PROJECT COPERNICUS: AN EARTH OBSERVING SYSTEM

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"Fifteen years will mean forever," the mission slogan for Project Copernicus, conveys the belief of the Hunsaker Aerospace Corporation and the Bush administration that sustained global observation for over a decade will benefit the Earth and its inhabitants for centuries to come. By examining the Earth's systems for only 15 years, scientists will develop a much better understanding of the global environment.

The Earth's system is in a constant state of change. Many of the processes that are creating this change are natural, while others are human induced. It is imperative that we reduce the scientific uncertainties associated with global change issues. Scientists need to be able to quantify human-induced changes in order to act as the catalyst for a major behavioral alteration within society. These changes not only affect biological, climatological, and hydrological processes, but they will also affect our society and the world economy.

Unexpected global change can be devastating. Changing weather patterns could affect the food supply of billions of people. Droughts or floods induced by global change can destroy countless acres of crops, destabilizing national and worldwide economies. Ozone deterioration is another significant change that will have ramifications for human civilization.

Society needs to understand how changes such as global warming, El Niño, and ozone depletion affect its current and future existence. With a better understanding of how the Earth system is changing, we can help stop the human-induced alterations. If scientists are capable of predicting global change, society will be able to reallocate resources to compensate for environmental changes.

President George Bush has recently recognized the need for this reallocation. As a first step, he has charged the U.S. Global Change Research Program (USGCRP) with examining the changes in the global Earth system. A major initiative of the USGCRP is the Mission to Planet Earth.

The Mission to Planet Earth will characterize the state of the entire planet and also quantify the regional variations in the environment. The regional variations are best studied with *in situ* measurements on land, in the oceans, or in the atmosphere. But, in order to achieve a global perspective, the observations must be conducted from outside the region of influence; thus they need to be made from space.

The Earth Observing System (EOS) is a space-based portion of the Mission to Planet Earth. EOS has been conceived to provide observations from vehicles in low Earth orbit. The objective of EOS is to provide an information system that will acquire data on geophysical, biological, and chemical processes. These data can then be examined in a comprehensive study of the entire planet. A large component of the EOS is the Data and Information System (EOSDIS). EOSDIS is intended to provide computing and networking to support EOS research activities.

Hunsaker Aerospace Corporation is presenting this proposal for Project Copernicus to fulfill the need for space-based remote sensing of Earth. Hunsaker is primarily a spacecraft design firm. The company therefore will concentrate on the means of data acquisition, rather than with the interpretation, modeling, distribution, archiving, and processing of EOS data. Hunsaker Aerospace Corporation is committed to designing and manufacturing this revolutionary space science mission. Copernicus is designed to be a flexible system of spacecraft in a low near-polar orbit. The project will be capable of accommodating continuously developing scientific mission requirements. Copernicus is an essential element of EOS and of the Mission to Planet Earth (see Fig. 1).

Hunsaker's goal is to acquire data so that the scientists may begin to understand many Earth processes and interactions. Table 1 shows these processes. They are classified into the science areas of Climate and Hydrological Systems, Biogeochemical Dynamics, and Ecological Systems and Dynamics. The importance of these priorities increases going up and to the left on the table. Hunsaker has adopted these scientific priorities from the questions that the USGCRP has posed in its assessment of the 1991 fiscal year plans.

The mission objective of Copernicus is to provide a space-based, remote-sensing measurement data acquisition and transfer system for 15 years. Many Earth processes are rapidly changing; others take over decades to complete their cycles. Project Copernicus must have continuity over the shorter timescales to provide data on rapidly changing processes. Copernicus must also last for 15 years in order to acquire data on slowly changing cycles.

