LA-UR- 98-1388

Title: TWO WIDE-ANGLE IMAGING NEUTRAL-ATOM SPECTROMETERS (TWINS)

Author(s):
David J. McComas, NIS-1
Bernard Blake, Aerospace Corporation
James Burch, Southwest Research Institute
Dr. Hans Fahr, University of Bonn
Herbert Funsten, NIS-1
Mike Gruntman, University of Southern California
Don Mitchell, Applied Physics Laboratory
Craig Pollock, Southwest Research Institute
Ed Roelof, Applied Physics Laboratory
Earl Scime, West Virginia University
Ruth Skoug, NIS-1

Submitted to: NASA

Los Alamos
NATIONAL LABORATORY

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Small Explorer and Missions of Opportunity
Investigation Summary Form

AO 97-OSS-03	Small Explorer Program and Missions of Opportunity

Principal Investigator			
Dr.	David	John	McComas
Title	*First Name*	*Middle Name*	*Last Name*
Department: Space and Atmospheric Science Group			
Company/Institution: Los Alamos National Laboratory			
Street Address: MS D466		City/Town: Los Alamos	
State: NM	Zip/Postal: 87545	Country: USA	
Telephone: (505) 667-0138	Fax: (505) 665-7395	E-Mail Address: dmccomas@lanl.gov	

Proposal Title

Two Wide-Angle Imaging Neutral-atom Spectrometers (TWINS)

Science Theme Supported (1 = primary; 2 = secondary)

[ ]Structure and Evolution of the Universe
[X]The Sun-Earth Connection
[ ]Astronomical Search for Origins and Planetary Systems

Abstract (Limit 150 words)

Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) is a revolutionary new mission designed to stereoscopically image the magnetosphere in charge exchange neutral atoms for the first time. We propose to fly two identical TWINS instruments as a mission of opportunity on two widely-spaced high-altitude, high-inclination United States Government spacecraft. Because the spacecraft are funded independently, TWINS can provide a vast quantity of high priority science observations (as identified in an ongoing new missions concept study and the Sun-Earth Connections Roadmap) at a small fraction of the cost of a dedicated mission. Because stereo observations of the near-Earth space environs will provide a particularly graphic means for visualizing the magnetosphere in action, and because of the dedication and commitment of the investigator team to the principles of carrying space science to the broader audience, TWINS will also be an outstanding tool for public education and outreach.

Small Explorer and Missions of Opportunity
Investigation Summary Form (Page 2)

Principal Investigator			
Dr.	David	John	McComas
Title	*First Name*	*Middle Name*	*Last Name*

Proposal Title

Two Wide-angle Imaging Neutral-atom Spectrometers

Mission Mode (Check one)	Cost
[ ]SmallExplorer	NASA Mission Cost $ 16.9
[X]Mission of Opportunity	Total Mission Cost $ 37.2 (est)

Anticipated Launch Vehicle:
US Government Spacecraft

Co-Investigator(s)

Name	Institution	E-mail
Dr. Bernard Blake	Aerospace Corporation	blake@dirac2.dnet.nasa.gov
Dr. James Burch	Southwest Research Institute	jburch@swri.edu
Dr. Hans Fahr	University of Bonn	UNF308@IBM.rhrz.uni-bonn.de
Dr. Herbert Funsten	Los Alamos National Laboratory	hfunsten@lanl.gov
Dr. Mike Gruntman	University of Southern California	mikeg@spock.usc.edu
Dr. Don Mitchell	Applied Physics Laboratory	don_mitchell@spacemail.jhuapl.edu
Dr. Craig Pollock	Southwest Research Institute	cpollock@swri.org
Dr. Ed Roelof	Applied Physics Laboratory	ed_roelof@spacemail.jhuapl.edu
Dr. Earl Scime	West Virginia University	scime@wvnvms.wvnet.edu
Dr. Ruth Skoug	Los Alamos National Laboratory	rskoug@lanl.gov

1.0 EXECUTIVE SUMMARY

The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) mission provides a new capability for stereoscopically imaging the Earth's magnetosphere. By imaging the charge exchange neutral atoms over a broad energy range ($1<E<\sim100$ keV) using two identical instruments on two widely-spaced high-altitude, high-inclination spacecraft, TWINS will enable the 3-dimensional visualization and the resolution of large scale structures and dynamics within the magnetosphere for the first time. These observations will provide a leap ahead in our understanding of the global aspects of the terrestrial magnetosphere and directly address a number of critical issues in the "Sun-Earth Connections" science theme of the NASA Office of Space Science.

While TWINS has numerous scientific goals that relate to the various individual regions that will be imaged, **the primary scientific goal of the TWINS investigation is to establish the global connectivities and causal relationships between processes in different regions of the magnetosphere.** While the IMAGE MIDEX mission will take the first important step in imaging the magnetosphere, TWINS will advance another major step forward by providing the capability to unfold the emission variation along the line-of-sight from the integrated ENA intensities obtained from each of the spacecraft. The stereo imaging of TWINS will counter a serious difficulty regarding magnetospheric imaging, that of interpreting structures viewed in an optically thin medium, and will greatly reduce the reliance on models for retrieving the three-dimensional magnetospheric structure and dynamics from the data.

The broad scientific objectives of TWINS are listed here. They build on the scientific objectives that have previously been established for NASA's IMAGE mission, and will provide a far less model-dependent path to achieving these goals. The TWINS investigation measurement goals are:

(1) Ion Dynamics: To view the global dynamics, composition, and energization of ions throughout the magnetosphere with approximately one minute time resolution using simultaneously obtained multi-vantage point images of key magnetospheric components.

(2) Plasma Origins and Destinies: To trace the sources, transport, and sinks of plasma populations.

(3) Magnetospheric Evolution: To observe the evolution of the global magnetospheric structure as solar wind coupling and internal processes change the state of the magnetosphere from quiet to disturbed.

(4) Magnetospheric Structure: To visualize and map the global configuration and organization of the magnetosphere in three dimensions using stereo imaging, forward modeling, and image inversion.

These measurement goals will provide the inputs required to establish the spatial connections and temporal causalities between the various magnetospheric components and regions for both active and inactive states of the magnetosphere. Unlike previous attempts to achieve these goals via in situ multi-spacecraft studies, TWINS will provide nearly continuous global stereo coverage, rather than local observations, of the magnetosphere and will not suffer from timing ambiguities between events observed in different regions of the magnetosphere.

Phase A Progress

During Phase A, we have resolved a number of critical issues in the TWINS development, and have made a great deal of progress in defining the instrument concept and spacecraft interfaces. In particular: 1) We have determined that the most logical instrument configuration is to combine the front end electronics, DPU, and power supplies in one box, which will be placed on top of the DPU, and have developed preliminary designs for this configuration. 2) The spacecraft volume envelope, mass, and power allocated to TWINS have been defined, and accommodate some growth in the instrument. 3) We have developed a plan whereby the Ly-α sensor will be provided by the University of Bonn, Germany, and have added Dr. Hans Fahr of the University of Bonn as a TWINS Co-investigator. Dr. Fahr has extensive experience both in the design and fabrication of Ly-α detectors and in the analysis and interpretation of data from these sensors in the magnetosphere. 4) We have developed much better cost estimates for all phases of the project. 5) We have negotiated with the spacecraft for a higher data telemetry rate, which now may be as high as 25 kbps, and will greatly enhance the science return of the mission. 6) We have developed more sophisticated procedures for performing image inversion of simultaneous images from two spacecraft.

Technical Approach

TWINS will fly as a mission of opportunity on two high-inclination, high altitude spacecraft provided by a non-NASA US organization. In this report we simply refer to these spacecraft as S/C-1 and S/C-2. Each spacecraft will be 3-axis stabilized, approximately nadir pointing, and will be placed in a Molniya orbit with 63.4° inclination and 7.2 R_E apogee. The orbits of these spacecraft are ideal for a magnetospheric imaging mission, providing a unique opportunity to obtain stereo images of the magnetosphere in the near future at low cost. S/C-1 will launch in late 2001 or early 2002 while S/C-2 will launch in late 2003 or early 2004. Once launched, S/C-1 and -2 will be given international designators, and all data will be made available for normal scientific data analysis, educational, and public outreach purposes. Depending on the exact TWINS timing and the duration of the IMAGE science phase, S/C-1 may overlap with the IMAGE mission, providing the first magnetospheric stereo images as early as 2001 or 2002. In any case, however, S/C-1 and -2 will provide a full two year stereo mission beginning in late 2003 or early 2004.

TWINS instrumentation is based on that developed for the IMAGE mission, and includes a neutral atom imager and a Ly-α detector. The ENA imager will acquire images of the magnetosphere in H, He, and O, with one-minute time resolution and 4°x4° angular resolution. UV-blocking gold transmission gratings, a new technology being developed for the IMAGE mission, are also planned for use in the TWINS imager. The Ly-α detector measures the density of the neutral H exosphere, which is used in the image inversion process. The instruments will be located on a rotating actuator platform to allow viewing over 360° in azimuth.

The TWINS instruments have extensive heritage and a mature design, leading to extremely low risk for this mission. We will be able to take advantage of the new UV-blocking transmission grating technology developed for the IMAGE mission without incurring the risks involved in the development process.

Management Approach

The TWINS team is based on two long-standing successful working relationships: space hardware development by LANL and SwRI, and mission development by Aerospace and the mission sponsor. These relationships will be maintained for TWINS, with LANL and SwRI developing the majority of the ENA imager, and Aerospace providing the DPU and interface to the host spacecraft. The Ly-α detector will be provided by the University of Bonn, Germany, at no cost to the project. LANL will have responsibility for the TWINS instruments at the system level, including project management, systems engineering, resource management, documentation production and control, system-level testing and integration, and delivery of the instrument to the host spacecraft.

Costs

At a total mission cost of $16.9 M (FY97$), including the outreach program and reserves, the TWINS Mission of Opportunity will provide the first stereo images of the magnetosphere and closure on a large fraction of stereo imaging science for a fraction of the cost of an independent imaging mission. Cost estimates were obtained by a bottom-up analysis based on the work breakdown structure, and are based on the costs of recent similar projects at each institution.

Education and Outreach

The TWINS team is committed to a full and vigorous Education and Outreach program, and as such has committed a full 2% of the TWINS budget to education and outreach activities. TWINS will provide the first stereo images of the Earth's environment, and will thus provide the public with the first opportunity to observe on a global scale how the Earth and the magnetosphere are affected by the Sun.

Our education activities will be centered around a LANL-based program in which K-12 teachers and their students will develop curriculum materials based on TWINS science. After the TWINS spacecraft are launched, we will involve the participating classes in the data analysis process, and will also invite high school students to visit TWINS institutions for more extensive work with the TWINS data.

Our outreach program will strive to reach a broad audience through the use of a world wide web page, press releases to the national media, and museum displays using TWINS science and TWINS data. We will coordinate our efforts with other outreach programs already in place at TWINS institutions, and in particular with the IMAGE project, to provide the greatest possible leveraging of TWINS outreach funds.

2.0 SCIENCE INVESTIGATION DESCRIPTION

There are no changes to the Science Investigation proposed for the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) mission. Details of the proposed science mission can be found in Section 1.0 of the TWINS proposal.

3.0 EDUCATION AND OUTREACH, TECHNOLOGY, AND SMALL DISADVANTAGED BUSINESS PLAN

3.1 Educational Program

Activities By providing the first stereo views of the Earth's magnetosphere, TWINS images will not only introduce a new avenue of magnetospheric and plasma space science, but will also excite the general public, science educators, and students with their dramatic portrayal through pictures of the structure and dynamics of the Earth's plasma environment. Through the TWINS images, magnetospheric physics will be able to join astrophysics in the ability to convey the thrill of discovery in vivid pictures in the news and education media. TWINS images will captivate the public as we explore the outer reaches of the Earth's space environs.

The TWINS team is committed to a full and vigorous Education and Outreach program. The outreach program, which will be managed from LANL, will include a Co-Investigator from each institution, who will coordinate outreach activities in their region. The team members will be: Dr. R. Skoug (LANL), Dr. C. Pollock (SwRI), Dr. M. Gruntman (USC), Dr. E. Scime (WVU), Dr. B. Blake (Aerospace), and Dr. E. Roelof (APL).

Our outreach program will be based on guidelines outlined in recent documents on national education, such as the NASA "Partners in Education" [1995] and the AAAS "Benchmarks" [1995] documents. The goals outlined in these documents include a strengthening of interest in science and exploration, as well as the development of science thinking skills and teaching of basic science concepts that cut across and unite the fields of science: energy, patterns of change, stability, systems and interactions, and scale and structure. Recommendations include developing partnerships with educational institutions and developing a wide range of educational tools to reach a diverse audience of the public and students. Our outreach plan will focus on these same guidelines.

Through its various Co-I institutions, the TWINS team has strong connections with a wide variety of educational institutions, listed in Table 3.1. We will tap into existing educational programs at TWINS team member institutions that provide teacher training and curriculum development and can assist with the identification of students for internship programs.

Table 3.1. TWINS Education and Outreach Connections

NASA	Teacher Resource Center Network Regional Teacher Resource Centers Space Grant Consortia Classroom of the Future
LANL	Science Education Group University Outreach Team Community Involvement and Outreach Office Bradbury Science Museum
SWRI	NASA IMAGE Mission Outreach program Young Scientist and Engineers (YES) program
USC	Educational Television Channel Instructional Television Network California Museum of Science and Industry
WVU	Wheeling Jesuit College -- NASA Classroom of the Future
AGU	American Geophysical Union
AIP	American Institute of Physics
AAAS	American Association for the Advancement of Science
NSTA	National Science Teachers Association
AIAA	American Institute of Astronautics and Aeronautics

The TWINS images will stimulate the interest of students by providing a picture of the environment of the Earth, the environment in which we live. TWINS science will demonstrate the effect of the Sun on the Earth, and show how different regions of the Earth's magnetosphere are affected by changes in the solar environment. Students will learn exciting concepts about the effects of the Sun on the Earth and on human life, both on Earth and in space. Topics will include:

- Neutral atoms and charged particles
- The Earth's magnetic field
- Geomagnetic storms and substorms
- Auroras
- The 11-year solar cycle
- Space weather. The effects of the Sun on human life on earth and in space.

A major component of the TWINS education plan will be a program in which we work directly with teachers to develop educational tools which can be used in the classroom to teach science in general and space science in particular to students at various levels. This program will be implemented through the Science Education Team in the Education Program Office at LANL, under the direction of Rick Alexander. The LANL Science Education Team has a great deal of experience in the development of educational programs for K-12 teachers and students.

In this program teachers and their students will work together to develop classroom lessons and activities based on TWINS science. The program will be based around a series of workshops, in which the teachers will come to LANL to learn the scientific background of the TWINS project from the TWINS scientists and to interact with the LANL education team to learn effective methods of helping their students to learn these concepts. Upon return to the classroom, the teachers and students will then work together to research the scientific topics and to develop classroom activities appropriate for the grade level and subject taught. The lessons and activities will then be collected on a web page developed by the teachers and students, allowing classes around the country to access these materials. During the TWINS development phase, education will focus on basic space science and technology.

Following the TWINS launch in 2002, we will also include the participating classes in TWINS data analysis activities.

The goals of this program will be to increase the scientific and technological literacy of the students and to develop their critical thinking and decision making skills. By producing web-based lessons, the impact will be extended beyond the immediately involved personnel to any classroom or individual who accesses the web page. We also plan to make the lessons available in a CD-ROM or paper format in order to reach students who do not have access to the Internet. We will strive to reach students from groups which are under-represented in science careers by recruiting teachers and classes from a range of schools and backgrounds. It is also expected that a subset of the middle- and high-school age students will develop lessons for teaching TWINS science to younger students. This mentoring program will further extend the reach of the TWINS education program and will also increase the level of understanding of the older students.

