NASA Contractor Report 3923

System Study of the Utilization of Space for Carbon Dioxide Research

Peter E. Glaser and Robert Vranka

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System Study of the Utilization of Space for Carbon Dioxide Research

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

BACKGROUND

The global growth in the use of fossil fuels has aroused concerns that the associated combustion processes may be increasing atmospheric CO_2 and causing environmental and climatic changes. If climatic changes are in fact occurring, actions must be taken to mitigate their impact. For these actions to be effective, they must be based on informed and timely decisions.

General circulation models (GCMs) are used for predicting climatic changes due to increasing atmospheric CO_2. The algorithms in the GCMs that characterize certain phenomena must be physically accurate and reliable. Therefore, they must be verified and defined in specific spatial and temporal zones if the GCMs' predictive capability is to reach a useful level. The ongoing research on atmospheric CO_2-induced climatic changes under the auspices of DOE, has produced numerous models of the climate and carbon cycle. In order to verify and discriminate among competing GCMs and to improve the predictive capabilities of the models, additional credible and verifiable data are needed. Data are also needed to validate and further develop these models.

Efforts must continue to identify the most sensitive parameters — those that can best serve as early indicators of long-term climatic changes that are due to increases in atmospheric CO_2. However, it is also important to investigate the various options for monitoring these parameters and acquiring the necessary data about them.

One of the most promising options is the use of satellites. Satellites, particularly as used in remote sensing, have already contributed importantly to the scientific study of the biosphere and atmosphere. The evolving capabilities of space-based sensor systems can provide new information that will increase our understanding of the effects of atmospheric CO_2 on the climate and the environment. In addition, a range of space transportation options is available for deploying a variety of satellites in selected orbits that will provide data on geographical areas that have not been studied and that will extend synoptic observations over longer periods.

STUDY OBJECTIVES

This study had three objectives:

- Compile and select those Scientific Data Requirements (SDR's)* pertinent to the DOE's CO_2 Research Program that have the potential to be more successfully achieved by utilizing space-based sensor systems.

*"Scientific Data Requirements" (SDRs) in the context of this study are the data specifications for selected parameters related to CO_2. (Appendix A)

- Assess the potential of space technology in monitoring those parameters which may be important first indicators of climate change due to increasing atmospheric CO_2, including the behavior of the West Antarctic ice sheet, and

- Determine the potential of space technology for monitoring those parameters to improve understanding of the coupling between atmospheric CO_2 and cloud cover.

STUDY SCOPE

The system study on utilization of space technology for CO_2 research was performed by Arthur D. Little, Inc., Ball Aerospace Systems Division and Boeing Aerospace Company, from April 1983 to April 1984, with ten months devoted to technical work and two months to documentation. The study was funded at a level of $250,000 and performed on behalf of the Marshall Space Flight Center, National Aeronautics and Space Administration.

The study consisted of the following tasks:

1.0 Space systems requirements definition including the formulation of scientific data requirements (SDRs) and determination of the SDRs that can be satisfied through effective use of space-based sensor systems.

2.0 Preliminary concept definitions of space-based sensor systems including present sensor systems, new system concepts and integrated system concepts.

3.0 System and subsystem recommendations for three (3) time frames: Level I, 0-5 years, Level II, 5-10 years, and Level III, 10-20 years.

4.0 Programmatics and cost estimates for recommended space-based sensor systems including project schedules, work breakdown schedules, and cost analyses.

5.0 Program reviews and documentation.

6.0 Data management concepts applicable to the CO_2 Research Program.

STUDY STRATEGY

The study strategy included the following:

- Compilation and selection of SDRs that have the potential to be satisfied through the utilization of space technology.

- Application of systems engineering approach to:
  - — Formulation of SDRs,
  - — Definition and selection of space-based sensor systems,

— Study of data-base management for CO_2 SDRs,
— Conceptual designs for satellite configurations, and
— Requirements for payload integration and for space transportation systems.

- Assessment of existing or modified space-based sensor systems and consideration of planned and new systems.

- Assessment of currently planned and future satellites and missions, as well as new satellites and missions.

- Investigation of data-base management concepts.

STUDY RESULTS

Science Data Requirements

SDRs were identified through contacts with the science community. Twenty-three SDRs which could potentially be met using space-based sensor systems were identified. Space-based sensor systems were selected that have the potential to satisfy these SDRs.

Space-Based Sensor System Selection

The 23 SDRs were matched to space-based sensor systems that are currently available or that may be developed during the three time frame levels. The new sensor system concepts include:

- An STS-Launched Recalibration Package to provide for continuity of measurement and intercalibration between different satellites. The Recalibration Package, which carries radiometers that are extremely accurate at selected wavelengths, could use cryogens to cool the detector and avoid measurement inaccuracies as a result of deterioration of detectors, optics and other sensor subsystems. The Package could be deployed in an orbit different from the orbit of a satellite with sensor systems that require periodic calibration by arranging for coincident views of selected target areas.

- A High Orbit Radiation Budget (HORB) satellite using radiometers could view an entire hemisphere in a higher than geosynchronous orbit. The HORB orbit and altitude could be chosen to meet spatial and temporal sampling requirements to establish the global radiation budget. Because the radiometers could measure the ratio of solar and terrestrial fluxes, the need for absolute calibration would be reduced to providing a stable, diffuse solar reflector.

- A High Altitude Powered Platform (HAPP) CO_2-monitoring system to provide high resolution continuous monitoring of selected regional climate parameters. Sensor systems at an altitude of about 20 km could provide high-resolution, continuous monitoring of CO_2-related phenomena in regions such as the West

Antarctic or the Amazon. Propulsion power to maintain the HAPP on a desired flight path could be obtained from solar cell arrays mounted on the HAPP or from microwaves beamed from a ground transmitter to a receiver on the HAPP.

- A Parallax Sensor based on optical correlation of consecutive images to provide cloud altitude. This sensor concept may provide data about the vertical distribution of clouds with optical correlation of consecutive cloud images because relative cloud motion would be small in relation to the parallax caused by the motion of a satellite.

- Direct Measurement of CO_2 by a passive method using the infrared region of the spectrum. Such a method could be based on obtaining the atmospheric temperature profile from the oxygen band in the microwave region and inverting the CO_2 band measurements using the temperature profile. Active sensing, using LIDAR, might be more accurate than passive atmospheric sounding when the accuracy and operating life of the required lasers have been improved.

CO_2 Research Satellite (CORS) Design Configuration

An existing Space Transportation System (STS) satellite bus concept for the Level II missions was selected to reduce satellite development costs. For the Level III mission, a primary structure using existing Spacelab pallets was selected to minimize development costs.

The selected design concept could reduce required ground operator interaction and control. A large, on-board command memory would permit longer intervals between command loads. On-board software status monitoring for detection, redundancy management and safety of operations could increase satellite autonomy and reduce operator duty requirements.

Consideration was given to using STS capability and to defining interfaces with the CORS without imposing special requirements on the STS for performing the missions. The Level II configuration would occupy one-eighth of the orbital cargo bay and about 17% of the STS launch capability by mass.

The CORS bus design concept provides exceptional sensor system placement capabilities and fields of view to increase mission science data return.

Data-Base Management System Concepts

Concepts for a data-base management system for the DOE CO_2 Research Program's use of the space-based sensor system data products were studied. These included the following:

- Centralized responsibilities for data base management systems.

- Timely access to highly segmented data.

- An alternative to publication as a means of scientific information exchange by means of a CO_2 data-base management center where processing, archiving, inventorying and accessing all classes of space-based sensor system data products could occur.

- Access to the analytical tools, data search strategies, and interpretive heuristics of scientific investigators.

These concepts took into account the interdependencies within and across SDRs and met requirements for partial measurements from several sensors, partial data recording and specialized data processing. The individual SDR parameters suggest that data bases be organized as small data units rather than as sensor outputs.

CONCLUSIONS

- Space-based sensor systems have the potential to satisfy the 23 SDRs and provide global coverage over very long periods.

- Several CO_2 climate parameters could be measured continuously or at frequent intervals for several decades after space-based sensor systems are operational.

- The data requirements for the space SDRs have the potential to be met by multichannel space-based sensor systems and systems with continuous spectral coverage.

- New data base management concepts are emerging to enable more flexible user data interfaces.

RECOMMENDATIONS

Specific efforts are recommended for Levels I, II and III to develop space-based sensor systems which could make effective use of future STS missions and to provide near-term data, data satisfying all SDRs and data of increasing value to the DOE CO_2 Research Program. Proceeding with efforts recommended for Levels I, II and III could ensure that information on pressing issues associated with CO_2-induced climate changes could be obtained consistent with the needs of the scientific community. Elimination of efforts recommended for Level I or Level II could delay obtaining significant data and increase space-based sensor system development risks.

Level I (0-5 Years)

The focus of this effort should be on:

- Development of a data acquisition system that will combine realtime output from NOAA, NASA and DMSP. This system should include a user-interface specifically designed to support the user requirements of the DOE CO_2 research program. It could make it possible for satellites differing in spatial and temporal coverage to provide information relevant to the DOE CO_2 Research Program.

- Development of a HAPP CO_2 monitoring system. A HAPP could maintain sensor systems above 20 km for extended periods to provide near-term data on cloud altitude and temperature, calibrate satellite data, and observe the formation and disposition of snow cover and other important selected regional phenomena.

Secondary efforts could include:

- Review and improvement of infrared and microwave sounding methods, especially with wider spectral coverage.

- Feasibility assessment of an STS Recalibration Package to provide continuity of measurements with subsequent generations of satellites and intercalibration among differing satellites operating simultaneously.

- Investigation of the potential of a HORB satellite, in a higher than geosynchronous orbit. An HORB may be capable of observing a large part of the hemisphere of the earth, to complement earth radiation budget data.

The expected results of Level I efforts are:

- An early start on the definition and development of a CO_2 data-base management system.

- Near-term use of existing space technology to meet some of the immediate needs of the DOE CO_2 Research Program.

- Definition of needed infrared and microwave measuring methods and sensor subsystems based on operational experience.

- Development and initial operation of a HAPP.

Level II (5-10 Years)

The focus of this effort should be on developing and placing into operation:

- A CO_2 Research Satellite (CORS) in polar sun-synchronous orbit for global coverage. The CORS should consist of improved versions of existing space-based sensor systems capable of remote measurements including atmospheric parameters and phenomena, surface phenomena, cloud structure, terrestrial and solar radiation, stratospheric aerosols and gases, sea level, wave height and Antarctic ice cap altitudes.

- The HAPP to provide high-resolution continuous monitoring of selected regional CO_2 climate parameters and information on cloud structure.

- The STS Recalibration Package to improve accuracy of infrared and microwave radiometers.

Secondary efforts could include:

- Continued development of advanced Fourier transform infrared and multi-channel microwave radiometers.
- Continued development of LIDAR.
- Identification of space-based sensor system for the potential HORB satellite.

Expected results of Level II efforts are:

- An operational CORS.
- An operational STS recalibration package.
- An operational HAPP.
- Development of advanced space-based sensor systems.

Level III (10-20 Years)

The focus of this effort should be on:

- Development of improved and new space-based sensor systems using a dedicated CORS which could be part of a free-flying, unmanned, space platform in a polar, sun-synchronous orbit, and serviced by the STS.
- Development of an advanced, very wide coverage Fourier transform spectrometer to provide better interpretation of atmospheric radiance data including the measurement of vertical temperature profiles and concentration of molecular species and aerosols which would result in more accurate CO_2 climate data.
- Deployment of LIDAR for vertical sounding, Doppler wind data, and altimetry measurement.
- Continued operation of HAPP and of the STS Recalibration package.

Expected results of Level III efforts are:

- Advanced space-based sensor systems.
- Advanced space-based sensor systems integrated with a free-flying space platform.
- Data which satisfy all SDRs.

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1.0 SPACE SYSTEMS REQUIREMENTS DEFINITION

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1.1 OBJECTIVES

The objectives of Task 1.0 were to compile CO_2 SDRs for space monitoring systems through iterative cycles of science review and measurement systems evaluations. The emphasis was on selecting parameters related to CO_2-induced climatic changes.

1.2 METHODOLOGY

The definition of the space systems requirement for a CO_2 climate monitoring system required the compilation of a set of SDRs of value to the CO_2 scientific research community. (See Appendix A.)

The compilation of SDRs were based on discussions with a representative cross section of the scientific community and a selective survey of the extensive literature dealing with the measurement of CO_2-induced climatic changes. This approach resulted in a baseline set of SDRs to determine what could be accomplished with space-based sensors.

The scientists contacted by this study team are listed in Table 1. These experts in climatology and general circulation models discussed those parameters which they believed to be the most important for long-term CO_2-induced climatic changes; explained the rationale for selecting these parameters; and where possible, provided requirements for the resolution, accuracy, and precision, as well as references, and other information considered relevant.

The key literature references surveyed as part of this task are listed in the bibliography. References specific to an SDR are provided in Appendix A.

The SDRs were compiled and reviewed to select those for which data could most effectively be provided by space-based sensor systems. Twenty-three SDRs emerged as the basis for the investigation of space systems in this study.

1.3 COMPILATION OF SCIENTIFIC DATA REQUIREMENTS (SDRs)*

The earth's climate is so complex and includes so many nonlinear interactions that it may not be possible to give a fully satisfactory accounting (either explanatory or predictive) of its behavior. In addition to the diurnal and seasonal cycles, the climate varies stochastically with time, and the geographical distribution of climatic patterns is constantly shifting. It is therefore very difficult today to identify the exact causes of a given climatic change because it is not certain whether an observed change is due to a permanent trend or to a random fluctuation. In addition, climatic changes occur gradually in time and space so both the rate of change and cumulative magnitude of change in each parameter must be determined. The climate system is deterministic, however, and predictions of an average expected state given a change in a specific driving force (such as CO_2 concentration) may be possible.

*See Appendix A for SDRs.

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TABLE 1

SCIENTISTS CONTACTED*

Name	Affiliation
Professor Reid Bryson	University of Wisconsin, Madison, WI
Dr. James Coakley	National Center for Atmospheric, Research, Boulder, CO
Dr. George Kukla**	Lamont-Doherty Geological Observatory, Columbia University, Palisades, NY
Professor Edward Lorenz	Massachusetts Institute of Technology, Cambridge, MA
Dr. Michael MacCracken	Lawrence Livermore National Laboratory, Livermore, CA
Dr. Roland Madden	National Center for Atmospheric Research, Boulder, CO
Dr. Syukuro Manabe	Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, NJ
Professor Michael McElroy**	Harvard University, Cambridge, MA
Dr. Jerome Namias	Scripps Institution of Oceanography LaJolla, CA
Dr. John Perry	National Research Council, National Academy of Sciences, Washington, DC
Professor Richard Pfeffer	University of Florida/GFDI
Professor David Staelin**	Massachusetts Institute of Technology, Cambridge, MA
Professor Peter Stone	Massachusetts Institute of Technology, Cambridge, MA
Dr. Wei-Chyung Wang**	Atmospheric and Environmental Research, Inc., Cambridge, MA
Dr. Warren Washington**	National Center for Atmospheric Research, Boulder, CO
Professor Jay Winston	University of Maryland, College Park, MD

*Scientists were identified in cooperation with the Office of CO_2 Research, DOE.

**These selected scientists also acted as consultants to the project, giving guidance on several issues.

Typically these predictions can be made by using mathematical models which represent the physics of climate as a series of coupled differential equations. The simplest models may be solved analytically, but normally they must be solved numerically using a computer.*

The most comprehensive models are known as general circulation models (GCMs). GCMs represent the underlying physics of the atmosphere, oceans, and cryosphere in considerable detail and give the expected global distributions of such climate indicators as sea surface temperature, soil moisture and snow cover. While other (i.e., non-GCM) classes of climate models provide valuable insights into certain aspects of climatic processes, only GCMs can provide long-term predictions for future DOE management decision-making with regard to fossil fuel and CO_2 reactions/interactions.

An assessment of CO_2-induced climatic change can be formulated addressing the following questions in succession:

- Is the climate changing on the timescale of observations, and if so, how are the changes defined?
- To what factors are the changes attributable?
- What are the predicted effects (nature, magnitude, location) of future climate changes?
- What components of climatic change are due to CO_2?

The question of whether a change is occurring may be answered by performing time series and other statistical analyses of modern, direct measurement data, as well as of historic data such as that from ice cores and tree rings. Discovering the cause of the change requires several classes of climate models executed in a steady-state mode. Determining future trends requires running the models in a time-dependent mode in order to describe fully the changing dynamics over a relatively long period.

The models in turn require descriptions of both short- and long-term dynamic effects, as well as an accurate measurement of the climate state for comparing and calibrating model predictions with observed conditions. The models also require information on parameters such as radiatively active gases believed to be causing the observed changes.

Figure 1 depicts the type of information required to answer the questions listed above as well as their interrelationships. (See Table 2 and the accompanying text for more information.) The information categories include:

- *Modern Measurements.* These provide data which can be employed to determine whether or not a climatic shift is occurring.

*An excellent overview of the hierarchy of climate models developed during the last fifteen years may be found in the Harper's Ferry Conference Proceedings referenced in the bibliography.

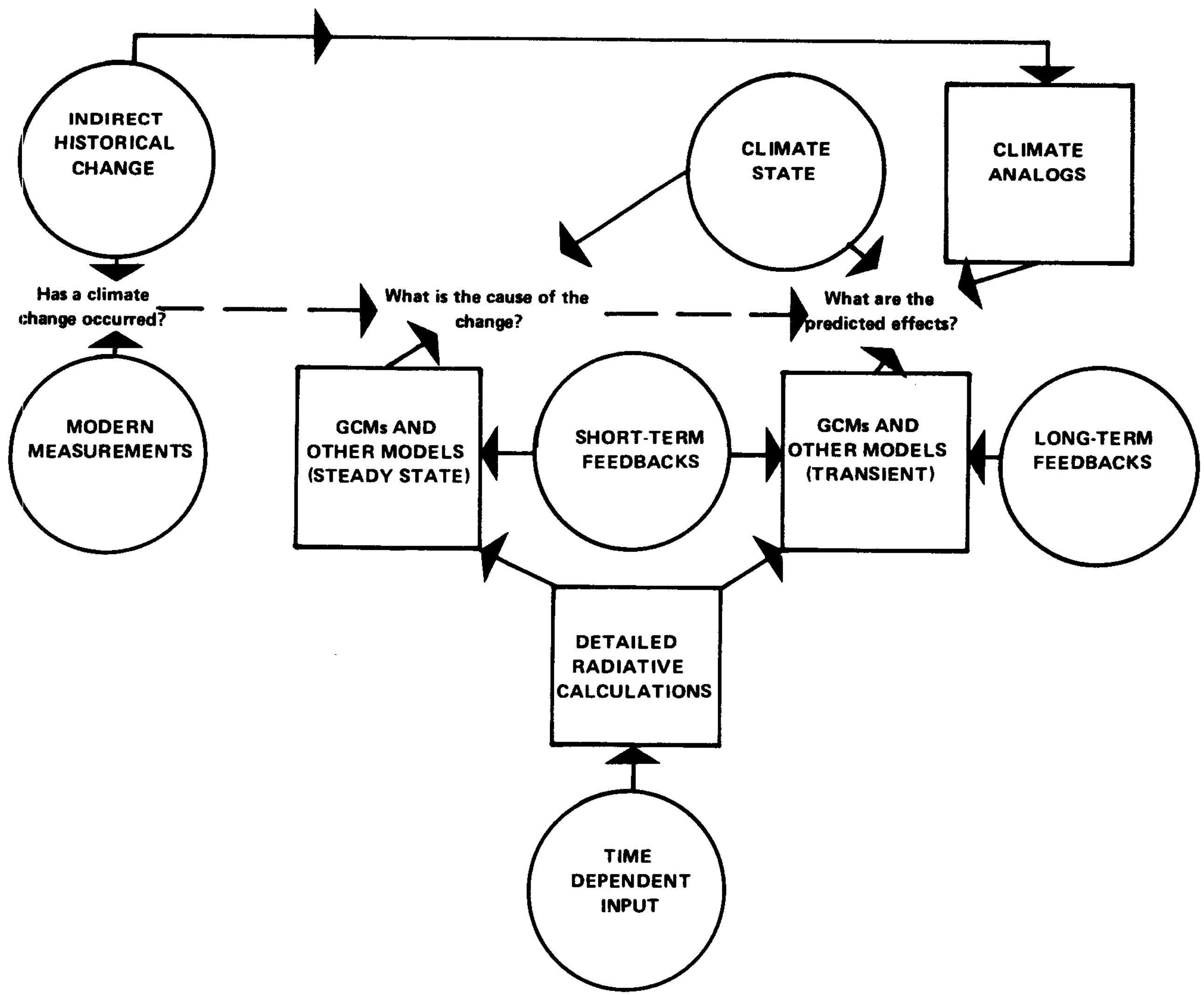


FIGURE 1 FLOW OF INFORMATION IN THE ASSESSMENT OF CLIMATE CHANGE

TABLE 2

LINKAGE OF THE SELECTED SCIENTIFIC DATA REQUIREMENTS TO THE DOE CO_2 CLIMATE PROGRAM

Scientific Requirements	Modern Measurements	Time Dependent Input	Climate State	Short-Term Feedbacks	Long-Term Feedbacks
Radiation (Incoming)		●			
Radiation (Outgoing)	●		●	●	
Clouds: % Coverage			●	●	
Clouds: Vertical			●	●	
Trace Gases		●			
Aerosols		●			
Temperature: Vertical	●		●	●	
Wind				●	
Precipitation			●	●	
Water: Vertical:			●	●	
Sea Surface Temp.			●	●	
Sea Ice Extent			●	●	
Ocean Current					●
Oceans: SFC. Winds					●
Sea Level	●				
Oceans: SFC. ATM. Pres.			●		
Soil Moisture			●	●	
Snow Cover	●		●	●	
Surface Albedo					●
Land Ice	●				●
Ground Temperature	●		●	●	
Biosphere			●		●

- *External Factors.* These parameters represent those factors independent of CO_2 concentration that can potentially affect climate as greatly as CO_2. Their variations over time provide a confounding effect which must be considered when attempting to establish causal mechanisms.

- *Short-Term Feedbacks.* These feedbacks involve parameters which interact with the rest of the climate system on a time scale of months to a few years. In general these parameters have large interannual fluctuations.

- *Long-Term Feedbacks.* These parameters are involved primarily in long-term climatic effects, i.e., those on a time scale of decades or more. In general they have relatively small interannual fluctuations.

- *Climate State.* These variables are those that calibrate models under steady-state conditions and serve to verify model predictions of time-dependent climatic behavior when modeling the transient response.

The analysis of likely CO_2-induced climatic change is a special case of the more general climate predictions. Its uniqueness lies in the fact that it is an externally-induced change occurring over many decades and with a relatively straightforward cause. Because the climate will continue to fluctuate randomly, it will be difficult to predict its year-to-year or decade-to-decade response to increasing levels of CO_2. Compounding these difficulties are the limitations of the GCMs used to make those predictions. Some of these limitations may be due to flaws in the GCM concept and some may be due to a lack of reliable data.

These difficulties will be resolved only gradually over a period of years as more data are gathered through routine meteorological and geographical measurements, special experiments (such as TOPEX), improved computational capabilities, and long-term measurements with space-based sensors systems. After the new data are analyzed, they must be incorporated in GCMs. The improved GCMs must be run again in order to reexamine CO_2 effects, and the entire process must be iterated. This process, while complex and difficult, is the most likely to provide reliable predictions of CO_2-induced climatic changes.

The SDRs address primarily macroscopic, physical quantities required in the assessment of climatic change caused by increases in CO_2 concentration. The information related to each SDR was formulated in such a way as to provide the basis for selecting space-based sensor systems. The SDRs include the following information:

- A brief description of the parameter and a short rationale for its inclusion;

- Temporal and spatial resolutions *(of the SDR itself, not necessarily of the measurements)*;

- Error tolerances required for model processing and for establishing climate change trends;

- Previous remote sensing experiences, if any; and

- Persons who may provide guidance on implementation details.

The information most difficult to determine was the specification of the required resolutions and error tolerances. The term "error tolerance" is used (rather than accuracy and precision) because it best describes the way in which the scientific community considers problems of accuracy and precision. In discussions with members of the scientific community, almost all of them stressed the difficulty of specifying the different requirements for accuracy and precision.

For the purposes of this study, it was critical that the distinction between accuracy and precision be made as explicitly as possible; this distinction is discussed in detail in Appendix B. Briefly put, the main problem is that accuracy and precision are defined only with respect to a specific averaging time and measurement frequency, and many of the parameters (e.g., soil moisture) have never been systematically measured over a long period of time on a global scale.

In addition to the previously mentioned difficulties there are requirements for:

- Monitoring the earth's climate for evidence that a change is occurring.

- Comparing climate model predictions with actual observations.

- Developing empirical parameterizations used in climate models to represent subgrid phenomena.

These requirements are difficult to separate in practice. For climate monitoring purposes, measurements which provide high precision but which have coarse resolution may be adequate. Comparison with GCM model outputs, on the other hand, requires that data should be available at least at the spatial resolution of the models themselves (typically as regional or zonal means). Finally, developing empirical approximations to be used in the models requires a still finer resolution and a much more severe set of accuracy and precision constraints.

The resolution of the derived information may be much coarser than that of the raw measurements. For example, if an instrument is designed to take daily measurements of a specific parameter on a 10-km grid in order to calculate monthly averages on a 20- or 100-km grid and if there is significant noise in these raw measurements, the weekly averages on a 20-km grid will be less reliable than the monthly averages on a 100-km grid because of the decrease in measurements per grid point. Finer-scale averaging can be done but there is no assurance that the quality of the results will be acceptable to the science community. If weekly averages on a 20-km grid are essential, an alternative measurement technique may be required. These trade-offs between resolution and accuracy are discussed further in Appendix B.

In order to permit tradeoffs to be made when required, a range of resolution and error tolerances that spans the possible uses of the data by the scientific community was indicated for many of the SDRs. In general, whenever a range of resolution and error tolerance is given, candidates for a space-based sensor system include all of those measurement techniques which can provide derived climatic data within those ranges.

1.4 DETERMINATION OF SDRs THAT CAN BE SATISFIED THROUGH EFFECTIVE UTILIZATION OF SPACE-BASED SENSOR SYSTEMS

The list of SDRs which could be satisfied using space-based sensors was constructed using the following criteria:

- The uniqueness of space-based measurements.
- The overall technical feasibility of a measurement technique.

Table 3 shows the final set of SDRs which met these criteria. The Table was developed using the procedure shown in Appendix C. Each SDR (see Appendix A) includes a general description, technical description, related parameters, geographical extent, resolution, error tolerance and references to applicable existing space-based sensor systems. The information provided for each SDR indicates the assumptions and the quality of available information which was used as the basis for evaluating the effective use of space-based sensor systems.

The following SDRs were found not to meet the criteria for effective utilization of space-based sensor systems or were included in the other SDRs for the reasons indicated:

1. *Diurnal cycle of clouds*: This SDR was included as a subset of "cloud coverage," or vertical structure of clouds, because data on diurnal cloud variations is considered part of general cloud coverage measurements and may be important on both a regional and a global scale.

2. *Air-sea temperature difference*: This parameter is more amenable to measurement at the surface; e.g., with a series of automatic instrumented buoys. Although sea surface temperature can be measured easily, as yet surface air temperature (from the vertical temperature profile) cannot be measured with sufficient accuracy to determine air-sea temperature differences.

3. *Ocean heat flux*: This extremely important parameter is calculated using two separate sets of measurements: ocean temperature and ocean currents. Moreover, poleward flux occurs throughout the boundary layer; thus measurements of this parameter from space would require extrapolation from surface conditions to the entire boundary layer.

4. *Thermocline depth*: Direct remote sensing of this parameter seems impractical. It may be possible to measure the thermocline depth with blue-green lasers but this possibility requires a detailed feasibility study. A series of instrumented buoys is the presently preferred method for making long-term measurements of this parameter.

TABLE 3

LIST OF SDRs

Clouds Vertical Distribution
Cirrus Clouds
Global Radiation Budget
Trace Gases (Including O_3)
CO_2
Soil Moisture
Temperature Vertical Profile
Temperature (Ground)
H_2O Vertical Distribution
Sea Ice
Cloud Percent Coverage
Sea Currents
Sea Level
Precipitation
Snow Cover
Vegetation Index
Aerosols
Surface Albedo
Sea Surface Temperature
Sea Surface Wind
Land Ice
Wind Field (Vertical)
Sea Surface Pressure

5. *River runoff*: This phenomenon conceivably could be established through space-based measurement by observing the color difference due to a silt "plume" created by rivers. Surface-based measurements appear preferable.

6. *Evaporation and evapotranspiration*: These two SDRs were eliminated because they are best measured indirectly by first observing other parameters, such as temperature, moisture, and wind, and then estimating moisture flux empirically.

Some of the SDRs for various parameters can serve several purposes. For example, some might be useful for monitoring climatic changes as well as being model-related (e.g., outgoing radiation); or some might be of interest to biologists, as well as to climatologists (e.g., soil moisture). For classification purposes, however, only primary requirements were considered. These primary requirements are indicated in Figure 2, where each SDR is identified with a specific aspect of the DOE CO_2 Research Program. The categories shown represent only a primary focus of each SDR, not their total range of usefulness.

1.5 ANALYSIS OF THE SPACE SDRs

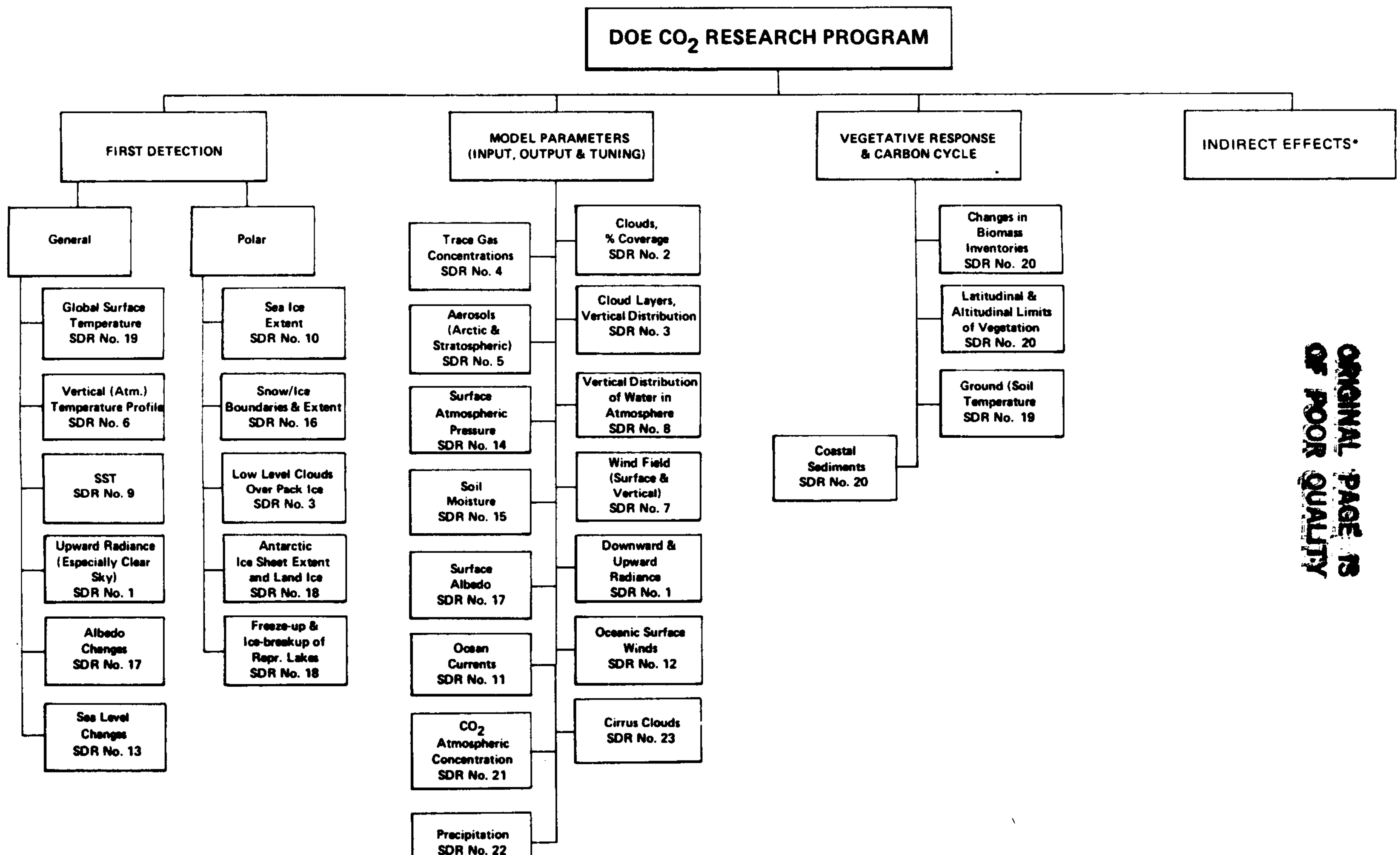
Analysis of the 23 space SDRs, interviews with the scientific community, (See Appendix A), and reviews of the selected literature resulted in the following findings which were used to guide systems engineering efforts.

1.5.1 Space-Based Sensor System Selection Considerations

- The goal for a space-based sensor system should be to provide global coverage of selected parameters.

- The primary requirement is for continuous measurements of several basic parameters (at relatively frequent intervals) for at least two decades. Most models predict that at least 20 years of increasing CO_2 levels will have to occur (assuming an eventual doubling in the next century) before the climatic changes can be detected. Many of the parameters that are related to first detection have been measured for short periods on other space missions such as the Nimbus series. However, there appears to have been no continuous (calibrated) record of these measured parameters. Long-term coverage is needed to help verify that climatic changes due to increasing CO_2 are occurring.

- Selected space-based sensor systems potentially should satisfy all the SDRs. Quasi-redundant coverage of SDRs by systems or overlapping of spectral ranges is potentially desirable to ensure system intercalibration and establish the reliability of the data output. Multispectral imaging (in visual, IR, UV and MW channels) by several systems with a coordinated field of view (FOV) has the potential to provide data for all the SDRs. Each SDR, however, will require different statistical treatment — e.g., zonal and regional gridding, daily/monthly/seasonal/annual averaging — and storage (as globally averaged contour maps, or in digitized form).



*Not included in the scope of this study

FIGURE 2 RELATION OF SDRs TO DOE CO_2 RESEARCH PROGRAM

- A polar sun-synchronous, fixed-attitude satellite will provide repetitive solar irradiation conditions and continuous exposure of solar cell arrays for maximum power.

- Satisfying some of the SDRs to be measured with space-based sensors may require additional ancillary equipment. For example, space measurement of sea surface temperatures, currents, and precipitation may require instrumented buoys and platforms on the ground. Examples are:

  — an IRLS (Interrogation, Recording and Location System), which determines the satellite position and collects data from ground stations.

  — a DCS (Data Collection System), to receive, process and store data from buoys and balloons and relay it to ground stations.

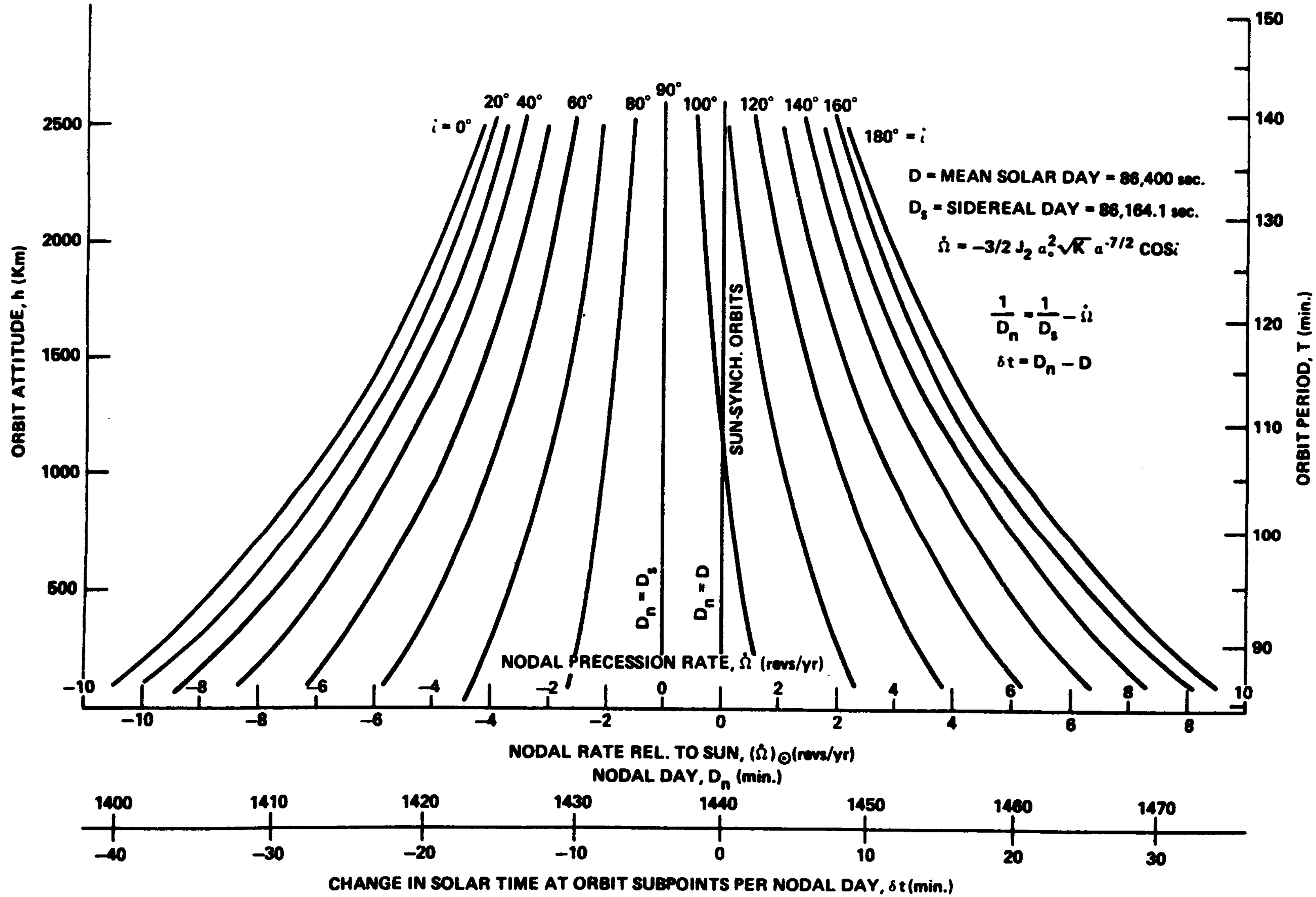
1.5.2 Orbit Selection Considerations

To obtain uniform geographic coverage with emphasis on polar regions, such as the West Antarctic, circular polar or near polar orbits are required. The most useful range of altitudes extends from about 800 to 1200 kilometers. The atmosphere sets a lower limit while ground resolution, the range of active sensors and the earth's radiation belts place an upper limit on altitude.

The orbital period is weakly dependent upon altitude. At ground speeds around 6.5 km/sec, satellites cross the equator about every 105 minutes, with the tracks between 25 and 30° apart. When the plane of the orbit is inclined with respect to the meridian, the oblateness of the earth causes it to precess, so that the satellite either becomes sun-synchronous or sweeps over local solar time in the course of weeks to years. Sun-synchronous orbits provide repetitive observations at constant local solar time.

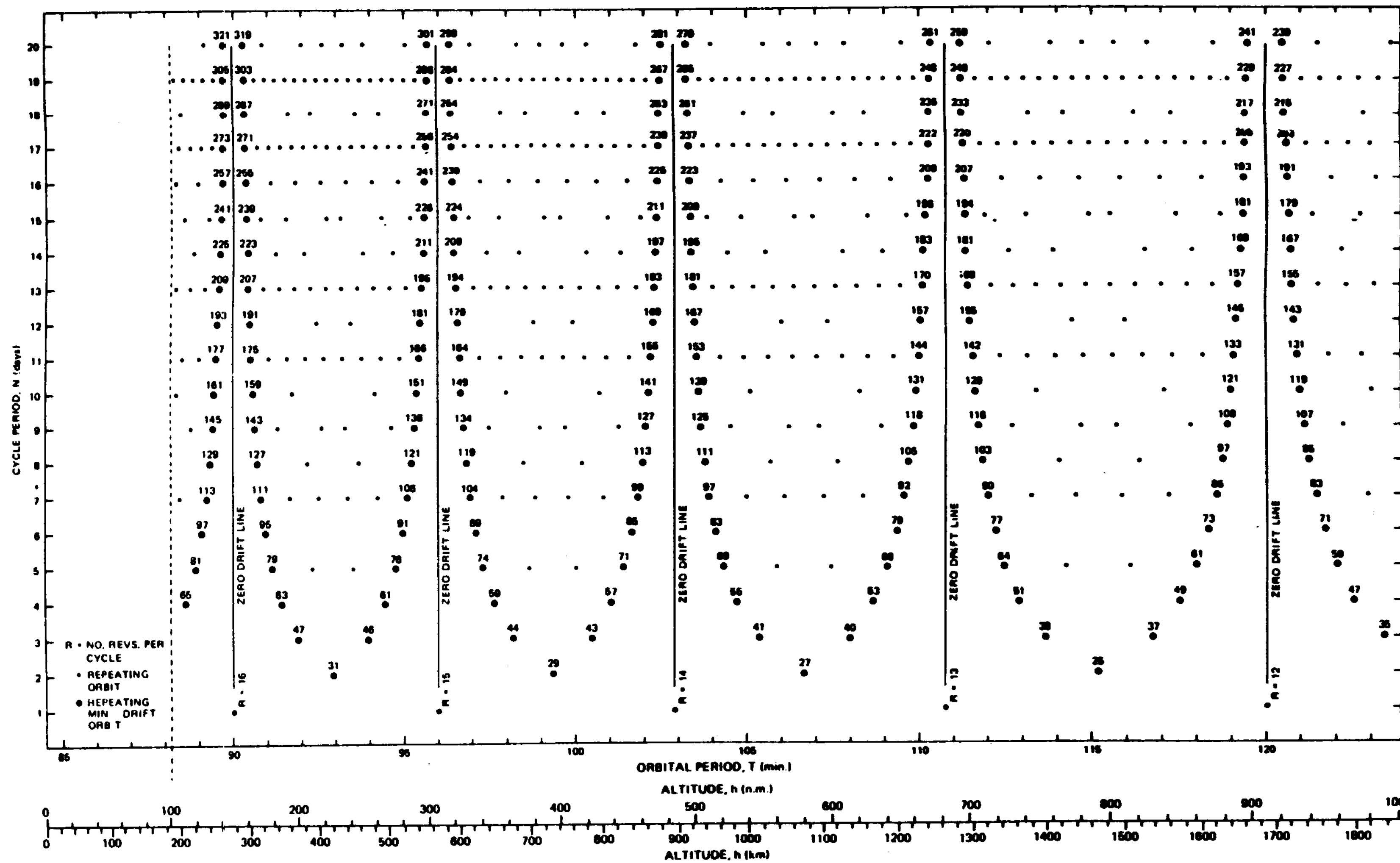
Swath width, i.e., the width of cross-track scan, is determined by permissible slant angle and distortion of the footprint. Swath width determines the revisit time for a given orbit pattern. A swath of about 2900 km samples the entire earth twice daily. Orbital parameters can be chosen to provide a repetitive ground trace with a set of revisit times that matches several different space-based sensor systems with SDRs. In such an orbit repeat cycle, instruments with narrower swath widths sample less frequently; that is they have longer revisit times. Figures 3 and 4 show these relationships and are accurate enough to allow a tentative choice of orbit pattern and repeat cycle.

An orbit and a repeat cycle provide both the required temporal coverage, i.e., revisit time and the required emphasis on high latitude observations. Table 4 shows the SDRs topics with their respective temporal sampling rates, local (solar) time requirements, accuracy requirements, grid size and "Appropriate Swath."



Source: Staelin, D.H., and Rosenkranz, P.W. High Resolution Passive Microwave Satellites. Massachusetts Institute of Technology, Cambridge, MA, April 1978.

FIGURE 3 SATELLITE ORBIT PRECESSION AND TABULATED VIEWING PARAMETERS



NOTE ABSCISSA SCALES (T and h) ARE CORRECT FOR SUN-SYNCHRONOUS ORBITS AND APPROXIMATE FOR OTHERS. SEE TEXT FOR CORRECTION PROCEDURE

Source: Staelin, D.H., and Rosenkranz, P.W. High Resolution Passive Microwave Satellites. Massachusetts Institute of Technology, Cambridge, MA, April 1978.

FIGURE 4 ARRAY OF ORBITS WHICH PRODUCE REPEATING SWATH PATTERNS

TABLE 4

SDRs AND ORBIT PATTERN AND REPEAT CYCLE

Sensor/System **SDR**	**Temporal Sampling Hours Days Months**	**Approx. Swath (km)**	**Achievable Temporal Sampling (Days)**	**Local Time Req't (Estim.)**	**Required Accuracy (SDR)**	**Grid Size (SDR) (km)**
Clouds Vertical Distrib.	0.5D	2300/3000	3/1	scan	1/2	200
Cirrus Clouds	1D (1M)	3000	1	scan	—	200
Global Radiation Budget	UV 1D Other 1M	3000	1	scan	0.1-5%	1000
Trace Gases Including O_3	1M	LIMB		any	0.5ppm,1%	1000
CO_2 High Accuracy	(1M)	2300	3	any	1ppm,0.3%	500
Soil Moisture	1M	800	4	scan	10%	500
Temperature Vertical Profile	(5D)	2300	3	scan	1-2°C	500
Temperature (Ground)	1M	3000	1	scan	1°C	500
H_2O Vertical Distribution	2D	2300	2	any	10(1)%	200
Sea Ice	5D	800/3000	4/1	any	1%	200
Cloud Percent Coverage	0.5H(5D)	2300/3000	3/1	scan	5(1)%	200
Sea Currents	1M	3000	1	any	2-5cm/s	200
Sea Level	1M	NADIR	4	any	10cm	200
Precipitation	1D	800	4	scan	10%	200
Snow Cover	5D	800/3000	4/1	any	5%	200
Vegetation Index	1M	3000	1	any	—	200
Aerosols	1M	LIMB		any	10%	1000
Surface Albedo	1M	3000/2300	4/2	any	2%	200
Sea Surface Temperature	5D	800/3000	4/1	scan	0.2-0.5°C	200
Sea Surface Wind	1M	800	4	scan	2m/s	100
Land Ice	12M	800/3000	4/1	any	1M Elevation	—
Wind Field (Vertical)	0.5D	—	4	scan	0.3m/s	500
Sea Surface Pressure	1M	—	4	scan	1.5mb	500

NOTE: ( ) refers to averages.

The following can be deduced from Table 4.

- The only requirement for a high observation rate is for cloud coverage. Two observations per hour are required, averaged over five days. This rate is possible from geostationary satellites.
- The SDRs for vertical cloud structure and vertical wind field require two observations per day. Neither SDR can be measured with present space-based sensor systems. For example, existing systems can observe only top cloud altitude. Cloud thickness and the extent of underlying cloud layers at present cannot be measured directly. Limited information can be obtained about underlying cloud layers in broken cloud fields. Adequate systems are not expected to be available in Level II. In Level III, the LIDAR may provide data on vertical wind fields.
- With the above exceptions, the temporal observation requirements range from 12 months to 1 day. Sensor swath widths range from 800 km (SMRR) to 3000 km (AVHRR). (See Figures 3 and 4.)
- The purpose of radar altimeters is to make observations at the Nadir.
- SAGE-2, the limb sensor for aerosols and trace gases, requires sunrise or sunset to make transmission measurements using the sun as the radiation source.

The following orbit and repeat cycles were selected to meet the requirements of Table 4:

55 orbits/cycle
4 nodal days/cycle
13.75 orbits/nodal day
982 km altitude
105 min. approx. period
99.4° inclination (sun-synchronous)

In this pattern, directly consecutive orbits are 2909 km apart at the equator. The entire orbit pattern shifts eastward every day by 727 km at the equator. A space-based sensor of 727 km swath width will scan the earth in 4 days while a sensor of 2900 km swath width will scan the earth daily. Each "scan" of a given location on the earth consists of one overflight in an ascending and another in a descending mode, 12 hours apart. The data sampling rates are thus double the number of "scans." The result is shown below.

Swath	Scans	Data Sampling Rate
800 km (SMMR)	4 days	2 days
2300 km (HIRS-2)	3 days	daily
3000 km (AVHRR)	daily	twice daily

The inclination of 99.4° makes the orbit sun-synchronous and allows single axis articulation of the solar arrays. In this orbital pattern, all data at a given latitude are taken at the same (two) solar times (ascending and descending modes). This restriction on scanning of climatic parameters is a trade-off against having to place the system on a satellite with a derotated platform, or having to provide two-axis articulation for the solar arrays. As a compromise and to regain some freedom to choose different local solar times, it would be possible to rotate the orbital plane with respect to the sun over a limited range at intervals of a few months.

2.0 PRELIMINARY CONCEPT DEFINITIONS OF SYSTEMS/SUBSYSTEMS

2.1 OBJECTIVES

The objectives of Task 2.0 were to identify and to develop, to the extent necessary, preliminary concepts for space-based sensor systems and subsystems to meet the SDRs identified in Task 1.0.

2.2 METHODOLOGY

The approach involved the identification of the useful portions of the electromagnetic spectrum, as well as the preparation of Subsystem Fact Sheets (SFSs) to summarize the data on remote sensing instruments presently available or under development.* The SFSs were then matched to the desired spatial resolution, geographic coverage, temporal sampling frequency or revisit time, precision and/or accuracy specified on the SDRs. Finally, any new sensors or system concepts that have the potential to complement the SFSs in order to satisfy the SDRs to the fullest extent possible were identified.

The various instruments were then assembled into systems and assigned to time frame levels, which are defined as follows:

Level I: 1 to 5 years; minor modifications to currently operating instruments.

Level II: 5 to 10 years; techniques presently in research and development. Successful experiments have been conducted.

Level III: 10 to 20 years; initial studies on the concept show scientific value and feasibility.

In order to establish the time frame levels for these sensor subsystems and their capabilities in satisfying the SDRs, specific sensor subsystems were selected based on the information contained in the SFSs relating to performance and characteristics of each sensor subsystem. Sensor subsystems which required additional development were identified and further information on their performance and characteristics was obtained from the literature and from interviews with knowledgeable individuals. The capability of a specific sensor subsystem to meet an SDR was determined by using the performance data and characteristics of sensor subsystems and applying the judgment of instrument developers in projecting the potential for growth in sensor subsystem capabilities. The results of using this methodology in relating sensor subsystems to SDRs for the three time frame levels were reviewed by the study team members, consultants, and subcontractors. The results were presented at reviews with NASA,

*The SFSs were prepared by Ball Aerospace Systems Division and are provided in Appendix D to this report.

DOE, and members of the science community, and their comments and suggestions were solicited for incorporation in the final assessment.

2.3 USES OF THE ELECTROMAGNETIC SPECTRUM

Space-based sensing of the climatic phenomena pertaining to the SDRs primarily take two forms: analysis of electromagnetic radiation and readout of ground station data. The fan diagram in Figure 5 indicates the electromagnetic spectral ranges that appear to be best suited to establish the parameters associated with the SDRs. Comparison of the possible space-based sensor systems with the SDRs led to the following findings:

- Meeting any individual SDR requires several channels in different spectral regions so that allowances can be made for the effects of the other parameters on the measurement and to discriminate against systematic errors that may be present in any single measurement channel.

- An SDR could require several spectral channels to permit the appropriate algorithms to be employed.

As these findings apply to a greater or lesser extent to all of the SDRs, the optimum space-based sensors would use broad spectral coverage from the microwave through the infrared and ultraviolet/visible regions. A number of SDRs can be equally well monitored in several of these regions, but if the SDRs are simultaneously monitored in different spectral regions, allowance can be made for interferences and systematic errors present in each experimental technique.

Such considerations have resulted in the development of a multichannel space-based sensor system such as the one flown on Nimbus 6.[1] Figure 6 shows 22 channels extending over the visible infrared and microwave regions which were used to make measurements of five SDR-related parameters. Future space-based sensor systems will benefit greatly from increasing the number of microwave channels and substituting continuous spectral coverage in a broad part of the infrared spectrum for the 16 channels shown in Figure 6. Broadband continuous coverage in the IR could improve information on: atmospheric temperature profile, surface temperature, cloud top altitude, trace gases including H_2O, CO_2, and O_3, aerosols, and surface emittance.

For instance, as shown in Figures 7 and 8, the spectral emittance of the surface or aerosols (including clouds) in the field of view shows significant departures from blackbody behavior. In Figure 7 the spectral variations are related to the surface emittance of various minerals in the Sahara Desert and Atlas Mountains. Not only does such information help diagnose the surface composition, it is necessary for a good estimate of the surface temperature, because the surface cannot be assumed to be a blackbody at any wavelength. The spectral signatures that are obtained over a broad wavelength range allow a better estimate of the correct blackbody temperature of the radiating surface. In Figure 8 it can be seen that haze and "cloud contamination" of the spectral data also cause departures from blackbody shape. Again it is possible, using infrared spectroscopy, to infer both composition and effective emittance (and thereby correct temperature), assuming that a sufficiently wide range of spectral data is obtained.[2,3]

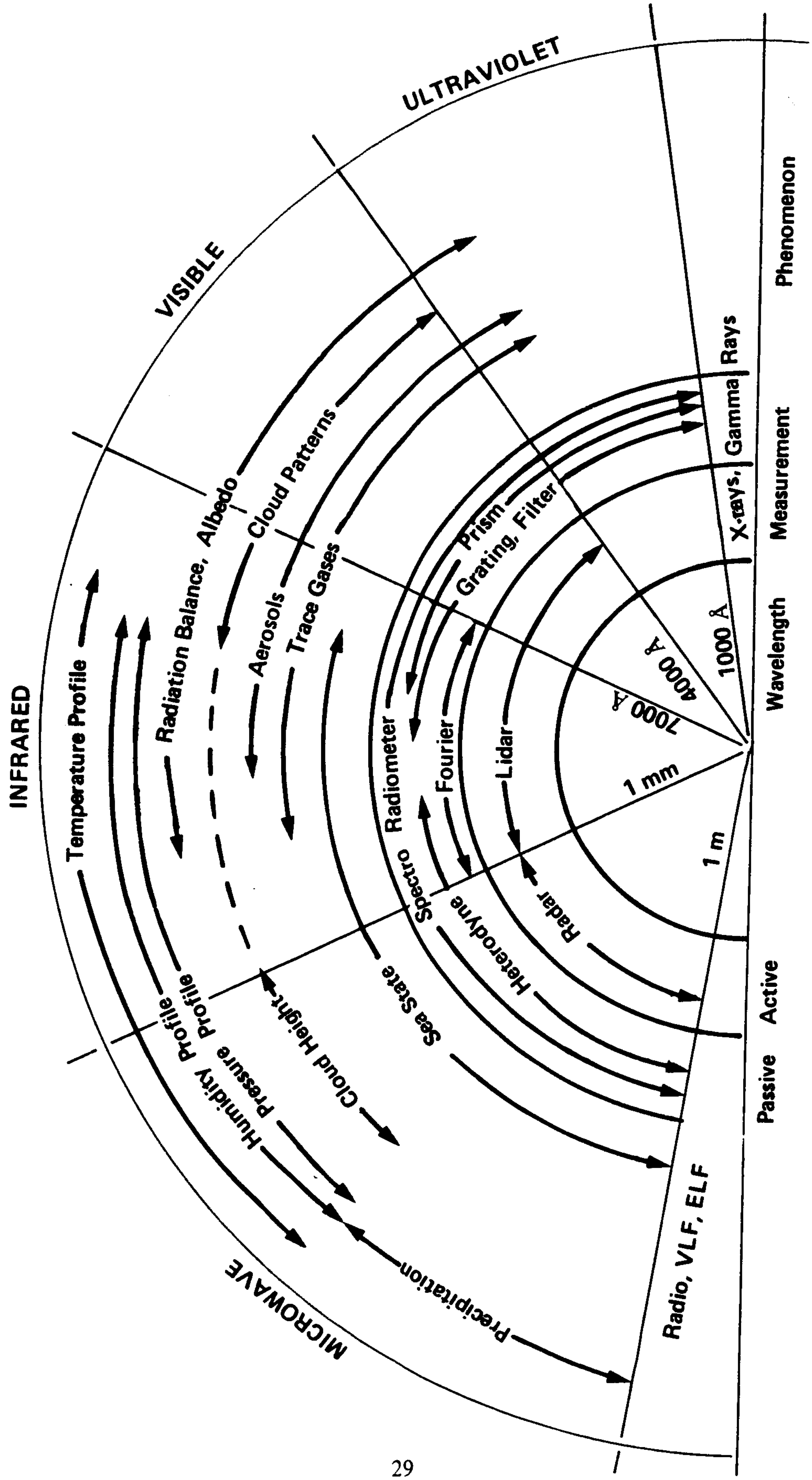
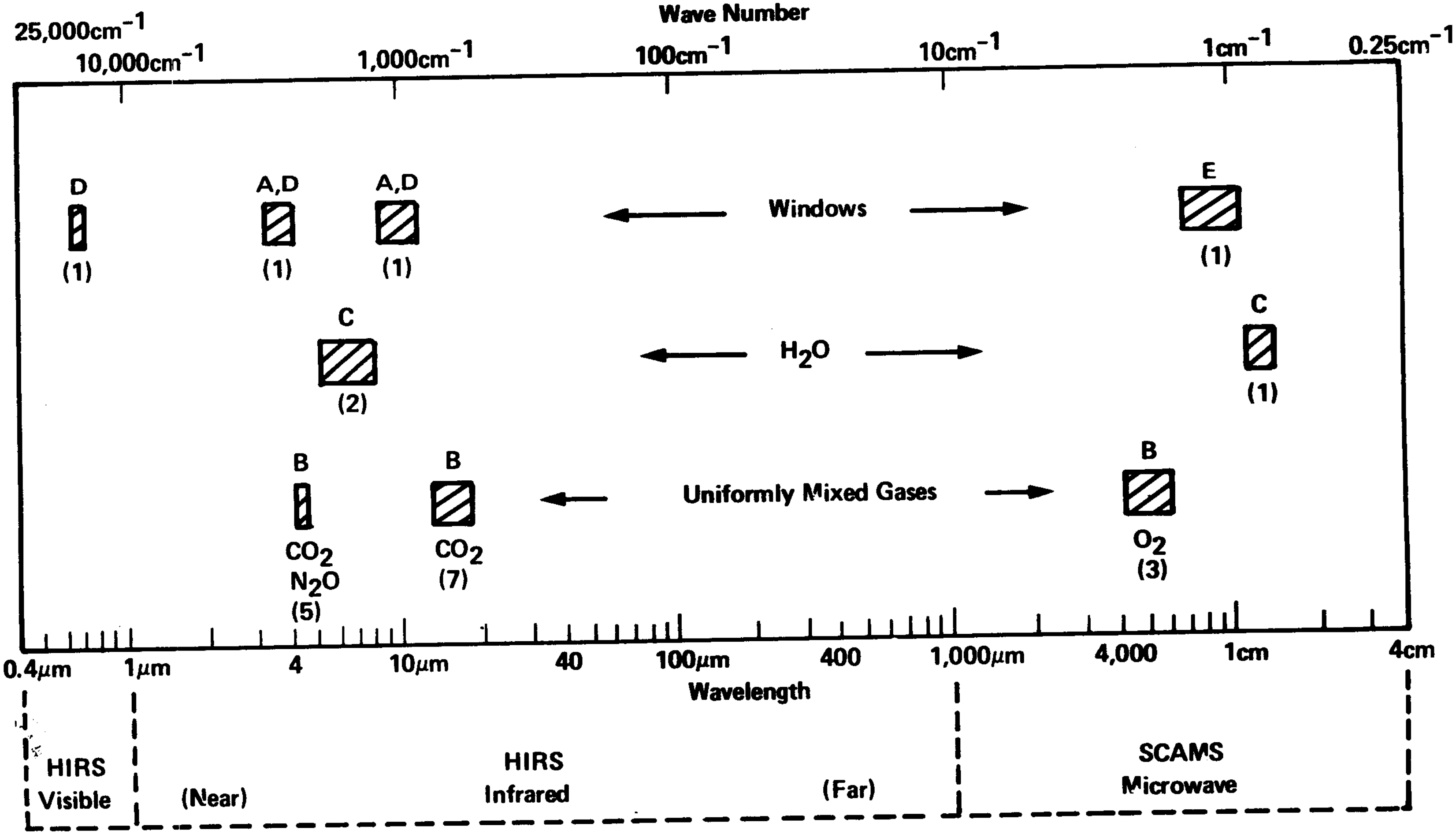


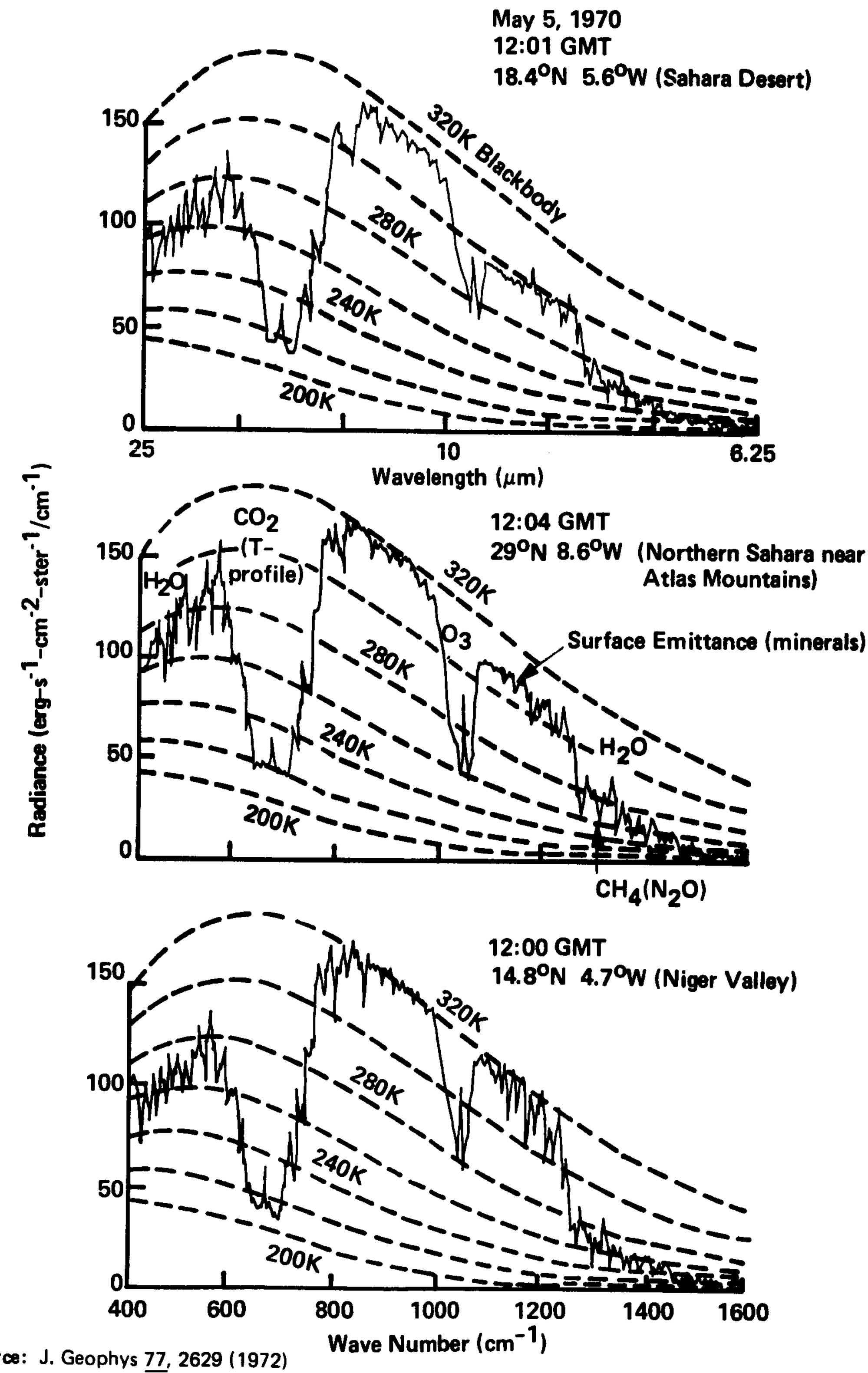
FIGURE 5 USES OF THE ELECTROMAGNETIC SPECTRUM



Legend: ( ) = # of Channels SDR's
A = Surface Temperature
B = Temperature Pressure Profile
C = Humidity Profile
D = Fractional Cloud Coverage & Height
E = Cloud Liquid H_2O Content

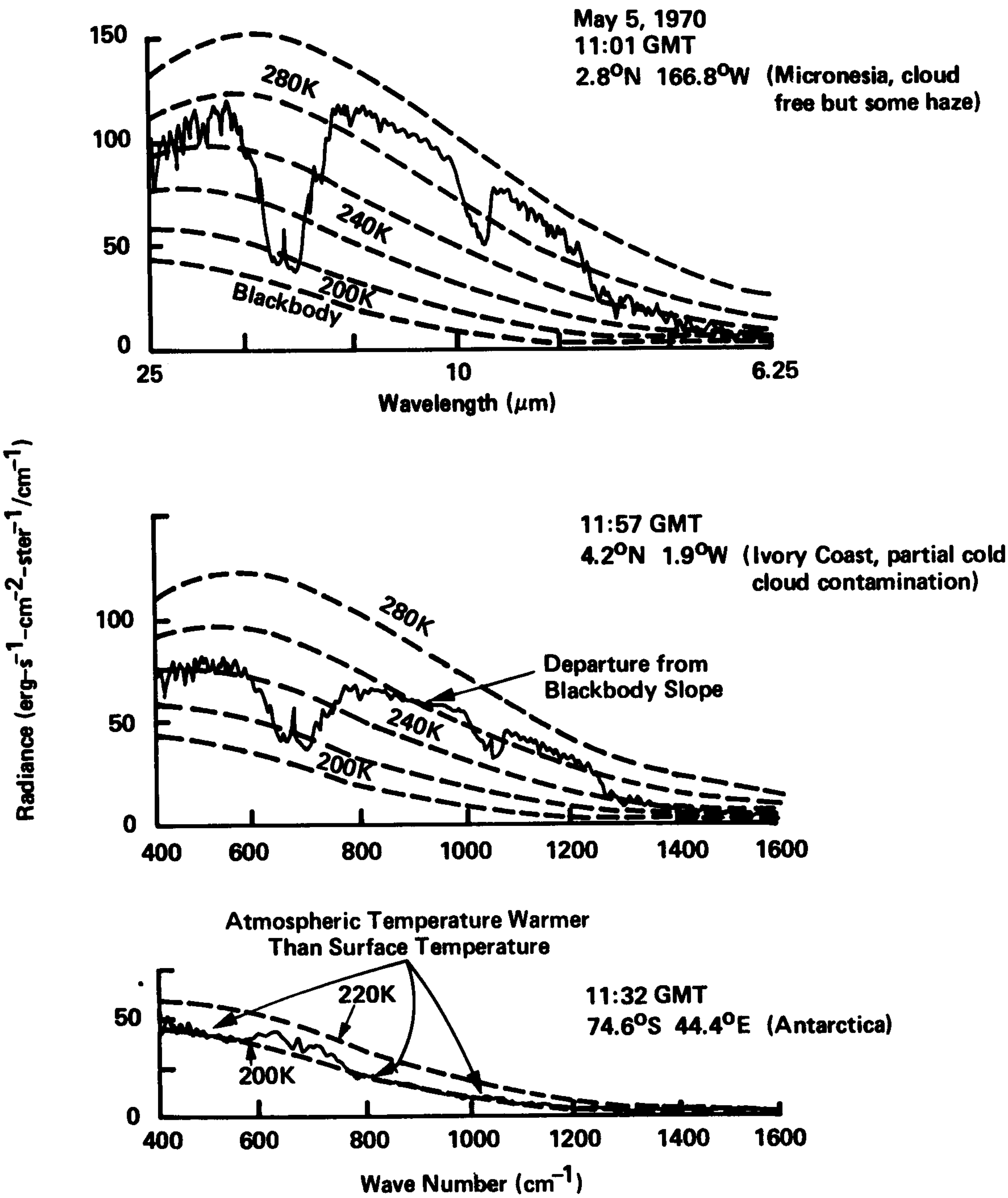
Source: J. ATM. SCI. 33, 1127 (1976)

FIGURE 6 TYPICAL MULTICHANNEL INSTRUMENT PACKAGE AND SDRs MEASURED, NIMBUS 6 (HIRS AND SCAMS)



Source: J. Geophys 77, 2629 (1972)

FIGURE 7 EXAMPLES OF SPECTRA OBTAINED BY HANEL ET AL. OVER NORTH AFRICA, NIMBUS 4 (IRIS)



Source: J. Geophys 77, 2629 (1972)

FIGURE 8 EXAMPLES OF SPECTRA OBTAINED BY HANEL ET AL. OVER POLAR AND PARTIALLY CLOUDY REGIONS, NIMBUS 4 (IRIS)

The data shown in Figures 7 and 8 were obtained more than a decade ago by the IRIS instrument. As Table 5 shows, Fourier transform spectrometer technology has evolved continuously since then. Although such instruments are not being used in operational meteorological satellites, they could be developed to obtain broadband information about most of the SDRs.

Radiance measurement in the 4.3-and 15-μm carbon dioxide bands have been used with partial success to estimate the atmospheric temperature profile. A similar method has been used in the microwave region with the 60-GHz oxygen band. While both the infrared and microwave temperature sounding methods, have advantages, it appears that the best temperature profile could be obtained by combining the two techniques.[4,5]

Atmospheric sounding is a fundamental measurement technique for obtaining data about most of the remaining SDRs. One such method is vertical sounding. For wavelengths at which the measured gas is very opaque, most of the radiation observed by the instrument will originate at the highest altitudes. Conversely, if the radiation measurement is in the wings of an absorption band or line, the gas appears relatively transparent so that the radiation originates at lower altitudes and suffers some attenuation. Figure 9 shows a typical set of weighting functions appropriate to radiance measurements that may be obtained from each of seven measurement channels as a function of altitude (Nadir viewing). (Assuming uniform CO_2 concentrations.) These weighting functions represent the contributions to the measured radiances from the absorbing and emitting gases at various altitudes in the atmosphere. The breadth of these functions indicates the vertical resolution obtainable in atmospheric sounding. This example is from the TIROS Operational Vertical Sounding Package (TOVS).

Measurements, such as the SAGE (Stratospheric Aerosol and Gas Experiment) are used in limb viewing to monitor the atmospheric aerosol content.[6] As shown by Figure 10, information on several of the trace gases may also be obtained by simultaneously using four measurement channels. Many channels are necessary to obtain sufficient information to distinguish not only the radiance originating from ozone and NO_2 from that of aerosol, but to distinguish the latter from molecular scattering. Figures 10 and 11 indicate that specific aerosols differ in their spectral extinction. As Figure 11 shows, aerosol type not only influences the slope and level of the aerosol extinction (and thereby, emission), but considerable structure is likely to occur in the infrared region.[7] The particular structure in Figure 11 originates from species such as sulfates.

Regardless of the origin, however, structure constitutes a serious interference in the infrared spectral region. Limb measurements below 1μm wavelength tend to obtain only a general level and slope for the aerosol extinction. They do not predict the individual bands of the varying kinds of aerosols. If such spectral features were present in the limited number of channels used in Nadir viewing by present infrared instrumentation, they would cause systematic errors.

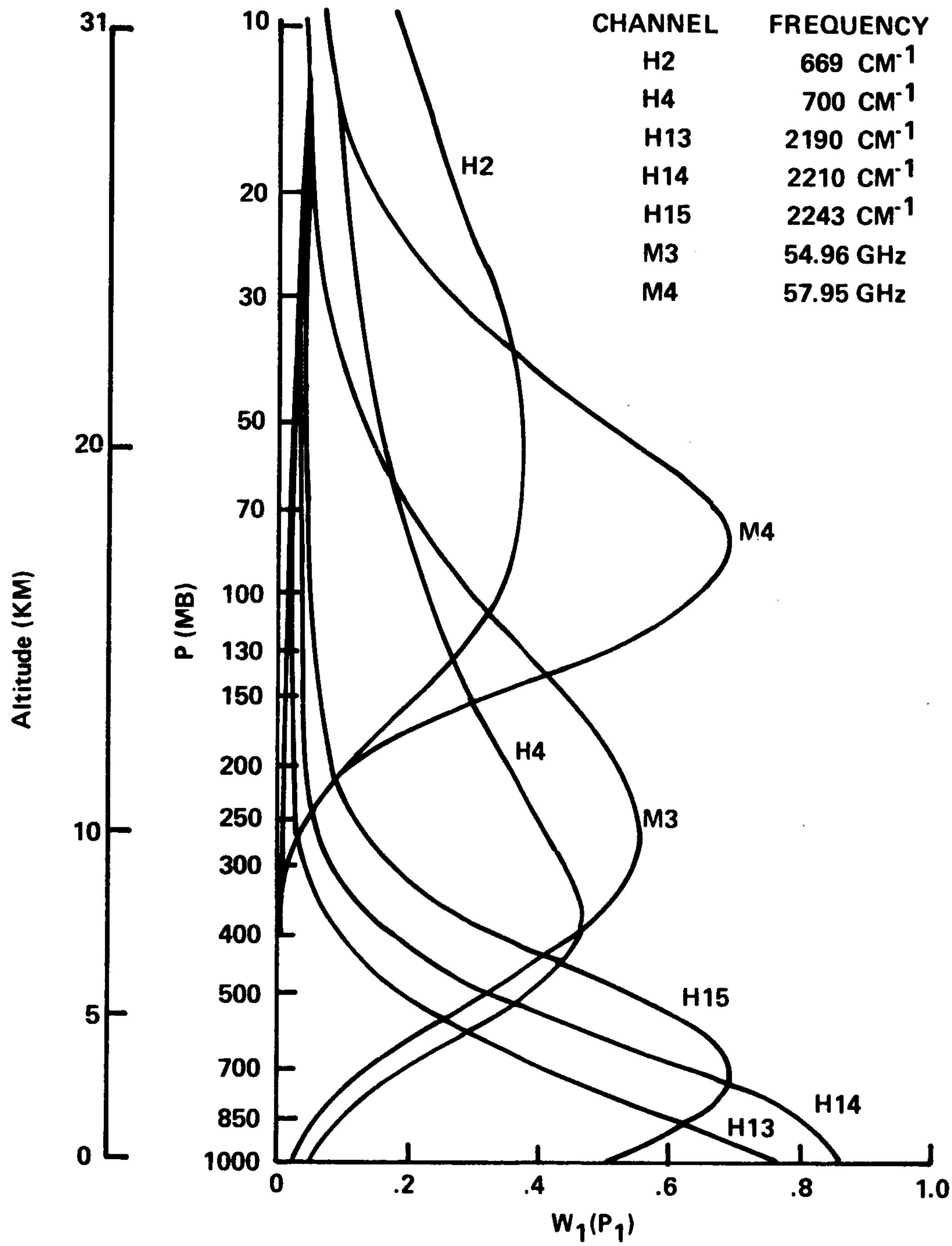
Aerosols have been studied principally for their effects on radiation balance. However, as shown in Figure 11 and discussed above, they also constitute an interference which may partially invalidate other infrared results. When these interferences in the infrared region are

TABLE 5

FOURIER TRANSFORM SPECTROMETER EVOLUTION

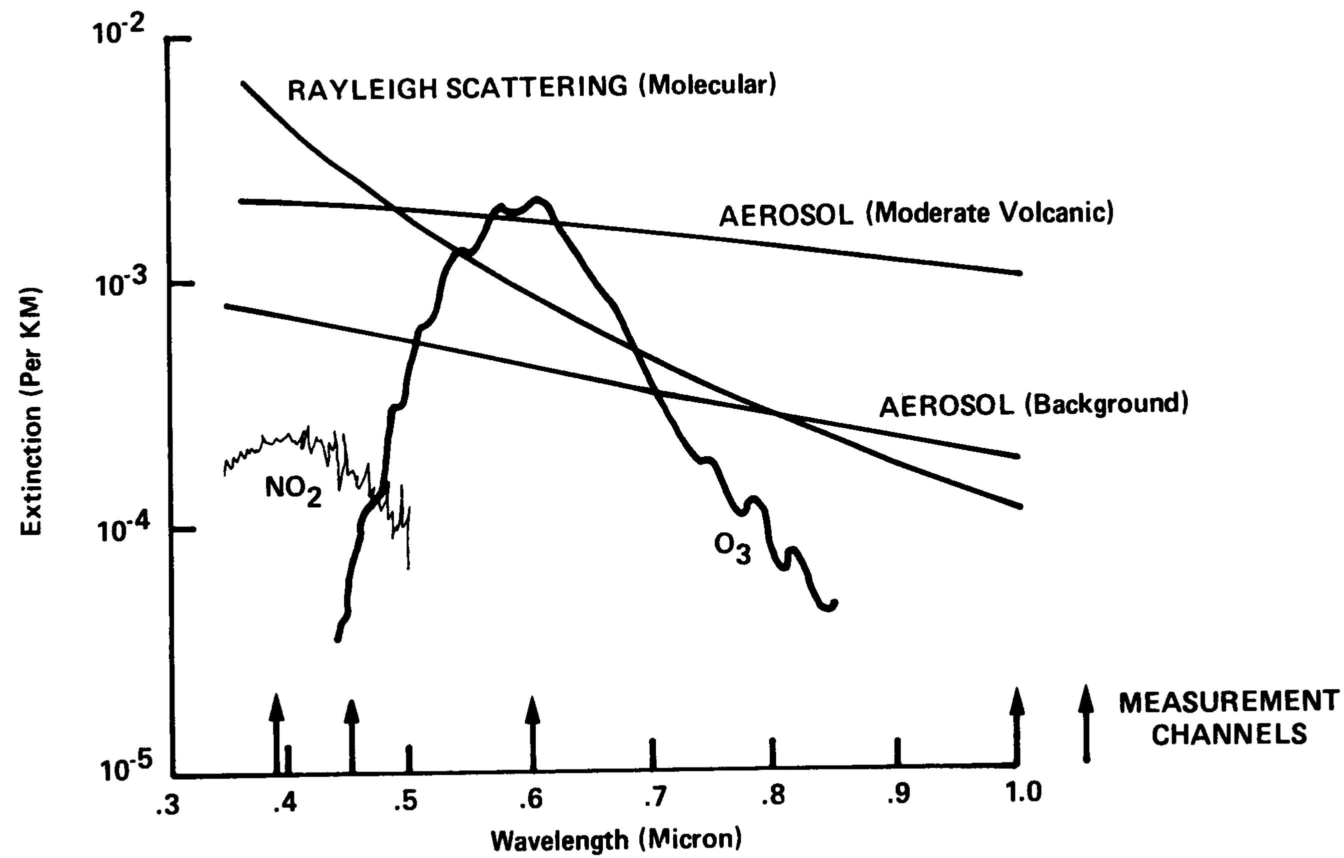
Sensor	Date	Platform	Spectral Range (mm)	Spectral Resolution (cm^{-1})	Time Per Interferogram (s)	Data Rate (kbs)
IRIS M	1972	Mariner-9	5-50	1.2	18.2	8.1
HIRIS	1975	Sounder Rocket	5-22	1.0	0.5	480
JPL-Mark I	1976	Balloon	2-5.5	0.09	1.20	48
Inst. of Aeronomy (Belgium)	1979	Balloon	2.5-14	0.08	1.0	
Univ. of Denver	1979	Balloon	8-17	0.01	40	500
IRIS-MOS	1980	Voyager	4-55	2.1	45.6	1.1
JPL-Mark II	(1981)	Balloon	2-16	0.01	120	65
ATMOS	(1982)	Shuttle	2-16	0.01	0.01	16,000

Source: P.G. Morse, 80-1914-CP, AIAA Sensor Systems for the 80s Conference, Colorado Springs, December 1980.