The Hunsaker Corporation, after a detailed review of the scientific priorities, chose NASA's EOS-A instruments for the baseline design of the Copernicus-A mission. The instruments selected for Copernicus-A not only measure a majority of the

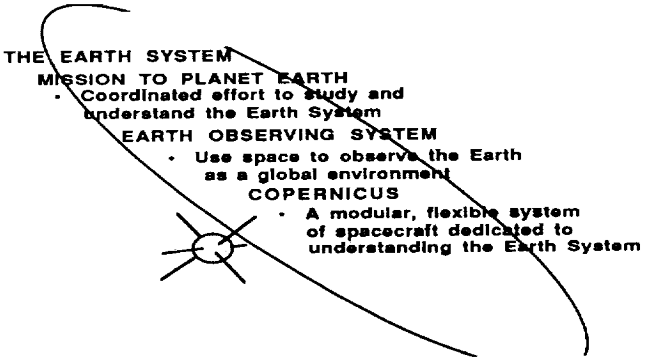
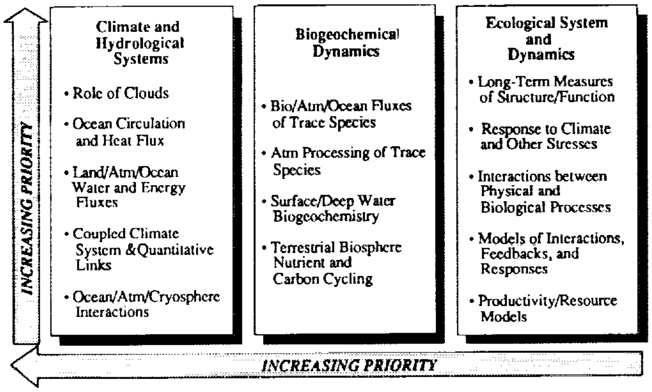


Fig. 1. Mission Flow-Down and Goals



Climate and Hydrological Systems	**Biogeochemical Dynamics**	**Ecological System and Dynamics**
• Role of Clouds • Ocean Circulation and Heat Flux • Land/Atm/Ocean Water and Energy Fluxes • Coupled Climate System &Quantitative Links • Ocean/Atm/Cryosphere Interactions	• Bio/Atm/Ocean Fluxes of Trace Species • Atm Processing of Trace Species • Surface/Deep Water Biogeochemistry • Terrestrial Biosphere Nutrient and Carbon Cycling	• Long-Term Measures of Structure/Function • Response to Climate and Other Stresses • Interactions between Physical and Biological Processes • Models of Interactions, Feedbacks, and Responses • Productivity/Resource Models

INCREASING PRIORITY

INCREASING PRIORITY

TABLE 1. Science Priorities

climatological variables (listed in Table 2), but they also provide a representative sampling of the sizes, data rates, and power requirements of other remote sampling instruments that could be mounted on present or subsequent Copernicus platforms as science priorities change. The Copernicus-A instruments, therefore, not only achieve scientific goals, but they also add flexibility to the Copernicus design. The constraints placed on the project by this representative sampling of instrument specifications define the requirements for the baseline Copernicus bus designs.

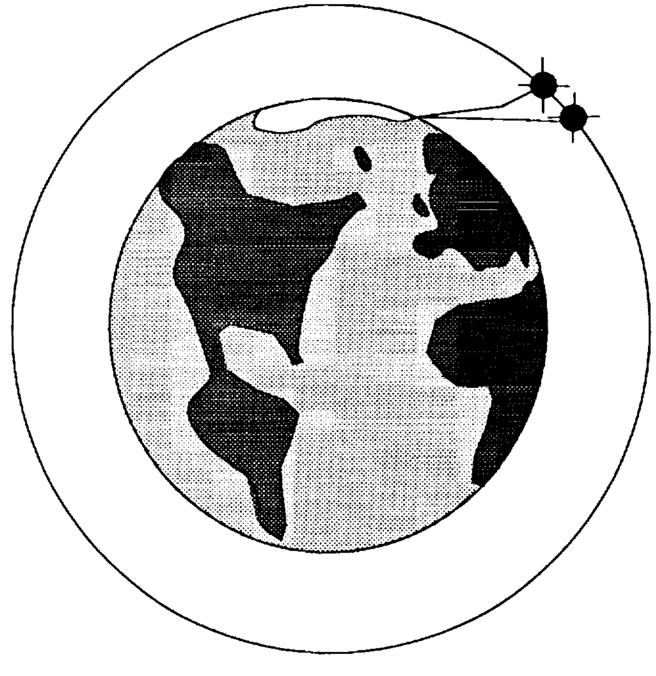


Fig. 2. Simultaneity Example for Atmospheric Correction

TABLE 2. Candidate Climatological Variables

Stratospheric Gases	Tropospheric Water Vapor	Ocean CO_2
Tropospheric Gases	Precipitation	Biomass Inventory
Atmospheric Aerosols	Cloud Cover/Height	Ocean Chlorophyll
Atmospheric Particles	Vegetation Cover/Type	Sea Ice Cover/Depth
Surface Emissivity/ Albedo	Soil Moisture	Surface Roughness
Solar Spectral Radiation	Snow Cover Depth/ Wetness	Sea Level Rise
Atmospheric Temperature	Surface Temperature	Volcanic Activity
Wind Fields	Solid Earth Motion	Forest Fire Evolution