The benefits of the program will be multifold:

1) Teachers and students will mentored by space physics scientists
2) Students will work with scientists using actual new magnetospheric data
3) Collaboration opportunities between schools
4) Access to vast array of learning resources from TWINS team and local teachers/schools
5) LANL will donate used computers to participating schools
6) Understanding of the magnetosphere and its processes

Evaluation of this education program will be performed by the LANL Education Program Office. They have an evaluation program in place which enables the outreach officer to evaluate the quality of the learning processes, student understanding of education material, and teacher and mentor effectiveness. Evaluation tools include monitoring the use of the web page, analysis of student-developed materials, student and teacher surveys, and observations by the program coordinators.

Another part of the TWINS education plan will be a summer internship program for high school students, in which students will spend several weeks at a TWINS institution and participate in the analysis of TWINS data. The benefits of this program will be two-fold. The high school students will develop an understanding of scientific research through work with the TWINS image data. In addition, upon return to their home schools, they can share what they have learned about space science with their peers and with younger students in their communities. As in the curriculum development program, we will seek to involve a diverse group of students in this program, including students from traditionally under-represented groups.

Through a program with the nearby NASA Center for Software Validation in Fairmont, WV, West Virginia University already involves high school students in summer research projects. During the summer of 1997, the physics department at WVU hosted three such students. As this NASA center is focused on software development and testing, the student's projects typically involve software related activities. The TWINS data set will provide an excellent opportunity to involve these students in state-of-the-art science while taking advantage of existing NASA programs.

TWINS images will also be a valuable addition to existing space physics educational tools. We will make these images available to schools and web sites for use in their space physics curricula. As an example of this: the WVU physics department has developed (through a NASA-funded grant) a world wide web based course that uses images and data products obtained by NASA spacecraft to teach non-science majors about our solar system and space physics. The images obtained by the TWINS spacecraft will provide an unique prospective of the near-Earth plasma environment and an important pedagogical aide in teaching about the impact of plasma physics on terrestrial phenomena.

In addition, since the TWINS data products are closely related to those produced by the NASA IMAGE mission, we will work with the IMAGE Education and Outreach team and extend their programs both through the inclusion of new data and through expanding their audience to include new institutions. We will also coordinate activities with other outreach programs already in place at team member institutions, such as the ACE and GENESIS outreach programs at LANL, to avoid duplication of efforts and to leverage the available funds to the fullest extent possible.

Budget The TWINS team has allocated a full 2% of the budget (excluding contingency funds) for education and outreach activities. This corresponds to $177 K (FY97$) in Phase B/C/D and $94 K in Phase E, for a total of $271 K (FY97$).

Schedule The TWINS educational program schedule will follow the TWINS mission schedule. During the TWINS Phase B (April-October, 1998), details of the teacher training program will be worked out, including the identification of teachers to participate in the program, development of a detailed project schedule, and selection of specific topics to be studied. During Phase C/D of TWINS (October, 1998 - March, 2002), the teacher training and curriculum development program will be implemented. During the TWINS Phase E (April, 2002 - March, 2007), participating classrooms will be involved in TWINS data analysis. Also during this time, we will begin the internship program for high school students, allowing them more in-depth experience with TWINS data.

3.2 Public Awareness

Activities An important part of the TWINS public outreach program will be the development of tools for viewing the 3D images produced by the TWINS imagers. This effort will include the development of a stereo viewer and the combination of images into movies that show changes of the plasma with time. Tools of this type will be suitable for inclusion in museum displays, planetarium shows, and classroom demonstrations, and we will strive to reach a broad audience with these displays through partnerships with local museums. The TWINS team already has connections with a number of museums, listed in Table 3.1, and we intend to extend our connections throughout the TWINS project.

To reach the general public, TWINS results will be distributed through press releases to newspapers and TV stations, and will be displayed on a TWINS World Wide Web page run at LANL. The movie format most suitable for viewing the images is also well suited to a television display.

The TWINS images themselves should be compelling for the general public, since they will provide a picture of the Earth's environment. In our outreach materials, we will focus on the effect of the Sun on the Earth, both from a scientific viewpoint and in terms of the effects on man-made satellites, power grids, and space travelers.

As with the education component, coordination with other NASA education programs will be a key element of our program. In particular, we will provide TWINS images for inclusion in displays which are based on IMAGE results.

Budget and Schedule As discussed in the previous section, Education and Outreach activities represent 2% of the TWINS budget. The schedule for outreach will be similar to that described for the education component. During Phase B (1998), we will develop a more detailed plan of activities. During Phase C/D (1998-2002) we will begin the process of implementing these plans, including web page development and making connections with museums. The outreach program will peak during Phase E (2002-2007), when TWINS data are available, including access to image data through a web page, delivery of data for museum displays, and press releases giving new results.

3.3 Small Disadvantaged Businesses

The TWINS team will substantially involve Small and Small Disadvantaged Businesses in meaningful roles throughout the program. LANL has estimated $245,000 in machine shop and other work to be purchased from local vendors, all of which qualify as small, minority-owned, or woman-owned small businesses. This amounts to over 8% of the LANL Phase B/C/D cost estimate. Similarly, the other hardware institutions, SwRI and Aerospace, have identified machine shop work, circuit board fabrication, and electronics and computer purchases to be performed by SDBs amounting to over 8% of their Phase B/C/D costs. In Phase E, TWINS team institutions plan to involve SDBs in data system purchase, set up, maintenance, and operation. Table 3.2 lists SDB vendors which the TWINS team members have used in the past and which we plan to use for the TWINS project.

Table 3.2. TWINS team SDB vendors

COMPANY	SB/SDB/WOB	SPONSOR	AMOUNT	TASK
Pajarito Travel Agency	SB/WOB	LANL	$80K	Travel
Coronado Machine Shop	SB/WOB	LANL	$50K	Machining
Hand Enterprises	SB/SDB	LANL	$50K	Machining
Holiday Inn Express	SB/SDB	LANL	$25K	Meetings
Abba Technology Inc.	SB/WOB	LANL	$25K	Equipment
HYTEC Inc.	SB	LANL	$15K	Engineering
Sun Circuits	SB	Aerospace	$20K	PCBs
A F Machine and Tool	SB/WOB	Aerospace	$50K	Machining
National Tech. Systems	SB	Aerospace	$32K	Testing
En Pointe Technologies	SDB/WOB	Aerospace	$30K	SW & Computers
D & D Machining	SDB	SwRI	$10K	Machining
Consolidated Office Systems	SB/WOB	SwRI	$20K	Presentation mat.
Speedy Circuits	SB	SwRI	$50K	Circuit Boards
ESI Plating	SB	SwRI	$10K	Plating/Coating
Aero-Tech Metal Finishing	SDB	SwRI	$10K	Plating/Coating
Alliance Electronics	SDB	SwRI	$100K	Electronics parts
B.G. Electronics	SDB	SwRI	$50K	Connectors/Wire
GTT Electronics	SDB	SwRI	$50K	Electronics parts
Texas Management Associates	SDB	SwRI	$69K	Software devel.

As the Lead Institution, LANL will direct and help team members identify areas of SDB involvement at each major institution. LANL will also lead an effort, if necessary, to locate qualified SDBs to match the tasks, using Internet news groups, the Thomas Register, other communication media, and the LANL Industrial Partnership Office. Obvious areas for SDB involvement include CADCAM operators, mechanical and electrical design engineers and consultants, printed circuit board fabrication and assembly vendors, test laboratories, software engineers, and data acquisition technicians. SDB involvement in all these areas have been used in the past by one or more of the TWINS team institutions

The search for qualified SBs and SDBs will continue through all phases of the TWINS program. The PI and PM will be kept informed of progress made in awarding subcontracts and purchase requests to small businesses. We will maintain a record of awards made to small disadvantaged businesses and report our efforts in this area to NASA's small business advocate.

3.4 New Technology

The strategy for the TWINS mission is to use existing instrument designs to minimize development time and risk. One new technology is used for the TWINS instrument: The TWINS mission will use freestanding gold gratings, which are a new technology that is planned to be first used and demonstrated by the MENA imager on the IMAGE mission (to be launched in 2000). The gratings are used to block ambient ultraviolet (UV) light, to which the detectors are sensitive, while allowing neutral atoms to pass. The gratings used for IMAGE have the following characteristic dimensions: 500 nm thickness, 200 nm period, and 55 nm gap width, which are optimized to attenuate UV light at a wavelength of 1216 Å. TWINS will advance this state-of-the-art technology without incurring the risks associated with the development process.

Attenuation of 584 Å light, which will be the dominant noise source on MENA/IMAGE, can be improved by increasing the grating thickness or decreasing the gap width. For the TWINS mission, the grating technology will be advanced to provide grating dimensions of 550 nm thickness and 45-50 nm gap width, both of which substantially reduce the 584 Å light that introduces the most noise in the detector. While this is an incremental advance over the technology used by the IMAGE mission, it will demonstrate the ability to remove more energetic UV light.

These gratings are a small, light-weight method of blocking ultraviolet light, and as such should prove very useful for future space experiments in which ultraviolet light is a significant source of noise.

4.0 TECHNICAL APPROACH

4.1 Mission Design

For this Mission of Opportunity, we have been invited to participate in missions on two identical non-NASA United States spacecraft, referred to in this report as S/C-1 and S/C-2. Once launched, S/C-1 and -2 will be given international designators, and all data will be made available for normal scientific data analysis, educational, and public outreach purposes. Flying as a mission of opportunity will enable the TWINS mission to provide closure on a large fraction of magnetospheric imaging science at a small fraction of the cost of an independent stereo imaging mission, since the satellites and launch vehicles will be provided by the mission sponsor.

For the TWINS Mission of Opportunity, a detailed discussion of mission design is not appropriate. In this section, we show how the host spacecraft mission design fulfills the TWINS mission requirements, and in fact demonstrate that the mission design is nearly ideal for a magnetospheric imaging mission.

Each host spacecraft will be placed in a Molniya orbit with an inclination angle of 63.4°, a perigee altitude of several hundred kilometers, and an apogee in the northern hemisphere at an altitude of 7.2 R_E. The specific inclination of 63.4° is used because it results in an orbit with a fixed argument of perigee. The semi-major axis is such that the spacecraft has a period of one half of a sidereal day, giving fixed longitudes of apogee. The local time of apogee moves through 24 hours every 326 days. The Atlantic apogee of the spacecraft is specified to be within 40 degrees West to 20 degrees East. The spacecraft are 3-axis stabilized, and are approximately nadir pointing.

The first of the TWINS satellites (S/C-1) will be launched in late 2001 or early 2002, with the second (S/C-2) launched approximately two years later, in late 2003 or early 2004. The launch vehicles will be provided by the mission sponsor. The precise launch dates are not known, and so we have used the delivery dates to the sponsor for developing the schedule outlined in this report. The design lifetime for each spacecraft is approximately 7 years, but the TWINS imagers will be designed with a nominal lifetime of 4 years. This represents a doubling of the design lifetime of the IMAGE/MENA imager, which is achievable through selective radiation shielding of the most sensitive components. In addition, the TWINS mission takes place further from solar maximum than the IMAGE mission, and thus TWINS will encounter a more benign radiation environment. The TWINS time scale provides stereo viewing during a two-year window of simultaneous observations by the imagers on the two spacecraft. Depending on the exact TWINS timing and the duration of the IMAGE science phase, S/C-1 may overlap with the IMAGE mission (to be launched in 2000), providing the first magnetospheric stereo images as early as 2001 or 2002. In any case, however, S/C-1 and -2 will provide a full two year stereo mission beginning in late 2003 or early 2004.

Communications with the TWINS spacecraft will be provided by the mission sponsor, including data telemetry, reception of data on the ground, and uplink commanding of the TWINS instruments.

The orbits, viewing, and timing of the TWINS host spacecraft are ideal for a magnetospheric imaging mission, providing a unique opportunity to obtain stereo images of the magnetosphere in the near future at low cost.

The ideal orbit for a magnetospheric imaging mission is one in which the spacecraft spends a large fraction of the time at relatively high altitudes (> 5 R_E) and high inclination angles (> 60°) so the imager can view the equatorial magnetosphere out to a distance of many Earth radii. From this viewing angle, the imager can simultaneously image different regions of the magnetosphere, allowing the evolution of and particle motions between different regions to be clearly observed. The Molniya orbit of these mission-of-opportunity spacecraft is ideal for this purpose, since it has a high altitude (7.2 R_E), a high inclination angle (63.4°), and the majority of the orbit period is spent near apogee.

It is also desirable that the imager spend much of the time pointed towards the region around the Earth, since obviously the magnetosphere can only be observed with these look directions. The TWINS spacecraft are approximately nadir pointing (within 25°), which means that the TWINS instruments will directly observe the magnetosphere throughout the mission.

A third criterion is that the imager be able to view a large range of directions, in order to observe asymmetries in the magnetosphere. Since the spacecraft for this mission are 3-axis stabilized, this range is achieved on TWINS with a rotating actuator platform, which allows the entire viewing cone to be mapped out on a 1 minute time scale. In short, the spacecraft orbits for this mission of opportunity are almost exactly those that would have been selected for an independent magnetospheric imaging mission, and are ideal for achieving the stereo viewing goals of the TWINS

The TWINS mission, with planned launches of the two TWINS in approximately late 2001 and late 2003, covers the immediate post-maximum phase of Solar Cycle 23. For this cycle, sunspot maximum is predicted for 2000 [Joselyn et al., 1997]. Historically, geomagnetic activity remains high for several years after sunspot maximum. Thus, during the first two years of the TWINS mission (2002 and 2003), the magnetosphere is expected to be near maximum activity. If the NASA IMAGE mission, scheduled for launch in 2000, is extended two years beyond its 2-year prime mission, then the ENA cameras on IMAGE and TWINS S/C-1 will provide stereo ENA viewing for the two years of maximum geomagnetic activity. During 2004 and 2005 when both TWINS are in orbit providing stereo ENA viewing, the predicted geomagnetic activity is expected to have dropped somewhat, but should still be well above minimum. The timing of the TWINS mission is thus nearly optimal for obtaining stereo observations of the active magnetosphere with inter-calibrated ENA cameras.

Table 4.1 summarizes this information in a traceability matrix, which demonstrates how the proposed instruments and mission design meet the TWINS science objectives and requirements stated in Section 1.0 of the TWINS proposal. Science and measurement objectives are listed on the left-hand side, and mission design elements along the top. An 'x' indicates that an objective is directly addressed by a given design element. It is clear that the proposed instruments and mission design are ideally suited to achieving the TWINS measurement and scientific goals.

Table 4.1. TWINS traceability matrix

	TWINS ENA imager	Ly-a detector	rotating actuator	two widely separated S/C	Molniya orbit S/C	nadir pointing S/C	mission near solar max
Visualize and map the global configuration of the magnetosphere in 3D.	X		X	X	X	X	
Observe evolution of magnetosphere through quiet and active times.	X			X	X	X	X

View ion dynamics throughout magnetosphere.	X		X	X	X	X	
Trace sources, transport and sinks of plasma.	X			X	X	X	
Image with approx 1- minute time resolution and 4° angular resolution.	X		X				
Image H, He, O with appropriate energy resolution.	X						
Invert ENA images to determine ion behavior.		X		X			

4.2 Spacecraft

A discussion of the host spacecraft design and characteristics is not appropriate for the TWINS Mission of Opportunity. A discussion of the spacecraft/instrument interfaces is given in Sections 4.3.3 and 4.4, below, and covers the spacecraft characteristics which are relevant for the TWINS instruments.