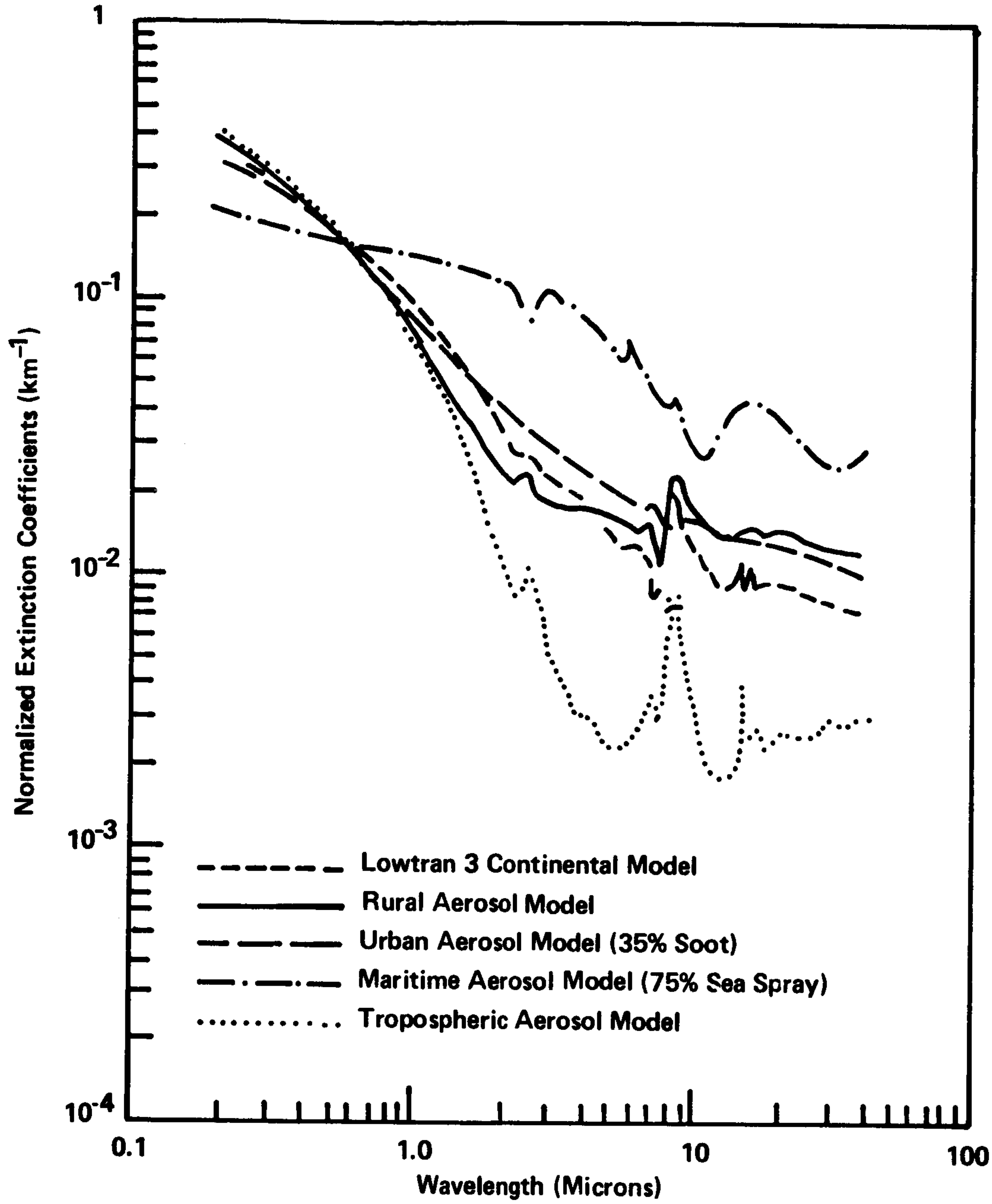
Source: Adapted from Susskind et al. NASA Technical Memorandum 84936 (1982)

FIGURE 9 WEIGHTING FUNCTIONS, FOR A U.S. STANDARD ATMOSPHERE AT NADIR VIEWING, FOR HIRS2-MSU CHANNELS USED TO DETERMINE THE TEMPERATURE PROFILE



Source: Adapted from Chu and McCormick (Appl. Opt. 18, 1404 (1979)

FIGURE 10 COMPUTED LIMB EXTINCTION FOR TYPICAL STRATOSPHERIC (18 KM ALTITUDE) AEROSOLS AND GASES TO BE MEASURED ON AEM-B SPACECRAFT (SAGE)



Source: Adapted from Shettle and Fenn, Proc. Conf., Optical Propagation in the Atmosphere, Lyngby, Denmark (1975).

FIGURE 11 SPECTRAL DEPENDENCE OF AEROSOL EXTINCTION significant, a broadband spectral examination of the data should reveal their presence and allow appropriate corrections to be made. The corrections would be difficult or even impossible with a limited number of channels. Fourier transform instruments could also be used to obtain limb spectral measurements. The entire infrared region could be covered to improve measurements of low concentrations of aerosols and trace gases.[8]

2.4 PRESENT SPACE-BASED SENSOR CONCEPTS

Both passive and active remote sensing techniques are needed to meet the SDRs. In the infrared and microwave regions of thermal emission passive sensing can indicate surface type, state and temperature, atmospheric profiling and constituents, and gases and aerosols (including clouds). In the ultraviolet, visible and near infrared spectral regions, passive techniques can sense solar radiation, useful for mapping albedo and measuring stratospheric species by backscatter or limb occultation.

Active methods are used chiefly in the microwave (radar) region, but more recently they have been used in the visible and infrared regions (LIDAR). In any of the active methods, timing of the return signal yields spatially resolved data directly, rather than inferentially as in passive vertical sounding methods.

In addition to passive and active methods, remote readouts of in situ data taken at ground stations, such as data buoys, balloons, and other meteorological stations may be utilized. For some of the SDRs such techniques may be necessary, particularly to improve accuracy.

Sensor measurement capabilities currently include:

- *UV/Visible/Infrared Sensors.* UV, visible, and infrared sensors directly measure the outgoing/incoming radiation as part of a radiation budget experiment. They provide information on the terrestrial albedo, the concentrations of H_2O, CO_2, O_3 (particularly in the infrared), and various trace gases, aerosols, and surface temperatures and provide information on the atmospheric temperature profiles. For the topmost cloud layer temperature can be determined. In broken cloud fields, it is possible to obtain some information on cloud layer temperature from a lower lying cloud level, but in general, as infrared radiation does not penetrate dense clouds, other measurement methods are necessary. Visible and near infrared mappers can be used for cloud coverage and motion and to map ice and snow.

- *Microwave Sensors.* Microwave multichannel radiometers also theoretically provide vertical profiles of temperature and water vapor and measure surface temperatures, sense snow/ice coverage, measure liquid water in the atmosphere, and sea surface conditions. While there is considerable overlap in what can be done in the microwave and infrared regions, the key feature of sensors in the microwave region is that measurements can be made through cloud cover.

Active microwave altimeters can sense altitude of ocean level and ocean wave height.

In all microwave sensor systems, except for synthetic aperture, radar antenna size limits the spatial resolution of the sensor. Side lobes; i.e., the wings of the diffraction pattern of the antenna, constitute a design challenge to compensate for the effects of spacecraft structural members near or in the "beam" of the antenna.

Subsystem Fact Sheets (SFS) were prepared for the 27 space-based sensor systems shown in Table 6.

In Tables 7 to 9 these 27 space-based sensor systems are categorized as multispectral scanners, radiometers or other types of instruments. Their availability in Level I, Level II, or Level III time frames is indicated.

Tables 10 to 12 show the estimate of the chosen sensor system's capability to meet the SDRs in the three time frame levels based on present knowledge of the state-of-the-art. An open circle indicates that measurements relating to the SDR can be made, but without having the desired accuracy or coverage. A half filled circle indicates that the SDR may be largely met. However, even if specific space-based sensor systems will significantly contribute to a SDR their contribution is not additive and the SDR may not be fully met. Two concentric circles indicate there is a potential that with further development over a 10 to 20 year period the SDR would be fully met.

2.5 NEW SPACE-BASED SUBSYSTEM CONCEPTS

As the open circles in Tables 10 to 12 show, sensor capabilities may evolve in the next 20 years. Future improvements in space-based sensors that will benefit the DOE CO_2 Research Program include:

- Continuous spectral coverage in the infrared region.
- More spectral channels in the microwave region.
- Periodic recalibration in space of satellite infrared and microwave radiometers.

The following activities could lead to better accuracy of surface temperature and radiation budget measurements and improve vertical resolution of atmospheric profiles:

- An STS-launched High-Orbit Radiation Budget (HORB) satellite to improve the accuracy of global data taken at higher latitude regions.
- A High-Altitude Powered Platform (HAPP) for continuous monitoring to improve CO_2 model parameters.
- Parallax cloud sensors to help resolve the vertical structure of clouds.

TABLE 6

SFSs FOR SPACE-BASED SENSORS

CZCS	—	Coastal Zone Color Scanner
SMMR	—	Scanning Multi-Channel Microwave Radiometer
OCI	—	Ocean Color Imager
AVHRR	—	Advanced Very High Resolution Radiometer
SSU	—	Stratospheric Sounding Unit
HRIS	—	High Resolution Infrared Sounder
TM	—	Thematic Mapper
MSU	—	Microwave Sounding Unit
SSH	—	Satellite Sounder Humidity
DCS	—	Data Collection System
AMSU	—	Advanced Microwave Sounding Unit
AMTS	—	Advanced Moisture and Temperature Sounder
SAR	—	Synthetic Aperture Radar
LIDAR	—	Light Detection and Ranging
LAMMR	—	Large Antenna Multi-Frequency Microwave Radiometer
LHS	—	Laser Heterodyne Spectrometer
CLIR	—	Cryogenic Limb-Scanning Interferometer and Radiometer
ERBE	—	Earth Radiation Budget Experiment
MOMS	—	Modular Optoelectronic Multispectral Scanner
SPOT	—	Systeme Probatoire d'Observation de la Terre
SAGE	—	Stratospheric Aerosol and Gas Experiment
SBUV	—	Solar Backscatter Ultraviolet Radiometer
MPS	—	Microwave Pressure Sounder
	—	Altimeter
	—	Scatterometer
IRIS	—	Infrared Interferometer Spectrometer
ATMOS	—	Atmospheric Trace Molecules Observed by Spectroscopy (High Resolution Interferometer Spectrometer)

TABLE 7

MULTI-SPECTRAL SCANNERS

	Level		
CZCS	I	—	Coastal Zone Color Scanner
OCI	I	—	Ocean Color Imager
AVHRR	I	—	Advanced Very High Resolution Radiometer
TM	I	—	Thematic Mapper
LAMMR	III	—	Large Antenna Multi-Frequency Microwave Radiometer
MOMS	I	—	Modular Optoelectronic Multispectral Scanner
SPOT	II	—	Systeme Probatoire d'Observation de la Terre

TABLE 8

RADIOMETERS

	Level		
SMMR	I	—	Scanning Multichannel Microwave Radiometer
SSU	I	—	Stratospheric Sounding Unit
HIRS-2	I	—	High Resolution Infrared Radiation Sounder
MSU	I	—	Microwave Sounding Unit
SSH	I	—	Satellite-Borne Sounder, Humidity
AMSU	II	—	Advanced Microwave Sounding Unit
AMTS	II	—	Advanced Moisture and Temperature Sounder
LHS	III	—	Laser Heterodyne Spectrometer
CLIR	II	—	Cryogenic Limb Scanning Interferometer and Radiometer
ERBE	I	—	Earth Radiation Budget Experiment
SAGE-1-2	I	—	Stratospheric Aerosol and Gas Experiments 1 and 2
SBUV-2	I	—	Solar Backscatter Ultraviolet Radiometer 2
IRIS	I	—	Infrared Interferometer Spectrometer
MPS	III	—	Microwave Pressure Sounder
ATMOS	I	—	Atmospheric Trace Molecules Observed by Spectroscopy (High Resolution Interferometer Spectrometer)

TABLE 9

OTHER TYPES OF INSTRUMENTS

	Level		
DCS	I	—	Data Collection System
SAR	I	—	Synthetic Aperture Radar
LIDAR	III	—	Light Detection and Ranging
SCAT	I	—	Scatterometer
ALT	I	—	Altimeter

TABLE 10
SPACE-BASED SENSOR SYSTEMS (BASELINE) – LEVEL 1

Sensor/System* / SDR	TOVS**			Mod. AVHRR	ERB	SAGE-2	SMMR	ALT	SDRs Met
	HIRS-2	SSU	MSU						
Clouds Vertical Distrib.	Top			Top					
Cirrus Clouds				○					○
Global Radiation Budget					○				○
Trace Gases Including O_3	○					○			○
CO_2, High Accuracy	○		○						○
Soil Moisture									
Temperature Vertical Prof.	◓	◓	◓						◓
Temperature (Ground)	○			○					○
H_2O Vertical Distribution	○								
Sea Ice				○			○		○
Cloud Percentage Coverage	○			○					○
Sea Currents				○				○	○
Sea Level								◓	◓
Precipitation							○		○
Snow Cover				○			○		○
Vegetation Index				◓					◓
Aerosols						◓			◓
Surface Albedo				○	○				○
Sea Surface Temperature	○			○			○		○
Sea Surface Wind							○		○
Land Ice				○			○	○	○
Wind Field (Vertical)									
Sea Surface Pressure									

Notes: ○ Meets SDR Partially
◓ Meets SDR Largely
*See Appendix D: "Subsystem Fact Sheets" for details.
**Tiros Operational Vertical Sounder

TABLE 11
SPACE-BASED SENSOR SYSTEMS — LEVEL II

SDR \ Sensor/System*	Adv. IRIS	AMSU	Improved AVHRR	Improved ERBE	Improved SAGE-2	Improved SMMR	ALT TOPEX	SDRs Met
Clouds Vertical Distrib.	Top	○	Top					○
Cirrus Clouds	○		◒					◒
Global Radiation Budget				◒				
Trace Gases Including O_3	◒				◒			◒
CO_2, High Accuracy	○	○						○
Soil Moisture						○		○
Temperature Vertical Prof.	◒	◒						◒
Temperature (Ground)	◒		○					◒
H_2O Vertical Distribution	◒	◒						◒
Sea Ice			○			◒		◒
Cloud Percent Coverage	○		◒					◒
Sea Currents	○		○				○	○
Sea Level							●	●
Precipitation		○				◒		
Snow Cover			○			◒		◒
Vegetation Index			◒					◒
Aerosols	◒				◒			◒
Surface Albedo	◒		○	◒				◒
Sea Surface Temperature	◒		◒			○		◒
Sea Surface Wind						◒		◒
Land Ice						◒	◒	◒
Wind Field (Vertical)								
Sea Surface Pressure								

Notes: ○ Meets SDR Partially
◒ Meets SDR Largely
● Meets SDR Fully
*See Appendix D for details.

TABLE 12

SPACE-BASED SENSOR SYSTEMS – LEVEL III

SDR \ Sensor/System*	Adv. FTS	Microwave Sounder	IR-Vis Mapper	ADV., HORB	LIDAR, Laser Altimeter	Microwave Mapper	Improved ALT TOPEX	Parallax Sensor	MPS	SDRs Met
Clouds Vertical Distrib.	◒	○	Top		Top			◒		◒
Cirrus Clouds	◒		◒		◒					●
Global Radiation Budget				●						●
Trace Gases Including O_3	◒	○			◒					◉
CO_2, High Accuracy	◒	○			◒					◒
Soil Moisture						○				◒
Temperature Vertical Prof.	◒	●								●
Temperature (Ground)	◒		◒			○				◉
H_2O Vertical Distribution	◒	●								●
Sea Ice			◒			●				●
Cloud Percent Coverage			●							●
Sea Currents			○		◒		○			◉
Sea Level							●			●
Precipitation						◒				◒
Snow Cover			◒			◒				◉
Vegetation Index			●							●
Aerosols	◒				◒					◉
Surface Albedo	◒		○							◒
Sea Surface Temperature	◒					●				●
Sea Surface Wind					●	◒				●
Land Ice					●	○	◒			●
Wind Field (Vertical)					●					●
Sea Surface Pressure									●	●

Notes: ○ Meets SDR Partially
◒ Meets SDR Largely
● Meets SDR Fully
◉ Potential for Fully Meeting SDR

*See Appendix D for details.

- Temporal and spatial integration of CO_2 column data for high-precision global CO_2 measurements.

- On-board data processing to reduce down-link data rates.

All the measurements made by remote sensing are radiometer based. The error sources in radiometry can come from the sensor, the atmosphere, or the surface. In the sensors, scatter and absorption in the infrared optics or microwave antennas or deterioration of front ends can attenuate signals, generate spurious signals, or change the field of view or antenna patterns. Detector performance will change with age and temperature. Passive coolers deteriorate and change the detector temperature. Other errors are the result of changes in the background being observed to meet a specific SDR. Aerosols can absorb and emit, and thus interfere with other measurements. Likewise, various trace gases have residual signatures that interfere with the measurements of other SDRs. Adequate allowances need to be made for these signatures in order to obtain accurate measurements for a specific SDR. Finally, the surface emittance is likely to be unknown unless broadband measurements are taken.

Both continuous coverage and discrete channels offer advantages. Continuous coverage provides the possibility of good spectral correlation and corroboration. Absorbing gaseous species and aerosols can be detected better in the infrared region than in other regions of the spectrum. Continuous coverage will be highly desirable to permit detection of unexpected effects; however, data management requirements will increase.

Discrete channels provide more economical data rates, involve simpler design, and permit some redundancy. In the multichannel radiometer, the detectors may be optimized, photon noise will be minimized, and the spatial and spectral scans will not interact.

Because of these engineering advantages, present systems employ discrete channels, either in the form of filter radiometers or grating (or prism) poly-chromators. Continuous spectral coverage was utilized successfully a decade ago both on the Nimbus program and on planetary missions such as Mariner.[9,10]

For continuous spectral coverage, the scanning grating monochromator has been the standard infrared radiometer even though it has comparatively small optical throughput. It is mechanically simple, but observes only one spectral resolution element at a time. Therefore, it collects comparatively little signal power, but it has low photon noise.

By contrast, for at least a decade the preferred concept for remote detection of a continuous spectrum of an extended object has been Fourier transform spectroscopy (FTS). The instrument of choice is a Michelson interferometer. These instruments have very large optical throughput and view the entire spectrum continuously, providing greater information rates than scanning grating monochromators can deliver.

Fourier transform spectrometers are mechanically complex and are potentially limited by photon noise in the instrument, which views all spectral elements simultaneously. The mechanical/optical problems can be solved, but the photon noise limitation is fundamental and can only be ameliorated not eliminated. Nevertheless, because of the advanced development of the FTS, there is no significant reason to use any other technique for remote spectroscopy of extended objects in the infrared region.

2.5.1 STS-Launched Recalibration Package

One of the major challenges in data acquisition with space-based sensors is to maintain long-term accuracy or precision. Therefore, periodic recalibrations of space-based sensors will allow data from sensors that have to be replaced at intervals to be standardized with data from replacement sensors. Also, recalibration would make useable space-based sensor data other than that dedicated to CO_2 research. An STS-launched calibration package carrying radiometers of high accuracy at selected wavelengths would be useful for this purpose. The short design life of such a package would allow the use of cryogens and limit the deterioration of detectors, optics, or other sensor parts. A simple pointing capability would suffice to arrive at certain points in time and provide the same footprint as the space-based sensor system being calibrated. It is likely that an atmospheric window, rather than atmospheric absorption channels, would provide the most uniform and thus best suited fields of view for calibration, especially over the ocean. The calibration package can be placed in an orbit that is not necessarily the same as that of the radiometer being calibrated as long as coincident views of the selected target areas are obtained. This procedure will transfer the radiance calibration of the recalibration package to the operating satellite radiometer.

The study of the feasibility of a recalibration package should include selection of the orbits to be used, definition of the required homogeneity of the fields of view and target areas, the required coincidence of viewing angles, the optimum spectral ranges, and an engineering specification for a very high accuracy radiometer. The specifications should include sensitivity criteria and consider international measurement standards.

2.5.2 High-Orbit Radiation Budget Satellite (HORB)

An STS-launched circular orbit satellite in higher and, therefore, slower than geosynchronous orbit would let the radiometers view almost an entire hemisphere at once. The inclination of the orbit and the altitude would be chosen to meet spatial and temporal sampling requirements for the global radiation budget. Because the sensor radiometers would measure the ratio of solar and terrestrial fluxes, the need for absolute calibration may be reduced to providing a stable diffuse solar reflector. Further study would be required to determine by how much this concept would improve the accuracy of earth radiation budget measurements.

2.5.3 High Altitude Powered Platform (HAPP) CO_2 Monitoring System

A HAPP CO_2 monitoring system could maintain a sensor system above 20 km altitude for long periods. It could have a useful field of view of about 120 km diameter and could hold its designated position within 7 km. Based on experiments performed in the early 1960's by Raytheon, it has been estimated that such high-altitude microwave powered aircraft can have very long lifetimes and carry payloads of more than 100 pounds. The propulsion power could be microwave energy radiated at a wavelength of 2.45 Ghz from a ground transmitting antenna to a thin-film etched circuit that forms the skin of the wings of the platform. Other energy sources for a HAPP could be lasers or solar energy. The principal value of such a platform would be in high-resolution, continuous-monitoring of CO_2 related phenomena in such regions as the West Antarctic and the Amazon. This capability could provide information required to improve the parameters and algorithms for CO_2-climate models.[11]

The HAPP could be suitable for the continuous high-resolution stereographic monitoring of clouds at selected locations to complement and calibrate lower-resolution satellite data.

Clouds are an important variable of the climate system. Climatic effects of increased atmospheric CO_2 may be more correctly assessed if the related changes in cloudiness could be correlated with CO_2 effects. The present data on cloud distribution is limited, partly because of their extremely high variability in space and time. Information from geostationary and polar orbiting satellites is limited in two important aspects: the vertical cloud distribution is difficult and sometimes impossible to define and the fractional cloud cover, which is on a scale smaller than the resolution of satellite sensors, can be recognized only partially.

Imagery from geostationary satellites is provided in 30 minute intervals and reaches only to approximately 55N latitude. Polar orbiting satellites view a scene twice a day, once during the daytime and once at night. This sampling frequency is insufficient for a reliable parameterization of daily cloudiness. Another problem is encountered in high latitudes where the ground or the sea ice is covered by snow. In such situations the cloud recognition is extremely difficult. A HAPP carrying twin television cameras operating in the visible spectrum and twin infrared imagers has the potential to solve these problems.

Figure 12 shows that HAPP could provide continuous stereoscopic imagery of an area around 100 km in diameter with horizontal resolution around 5m and vertical resolution of around 10m at wavelengths of approximately 0.70 to 0.75μm and 10.5μm. Since these bands are the most commonly used by satellite cloud sensors, the comparison with satellite imagery will be facilitated.

The information that might be derived from the HAPP data includes:

- Highest cloud top height.
- Middle level cloud top height and the highest cloud base height in the openings of the high cloud.
- Same for the low cloud.
- Relative temperatures of individual cloud top levels.
- Fractional coverage of the highest opaque cloud.
- Daytime and night time averages of the above parameters.
- Effects of volcanic activity.

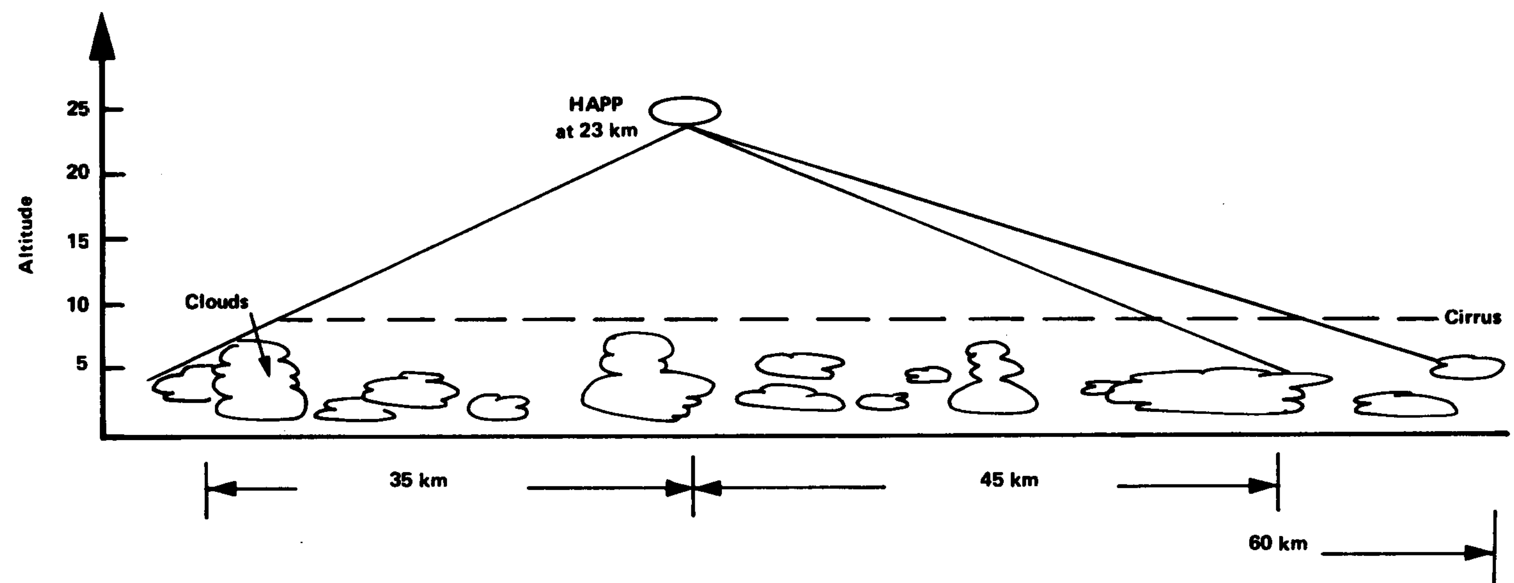


FIGURE 12 HAPP USEFUL FIELD OF VIEW

Examples of potential observation sites and times are:

1. Arctic basin. Sea ice site off Alert, Canada, or Point Barrow, Alaska. Observation time: 1 year. This site would provide calibration of polar orbiting satellite data from the general area, which according to climate models is highly sensitive to CO_2 warming. Sea ice is present throughout most of the year, snow cover on top of the ice undergoes seasonal melt in summer, the site has polar night for six months and the low or middle level clouds are frequently warmer than the surface or the high altitude clouds, which makes the recognition of cloud levels and the differentiation of clouds from the surface especially difficult.

2. Ross Sea off MacMurdo. Observation time: 1 year. Similar position in the climate system and similar problems with recognition of cloud levels as in the Arctic.

3. Rocky Mountains in Colorado or Montana. Observation time: 6 months from November through April. Monitoring of fractional cloud cover over snow. Area of very high daily variability.

4. North Dakota or Minnesota. Observation time: 6 months from November through April. Area of frequent occurrence of multilayered clouds.

5. Additional areas within the Snow and Ice Transition Zone (SITZ). During spring and fall, when the snow cover changes. The role of the clouds in the process and the interaction of the clouds and the surface in SITZ are poorly known. Improved observational data from this area could be utilized.

6. In the design of the HAPP system, attention should be paid to system mobility to enable cost-effective relocations once or twice a year.

HAPP could be operational near the end of the Level I time frame and potentially contribute to the DOE CO2 Research Program.

2.5.4 PARALLAX CLOUD SENSOR

A sensor concept based on optical correlation of consecutive images could provide parallax and, possibly, vertical resolution of cloud images. This concept would require that features or edges between successive images be correlated and that the effect of uncertainty in the relative cloud motion be small compared to the parallax that is due to the satellite motion.

On-board optical or video correlation may be required to reduce the down-link data rates.

2.5.5 DIRECT CO_2 MEASUREMENT

High accuracy remote measurement of atmospheric CO_2 is difficult. Present knowledge concerning the increase of atmospheric CO_2 is based on surface station measurements. In addition, global or regional measurements of CO_2 may be useful as a direct comparison with the global and regional measurements of other parameters. Two methods might be employed. The first method would use passive measurement of the CO_2 bands that occur in the infrared region of the spectrum. The method consists of obtaining the atmospheric temperature profile from the oxygen band in the microwave region and inverting the CO_2 band measurements using the temperature profile. Considerable work will be required to establish the probable errors in using such a method. However, if the method is relatively sensitive, it would have the advantage that the same areas (volumes) would be sampled while other SDRs are being monitored. Techniques for accurate global and/or regional averaging will need to be developed. This concept would complement the present technique of inferring global concentrations from a limited number of point measurements at selected sites.

A second method that is applicable is based on sensing by LIDAR. This technique could be more accurate than passive atmospheric sounding, but the present reliability and operating life of the required lasers are not yet sufficient for long-term missions.

2.5.6 On-Board Data Processing

Data management capabilities could improve over the next decades. However, the extremely large quantities of data expected to be gathered on a long-term CO_2 mission dedicated to measuring many parameters to meet the SDRs, and the different spatial and temporal sampling requirements, suggest that sophisticated data processing methods might be required. In one obvious approach, averages and standard deviations of the individual measurements would be obtained, although the individual data sets should also be archived. The particular averages taken will depend on the individual SDR being met, but at a very minimum, the data should be segregated with respect to time of day and season, geography of the observation (arctic regions, forests, deserts, tropical oceans, etc.) as well as cloud cover.

An advanced on-board averaging system is justifiable when the down-link or recording/playback capacity on the satellite is insufficient. In general, data processing on the ground is preferable because it is expandable and flexible, and it is also easier to achieve sufficient hardware reliability. In addition, the multilayer processor and memory capacity that is available allows more sophisticated and comprehensive algorithms to be used and leads to more reliable detection of faulty data.

2.6 SELECTED SPACE-BASED SENSOR SYSTEMS

Space-based sensor systems were selected for inclusion in future dedicated satellite missions in three time-frame levels. Existing space-based sensor systems were clustered into the package appropriate for Level I (0-5 years). This cluster of systems was used as the baseline for system design and cost estimating purposes and as a comparison with Level II (5-10 years) and Level III (10-20 years) space-based sensor packages. At the outset, data from existing satellites were considered a preferred approach to provide near-term information for the DOE CO_2 Research Program rather than the development of a satellite incorporating Level I space-based sensor systems.

2.6.1 Level I (0-5 years), CO_2 Research Satellite (CORS) Baseline

Space-based sensor systems for CORS were considered as a means of providing a basis for comparing of possible mission options. The Level I CORS could include the following:

- The TOVS (Tiros Operational Vertical Sounder) which consists of three instruments:

  — HIRS-2 (High Resolution Infrared Radiation Sounder), comprising twelve CO_2 temperature sounding channels, two IR window channels near 10μm, two water vapor absorption channels, and one visible channel.

  — MSU (Microwave Sounding Unit), comprising three CO_2 temperature sounding channels and one window channel, near 50 Ghz.

  — SSU (Stratospheric Sounding Unit), comprising three pressure modulated CO_2 temperature sounding channels near 15μm.

The operation, performance and data processing of the TOVS system have been described in detail in References 12, 13, and 14. TOVS provides information on:

— Temperature vertical profiles.

— Ground and sea surface temperatures.

— Water vertical distribution.

— CO_2 distribution, if independent vertical temperature profile from MSU is available.

— Some trace gases

— Approximate cloud vertical distribution and percent coverage from analysis of the HIRS 2 data.

- *AVHRR-2 (Advanced Very High Resolution Radiometer).* A high-resolution multispectral mapper operating in visible and infrared atmospheric window channels at five wavelengths. Its high spatial resolution allows correction of TOVS data for clouds and mapping of surface spectral features. Its five channels give ground and sea temperatures, percent cloud coverage, some data on sea ice distribution, snow cover, land ice, surface albedo, and a "vegetation index" from the ratio of two near infrared channels. The operation and performance and data reduction of AVHRR have been described in detail in References 13, 15, 16.

- *ERB (Earth Radiation Budget).* Measures solar radiation in ten spectral channels and radiation from the earth in several spectral ranges. The earth is scanned with eight narrow angle and four wide angle fields of view. A primary goal in the design of ERB was to improve the models of angular distribution of terrestrial radiation, in particular reflected solar radiation. A knowledge of the earth's bidirectional reflectance properties is necessary before the earth radiation budget can be measured with a non-scanning "flat plate" radiometer to high accuracy. The ERB has been described in detail in References 17, 18, 19.

- *SAGE-2 (Stratospheric Aerosol and Gas Experiment).* A four-channel radiometer looking at the sun through the earth's limb. At sunrise or sunset it provides vertical profiles of ozone, NO_2, and aerosols with simple and reliable uncooled sensors. Because SAGE requires sunrise or sunset, its orbital requirements must be coordinated carefully with those of the other instruments. Sun-synchronous orbits, for example, restrict SAGE's geographic coverage. (See References 19 and 20.)

- *ALT (Radar Altimeter).* Provides data on sea level and the Antarctic cap to an accuracy of approximately 10 cm. The radar altimeter, similar to the one flown on SEASAT A will penetrate clouds and requires no special pointing accuracy (0.1° will suffice) because it automatically measures distance to the nadir. Its pulse leading-edge detection circuitry in effect averages altitude over approximately a 1.6-km diameter. At 20 pulses per second, samples are taken at 300 to 350 meters spacing and a 1.6-km footprint provides an appropriate low-pass filter to prevent sampling (aliasing) errors. Because the antenna beam width of the altimeter corresponds to approximately a 20-km diameter on the ground while the leading-edge pulse detection circuitry produces an approximately 1.6-km diameter footprint, all data are necessarily taken along the ground track of the satellite. Over the ocean, subsequent ground tracks will be close enough to produce useful maps even in short periods. To map the Antarctic ice cap in detail, the orbit has to be chosen to provide a sufficiently contiguous close pattern of ground track within the desired observation time. (See References 19 and 21.)

- *SMMR (Scanning Multichannel Microwave Radiometer).* A dual polarization, constant angle of incidence (50°), microwave mapper operating at five window frequencies. It detects clouds, measures sea surface temperature, sea state, i.e., wind, sea ice from polarization ratio or brightness temperature, snow from brightness/temperature ratios, and systematic ocean temperature fields indicating sea currents. It also allows some estimates of soil moisture to be made. (References 17, 19, 21, 22.)

2.6.2 Level I, Data Collection System

Because of the time and cost required to develop the CORS (see Section 4.3), even using state-of-the-art space-based sensor systems, the approach selected for Level I is to utilize data relevant to the CO_2 Research Program provided by existing space-based sensors. The Level I baseline system would consist of data from various satellites and from HAPP.

2.6.2.1 Data Collection from NOAA/NASA/DMSP Satellites

The operational meteorological satellite systems — TIROS, Nimbus and DMSP — will be continuously available during the next 5 years. Much of the necessary data that would be available from such a dedicated CO_2 research satellite could be extracted from them and from other planned satellite systems as TOVS, ERB, AVHRR, and the DCS on TIROS. SBUV (Solar Backscattered Ultraviolet) would provide ozone distribution, but no aerosol data.

Topographic data on sea surface and polar ice caps can be provided by TOPEX. Microwave mapping with the SMMR could be performed from NIMBUS. The ERBS (Earth Radiation Budget Satellite) is planned in cooperation with NOAA F and G. Geosynchronous satellites were assumed not to be relevant because polar regions cannot be adequately observed. Such satellites are most useful for observations in the tropics and middle latitudes.

A data collection system, which would interface with the present operational NOAA, NASA and DMSP satellites would be required because the data now obtained are not available in a suitable form with respect to access procedures and the geographical and temporal distribution data requirements of the DOE CO_2 Research Program. Such a data collection system should be developed to provide a data stream at an early stage from these satellites. This system would combine the data from different satellite sensor systems that differ in spatial and temporal coverage to provide the required information. Continuity between subsequent generations of TIROS and intercalibration between different satellites operating simultaneously could be a primary requirement for this approach. The shuttle recalibration package might provide that capability. The advantages of such a data collection system are:

- The program could start receiving suitable data at an early date.
- Experience would be obtained in using the data to develop the methodology for SDR analysis.

The disadvantages of this alternative are:

- Coverage of SDRs will be limited to the information presently obtainable from existing satellites.
- There will be uncertainty with respect to continuity in performance and operation of pertinent satellites.

2.6.2.2 Level I, High Altitude Powered Platform (HAPP)

HAPP could be a component of the Level I system. The description of HAPP was presented in Section 2.5.3. The HAPP CO_2 system has the potential to be operational in five to six years.

2.6.3 Level II (5-10 years) CO_2 Research Satellite (CORS)

A Level II CORS (see Figure 13) could consist of the following space-based sensor systems: (Refer to Appendix D on Subsystem Fact Sheets for details.)

- *Advanced IRIS (Infrared Interferometer/Spectrometer).* A wide band Fourier transform spectroradiometer covers the infrared region from 6.5 to 40μm. This region includes many atmospheric windows as well as absorption bands and lines of molecular species. The wide band coverage provides greater accuracy and certainty in vertical profiling of temperature and/or concentration. This system offers potentially a better interpretation of atmospheric radiance data and should provide more reliable CO_2 climate data.

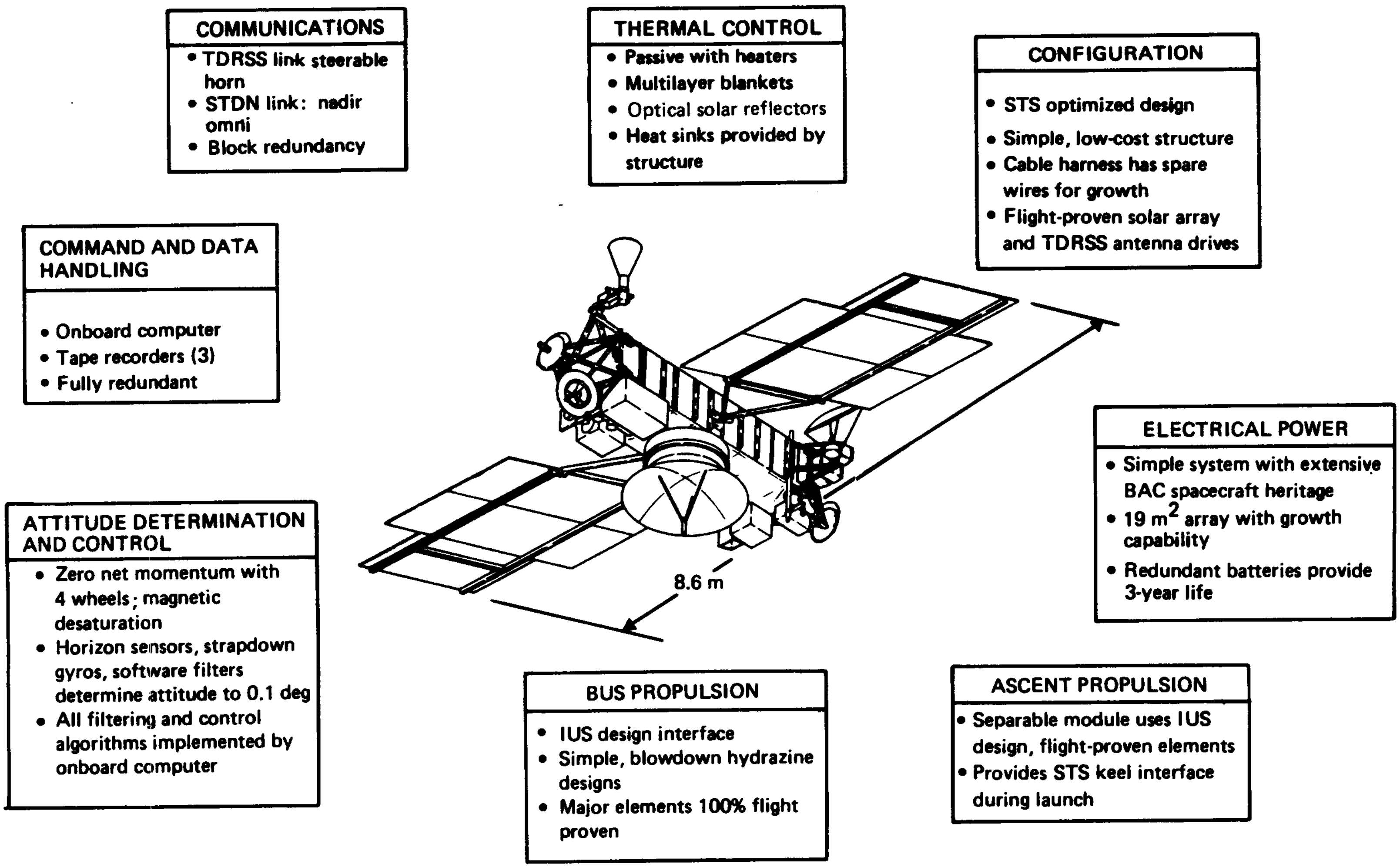


FIGURE 13 CO_2 RESEARCH SATELLITE (CORS) LEVEL I, BASELINE

- *AMSU (Advanced Microwave Sounding Unit).* A 20-channel microwave radiometer operating at about 18 to 180 Ghz performs vertical temperature sounding from oxygen emission lines, and humidity soundings at 22 and 180 Ghz. Atmospheric window channels permit measurements of surface temperature and lower atmospheric phenomena; e.g., precipitation.

- *AVHRR (Advanced Very High Resolution Radiometer).* A next-generation AVHRR will include improved on-board data processing, spectral channels optimized for determining vegetation index, and detectors capable of operating effectively in the desired channels to obtain more accurate temperature data.

- *ERBE (Earth Radiation Budget Experiment).* A next-generation ERB is an improved earth radiation budget sensor system consisting of two subsystems. The first is a wide/medium optical field or view subsystem which contains five channels, of which four are mounted on a single-axis gimbal to allow periodic viewing of the sun. The fifth channel views the sun continuously. The second is a scanning subsystem with three spectral channels that are scanned from horizon to horizon.

- *SAGE-2 (Stratospheric Aerosol and Gas Experiment).* Serves the same purpose as in Level I.

- *SMRR (Scanning Multi-channel Microwave Radiometer).* Serves the same purpose as in Level I. Its beam pattern could be improved by removing spacecraft structural obstructions and reflections in and near its field of view and by increasing antenna diameter as far as practical on the available spacecraft.

- *ALT TOPEX (Radar Altimeter).* The only active instrument on board is an improved version of the instrument used in Level I. In addition to measuring altitude, it senses wave height from the spreading of the return pulses as well as precipitation. Improvements could include simultaneous operation at two frequencies to reduce errors from ionospheric propagation uncertainties.

- *HAPP CO_2 (High-Altitude Powered Platform).* Could be operational in about five years from start of development effort. It will provide inputs to CO_2 climate models in a specified region, especially on details of cloud structure.

- *Shuttle Recalibration Package* is a concept to improve the accuracy of radiance data from space-based sensors. This package should provide inter-calibration: a) between successive generations of one type of space-based sensor system such as IR and microwave mappers or sounders, and b) between different satellites.

2.6.4 Level III (10-20 years), CO_2 Research Satellite

A Level III CORS shown in Figure 14 could consist of the following systems:

- *FTS (Fourier Transform Spectrometer).* The FTS is being developed for next-generation IRIS and other ongoing developments such as ATMOS (Atmospheric

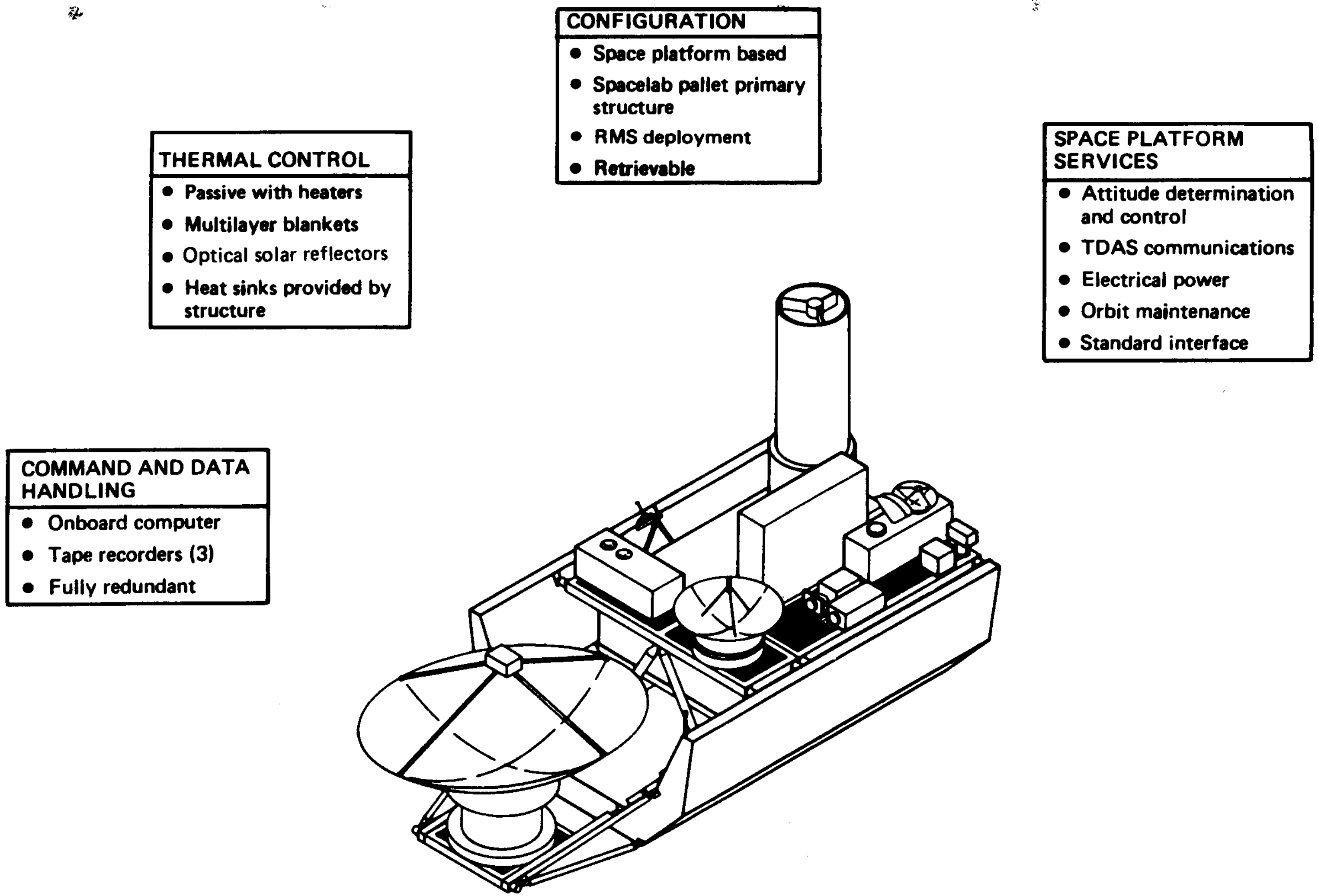


FIGURE 14 CORS LEVEL III DESIGN

Trace Molecules Observed by Spectroscopy). Improvements would be sought in larger optical throughput, integrity of alignment, long-term reliability, and, particularly, in solving the photon noise problem inherent to FTS instruments. On-board data processing to reduce the very large data flow would be desirable as long as sufficient flexibility in algorithms and processing methods can be provided in the satellite.

- *Microwave Sounder.* An advanced AMSU with better front end to reduce noise and with added channels to measure trace gases.

- *IR-VIS Mapper.* Derived from AVHRR with improved image data processing and long-term radiance accuracy, e.g., wavelengths selected to meet specific requirements such as determining the vegetation index: improved spectral selectivity with suitable filters, higher detector sensitivity and larger optics to increase signal-to-noise ratio.

- *HORB (High Orbit Radiation Budget).* A system concept to complement earth radiation budget data by measurements taken from a satellite in very high orbit where a large part of one hemisphere of the earth can be observed at once.

- *LAMMR (Large Antenna Multifrequency Microwave Radiometer).* A next-generation Scanning Multichannel Microwave Radiometer with more channels at lower frequencies and a better defined narrower beam pattern. These features would provide better detection and mapping of ice and snow as well as soil moisture. The larger antenna should provide high resolution even at lower frequencies.

- *Parallax Sensor.* This system would provide information for estimating cloud top altitude by correlating consecutive high-resolution images. On-board image processing could help to reduce the down-link data rate.

- *LIDAR (Light Detecting and Ranging).* A multi-purpose instrument to provide altitude-resolved data on atmospheric species from backscatter at several wavelengths and/or from Raman-shifted backscatter and to help determine cloud vertical profiles by comparing optical returns from clouds with radar altimeter returns.

In addition, the LIDAR could perform optical altimetry on the surface of the ice caps at positions off the track of the satellite. In contrast to radar altimeters, its beam is narrow enough to be pointed off the nadir. In that mode, however, the pointing angle has to be measured to high accuracy; e.g., to 0.1 arc second, in order to measure height to 10 cm. Present attitude sensors are not that accurate. However, the accuracy goal appears technically feasible in the time available.

- *ALT TOPEX (Radar Altimeter)* unchanged from Level II.

- *MPS (Microwave Pressure Sounder)*. This system will provide sea level atmospheric pressure data over the oceans directly beneath the spacecraft. Radar absorption measurements at two frequencies near 53 GHz must be corrected by water vapor and other measurements at nearby frequencies for discrete locations.

- *HAPP (High Altitude Powered Platform)*. Continued in operation from time Level II CORS.

- *Shuttle Recalibration Package*. Continued in operation from time Level II CORS.

2.7 PRELIMINARY INTEGRATED SYSTEM CONCEPT

Many options significantly affect the programmatics, structure, cost, and operation of the DOE CO_2 Research Program. The advantages and disadvantages of each of the major options are discussed below for the preliminary integrated system concept for CORS.

2.7.1 DOE Agency Options

There are four different approaches to a new CO_2 mission:

1. Add DOE CO_2 Research Program, data requirements to other agency's existing or currently planned space programs.

2. Implement a new NASA CORS mission.

3. Initiate a new DOE CORS mission.

4. Initiate a new International CORS mission.

- *Add-on to Another Program*. It is possible that arrangements could be made to obtain existing data and perhaps add payload sensors to existing or currently planned satellite programs. Candidate programs could include NOAA meteorological satellite programs (TIROS), the DOD defense meteorological satellite program (DMSP), or new NASA programs such as the topographic oceanography experiment (TOPEX) or search and rescue satellite program (SARSAT).

The advantage of this approach is that it could be implemented much sooner and at a lower cost. Useful data would be available sooner than from a dedicated CORS.

The disadvantages are that new organizational procedures might have to be developed. Data formats, coverage and access procedures might be different to meet the DOE CO_2 Research Program requirements.

- *A New NASA Mission*. A new NASA CORS mission could meet all SDRs, maximizing NASA's expertise developed on many programs. The potential disadvantage is that a NASA CORS mission might compete with other NASA missions, unless funded by DOE.

- *A New DOE Mission.* A new DOE CORS mission could meet all SDRs and assure a timely program start. Arrangements could be made to utilize NASA expertise and technical support. Such an approach could require new organizational relationships.

- *A New International Mission.* CO_2-induced climatic changes are of worldwide concern, and any mitigation strategies may have to be implemented on a worldwide basis. It would be useful to obtain international support for a CORS mission from the very beginning. An approach involving cooperative research, with other nations would accomplish this purpose. In addition, an international mission offers potential advantages in cost sharing and added international cooperation.

The major disadvantages of this approach are that it could increase organizational complexity and could delay meeting program goals.

2.7.2 DOE Mission Mode Options

There are three mission mode options:

1. Use data from existing or currently planned missions,
2. Provide additional instruments for currently planned satellites,
3. Build dedicated CORS for the mission.

- *Use Data from Other Programs.* The advantage to this approach is that data from an existing program could be available in the near term. Such data could be used to help establish the requirements for follow-on CO_2 missions; to develop necessary organizational relationships and data management's capabilities; and to provide a baseline for CO_2 measurement and calibrations.

Some of the disadvantages of this approach are that not all SDRs will be satisfied, global coverage may not be available, and the data may not be available in the DOE CO_2 Research Program format. Formats may vary, and thereby increase processing costs and reduce data return.

- *Provide Additional Space-Based Sensor Systems to Currently Planned Satellites.* This option provides near-term data return, allowing a gradual program build-up with early concentration on CO_2 user interfaces and data handling tasks. It should allow an orderly progression to a dedicated CORS. This approach could potentially meet most SDRs, maximize data management and acquisition, and lower CO_2 mission cost.

The potential disadvantage of this option is that the opportunities to share a mission may be limited.

- Build Dedicated CO_2 Research Satellites (CORS). The advantages of a dedicated CORS make it a desirable approach for Levels II and III. This approach could meet all SDRs and it would be user controlled.

The disadvantages of a dedicated CORS are that data return would be delayed until a satellite is operational.

2.7.3 Launch Vehicle Options

The desired orbit is a sun-synchronous orbit at about 1000-km altitude, as discussed in Section 1.5.2. Four launch vehicle options considered within the scope of this study are:

1. Space Transportation System (STS) launched from the Western Test Range (WTR),
2. Delta launched from WTR,
3. Ariane launched from French Guiana,
4. Atlas Centaur launched from WTR.

- *STS*. The advantages of the Space Shuttle launch make it the preferred launch vehicle option. The estimated mass of a CORS is 2000 kg; the CORS therefore would use only about 10 percent of the STS capability. Sharing the orbiter's payload bay would reduce launch costs. Furthermore,the Space Shuttle provides on-orbit capabilities. In the near future several flight-proven STS optimized satellite designs will be available from which to select designs for a CORS.

The disadvantage of this option is that a separate ascent propulsion module will be required for polar orbit insertion and circularization. At the present time, flights from the Western Test Range will be limited to no more than four per year, which may make manifesting of the CORS more difficult.

- *Delta*. The advantage of the Delta expendable launch vehicle is that it provides launch on demand to the final desired orbit. No additional ascent propulsion stage will be needed. Launch costs should be higher than with the STS, but less than for other expendables. A disadvantage is that payload capability to polar orbit and orbit circularization will be marginal for a 2000 kg satellite. Fewer services are available than with the STS.

- *Ariane*. The advantages and disadvantages of the Ariane expendable launch vehicle are similar to the Delta's. A shared launch might lead to costs that are comparable to those of the Delta. If a joint international mission is selected, the Ariane might be attractive.

- *Atlas-Centaur*. The Atlas-Centaur also has advantages and disadvantages similar to the Delta. It does have a greater payload weight for polar orbit insertion, but it is considerably more expensive.

2.7.4 CORS Serviceability Options

Four serviceability options are considered in this activity:

1. A non-serviceable satellite,

2. An STS serviced satellite,
3. An Orbital Maneuvering Vehicle (OMV) serviced satellite, or
4. A space station based and serviced mission. OMV and space station servicing will be candidates for Level II and III missions.

- *Non-serviceable.* This is the preferred approach for Level II. A non-serviceable CORS would have a lower initial cost, and lower weight, better FOV, reduced propellant requirements for orbit adjustments, and less degradation of pointing communications and thermal capability than one that is designed for on-orbit servicing.

- *STS Serviced.* STS servicing would allow less redundancy in some satellite subsystems because a failure could be corrected by manually replacing the failed module. On the other hand, the CORS would have to carry a descent propulsion stage to allow it to come down from its operational orbit to meet the orbiter.

- *OMV (Orbital Maneuvering Vehicle) Serviced.* The OMV could eliminate the need for an additional satellite descent propulsion system. It could also provide the capability to retrieve a disabled satellite, further reducing the need for satellite subsystem redundancy. A potential disadvantage is that the repair opportunities may be infrequent until space station based OMVs are operational.

- *Space Station Serviced.* This option is preferred for Level III. A space-station-based mission could provide frequent repair opportunities, and potentially some manned operation and film return which could increase scientific data return. Further, the space-based sensor systems could use space station facilities such as power, communications and thermal protection.

2.7.5 CORS Data Transmission Options

Three data transmission options were considered for the CORS:

1. Use of dedicated ground stations,
2. Use of the NASA Tracking and Data Relay Satellite System (TDRSS), or
3. Use of the Tracking and Data Acquisition System (TDAS).

- *Dedicated Ground Stations.* Dedicated ground stations can operate at high data rates, but they have two major problems. First, they have relatively high installation and operation costs. Second, they would be in view of the CORS in polar orbit only twice a day, therefore, either many ground stations would be required for global data coverage, or the satellite would have to store data until it was over a ground station when it would dump the data at a high rate.

- *TDRSS (Tracking and Data Relay Satellite System).* The TDRSS system should meet the SDRs and is available today. This is the preferred approach for Level II. TDRSS has 3M bps S-band single-access capability. The disadvantages are that on-board data storage would be required for the periods when a TDRSS satellite was not in view or not available. Single-access TDRSS service would be required to meet CORS data rate requirements, which may put a significant strain on TDRSS availability.

- *TDAS (Tracking and Data Acquisition System).* The TDAS system is planned to be the successor to TDRSS around 1994. It is the preferred approach for Level III. It will have significantly increased capability with 600-1000M bps at 20/30 GHz. Because multiple satellites with high capacity cross links will be available no on-board storage is required. The disadvantage is that it will not be available until 1994.

2.7.6. CORS Bus Options

A satellite bus can be a new design or a modification of an existing design. For Level II an existing STS optimized design could be modified. This approach could reduce satellite-bus recurring costs. The integration process would be easier because the interfaces would be known, and previously proven approaches could be used. This approach would also shorten the satellite development schedule. An STS optimized satellite bus could be used to take advantage of STS capabilities — several proven candidates would be available by 1988. If the full width of the orbiter cargo bay were used and satellite length minimized, launch costs could be reduced significantly, and large instrument mounting areas would become available with good fields of view and good thermal characteristics. In addition STS on-orbit deployment and checkout capabilities can be used to reduce risk.

For Level III, an equipment rack on a potential solar Space Station platform is desirable. This option could reduce space-based sensor system support requirements, while providing many services and minimizing costs.

2.7.7 A Preliminary Integrated System Concept for CORS

The following is an example of a preliminary integrated system concept for a Level II CORS mission. The CORS concept (Figure 15) would include the following space-based sensor systems:

- Infrared Interferometer/Spectrometer (IRIS) — advanced version
- Advanced Very High Resolution Radiometer (AVHRR) — improved
- Advanced Microwave Sounder Unit (AMSU)
- Scanning Multichannel Microwave Radiometer (SMMR) — improved
- Stratospheric Aerosol and Gas Experiment (SAGE-2) — improved
- Earth Radiation Budget Experiment (ERBE) — improved
- Topex Radar Altimeter (ALT)
- Data Collection System (DCS) — improved

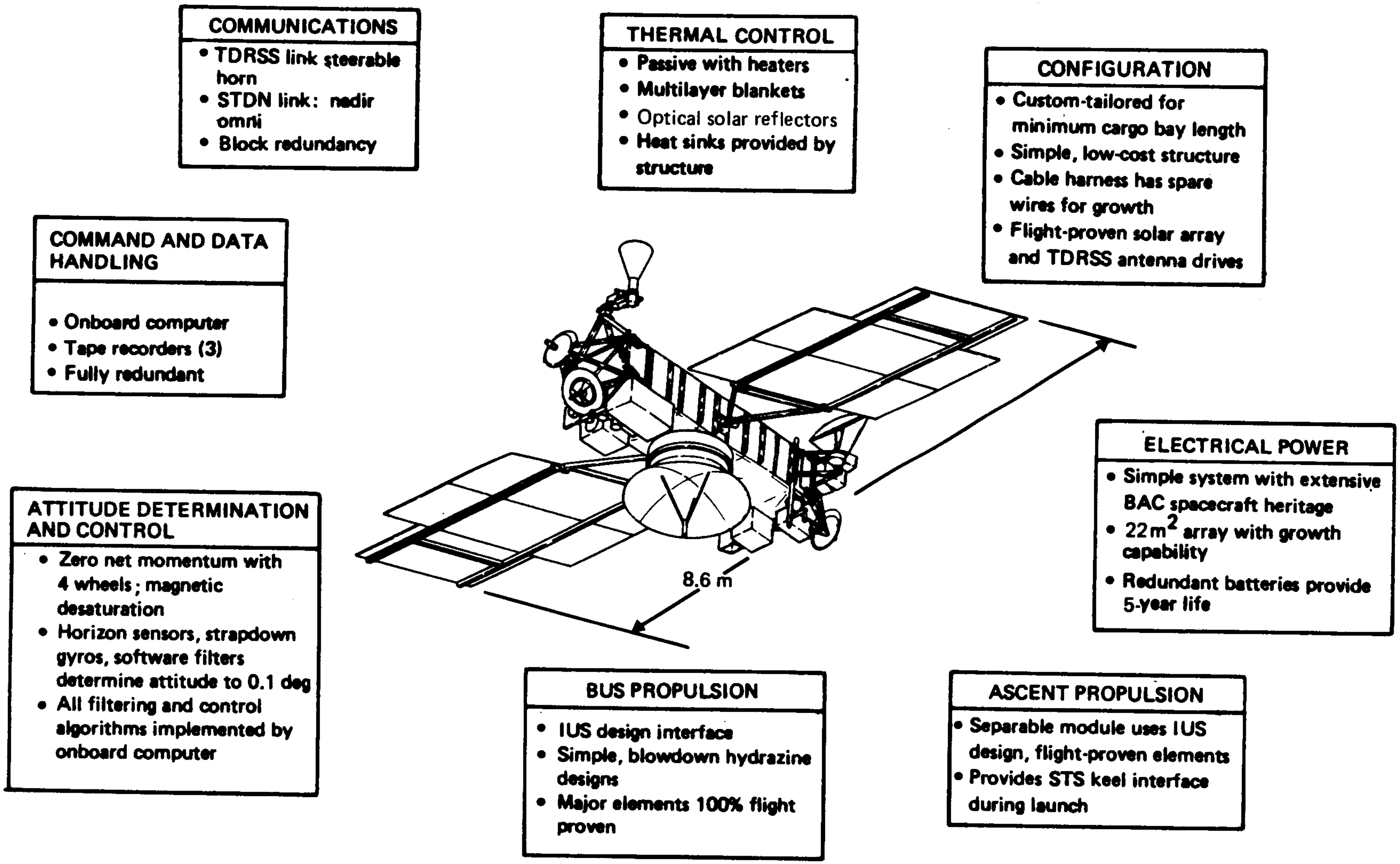


FIGURE 15 CORS LEVEL II DESIGN

This instrument package will weigh approximately 470 kg, will require approximately 600 watts dc power, and will transmit data at approximately 750K bps.

The CORS would be launched by the STS from the Western Test Range (WTR) into a circular orbit at 99.5° inclination and 150 nautical miles altitude. The CORS would occupy approximately one-eighth of the STS cargo bay. Launch costs could be shared among several payloads. The CORS could be charged on the basis of payload bay length, rather than weight.

The CORS would be checked out in the payload bay. It would then be lifted from the payload bay by the STS remote manipulator arm. Final checkout would be performed while the CORS was attached to the arm and the satellite then released to ascend to its operational orbit at 1000 km using a separable hydrazine propulsion module.

The STS optimized satellite bus which spans the orbiter cargo bay provides a large surface area and good fields of view for ease of instrument locating. A three-axis attitude control system would provide nadir pointing to 0.2° throughout the mission. Electrical power would be supplied by an articulated solar array and NiCd batteries. Communication with the CORS payload operation control center could be via TDRSS. An on-board computer would control satellite operations, and tape recorders would be used to store data when a TDRSS satellite is not in view. Station keeping would be performed periodically using an on-board hydrazine propulsion system. Thermal balance is achieved by a largely passive design using multi-layered insulation and optical solar reflectors, supplemented by heaters.

The ground system consists of user receiver stations for DCS and AVHRR users, in-situ measuring units and their transmitters for the DCS, a mission operations system (MIS) including a payload operations control center (POCC), an orbit determination and tracking system, and an Information Processing System (IPS). The IPS would receive, process, archive and distribute the data. The engineering bus conceptual design is discussed in detail in Appendix E.

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3.0 SYSTEM/SUBSYSTEM CONCEPT RECOMMENDATIONS

3.1 OBJECTIVES

Based on the results of Task 2.0 the objective of Task 3.0 is to recommend space-based sensor systems to meet the SDRs. These recommendations are to serve as the inputs for the Task 4.0 efforts.

The recommendations for space-based sensor systems are based on the following criteria:

- Potential for early data acquisition.
- Established space-based sensor system performance.
- Ongoing development efforts to improve specific sensor subsystems.
- Potential for growth of sensor subsystems capabilities.
- Potential for utilization of advanced space technology.

Specific efforts are recommended for Levels I, II and III to develop space-based sensor systems which could make effective use of future STS missions during several decades and to provide near-term data, data satisfying to all SDRs and data of increasing value to the DOE CO_2 Research Program. Proceeding with efforts recommended for Levels I, II and III could ensure that information on pressing issues associated with CO_2-induced climate changes could be obtained consistent with the needs of the scientific community. Elimination of efforts recommended for Level I or Level II could delay obtaining significant data and increase space-based sensor system development risks.

3.2 LEVEL I (0-5 YEARS)

The efforts should focus on:

- Development and establishment of a data acquisition and management system which will combine realtime data output from existing NOAA, NASA, DMSP satellites that differ in spatial and temporal coverage.

- Development of the High-Altitude Powered Platform (HAPP).

Secondary efforts could include:

- Review and improvement of infrared and microwave sounding methods, especially with wider spectral coverage.

- Feasibility assessment of the STS Recalibration Package.

- Investigation of the potential of a High-Orbit Radiation Budget (HORB) satellite.

The expected results of Level I efforts are:

- An early start on the definition and development of a CO_2 data management system.
- Near-term use of existing space technology to meet the needs of the DOE CO_2 Research Program.
- Definition of infrared and microwave measuring methods and sensor subsystems based on operational experience.
- Definition studies and engineering development of a HAPP.

3.3 LEVEL II (5-10 YEARS)

The focus of this effort should be on developing and placing into operation:

- A CO_2 research satellite (CORS) with the instrument set shown in Task 2.0, Table 11, "Space-based Sensor Systems — Level II," for global coverage.
- The HAPP to provide high resolution continuous monitoring of selected regional climate parameters and information on cloud structure.
- The STS Recalibration package to improve calibration of in-flight infrared and microwave satellite radiometers.

Secondary efforts could include:

- Continued development of advanced Fourier transform infrared and multichannel microwave radiometers.
- Continued development of LIDAR.
- Identification of the space-based sensor system for the potential High-Orbit Radiation Budget (HORB) satellite.

Expected results of Level II efforts are:

- An operational CORS.
- An operational STS recalibration package.
- An operational HAPP.
- Development of advanced space-based sensor systems.

3.4 LEVEL III (10-20 YEARS)

Space-based sensor systems for Level III might depend strongly on the outcome of studies, data, and development of systems during the time frames of Levels I and II. The focus of this effort should be:

- Development of advanced space-based sensor systems as shown in Task 2.0, Table 12 "Space-based Sensor Systems — Level III." They include advanced very wide coverage Fourier transform spectrometers to provide more accurate CO_2 climate data and LIDAR for vertical sounding, Doppler wind data, and altimetry for a dedicated CORS which could be part of a free-flying, unmanned, space platform in a polar, sun-synchronous orbit and which could be serviced by the STS.

- Continued operation of HAPP and of the STS Recalibration package.

Expected results of these efforts are:

- Advanced space-based sensor systems.
- Space-based sensor systems integrated with a free-flying space platform.
- Data which satisfy all SDRs.

4.0 PROGRAMMATICS AND COST ESTIMATES FOR RECOMMENDED SPACE-BASED SENSOR SYSTEMS

4.1 OBJECTIVES

The objectives of Task 4.0 were to: provide preliminary concept designs of the engineering bus configurations for a CO_2 research satellite (CORS); provide cost estimates and schedules for these configurations, including launch and ground operations; and define the products and services to be developed in the implementation phase of a CORS.

4.2 METHODOLOGY

The CORS engineering bus concepts for Levels I, II and III were used to establish project schedules, develop Work Breakdown Structures (WBSs), and perform cost analyses. The CORS concepts are based on:

- Flight-proven major elements and a design optimized for use on a space transportation system (STS) to substantially reduce technical, cost, and scheduling risks.
- Minor modifications to an existing satellite design. The CORS Level II missions can use the topological oceanography experiment (TOPEX) satellite bus. For the Level III mission, a design based on Spacelab pallets attached to an unmanned polar space platform is proposed.
- Existing technology so that no new engineering bus technology is required. Flight-proven, off-the-shelf hardware, with known heritage and performance, is used throughout the CORS engineering bus. All new design components will be based on currently existing technology and proven capabilities or on technology that will have been proven prior to award of the implementation phase contract.

4.3 CORS DESIGN CONSIDERATIONS

The design goal is to provide significant space-based sensor system data with low risk at a minimum overall mission cost.* This goal could be accomplished by providing long-term global coverage with gradual phasing from an early initial capability to more capable systems as the program matures. For the CORS development program three missions are identified:

- Level I — A system design baseline developed for cost estimation purposes to provide a comparison with Levels II and III.

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- Level II — An intermediate-term mission to be flown in five to ten years using modifications of existing space-based sensor systems.

- Level III — A long-term mission with a new system complement to be developed and flown in ten to twenty years.

Figure 13 illustrated the CORS baseline satellite design. The design meets CORS mission goals and requirements, providing the functions necessary for a mission life of at least three years. Major elements of the proposed design are summarized below.

A separable ascent propulsion module was designed to carry the satellite from the STS parking orbit to the observational orbit. The engineering bus propulsion system would provide trim and orbit maintenance maneuvers. The tracking and data relay satellite system (TDRSS) would provide primary command and telemetry links and doppler and ranging data for orbit determination. In addition to the TDRSS antenna, an omnidirectional nadir-pointing antenna would be used to facilitate emergency direct ground communications. The command and data handling subsystem (CDHS) is based on Application Explorer Mission (AEM) equipment which Boeing built for the NASA Goddard Space Flight Center (GSFC).

Tape recorders would store data and allow simultaneous data recording and playback. Playback would be compatible with the attitude determination and control subsystem (ADCS) and would provide the required nadir-pointing accuracy. The ADCS would also ensure accurate thruster pointing and control during orbit maintenance maneuvering. The electrical power subsystem would generate and distribute power during periods of occultation. The thermal control subsystem would use passive methods supplemented by heaters to maintain the payload instruments and subsystem equipment within permissible temperature ranges.

Modifications required for the Level II mission bus (shown in Figure 15), are minimal and are limited to minor structural changes, additions to the electrical power subsystem to accommodate changed payload requirements, and the addition of redundant components to meet a five-year life requirement.

For the Level III mission (shown in Figure 14), two Spacelab pallets would provide the primary structure which would be attached in orbit to a free flying, unmanned, space platform using a "standard" space platform docking interface. The space platform would provide electrical power, communications, and attitude control services to the CORS module.

The technical approach minimizes overall system cost; hence, the design minimizes the cost of operations, launch vehicle integration, and payload integration as well as satellite bus costs.

The design minimizes required ground operator interaction and control of the CORS. A large onboard command memory permits relatively longer intervals between command loads. Onboard software status monitoring, fault detection, redundancy management, and safing increase satellite autonomy and reduce operator duty requirements.

*The complete satellite bus definitions, cost estimates, project schedules, and work breakdown structures are provided in Appendix E.

The CORS baseline design uses existing, proven STS interfaces and release mechanisms, thereby making maximum use of STS capabilities and interfaces without imposing special requirements on the STS.

Benefits derived from an STS-optimized satellite include improved ability to perform on-orbit checkout and to establish TDRSS communications and solar array deployment before releasing the satellite from the remote manipulator system (RMS). By allowing on-orbit checkout of a more complete, deployed satellite, STS capability could save the cost of a replacement satellite. The large diameter of the orbiter permits booms to be fixed, rather than stored and later deployed. It also provides a large satellite volume that allows us to position various electronic boxes to optimize wire harness layout and meet thermal design objectives.

For the baseline Level I mission, a shared launch would be feasible and desirable to minimize launch costs. The CORS baseline configuration would occupy one-eighth of the Orbiter cargo bay and approximately 16 percent of STS launch capability by weight. The Level II configuration would occupy one-eighth of the Orbiter cargo bay and approximately 17 percent of the STS launch capability by weight. A third tank could be added to the separable ascent propulsion module to increase performance without affecting the engineering bus should the CORS need to accommodate a change in plane or increased velocity.

For Level III, an STS launch and rendezvous with an existing space platform is assumed. For this Level III mission the CORS payload would require a dedicated STS launch.

Because of the large size of the payload deck, the CORS design provides exceptional instrument placement capabilities and fields of view (FOV's), increasing mission science data return. Because there are large volume and weight margins, the CORS baseline design accommodates the increased payload requirements of the Level II mission with only minor structural changes.

An existing STS-optimized satellite bus for the Level II mission is proposed in order to minimize satellite development costs. The TOPEX bus design is very close to that required for the CORS program, and will require only minor modifications for use in the CORS program. Using existing sensors will also minimize satellite costs.

Similarly, the primary structure proposed for the Level III mission uses existing Spacelab pallets to minimize development costs. Development of new sensors will be the major cost driver for the Level III mission.

A three-phased mission approach would permit near-term data collection at reasonable cost, while allowing a gradual transition to a system that is capable of providing comprehensive long-term global measurement. The effect of changing atmospheric CO_2 concentrations would require a long observation period, so it is essential to receive early measurement data. On the other hand, it is not yet clear exactly which measurements would be most meaningful.

Furthermore, an optimal sensor package for the CORS mission would not become available until a number of years after ideal measurement criteria are determined.

For the Level II mission, the STS would release the CORS in a circular parking orbit at 99.4° inclination at 250-km altitude. The proposed reference ascent orbit is a Hohman transfer from the parking orbit to the observational orbit, at which point the satellite will separate from its ascent propulsion module and perform a circularization trim maneuver. For the Level III mission the STS would attach the CORS instrument module to a sun-synchronous, unmanned, space platform which will provide communications, attitude determination and control, and electrical power to the instrument platform.

Table 13 shows the satellite orbital parameters. The selected orbit for each mission Level is sun-synchronous with a four-day repeat cycle for ground track coverage. Local time at the subsatellite point for the descending equatorial nodal crossing is 12:00 AM because the Earth-Sun line lies in the satellite orbital plane.

The mission design lifetime will be five years for Level II and ten years for Level III. Level II would have no satellite servicing. Solar arrays, batteries and station keeping propellant would be sized for the required lifetime. The elimination of critical single points of failure would be considered in future cost/reliability trades and would be especially desirable for the Level II mission.

For Level II the sensor system platform could be designed to be disconnected from the space platform and brought back to Earth by the STS for refurbishment and repair. However, limited on-orbit servicing capability would permit some malfunctions to be corrected by astronaut extravehicular activity (EVA) from the orbiter.

4.4 CORS DATA COLLECTION CONSIDERATIONS

Three basic types of data will be transferred between the CORS satellite and the ground system: telemetry, command, and tracking. This data would be relayed using existing NASA TDRSS links. The NASA communications (NASCOM) network will handle ground data flow between the TDRSS ground station at White Sands and the payload operations centers.

Telemetry data, consisting of housekeeping and science information, would be down linked to the POCC in real-time and tape recorder playback form. On arrival at the POCC, the real-time data would be used for command verification and for spacecraft and instrument health checks. Tape recorder playback data would be formatted and forwarded to the information processing system (IPS) for processing, archival storage and distribution. The POCC would control satellite operations by issuing real-time commands and command memory loads which are transmitted by TDRSS to support operational orbit determination. In operational ephemeris data would then be sent to the POCC so the appropriate maneuver activity can be initiated.

