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REMOTE SENSING OF EARTH RESOURCES USING MANNED SPACECRAFT

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I. Summary - Manned Earth Resource Programs

Many NASA and industry-sponsored studies during the past several years have concluded that both synoptic and continuous remote sensing of the earth environment from orbital spacecraft offer unique advantages over similar aircraft sensor configurations. Wider earth resource coverage, extended duration capability, repeated orbital traces over ground-truth sites are some of the more apparent advantages. Still, the problem of data management and experiment programming,specifically data taking and on-line data evaluation,are significantly large and yet unresolved.

One of the more promising techniques for providing timely and expert data management, as well as having the benefit of human visual surveillance and target-of-opportunity selection from orbit, involves the use of manned spacecraft. A crew observer/experimenter with appropriate optical aids and sensor displays may play the dual role of systems manager as well as experimenter/evaluator. Of course, duties such as sensor aiming, preparation, replenishment, retrieval, maintenance and data transmission are adjuncts to the primary experimenter activities which make the approach even more attractive.

This manned experimentation role has been extensively studied at TRW Systems in the context of earth resource orbital missions utilizing Apollo follow-on hardware (AAP) with short and long-term experiment carriers, Manned Orbiting Laboratory (MOL) Vehicles fitted with similar sensor payloads, and extended duration orbital workshops incorporating Saturn launch vehicle spent stages with appropriate man-rated laboratory areas.

One particular program conducted during the past year was an in-house study of an earth resource payload for a MOL-type vehicle. The study objective was to determine the engineering feasibility of incorporating such a payload within the laboratory area of a MOL vehicle. The advantages of this approach are apparent in that the MOL has (or can have) an orbital duration of up to 3 months without logistic resupply providing the capability (depending on orbital inclination and altitude) of repeated coverage of earth several times within this 90-day period.

In this mission, a trained crew observer/experimenter utilizing a telescope, several sensor displays, and on-board photographic processing equipment, would select targets, program sensors, initiate data taking, and manage data transmission for the entire experiment program. Through communication with ground stations, sequences of data taking activities could be modified as a function of prevailing ground weather conditions (as detected by the spacecraft in advance of the target area) or through reports relayed from station to station and to the crew experimenter. Since the return payload would be limited to a few hundred pounds, through on-board photographic processing and transmission via TV link, data may be evaluated on-board or on the ground.

The engineering feasibility of such a program was demonstrated and it was concluded that the presence of man in this mission represented an important asset to an orbital earth resource program.

Although problems associated with man-rating a space station for longer duration earth resource missions are significant, particularly those related to long term weightlessness, there is much current thinking that a combined earth resource, astronomy, meteorology, and space physics program, would meet the needs and data objectives of the scientific community and several government agencies.

II. Mission and Crew Related Factors Precluding Extensive Experimentation During Mercury, Gemini and Apollo Programs

Mission Related Factors

While the Mercury, Gemini, and the first Apollo missions have provided invaluable engineering and operations feedback toward design refinement, man-rating, and, in general, crew capability during manned space missions, orbital experiments oriented toward specific data objectives have been typically relegated to a "secondary objective" category. This has been a function of (a) high crew workloads within a limited mission duration, (b) weight and space limitations precluding other than small cameras, and (c) the need to perform in-orbit checkout and evaluation of basic spacecraft systems while running through spacecraft maneuvering sequences. In short, time, space, weight, and operations requirements have dictated priorities which have precluded extensive experiment operations. Nevertheless, the orbital photography during Gemini missions V, VI, and VII, and Apollo 7 and 8 and the TV transmission during the latter was exceptional; perhaps providing a limited preview of the type and quality of data which might be obtained from orbit.

Safety and Backup Crew Factors

Another important consideration, although not mission related, which tended in the past to limit the extent and scope of experimental work, is the overall crew qualifications level. A distinction must be made here between purely flight qualified personnel and scientific non-flight qualified personnel. Heretofore, the most important principle in determining crew make-up (i.e., whether the crew is composed of flight qualified personnel, flight qualified and scientific personnel or scientific non-flight qualified personnel) was that concerned with both spacecraft reliability, crew workload, and the hazards inherent to the mission. In an Apollo lunar landing mission, for example, a crew of two will be designated to man the Lunar Module, while one crewman remains in an orbiting Command and Service Module. All three crewmen, in this case, will be flight-qualified. In an earth orbital mission, such as an early AAP mission (requiring no EVA), possibly only two crewmen would be flight qualified,with the third having only a rudimentary knowledge of flight control procedures to be used as a last resort (i.e., if the two flight crewmen were incapacitated).

The point that is intended here is that with adequate back-up personnel, it is not necessary for the entire crew to be flight-qualified; thus providing additional latitude for including scientific non-flight qualified personnel for primary "experimenter" roles.

Engineering Objectives and Astronaut Selection Criteria

A third factor, crew selection criteria, applied during the astronaut screening program for Mercury, Gemini, and Apollo, was that these criteria were oriented to the choice of personnel with exceptional flight operational ability, research and experimental pilot backgrounds, and substantial engineering experience in space and aircraft systems design. Clearly, the intent was to provide for expert command decisions through the use of highly trained pilots and perhaps even moreso, to gain the insights and feedback of these pilots for purposes of establishing future design criteria. As such, the process of decision and design was characteristically iterative; flight experience on Mercury and Gemini providing the basis for systems design on Apollo. An analogy may be drawn from the iterative design and decision process described above tothat of the relation of early Apollo flights to later more sophisticated orbiting space station flights. This is, that based upon information on remote sensing, targets-of-opportunity, and on-line evaluation/observation functions derived from these early flights, the on-board sensor equipment, experiment parameters, and crew functions for later flights, will be established. Although objectives for some of these programs have been stated in several recent reports [Ref. 2] in the areas of earth resources, meteorology, and oceanography from space, it is, nevertheless, difficult to ascertain precisely how a scientist-astronaut will accomplish these objectives. Some insight, however, may be gained from NASA's current plans for an earth orbiting space laboratory and selection of this laboratory's potential astronaut personnel.

Scientist/Astronaut Participation in Post Mainline Apollo Missions

Contrasted with the very stringent weight and volume limitations on the Mercury, Gemini, early Apollo missions, and AAP missions, NASA is currently working toward the development of a new generation of orbiting space stations and long mission duration space vehicles. Some of these concepts,envisioning the use of existing Apollo equipment such as spent Saturn IV (SIV), Lunar Module (LM) stages, USAF manned orbiting labs, and empty intermediate Saturn stages orbiting laboratories have been proposed; these offering substantial volume advantages over existing Apollo Command Module (CM) hardware. The implications are that new multi-purpose space vehicles will, in the 1970's through increased scientific payload and logistics capacity, be available for extended duration missions. One of the most important aspects of these programs will be the availability of Scientist/ Astronauts who will perform not as members of the flight crew, but strictly as experimenters/observers in a non-flight operational capacity.

Scientist/Astronaut Selection Program

In this role, the Scientist/Astronaut will perform several real-time observations, experiments, and evaluation functions. Some insight into NASA's plans for these extended missions may be gained from the Astronaut/Scientist selection program objectives material. This selection program calls for "astute and imaginative observers whose observations are accurate and impartial, possessing the ability to quickly identify important factors in a variety of unfamiliar situations and investigate them. From these investigations, he must be able to develop and test tentative hypotheses and recognize significant results." To do these things properly, NASA indicates, the Scientist/ Astronaut must operate at four different cognitive levels:

1. Evaluative - in which he decides upon a course of action.

2. Manipulative - in which he performs manual actions.

3. Sensory - in which he serves as an observer and on-line sensor.

4. Investigative - in which he develops and carries out experiments.

Backgrounds - These Scientist/Astronauts will present backgrounds in a wide variety of scientific, medical and engineering disciplines. The selection process will identify the broad category of experimentation within which each person will function most effectively. Three categories are readily recognized:

1. Science - The fields of science included in the manned space program are astronomy, physics, chemistry, biology, atmospheric science and earth resource sciences.

2. Technology - Areas of technology requiring continuing experimentation including communication, life support, guidance and control, and propulsion.

3. Operations - Experiments in this field include biomedical, behavioral, extravehicular engineering and various other orbital and non-orbital operational considerations.

Applications - A specific area within which such specialties as physics, geophysics, geology, oceanography and biology may be utilized in data collection and experimentation in the earth sciences resource program. This would include experiments in the field of:

1. Agriculture and forestry
2. Geography and cartography
3. Geology and hydrology
4. Oceanography and marine technology

The selection criteria further indicates that, by virtue of the unique combination of a particular scientific discipline and the knowledge and training of an astronaut, the Scientist/Astronaut will represent an unusual and valuable addition to the nation's man-in-space capability, providing a link between ground research and development and space application of methods and equipment for data collection and experimentation. He will also provide a means whereby the optimum combination of man and instruments can be applied to the acquisition and study of terrestrial, natural, and cultural resource data from spacecraft.

Training - To function effectively, it will be necessary for this Scientist/Astronaut to become thoroughly familiar with the particular spacecraft instrumentation as well as the conceptual aspects of each experiment, requiring training sessions with principal investigators. Typical training sessions will involve an exchange of knowledge and ideas that should result in a successful union of spacecraft, investigator, and experiment.[8]

Functions - Two classes of experimenter functions are recognized, related to the operating levels identified earlier. These may be categorized as:

(A) experiment support functions

(B) on-line observer/experimenter functions

The first group is illustrated in Figure 1

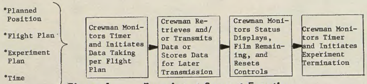


Figure 1 Experiment Support Functions

The crew functions in this group are relatively simple and do not require any special evaluative or interpretive skills but, nevertheless, support the experiment program. In this case, the spacecraft position is determined in inertial-space and the sensors point in a fixed direction. Data taking as required over successive targets is a function of spacecraft position. On-line observer/experimenter functions, however, presuppose several unique crew capabilities; these include the ability to recognize and evaluate target conditions, and the ability to override a planned sequence of activities based upon a target of interest or targets-of-opportunity. Obviously, this requires the utilization of displayed target information and involves substantially more discretionary functions on the part of the observer/experimenter. These are illustrated conceptually in Figure 2.

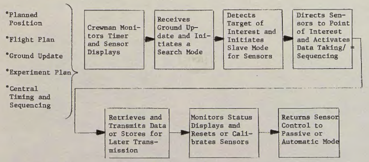


Figure 2 On-Line Observer/Experimenter Functions

The above are characterized by evaluation monitoring and discretionary selection functions which are performed in real-time by the observer/experimenter trained to recognize phenomenon of interest.

How might these observer/experimenter functions serve the objectives of an orbital earth resource sensing program or, more specifically, how might a trained crewman perform functions that would insure the return of timely, valuable, and appropriate, yet limited data? The ensuing material will attempt to answer these questions.