The driving force behind the design of Project Copernicus is simultaneity. Simultaneity, simply defined, is two or more instruments looking at the same ground pixel at the same time. There is a more stringent form of simultaneity, called congruency, that requires spatial and temporal coincidence. For example (see Fig. 2), if one instrument is measuring a process on the Earth, its data may be incorrect because of some disturbing phenomenon such as water vapor in the atmosphere or radiation emitted from Earth. A second instrument could be flown with the first instrument or on another bus in formation with the first. This second instrument would measure the disturbing phenomenon and allow the data for the first instrument to be corrected.

If any type of simultaneity is required, it is preferable to fly the simultaneous instruments either on the same bus, or on buses that are flying in formation. The simultaneity requirements of the instruments selected for Copernicus-A have yielded two designs. The instruments are either all grouped together on a single large bus, or are placed in congruent groups on a series of small buses. For the Copernicus-A design, formation flying was not implemented. The small bus design was able to accommodate entire groups of congruent instruments, thereby eliminating the necessity of formation flying and the complications associated with it.

In addition to stipulating requirements for the vehicles themselves, the instruments also require a certain orbit for functionality. The orbit, in turn, dictates a large portion of the spacecraft design for stationkeeping requirements. For the Copernicus-A design Hunsaker has selected a near-polar, Sun-synchronous circular orbit at an altitude of 727.5 km with a 98.3° inclination. This orbit provides coverage of the entire globe with constant resolution. At the selected altitude, coverage of the entire Earth is accomplished every two days.

To enter this orbit, Copernicus will be launched on a Titan IV launch vehicle to a 185-km × 727.5-km orbit. The small bus vehicles will then be circularized by periapsis firings of onboard thrusters (see Fig. 3). The large bus vehicle will circularize by an impulse burn of its onboard thrusters. By using the onboard thrusters for circularization, a kick stage does not need to be implemented into the launch system. By eliminating the need for a kick stage, Hunsaker is eliminating a source of space debris.

Hunsaker recognizes that space debris is becoming a monumental problem for space missions. In keeping with the environmentally conscious theme of Project Copernicus, Hunsaker has made every effort to eliminate space debris from the project. This requirement not only results in onboard thrusters being used for orbital insertion, but it also results in

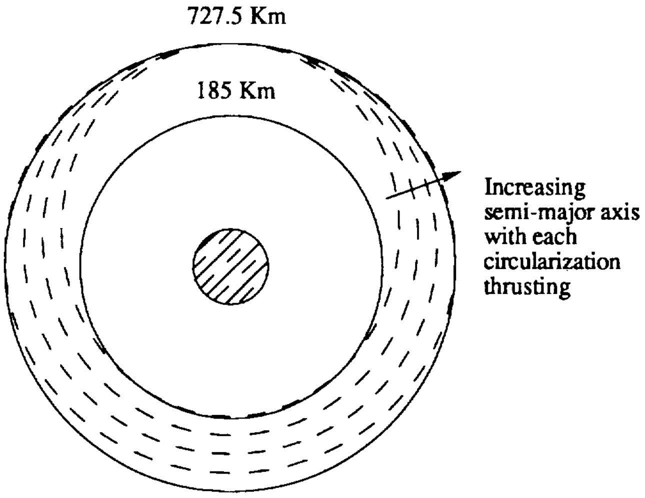


Fig. 3. Small Bus Orbital Insertion

a spacecraft deorbit requirement. At the end of the mission, the vehicles themselves will be deorbited and break up safely over the ocean.