A simplified version of the CORS satellite-ground mission data collection and handling flow is illustrated in Figure 16. For the Level III mission the proposed NASA Tracking and Data Acquisition System (TDAS) would replace TDRSS for communications relay, with considerably improved capabilities.

TABLE 13

CO_2 RESEARCH SATELLITE ORBITAL PARAMETERS

Orbital Parameters	Level I (Baseline)	Level II	Level III
Orbital Inclination (degrees)	99.4	99.4	97.4
Orbital Altitude (km)	982	982	491
Nodal Period (minutes)	104.73	104.73	94.73
Number of Ascending Nodal Crossings/Day	13.75	13.75	15.25
Repeat Cycle (for Ground Track Coverage) (days)	4 (55 Orbits)	4 (55 Orbits)	4 (61 Orbits)
Longitude Difference Between Successive Ascending Nodes (degrees)	−26.11	−26.11	−23.94

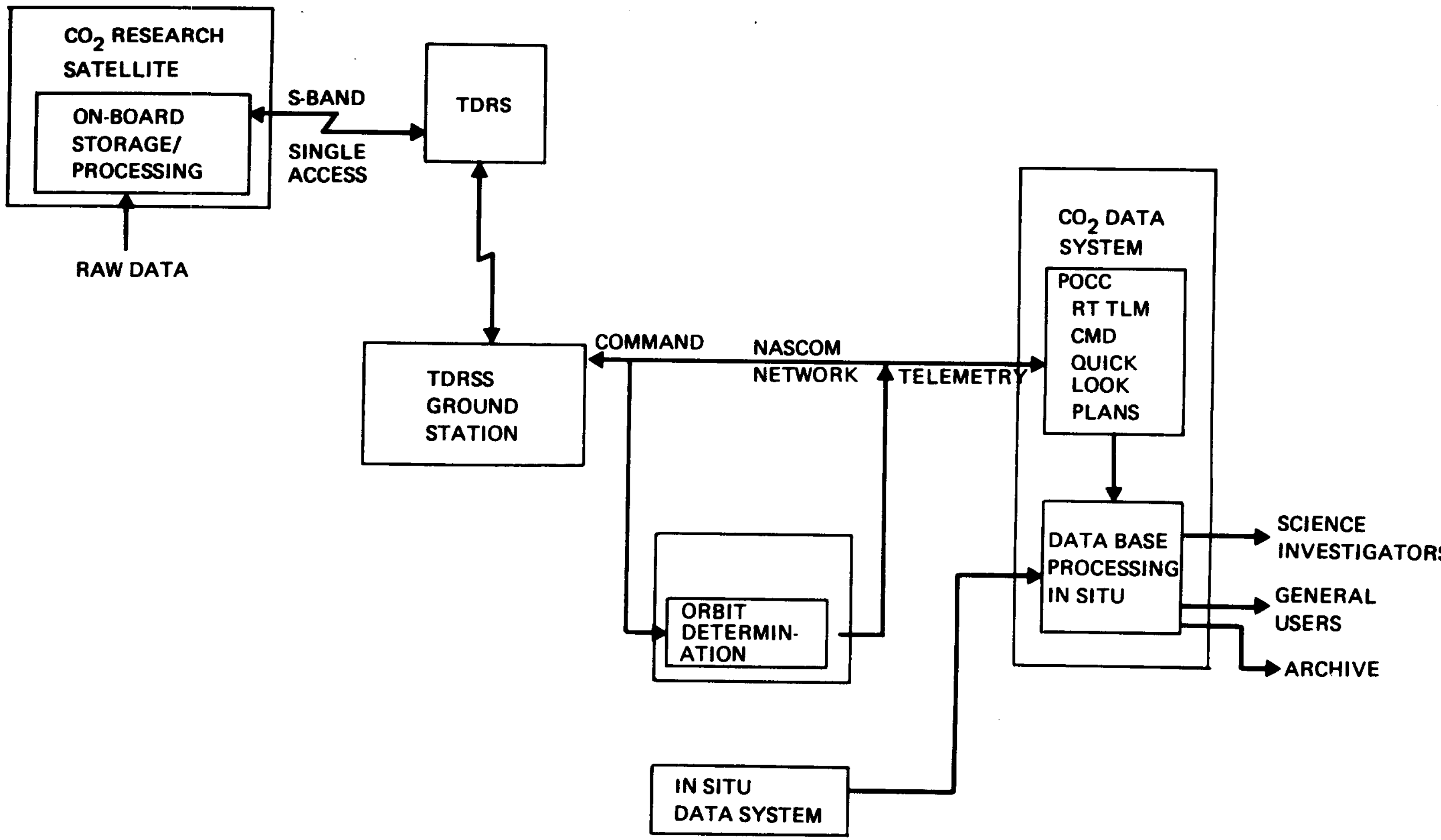


FIGURE 16 MISSION DATA COLLECTION AND HANDLING BLOCK DIAGRAM

4.5 CORS SPACE-BASED SENSOR SYSTEM CONSIDERATIONS

Sensor complements and major sensor characteristics for each mission level are shown in Table 14.

The elements that contribute to the instrument accommodation capability offered by the CORS bus include:

1. A large nadir-pointing deck area for sensor mounying to accommodate multiple sensors without interference in sensor FOV's.

2. Ample mounting area on the interior of the engineering bus equipment pallets to provide a thermally benign environment for internally mounted payload elements.

3. Volume allowing for accommodation of instruments mounted on masts to satisfy FOV requirements without deployment.

4. A flexible command and data handling architecture to allow a wide variety of experiment command and data handling requirements to be accommodated.

These factors have allowed the Level II payloads to be accommodated on the same engineering bus with only minor bus modifications. The Level III mission, with its much larger power requirements, telemetry rates and bulk, requires a different platform design. Sensor locations for the CORS baseline mission are shown in Figure 17.

Level II sensor systems are identical to those of the baseline Level I with the following exceptions:

- The AVHRR is an improved version with satellite interfaces similar to those of Level II.

- The DCS has additional component boxes needed to increase simultaneous processing capability and to provide redundancy necessary for a five-year mission. The additional boxes are also located along the −X wall of the engineering bus.

- The SAGE-2 instrument is an improved version with satellite interfaces similar to those of Level I.

- The SMMR is an improved version with satellite interfaces similar to those of Level I. It was desired originally to increase the SMMR antenna diameter to 4 meters. This was found to present challenges to the engineering bus design which would significantly increase mission cost. For this reason the antenna diameter was left unchanged.

- The HIRS-2, MSU, and SSU were dropped and replaced by the IRIS and AMSU instruments.

TABLE 14

SENSOR CHARACTERISTICS SUMMARY

Sensor	**Mass (kg)**	**Average Power (W)**	**Average Telemetry Data Rate (KOPS)**
Level I Mission (Baseline)	(365)	(449)	(368)
• Modified Advanced Very High Resolution Radiometer (AVHRR)	27	25	335
• Data Collection System (DCS)	29	27	1
• Stratospheric Aerosol and Gas Experiment (SAGE-2)	30	10	8
• Earth Radiation Budget Experiment (ERBE)	55	50	1
• Scanning Multichannel Microwave Radiometer (SMMR)	52	60	12
• Topex Radar Altimeter (ALT)	99	199	7
• High-Resolution Infrared Sounder (HIRS-2)	32	23	2
• Microwave Sounding Unit (MSU)	32	40	1
• Stratospheric Sounding Unit (SSU)	9	15	1
Level II Mission	(401)	(562)	(370)
• Improved Advanced Very High Resolution Radiometer (AVHRR)	27	25	335
• Improved Data Collection System (DCS)	41	36	1
• Improved Stratospheric Aerosol and Gas Experiment (SAGE-2)	30	10	8
• Earth Radiation Budget Experiment (ERBE)	55	50	1
• Scanning Multichannel Microwave Radiometer (SMMR)	52	60	2
• Topex Radar Altimeter (ALT)	99	199	7
• Infrared Interferometer/Spectrometer (IRIS)	17	12	12
• Advanced Microwave Sounding Unit (AMSU)	80	170	4
Level III Mission	(2205)	(3990)	(1154)
• Infrared Visual Mapper (IRVM)	30	25	700
• Improved Data Collection System (DCS)	42	36	1
• Light Detecting and Ranging (LIDAR)	1300	3000	250
• Infrared Interferometric Radiometer(FTS)	300	150	40
• Microwave Pressure Sounder (MPS)	50	100	1
• Advanced Microwave Sounder (AMS)	80	170	4
• Microwave Mapper (MM)	220	235	50
• Topex Radar Altimeter (ALT)	99	199	7
• Parallax Sensor (PS)	30	25	100
• Advanced Earth Radiation Budget Experiment (ERBE)	55	50	1

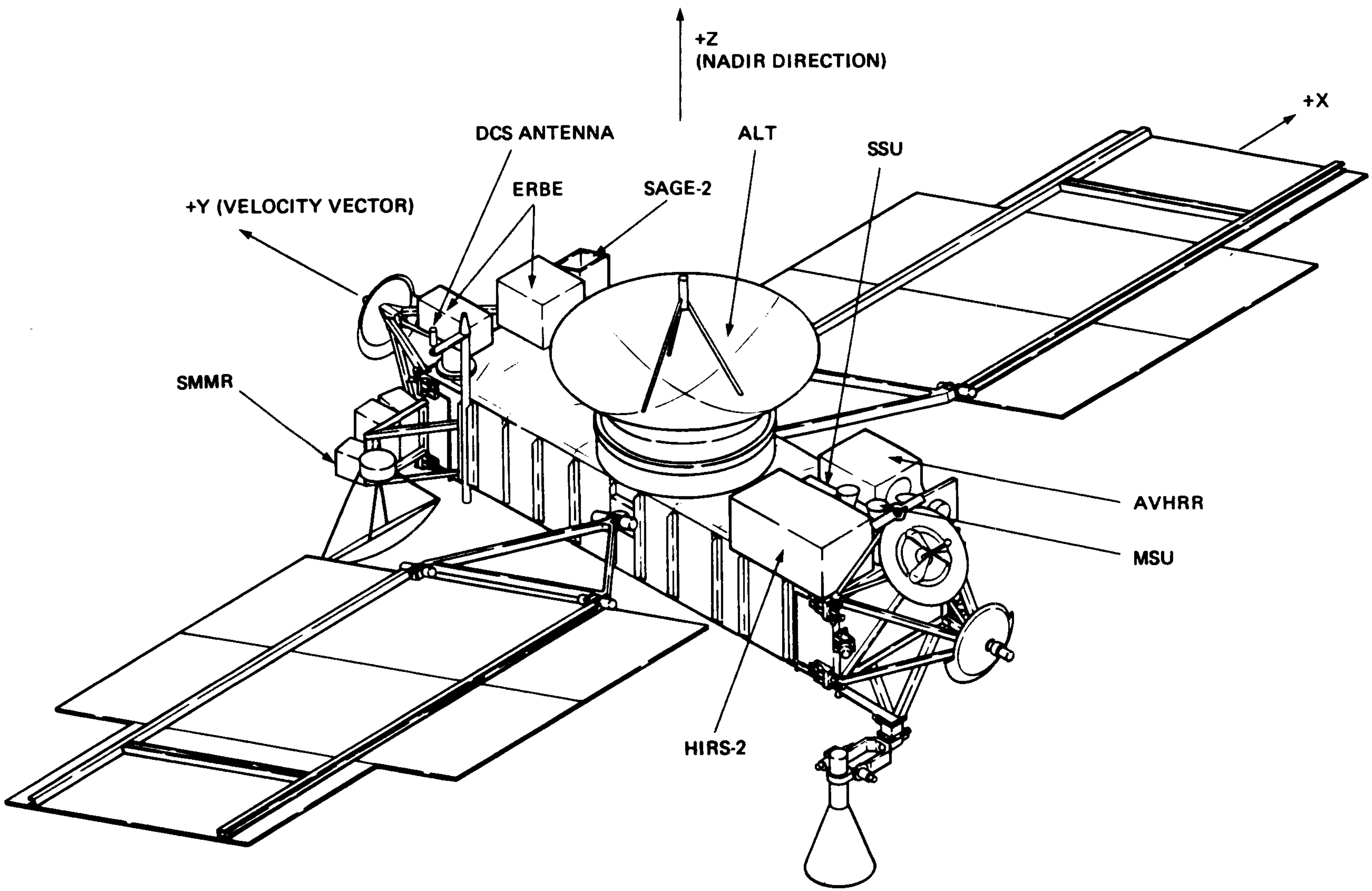


FIGURE 17 CORS BASELINE SENSOR ARRANGEMENT

Figure 18 shows the general arrangement of sensor systems for the Level III mission.

The STS mechanical, electrical, avionics, and environmental interfaces are defined in JSC ICD 2-19001 with which the CORS satellite system is completely compatible. Mechanical interfaces and deployment methods are simple and flight proven.

The structural and mechanical interface between CORS and the STS provided active longeron and keel attachment fittings. The mechanical interface is flight proven on the SPAS payload on STS-7, as was the RMS grapple fitting which is used in CORS deployment operations.

Cargo bay electrical interfaces, except for the RF interfaces, are physically located near the trunnion interface to minimize cable lengths. The interface unit (IU), which provides the electrical interface between CORS and the STS, is mounted in its position along the port longeron bridge. A standard umbilical retraction system (SURS), with its compatible ball-jointed receptacle connector mounted on the CORS satellite, which is supplied by the STS, completes the electrical interface between CORS and the STS. The grapple fixture incorporates an integral electrical connector that engages a connector on the RMS end effector when the end effector becomes rigid.

Display and control functions involved in launch and deployment of the CORS are accomplished using crew-controlled equipment. The payload retention control panel is used to control the active longeron and keel fittings. One section of the standard switch panel (SSP) is used to monitor critical CORS parameters in the power, pyrotechnic, and propulsion subsystems.

The principal interface between CORS and TDRSS is the signal format used by TDRSS; secondary requirements include antenna pointing and link margins. The proposed design using redundant NASA standard transponders satisfies all CORS/TDRSS interface requirements.

The mission operations system (MOS) is responsible for all elements — tracking and data acquisition, ground data system, and mission control — needed to operate the satellite, and the information processing system (IPS) activities (processing and data distribution) relating to the production of CORS data output for scientific use. The majority of MOS and IPS elements and functions could be consolidated in a single facility to maintain an effective operations structure. These MOS functions include:

- All activities related to the operation of the satellite from launch to the end of the mission.

- Collection of measurement data.

- Formatting of satellite, ephemeris, and surface measurement data for use by the IPS.

- Development, operation, and maintenance of the TOPEX data system for use by both the MOS and IPS.

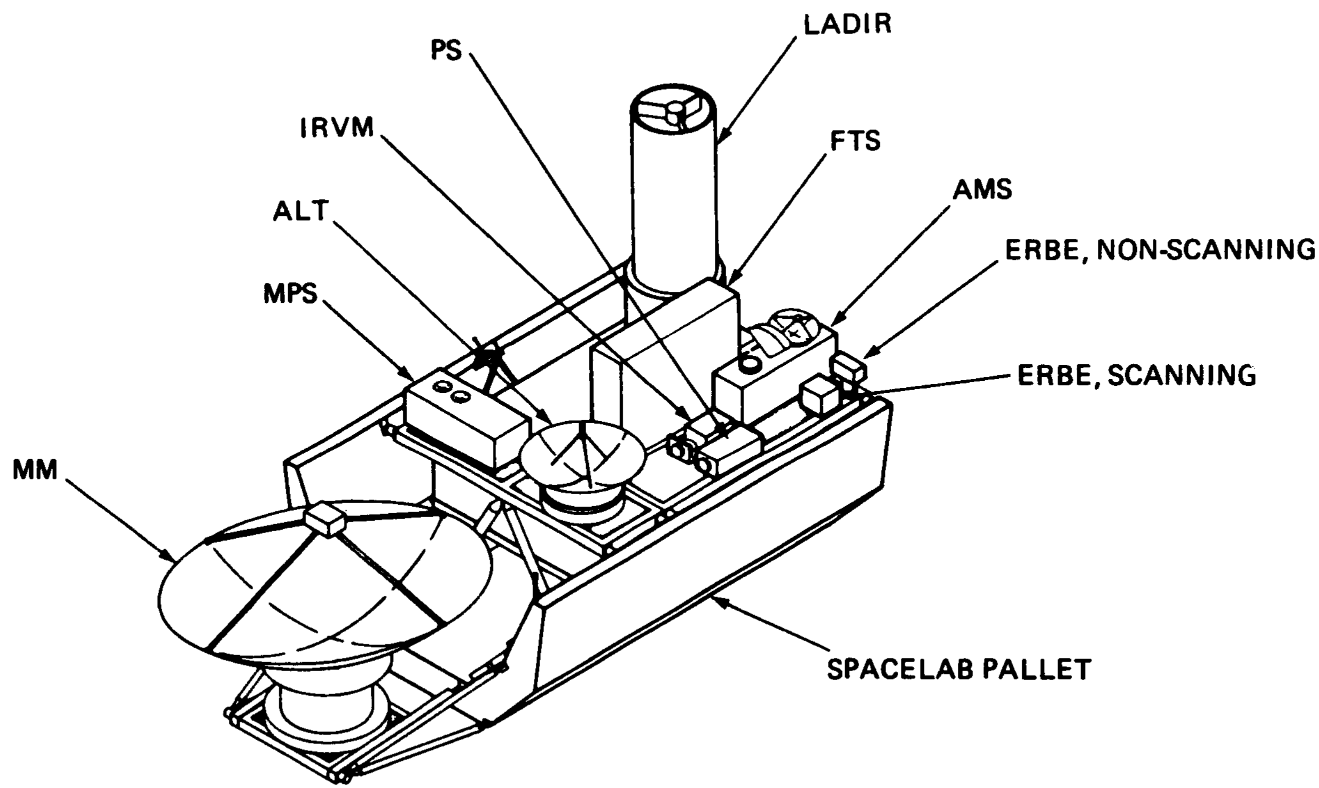


FIGURE 18 CORS LEVEL III SENSOR ARRANGEMENT

- Interfacing with GSFC for NASCOM and TDRSS scheduling and the receipt of orbit ephemerides.

The payload operations control center (POCC), located at MSFC, is designated as the central facility for controlling the CORS satellite. Satellite health and status, based on real-time data, would be monitored at the POCC. Additionally, tape recorder playback data received would be formatted for IPS analysis and processing. Real-time commands, initiated by the POCC, would be relayed to the satellite during tracking and data relay satellite (TDRS) view periods, while command memory loads would be formulated and uplinked one or two times per day. Telemetry and command links between the CORS satellite and the POCC would be relayed to the satellite during tracking and data relay satellite (TDRS) view periods, while command memory loads would be formulated and uplinked one or two times per day. Telemetry and command links between the CORS satellite and the POCC would be via TDRSS and the NASCOM network.

The detailed engineering bus conceptual design is given in Appendix E.

4.6 CORS PROJECT SCHEDULES

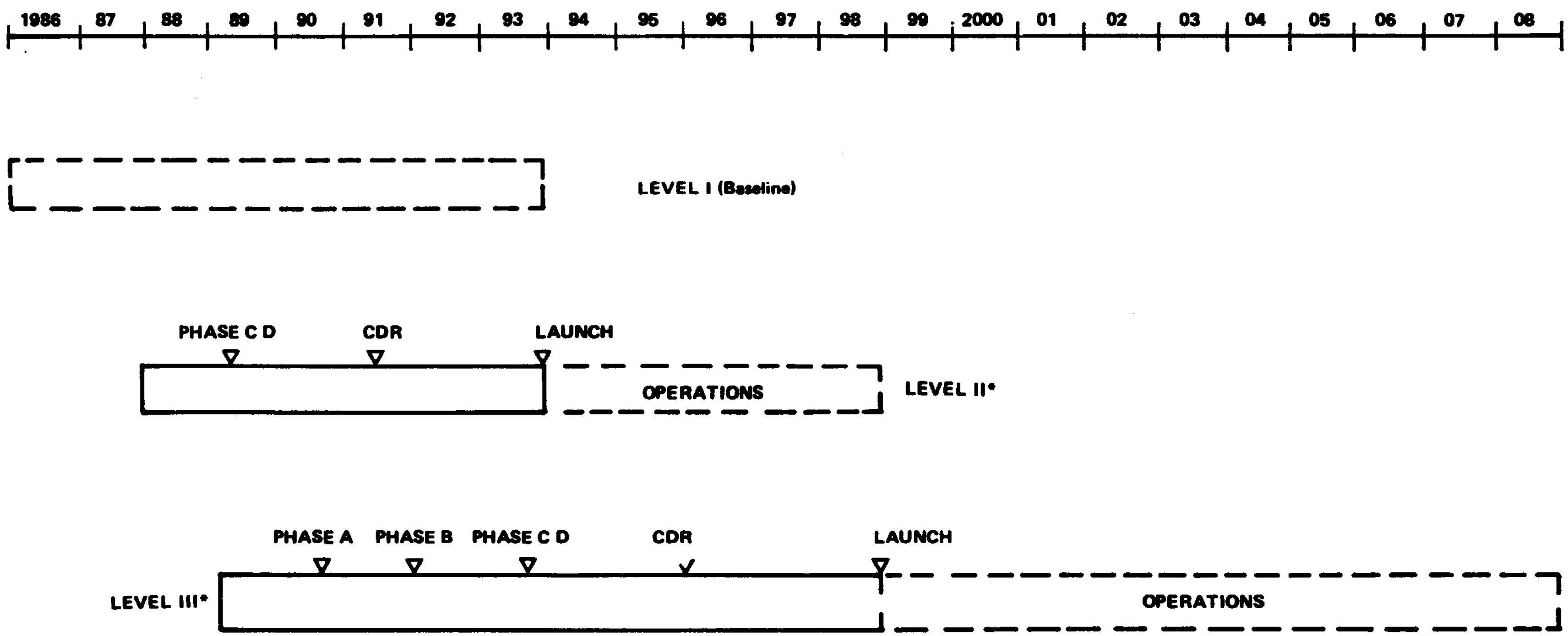
A summary of the CORS development program phasing schedule for a two-mission program is shown in Figure 19. This schedule shows a separate series of phased contracts for mid-term, and long-term missions (Levels II and III, respectively). For each of the two levels, cost was considered as the primary schedule design criteria.

The two missions could be part of a comprehensive DOE CO_2 Research Program. Alternatively, either of the missions could be flown independently. The Level II mission could be started as early as 1984 or as late as desired. The Level II mission schedule presupposes the existence of a polar space platform and the Tracking and Data Acquisition System (TDAS) follow-on to the current Tracking and Data Relay Satellite System (TDRSS). For this reason, a Level III start was assumed no sooner than approximately 1987. Each of the schedules assumes that shared STS launch opportunities will be available as required.

The Level II mission assumes use of a modified, existing Shuttle optimized satellite bus and modified existing science instrument complement.

The Level III mission assumes use of Spacelab derived instrument pallets to support the scientific instrument complement. The Spacelab pallets would be based on an unmanned space platform in polar orbit which would have been separately developed and in place for use by the DOE CO_2 Research Program. It is assumed that the space platform would have a standard interface for separable science modules and that it will supply electrical power, communications, and attitude control functions sufficient to meet the needs of the Level III CORS mission.

The major task for the Level III mission is development and qualification of new sensor systems. Feasibility demonstrations using aircraft would be required prior to implementation of space-based sensor systems. Technology studies would be required prior to the start of the Level III schedule to develop sensor system concepts and breadboard designs to the point where a feasibility demonstration is needed. Detailed project schedules are provided in Appendix E.



*Levels II and III could be done independently or consecutively.

FIGURE 19 CORS PROGRAM PHASING SCHEDULE

4.7 WORK BREAKDOWN SCHEDULES

The Work Breakdown Structures (WBSs) for the potential CORS missions for Levels II and III providing a product oriented family tree hierarchy which contains levels of work required to produce, launch, and operate a CORS. The WBS was developed by starting with this end objective and subdividing into systems, subsystems, and components which are the logical and necessary steps needed to achieve the project objective. The total estimated cost for any item at any level is equal to the sum of the estimated costs for all the items below it. The WBS dictionary — a book of definitions numbered to correspond to the WBS describing the contract objectives in terms of hardware, software, services, and other manageable tasks to be accomplished in the performance of the total program objective — is provided in Appendix E. Tables 15 and 16 provide a WBS for each mission.

4.8 COST ANALYSES

The primary tool used for estimating acquisition costs is the Boeing Parametric Cost Model (PCM).* The PCM developed costs from physical hardware description and program schedules, and allowed the integration of any known costs (or outside generated costs such as subcontractor or vendor estimates) into the total estimate. In this way, a program cost from the best available source data was assembled.

The cost summary for the Level II and III missions is shown in Table 17.

The assumptions underlying costing for the recommended Level I data collection from existing satellites are as follows:

- Class O data, acquired directly from operating satellites would be available to the DOE CO_2 Research Program.
- Real-time satellite data are the only required input, archival data are not required.
- The data so acquired will have temporal and spatial gaps.
- Management, programmatic and administrative issues are excluded from consideration, with respect to either costs or feasibility of alternative organizational or administrative arrangements.

The cost estimates for the recommended Level I system are determined solely by the costs for the ground data-management center. (See Chapter 6.0.) These costs are assumed to be unaffected by the difference in satellite mission-support between Level II and III and the use of existing and relevant NOAA and NASA missions. Costs for the recommended Level I system exclusive of HAPP are summarized in Table 18.

*The PCM has been developed by the Boeing Aerospace Company.

TABLE 15

WORK BREAKDOWN STRUCTURE — LEVEL II MISSION

1.0	Program Management
2.0	Systems Engineering and Integration
3.0	Satellite Bus Design, Fabrication and Test
3.1	Structures and Mechanisms
3.2	Attitude Control and Determination Subsystem
3.3	Command and Data Handling Subsystem
3.4	Communications Subsystem
3.5	Electrical Power Subsystem
3.6	Orbit Maintenance Propulsion Subsystem
3.7	Thermal Subsystem
3.8	Wiring Harness and Cabling
3.9	Ascent Propulsion Stage
3.10	Bus Integration and Checkout
4.0	Payload Design, Fabrication and Test
4.1	Improved Advanced Very High Resolution Radiometer (AVHRR)
4.2	Improved Data Collection System (DCS)
4.3	Improved Stratospheric Aerosol and Gas Experiment (SAGE-2)
4.4	Earth Radiation Budget Experiment (ERBE)
4.5	Improved Scanning Multichannel Microwave Radiometer (SMMR)
4.6	TOPEX Radar Altimeter (ALT)
4.7	Infrared Interferometer/Spectrometer (IRIS)
4.8	Advanced Microwave Sounding Unit (AMSU)
4.9	Payload Integration and Checkout
5.0	System Test and Evaluation
6.0	Test Support
6.1	Tooling and Special Test Equipment
6.2	Peculiar Support Equipment
7.0	Airborne Support Equipment
8.0	Critical Flight Spares
9.0	Software
10.0	Reliability, Quality Assurance and Safety
11.0	Launch Vehicle Integration and Flight Support
12.0	Ground Operations
12.1	Dedicated Ground Station Facilities
12.2	Information Processing System
12.3	Mission Operations
13.0	Launch Services

TABLE 16

WORK BREAKDOWN STRUCTURE — LEVEL III MISSION

1.0	Program Management
2.0	Systems Engineering and Integration
3.0	Payload Support System Design, Fabrication and Test
3.1	Payload Support Equipment
3.2	Spacelab Pallet
3.3	Payload Support Equipment Assembly and Checkout
4.0	Payload Design, Fabrication and Test
4.1	Infrared Visual Mapper (IRVM)
4.2	Improved Data Collection System (DCS)
4.3	Light Detecting and Ranging (LIDAR)
4.4	Infrared Interferometric Radiometer (FTS)
4.5	Microwave Pressure Sounder (MPS)
4.6	Advanced Microwave Sounder (AMS)
4.7	Microwave Mapper (MM)
4.8	TOPEX Radar Altimeter (ALT)
4.9	Parallax Sensor (PS)
4.10	Advanced Earth Radiation Budget Experiment (ERBE)
4.11	Payload Integration and Checkout
5.0	System Test and Evaluation
6.0	Test Support
6.1	Tooling and Special Test Equipment
6.2	Peculiar Support Equipment
7.0	Airborne Support Equipment
8.0	Critical Flight Spares
9.0	Software
10.0	Reliability, Quality Assurance and Safety
11.0	Launch Vehicle Integration and Flight Support
12.0	Ground Operations
12.1	Dedicated Ground Station Facilities
12.2	Information Processing System
12.3	Mission Operations
13.0	Launch Services

TABLE 17

INTEGRATED SATELLITE COST SUMMARY
(millions of 1984 dollars)

	Baseline* (Level I)	Level II	Level III
Flight Hardware and Support	$150	$170	$370
Contingency at 20%	$ 30	$ 35	$ 74
Contract Fees at 15%	$ 20	$ 25	$ 56
Total Cost	$200	$230	$500

*For cost comparison purpose only

TABLE 18

COST ESTIMATES FOR LEVEL I DATA MANAGEMENT CENTER

Capital Cost

Central Computer, Control Data Cyber 176	$ 7,000K
Class O Data Recording, 3 HDDR @ 200K	600K
Class O Data Buffer, 4 Disks @ 100K	400K
Ephemeris Data Buffer, 1 Disk @ 100K	100K
Class 1 Data Storage, 4 Tape Drives @ 50K	200K
Class 1 Data Buffer, 4 Disks @ 100K	400K
Telemetry De-Multiplex	200K
Computer Support, 2 Tape Drives @ 50K	100K
4 Disks @ 200K	800K
Conditioned Power	100K
Air Conditioning	200K
Utilities	400K
Buildings	
Computer Center, 20,000 ft^2 @ $100	2,000K
Storage, 40,000 ft^2 @ $50	2,000K
Systems Software	2,000K
	$16,500K

Operations-Yearly

Shift Crew, 5 persons x 6 sections, 30 @ 100K/person	$ 3,000K
Quality Control and Analysis, 10 @ 100K	1,000K
Tape and Supplies	500K
Computer Maintenance	400K
Utilities	500K
	$ 5,400K

5.0 PROGRAM REVIEWS AND DOCUMENTATION

Task 5.0 was an administrative task in the study. Its objectives were to be responsive to the Data Procurement Documents and to develop all necessary documents listed as deliverables in the contract.

6.0 DOE CO_2 DATA MANAGEMENT CONCEPT

6.1 OBJECTIVE

The objective of Task 6.0 was to conceptualize a potential data management system for the CO_2 space-based sensor system data products. Emphasis was placed on the issues to be considered, preliminary definition of design considerations, review of existing data management systems and data design approaches, and development of candidate data management system concepts applicable to the DOE CO_2 Research Program.

6.2 METHODOLOGY

The data management system approach was directly related to CO_2 user operational considerations rather than to present space-based sensor systems. Therefore, an organizational model applicable to the data management of the DOE CO_2 Research Program was constructed. Other models also were explored which could serve as practical alternatives, provide evaluation criteria, and be used for comparative assessments.

6.3 DATA STRUCTURE FOR SDRs

Interviews with scientists, to determine how space-based sensor data are used to measure surface, climatological and atmospheric properties, indicated that:

- There are many interdependencies among parameters of an SDR with respect to an appropriate measurement strategy.*

- There are many interdependencies among similar parameters for different SDRs because an appropriate measurement strategy for the parameters of one SDR may not be the same as those for the appropriate measurement strategy of another SDR with overlapping or similar parameters. These interdependencies involve:

  — space-based sensor characteristics, calibration and operational performance,

  — spectral ranges, and

  — methods for processing raw and aggregated data.

These interdependencies are in turn affected by the selected space-based sensor systems and the extent to which a measurement strategy is fixed or adjustable (remotely or by a space platform-based intelligent system or both) during the mission. The measurement strategies for each SDR taken independently, the actual interdependencies resulting from combinations of strategies across SDRs, and the constraints on effective measurement imposed by system performance will ultimately define the data management system for the DOE CO_2 Research Program.

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*Measurement strategy refers to the selection, from among several options of measurement processing alternatives and aggregated results, i.e., the set of data for meeting an SDR.

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Consider, for example, the multiple requirements for a typical Level III sensor system, the microwave mapper. Such a system has the potential for wholly or partly satisfying several SDRs related to surface phenomena:

- Soil moisture
- Ground temperature
- Sea ice
- Precipitation
- Snow cover
- Sea surface temperature
- Sea surface wind
- Land ice

Sea ice coverage requires high-resolution data near the edges of the ice in order to derive differences in surface texture; additional data processing could also provide information concerning flow size and melting conditions. Using the mapper for deriving precipitation, on the other hand, requires processing over a very coarse grid, and gives the best results for precipitation within strong convective cells.

Measuring sea surface temperature with such a mapper introduces another series of constraints which relate primarily to resolution because it is an excellent tool for examining small-scale features such as Gulf Stream position, but it is inappropriate for mapping an entire ocean.

If one attempts to satisfy pertinent SDRs, e.g, for winter conditions in the North Atlantic, the interdependencies which will develop between SDRs are apparent. Further complexity occurs when the data from a microwave mapper are supplemented with those from another space-based sensor system, such as a combined IR-visual mapper, with its specific advantages and disadvantages.

It was assumed that there are no one-to-one relationships between space-based sensor system outputs and SDRs. Second, as noted above, each individual SDR has associated with it parameters that uniquely relate to combinations of measurement streams and processing approaches. These parameters could be integrated with the data bases and stored in the data base management system. The data architecture should then be based on this level of the data structure, rather than at the level of the SDRs.

As summarized in Table 19, the data architecture and the data base management systems used to provide access to the data systems must take into account the relationship among sensor and SDR's. The implication is that newer methods of data base design and data base management are needed. Existing systems are based on a one-to-one relationship of space-based sensor or mission to a climate, surface or atmospheric parameter. DOE CO_2 Research Program data base design and management systems should support multiple relationship and interdependence between SDR's.

TABLE 19

IMPLICATIONS OF SDR-RELATED DATA SYSTEM ARCHITECTURE AND DATA-BASE MANAGEMENT

- Interdependencies Across SDRs
  - Partial Measurements from Several Sensors
  - Partial Data Recording
  - Specialized Data Processing Requirements
- No One-to-One Mapping of Sensor Output to SDRs
- Individual SDR Properties Require that Data Bases Be Organized into Small Data Units Rather than as Sensor Outputs
- New Methods of Data System Architecture and Data-Base Management Needed Because Existing Systems Are:
  - Built on One-to-One Mapping
  - Organized Around Single-Sensor Measurements
  - Data Formats, Retrieval Systems, and Processing Structure Proceeds from Individual Sensor Output Data to Parameter Data Sets

C-2

6.4 ARCHITECTURES OF EXISTING DATA SYSTEMS

The existing data system architectures have been organized around single sensor measurements and physical characteristics of the space-based sensor system producing the measurement. From the data base design point of view, data can be described on three different levels:

- *Physical:* The internal level of data-base description. This level describes how data is embodied physically in a data storage mechanism. Descriptive parameters include storage medium (tape, optical disk, microfiche, etc.) formats of the data on the medium, encoding methods, length of files, and read requirements.

- *Application:* The external level of data-base description. The data base is described from a particular view for a particular purpose.

- *Conceptual:* The logical level of data description. The rules for interpreting the meaning of a data base are provided as part of the data description. At this level, data description identifies real-world objects which are represented in the data base and deals with how these representations are to be related to each other.

The actual work in data-base design and cataloguing at NASA for satellite sensor data has been oriented toward physical data description. For example, the Pilot Climate Data Base Management System (PCDBMS) at Goddard Space Flight Center has been under development since 1980. The PCDBMS has concentrated, thus far, on developing a comprehensive catalog of existing climate data bases generated from NASA missions. The formal descriptions that are tied to physical entities, such as tapes that are included in their inventory, are primarily physical descriptions, with the user expected to know and supply applications relevant knowledge of the significance of a space-based sensor data product as well as the representational features of the data from each mission. The data itself has not been standardized in all cases so, for example, complete information on sensor characteristics, sensor operating modes, errors, ephemeris data, etc., have not been added to the data file and exist physically in different locations.[1]

The PCDBMS represents a significant operational example of the utility of using conventional data base management techniques — in this case a commercially available product, ORACLE. The major effort in developing the PCDBMS system was spent on establishing data descriptions for existing data sets widely distributed throughout NASA among scientists and PIs. The descriptions provided are largely text in loosely structured formats. These descriptions include general information on the sensors and processing but are not directly related to information contained in the data records. The system was designed to build a data-base management system for existing data and reflects the difficulties of achieving that objective for NASA sensor data sets. By 1983, fourteen data sets had been described and catalogued. The system development effort offers baseline information on costs, utility of approaches and hardware, that would be very useful for the recommended Level I data collection system.

More advanced systems development concepts are being considered in the System Z concept program. The preliminary work for that system concept has focused on an applications type data system architecture. The major difference between the data design concept for System Z and that proposed for other programs such as PCDBMS is that explicit provisions are made for the different requirements of producers and users at the point of primary measurement data collection, allowing users to change data requirements without affecting other users, and organizing only "what" is done but not "how" it is done.[2,3]

The work on System Z, although relevant, is of limited value to this study because its architectural design isolates the data system from user requirements. The interdependencies between measurement strategies and between processing options, and space-based sensor system selection and operation for the DOE CO_2 Research Program are significant. Therefore, it is not appropriate to develop an architectural design concept that so clearly segments the data user from the data producer. Such a separation would likely lead to inadequate attention to the effects of interdependencies between the data producer and user.

Existing NASA data management systems offer valuable and relevant experience in handling existing data and in designing new applications oriented data management systems for the recommended three time-frame levels for the DOE CO_2 research program.[4,5]

6.5 A CANDIDATE DATA MANAGEMENT SYSTEM CONCEPT

Based on a review of existing data management systems and their architectures, the SDRs and space-based sensor systems, the CO_2 data system concept involves the following considerations:

- Space-based sensor systems would be multi-channel to meet the data requirements of different SDRs.
- The data system will be large in terms of data volumes and storage requirements, as indicated by Table 20 and composed of many different data bases, as illustrated in Figure 20.
- User requirements will not be completely or irrevocably articulated at the start of the final design phase of the CORS development program.
- Increases in processing speed will allow much of the intermediate (i.e., category 2) results to be created on an "as needed" basis, thus helping to minimize real-time computational requirements.
- Data system technology is changing rapidly and costs for some items are expected to drop.
- New data base management techniques are emerging, using knowledge engineering technology to enable more flexible user-data interfaces.

TABLE 20

ILLUSTRATIVE SENSOR DATA VOLUMES AND DATA STORAGE REQUIREMENTS

Sensor Type	Data Rates	Feasible Storage Method
Multi-Channel, High Resolution, Optical (approximately 1 km)	Approximately 1 MB/SEC	HDDR (9T, 6250 BPI)
High Resolution Microwave	Approximately 100 MB/SEC	Optical Disk (10^{12} BITS), 200 Disks/Year)
Broad Band, Very High Resolution, Optical (approximately 1 km)	Approximately 300-1,000 MB/SEC	Mass Storage (10^{14}-10^{15} BITS), One Year On-Line

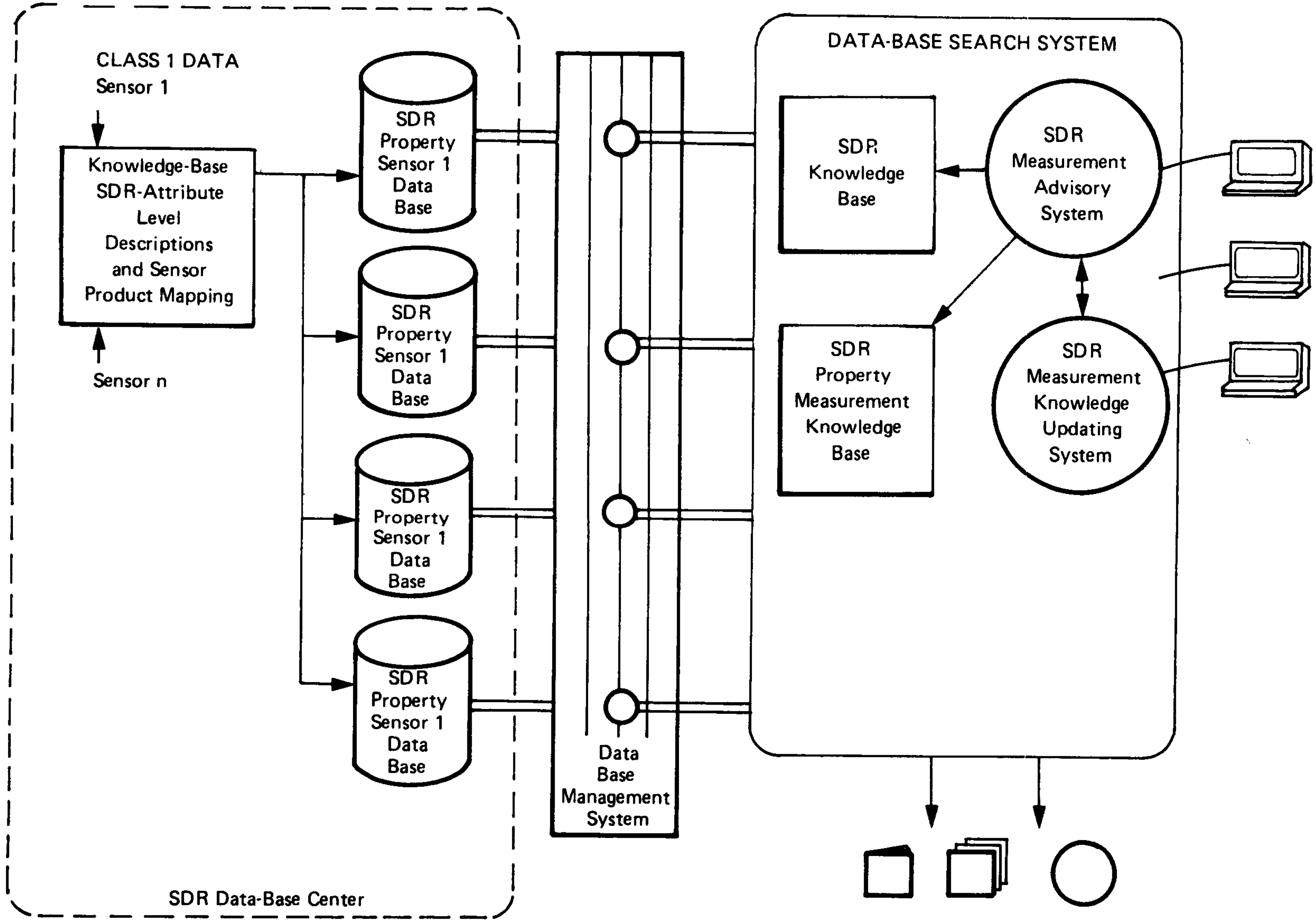

FIGURE 20 CONFIGURATION DIAGRAM FOR DATA-SYSTEM ARCHITECTURE CONCEPT

In this situation, the data design architecture for the DOE CO_2 Research Program Space SDR's can:

1. Be built around data bases containing individual sensor measurements and structured to allow efficient search for the parts of the measurement stream from each sensor needed to define the parameters of an SDR.

2. Contain a data base management system that:

   a. "Knows" about each individual sensor data base, its physical format, applications oriented structure, and constraints on the possibilities for combining data from different sensors. (These constraints will be space-based sensor system performance, operational, and measurement based.)

   b. Assists users to build up a measurement strategy from knowledge of these constraints and user-supplied guidance.

   c. "Knows" about initial user expertise related to use of ancillary data, processing requirements and measurement options.

3. Contains a decision support system to help users evaluate data quality.

Figure 20 presents a configuration diagram for the data design architecture concept described above.

6.6 DATA MANAGEMENT CONCEPT SYSTEM DESIGN ISSUES

Figure 21 presents the concept of an organizational model for CO_2 data-base management. The model indicates the types of interfaces between a data-base management center(s) and users that would have to be specified in some detail before the data center itself or the data system component could be defined. At this point, neither the users to be supported by the center(s) nor their organizational, financial, or operational relationship to the DOE CO_2 Research Program have been identified. A potential area of future study is the system architecture through which data would be received from the space-based sensor systems.

Presently NASA and NOAA disseminate data derived from space-based sensors. NASA's data management centers have been designed primarily to support users associated directly with NASA. NOAA's centers for space-derived meteorological data are designed primarily to serve the organizational, operational and computational requirements of different weather forecasting communities, including the National Weather Service, news media, air traffic controllers, airlines and other transportation-related users of weather information.

A key part of the organizational model in Figure 21 which distinguishes it from other data center concepts is the DOE CO_2 data-base management center. This centralized facility would

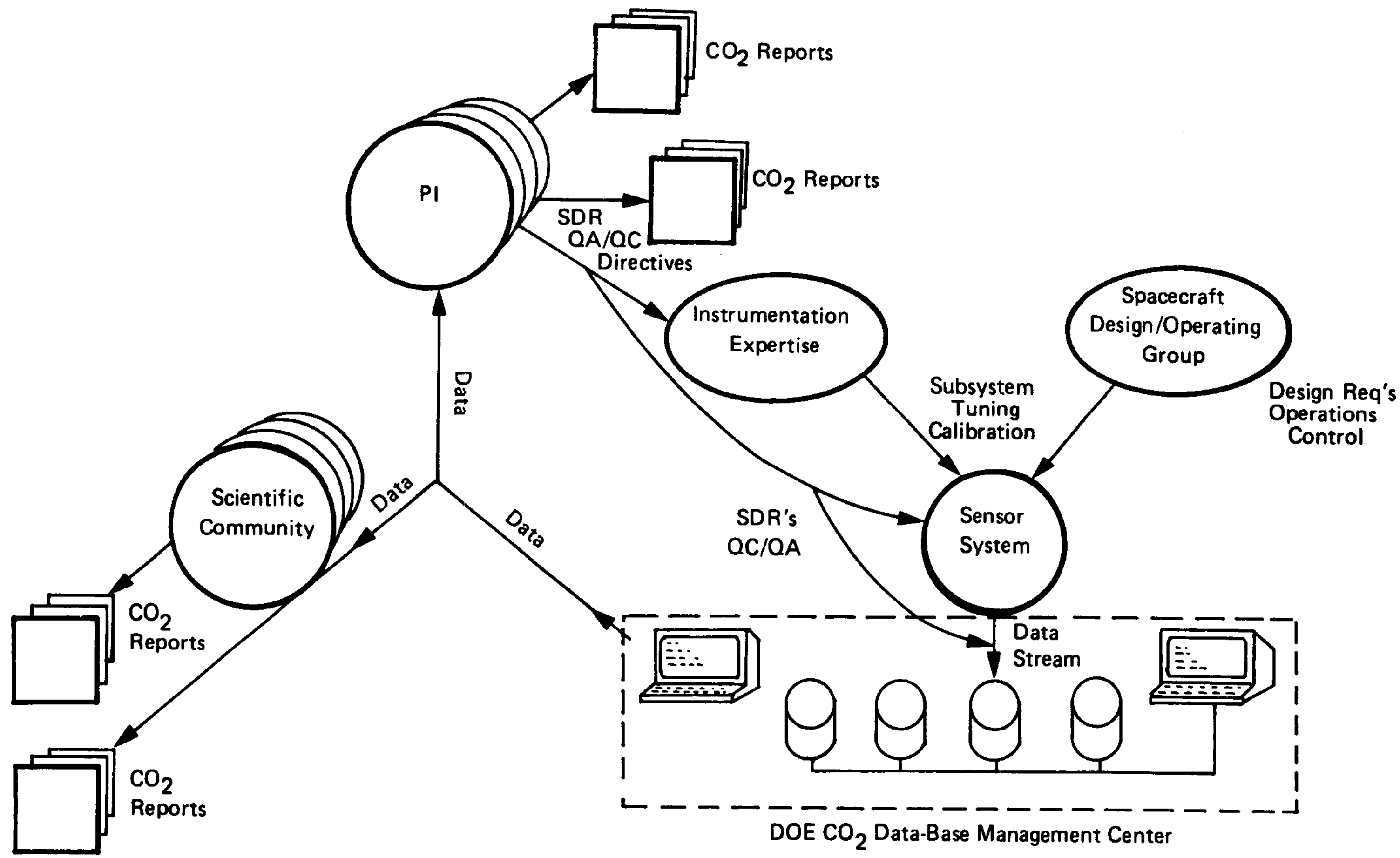

FIGURE 21 ORGANIZATIONAL CONTEXT OF A POTENTIAL DOE CO_2 DATA-BASE MANAGEMENT SYSTEM CONCEPT

be dedicated to and designed for space-based sensor system data inputs and outputs. It is the site where all classes of sensor data will be processed, archived, inventoried, and accessed. The center would not necessarily be a governmental organization; it could be organized, managed and run by a private entity. Ultimately, a distributed facility may be a more desirable or cost-effective alternative to the centralized organization presented. Additional information on the operational, organizational and computational environment of actual CO_2 space-derived data will be needed before this alternative can be defined.[6,7]

For example, after a new space-based sensor system has been developed and data are returned from successful flights, primary responsibility for data outputs during the scientific validation phase would rest with the Principal Investigator (PI). Responsibility for disseminating all data would pass from the PI to the data center after a limited period. During the beginning of this period the PI would be solely responsible, at the end of the period the data center would be solely responsible. There will be a transition period when responsibilities would be transferred from the PI to the data center on an agreed-upon schedule. This approach permits the data center to define the user needs, the data output format and the data dissemination costs. The PI would validate the science but would not perform a continuous data dissemination function.

The concept of a data management system architecture for the DOE CO_2 Research Program was developed based on the following considerations:

- The scope of the data management system would be limited to processing data from space-based sensors.

- Multiple measurement strategies might be used, at the discretion of PI and other researchers, for each individual SDR as a function of the measurements for that SDR in a given monitoring, modeling or prediction/evaluation study. There are a very large number of ways to combine "raw" data into useful information that will satisfy an SDR(s). Moreover, each is appropriate under a certain set of conditions and needs, and there could be a built-in advisory capability which assists the PIs (or other users) in choosing the best alternatives.

As a general rule, because of redundancy to protect against environmentally caused losses, there will be a larger volume of data than can be examined completely. Therefore, ways must be found to determine near-optimal processing strategies (for extracting various types of particular information) before hooking up the data stream to a larger computer and consuming its processing capacity for a significant time. The data management system concept should be flexible enough, therefore, to allow PIs to select the following options:

1. The set of space-based sensor measurements by sensor system, time of observation, location, aggregation and simultaneously with other selected space-based measurements to build a desired base for an SDR.

2. The processing approach for producing parameterized measures or other forms of data products.

As a result, the data representation scheme built into the data base management system would have to "know" four kinds of things about the data:

1. What space-based sensors, in what orbital positions, with what coverage area, at what operating conditions, etc., created the measurement stream?

2. How was the measurement stream processed, by what assumptions, by what analysis methods?

3. How can the available measurement streams be combined to provide the preferred measure for any SDR or combination of SDRs, for particular uses?

4. What space-based measurements could substitute adequately for others, e.g., for those not working or for those measurement conditions, such as a dense cloud cover, that make their measurements invalid?

It was further assumed that some of the SDRs cover the phenomena of interest to the scientists interviewed but that other members of the science community would use very specific space-based data at a much finer level of detail. For example, while cloud cover is of concern, scientists prefer to analyze certain properties of clouds (e.g., liquid water content or cirrus formation). These properties are the actual subjects of their direct measurement efforts, while cloud cover itself (or the other SDR parameters) are second- or third-order phenomena, derived from first-order direct measurements of, for example, optical properties of clouds. When viewed from this perspective, the development of a data management system is more difficult because, for some SDRs, the measurable parameter for a single SDR can involve different locational, temporal and spectral constraints. Table 21 shows the measurement requirements for the percent cloud cover SDR and its associated parameters. These parameters will be important depending, for example, on where and when radiance data from a particular space-based sensor are collected, and the conditions on the surface of the earth when the measurements are made, because not all of these parameters will be important all of the time or will require continuous global measurements. Therefore, the measurement stream should be controlled to exclude irrelevant data.

TABLE 21

SENSOR MEASUREMENT REQUIREMENTS FOR A REPRESENTATIVE SDR: % CLOUD COVER

Identifying Properties:

- Temperature — Surface (Cloud)
Internal (To Cloud)
- Liquid-Water Content (Mass)
- Ice Content
- Cloud Top Height —
(Horizontal Shape)
(Vertical Profile)
- Form/Structure

Relationships to:

- Distance From Earth Surface (Cloud Bottom)
- Difference/Similarity with Surface Phenomena (Ice, Snow)

Sensor Measurement Requirements

Global Coverage

Multiple-Spectral Ranges

Measurement Strategy

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GLOSSARY

ADCS:	Attitude Determination and Control Subsystem
ADL:	Arthur D. Little, Inc.
AEM:	Application Explorer Mission (Boeing Satellite Series Built for GSFC)
ALT:	TOPEX Radar Altimeter
AMS:	Advanced Microwave Sounder
AMSU:	Advanced Microwave Sounding Unit
AMTS:	Advanced Moisture and Temperature Sounder
APM:	Ascent Propulsion Module
ATMOS:	Atmospheric Trace Molecules Observed by Spectroscopy
AVHRR:	Advanced Very High Resolution Radiometer
BAC:	Boeing Aerospace Company
BASD:	Ball Aerospace Systems Division
BOL:	Beginning of Life
CDHS:	Command and Data Handling Subsystem
CLIR:	Cryogenic Limb-Scanning Interferometer and Radiometer
CO_2:	Carbon Dioxide
CORS:	CO_2 Research Satellite
CZCS:	Coastal Zone Color Scanner
DBMS:	Data-Base Management System
DCP:	Data Collection Platform
DCS:	Data Collection System
DIAL:	Differential Absorption LIDAR
DMS:	Data-Management System
DMSP:	Defense Meteorological Satellite Program
DOD:	Department of Defense (also Depth-of-Discharge)
DOE:	Department of Energy
DRIRU:	Dry Rotor Inertial Reference Unit
EBPS:	Engineering Bus Propulsion System
EOL:	End-of-Life
ERBE:	Earth Radiation Budget Experiment
ERBS:	Earth Radiation Budget Satellite
ESA:	European Space Agency
EVA:	Extra Vehicular Activity
FIRE:	First ISCCP Regional Experiment
FTS:	Fourier Transform Spectrometer
FOV:	Field of View
GCM:	General Circulation Model
GMT:	Greenwich Mean Time
GN_2:	Gaseous Nitrogen
GOES:	Geostationary Operational Environmental Satellite
GSFC:	Goddard Space Flight Center
HAPP:	High Altitude Powered Platform
HDRR:	High Data Rate Recorder
HIRS:	High Resolution Infrared Sounder

HORB:	High Orbit Radiation Budget
HZ:	Hertz
ICD:	Interface Control Document
IPS:	Information Processing System
IR:	Infrared
IRIS:	Infrared Interferometer Spectrometer
IRLS:	Interrogation, Recording, and Location System
IRVM:	Infrared Visual Mapper
ISCCP:	International Satellite Cloud Climatology Project
IU:	Interface Unit
IUS:	Inertial Upper Stage
JSC:	Johnson Space Center
LAMMR:	Large Antenna Multi-Frequency Microwave Radiometer
LHS:	Laser Heterodyne Spectrometer
LIDAR:	Light Detection and Ranging
MHZ:	Megahertz
MM:	Microwave Mapper
MIT:	Massachusetts Institute of Technology
MOMS:	Modular Optoelectronic Multi-Spectral Scanner
MOS:	Mission Operations System
MPS:	Microwave Pressure Sounder
MSFC:	Marshall Space Flight Center
MSU:	Microwave Sounding Unit
MW:	Microwave
N:	Newton
NASA:	National Aeronautics and Space Administration
NASCOM:	NASA Communications Service
NCAR:	National Center for Atmospheric Research
NiCd:	Nickel Cadmium
NIMBUS:	Name of NASA Satellite
NOAA:	National Oceanic and Atmospheric Administration (also, name of a satellite)
OCI:	Ocean Color Imager
OMV:	Orbital Maneuvering Vehicle
OSR:	Optical Solar Reflector
OTS:	Off-the-Shelf
PCDBMS:	Pilot Climate Data Base Management System
PCM:	Parametric Cost Model
PI:	Principal Investigator
POCC:	Payload Operations Control Center
PS:	Parallax Sensor
R:	Recorder
R&D:	Research and Development
REM:	Reaction Engine Module
RF:	Radio Frequency
RMS:	Remote Manipulator System
SAGE:	Stratospheric Aerosol and Gas Experiment
SAMI:	Stratospheric Aerosol Measurements I

SAR:	Synthetic-Aperture Radar
SBUV:	Solar Backscatter Ultraviolet Radiometer
SCAMS:	Scanning Microwave Spectrometer
SCAT:	Scatterometer
SDR:	Scientific Data Requirement
SFS:	Subsystem Fact Sheet
SITZ:	Snow and Ice Transition Zone
SMMR:	Scanning Multichannel Microwave Radiometer
SPOT:	Systeme Probatoire d'Observation de la Terre
SSA:	S-Band Single Access
SSH:	Satellite-Borne Sounder, Humidity
SSP:	Standard Switch Panel
SSU:	Stratospheric Sounding Unit
STDN:	Spaceflight Tracking and Data Network
STS:	Space Transportation System
SURS:	Standard Umbilical Retraction System
TDRS:	Tracking and Data Relay Satellite
TDRSS:	Tracking and Data Relay Satellite System
TIROS:	Television and Infrared Observation Satellite
TM:	Thermatic Mapper
TMS:	Teleoperator Maneuvering System
TOPEX:	Topological Oceanography Experiment
TOVS:	TIROS Operational Vertical Sounding Package
WBS:	Work Breakdown Structure
WTR:	Western Test Range

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APPENDIX A

SCIENTIFIC DATA REQUIREMENTS

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TABLE OF CONTENTS

GUIDE TO SDR FORMS

CO_2 Climate Research Program	Location of the SDR in the CO_2 Climate Research Program.
Professional Discipline	The professional discipline which uses the SDR.
General Description	Provides narrative summary of SDR.
Technical Description	Technical synopsis of SDR.
Related Parameters	Parameters which affect or are affected by the SDR.
Geographic Extent	Extent of observation for monitoring, model comparison, and improving parameterization.
Resolution	Specifies the spatial and temporal measuring requirements that are needed to satisfy the given SDR. For some SDR's two levels of resolution may be required, one for model parameterization ("grid") and one for the raw data measurement ("spatial").
Error Tolerance	Refers to the combined precision and accuracy requirements to satisfy the given SDR.
Space-Based Sensor Systems	Past, present, and planned satellite based systems providing data related to SDR.
Person with whom SDR was discussed	Scientist(s) contacted (see pg. iii) who discussed the importance of the SDR to CO_2 research.
Implementation Expert	Scientists having implementation experience with the SDR.
References	Publications relevant to the SDR.

ACKNOWLEDGEMENTS

We wish to thank the following scientists whom we contacted and with whom we carried on useful discussions concerning the measurement needs of the CO_2/climate research community.

NAME	AFFILIATION
Professor Reid Bryson	University of Wisconsin Madison, WI
Dr. James Coakley	National Center for Atmospheric Research, Boulder, CO
Professor Edward Lorenz	Massachusetts Institute of Technology, Cambridge, MA
Dr. Michael MacCracken	Lawrence Livermore National Laboratory, Livermore, CA
Dr. Roland Madden	National Center for Atmospheric Research, Boulder, CO
Dr. Syukuro Manabe	Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, NJ
Dr. Jerome Namias	Scripps Institution of Oceanography LaJolla, CA
Dr. John Perry	National Research Council, National Academy of Sciences, Washington, DC
Professor Richard Pfeffer	University of Florida/GFDI
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Professor David Staelin	Massachusetts Institute of Technology, Cambridge, MA
Professor Peter Stone	Massachusetts Institute of Technology, Cambridge, MA
Professor Jay Winston	University of Maryland, College Park, MD

RADIANCE AT TOP OF THE ATMOSPHERE
SDR NO. 1

CO_2 Climate Research Program	Professional Discipline
First detection (general)	Meteorology
Upward Radiance (especially clear sky)	Atmospheric Chemistry
Model Parameters	Modeling
Downward & upward radiance	

General Description

This climatic parameter is the most fundamental because it describes the planetary radiation balance. The solar UV flux (A) is highly variable and has a large potential impact on atmospheric chemistry (and should be measured with high spectral density), while the solar flux (B) must be measured to monitor its suspected temporal variation. The incident and reflected radiation (C) is the measure of the planetary albedo. The emitted radiation (D,E) is an integrated quantity. Note that measurement of so-called "clear-sky radiance" is critical for deduction of other climatic parameters of interest.

Technical Description	Related Parameters
Upward and downward radiances at top of the atmosphere:	Temperature
(A) UV flux	Humidity
(B) Total solar flux	Trace gas concentration
(C) Visible and total reflected solar	Cloud amount
(D) IR Window (8-12 μm)	Surface albedo
(E) Total IR	Aerosol concentration
	Surface Temperature
	Solar activity

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Earth - global	Spatial: 1,000 km (A,B)	0.1% (B)
Sun - full disk	500 km (C,D,E)	10% per 5 nm (A)
	Grid Size: 500 km	
	Temporal: Monthly-annual (C,D,E)	1-5 Wm^{-2} (D,E)
	Daily-monthly (A,B)	5% (C)

Space-Based Sensor Systems

ERBE: flat plate radiometer method minimizes integration assumptions.
NIMBUS: wide angle, narrow angle scanning

Person with whom SDR was discussed

Reid Bryson
Syukuro Manabe
Wei-Chyung Wang

Implementation Expert

B. Barkstrom, NASA/Langley
T.H. Vonder Haar, Department of Atmospheric Sciences, Colorado State University
J. Winston and team, University of Maryland
E. Raschke, University of Cologne

Notes

Outward: limb scanning
Planetary albedo is "ultimate constraint" (Manabe)
Looking downward not sufficient
Cloudless radiance preferred: (C) could be used

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FRACTIONAL CLOUD COVERAGE
SDR NO. 2

CO_2 Climate Research Program	Professional Discipline
Model parameters (input,output, & #tuning) Clouds, % coverage	Climate Modeling Meteorology

General Description

Small changes in cloud cover may lead to major changes in the climate. Although satellite images of cloud cover are regularly taken, it is difficult to deduce from these pictures accurate quantitative measures of cloudiness, due to high cloud variability in time.

Data provided by current measurement techniques are good when fractional cloud cover is measured over oceans; fair, but acceptable over land; and poor over ice and snow.

The crux of the problem is the estimate of the ground level radiation exchange below clouds.

Technical Description	Related Parameters
Clouds: percentage coverage in at least 3 levels	Ice/snow cover Humidity Temperature Albedo (surface and planetary) Vertical motion

Geographical Extent

Global

Resolution

	(Parameterized Data)	(Raw Data Sampling)
Spatial:	100 km	<1 km
Grid Size:	200 km	-
Temporal:	5 days	2 hrs
Error Tolerance:	1%	5%

Space-Based Sensor Systems

HRIR - IR imaging radiometer for night cloud coverage
THIR - Temperature humidity IR (maps cloud cover and humidity)
(USAF) - Satellite Cloud Climatology Atlas

Person with whom SDR was discussed

James Coakley	Peter Stone
Michael Schlesinger	Roland Madden
Michael MacCracken	Jay Winston
Syukuro Manake	John Perry

Implementation Expert

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R. Curran, NASA/Headquarters
W. Rossow - GISS/NASA
Henderson-Sellers-University of Liverpool

Notes

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VERTICAL CLOUD STRUCTURE
SDR NO. 3

CO_2 Climate Research Program	Professional Discipline
First detection Polar Climate Low level clouds over pack ice Model parameters (input, output, & tuning) Cloud layers, vertical distribution	Climate Modeling Meteorology

General Description

While this set of measurements is extremely critical for climate prediction, currently no operational measurements are being performed of cloud vertical distribution. It appears that obtaining anything significant in the way of vertical cloud distribution from satellites only is not likely in the near term, except perhaps for two layers under broken field conditions. Better measurements are possible by combined satellite-ground-aircraft systems, such as the one used by the USAF.

Technical Description	Related Parameters
Clouds: vertical distribution (3 layers: high, middle, low) with ice/water transition	Same as "% coverage" Vertical motion

Geographical Extent	Resolution	Error Tolerance
First detection: polar regions, esp. important level clouds and cirrus Model parameters: selected grids useful for input to parameterization.	(Parammeterized Data) Spatial: 100 km (horizontal) 1 km (vertical) Grid Size: 200 km Temporal: 5 days Raw data: Twice daily	Vertical: ½ km or 1°C

Space-Based Sensor Systems

HIRS

Person with whom SDR was discussed

James Coakley
Michael Schlesinger
Michael MacCracken
Syukuro Manabe
Peter Stone
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M. Chahine, JPL
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W. Shenk, NASA/GSFC
R. Curran, NASA/Headquarters
A. Henderson-Sellers, University of Liverpool

Notes

Cloud top heights, should be measured in visible (.5-.75 μm) and infrared bands (10.5-12.5 μm) in stereo; also by multispectral passive microwave. Snow and ice transition zones, in particular. Cloud types implicitly involved.

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US AFGWC Cloud cover 3-0 nephanalysis.

TRACE GAS CONCENTRATIONS
SDR NO. 4

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning)	Modeling
Trace gas concentrations	Atmospheric Chemistry & Radiation

General Description

The combined climatic effect of trace gases is estimated to be comparable to that due to CO_2 increase. The data obtained from current measurements of trace gases are presently sparse. Trace gases separate into long-lived (lifetimes of years) and short-lived (lifetime of days or weeks) types which require different measurement strategies.

Technical Description	Related Parameters
Concentration of trace gases (ozone: vertical distribution) Long-lived: $N_2O, CCl_4, CH_4, CCl_2F_2$ Short-lived: $SO_2, NH_3, C_2H_4, CH_3Cl, CO, O_3$	Cloud cover H_2O in stratosphere and troposphere High level clouds UV flux Albedo Temperature

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Global	Spatial: 500 km	1%
	(ozone: 2 km vertical)	.5 ppm (ozone)
	Grid Size: 1,000 km (Short-lived) hemisphere (Long-lived)	
	Temporal: monthly (Short-lived) annual (Long-lived)	

Space-Based Sensor Systems

See NASA/WMO Report
UARS: 8-14 μm band

Person with whom SDR was discussed

Wei-Chyung Wang

Implementation Expert

W-C. Wang, Atmospheric and Environmental Research, Inc.
Yuk Yung, California Institute of Technology
Donald Heath, NASA/GSFC
Michael McCormick, NASA/Langley
D. Murcray, University of Denver

Notes

Need to clearly distinguish trace gas signal from CO_2 signal in climate models.

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AEROSOL CONCENTRATION
SDR NO. 5

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning) Aersols (arctic & stratospheric)	Cloud Microphysics Meteorology Climate Modeling

General Description

The climatic effects of aerosols are similar in magnitude to trace gases (e.g., stratospheric sulfate aerosols formed as a result of volcanic activity). Stratospheric aerosols cool the surface while tropospheric aerosols may cool or warm the surface depending on their type. The current measurements of stratospheric aerosols with the SAGE and SAM satellites are about to end; ground-based lidar measurements, though useful, have limited spatial resolution.

Also important is the release of industrial aerosols into the troposphere, their transport and deposition in the Arctic Basin and their impact on clouds, or snow and ice, and on surface radiation in general.

Technical Description	Related Parameters
Concentration of aerosols (esp. stratosphere) Composition: maritime, arctic, desert, volcanic, industrial	Ground lidar measurements O_3 Humidity Stratospheric H_2O Refractive index (of aerosol) Ocean temperature Volcanic Activity

Geographical Extent	Resolution	Error Tolerance
Global	Spatial: 500 km (latitudinal distribution) Grid Size: 1,000 km Temporal: monthly	10%

Space-Based Sensor Systems

SAM and SAGE
AVHRR

Person with whom SDR was discussed

Michael MacCracken
Syukuro Manabe
Wei-Chyung Wang

Implementation Expert

Michael Matson, NOAA
M. McCormick, NASA/Langley
F. Fernald, University of Denver

Notes

See dust veil index in Hansen '81.
Arctic haze.

References

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Rahn, K.A. "Atmospheric, Riverine, and Oceanic Sources of Seven Trace Constituents to the Arctic Ocean." University of Rhode Island, Kingston. Atmospheric Environment, Vol. 15, No. 8, 1981, 1507-1516.

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VERTICAL TEMPERATURE PROFILE
SDR NO. 6

CO_2 Climate Research Program	Professional Discipline
General Vertical (Atm.) temperature profile	Meteorology Modeling

General Description

Vertical temperature profile measurements are prerequisites for remote sensing of most climate parameters, including analyses of radiative processes.

Technical Description	Related Parameters
Atmosphere: vertical temperature profile	Ground temperature Trace gas concentration Clouds Humidity O_3 profile

Geographical Extent	Resolution	Error Tolerance
Global	(Parameterized Data) Spatial: 500 km horizontal 100 mb vertical Temporal: 5 days	1 - 2 °C

Space-Based Sensor Systems

HIRS on TIROS-N Series Satellites

Person with whom SDR was discussed

General consensus among scientists contacted

Implementation Expert

W.L. Smith, University of Wisconsin
M. Chahine, JPL, NASA

Notes

Current resolution is 1 - 3 km vertically;
Averaged for < 6 layers at 0 - 30 km
Global monitoring with the accuracy needed for climate change studies will require on board data processing

References

Chahine, M.T. "Passive Optical and Infrared Meteorology." JPL, Pasadena, CA. International Geoscience and Remote Sensing Symposium (IGARSS '81), Vol. 1. June 8-10, 1981, Washington, D.C., IEEE, New York, 1981.

Aumann, H.H., and Chahine, M.T. "Infrared Multidetector Spectrometer for Remote Sensing of Temperature Profiles in the Presence of Clouds." JPL, Pasadena, CA. Applied Optics, Vol. 15, No. 9, September 1976, 2091-2094.

Chahine, M.T. "Analytical Transformation for Remote Sensing of Clear-Column Atmospheric Temperature Profiles." JPL, Pasadena, CA. Journal of Atmospheric Science, Vol. 32, No. 10, October 1975, 1946-1952.

WIND FIELD
SDR NO. 7

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning)	Meteorology
Wind field (surface & vertical)	Modeling

General Description

The measurement of vertical wind fields is important in relating the upward and downward movements of air masses to the formation and dissipation of clouds and precipitation.

Technical Description	Related Parameters
Atmosphere: wind field	sfc. pressure Clouds Sensible heat transport Ocean transport

Geographical Extent	Resolution	Error Tolerance
Global or key regions (zones) e.g., tropics and midlatitudes	(Parameterized Data) Spatial: 500 km horizontal 200 mb vertical Grid Size: 500 km Temporal: daily (Raw Data) Twice Daily	3 m/sec (speed) and 10° (direction) in horizontal (vertical derived using the continuity equation)

Space-Based Sensor Systems

Radar Altimeter GEOS 3

Person with whom SDR was discussed

Roland Madden
Edward Lorenz

Implementation Expert

D. Atlas, NASA/GSFC
L. Kaplan, Atmospheric and Environmental Research, Inc.
F. Hall, NOAA, Boulder

Notes

Important because of high variability due to time of day

References

ATMOSPHERIC WATER
SDR NO. 8

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning) Vertical distribution of water in atmosphere	Meteorology Climate-Modeling

General Description

Atmospheric water content is one of the most important parameters governing the earth's long-wave radiation balance. Because the radiative effects of water in the atmosphere are dependent on both phase and height, it is important to know the proportion of liquid to vapor content, as well as to know their relative amounts in the troposphere and stratosphere.

Technical Description	Related Parameters
Atmosphere: water content of vertical column o Vapor, liquid and solid phases o Vertical distribution (stratosphere-troposphere)	Temperature Clouds

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Global and selected areas for parameterization	Spatial: 100 km Grid Size: 200 km Temporal: 1-2 days	10% for vertical distribution 1% for column

Space-Based Sensor Systems

SMMR on NIMBUS 7
TOVS on TIROS N
Water vapor channel on GOES

Person with whom SDR was discussed

James Coakley
Michael Schlesinger
Michael MacCracken
Wei-Chyung Wang
Warren Washington

Implementation Expert

L. Kaplan, Atmospheric and Environmental Research, Inc.
J. Coakley and F. Bretherton, NCAR Cloud-Radiation Interactions Group (using imagery data for oceans only).

Notes

Very important since climate models show large correlation between temperature and water vapor content. Need long time average.

References

Wang, W-C., et. al. "Greenhouse Effects Due to Man-Made Perturbations of Trace Gases." Science, Vol. 194, No. 4266, November 12, 1976.

Spencer, R.W., et. al. "Satellite Microwave Radiance. Correlated with Radar Rain Rates over Land." Nature, Vol. 304, July 14, 1983, 141-143.

Peixoto, J.P., et.al. "Interannual Variation in Large-Scale Moisture Fields." Journal of Geophysical Research, Vol. 86, C2, 1981, 1255-1264.

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SEA SURFACE TEMPERATURE
SDR NO. 9

CO_2 Climate Research Program	Professional Discipline
First detection	Oceanography
General	Glaciology
SST	Meteorology

General Description

Measurements of the dynamic changes in sea-surface temperature (SST) are of great importance to evaluate effects on climatic time scales. Current measurements of SST may be sufficient for this purpose.

Technical Description	Related Parameters
	Mixed layer depth
	Ocean surface albedo
	Air-sea temperature difference
	Sensible heat flux

Geographical Extent	Resolution	Error Tolerance
Global	Spatial: 50 km	.2 - .5 °C
	Grid Size: 200 km	
	Temporal: 5 days	

Space-Based Sensor Systems

SMMR - NIMBUS 7
VISSR - SS51, 2
AVHRR - NOAA 6, & TIROS N

Person with whom SDR was discussed

Jerome Namias
George Kukla

Implementation Expert

K. Bryan
B. Weare, University of California (Davis)
W. Hovis, NOAA

Notes

References

Chahine, M.T. "Remote Sounding of Cloudy Atmospheres, I. The Single Cloud Layer." Journal of Atmospheric Science, Vol. 31, 1974, 233-243.

Byran, K. "Climate and the Ocean Circulation, III. The Ocean Model." Monthly Weather Review, Vol. 97, No. 11, 1969, 806-827.

SEA ICE
SDR NO. 10

CO_2 Climate Research Program	Professional Discipline
First detection Model parameters (ocean-atmos coupled model) Polar Sea ice extent	Glaciology Oceanography Modeling

General Description

The extent and thickness of sea-ice are two of the most sensitive climatic parameters indicating a trend of climate change. Sea-ice provides a significant positive feedback to increasing temperature. Current operational measurements are not sufficiently accurate for analysis of climatic change.

Technical Description	Related Parameters
Sea ice extent, thickness if possible	Low-level cloud cover Sensible heat transport Turbulent heat mixing

Geographical Extent	Resolution	Error Tolerance
Polar regions, 50° to 90° latitude	Spatial: 50 km Grid Size: 200 km Temporal: 5 days	1%

Space-Based Sensor Systems

VIS, NIR and IR Channels on NOAA, LANDSAT & DMSP Operational mapping. ESMR, SMMR, microwave, radar altimeters and scatterometers on NIMBUS. CZCS on NIMBUS 7.

Person with whom SDR was discussed

General consensus among 25 scientists contacted

Implementation Expert

D. Horn, MIZEC Program, ONR
M. Kelly, Climate Research Unit, University of E. Anglica
J. Zwally, NASA
C. Parkinson, NASA
G. Kukla-Lamont Doherty
W. Washington, NCAR
J. Walsh, Illinois

Notes

Long-term much more important than high accuracy
Floe-size distribution
Surface roughness

References

Zwally, H.J.; Parkinson, C.L.; and Comiso, J.C. "Variability of Antarctic Sea Ice and Changes in Carbon Dioxide." NASA Goddard Space Flight Center, Greenbelt, MD. Science, Vol. 220, No. 4601 3 June.

OCEAN CURRENTS
SDR NO. 11

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning) Ocean currents (surface)	Oceanography Glaciology Climate-Modeling

General Description

Ocean currents provide a significant fraction of all poleward heat transport, thereby critically influencing Earth's climate. This transport may be strongly affected by the CO_2-induced warming trend because the polar regions are expected to warm significantly more than the tropics; the polar warming affects the meridional temperature gradient which, in turn, affects winds, the prime mover for ocean currents. There are no existing operational measurements of ocean currents.

Technical Description	Related Parameters
Oceans: surface currents	Surface wind speed Ocean heat transport Ocean general circulation Ocean-atmosphere momentum change

Geographical Extent	Resolution	Error Tolerance
Global	Spatial: 10 km Grid Size: 200 km Temporal: monthly	5 cm sec^{-1}

Space-Based Sensor Systems

TOPEX for relative currents, still require gravitational mapper

Person with whom SDR was discussed

Warren Washington
Edward Lorenz
Richard Pfeffer
Jerome Namias

Implementation Expert

Scientists at Woods Hole and Scripps
W. Hovis, NOAA
C. Wunsch, MIT

Notes

May require insitu measurements

References

Wunsch, C. and Gaposchkin, E.M. "On Using Satellite Altimetry to Determine the General Circulation of the Oceans with Application to Geoid Improvement." Rev. Geophys. Space Phys., Vol. 18, No. 4, Nov. 1980, 725-745.

OCEAN SURFACE WINDS
SDR NO. 12

CO_2 Climate Research Program

Model parameters (input,output, & tuning)
Ocean surface winds

Professional Discipline

Oceanography
Meteorology
Modeling

General Description

Through wind stress, ocean surface winds are primary drivers of both vertical mixing and horizontal currents. On climatic time scales, these winds exert a large influence on the overall response time to atmospheric warming (through heat exchange with subsurface water), as well as meridional heat balance.