User Agency Data Objectives and Crew Observer Experimenter Functions

In recent years, a substantial case has been made for remote sensing of earth resources [2] using orbital sensing systems. There are many potential advantages to be derived from surveying the entire earth, or major parts of it, using these systems. For sizeable areas within the field of view of the sensors, spacecraft coverage is synoptic and rapid, avoiding the problem of creating and interpreting large scale mosaics. With orbital sensing, coverage can be obtained by uniform types of equipment. Advantages also result from the precise regularity of spacecraft motion and from the lack of vibration. The advantages of remote sensing from space are recognized as: [1]

- Synoptic pictures for sizeable areas
- Acquisition of real-time information
- Repeated coverage to detect changing phenomena
- Reduced data acquisition time
- Freedom from distortion
- Coverage of areas beyond practical range for aircraft
- Global survey without large on-site support requirements
- Possible substantial reductions in costs

A list of User Agency data objectives recently compiled by NASA [4] indicates numerous data objectives in the areas of Agriculture and Forestry, Geography and Cartography, Geology, Hydrology, and Oceanography and Marine Technology. Table 1 lists these broad objectives along with the potential crew activities before, during, and subsequent to, orbital overfly. While without sensory aids, these activities relate to only visually discernible phenomena, as will be seen in Section III; with appropriate displays, observations may be made in other spectral regions. Similarly, with optical and viewing aids, observations may be made of objects of a few meters in size.

The crew observer/experimenter functions, as they relate to these objectives, are summarized in Table 1

Unmanned/Automated vs. Manned Experimentation and Support

While, in a very theoretical sense, many of the sensing functions and resultant data gathering could be accomplished using fully automatic systems not requiring manned intervention, there are many practical reasons why, at this point in time, such a system would be cumbersome and expensive to operate. First, consider the reliability which would have to be built into a system - a 70mm orbital camera system for example - for it to remain operational for several months if the mission objective for this sensor were to have it photograph a large land mass during two successive seasons. Then consider this 70mm film format and the related logistics and replenishment cycle for this camera. Third, consider the factors of command encoding, initiation and termination systems, storage, cryogenics; it becomes apparent that the automatic equipment required to operate a relatively simple camera system creates an almost impractical situation. Compounding the problem of an automatic system further, are problems associated with cloud cover over target areas which would either have to be dealt with through use of a complex ground weather reporting system (in order to initiate automatic commands to not take data), or by running the risk of marginal data return. These situations could, however, be overcome through engineering perfection of the automatic systems design, but possibly at costs disproportionate to the value of the returned data. Multiplying the weights and complexities for the fully automatic operation of several sensor systems operating concurrently, results in an even more unfavorable cost comparison.

There are numerous other reasons for considering manned operation of an orbital earth resource station. A few of the more important ones will be presented here, but these can be succinctly characterized as man's inherent intelligence, discrimination ability, and adaptability. How these inherent abilities may be exploited for an earth resource space mission will be the subject for the remainder of this paper. Before discussing sensor payloads and data objectives, it is appropriate to discuss the two divisions or classes of crew functions in terms of how these functions would support such a mission. These classes were identified as experiment support functions and on-line observer/experimenter functions.

The first group, experiment support functions, consist of such activities as deployment and cryogenic preparation (possibly including EVA for deployment of large arrays, antennas, or booms), initial and interim calibration, boresighting, loading and replenishing film (and other expendable supplies), retrieving film through EVA when applicable, deployment of sensor lens covers, and precision attitude control maneuvering prior to data taking.

The on-line observer/experimenter functions include scanning of potential target areas,using a variety of optical aids, on-line data evaluation and data quality control, on-board photographic processing,possibly using Polaroid film and other processes, voice annotation, and target-of-opportunity selection.

Table 1

USER AGENCY OBJECTIVES	ON-LINE OBSERVER EXPERIMENTER FUNCTIONS
Agriculture and Forestry To determine and define the potential scientific/economic value of performing agricultural and forestry research from space relative to the following: o Detection of disease, drought and fire o Assessment of crop and timberstand vigor and prediction of future yields o Determination of soil characteristics o Recognition and establishment of the relationships among productivity, distributions, and concomitant natural and man-made phenomena.	o Sensor Pointing and Tracking o Distinguishing between tree types, crown diameters, densities, growth patterns. o On-line evaluation of health and crop vigor using IR display techniques. o Qualitative annotation of sensor data. o Correlation with other sensor data for determination of timberline. o Comparison of signature data of known plants with data over unknown areas.
Geography and Cartography To determine and define the potential scientific/economic value of performing geographic/cartographic research from space	o Sensor pointing and tracking-coastlines and city boundaries. o Indexing photography o Population center survey o Qualitative annotation of plant cover o Evaluation of energy-heat balance through use of displayed data.
Geology The study of the dynamic qualities of the Earth's surface and crust with an aim toward developing an ability to predict earthquakes, volcanic eruptions, and toward achieving a better understanding of the forces that deform the Earth's crust.	o Detection and sensor pointing-tracking toward fault lines, earth folds and other topographic features. o Qualitative description of glacial activity and volcanic activity. o Ore deposit detection - location
Hydrology The measurement and distribution of rain and snowfall, runoff and water retention in drainage basins of differing size, topography and geologic environment. Such measurements will include variations of cooling and subsequent heating of Earth after a rainfall.	o On-line sensing for location of ground water discharge. o Flood prediction, warning and damage assessment o Detection and data gathering of erosion damages.
Oceanography & Marine Technology To develop and test new techniques for use of oceanographic spacecraft observations to fill gaps existing in present techniques. To determine which sensor signatures can be quantiatively determine which sensor signatures can be quantiatively detected from orbital altitudes, free of ambiguity and environmental noise. To establish reliability by comparison with ground truth.	o Pointing and tracking of currents and tidal variations. o Ice field location and warning o Shoal napping o Scans and track of fish school location

While the attractiveness of the manned approach derives partly from the myriad of functions in the experiment support area which may be accomplished efficiently by a crewman rather than automatic equipment, by far the major advantages accrue from the on-line observer experiment functions. Although the observer is limited in that, unaided, he can only see objects or phenomena in the visible spectrum, with appropriate optical aids and displays, his capability to function as a sensor is much expanded.

Man's inherent ability to rapidly reprogram his own activities, as well as his onboard programming sequencing equipment, represents another important capability. Provided with the equipment to augment his sensory ability, such as optical aids and sensor displays, the observer/experimenter can perform another group of functions, generically referred to as target-of-opportunity selection functions. These are defined as deviations from the preprogrammed sequence of data taking operations based on the appearance of (a) a rare or unusual ground phenomenon (e.g., forest fire), (b) a sudden break in the cloud cover, (c) an unusual sensor reading, and (d) combinations of a, b, and c. These functions expressed in terms of man's inherent abilities are summarized in Table 1A.

(A) THE ABILITY TO RECOGNIZE AND CATEGORIZE GROUND FEATURES FROM ORBIT BASED UPON STORED MATERIAL, PHOTOGRAPHS, AND PREVIOUS KNOWLEDGE AND INFER FROM THIS INFORMATION THE NATURE AND PROPERTIES OF AN UNKNOWN TARGET AREA.

(B) THE ABILITY TO VISUALLY DISCRIMINATE FROM A TREMENDOUS RANGE OF COLORS AND HUES CHARACTERISTIC OF VEGETATION COLORATIONS.

(C) THE ABILITY TO DISTINGUISH CONTRASTING OBJECTS TO ABOUT .01 OR ONE UNIT IN ONE HUNDRED.

(D) THE ABILITY TO PERCEIVE PATTERNS AMID CLUTTERED VISUAL CONTEXTS

(E) THE ABILITY TO STRUCTURE A PROBLEM BASED ON VERY LIMITED OR INCOMPLETE DATA.

(F) THE ABILITY TO CORRELATE SEVERAL SEEMINGLY UNRELATED DATA POINTS AND MAKE TENTATIVE PREDICTIONS AND CONCLUSIONS BASED ON THESE DATA.

(G) THE ABILITY TO LOCATE AND ACCURATELY TRACK GROUND OBJECTS.

Table 1A Target of Opportunity (Sensing) Functions

Quality control procedures, particularly toward on-board evaluation of photographic quality through initial and interim use of Polaroid camera backs, TV monitors, and on-board film processors would enable quick-look data evaluation and, as well, indicate sensor malfunction (i.e., fogging of lenses) again serving the purpose of film and power conservation.

Pointing and target tracking through a telescope, in conjunction with experiments requiring data from several degrees forward and aft of the nadir, is feasible,providing there is sufficient time to identify a potential target. As will be seen in the next section, even at orbital velocity with adequate lead, a target can be detected and tracked with considerable accuracy. Slaving gimballed sensors to such a telescope would enable off track pointing, based on the appearance of a target-of-opportunity.

Considering the sheer volume of data to be handled during an extended duration mission, its management represents a significant problem. As a result, one of the unique crew capabilities called upon is the selection of data for retention and/or transmission. The source of information on selection is primarily visual, in that most decisions to take data will be based upon either the use of a scanning telescope, video displays of sensor data, or both concurrently. It is, however, possible, although limiting in scope, to provide ground-to-spacecraft voice communication on prevailing weather conditions or other significant factors as they pertain to the target area. One other method of management previously mentioned, was Polaroid photography or a comparable method of on-board photographic development; it was mentioned, however, in the context of quality control. In a similar manner, high resolution photographs taken on board could either be stored, transmitted, or when of poor quality, discarded. With considerable training in target identification and data interpretation, the observer/experimenter could select targets (based on a general flight plan); decide whether or not to take data; commence data taking; select duration, coverage, and sensors to be operated; collect and interpret this data. He defers his decision as to storage or transmission, however, until its quality could be ascertained.

Techniques of tape-film conversion for specific sensor group as they apply to on-board data management will also be discussed in the next section, as will techniques of data transmission.

III. Engineering Feasibility Studies Toward Manned Earth Resource Spacecraft

As noted in the previous section, several studies have been conducted at TRW relating to the definition, design, and integration of earth resource sensor payloads with existing and planned space hardware. Apollo Applications Carriers, MOL, modularized space stations, and integrally launched space stations have each been the subject of in-house studies with sensor payloads for earth resource, oceanology, and meteorology.

Each of these studies posed unique problems specific to the size, weight, power, logistic and orbital duration capability of the hardware, along with common problems of crew integration, partial and zero gravity, data management, and user agency data requirements. The Apollo Applications short-term carrier studies identified several diverse sensors that could be installed aboard a CSM docked to a small sensor carrier for a 14-day earth orbital mission. [11] Volume, power, attitude constraints, field-of-view restrictions, and crew movement perturbations each contributed to limiting the scope and data return potential for such missions. Further studies toward a long-term experiment carrier, separate from the Apollo CSM, (but also docked to it) relieved many of these constraints; however, available experiment volume and return payload, specifically tapes and exposed film, was still essentially limited to the 2-300 pound range.