4.3 Science Payload

For the TWINS mission, we have placed strong emphasis on maximizing the scientific return while minimizing the mission cost, risk, and development time. Our strategy to accomplish this goal is to utilize state-of-the-art instrumentation which we are currently developing for the IMAGE mission and to perform the minimum required modifications to accommodate the particular spacecraft. Specifically, TWINS will duplicate the instrumentation of the Medium Energy Neutral Atom (MENA) Imager on the IMAGE mission and adapt it to these mission of opportunity spacecraft.

The sensor heads and the signal processing electronics of TWINS, including signal amplification, trajectory calculation, time-of-flight determination, and pulse height analysis, are identical to those of MENA, reducing cost, risk, and development time. While the TWINS DPU and actuator are different from MENA, they have extensive heritage and do not add substantial cost, risk, or development to the TWINS mission. The transmission grating technology has required significant advanced technology development during the MENA program to attain the extremely narrow grating dimensions that are necessary to sufficiently block UV. However, further grating development will not be required for TWINS, eliminating the cost, time and risk associated with such development.

During Phase A, we have made a great deal of progress in defining the TWINS instrument configuration and interface with the host spacecraft. The neutral atom imager measurement concept is identical to that described in Sections 1.2.1 and 1.2.2 of the TWINS proposal. However, we have resolved the issue of the volume envelope allocated to TWINS by the spacecraft and have fixed the mass and power envelopes for the TWINS instruments. The larger volume, mass, and power allocations have allowed us to optimize the configuration of the TWINS instruments to simplify the mechanical and electrical interfaces to the host spacecraft and to retain maximum heritage from the IMAGE/MENA instrument and from previous Aerospace DPUs. We have determined that the most straightforward instrument layout is to combine the front end electronics, power supplies, and DPU boards into a single box, which will be located on top of the actuator platform. The details of this configuration are discussed in Section 4.3.3, below.

We have also developed a plan for the acquisition of the Ly-α sensors and have developed a preliminary instrument design. These sensors will be provided by Dr. Hans Fahr from the University of Bonn, Germany, at no cost to NASA. A description of the Ly-α sensors is given below, in Section 4.3.1.

Also during Phase A, we have negotiated with the host spacecraft to increase the telemetry bit rate allocated to the TWINS instruments. The bit rate will be increased from the 4 kbps estimated in the proposal to possibly as high as 25 kbps. This increased bit rate will obviously have a strong positive impact on the science return of the TWINS mission, since it will allow us to send down a more complete data matrix, as opposed to doing data compression or collapse on board. Possible TWINS data products based on the increased data rate are discussed further below, in Section 4.3.4.

4.3.1 Instrumentation

Figure 4.1 shows a TWINS sensor head and measurement technique. Below, we review the components of the TWINS instruments, and describe any changes from the proposal.

Collimator Plates The collimator plates, which are identical to those of IMAGE/MENA, have a 2.68 cm inner radius and a 8.99 cm outer radius. The gap between adjacent plates is 0.44 cm. This geometry yields a 4° FWHM azimuthal field of view (FOV) and, with the plates alternately grounded and biased to +10 kV, rejects ions and electrons up to an energy of 130 keV/*q*, where *q* is the ion charge. The plates are blackened with a cupric oxide, highly dendritic coating that acts as an efficient absorber for UV photons, ions, and electrons.

Transmission Gratings Similar transmission gratings have been or will be used on the SOHO spectrophotometer SEM [Ogawa et al., 1993], the HETG spectrometer on AXAF [Schattenburg et al., 1994], and IMAGE/MENA. The gratings block UV by their waveguide properties while allowing ENAs to pass through into the sensor.

A freestanding transmission grating, illustrated in Figure 4.2, consists of a series of gold bars, fabricated using holographic lithography, on top of a support grid. Considerable experimental and theoretical work has been performed to characterize the UV and ENA transmission properties of the gratings [Gruntman, 1995; 1997; Scime et al., 1995]. Figure 4.3 shows experimental and theoretical results for a prototype grating 494 nm thick with a 200 nm period and an inter-bar gap of 62 [Gruntman, 1997; Funsten et al., 1997]. The experimental data (symbols) show excellent agreement with theoretical simulations (dashed line) for zeroth-order diffraction. The solid line, which is a theoretical result with all diffraction orders included, is representative of the grating performance for unpolarized light and follows a general exponential decrease of transmittance with increasing wavelength from 0.06 at 304 Å to 4×10^{-5} at 1216Å.

The MENA/IMAGE gratings, which are significantly improved from this prototype grating, have a bar width of 145 nm, a period of 200 nm, gap width of 55 nm, and a thickness of approximately 500 nm. These gratings will be delivered in the spring of 1998. Theoretical and laboratory results for this grating geometry show an ENA transmission of 10-12% and a UV transmission at 1216 Å of approximately 3×10^{-5}. The TWINS gratings will have a slight improvement over the MENA gratings: the gap width is expected to be 45-50 nm. This reduced gap width will significantly reduce the background noise counts from 584 Å light, which will be the dominant noise source for MENA/IMAGE.

Carbon Foil Immediately behind the transmission grating lies a nominal 50 Å thick carbon foil, which is mounted on a 333 line-per-inch, electroformed grid and is used to generate secondary electrons. These electrons produce the start pulse for a time-of-flight measurement of the ENA between the foil and the detector. Over an ENA energy range of 10-90 keV, the secondary electron yields have been measured to range from 2.1-4.5 for H, 2.3-5.8 for He, and 3-6.9 for O [Ritzau, 1997]. Identical foils are used on the Cassini Ion Mass Spectrometer (IMS) and will be used on IMAGE/MENA.

Angular scattering of projectiles in these foils is described by the equation $k_F = E\psi_{1/2}$, where k_F is a constant for a particular foil and projectile combination, E is the projectile energy, and $\psi_{1/2}$ is the angular scattering halfwidth at half maximum [Funsten et al., 1993; 1995]. For hydrogen, $k_F = 13$ keV-deg, giving $\psi_{1/2} = 3.4°$ at 4 keV and $\psi_{1/2} < 1°$ for $E > 13$ keV. This result shows that angular scattering in the foil slightly degrades ENA imaging resolution in the polar angle at energies less than 5 keV. Note that the azimuthal resolution is fixed by the collimator plates and is independent of foil scattering so that full image resolution is retained in this dimension. In addition, energy loss of projectiles transiting these ultrathin foils is minimal [Funsten et al., 1995]. All TWINS flight foils will be fully characterized for thickness and pinhole content [Funsten et al., 1992a; 1992b].

While sputtering of the ultrathin foil due to ENAs and energetic plasma ions that transit the collimator is negligible [Funsten and Shappirio, 1997], sputtering of carbon by geocoronal oxygen can be quite high, with a sputter yield of 0.13 [Ngo et al., 1994]. Calculations show significant sputtering of the foil if it is exposed to ram oxygen for 50 hours at 600 km altitude; this increases to 2,100 hours at 900 km altitude. Therefore, to maximize foil lifetime, at low altitudes the TWINS sensor heads will either (1) be oriented to a fixed position such that the spacecraft velocity vector does not lie within the field of view of the sensors so the foils are not exposed to ram oxygen or (2) be covered by a reclosable door, which will be closed when the instrument points near the ram direction.

Acceleration Grid The grating-foil assembly is biased to –1 kV. This bias sets up an electric field between the foil and the acceleration grid, which is located 1.5 mm behind the foil and is at ground potential. The field then accelerates secondary electrons directly downward to the detector. This acceleration enables the detected position of the secondary electrons on the detector to accurately represent the location at which the ENA transited the foil. The trajectory measurement is obtained using the detected positions of an ENA and its associated secondary electrons. The time-of-flight measurement is derived from the time difference between detection of the secondary electrons, which are detected first, and the ENA.

MCP Detector ENAs and associated secondary electrons strike a standard 10x10 cm microchannel plate (MCP) detector in a chevron (2-plate) configuration. An electric field, which is applied at the entrance surface of the MCP detector using a grounded suppression grid and a +100 V bias on the front of the MCP detector increases both the detection efficiency and the spatial resolution [Funsten et al., 1996]. TWINS will employ MCPs with a 60:1 length-to-diameter channel ratio. These MCPs are thicker and therefore mechanically more robust than conventional 40:1 MCPs, and produce a narrower pulse height distribution, which enhances identification of ENA species derived using pulse height analysis.

Detector Anode The ENA trajectory determination requires independent measurements of the one-dimensional (1-D) positions of the detected ENA and its associated secondary electrons. Furthermore, the time-of-flight (TOF) measurement requires independent measurements of the detection time of the secondary electron (start time) and that of the ENA (stop time). Therefore, the detector anode is segmented into two regions: the Start region, in which secondary electrons from the start foil are detected, and the Stop region, in which ENAs are detected. Each of these anode regions provides 1-D position encoding using a wedge-wedge charge division technique. Each of the two (A and B) output pulses from each anode are capacitively coupled and then are input into charge-sensitive preamplifiers. The relative pulse amplitudes on the A and B sides vary linearly with event position, allowing standard ratiometric position determination.

The system supports independent position determination on the Start and Stop anode regions to a full width spatial resolution of 1 mm, and TOF determination to a resolution of <20% for time ranges greater than approximately 7 ns, corresponding to the travel time of a 100 keV H atom at normal incidence. The independent position determination provides 1-D angular resolution of 3.8°, considering the 3 cm flight path between the Start foil and the MCP input face. The intrinsic energy resolution of the imager is $\Delta E/E = 2(\Delta t/t) = 0.4$, based on the 20% time resolution. The actual energy resolution can be set to any value larger than this. For TWINS, the energy resolution will be chosen to be no worse than $\Delta E/E = 1$. If the data rate permits, higher energy resolution may be obtained.

Pre-Amplifier Figure 4.4 shows a block diagram of the TWINS electronics. The pre-amplifier circuits are based on the Amptek A225 charge sensitive pre-amplifier. There are two pre-amplifiers (Start-A and Start-B) for the Start anode segment and two (Stop-A and Stop-B) for the Stop segment. For both the Start and Stop anodes, the A225 shaping amplifier outputs A and B are subjected to ratio analysis for position determination, while the fast A225 timing pulses are passed to the TOF card.

The Pulse Height Analysis (PHA) Card is used to determine the MCP pulse height and the 1D position of events on the Start and Stop anodes. The PHA Card has as inputs the shaped signals from the four pre-amplifiers. This card uses a peak and hold circuit to detect pulse peaks (via the zero cross on a first derivative signal), hold the level of the pulse peak, and disable further input until all signal processing for the current event is complete. The A & B signals are then fed to the inputs of a summing amplifier, and the sum is presented to the input of an A/D converter, which produces an 8-bit word representative of the MCP pulse amplitude. Additionally, the A signal (numerator) and the sum of A & B (denominator) are presented to a divider circuit, producing a ratio which is digitized to 8-bits. This 8-bit word is representative of the 1D position where the event occurred on the anode segment. This circuitry is implemented twice on the PHA card, to independently determine the pulse height and position of the event on the Start anode and on the Stop anode.

The Time of Flight (TOF) Card is used to measure the time between Start and Stop for valid events. It uses the fast rising timing pulse outputs of the Amptek A225 charge amplifiers, which have not been processed with shaping filters. These fast rising pulses are fed into a constant fraction discriminator, which is used to control a time to amplitude converter. This amplitude is digitized and represents the time of flight of the primary ENA from the Start foil to the MCP input plane.

Lyman-α detector The Lyman-α detector consists of two completely independent sensors with an angle of 10° between their lines of sight. Each sensor has a FWHM field of view of 4 degrees defined by collimation hole baffles, uses Lyman-α interference filters as narrow band transmission filters (+/- 50 Å), and applies a KBr or CsI photodiode (with very low sensitivity for wavelengths larger than 1800 Å) for photon detection. The count rate from each monitor is measured every 1.33 seconds, corresponding to one pixel (4°) in azimuth on the ENA imagers.

Figure 4.5 shows a block diagram of the Ly-α detector electronics. The channel electron multipliers (CEM) are supplied by dual high voltage converters, HVC1 and HVC2. The HVC output voltages are controlled by two analog voltages and two logic enable lines from the TWINS DPU. The CEM outputs are amplified by two charge-sensitive preamplifiers with discriminators, type A-101 from AMPTEK (TBC). The amplifiers deliver digital pulses which are counted by the TWINS DPU. The gain of both preamplifiers is controlled by two analog voltages which come from the TWINS DPU. A housekeeping unit (HKU) collects various voltages and the output from one temperature sensor. The HKU input signals are switched by a multiplexer to a common output amplifier. The multiplexer is controlled by the TWINS DPU through 3 logic lines. The HKU output is an analog voltage with a normalized voltage range (TBD). The Lyman-α detector electronics does not need or contain any own digital controller.

HVPS The TWINS High Voltage Power Supply (HVPS) produces –1, +4, and +10 kV power on a single board. These provide the required HV bias to the carbon foil, the MCP stack and the Lyman-α CEM, and the collimator plates, respectively. The instrument will use one such board for each sensor head, providing redundancy. The supplies are all switching supplies and can, if required, be synchronized. The topology used is resonant-flyback. This topology has been used on numerous instruments developed for flight or prototype, such as Cassini/CAPS, ELOP, MOSS, and DS1/PEPE.

Actuator To allow the TWINS instrument to view a range of azimuthal directions on these 3-axis stabilized spacecraft, each imager is located on a rotating actuator platform. The platform will rotate about the nadir direction (aligned with the center of the imager FOV) through a 360° range at a rate of 3° per second. This rotation rate, along with the symmetric orientation of the sensor heads, allows the entire field of view to be mapped out every 60 seconds (180°). The actuator has been used for Cassini/CAPS. It has a 4 year operational lifetime, and was designed to operate with minimal mechanical disturbances to the spacecraft. Control of the actuator platform will be provided by the DPU.

The existing Actuator design may need to be modified slightly to accommodate small, specific differences between Cassini/CAPS and TWINS. These decisions will be made during Phase B.

DPU The Data Processing Unit (DPU) is based on a flight-proven design and uses high performance electronics to provide an intelligent and flexible control point for the TWINS instrumentation. Through the use of ground commands and stored command macros, the DPU software provides autonomous control of the TWINS sensors and a flexible means of allocating telemetry resources. The TWINS DPU is similar to that used for the Charged Particle Telescope (CPT), which has been performing nominally since launch late in 1997.

The DPU is composed of a data section and a power section enclosed in a single chassis (which will also contain the FEE boards). The data section is comprised of three multilayer printed circuit boards (PCB): a CPU board, a spacecraft interface board, and a sensor interface board, which plug into a motherboard backplane. The CPU board uses an Intel 80C186 microprocessor. The data interface to the vehicle is accomplished through a MIL-STD-1553B bus interface protocol. Telemetry packetization and command reception and verification are performed by the spacecraft interface board through the use of a UTMC Summit 1553 protocol chip. The spacecraft interface board also provides control of the actuator and digitization of DPU housekeeping information such as temperature monitors, low and high voltage monitors, and current monitors. The sensor interface board provides data acquisition, image processing, high voltage control, and other sensor control functions. The power supply resides in a separate internal Faraday cage to minimize crosstalk between the DPU electronics and the power converters. The DPU supplies +5-volt power, ± 5-volt quiet analog power, and ±12-volt power to the TWINS instruments through thin film hybrid DC/DC converter modules.