Technical Description

Oceans: surface wind speed

Related Parameters

Surface pressure
Ocean-atmosphere momentum and heat exchanges
Moisture flux from ocean to atmosphere

Geographical Extent

Global

Resolution
(Parameterized Data)
Spatial: 50 km
Grid Size: 100 km
Temporal: monthly

Error Tolerance

2 m/sec

Space-Based Sensor Systems

Radar altimeter - Seasat
- Geos 3
- TOPEX

Scatterometer - US Navy

Person with whom SDR was discussed

Warren Washington
Michael Schlesinger
Jerome Namias
Wei-Chyung Wang

Implementation Expert

F. Hall, NOAA, Boulder, CO
W. Hovis, NOAA

Notes

References

Atlas, D. and Korb, C.L. "Weather and Climate Needs for Lidar Observations from Space and Concepts for Their Realization." Bulletin of the American Meteorological Society, Vol. 62, No. 9, September 1981, 1270-1285.

SEA LEVEL
SDR NO. 13

CO_2 Climate Research Program

First detection
General
Sea level change

Professional Discipline

Oceanography
Glaciology

General Description

Global sea level is directly affected by glacial melting and thermal expansion of the oceans due to increases in temperature.

Land-based measurements of sea level are confounded by continental subsidence and fluctuations in oceanic surface winds.

Technical Description

Sea level
Temperature

Related Parameters

Global ice volume

Precipitation

Geographical Extent

Global

Resolution
(Parameterized Data)
Spatial: 100 km
Grid Size: 200 km
Temporal: monthly

Error Tolerance

1 cm

Space-Based Sensor Systems

TOPEX Altimeter, also requires gravitational mapper

Person with whom SDR was discussed

Warren Washington
Michael MacCracken
Michael McElroy

Implementation Expert

W.F. Townsend, NASA/HQ

Notes

Measurements may be needed on long time scale to monitor volume of water changes due to ice melt or temperature increase.

References

Gornitz, V., et. al. "Global Sea Level Trend in the Past Century." Science, Vol. 215, 1982, 1611-1614.

SURFACE ATMOSPHERIC PRESSURE
SDR NO. 14

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning) Surface atmospheric pressure	Meteorology Modeling

General Description

Pressure gradients are related to surface wind measurements.

Technical Description	Related Parameters
Oceans: surface atmospheric pressure	Wind

Geographical Extent	Resolution	Error Tolerance
Global	Spatial: 100 km Grid Size: 500 km Temporal: monthly averages	1.5 mb

Space-Based Sensor Systems

Person with whom SDR was discussed

Jerome Namias

Implementation Expert

C.L. Korb, NASA/GSFC

Notes

References

Peckham, et. al. International Journal of Remote Sensing, 1983, in press. [Optimizing a Remote Sensing Instrument for Measuring Surface Pressure.]

SOIL MOISTURE
SDR NO. 15

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning)	Biology Modeling Meteorology

General Description

Soil moisture is a key link in the hydrological cycle, as it is the source of evaporation from the land surface. It is very sensitive to a general warming trend.

Technical Description	Related Parameters
Top Soil moisture	Precipitation Evaporation Run-off Snow Ice Evapotranspiration

Geographical Extent	Resolution	Error Tolerance
Global	(Parmeterized Data) Spatial: 100 km Grid Size: 500 km Temporal: monthly	10% of magnitude

Space-Based Sensor Systems

SMMR on Nimbus

Person with whom SDR was discussed

Warren Washington
Michael Schlesinger
Michael MacCracken
Jerome Namias
David Staelin
Wei-Chyung Wang
George Kukla

Implementation Expert

W. Marlott, Colorado State University
W. Hovis, NOAA
Schmugge, NASA/GSFC
Jackson Thomas, USDA

Notes

Warm season, especially
Shows strong CO_2 signal in 3D models. Very important for agriculture.

References

Carlson, T.N. "Satellite Estimation of the Surface Energy Balance, Moisture Availability, and Thermal Inertia." Journal of Applied Meteorology, Vol. 20, No. 1, 1981, 67-87.

Haydn, C.M., et. al. "Determination of Moisture from NOAA Polar-Orbiting Satellite Sounding Radiances." Journal of Applied Meteorology, Vol. 20, No. 4, 1981, 450-466.

Schmugge, T.J., et. al. "Survey of Methods for Soil Moisture Determination." Water Resources Research, Vol. 16, No. 6, December 1980, 961-979.

Rangu, A., et al "Effective Use of Landsat Data in Hydrologic Models." (Paper No. 82111 of the Water Resources Bulletin). Water Resources Bulletin, Vol. 19, No. 2, April 1983, 165-174.

SNOW COVER
SDR NO. 16

CO_2 Climate Research Program

First detection
Polar
Snow/ice boundaries & extent

Professional Discipline

Climatology-Modeling
Glaciology
Meteorology

General Description

Similar to sea ice, snow cover exerts a large positive feedback on changes in temperature through albedo change. Near the margin of the snow covered zone, GCMs predict the largest changes in surface temperature due to albedo feedback.

Current estimates of snow cover (as derived from satellite observations) are very poor in cloudy regions. Differentiation between new, old and melting snow is of high interest for estimating the surface radiation exchange and for understanding the dynamics of snow cover fluctuations.

Technical Description

Snow cover: presence, depth, age, and fractional cover

Related Parameters

Low-level cloud cover
Run-off
Soil moisture
Temperature

Geographical Extent

Middle & high latitudes

Resolution

(Parameterized Data)
Grid Size: 200 km
Temporal: 5 days

Error Tolerance

5% of area
at boundaries
2 cm depth
2 days age

Space-Based Sensor Systems

SMMR, multispectral on Nimbus
Visible, NIR, and IR in clear skies on the NOAA and DMSP polar orbiters and on GOES.

Person with whom SDR was discussed

General consensus among scientists contacted

Implementation Expert

M. Matson, NOAA
G. Kukla, Lamont-Doherty
J. Dozier, University of California

Notes

Old snow vs new snow
(Manabe) for depth use microwave with more that 1 wavelength
Shows strong CO_2 signal in climate models
Ground truth critical

References

Dewey, K.F., et. al. "Satellite Observations of Variations in Northern Hemisphere Seasonal Snow Cover." BAMS, Vol. 63, 1982.

Warren, S.J. "Optical Properties of Snow." Rev. Geophys. Space Physics, Vol. 20, No. 1 1982, 67-89.

Kukla, G., editor. Glaciological Data: Snow Watch 1980. Columbia University, Palisades, NY. World Watch Center A for Glaciology [snow and ice], Boulder, CO, October 1981.

Stiles, W.H. and Ulaby, F.T. "Active and Passive Microwave to Snow Parameters - 1. Wetness." Journal of Geophysical Research, Vol. 85, No. C2, February 20, 1980, 1037-1044.

Lillisand, T.M., et. al. "Use of GOES and TIROS/NOAA Satellite Data for Snow-Cover Mapping." Photogrammetric Engineering & Remote Sensing, Vol. 48, No. 2, February 1982, 251-259.

Kong, J.A., et. al. "Theory and Experiment for Passive Microwave Remote Sensing of Snow Packs." Journal of Geophysical Research, Vol. 84, No. B10, September 10, 1979, 5669-5673.

SURFACE ALBEDO
SDR NO. 17

CO_2 Climate Research Program

Model parameters (input, output, & tuning)
Surface albedo

Professional Discipline

Meteorology
Modeling

General Description

Surface albedo has a considerable effect on the climate because it governs the amount of solar radiation absorbed by the earth's surface. Current measurements of albedo have excellent coverage, but are inadequate because they require extensive extrapolation from a set of narrow spectral bands to the entire spectrum, corrections of bidirectional reflectance for the hemispheric albedo, and corrections for atmospheric path. They can not be made under clouds.

Technical Description

Land and ocean surface albedo:
spectral dependence
(Snow & Ice - fill)

Related Parameters

Wind surface moisture
Snow cover
Vegetative cover
Sea ice

Geographical Extent

Global

Resolution

(Parameterized Data)
Spatial: 50 km
Grid Size: 200 km
Temporal: monthly

Error Tolerance

± 2% (absolute)

Space-Based Sensor Systems

Visible, NIR, IR, Microwave channels on LANDSAT, TIROS(NOAA), NIMBUS

Person with whom SDR was discussed

General concensus among scientists contacted

Implementation Expert

R. Dickinson, NCAR
T.H. Vonder Haar, Colorado State University
W. Hovis, NOAA
G. Kukla, Lamont-Doherty Geol. Obs.

Notes

Clear sky radiance important to measure as actual albedo

References

Kukla, G., and Robinson, D. "Annual Cycle of Surface Albedo." Monthly Weather Review, Vol. 108, No. 1, 1980, 56-68.

LAND ICE
SDR NO. 18

CO_2 Climate Research Program	Professional Discipline
Polar Antarctic ice sheet extent and land ice	Glaciology

General Description

Large-scale melting of polar glaciers would provide conclusive evidence of a global warming trend. However, determining a CO_2-induced warming trend through land ice would require centuries-long observations. Ice volume can be calculated from acccuately measured altitude of the ice. This measurement is done with altimeter systems.

Technical Description	Related Parameters
Ice sheet extent and height	Temperature Precipitation as rainfall/ snow

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Polar to 65° latitude	Spatial: 50 m Grid Size: 50 km Temporal: annual	1m elevation

Space-Based Sensor Systems

Radar Altimeter - Seasat
Laser Altimeter

Person with whom SDR was discussed

Michael MacCracken
George Kukla
Peter Stone

Implementation Expert

C. Parkinson, NASA/GSFC
Bentley, University of Wisconsin, Madison

Notes

References

Snow and Ice Research, An Assessment, Committee on Glaciology, Polar Research Board, NAS, 1983.

Scientific Committee on Antarctic Research (SCAR), Report of the SCAR Group of Specialists on Antarctic Climate Research, "Basis for a Plan on Antarctic Climate Research," May 1981.

GROUND (SOIL SURFACE) TEMPERATURE
SDR NO. 19

CO_2 Climate Research Program	Professional Discipline
Model parameters (input, output, & tuning)	Meteorology
Vegetative response and carbon cycle	Biology
	Modeling

General Description

Ground (soil) temperature is a significant parameter which governs climate processes and human habitability. Ground temperature must be known when estimating a vertical temperature profile. Microwave measurement of surface temperature will require obtaining the soil moisture profile.

Technical Description	Related Parameters
	Surface IR emittance
	Sensible heat flux
	Latent heat flux
	Solar and thermal
	Radiation flux
	Evaporation

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Global	Spatial: 100 km	1° C
	Grid Size: 500 km	
	Temporal: monthly	

Space-Based Sensor Systems

SMMR
HIRS

Person with whom SDR was discussed

Michael Schlesinger
Michael MacCracken
Roland Madden
Jay Winston

Implementation Expert

W. Smith, University of Wisconsin
W. Hovis, NOAA
T. Vonder Haar, Colorado State University

Notes

References

Hanel, R.A., et. al. "The NIMBUS 4 Infrared Spectroscopy Experiment 1. Calibrated Thermal Emission Spectra." Journal of Geophysical Research, Vol. 77, No. 15, May 20, 1970, 2629-2641.

CO_2 Climate Research Program	Professional Discipline
Vegetative response & carbon cycle changes in biomass inventories, latitudinal limits of vegetation.	Biology Ecology

General Description

Biospheric changes may be the indirect result of CO_2-induced climatic change or the direct result of increasing CO_2 concentration in the atmosphere.

Technical Description	Related Parameters
Monitor biomes and transitions between ecosystem types, i.e., measure latitudinal and altitudinal limits of trees and other vegetation. Also leaf cover index (measure of leaf surface area).	-Concentrations of CO_2 and trace gases -Precipitation -Temperature

Geographical Extent	Resolution (Parameterized Data)	Error Tolerance
Global or selected zones such as the tropical forest	Spatial: 1 km Grid Size: 200 km Temporal: selected intervals ($\sim$bimonthly through growing season)	1-10 km boundary changes

Space-Based Sensor Systems

Visible and NIR channels on TIROS and Landsat.

Person with whom SDR was discussed

Michael McElroy
John Perry

Implementation Expert

Vincent, NASA/GSFC

Notes

References

MacCracken, M., et. al. "The First Detection of Carbon Dioxide Effects: Workshop Summary, June 8-10, 1981, Harpers Ferry, W. VA." Bulletin of the American Meteorological Society, Vol. 63, 1982, 1164-1178.

Woodwell, G.M., et al, "Deforestation Measured by Landsat: Steps Toward a Method," Technical Report prepared at The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.

Woodwell, G.M., Editor, The Role of Terrestrial Vegetation in the Global Carbon Cycle: Measurement by Remote Sensing, Publication by the Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.

CO_2 ATMOSPHERIC CONCENTRATION
SDR NO. 21

CO_2 Climate Research Program

Model parameter (input)

Professional Discipline

Meteorology
Modeling

General Description

Long-term changes and global distribution of atmospheric CO_2 concentration are needed to supplement ground station data.

CO_2 concentration gradient measurements are also needed to detect sources and sinks for special flux studies. High precision and accuracy measurements are needed to detect these gradients.

Technical Description

Related Parameters

Temperature
Cloud Cover
Albedo
Radiation budget
O_3

Geographical Extent	Resolution	Error Tolerance
Global	Grid Size: 500 km Monthly Avg.	0.3 ppm

Space-Based Sensor Systems

HIRS-2

Person with whom SDR was discussed

Wei-Chyung Wang

Implementation Expert

Lester Machta, NOAA
C.D. Keeling, Scripps Institution of Oceanography

Notes

References

Machta, L. "Atmospheric Measurement of Carbon Dioxide." Proceedings of Workshop on the Global Effects of Carbon Dioxide from Fossil Fuels, DOE Pub. No. CONF-770385, May 1979.

PRECIPITATION
SDR NO. 22

CO_2 Climate Research Program	Professional Discipline
Model parameter (input, output & tuning) General	Meteorology Modeling

General Description

Effects of CO_2 on climate may cause changes in the temperature-precipation (T-P) regimes, with impact on agriculture.

Technical Description	Related Parameters
	Clouds Temperature Latent heat Soil moisture Snow/ice

Geographical Extent	Resolution	Error Tolerance
Global or selccted regions for model verification	Grid Size: 200km Temporal: daily	1-5 mm/day or 10%

Space-Based Sensor Systems

ESMR-NIMBUS 5
SMMR-NIMBUS 7

Person with whom SDR was discussed

Wei-Chyung Wang

Implementation Expert

J.A. Weinman, Space Science & Engineering Center, University of Wisconsin, Madison

Notes

References

Spencer, R.W., et al "Satellite Microwave Radiances Correlated with Radar Rain Rates Over Land." Nature, Vol. 304, July 14, 1983, 141-143.

CIRRUS CLOUDS
SDR NO. 23

CO_2 Climate Research Program	Professional Discipline
Model parameter (input, output, & tuning) General	Meteorology Modeling

General Description

Since cirrus clouds have extensive coverage and are almost transparent to thermal infrared radiation, they have significant effects on climate and radiation balance of the earth-atmosphere system which differs from over clouds. The principal advantages of monitoring the cirrus from space-based sensor systems are their relatively long life time and high altitudes.

Technical Description	Related Parameters
	Temperature Albedo (surface & lower level clouds)

Geographical Extent	Resolution	Error Tolerance
Global or selected regions for model verification	(Parameterized Data) Grid Size: 200 km Temporal: daily Monthly average	

Space-Based Sensor Systems

HIRS and AVHRR on NOAA - 7

Person with whom SDR was discussed

Wei-Chyung Wang

Implementation Expert

J.A. Coakley & F.P. Bretherton, NCAR
Moustafa Chahine, JPL

Notes

Because cirrus clouds are generally semi-transparent, the variable emissivity can present a problem when trying to determine their radiative properties.

References

Coakley, J.A., and Bretherton, F.P. "Cloud Cover from High Resolution Scanner Data: Detecting and Allowing for Partially Filled Fields of View." Journal of Geophysical Research, Vol. 87, 1982, 4917-4932.

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P-14

APPENDIX B

MEASURES OF MEASUREMENT ADEQUACY

The adequacy of a measurement instrument is often characterized in terms of the precision, accuracy, and confidence that can be assigned to the measurements that it produces. It is useful to distinguish among these three concepts. Suppose that a variable, such as surface temperature at a particular place and time, is being measured. Let X denote the true (but unknown) value of this variable, and let m(X) be the measured value produced by the measurement instrument. For example, X might be the true temperature that would be measured by someone standing on the ground at the time and place in question, while m(X) could be the estimated temperature produced by a space-based

- The accuracy of the measurement m(X) may be defined as the size of the difference between the true and measured values, i.e., as $|X - m(X)|$

- The precision of the system over a large number of measurements may be defined in terms of the sample standard deviation, e.g.,

  $$1/\sqrt{E[m(x)-E[m(x)]]^2},$$

  where E(x) denotes the expected value (i.e., the mean, or arithmetic average) of the quantity x. Alternatively, if the system produces data in the form of intervals (such as $m(X) \pm d$, where d is a "tolerance limit") that are known with high confidence to contain the true value, X, then the precision of the system (at that confidence level) may be defined as the reciprocal of the length of the interval (e.g. 1/2d). Wide intervals indicate low precision.

- The confidence in an interval-valued measurement, such as $m(X) \pm d$, may be defined as the probability that this interval contains the true value, e.g., as

  $$Pr[m(X)-d \leq X \leq m(X) + d].$$

(This should not be confused with the "confidence interval" of classical statistics.) Note that there always tends to be a tradeoff between the confidence and precision of a measurement, i.e. between the width of an interval and the probability that it contains the true value.

The concept of "accuracy" for a system must be extended when measurement is distributed over time, rather than being made instantaneously. Let the "true" value of the variable being measured be X_t at time t, and let its measured value be denoted by $m(X_t) = \hat{X}_t$. Then, the measurement error at time t may be defined as

$$u_t = |X_t - \hat{X}_t|, \tag{1}$$

the magnitude of the difference between the true and measured values. In general, X_t may be (and remain) unknown, so that the error u_t is not directly observable. In this case, it is necessary to specify a hypothesized <u>model</u> relating measured values to each other, e.g.,

$$X_{t+1} = F(X_t), \hat{X}_t = X_t + u_t \tag{2}$$

where u_t is assumed to be a <u>random</u> error component, e.g. normally distributed with mean 0, variance σ^2:

$$u_t \sim N(0, \sigma^2). \tag{3}$$

If the model is given by (2) and (3), then the relation between observable (measured) values is

$$\hat{X}_{t+1} = F(\hat{X}_t - u_t), u_t \sim N(0, \sigma^2), \tag{4}$$

where the unobservable construct X_t has been eliminated, leaving u_t as the only unobservable. If the "system dynamics" represented by the function F are known, then the accuracy may be estimated. For example, suppose that the variable being measured is hypothesized to have a fixed "true" value that remains constant over time, so that the underlying model (2) becomes $X_t = X_0$, $\hat{X}_t = X_0 + u_t$. This is equivalent to the reduced model $\hat{X}_t \sim N(X_0, \sigma^2)$, and the problem at time T is to estimate X_0, the variable's "true" value, from the sequence of measurements $\{\hat{X}_1, \hat{X}_2, \ldots \hat{X}_T\}$.

From elementary statistics, it is known that the "best" estimate of X_0, i.e., the estimate that minimizes the expected squared measurement error (or maximizes the expected measurement accuracy) is the sample mean,

$$\bar{X}_T = \frac{1}{T} \sum_{t=1}^{T} \hat{X}_t \qquad (5).$$

That is, the best estimate of the true value of the variable being measured is, at any time T, the simple (unweighted) arithmetic average of the measured values observed so far. The expected square error in this estimate, $E[(\bar{X}_T - X_0)^2]$ is given by σ^2/T which approaches zero (although more and more slowly) as T increases towards infinity. After T observations, the probability that the error $|\bar{X}_T - X_0|$ exceeds $2\sigma/\sqrt{T}$ is less than 5%, and this probability continues to decrease with increasing T, corresponding to a steady increase in probable accuracy (assuming that the underlying model), $\hat{X}_t \sim N(X_0, \sigma^2)$, is correct.)

What this example demonstrates is that even though the expected error in any <u>single</u> measurement taken by a system may remain constant (it is equal to σ in the present case), the accuracy of the <u>estimate</u> formed by averaging measurements over time may be made arbitrarily good if enough observations are available (and if the underlying assumptions of a fixed "true" value and normally distributed $N(0, \sigma^2)$ additive measurement error are correct.) Thus, the concept of a system's "accuracy," from the standpoint of the accuracy of the estimates that it supports, must take into account both the number of observations that the system provides (e.g. by a given date), and the accuracy (e.g., the standard deviation) of each observation.

Figure 1 provides an example. Time is plotted on the horizontal axis, and it is assumed that one measurement is taken in each period. At any point T on the horizontal axis, there is a 95% confidence probability that the estimate $\hat{X}_T$ will fall between the upper and lower curves at that point. The upper and lower curves converge (slowly) to the true value, X_0, as the number of measurements, T, increases. It is assumed throughout that observations are independent. To obtain an accuracy of $\pm$ .5 with a confidence probability of 95%, four observations are required (when $\sigma = .5$). To double this accuracy to $\pm$ .25 at the same level of confidence requires $4^2 = 16$ observations. To double it again would require $16^2 = 256$ observations, and so forth. There are sharply diminishing returns, in terms of improved accuracy, associated with increasing the number of observations.

Figure 1 essentially describes the accuracy/observation number tradeoff for any system taking measurements of a fixed constant with normally distributed, serially uncorrelated, measurement noise having known mean and variance. To apply the curve in Figure 1 to a system taking N observations per unit time and having zero-mean measurement noise with arbitrary variance σ, it is only necessary to rescale the horizontal axis by multiplying each number by $\sigma/2\sqrt{N}$. A similarly- shaped pair of curves (based on the "t-statistic") can be derived for the case

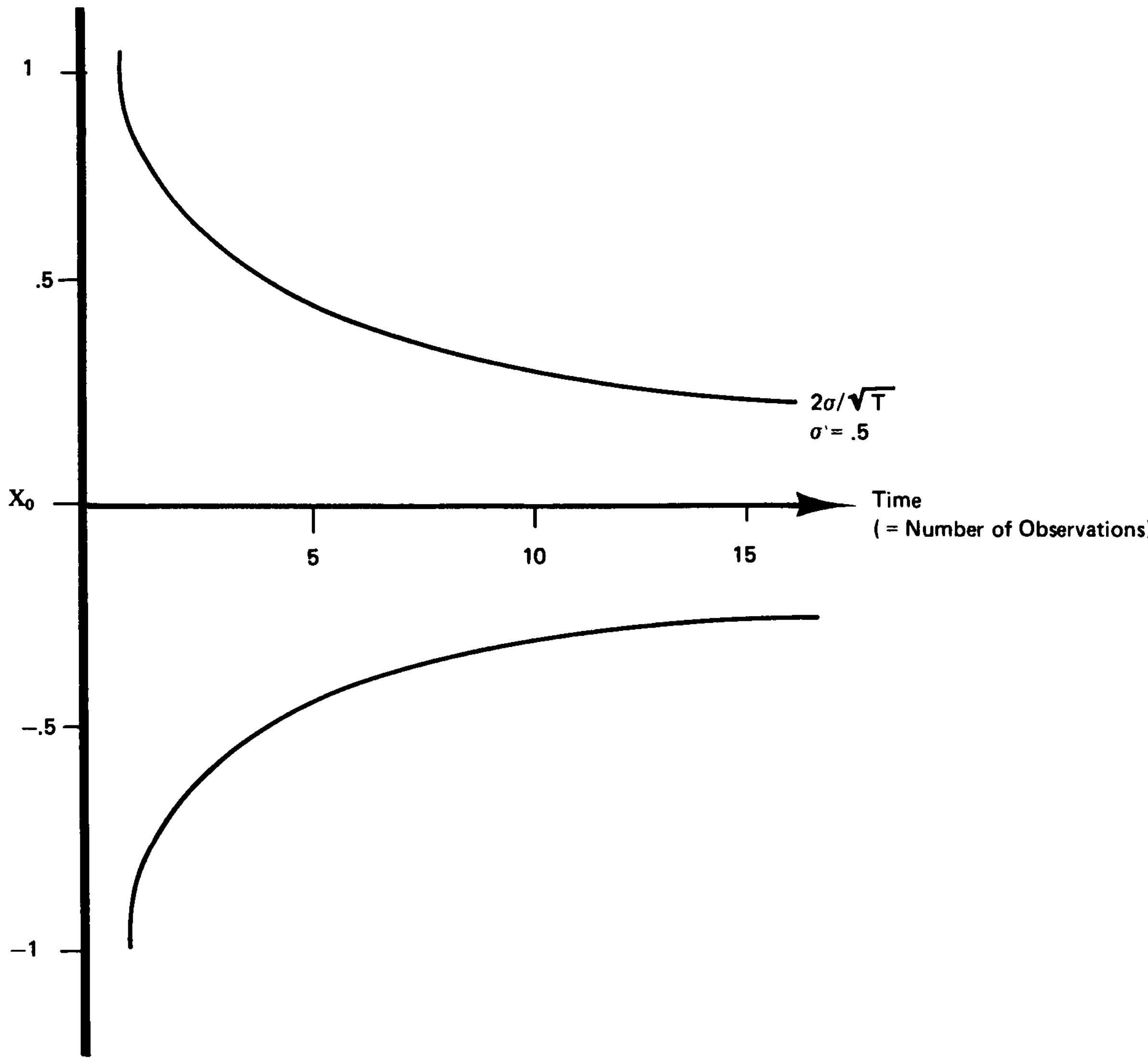

FIGURE 1 95% ERROR BOUNDS AS A FUNCTION OF NUMBER OF OBSERVATIONS where σ is unknown. In any case, if cost is of order $O(N)$, where N is the number of observations, the shape of the error bounds in Figure 1 suggests that an optimal data collection strategy will be to monitor for a limited number of observations, until the marginal cost of continued measurement exceeds the value of the marginal improvement in estimate accuracy, and then to cease monitoring.

When the variable being monitored has a value that changes over time -- which is the case for nearly all variables useful in describing the climate -- the analysis of measurement accuracy becomes more difficult. Suppose that the above example is generalized to a first-order autoregressive process, with the "true" value being measured evolving according to the equation

$$X_{t+1} = \alpha X_t + V_t, \; V_t \sim N(0, b^2), \tag{6}$$

and with the measurements being given by

$$\hat{X}_t = X_t + u_t, \; u_t \sim N(0, \sigma^2), \tag{7}$$

just as before. It is assumed that V_t, u_t, V_{t+L} and u_{t+L} are mutually independent, for all values of t and L. Thus, the true parameter value at time t is equal to a fraction α of its value in the preceding period, plus a random increment with mean 0, variance b^2. We assume that α (the "decay rate") is a known fraction between -1 and +1. The simple example studied above and illustrated in Figure 1 corresponds to the special case $\alpha = 1$, $b = 0$.

The "best estimate" of X_t, in this case, is given by a recursive filter known as the "Kalman filter"; it may be expressed as

$$\bar{X}_t = (K_t)(\alpha\bar{X}_{t-1}) + (1 - K_t)\ \hat{X}_t. \tag{7}$$

That is, the estimated value of X_t which gives the lowest expected squared error of any estimate, denoted by $\bar{X}_t$, is a weighted sum of (i) The best "predicted" value of X_t, based on previously available information (namely, $\alpha\bar{X}_{t-1}$); and (ii) The actually measured value of X_t, namely $\hat{X}_t$. $\bar{X}_t$ also turns out to be the <u>most likely</u> value of X_t, given all the measurements available up through period t. The values of the "Kalman gain factor," K, which defines the weights in Equation (7) may be computed from

$$K_t = \frac{\sigma}{r_t + \sigma}\text{, where} \tag{8}$$

$$r_t = [(\alpha^2\sigma r_{t-1})/(r_{t-1} + \sigma)] + b \tag{9}.$$

Thus, the complete sequence of weights K_t can be determined (through iteration of Equation (9)) once the initial value r_1 has been specified. Now it turns out that

$$r_t = \alpha^2 P_{t-1} + b \text{ and} \tag{10}$$

$$P_t = \frac{\sigma r_t}{\sigma + r_t} = K_t r_t \tag{11},$$

where P_t is the variance (= expected squared error, since the estimate is unbiased) of the optimal estimate $\bar{X}_t$. Hence, $r_1 = b$ if the initial state, X_0, is completely known, and $r_1 = \infty$ if the initial state is completely unknown. In any case, the variance of $\bar{X}_t$ quickly converges to a steady-state value equal to the positive value of

$$P_\infty = \lim_{t\to\infty} \mathrm{Var}\,(\bar{X}_t) = \frac{\alpha^2\sigma - b - \sigma}{2\alpha^2} \pm \sqrt{\left(\frac{\alpha^2\sigma - b - \sigma}{2\alpha^2}\right)^2 + \frac{b\sigma}{\alpha^2}} \quad , \qquad (12)$$

regardless of its initial value.

The above analysis can be extended to arbitrary moving average and/or autoregressive processes through a simple device known as "state vector augmentation," with all equations being replaced by their vector/matrix equivalents. Note that Equation (7), may be rewritten as

$$\bar{X}_t = \hat{X}_t + K_t\,(\alpha\bar{X}_{t-1} - \hat{X}_t), \qquad (7')$$

which says that the best estimate of X_t is equal to the observed value plus a correction which is proportional to the difference between the predicted and observed values. Equation (12) gives the unavoidable error associated with this "best estimate," and shows how it depends on measurement noise, σ^2, and process noise, b^2. Note that "perfect" estimation is possible in the long run, despite measurement noise, if $b = 0$.

Figure 2 shows how the achievable accuracy of the estimate $\bar{X}_t$ produced by the optimal filter varies with the stability and noisiness of the variable being measured. If the process described by Equation (6) is "stable" (meaning that $-1 < \alpha < 1$) or if it is a "random walk" (meaning that $\alpha = 1$) then the filtered measurement $\bar{X}_t$ homes in on the true value X_t with increasing accuracy as long as the process generating X_t is free of noise ($b = 0$ in Equation (6).) The filtered measurement approaches perfect accuracy (zero expected error) asymptotically as $t \to \infty$ in this case, which is the one illustrated in Figure 1 and in the lowermost curve

Figure 2a:
Expected Squared Error in Estimate
(= Variance)

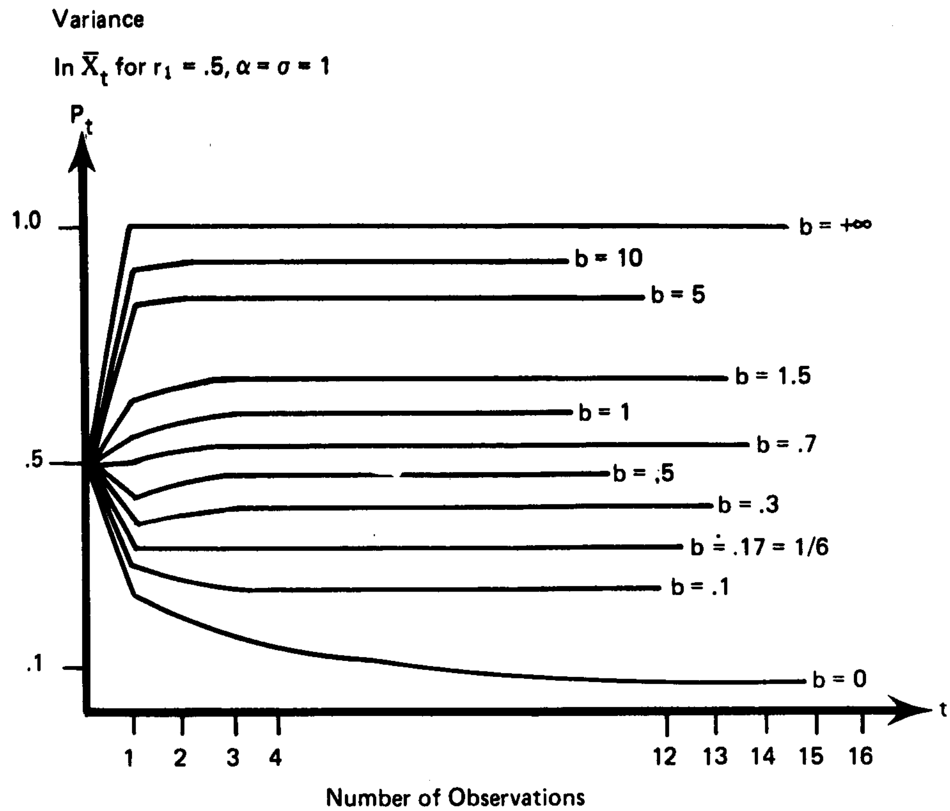

Figure 2b:
Irreducible
("Steady State")
Variance in Filtered Estimate of Process State
(σ = 1)

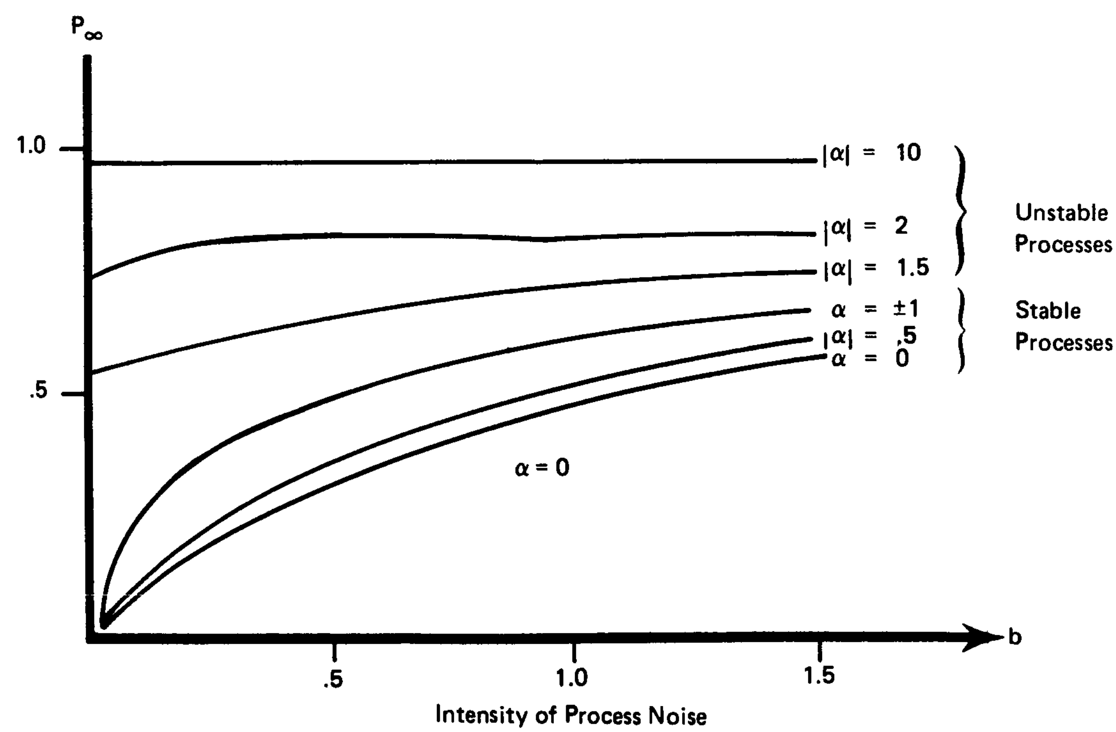

FIGURE 2 ERROR CHARACTERISTICS OF THE OPTIMAL FILTER FOR AN AUTOREGRESSIVE PROCESS

(corresponding to $b = 0$) in Figure 2a. As the intensity of noise in the process generating X_t -- measured by b -- increases above zero, however, the irreducible expected squared error (i.e., variance) in the filtered estimate $\bar{X}_t$, even if an arbitrarily large number of observations is available, also becomes positive. This is shown in Figure 2 by the increase in steady-state variance with increasing b. For unstable systems ($|\alpha|>1$), moreover, the steady-state accuracy of the filtered measurements is limited even when $b = 0$. This is because the value of the variable being measured changes faster than the filter can track it.

From this analysis, it is seen that the intensity of measurement noise, σ, is chiefly important in determining how long it takes the filtered measurement to stabilize in achieving its steady-state variance (that is, to reach its limiting mean squared error), while the process noise, b, helps determine how large this steady-state mean squared error will be. The steady-state mean squared error increases with increasing process noise, b, or instability, $|\alpha|$, and (asymptotically) perfect accuracy is achievable if and only if (i) The process is not unstable, i.e., $|\alpha| \leq 1$; and (ii) Either process noise or measurement noise (or both) equals zero, i.e., $b\sigma = 0$.

Figure 3 shows how the limiting mean squared error, or steady-state variance, increases with increasing measurement noise for a marginally stable system ($\alpha = 1$). Note that the horizontal axis is scaled by a factor of 5 relative to the vertical axis, since steady-state variance is relatively insensitive to noise in the system for small values of the process noise parameter, b.

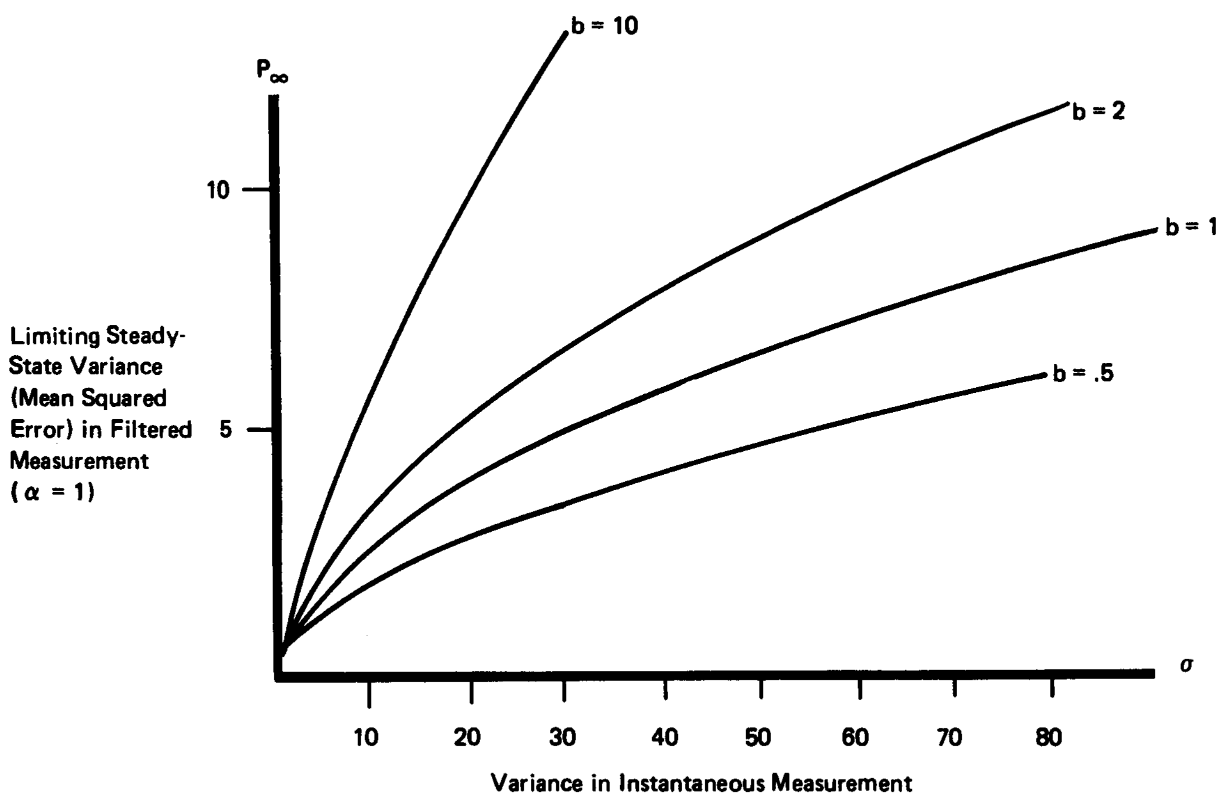

FIGURE 3 INSTANTANEOUS MEASUREMENT VARIANCE VS. STEADY-STATE FILTERED MEASUREMENT VARIANCE, FOR DIFFERENT PROCESS NOISE INTENSITIES

For variables with autoregressive lags of length greater than one, the above discussion must be expressed more generally in vector-matrix notation, with variances being replaced by variance-covariance matrices, and with parameter α being generalized with to the set of "eigenvalues" for the process. However, the qualitative insights in Figures 1 to 3, relating instantaneous mean squared measurement error, σ^2, process stability, $|\alpha|$, and process noise, b, to the limiting mean squared error of the filtered measurement, P_∞, remain essentially valid.

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APPENDIX C

A PROCEDURE FOR SPACE SDR PRIORITIZATION

1.0 INTRODUCTION

At the beginning of the study, it was thought that more space SDRs would be compiled than could be investigated within the scope of the study. Therefore, a prioritization procedure, based on anticipated sensor system limitations, was developed to screen the SDRs. However as space-based sensor systems were identified it was found that they could meet all the SDRs and, therefore, the need for prioritization diminished. Since effort was expended on this procedure, it is included as part of the study documentation.

It was first necessary to arrive at a common set of attributes which described the relative importance of each SDR to the DOE CO_2 Research Program. Many attributes were considered. Some (e.g., data management requirements and existence of proven algorithms) were rejected because they related more to engineering considerations than to scientific ones. Finally, four were selected:

- Importance for early detection of CO_2-induced effects.
- Need for additional measurements.
- Importance for model inputs.
- Importance for model outputs.

Each SDR was scored on these attributes. These scores were categorical (for example, low, medium, and high) and formed the basis for assigning a relative value to each SDR. For this ranking a methodology based on "dominance theory" was used. The methodology and the selected SDRs are discussed below.[1]

2.0 IMPORTANCE FOR FIRST DETECTION OF CO_2 EFFECTS

The objective of this attribute is to identify those SDRs which are very sensitive to a global warming and which respond to that warming relatively quickly (i.e., on a timescale of a few years). Sea level, for example, is sensitive to a global warming trend, but its response time is so slow that it is of marginal significance to first detection.

The importance of first detection was considered:

- *High* if the parameters to be measured were determined to be very sensitive to an overall global warming, and if it responded to that warming within a decade.

- *Medium* if the parameters were considered very sensitive to global warming, but responded slowly to that warming.

- *Low* if the effects were small effects or not known.

The SDRs which received a score of "High" for first detection of CO_2 effects included:

- Global radiation balance.
- Cloud coverage and vertical structure.
- Temperature, both the vertical distribution and surface.
- Sea ice.
- Snow cover.

The SDRs which received a score of Medium (because of their slow response times) were:

- Sea surface temperature.
- Sea level.
- Surface albedo.
- Land ice.
- Biosphere characteristics.

All other SDRs received a score of Low.

3.0 NEED FOR ADDITIONAL MEASUREMENTS

This SDR attribute is the most difficult to define precisely. Clearly no climatically significant parameters are known with such certainty that they require no additional measurements. However, review of the literature and interviews with members of the scientific community revealed several data inadequacies in general:

- Coverage is geographically limited. Mostly lacking are oceanic and polar data.

- Measurements are unable to resolve long-term changes. Often data are adequate for most purposes, but not precise enough for climatic studies. Sea ice, for example, is measured routinely, but the significance of measured inter-annual and decadal changes is not well known.

- Measurements are made for only a short time. This limitation is especially true of satellite instruments, which often provide "experimental" information and are operational for a few years (ERB) or only a few weeks (TOPEX).

To be useful, therefore, measurements must be global, accurate and precise. Just as importantly, they must be made routinely over a very long period (usually decades).

The need for additional measurement, therefore, was considered:

- *High* if two of the following descriptions applied to current measurements:

  — not global in coverage
  — measurement of insufficient resolution.

- *Medium* if one of the above descriptions applied to current measurements.
- *Low,* if neither of the above descriptions applied.

The SDRs were scored for additional measurement need as follows:

- *Radiation Balance* (Medium)

  Current remote observations (ERBE program) are acceptable but are scheduled to be performed for only a few years.

- *Clouds: Percent Coverage* (Medium)

  Reliable measurements in the polar regions are almost totally lacking and reliability over the continents needs improving. Current routine measurements over the oceans are good.

- *Clouds: Vertical Structure* (High)

  There are virtually no global estimates of this parameter.

- *Trace Gases* (High)

  The scattered measurements being performed are irregular in both time and space.

- *Aerosols* (Medium)

  Present measurements (DIAL, SAMI, SAGE) are adequate but are not part of an ongoing, routine measurement program.

- *Temperature: Vertical Profile* (Medium)

  Current observations provide regular global coverage, but are neither accurate nor precise enough for climate studies.

- *Precipitation* (Medium)

  The current network of land-based stations is adequate over the continents, and moreover, is densest in those agricultural regions most sensitive to fluctuations in precipitation. Oceanic data is inadequate.

- *Atmospheric Water Content* (High)

  Current measurements are precise but inaccurate. They also provide no information concerning relative liquid and vapor content, nor do they provide any vertical resolution.

- *Sea Surface Temperature* (Low)

  Except for relatively minor problems with accuracy and precision, current measurements are adequate.

- *Sea Ice* (Medium)

  Current routine measurements have inadequate accuracy.

- *Ocean Currents* (High)

  There are no operational measurements of this parameter.

- *Oceans: Surface Winds* (High)

  There are no operational measurements of this parameter.

- *Sea Level* (High)

  Current land-based measurements provide inadequate resolution, and moreover, are confounded by local patterns of wind and coastal subsidence.

- *Soil Moisture* (High)

  Current satellite estimates of this parameter are irregular and subject to large errors.

- *Snow Cover* (Medium)

  Current operational measurements provide sufficient accuracy for resolution of climatic change, but they are inaccurate in cloudy regions.

- *Surface Albedo* (Medium)

  Current observational measurements are uncertain: radiance observations are unidirectional within a set of narrow bands and yet are extrapolated to the entire spectrum.

- *Ground Temperature* (Medium)

  These are closely related to measurements of atmospheric temperature profile; therefore, ground temperature measurements suffer from large errors.

- *Biosphere* (High)

  There are no operational measurements providing biosphere characteristics.

4.0 SIGNIFICANCE FOR MODEL INPUT

Two aspects of GCM model input were considered.

First, those parameters which affect the earth's climate independently of any increase in CO_2 must be isolated. These parameters provide a confusing influence which must be considered when one assesses a model's ability to represent the dynamics of climatic change over a period of many years.

Second, it must be recognized that certain parameters are used to "tune" models. In other words, all GCMs contain certain empirical constants which have no other physical meaning than to enable the model to reproduce the observed climate. These constants, which often must be estimated using very limited data, form the basis for parameterizations of various processes too complicated to model directly. Typically such so-called "tuning parameters" are related to long-term fluxes of sensible and latent heat.

The SDRs' importance for model input was considered:

- *Very High* if the parameters were:
  - — an independent variable (e.g., the solar constant), or
  - — required for calculating an empirical tuning parameter which affects the sign of the response to a CO_2 increase.
- *High* if they were required for calculating a tuning parameter other than the type described above.
- *Medium* if they were an input parameter different from that described above.
- *Low* if they were not a model input.

External factors (i.e., independent variables) which received a score of Very High included:

- Incoming solar radiation (part of radiation balance).
- Trace gas concentrations.
- Aerosol concentrations.

Those dependent variables related to tuning parameters which received a score of Very High were:

- Vertical cloud distribution.
- Vertical profile of water vapor.

Other dependent variables related to tuning parameters (and which received a score of High) included:

- Soil moisture (required for evaporation).
- Ground temperature (and surface air temperature required for sensible heat flux).
- Sea ice.
- Snow cover.

Additional model inputs that did not fall into the above categories (and, therefore, which received a score of Medium) were:

- Sea surface temperature.

- Surface albedo.
- Land ice.

The remaining SDRs received a score of "Low."

5.0 SIGNIFICANCE FOR MODEL OUTPUT

Dependent variables were first separated into those variables which are modeled directly (i.e., according to "first principles") and those which are modeled indirectly (i.e., using empirical parameterizations). There is greater confidence in those aspects of climate which are modeled directly than in those which are modeled indirectly. In addition, interest was highest in those outputs which models show to be very sensitive to global warming.

The importance for model output was considered:

- *Very High* if the parameters were a dependent variable and were
  — closely related (physically) to global warming
  — modeled *directly*.

- *High* if they were the same as Very High but modeled *indirectly*.

- *Medium* if they were a dependent variable but not particularly sensitive to a global warming.

- *Low* if they were not a model output.

The SDRs most significant for model outputs and receiving a score of "Very High" included:

- Outgoing radiation flux.
- Cloud coverage and vertical structure.
- Sea surface and ground temperatures.
- Vertical temperature profile.

Less significant model outputs (those sensitive to warming which are modeled indirectly) which received a score of High included:

- Precipitation.
- Sea ice.
- Soil moisture.
- Snow cover.

Other model outputs which received a score of Medium were:

- Sea currents.

- Atmospheric winds.
- Oceanic surface atmospheric pressure.

All the remaining SDRs received a score of Low.

6.0 ASSESSING SDR IMPORTANCE

Once the SDRs were evaluated, their importance to the DOE CO_2 Research Program was assessed using a technique known as "dominance theory." Dominance theory provides an objective means for assessing the relative importance (or desirability) of independent options.

The basic assumption of dominance theory is that each option to be analyzed is described by a number of attributes, with a score assigned to each attribute for each option. By convention, low scores indicate low importance and high scores indicate high importance. To say that option A dominates option B implies that:

- A is at least as important as B on all attributes;
- A is more important than B on at least one attribute.

Typically, the first step of a dominance analysis is the construction of a dominance matrix. This matrix is formed by crossing the set of options with itself, so that if there are N options, the dominance matrix is of size N x N. The matrix contains a 1 in a row i and column j if, and only if, option i dominates option j, and a O otherwise. The dominance matrix gives an overview of how disparate the options actually are. A dominance matrix filled with all O's, for example, implies that all options are roughly equivalent. Furthermore, an approximate measure of importance can be gained by adding the number of 1's in each row of the matrix, which gives the number of other options dominated by each individual option.

The chief value of the dominance matrix is that it allows a definition of *dominance classes*, which are sets of options satisfying the following:

- Each option in a given class is dominated only by members of classes above it.
- Each option in a given class dominates only members of classes below it.

Construction of dominance classes is analogous to a partial ranking because, for decision-making purposes, choosing one option over another within the same dominance class is completely arbitrary.

The power of dominance theory as an analytical tool lies in its lack of assumptions. No assumptions are made concerning the relative importance of the individual attributes. Moreover, the dominance relation is extremely robust: if option A dominates option B, A will always outscore B no matter how the individual attributes are weighted.

The scores assigned to the selected SDRs described above are presented in Table 1. For convenience, brief sets of score definitions are included. These scores provide the basis for the dominance analysis.

TABLE 1

ATTRIBUTE SCORES FOR THE SELECTED SDR LIST

	1st Detection	Measured Need	Model Input	Model Output
Global Rad Bal	2	1	3	3
Cloud PCT	0	1	0	3
Cloud Vert	0	2	3	3
Temp Vertical	2	1	2	3
Temp (Ground)	2	1	2	3
Trace Gases	2	2	3	0
Aerosols	2	1	3	0
Water Vert	0	2	3	1
Wind Vert	0	0	0	1
Precipitation	0	1	0	2
Sea Sfc Temp	0	0	0	3
Sea Ice	2	1	2	2
Sea Currents	0	2	1	1
Wind (Sfc Ocean)	0	2	0	1
Press (Sfc Ocean)	0	0	0	1
Sea Level	1	2	0	0
Soil Moisture	0	2	2	2
Snow Cover	2	1	2	2
Albedo (Sfc)	1	1	1	1
Ice (Land)	1	0	1	0
Biosphere	1	2	0	0

First Detection

2: Very sensitive to warming, response time less than decade
1: Very sensitive to warming, response time greater than decade
0: Either not very sensitive or unknown

Measurement Need

2: Coverage is not global, cannot resolve change and is not routine
1: Coverage meets at least 2 of the criteria above
0: Coverage meets either 1 or 0 of the criteria above

Model Inputs

3: External factors or tuning parameters which change sign of response
2: Other tuning parameters
1: Other model inputs
0: Not model inputs

Model Outputs

3: Those both highly affected by warming and modeled directly
2: Those highly affected by warming but modeled indirectly
3: Connection to global warming indirect
0: Not model outputs

The dominance matrix derived from these scores is presented in Table 2. (Note that there is a 1 in row i and column j if, and only if, option i dominates option j.) Here the rows and columns of the matrix have been sorted by row in order to give a rough measure of relative importance. Several aspects of this matrix should be noted.

- Vertical cloud distribution is clearly *the* dominant SDR, as it dominates all others.

- Vertical wind distribution and oceanic surface pressure are of little interest because they dominate nothing and are dominated by all other options.

- Because their rows and columns are identical, the following pairs of SDRs are completely equivalent for decision-making purposes:
  - ground temperature and vertical temperature profile
  - snow cover and sea ice
  - surface oceanic winds and biosphere characteristics

The dominance clusters implied by the dominance matrix of Table 2 are shown in Table 3. These dominance classes correspond to a final ranking of the SDRs in terms of their importance to the CO_2 Research Program for the purposes of this study. The order within dominance clusters in Table 5 is not meaningful: the only significance is in the cluster membership of the individual SDRs.

It is important to recognize that the relative ranking shown in Table 3 applies only to the individual value of the SDRs. It does not take into account the various interactions between SDRs which must be considered when choosing space-based sensors. For example, the ranking does not concern itself with practical measurement issues, for example, in considering surface albedo note that the ranking of this SDR (dominance class 4) is based on the value of surface albedo independently of all other SDRs, and might appear to imply that surface albedo is relatively unimportant. On the contrary, to make almost any spaced-based measurements (looking downward) requires an extremely accurate value for clear-sky radiance which for all intents and purposes gives surface albedo!

Alternatively, measurements may be required which illuminate a specific feedback mechanism in order to improve some parameterization used in climate models. For example, the long-term mechanisms of cloud formation involve an extremely complex interaction between the hydrological cycle, the atmospheric temperature field and large-scale wind patterns. Therefore, to make measurements which capture the details of how and why clouds form, several SDRs must be satisfied simultaneously. The dominance classes in Table 3 provide guidance about which parameters to measure for this purpose, but they do not provide all the information required for decisions. An important input to these decisions will be the performance, the estimated costs, and the program for implementation of space-based sensor systems.

REFERENCE

1. R.L. Keeney, and H. Raiffa. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. John Wiley and Sons, New York, 1976.

TABLE 2

ORDERED DOMINANCE MATRIX FOR SELECTED SDRs

						5					10					15					20	
1	Cloud Vert	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Global Rad Bal	0	0	1	1	0	1	0	1	1	0	0	0	1	0	1	1	1	0	1	1	1
3	Temp Vertical	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	1	0	1	1	1
4	Temp (Ground)	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	1	0	1	1	1
5	Trace Gases	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	1	1
6	Sea Ice	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1
7	Soil Moisture	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	1
8	Snow Cover	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	1
9	Cloud PCT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1
10	Water Vert	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1
11	Sea Currents	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
12	Sea Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
13	Albedo (SFC)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
14	Biosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
15	Aerosols	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
16	Precipitation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
17	Sea SFC Temp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
18	Wind (SFC Ocean)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
19	Ice (Land)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
20	Wind Vert	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Press (SFC Ocean)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 3

LIST OF SDRs

Dominance Class	SDR
1	Clouds Vertical Distribution Cirrus Clouds
2	Global Radiation Budget
3	Trace Gases (Including O_3) CO_2 Soil Moisture Temperature Vertical Profile Temperature (Ground)
4	H_2O Vertical Distribution Sea Ice Cloud Percent Coverage Sea Currents Sea Level Precipitation Snow Cover Vegetation Index Aerosols Surface Albedo Sea Surface Temperature Sea Surface Wind
5	Land Ice Wind Field (Vertical) Sea Surface Pressure

P-212

N86-32010

System Study of the Utilization of Space for CO_2 Research

Appendix D: Scientific Fact Sheets

SUBSYSTEM FACT SHEETS

FOR NASA CO_2 PROJECT

Tom Lookabaugh
BALL AEROSPACE SYSTEMS DIVISION

REVISION A
9 NOVEMBER 1983

This document contains 27 Subsystem Fact Sheets (SFS) produced by Ball Aerospace Systems Division in partial fulfillment of Contract 6300-7107 for Arthur D. Little. The SFS's address the following instruments/systems:

SFS- 1 Coastal Zone Color Scanner

SFS- 2 Scanning Multi-channel Microwave Radiometer

SFS- 3 Ocean Color Imager

SFS- 4 Advanced Very High Resolution Radiometer

SFS- 5 Stratospheric Sounding Unit

SFS- 6 High Resolution Infrared Sounder

SFS- 7 Thematic Mapper

SFS- 8 Microwave Sounding Unit

SFS- 9 Satellite Sounder, Humidity

SFS-10 Data Collection System

SFS-11 Advanced Microwave Sounding Unit

SFS-12 Advanced Moisture and Temperature Sounder

SFS-13 Synthetic Aperture Radar

SFS-14 Light Detection and Ranging

SFS-15 Large Antenna Multi-Frequency Microwave Radiometer

SFS-16 Laser Heterodyne Spectrometer

SFS-17 Cryogenic Limb-scanning Interferometer and Radiometer

SFS-18 Earth Radiation Budget Experiment

SFS-19 Modular Optoelectronic Multispectral Scanner

SFS-20 Systeme Probatoire de l'Observation de la Terre

SFS-21 Stratospheric Aerosol and Gas Experiment

SFS-22 Solar Backscatter Ultraviolet Radiometer

SFS-23 Microwave Pressure Sounder

SFS-24 Altimeter

SFS-25 Scatterometer

SFS-26 Infrared Interferometer Spectrometer

SFS-27 Atmospheric Trace Molecules Observed by Spectroscopy

SUBSYSTEM FACT SHEET 1

COASTAL ZONE COLOR SCANNER (CZCS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel image-scanning radiometer.

1.2 PARAMETERS SENSED:

Radiation in five visible and one infrared bands.

1.3 STATE OF DEVELOPMENT:

Successfully flown and operating on NIMBUS-7.

1.4 DESIGN DATE:

1978

1.5 PRINCIPAL INVESTIGATOR:

Dr. Warren Hovis (NOAA)

1.6 MANUFACTURER:

Ball Aerospace Systems Division, Boulder, Colorado

1.7 REFERENCES

1) "Final Report F78-11, Rev. A: Development of the Coastal Zone Color Scanner for NIMBUS-7". Prepared for Goddard Space Flight Center (NASA) by Ball Aerospace Systems Division, 1979.

2) "NIMBUS-7 User's Guide". Landsat/NIMBUS Project, Goddard Space Flight Center (NASA), 1978.

3) "The Marine Resources Experiment (MAREX)". Report of the Ocean Color Science Working Group, Goddard Space Flight Center (NASA), 1982.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

42 kg

2.2 AVERAGE POWER CONSUMPTION:

48 W

2.3 DIMENSIONS:

78 cm x 53 cm x 37 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Power requirements of other satellite instruments limit CZCS to 30% operation mode. Two stage radiative cooler for IR focal plane is included.

3. DATA

3.1 DATA RATE:

3.5 Mbps (max.), 400 kbps (ave.)

3.2 COMMANDS:

Controllable gain for first four visible channels. Controllable tilt on scan mirror in order to eliminate sun glint.

3.3 ON BOARD PROCESSING:

Digitization with controllable offset for improved resolution.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Data is recorded and archived at GSFC. User algorithms may be used, or NASA/GSFC derived tapes and photographs may be obtained.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

955 km

4.3 REVISIT TIME, COVERAGE:

Global coverage

4.4 ORIENTATION TO SUN:

Ascending node at 12:00 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A cassegrain telescope focusses radiation on a dichroic beam splitter. Visible light goes to a polychromator and then to five Si photo-diodes; infrared radiation goes to a cooled (120°K) HgCdTe photo-conductor. The 11.5 µm channel provides the information on sea surface temperature.

5.2 TYPE OF SCAN:

Mechanical, rotating mirror at 45° to optical axis.

5.3 FIELD OF VIEW:

IFOV: .865 mrad x .865 mrad
.825 km x .825 km
FOV: 1.37 rad
Swath Width: 1570 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Sampling Period: 123.73 ms
Scan rate (mirror): 8.08 rps

5.5 CALIBRATION:

Internal: for visible channels, incandescent light; for IR, honeycomb black body at known temperature.
External: View of deep space.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER WAVELENGTH μ	RESOLUTION μ	SNR	NETD
1	.443	.02	150	-
2	.520	.02	140	-
3	.550	.02	125	-
4	.670	.02	100	-
5	.750	.02	100	-
6	11.5	2	-	.220°K at 270°K

6. IMPLEMENTATION SCHEDULE

Flown successfully on NIMBUS-7, October 1978.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Successfully flown and still operating. The CZCS has been used to obtain the following results:

1) Chlorophyll concentration with an accuracy of ±30%, no clouds, low suspended sediment concentration.

2) Diffuse Attenuation Coefficient with an accuracy of ±15% under the same conditions.

Processing of CZCS data proved more difficult than anticipated due to its large volume [see reference (3)]. However, analysis of data showed good correlation with ground truth measurements of pigment concentrations and diffuse attenuation coefficients in open oceans, with quality degrading in areas of high suspended sediment concentration due to the limited number of spectral bands available.

SUBSYSTEM FACT SHEET 2

SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Scanning reflector multiple frequency microwave radiometer.

1.2 PARAMETERS SENSED:

Orthogonally polarized antenna temperature at each of five microwave frequencies.

1.3 STATE OF DEVELOPMENT:

Successfully flown and operating on NIMBUS-7.

1.4 DESIGN DATE:

1977

1.5 PRINCIPAL INVESTIGATOR:

Dr. Per Gloersen (NOAA)

1.6 MANUFACTURER:

Jet Propulsion Laboratory, Pasadena, CA

1.7 REFERENCES

1) "The NIMBUS-7 User's Guide." The Landsat/Nimbus Project, Goddard Space Flight Center (NASA), 1978.

2) "The Marine Resources Experiment Program (MAREX)." Report of the Ocean Color Science Working Group, Goddard Space Flight Center (NASA), 1982.

3) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

4) "NOSS: National Oceanic Satellite System." Washington, D.C., NASA, 1978.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

52.3 kg

2.2 AVERAGE POWER CONSUMPTION:

60 W

2.3 DIMENSIONS:

2 15.3 cm x 33.0 cm x 20.4 cm modules
1 15.3 cm x 16.5 cm x 70.4 cm modules

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Utilizes an oscillating offset reflector for scanning. Power consumption limits SMMR to 50% operational mode. Requires a parabolic section antenna (80 cm dia).

3. DATA

3.1 DATA RATE:

2 kbps

3.2 COMMANDS:

12

3.3 ON BOARD PROCESSING:

A/D and serial bit stream formation.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Grounding receiving station.

3.6 DATA HANDLING/REDUCTION:

Raw data is processed by Meteorological Operations Control Center into user formatted tape. This is then processed by the Science and Applications Computer Center to produce temperature and other tapes available to the community. Further processing and formation of images for various geophysical variables is done at the Information Processing Division (GSFC).

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

955 km

4.3 REVISIT TIME, COVERAGE:

Global coverage; 6 day revisit.

4.4 ORIENTATION TO SUN:

Ascending node at 12:00 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A 42° offset parabolic reflector feeds all five frequencies into a single feed horn. Six Dicke-type radiometers are used - the four low-channels scan different polarizations alternately, the highest channel scans both polarizations continuously.

5.2 TYPE OF SCAN:

Oscillating parabolic reflector.

5.3 FIELD OF VIEW:

Channel	1	2	3	4	5
Antenna Beam Width (±0.2°)	4.2°	2.6°	1.6°	1.4°	0.8°

FOV: ±25° with constant angle of earth incidence of 50.3°.

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Channel	1	2	3	4	5
Integration Time (ms)	126	62	62	62	30

5.5 CALIBRATION:

Internal: Ambient RF termination

External: Horn antenna view of deep space; other constants checked against targets of known properties (groundtruth).

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	FREQUENCY (GHz)	RESOLUTION (MHz)	DOUBLE SIDEBAND NOISE (dB)	ABSOLUTE ACCURACY (°K rms)	TEMPERATURE RESOLUTION (°K per IFOV)
1	6.6	250	<5.0	<2.0	0.9
2	10.69	250	<5.0	<2.0	0.9
3	18.00	250	<5.0	<2.0	1.2
4	21.00	250	<5.0	<2.0	1.5
5	37.00	250	<5.0	<2.0	1.5

6. IMPLEMENTATION SCHEDULE

Successfully flown and still operating on NIMBUS-7.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Obtainable measurements and accuracies include:

1) Sea Surface Temperature (±4°C).

2) Wind Speed (±2.5 m/s, no direction).

3) Fractional Ice Coverage (±15%, providing no rain, heavy clouds, sunglint or RFI).

Other obtainable measurements are:

1) Mesoscale soil wetness index.

2) Snow accumulation rates over continental ice sheets.

3) Subsurface physical temperatures in snow cover.

4) Total water vapor, total non-precipitating liquid water, and rainfall rate over open ocean.

An improved version of SMMR has been proposed with the following characteristics:

Weight: 350 kg
Dimensions: 15 m^3
Average Power Consumption: 150 W

A 4 m rotating parabolic antenna would yield a swath width of 1350 km. Spectral characteristics are as follows:

Channel	Frequency (GHz)	Beamwidth (deg)	Surface Resolution (km)	Integration Time (msec)	Temperature (°K)
1	4.3	1.22	22 x 34	7.7	400
2	10.65	0.49	9 x 14	3.1	500
3	18.7	0.28	5 x 7.8	1.8	400
4	21	0.25	4.5 x 7	1.6	400
5	36.5	0.25	4.5 x 7	1.6	800
6	91	0.25	4.5 x 7	1.6	1200

Anticipated performance is as follows:

Wind Speed

Precision: 2 m/s
Accuracy: 2 m/s
Resolution: 15 km

Atmopsheric Liquid Water

Precision: 3 mg/cm^2
Resolution: 9 km

Atmospheric Water Vapor

Precision: 150 mg/cm^2
Resolution: 9 km

Surface Temperature

Precision: 7° K

Ice Age

Precision: ± 10%
Resolution: 3.5 km

Ice Coverage

Precision: 7%
Resolution: 7 km

Precipitation Over Land

Resolution: 9 km

Precipitation Over Water

Precision: ±1 octave
Resolution: 9 km

A suspected hardware design flaw related to leakage across a switch which changes from horizontal to vertical polarization mode may cause deletion of this design in favor of LAMMR.

SUBSYSTEM FACT SHEET 3

OCEAN COLOR IMAGER (OCI)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel image-scanning radiometer.

1.2 PARAMETERS SENSED:

8 visible channels.

1.3 STATE OF DEVELOPMENT:

Phase B studies.

1.4 DESIGN DATE:

Late 1980's.

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

Ball Aerospace Systems Division internal documentation.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

50 Kg (57 Kg with diffuser).

2.2 AVERAGE POWER CONSUMPTION:

60 W

2.3 DIMENSIONS:

56.0 cm x 41.0 cm x 87 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Includes rotating scan mirror and optional diffuser.

3. DATA

3.1 DATA RATE:

3.33 Mbps (max.), 779 kbps (ave.)

3.2 COMMANDS:

33

3.3 ON BOARD PROCESSING:

Color Data Processor (to be built by RCA) will provide buffered frames and calibration data. Data averaging is available on command.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

NOAA and GSFC will share computer analysis and create a User Interface Facility for production of images.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, polar, sun-synchronous.

4.2 ALTITUDE:

870 km

4.3 REVISIT TIME, COVERAGE:

Global coverage, 2 weeks revisit.

4.4 ORIENTATION TO SUN:

Ascending node at 1:30 p.m. LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Exactly the same as the Coastal Zone Color Scanner, (see SFS-1). but with larger field of view.

5.2 TYPE OF SCAN:

Rotating mirror (6 Hz at 45° to optical axis).

5.3 FIELD OF VIEW:

IFOV:	1.30 mrad x 1.30 mrad
	1.13 km x 1.13 km
FOV:	1.45 rad
Swath Width:	1542 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan rate: 6 Hz
Sample time: 32.05μs
5200 samples per scan

5.5 CALIBRATION:

Internal: Visible calibration lamps
External: Diffuser looking at sun, view to deep space.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	WAVELENGTH (μm)	RESOLUTION (μm)	SNR
1	.443	.02	789
2	.490	.02	681
3	.520	.02	688
4	.560	.02	638
5	.590	.02	472
6	.670	.02	430
7	.765	.04	383
8	.867	.05	537

6. IMPLEMENTATION SCHEDULE

Present: Phase B

Late 1980's: Phase C/D

1989: Launch

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

No difficult problems except for new ground in developing the diffuser. There is some talk of modifying channel 7 to block a particularly strong absorption band.

SUBSYSTEM FACT SHEET 4

ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Four channel image-scanning radiometer.

1.2 PARAMETERS SENSED:

One channel visible light, one near infrared, and two infrared radiation.

1.3 STATE OF DEVELOPMENT:

Successfully flown on TIROS/NOAA.

1.4 DESIGN DATE:

Late 1970's.

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

ITT Aerospace/Optical Division, Fort Wayne, IN

1.7 REFERENCES

(1) "The TIROS-N/NOAA A-G Satellite Series." NOAA Technical Memorandum NESS-95, Arthur Schwalb, August 1979.

(2) "AVHRR-FM Advanced Very High Resolution Radiometer, Final Engineering Report." ITT Aerospace/Optical Division, Fort Wayne, IN for NASA (NASA contract NAS5-21900).

(3) "Advanced Very High Resolution Radiometer, Mod. 2, Engineering Reports, Final Report." ITT Aerospace/Optical Division, Fort Wayne, IN for NASA (NASA contract NAS5-23400).

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

27 kg

2.2 AVERAGE POWER CONSUMPTION:

24.92 W

2.3 DIMENSIONS:

58.27 cm x 24.77 cm x 35.72 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Utilizes a rotating scan mirror. Requires a temperature controlled mounting platform and a radiant cooler.

3. <u>DATA</u>

3.1 DATA RATE:

665 kbps @ High Resolution
41 kbps @ Global Resolution

3.2 COMMANDS:

28.

3.3 ON BOARD PROCESSING:

Amplification, multiplexing, A/D, and delivery to NOAA satellite's MIRP high data rate processor. On-board averaging for global resolution.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Data is provided in the form of global area coverage with 4 km x 4 km resolution, selected local area coverage with 1 km x 1 km resolution, and direct readout to users capable of receiving it.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 1400-1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Rotating mirror feeds a cassegrain telescope then dichroics and beamsplitters. The visible and near infrared radiation is received by Si detectors, the infrared by InSb and HgCdTe detectors.

5.2 TYPE OF SCAN:

360 rpm rotating mirror.

5.3 FIELD OF VIEW:

IFOV: 1.3 mrad x 1.3 mrad (±0.1 mrad)
1.0 km x 1.0 km

FOV: 1.33 rad
112°

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan rate: 360 scan/minute.

5.5 CALIBRATION:

Internal: Warm housing at known temperature is viewed.
External: View of deep space.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER WAVELENGTH μ	RESOLUTION μ	SNR	NETD
1	.725	.35	>3:1	-
2	.91	.38	>3:1	-
3	3.74	.38	-	.12°K*
4	11.0	1.0	-	.12°K*

*at 300°K

6. IMPLEMENTATION SCHEDULE

Successfully flying on TIROS-N/NOAA series of satellites.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Measurements of hydrological, oceanographic, and meteorological parameters - clouds, land/water, snow and ice extent, and sea temperature, have been obtained.

Modification AVHRR/2 has the following characteristics:

Size:	76.84 cm x 28.42 cm x 36.35 cm
Weight:	28.7 kg
Power:	26.18 W

CHARACTERISTICS

SPECTRAL CHANNEL	WAVELENGTH (μm)	RESOLUTION (μm)	NETD
1	.63	.10	-
2	.91	.38	-
3	3.74	.38	<.12
4	10.8	1.0	<.12
5	12.0	1.0	<.13

SUBSYSTEM FACT SHEET 5

STRATOSPHERIC SOUNDING UNIT (SSU)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Selective absorption pressure-modulated cell 3 channel radiometer.

1.2 PARAMETERS SENSED:

Infrared radiation in three channels.

1.3 STATE OF DEVELOPMENT:

Successfully flown on TIROS-N/NOAA satellites.

1.4 DESIGN DATE:

1973

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Marconi Space and Defense Systems, Ltd., Camberley, England for the U.K. Meteorological Office

1.7 REFERENCES

(1) "The TIROS-N/NOAA A-G Satellite Series." NOAA Technical Memorandum NESS-95. Arthur Schwalb, 1979.

(2) "Preliminary Design Report for the TIROS-N Stratospheric Sounding Unit," Volumes I and II, Marconi Space and Defense Systems, Ltd., Camberley, England.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

9.06 Kg

2.2 AVERAGE POWER CONSUMPTION:

15 W

2.3 DIMENSIONS:

17.78 cm x 17.78 cm x 25.4 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Requires an 8-cm (dia.) scan mirror.

3. DATA

3.1 DATA RATE:

480 bps

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

Measurements are digitized and fed to the NOAA satellite low data rate processor, TIP.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

No information.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 1400-1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Pressure modulated CO_2 cells filter incoming radiation. Radiation is measured by Triglycerine Sulphate pyroelectric detectors.

5.2 TYPE OF SCAN:

Step-scanning mirror.

5.3 FIELD OF VIEW:

IFOV:	.18 rad x .18 rad
	150 km x 150 km
FOV:	1.2 rad
Swath Width:	1473 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan period: 32 seconds

5.5 CALIBRATION:

Internal: Black body at known temperature.
External: View of deep space.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTRAL WAVE NO (cm^{-1})	EQUIVALENT SPECTRAL BANDWIDTH (cm^{-1})	NESR/UNIT SPECTRAL BANDWIDTH $\frac{erg - cm^2}{s\text{-}ster\text{-}cm^{-1}}$	NETD
1	668	2.0	.125	.147°K at 214°K
2	668	1.0	.25	.22°K at 240°K
3	668	4.0	.625	.45°K at 270°K

6. IMPLEMENTATION SCHEDULE

Successfully flown and operating on TIROS-N/NOAA series of satellites.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

N/A

SUBSYSTEM FACT SHEET 6

HIGH RESOLUTION INFRARED SOUNDER (HIRS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel filter radiometer.

1.2 PARAMETERS SENSED:

Six short wave infrared, ten long wave infrared and one visible light channels.

1.3 STATE OF DEVELOPMENT:

Flown successfully on NIMBUS-6.

1.4 DESIGN DATE:

1970

1.5 PRINCIPAL INVESTIGATOR:

Bill Smith, University of Wisconsin.

1.6 MANUFACTURER:

ITT Aerospace/Optical Division, Fort Wayne, IN.

1.7 REFERENCES

1) "NIMBUS-6 User's Guide," Landsat/NIMBUS Project, Goddard Space Flight Center (NASA), 1975.

2) "TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS-95, Arthur Schwalb, Washington, D.C., August, 1979.

3) "Feasibility of Modifying the High Resolution Infrared Sounder (HIRS) for Measuring Spectral Components of the Earth Radiation Budget," Edward W. Koenig and Kent A. Hullimen, ITT Aerospace/Optical Division, Fort Wayne, IN, 1975 (NASA Contract NAS7-16188).

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

32.3 kg

2.2 AVERAGE POWER CONSUMPTION:

22.8 W

2.3 DIMENSIONS:

65 cm x 40.4 cm x 35.3 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

2 kbps

3.2 COMMANDS:

9 bits for command status.

3.3 ON BOARD PROCESSING:

Amplification, integration, and A/D.

3.4 ON BOARD STORAGE:

High Data Rate Storage System of the NIMBUS-6, a five channel digital tape recorder which can store approximately 123 minutes of data.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Tapes of calibrated, located radiances are produced at Goddard Institute for Space Studies. Tapes containing derived clear-column radiances and atmospheric parameters are produced by NOAA. Images are available.

4. <u>ORBIT REQUIREMENTS</u>:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

1100 km

4.3 REVISIT TIME, COVERAGE:

Global coverage, 12 hour revisit.

4.4 ORIENTATION TO SUN:

Ascending node at 12:00 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Cassegrain telescope feeds chopper and filter wheel assembly. Radiation is focussed and divided by dichroic and refractive elements and measured by cooled detectors (120°K) in the infrared (PbSe for SWIR, HgCdTe for LWIR) and 300°K Si detectors for visible light.

5.2 TYPE OF SCAN:

Mechanical, rotating mirror.

5.3 FIELD OF VIEW:

IFOV:	23 mrad (dia) circle
	25 km (dia)
FOV:	.955 rad
Swath Width:	1050 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan period per IFOV: 106ms
Scan period per line: 4.5s

5.5 CALIBRATION:

Internal: Two black-body targets.
External: View of deep space.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER WAVE NUMBER cm^{-1}	RESOLUTION (cm^{-1})	NESR (mw/m^{-2} ster cm^{-1}) T_D=188°K	NESR (mw/m^{-2} ster cm^{-1}) T_D=124°K	NETD Source Temp. = 290°K T_D=188°K	NETD Source Temp. = 290°K T_D=124°K
1	668	2.8	3.0	6.0	1.00	3.80
2	679	13.7	0.66	1.5	0.41	0.94
3	690	12.6	0.45	0.75	0.28	2.47
4	702	15.9	0.27	0.44	0.17	0.27
5	716	17.5	0.52	0.85	0.32	0.52
6	733	17.6	0.23	0.38	0.14	0.23
7	749	18.4	0.27	0.42	0.16	0.26
8	900	34.6	0.19	0.30	0.12	0.19
9	1,224	63.4	0.15	0.24	0.14	0.23
10	1,496	87.6	0.13	0.19	0.21	0.31
11	2,190	20.6	0.12	0.12	0.13	0.13
12	2,212	22.5	0.003	0.003	0.04	0.04
13	2,242	21.6	0.006	0.006	0.08	0.08
14	2,275	35.2	0.002	0.002	0.03	0.03
15	2,357	23.0	0.003	0.003	0.06	0.06
16	2,692	296.9	0.001	0.001	0.06	0.06
17	14,443	892.2	-	-	-	-

6. IMPLEMENTATION SCHEDULE

Successfully flown on NIMBUS-6.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The HIRS has been modified to HIRS/2, which incorporates 20 spectral channels, a 15 mrad IFOV, and optics to eliminate vignetting and out-of-field energy. A further modification in order to use HIRS for Earth Radiation Budget measurements has been suggested [see reference (3)]. Four spectral channels (at .3, 1.0, 1.6, and 18-25··m) would be added, yielding profile and origin (e.g., H_2O, O_2, O_3, and surface) of radiation excitance. This modification would result in an increase in length of 7.9 cm, an increase in mass of 3.00 kg, and an increase in power consumption of .1 W.