The mission profile consists of launching a selected number of remote-sensing measurement instruments on a modular bus system. This bus(es) will be inserted into a low Earth, near-polar orbit. To achieve the polar inclination, Copernicus will be launched from the Western Test Range at Vandenberg, California. If several satellites are used to carry the instruments, the vehicles need not be constrained to the same orbit. The instruments will perform measurements, and the satellite(s) will transmit the data down to the EOSDIS center at NASA's Goddard Space Flight Center. Additional operations will be performed as commanded by groundbased operators. When the spacecraft system is nearing end of life, the existing vehicles will be deorbited as per the deorbit criteria. The vehicle(s) will break up and fall into the ocean. Prior to deorbit, another satellite will be launched. Once adequate data is no longer being received from one system, the next bus(es) in the series will be launched.

Hunsaker's design philosophy consists of program priorities and design ground rules for the spacecraft design. The design considerations are prioritized in the following order: (1) reliability, (2) system performance, (3) flexibility, (4) cost, (5) manufacturability, (6) supportability, and (7) schedule.

The mission of Project Copernicus, the study of the Earth's environment, gives the scientific goals of the mission with the utmost priority in every aspect of the design process. These goals are balanced with engineering capability to produce a feasible design.

The design priorities are closely interrelated with the ground rules. The ground rules are selected to ensure that Project Copernicus meets the scientific requirements placed upon it. The ground rules include design to ensure continuity, to achieve unprecedented scientific results, and for maximum flexibility.

Hunsaker recognizes that data continuity is essential to the principal investigators of the instruments. Data continuity on short timescales of days or weeks is important since many Earth processes are rapidly changing. Continuity is also equally important on longer timescales of years or decades. Any interruption in the data flow for either timescale would jeopardize the scientific understanding of these phenomena.

Hunsaker is also concerned with integrating Project Copernicus with other EOS projects. This will increase the available data on many of the Earth processes that Copernicus is to examine.

The continuity ground rule affects a large portion of the spacecraft design. Issues such as reliability levels and redundancy levels flow directly from the continuity ground rule. If the spacecraft becomes dysfunctional or loses a primary instrument, it must be serviced in orbit or another satellite must be launched. For the Copernicus program, serviceability will not be employed. Instead Hunsaker will rely on the programmatic flexibility built into the system and launch another spacecraft. Continuity also raises concerns about orbit maintenance. The orbit of the Copernicus satellites must be maintained to sustain the appropriate viewing altitude and inclination. This results in requirements on the onboard thrusters, guidance, and navigation systems. The space environment also provides unique challenges: Micrometeorites, radiation, and thermal effects all affect the spacecraft and must be compensated for in the design of Copernicus to ensure continuity.

Continuity is needed for the mission lifetime of 15 years. Hunsaker considered whether a single vehicle should be launched, or similar satellites should be relaunched periodically. If the relaunch option is chosen, the redundancy and amount of consumables aboard can both be reduced substantially.

Hunsaker's costing analysis indicated that if the large bus option was selected, a new bus should be relaunched after seven and a half years. If the small bus option is launched, a new set of buses will be launched after five years. This relaunch schedule requires that there be an extra, large bus produced in case of catastrophic failure of the large bus. There will be enough small buses produced so that if one fails, the next in the launch series can be launched earlier.

The second ground rule is to design for excellent scientific results. This groundrule includes such issues as simultaneity and orbital selection and orbital maintenance (stationkeeping).

The third ground rule is to design to ensure flexibility. Copernicus must have sufficient programmatic flexibility so that if a budget cut or unexpected scientific priority change confronts the project, it will rapidly and efficiently adapt. The spacecraft of Project Copernicus must also be flexible. If there is an instrument change or modification because of continuously changing scientific priorities, the spacecraft should be able to easily accommodate this change.

To facilitate the design of the two buses, Hunsaker created the organization seen in Fig. 4. The systems integration group and the program planning group set the scientific and programmatic requirements to achieve Copernicus' goals. These requirements were then communicated to the small and large bus groups who were responsible for designing a system of spacecraft capable of meeting them. The bus groups used a number of subgroups to design the subsystems. The subgroups included Power and Propulsion; Command, Control, and Telemetry; Structures and Thermal Control; and Guidance, Navigation, and Control.