The DPU employs several risk mitigation techniques. It incorporates spaceflight quality radiation hardened components and latchup immune electronic devices. Single Event Upsets (SEU) are made nil through the use of voting logic in all gate array designs. Dual redundant and cross-strapped spacecraft interfaces minimize the risk of a spacecraft interface failure. The DPU has exceptional durability, achieved through the use of multilayer PCB technology and by minimizing internal harnessing through the use of right-angle PCB mounted connectors and a motherboard interface to all circuit cards. In-flight maintenance of the flight software, though not expected, is realizable through memory upload commands, and all memory can be examined through a special memory dump telemetry mode.

The DPU packaging will be modified to incorporate the front end electronics boards and to mount on the actuator. The DPU will provide the electrical interfaces (low voltage power, command and telemetry) to the front end electronics, the Ly-α detector, and the actuator.

4.3.2 Instrument Characteristics

Table 4.2 compares the UV transmission and ENA transmission for the full instrument, including all components of a sensor head. Figure 4.6 shows the dayglow UV flux at solar minimum as a function of wavelength both before and after the transmission grating, for the prototype grating discussed above. Although the grating is less efficient at blocking UV at shorter wavelengths, the geocoronal flux at these wavelengths is far less than at 1216 Å. The integrated dayglow flux is 5.5×10^4 R [Meier, 1991] and the total flux transmitted through the prototype grating is 14 R (from Figure 4.6). Based on the instrument geometry factor and the UV transmission rate (Table 4.2), this corresponds to a count rate of $\sim10^3$ cts/sec on the secondary electron anode and $\sim3\times10^3$ cts/sec on the ENA anode. Assuming a time-of-flight window of 200 ns, the coincidence rate due to UV is approximately 0.6 events/sec.

Table 4.2: UV and ENA Transmission and Detection

Part	UV (1216 Å) Transmission	ENA Transmission	Technique
Grating: - Prototype - TWINS	 $4x10^{-5}$ $5x10^{-6}$	 0.12 0.12	 measured calculated
Foil	0.4	1	measured
Grids: - collimator - Foil mount - Acceleration - SE Suppression	 0.95 0.8 0.85 0.85	 0.95 0.8 0.85 0.85	 vendor spec. measured vendor spec. vendor spec.
MCP sensitivity	0.02	0.9 (ions) 0.7 (electrons)	measured estimated
Total: - Prototype - TWINS	 $1.8x10^{-7}$ $2.2x10^{-8}$	 0.042 0.042	

The full TWINS instrument specifications discussed above are listed in Table 4.3. As was shown in Section 1.2.2 of the proposal, these characteristics are sufficient to meet the scientific measurement goals of the TWINS mission.

Table 4.3: TWINS Specifications

Parameter	Value	Comment
Geometric Factor	0.038 cm^2sr	Two heads
Polar FOV	+60 to -60° FWHM	Imaged
Polar Resolution [a]	4° FWHM	Imaged, Best case
Azimuthal FOV	±2° FWHM	Collimated
Azimuthal Resolution	4° FWHM	Collimated
Energy Range	1-100 keV	TOF Window for H
Mass Identification	H, He, O	TOF + PHD
Energy Resolution, ($\Delta E/E$) [b]	0.4	TOF + mass
Time Resolution	60 sec	Actuator rotation period
UV Rejection (1216 Å)	$2.2x10^{-8}$	Expected (see Table 4.2)

[a] Mass and energy dependent. Angular resolution is slightly degraded in one dimension for H atoms with $E < 5$ keV and O with $E < 40$ keV.

[b] Speed measured by TOF and trajectory; energy inferred from species identification and speed.

4.3.3 Accommodation on spacecraft

As a result of the Phase A study, it was decided that the most straightforward mechanical configuration is to combine the FEE and DPU electronics inside a single box, which will be located on the actuator platform. This change was made possible by an increase in the overall envelope allocated to TWINS by the spacecraft. The new design has several advantages: it provides a single mechanical interface between the TWINS instruments and the spacecraft; it minimizes the number of lines which must be passed through the actuator; it provides maximum EMI shielding; and it allows maximum usage of heritage electronics boards.

Figure 4.7 shows a sketch of the TWINS instrument layout on the spacecraft platform. Mechanical interface to the spacecraft is through the actuator, with the entire TWINS instrument located on top of the rotating actuator platform. The TWINS FEE, power supply, and DPU electronics are all contained within a single box. The two sensor heads, including the detectors and collimator plates, are located on top of the electronics box. They are tilted at angles of +15° and −15° to the actuator rotation axis to provide the maximum field of view and an approximately uniform response function (shown in Figure 1.11 of the TWINS proposal). The Ly-α detector is attached to the side of the electronics box, allowing easy connections between the Ly-α electronics box and the DPU. The side mounting also ensures that the Ly-α sensor and the ENA imager do not block each other's field of view. During Phase B, we will study the feasibility of positioning the Ly-α electronics inside the DPU box to further simplify the mechanical configuration.

Figure 4.8 shows a sketch of the electronics box. The box is divided into three sections: the FEE section, the power supply section, and the DPU section. The FEE section consists of the IMAGE/MENA FEE boards (PHA, TOF, HVPS), in the same configuration as is used for MENA. Since the TWINS instrument has two sensor heads, as compared to three for MENA, two thirds as many boards will be required for TWINS. Minor modifications to the MENA boards may be required due to differences in the connections to the DPU and sensor heads, and will be identified during Phase B. The power supply (PS) section is located between the DPU and FEE sections, and is enclosed in a separate internal Faraday cage to minimize cross talk between the power converters and the instrument electronics. The DPU section will contain heritage DPU boards from previous Aerospace projects. Again, some modifications will be required to accommodate the specific TWINS interfaces, and these will be defined during Phase B. The box is constructed from a single piece of aluminum with a tongue-and-groove joint used to attach the cover, providing maximum EMI shielding and minimizing the impact of the TWINS instrument on the host spacecraft. The box cover is designed to allow space for running cables between the different instrument components, providing shielding and protection for these wires.

Table 4.4 gives the dimensions for each component of the instrument. The total envelope of the TWINS instrument in the launch configuration is a rectangular box of size 14.6 x 14.8 x 19.8 inches. In the operational configuration, the actuator platform is used to rotate the instruments, giving a cylindrical envelope with a diameter of 21 inches and a height of 19.8 inches.

Tables 4.5 and 4.6 give the mass and power requirements for the various parts of the TWINS instrument. The total mass of the TWINS instruments, not including margin, is 17 kg, and the power consumption is 22 W. Voltages of ±5, ±12, and +20 V will be required by the various instrument components. At this stage in the design process, a mass margin of 18% and a power margin of 25% are included in the estimates, giving a not-to-exceed mass value of 20 kg, and power of 27.3 W. Because of the extensive heritage of the TWINS instrument components and the maturity of the TWINS design, the best estimates given in Tables 4.5 and 4.6 are quite accurate, and thus larger resource margins are not required at this stage. The mass and power margins shown will be reserved by the project for system level requirements, and will be allocated only after consideration of other possible alternatives.

Table 4.4. TWINS volume estimates

Instrument Component	Dimensions (inches)
Sensor Heads (2 heads)	10.7 x 11.3 x 7.2
Electronics Box	12.6 x 14.7 x 7.4
Actuator	8.0 x 8.0 x 3.9
Ly-α sensor mount	2.4 x 2.4 x 4.3
Ly-α electronics box	2.4 x 4.3 x 5.5
Overall Envelope (launch)	14.6 x 14.8 x 19.8
Overall Envelope (operational)	21.0 x 21.0 x 19.8

Table 4.5. TWINS mass estimates

Instrument Component	Mass (kg)
Sensor Heads	4.16
Front end electronics	2.35
DPU and power supply electronics	1.31
Electronics Box	3.18
S/C to DPU Harnesses	0.62
Actuator	3.40
Ly-α	0.90
Actuator Interface Plate	0.50
Cables/Hardware	0.50
Total	16.92
Margin	3.08
Total	20.00

Table 4.6. TWINS power estimates

Instrument Component	Power (W)
Sensor Heads (Door)	3.0 (for 3 sec/orbit)
Front end electronics	7.42
DPU and power supply electronics	8.0
Actuator	2.83
Ly-α	0.6
Total	21.8
Margin	5.5
Total	27.3

4.3.4 New Technology

The freestanding gold transmission gratings represent the one new technology used in the TWINS and IMAGE/MENA instruments. These gratings are being developed for the MENA instrument, and we anticipate that the gratings will be available for use by TWINS. However, if for some reason we are unable to procure these gratings, backup plans do exist which would allow us to meet the scientific goals of the TWINS mission.

One possible back-up plan is to use neutral atom imagers based on the LENA-P design rather than on the MENA design. The LENA-P instrument was developed at LANL, using funding from a non-NASA source, and was launched in late 1997 on a spacecraft similar to the TWINS spacecraft. It is currently in orbit, functioning nominally, and producing neutral atom image data. This instrument concept uses the same type of detectors as described above, but ionizes the neutral atoms and then uses an electrostatic analyzer to eliminate the UV background. No published data are yet available, but the measurement concept is described in several publications [McComas et al., 1991; 1997; Funsten et al., 1995]. We are also investigating advanced foil materials and technologies which might allow UV background suppression without the use of the transmission gratings.

4.3.5 Data Products

During Phase A, we have considered the impact of various data compression and collapse schemes devised to allow maximum information to be retained in a limited telemetry allocation. It was determined that performing 2-D collapses over any one dimension could have a significant impact on our ability to deconvolve the neutral atom images. One method devised for reducing the data volume is to reduce the number of azimuthal angle bins at polar angles near the spin axis. Choosing the azimuthal width of each bin to give approximately equal solid angle ($d\Omega$) coverage for each bin results in reducing the data volume to approximately 65% of the original value (1080 angular bins are reduced to 705). Another plan is to use a lossless compression scheme in the DPU before transmitting the data. Since the count rates are often expected to be small, this type of compression will usually lead to significant savings in data volume.

We have also learned during Phase A that the data rate allocated to the TWINS instrument is likely to be increased from 4 kbps to as much as 25 kbps. A final decision on the TWINS data rate will be made by the mission sponsor during Phase B. The higher data rate corresponds to 187500 8-bit words for each 60-second image (c.f. 30000 words/image for the lower data rate). Approximately 5000 words per image are required for direct events, Ly-α data, and housekeeping, leaving the majority of the data for transmitting neutral atom images. This data rate increase greatly reduces the need for data compression schemes, since the new data rate is sufficient for sending down images with simultaneous high resolution in species, energy, polar angle, and azimuthal angle. Sample 60-second data histograms for both the low and high data rate options are shown below.

- Low data rate image: 24 polar x 45 azimuthal x 2 sensors x (10 species+energy) = 21.6 kBytes
- Low data rate image: 16 polar x 30 azimuthal x 2 sensors x (24 species+energy) = 23.0 kBytes
- Low rate image (equal $d\Omega$ bins): 705 angular x 2 sensors x (17 species+energy) = 24.0 kBytes
- High data rate image: 24 polar x 45 azimuthal x 2 sensors x 3 species x 25 energies = 162 kBytes
- High rate image (equal $d\Omega$ bins): 705 angular x 2 sensors x 3 species x 25 energies = 106 kBytes
- Ly-α data: 2 pixels x 45 azimuthal bins x 14 bits = 158 Bytes
- Singles data: 8 bit start + 6 bit stop + 8 bit TOF + 6 bit PHA start + 6 bit PHA stop = 34 bits

4.3.6 Space Qualification Plan

The TWINS space qualification plan is an inclusive plan to verify instrument function, performance, and environmental qualification for the Host mission. Included are functional tests at the component level (e.g., DPU, FEE, sensor, etc.), system level functional and performance tests, sensor calibration, and environmental tests. The qualification plan will demonstrate, by test or analysis, that the TWINS hardware meets all the performance requirements for the mission. The specifications for functional and calibration tests will be the responsibility of engineering and science teams responsible for the TWINS hardware, and will be developed as part of the test and verification plan for the instrument. The predicted environments for the TWINS mission (thermal, electromagnetic, vibration, etc.) will be specified in the TWINS/HOST interface control document (ICD), which will be developed during Phase B. This ICD will be developed under Aerospace leadership, as a cooperative effort between the TWINS team and the Host spacecraft developer. The ICD will include test levels for EMC/EMI, vibration, pyro-shock, and acoustic environments; verification matrices as applicable; and other information relevant to unit acceptance by the Host.

The TWINS complement will be qualified according to the requirements defined in the TWINS/HOST ICD prior to delivery to the Host. TWINS will also participate in spacecraft level environmental testing.

4.4 Payload Integration

4.4.1 Spacecraft Interfaces and Resources

During Phase A, we have defined the spacecraft resources required for the TWINS instrument, and have developed a plan for the mechanical and electrical interfaces to the Host spacecraft. In parallel with the TWINS Phase B, the host organization will perform a Host TWINS Accommodation Study. As a result of this study and the TWINS design phase, the final details of the TWINS/Host interface and integration requirements will be defined.

A detailed list of the spacecraft resources required for the TWINS instrument is given in Table 4.7. The total mass of the scientific instruments is approximately 17 kg, the total power consumption is 22 W, and the data rate is expected to be 25 kbps. Commanding will be provided through the DPU by one 16-bit command word. The scientific instruments will be located on a platform on the bottom of the spacecraft, nominally pointing in the nadir direction. The dimensions of the platform are 24 x 36 inches. During launch, the volume allocated to the instruments is shaped like a "roll-top desk", with a height of 12 inches on one side, and 24 inches on the other. After launch, the entire 24x36x24 inch volume will be available to the instruments, providing the ±60° field of view required by the imager. Figure 4.9 shows the TWINS instruments inside the spacecraft envelope. The instrument outline shows the launch configuration envelope, the solid lines show the operational envelope, and the dashed lines indicate the spacecraft envelope. This is a worst case sketch, in which the height variation of the envelope is assumed to be linear. The TWINS instruments easily fit within the spacecraft envelope, both in the launch and operational configurations. Since the spacecraft is 3-axis stabilized, the sensors are located on an actuator platform to allow viewing in different directions. The actuator rotates through 360° in a windshield-wiper motion with a rotation speed of 3° per second. Since the two heads are symmetrically oriented about the nadir direction, the full distribution is mapped out every 60 seconds.

Table 4.7: Instrument Resources

	Expected	NTE
Mass	16.9 kg	20.0 kg
Power	21.8 W	27.3 W
Envelope	21 x 21 x 20 in.	24 x 36 x 24 in.
FOV	± 60°	
Commands	1 16-bit word	
TM Rate	25 kbps	

Power and telemetry for the TWINS instruments will be provided by the spacecraft. The electrical interface to the spacecraft is a 1553 bus, which will provide full redundancy for all power and data lines. All electrical connections between TWINS and the spacecraft (power, command and telemetry) are through a cable bundle to the DPU. The DPU box will provide power regulation and formatting of the data signal to be sent to the spacecraft telemetry system. Data telemetry, uplink commanding, recording of data on the ground, and preliminary data processing to extract the scientific data will be provided as part of normal mission operations. As discussed above (Section 4.3.5), the telemetry rate will be at least 4 kbps, and is expected to be 25 kbps. One 16-bit word will be provided for uplink commanding of the TWINS instruments.

The mechanical interface between the spacecraft and the TWINS instruments is a single mounting interface at the baseplate of the actuator. The neutral atom and Ly-α imagers and associated electronics all sit on the rotating actuator platform. This configuration provides a simple interface to the spacecraft, minimizes the number of lines which must be passed across the actuator platform, and simplifies the interface between the instrument DPU and front end electronics boxes. These single-point electrical and mechanical interfaces minimize the need for extensive and continued interactions between the Host and the TWINS development team, thereby minimizing the cost of integration.

Table 4.8 shows the thermal limits for the TWINS instrument components. In addition, the actuator requires minimal heat load (<1W) from the electronics. Thermal design and control for TWINS will be an important Phase B activity.