SUBSYSTEM FACT SHEET 7

THEMATIC MAPPER (TM)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-spectral image scanner.

1.2 PARAMETERS SENSED:

Three visible, three near infrared, and one thermal infrared channels.

1.3 STATE OF DEVELOPMENT:

Presently flying on Landsat-D.

1.4 DESIGN DATE:

1979

1.5 PRINCIPAL INVESTIGATOR:

Dr. Vincent V. Salomonson, GSFC (NASA)

1.6 MANUFACTURER:

Hughes Santa Barbara Research Center, Santa Barbara, CA

1.7 REFERENCES

(1) J. L. Engel, "Thematic Mapper - An Interim Report on Anticipated Performance," AIAA Sensor Systems for the 80's Conference, American Institute of Aeronautics and Astronautics, 1980.

(2) Jack C. Lansing, Jr., Timothy D. Wise, Edward D. Harvey, "Thematic Mapper Design Prediction and Performance Prediction." The Society of Photo Optical Instrumentation Engineers, Huntsville, Alabama, 1979.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

243 kg

2.2 AVERAGE POWER CONSUMPTION:

332 W

2.3 DIMENSIONS:

66 cm x 110 cm x 200 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Two stage radiative cooler for Bands 5, 6, and 7

3. DATA

3.1 DATA RATE:

84.9 Mbps

3.2 COMMANDS:

Images and bands covered are selectable.

3.3 ON BOARD PROCESSING:

Amplification, digitization, multiplex.

3.4 ON BOARD STORAGE:

No on-board storage.

3.5 GROUND RECEIVING STATION/TDRSS:

Data was to be sent both directly to ground stations and to the TDRS system.

3.6 DATA HANDLING/REDUCTION:

Large data rate requires initial processing (geometric and radiometric corrections) at Landsat-D Data Management System facility, capable of accepting 100 TM scenes/day. Data is then sent to the Landsat-D Assessment System facility for user-oriented processing.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

705 km

4.3 REVISIT TIME, COVERAGE:

Revisit time 16 days; global coverage.

4.4 ORIENTATION TO SUN:

Descending node at 9:30 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A forward and reverse scanning plane mirror delivers radiation to a Ritchey-Chretien telescope. Between the primary mirror and prime focal plane, a Scan Line Corrector provides optical correction for spacecraft motion and mirror turnaround. Si detectors for the first four bands are located at the uncooled primary focal plane: the remaining bands are optically relayed to a cooled (90°K) focal plane, where detectors for bands 5 and 7 are InSb and band 6 is HgCdTe.

5.2 TYPE OF SCAN:

Plane mirror with forward and reverse scan (10ms turnaround time).

5.3 FIELD OF VIEW:

IFOV:	42.5 rad	(bands 1-4)	30 m x 30 m
	43.8 rad	(bands 5,7)	31 m x 31 m
	170 rad	(band 6)	120 m x 120 m
FOV:	.26 rad		
Swath Width:	185 km		

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan rate: 70 Hz

5.5 CALIBRATION:

During mirror turnaround, a black reference surface and tungsten lamps for bands 1-5 and 7, and a black body of known temperature for band 6.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	WAVELENGTH (μm)	RESOLUTION (μm)	NOISE EQUIVALENT REFLECTANCE	NETD (°K)
1	0.49	0.04	0.8%	-
2	0.56	0.04	0.5%	-
3	0.66	0.03	0.8%	-
4	0.83	0.07	0.5%	-
5	1.65	0.10	1.0%	-
6	11.45	1.05	-	0.57
7	2.22	.14	2.4%	-

6. IMPLEMENTATION SCHEDULE

September, 1981: Complete Hardware delivery to NASA
1982: Launch on Landsat D

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Failure of X-band communications link has interrupted data transmission until TDRSS comes on line.

SUBSYSTEM FACT SHEET 8

MICROWAVE SOUNDING UNIT (MSU)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel microwave radiometer.

1.2 PARAMETERS SENSED:

Four channels of microwave radiation around the 5.5 mm oxygen region.

1.3 STATE OF DEVELOPMENT:

Successfully flown on TIROS/NOAA satellites.

1.4 DESIGN DATE:

1975

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Jet Propulsion Laboratory, Pasadena, CA

1.7 REFERENCES

(1) "The TIROS/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS-95, Arthur Schwalb, August 1979.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

2.2 AVERAGE POWER CONSUMPTION:

2.3 DIMENSIONS:

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Requires two rotating antennas.

3. DATA

3.1 DATA RATE:

320 bps

3.2 COMMANDS:

Can be commanded into orbit or launch mode. All channels may be turned on or off. A reset mode and manual setting of antenna position are available.

3.3 ON BOARD PROCESSING:

Amplification, multiplex, and A/D; data is fed to the TIROS Information Processor (TIP) for formatting and multiplexing with other instrument data.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station (TIP downlink at 8320 bps).

3.6 DATA HANDLING/REDUCTION:

No information.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 1400 - 1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Two stepping reflector/antenna systems feed four Dicke superheterodyne receivers.

5.2 TYPE OF SCAN:

Stepping reflector.

5.3 FIELD OF VIEW:

IFOV:	131 mrad
	109 km (dia)
FOV:	1.65 rad
Swath Width:	2352 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

IFOV Integration Time: 1.82 sec
Scan period: 25.6 sec

5.5 CALIBRATION:

Internal: Hot reference body
External: View of deep space

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	FREQUENCY (GHz)	BANDWIDTH (MHz)	NETD (°K)
1	50.3	220	<0.3
2	53.74	220	<0.3
3	54.26	220	<0.3
4	57.05	220	<0.3

6. IMPLEMENTATION SCHEDULE

Successfully flown on TIROS/NOAA series of satellites.

7. <u>EXPERIENCE/PROBLEMS/MODIFICATIONS</u>

N/A

SUBSYSTEM FACT SHEET 9

SATELLITEBORNE SOUNDER, HUMIDITY (SSH)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Scanning multi-channel filter radiometer.

1.2 PARAMETERS SENSED:

16 channels of radiation in CO_2 and H_2O absorption bands.

1.3 STATE OF DEVELOPMENT:

Successfully flown on DMSP.

1.4 DESIGN DATE:

1973

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Barnes Engineering Company

1.7 REFERENCES

"Description of the Air Force Infrared Temperature and Humidity Sounder (SSH)," J. Richard Yoder, Barnes Engineering Company.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

13.2 kg

2.2 AVERAGE POWER CONSUMPTION:

8 W

2.3 DIMENSIONS:

31.8 cm x 26.4 cm x 22.3 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

No information.

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

Amplification, A/D, formatting and buffering.

3.4 ON BOARD STORAGE:

No information.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Computer inversion is done to get temperature and water vapor profiles.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

830 km

4.3 REVISIT TIME, COVERAGE:

No information.

4.4 ORIENTATION TO SUN:

No information.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A step rotating scan mirror feeds a casseyrain telescope. A chopper intercepts radiation before it goes to dichroic mirrors, filter wheels, and finally pyroelectric detectors.

5.2 TYPE OF SCAN:

Mechanical, step-rotating mirror.

5.3 FIELD OF VIEW:

IFOV:	47 mrad
	30.3 km (dia)
FOV:	1.75 rad

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan period: 32 seconds.

5.5 CALIBRATION:

Internal: Blackbody
External: View to deep space

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER WAVE NUMBER (cm^{-1})	BANDWIDTH (cm^{-1})	NESR ($ergs/s\text{-}cm^2\text{-}str\text{-}cm^{-1}$)
1	1022	12.5	.05
2	835	8	.11
3	747	10	.12
4	725	10	.11
5	708	10	.11
6	695	10	.10
7	766	10	.09
8	688.5	3.5	.30
9	535	16	.15
10	408.5	12	.14
11	441.5	18	.09
12	410	20	.12
13	374	12	.18
14	397.5	10	.16
15	355	15	.25
16	353.5	11	.33

6. IMPLEMENTATION SCHEDULE

Successfully flown on DMSP.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

N/A

SUBSYSTEM FACT SHEET 10

DATA COLLECTION SYSTEM (DCS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Environmental monitoring communication and data relay system.

1.2 PARAMETERS SENSED:

Receives radio messages.

1.3 STATE OF DEVELOPMENT:

Successfuly flown on TIROS/NOAA series of satellites.

1.4 DESIGN DATE:

1976

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Centre National d'Etudes Spatiales, Tolouse, France.

1.7 REFERENCES

(1) "Advanced TIROS-N Spacecraft Series, Programming and Control Handbook, Vol. II," RCA Government Systems Division, Princeton, N.J., for Goddard Space Flight Center (NASA), 1982 (Contract NAS5-23700).

(2) "The TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS-95, Arthur Schwalb, Washington D.C., 1978.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

2.2 AVERAGE POWER CONSUMPTION:

2.3 DIMENSIONS:

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Vertical linear polarization antenna.

3. DATA

3.1 DATA RATE:

DCS output data rate is controlled at 720 bps.

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

After processing by DCS, data is handled by the low data rate TIROS information processor before being transmitted to ground.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Identity, location, and motion of earth platforms as well as information content of the message can be ascertained.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending mode at 1400-1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

The DCS is comprised of a receiver and search unit, four data recovery units, and a command and control unit. The receiver and search unit locates and receives signals. When a valid signal is being received the command and control unit allocates it to one of the data recovery units (allowing simultaneous processing of several messages) which performs acquisition of the carrier, signal demodulation, bit synchronization, frame synchronization, doppler counting, decommutation. The data is then moved into a temporary buffer memory before being sent to TIP for spacecraft processing, storage, and transmission.

5.2 TYPE OF SCAN:

N/A

5.3 FIELD OF VIEW:

Up to 459 platforms may be in view.
Up to 2000 platforms can be covered globally.

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Message length 360-920 ms.

5.5 CALIBRATION:

N/A

5.6 SPECTRAL CHARACTERISTICS:

Carrier Frequency 401.650 MHz ± 12 KHz

6. IMPLEMENTATION SCHEDULE

Flown successfully on TIROS-N/NOAA satellite series.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Platform location accuracy: 3-5 km rms

Platform velocity accuracy: 0.5-1.5 mps rms

SUBSYSTEM FACT SHEET 11

ADVANCED MICROWAVE SOUNDING UNIT (AMSU)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel microwave radiometer.

1.2 PARAMETERS SENSED:

20 channels of microwave radiation in the range 18-183 GHz.

1.3 STATE OF DEVELOPMENT:

Studied.

1.4 DESIGN DATE:

N/A

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "Final Report: AMSU Design Study," Aerojet Electrosystems Company for Goddard Space Flight Center (NASA), 1980.

(2) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

(3) "Meteorological Satellites, Past, Present, and Future." NASA Conference Publication 2227, 1982.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

63.4 kg (80 kg spec)

2.2 AVERAGE POWER CONSUMPTION:

125 W (170 W spec)

2.3 DIMENSIONS:

0.5 x 1.6 x 0.6 m

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Multiple antennas.

3. DATA

3.1 DATA RATE:

60 kbps (max.), 3225 bps (ave.)

3.2 COMMANDS:

8

3.3 ON BOARD PROCESSING:

Step automatic gain control, 12 bit A/D, automatic bias subtraction.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Computer inversion for temperature profile.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 1400-1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Three antennas (90-183 GHz, 50-57 GHz, and 18-31 GHz) acquire radiation. A quasi-optical feed is used for channels 16-20, a low flare angle, multi-frequency feed horn for channels 1-3, and a shrouded, offset paraboloid antenna for channels 4-15. All channels utilize total power, diode sideband radiometers.

Water vapor emission lines (22, 180 GHz) will be used for humidity sounding and near oxygen emission lines (50-60 GHz) will be used for temperature sounding. Three "window" channels (18, 31 and 90 GHZ), which measure low atmospheric and surface effects, are included in the set of channels.

5.2 TYPE OF SCAN:

Reflector step scan for channels 1-15, continuous scan for channels 16-20.

5.3 FIELD OF VIEW:

IFOV:	Channels 1-15: 50 km (60 mrad)
	Channels 16-20: 15 km (18 mrad)
FOV:	1.745 rad

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Channel	Integration Time (ms)
1-3	173
4-15	190
16-20	16.7

5.5 CALIBRATION:

Internal: Warm body
External: View of deep space

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER FREQUENCY (GHz)	BANDWIDTH (MHz)	NETD (°K)
1	18.500	100	1.0
2	22.230	100	1.0
3	31.650	100	1.0
4	50.300	100	0.5
5	52.85	100	0.5
6	53.400	100	0.5
7	54.350	100	0.5
8	54.900	100	0.5
9	55.500	100	0.5
10	57.968185	100	0.5
11	57.968185	60	0.5
12	57.958185	39	0.5
13	57.968185	20	0.5
14	57.968185	6	0.5
15	57.968185	1	0.5
16	80.0	1000	2.0
17	150.0	1500	1.0
18	183.311	500	1.0
19	183.311	1000	1.0
20	183.311	1500	1.0

6. IMPLEMENTATION SCHEDULE

Presently not under development. AMSU is still being studied by NOAA for possible flight on future meteorological satellites beyond the current Advanced TIROS-N series.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The AMSU will be able to:

(1) Sound temperature in both the troposphere and stratosphere.

(2) Sound humidity in the troposphere.

(3) Make precipitation measurements.

Studies have been conducted on reduced capability instruments with 15 channels and 12 channels (without water vapor and some window channels).

SUBSYSTEM FACT SHEET 12

ADVANCED MOISTURE AND TEMPERATURE SOUNDER (AMTS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel grating spectrometer.

1.2 PARAMETERS SENSED:

Integrated radiance levels from various altitudes of the Earth's atmosphere and from the surface of the Earth within a number of discrete, narrow spectral bandwidth IR channels.

1.3 STATE OF DEVELOPMENT:

Being considered for shuttle flight.

1.4 DESIGN DATE:

N/A

1.5 PRINCIPAL INVESTIGATOR:

Dr. Moustafa T. Chahine, JPL

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "Advanced Moisture and Temperature Sounder," (AMTS) Study Proposal for FY '80," Jet Propulsion Laboratory, Pasadena, CA 1979.

(2) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

288 kg

2.2 AVERAGE POWER CONSUMPTION:

150 W

2.3 DIMENSIONS:

Instrument: 108 cm x 80 cm x 236 cm
Including two radiative coolers: 224 cm x 232 cm x 236 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Two radiative coolers.

3. DATA

3.1 DATA RATE:

37 kbps

3.2 COMMANDS:

Cooler cover open/close
Calibration target set
Grating angle set

3.3 ON BOARD PROCESSING:

Amplification, multiplex, A/D.

3.4 ON BOARD STORAGE:

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Will use buffered data and "look ahead/look behind" calibration to improve radiometric accuracy. All processing will be done on the ground, with an anticipated cycle time of 30 days.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

TBD

4.4 ORIENTATION TO SUN:

TBD

5. SENSOR

5.1 OPERATING PRINCIPLE:

A grating spectrometer, with controllable grating angle and cooled HgCdTe (80°K) for IR wavelengths.

5.2 TYPE OF SCAN:

Mechanical "step and stare".

5.3 FIELD OF VIEW:

IFOV: 11 mrad x 11 mrad
10 km x 10 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Dwell time per sample: 140 ms
Scan time per line: 1.55

5.5 CALIBRATION:

Internal: Black body at known temperature
External: View of deep space
Extensive groundtruth measurements for "look ahead/look behind" calibration

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTRAL WAVE NUMBER (cm^{-1})	RESOLUTION (cm^{-1})	MINIMUM EQUIVALENT TARGET TEMPERATURE (°K)
1	606.96	0.50	216
2	623.20	0.50	214
3	527.80	0.50	213
4	643.30	0.50	212
5	646.60	0.50	210
6	652.75	0.50	207
7	665.55	0.50	209
8	666.85	0.50	209
9	668.13	0.50	213
10	669.45	0.50	220
11	1203.0	0.50	216

CHANNEL	CENTRAL WAVE NUMBER (cm^{-1})	RESOLUTION (cm^{-1})	MINIMUM EQUIVALENT TARGET TEMPERATURE (°K)
12	1231.80	1.00	216
13	1718.20	1.00	216
14	1809.50	1.50	216
15	1839.40	1.50	216
16	1844.50	1.50	216
17	1850.90	1.50	216
18	1889.57	1.50	216
19	1930.10	1.50	216
20	2384.00	2.00	214
21	2386.10	2.00	214
22	2388.20	2.00	215
23	2390.20	2.00	215
24	2392.35	2.00	217
25	2394.50	2.00	217
26	2424.00	2.50	214
27	2505.00	2.50	214
28	2616.50	2.50	214

Absolute channel wavelength number setting accurate to 7.5×10^{-5} parts of channel wave number.

Knowledge of channel wave number setting accurate to 7.5×10^{-5} parts of wave number.

6. IMPLEMENTATION SCHEDULE

A shuttle proving flight is expected soon. Funding for a free-flyer may happen in FY85-86.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Required radiometric accuracy is obtainable but difficult. Several versions of this instrument have been studied, including an interferometer. Predicted performance include RMS temperature error of 1.5°C with up to 3 layers of cloud totalling 90% of cloud cover.

SUBSYSTEM FACT SHEET 13

SYNTHETIC APERTURE RADAR (SAR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Radar image.

1.2 PARAMETERS SENSED:

Surface topography by reflected radio waves.

1.3 STATE OF DEVELOPMENT:

Successfully flown on SEASAT and Shuttle.

1.4 DESIGN DATE:

1974

1.5 PRINCIPAL INVESTIGATOR:

Charles Elachi, JPL.

1.6 MANUFACTURER:

Ball Aerospace Systems Division, Boulder, CO.
Jet Propulsion Laboratory, Pasadena, CA

1.7 REFERENCES

(1) Ball Aerospace Systems Division Internal Documentation (Antenna AN122A).

(2) "Seasat Final Report; Volume 1: Program Summary," Ed.: E. Pounder, Jet Propulsion Laboratory for NASA, 1980. (NASA contract NAS7-100).

(3) "Space Research and Technology Program and Specific Objectives FY '84." NASA: Office of Aeronautics and Space Technology, 1983.

(4) "OSTA-1 Experiments," Lyndon B. Johnson Space Center, February, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

(SEASAT - Antenna) -104 Kg
(SIR-A Electronics) - 218 Kg
(SIR-A Antenna) - 219 Kg

2.2 AVERAGE POWER CONSUMPTION:

SIR-A: Standby Power: 115 W
Average Operating Power: 775 W
Maximum Operating Power: 897 W

2.3 DIMENSIONS:

SIR-A Antenna: 9.35 m x 2.16 m x .15 m
SIR-A Electronics: 1.5 m x 1 m x .25 m

SEASAT Folding antenna:
folded: .254 m x 1.33 m x 2.29 m
unfolded: 10.67 m x 2.79 m x .076 m

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Facilities for folding antenna.

3. DATA

3.1 DATA RATE:

SIR-A data was recorded optically.
Very high data rate for direct transmission.

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

None

3.4 ON BOARD STORAGE:

None

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Requires SAR data system to convert digital range doppler information into range along-track image of surface. Optical and digital processors are used.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, non-sun-synchronous.

4.2 ALTITUDE:

800 Km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Inclination of 108° to equator.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A fixed antenna is used to simulate a much larger phase array antenna through signal processing of reflected signal. This results in constant resolution with distance.

5.2 TYPE OF SCAN:

Pushbroom scan.

5.3 FIELD OF VIEW:

25 m resolution
100 km swath width

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

N/A

5.5 CALIBRATION:

N/A

5.6 SPECTRAL CHARACTERISTICS:

Radar at 1275 MHz
Bandwidth ± 11 MHz

6. IMPLEMENTATION SCHEDULE

Successfully flown on SEASAT.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

SAR successfully measured:

(1) Sea wavelength (± 10%)
(2) Sea wave direction (± 20°)
(3) Sea wave significant height (1.1m - 2.5m)
(4) Tide and current generated internal waves.

The most difficult aspect of SAR is the tremendous amount of data processing necessary to recover images. Consequently NASA has an internal research and development program to develop a real time SAR processor by FY '86.

SUBSYSTEM FACT SHEET 14

LIGHT DETECTION AND RANGING (LIDAR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Active laser-based delay and doppler shift measuring system.

1.2 PARAMETERS SENSED:

Range and velocity of particles.

1.3 STATE OF DEVELOPMENT:

Studied.

1.4 DESIGN DATE:

1983

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "Shuttle Atmopsheric Lidar Research Program Final Report of the Atmospheric Lidar Working Group," NASA SP-433, 1979.

(2) "Space Shuttle Capabilities and Constraints Relevant to LIDAR Measurements of Wind Fields," Ball Brothers Research Corporation, Boulder, CO for Wave Propogation Laboratory, NOAA/Environmental Research Laboratories, 1977.

(3) "Atmospheric LIDAR Multi-user Instrument Definition Study," General Electric Space Division for Langley Research Center (NASA), 1978. (NASA contract NAS7-15476).

(4) "Weather and Climate Needs for LIDAR Observations from Space and Concepts for their Realization," David Atlas and C. Laurence Korb, Bull. Amer. Met. Soc., 62, 9, p. 1270.

(5) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS (Based on reference [5])

2.1 WEIGHT:

Total Weight: 1300 kg
Receiver Telescope: 693 kg
Laser Module: 170 kg
CW-CO_2 Laser: 2 kg
Pulsed CO_2 Laser: 210 kg
Detector Subsystem: 64 kg
Power Conditioning: 139 kg

2.2 AVERAGE POWER CONSUMPTION:

2.53 - 4.23 kW (ave.)
6.3 kw (peak)
Telescope Receiver: 30 W
Laser Module: 1870 W
CW-CO_2 Module: 200 W
Pulsed CO_2 Module: 3750 W
Detector Subsystem: 405 W
Power Conditioning: 20 W

2.3 DIMENSIONS:

Overall Dimensions: 4.35 x 2.9 x 4.1 m

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

This is a multi-use modular system. Configuration and requirements are dependent on usage.

3. DATA

3.1 DATA RATE:

TBD

3.2 COMMANDS:

On shuttle flights, probably overseen by shuttle crew.

3.3 ON BOARD PROCESSING:

Variable.

3.4 ON BOARD STORAGE:

Variable.

3.5 GROUND RECEIVING STATION/TDRSS:

Either.

3.6 DATA HANDLING/REDUCTION:

Will require sophisticated computer handling to extract data from delay and doppler shift measurements.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

TBD

4.2 ALTITUDE:

Approximately 650 km.

4.3 REVISIT TIME, COVERAGE:

TBD

4.4 ORIENTATION TO SUN:

Variable.

5. SENSOR

5.1 OPERATING PRINCIPLE:

The design noted above is a general LIDAR system that could be flown either on a free flyer or on the shuttle. In addition, the Shuttle Atmospheric Lidar Research Program is proposing a modular approach to a continuing series of experiments from the shuttle using LIDAR. The main components would be changed with different needs and improved technology. These components are:

(1) Laser/Transmitter
(e.g., visible/NIR based on Nd lasers, CO_2 lasers)

(2) Telescope Return-Signal Collector
(has the most demanding physical tolerances).

(3) Detector
(e.g., photomultipliers, sodium absorption cells, Fabry-Perot detector, heterodyne detectors).

(4) Data processing electronics.

All of these components present several options; the appropriate combination would be selected on the basis of mission objectives and availability.

5.2 TYPE OF SCAN:

Variable.

5.3 FIELD OF VIEW:

(Conical scan, 1250 km see reference [2])

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

1.5 rpm - 12 rpm

5.5 CALIBRATION:

TBD

5.6 SPECTRAL CHARACTERISTICS:

Lasers at energies from .2 μm to 12 μm.

6. IMPLEMENTATION SCHEDULE

N/A

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The Shuttle Atmospheric Lidar Research Program has proposed using Lidar to make the following measurements:

(1) Cloud top heights
(2) Tropospheric cloud and aerosol profiles
(3) Cirrus ice-water discrimination
(4) Noctilucent clouds and circumpolar particulate layer profiles
(5) Surface Albedo
(6) Stratospheric aerosol profiles
(7) Alkali atom density profiles (Na, K, Li)
(8) Ionospheric Metal Ion Distribution (Mg^+, Fe^+, Ca^+)
(9) Water-vapor profiles
(10) Trace species measurements (O_3, H_2O, NH_3, CFM's, etc.) - total burden; rough profiles
(11) Chemical release diagnosis
(12) Stratospheric ozone profiles
(13) Upper atmosphere trace species profiles (two satellites)
(14) Na temperature and winds
(15) Surface and cloud-top pressure measurements
(16) Tropospheric pressure profiles
(17) Tropospheric temperature profiles
(18) Trace species (O_3, H_2O, NH_3, C_2H_4, etc.) profiles
(19) Cloud top winds
(20) Aerosol winds
(21) OH density profiles
(22) Metal atom/ion/oxide profile ($Mg/Mg^+/MgO$, 80-600 km)
(23) Troposphere NO_2 burden profile
(24) Stratospheric aerosol composition
(25) NO density profiles (70 to 150 km)
(26) Atom oxygen profiles (80 to 150 km)

Note that these experiments would require many different Lidar configurations and orbits. Another version, detailed below, has been proposed by NOAA for WINDSAT. It would measure doppler shifted backscatter from wind drifted tropospheric aerosols.

Dimensions: 0.17 m^3	Average Power Consumption: 186 W
Weight: 50.5 kg	Data Rate: 1 Mbps

It requires a stable frequency 9-10 μm laser capable of 10^9 shots, and massive ground data processing capability.

SUBSYSTEM FACT SHEET 15

LARGE ANTENNA MULTI-FREQUENCY MICROWAVE RADIOMETER (LAMMR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multichannel, dual linear polarization microwave radiometer.

1.2 PARAMETERS SENSED:

Radiation in five basic microwave frequencies, with option for two more microwave frequencies and two radar frequencies.

1.3 STATE OF DEVELOPMENT:

Studied.

1.4 DESIGN DATE:

N/A

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "Final Report. Large Antenna Multi-Frequency Microwave Radiometer Design Definition Study (LAMMR)," General Electric Space Division for Goddard Space Flight Center (NASA), 1980. (NASA Contract NAS5-25582/5).

(2) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

220 kg

2.2 AVERAGE POWER CONSUMPTION:

235 W

2.3 DIMENSIONS:

"Swept Volume" - 140 m^3

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Focal point feed radiometer is deployed in orbit. A four meter (dia) reflector is used.

3. DATA

3.1 DATA RATE:

29 kbps
37 kbps with optional channels

3.2 COMMANDS:

See below.

3.3 ON BOARD PROCESSING:

The analog data from the radiometers will be digitized to 12 bit accuracy on the rotating structure to form a digital bit stream which is passed through the slip rings to the donwlink telemetry system. An on-board processor will be used to serve three functions: 1) control the operation of the radiometers and to monitor the system performance with diagnostic checkouts; 2) format the data into a digital bit stream; 3) calibrate and convert the radiometric temperatures into geophysical units for near real time lower resolution transmission to the ground.

3.4 ON BOARD STORAGE:

TBD

3.5 GROUND RECEIVING STATION/TDRSS:

TBD

3.6 DATA HANDLING/REDUCTION:

LAMMR requires removal of crosstrack bias on both temperature and wind observations.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

Sun-synchronous

4.2 ALTITUDE:

~700 Km

4.3 REVISIT TIME, COVERAGE:

TBD

4.4 ORIENTATION TO SUN:

TBD

5. SENSOR

5.1 OPERATING PRINCIPLE:

A four meter reflector focusses radiation on a microwave radiometer. TRF receivers are used at 1.4, 4.5, and 10.05 GHz. Heterodyne receivers with commandable redundant GDO are used on all other chan.els.

5.2 TYPE OF SCAN:

Conical scan; antenna rotates 360° at approximately 1 revolution per second.

5.3 FIELD OF VIEW

Down Track IFOV:	7.2 km x 7.2 km (37 GHz) 36 km x 36 km (4.5 GHz)
Down Track Swath Width:	1361.1 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

CHANNEL	CELLS PER SCAN	INTEGRATION TIME PER CELL (ms)
1	32	12.95
2	128	3.19
3	256	1.56
4	256	1.56
5	256	1.56
6	256	1.56
7	256	1.56

5.5 CALIBRATION:

View of deep space (4 calibration horns) and ambient loads.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTER FREQUENCY (GHz)	BANDWIDTH (GHz)	TEMPERATURE RESOLUTION (°K)
1*	1.4	.028	0.5
2	4.3	0.2	0.2
3	10.05	0.1	1.0
4	18.7	0.2	1.5
5	21.3	0.2	1.5
6	36.5	1.0	1.5
7*	91.0	2.4	2.0

* Optional
All channels measure both vertical and horizontal polarization.

6. IMPLEMENTATION SCHEDULE

LAMMR was projected for use on NOSS. However, since this system was cancelled, development has not proceeded.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Anticipated Performance:

Sea Ice		
	Concentration:	Accuracy: 2%
		Resolution: 25 km
	Type:	Accuracy: 10%
		Resolution: 1 km
	Surface Melting:	Resolution: 25 km
Sea Surface Temperature		Accuracy: 0.2° k
Wind Velocity Vector		Accuracy: 2 m/s (10° direction)
		Resolution: 25° azimuth
Ice Sheet		Accumulation rate: Accuracy 10%
Snow Cover		% of Cover: Accuracy 5%

SUBSYSTEM FACT SHEET 16

LASER HETERODYNE SPECTROMETER (LHS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Both passive and active instrument utilizing local oscillator (laser) mixing with incident radiation to increase sensitivity.

1.2 PARAMETERS SENSED:

Infrared to visible radiation.

1.3 STATE OF DEVELOPMENT:

Under study.

1.4 DESIGN DATE:

N/A

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

BASD internal documentation.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

TBD

2.2 AVERAGE POWER CONSUMPTION:

TBD

2.3 DIMENSIONS:

TBD

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Active system will require large, high pressure/high power gas laser. Both systems will require low power (milliwatt) lasers for local oscillator operation.

3. DATA

3.1 DATA RATE:

TBD

3.2 COMMANDS:

TBD

3.3 ON BOARD PROCESSING:

TBD

3.4 ON BOARD STORAGE:

TBD

3.5 GROUND RECEIVING STATION/TDRSS:

Shuttle data system.

3.6 DATA HANDLING/REDUCTION:

Extensive ground (computer) processing.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

Shuttle orbit.

4.2 ALTITUDE:

350 Km

4.3 REVISIT TIME, COVERAGE:

Variable, limited coverage.

4.4 ORIENTATION TO SUN:

Experiment must view both earth and atmosphere limb.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A tunable laser emission is combined with incoming radiation to form a heterodyne band limited signal. The IF signal is amplified, synchronously detected, and integrated, providing a DC Voltage proportional to the intensity of the incident radiation. Two modes of experiment are envisioned:

(1) A passive experiment in which external radiation sources will be used, including solar radiation, upwelling thermal radiation of the earth and the atmosphere, and radiation emitted by the earth's limb.

(2) An active experiment in which a high pressure/high energy tunable laser is carried on the space shuttle. The laser beam is transmitted vertically downward to the surface of the earth, reflected and received by a heterodyne receiver located on board the shuttle.

5.2 TYPE OF SCAN:

TBD

5.3 FIELD OF VIEW:

Variable

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

TBD

5.5 CALIBRATION:

TBD

5.6 SPECTRAL CHARACTERISTICS:

Heterodyne receiver should operate in 2-15 μm region.

6. IMPLEMENTATION SCHEDULE

A balloon test article is under fabrication at Langley Research Center (NASA). No plans are presently being developed for space-borne instrumentation.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The LHS has been principally baselined for measurement of the total burden and vertical distribution of atmospheric molecules, both atmospheric constituents (H_2O, CO_2, O_3) and atmospheric pollutants, in the stratosphere and troposphere. The passive instrument would be useful for examining the vertical distribution of molecules in the stratosphere and upper troposphere, the active experiment would examine the distribution below the tropopause.

SUBSYSTEM FACT SHEET 17

CRYOGENIC LIMB SCANNING INTERFEROMETER AND RADIOMETER (CLIR)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Thermal emission, multi-user instrument for remote sensing of atmospheric limb properties.

1.2 PARAMETERS SENSED:

Radiation in 2.5 - 25 μm range (interferometer)
and 1.5 - 25 μm range (radiometer)

1.3 STATE OF DEVELOPMENT:

Study complete.

1.4 DESIGN DATE:

1979

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "Cryogenic Limb-scanning Interferometer and Radiometer (CLIR), Report of the Spectroscopy Facility Definition Team," Goddard Space Flight Center (NASA), 1978.

(2) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

(3) "Cryogenic Upper Atmospheric Limb Emmision Radiometer (CULER)." Proposal to NASA by National Center for Atmospheric Research, 1978.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

480 Kg

2.2 AVERAGE POWER CONSUMPTION:

120 W

2.3 DIMENSIONS:

1 m x 1 m x 3 m

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Entire instrument is cooled,

Detectors:	10°K;
Optics:	30°K;
Telescope Baffles:	115°K;

Cooling system is single stage supercritical helium cooler (550 l for 30 day flight)

3. DATA

3.1 DATA RATE:

524 kbps

3.2 COMMANDS:

Ordinarily automatic pointing and scanning, but manual override.

3.3 ON BOARD PROCESSING:

Low resolution Fourier transform for interferometer performance only.

3.4 ON BOARD STORAGE:

Shuttle storage system.

3.5 GROUND RECEIVING STATION/TDRSS:

Shuttle data system, then to ground.

3.6 DATA HANDLING/REDUCTION:

Extensive computer analysis of spectral information.

4. <u>ORBIT REQUIREMENTS</u>:

4.1 TYPE:

Shuttle Orbit, LEO.

4.2 ALTITUDE:

20 - 140 km

4.3 REVISIT TIME, COVERAGE:

Variable, limited coverage.

4.4 ORIENTATION TO SUN:

Variable, instrument requires limb view.

5. <u>SENSOR</u>

5.1 OPERATING PRINCIPLE:

The CLIR instrument is essentially composed of three elements:

(1) A 25 cm (dia) mirror telescope, field stop and Lyot stop.

(2) Optics to feed and focus beam on an Ebert-grating 25 channel spectrometer with modular focal plane detector array.

(3) Same optics feed a cat's eye Michelson interferometer, with laser source.

5.2 TYPE OF SCAN:

N/A

5.3 FIELD OF VIEW:

Vertical resolution of 2 km.

FOV: 3.2 (vert) x 6.2 (horiz) mrad
IFOV: 1.0 (vert) x 2.0 (horiz) mrad

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Integration time: 10 s for .1 cm^{-1} resol.

(interferometer) 1 s for .1 cm^{-1} resol.

Sampling period: .05 s

(radiometer)

5.5 CALIBRATION:

(1) Temperature controlled blackbody, integrating sphere.
(2) Hot wire (for short wavelengths).
(3) External door (115°K) for system calibration.

5.6 SPECTRAL CHARACTERISTICS:

Interferometer:

Spectral range: 400 - 4000 cm^{-1}
Spectral resolution: 0.1 cm^{-1} to 1 cm^{-1}

NESR: $2 \times 10^{-12} \dfrac{W}{cm^2 - ster - cm^{-1}}$ at 500 cm^{-1}

CHANNEL	CENTER WAVELENGTH (μm)	RESOLUTION (μm)	NOISE EQUIVALENT RADIANCE $\frac{W}{cm^2 - ster}$
1	1.5	.11	8.5×10^{-12}
2	1.6	.04	7.0×10^{-12}
3	1.7	.22	4.7×10^{-11}
4	2.0	.40	3.9×10^{-11}
5	2.7	.15	2.8×10^{-11}
6	2.8	.04	-
7	3.0	.27	1.9×10^{-11}
8	4.3	.19	9.0×10^{-12}
9	4.7	.22	7.5×10^{-12}
10	5.1	.15	1.1×10^{-12}
11	5.2	.16	9.0×10^{-12}
12	5.5	.20	9.0×10^{-12}
13	6.2	.31	9.5×10^{-12}
14	6.3	.64	4.5×10^{-12}
15	7.7	.15	4.0×10^{-12}
16	9.6	1.38	6.0×10^{-12}
17	10.0	2.50	1.7×10^{-12}
18	10.6	0.80	5.5×10^{-13}
19	11.3	0.90	5.5×10^{-13}
20	11.7	0.14	1.1×10^{-12}
21	15.0	4.08	1.6×10^{-12}
22	15.0	1.04	9.5×10^{-13}
23	17.5	1.07	1.1×10^{-12}
24	19.0	1.82	2.4×10^{-13}
25	25.0	3.14	2.0×10^{-13}

6. IMPLEMENTATION SCHEDULE

Proposed and studied for shuttle and UARS flights. Presently not funded and not under development.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

CLIR should be able to:

(1) Observe constituents in the upper atmosphere which are present in the 10^{-9} to 10^{-12} range.

(2) Provide data on linkage between mesosphere and lower thermosphere.

(3) Provide data on chemical excitation and emission (atmospheric emission and energetics) in the upper atmosphere.

(4) Provide data on solar-terrestrial coupling.

A similar instrument was proposed (and rejected) for UARS. This was the Cryogenic Upper Atmosphere Limb Emission Radiometer (CULER).

The CULER instrument would be a cryogenically cooled telescope of 15 cm aperture with a limb scanning mirror feeding a 24 channel radiometer and a circular variable filter (CVF) spectrometer. The fixed radiometer channels, selected by grating-filter combinations between 370-7000 cm^{-1}, would be tailored to specific measurements, such as temperature sounding, concentration of predetermined chemical species, or emissions from specific excitation mechanisms. The spectrally selective CVF would have would have 1% resolution between 600-5000 cm^{-1}.

Extrinsic Si detectors would be cooled to 10°K by solid hydrogen cryogen, which would also cool the entire optical system, resulting in NESR's in the range of 2 to 10 x 10^{-12} W/cm^2-ster. Field of view would be 2 km x 11 km at the limb.

For a 24 month life, the instrument would be 1.48 m (dia), 2.84 m (length), weight 529 kg at launch (91 kg solid hydrogen). Average power consumption would be 30 W (45 W peak). Data rate would be 20 kbps for a 3 second scan, but slower scans could be used.

SUBSYSTEM FACT SHEET 18

EARTH RADIATION BUDGET EXPERIMENT (ERB)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Solar and earth viewing, fixed wide-angle and scanning narrow angle multi-channel radiometer.

1.2 PARAMETERS SENSED:

22 Optical Channels:

10 solar
4 Earth, wide FOV
8 Earth, scanning small FOV

1.3 STATE OF DEVELOPMENT:

Successfully flown on NIMBUS-7.

1.4 DESIGN DATE:

1977

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

TRW Corporation.

1.7 REFERENCES

(1) "The NIMBUS-7 User's Guide," The Landsat/Nimbus Project, Goddard Space Flight Center (NASA), August 1978.

(2) "Earth Radiation Budget Experiment (ERBE) Science Implementation Plan," Langley Research Center (NASA), 1981.

(3) "NASA Space Systems Technology Model." Vol. 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

32.7 Kg

2.2 AVERAGE POWER CONSUMPTION:

15 W

2.3 DIMENSIONS:

33 cm x 36 cm x 48 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

~ 300 Bps

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

Amplification, multiplex, A/D.

3.4 ON BOARD STORAGE:

Digital Tape Recorder

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Raw ERB telemetry is processed at GSFC, and sent to the Science and Applications Computer Center. Master archive, mapped data, solar and earth flux, and zonal means tapes are produced.

4. <u>ORBIT REQUIREMENTS</u>:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

955 Km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 12:00 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

The solar channels are rotatable to view the sun. No imaging optics are used; solely filters, windows, and apertures feeding wire-wound thermopiles. The fixed FOV channels view the entire earth surface, using a similar method. The scanning, narrow channels FOV have a four telescope scan head, and utilize pyroelectric detectors.

5.2 TYPE OF SCAN:

Mechanical scan head.

5.3 FIELD OF VIEW:

IFOV: 4.36 mrad x 89 mrad
4 km x 85 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan period: 112 seconds.

5.5 CALIBRATION:

Electrical heaters for thermopile calibration, space-look and light for scanning channels.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	WAVELENGTH LIMITS (μm)	NOISE EQUIVALENT IRRADIANCE (mW/m^2)
SOLAR CHANNELS:		
1	0.2 - 3.8	17.7
2	0.2 - 3.0	17.4
3	0.2 - 50	14.3
4	0.526 - 2.8	19.4
5	0.698 - 2.8	19.1
6	0.395 - 0.508	35.8
7	0.344 - 0.400	57.3
8	0.300 - 0.410	75.5
9	0.275 - 0.360	9.4
10	0.2 - 50	23.9
FIXED WIDE-ANGLE FOR CHANNELS:		
11	<0.2 to >50	65.5
12	<0.2 to >50	65.5
13	0.2 to 3.8	65.5
14	0.695 to 2.8	66.5

SCANNING CHANNELS:		$(w/cm^2\text{-ster})$
15		3.7×10^{-3}
16		3.7×10^{-3}
17		3.7×10^{-3}
18		3.7×10^{-3}
	0.2 to 4.8	
19		1.8×10^{-3}
20		1.8×10^{-3}
21		1.8×10^{-3}
	4.5 to 50	
22		1.8×10^{-3}

6. IMPLEMENTATION SCHEDULE

Successfully flown on NIMBUS-6 and NIMBUS-7.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

ERB is used to simultaneously measure incoming solar radiation and both terrestrial flux and narrow angle sampling of out-going shortwave (reflected) and longwave (emitted) earth radiation, as well as confirmation of angular models of reflection and emission of radiation from clouds and earth surfaces.

The next generation Earth Radiation Budget Experiment (ERBE) is scheduled to fly on ERBS, NOAA-F and NOAA-G (launches in 1984-1985 period). Both scanner and non-scanner packages will be used. It will have the following characteristics:

Size: non-scanner .7 x .6 m
scanner .5 dia x .6 m

Mass: 61 kg non-scanner: 32 kg
scanner: 29 kg
Power: 50 W (ave.)
Data Rate: 1.120 kbps

It will make large (limb to limb) integrated measurements (non-scanner) and will scan a 10% FOV with a 3° x 4.5° IFOV (scanner). There will be 5 non-scanner channels (shortwave .2 - 5.0 μm and total radiation) and 3 scanner channels (5 - 50 μm). Anticipated accuracies are as follows:

Solar flux density accuracy: 0.5%
Earth Albedo accuracy:
Global: 1 W/m^2
1000-km Zones: 5.2 W/m^2 longwave, 5.3 W/m^2 shortwave
Equator to pole gradient:
1000 km regions: 9.4 W/m^2 longwave, 10.3 W/m^2 shortwave
250-500 kg regions: 9.4 W/m^2 longwave, 10.4 W/m^2 shortwave

SUBSYSTEM FACT SHEET 19

MODULAR OPTOELECTRONIC MULTISPECTRAL SCANNER (MOMS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

High resolution optoelectronic scanner.

1.2 PARAMETERS SENSED:

Radiation in visible and IR ranges.

1.3 STATE OF DEVELOPMENT:

Flown successfully on SPAS-01/STS-7.

1.4 DESIGN DATE:

1980

1.5 PRINCIPAL INVESTIGATOR:

Dr. J. Bodechtel, Zentralstelle fur Geophotoyrammetrie und Fernekundung, Munich, FRG

1.6 MANUFACTURER:

Messerschmitt - Bulkow - Blohm, Gmbh, Munich, FRG

1.7 REFERENCES

"Modular Optoelectronic Multispectral Scanner," Messerchmitt - Bulkow - Blohm, Munich, 1982.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

140 Ky

2.2 AVERAGE POWER CONSUMPTION:

350 W

2.3 DIMENSIONS:

No information.

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Flies on retrievable Shuttle Pallet Satellite (SPAS) built in Germany.

3. DATA

3.1 DATA RATE:

40 Mbps

3.2 COMMANDS:

5 discrete and 1 PCM command channel.

3.3 ON BOARD PROCESSING:

PCM and formatting.

3.4 ON BOARD STORAGE:

Bell and Howell tape recorder (30 minutes).

3.5 GROUND RECEIVING STATION/TDRSS:

Recorded.

3.6 DATA HANDLING/REDUCTION:

No information.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

Shuttle orbit.

4.2 ALTITUDE:

300 Km

4.3 REVISIT TIME, COVERAGE:

Limited coverage.

4.4 ORIENTATION TO SUN:

Variable.

5. SENSOR

5.1 OPERATING PRINCIPLE:

Dual refractive lens system directs radiation to linear array at focal plane. Array is scanned (electronically) and recorded for processing after return.

5.2 TYPE OF SCAN:

Pushbroom scan (6912 pixels).

5.3 FIELD OF VIEW:

IFOV: 20 m x 20 m

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

No information.

5.5 CALIBRATION:

No information.

5.6 SPECTRAL CHARACTERISTICS:

CHANNELS	WAVELENGTHS (nm)	RESOLUTION (nm)
1	600	25
2	900	75

6. IMPLEMENTATION SCHEDULE

Successfully flown on STS-7.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Modifications being planned include more channels, stereo imaging, thermal infrared, adaptation to coastal/ocean monitoring.

SUBSYSTEM FACT SHEET 20

SYSTEME PROBATOIRE D'OBSERVATION DE LA TERRE (SPOT)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multispectral linear array scanner.

1.2 PARAMETERS SENSED:

3 bands (VIS, NIR, and IR) plus panchromatic (wideband VIS).

1.3 STATE OF DEVELOPMENT:

No information.

1.4 DESIGN DATE:

1979

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Centre National d'Etudes Spatiales, Paris, France.

1.7 REFERENCES

"The SP/VOT Satellite Remote Sensing Mission," Michele Cherel, Michel Courtois, Gilbert Weill. Photogrammetric Engineering and Remote Sensing Vol. 47, No. 8, August 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

No information.

2.2 AVERAGE POWER CONSUMPTION:

No information.

2.3 DIMENSIONS:

No information.

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

30 Mbps

3.2 COMMANDS:

Steerable line of sight (91 positions).

3.3 ON BOARD PROCESSING:

No information.

3.4 ON BOARD STORAGE:

No information.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Extensive computer data reduction.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

Sun-synchronous, polar LEO.

4.2 ALTITUDE:

600 - 1200 km

4.3 REVISIT TIME, COVERAGE:

Global coverage, 26 day revisit time.

4.4 ORIENTATION TO SUN:

Ascending node at 0800 - 1600 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A folded pseudo-Schmidt telescope focusses radiation on dichroic prisms and beam splitters (for optical butting of chips). CCD linear arrays with 13 μm pixel separation are used for imaging.

5.2 TYPE OF SCAN:

Pushbroom.

5.3 FIELD OF VIEW:

IFOV: 20 m x 20 m

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Scan period: color: 3 ms; panchromatic: 1.5 ms

5.5 CALIBRATION:

No information.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	SPECTRAL RANGE (nm)
1	500 - 590
2	610 - 680
3	790 - 890
4	510 - 730

6. IMPLEMENTATION SCHEDULE

Early 1984 launch.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Spot can produce stereo imaging by utilizing adjacent passes 23 hours apart. The United States is considering development of a similar instrument with several more spectral bands, including possible thermal infrared, called the Multispectral Linear Array. The instrument has been studied at the Phase A level by several companies. Present plans are to fund a development program at JPL for a scaled-down shuttle-based prototype to fly around FY86.

SUBSYSTEM FACT SHEET 21

STRATOSPHERIC AEROSOL AND GAS EXPERIMENTS I AND II (SAGE I AND II)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Multi-channel limb-scanning sun tracking radiometers.

1.2 PARAMETERS SENSED:

Four channels (SAGE 1)
Seven channels (SAGE 2)

1.3 STATE OF DEVELOPMENT:

SAGE 1	Successfully flown
SAGE 2	Undergoing integration and testing

1.4 DESIGN DATE:

1978

1.5 PRINCIPAL INVESTIGATOR:

Dr. Pat McCormick, Langley Research Center (NASA)

1.6 MANUFACTURER:

Ball Aerospace Systems Division, Boulder, CO

1.7 REFERENCES

1) Internal BASD documentation.

2) "NASA Space Systems Technology Mode." Vol. 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

SAGE 1: 30.2 Kg
SAGE 2: 29.5 Kg

2.2 AVERAGE POWER CONSUMPTION:

SAGE 1: 2.5 W
SAGE 2: 10 W

2.3 DIMENSIONS:

SAGE 1: 41 cm x 69 cm x 99 cm
SAGE 2: 71.5 cm x 34.1 cm (dia) sensor
24.4 cm x 37.9 cm x 21.4 cm box

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

8.2 kbps

3.2 COMMANDS:

No information.

3.3 ON BOARD PROCESSING:

Amplification, multiplex, A/D.

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

No information.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

955 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Limb-viewing instrument.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A scan mirror directs radiation to a casseyrain telescope. A single aperture images the radiation on a Rowland Circle spectrometer and then on Si detectors.

5.2 TYPE OF SCAN:

Mechanical.

5.3 FIELD OF VIEW:

IFOV: 4 km (altitudinal)

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

(SAGE II) Scan rate: 15 km/sec
Sampling rate: 64/sec

5.5 CALIBRATION:

View of unattenuated solar disk just after sunrise or before sunset.

5.6 SPECTRAL CHARACTERISTICS:

CHANNEL	CENTRAL WAVELENGTH (μm)	RESOLUTION (μm)
SAGE 1:		
1	0.385	0.02 - 0.03
2	0.450	0.01 - 0.02
3	0.030	0.02 - 0.03
4	1.000	0.03 - 0.05
SAGE 2:		
1	1.030	SNR = 1.5×10^5
2	0.940	
3	0.600	
4	0.525	
5	0.453	
6	0.448	
7	0.385	

6. IMPLEMENTATION SCHEDULE

SAGE 1 was successfully flown on Applications Explorer Mission 2 in February 1979. SAGE 2 is scheduled for launch on ERBS by Space Shuttle in 1984.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Anticipated Performance, SAGE II:

1) Radiometer Resolution: 4000:1
2) Ozone Accuracy: $\leq$ 5%
3) Aerosol Accuracy: $\leq$ 10%
4) Molecular Rayleigh Extinction Accuracy: $\leq$ 30%
5) Nitrogen Dioxide Accuracy: $\leq$ 10%
6) Altitude Resolution: 1 km

SUBSYSTEM FACT SHEET 22

SOLAR BACKSCATTER ULTRAVIOLET RADIOMETER 2 (SBUV/2)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Double UV spectrum-scanning radiometer.

1.2 PARAMETERS SENSED:

UV spectrum in the range 160-400 nm

1.3 STATE OF DEVELOPMENT:

Delivery in Septemer 1983.

1.4 DESIGN DATE:

1982

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

Ball Aerospace Systems Division, Boulder, CO

1.7 REFERENCES

BASD internal documentation.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

Sensor 21.8 kg; Electrical Module: 13.7 kg

2.2 AVERAGE POWER CONSUMPTION:

12 W

2.3 DIMENSIONS:

Sensor: 31.1 cm x 35.6 cm x 51.1 cm
Electrical Module: 19.1 cm x 33.0 cm x 33.0 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

320 bps

3.2 COMMANDS:

Scan modes are commandable.

3.3 ON BOARD PROCESSING:

Amplification, multiplex, A/D.

3.4 ON BOARD STORAGE:

TIP and TIROS digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Computer inversion on ground.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous polar.

4.2 ALTITUDE:

833 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 1400-1800 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

UV radiation from the earth and diffused radiation from the sun are viewed through an aperture, depolarized, chopped at 20 Hz and fed to a Ebert-Fastie monochromator with driveable grating for spectral scan and also to a photometer operating at 380 nm for determining cloud cover.

5.2 TYPE OF SCAN:

Spectral scan (not FOV).

5.3 FIELD OF VIEW:

IFOV: .2 rad x .2 rad
164 km x 164 km

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Integration time: continuous sweep - .10 sec
discrete steps (12 wavelengths) - 1.2 sec

5.5 CALIBRATION:

Internal: Calibration lamp
External: Deployable solar diffuser

5.6 SPECTRAL CHARACTERISTICS:

Scans 160-400 nm.
Spectral Resolution: .2 nm

6. IMPLEMENTATION SCHEDULE

The first unit will be delivered to GSFC (NASA) in September, 1983 for anticipated launch in 1984. A further 3 units are anticipated for the advanced TIROS-N series of satellites.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

N/A

SUBSYSTEM FACT SHEET 23

MICROWAVE PRESSURE SOUNDER (MPS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Dual antenna multi-channel active microwave sounder.

1.2 PARAMETERS SENSED:

6 Microwave Channels

1.3 STATE OF DEVELOPMENT:

Conceptual

1.4 DESIGN DATE:

N/A

1.5 PRINCIPAL INVESTIGATOR:

Dr. Dennis A. Flower, JPL

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

"NASA Space Systems Technology Model." Volume 1B. Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

50 kg

2.2 AVERAGE POWER CONSUMPTION:

<100 W

2.3 DIMENSIONS:

<$0.5 m^3$

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Two 0.2 m^2 Antennas

3. DATA

3.1 DATA RATE:

1 kbps (max.)

3.2 COMMANDS:

TBD

3.3 ON BOARD PROCESSING:

TBD

3.4 ON BOARD STORAGE:

TBD

3.5 GROUND RECEIVING STATION/TDRSS:

TBD

3.6 DATA HANDLING/REDUCTION:

Computer inversion of microwave data.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

Shuttle or Free-Flyer (LEO)

4.2 ALTITUDE:

500 km or 800 km

4.3 REVISIT TIME, COVERAGE:

TBD

4.4 ORIENTATION TO SUN:

TBD

5. SENSOR

5.1 OPERATING PRINCIPLE:

Two system designs are envisioned: a fixed frequency and a swept frequency design. Details (where different) of the swept frequency design are given in Section 7.

5.2 TYPE OF SCAN:

N/A

5.3 FIELD OF VIEW:

No information.

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Integration time: 12 sec

5.5 CALIBRATION:

No information.

5.6 SPECTRAL CHARACTERISTICS:

Operating Frequencies:	29.2555 GHz
	36.5555 GHz
	44.80 GHz
	52.80 GHz
	67.51 GHz
	73.01 GHz
Receiver Bandwidth:	76.1 KHz at 500 km alt.
	74.5 KHz at 800 km alt.

6. IMPLEMENTATION SCHEDULE

Under study.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The swept frequency design has the following characteristics:

Altitude		500 km	800 km
Pulse Length		3.53 msec	5.33 msec
Sweep Rep. Time		18.4 μsec	18.8 μsec
Total Sweep	Ch. 1	14.100	8.510
(MHz)	Ch. 2	22.00	13.700
	Ch. 3	33.00	20.60
	Ch. 4	45.90	28.70
	Ch. 5	75.00	46.90
	Ch. 6	87.80	59.80
Sweep	Ch. 1	0.766	0.469
Rate	Ch. 2	1.20	0.732
$\left(\frac{\text{MHz}}{\mu\text{sec}}\right)$	Ch. 3	1.80	1.10
	Ch. 4	2.49	1.53
	Ch. 5	4.08	2.50
	Ch. 6	4.77	2.92

SUBSYSTEM FACT SHEET 24

ALTIMETER (ALT)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Nadir looking pulse limited radar altimeter.

1.2 PARAMETERS SENSED:

Range from satellite to surface.

1.3 STATE OF DEVELOPMENT:

Successfully flown on SEASAT as SASS. Several modifications have been proposed.

1.4 DESIGN DATE:

1977

1.5 PRINCIPAL INVESTIGATOR:

N/A

1.6 MANUFACTURER:

N/A

1.7 REFERENCES

(1) "NOSS: National Oceanic Satellite System." Washington, D.C.: NASA, 1979.

(2) "NASA Space Systems Technology Model." Vol. 1B, Washington, D.C.: NASA, 1981.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

93.8 kg

2.2 AVERAGE POWER CONSUMPTION:

164 W

2.3 DIMENSIONS:

0.75 m^3 electronics package

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

1 m antenna

3. DATA

3.1 DATA RATE:

8.5 kpbs

3.2 COMMANDS:

Very limited.

3.3 ON BOARD PROCESSING:

None

3.4 ON BOARD STORAGE:

None

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Relatively simple for range. Other measurements (e.g., wind speed) require more computation.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, non-sun-synchronous

4.2 ALTITUDE:

800 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Inclination of 108° to equator.

5. SENSOR

5.1 OPERATING PRINCIPLE:

SEASAT utilized a simple single-beam radar. Other options include going to multiple beams and using interferometric techniques.

5.2 TYPE OF SCAN:

Fixed.

5.3 FIELD OF VIEW:

1.6 - 12 km swath

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Sample rate: 1 Hz

5.5 CALIBRATION:

N/A

5.6 SPECTRAL CHARACTERISTICS:

N/A

6. IMPLEMENTATION SCHEDULE

Successfully flown on SEASAT.
Proposed for NOSS.
Proposed for TOPEX.
Proposed for Shuttle Pallet instrument (possible launch in late 1980's).

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

The following provides a summary of several modified ALT designs proposed for NOSS (NOSS was cancelled), along with measurements of climatic interest for both SASS and the modified ACT versions.

A laser altimeter has also been proposed as a shuttle pallet experiment. This device would provide precision, high resolution topographic measurement of ice surface as well as ranging to fixed retro reflective targets for purposes of precision orbit determination and/or measuring ice sheet motion. Additionally, when operated simultaneously with a radar altimeter system, it could provide a calibration of that system as well as a measurement of ionospheric and wet tropospheric losses. Under microprocessor control, a short pulse ND:YAG laser would transmit at 10-20 pulses/second to the surface and, using the scanning capability, to retro reflective targets at known locations, while providing on overall ranging accuracy of 5-10 cm.

	SEASAT	OPTION-A	OPTION-B	OPTION-C
Size - Antenna	1m	1m	1m	Dual 1.4m
- Electronics Package	.75 m^3	.4 m^3	.4 m^3	.4 m^3
Weight	93.8 kg	104 kg	170 kg	200 kg
Power	104 W	108 W	168 W	168 W
Increased Capability (over SEASAT)		ground loaded program modification for 25 m sea & rain detection	dual beam; 25 km spread; $\sqrt{2}$ improve at nadir	4 beam; 50 km spread; $\sqrt{2}$ improve at nadir
MEASUREMENTS:				
Altitude (precision)				
Nadir	10 cm	10 cm	7 cm	7 cm
Off-Nadir	--	--	35 cm	18 cm
Coverage	100 km grid in 3 days	50 km grid in 30 days	23 km grid in 30 days	50 km grid in 10 days
Winds				
Accuracy	<20%	<20%	<20%	<20%
Resolution	<15 km	<15 km	<15 km	<15 km
Sea State				
Precision	.5 m	.5 m	.5 m	.5 m
Accuracy (<5 m)	± 50 cm	± 50 cm	± 50 cm	± 50 cm
(>5 m)	± 10%	± 10%	± 10%	± 10%
Resolution	<10 km	<10 km	<10 km	<10 km
Ocean Currents				
Speed	15 cm/s	15 cm/s	10 cm/s	10 cm/s
Direction	10°	10°	5°	5°
Ice				
Cover	10%	10%	10%	10%
Resolution	<15 km	<15 km	<15 km	<15 km

SUBSYSTEM FACT SHEET 25

SCATTEROMETER (SCAT)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Active radar scatterometer.

1.2 PARAMETERS SENSED:

Scattered RF radiation.

1.3 STATE OF DEVELOPMENT:

Has flown successfully as SASS on SEASAT.

1.4 DESIGN DATE:

1977

1.5 PRINCIPAL INVESTIGATOR:

No information.

1.6 MANUFACTURER:

No information.

1.7 REFERENCES

(1) "NASA Space Systems Technology Model." Volume 1B, Washington, D.C.: 1981.

(2) "NOSS: National Oceanic Satellite System." Washington, D.C.: NASA, 1978.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

224 kg

2.2 AVERAGE POWER CONSUMPTION:

309 W

2.3 DIMENSIONS:

0.7 m^3

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Uses six 3-m stick array antennas.

3. DATA

3.1 DATA RATE:

100 kpbs

3.2 COMMANDS:

None

3.3 ON BOARD PROCESSING:

None

3.4 ON BOARD STORAGE:

None

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

No information.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous

4.2 ALTITUDE:

800 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

No special requirements.

5. <u>SENSOR</u>

5.1 OPERATING PRINCIPLE:

SCAT is an active radar scatterometer, the design of which is based on SEASAT SASS. It utilizes an array of stick antennas to measure back-scattered RF radiation.

5.2 TYPE OF SCAN:

Fixed.

5.3 FIELD OF VIEW:

1200 km swath width

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

No information.

5.5 CALIBRATION:

No information.

5.6 SPECTRAL CHARACTERISTICS:

Will operate at 14.6 GHz.

6. IMPLEMENTATION SCHEDULE

SASS has flown on SEASAT. SCAT could fly in 1986 with a modified TIROS bus.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

Anticipated Performance:

Wind Speed

Accuracy: 2m/sec
Range: 0-50 m/sec
Precision: 0.5 m/sec
Horizontal Resolution: 25 km

Wind Direction

Accuracy: 10°
Range: 0-360°
Precision: 5°
Horizontal Resolution: 50 km

Other versions of SCAT considered (for NOSS) include those detailed below:

	SCAT-A	SCAT-B	SCAT-C
Weight	224 kg	297 kg	446 kg
Volume	2.7 m^3	1.3 m^3	2.3 m^3
Power	309 W	312 W	340 W
Antennas	6 per spacecraft	4 per spacecraft - electrical scan - more gain - active heaters	8 per spacecraft - electrical scan - more gain - active heaters
Electronics	All Systems might include:		

Doppler Filtering
Subsystem Redundancy
Cross Polarization

SUBSYSTEM FACT SHEET 26

INFRARED INTERFEROMETER SPECTROMETER (IRIS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Michelson interferometer.

1.2 PARAMETERS SENSED:

Radiation spectrum from 500 to 2000 cm^{-1}.

1.3 STATE OF DEVELOPMENT:

Successfully flown on NIMBUS-3.

1.4 DESIGN DATE:

1967

1.5 PRINCIPAL INVESTIGATOR:

Rudolf Hanel, NASA

1.6 MANUFACTURER:

Texas Instruments

1.7 REFERENCES

"The Nimbus III User's Guide," Nimbus Project, NASA (GSFC).

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

Optical Module: 12.5 kg
Electronics: 4.2 kg

2.2 AVERAGE POWER CONSUMPTION:

16 W

2.3 DIMENSIONS:

Optical Module: 39 x 33 x 21 cm
Electronics: 20 x 17 x 17 cm

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

N/A

3. DATA

3.1 DATA RATE:

3750 bps

3.2 COMMANDS:

Limited

3.3 ON BOARD PROCESSING:

None

3.4 ON BOARD STORAGE:

Digital tape recorder.

3.5 GROUND RECEIVING STATION/TDRSS:

Ground receiving station.

3.6 DATA HANDLING/REDUCTION:

Standard interferogram transform.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, sun-synchronous

4.2 ALTITUDE:

1200 km

4.3 REVISIT TIME, COVERAGE:

Global coverage.

4.4 ORIENTATION TO SUN:

Ascending node at 12:00 LST.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A beam splitter divides incoming radiation between a fixed and moving mirror. After reflection, the two beams interfere and intensity is measured as a function of moving mirror position (which is controlled by the spacecraft clock). The mirror moves .2 cm at 0.0183 cm/sec.

5.2 TYPE OF SCAN:

Spectral scan.

5.3 FIELD OF VIEW:

8° FOV, circular
Approx. 150 km (dia).

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Duration of interferogram: 10.9 sec

5.5 CALIBRATION:

Internal: temperature controlled blackbody
External: View of deep space

5.6 SPECTRAL CHARACTERISTICS:

500 - 2000 cm^{-1}
Spectral resolution: 5 cm^{-1}

6. IMPLEMENTATION SCHEDULE

Successfully flown on NIMBUS-3.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

N/A

SUBSYSTEM FACT SHEET 27

ATMOSPHERIC TRACE MOLECULES OBSERVED BY SPECTROSCOPY (ATMOS)

1. DESCRIPTION

1.1 SUBSYSTEM DESCRIPTIVE NAME:

Continuous Scanning Fourier Interferometer.

1.2 PARAMETERS SENSED:

Spectral components 2-16 μm

1.3 STATE OF DEVELOPMENT:

Hardware Construction.

1.4 DESIGN DATE:

1980

1.5 PRINCIPAL INVESTIGATOR:

Dr. C. B. Farmer, California Institute of Technology

1.6 MANUFACTURER:

JPL

1.7 REFERENCES

(1) "NASA Space Systems Technology Model," Vol. 1B, Washington D.C.: NASA, 1981.

(2) "Spacelab Mission 3 Experiment Descriptions," NASA TM-82502, Washington, D.C.: NASA, 1982.

2. PHYSICAL CHARACTERISTICS

2.1 WEIGHT:

195 kg

2.2 AVERAGE POWER CONSUMPTION:

435 W

2.3 DIMENSIONS:

$1.5\ m^3$

2.4 SPECIAL PHYSICAL CHARACTERISTICS OR REQUIREMENTS:

Pointing at sun (uses sun-tracker).

3. DATA

3.1 DATA RATE:

15.7 Mbps

3.2 COMMANDS:

Bandpass filters and FOV are shuttle crew and ground control commandable.

3.3 ON BOARD PROCESSING:

None

3.4 ON BOARD STORAGE:

Shuttle storage.

3.5 GROUND RECEIVING STATION/TDRSS:

Shuttle telemetry link.

3.6 DATA HANDLING/REDUCTION:

Appropriate transform.

4. ORBIT REQUIREMENTS:

4.1 TYPE:

LEO, shuttle orbit.

4.2 ALTITUDE:

300 km

4.3 REVISIT TIME, COVERAGE:

Variable

4.4 ORIENTATION TO SUN:

Instrument must view sun through upper atmosphere.

5. SENSOR

5.1 OPERATING PRINCIPLE:

A sun tracker aims a telescope at the solar disk. The concentrated light is sent to a beamsplitter and then to fixed and moving (cat's-eye) retro-reflectors in a conventional Michelson interferometer layout. The detector is cryogenically cooled HgCdTe (77°K).

5.2 TYPE OF SCAN:

Spectral scan.

5.3 FIELD OF VIEW:

1×10^{-3} or 2×10^{-3} rad, selectable.

5.4 SAMPLE, SCAN RATE; INTEGRATION TIME:

Integration time: 1 second

5.5 CALIBRATION:

No information.

5.6 SPECTRAL CHARACTERISTICS:

Scans 2-16 μm
Resolution .01 cm^{-1}

6. IMPLEMENTATION SCHEDULE

Will fly on Spacelab 3 in late 1984.

7. EXPERIENCE/PROBLEMS/MODIFICATIONS

ATMOS is designed to measure the following species:

CFM, $ClONO_2$, $CHCl_3$, NH_3, HNO_3, O_3, ClO, N_2O_5, NO_2, SO_2, CO_2 CH_4, H_2O, H_2O_2, COF_2, MCl, HBr, CH_3Cl, CH_3F, CH_3Br, N_2O, H_2CO, HOCl, HDO, NO, CO, NO_2, ClO_2, HF.

SUBSYSTEM FACT SHEETS

TABLE OF ACRONYMS

AIAA	-	American Institute for Aeronautics and Astronautics
ALT	-	Altimeter
AMSU	-	Advanced Microwave Sounding Unit
AMTS	-	Advanced Moisture and Temperature Sounder
ATMOS	-	Atmosphere Trace Molecules by Spectroscopy
AVHRR	-	Advanced Very High Resolution Radiometer
A/D	-	Analog to Digital Conversion
BASD	-	Ball Aerospace Systems Division
CCD	-	Charge Coupled Device
CLIR	-	Cryogenic Limb-scanning Interferometric Radiometer
CULER	-	Cryogenic Upper Atmospheric Limb Emmision Radiometer
CZCS	-	Coastal Zone Color Scanner
DCS	-	Data Collection System
DMSP	-	Defense Meteorological Satellite System
ERB	-	Earth Radiation Budget
FOV	-	Field of View

SUBSYSTEM FACT SHEETS
TABLE OF ACRONYMS
(Continued)

FY	-	Fiscal Year
GDO	-	Gunn Diode Oscillator
GSFC	-	Goddard Space Flight Center
HIRS	-	High Resolution Infrared Sounder
IF	-	Intermediate Frequency
IFOV	-	Instantaneous Field of View
IR	-	Infrared
IRIS	-	Infrared Interferometer Spectrometer
ITT	-	International Telephone and Telegraph
JPL	-	Jet Propulsion Laboratory
LAMMR	-	Large Antenna Multi-channel Microwave Radiometer
LEO	-	Low Earth Orbit
LHS	-	Laser Heterodyne Spectrometer
LIDAR	-	Light Detection and Ranging
LST	-	Local Solar Time

SUBSYSTEM FACT SHEETS

TABLE OF ACRONYMS

(Continued)

LWIR	-	Long Wave Infrared
MAREX	-	Marine Resources Experiment
MIRP	-	Manipulated Information Rate Processor
MPS	-	Microwave Pressure Sounder
MSU	-	Microwave Sounding Unit
NASA	-	National Aeronautic and Space Administration
NESR	-	Noise Equivalent Spectral Radiance
NESS	-	National Earth Satellite System
NETD	-	Noise Equivalent Temperature Difference
NOAA	-	National Oceanic and Atmospheric Administration
NOSS	-	National Oceanic Satellite System
N/A	-	Not Applicable
OCI	-	Ocean Color Imager
PCM	-	Pulse Code Modulated
RF	-	Radio Frequency

SUBSYSTEM FACT SHEETS
TABLE OF ACRONYMS
(Continued)

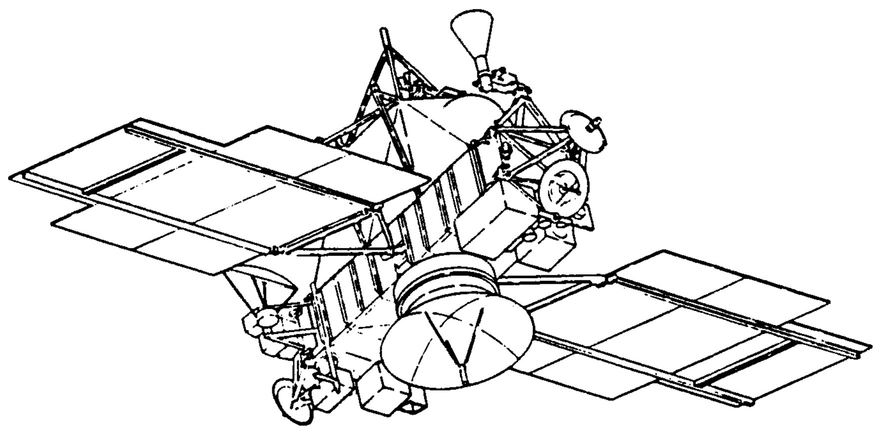
RFI	-	Radio Frequency Interference
SAR	-	Synthetic Aperture Radar
SBUV	-	Solar Backscatter Ultra-Violet
SCAT	-	Scatterometer
SFS	-	Subsystem Fact Sheet
SNR	-	Signal to Noise Ratio
SMMR	-	Scanning Multichannel Microwave Radiometer
SPAS	-	Shuttle Pallet Satellite
SPOT	-	Systeme Probatoire d'observation de la Terre
SSH	-	Satellite Sounder, Humidity
SSU	-	Stratospheric Sounding unit
STS	-	Space Transportation System
SWIR	-	Short Wave Infrared
TBD	-	To Be Determined
TDRSS	-	Tracking and Data Relay Satellite System

SUBSYSTEM FACT SHEETS

TABLE OF ACRONYMS

(Continued)

TIP	-	TIROS Information Processor
TIR	-	Thermal Infrared
TIROS	-	Television and Infrared Observational Satellite
TM	-	Thematic Mapper
TRF	-	Tuned Radio Frequency
UARS	-	Upper Atmosphere Research Satellite
UV	-	Ultraviolet
VIS	-	Visible Light



UTILIZATION OF SPACE FOR CO_2 RESEARCH -- ENGINEERING BUS CONCEPTUAL DESIGN

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WILL BE FOUND ON A SEPARATE LIMITATIONS SHEET.

PREPARED BY C. Case Carl M. Case 2-1635 December 15, 1983

CHECKED BY

SUPERVISED BY A. Hill

APPROVED BY

SIGNATURE ORGN DATE

ABSTRACT

This document provides initial conceptual designs for three engineering buses to be furnished in the Implementation Phase of a CO_2 Research Satellite (CORS) program. CORS is envisioned as arising from a joint study effort of the DOE and the NASA MSFC. The operational satellite program will monitor global climate patterns in an attempt to better understand underlying trends and drivers. These conceptual designs are used in developing schedule and cost estimates for the study on Utilization of Space for CO_2 Research. CORS program schedules are included with the conceptual designs in this document volume. Work breakdown structures and rough order of magnitude cost estimates are included in volumes 2 and 3 of this study report.

ACTIVE SHEET RECORD

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REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

TABLE OF CONTENTS

ABBREVIATIONS

ADCS	Attitude determination and control subsystem
ADL	Arthur D. Little, Inc.
AEM	Application Explorer Mission (Boeing satellite series built for GSFC)
ALT	TOPEX radar altimeter
AMS	Advanced microwave sounder
AMSU	Advanced microwave sounding unit
APM	Ascent propulsion module
AVHRR	Advanced very high resolution radiometer
BAC	Boeing Aerospace Company
BASD	Ball Aerospace Systems Division
BOL	Beginning-of-Life
CDHS	Command and data handling subsystem
CORS	CO_2 research satellite
DCS	Data collection system
DOD	Depth-of-discharge
DOE	Department of Energy
DRIRU	Dry rotor inertial reference unit
EBPS	Engineering bus propulsion system
EOL	End-of-life
ERBE	Earth radiation budget experiment
EVA	Extra-vehicular activity
FOV	Field of view
FTS	Infrared interferometric radiometer
GN_2	Gaseous nitrogen
GSFC	Goddard Space Flight Center
HIRS-2	High-resolution infrared sounder
ICD	Interface control document
IPS	Information processing system
IR	Infrared
IRIS	Infrared inteerferometer spectrometer
IRVM	Infrared visual mapper
IU	Interface unit
IUS	Inertial upper stage

JSC	Johnson Space Center
LIDAR	Light detecting and ranging
N	Newton
MM	Microwave mapper
MOS	Mission operations system
MPS	Microwave pressure sounder
MSFC	Marshall Space Flight Center
MSU	Microwave sounding unit
NASA	National Aeronautics and Space Administration
NASCOM	NASA communications system
OMV	Orbital maneuvering vehicle
OSR	Optical solar reflector
OTS	Off-the-shelf
POCC	Payload operations control center
PS	Parallax Sensor
REM	Reaction engine module
RF	Radio-frequency
RMS	Remote manipulator system
SSA	S-band single access
SSP	Standard switch panel
SSU	Stratospheric sounding unit
STDN	Spaceflight tracking and data network
STS	Space transportation system
SURS	Standard umbilical retraction system
TDAS	Tracking and data acquistion system (planned TDRSS successor)
TDRS	Tracking and data relay satellite
TDRSS	Tracking and data relay satellite system
TOPEX	Topological oceanography experiment
WTR	Western test range

1.0 INTRODUCTION

This document provides a description of the initial conceptual design of three engineering bus configurations for a CO_2 Research Satellite (CORS) program. CORS is envisioned as an operational program arising from a joint study effort of the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) titled "Utilization of Space for CO_2 Research". The operational satellite program will monitor global climate patterns in an attempt to better understand underlying trends and drivers.

Arthur D. Little, Inc. (ADL), the prime contractor for this study, provided requirements, mission analysis, sensor selection, and ground system definition. Ball Aerospace System Division (BASD) provided sensor data. The Boeing Aerospace Company (BAC) was responsible for recommending overall system concepts, providing satellite bus definition, developing program schedules and work breakdown structures, and performing the cost analysis.

Key features of the Boeing engineering bus design for these missions include--

a. Use of flight-proven major elements and a design optimized for use on a space transportation system (STS) to substantially reduces technical, cost, and schedule risk.

b. Minimized modifications to an existing satellite design. We are proposing the use of the topological oceanography experiment (TOPEX) satellite bus for CORS Level 1 and Level 2 missions. For the Level 3 mission, we are proposing to use a design based on Spacelab pallets attached to an unmanned polar space platform.

c. Use of existing technology. No new engineering bus technology is required. Flight-proven, off-the-shelf hardware, with known heritage and performance, is used throughout the engineering bus. All new design components will be based on currently existing technology and proven capabilities or on technology that will have been proven prior to award of the implementation phase contract.

1.1 OBJECTIVES

The design goal is to provide significant environmental data with low risk at a minimum overall mission cost. It is envisioned that this will be accomplished by providing long-term global coverage with gradual phasing from an early initial capability to more capable systems as the program matures. For the CORS program three missions are identified.

a. Level 1 - A near-term mission to be flown as soon as practical with existing instruments.

b. Level 2 - An intermediate-term mission to be flown in five to ten years using using modifications of existing instruments.

c. Level 3 - A long-term mission with a new instrument complement to be developed and flown in ten to twenty years.

Minimization of total system cost, consistent with provision of meaningful scientific data, is the primary design objective for each phase.

1.2 DEFINITIONS

For the purpose of this document and the other material prepared in this study, the following terminology has been used:

(1) Engineering bus or Satellite platform: the basic structure and engineering subsystems provided by the implementation phase satellite contractor.