During the latter part of 1967 and early 1968, several studies emanating from NASA's Marshall, Langley, and Manned Spacecraft Centers, identified plans for utilization of large spent Saturn Stages for compartmentalized and open space laboratories to conduct experiments in the areas of Astronomy, Biology, Earth Sciences, and Meteorology areas. At about the same time, the President's Scientific Advisory Committee (PSAC) Report on the Space Program at the Post Apollo Period [7] identified a potential role for utilization of MOL-type vehicles for NASA missions involving both physiological and psychological studies of man during extended space mission. Regarding the capabilities of such a carrier, the report noted:

> "Available (MOL) volumes would be greater than in the Apollo Spacecraft although substantially smaller than the Uprated Saturn I (second stage), with the opportunity to test man for periods of 30 days or longer in a "shirt-sleeve" environment. Utility of this vehicle for biomedical qualification would depend to some degree on the date at which it might be available for use in detailed biomedical testing. . . the MOL program will be providing basic experience and biomedical data on 30-day flights in 1969-71. Because of the rigorous demands that detailed attention to experimental procedures will place on man's ability to perform and the availability of an adequate pressurized living and working space, MOL could provide useful and timely data in addition to that obtained by NASA, which would be pertinent to qualifying man for planetary flight. . ."
> "...It may be desirable for NASA to acquire MOL vehicles for its use in biomedical qualification, particularly if delivery by 1960 or 1971 can be arranged. This will be the more feasible if NASA were to make a decision soon to acquire MOL vehicles and start the initial funding so that increased production could be arranged in a timely manner. . . . Starting with MOL components, one might consider using the basic Bemini B, two MOL laboratory modules joined together and modified for docking, and a rendezvous of two of these complexes to get the necessary space and crew size . . ."

Based on the identification of the utility of MOL for such extended qualifying studies, the report went on to make several recommendations. Among these recommendations were:

> ". . . Before substantial funds are committed to the AAP plan to modify Apollo hardware or to utilize the orbital workshops for extended periods, a careful study should be made of the suitability, cost and availability of Titan III/MOL systems for biomedical studies of man for periods up to 60 days. . ."

> ". . .Arrangements should be developed between NASA and the USAF to use the MOL program as an important source of data on the capabilities of man for space missions lasting 14 to 30 days, in addition to experience to be gained in early Apollo Applications missions. . ."

With these recommendations as a basis, TRW, in conjunction with another major aerospace company, undertook a cooperative program to determine the engineering and operational feasibility for incorporating an earth resource sensor payload within the manned operational laboratory area of an MOL-type spacecraft, for a 90-day earth orbital mission. [9] The study objectives during this program were:

1. Determination of the sensor instruments and their supporting subsystem requirements for the collection of Earth Resources Data.

2. Design and integration analysis for locating the sensors and supporting equipment in an experiment module.

3. Data management systems engineering to indicate a feasible system and method for data handling.

4. Human factors analysis to determine the scope of crew participation in mission operations.

5. Analysis of orbit parameters and data acquisition, crew time-lines, and definitions of the interfaces between the space vehicle and Earth Resource Sensors.

Space limitations within this paper precludes an exhaustive summary of the engineering analysis and conclusions during this study; however, appropriate detail will be devoted to user (data) requirements, sensor selection rationale, mission analysis, and configuration design.

More importantly though, the crew-mission interface will be emphasized since the approaches taken in areas of sensor selection, support subsystems, and on-board data management derive their feasibility from the manned operations aspects.

Laboratory and Experiment Volume

A Titan III launched extended MOL-type experiment carrier would consist of the basic MOL vehicle and an experiment module as depicted in Figure 3. The aft section of this vehicle is the experiment carrier; approximately 28 feet long and 10 feet in diameter. Part or all of this volume may be pressurized; however, during the program's operations analysis, it was recommended that the entire volume (approximately 2000 cu.ft.) be pressurized in order to provide a habitable shirtsleeve environment for the crew during the periods the station is manned. Within this experiment volume (the experiment module), the crew experiment station and related consoles, sensor equipment, and support subsystems provide a self-contained duty station which may be manned by one crewman (or occasionally two) for several hours at a time. Forward of the experiment module is the crew quarters and mission module. For the purpose of the present discussion, the experiment module only will be considered, bearing in mind that subsystem support for experiment (i.e., guidance and navigation, environmental control, and power) is dependent upon the mission module.

Because there is no provision for artificial gravity, the operating environment will be a zero "g," two gas environment pressurized between 3.5 and 5.0 psi. For the earth resource oriented mission, the entire vehicle would assume a flight path with its longitudinal axis parallel to the ground such that the underside would always face in the direction of the earth. In addition to the experiment volume within the experiment module, potentially two to three hundred pounds of data could be returned within the storage bays of the returning reentry vehicle. This could consist of films, video tapes, data logs and voice tapes. Figure 3 illustrates this conceptual configuration along with a list of subsystems, design groundrules, and payload limitations.

User Data Requirements

Those interested in and qualified to use the data from orbital earth resource are likely to be the earth scientists in research organizations or universities; engineers and economists in government agencies; and planning and operations personnel in commercial organizations. Many governmental and industrial organizations are now using remote sensing techniques to collect earth resource data. Data on earth resources are routinely collected by the U.S. Departments of Defense, Agriculture, Interior, Commerce, and Health, Education, and Welfare. In addition, state and local governments use remotely sensed information to solve problems of urban planning, land use, civil defense, and resources development. Industries concerned with food production, minerals, petroleum, logging, fishing, construction, and real estate today use earth resources data. Eventually, the user list could expand to include, for example, individual farmers and fishermen who would use information on crop status and fish location in much the same manner as they now rely on weather reports. [1]

A partial summary of data objectives in the several earth science disciplines is given in Table 2 . The resources applications for each discipline are expanded in Table 3 and grouped by resolution requirement. Resolution is the key parameter in any analysis of data requirements since it is explicitly tied to factors involving sensor hardware, security classification political implications, sensor design and development, data processing and interpretation, and program costs. Resolution is defined as the earth surface distance that can be determined accurately on a resolvable object at a contrast of 2:1 under actual flight conditions.

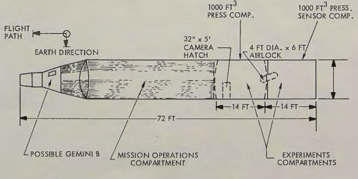


Figure 3

OTHER PERTINENT PAYLOAD LIMITATIONS AND GROUND RULES ARE:

- WEIGHT - 7000 LB MAX
- CREW SIZE - 2 MEN
- LAUNCH DATE - CIRCA 1972 FROM ETR BY TITAN 3M
- MISSION DURATION - 90 DAYS WITH NO INTERMEDIATE RESUPPLY
- INCLINATION
- ALTITUDE - 200 N.M.

EXPERIMENT COMPARTMENT

- EARTH RESOURCE EXPERIMENT SENSORS
- SENSOR SUPPORT EQUIPMENT
- SPARE PARTS, FILM, TAPE
- DATA HANDLING EQUIPMENT
- EXPERIMENT CONTROL CONSOLES
- OPTICAL SUBSYSTEMS
- COMMUNICATION EQUIPMENT SPECIFICATION TO THE MISSION

AGRICULTURE/FORESTRY

APPLICATION	TYPE OF DATA REQUIRED	DATA USE
AGRICULTURE	INVENTORY AND DISTRIBUTION	FARM/FOREST INTERFACES BOUNDARIES TOPOGRAPHIC MAPS CROP TYPE AND DENSITY CROP EXPECTED YIELD LIVESTOCK CENSUS
	INFESTATION	DISEASE DAMAGE INSECT DAMAGE INFESTATION PATTERNS
	LAND USE	SOIL TEXTURE SOIL MOISTURE AND IRRIGATION REQUIREMENTS SOIL QUALITY TO SUPPORT VEGETATION FARM PLANNING
FORESTRY	INVENTORY AND DISTRIBUTION	FOREST TEXTURE BOUNDARIES TOPOGRAPHIC MAPS TREE TYPES AND COUNT LOGGING YIELD AND PRODUCTION LOCATION OF TREE TYPES
	FIRE, DISEASE, AND RECLAMATION	FIRE LOCATION AND DAMAGE PATTERN AND DISCONTINUITY SOIL MOISTURE AND TEXTURE INSECT AND DISEASE DAMAGE

GEOGRAPHY

APPLICATION	TYPE OF DATA REQUIRED	DATA USE
TRANSPORTATION	IDENTIFY FEATURES	LOCATE TERMINALS, BUILDINGS LOCATE ROADS, TRACKS TRAFFIC COUNT
	LOCATE NEW FACILITIES	MAKE MAPS AT SCALES OF: 1:25,000 to 1:250,000 CULTURAL FACTORS ECONOMIC FACTORS
NAVIGATION	TOPOGRAPHY	MAKE MAPS AT SCALES OF: 1:100,000 to 1:250,000
URBAN PLANNING	LOCATE SETTLEMENTS	BOUNDARY AND TOPOGRAPHY
	TYPE OF SETTLEMENTS	COLOR, TEXTURE, CONTRAST
	DISTRIBUTION OF SETTLEMENTS	PATTERN OF HOUSING DENSITY
	OCCURANCE OF RECREATION AREAS	COLOR, TEXTURE, SHAPE
	POPULATION DISTRIBUTION	POPULATION COUNT
	CLASSIFICATION OF FACILITIES	INDUSTRIAL PLANNING 1:50,000 SCALE MAPS CULTURAL/ECONOMIC FACTORS LAND USE INTENSITY SPECTRAL SIGNATURES HEAT BUDGETS

HYDROLOGY

APPLICATION	TYPE OF DATA REQUIRED	DATA USE
WATER INVENTORY	WATER INFLOW INTO BASINS, RIVERS, AND STREAMS	RIVER EFFLUENTS RESERVOIR LEVELS DRAINAGE BASIN FEATURES GROUND WATER SURVEYS IRRIGATION ROUTES
FLOOD CONTROL	EXCESS SURFACE WATER	FLOOD LOCATION DAMAGE ASSESSMENT RAINFALL MONITOR EROSION PATTERNS
WATER POLLUTION	NATURAL AND INDUSTRIAL POLLUTION	COLOR SPECTRAL SIGNATURE POLLUTION CONTENT SALT CONTENT
WATER CONSERVATION	EVAPORATION AND TRANSPIRATION	EVAPOTRANSPIRATION
WATER RESOURCES	SEEPS AND SPRINGS	TEMPERATURE VARIATION WATER QUALITY
	GLACIOLOGY	FROZEN WATER INVENTORY SNOW SURVEYS