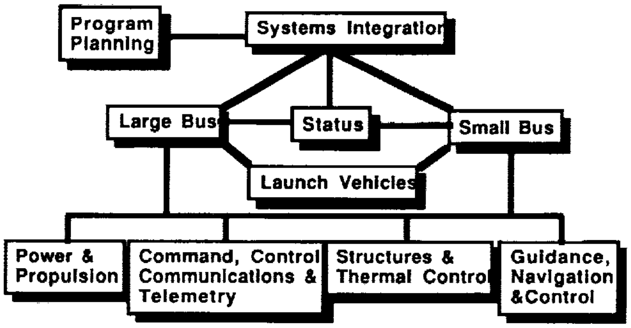


Fig. 4. Hunsaker Organizational Chart

The status group was responsible for monitoring the spacecraft's systems for the duration of the mission and communicated primarily with the bus groups and systems integration.

Finally, the launch vehicle group communicated with the bus groups to determine which launch vehicle would meet the bus group's needs. The launch vehicle group then helped interface the satellite with the selected vehicle.

The Hunsaker Corporation was responsible for two bus designs, each of which could achieve the goals of Project Copernicus. The Large Bus design was created as a single satellite that would contain all of the chosen EOS-A instruments and their associated support equipment. The Small Bus design would consist of several smaller satellites, each of which would carry a specified group of the EOS-A instruments.

Both bus designs had to meet the primary mission objectives: continuity, flexibility, and scientific results. From these three objectives come the primary design issues. Continuity raises issues of complexity of design and manufacture, hardware reliability, and levels of system redundancy. Flexibility poses the problem of design for modularity and adaptability to future instruments and requirements. Scientific results translate to level of system performance, instrument support, and maintenance of proper orbit. These issues were reflected in the mission priorities of reliability, performance, and flexibility, as laid down by Hunsaker.

In designing a superstructure for the Large Bus, these and additional, more specific issues had to be addressed. To contain all 15 of the baseline EOS-A instruments, the bus would require a large area on which to mount them, while restraining the mass and dimensions of the bus to the abilities of launch vehicles in production or under design. Because of its large size the superstructure of the Large Bus could become increasingly difficult to manufacture maintaining tolerances over many components. In terms of reliability, such a structure should be simple enough in design to avoid single-point failure during operation, as such a failure could jeopardize the entire mission. In addition, size constraints may limit the flexibility of moving or replacing instruments on the bus.

Hunsaker proposed several Large Bus structural designs, two of which were deemed suitable in terms of maintaining all instruments and equipment within launch vehicle constraints. The first was a folding plate design that would support the instrument packages on one face while carrying the support equipment on the other. Folded into three sections within the launch vehicle, the structure would be deployed in orbit. The second design was a simple box truss, one face of which would carry all the instruments, while all the support equipment would be internalized within the body of the truss (Fig. 5).

After close comparison of the two designs, the box truss design was deemed superior in its abilities to meet the mission requirements. In terms of structural strength, instrument stability, and complexity of operation, the box truss was clearly the superior design. The major drawback was its compact size, which reduced the effective area for instrument placement.

The final design, although still a box truss, was modified somewhat to accommodate MIMR, the largest instrument of the EOS-A package, and the power generating solar arrays. All the EOS-A instruments, with the exception of MIMR, are suspended from the lower face of the truss, which will face the Earth at all times. The construction consists primarily of 2-in-diameter aluminum truss members, with aluminum plates used as instrument attachments to the truss. The overall structural dimensions are 7.0 m long, 3.2 m wide, and 1.5 m high. The mass is approximately 1000 kg. Figure 6 illustrates the structure.

In designing the structures for the Small Bus design, Hunsaker had to optimize not only the satellite structure, but also the number of satellites in the system. Four distinct designs were proposed, each with a particular design criterion as its primary