(2) Payload: the complement of sensors provided by instrument subcontractors or as GFE to the implementation phase satellite contractor.

(3) Integrated Satellite: The composite of the engineering bus and payload after payload integration, in a flight ready condition or after launch.

(4) Satellite System: a term used in describing more than one subsystem. It is normally used for describing in-flight performance of the integrated satellite.

1.3 ENGINEERING BUS DESCRIPTION

The primary goal of the CORS mission is to gain a better understanding of long-term climate changes through remote sensing techniques. Figure 1-1A illustrates the proposed satellite design for the Level 1 mission. The design meets all CORS mission goals and requirements, providing all functions

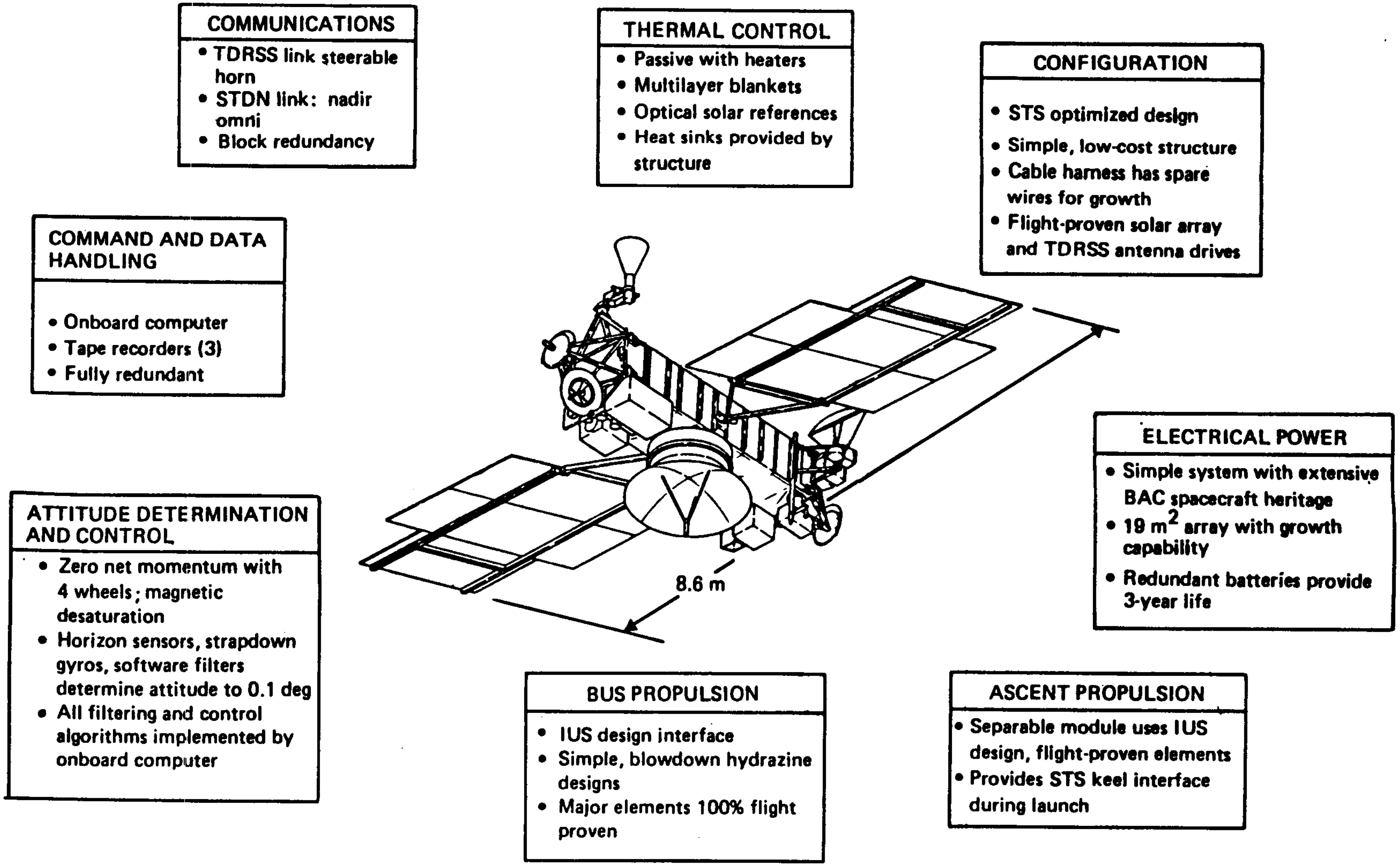


Figure 1-1A. CO_2 Research Satellite (CORS) Level 1 Design Summary necessary for a mission life of at least 3 years. Major elements of the proposed design are summarized below.

A separable ascent propulsion module has been designed to carry the satellite from the STS parking orbit to the observational orbit. The engineering bus propulsion system will provide trim and orbit maintenance maneuvers. The tracking and data relay satellite system (TDRSS) will provide primary command and telemetry links and doppler and ranging data for orbit determination. In addition to the TDRSS antenna, an omnidirectional nadir-pointing antenna will be used to facilitate emergency direect ground communications. The command and data handling subsystem (CDHS) is based on Application Explorer Mission (AEM) equipment which Boeing built for the NASA Goddard Space Flight Center (GSFC). Tape recorders will store data and allow simultaneous data recording and playback. Playback will be compatible with the TDRSS S-band single-access (SSA) link. Three-axis stabilization, provided by the attitude determination and control subsystem (ADCS), will provide the required nadir-pointing accuracy. The ADCS will also ensure accurate thruster pointing and control during orbit maintenance maneuvering. The electrical power subsystem will generate and distribute power required throughout mission life, with NiCd batteries providing power during periods of occultation. The thermal control subsystem will use passive methods supplemented by heaters to maintain the payload instruments and subsystem equipment within permissible temperature ranges.

Modifications required for the Level 2 mission bus, as outlined in fugure 1-1B, are minimal and are limited to minor structural changes, additions to the electrical power subsystem to accomodate changed payload requirements, and the addition of redundant components to meet a five-year life requirement.

For the Level 3 mission, as shown in Figure 1-1C, two Spacelab pallets will provide the primary structure which will be attached in orbit to a free flying, unmanned, space platform using a "standard" space platform docking interface. The space platform will provide electrical power, communications, and attitude control services to the CORS module.

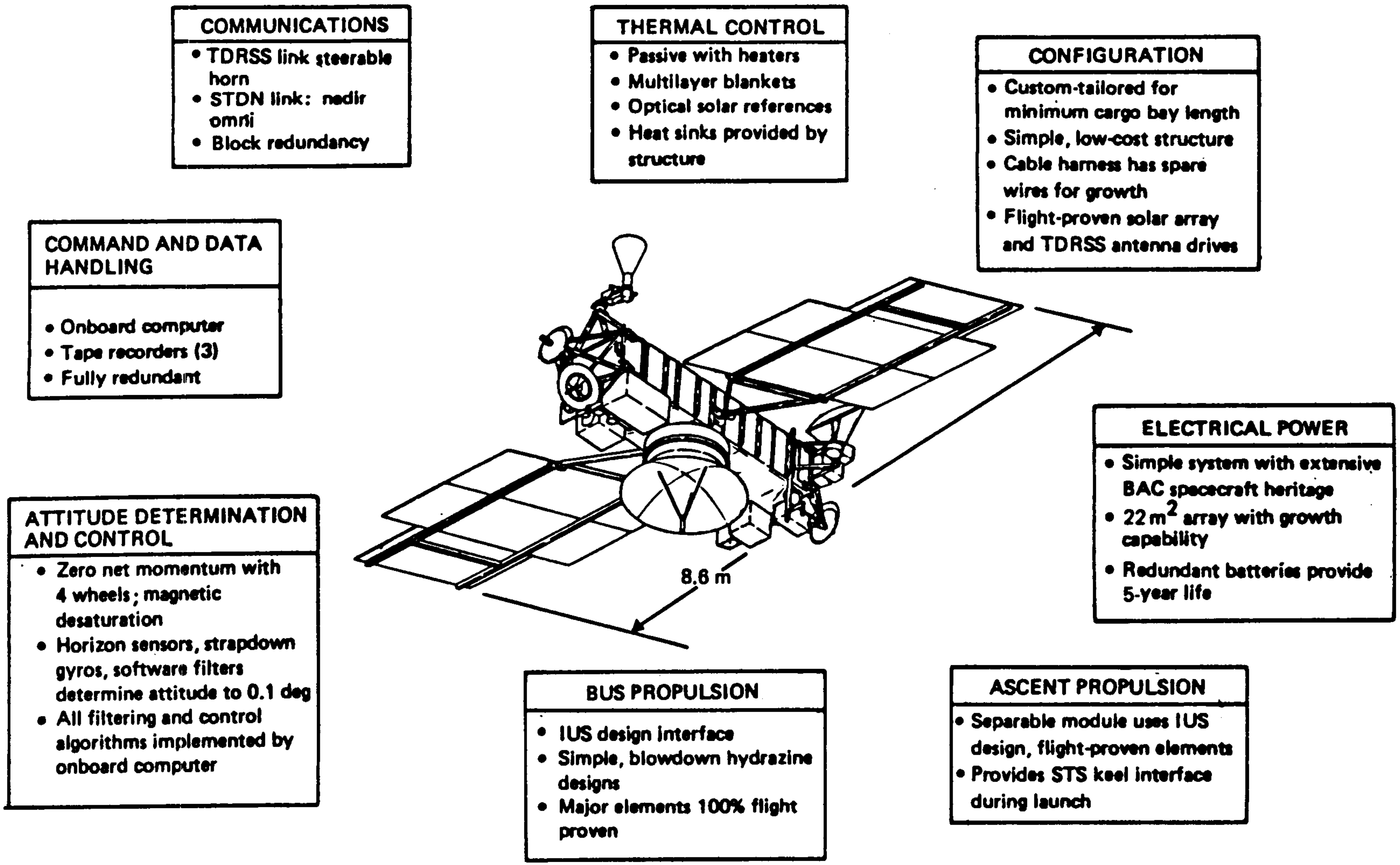


Figure 1-1B. CORS Level 2 Design Summary

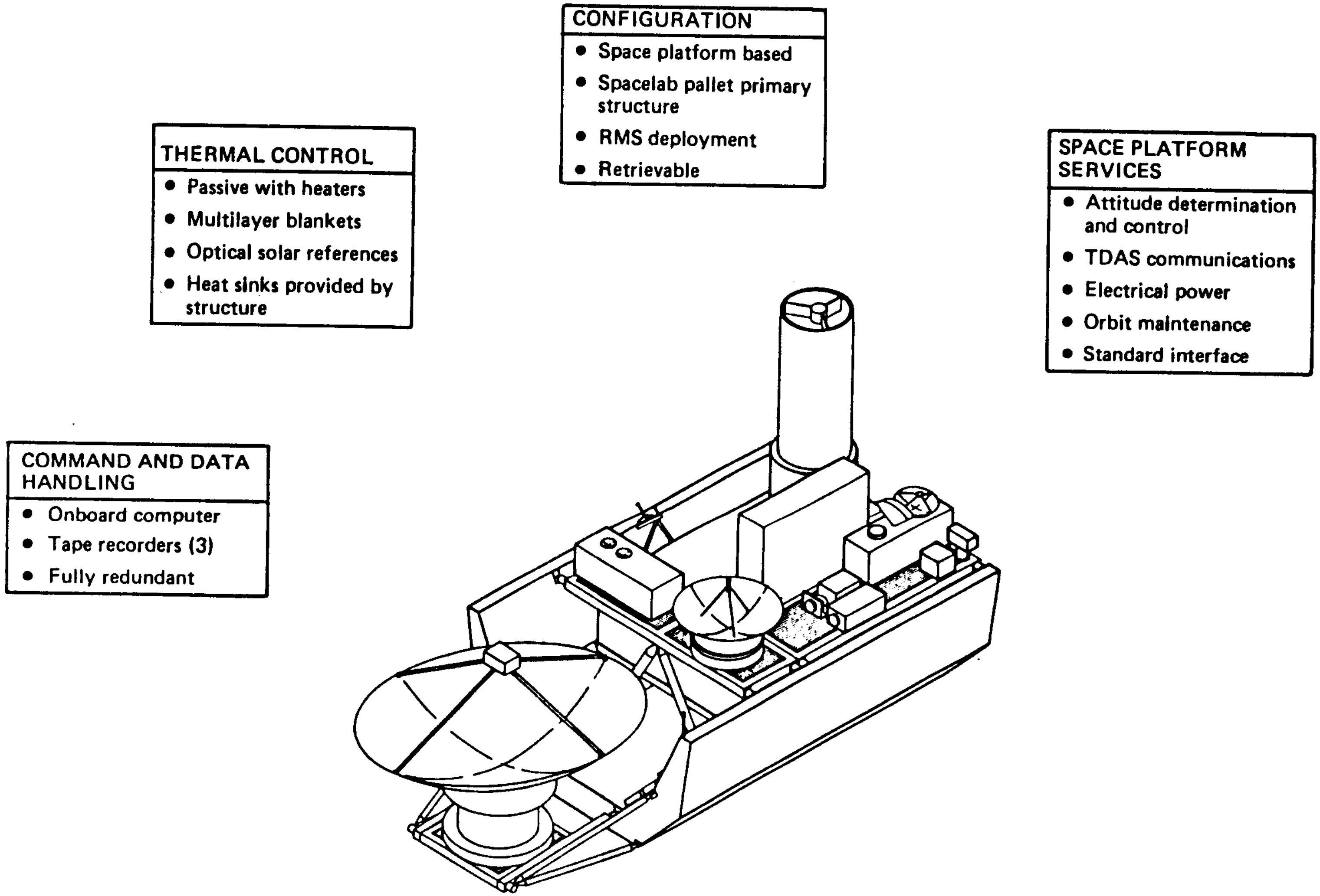


Figure 1-1C. CORS Level 3 Design Summary

1.4 OVERALL MISSION COST IMPLICATIONS

Our technical approach is guided throughout by the requirement to minimize overall system cost; hence, our design minimizes the cost of operations, the launch vehicle, launch vehicle integration, and payload integration as well as satellite bus costs.

OPERATIONS.

Our design minimizes required ground operator interaction annd control of the CORS satellite. A large onboard command memory permits relatively longer intervals between command loads. Onboard software status monitoring, fault detection, redundancy management, and safing increase satellite autonomy and reduce operator duty requirements.

LAUNCH VEHICLE AND LAUNCH VEHICLE INTEGRATION.

We have optimized our CORS satellite design to use existing, proven STS interfaces and release mechanisms. This allows us to make maximum use of STS capabilities and interfaces without imposing special requirements on the STS.

Benefits derived from an STS-optimized satellite include improved ability to perform on-orbit checkout and to establish TDRSS communications and solar array deployment before releasing the satellite from the remote manipulator system (RMS). By allowing on-orbit checkout of a more complete, deployed satellite, STS capability could save the cost of a replacement satellite. The large diameter of the orbiter permits booms to be fixed, rather than stored and later deployed. It also provides a large satellite volume that allows us to position various electronic boxes to optimize wire harness layout and meet thermal design objectives.

For Level 1 and Level 2 missions a shared launch is feasible and desirable to minimize launch costs. The Level 1 CORS satellite will occupy one eighth of the Orbiter cargo bay and approximately 16% of STS launch capability by weight. The Level 2 configuration will occupy one eighth of the Orbiter cargo bay and approximately 17% of the STS launch capability by weight. A third tank could be added to the separable ascent propulsion module to increase performance without affecting the engineering bus should the CORS satellite need to accommodate plane change or increased velocity change requirements.

For Level 3, a STS launch and rendezvous with an existing space platform is assumed. For this Level 3 mission the CORS payload will require a dedicated STS launch.

PAYLOAD INTEGRATION.

Because of the large size of the payload deck, our CORS design provides exceptional instrument placement capabilities and fields of view (FOV's). This will increase mission science data return. Because we have large volume and weight margins, our CORS Level 1 design will accomodate the increased payload requirements of the Level 2 mission with only minor structural changes.

SATELLITE.

We are proposing to use an existing STS optimized satellite bus for the Level 1 and Level 2 missions in order to minimize satellite development costs. The TOPEX bus design is very close to that required for the CORS program, and will require only minor modifications for use in the CORS program. Use of existing sensors will also minimize satellite costs.

Similarly for the Level 3 mission, we are proposing a primary structure using presently existing Spacelab pallets in order to minimize development costs. Development of new sensors will thus be the major cost driver for the Level 3 mission.

2.0 MISSION REQUIREMENTS

2.1 MISSION DESCRIPTION

The objective of the CORS mission is to monitor global climate patterns in an attempt to better understand underlying trends and drivers. A three phased mission approach will permit near-term data collection at reasonable cost, while allowing a gradual transition to a system that is capable of providing comprehensive long-term global measurement. The effect of changing atmospheric CO_2 concentrations will require a long baseline observation period, so it is essential to receive early measurement data. On the other hand, it is not yet clear exactly which measurements would be most meaningful. And furthermore, it will be a number of years after ideal measurement criteria are determined before an optimal sensor package for the CORS mission is available.

For Level 1 and Level 2 missions the STS will release the CORS satellite in a circular parking orbit at 99.4 deg inclination at 250 km altitude. The proposed reference ascent orbit is a Hohman transfer from the parking orbit to the observational orbit, at which point the satellite will separate from its ascent propulsion module and perform a circularization trim maneuver. For the Level 3 mission the STS will attach the CORS instrument module to a sun-synchronous, unmanned, space platform which will provide communications, attitude determination and control, and electrical power to the instrument platform.

ORBIT.

Figure 2.1-1 shows the satellite orbital parameters. Note that the selected orbit for each mission Level is sun-synchronous with a four day repeat cycle for ground track coverage. Local time at the subsatellite point for the descending equatorial nodal crossing is 12:00 AM, as the Earth-Sun line lies in the satellite orbital plane.

LIFETIME AND RELIABILITY.

The Level 1 mission design lifetime will be three years; for Level 2 the lifetime will be five years; for Level 3 it will be ten years. For Level 1 and Level 2 there will be no satellite servicing. Solar arrays, batteries and stationkeeping propellant will be sized for the required lifetime. The elimination of critical single points of failure will be considered in future

ORBITAL PARAMETERS	LEVEL 1	LEVEL 2	LEVEL 3
ORBITAL INCLINATION	99.4 DEG	99.4 DEG	97.4 DEG
ORBITAL ALTITUDE	982 KM	982 KM	491
NODAL PERIOD	104.73 min	104.73 min	94.73 min
NUMBER OF ASCENDING NODAL CROSSINGS/DAY	13.75	13.75	15.25
REPEAT CYCLE (FOR GROUND TRACK COVERAGE)	4 DAYS (55 ORBITS)	4 DAYS (55 ORBITS)	4 DAYS (61 ORBITS)
LONGITUDE DIFFERENCE BETWEEN SUCCESSIVE ASCENDING NODES	-26.11 DEG	-26.11 DEG	-23.94 DEG

Figure 2.1-1. CO_2 Research Satellite Orbital Parameters

cost/reliability trades and will be especially desirable for the Level 2 mission.

For Level 3 the instrument platform will be designed so that it may be disconnected from the space platform and brought back to Earth by the STS for refurbishment and repair. However, limited on-orbit servicing capability will exist enabling some malfunctions to be corrected by astronaut extravehicular activity (EVA) from the orbiter.

DATA COLLECTION AND HANDLING.

The success of the CORS mission is highly dependent on minimal data loss and straight forward data collection and handling flow. Three basic types of data will be transferred between the CORS satellite and the ground system: telemetry, command, and tracking. This data will be relayed using existing NASA TDRSS links. The NASA communications (NASCOM) network will handle ground data flow between the TDRSS ground station at White Sands, GSFC orbit determination facilities, and the MSFC payload operations control center (POCC).

Telemetry data, consisting of housekeeping and science information, will be downlinked to the POCC in real-time and tape recorder playback form. On arrival at the POCC, the real-time data will be used for command verification and spacecraft and instrument health checks. Tape recorder playback data will be formatted and forwarded to the information processing system (IPS) for processing, archival and distribution. The POCC will control satellite operations by issuing real-time commands and command memory loads. TDRSS S-band doppler and ranging data will be relayed from the TDRSS ground station to GSFC to support operational orbit determination. Resulting operational ephemeris data will then be sent to the POCC so the appropriate maneuver activity can be initiated.

A simplified version of the CORS satellite-ground mission data collection and handling flow is illustrated in figure 2.1-2. For the Level 3 mission the proposed NASA Tracking and Data Acquisition System (TDAS) will likely replace TDRSS for communications relay, with considerably improved capabilities.

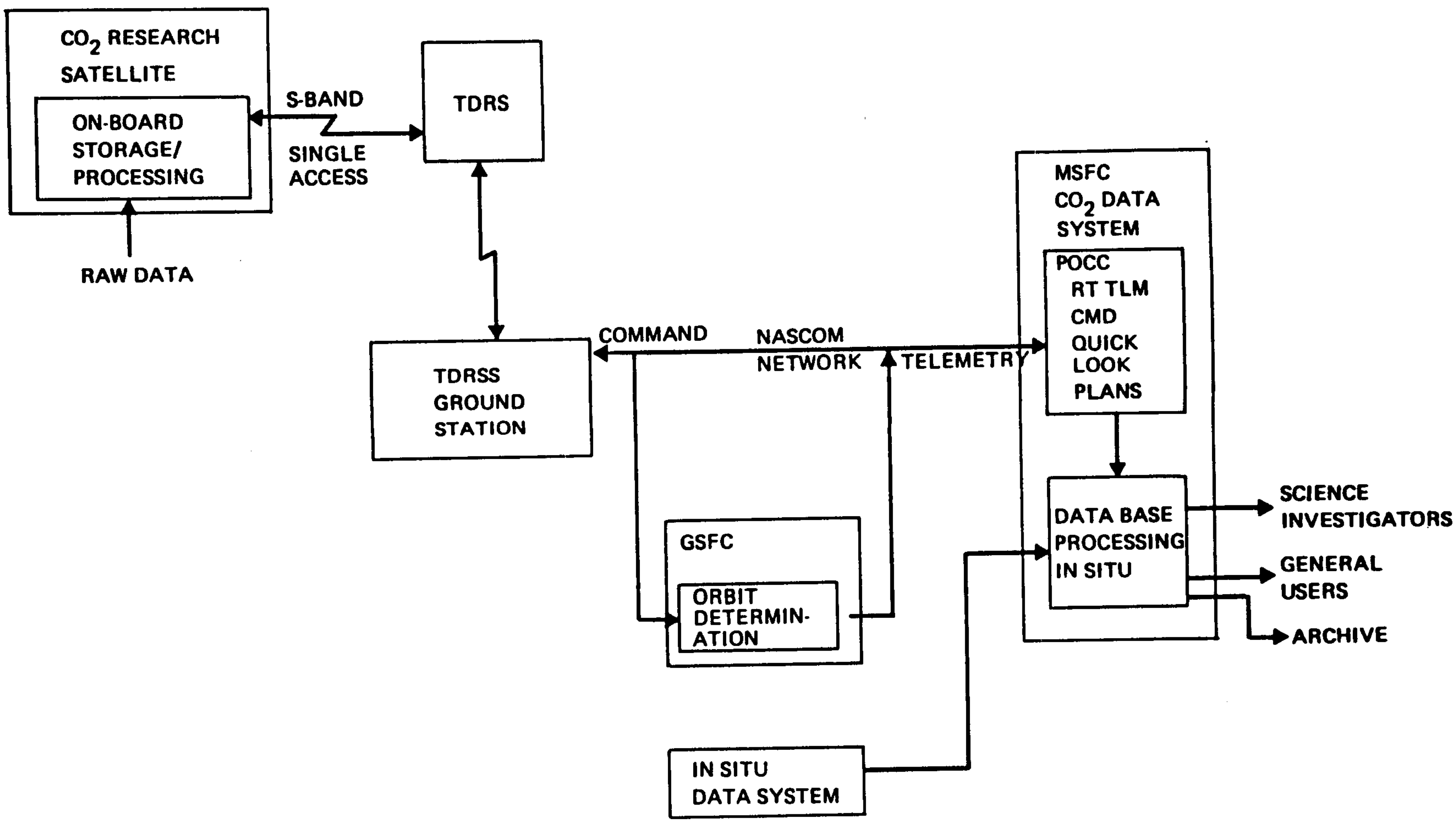


Figure 2.1-2. Mission Data Collection and Handling Block Diagram

2.2 SYSTEM INTERFACES

The design approach adapted for the CORS engineering bus emphasizes simple interfaces for major elements of the overall system. Major system interfaces with the payload, launch vehicle, TDRSS, mission operations system, and the satellite environment have been analyzed for their impact on the proposed satellite design, including cost tradeoffs.

PAYLOAD INTERFACES.

Sensor complements and major sensor characteristics for each mission level are shown in figure 2.2-1.

The elements contributing to the instrument accommodation capability offered by the Boeing CORS engineering bus include (1) a large nadir--pointing deck area for sensor mounting to accommodate multiple sensors without interference in sensor FOV's, (2) ample mounting area on the interior of the engineering bus equipment pallets to provide a thermally benign environment for internally mounted payload elements, (3) volume allowing for accommodation of instruments mounted on masts to satisfy FOV requirements without deployment, (4) a flexible command and data handling architecture to allow accommodation of a wide variety of experiment command and data handling requirements.

These factors have allowed accommodation of the Level 1 and Level 2 payloads on the same engineering bus with only minor bus modifications. The Level 3 mission, with its much larger power requirements, telemetry rates and bulk, requires a different platform design.

Level 1 Mission Sensors. Sensor locations for the Level 1 mission are shown in figure 2.2-2A.

The modified advanced very high resolution radiometer (AVHRR) is a multispectral radiometer operated in the scanning mode. The AVHRR measures emitted and reflected radiation in the folloowing spectral intervals: channel 1 (visible), 0.55 to 0.9 micrometer; channel 2 (near IR), 0.725 micrometer to detector cut off around 1.3 micrometers; channel 3 (IR window), 10.5 to 11.5 micrometers; and channel 4 (IR window), 3.55 to 3.93 micrometers. The satellite motion is used to provide scanning normal to the rotating mirror's cross-track scanning. Radiation is reflected off the mirror through an afocal Cassegrain telescope and filtered into visible and IR components. The IR

SENSOR	MASS (Kg)	AVERAGE POWER (W)	AVERAGE TELEMETRY DATA RATE (KOPS)
LEVEL 1 MISSION	(365)	(449)	(368)
• MODIFIED ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR)	27	25	335
• DATA COLLECTION SYSTEM (DCS)	29	27	1
• STRATOSPHERIC AEROSOL AND GAS EXPERIMENT (SAGE-2)	30	10	8
• EARTH RADIATION BUDGET EXPERIMENT (ERBE)	55	50	1
• SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)	52	60	12
• TOPEX RADAR ALTIMETER (ALT)	99	199	7
• HIGH-RESOLUTION INFRA-RED SOUNDER (HIRS-2)	32	23	2
• MICROWAVE SOUNDING UNIT (MSU)	32	40	1
• STRATOSPHERIC SOUNDING UNIT (SSU)	9	15	1
LEVEL 2 MISSION	(401)	(562)	(370)
• IMPROVED ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR)	27	25	335
• IMPROVED DATA COLLECTION SYSTEM (DCS)	41	36	1
• IMPROVED STRATOSPHERIC AEROSOL AND GAS EXPERIMENT (SAGE-2)	30	10	8
• EARTH RADIATION BUDGET EXPERIMENT (ERBE)	55	50	1
• SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)	52	60	2
• TOPEX RADAR ALTIMETER (ALT)	99	199	7
• INFRA-RED INTERFEROMETER/SPECTROMETER (IRIS)	17	12	12
ADVANCED MICROWAVE SOUNDING UNIT (AMSU)	80	170	4
LEVEL 3 MISSION	(2206)	(3990)	(1154)
• INFRA-RED VISUAL MAPPER (IRVM)	30	25	700
• IMPROVED DATA COLLECTION SYSTEM (DCS)	42	36	1
• LIGHT DETECTING AND RANGING (LIDAR)	1300	3000	250
• INFRA-RED INTERFEROMETRIC RADIOMETER (FTS)	300	150	40
• MICROWAVE PRESSURE SOUNDER (MPS)	50	100	1
• ADVANCED MICROWAVE SOUNDER (AMS)	80	170	4
• MICROWAVE MAPPER (MM)	220	235	50
• TOPEX RADAR ALTIMETER (ALT)	99	199	7
• PARALLAX SENSOR (PS)	30	25	100
• ADVANCED EARTH RADIATION BUDGET EXPERIMENT (ERBE)	55	50	1

Figure 2.2-1. Sensor Characteristics Summary

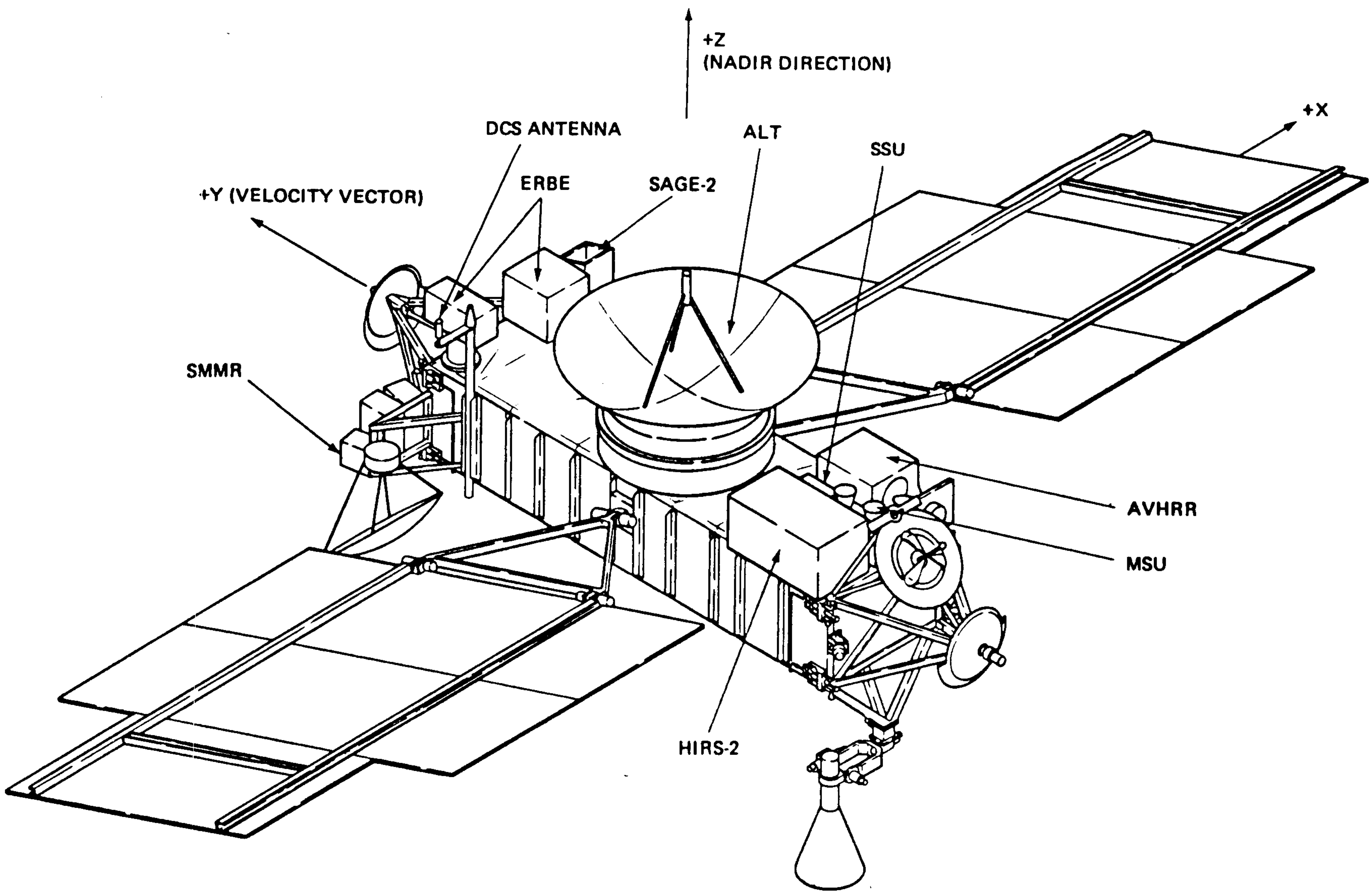


Figure 2.2-2A. CORS Level 1 Sensor Arrangement

detectors are radiatively cooled to 105°K. The AVHRR is located on the aft payload deck with a clear nadir FOV for its scan mirror. Its cooler is facing in the +X direction and will consequently be looking to deep space throughout the mission.

The data collection system (DCS) consists of 401.65 MHz and VHF antennas, a receiver, a VHF transmitter, and a processor unit. The DCS system receives data from remote transmitters located in vessels such as bouys and weather balloons. The DCS system receives the transmitted data, appends a time tag to the data, performs doppler analysis and stores the information for later transmission to the ground. Data dumps twice a day provide information to investigators including the data received, the time of receipt, and the position of the transmitter in longitude, latitude and altitude with an accuracy of approximately 1 km. A VHF emitter is included for low rate real-time data return to various investigators. The DCS antennas are located on a nadir pointing fixed boom together with the engineering bus omnidirectional antenna. The DCS electronics are mounted inside the engineering bus structure on the -X wall.

The stratospheric aerosol and gas experiment (SAGE-2) sensor is a multispectral channel radiometer which measures the extinction of solar radiation intensity during solar occultation. As the spacecraft emerges from the Earth's shadow during each orbit, the sensor will acquire the Sun and measure the solar intensity in wavelength bands centered between 0.385 and 1.0 microns as it scans the Sun vertically. As the satellite continues in orbit, the line-of-sight from the spacecraft to the rising Sun will scan the Earth's atmosphere, resulting in a measurement of the attenuated solar intensity at different heights in thee atmosphere. The optical subassembly consists of a flat scanning mirror, Cassegrain optics, and a detector package. The entire subassembly is gimballed in azimuth to acquire and scan the Sun. The SAGE-2 instrument is mounted on the outside of the engineering bus, attached to the fore side of the +X wall where it will have an unobstructed view of the rising sun.

The Earth radiation budget experiment (ERBE) consists of two radiometer instrument packages, the wide and medium field of view (W/MFOV) instrument and the scanner instrument. Both instrument packages are mounted on fore side of the payload deck with excellent FOV's to nadir. The scan drum is oriented to perform cross-track scanning and sufficient deck space is available to allow for gimbal rotation. The scanner and W/MFOV instruments will be aligned using a common mounting plate.

The scanning multichannel microwave radiometer (SMMR) is a ten-channel instrument delivering orthogonally polarized antenna temperature data at five microwave wavelengths centered at 0.8 cm, 1.4 cm, 1.7 cm, 2.8 cm, and 4.6 cm. Polarization components of the microwave radiation are extracted for each channel. The smallest cell resolution is about 20 km for the 0.8 cm channel. The SMMR will be mounted on the fore end of the -X side of the engineering bus with a clear FOV to nadir and along the velocity vector. A 42 deg offset parabolic reflector focuses the received power into a single feedhorn. Scanning is accomplished by oscillating the reflector about an axis coincident with the axis of the feedhorn.

The TOPEX radar altimeter (ALT) is a two channel sensor used to measure the instantaneous round trip light time from the satellite to the average surface in the footprint at the nadir point. The altimeter uses two frequencies or channels: a prime channel at Ku-band and a secondary channel at C-band. The purpose of the secondary channel is for calculating the actual ionospheric propigation delay caused by the electron content in the nadir column. The ALT packages consist of a signal processor and a combined radio-frequency (RF) section and antenna. The RF/antenna package is mounted on the center of the payload deck. The signal processor is mounted inside the engineering bus under the RF/antenna package near the center of the +X wall.

The high resolution infrared sounder (HIRS-2) measures radiances primarily in five spectral regions: (1) seven channels near the 15 micrometer CO_2 absorption band, (2) two channels in the IR window, 11.1 and 3.7 micrometers, (3) two channels in the water vapor absorption band, 8.2 and 6.7 micrometers, (4) five channnels in the 4.3 micrometer band, and (5) one channel in the visible window 0.69 micrometer region for cloud detection. The sounder consists of a Cassegrain telescope, scanning mirror, dichromatic beam splitter, filter wheel, chopper, and associated electronics. HIRS-2 is located on the aft side of the payload deck towards the -X axis with an unobstructed nadir FOV.

The microwave sounding unit (MSU) is a spectrometer operating in the 50 to 60 GHz oxygen band (50.3, 53.7, 55.0, and 57.9 micrometers) to obtain temperature profiles which are free of cloud interference. It is a cross course scanning device utilizing a stepper motor to provide a traverse scan while the orbital motion of the satellite provides scanning in the orthogonal direction. The MSU is located along the X-axis on the aft side of the payload deck. It has a clear FOV to nadir.

The stratospheric sounding unit (SSU) has three channels operating at 14.97 micrometers using selective absorption by passing the incoming radiation through three pressure modulated cells containing CO_2. The SSU is located on the payload deck adjacent to the MSU.

Level 2 Sensor Instruments. Level 2 instruments are identical to those of Level 1 with the following exceptions--

a. The AVHRR is an improved version with satellite interfaces similar to those of Level 1.

b. The DCS has additional component boxes needed to increase simultaneous processing capability and to provide redundancy necessary for a five year mission. The additional boxes are also located along the -X wall of the engineering bus.

c. The SAGE-2 instrument is an improved version with satellite interfaces similar to those of Level 1.

d. The SMMR is an improved version with satellite interfaces similar to those of Level 1. It was desired originally to increase the SMMR antenna diameter to 4 meters. This was found to present challenges to the engineering bus design which would significantly increase mission cost. For this reason the antenna diameter was left unchanged.

e. The HIRS-2, MSU, and SSU were dropped and replaced by the IRIS and AMSU instruments which are described below.

The infrared interferometer spectrometer (IRIS) is a Twyman-Green modification of a Michelson interferometer spectrometer operating in the 6.5 to 40 micron wavelength region. Radiation from a cylinder of atmosphere is reflected into the instrument from a rotating plane mirror. The radiation is split into two beams, one of which is reflected from a moving mirror, recombined and focused onto a bolometer detector. Interference effects result from the path length differences in the two beams as the mirror moves. After recording several interferograms, two calibration observations are made, one for a reference blackbody at $300^{o}K$ and one for deep space. The IRIS is mounted on the aft payload deck centered over the X-axis with both nadir and space FOV's.

The advanced microwave sounding unit (AMSU) is a 20 channel microwave radiometer with operating bands from about 18 to 180 GHz. It will measure microwave radiation emitted near water vapor emission lines to perform humidity sounding, and near oxygen emission lines to perform temperature sounding. Three window channels are used to measure low atmospheric and surface effects. The AMSU will be able to perform stratospheric and tropospheric temperature sounding, as well as tropospheric humidity sounding and precipitation measurement. It will be mounted on the aft -X outside of the engineering bus.

Level 3 Instrument Sensors. Figure 2.2-2C shows the general arrangement of instrument sensors for the Level 3 mission. The DCS, ERBE, and ALT are described above for the Level 2 mission are also found in the Level 3 instrument complement. Other Level 3 instruments which are not yet defined in detail, include an infrared visual mapper (IRVM), a light detecting and ranging (LIDAR) instrument, an infrared interferomeetric radiometer (FTS), a microwave pressure sounder (MPS), an advanced microwave sounder (AMS), a microwave mapper (MM) based on the large antenna microwave mapper, and a parallax sensor (PS).

LAUNCH VEHICLE INTERFACES.

The STS mechanical, electrical, avionics, and environmental interfaces are defined in JSC ICD 2-19001 with which the CORS satellite system is completely compatible. Mechanical interfaces and deployment methods are simple and flight proven.

The structural and mechanical interface between CORS and the STS orbiter consists of two longeron trunnions and one keel trunnion that will attach to STS provided active longeron and keel attachment fittings. The mechanical interface is flight proven on the SPAS payload on STS-7, as was the RMS grapple fitting which is used in CORS deployment operations.

Cargo bay electrical interfaces, except for the RF interfaces, are physically located near the trunnion interface to minimize cable lengths. The interface unit (IU), which provides the electrical interface between CORS and the STS, is mounted in its position along the port longeron bridge. A standard umbilical retraction system (SURS), with its compatible ball-jointed receptacle connnector mounted on the CORS satellite, which is supplied by the

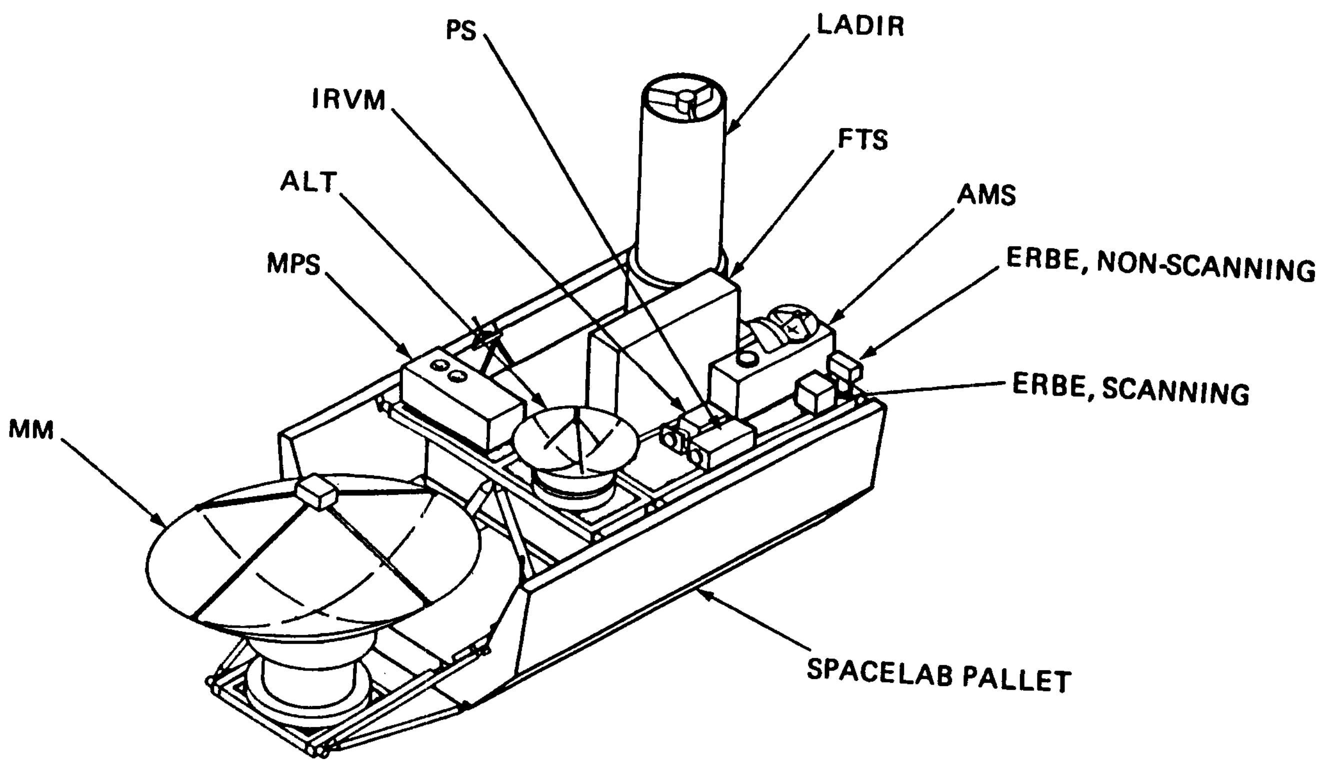


Figure 2.2-2C. CORS Level 3 Sensor Arrangement

STS completes the electrical interface between CORS and the STS. The grapple fixture incorporates an integral electrical connector, which engages a connector on the RMS end effector when the end effector becomes rigid.

Display and control functions involved in launch and deployment of the CORS are accomplished using crew controlled equipment. The payload retention control panel is used to provide control oof the active longeron and keel fittings. One section of the standard switch panel (SSP) is used to monitor critical CORS parameters in the power, pyrotechnic, and propulsion subsystems.

TRACKING AND DATA RELAY INTERFACES.

The principle interface between CORS and TDRSS is the signal format used by TDRSS; secondary requirements include antenna pointing and link margins. The proposed design using redundant NASA standard transponders satisfies all CORS/TDRSS interface requirements.

MISSION OPERATIONS SYSTEM INTERFACES.

The mission operations system (MOS) is responsible for all elements--tracking and data acquision, ground data system, and mission control--needed to operate the satellite, and the information processing system (IPS) activities (processing and data distribution) relating to the production of CORS data output for scientific use. The majority of MOS and IPS elements and functions will be consolidated in a single facility at MSFC to maintain an effective opeartions structure. These MOS functions include--

a. All activities related to the operation of the satellite from launch to the end of the mission.

b. Collection of measurement data.

c. Formatting of satellite, ephemeris, and surface measurement data for use by the IPS.

d. Development, operation, and maintenance of the TOPEX data system for use by both the MOS and IPS.

e. Interfacing with GSFC for NASCOM and TDRSS scheduling and the receipt of orbit ephemerides.

The payload operations control center (POCC), located at MSFC, is designated as the central facility for controlling the CORS satellite. Satellite health and status, based on real-time data, will be monitored at the POCC. Additionally, tape recorder playback data receiveed will be formatted for IPS analysis and processing. Real-time comannnds, initiated by the POCC, will be relayed to the satellite during tracking and data relay satellite (TDRS) view periods, while command memory loads will be formulated and uplinked one or two times per day. Telemetry and command links between the CORS satellite and the POCC will be via TDRSS and the NASCOM network.

3.0 CO_2 RESEARCH SATELLITE DESIGN

3.1 DESIGN APPROACH

This section describes the design approach used to meet the primary constraints on the CORS satellite design which include:

a. Minimizing overall mission cost.

b. Providing functional reliability sufficient to meet mission lifetime requirements.

c. Providing flexibility to minimize the impact of the engineering bus design on data collection.

d. Minimizing the risk in development and operation of the satellite system.

Our design uses minor modifications of the existing TOPEX satellite bus hardware to meet CORS mission requirements. Our approach takes full advantage of the cost savings inherent in use of an existing bus. Similar mission encourage use of the TOPEX bus for the CORS mission. Changes in the command and data handling subsystem will be required to support CORS data rates, and secondary structural modifications will be required to support the new instrument complement. Other modifications should be minimal.

The satellite general arrangement and key features contributing to the satisfaction of mission constraints are illustrated in figure 3.1-1A for Level 1 and Level 2 missions and in figure 3.1-1C for the Level 3 mission.

3.2 SATELLITE CHARACTERISTICS

This section gives an overview of the CORS satellite configuration, mass properties and mission. Satellite subsystem characteristics are summarized in figures 3.2-1A,-B, and -C for Level 1,-2, and -3 missions respectively.

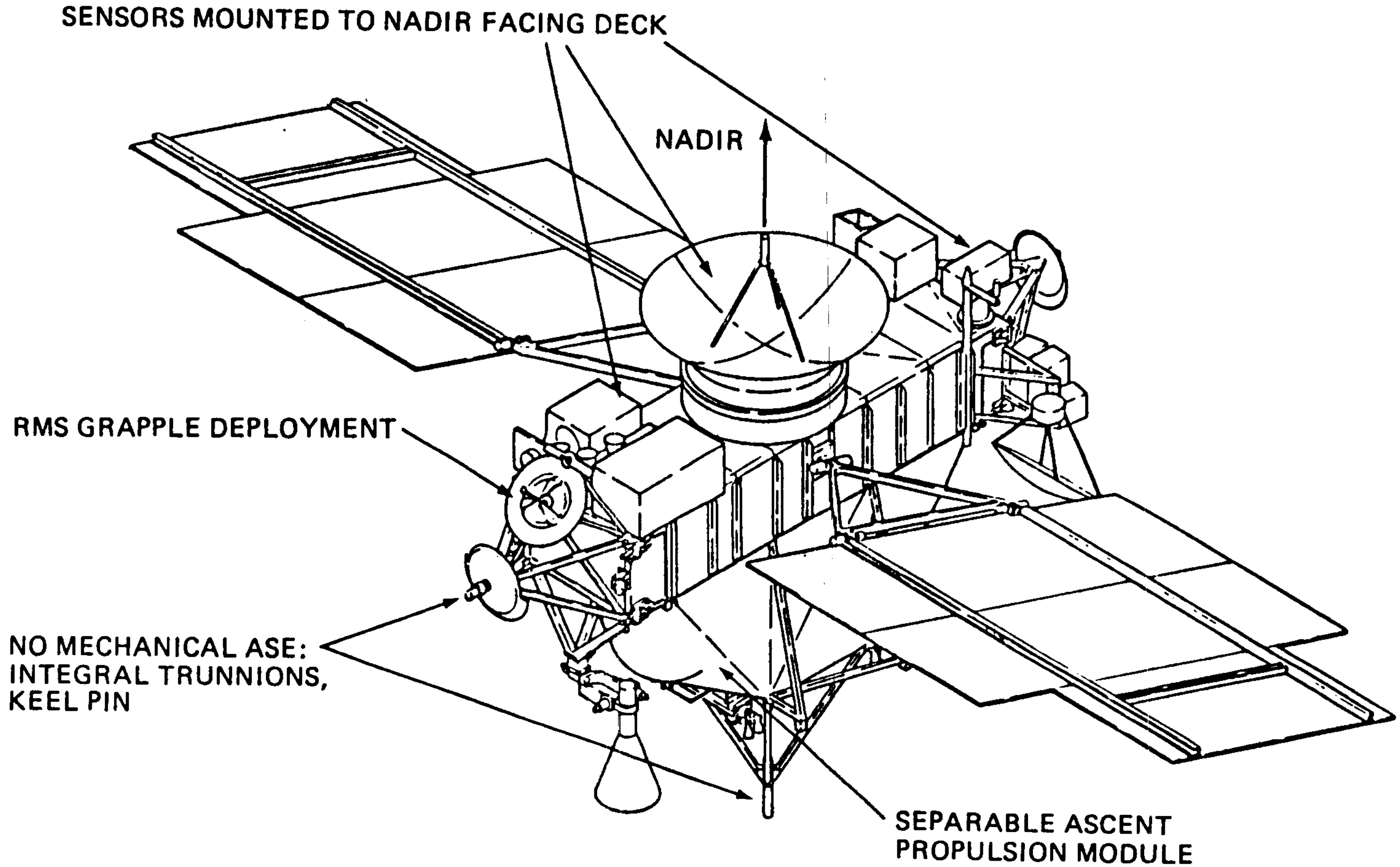


Figure 3.1-1A. CORS Level 1 Satellite Design Approach

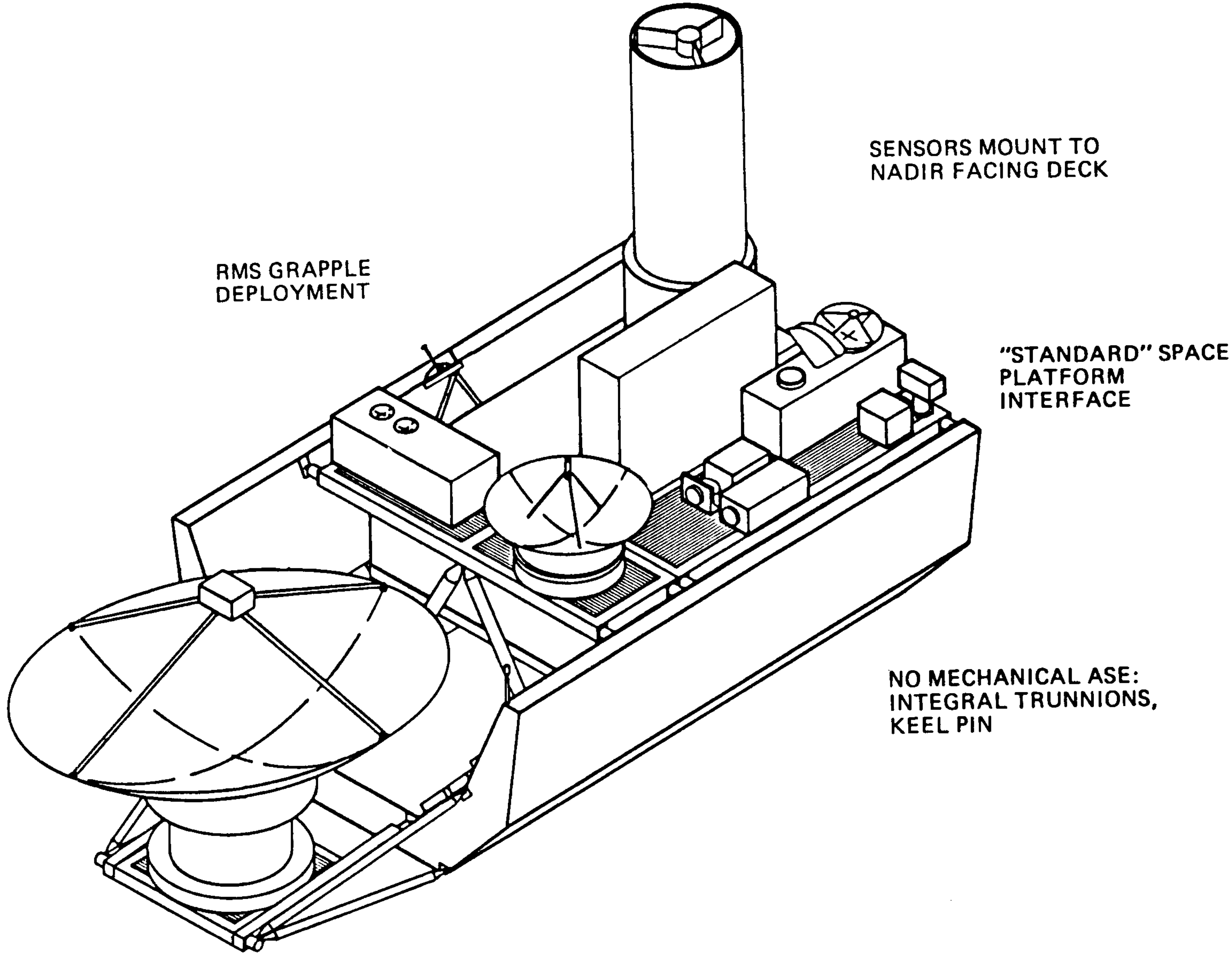


Figure 3.1-1C CORS Level 3 Satellite Design Approach

Communications
- TDRSS link using steerable horn
  - Nominal single-access mode
    - 1K bps command
    - 1.8 Mbps
- Direct ground link using omnidirectional antenna
  - 125 bps command
  - 1.8 Mbps telemetry

Command and data handling
- Redundant centralized computer
- Ultrastable oscillator provides 5-MHz clock
- Autonomous response to onboard interrupts
- Commands
  - Command validity checks
  - 1024 command storage
- Data
  - 2-rev data storage
  - Simultaneous record and playback

Attitude determination and control
- Three-axis stabilization using reaction wheels desaturated with electromagnets
- Nadir pointing
- Onboard software provides autonomous operation
- Attitude determination provided by—
  - Horizon sensors
  - Inertial reference unit
  - Magnetometer
- Pitch-and-roll attitude determination better than 0.1 deg

Thermal control
- Complies with science instrument thermal control requirements
- Passive design with heaters
  - Multilayer insulation blankets
  - Optical solar reflector mirrors
  - Cold and warm plates

Electrical power and pyrotechnics
- 28V ± 4V dc regulated bus
- Articulated solar array, 22 m^2
  - On common shaft
  - Sun-oriented by dual stepper motors
  - 1600 W EOL average power output

Four 25-Ah NiCd batteries
  - 700 Wh based on average occultation period over mission life
  - 17% DOD

Structure, cabling, and mechanisms
- Custom-tailored, minimized length construction
  - Major elements
    - Base module
    - Trunnion support truss
    - Ascent module and RMS fitting
  - Construction
    - Standard aluminum structural shapes
    - Machined fittings
    - Mechanical fasteners
- Cable harness leads sized for less than 1% power loss, spare wires provided for growth and replacement
- Drive mechanisms for
  TDRS antenna 2-axis articulation
  Solar array elevation articulation
- High-shear separation nuts provide array tiedown
- Explosive nuts provide ascent module to base module attachment

Propulsion
- Ascent module
  - Two 71-cm-diameter hydrazine tanks
  - Four rocket engine modules, each with two 30-lb_f thrusters
  - Capable of providing greater than 410 m/s ΔV
- Engineering bus
  - Two 39-cm-diameter hydrazine tanks
  - Eight rocket engine modules, each with three 1-lb_f thrusters
  - Capable of providing greater than 65 m/s ΔV

Figure 3.2-1A. CORS Level 2 Bus Design Summary

Communications
- TDRSS link using steerable horn
  - (single-access mode)
  - 1K bps command
  - 1.8 Mbps telemetry
- Direct ground link using omnidirectional antenna
  - 125 bps command
  - 1.8 Mbps telemetry

Command and data handling
- Redundant centralized computer
- Ultrastable oscillator provides 5-MHz clock
- Autonomous response to onboard interrupts
- Commands
  - Command validity checks
  - 1024 command storage
- Data
  - 2-rev data storage
  - Simultaneous record and playback

Attitude determination and control
- Three-axis stabilization using reaction wheels desaturated with electromagnets
- Nadir pointing
- Onboard software provides autonomous operation
- Attitude determination provided by—
  - Horizon sensors
  - Inertial reference unit
  - Magnetometer
- Pitch-and-roll attitude determination better than 0.1 deg

Thermal control
- Complies with science instrument thermal control requirements
- Passive design with heaters
  - Multilayer insulation blankets
  - Optical solar reflector mirrors
  - Cold and warm plates

Electrical power and pyrotechnics
- 28V ± 4V dc regulated bus
- Articulated solar array, 19 m^2
  - On common shaft
  - Sun-oriented by dual stepper motors
  - 1450W EOL average power output

Three 25-Ah NiCd batteries
  - 525 Wh based on average occultation period over mission life
  - 26% DOD

Structure, cabling, and mechanisms
- Custom-tailored, minimized length construction
  - Major elements
    - Base module
    - Trunnion support truss
    - Ascent module and RMS fitting
  - Construction
    - Standard aluminum structural shapes
    - Machined fittings
    - Mechanical fasteners
- Cable harness leads sized for less than 1% power loss, spare wires provided for growth and replacement
- Drive mechanisms for
  TDRS antenna 2-axis articulation
  Solar array elevation articulation
- High-shear separation nuts provide array tiedown
- Explosive nuts provide ascent module to base module attachment

Propulsion
- Ascent module
  - Two 71-cm-diameter hydrazine tanks
  - Four rocket engine modules, each with two 30-lb_f thrusters
  - Capable of providing greater than 435 m/s ΔV
- Engineering bus
  - Two 39-cm-diameter hydrazine tanks
  - Eight rocket engine modules, each with three 1-lb_f thrusters
  - Capable of providing greater than 70 m/s ΔV

Figure 3.2-1B. CORS Level 1 Bus Design Summary

Communications
- Space platform provided

Command and data handling
- Redundant centralized computer
- Ultrastable oscillator provides 5-MHz clock
- Autonomous response to onboard interrupts
- Commands
  - Command validity checks
  - 1024 command storage
- Data
  - 2-rev data storage
  - Simultaneous record and playback

Attitude determination and control
- Space platform provided

Thermal control
- Complies with science instrument thermal control requirements
- Passive design with heaters
  - Multilayer insulation blankets
  - Optical solar reflector mirrors
  - Cold and warm plates

Electrical power and pyrotechnics
- Space platform provided

Structure, cabling, and mechanisms
- Space lab pallets provide primary structure
- Space platform standard interfaces

Propulsion
- STS/OMV/Space platform provided

Figure 3.2-1C. .CORS Level 3 Bus Design Summary

CONFIGURATION.

Figure 3.2-2A, -B, and -C illustrate the general CORS satellite arrangements showing vehicle axes and key dimensions.

The Boeing CORS engineering bus offers: (1) a large nadir-pointing deck area for multiple sensor mounting without sensor fields of view (FOV) interference, (2) ample mounting area on the interior of the engineering bus equipment pallets to provide a thermally benign environment for internally mounted payload elements, (3) flexible arrangement for externally mounted instruments for efficiennt use of the STS cargo bay, (4) sufficient volume to allow accommodation of instruments mounted on masts to satisfy FOV or electromagnetic compatibility (EMC) requirements without deployment, and (5) a flexible command and data handling architecture to accommodate a wide variety oof experiment command and telemetry requirements.

The large internal volume of our CORS design allows us to locate subsystem components to provide cable harness channels, minimize cable harness weight and complexity, and provide for thermal requirements.

Considerable contingency area exists in the Level 1 central equipment bay on both the +X and -X-axis equipment pallets. This area could be used to accommodate growth in instrument or subsystem units as is seen in the Level 2 mission, or perhaps the addition of new Level 1 instrumentation.

Figure 3.2-3A shows the Level 1 satellite ascent mode in isometric form with the axes labelled. The Level 2 satellite ascent mode is similar. Figure 3.2-3C shows the Level 3 module in isometric form.

Figure 3.2-4A shows the Level 1 satellite operational and maneuvering mode in isometric form with the axes labelled. The Level 2 satellite operational mode is similar. Figure 3.2-4C shows the Level 3 module in an operational mode, attached to a space platform which provide communications, attitude determination and control, and electrical power to the CORS module.

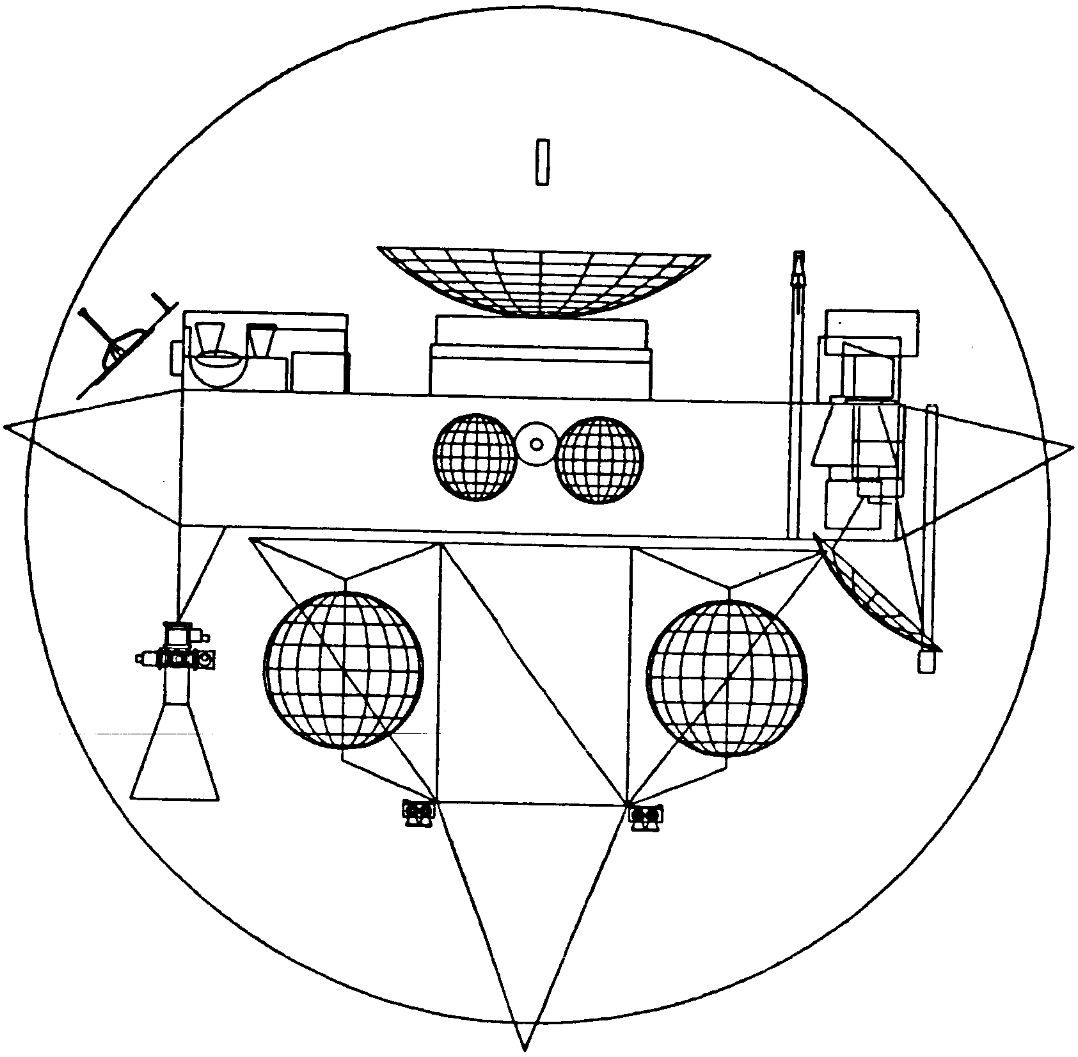


Figure 3.2-2A-1. CORS Level 1 STS Dynamic Envelope

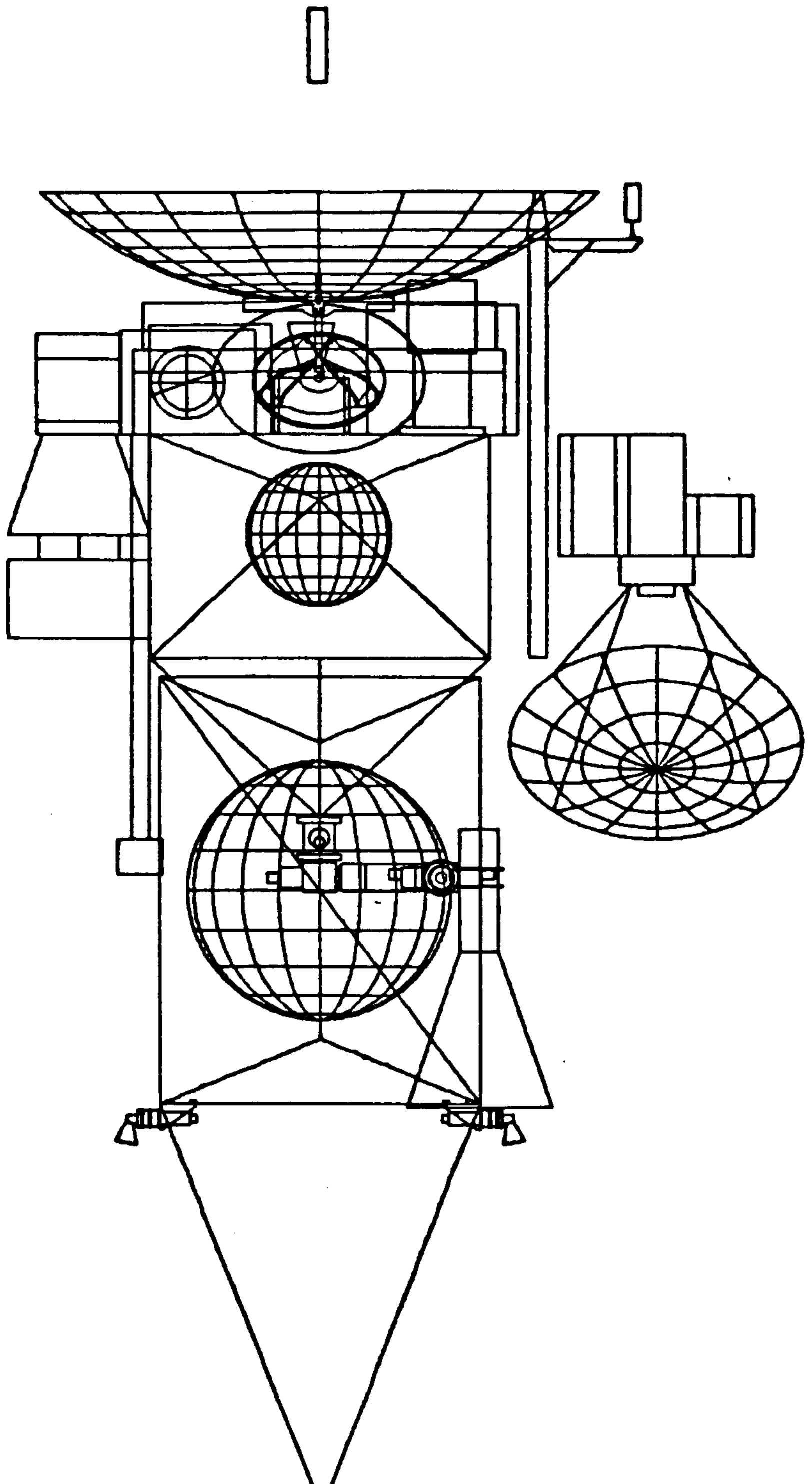


Figure 3.2-2A-2. CORS Level 1 Side View

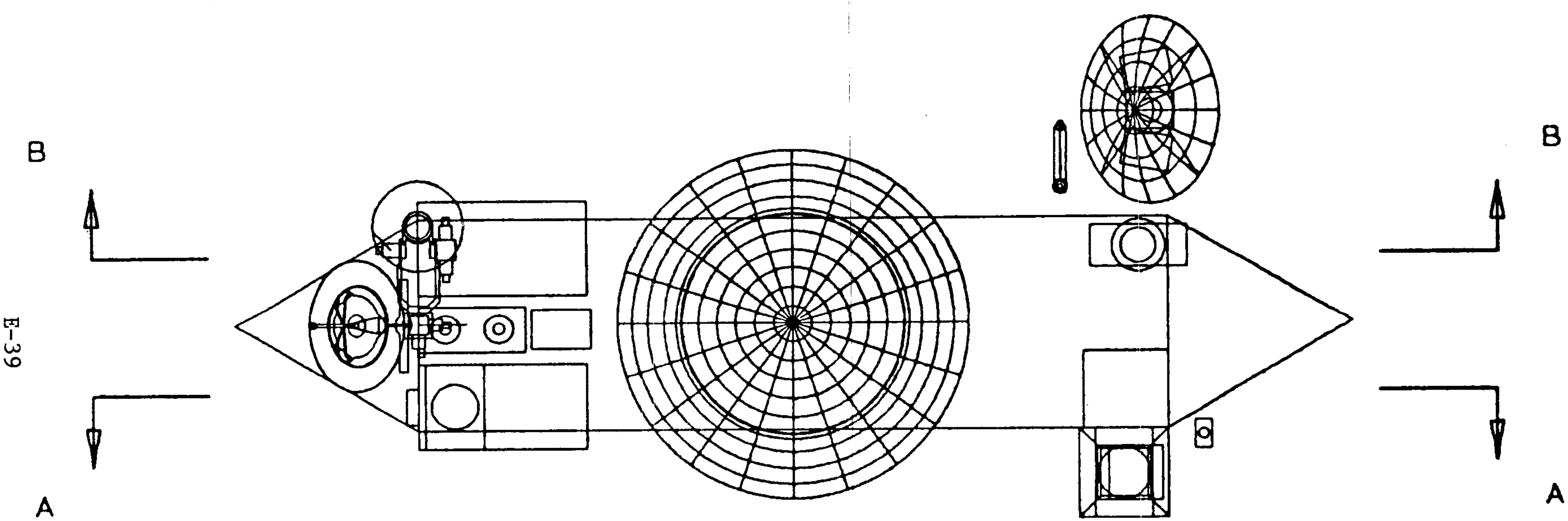
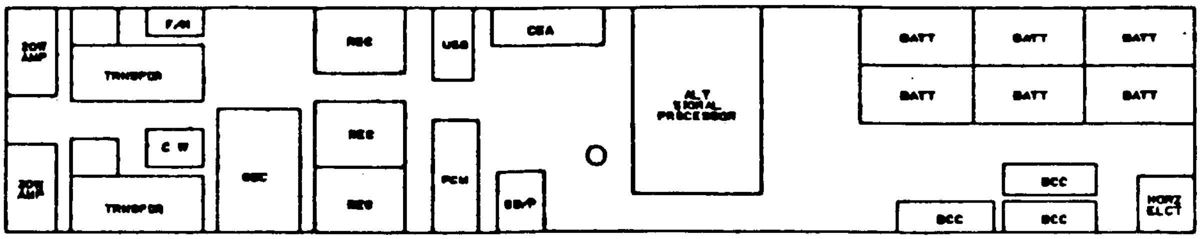
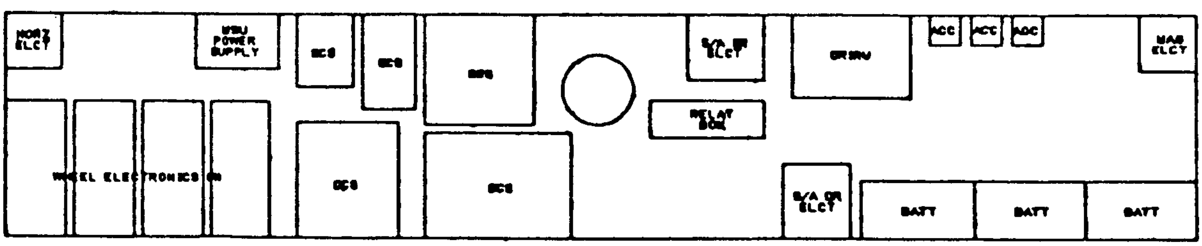