OCEANOGRAPHY

APPLICATION	TYPE OF DATA REQUIRED	DATA USE
SHIPPING	SEA STATE	WAVE HEIGHT
	CURRENTS	SURFACE TEMPERATURE TEMPERATURE GRADIENTS WATER COLOR
	HAZARDS, ICEBERGS, AND ICE MASSES	TEMPERATURE ANOMALIES WATER/ICE INTERFACE
SEA FOOD PRODUCTION	UPWELLING	SURFACE TEMPERATURE GRADIENT
	CURRENTS AND EDDIES	WATER TEMPERATURE GRADIENT WATER COLOR
	BOTTOM TOPOGRAPHY	WAVE REFRACTION AND COLOR TONES
	OIL SLICKS	VAPOR SIGNATURE
COASTAL GEOGRAPHY	SHORELINE TOPOGRAPHY	LAND/WATER INTERFACE COLOR TONES AND CONTRAST
	WATER EFFLUENTS AND SEDIMENT TRANSPORT	WATER COLOR TONE
	SEA LEVELS AND SLOPES	SURFACE ELEVATION
MARINE BIOLOGY	BIOLUMINESCENCE	COLOR TONES
	RED TIDES	COLOR TONES
	PLANKTON	COLOR TONES
	SCHOOLS OF FISH AND ALGAE	COLOR TONES

GEOLOGY

APPLICATION	TYPE OF DATA REQUIRED	DATA USE
PETROLEUM AND MINERALS DETECTION	SURFACE AND SUBSURFACE PATTERNS	LITHOLOGY STUDIES OUTCROP PLOT MAGNETIC FIELDS EARTH FOLDS DRAINAGE PATTERNS SOIL COMPACTING AND STABILITY SOIL DENSITY SURFACE STRATIFICATION AND ELECTRICAL CONDUCTIVITY
VOLCANO PREDICTION	SURFACE FEATURE CHANGES	TEMPERATURE VARIATION LITHOLOGIC IDENTIFICATION SPATIAL RELATIONS
EARTHQUAKE PREDICTION	SURFACE STRESS AND DISCONTINUITIES	LINEAR MICROTEMPERATURE ANOMALIES SLOPE DISTRIBUTION CRUST ANOMALIES SOIL MOISTURE
ENGINEERING GEOLOGY	GEOTHERMAL POWER SOURCES	TEMPERATURE ANOMALIES SURFACE GAS
	LANDSLIDE PREDICTION	SOIL MOISTURE SLOPE DISTRIBUTION CRUST ANOMALIES

Table 2   Earth Resource Data Objectives

Spatial Resolution	Agriculture/ Forestry	Geography	Geology	Hydrology	Oceanography
2 to 20 Meters	Timber-, water- and snowline studies Grass, brush, and timberland interfaces Vegetation density Tree count Tree crown diameter Crop species Crop acreage Irrigation studies Small fields (10 acres or less) Livestock census Infestation surveys Soil texture	Population and cultural studies Fishing boat activities Land use studies Topographic mapping 1:250,000 and larger scales Plant cover and soils Forest types Thematic mapping Urban development survey Classification of facilities	Delineation of small folds, small linear elements and stratigraphic sequences Lithologic units Soil compaction Slope stability Permeability studies Ore deposits Local geothermal anomalies Tectonic studies Glaciological studies (local)	Groundwater discharge Subaqueous features of lakes Detection of water pollution, inland areas (rivers, lakes, bays) Effluents of major rivers Monitoring lake and reservoir levels Evapotranspiration Water surface roughness Rainfall Salt content Drainage basins Water regimens of valley glaciers Snow surveys Reservoir sedimentation	Ice surveillance Snow/ice and ice/water interface studies Wave profile Shoals and coastal mapping (bottom topography) Currents (long shore) Coastal marine processes (tidal variations) Estuarine and shoreline morphology Sea level and sea slope Sea mammals detection Navigation hazard survey Glacier location
20 to 100 Meters	Timber- and snowline studies Fields of larger sizes, 10 acres or more Soil temperature Detection of forest fires Farm planning	Water resources Gross cultural studies Geomorphology studies Gross land use studies Topographic mapping, scales smaller than 1:250,000 Pollution (air, land, water) Thematic mapping Transportation studies	Delineation of folds and linear elements Soil compaction Slope stability Gross geothermal studies Geomorphic studies Glaciological studies Mineral belts Permafrost Earthquake damage surveys	Evapotranspiration Water surface roughness Rainfall Salt content Drainage basins Water regimens of valley glaciers Snow surveying Reservoir sedimentation Ground water surveys	Sea surface thermal mapping Cold region thermal structure Fresh/salt water interface Water pollution, large areas, oceanic, harbor areas Ocean waves Currents (offshore) Biological studies (fish) and other populations) Wave refraction studies Volcanic activity
100 to 300 Meters	Timber-, snow- and desertline studies Fields of gross sizes (rangelands, etc.) World timber inventory	Land use studies Thematic mapping Global population	Delineation of large folds and linear elements Lithologic units Geothermal studies Volcanic studies Metallogenic provinces Inventory of ice features	Evapotranspiration Water surface roughness Rainfall Monitoring lake and reservoir levels	Currents (offshore) Water masses upwelling areas Fish location Ocean mapping
Greater Than 300 Meters	Soil moisture World gross crop inventory	Cloud studies Land use studies Thematic mapping of regions and continents	Delineation of large folds and faults Slope stability Gross and local geothermal studies Internal magnetism Metallogenic provinces Gravity gradients Isostasy Continental drift	Evapotranspiration Rainfall Snow surveys	Sea state Delineation of pack and cap ice margins Sea water color analysis

Table 3 Resource Applications Grouped by Data Requirements

Sensor Selection Rationale

Selection of sensors for this mission was predicated in large part upon user requirements and strongly influenced by the fact that a trained crewman would be available for activities such as target selection, sensor aiming, and photographic interpretation during a substantial portion of each day. In addition to the availability of a crewman for selection and aiming, the data management functions (i.e., on-board photographic processing and transmission) allow for considerable flexibility in the choice of sensor configuration. Three classes of sensors were identified in terms of their development status: Operational sensors - those that have been tested during aircraft programs for which considerable flight data is available. These are presently "aerial hardware" and are well on their way to being qualified for space applications. Aerial cameras are of this class. The function of this class of sensor would be to gather operational data. Development sensors - those that are less well developed and with which little flight experience is available. While some of these have been flown during aircraft programs, there are still many engineering and operational problems associated with their use before a space qualified instrument is available. For this reason, manned support activities, particularly malfunction isolation, repair, and spares installation, lend themselves well to the use of these instruments. The function of this class of sensor is twofold; to gather operational data and act as a test bed for subsequent refinement on their design. Experimental sensors - those sensors whose development is little beyond the prototype stage. The purpose for the inclusion of these is primarily for research and development.

A further criterion for sensor selection is the degree of astronaut participation and station attitude control which is required. For example, there are three basic types of IR sensors: fixed field of view, area scanners, and point trackers. The fixed field of view is normally a radiometer with its receiving optics fixed to the spacecraft; this sensor looks directly down with a fixed field of view sweeping out a strip parallel to the ground track of the spacecraft. The function of the crew experimenter is that of pilot only. Once he has activated the instrument, his sole responsibility is to maintain attitude so that it follows along the proper ground track with an appropriate one nautical mile resolution.

The area scanner has a small ground path size and achieves area coverage by mechanically scanning across the ground track. The pilot requirements are less pronounced since precision is achieved by a small, instantaneous field of view rather than tight attitude control with area coverage provided by the scanning.

The point tracker, on the other hand, utilizes the astronaut almost exclusively as an experimenter. The requirement for operation of this instrument is to acquire a point on the surface, evaluate its properties, and track it as the spacecraft passes by. Spacecraft motions are less important because the point of interest is tracked by the astronaut using the sensor itself. Implementation of such techniques,using a telescope and sleeved sensor method,will be discussed in the next section. Table 4. lists the sensors, their field of view, and their observable information. A viewing telescope is also included, although not strictly a sensor; its function will become clear in the Support Systems Section.

Table 4 Sensors, Field of View and Observable Information

SENSOR	OBSERVABLE	TOTAL FOV
METRIC CAMERAS (2)	REFLECTED VISIBLE SOLAR	36° x 36° 238 KM SQ.
INFRARED SCANNER	REFLECTED INFRARED SOLAR	36° SWATH 238 KM
	INFRARED SELF EMISSION	
MICROWAVE SCANNER	MICROWAVE SELV EMISSION	36° SWATH 238 KM
INFRARED SPECTROMETER	INFRARED SELF EMISSION	3° 19 KM
LASER ALTIMETER	LOCAL ALTITUDE OF SPACECRAFT	0.006° 37 M
DAY/NIGHT CAMERA	SURFACE PANORAMA AND WEATHER	104° 945 KM
VIEWING TELESCOPE	SURFACE PANORAMA AND WEATHER	60° 388 KM
TELESCOPE CAMERA	SURFACE DETAIL	26° 171 KM
INDEX CAMERAS (2)	LOCATION ON EARTH SURFACE	± 70°

Cameras and Films - The required image resolution was derived from user requirements to be about 100 feet per photographic line (50 feet per TV line) for the mapping function. There are available high-definition panchromatic films which would provide this resolution on a 70-mm format (e.g., Kodak 3404), but at the cost of film speed. Unfortunately, the need for high resolution is found in the same areas which require sensitivity in the optical infrared, forcing the conclusion that no commercially available film with the high definition desired can provide the necessary spectral response. Although the saving in return weight of the film would be of the order of a factor of ten, the high-definition material is considered to be a poor choice for this application. A further complication avoided by the use of moderate resolution stems from the absence of a requirement for image motion compensation (IMC).

Films with sensitivity extending into the optical infrared are available, and extensive use has been made of them in studies of vegetation. Except for some types of oceanographic investigation, they seem preferable for all Earth Resource studies to the films sensitive only to the visible spectrum. In either case, the exclusive use of color film for return is the recommendation, in that it provides significantly higher information density in its color data than does monochromatic.

Supporting the films to be returned are Polaroid films for on-board analysis. These will provide multiple purpose data, allowing the crew experimenter to verify exposure and lighting conditions of unusual character, to examine these images in order to determine the need for additional data on a later pass over the same site, and to finally transmit the imagery to the ground (at a scale to be determined in flight) so that investigators on the Earth may interpret the data during the mission. A wide range of films is available, including type 413. With this film infrared response similar to that of the infrared Ektachrome is obtained; when paired with conventional color or the high-speed panchromatic film, this provides a full range of data representative of that which will be obtained from the films to be returned.