Box Truss

Folding Plate

Fig. 5. Large Bus Configurations

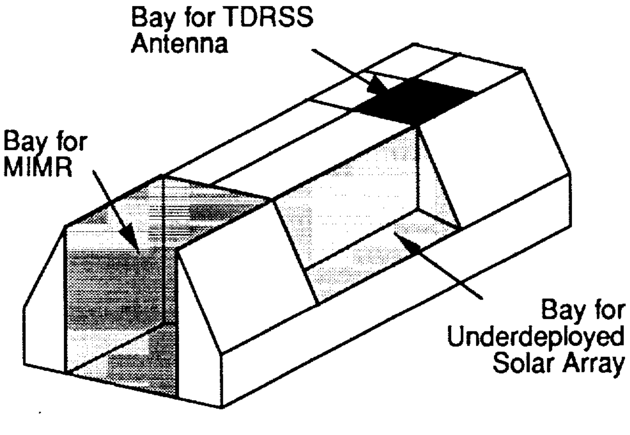


Fig. 6. Large Bus Truss Structure

target. The first, Synchronious, consisted of five satellites aimed at maintaining simultaneity in measurement. The second, Modularious, was composed of six satellites designed around maximizing instrument flexibility. The third, Pointious, had five satellites designed to meet and exceed instrument pointing requirements. Lastly, Mixious consisted of nine satellites carrying multiple versions of each instrument to maximize system redundancy. The final configuration chosen was none of the above, but rather a modification of Synchronious, named Phoenix, consisting of four slightly larger satellites. Each satellite carries two to four instruments, each group of instruments satisfying simultaneity requirements on a single satellite.

The issues facing the Small Bus design were similar to those of the Large Bus. With a reduced number of satellites, the bus needed to maintain flexibility in moving instruments on a given platform or from one satellite to another. This also required a simple design that could adapt to instruments of varying shape and size.

The final structural design of Phoenix consists of four identical octagonal trusses with an open center for support equipment (Fig. 7). Of the two larger faces of the truss, one is used as a platform for up to four instruments. This face is fitted with a sandwich plate consisting of two aluminum plates encasing a honeycomb core. The overall structure has a diameter of 3.6 m, and is 1.0 m thick.

Other technical issues that affect both bus designs, such as system redundancy, partial mission success, and formation flying cannot be answered by the structure alone. The additional subgroups of Thermal Control, Power, Guidance, Control, and Communications and Data Handling provide the needed support to achieve the mission objectives. Because the subgroup designs are nearly indentical in concept on both buses, they will each be treated as a single design.

Thermal control, the means by which the spacecraft dissipates heat and maintains the operating temperatures of the instruments within narrow margins, was designed as a passive system on a component level. Each instrument and power-consuming device onboard each satellite is mounted onto a Freon-filled cold plate that is connected to a heat pipe. The Freon is circulated through the cold plate, then fed through the heat pipe via capillary action to the external end of the pipe, where the heat is dissipated into cold space. In addition, each instrument is insulated by MLI Mylar and polished metal sheets that cover its exposed surfaces.

The Power subgroup, whose purpose was to design a system to generate and store sufficient power to operate a satellite's instruments and support equipment, proposed the use of photovoltaic solar arrays and nickel hydrogen batteries. The systems onboard the Large Bus operate at 120 V, whereas the Small Bus operates at 28 V. The solar arrays of the Large Bus are 130 sq m in area, generating 10,500 W of power at mission start. Each Small Bus requires about half as much power, and has proportionately smaller arrays. The batteries can store sufficent energy to operate each satellite for the 40 min the spacecraft is out of the Sun's view. Figure 8 illustrates the power flowdown for the Large Bus.

The Guidance & Control subgroup is composed of four major divisions: attitude determination, attitude control, position determination, and position control. Attitude determination is required to orient the spacecraft and instruments in orbit with great accuracy. The pointing requirements are particularly stringent for Project Copernicus because of the presence of several instruments that are designed to resolve climatological and surface changes on a scale of hundreds of meters. This sets accuracy requirements as low as 60 arcsec for control and 100 arcsec/sec for stability. Therefore, the Large Bus and two of the four Small Bus satellites implement two Ball Brothers Star Mappers each. The secondary system is the Microcosm Autonomous Navigation System (MANS). Attitude control is performed by two sets of three-axis reaction wheels and copper coil magnetorquers. Position determination, necessary to maintain the correct global coverage and equatorial crossing