Table 4.8. TWINS Thermal Requirements

Component	Operating (°C)	Non-operating (°C)
Sensor	-10/+30	-30/+50
FEE	-10/+30	-25/+45
DPU	-35/+55	-50/+70
Actuator	-30/+40	TBD

4.4.2 Integration to Host Spacecraft

During TWINS Phase B, spacecraft environmental constraints will be identified and provided to the TWINS team for consideration during hardware design. Factors having potential design impact are: radiation environment, electromagnetic interference and susceptibility, thermal environment, and perturbations to the spacecraft by the actuator. The Aerospace team members have extensive experience with similar host spacecraft that will enable them to identify risk areas and help determine mitigation strategies.

Aerospace will have the primary responsibility for delivering the TWINS instrument to the Host. A Bench Acceptance Test (BAT) will be performed at the Host facility prior to integration with the spacecraft. The Aerospace GSE (AeroGSE) which will support TWINS during system level tests (e.g., functional, calibration, environmental), will also be used during the BAT, and at subsequent Host tests as practical or required. Once integrated with the spacecraft, TWINS testing will be primarily limited to aliveness testing; TWINS functional tests are not planned during spacecraft level testing.

Spacecraft environmental tests will be supported by Aerospace on an "on call" basis. Since extensive TWINS testing is not envisioned during these tests, full time support is unnecessary. This test strategy has been used previously by Aerospace in similar programs, and has proven cost effective while minimizing risk to both instrument and spacecraft. Data from spacecraft environmental tests will be limited to housekeeping and limited telemetry data available through the spacecraft data system; test points will be limited to those required to ascertain the safe functioning of TWINS.

4.4.3 Payload Testing

Testing of the TWINS payload prior to integration with the host spacecraft is discussed in the next section, Section 4.5, and will not be repeated here.

4.5 Manufacturing, Integration, and Test

4.5.1 Manufacturing Plan

Because of the extensive heritage of the TWINS instruments, the majority of instrument components will already have been fabricated for another project prior to the TWINS development phase, greatly simplifying the TWINS manufacturing process. Our manufacturing plan is based on this heritage: we plan to use existing designs and circuit board layouts to the maximum extent possible. This use of heritage parts will be facilitated by the single electronics box design developed during the Phase A study.

The manufacturing process will begin during Phase B with early parts definition and procurement. We have already identified the gratings and actuators as long-lead items, and will work during Phase B to identify other long-lead components. As much as is practical, we will use a common-buy approach among the various team members for specialized parts. Our manufacturing approach includes component machining by SDBs, and source inspection and subsystem fabrication, assembly, and test by each team member organization. Production data products include engineering drawings, materials usage lists, and build logs.

4.5.2 Development, Integration, and Test

Figure 4.10 is a flowchart showing the system development and verification process for the TWINS instruments. Figure 4.11 gives further details of the development process for each part of the TWINS instrument. TWINS instrument development will be based on the early construction and testing of a proto-flight model, which will then be refurbished as needed to form the first flight unit.

The individual parts of the instruments will be developed by different institutions, and will undergo environmental and functional testing at those institutions prior to delivery to LANL for system integration. Following integration, the system will undergo environmental testing at LANL as well as EMI testing at Aerospace. This procedure will allow early detection of any EMI or other environmental problems with the instrument.

Table 4.9 shows a preliminary schedule for manufacturing, integration, and test activities. Deliverables shown include the proto-flight model and the two flight models to LANL for instrument integration, and the flight systems to Aerospace for spacecraft integration.

Table 4.9 TWINS manufacturing, integration, and test schedule.

Activity	Date	Phase
Finalize Design	Apr 1998 - Oct 1998	Phase B
Finalize S/C interface requirements	Apr 1998 - Oct 1998	Phase B
Preliminary engineering drawings	Apr 1998 - Oct 1998	Phase B
Develop parts list (preliminary)	Apr 1998 - Oct 1998	Phase B
Procurement of long-lead items	Apr 1998 - Oct 1998	Phase B
Final engineering drawings	Oct 1998 - Apr 1999	Phase C/D
Final parts list	Oct 1998 - Apr 1999	Phase C/D
Parts procurement and fabrication	Oct 1998 - May 1999	Phase C/D
Proto-flight model subsystem development	May 1999 - Feb 2000	Phase C/D
Proto-flight model to LANL for integration	Feb 2000	Phase C/D
Proto-flight functional and environmental testing	Feb 2000 - Jun 2000	Phase C/D
Refurbishment of Proto-flight model into FM#1	Jul 2000 - Sep 2000	Phase C/D
FM#1 functional and environmental testing	Oct 2000 - Nov 2001	Phase C/D
FM#1 calibration	Dec 2000 - Jan 2001	Phase C/D
FM#1 delivery to Aerospace/spacecraft	Jul 2001	Phase C/D

FM#2 subsystem buildup	Sep 1999 - Oct 2000	Phase C/D
FM#2 integration at LANL	Oct 2000	Phase C/D
FM#2 functional and environmental testing	Oct 2000 - Jul 2001	Phase C/D
FM#2 calibration	Aug 2001 - Oct 2001	Phase C/D
FM#2 delivery to Aerospace/Spacecraft	Jul 2003	Phase C/D

Testing of the sensor heads will take place at LANL, using special vacuum chambers equipped with appropriate ion and neutral atom beams. Tests will include the rejection of charged particles by the collimator plates as well as the detection of neutral atoms through the detector system. Tests on the gratings, including both UV rejection and particle transmission, will also be performed at LANL, using a grating test facility developed for the MENA project. Preliminary testing of the gratings during the development stage will be done by WVU in a new facility to be built for the TWINS project. This test facility will greatly expedite gratings characterization and subsequent evolution.

For the production of the TWINS Lyman-α Sensor units the University of Bonn will subcontract the space industry firm Von Hoerner & Sulger in Schwetzingen. Under University of Bonn supervision they will develop and produce the sensor hardware. The qualification tests and the calibration of the sensors will be carried out by staff personnel from the University of Bonn at space-qualified test facilities which have been used in the past for other projects.

Testing of the FEE electronics will be performed at SwRI by personnel from the Instrumentation and Space Research Division. This Division is dedicated to the design, fabrication, qualification and calibration of spacecraft and instrumentation for scientific exploration of space spacecraft and instrumentation for scientific exploration of space. Capabilities include thermal/vacuum testing, calibration, and radiation analysis. Facilities are available in other Southwest Research Institute departments to support EMI/EMC and vibration testing. A detector simulator and a DPU simulator will be fabricated for use in testing the front end electronics.

The DPU electronics will be tested at Aerospace. Aerospace test equipment includes a Mac-based GSE system (AeroGSE), which is used to test DPUs for many projects. Software modules will be developed to allow this system to be used with the TWINS DPU. The AeroGSE will also be used for system level testing of the TWINS instruments.

Following integration and testing of the flight system, instrument calibration will be performed at LANL using the neutral beam facilities available there. The entire instrument will then be delivered to Aerospace for delivery to the mission sponsor and integration with the host spacecraft. The TWINS instruments are designed for easy interface to the host spacecraft, with only a single mechanical and electrical interface. It is thus anticipated that only limited testing of the TWINS instruments will be required following spacecraft integration. Aerospace personnel will provide oversight for any required spacecraft integration activities.

In order to minimize development time and costs, the two TWINS instruments (for the two satellites) will be developed and fabricated at the same time, with the second instrument lagging the first by 6-9 months. Both instruments will thus be completed prior to the first spacecraft launch. Calibration checks and minor refurbishment as needed will be performed on the second instrument prior to delivery two years later.

4.5.3 Flight Software Development

Flight software will be developed for the DPU by the Aerospace Corporation, which will serve as the single software control point for the TWINS mission. The flight software will be developed jointly with the flight hardware. The first step will be to define the functional interfaces between the DPU hardware and software. Next, flow diagrams that correspond to the tasks to be performed by the flight microprocessor will be developed along with estimated processing times and code allocations to complete each process. The third step will be to define detailed interfaces between each of the modules and to develop code.

To the maximum extent possible, the code will be modular. The flight software will be developed using a development system which emulates the DPU microprocessor and provides 100% visibility into the microprocessor.

The flight software will be a major subject of the TWINS design reviews. Major modules of the flight software will be implemented in prototype form on the development system prior to the TWINS CDR. Following the CDR, coding of software modules will be completed, debugged, and executed on the development system. At that point, the software will be run with the prototype data processing unit to verify compatibility.

The flight software will ultimately reside in PROM on the data processing card in the DPU. Nonvolatile memory will be designed into the DPU to accommodate inflight code modifications. PROMs will be programmed prior to the DPU assembly and environmental tests. Configuration control of the flight software begins at the time of TWINS delivery to the vehicle. Changes to the code after delivery will be made through command uploads and will be documented and maintained under configuration control.

4.6 Mission Operations, Ground, and Data Systems

4.6.1 Mission Operations

Mission operations for TWINS, including spacecraft tracking, data reception and recording on the ground, and uplink communications with the spacecraft will be provided by the mission sponsor.

During Phase B, a TWINS concept of operations (CONOPS) will be drafted that covers instrument activation, standard operating modes, on-orbit calibration, and other procedures that may be required to insure the safe operations of TWINS. Aerospace will have the lead in developing the TWINS CONOPS to insure compatibility with mission ground segment procedures and processes. When approved, the TWINS CONOPS will be integrated into the Host mission operations plan in a way that insures the TWINS science objectives can be met while minimizing the impact of TWINS-unique requirements on Host operations.

Possible additional requirements for TWINS-specific ground data processing will be discussed as part of the Host TWINS Accommodation Study. For example, the installation of a dedicated workstation to process raw data may facilitate more rapid distribution of TWINS images. Otherwise, it is intended that TWINS will be supported by existing systems, personnel and facilities.

The TWINS instrument will be designed with minimal need for contact with the ground. We intend that the instrument will function autonomously throughout its lifetime. At most times, the instrument will operate in a single mode, reducing the need for commanding and simplifying data analysis. The instruments will be commandable from the ground for the purpose of: turning power on/off, turning HV on/off, setting HV levels, uploading lookup tables, and opening/closing the door.

4.6.2 Ground data system

Figure 4.12 shows the flow of TWINS data from the spacecraft through ground-based processing and analysis. The sponsor will extract the TWINS science data from the raw telemetry stream and forward these data packets to the Aerospace Corporation. Aerospace, under the direction of Co-I Dr. B. Blake, will be responsible for organizing these raw data by viewing direction. We define the data produced by the Aerospace processing to be Level 0 data. These data will then be forwarded to LANL for subsequent processing. LANL processing (Level 1) will map instrument counts onto geomagnetic and geographic coordinate systems so that images may be easily compared to each other and to previous and complementary data sets. Higher level LANL processing will incorporate the instrument response function and combine data from the two TWINS spacecraft. LANL will be responsible for distribution of data to other members of the TWINS team and for making the data available to the scientific community. Web access to the TWINS data server will provide easy access to the data.

Data processing servers dedicated to the TWINS mission will be used at both Aerospace and LANL for initial processing of the TWINS data. Both institutions have extensive experience in performing these data processing tasks (e.g. LENA-P, ULYSSES/SWOOPS, ACE/SWEPAM), and the TWINS data system (both hardware and software) will be based on this heritage. The ground data processing software will be adapted from software used for other projects, and will be developed in conjunction with the flight software and the GSE software used for testing the DPU.

All data will be archived at LANL as soon after processing and validation as possible. This time frame will range from hours to months depending on the complexity of the specific data product. The basic data unit for TWINS consists of 1-minute histograms of instrument counts as a function of azimuth, polar angle, velocity and mass. Both raw, validated data and histograms corrected for instrument response will be archived. Lyman-α data, consisting of counts as a function of look direction, will also be archived. In addition, we will archive higher level data products, including both single spacecraft and stereo images. The format for these data will be standardized for easy access and use by the TWINS team and by other researchers, and will be defined during Phase C/D. We also plan to provide TWINS data to the National Space Science Data Center (NSSDC) to facilitate dissemination to the scientific community and to supply a permanent NASA archive.

4.7 Facilities

The majority of the TWINS project can be carried out using existing facilities and equipment. However, there are several areas in which facilities will be modified or upgraded for the TWINS mission.

(1) The Space and Environment Technology Center (SETC) computing facilities at Aerospace will be augmented with a data processing server dedicated to the TWINS mission (e.g., UNIX based data server). The system will be configured with hardware, software and service contracts to perform initial data processing for distribution to LANL.

Procurement, installation and testing of the computing equipment is proposed for FY01, prior to the first launch. There are no anticipated long-lead time items as the system will be comprised of standard hardware and software.

(2) Two sets of Aerospace Ground Support Equipment (AeroGSE) will be developed for TWINS. The AeroGSE is a Mac-based system which will run the Aerospace Generic GSE system, with TWINS modules. The AeroGSE will be used to test the Aerospace DPU during its design and development, and will be used to support TWINS testing at the system level. The AeroGSE will perform the function of the spacecraft for command and telemetry processing during DPU and TWINS system testing.

Procurement of the Macintosh computers are projected as a FY99 activity for immediate availability to DPU development. There are no anticipated long-lead time items as the system will be comprised of standard hardware and software.

(3) At LANL, the TWINS project will warrant the purchase of up to three new pieces of equipment: 1) a cryo-pump for the vacuum test chamber, 2) a UNIX machine for image inversion processing, and 3) a UNIX machine or high powered PC for data relay, processing and archiving. None of these items are lead time critical and will be purchased on an as needed basis.

(4) To increase the signal-to-noise ratio of the neutral atom imagers aboard TWINS, gratings with smaller EUV transmission coefficients are desirable. Although the final testing of the flight gratings will take place at the Los Alamos National Laboratory facilities, a facility for testing prototype gratings will be constructed at WVU. The testing facility will provide two dimensional images of the EUV and particle transmissions of the gratings. An energetic electron beam will be used for particle transmission measurements and a monochromatic, 121.6 nm, light source will be used for EUV transmission measurements. The WVU group will work closely with the gratings developers, using their existing modeling capabilities to predict grating performance and then testing the gratings. This facility will be constructed in FY99, so that it is available for the gratings development process.

4.8 Product Assurance and Safety

4.8.1 Product Assurance and Quality Control

The LANL, Aerospace, and SwRI R&QA teams will develop a QA Plan during Phase B for presentation to the Mission Management Team. This plan will satisfy all guidelines listed in the MIDEX QA plan and ISO 9001 quality assurance document. The plan will incorporate the established internal QA plans used by each individual institution.

A major factor in making sure instrument design and performance meet specifications is the review process. The project plan requirements specify the team will participate in the standard series instrument development reviews. These include the Requirements Review (completed in Jan. 1998), Concept Review Report (this document), Preliminary Design Review, Critical Design Review, Pre-Environmental Review, Pre-Ship Review, and Flight Readiness Review. In addition, peer reviews will be held during all stages of the design and development process.

Another major factor in design and performance assurance is the verification process. The Verification Plan, to be developed in Phase B, will include all standard environmental stress and functional parameters.

4.8.2 Parts Selection and Control

The TWINS parts selection strategy will be the same as the plan for the MIDEX IMAGE Program. The TWINS instrument teams will use, at a minimum, Grade 3, MIL-S-19500 JANTX semiconductor; MIL-STD-883, Class B screened plus PIND testing.

Standard parts as listed in the NASA Preferred Parts List 21 (PPL21), the NASA Standard Parts List (NSPL), or MIL-STD-975 will be used to the extent possible. Class B microcircuits or JANTXV semiconductors (by vendor qualification) will also be considered for flight. Parts not inherently meeting the sponsor's part requirement will be consider as nonstandard. All parts will be kept in a bonded storage facility.