The choice of film format was dictated in part by the availability of cameras of suitable precision and to a more significant extent by the desire for a relatively wide field with low distortion. The field selected is slightly more than 120 nautical miles in each direction, providing a moderately wide swath with an included angle of approximately 36°.

Visible/IR Line Scanner - An infrared scanner would be carried to extend the mapping capability from the visible and very near IR of the metric camera to the reflective and thermal IR. The infrared scanner will measure the reflected sunlight and the self emission of the surface in several bands between 0.45 and 2.5μ and between 8 and 13μ, providing data on shape, surface roughness, and gross composition of the surface in terms of the effective surface temperature at each of the pass bands. A great deal of flight test experience has been gained with this type of device at IR wavelengths and the hardware is very close to being of operational status.

Concurrent camera coverage must be provided when the scanner is being used. The best time of day is near sunrise and sunset when temperature contrasts are enhanced. Night-time operation is possible, but of course, there could be no corresponding photographic coverage.

Microwave Scanning Radiometer - The mapping capability will be extended into the microwave frequencies by an electrically-scanned microwave radiometer. Microwave emission can penetrate clouds unless they contain large water drops, so this sensor will be able to gather resource data when the surface is obscure to infrared and visible frequencies. State-of-the-art radiometers have relatively coarse ground resolution, so this device supplements IR and visible frequencies in mapping lakes and rivers, watersheds, coast lines and similar large size resource areas. A radiometer senses the brightness temperature of the surface which is a measure of the degree of vegetation or bare soil. Vegetation has the highest brightness temperature, dry bare ground has a relatively moderate temperature and wet soil the lowest brightness temperature. The measurements are sensitive also to the character of the subsurface, particularly to the water content, although the practical utilization of this ability may be in the future.

Infrared and Visible Spectrometers - The infrared spectrometer is one of the set of three sensors used for detailed analysis of specific resource regions. The other two are the tracking optical telescope for visual and very near IR analysis and the laser altimeter for profiling. The IR spectrometer would be used to relate the spectral reflectivity and emissivity of small resource regions to the type of ground cover, moisture content and species of surface material. Concurrent photographic coverage is required and IR scanner coverage is highly desirable.

The spectrometer will be slaved to the tracking telescope. It will be programmed to take data only when the resource data is within plus or minus ten degrees of nadir.

Laser Altimeter - The laser altimeter inherently is capable of measuring range with high accuracy; it would be utilized in conjunction with a metric camera system to assist the photogrammetrist in mapping of the surface from orbit. The laser altimeter actually is classified here as an experimental sensor rather than a developmental sensor because it is highly specialized in its application and its hardware development is expected to proceed more slowly. Ultimately, the laser altimeter will be a valuable tool in Earth Resources sensing, because it inherently is capable of very precise range measurement and can produce data on terrain contours.

Day/Night Television Camera - A television similar to the Day/Night Camera developed for use on AAP will be part of the resource data would be mapping sensor set. Its purpose is to provide the astronauts with a continuous view day and night of the area contained within the field of view of the sensors. Monitors will be located in space station compartments where no viewing ports are located and will enable the crew to keep abreast of the geographical area they are passing over, illumination level and cloud cover.

Since the camera is used principally for orientation and sensiometric evaluations, the field of view should be large. The field chosen is 104 degrees, that covering a 945 km circle on the Earth. The resolution is 1.1 km per TV line. While this resolution is good enough for decisions on whether or not the location, illumination and cloud cover are satisfactory for sensor operation, it is too coarse for resource identification.

Supporting Systems

Field of View Monitors - A complex of instruments operating in conjunction with articulated optics will provide the opportunity for the crew to monitor the field imaged by the sensors. The monitoring of the set of imaging sensors used for Earth Resource mapping will be done by the day/night television camera and monitoring of the sensors used for resource analysis and identification will be done by a telescope. Both of these monitors will be located at an experiment control console.

In the search mode, the telescope will have a field of view of 60° and the line of sight may be directed 30° forward and aft of the nadir. The crewman will be able to recognize resource areas with enough lead time to assure acquisition, for example, well before the spectrometer tracking must be initiated (the total spectrometer travel is ± 10° from nadir). Lateral travel of ± 10° will provide the capability to track objects lying off the ground track at relatively little increase in the cost or complexity of the mechanism. When not tracking, the line of sight of the telescope will point to the nadir.

Tentative specifications for the telescope would be as follows:

field of view	60° to 6°
magnification	1X to 10X
objective lens	70mm, f/10
exit pupil	7mm
length	85 cm

A large exit pupil of 7mm was chosen to permit considerable eye travel and thus lessen the burden on the astronaut.

The telescope would be located in the pressurized experiment compartment, immediately above the jettisonable door to provide unobscured viewing. It is intended that this optical system be used in connection with a 70mm camera capable of resolving 30 meters on the surface. This camera, mounted on the telescope barrel, is boresighted with it. In operation, by depressing a take-button, single or sequential pictures may be taken of any particular target of interest.

During crew-initiated scanning and photographic operation modes, magnification may frequently be desired, based on some visible aspect of the target area. Small areas of storm activity, forest fires, or visually discernible ocean current patterns would call for closer examination, enhancing the value of crew interpretation and photography. Because of the rapidity with which the image traverses the telescope, changing of the eyepiece or other time-consuming activities are ruled out. For this reason, a lens with a rapid zoom capability from 1X to 10X was deemed necessary with the actuation accomplished by a control at the eyepiece.

A field of view of 60° at 1X corresponding to ground coverage of a circle with a 116 n.m. radius (instantaneous coverage of some 31,800 n.m.^{2}) would provide 28 seconds (time-to-target) when the telescope is in a null or vertically pointing position. In order to augment the field of view, particularly in terms of time-to-target, as well as to allow off-track pointing, the telescope would articulate forward and aft 30° as well as 10° to each side.

To point the telescope's line of sight to a ground target, a two-axis hand controller would be provided with proportional output. Deflection of this controller will initiate a signal to the servos slaving a scanning mirror/prism assembly in the desired direction. Both single axis and bias commands would be accepted. Once the desired pointing was accomplished and the tracking rate established, pointing, tracking, or hold commands would be initiated; this capability incorporated by means of a switch mounted on the pointing/tracking hand controller. Using the above tracking signals, single or multiple sensors could then be slaved to the optical system.

A pictorial record of the resource area that is being analyzed by such sensors as the infrared spectrometer and observed by the astronaut through the telescope, may be made by a framing camera that is part of the assembly. The camera, similar in design to the Maurer Model 318 used in the Apollo and Gemini programs, will be a sequential 70mm format camera. It would be boresighted with the telescope and will use the same scanning optics to enable the astronaut to photograph resource areas located ahead or to the side.

Crew Experiment Support Operations and Observer/Experimenter Activities

In support of this mission, the crew experimenter will essentially act as an on-line sensor, using the telescope, day/night camera, and sensor displays to provide a forward looking capability in anticipation of a target area or ground site, and the displays to monitor sensor data as it is received. With the telescope, the experimenter can look out up to 60° forward of the nadir to gain the time advantage necessary to initiate sensor operation. Although target definition, in terms of its recognizable elements, is degraded at these pointing extremes by poor texture resolution and reduced contrast, as the target closes, several discernible elements may be present to aid in selection. These are, for example, contrast ratios (vegetation), surface texture (geology), discrete landmarks (lakes or rivers), cloud formations (cyclical patterns), and ocean currents. Use of the zoom lens will enable closer and more detailed examination of objects of interest by the crew experimenter.

Typically, the crew experimenter will select a target and evaluate its visible characteristics in order to decide whether or not to take data. Visible phenomena such as heavy cloud cover would preclude the use of certain sensors during a particular orbit. Utilizing a programmer at the experiment control station, the crew experimenter will initiate sensor operations, based on a gross mission plan and periodic ground communication. It would be necessary to input ephemeris data to the experiment console; this information presumably obtained from a spacecraft computer.

One sensor, the IR radiometer, will be slaved to the telescope. This will require the crew experimenter's control in first selecting, then tracking the target from a point 10° forward to 10° aft of the nadir; tracking to be accomplished through the use of a two-axis telescope drive controller, which will slave the gimballed radiometer to the telescope. In order to obtain additional photographic coverage of unusual ground phenomena and points of specific interest, a 70mm camera will be boresighted to coincide with the telescope pointing axis as described earlier.

Support Operations

On-Line Data Analysis and Data Quality Control - Although the sensors will essentially be fixed with respect to operating parameters, provision for calibration will be made where practical. In order to evaluate photographic data quality, Polaroid back(s) will be provided on certain cameras for quick-look purposes, especially during the initial stages of the mission. Using these high quality photographs, the crew experimenter may make minor adjustments to a sensor as well as send images via video link for ground analysis.

Data Management - Data Management is of primary importance considering logistic and payload limitations. Two separate modes of operation and three combinations of these modes are envisioned to achieve optimum management. The first calls upon the skills of the crew experimenter who, with his telescope, visually scans the ground scene in anticipation of an overflight, making his decision to initiate data taking or to conserve available film for a better set of conditions. The second method utilizes voice communication with a ground station for information updates regarding weather or phenomena of interest which would be communicated to the spacecraft to accomplish the same objective. Using a combination of visual scanning from the spacecraft and ground voice communication, the objective of film, power, and time conservation is greatly enhanced. An example of this combined activity would be to take data when over intermittent cloud breaks, although the prevailing weather might be unfavorable. Finally, learning phenomena will, of course, be operative in that, using prior experience, developed (Polaroid) photographs, and ground evaluation of data, the experimenter will, no doubt, improve his management techniques during the later phases of the mission.

Voice Annotation and Qualitative Description - As a trained observer, the experimenter can provide an important increment to data interpretation through the use of a voice tape to correspond in time and location with both the imaging and non-imaging sensors. This qualitative description would be primarily a description of the visible context of the target area and would provide information on sun angles, shadows, and surface characteristics.

Communications with Principal Investigators and Ground Stations - In order to modify the mission plan based upon ground evaluation of transmitted data, a communication link will be desirable among mission operations, spacecraft and principal investigators. The qualitative data and on-board photographic interpretation will provide the material and basis for such communication. An important aspect of these activities will be modifications of mission plans. If for some reason data have been consistently below standard because of ground conditions or sensor malfunction, a modification decision will be made.

Experiment Control/Status Monitoring - In addition to the target selection procedures, the crew experimenter will perform control and housekeeping functions for the experiments by monitoring status displays and operating cryogenics, lens cover deployment, on-off, and warmup controls; these performed at the experiment control station. Experiment status (i.e., time remaining, cryogenic functions, and electrical indications) will appear on the station console.

Fault Isolation and Maintenance - In a long-duration mission, characterized by extended periods of inactivity, a degree of fault isolation can be accommodated, provided that equipment and spares are available. This activity will be limited to replacement of modular units, bulbs, and small parts.