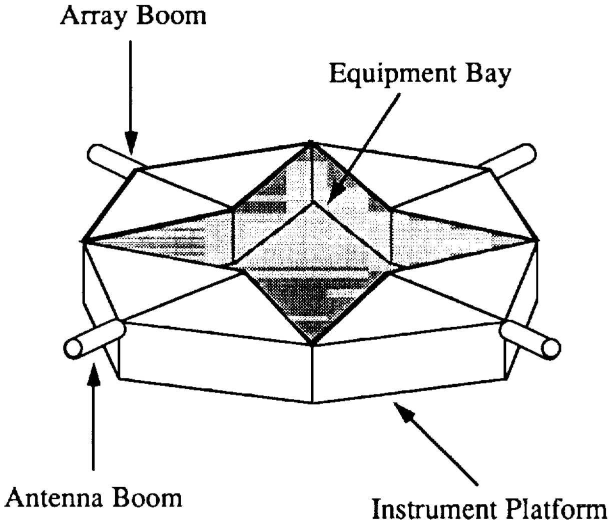


Fig. 7. Small Bus Structure

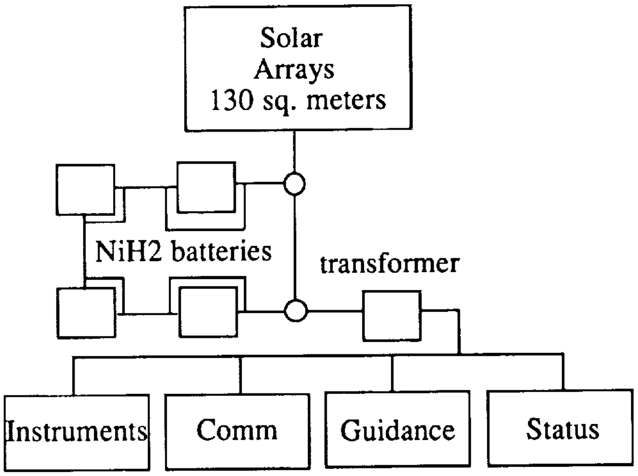


Fig. 8. Large Bus Power Flowdown

time of 1:30, is performed primarily by a Motorola Global Positioning Receiver operating at 10 Hz. The optimal position accuracy is within 0.6 m. Position control is controlled by two pairs of 46-N hydrazine thrusters, conducting stationkeeping maneuvers through Hohmann transfers.

The Command, Control, Communications, and Telemetry group had three major areas of concern: data handling, communications, and command and control. The data handling system is the same for the Large and Small Bus. Each instrument sends information to a Hunsaker-designed data handling computer, distinguished by its low speed of 6 MHz and wide data path of 48 bits, allowing the computer to handle 300 megabits per second. The data is then transmitted or stored on optical disks. Data transmission will take place primarily via a Ku-band downlink through the high-gain Tracking Data Relay Satellite System (TDRSS) antenna. Commands from the ground will be uplinked through the Ku-band or the multiple-access S-band. On each bus there are two omnidirectional antennae to relay commands if the high-gain antennae fails, or if the guidance and control system fails and the antennae cannot be aimed at a TDRSS satellite. The commands uplinked from the ground are processed by the command, control, and telemetry system consisting of sensors, Built-in-Test Managers (BIT), and On-Board Computers (OBC).

Once the designs of the two bus systems were complete, Hunsaker was able to choose which system could more easily meet the programmatic priorities. Hunsaker recognized that the scientific goals of Copernicus had the highest priority, but these goals had to be balanced with rational design.

Both Large and Small Bus systems were similar in terms of the reliability and performance priorities. The next two design priorities are flexibility and cost. The Small Bus System is significantly more flexible. Small Bus is a more robust system which could more easily adapt to changes in instrument payloads. Small Bus could also more easily accommodate a change in launch vehicle. Additionally, if the program's budget is unexpectedly cut, Small Bus can scale back the system. Large bus, alternatively, would have to be cancelled if confronted with significant budget cuts. Small Bus is also much less costly. Furthermore, the Small Bus is much more manufacturable than the Large Bus because of the smaller number of parts and connections.

Hunsaker Aerospace Corporation has selected the Small Bus design for the Project Copernicus mission. The flexibility of the Small Bus is very attractive not only for Copernicus-A instruments, but also for Copernicus-B instruments. Small Bus is a more robust design; it can more easily accommodate unexpected changes in instruments, instrument usage, or budgetary alterations. Hunsaker is confident that the Small Bus design will be capable of achieving the lofty goals of Project Copernicus.