Qualification testing will be performed when necessary. Part re-burn-in and re-screening data will be kept on file and under inventory control by the Product Assurance Manager (QAM).

An electrical, electronic, and electromechanical (EEE) parts identification list will be maintained and made available to the NASA and to the mission sponsor. The parts/devices will be listed by component and/or function. The list will be updated by the cognizant engineers of each subsystem and an overall parts list will be maintained by the QAM and Project Manager. As a minimum, the inventory parts list will include device type, manufacturer, part number (including applicable dash numbers or specific values for passive components), and lot date code (after order completion and traveler generation).

Parts and devices will be selected to meet mission performance requirements found in the expected radiation environment. Particular attention will be paid to the use of microcircuit memory devices or microcircuits containing memory (i.e., microprocessors), that may be subject to failures, either latchup or upset, induced by energetic particles or cosmic rays.

LANL shall submit a parts, materials, and processes list to the Explorer Office identifying all parts, materials and processes used in developing the flight hardware.

4.8.3 Trade Studies

Trade studies are an important component of the TWINS product assurance plan. During Phase A, we have completed a number of trade studies concerning the TWINS instrument configuration and use of resources. Results of these studies are discussed in detail in Section 4.3, and include: 1) the FEE and DPU electronics will be combined in a single box, 2) the electronics box will be located on the actuator platform, and 3) the Ly-α sensor will be provided by the University of Bonn, according to the design described in Section 4.3. These decisions were made to preserve maximum heritage design (from IMAGE/MENA, the Aerospace DPU, and the Cassini/CAPS actuator) and to simplify the interfaces between the TWINS instruments and the host spacecraft.

Also during Phase A, we have identified a number of trade studies to be performed during Phase B. These studies are discussed in detail in Section 6.0, and include the selection of electronics components, finalization of the actuator design, and a study of the impact of ram oxygen on the TWINS instruments. Further trade studies will be identified during Phase B through the TWINS weekly telecons and through peer reviews. Trade studies will be resolved by considering all technical aspects of the issue, including effects on the scientific mission, resource allocations, and cost/schedule impact.

4.8.4 Problem/failure reporting

Problem/failures (P/F) that occur below the sub-system level shall be thoroughly documented in the appropriate lab/instrument notebooks and reported to the corresponding Team Co-Investigator. P/Fs at the subsystem level will be immediately reported to the LANL Project Manager. The P/F information, including description of the problem with exact test results, how this differs from nominal function, expected/proven cause of the problem, and corrective action recommended, shall be documented and also sent to the LANL Management/Engineering Team. The Management Team will discuss the P/F with the development team to determine a course of action or give direction for further investigation.

4.8.5 Inspections

As with previous NASA-sponsored programs, LANL welcomes visits by NASA. However, because LANL is a U.S. Department of Energy (DOE) facility, formal oversight by non-DOE sponsors is not allowed per se. Instead, formal oversight of LANL facilities will be the responsibility of the Albuquerque DOE QA Office. The QA Officer assigned to the NASA space flight instrumentation programs is Gary Echert, who can be reached by phone at 505-667-7171. He will act as a liaison between LANL and NASA and provide QA oversight for the NASA Management Office.

LANL will provide team member inspections on the limited basis of one a year for routine visits. In addition, the LANL team will provide assistance to any team institution emergency as needed. NASA oversight of TWINS Co-I institutions will be negotiated with each institution on an individual basis.

4.8.6 Safety Assurance

Although the instruments are inherently quite safe, there are a few personnel safety issues to be considered: 1) the instruments are capable of rotating under power, 2) the instruments use high voltages, and 3) the instruments use dimple motors. These are common issues related to this type of instrumentation and a safety assessment and mitigation plan will be developed during Phase B. In the past, the risks involved with these issues have been minimized by using measures such as covers, guards, procedures, and checklists.

Each hardware institution complies with all OSHA and other safety programs regarding facility and personnel safety issues. However, the project will prepare a top level safety analysis to ensure that all conditions of the *Hazardous Material Identification and Material Safety Data, Potentially Hazardous Items, Notice of Radioactive Materials,* and other issues are met.

To ensure the safety of the instrument, the project will define an instrument safety plan that will include contaminant materials, ESD protection, handling and mounting procedures, storage, and transportation.

4.8.7 Software Validation

Flight software development will be carried out in accordance with the Aerospace or SwRI Product Assurance Implementation Plan (PAIP). Code verification is performed using test data sets deemed to test all major and minor design functions; the AeroGSE, acting as S/C simulator and data display station, will support DPU tests performed for software validation. The SwRI GSE will act as a DPU/instrument simulator and will be able to test all interface and operating functions

Software test data sets are developed to test limit/boundary conditions and functional operation. All functional tests are scripted, using a feature of the AeroGSE, to assure the repeatability of tests and comparison of the results. Test data is exportable for analysis by other team members.

5.0 MANAGEMENT PLAN

5.1 Team Member Responsibilities

5.1.1 Organizational Structure

TWINS is organized around two existing and successful working relationships and has only three institutions involved in the instrument hardware development and delivery. In addition to close collaboration on Cassini/IMS and DS-1/PEPE, LANL and SwRI are presently jointly developing the IMAGE/MENA instrument which is the basis for TWINS. This relationship will be maintained for TWINS, and these two institutions will build the bulk of the proposed hardware. The Aerospace Corporation personnel have decades of experience working with the sponsoring spacecraft organization and building space science instrumentation including data processing units and spacecraft interfaces for numerous space instruments; for TWINS they will perform these DPU and interface functions. In addition, Aerospace and LANL have recently completed joint development of a neutral atom imager instrument (LENA-P) and are currently in the MO&DA stage. The instrument development and MO&DA efforts for this project (including working with the S/C agency) are very similar to the effort needed for the TWINS Mission.

The project organization chart is shown in Figure 5.1. The Principal Investigator (PI) will be assisted by the Project Manager (PM) in the day-to-day management of the TWINS program. Interface with the TWINS mission sponsor will be provided by Aerospace personnel, who will be in contact with both the PI and PM and with the spacecraft sponsor on a regular basis. Dr. B. Blake is the Co-I in charge of interface to the host, L. Friesen will provide integration management, and B. Crain will be responsible for the engineering interfaces.

The TWINS instrument development will be led by the Systems Engineer, B. Crain, with assistance from a System Mechanical Engineer (S. Storms) and a System Integration and Test Engineer (B. Spurgeon). These lead engineers will work closely together, and will provide weekly reports of engineering progress to the PM. Engineering teams at each of the hardware institutions have been identified, and personnel are listed by name in the instrument development team section of the figure. Within each of the institutions building hardware, a single Co-I point of contact will interface with the systems engineering and LANL project management teams.

All Co-investigators will serve on the TWINS science team, providing scientific and technical support for the TWINS investigation. Dr. J. Burch, IMAGE PI and Co-I on this proposal, will provide technical and scientific coordination between the IMAGE and TWINS investigations. A dedicated subset of the TWINS Co-Is, under the leadership of Dr. R. Skoug, will comprise the TWINS Outreach Team.

The TWINS management team proposes to employ the NASA/GSFC cost/progress reporting and review process to review cost, schedule, and technical performance. Our management team has been intentionally streamlined to ensure quick and accurate communications, reduce management cost, and provide our team members with clear and simple lines of authority and communications.

Table 5.1 contains a list of specific responsibilities in the development of the TWINS flight hardware and software, the organization which will carry out each task, and the point of contact for each item. Also included in the table are GSE and data processing responsibilities. Each team member is experienced and equipped to carry out these responsibilities. The infrastructure exists at each institution to support the performance assurance, fabrication, integration, functional and environmental testing, and personnel training necessary to insure high reliability flight equipment.

As the PI institution, LANL will have overall responsibility for all aspects of the TWINS project. LANL will serve as the NASA interface for TWINS. LANL will provide project management and will be responsible for the systems aspects of TWINS, including the development of interface documents, quality control, and outreach activities. In addition to developing the TWINS sensor heads, LANL will be responsible for integration, test, and calibration of the entire TWINS instrument. LANL will also be responsible for data processing and archiving, and for providing TWINS data to the Co-I institutions. The LANL team has a great deal of experience in the development of space hardware. The instrument team has been developing and operating satellite-borne instruments since 1962 and has successfully deployed over 100 instruments for over 30 different NASA and DOE projects. LANL has also developed the (successful) first neutral atom imaging system for space flight, the Low Energy Neutral Atom Imager Prototype Project and is now is now co-developing (with SwRI) the Medium Energy Neutral Atom Imager on IMAGE for exploration of the magnetosphere.

In addition to the DPU development, Aerospace has sole responsibility for acting as the interface between the TWINS team and the Host and Sponsor. Aerospace will be responsible for developing the necessary interface documents that will govern the integration of TWINS to the Host, for communicating TWINS mission needs to the Host and Sponsor, and for insuring that integration, test, and mission operations can be carried out in a cost-effective manner for the TWINS program. Aerospace has extensive experience in developing secondary or tertiary payloads (experiments) and integrating them successfully on similar missions. The Aerospace team has worked together on numerous NASA and government-sponsored projects in the past 8-10 years, including missions of opportunity similar to TWINS. The team has extensive experience in all phases of hardware development, integration and test, and on-orbit mission support.

SwRI will have responsibility for the imager front end electronics, including the detectors, time-of-flight and pulse height analysis hardware, and high voltage power supplies. The SwRI team has over 20 years of experience in the development of hardware for space missions. In particular, they are co-developing (with LANL) the MENA imager for the IMAGE spacecraft, on which the TWINS instruments are based. SwRI is also the PI institution for the IMAGE MIDEX spacecraft, a role which will facilitate close collaborations between the IMAGE and TWINS science teams.

The TWINS Science Team consists of the Co-Investigators and related personnel at the Co-I institutions for this mission. They bring a unique blend of expertise in magnetospheric physics and image deconvolution techniques and algorithms. Appendix 1 gives detailed resumes and specific areas of expertise for each of the Co-Investigators.

NASA funding will be provided directly to LANL, to the Aerospace Corporation, and to the Applied Physics Laboratory. Other team member institutions will be funded through subcontracts from Aerospace, to reduce the indirect costs associated with funding these investigators. Each Co-I institution will report costs to LANL using the established NASA 533 cost reporting process. These costs will then be rolled up into LANL total costs, and submitted to GSFC. LANL will be responsible for the technical and financial performance of all TWINS team members.

5.1.2 Experience and Commitment of Key Personnel

Table 5.2 shows the time commitments for key personnel during the TWINS Phase B/C/D. Management, engineering, and scientific personnel at the three hardware institutions (LANL, Aerospace, SwRI) are identified by name, and their time commitments given as a percent of time per month by fiscal year. The experience of all TWINS personnel can be found in the resumes given in Appendix 1, and the specific responsibilities of key personnel are described below.

Principal Investigator

The TWINS Principal Investigator (PI) is David J. McComas at Los Alamos National Laboratory. Dr. McComas is responsible to NASA for all aspects of the TWINS mission. His specific responsibilities include 1) making top level plan and policy decisions regarding the sponsor and Co-I institutions, 2) oversight of budget and schedule issues, 3) decisions regarding problem/failure resolution, 4) making the ultimate determination as to whether the project instruments are ready for flight, and 5) acting as chairman for all top level science and technical reviews, reports and other activities. He will spend 25% of his time performing these duties during Phases B/C/D and 20% during Phase E.

Dr. McComas can be reached at:

Space and Atmospheric Science Group
MS D466
Los Alamos National Laboratory
Los Alamos, NM 87545
505-667-2701
dmccomas@lanl.gov

Project Manager

The Project Manager for the TWINS project is Phil Barker at Los Alamos National Laboratory. Mr. Barker has a great deal of experience in managing instrument projects on satellite missions, including Cassini CAPS, ACE SWEPAM, LENA-P, IMAGE MENA, and Lunar Prospector. Mr. Barker will spend 50-70% of his time on TWINS during the project development years (FY98-FY01), and then will continue to commit 10-20% of his time to managing the TWINS project. Mr. Barker will be responsible for the daily management of the TWINS project and will oversee the TWINS instrument development process on a project-wide basis. His job includes working with the Systems Manager and Engineer to collect and control technical information and report it to the project leader, project scientists, and the NASA Explorer Office.

His specific responsibilities as Project Manager include (on a project wide basis) 1) monitoring the overall project status and ensuring that the project is headed in the right direction, 2) heading up the efforts of development team agency managers in planning schedules and resources and solving problems in these areas, 3) reporting cost and schedule status to the NASA, 4) securing and monitoring contracts for all involved agencies, 5) assisting with all management problems that may develop during the course of the project, 6) providing project information to the PI, 7) acting for the PI in certain capacities, 8) acting as point of contact for all project management issues, and 9) coordinating and aiding the efforts of the Systems Manager and Project Engineers to ensure technical success of the project.

Mr. Barker can be reached at:

Space and Atmospheric Science Group
MS D466
Los Alamos National Laboratory
Los Alamos, NM 87545
505-667-0057
pbarker@lanl.gov

Systems Engineer

Bill Crain at Aerospace will serve as the systems engineer for TWINS and as the engineering interface to the Host spacecraft. He will be responsible for the overall systems design of the TWINS instrumentation. Mr. Crain has 8 years of experience designing and developing spaceflight hardware and managing hardware development projects. He designed the HIT and MICS DPUs on the CAMMICE/POLAR instrument and the CLEMENTINE charged particle telescope. He was the Project Engineer/Manager for the LENA-P and CPT DPUs and for the GUVI/TIMED instrument. He has worked on numerous projects with the TWINS mission sponsor, and is familiar with the requirements of interfacing an instrument to this type of host spacecraft. Mr. Crain will spend 50-100% of his time on TWINS activities during the initial design and development phases, and then 10-15% of his time after the design has been completed.

Specific system-level responsibilities include: 1) planning and verification of all mechanical and electrical interfaces, 2) working the engineering details of the spacecraft/instrument interface, 3) system thermal analysis, 4) radiation shielding analysis, 5) interfacing the actuator and Ly-α detector to the DPU, 6) defining environmental test specifications, 7) being point of contact and responsible for TWINS system configuration control, and 8) serving as TWINS engineering contact for integration of the instrument to the host spacecraft.

In addition to his system-level duties, Mr. Crain will be responsible for the design, development, and testing of the TWINS DPU system.

System Mechanical Engineer

Steve Storms at LANL will serve as the system mechanical engineer. He will be responsible for the overall mechanical design of the TWINS instrumentation. Mr. Storms has a great deal of experience in the development of spaceflight hardware and in managing hardware development projects. He was the mechanical engineer for three instruments on the Lunar Prospector Mission and for the LENA-P instrument, and is currently the LANL mechanical engineer for MENA/IMAGE, PEPE/New Millennium DS-1, and the solar wind concentrator for Genesis. Mr. Storms will spend 20-25% of his time on TWINS during the design phase (FY98 and FY99), and approximately 5% of his time during fabrication and testing.

Specific system-level responsibilities include: 1) planning and verification of all mechanical interfaces, 2) system mass, envelope, and CG analysis, 3) overseeing all mechanical interface activities at LANL, 4) overseeing all mechanical tests performed at LANL, and 5) being point of contact for TWINS system mechanical configuration control.

In addition to his system-level duties, Mr. Storms will be responsible for the design and development of the sensor head subsystem. He will review the design/drawings that were generated for the

IMAGE-MENA instrument and make modifications as necessary to meet the new interface to the TWINS electronics package.