Data Retrieval, Transmission and Storage - The design approach taken will permit the astronaut to retrieve exposed film from the camera magazines without the necessity of depressurization of the camera compartment or EVA. As indicated earlier, a subject which would require further study is the method of storage (i.e., whether tape data will be transferred to an interim storage unit or transferred to a unit which will enable transmission at appropriate reporting intervals).

Sensor Replenishment - An additional group of crew support operations includes resupplying camera sensor, removing exposed film, packaging and storing for subsequent return.

Other Functions - Three additional areas of crew activities which have not been defined in detail are unmanned sensor preparation,* integrated spacecraft maneuvers in support of experiment operations, and EVA support functions. It is clear the first two groups of activities represent anticipated crew functions for this experiment mission. The third, EVA Support Functions, may be considered as a one-time support activity or for periodic maintenance of exterior sensor surfaces (such as cleaning lenses).

Manned Experiment Operations (Typical Experiment-Imaging Group)

Table 5 depicts typical experiment support activities for the imaging sensors group.

Table 5 Typical (Manned) Support Activities in Support of an Imaging Group Experiment

	Crew Operation	Estimated Required Time (Min.)	Time to Target (Min.)
1.	(Dark Side) Review Flight Plan	5	56
2.	(Dark Side) Communicate with Ground Station	5	51
3.	(Dark Side) Select Experiment Plan	5	46
4.	(Dark Side) Confirm with Ground Station	5	41
5.	(Dark Side) Complete Statian Keeping Duties	5	36
6.	(Dark Side) Pre-select Target Area	2	31
7.	(Dark Side) Turn on Cryogenics	15	29
8.	(Dark Side) Deploy Lens Covers	1	14
8a.	(Dark Side) Monitor Stotus Displays	1	13
9.	(Light Side) Warm Up Sensors	2	12
10.	(Light Side) Select Data Sequence	1	10
11.	(Light Side) Select Data Disposition (1)	1	09
12.	(Light Side) Select Frame Overlap Control	1	08
13.	(Light Side) Select Telescope Scan Mode	1	07
14.	(Light Side) Survey Target Area	1	06
15.	(Light Side) Decision to Take Data	1	05
16.	(Light Side) Select Target Area	1	04
17.	(Light Side) Select Telescope Track Mode	1	03
18.	(Light Side) Track Target - Commence Voice Annotation	1	02
19.	(Light Side) Initiate Target Photography (70 mm Camera)	1	01
20.	(Light Side) Initiate Data Acquisition	1	00
21.	(Light Side) Monitor Status Displays	1	00
22.	(Light Side) Terminate Data Acquisition	1	20
23.	(Light Side) Decision not to Turnoff Crvogenics (2)	1	19
24.	(Light Side) Remove Exposed Film	3	16
25.	(Light Side) Secure New Cassette	1	15
26.	(Light Side) Store Exposed Film	1	14
27.	(Light Side) Install New Cassette	3	11
28.	(Light Side) Return to Experiment Console	1	10
29.	(Light Side) Repeat Steps 10 thru 21	10	00
30.	(Dark Side) Terminate Data Acquisition	1	-
31.	(Dark Side) Turn Off Cryogenics	1	-
32.	(Dark Side) Turn Off Power	1	-
33.	(Dark Side) Replace Lens Covers	1	-
34.	(Dark Side) Communicate with Graund Station	5	-
35.	(Dark Side) Store or Transmit Data	15	-

(1) Data Disposition may be to pre-store or permanently store data.
(2) Decision is predicated on multiple targets during same light-side orbit.

During activities preparatory to taking data, preferably during the dark side periods, the crew experimenter refers to his flight plan to determine in gross manner which experiments are scheduled for the next pass. At this time, communication with ground personnel may be implemented. Once this is done, any required stationkeeping duties are completed to free the crewman for experimental support activities.

In preparation for data taking, the sensor cryogenics are turned on, lens covers are deployed, the data sequences are selected. The telescope is then used in a scan mode until the target area is in view. Based on such conditions as heavy cloud cover, a decision will be made whether or not to take data. When the decision is to take data, a target area will be selected and data taking will commence.

When multiple targets are separated by only a short time during a particular orbital pass, sensor cryogenics may be left on and the sensors will be kept in a ready state. For illustrative purposes, sensor replenishment was included in the outlined tasks; this, however, will obviously not be representative of each data taking pass. Essentially, the plan for each mission segment will be to accomplish as many peripheral tasks as possible prior to a data taking pass.

* NOTE: One of the initial study program objectives was that the sensors be set for unmanned modified operation after the manned portion of the mission was concluded.

Finally, depending on the choice of data disposition (Step 11), data will either be stored for later transmission, or permanently stored for payload return.

Mission Timeline

This section provides a representative timeline for the experimental mission during a normal day in which the experiment station is manned and data is being taken. Initial activities such as checkout of sensors and equipment, installation of cameras, and system checks, as well as terminal functions associated with unmanned-phase sensor preparation (mentioned previously) and storage of payload films are, for the present purpose, deliberately omitted because of the one-time nature of these activities.

Two approaches toward crew work-rest cycles were examined; one staggered and the other uniform. These are defined respectively as (staggered) one in which the two crewmen sleep at different times and (uniform) one in which the two crewmen sleep at the same time. Obviously, many variations are possible (i.e., the sleeping period may be broken into two or more separate periods); however, the cycles chosen represent two sequences of daily operations at opposite ends of a scale.

Since it is difficult to address the timeline to every mission phase during which it is desirable to have the experiment station manned by one of the two crewmen without compromising some other aspect of the mission, it is first necessary to specify which items are more important than others.

This list of considerations includes mission, physical, and crew-related factors used to determine a priority.

Some of the pertinent mission aspects fixed by the orbit and inclination are:

- o Coverage of Land Masses
- o Coverage of Ground Truth Sites
- o Coverage of Continental U.S.
- o Coverage of Communications Stations and Required Reporting Intervals

Other aspects not related to the orbit parameters, but to the spacecraft systems are:

- o Operations requirements, including orbitkeeping and navigational maneuvers
- o Subsystem maintenance requirements
- o Housekeeping requirements - food and waste management
- o Sensor management cycles (replenishment/retrieval)

Finally, crew safety and welfare enter importantly into consideration in the specification of time-on-duty, personal hygiene cycles, and also of the influences of boredom and fatigue.

Figure 4

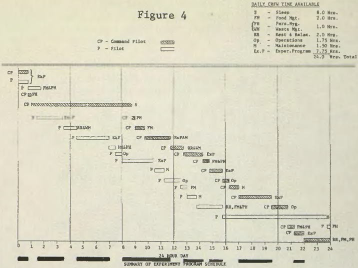
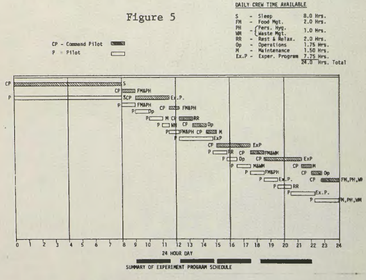


Figure 5



Figures 4 and 5 depict staggered and uniform crew work-rest cycles respectively. Several ground rules were established which were necessary in the planning of crew duty cycles,

Mission

- o Inclination: 50°
- o Altiuude: 200 n.m.
- o Seasons: Summer and Fall
- o 15-day repeated orbital trace

Spacecraft

- o "Operations" may be spaced at intervals up to 4.5 hours
- o "Maintenance" may be spaced at intervals up to 3.0 hours
- o Communications may be accomplished from the experiment control stations

Crew

- o Crewman may remain awake up to 16 hours
- o Eating (food management) may be spaced at up to 6.0 hour intervals
- o At least one meal taken with both crewmen eating together
- o Uninterrupted 8-hour sleep period
- o Negligible time required to get from one work station to another
- o Food management, personal hygiene, waste management, and rest/relaxation period, or any combinations thereof, may be scheduled to overlap

- o At least one period of overlapping activity in the experiment station for daily data exchange between crewmen

Mission Objective

- o Maximum experiment station manning desirable during daylight-side orbits over land or ocean areas
- o Sensor preparation (warm-up, etc.) may be accomplished by pre-programming of experiments during previous station manning periods

In addition, the crew participation in the experiment program was oriented, through scheduling, toward the daylight side of each Earth orbit, permitting maximum crew coverage during these periods. Based on equal day-night periods, there are sixteen 45-minute daylight periods during which the experiment station may be manned. Another factor considered was preparation time prior to the daylight period; this, however, was a secondary consideration since many of the experiments may be pre-programmed.

Staggered Crew Work-Rest Cycle - From Figure 4 and its corresponding Table 6, it can be seen that the experiment station may be manned for 14.75 hours per day or 7.75 per crewman with a .75 overlap daily for purposes of debriefing and data exchange. Each crewman sleeps for an 8.0 hour uninterrupted period; in the example shown, the command pilot sleeps from 0100 to 0900 with the experiment pilot sleeping from 1545 to 2345. Table 9 tabulates the information in Figure 4 with several additional points of information. These are corresponding daylight period of Earth orbit, and percent of daylight period of orbit covered during experiment station manning and the cumulative percentage of experiment station coverage, which is based on sixteen 45-minute daylight periods. It can be seen that this staggered sleep cycle permits 72% coverage of the daylight orbit periods, the experiment station being manned during 13 of the 16 daily orbits.

Uniform Crew Work-Rest Cycle - Figure 5 and Table 7 similarly schedule crew activity with the distinction being that the two crewmen are on a uniform work-rest cycle and sleep at the same time (2400 - 0800) daily. Upon examination of the dashed heavy line summary at the bottom of Figure 5 , it becomes apparent that the experiment station is manned less frequently, but for greater durations, with more substantial overlap between the two crewmen. Table 10 indicates that although more preparation time exists before a daylight period, manned operations do not start until the 7th orbit. The cumulative coverage of the daylight portions of the sixteen orbits is 57%.

It is apparent that the staggered work-rest cycle is superior to the uniform work-rest cycle, from the standpoint of experiment station manning. [As a final point, it should be noted that these two crew timeline summaries include several assumptions regarding permissible maintenance, operations, reporting, and personal maintenance intervals. Similarly, land-mass overflight and truth site data must be superimposed since the daylight periods occur over ocean areas more often than land areas.]