Figure 3.2-2A-3. CORS Level 1 Plan View



SECT A-A



SECT B-B

Figure 3.2-2A-4. CORS Level 1 Interior Arrangement

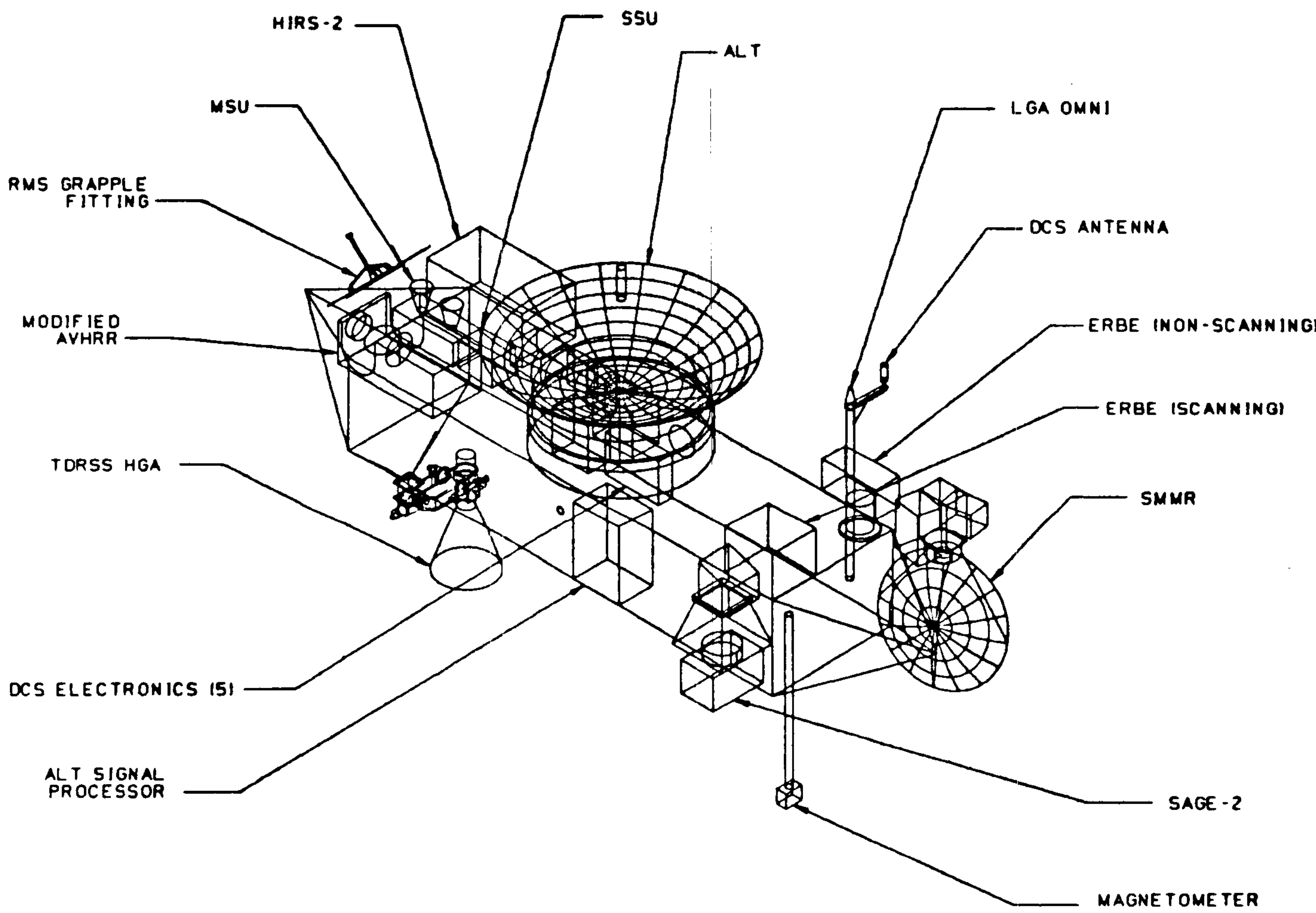


Figure 3.2-2A-5. CORS Level 1 On-Orbit Configuration

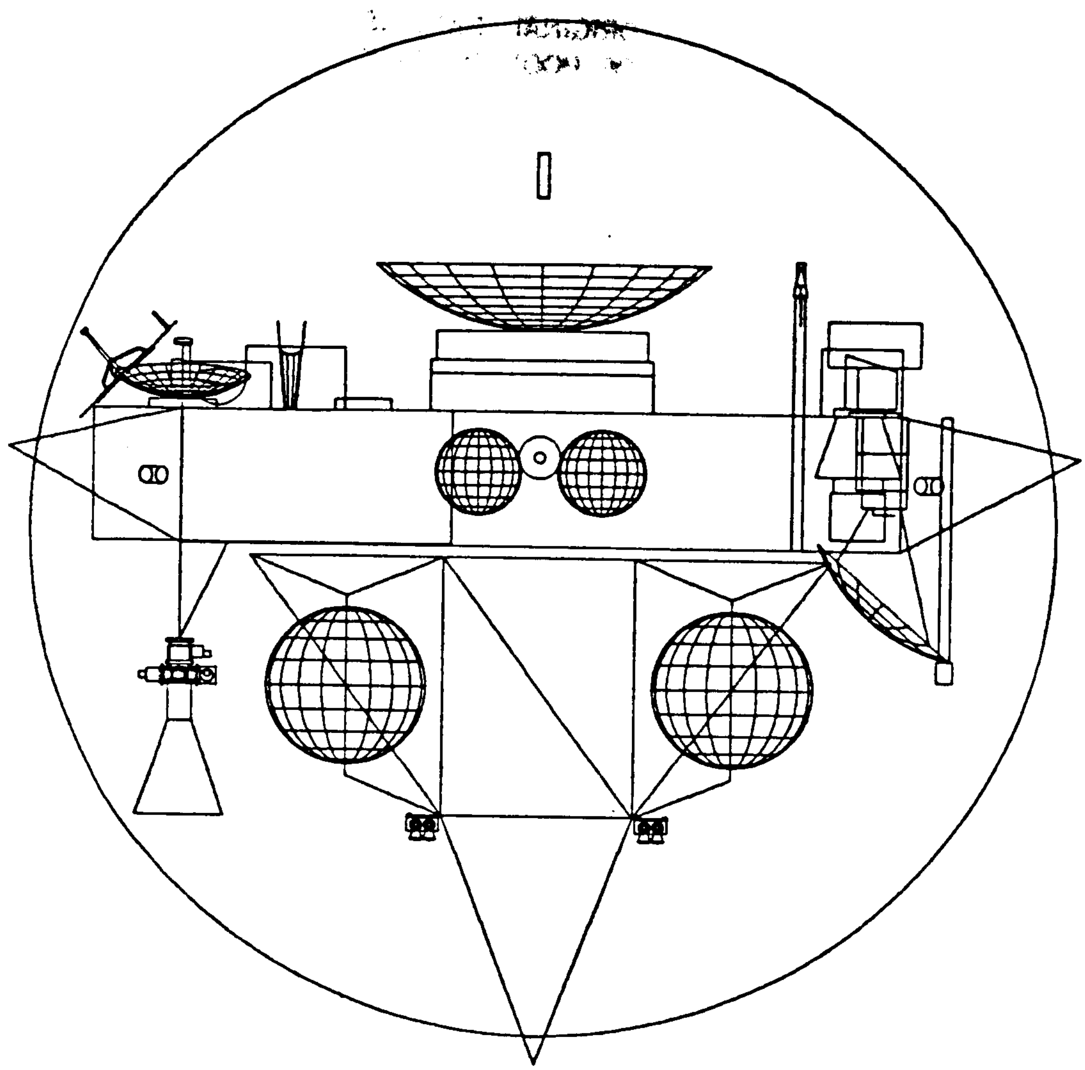


Figure 3.2-2B-1. CORS Level 2 STS Dynamic Envelope

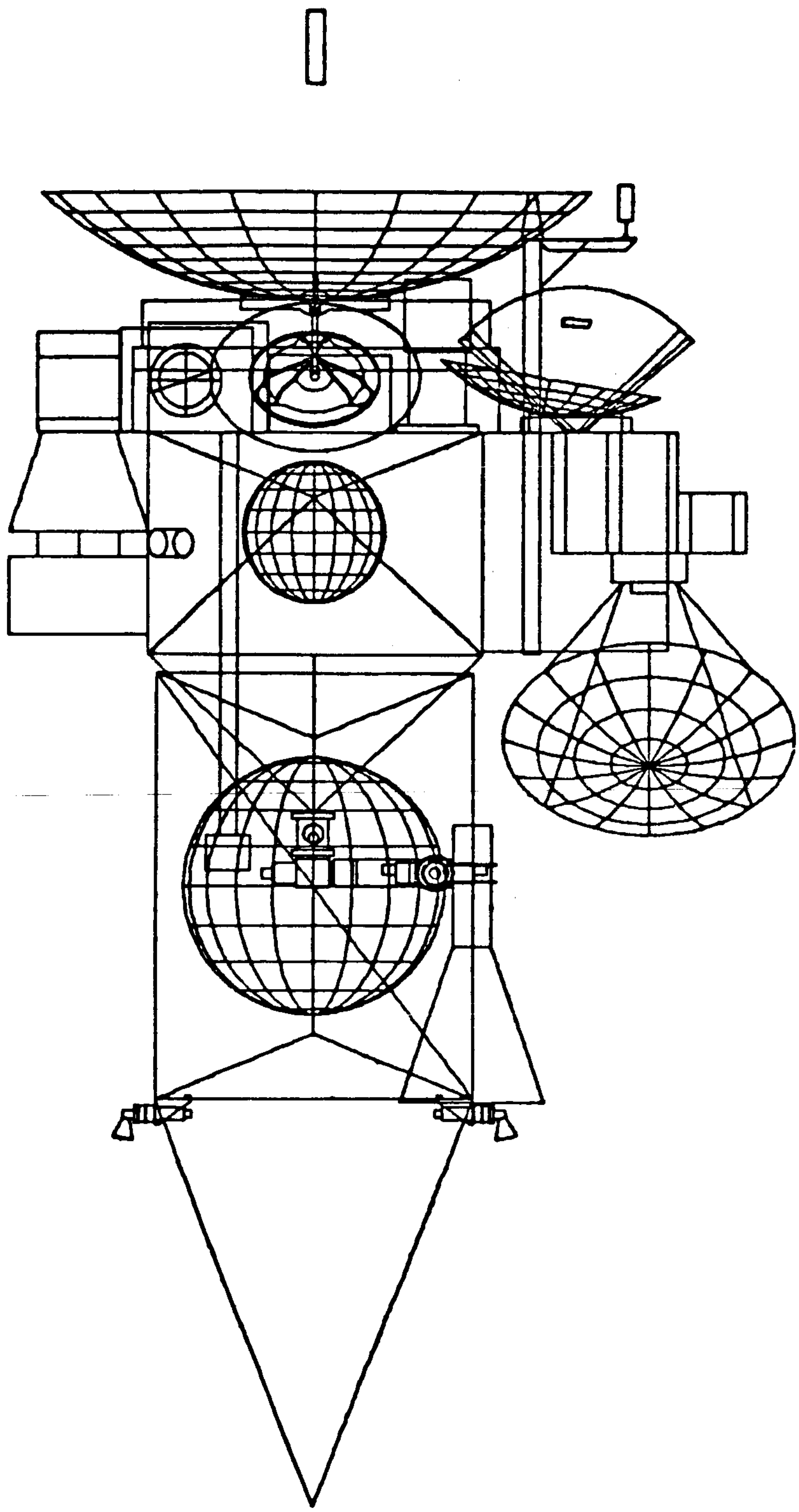


Figure 3.2-2B-2. CORS Level 2 Side View

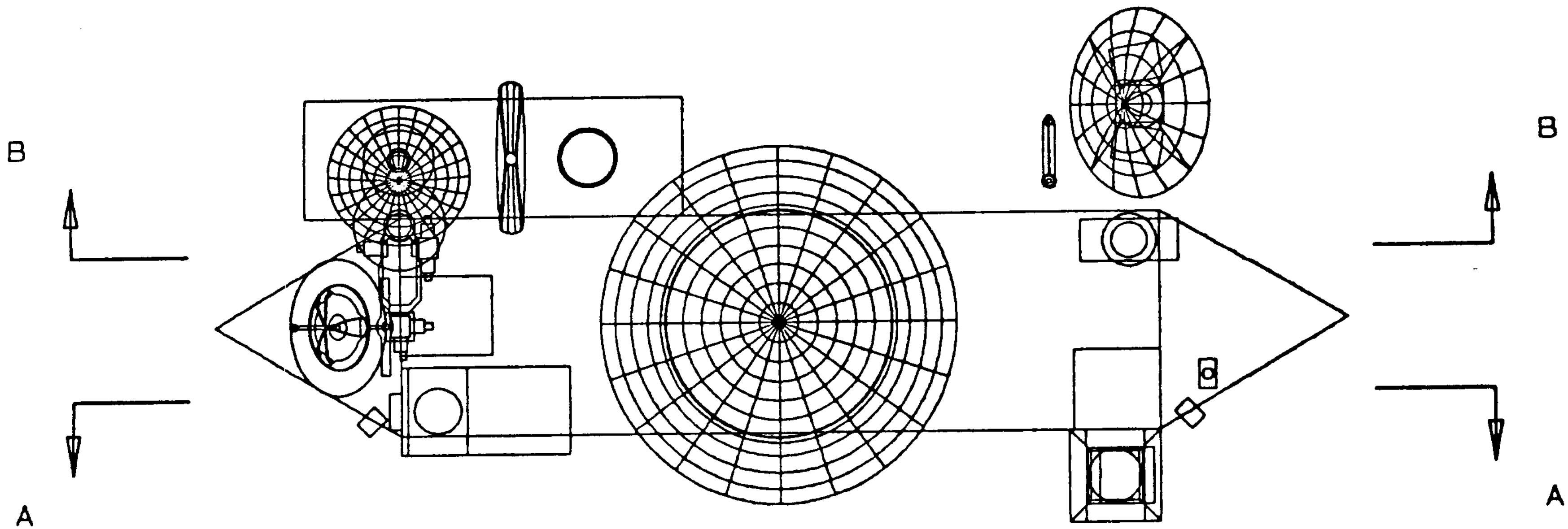
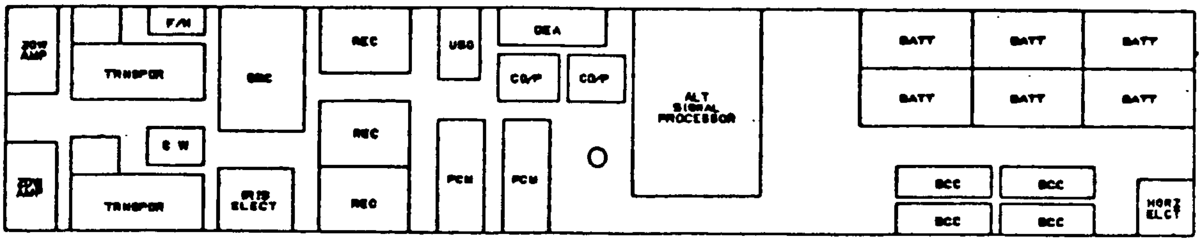
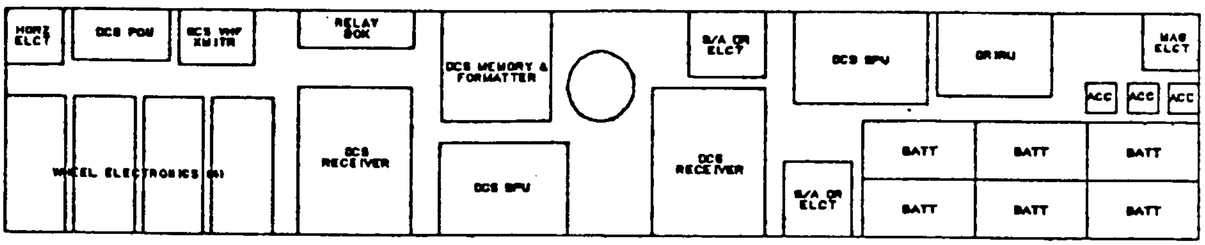


Figure 3.2-2B-3. CORS Level 2 Plan View



SECT A-A



SECT B-B

Figure 3.2-2B4. CORS Level 2 Interior Arrangement

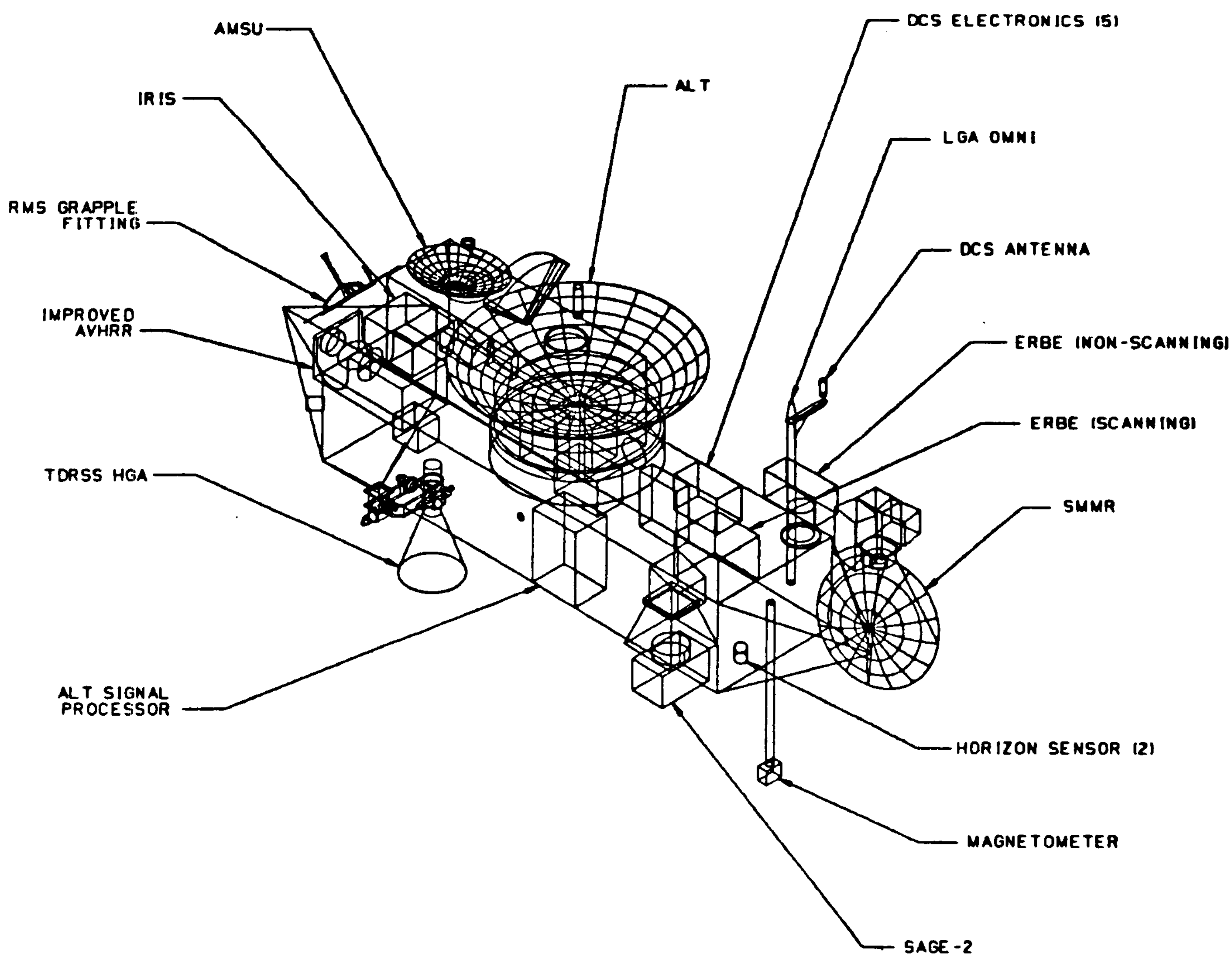


Figure 3.2-2B5. CORS Level 2 On-Orbit Configuration

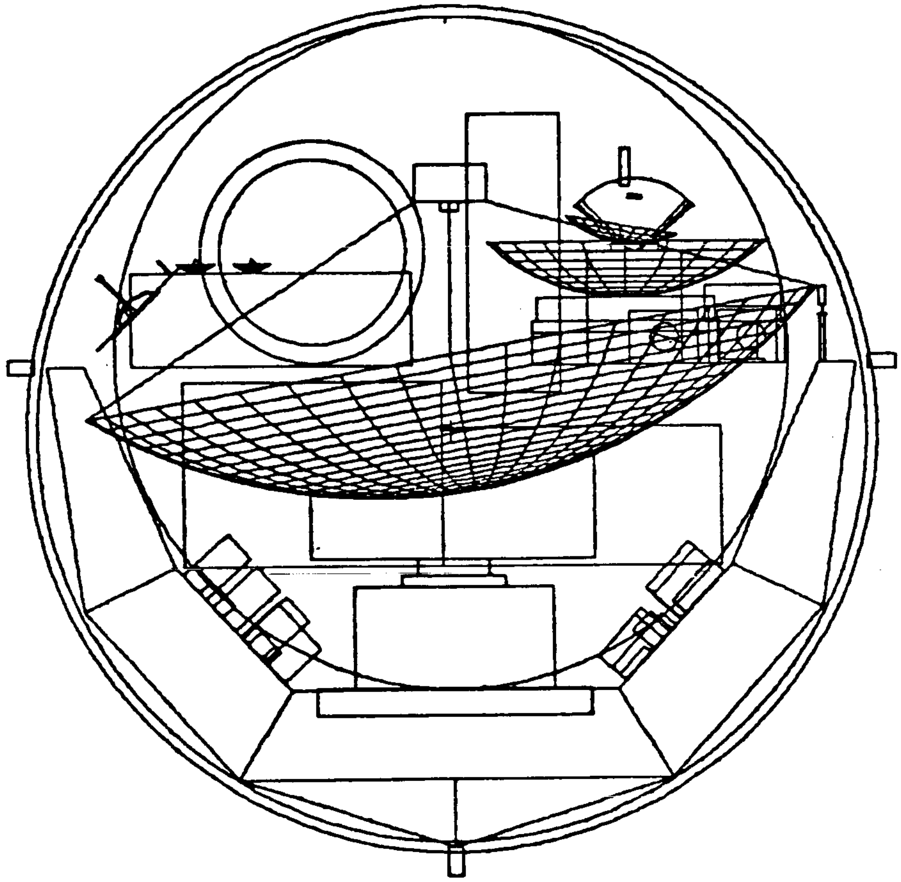


Figure 3.2-2C-1. CORS Level 3 STS Dynamic Envelope

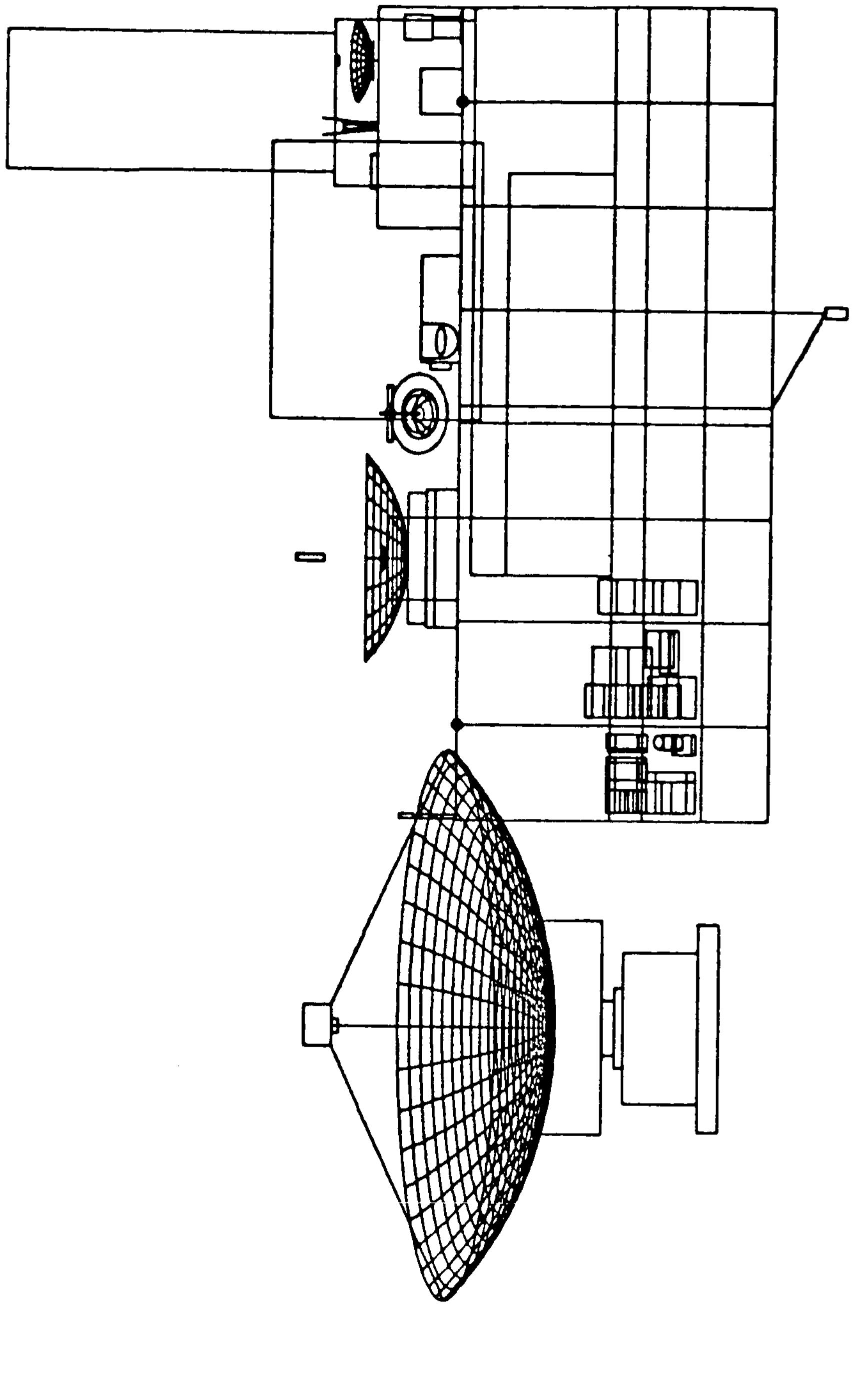


Figure 3.2-2C-2. CORS Level 3 Side View

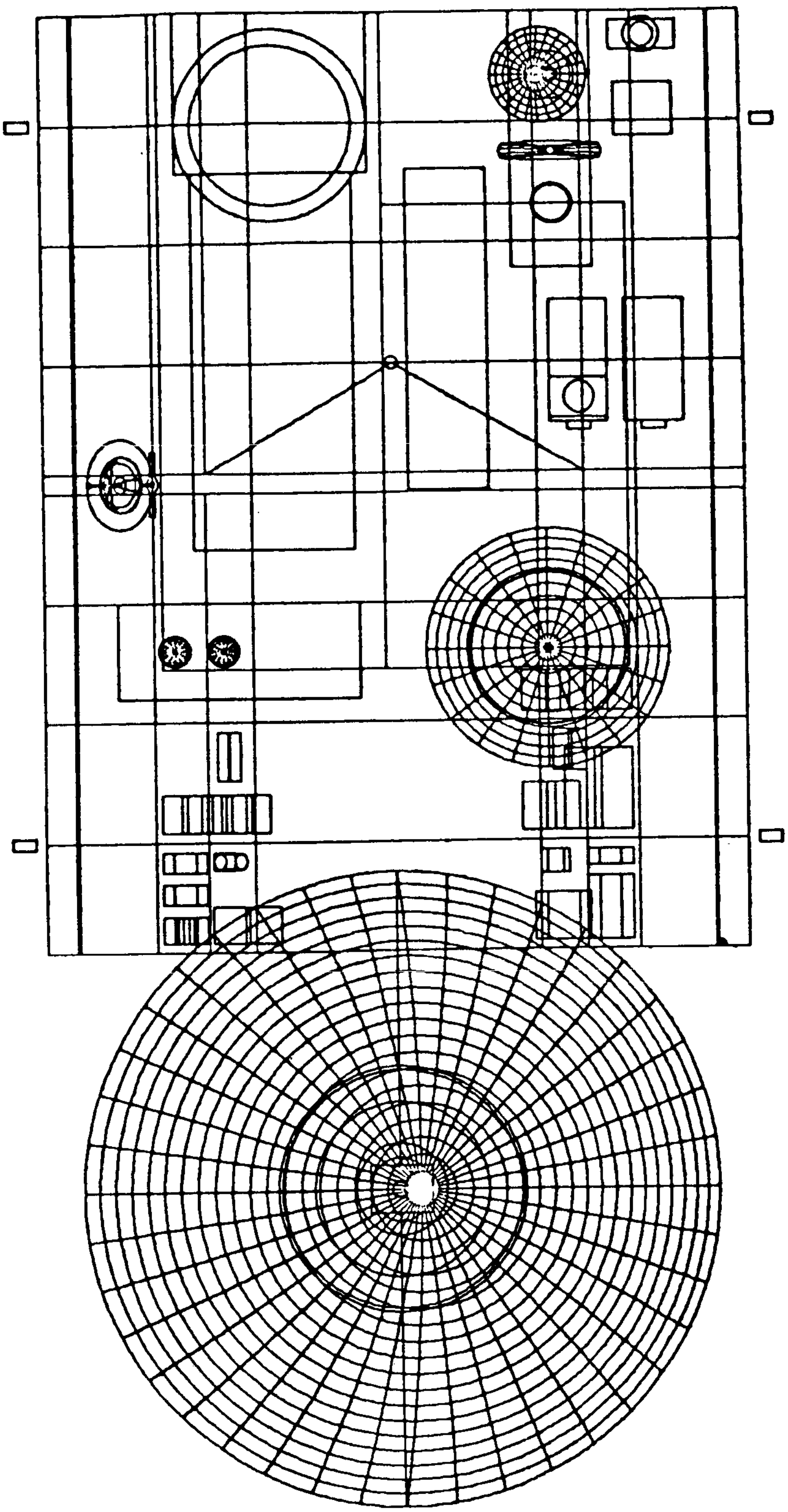


Figure 3.2-2C-3. CORS Level 3 Plan View

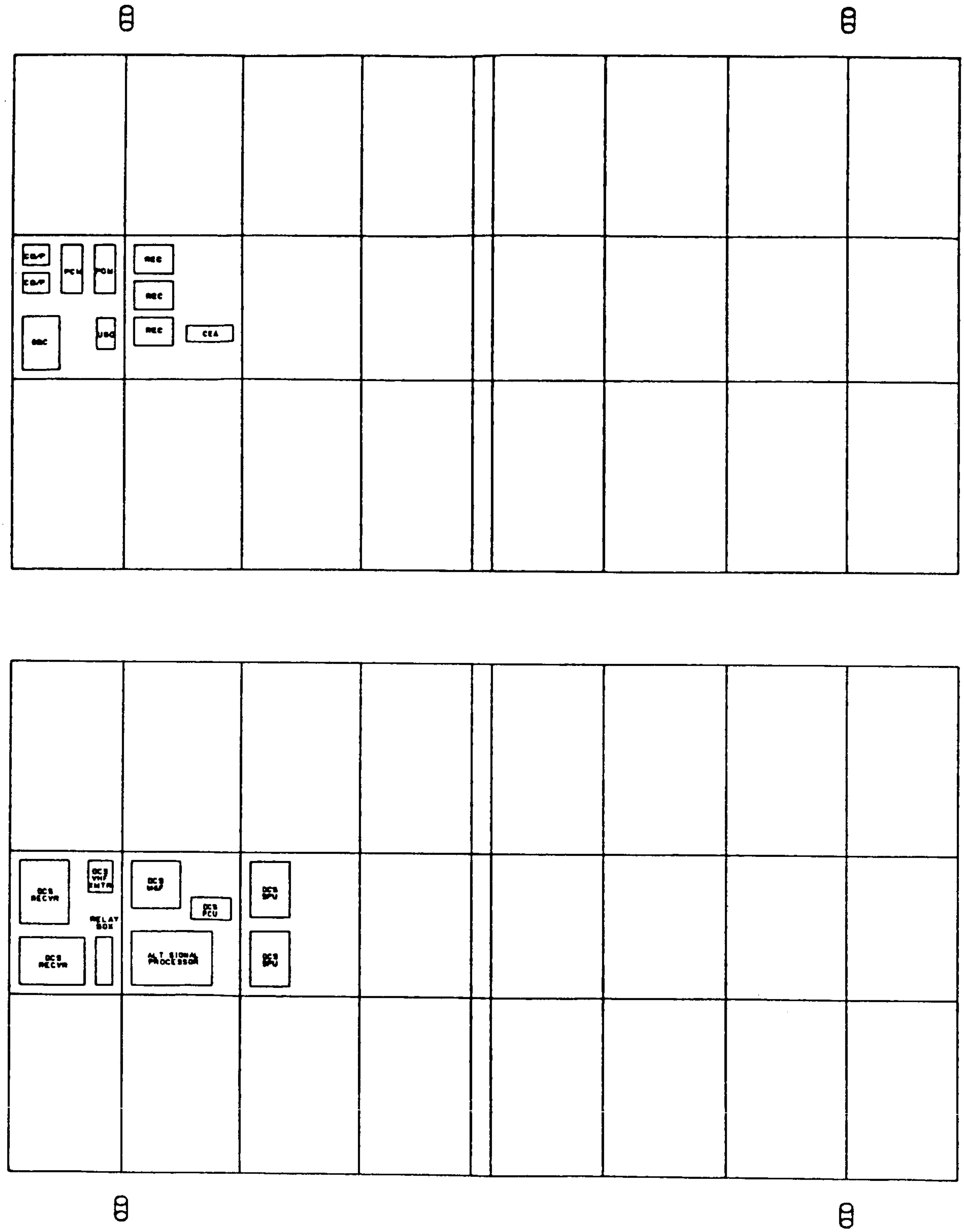


Figure 3.2-2C4. CORS Level 3 Interior Arrangement

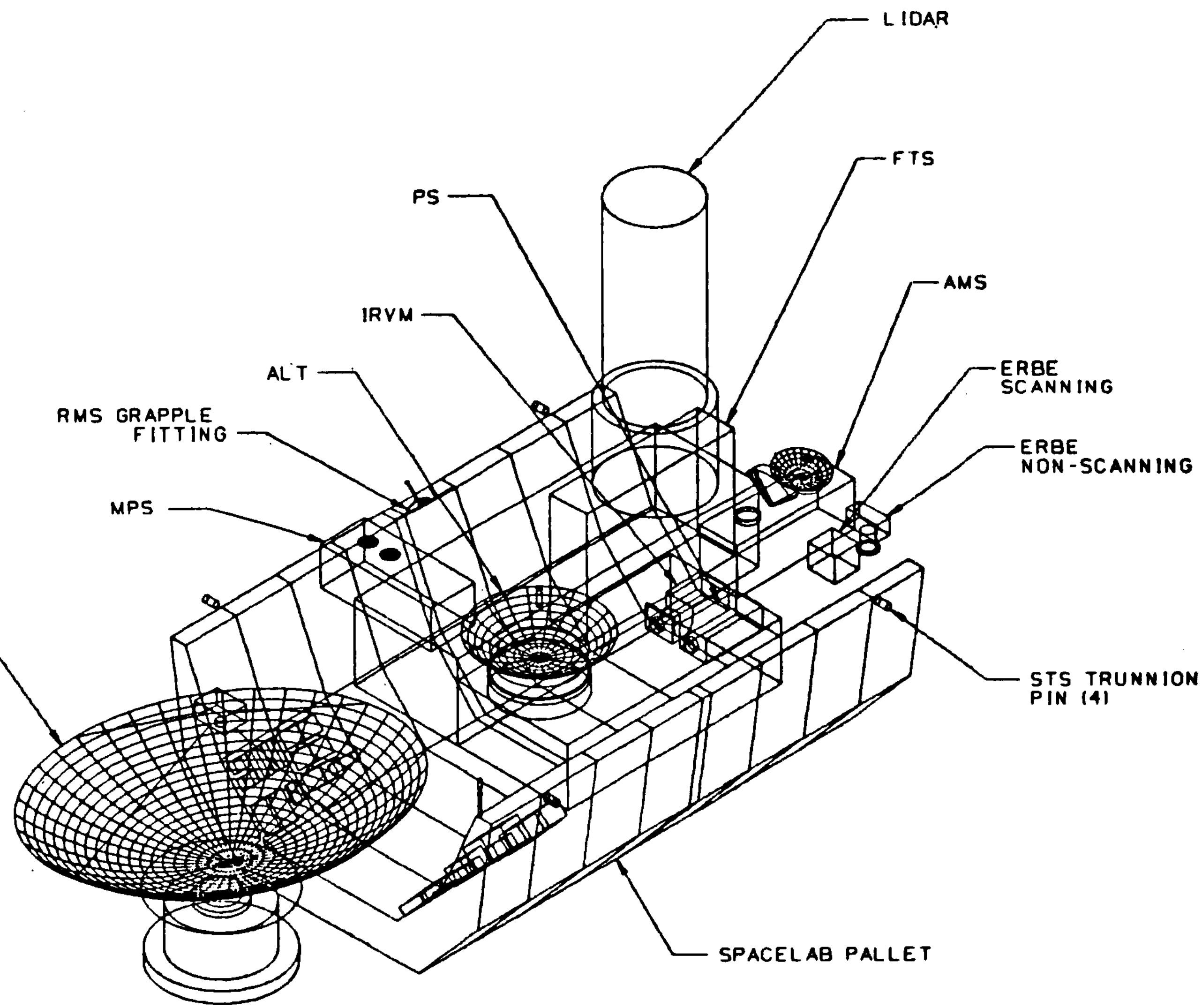


Figure 3.2-2C-5. CORS Level 3 on Orbit Configuration

MASS SUMMARY (kg)	
SATELLITE MASS	1,209
APM INERT MASS	125
APM PROPELLANT	316
ASCENT INITIAL MASS	1,650
CONTROL LENGTH	230 CM

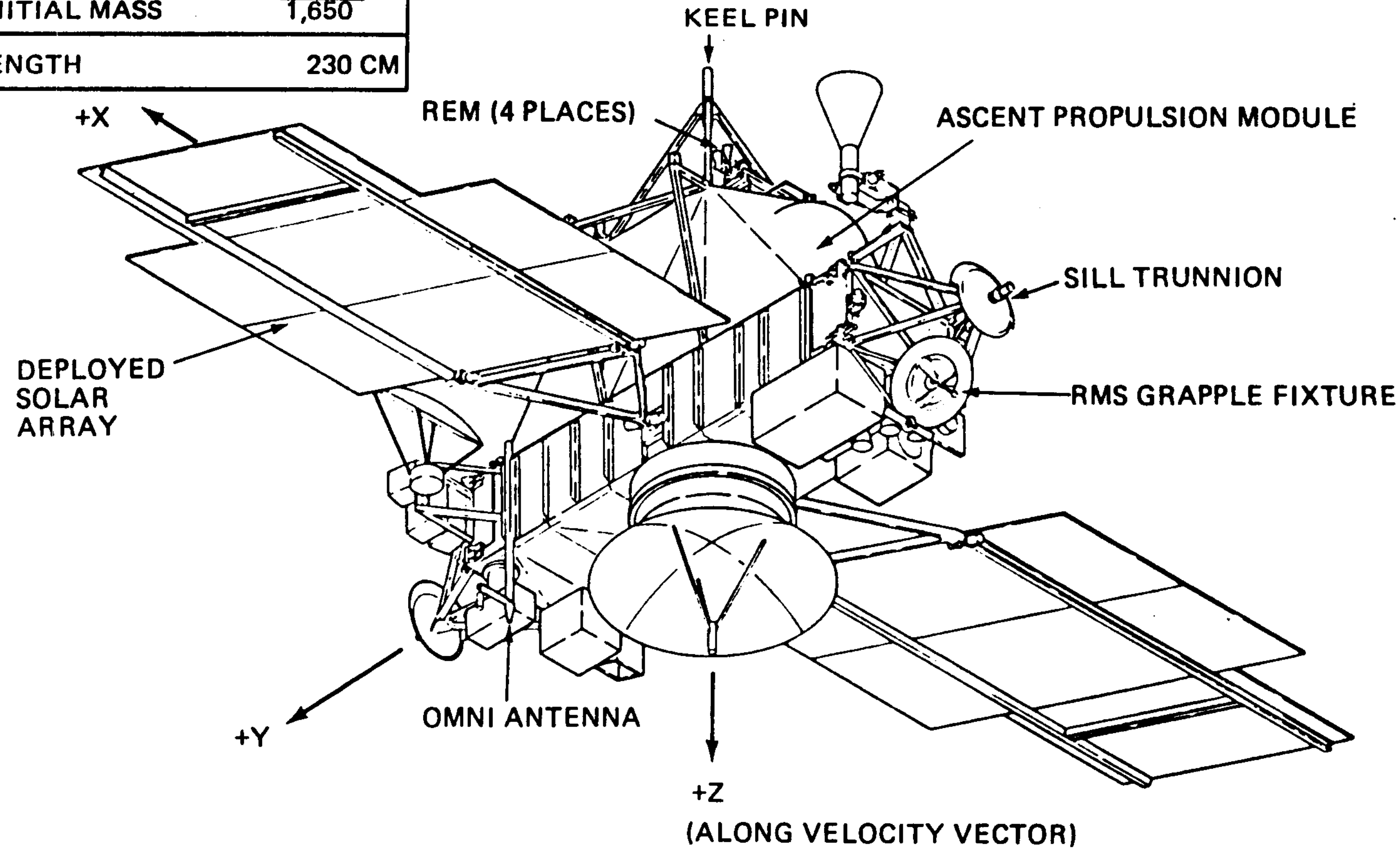


Figure 3.2-3A. CORS Level 1 Ascent Mode

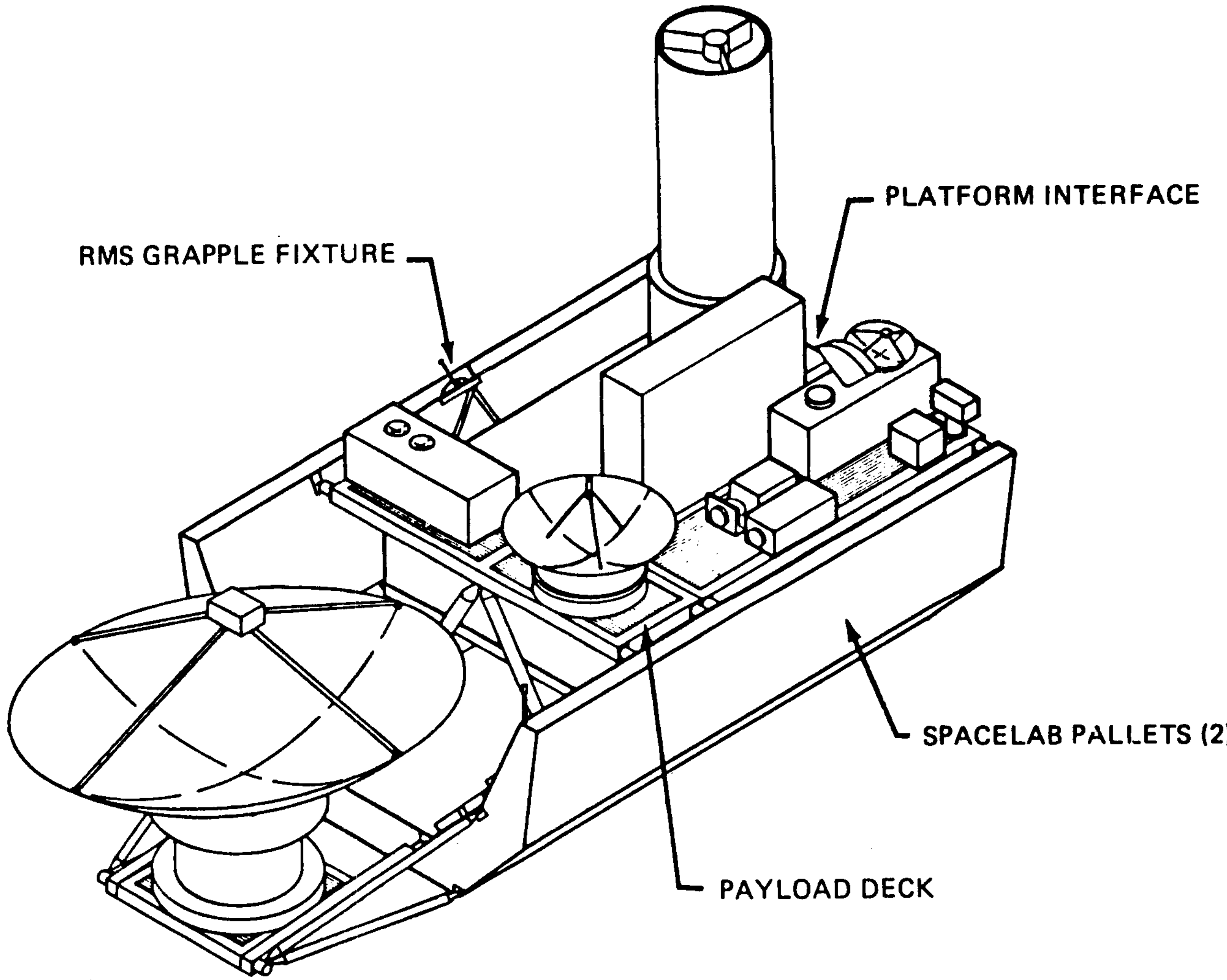


Figure 3.2-3C. CORS Level 3 Equipment Module

MASS SUMMARY (kg)	
SATELLITE BURNOUT MASS	1,165
USABLE PROPELLANT	40

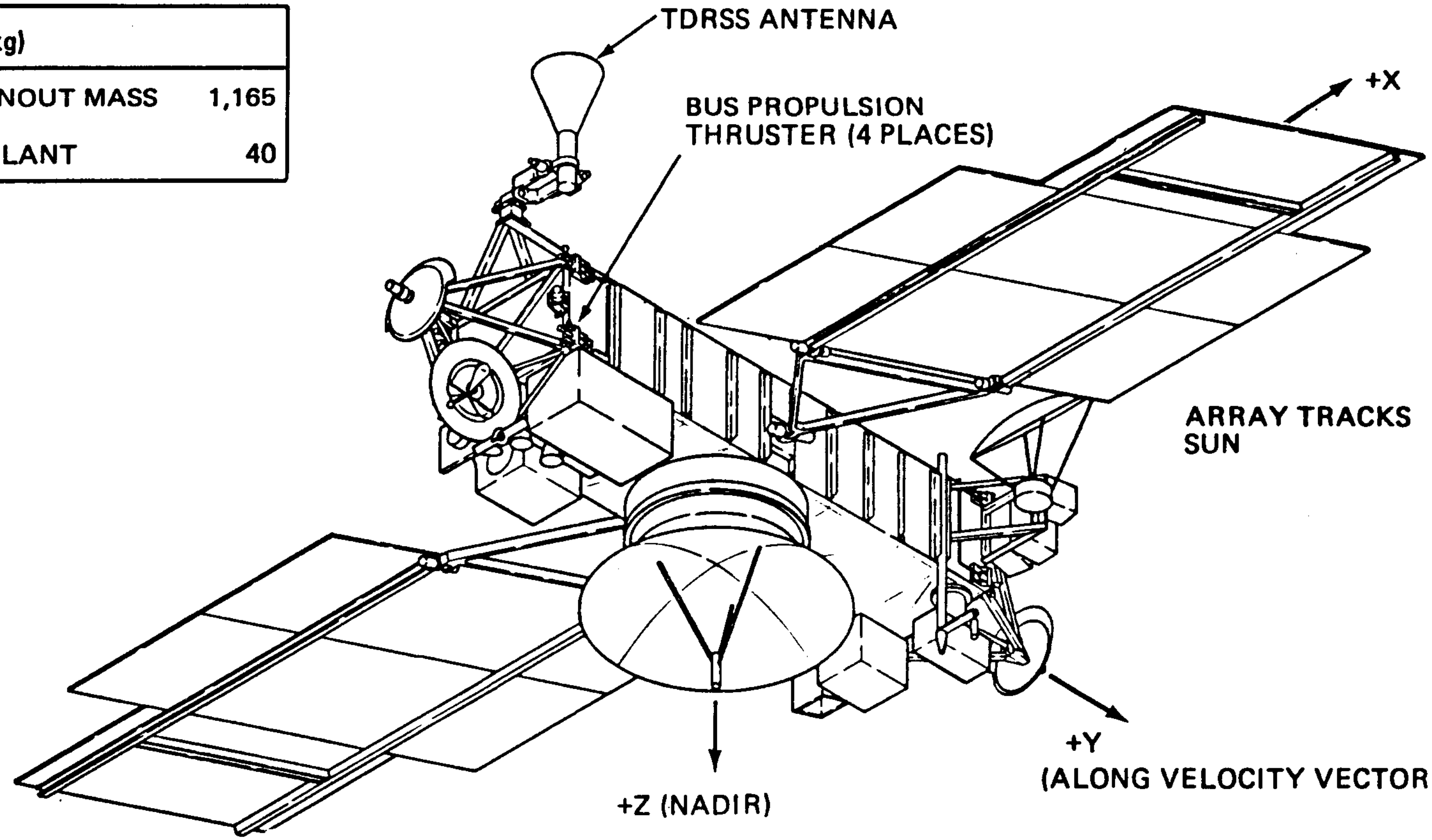


Figure 3.2-4A. CORS Level 1 Observation and Maneuver Mode

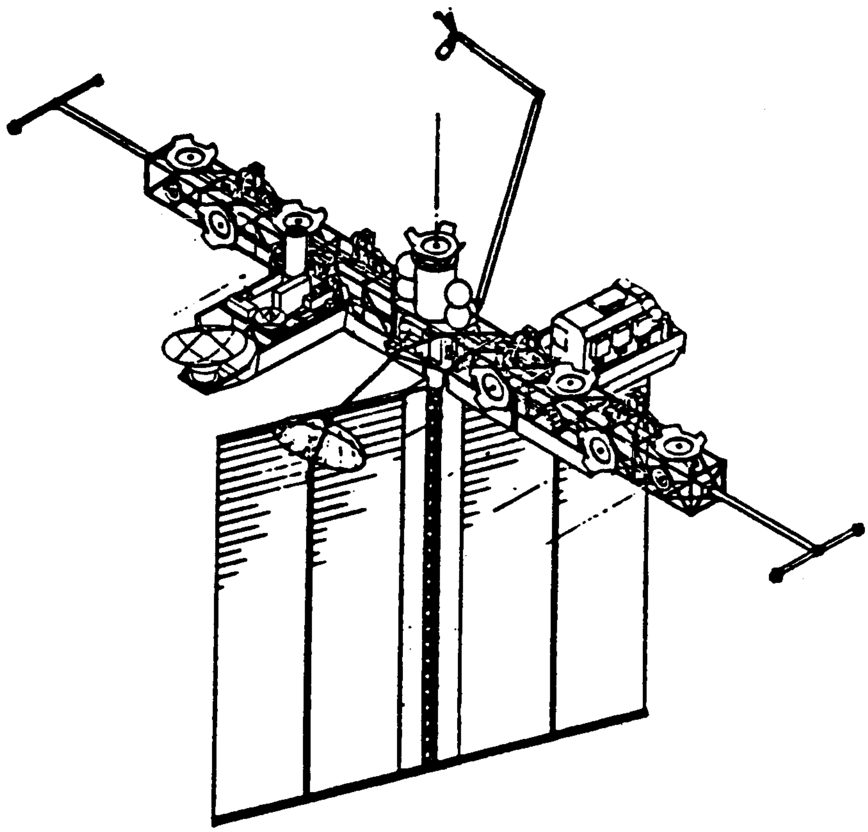


Figure 3.2-4C CORS Level 3 Operational Configuration

MASS SUMMARY.

The mass summary for the three CORS missions is shown in figure 3.2-5. The indicated delta V capabilities reflect nominal thruster performance and have significant margins, for both Level 1 and Level 2, above the presently defined requirement of 396 m/s capability for ascent propulsion, and 60 m/s capability for bus propulsion.

MISSION DESCRIPTION.

In the baseline mission, the Level 1 and Level 2 satellite experiences three distinct flight regimes:

a. The satellite is carried from the western test range (WTR) by the STS to a circular parking orbit where it is checkout on the RMS prior to release.

b. The satellite is released from the STS RMS and uses its ascent propulsion module to raise its altitude to the operational orbit.

c. After jettisoning its ascent propulsion module, the satellite undergoes on-orbit checkout, performs orbit trim maneuvers, and maintains the observational orbit acquiring data for the balance of its design life.

For the Level 3 mission, the CORS module be directly attached to a space platform by the STS RMS, where checkout would occur prior to RMS release.

Figure 3.2-6 shows the launch, deployment and ascent operations sequence for the Level 1 and Level 2 missions.

	Level 1		Level 2		Level 3
Science payload	(365)		(401)		(2200)
Bus subsystems (dry)	(699)		(756)		(1320)
Communications	42		42		–
Command and data handling	60		80		60
Attitude determination and control	82		82		–
Electrical power and pyrotechnics	130		150		30
Thermal control	25		27		30
Structure, cabling, and mechanisms	335		350		1200
Propulsion	25		25		–
Pressurant and residual propellant	(1)		(1)		–
Allocatable reserve	(100)		(100)		(100)
Satellite on-orbit burnout mass	1165		1258		–
Bus usable propellant, on-orbit	(40)	I_{sp} = 212	(40)	I_{sp} = 212	
Satellite on-orbit initial mass	1205	ΔV = 70 m/s	1298	ΔV = 65	3620
Bus usable propellant, ascent roll control	(4)		(4)		–
Ascent module (dry)	(125)		(125)		–
Propulsion	50				
Structure, cabling, and mechanisms	65				
Thermal control	10				
Pressurant and residual propellant	(4)		(4)		–
Allocatable reserve	(20)		(20)		–
Satellite ascent phase burnout mass	1358		1451		–
Ascent module usable propellant	292	I_{sp} = 228	292	I_{sp} = 228	–
Satellite ascent phase initial mass	1650	ΔV = 435 m/s	1743	ΔV = 410	–
Airborne support equipment	(370)		(370)		(500)
Allocatable reserve	(30)		(30)		(50)
Satellite system launch mass	2050		2143		4170

*Units in kilograms

Figure 3.2.5. CO_2 Research Satellite Mass Status Summary

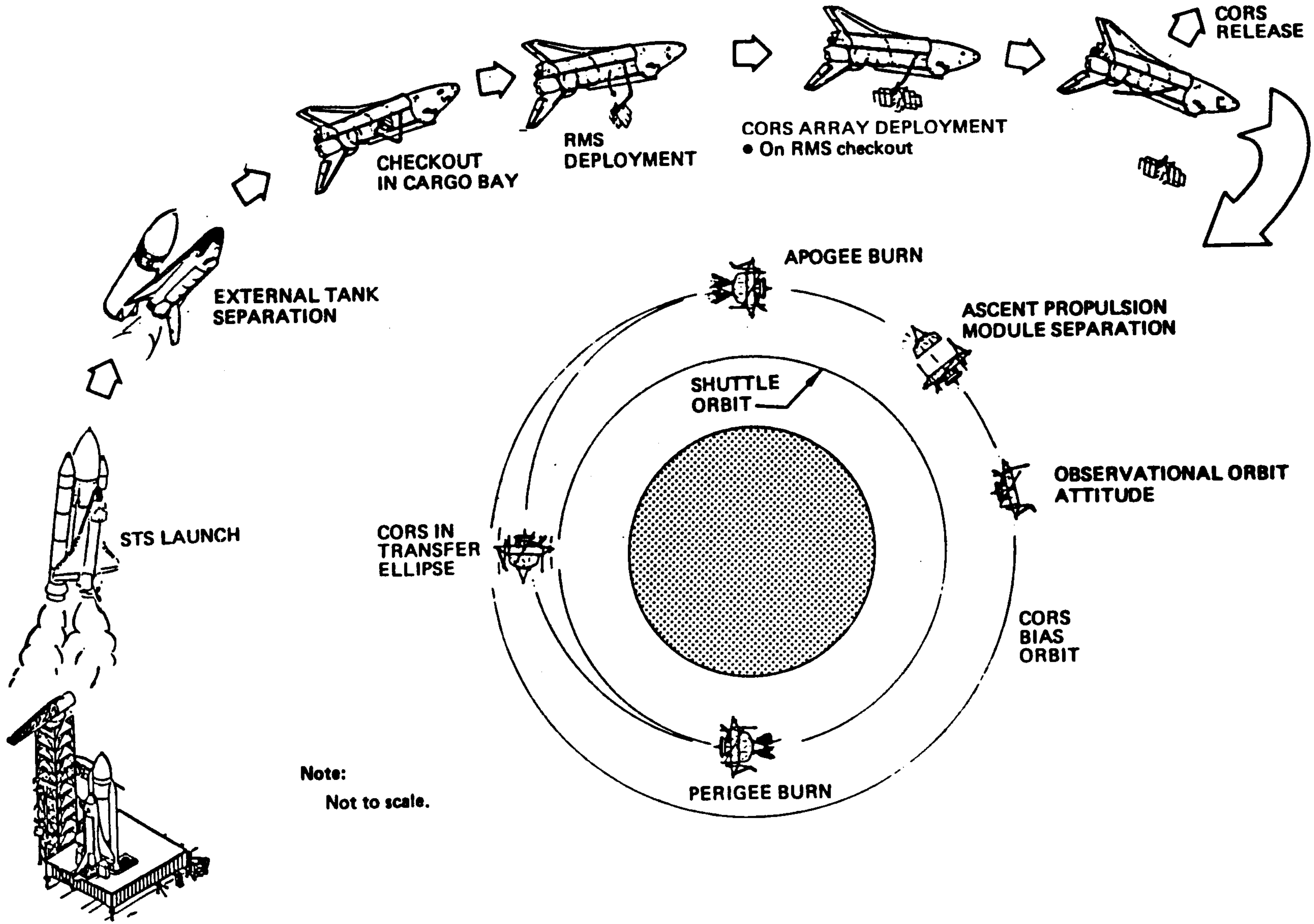


Figure 3.2-6. Launch, Deployment, and Ascent Operations Sequence

3.3 SUBSYSTEM DESIGN

COMMUNICATIONS SUBSYSTEM.

The CORS communications subsystem features low-risk implementation characterized by using flight-proven hardware elements. The subsystem will provide communications with the ground via the S-band Single Access (SSA) TDRSS link; backup communications are provided by a direct CORS satellite-to-ground link.

CORS communications requirements are summarized below. An overall bit error rate less than 10^{-5} is provided for all links.

a. Provide on-orbit TDRSS SSA forward and return link service

Command	1K bps
Telemetry	1.8M bps (playback)
	740K bps (real time)
	36K bps (real time)
Ranging	(two-way)
Doppler	(one-way or two-way)

b. Provide backup on-orbit direct-to-ground link service

Telemetry	1.8M bps (SSA format)

c. Provide ascent TDRSS SSA forware and return link service

Command	1K bps
Telemetry	8K bps

The approach used to meet these requirements consists of--

a. Using a two-axis, steerable, 20-dB horn antenna and 20W power amplifier to close the CORS-to-TDRS ascent and on-orbit return links.

b. Using the same 20-dB horn antenna to close the CORS-to-TDRS forward links.

c. Using a conical log spiral, 120-deg field-of-view omni antenna to close the direct link to ground.

d. Using the NASA standard TDRSS transponder to provide TDRSS compatible modulation.

e. Providing redundant flight hardware to eliminate single-point failures.

Figure 3.3-1 shows the on-orbit margins for the SSA and ground station

Link parameters	S-band Single Access Service		Ground station	
	Q-channel	I-channel	Q-channel	I-channel
Data rate (K bps)	1800	1	1800	1
Transmitted power (dBW)	12	6	12	6
L_{STD}(dB)	192.2	192.9	—	—
Space loss (dB)	- 192.9	- 192.2	- 171.3	- 171.3
Pointing loss (dB)	-0.3	-0.3	—	—
Polarization loss (dB)	-0.3	-0.3	-0.3	-0.3
Antenna gain (dB)	20	20	-2.0	-2.0
Ohmic losses (dB)	-1.6	-1.6	-1.6	-1.6
Data rate (dB-Hz)	-62.5	-30.0	-62.5	-30.0
TDRSS constant (dB)	35.7	34.7	231.6*	231.6*
Margin (dB)	2.3	27.8	5.9	32.4

* Equivalent ground station constant

Figure 3.3-1. CO_2 Research Satellite Telemetry Link Margins telemetry links. The ascent mode telemetry was not addressed in figure 3.3-1 because it uses the same signal path with a lower data rate than the on-orbit mode, and hence will have greater margins. Command link margins will be easily met, so they are not included in the link calculation.

COMMAND AND DATA HANDLING SUBSYSTEM.

The command and data handling subsystem (CDHS) accepts and distributes commands, gathers and formats telemetry, provides clock and timing control, and performs real time processing for onboard control functions.

Commands may be received from the STS before separation or from the CORS communications subsystem. Delayed action ground commands or programmed command sequences can be stored in the CDHS for later execution. Telemetry data can be provided to the STS or CORS communications subystem for transmission to the ground. Telemetry can also be recorded in the CDHS main memory or on the satellite tape recorders. Telemetry formats are programmable from the ground and controlled by onboard software. The CDHS uses a 5 MHz clock. Real time processing consists of gathering required measurement data to which programmed algorithms or logic functions aree applied in order to generate control commands. The primary onboard computer functions are attitude control, power management, maneuver thrust control, sequencing and scheduling tasks, configuration and resource management, and data compression. CDHS performance characteristics are summarized in figure 3.3-2.

ATTITUDE DETERMINATION AND CONTROL SUBSYSTEM.

The CORS attitude determination and control subsystem (ADCS) provides 0.1 deg attitude determination for nadir pointing using two horizon sensors and the DRIRU II gyro package. For orbit injection, the Z-axis is maintained within 1.5 deg of the velocity vector and yaw is controlled within 4 deg. On-orbit attitude is controlled to 4 deg in yaw and 0.1 deg in pitch and roll. Solar array and TDRSS antenna pointing are maintained within 4 deg.

Four reaction control wheels provide a smooth source of torque to control spacecraft attitude during the operational orbit. Three electromagnetic torque rods are used to desaturate the wheels. Orbit injection control requirements are achieved using a reaction control system.

The ADCS block diagram is shown in figure 3.3-3. Three control modes are necessary for performing the CORS mission.

FUNCTION	VALUE
• PROCESSOR THROUGH-PUT	477 K OPS/SEC
• MEMORY WORDS (22 BIT)	128 K
• COMMAND DATA RATE	1000 BPS
• COMMAND STORAGE ALLOCATION	1024
• MAXIMUM TAPE RECORDER CAPABILITIES (3 RECORDERS)	
• TELEMETRY STORAGE CAPACITY	$4.5 * 10^9$ BITS
• RECORD TIME AT 740 K BPS	97.7 MIN
• RECORD TIME AT 36 K BPS	34.7 HR
• PLAYBACK TIME AT 1.8 M BPS	41.7 MIN
• TYPICAL RECORDER USE	
• RECORD FOR 25 MIN AT 740 K BPS	
• PLAYBACK FOR 10.3 MIN AT 1.8 M BPS	

Figure 3.3-2. Command and Data Handling Performance

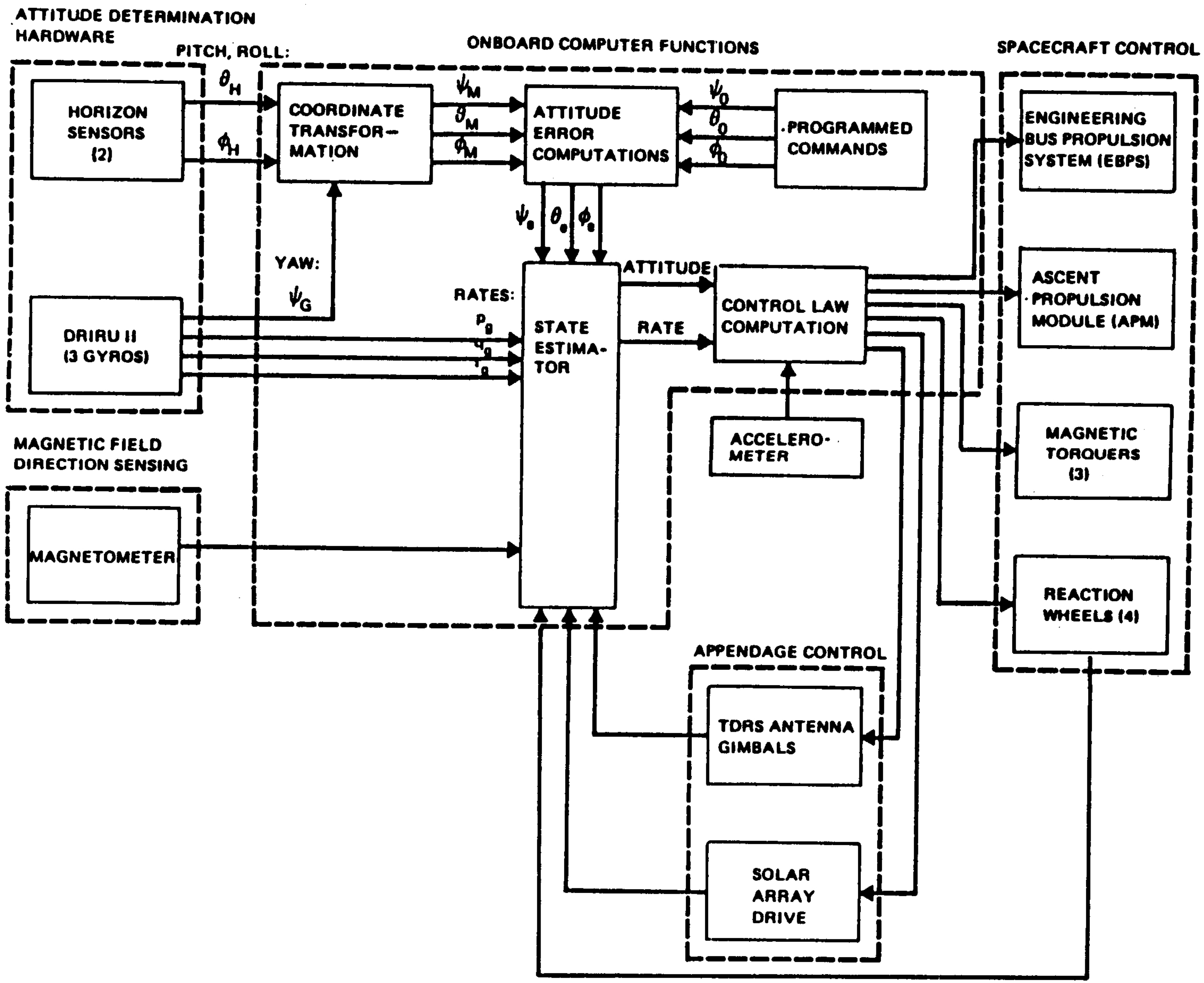


Figure 3.3-3 CORS Attitude Determination and Control System Block Diagram

ASCENT CONTROL MODE.

The first mode is ascent control, which provides attitude determination and control during transfer to the operational orbit following separation from the orbiter. Three two-axis DRIRU II gyros provide an attitude reference and an onboard computer is used to compute actuator commands for the thrust vector control system. The other two modes provide attitude determination and control during the data collection phase.

On-Orbit Control Mode. The on-orbit control mode employs four reaction wheels in a zero-net-momentum system with electromagnetic desaturation. Attitude reference is provided by the DRIRU II gyro package and horizon sensors, and the onboard computer will calculate vehicle attitude and body rates using a Kalman filtering state estimator. Control laws for the reaction wheels, solar array, and TDRSS antenna are formulated in the onboard computer.

Orbit-Adjust Control Mode. The orbit-adjust control mode consists of eight clusters of 1-lb thrusters, which will be used for orbit--adjust maneuvers and orbit circularization trim. The control system logic for ascent will also be used during orbit adjust, with an accelerometer used for thrust cutoff control. The reaction jets are used in an off-pulsing mode to make the required orbit adjustment and attitude control.

ELECTRICAL POWER AND PYROTECHNICS SUBSYSTEM.

The electrical power and pyrotechnics subsystem supplies all the vehicle electrical power requirements and the ordnance firing. Figure 3.3-4 shows a block diagram the the CORS Level 2 mission electrical power subsystem.

Voltage at the power bus is kept withinn the range of 28+4V dc by (1) the spacecraft NiCd batteries which automatically supply power whenever the solar array output voltage falls below battery voltage and (2) charge controllers which limit bus voltage to 32V maximum, depending on the charge status of the batteries.

The power control and distribution unit is contained in the relay box, as is the pyrotechnics control unit. Switching connectors, current sensors, and a termination board for command and telemetry are contained in this unit. Power is distributed to loads from the 28V dc power bus through control relays and fuses. Each redundant load has its own relay with redundant contacts. Loads that are not redundant are supplied from two relays.

The control electronics assembly is an electronics box designed to--

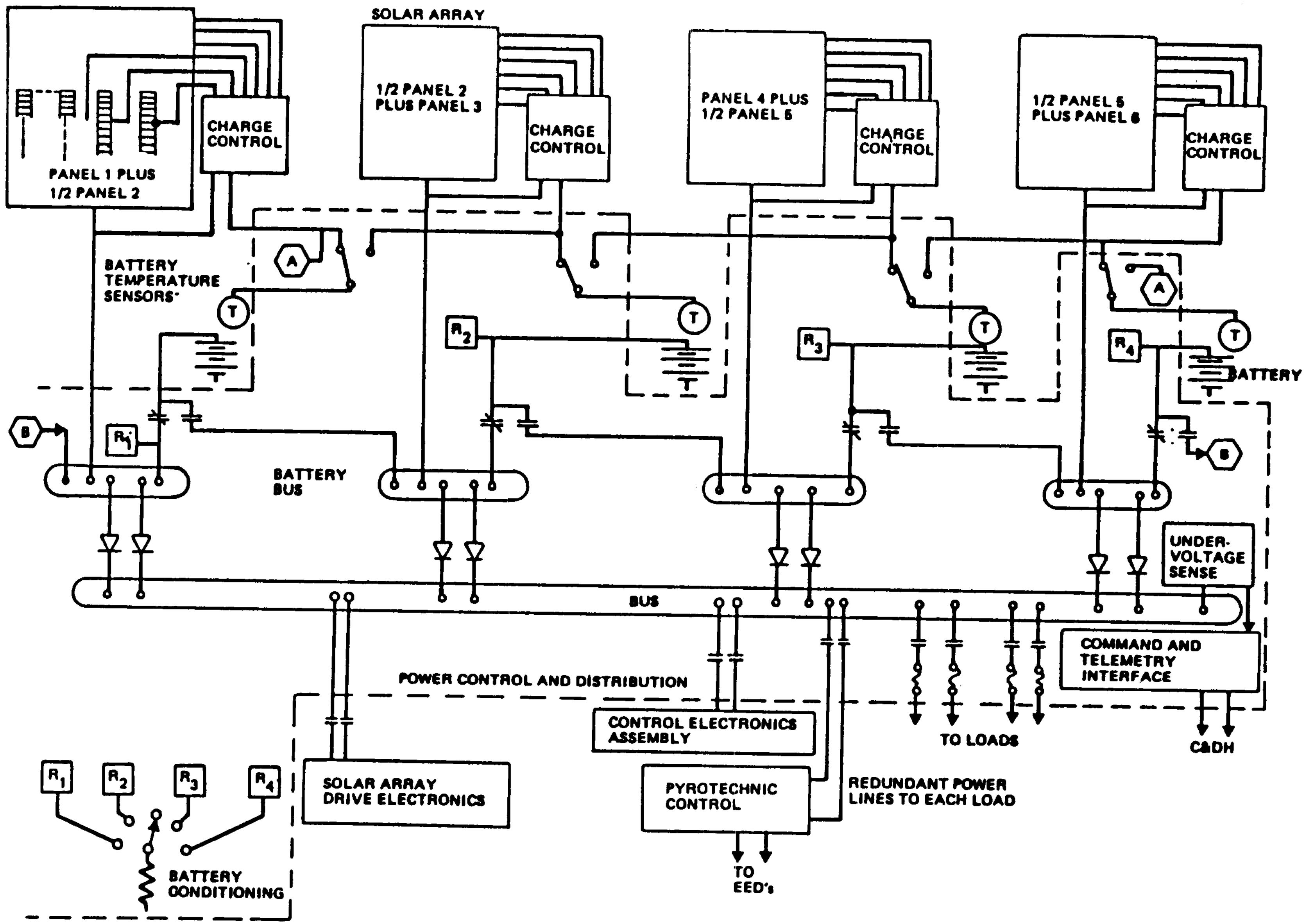


Figure 3.3-4. Electrical Power and Pyrotechnics

a. Provide computer failure detection and switching.

b. Provide for manual override for ground command.

c. Provide power and polarity switching for the solar array and TDRSS antenna drive motors.

d. Provide fault protection.

Batteries are sized to meet CORS satellite power requirements with depth of discharge limits to ensure proper operational lifetime. Reliability enhancing features such as temperature sensors, selectable charge-voltage limits, cell redundancy, and load sharing will be incorporated into the battery design.

The solar array will have six panels, three on each side of the satellite, supported on a common shaft. The panels are deployed after launch while the satellite is attached to the STS RMS. The solar array is sized to provide a 5% reserve at end of mission life. This allow the arrays to provide full required power output even while for operating slightly off the sun line.

THERMAL CONTROL SUBSYSTEM.

The thermally sensitive components on the CORS satellite consist of two types (1) instruments for which active thermal control techniques are or will be required; and (2) all other sensors, electronics, electromechanical devices, electrical power system components, and miscellaneous equipment, including any distortion-sensitive structure that is thermally controlled. We propose to provide thermal control for those items in the first category as required by the instrument. For those items in the second category, we will provide thermal control using totally passive techniques.

Equipment Bus. The majority of the second-category components are located in the equipment bus, and most of these components are mounted along the +X and -X walls of the bus. Heat rejection from the bus walls to space will be by appropriately sized optical solar reflector (OSR) panels located on the +X and -X walls of the bus and on the +Y end. The remainder of the bus will be covered with multilayer insulation blankets. These blankets will be grounded to minimize static-charge buildup in space. The total electrical load in the equipment bus is nearly constant throughout the mission lifetime. In addition, the vehicle orientation (Y-Z plane continuously aligned with the Sun) is such that there is limited exposure of the bus OSR panels to direct solar radiation. As a result, a heat balance can be established for the equipment bus during all mission operational conditions when bus components are maintained within allowable temperature extremes.

The OSR mirror panels are sized to bias the spacecraft thermal balance toward the cold side of the component allowables range at beginning of life (BOL). As end of life (EOL) is approached, degrading mirror properties will cause more incident environmental heat to be absorbed; the requirement for heater power will be reduced, then eliminated; and component temperatures will rise to midrange or upper range in the allowables band. During BOL, cold-case conditions, a small amount of heater power is required to maintain certain components above allowable temperature minimums; provision for this power has been included in the electrical power budget. No active components (e.g., louvers, heat pipes) are required for equipment bus thermal control.

STRUCTURE, CABLING, AND MECHANISMS SUBSYSTEM.

The CORS bus is a slightly modified Boeing TOPEX bus. The basic bus design is a mature, all-aluminum construction. This design will minimize orbiter payload bay length. Key requirements of the structural system are to provide strength for support; structural stiffness to avoid adverse dynamic coupling; mass consistent with performance requirements; and reliability. The major elements of the CORS bus structure as shown in figure 3.3-5 meet all CORS structural requirements.

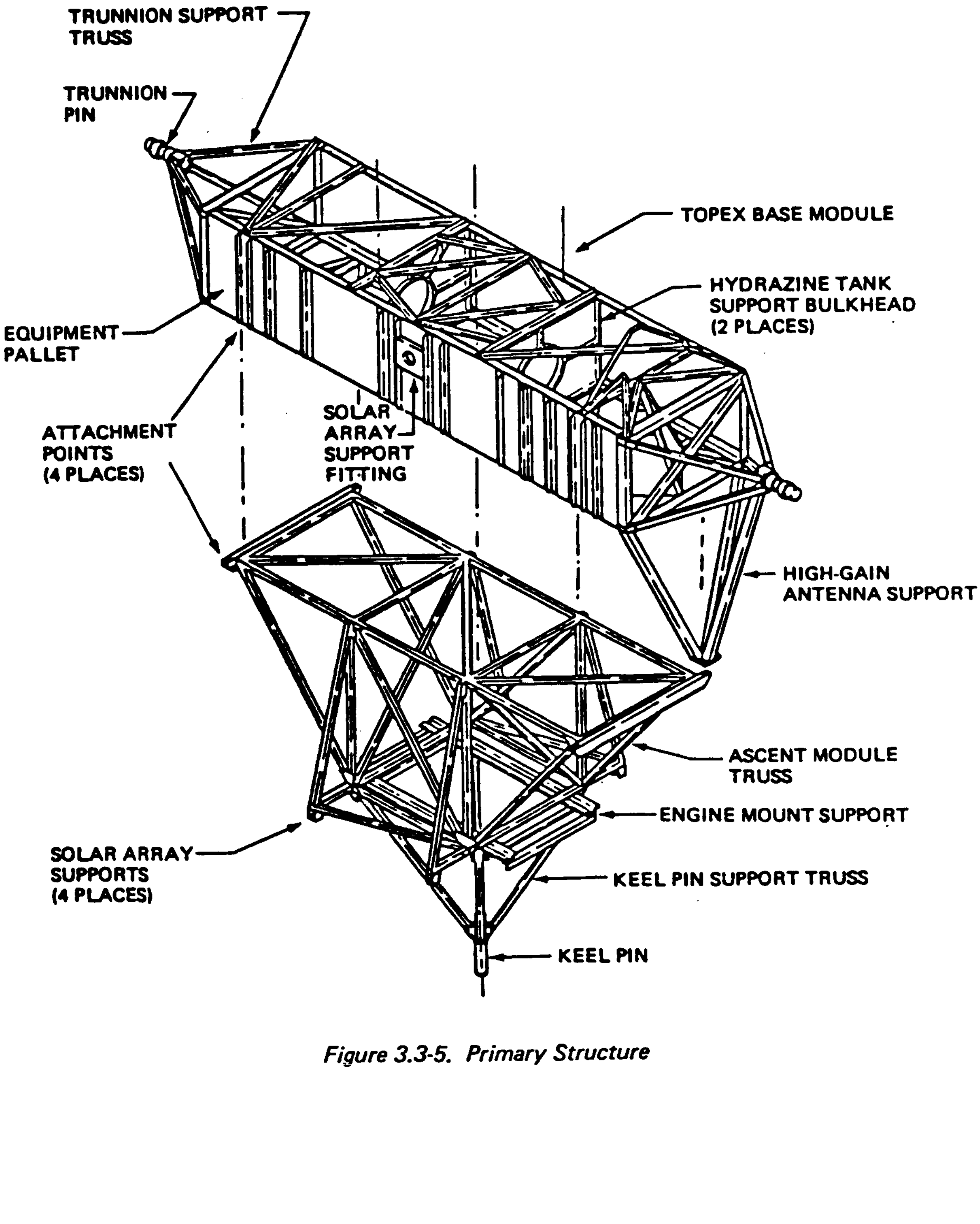


Figure 3.3-5. Primary Structure

PROPULSION SUBSYSTEM.

The baseline design for CORS propulsion is a monopropellant hydrazine system that is ideally suited for CORS because of its low cost, high reliability, and available space-flight proven components. The system has an ascent portion for a few minutes operation and a bus component for operations while in the observational orbit.

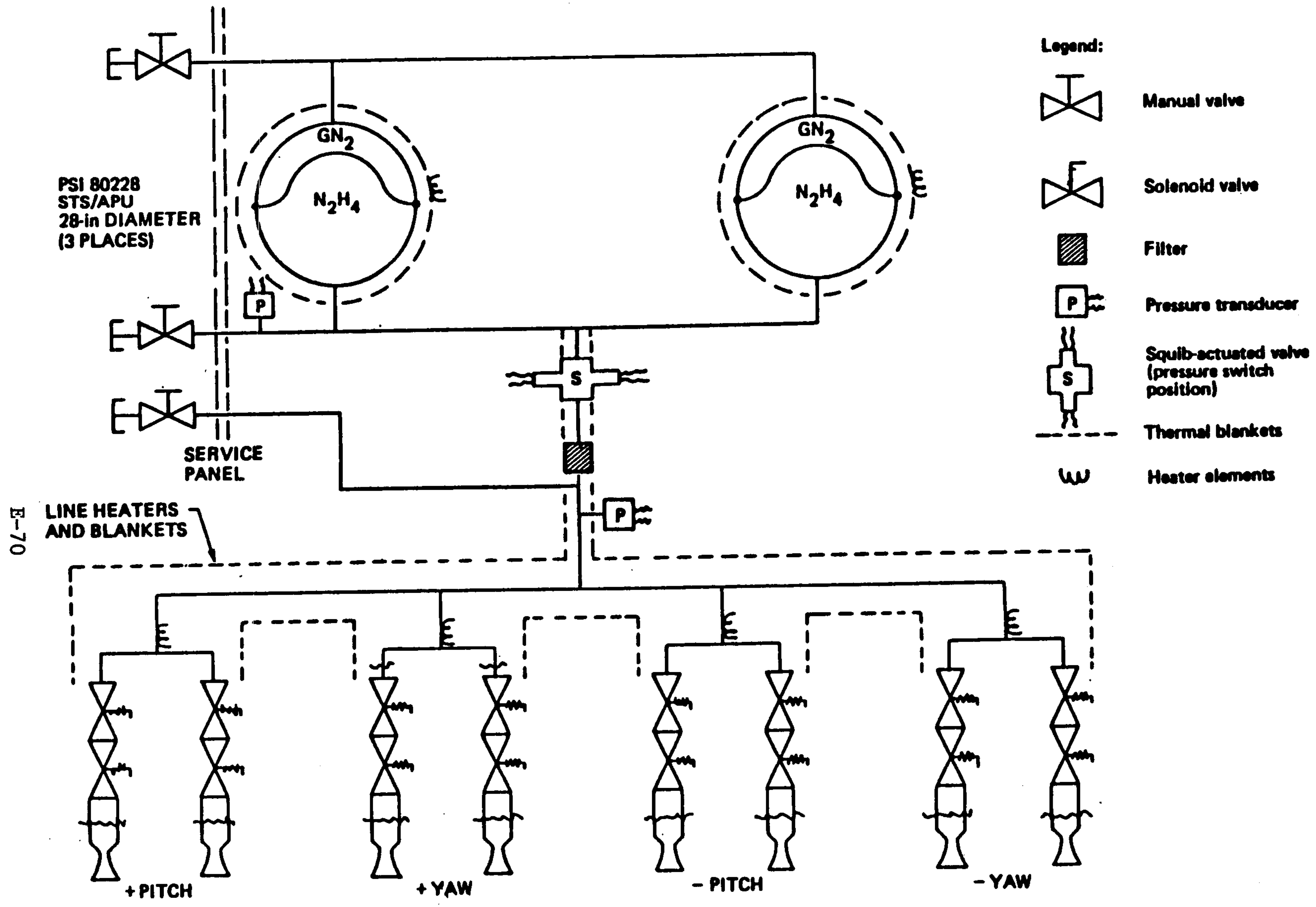
Delta V requirements are—

a. Ascent Propulsion Module	
Perigee Burn	200 m/s
Apogee Burn	195 m/s

Total Ascent Stage Rqmts	395 m/s
b. Engineering Bus Propulsion System	
Satellite Orbit Trim	30 m/s
Five Year Stationkeeping	30 m/s

Total Bus Requirements	60 m/s

Figure 3.3-6 shows a block diagram of the separable ascent propulsion module (APM). The APM transfers the satellite from the STS orbit at 250 km altitude and 99.4 deg inclination to the 982 km altitude operational orbit. The APM has two 146 kg hydrazine tanks, a feed system, and eight 133N (30-lb) IUS thrusters, based on four IUS rocket engine modules (REM). The hydrazine will be GN_2 pressure-fed in a blowdown mode from 2413 kPa to 586 kPa. The isolation of hydrazine for the APM will be identical to the IUS design. The manifold and thrusters will be dry and inert during launch and only after deployment from the orbiter will the system be armed by a pyrotechnic squib valve. Following that, the system will have a few warming pulses for the thrusters, then a commit-to-ascent burn signal will start all eight IUS thrusters. The valve heaters will not be used during the next 12 hr. Thermal control of the REM's will be provided by warming pulses every 15 min (0.25 sec pulses). A nominal 1063N thrust will be provided at initiation of the ascent burn which lasts for about 15 minutes. This is followed by a circularization firing of about 30 min duration at apogee. Thrust vector control during ascent



• Eight 30-lb-thrust (IUS-REMS-H/S 290-21002-1) engines.