System Integration, Testing, and Calibration Engineer

Bill Spurgeon at LANL will serve as the system integration and testing engineer. He will be responsible both for the testing of the TWINS sensor heads developed at LANL and for the integration and testing of the entire TWINS instrument at LANL. Mr. Spurgeon has extensive experience in the design and testing of spaceflight hardware. He had a lead role in the development of the LENA-P instrument, and has worked on ground-based transmitter systems for the ALEXIS satellite and other magnetospheric physics experiments. He is also the LANL electrical engineer in charge of MENA/IMAGE, including design and testing of the instrument. Mr. Spurgeon will spend approximately 20% of his time on TWINS throughout the design, fabrication, and testing phases (B/C/D). Specific responsibilities include: 1) functional and environmental testing of the sensor heads, 2) overseeing all electrical interface activities at LANL, 3) integration of the TWINS instrument at LANL, 4) functional and environmental testing of the integrated TWINS instrument, and 5) calibration of the TWINS instrument.

Sponsor Contacts

Contact with the TWINS Mission Sponsor will be provided by Aerospace personnel. Lynn Friesen will be the Integration System Manager. Ms. Friesen has 26 years of experience in spaceflight instrumentation, including data processing and analysis; real-time data acquisition systems; instrument development, integration and test; and project management. She was the GSE Engineer for the CEPPAD/POLAR instrument, and has served as System Integration Manager on missions of opportunity similar to TWINS funded by the US government. Ms. Friesen will spend from 20-70% of her time on TWINS during the peak development years (Phase B/C/D), and approximately 10% of her time during Phase E. Her specific responsibilities for TWINS include: 1) acting as the interface to the Mission Sponsor and the Host, 2) communicating TWINS mission needs to the Host and Sponsor, 3) overseeing the integration of TWINS to the host spacecraft, 4) project management of the Aerospace part of TWINS.

Bill Crain will serve as the engineering interface to the Host spacecraft. His experience and TWINS responsibilities are discussed above, as the TWINS Systems Engineer.

Dan Mabry will be the flight software engineer for the TWINS project. Mr. Mabry has 12 years of experience designing spaceflight software and hardware. He was the Project Manager/Flight Software Engineer for SAMPEX and CEPPAD/POLAR, and the flight software engineer for the LENA-P and CPT DPUs. Mr. Mabry will spend approximately 50% of his time on TWINS during the design and development phase (Phase B/C). He will be responsible for providing the software interface between the TWINS instrument and the Host spacecraft, including the link between the TWINS data and the host telemetry system.

5.2 Management Processes and Plans

TWINS activities will be coordinated with the PM and the PI through management team meetings concerning the status of activities, problem resolution, and resource allocation. These meetings will occur at least monthly and more frequently as needed to address any critical issues or problems. We will report results to the Explorer Project Office at the end of each of these management team meetings.

We will utilize LANL's strong system engineering support to identify and solve any instrument issues. Systems trade studies will be managed with the goal of obtaining the highest probability of success and best science within contract resource limitations. The PI will be responsible for making final decisions relating to the results of trade studies. Close coordination among the three hardware institutions will be maintained throughout the systems engineering process.

The TWINS Systems Engineer will be in close contact with the Project Manager concerning all system-level engineering developments. They will communicate at least weekly (and more often as needed) by telephone and/or email concerning engineering issues, resource management, and schedules. The System Mechanical and Test engineers will also work closely with the Systems Engineer and the PM, and will provide weekly reports of their activities.

The entire TWINS team will participate in weekly telecons, which will provide a forum for each team member to report progress and to address any concerns. These telecons will provide the PI and PM with a regular status update, and will be the best mechanism for identifying trade studies and receiving team member input on technical and management issues. Periodic team meetings will also be held, which will allow face-to-face discussions among team members.

In addition, subteam meetings, in particular of the engineering personnel, will be held as necessary. The person in charge of each engineering meeting is required to report all design/requirement/resource issues, decisions, and changes to the Project Manager. The project manager is responsible for distributing this information to the Project leader and other involved Co-Is for evaluation. By following this strategy we hope to minimize confusion about the development process and avoid major communication problems by ensuring that all involved Co-Is are aware of the instrument development status. The key here is accurate and timely distribution of pertinent information to the relevant personnel.

5.2.1 Hardware and Software Acquisition

Hardware and software will be developed internally. Some of the machining and component parts will be purchased from/manufactured by local vendors, including SDBs, that have long-standing relationships with the team member organizations. Incoming items will undergo a series of visual and functional inspections. Components and processes such as materials, electronics components, and coatings will be accompanied by the appropriate certifications for Class C space flight hardware. Printed circuit boards shall be subjected to the GSFC coupon inspection process.

Development of major components of the project will follow the corresponding phases, culminating in the appropriate review. Midway through Phase A, each individual team member institution developed its own set of subsystem interface and functional requirements including those items for the Ly-α detector and spacecraft. For the TWINS mission, these items are well known because all components are heritage items. A requirements review was held and concerns were expressed, action to conduct trade studies of areas of incompatibility were planned, and a optimum configuration was developed.

As the project progresses, follow on phases and development will be handled in a similar manner. Phases and end items included are the 1) preliminary design, trade studies and simulations (culminating in the Preliminary Design Review), 2) detailed designs and shop drawings (culminating in the Critical Design Review), 3) proto-flight model development, functional and qual level environmental testing, 4) proto-flight model systems integration and functional and EMI testing (culminating in the Pre-Environmental Review), 5) refurbishment of the proto-flight model into the first flight unit, 6) flight model calibration and characterization (culminating in the Pre-ship Review), 7) shipment to the S/C contractor and subsequent integration and S/C level environmental testing, 8) refurbishment of contamination sensitive components and subsequent testing and reintegration (culminating in the Flight Readiness Review), and finally 9) launch, launch+30 day turn-on and tuning, and data verification activities.

Major components included in the TWINS system are the sensor heads (LANL), front-end electronics (SwRI), data processing unit (Aerospace), actuator (VTT/LANL), and the Ly-α detectors (Univ. of Bonn/LANL). Each institution mentioned above has developed almost exact duplicates of the TWINS instruments before (different configurations) and have unique facilities and vast experience in their areas of expertise. The sensor heads and front-end electronics were developed for the IMAGE Mission, the DPU and S/C interface was developed for the LENA-P Mission, the actuator was developed for the Cassini Mission, and the Ly-α detectors come form a long line of heritage instruments developed by the University of Bonn.

5.2.2 Systems Engineering and Integration

Integrated systems engineering is crucial in defining and meeting the overall TWINS mission requirements. This integration will be accomplished by detailed interface requirements documentation at the systems level by the systems mechanical and electrical engineers at LANL. Detailed TWINS/HOST interface requirements will be developed by Aerospace. These documents will be completed during Phase B.

5.2.3 Requirements Development

Appendix 3 contains a draft version of the TWINS Program Requirements Document. This document will be finalized during Phase B, and will be signed by the appropriate TWINS project, NASA, and mission sponsor personnel.

Interface requirements will be defined by an Interface Control Document, to be completed during Phase B.

5.2.4 Configuration Management

During Phase B, the team, under the leadership of the PM, will establish and implement an integrated Configuration Management (CM) plan. This plan will include a numbering, revision and review, and records plan. LANL will be responsible for strict enforcement of interface configuration control between TWINS subsystems, and each team member will be subject to a CM audit. Subsystem interfaces will be documented and controlled by the use of an Interface Control Document (ICD). Interfaces between TWINS and the spacecraft will be documented and controlled as part of a separate TWINS/HOST ICD. Configuration control of the flight software will begin at the time of TWINS delivery to the host spacecraft. Changes to the code after delivery will be made through command uploads and will be documented and maintained under configuration control.

5.2.5 Schedule Management

Each of the three hardware organizations will be responsible for maintaining detailed schedules for their respective activities. The PM will integrate these individual schedules into a master TWINS schedule. Each month the respective schedules will updated and the integrated schedule will be reported to NASA. This process will not only produce a complete and accurate schedule, but it will also highlight both schedule and resource conflicts.

5.2.6 Team Member Coordination and Communication

The key members of the TWINS management team are the Project Manager Phil Barker (LANL), Jim Cravens (SwRI), and Lynn Friesen (Aerospace). These key people at each organization will be in contact, as a minimum, on a weekly basis to discuss and work out key issues and problems. These people work side by side with the corresponding Investigators at each institution - Dave McComas at LANL, Craig Pollock at SwRI, and Bern Blake at Aerospace. In addition, each of the three institutions involved in hardware development is in intimate contact with their own in-house engineers: Steve Storms (mechanical) and Bill Spurgeon (electrical) at LANL, Susan Pope (mechanical) and Scott Weidner (electrical) at SwRI, and Bill Crain (electrical) and Mazaher Sivjee (mechanical) at Aerospace. These key people work together as a long standing existing team and are in complete contact with each other.

The System Mechanical and Integration and Test engineers will communicate at least weekly with the Systems Engineer concerning system-level engineering and testing issues. They will also be in regular contact with the instrument development teams at each hardware institution, to ensure that all development personnel are aware of the system-level hardware requirements and to provide guidance in resolving any engineering issues. The Systems Engineer and the PM will be in contact on at least a weekly basis to ensure that any engineering issues are brought to the awareness of the management team.

Weekly telecons will provide a forum for communication among the entire TWINS team. In addition, subgroup telecons (e.g. the engineering subteam or the data subteam) will be held as needed to identify and solve any problems. The TWINS team has already begun use of a web page for sharing documents, and will expand this usage during later mission Phases. The project manager will collect technical information from these forums and report to the instrument scientists and the NASA Explorer office.

5.2.7 Progress Reporting

The project will be planned and tracked using an integrated schedule under the coordination of the Project Manager at LANL. Progress as percent complete of each task in the current activity window will be updated and examined monthly. Weekly telecons will be held to discuss technical issues as well as discussion and mitigation of any problems. The NASA Explorer Office will receive a monthly report from the PM which will include progress, budget, technical and management problem areas as well as QA and safety issues. In addition the project will hold periodic reviews and team meetings to pull together issues at hand. NASA, Mission Sponsor, and DOE key personnel will be invited and are encouraged to attend these meetings.

The project manager at each hardware institution (Barker, Cravens, and Friesen) is responsible for coordinating progress, cost, and technical reporting items. These items in turn will be reviewed by their corresponding agency Investigators. The PM will correlate the information submitted by the team member institutions and it will be reviewed by the LANL management team, and then passed on to the Explorer Project Office as part of the monthly report.

5.2.8 Performance Measurement

Project performance will be measured by 1) comparing percent of budget spent to percent of work completed, and 2) monitoring/inspecting the work completed, and 3) comparing schedule milestones to actual completion levels.

Technical performance will be measured by 1) reviewing functional test plans to ensure that they will measure the functional requirements necessary to attain the science data goals, and 2) reviewing test results to verify that actual operation of the instrument meets the specifications. The sub-system and system verification plans and subsequent verification matrices will be used in satisfying this requirement.

Performance with respect to reliability requirements will be measured by the environmental test plan and test matrix. Appropriate thermal, vibration and vacuum testing will performed to assess instrument reliability.

5.2.9 Resource Management

Resource management will be the responsibility of the PI and the PM. Spacecraft resources, including mass, power, and data rate, have been allocated to the various instrument subsystems as described in Section 4.3.3. The estimates given there represent the current best estimates by each of the instrument teams as to what resources each subsystem will require. Both cost and technical margins will be reserved by the project, under control of the PI and the PM, and will be allocated only after consideration of the request and the other options available.

5.3 Schedules

Figure 5.2 shows a top-level development schedule for the TWINS investigation. Each of the three hardware organizations will be responsible for maintaining detailed schedules for their respective activities. The PM will integrate each of these individual schedules into a master TWINS schedule. Each month the respective schedules will updated and the integrated schedule will be reported to GSFC. Not only will the process just described produce a complete and accurate schedule, but it will also highlight both schedule and resource conflicts.

The TWINS schedule margins allow for a low-risk development schedule. The schedule includes seven months of margin for the delivery of the first TWINS instrument to the spacecraft. We plan to develop the instruments for the second spacecraft at the same time as those for the first spacecraft (with a lag of about 6 months), giving a margin of nearly two years for delivery of the second TWINS instrument to the spacecraft.

The schedule indicates dates for TWINS project reviews and for delivery of the flight instruments both to LANL for system integration and to Aerospace for integration with the spacecraft. Project deliverables are discussed further in the Phase B/C/D plan given in Section I.

Critical path

Each development team member has looked closely at the schedule and has agreed that the project can be comfortably completed under the current plan. Several items were identified as possible critical path areas: EEE parts availability, actuator development to meet instrument and host spacecraft requirements, gratings development, and door mechanism development. These issues are being dealt with early in the project in order to give ample schedule reserve to resolve any problems in these areas.

The actuator, door assembly, and mechanical items, in general, are on the initial critical path. To be more precise, the testing and analyses required for the above items are critical in order to proceed with the necessary designs. The electronics are not included in the critical path at this point because of their extensive heritage. This heritage will enable us to develop a parts list at an early stage, allowing time to deal with any parts delivery/availability problems.

Later in the project, the items which will be critical are electrical integration of the FEE to the DPU and mechanical integration of the FEE/DPU/Sensor assembly to the actuator.

An EMI survey of the actuator is to be performed during Phase B. If modifications are required, they could affect the early critical path. This risk is mitigated by the fact that the actuator is required late in the systems integration phase and is not needed for FEE/DPU/Sensor integration and test.

We will continue to monitor the schedule throughout Phases B/C/D to provide early identification of critical schedule items.

Long-lead procurements

The TWINS instrument includes two long-lead time items for which procurement needs to begin during Phase B: the gold transmission gratings and the actuators. As discussed above, the transmission gratings will be improved over those used for IMAGE/MENA, and this development process must begin in Phase B in order to meet the TWINS schedule. The actuator is also required early in the instrument development process so that interface requirements and EMI specifications can be defined.

Other long lead items are various electronics components, which will be identified early in Phase B. Examples are specially packaged components (i.e., "rad pack") and radiation hardened gate arrays or memory chips. To facilitate a fast development cycle (Phase C/D), long lead items will be procured as early allowable, once they are identified.

5.4 Risk Management

Throughout the TWINS development program we will apply the classic elements of risk management: identification, avoidance, and control. Although we generally associate risk control with the use of unproven technologies, it can include schedule, cost control, or instrument performance risk. TWINS relies only on proven technologies, which have been developed for previous missions such as IMAGE (MENA) and Cassini (the CAPS Actuator), and many years of experience working with the spacecraft organization which is providing the ride of opportunity and with their missions. This extensive heritage is a very important factor in our risk management plan, as it allows us to minimize our instrument design efforts and concentrate instead on interface issues. The maturity of the instrument design also allows us to carry reduced mass and power margins, since many of the instrument components have already been fabricated and are thus well understood.

Our approach to risk is based on early identification of any risk areas. As part of this procedure, during Phase A we have identified and evaluated possible risk areas. No show-stopping issues were found, and no risk issues were found with the heritage designs of each of the subsystem components. Issues of concern were related to the TWINS configuration of the heritage hardware and the interface with and effects on the host spacecraft. These technical issues have been resolved, as discussed in Section 4.0, above, and we are not currently aware of any major risk areas for TWINS.

Future technical risks will be mitigated by weekly telecons and periodic reviews. In addition, any technical issues will be resolved in a timely manner by performing the appropriate testing or simulations. Schedule and cost risks will be mitigated by comparing costs incurred to schedule progress or foreseen problems. The LANL project management team will collect schedule and cost information each month for analysis and in turn report this information to the NASA Explorer Project Office. Schedule and cost items will also be monitored and discussed in the scheduled telecons and reviews. The risk elements, technical, schedule, and cost, as well as possible descope options are discussed further below.