Table 6 CREW TIMELINE SUMMARY FOR STAGGERED WORK/REST CYCLE

Experiment Station Manning Starts At ____	Duration of Manning Period From - To	Cumulative Experiment Station Time (Minutes)	Earth Orbit Number	Corresponding Daylight Period of Earth Orbit From - To	Preparation Time Available Prior to Daylight Period of Earth Orbit	Manned Experiment Station Operations During Daylight Period of Earth Orbit	
						Percent of Daylight Period Covered	Cumulative * Percentage
2400	2400-0045	45 min	(1)	2400-0045	No	100% 1st Orbit	6.25
0130	0130-0330	165 min	(2) (3)	0130-0215 0300-0345	No Yes	100% 2nd Orbet 66% erd Orbit	12.50 16.66
0430	0430-0700	315 min	(4) (5)	0430-0515 0600-0645	No Yes	100% 4th Orbit 100%5th Orbit	23.00 29.25
0800	0800-1030	465 min	(6) (7)	0730-0815 0900-0945	No Yes	66% 6th Orbit 100% 7th Orbit	33.33 39.60
1030	1030-1145	540 min	(8)	1030-1115	No	100% 8th Orbit	45.90
1245	1245-1415	630 min	(9) (10)	1200-1245 1330-1415	No Yes	0% 9th Orbit 100% 10th Orbit	45.90 52.00
1445	1445-1545	690 min	(11)	1500-1545	No	100% 11th Orbit	59.00
1700	1700-1930	840 min	(12) (13) (14)	1630-1715 1800-1845 1930-2015	No Yes No	33% 12th Orbit 100% 13th Orbit 0% 14th Orbit	61.00 67.25 67.25
2115	2115-2200	885 min	(15) (16)	2100-2145 2230-2315	No No	66% 15th Orbit 0% 16th Orbit	71.50 71.50

* Based on 16, 45 minute daylight periods available.

Table 7
CREW TIMELINE SUMMARY FOR UNIFORM CREW WORK/REST CYCLE

Experiment Station Manning Starts At ____	Duration of Manning Period From - To	Cumulative Experiment Station Time (Minutes)	Earth Orbit Number	Corresponding Daylight Period Of Earth Orbit From - To	Preparation Time Available Prior to Daylight Period of Earth Orbit	Manned Experiment Station Operations During Daylight Period of Earth Orbit	
						Percent of Daylight Period Covered	Cumulative Percentage
0900	0900-1130	150 min	(7) (8)	0900-0945 1030-1115	No Yes	100% 100%	6.25 12.50
1215	1215-1445	300 min	(9) (10)	1200-1245 1330-1415	No Yes	66% 100%	15.63 21.87
1500	1500-1730	450 min	(11) (12)	1500-1545 1630-1715	No Yes	100% 100%	22.12 28.37
1730	1730-2115	675 min	(12) (13) (14) (15)	1630-1715 1800-1845 1930-2015 2100-2145	Yes Yes Yes Yes	100% 100% 100% 100%	34.62 40.87 47.12 53.37
2115	2115-2215	735 min	(15)	2100-2145	Yes	66%	56.62

Mission Duration - Using the 90-day mission as a basic assumption, and considering that at least 2 days would be consumed at each end of the mission, (orbit attainment and de-orbit operations) with another three consumed in equipment repairs, there are potentially 85 days during which experiment operations can be carried out. At six hours per day, there would be about 510 hours per crewman, or a total of 1020 hours for crew-supported experiment operations.

Fifteen-Day Timelines - Extending the one-day staggered timeline over a fifteen-day period permits repeated sensing of previously covered targets under much the same conditions as during the previous passes. This provides, in part, experiment repeatability and is particularly important for ground truth site sensing (although over a period of 15 days, there will be sun angle shifts). With the appropriate modifications in the experimental plan and data interpretation, it may be possible to compensate for the illumination and seasonal changes.

Although no attempt has been made to ascertain voice reporting or data transmission intervals, the staggered work-rest cycles depicted permit these activities during the times indicated in Table 8.

Table 8

DAILY VOICE REPORTING-DATA TRANSMISSION TIMES AVAILABLE DURING EXPERIMENT STATION MANNED ACTIVITIES (STAGGERED WORK-REST CYCLE.)

TIME	PILOT	DURATION
2400*	CP/P	.75 Hrs.
0130	P	2.00 Hrs.
0430	P	2.50 Hrs.
0800	P	2.50 Hrs.
1030	CP	1.25 Hrs.
1245	CP	1.50 Hrs.
1445	CP	1.00 Hrs.
1700	CP	2.50 Hrs.
2115	CP	.75 Hrs.
		14.75 Hrs. (cumulative)

* Overlapping Coverage of Experiment Station

Use of Support Subsystems

In order to provide the crewman with the means to accomplish target selection, point specific sensors, and qualitatively comment on the visible characteristics of the target area, an optical system is required. In addition, sensor displays showing the direct output of certain sensors should be included.

Sensor Displays - Sensor displays are a class of pictorial displays presenting the direct output of sensors in a visually intelligible form. These provide pictorial information gathered by pattern sensors such as radar, TV, or IR. The human function is one of target or type-matching with some preconceived or scored model.

There are several ways in which the crew experimenter may use these sensor displays as well as several methods of information presentation. One method is to store prepared imagery, calling it up when the navigation system senses that the time for a target area has arrived (or on demand) and compare this imagery with that originating with a live sensor in order to identify checkpoints, areas, or features whose coordinates are known. Another way would be to assign a symbol to each broad class of landmark, store the coordinates, then superimpose the symbols on the raw data display in accordance with the navigation system's prediction.[12]

As for management of sensor operation, it is apparent that when trained to recognize characteristic patterns, even in the absence of direct visual contact (i.e., at night), the astronaut could readily determine that cloud cover exists over an area, making sensing operations not feasible at a particular time for a specific sensor group.

Optical Scanning Equipment

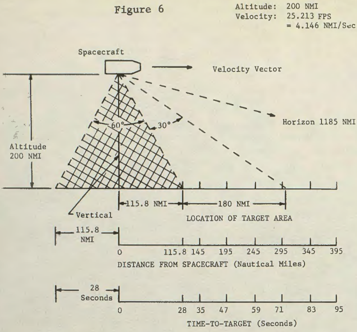
The usefulness of the scanning telescope in this mission becomes apparent in two classes of activity: the first of these is monitoring - in advance of the spacecraft position - the weather state of the potential target area, including a selective override (either shut down or activate) of a pre-programmed sequence of sensor operations. The second is for target-of-opportunity selection, where unprogrammed events of scientific interest are occurring prior to (and even during) data-taking operations, as well as during programmed sensor "off" periods. With the parameters of altitude and velocity fixed by launch and mission requirements, the problem becomes one of selecting optical equipment which will permit timely and meaningful evaluation of target area features, both in anticipation of the overflight and subsequent to it. By "in anticipation of," the ability is implied for the crewman and his systems to plan a course of action and to respond to some unprogrammed event in sufficient time to select a sensor sequence which would record that event. (This does not mean that this activity would necessarily constitute a nominal sequence of events; it would constitute an additional capability to be used when a situation called for crew-selected sensor operations.) Similarly, "subsequent to" implies the ability to add voice annotations and qualitative descriptions after the target has been passed.

Field of View Requirements - At an altitude of 200 n.m., the spacecraft velocity is 25,000 feet per second or over 4 n.m. per second. The horizon at this altitude is at about 1180 n.m. distant. When a target on the ground is detected and recognized, depending on its location, it proceeds past the view of an observer (at the nadir) at a relatively constant 4 n.m./sec. A vertically aligned optical instrument at 1X magnification with a 60° field of view and circular viewing aperture would, at any given time, provide a view of a ground scene of about 31,800 n.m.^{2} (a circle with a 116 n.m. radius). At the stated velocity, from the time of target detection (assuming detection as soon as the target entered the optical field) the target would remain in view for 56 seconds, or 28 seconds forward and aft of the nadir. Under these conditions, from detection to data taking with a vertically aligned sensor, 28 seconds is available for preparation; this includes the human components of detection and recognition, response lags (both sensory and motor), and machine lags associated with warm-up and tracking error. Although it is not impossible for a trained crewman to respond in this amount of time, it is nevertheless difficult. In addition to the time-to-target limitations, there are the requirements to monitor the equipment status during this 28-second period.

Figure 6 illustrates the interaction of field of view, altitude, and velocity. For the 60° F.O.V., as indicated, the crewman has about 28 seconds to respond; however, if the same 60° were augmented by 30" of forward articulation (30° from the normal vertical looking position), an additional 180 n.m. (forward visibility) is gained with the "time-to-target" increasing to 71 seconds. Similarly, the target would remain in view longer if rearward articulation were also possible. For this reason, it is recommended that the optical device be positionable in all directions within a 30° cone.

Magnification - The purpose of the viewing optics is to intensify (by gathering) the available light emanating from a target area. Through the use of a view-finder, the crewman may distinguish important ground phenomena with resolution limited only by his eye. Increasing magnification, while increasing the apparent size of the target area, also increases the speed with which it traverses his visual field.

Figure 6



In order to improve monitoring capability with respect to surface detail, the ability to employ higher magnification (up to 10X) should be incorporated. The V/H is small enough to allow this magnification to be employed without unduly increasing the difficulty of tracking. The time required for the image to traverse the minimum field when the telescope is not tracking is five seconds.

Experiment Control Consoles

Two experiment consoles are planned; the first (Console A) located in the pressurized compartment forward of the sensor compartment and the second (Console B) in the sensor compartment.(also pressurized).

Console A (Figure 7) is the main experiment control console containing all controls, displays, status indicators, deployment controls, and a caution warning system. Its location, as indicated, is in the forward compartment and it is conceived of as a single-place console with a suitable crew-restraint system. This work station will include the equipment associated with the following functions:

a. Experiment Planning and Sequencing
b. Experiment Status Monitoring
c. Experiment Activation/Termination
d. Experiment Support Functions (Cryogenics, Electrical Power, Calibration)
e. Caution Warning Monitoring
f. Data Processing (Polaroid photographics)
g. Data Management Subsystem
h. Communication
i. Data Transmission
j. Day/Night TV Monitoring

Data Subsystem. About 7 switches will be required to operate the data subsystem. With these controls the astronaut selects the type of data to be taken and routes it to the tape recorder storage or from storage to the telemetry. The time, orbit number and attitude of the space station should be recorded for each operation of the sensor. The Voice Annotation Channel is used to introduce each experiment, describe the parameters and to record comments by the experiment operator on the general functioning of each experiment.

Status Displays. About 50 status indicators will be needed. Two cathode ray tubes are carried for pictorial display of the sensor function and for display of the imagery taken by the imaging scanners. The Day/Night Camera is carried to provide a view of the surface day or night so the astronaut can orient himself and can locate cloud-free areas where the optical sensors can observe the surface.

Controls. The experimenter would need about 40 individual controls to operate the instrumentation.

Data Channels. About 132 individual channels of scientific and sensor status data would be recorded. Voice annotation, time, index camera operation and vehicle orbit position and attitude would be recorded for all sensors.

Operations. The philosophy under which the control station would be configured is that it should be possible to perform all sensor maintenance functions other than the changing of films and the taking of photographs for on-board processing from that station.

