission set against a given criterion. For the set studied, the criteria have been directed at (1) benefits associated with the achievement of the mission goals and objectives, (2) savings in terms of mission equipment and support requirements, (3) constituencies in terms of sources of support and interest in the missions, and (4) risk factors which are a measure of the confidence in the development of the mission payloads and executing the mission and effective return of useful results. Analysis of the factors concerned by the experts whose judgment was the basis of quantifying the assessments has been able to reduce the data to the point where two discriminants have been defined which classify each mission in accordance with attributes which describe the missions "appeal" and the missions "economy." In this process, the missions are found to cluster into "constellations" exhibiting similar attributes.

The benefits analysis has proven a useful frame of reference from which auxiliary studies can readily be executed. These studies, although hardly examined and certainly not exhaustively pursued, have included sensitivities, searches for gaps and go-backs if biases seem evident. In this respect, this type of mechanized analysis involving methodical pursuit of expert opinion should be pursued in the future. This is particularly germane if the mission definitions are changed or altered by means of added detail and description.

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