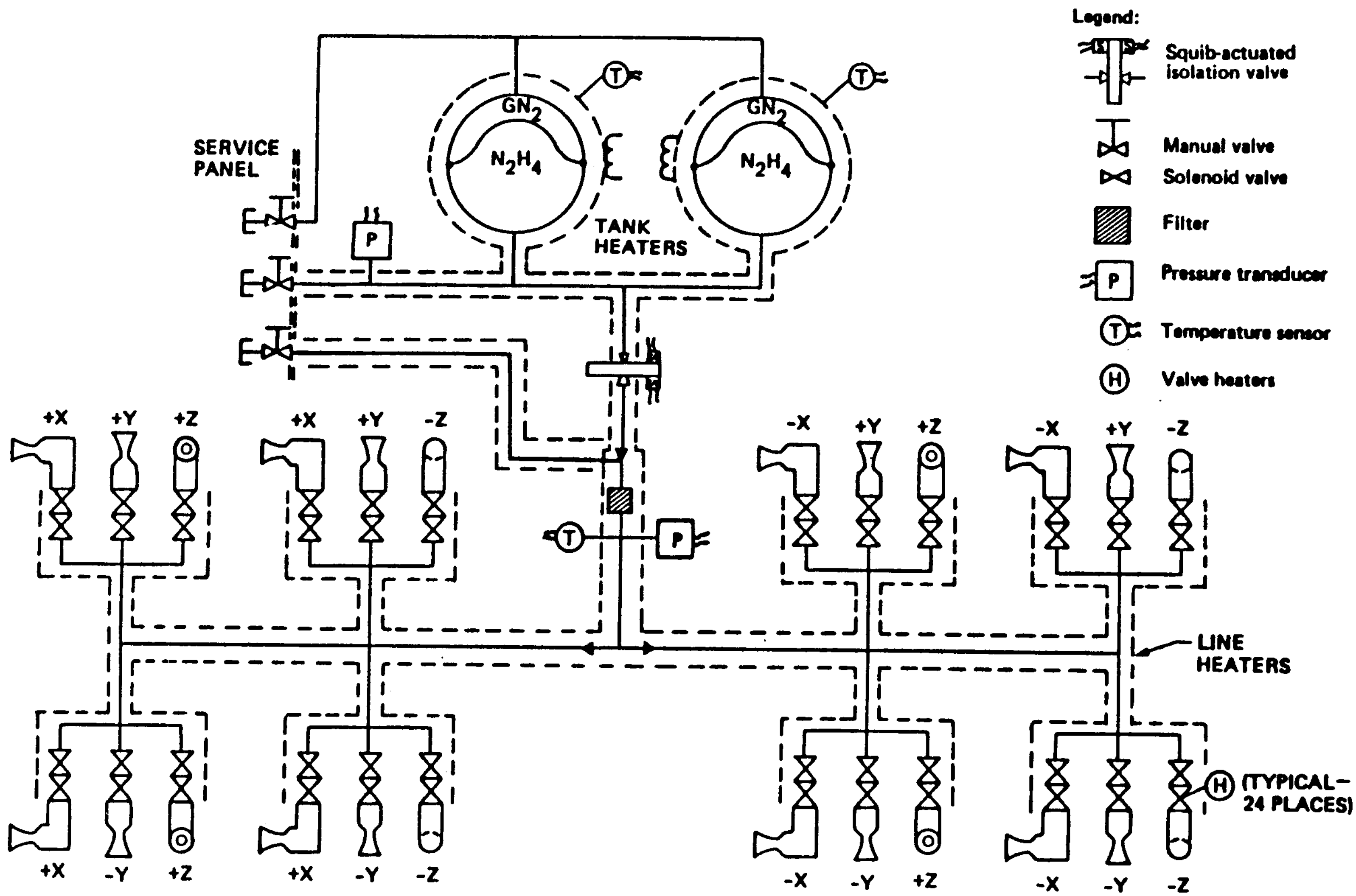
Figure 3.3-6. CORS Ascent Propulsion Module Schematic is provided by pulsing the pitch and yaw REM's and the engineering bus thrusters for roll. When all ascent firing is completed (approximately 3 hours), the APM will be separated from the satellite.

Figure 3.3-7 shows a block diagram of the engineering bus propulsion system (EBPS). The EBPS is used to circularize the final orbit and for stationkeeping maneuvers throughout the mission life. The EBPS is a scaled down version of the APM. The thrusters are 4.4N (1-lb) thrust each and the nominal propellant load is 45.4 kg for two tanks. All other components are similar to those of the APM, though the manifold tubing diameter is 0.64 cm instead of 1.27 cm.

3.4 SYSTEM TEST

The test program for the CORS satellite has two basic guidelines: (1) use of the protoflight concept of testing whereby the flight satellite is the test article for all environmental and performance testing, and (2) performing only those tests necessary to produce a functionally sound satellite. This approach produces a cost-effective test program and a satellitee capable of meeting all environmental and performance requirements.

As is shownn in figure 3.4-1 the test program is functionally composed of three phases (1) structure verification, (2) electrical performance, and (3) environmental testing.



- Eight 3-axis attitude control thruster modules.
- 24 1-lb-thrust engines (Hamilton Standard REA 17 (DSCS Heritage)).

Figure 3-3-7. CORS Engineering Bus Propulsion System Schematic

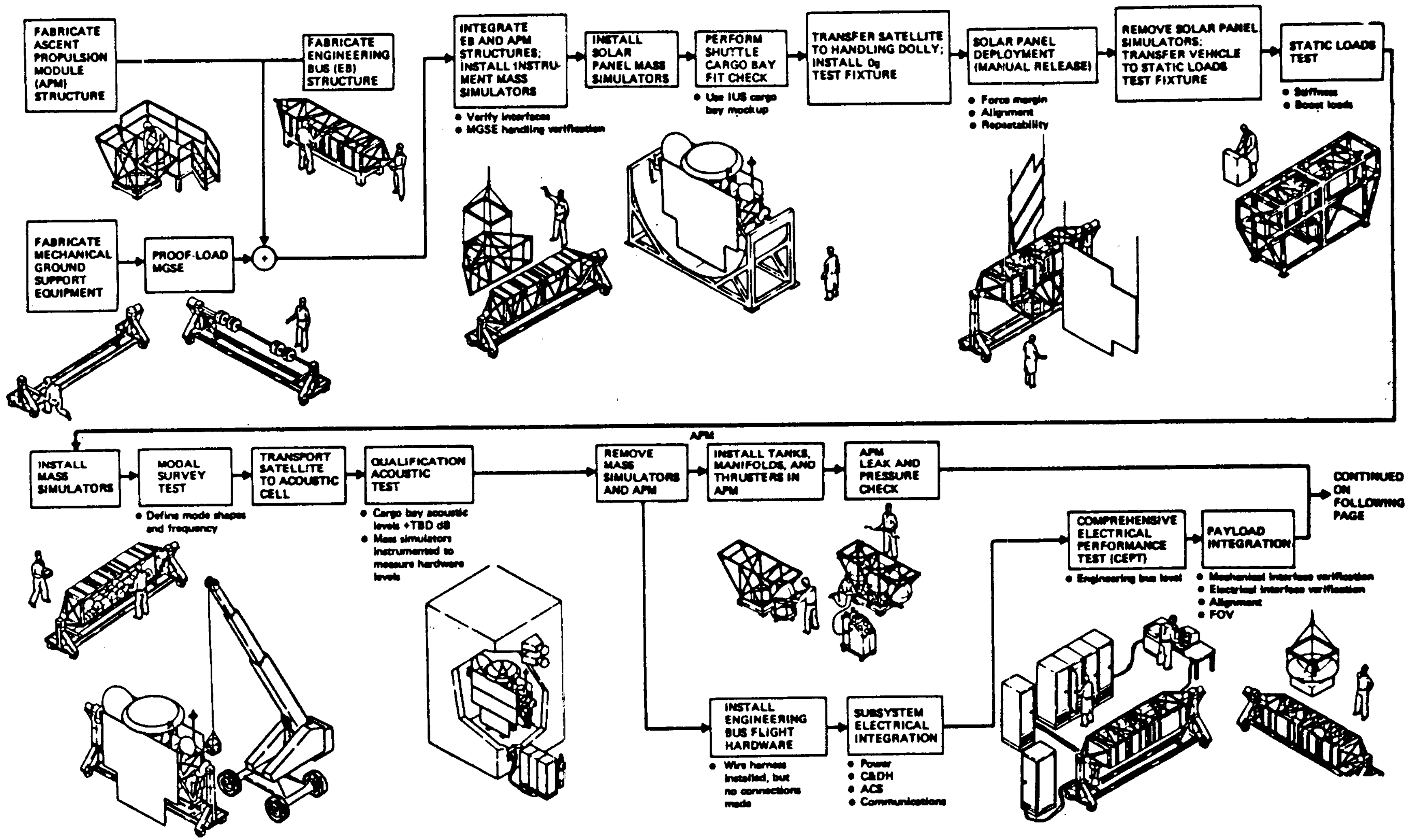


Figure 3.6-1. System Test and Integration Flow (Sheet 1 of 2)

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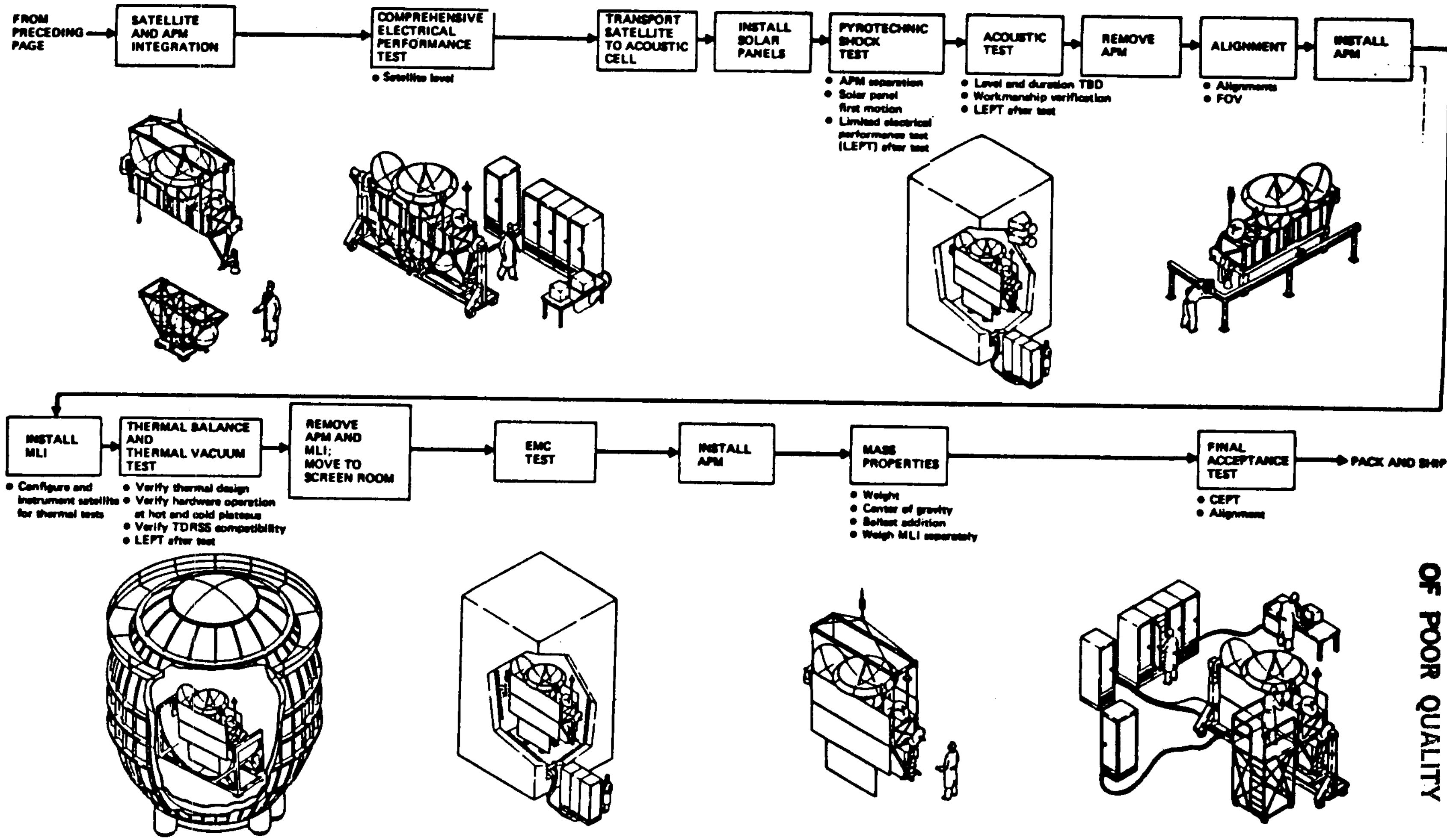

Figure 3.6-2. System Test and Integration Flow (Sheet 2 of 2)

4.0 CO_2 RESEARCH SATELLITE PROGRAM SCHEDULES

A summary of the proposed CO_2 Research Satellite program phasing schedule for a three mission program is shown in figure 4-1. This schedule shows a separate series of phased contracts for near-term, mid-term, and long-term missions (Level 1, 2 and 3 respectively). For each of the three levels, cost was considered as the primary schedule design criteria. The schedules presented represent our assessment of a CO_2 research satellite program designed for minimum total system cost.

The three missions could be part of a comprehensive CO_2 research program phased as shown in figure 5-1. Alternatively, any of the missions could be flown independently. Level 1 or Level 2 missions could be started as early as 1984 or as late as desired. The Level 3 mission schedule presupposes the existence of a polar space platform and the Tracking and Data Acquisition System (TDAS) follow-on to the current Tracking and Data Relay Satellite System (TDRSS). For this reason, a Level 3 start is assumed no sooner than approximately 1987. Each of the schedules assumes that shared STS launch opportunities will be available as required.

The purpose of competitive, multiple award, six month Phase A study contracts is to determine technical and financial feasibility, and to identify and evaluate various design concepts. Phase A is not intended to lock in specific hardware, performance characteristics, or costs. The function of the competitive, multiple award, six month Phase B effort is to gather data sufficient to make a detailed system hardware and cost proposal. In order to reach this point detailed trade studies will be made, the preliminary platform design will be defined, a make/buy plan will be created using supplier quotes for input, and mission plans and specifications will be established. The competitive, single award, Phase CD Implementation contract will result in delivery and on-orbit checkout of a the CO_2 research satellite.

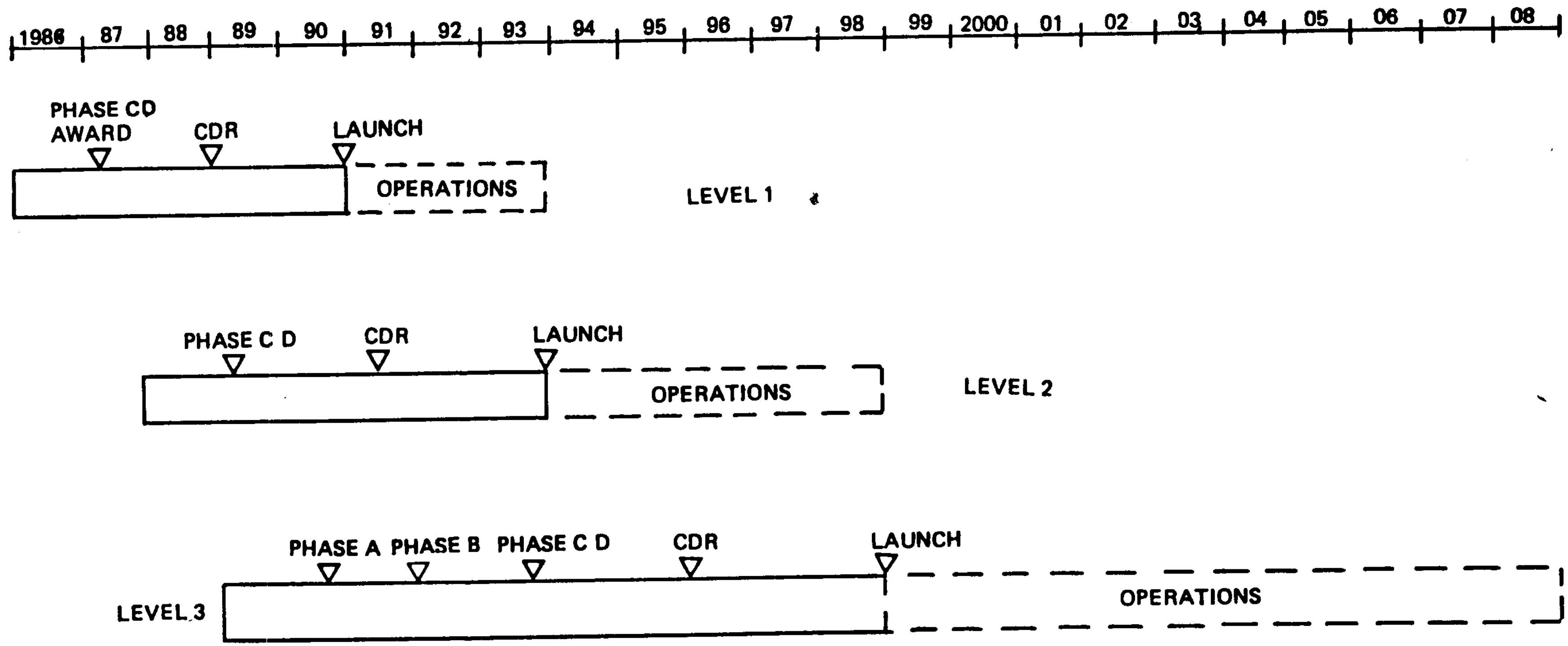

Figure 4-1. CO_2 Research Program Phasing Schedule

4.1 LEVEL 1 PROGRAM SCHEDULE

Figure 4-2 shows a program schedule for the Level 1 mission. An attempt was made to compress the Level 1 schedule in line with considerations of low cost, so as to minimize the time required before data is returned. For this reason we assume that the CO_2 research satellite will follow the protoflight concept in which the test article will also be the flight unit. This implies a non-destructive test philosophy. Further, the assumption was made that we could modify and use an existing Shuttle optimized satellite bus such as that for the NASA-JPL Topological Oceanography Experiment (TOPEX) mission, which is scheduled for launch in 1989. This allows us to use a much tighter schedule than would otherwise be the case. If in addition, the first CO_2 research satellite mission closely followed the TOPEX mission, it would be possible to further compress the Level 1 schedule—perhaps by as much as another six months. In this case, it is likely that purchase of long lead items would be required prior to PDR.

Phases A and B will concentrate on mission analysis, ground data processing, and modifications to existing instrument and satellite bus design—as no new technology or major development efforts are required. Phase CD timing of 20 months from contract award to system CDR ensures a low schedule/technical risk program. Because some instruments are likely to be out of production lead times for science instrument procurement is likely to be the pacing item in the Level 1 mission. The final instrument PDR is scheduled four months after contract award, as only existing instruments will be flown.

4.2 LEVEL 2 PROGRAM SCHEDULE

Figure 4-3 shows a program schedule for the Level 2 mission. The Level 2 mission assumes use of a modified, existing Shuttle optimized satellite bus and modified existing science instrument complement. The main difference from the Level 1 schedule is that Phase A studies are expanded to provide additional concept formulation and feasibility data, while Phase B studies are deleted because the scientific instruments as well as the satellite bus are derived from pre-existing designs. Also the Phase CD contract is paced by a more comprehensive instrument development effort than was seen in the Level 1 mission.

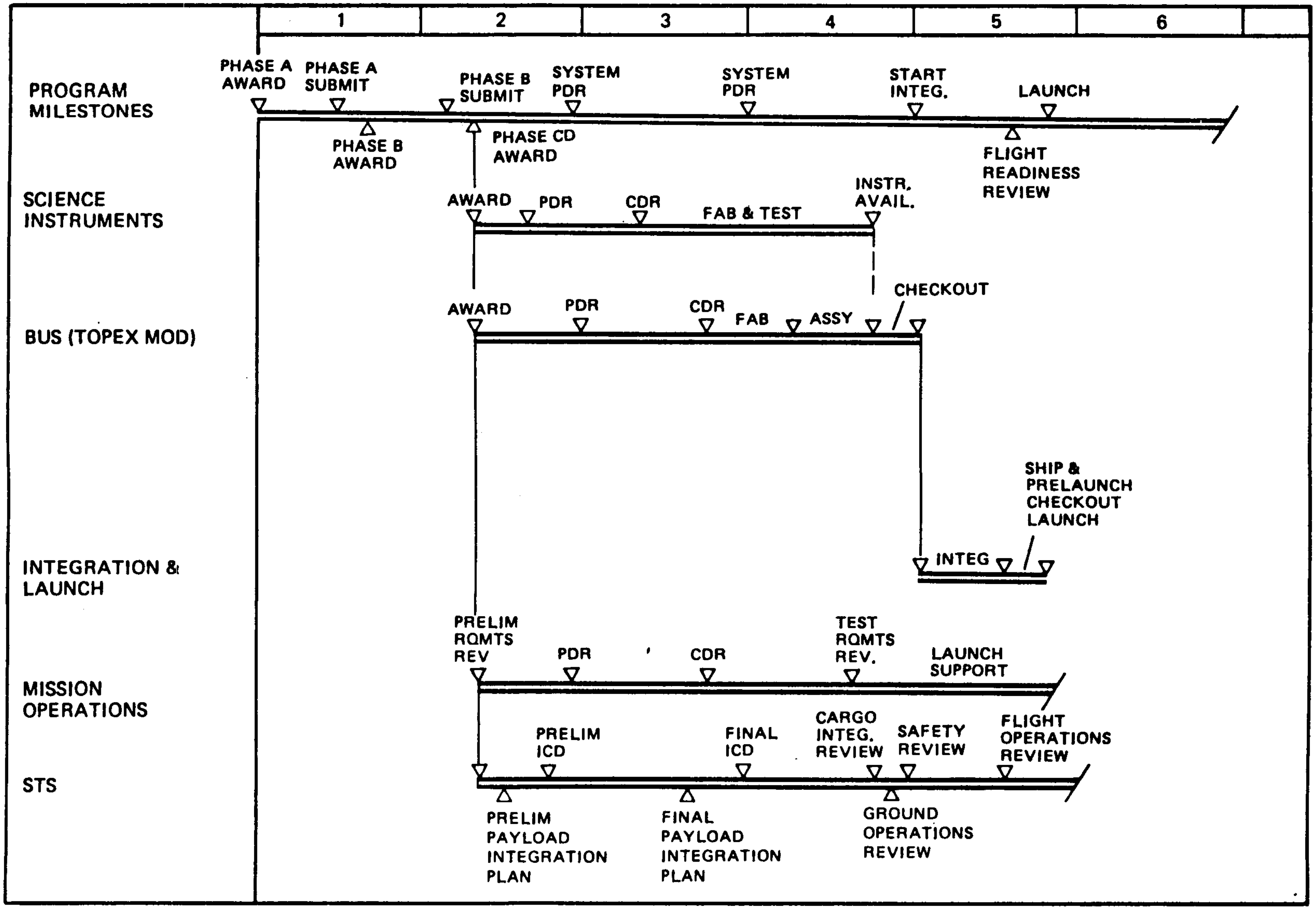

Figure 4-2. CO_2 Research Level 1 Mission

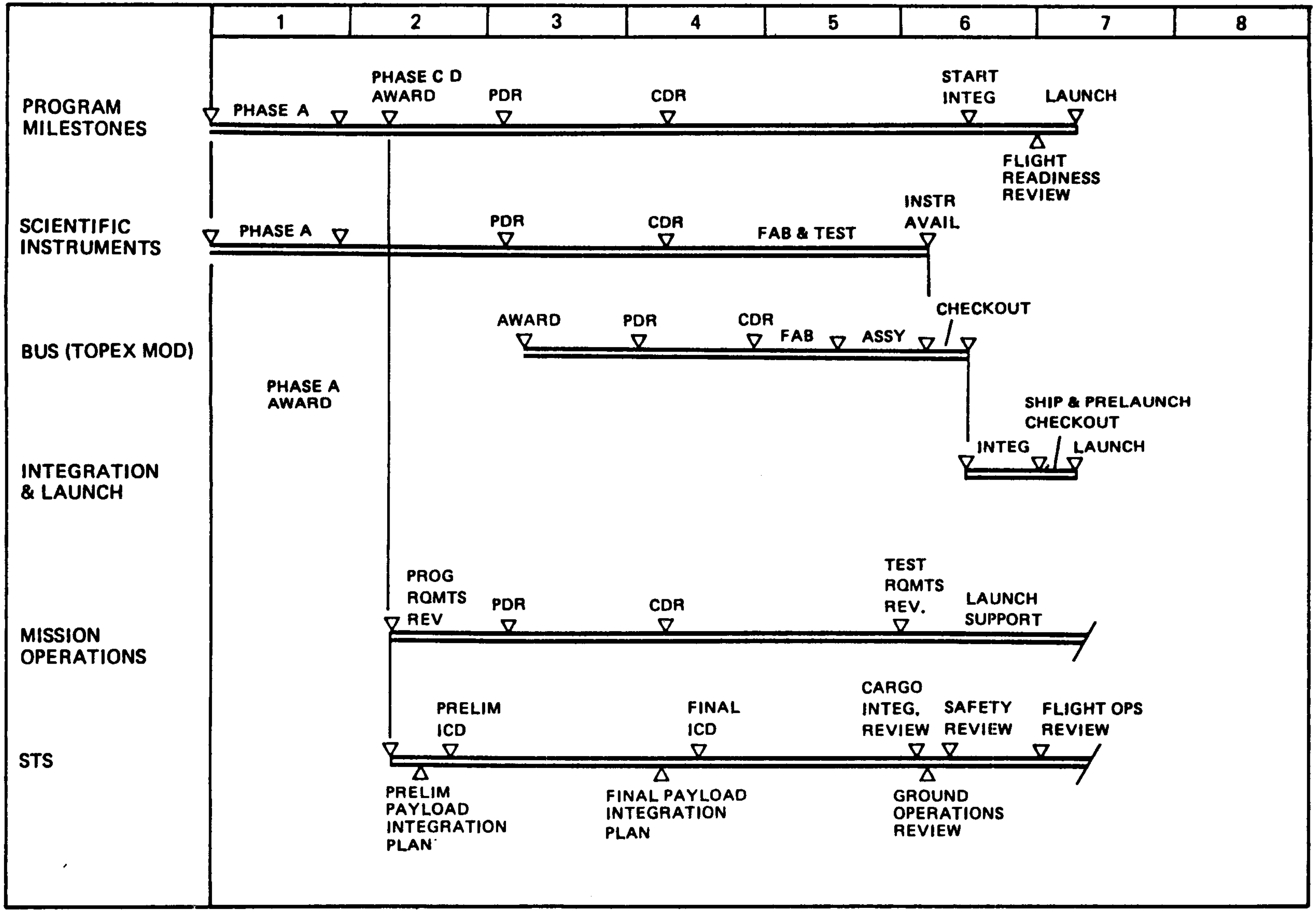

Figure 4-3. CO_2 Research Level 2 Mission

4.3 LEVEL 3 PROGRAM SCHEDULE

Figure 4-4 shows a program schedule for the Level 3 mission. The Level 3 mission assumes use of Spacelab derived instrument pallets to support the scientific instrument complement. The Spacelab pallets would be based on an unmanned space platform in polar orbit which will have been separately developed and in place for use by the CO_2 research program. It is assumed that the space platform will have a standard interface for separable science modules and that it will supply electrical power, communications, and attitude control functions sufficient to meet the needs of the Level 3 CO_2 research mission.

The major task for the Level 3 mission is development and qualification of new instruments. It is envisioned that an instrument feasibility demonstration using an aircraft will be required prior to implementation of the space based Phase A study. Technology studies should be let prior to the start of the Level 3 schedule to develop instrument concepts and breadboard designs to the point where a feasibility demonstration is needed.

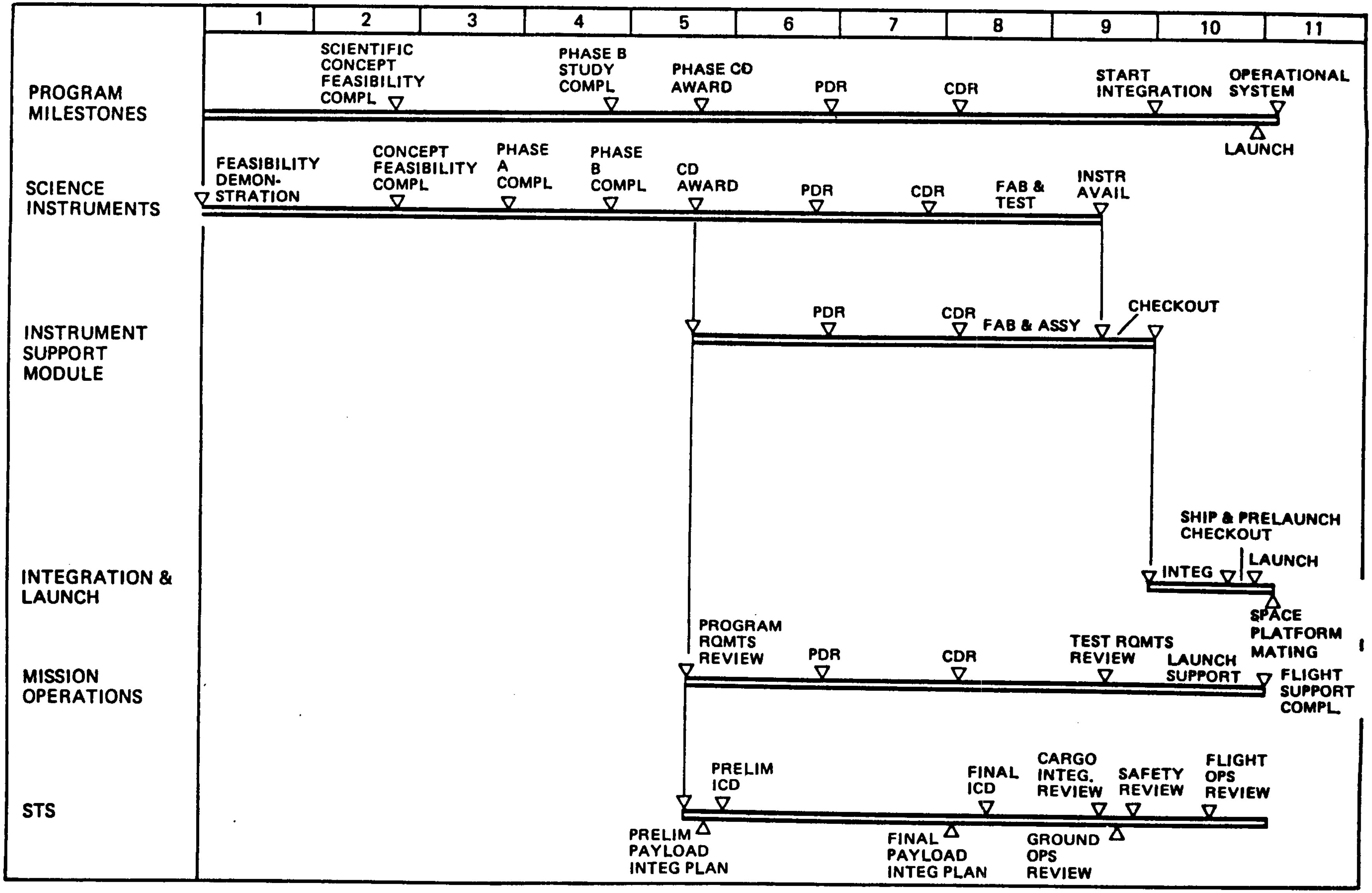

Figure 4-4. CO_2 Research Level 3 Mission

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PREPARED BY C. Case Carl M. Case 2-1630 December 14, 1983

SUPERVISED BY A. Hill

APPROVED BY

ABSTRACT

This document displays and defines the products and services to be developed or furnished in the Implementation Phase of a CO_2 Research Satellite (CORS) program and relates each of the elements of work to be accomplished to the appropriate end item through a defined and organized project structure. CORS is envisioned as arising from a joint study effort of the DOE and the NASA. The operational satellite program will monitor global climate patterns in an attempt to better understand underlying trends and drivers. This volume contains a work breakdown structure (WBS), for each of three potential missions, and a WBS dictionary. Volume 1 contains satellite descriptions and schedules. Volume 3 contains system cost estimates.

ACTIVE SHEET RECORD

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TABLE OF CONTENTS

INTRODUCTION

This document displays and defines the products and services to be developed or furnished in the Implementation Phase of a CO_2 Research Satellite (CORS) program and relates each of the elements of work to be accomplished to the appropriate end item through a defined and organized project structure. The CORS program is envisioned as developing from a joint study effort of the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) on "The Utilization of Space for CO_2 Research". The operational satellite program will monitor global climate patterns in an attempt to better understand underlying trends and drivers.

This document contains a Work Breakdown Structure (WBS) for each of three potential missions and a WBS dictionary. The WBS provides a product oriented family tree hierarchy which contains levels of work required to be accomplished in order to produce, launch, and operate a CO_2 research satellite. The WBS is developed by starting with this end objective and subdividing into systems, subsystems, and components which are the logical and necessary steps needed to achieve the project objective. The total estimated cost for any item at any level is equal to the sum of the estimated costs for all the items below it. The WBS dictionary is a book of definitions numbered to correspond to the WBS describing the contract objectives in terms of hardware, software, services, and other manageable tasks to be accomplished in the performance of the total program objective.

OBJECTIVES

The design goal is to provide significant environmental data with low risk at a minimum overall mission cost. It is envisioned that this will be accomplished by to providing long-term global coverage with gradual phasing from an early initial capability to more capable systems as the program matures. For the CORS program three missions are identified.

- o Level 1 - A near-term mission to be flown as soon as practical with existing instruments.
- o Level 2 - An intermediate-term mission to be flown in five to ten years using using modifications of existing instruments.
- o Level 3 - A long-term mission with a new instrument complement to be developed and flown in ten to twenty years.

Minimization of total system cost, consistent with provision of meaningful scientific data, is the primary design objective for each phase.

DEFINITIONS

The performance requirements on the satellite can be defined at both the system level and at the the subsystem level. For the purpose of this document and the other material prepared in this study, the following terminology has been used:

(1) Engineering bus or Satellite platform: the basic structure and housekeeping subsystems provided by the implementation phase satellite contractor.

(2) Payload: the complement of sensors provided by instrument subcontractors or as GFE to the implementation phase satellite contractor.

(3) Integrated Satellite: The composite of the engineering bus and payload after payload integration, in a flight ready condition or after launch.

(4) Satellite System: a term used in describing performance requirements which affect more than one engineering subsystem. It is normally used for describing in-flight performance of the integrated satellite.

WORK BREAKDOWN STRUCTURE — LEVEL I MISSION

1.0 Program Management

2.0 Systems Engineering & Integration

3.0 Satellite Bus Design, Fabrication and Test
- 3.1 Structures and Mechanisms
- 3.2 Attitude Control and Determination Subsystem
- 3.3 Command and Data Handling Subsystem
- 3.4 Communications Subsystem
- 3.5 Electrical Power Subsystem
- 3.6 Orbit Maintenance Propulsion Subsystem
- 3.7 Thermal Subsystem
- 3.8 Wiring Harness and Cabling
- 3.9 Ascent Propulsion Stage
- 3.10 Bus Integration and Checkout

4.0 Payload Design, Fabrication and Test
- 4.1 Modified Advanced Very High Resolution Radiometer (AVHRR)
- 4.2 Data Collection System (DCS)
- 4.3 Stratospheric Aerosol and Gas Experiment (SAGE-2)
- 4.4 Earth Radiation Budget Experiment (ERBE)
- 4.5 Scanning Multichannel Microwave Radiometer (SMMR)
- 4.6 TOPEX Radar Altimeter (ALT)
- 4.7 High-resolution Infra-Red Sounder (HIRS-2)
- 4.8 Microwave Sounding Unit (MSU)
- 4.9 Stratospheric Sounding Unit (SSU)
- 4.10 Payload Integration and Checkout

5.0 System Test and Evaluation

6.0 Test Support
- 6.1 Tooling and Special Test Equipment
- 6.2 Peculiar Support Equipment

7.0 Airborne Support Equipment

8.0 Critical Flight Spares

9.0 Software

10.0 Reliability, Quality Assurance and Safety

11.0 Launch Vehicle Integration and Flight Support

12.0 Ground Operations
- 12.1 Dedicated Ground Station Facilities
- 12.2 Information Processing System
- 12.3 Mission Operations

13.0 Launch Services

Work Breakdown Structure — Level II Mission

1.0 Program Management

2.0 Systems Engineering & Integration

3.0 Satellite Bus Design, Fabrication and Test
3.1 Structures and Mechanisms
3.2 Attitude Control and Determination Subsystem
3.3 Command and Data Handling Subsystem
3.4 Communications Subsystem
3.5 Electrical Power Subsystem
3.6 Orbit Maintenance Propulsion Subsystem
3.7 Thermal Subsystem
3.8 Wiring Harness and Cabling
3.9 Ascent Propulsion Stage
3.10 Bus Integration and Checkout

4.0 Payload Design, Fabrication and Test
4.1 Improved Advanced Very High Resolution Radiometer (AVHRR)
4.2 Improved Data Collection System (DCS)
4.3 Improved Stratospheric Aerosol and Gas Experiment (SAGE-2)
4.4 Earth Radiation Budget Experiment (ERBE)
4.5 Improved Scanning Multichannel Microwave Radiometer (SMMR)
4.6 TOPEX Radar Altimeter (ALT)
4.7 Infra-Red Interferometer/Spectrometer (IRIS)
4.8 Advanced Microwave Sounding Unit (AMSU)
4.9 Payload Integration and Checkout

5.0 System Test and Evaluation

6.0 Test Support
6.1 Tooling and Special Test Equipment
6.2 Peculiar Support Equipment

7.0 Airborne Support Equipment

8.0 Critical Flight Spares

9.0 Software

10.0 Reliability, Quality Assurance and Safety

11.0 Launch Vehicle Integration and Flight Support

12.0 Ground Operations
12.1 Dedicated Ground Station Facilities
12.2 Information Processing System
12.3 Mission Operations

13.0 Launch Services

Work Breakdown Structure -- Level III Mission

1.0 Program Management

2.0 Systems Engineering & Integration

3.0 Payload Support System Design, Fabrication and Test
3.1 Payload Support Equipment
3.2 Spacelab Pallet
3.3 Payload Support Equipment Assembly and Checkout

4.0 Payload Design, Fabrication and Test
4.1 Infra-Red Visual Mapper (IRVM)
4.2 Improved Data Collection System (DCS)
4.3 Light Detecting And Ranging (LIDAR)
4.4 Infrared Interferometric Radiometer (FTS)
4.5 Microwave Pressure Sounder (MPS)
4.6 Advanced Microwave Sounder (AMS)
4.7 Microwave Mapper (MM)
4.8 TOPEX Radar Altimeter (ALT)
4.9 Parallax Sensor (PS)
4.10 Advanced Earth Radiation Budget Experiment (ERBE)
4.11 Payload Integration and Checkout

5.0 System Test and Evaluation

6.0 Test Support
6.1 Tooling and Special Test Equipment
6.2 Peculiar Support Equipment

7.0 Airborne Support Equipment

8.0 Critical Flight Spares

9.0 Software

10.0 Reliability, Quality Assurance and Safety

11.0 Launch Vehicle Integration and Flight Support

12.0 Ground Operations
12.1 Dedicated Ground Station Facilities
12.2 Information Processing System
12.3 Mission Operations

13.0 Launch Services

WORK BREAKDOWN STRUCTURE DICTIONARY

WBS 1.0 Program Management

This task group encompasses all efforts required to provide CO_2 Research Satellite (CORS) program management. It includes technical direction and management during all required phases of the program, including design, fabrication, assembly, testing, integration, launch, and operations support of all CORS program efforts. This task group also encompasses schedule, budget, and configuration control as well as the management function for all subcontractors. It specifically includes the efforts of the program manager's staff and contract administrative support. Travel and living expenses required for contract personnel also fall under the program management category.

Program management encompasses all efforts required for program technical integration, direction and management to direct performing functional groups. The program management task group includes participation on the configuration control board, management and integration of customer interfaces, liaison meetings, and the effort to develop and maintain program control by maintaining a master program schedule and subtiered support schedules.

Configuration identification will be maintained from an established baseline with hardware item identification provided with serial and lot numbers, which will facilitate traceability though the drawing release and recording system. Configuration control will include the implementation of basic and change control boards together with appropriate mechanisms for the definition coordination, and disposition of all proposed changes in terms of technical, cost, and schedule impact. Configuration accountability will provide on a current basis the baseline status of all deliverable hardware; a systematic record of pending and approved changes with scheduled and actual change incorporation dates; and the capability of identifying the as-designed and as-built configuration of all deliverable items.

The program managment task includes documentation and data control for all program documentation. It also includes financial management and reporting, and the duties required to obtain, maintain, and account for the real property and equipment required for producing and testing the CO_2 satellite(s).

WBS 2.0 Systems Engineering & Integration

This task group includes the total design and analysis of the CO_2 satellite. It encompasses the development of design requirement specifications and evaluation of technical adequacy of systems, subsystems, and components. Included in the systems engineering and integration task group is system analysis for the entire CO_2 satellite to verify system performance, such as structural analysis, control system computer simulations, analysis of all testing performed, and analysis of essential components of the system.

This task will define the requirements for interface design control and compatibility for ensuring complete documentation of interface requirements in drawings and providing for review of all changes for interface impact. It encompasses all other system engineering tasks, including technical direction associated with system, subsystem, and equipment integration for the satellite platform, payload/platform integration, launch vehicle/satellite integration, and preparation of on-orbit operations requirements and operations documentation.

WBS 3.0 Satellite Bus Design, Fabrication and Test

This task group contains the efforts required to design, fabricate, assemble, and integrate protoflight satellite bus subsytstem components to meet CO_2 satellite specifications. These tasks cover the efforts required to develop supplier specifications, monitor supplier activities, develop PDR and CDR data, complete final designs of each subsystem, fabricate, redesign as necessary, assemble, install, develop test procedures, and test the CO_2 satellite bus subsystems.

WBS 4.0 Payload Design, Fabrication and Test

This task group contains the efforts required to design, fabricate, assemble, and integrate scientific payload instruments necessary to meet CO_2 satellite payload specifications. These tasks cover the efforts required to develop supplier specifications, monitor supplier activities, develop PDR and CDR data, complete final designs of each instrumennt, fabricate, redesign as necessary, assemble, develop test procedures, and test the CO_2 satellite scientific instruments.

WBS 5.0 System Test and Evaluation

This task contains the efforts required to prepare the overall system test plan and schedule, develop system integration and system test procedures for the integrated satellite, prepare the system tests, and analyze and evaluate the test results. The test program is functionally composed of three phases: (1) structure verification, (2) electrical performance, and (3) environmental testing. The test program includes: component testing, physical integration, solar panel deployment, static loads, modal survey, acoustic, vibration, subsystem integration, electrical performance, payload integration, pyrotechnic shock, alignment verification, thermal balance and thermal vacuum, electromagnetic compatibility, mass properties, and final acceptance tests.

WBS 6.0 Test Support

This task group includes tooling and special test equipment (STE) developed to support specialized equipment tests during the fabrication of mission hardware. It also includes mission peculiar support equipment (PSE) such as vehicles, tools, cradles, and shipping crates.

WBS 7.0 Airborne Support Equipment

This task contains the efforts required to design, fabricate, assemble, integrate, and test equipment which is needed by the satellite in the launch vehicle, but which is not released by the launch vehicle with the satellite.

WBS 8.0 Critical Flight Spares

This task covers fabrication, testing, qualification, and storage of spares. Where refurbished units, such as engineering units, are proposed as spares, this task covers only the efforts to bring the units up to fully tested flight quality.

WBS 9.0 Software

This task group contains the efforts associated with system software requirements definition, development, documentation, and test. Flight software, test and simulation software, operations software, and data handling software are the four major software program elements which will be modified and/or developed under this task group. The software development effort includes developing software specifications, writing the code, verifying proper operation of software modules, and performing software validation testing.

WBS 10.0 Reliability, Quality Assurance and Safety

This classification covers all effort, equipment, and material necessary to plan, document, and implement the reliability assurance, quality assurance, and safety programs. The reliability assurance effort will support design, test, malfunction reporting and correction, failure mode effect and criticality analysis, and design and readiness reviews. The quality assurance program will provide government source inspection, quality assurance aspects of subcontractor control, and fabrication controls. The safety program will include preliminary hazards analysis, analysis of special measures required for safe handling of hardware, and analysis of launch vehicle and launch site safety requirements.

WBS 11.0 Launch Vehicle Integration and Flight Support

This task includes engineering support at the Payload Operations Control Center (POCC) and at the launch site to verify proper installation of the CORS and to assist in satellite on-orbit checkout and initial operations.

WBS 12.0 Ground Operations

This task group includes dedicated ground station facilities, the information processing system, and mission operations system. Included in this task group are communications services, data analysis and distribution functions, tracking and orbit determination functions, mission planning, and satellite operations.

WBS 13.0 Launch Services

This task includes the launch and other services provided by the launch organization such as launch vehicle integration support, facilitating satellite/POCC communications while the satellite is in the orbiter cargo bay, satellite post-launch checkout, and remote manipulator system (RMS) operation.

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PREPARED UNDER

CONTRACT NO. - Arthur D. Little, Inc.
P.O. No. 551174
(In support of NAS8-35357)

IR&D

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FILED UNDER

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MODEL

TITLE CO_2 Research Satellite Study - Cost Estimate

ORIGINAL RELEASE DATE December 14, 1983

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ABSTRACT

This document presents costs, and a description of the costing methodology used for the CO_2 Research Satellite (CORS) study contract P.O. number 551174, in support of NAS8-35357.

This volume contains the cost data for the Level I, Level II, and Level III missions. Each mission's costs are displayed in a separate section following a General/Introduction section.

This estimate is a parametric estimate, and is provided as a ROM (rough order of magnitude) for informational purposes only. This is neither an offer nor a commitment by The Boeing Company to perform the tasks estimated herein.

TABLE OF CONTENTS

SECTION 1 - GENERAL/INTRODUCTION

INTRODUCTION

This document provides the cost estimates for three engineering bus configurations for a CO_2 Research Satellite (CORS) program as well as for launch and ground operations costs. CORS is envisioned as an operational program arising from a joint study effort of the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) titled "Utilization of Space for CO_2 Research." The operational satellite program will monitor global climate patterns in an attempt to better understand underlying trends and drivers.

Key features of the Boeing engineering bus design for these missions include:

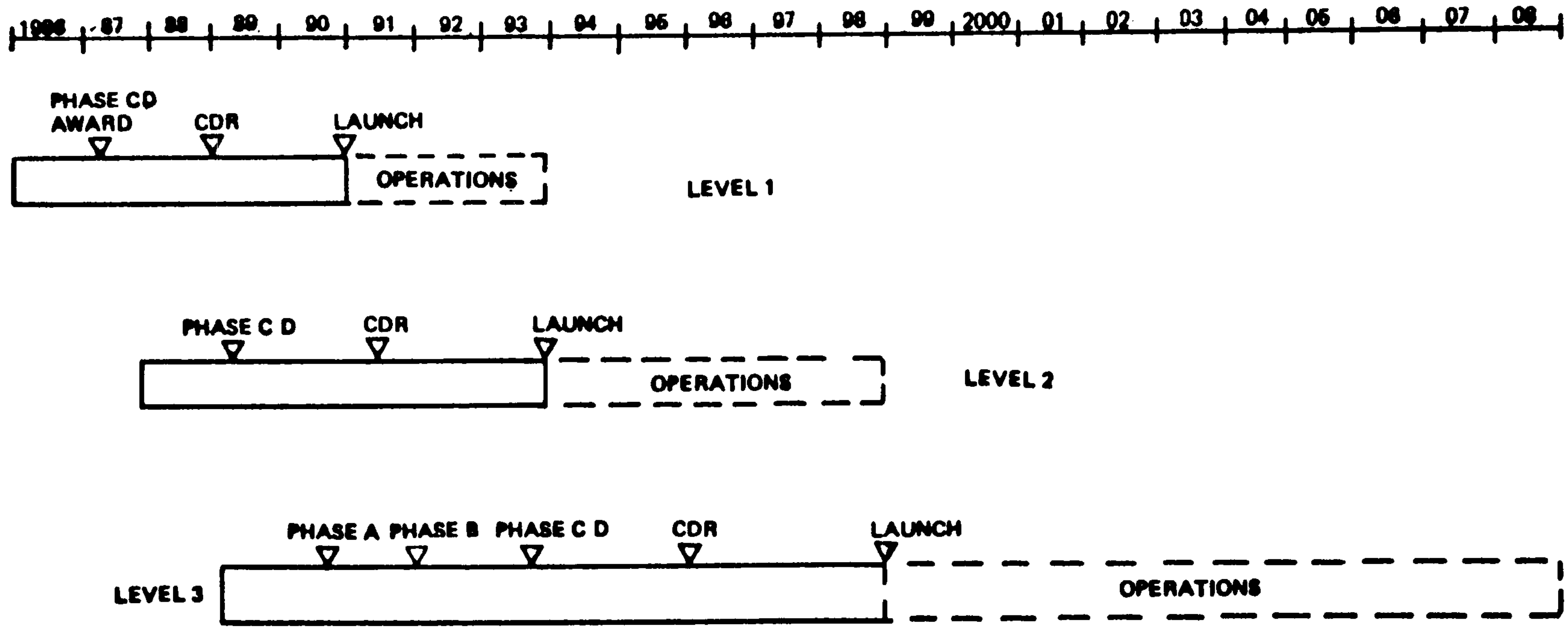
a. Use of flight-proven major elements and a design optimized for use on a space transportation system (STS) to substantially reduce technical, cost, and schedule risk.

b. Minimized modifications to an existing satellite design. We are proposing the use of the Topological Oceanography Experiement (TOPEX) satellite bus for CORS Level I and Level II missions. For the Level III mission, we are proposing to use a design based on spacelab pallets attached to an unmanned polar space platform.

c. Use of existing technology. No new engineering bus technology is required. Flight-proven, off-the-shelf hardware, with known heritage and performance, is used throughout the engineering bus. All new design components will be based on currently existing technology and proven capabilities or on technology that will have been proven prior to award of the implementation phase contract.

Arthur D. Little, Inc. (ADL), the prime contractor for this study, provided requirements, mission analysis, sensor selection, and ground system definition. Ball Aerospace System Division (BASD) provided sensor data. The Boeing Aerospace Company (BAC) was responsible for recommending overall system concepts, providing satellite bus definition, developing program schedules and work breakdown structures, and performing the cost analysis.

CO_2 Research Satellite
Program Schedule



CO_2 Research Program Phasing Schedule

PRICE SUMMARY

Acquisition Costs*
(1984 Dollars in Millions)

	Level I	Level II	Level III
Flight Hardware	$ 116.4	$ 134.1	$ 307.4
Support	36.0	33.4	64.5
Subtotal Cost	$ 152.4	$ 167.5	$ 371.9
Contingency @ 20%	30.5	33.5	74.4
Contract Fee @ 15%	22.9	25.1	55.8
TOTAL PRICE	$ 205.8	$ 226.1	$ 502.1

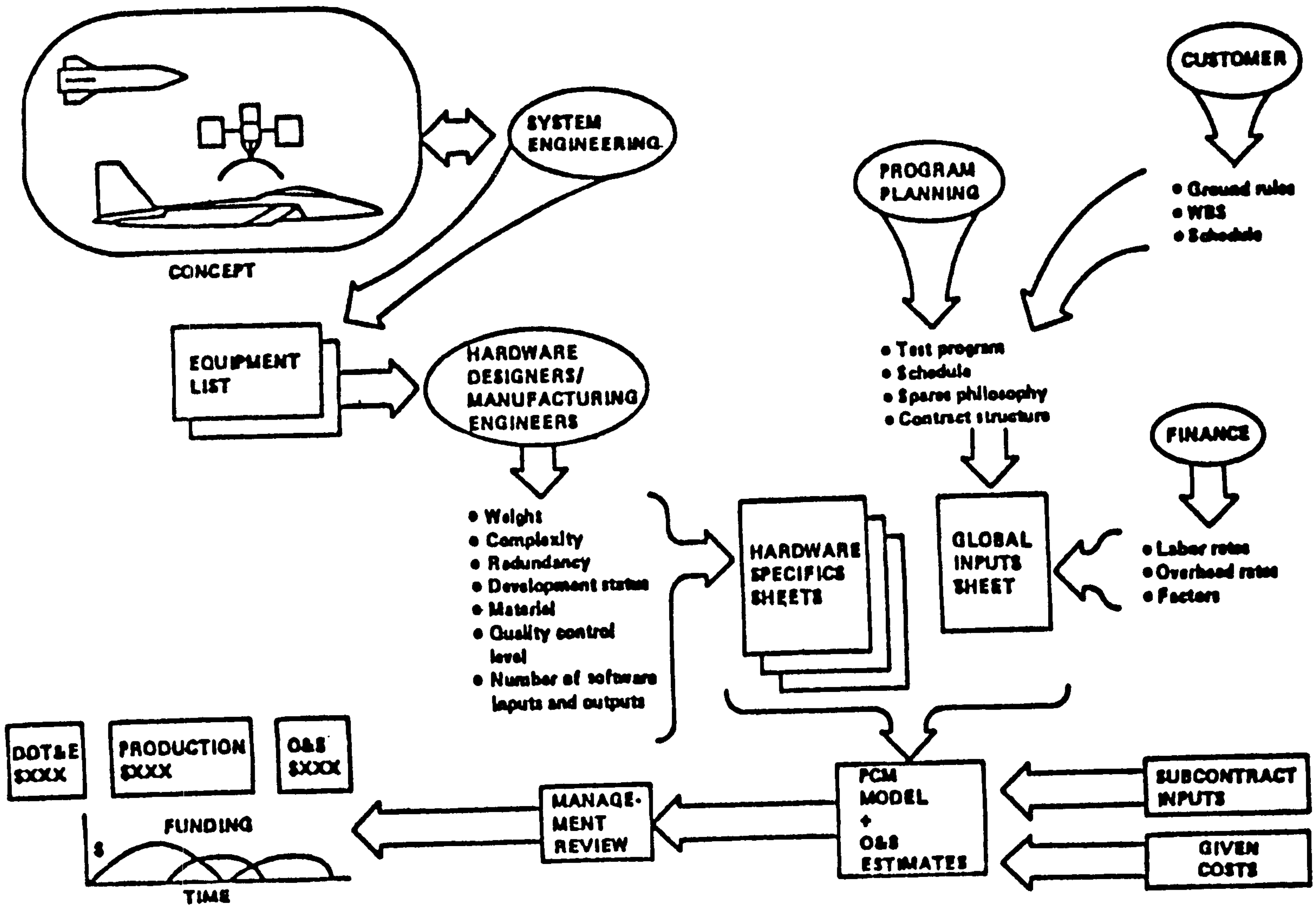
*Does not include ground operations or launch costs.

ESTIMATING METHODOLOGY

The primary tool used for estimating acquisition costs is the Boeing developed parametric cost model (PCM). PCM develops costs from physical hardware descriptions and program schedules, and allows the integration of any known costs (or outside generated costs such as subcontractor or vendor estimates) into the total estimate. In this way, Boeing can assemble a program cost from the best available source data.

Figure 1 is an overview of the PCM estimating method and illustrates the source, type, and level of information handled and delivered from this estimating process. As depicted in the illustration, the scope of the program relative to quantities, program time period, WBS structure, and associated ground rules and assumptions is established by the customer. Contractor program planners amplify the customer furnished directives into a design, development, fabrication, test, and spares philosophy required to support the implementation of the program. This data, along with financial information relative to labor, support, and overhead rates is input to the PCM model. This information defines the program level constraints that the cost model will work within. To develop individual component hardware estimates, engineering and manufacturing functionals describe the components that make up the subsystems. This description requires a weight, hardware type, redundancy, hardening, and circuitry type definition; and an assessment of complexity, development status, manufacturing process, and required quality control level. These hardware data, in conjunction with programmatic level "global" inputs, are processed in the PCM cost model to generate cost estimates.

Figure 1



PCM Estimating Model

The PCM is a collection of relationships and factors that have been developed from Boeing's historical data base; this data base consisting of manhour and dollar data contained in the Executive Information System (EIS). EIS is a company-wide data bank providing raw information from which (in the case of PCM) functional manhour estimating relationships (MER's) have been derived. These MER's relate program inputs to the model's internal working logic. Each major functional area (project engineering, developmental shop, etc.) making up Boeing's organization is represented and inter-related in the model. These functional areas are ultimately expressed in terms of manhours required to fulfill the objectives of the program. These manhours are converted to dollars using dollar per hour rates and estimating factors that are appropriate for the time period of the estimate.

Inputs to PCM at the program level include consideration of the following elements:

- Production quantity and rate.
- Schedule - too long, too short, nominal.
- Include or exclude Class I changes.
- Spares as a percent of hardware produced.
- Rates for engineering, developmental shop, manufacturing, quality control, tooling.
- Number of recurring sets of support equipment.
- Flight test program support hours.
- Support levels of system engineering, software, system test, support equipment design and manufacturing, and tooling design.
- Level of automation/mechanization.
- Simplicity of end item final assembly and checkout.
- Level of developmental shop support to engineering, and quality assurance to production.

At the hardware level, inputs to PCM have been divided into the categories of Boeing build, vendor furnished, and customer furnished.

With customer furnished thruput, costs are acknowledged and displayed but not added to the total estimate; however, related integration and system test effort is assessed and included in Boeing cost.

With vendor furnished thruput (design and manufacture), quoted costs are carried through by PCM without change; however, required integration and system test effort related to vendor hardware is assessed and integrated into Boeing cost.

In order to estimate Boeing build hardware, PCM considers the following elements for both design and manufacture:

- o What hardware category best describes the item: mechanical, electrical, electro-mechanical, propulsion.
- o The basic parametric measure of the hardware, in most cases weight.
- o The complexity factor to design/manufacture the hardware.
- o Program platform - space, missile, airplane, or ground hardware.
- o Electronics - discrete or integrated circuits.
- o Structural material.
- o Operational environment - nuclear or non-nuclear.
- o Hardware redundancy.
- o Applicable learning curve (manufacturing only).
- o Extent of using new hardware and/or existing hardware with modifications.
- o Complexity of integration of components.

Cost credibility is a function of: (a) program and hardware definition, (b) the depth of analysis which translates this definition into PCM estimating inputs, and (c) the ability of the estimating method to convert good inputs into realistic cost estimates.

The PCM cost model has been validated with historical actual Boeing cost data for components of all four basic hardware categories. Variance analysis has shown that the model will develop estimates with $\pm 23\%$ at a one sigma confidence level if the inputs are accurate.

In addition to PCM, the RCA PRICE H estimating model was used to estimate the acquisition cost of those electronics instruments not previously priced. PRICE H is a widely used and accepted parametric estimating model developed by RCA and available on several computer network services.

SECTION 2 - LEVEL I MISSION

GROUND RULES & ASSUMPTIONS

1. All values expressed in constant 1984 dollars.
2. Unless otherwise indicated, all dollars are expressed in millions.
3. Estimate assumes Boeing has been previously under contract for the Ocean Topography Experiment Satellite (TOPEX).
4. CO_2 Research Satellite is a TOPEX derivative.
5. Program estimate based on protoflight concept - no flight test vehicles.
6. Costs for science payload instruments provided by Ball Aerospace; except for MSU, SMMR, and Altimeter.
7. Costs for ground operations provided by Arthur D. Little, Inc.
8. Launch costs assume full orbiter cost, in 1984 dollars, of $85 million.
9. Costs are not included for:
   a. Space operations
   b. Use of TDRSS
   c. Allowance for Class I changes.
10. Assumptions from Arthur D. Little, Inc., used for pricing the ground facilities are as follows:
    a. No receiving station or satellite control system costs included.
    b. Raw telemetry data plus ephemeris data forwarded to processing center.
    c. Data is only processed to Class 1 level - converted to calibrated engineering units. Compression rates for conversion assumed to be about 10 to 1.
    d. No user interface is provided. Class 1 data put on 9-track magnetic tape.
    e. Yearly center operating costs are estimated as well.
    f. Telemetry data flow is assumed to be about 1 Megabit/second plus daily ephemeris updates.

COST SUMMARY

	Nonrecurring	Recurring	Total
Acquisition	$ 40.2	$ 112.2	$ 152.4
Operations (1 Year)	-	5.4	5.4
Launch	-	18.2	18.2
Ground Facilities	16.5	-	16.5

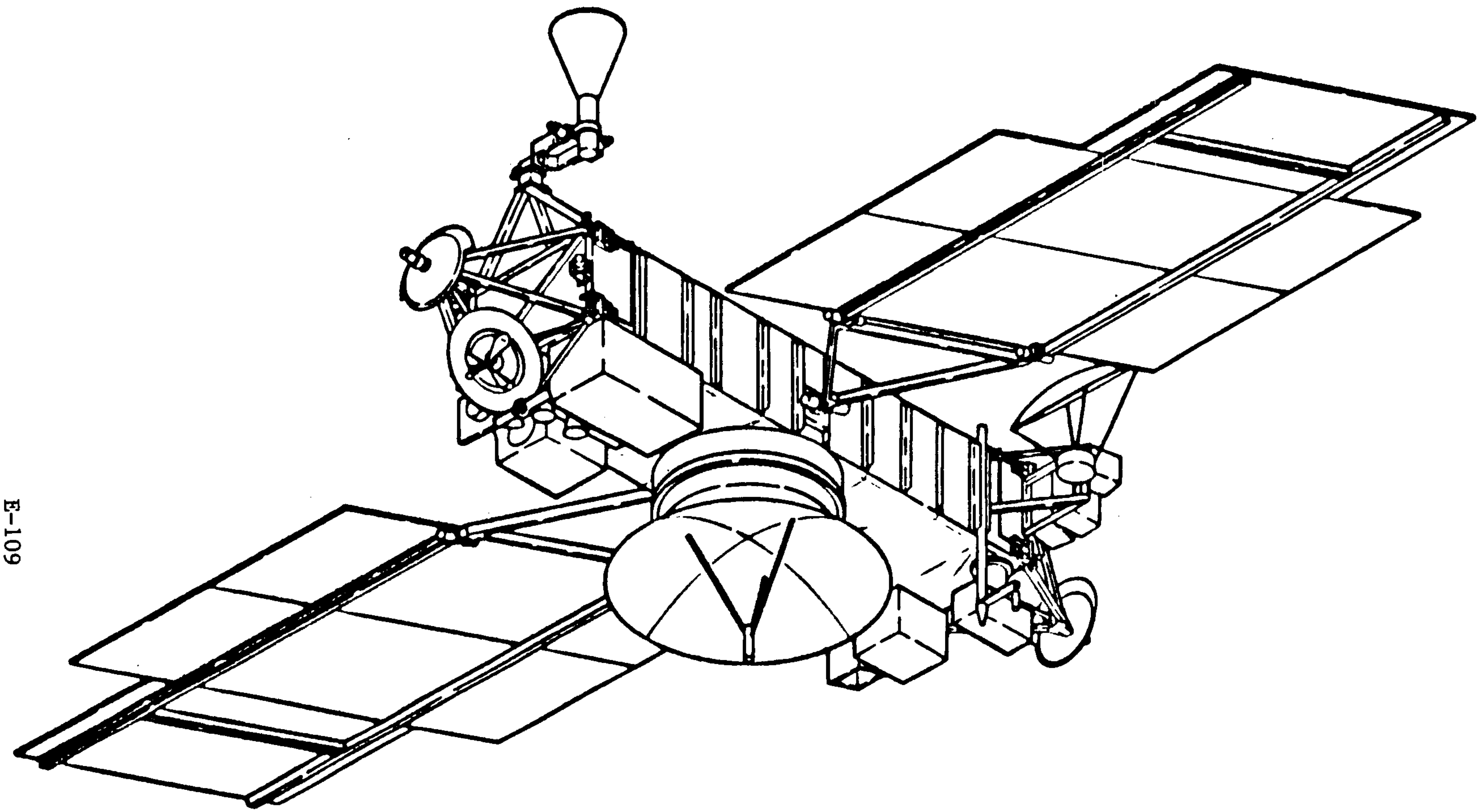
MISSION DESCRIPTION - LEVEL I

The primary goal of the CORS mission is to gain a better understanding of long term climate changes through remote sensing techniques. Figure 2 illustrates the proposed satellite design for the Level I mission. The design meets all CORS mission goals and requirements, providing all functions necessary for a mission life of at least 3 years. Major elements of the proposed design are summarized below.

Level I

The Level I mission is a near-term mission to be flown as soon as practical with existing instruments. It has a separable ascent propulsion module which has been designed to carry the satellite from the STS parking orbit to the observational orbit. The engineering bus propulsion system will provide trim and orbit maintenance maneuvers. The tracking and data relay satellite system (TDRSS) will provide primary command and telemetry links and doppler and ranging data for orbit determination. In addition to the TDRSS anetenna, an omni-directional nadir-pointing antenna will be used to facilitate emergency direct ground communications. The command and data handling subsystem (CDHS) is based on Application Explorer Mission (AEM) equipment which Boeing built for the NASA Goddard Space Flight Center (GSFC). Tape recorders will store data and allow simultaneous data recording and playback. Playback will be compatible with the TDRSS S-band single-access (SSA) link. Three-axis stabilization, provided by the attitude determination and control subsystem (ADCS), will provide the required nadir-pointing accuracy. The ADCS will also ensure accurate thruster pointing and control during orbit maintenance maneuvering. The electrical power subsystem will generate and distribute power required throughout mission ljfe, with NiCd batteries providing power during periods of occultation. The thermal control subsystem will use passive methods supplemented by heaters to maintain the payload instruments and subsystem equipment within permissible temperature ranges.

Figure 2



CO_2 Research Satellite

ACQUISITION COST SUMMARY

WBS	Nomenclature	Cost	
1.0	Program Management		$ 8.9
2.0	Systems Engineering and Integration*		7.4
3.0	Satellite Bus Design, Fabrication, & Test		31.2
3.1	Structures and Mechanisms	$ 3.9	
3.2	Attitude Control & Determination Subsystem	4.8	
3.3	Command & Data Handling Subsystem	5.7	
3.4	Communications Subsystem	3.3	
3.5	Electrical Power Subsystem	6.2	
3.6	Orbit Maintenance Propulsion Subsystem	1.4	
3.7	Thermal Subsystem	1.3	
3.8	Wiring Harness and Cabling	.3	
3.9	Ascent Propulsion Stage	1.3	
3.10	Bus Integration and Checkout	3.0	
4.0	Payload Design, Fabrication, and Test		85.2
4.1	Mod Adv Very High Resolution Radiometer (AVHRR)	9.2	
4.2	Data Collection System (DCS)	8.1	
4.3	Stratospheric Aerosol & Gas Exper (SAGE-2)	5.8	
4.4	Earth Radiation Budget Exper (ERBE)	17.3	
4.5	Scan. Multichannel Microwave Radiometer (SMMR)	2.8	
4.6	TOPEX Radar Altimeter (ALT)	10.5	
4.7	High-resolution Infra-red Sounder (HIRS-2)	11.5	
4.8	Microwave Sounding Unit (MSU)	2.4	
4.9	Stratospheric Sounding Unit (SSU)	6.9	
4.10	Payload Integration and Checkout	10.7	
5.0	System Test and Evaluation		3.4
6.0	Test Support		6.8
6.1	Tooling and Special Test Equipment	5.1	
6.2	Peculiar Support Equipment	1.7	
7.0	Airborne Support Equipment		1.7
8.0	Critical Flight Spares		2.5
9.0	Software		3.7
10.0	Reliability, Quality Assurance, and Safety		1.2
11.0	Launch Vehicle Integration and Flight Support		.4
	TOTAL ACQUISITION**		$ 152.4

*Includes engineering liaison and data.

**Does not include fee and contingency

OPERATIONS/LAUNCH COST SUMMARY

WBS	Nomenclature	Cost
12.0	Ground Operations	$ 21.9
13.0	Launch Services	18.2

FISCAL YEAR FUNDING REQUIREMENTS - (See Schedule Page 3)

Fiscal Year	Acquisition Cost*
1986	$ 20.6
1987	41.2
1988	51.4
1989	61.7
1990	30.9
TOTAL	$ 205.8

*Includes fee and contingency; no operations.

GROUND RULES & ASSUMPTIONS

1. All values expressed in constant 1984 dollars.
2. Unless otherwise indicated, all dollars are expressed in millions.
3. Estimate assumes previous go-ahead for the CO_2 Level I mission and TOPEX satellite.
4. Program estimate based on protoflight concept.
5. Costs for science payload instruments provided by Ball Aerospace; except for SMMR, AMSU, and Altimeter.
6. Costs for ground operations provided by Arthur D. Little, Inc.
7. Launch costs assume full orbiter cost, in 1984 dollars, of $85 million.
8. Costs are not included for:
   a. Space operations
   b. Use of TDRSS
   c. Allowance for Class I changes.
   d. Additional ground facilities.

COST SUMMARY

	Nonrecurring	Recurring	Total
Acquisition	$ 39.0	$ 128.5	$ 167.5
Operations*	-	5.4	5.4
Launch	-	19.2	19.2

*Assumes no additional costs for ground facilities and includes 1 year of operational costs only.

MISSION DESCRIPTION

This is an intermediate term mission to be flown in five to ten years using modifications of existing instruments. Modifications required for the Level II mission bus are minimal and are limited to minor structural changes, additions to the electrical power subsystem to accommodate changed payload requirements, and the addition of redundant components to meet a five-year life requirement.

ACQUISITION COST SUMMARY

WBS	Nomenclature	Cost	
1.0	Program Management		$ 9.0
2.0	Systems Engineering and Integration*		7.9
3.0	Satellite Bus Design, Fabrication, & Test		34.6
3.1	Structures and Mechanisms	$ 4.0	
3.2	Attitude Control & Determination Subsystem	4.8	
3.3	Command & Data Handling Subsystem	9.0	
3.4	Communications Subsystem	2.9	
3.5	Electrical Power Subsystem	6.7	
3.6	Orbit Maintenance Propulsion Subsystem	1.4	
3.7	Thermal Subsystem	1.3	
3.8	Wiring Harness and Cabling	.3	
3.9	Ascent Propulsion Stage	1.2	
3.10	Bus Integration and Checkout	3.0	
4.0	Payload Design, Fabrication, and Test		99.5
4.1	Imp Adv Very High Resolution Radiometer (AVHRR)	13.9	
4.2	Improved Data Collection System (DCS)	10.8	
4.3	Imp Stratospheric Aerosol & Gas Exper (SAGE-2)	9.2	
4.4	Earth Radiation Budget Exper (ERBE)	17.3	
4.5	Imp Scan Multichan. Microwave Radiometer (SMMR)	2.8	
4.6	TOPEX Radar Altimeter (ALT)	10.5	
4.7	Infra-red Interferometer/Spectrometer (IRIS)	17.3	
4.8	Advanced Microwave Sounding Unit (AMSU)	4.7	
4.9	Payload Integration and Checkout	13.0	
5.0	System Test and Evaluation		3.2
6.0	Test Support		6.9
6.1	Tooling and Special Test Equipment	5.4	
6.2	Peculiar Support Equipment	1.5	
7.0	Airborne Support Equipment		.4
8.0	Critical Flight Spares		2.7
9.0	Software		1.6
10.0	Reliability, Quality Assurance, and Safety		1.3
11.0	Launch Vehicle Integration and Flight Support		.4
	TOTAL ACQUISITION**		$ 167.5

*Includes engineering liaison and data.

**Does not include fee or contingency.

OPERATIONS/LAUNCH COST SUMMARY

WBS	Nomenclature	Cost
12.0	Ground Operations	$ 5.4
13.0	Launch Services	19.2

FISCAL YEAR FUNDING REQUIREMENTS - (See Schedule Page 3)

Fiscal Year	Acquisition Cost*
1988	$ 22.6
1989	33.9
1990	45.3
1991	56.5
1992	45.2
1993	22.6
TOTAL	$ 226.1

*Includes fee and contingency; no operations.

SECTION 4 - LEVEL III MISSION

GROUND RULES & ASSUMPTIONS

1. All values expressed in constant 1984 dollars.
2. Unless otherwise indicated, all dollars are expressed in millions.
3. Estimate assumes previous go-ahead for the CO_2 Level I and II missions as well as TOPEX.
4. Costs for science payload instruments provided by Ball Aerospace; except for the LAMMR, Altimeter, AMSU, and MPS.
5. Spacelab pallet costs were estimated assuming design will be 100% off-the-shelf.
6. Estimate assumes the space platform will be in existance and operational.
7. Costs for ground operations provided by Arthur D. Little, Inc.
8. Launch costs assume full orbiter cost, in 1984 dollars, of $85 million.
9. Costs are not included for:
    a. Electrical power, attitude control, or communications - assumed that space platform will handle these functions.
    b. Use of TDRSS.
    c. Space operations.
    d. Allowance for Class I changes.
    e. Additional ground facilities.

COST SUMMARY

	Nonrecurring	Recurring	Total
Acquisition	$ 227.9	$ 144.0	$ 371.9
Operations*	-	5.4	5.4
Launch	-	85.0	85.0

*Assumes no additional costs for ground facilities and includes costs for 1 year of operations only.

MISSION DESCRIPTION

Level III is a long-term mission with a new instrument complement to be developed and flown in ten to twenty years. For the Level III mission two Spacelab pallets will provide the primary structure which will be attached in orbit to a free flying, unmanned, space platform using a "standard" space platform docking interface. The space platform will provide electrical power, communications, and attitude control services to the CORS module.

ACQUISITION COST SUMMARY

WBS	Nomenclature	Cost	
1.0	Program Management		$ 19.2
2.0	Systems Engineering and Integration*		19.2
3.0	Payload Support System Fabrication, & Test		20.5
3.1	Payload Support Equipment	$ 13.4	
3.2	Spacelab Pallet	5.8	
3.3	Payload Support Equip Assembly & Checkout	1.3	
4.0	Payload Design, Fabrication, and Test		286.9
4.1	Infra-Red Visual Mapper (IRVM)	26.2	
4.2	Improved Data Collection System (DCS)	10.8	
4.3	Light Detecting and Ranging (LIDAR)	78.8	
4.4	Infra-Red Interferometric Radiometer (FTS)	26.2	
4.5	Microwave Pressure Sounder (MPS)	4.0	
4.6	Advanced Microwave Sounder (AMS)	4.7	
4.7	Microwave Mapper (MM)	16.0	
4.8	TOPEX Radar Altimeter (ALT)	10.5	
4.9	Parallax Sensor (PS)	21.0	
4.10	Adv Eart Radiation Budget Exper (ERBE)	52.5	
4.11	Payload Integration and Checkout	36.2	
5.0	System Test and Evaluation		12.8
6.0	Test Support		7.3
6.1	Tooling and Special Test Equipment	3.7	
6.2	Peculiar Support Equipment	3.6	
7.0	Airborne Support Equipment		.4
8.0	Critical Flight Spares		2.1
9.0	Software		2.1
10.0	Reliability, Quality Assurance, and Safety		1.0
11.0	Launch Vehicle Integration and Flight Support		.4
	TOTAL ACQUISITION**		$ 371.9

*Includes engineering liaison and data.

**Does not include fee or contingency.