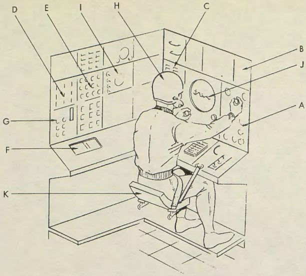
Since this station would serve as the major operating base for one crew member during much of the mission, full facilities for his operation there in a shirt-sleeve environment would be provided.

Console B is the secondary experiment control console located in the sensor compartment containing the telescope, telescope slew controls, a day/night TV monitor, and a simplified caution-warning display (possibly an auditory warning system which indicates a malfunction in a system). This station will also contain override controls to override the experiment selection/sequence based on the experimenter's visual scanning activities.

Since most of the qualitative descriptions are based on these scanning activities, a voice tape unit will be incorporated in this section. Console B will also include provision for seating and restraint of a single crewman. Figures 7 and 8 indicate the general crew-equipment arrangements for each console.

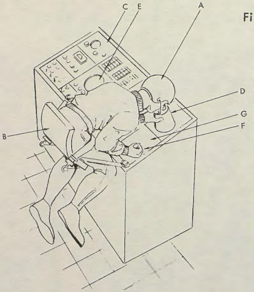
The concluding section to follow will provide some material on several approaches and problems associated with even longer duration missions incorporating many of the same data objectives as those which were stated in this section.

Figure 7 Main Experiment Console



A. EXPERIMENT PLANNING & SEQUENCE
B. EXPERIMENT STATUS MONITORING
C. EXPERIMENT ACTIVATION/TERMINATION
D. EXPERIMENT SUPPORT FUNCTIONS
E. CAUTION WARNING MONITORING
F. DATA PROCESSING
G. DATA MANAGEMENT
H. COMMUNICATION
I. DATA TRANSMISSION
J. DAY/NIGHT TV MONITORING
K. PELVIC RESTRAINT

Figure 8 Auxiliary Experiment Console



A COMMUNICATIONS
B PELVIC RESTRAINT
C CAUTION WARNING
D TELESCOPE
E DAY-NIGHT TV MONITOR
F TELESCOPE SLEW CONTROL
G VOICE TAPE UNIT

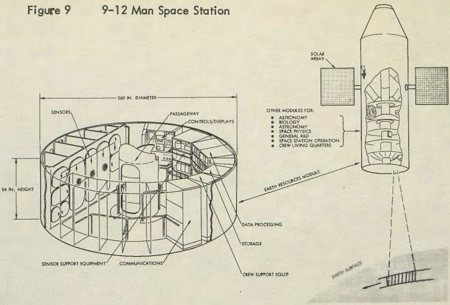
IV. Extended Zero "g" Spacecraft and Mission Programs

The mission, vehicle, and crew participation in earth resource data gathering described in the previous section, it is felt, were feasible from an engineering and operations standpoint. More specifically, however, the payload and crew were housed in what may be considered to be an operational vehicle within a one-or two-year timeframe. There is actually a variety of vehicles which could provide the required volume for such a configuration and, as well, the payload return capability. Although the sensor and return payload could by no means be considered unlimited, several space station concepts are currently under study which would substantially increase volume, weight, logistics, and mission duration capability and, as well, provide a unique capability for orbital experiments in other disciplines such as astronomy, space physics, biomedicine, and the behavioral sciences. Generically, these extended duration space station concepts have been referred to as Earth Orbiting Space Laboratories (EOSL), Future Space Station (FSS), and Earth Orbiting Space Station Modules. Some incorporate plans for a multi-man (9-12) crew with mission durations from up to two full years. Experiments in the areas mentioned include Space Astronomy, Meteorology, Space Biology, Communications, Earth Resources, Navigation, Space Physics, and a group of experiments described as Manned Space Flight Capability [4].

Of the many concepts being explored, one in particular, a compartmentalized space station utilizing an expended Saturn II stage for an extended duration mission with logistic resupply, appears singularly attractive. It is probably the most advanced concept for an earth orbital space station and is illustrated in Figure 9.

NASA [3] has studied the use of this 9-12 man station for conducting experiments and orbital operations in the mid-to late 1970's; these relating to the disciplines mentioned above. This station would be placed on a circular orbit of approximately 260 nautical miles at a 50-to 70-degree inclination by the first 2 stages of a Saturn V launch vehicle. The station itself would replace the SIV-B stage atop the SII, with possibly SIV used as the first stage.

Figure 9 9-12 Man Space Station



The earth resource sensors and supporting equipment would be housed in one of the compartments or modules of the station. In all probability, the earth resource module would be on the "bottom of the stack" (as depicted in Figure 9) of modules making up the station. This bottom location would be desirable for exposing the entire lower surface of the module toward the earth for better sensor viewing and positioning of antennas. The space station systems would provide the earth resource module with electrical power, thermal control, environmental control and attitude positioning. The module itself, however, would have to be self-sustaining in regard to maintaining the environment and more of the space station's crew members. A separate crew quarters module would be used for extended rest, recreation, and eating periods. [1]

A vehicle such as this would allow for a selection of a large amount of earth resource sensor instrumentation. The list below is characteristic of some of these instruments:

- Television Cameras
- Panoramic Cameras
- Metric Cameras
- Synoptic Multi-Band Camera
- Tracking Telescope
- IR Radiometer and Scanner
- IR Spectrometer
- RF Reflectometer
- Microwave Radiometer
- Radar Altimeter
- Passive Microwave Scanner
- Radar Imager
- Optical Scanner
- Laser Altimeter
- Magnetometer
- Sferics Detector
- Star Tracker
- Polarimeter

The above constitutes a total weight of approximately 7000 pounds, with 8000 pounds required for structure (module) and another 5000 pounds for computers, on-board processing equipment, spares, film, tape, and auxiliary life support systems. This adds to a total weight of 20,000 pounds within a 200,000 pound spacecraft.

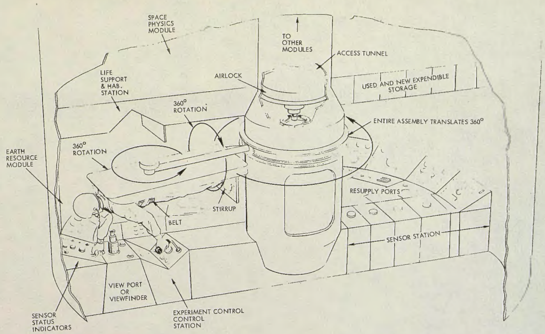
During TRW's in-house studies on earth resource sensor payloads for this spacecraft, numerous engineering and operational problems were dealt with; one of the more critical of these being mobility and restraint for the observer/experimenter during the extended periods this module would be occupied. The equipment, illustrated in Figure 10, was conceptually designed to provide access to equipment around the entire radius of the 22' diameter by 7' high module.

Partial "g" Space Station Programs

For the past 8 years, and perhaps longer, there have been many studies of human factors and biomedical problems associated with long duration space flight. These problems specifically have centered about possible harmful biological effects as well as operations problems inherent in zero g operation. Although the information to date has been largely inconclusive, (although some biological effects have been observed in the Mercury and Gemini pilots) one point of general agreement among mission planners and space hardware designers has been regarding the desirability of providing an operating environment which is as close as possible to the earth environment.

Providing such an environment similar with respect to earth gravity is important, not only from the point of biologic effects, but from an operating feasibility standpoint as well. Operating feasibility, in this context, means neither operation of on-board experiment equipment nor operation of the spacecraft support systems, since these, in many respects, operate equally well in zero or partial gravity environments [5,7]. Operating feasibility, as NASA [4] states, is "....the habitability problem which is at present the reason for considering artificial gravity. In essence, the argument is that it may prove

Figure 10 Crew Experimenter Restraining and Positioning Equipment

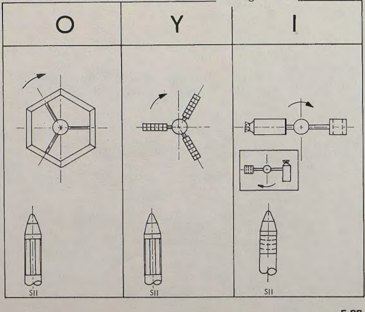


cheaper to rotate the entire station than to design the spacecraft to handle the nearly countless special engineering tasks associated....... with operating at zero gravity..."

Several of the configurations have been reviewed by NASA and the USAF. NASA [3, 4] reviewed three configurations, each utilizing combinations of Saturn workshops. These are illustrated in Figure 11. These are identified as "I," "Y," and "O." Similarly, the USAF. [6] identifies two of these configurations as radially and axially expanded "dumbbells," and the "torus" configuration. For purposes of comparative discussion:

NASA Designation	USAF Equivalent Designation
"I" Configuration	Axially Expanded Dumbbell Radially Expanded Dumbbell
"Y" Configuration	None
"O" Configuration	Torus

Figure 11



The USAF Torus and Dumbbell Configurations, (not identified in terms of boosters) are illustrated in Figures 12 and 13.

The Air Force and NASA configuration designations were established analytically, considering the interaction of practical engineering limitations and human factors or crew considerations. The crew and human factors considerations were initially established, based upon human centrifuge studies and reduced gravity aircraft programs, and later, based on the Mercury and Gemini Flights.

Figure 12 Torus Space Station Configuration

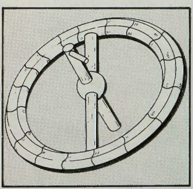
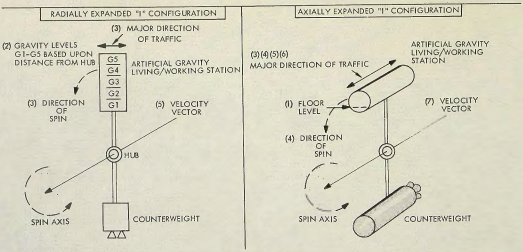


Figure 13



V. Conclusions

As indicated earlier, the feasibility and attractiveness of a manned approach for an orbital earth resource sensor payload derives from the many support and experimenter functions which a highly trained crewman may perform. Perhaps even more basic than that is the fact that man's presence in such a mission is only justified by the increment he adds in reliability, response to unprogrammed events, target selection, and on-board data management. This increment must, of course, account for the very high cost of man-ratings spacecraft and sustaining a man in orbit.

Unless the presence of man and the functions he performs in terms of the value of returned data (i.e., the selection, processing, and transmission of meaningful data) is significantly higher than that of an unmanned configuration with a similar sensor payload, the net yield cannot justify a manned approach. Although the volume of data to be physically returned in the mission described in Section III was modest (in the 2 - 500 pound area), the management and selection techniques anticipated to be employed by the crew would very probably result in a much higher percentage of usable data than if an unmanned approach were taken.

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