5.4.1 Technical/Performance Risks

The maturity of the TWINS instrument design means that the technical risks for this project are very low. However, we have maintained a mass margin of 18% and a power margin of 25%. These margins are sufficient that they could be used to mitigate cost or schedule risks if such becomes an issue (for example, use heavier but less expensive parts).

5.4.2 Schedule Margins

We have included adequate schedule margin in the instrument development phase to minimize risk. Seven months of schedule margin are allocated for delivery of the first TWINS instrument to the spacecraft. Because the two TWINS instruments will be developed at the same time (shifted by a few months), the second instrument delivery has an extremely relaxed schedule. Nearly two years of schedule margin are allocated for delivery of the second TWINS instrument to the spacecraft. These funded schedule slack periods can be seen in the TWINS project schedule, Figure 5.2.

5.4.3 Cost Reserve

Cost reserves for the TWINS project are currently 12% of all Phase B/C/D costs. These values are somewhat lower than the 15% reserves given in the proposal due to refinements in cost estimates developed during Phase A. The major TWINS cost issues have been addressed and solved during Phase A, and thus it is appropriate to carry a lower cost reserve at this stage.

Phase E costs include reserves of 10%. If the IMAGE mission is extended beyond 2002, the TWINS mission may require additional data processing funds to begin stereo data analysis during 2002-2004. The Phase E reserves are intended to cover these costs. Phase E costs do not include mission operations and data telemetry costs, which will be provided by the mission sponsor, and so no reserves are included for these activities.

It is the policy of the TWINS project that the reserves are not entitlement funds. The reserves will be pooled and allocated by the PI and PM after evaluation of the merit of the request and consideration of other alternatives which take into account all aspects of risk mitigation and avoidance. The process for reserve allocation will be both systematic and rigorous and will include the identification of problem areas, developing options for resolution, a description of the costs and impacts of various options, and the assignment of the best team to implement the solution. We will also consider applying (excess) reserves to non-problem activities which result in improvement of the overall reliability, schedule, or science return of the mission.

5.4.4 Descope Options

The TWINS mission does not include a large number of descope options. As discussed above, we do have the options of 1) expending mass/power margins to minimize cost or schedule risk, or 2) using cost margins to develop methods to decrease mass and/or power consumption.

However, since the TWINS instrument has already been streamlined to make the desired measurements within the resources allocated by the spacecraft, very few other descope options exist, and none are particularly satisfactory from a science point of view. Below we describe two possible descope options, but we are confident that the heritage and maturity of the TWINS instruments will allow us to meet the cost, schedule, and technical constraints and achieve the mission goals without resorting to a descope plan.

One descope would be elimination of the Ly-α detector. This option would have a minimal effect on costs, since the Ly-α sensor is being provided by the University of Bonn at no cost to NASA. Since the Ly-α sensor uses only a small fraction of the TWINS resource allocation, there would be only a slight effect on the mass and power budgets. However, this option will be considered if mass or power becomes a significant driver. This descope would also affect the science return, but would not affect the chances of mission success, since the Ly-α detector is not part of the Level 1 science requirements.

Another possibility would be to reduce the ENA imager to a one-headed instrument. This descope could provide a savings in cost and schedule, if selected during Phase B, and would obviously lead to a significant savings in mass and power budgets. However, this option would have a significant deleterious effect on the science return, by reducing the field of view and the response function of the instrument. It also adds additional risk by eliminating the redundancy provided by having two heads.

5.5 Government Furnished Property, Services, and Facilities

No government support is required from NASA other than Project Management provided by the Explorer Project through GSFC, and interface to the NSSDC required for the archiving of TWINS data.

Other government furnished support will be supplied by the TWINS mission sponsor (a US government agency), who will provide the TWINS host spacecraft, launch, and mission operations at no cost to NASA.

5.6 Reporting and Reviews

Reviews

Major reviews are planned at key phases of the program to ensure that cost, schedule, and technical requirements are being met. These reviews follow the review schedule outlined in the SMEX AO under which TWINS was selected. NASA personnel are invited to attend these reviews. The tentative dates for these reviews are as follows:

Preliminary Design Review and Confirmation Review	October 1998
Critical Design Review	March 1999
Pre Environmental Review (Unit 1)	April 2000
Pre Environmental Review (Unit 2)	April 2001
Pre Ship Readiness Review (Unit 1)	January 2001
Pre Ship Readiness Review (Unit 2)	October 2001
Flight Readiness Review (Unit 1)	February 2002
Flight Readiness Review (Unit 2)	February 2004

Another important element in the TWINS review process is the use of peer reviews. These reviews will be conducted by each hardware institution at appropriate points in the instrument hardware and software development process. Peer reviews will also be held prior to each major review listed above, to provide feedback and ensure that the project is prepared for the comprehensive review.

The TWINS team also plans to hold weekly telecons and periodic team meetings, all of which Explorer Office personnel are invited to attend.

Reporting

Progress reports will be compiled monthly by the PM and sent to the Explorer Project Office. These reports will contain progress information from each of the TWINS Co-I institutions, which the PM will collate into a single report. Information to be included in the monthly reports are technical issues, schedule/progress, cost/budget, QA, safety, and outreach issues. Problem areas will be noted and answers to any questions from the Explorer Office will be provided. The TWINS integrated project schedule will be updated monthly and included in the report. Progress will be reported as percent of activity items completed, and project milestones will be monitored.

6.0 DEFINITION, DESIGN, AND DEVELOPMENT (PHASE B/C/D) PLAN

6.1 Phase B

The TWINS Phase B is planned to be a 6-month process which will culminate in the Preliminary Design Review. During Phase B, the TWINS team plans to complete the preliminary design of all the instruments, including the sensor heads, front-end-electronics, DPU, Ly-α detector, flight software, and GSE.

Definition of interface requirements is a key part of Phase B activities. During Phase B, we will develop the mechanical and electrical Interface Control Documents (ICDs) for the TWINS instruments, and also will develop a TWINS/Host ICD. Because of the nature of this Mission of Opportunity, it is particularly important that the interfaces to the Host spacecraft be defined early, and so our goal is to complete these documents during Phase B.

Other documentation to be drafted during Phase B includes a definition of the radiation shielding requirements for the TWINS instruments. This document will specify the radiation dose allowed for TWINS to meet the design lifetime, and will explore various shielding mechanisms for specific electronics components, including the use of rad-hard parts, spot shielding, and overall box thickness. We will perform preliminary structural and thermal analyses of the TWINS instrument, and will work with the Host to better define the environmental requirements for the TWINS instrument.

On the management side, we will develop a draft QA plan, which uses the quality assurance plans currently in place at TWINS institutions, but specifies overall guidelines and requirements for the TWINS project. We will implement a CM plan and begin applying these procedures to the instrument designs. The TWINS Level 1 requirements document will be finalized during Phase B, and will be signed by the appropriate TWINS, NASA, and Sponsor personnel.

The Host mission schedule somewhat lags the TWINS schedule in time, giving TWINS the opportunity to remain ahead of the overall mission schedule. The fact that TWINS leads the spacecraft timeline reduces the risk associated with potential TWINS delays on the Host, an important factor for a mission of opportunity. Through Aerospace's coordination, the TWINS team will be in contact with the Host and Sponsor throughout Phase B/C/D to address interface, resource, and operations questions from both sides.

During Phase A, we have identified a number of studies which will be addressed in Phase B. These include:

1) Selection of a DC-DC power converter for DPU. The power converters used on previous instruments may not be suitable for TWINS. Aerospace will consider a replacement converter as part of Phase B.
2) Selection of DPU microprocessor. Aerospace has used 80C186 processors for previous instruments, however, the availability of the processor and support equipment may be an issue for TWINS. Investigation of other available processors and processor selection will occur during Phase B.
3) Selection of an optimum design for the actuator will take place during Phase B after EMI testing has been performed on a heritage model. The selection will be made based on science and host spacecraft requirements and on risk analysis of each option.
4) Finalization of the requirements placed on the actuator, including the number of control lines required, the rotation method, and the method of passing data through the actuator.
5) Analysis of the orbital exposure to RAM oxygen and, if required, determination of the method to be used to avoid RAM oxygen impact on the foils: a reclosable door or selective pointing of the actuator at low altitudes.
6) Finalize the electrical and mechanical interfaces to the Host.
7) Examine the effect of sunlight on the carbon foils. If this is a problem, the same methods used to avoid RAM oxygen could be used to avoid sunlight.
8) Consider the possibility of including the Ly-α electronics inside the FEE/DPU box. This is a trade between the simplicity of a single electronics box and the simplicity of having the Ly-α instrument delivered by the University of Bonn as a single unit.

We have identified several long-leadtime items, which will need to be purchased during Phase B. These include the gold transmission gratings, the actuators, and various electronics components, as discussed above (Section 5.3).

During Phase B, a final decision will be made by the sponsor concerning the data telemetry rate allocated to TWINS. As part of the TWINS Phase B, we will continue to study data telemetry schemes, and will select the optimal data format once the telemetry rate is known. We will also continue planning for TWINS data processing and data analysis, including further development of inversion models for the interpretation of data.

Education and outreach activities during Phase B will also focus on the design and development of the program. We will begin the process of identifying the teachers who will participate in the curriculum development program. The Phase B time frame corresponds nicely to the school-year calendar, since the identified teachers will then be able to begin working on the project shortly after the beginning of the 1998-99 school year. We will also develop a specific schedule for this project, and will more clearly define the initial scientific topics to be covered by the project.

Table 6.1 gives a list of deliverables and milestones for Phase B, along with delivery dates for these items.

Table 6.1. Phase B Deliverables/Milestones

Item	Date Due
Monthly reports to NASA	monthly
Actuator EMI test results	5/15/98
QA plans finalized	7/15/98
Interface information	8/15/98
Radiation shielding analysis	8/15/98
Prelim. Thermal/struct. anal.	8/15/98
Interface control documents	9/1/98
Radiation shielding document	9/1/98
Phase C/D contract info	9/1/98
QA document	9/1/98
Level 1 Req document	9/15/98
PDR material	9/15/98
PDR	10/1/98

6.2 Phase C/D

The TWINS Phase C/D is schedule to last from October, 1998 through April, 2004, following the launch of the second TWINS spacecraft. Our plan is to construct all TWINS hardware prior to the launch of the first spacecraft, but Phase C/D will continue at a low level of support for the period between the launches, and will include possible continued testing, refurbishment of the second instrument, and integration of the second instrument to the spacecraft. Phase E will begin 30 days after the launch of the first spacecraft, and will be the primary TWINS activity from 2002-2004.

Phase C/D will be characterized by (a) the completion of the system design, culminating in the CDR, and (b) the development the flight hardware.

Our strategy for fabrication of the instruments will be to build a proto-flight model (PM), which will be integrated and subjected to functional, environmental, and EMI tests. Building this proto-flight model early will allow us to identify any potential problems with the interface to the host early in the process. Following the successful completion of environmental testing, the proto-flight model will be refurbished into the first flight unit. Simultaneously, we will build up the second flight unit, with a time lag of 6-9 months at each step, with extra time built into the schedule for test and verification at appropriate steps. This "back to back" development procedure will be very efficient, allowing both units to be completed prior to the launch of the first spacecraft. Each unit will be thoroughly tested by the appropriate development team, then sent to LANL for system integration and testing. Calibration of the flight model units will also be done at LANL, and the units will then be sent to Aerospace for delivery to the host spacecraft.

Definition of the TWINS data telemetry will be finalized early in Phase C/D, and the flight software and GSE will be developed based on these definitions. Also during Phase C/D, we will define the data formats to be used for the Level 0 and Level 1 TWINS data products, and will develop the ground support equipment needed for TWINS data processing. The TWINS science team will also work to develop data analysis software, including methods for visualization of the 2D and 3D TWINS images and image inversion techniques for interpretation of the images.

Phase C/D will be an important time period for education and outreach activities. During this period, we will implement the teacher training program, and will work with the teachers as they develop lesson plans based on TWINS science topics. We will also make plans for involving both classes and individual students in TWINS data analysis, and will ensure that the infrastructure for data analysis is in place prior to Phase E. We will continue to develop connections with museums and other public outreach organizations, and will continue development of the TWINS web page so that it is accessible and interesting to a broad audience.

Table 6.2 gives a list of deliverables and milestones for Phase C/D, along with delivery dates for these items.

Table 6.2. Phase C/D Deliverables/Milestones

Item	Date Due
Monthly reports to NASA	monthly
Critical Design Review	3/99
Proto-flight model (all subsystems)	2/00
Pre-Environmental Review (#1)	4/00
Flight model #1 (all subsystems)	10/00
Pre-Ship Review (#1)	1/01
FM#1 delivery to spacecraft	8/01
Flight Readiness Review (#1)	2/02
Flight model #2 (all subsystems)	10/00
Pre-Environmental Review (#2)	4/01
Pre-Ship Review (#2)	10/01
FM#2 delivery to spacecraft	8/03
Flight Readiness Review (#2)	2/04

7.0 COST PLAN

This cost plan provides information about all anticipated costs for all phases of the TWINS project, and is divided into three parts: the first section gives costs for Phases B/C/D, the second gives Phase E costs, and the third summarizes the total costs for the TWINS mission. As a Mission of Opportunity with a foreign Co-Investigator, the project also has significant non-NASA contributions, which are listed in the Contributed Costs sections for the appropriate phases.

The impact of the Phase A study on the TWINS cost estimate has been significant. During the past 5 months we have conducted cost analysis and negotiating sessions with each participating institution with the following results: 1) an increase (from our rough estimate) in the S/C contractor agency costs, but an increased commitment to TWINS on their part, 2) a change in funding profile for the S/C agency from the proposal - the S/C agency has strongly requested all funding in the first two years of the project, 3) an increase in the gratings cost estimate due to the providing agency requiring more infrastructure support than originally estimated, 4) an increase in Co-I institution costs almost across the board, but with a much better understanding of the effort which will be required to complete the TWINS obligation to NASA, and 5) an increase in the estimate for management efforts at LANL to further mitigate risk factors by ensuring adequate communication, attention to detail, and study, analysis, and reporting of management and technical issues to TWINS and Explorer project personnel. Also during Phase A, we have also obtained a firm commitment from the University of Bonn to provide the Ly-a detectors and analysis of the Ly-a data at no cost to NASA.

As a result of Phase A activities, our current cost estimate for Phase B/C/D has increased by 16% (within the AO guidelines of 20% maximum) over the original proposal. We have included worst case situations and the highest cost options in every case to give a conservative cost estimate. As a result, we have lowered the overall project reserve to 12% (from the 15% stated in the proposal). We feel that this 12% figure represents the real reserve required to ensure technical success, and no longer includes cost, management, and other non-technical uncertainties which were included in the reserves in the proposal. To ensure the fixed-price nature of the TWINS project, we have received firm personal commitments to the costs listed in this report from Co-Investigators whose institutions are not allowed to write fixed price contracts.

We have discussed the TWINS yearly funding profile with the Explorer Financial Office and they have expressed a concern about shortage of overall Explorer Program Funding for FY98 and FY99. At their suggestion, we have agreed to delay receiving payment of our TWINS FY98 and FY99 reserves until FY00, and let the Program use the funds elsewhere to offset any shortfalls (although this scheme is NOT indicated in the cost charts shown in this report). Both GSFC and TWINS management agreed that if the reserves were needed, it would most likely be in the out years.

7.1 Phase B/C/D cost proposal

7.1.1 Contract Pricing Proposal Cover Sheet

The Contract Pricing Proposal Cover Sheet, form SF 1411, has been signed and is attached as Table 7.1.

7.1.2 Work Breakdown Structure

Table 7.2 gives the work breakdown structure (WBS) for Phase B/C/D. This WBS includes all management, science, instrument development and testing, and outreach activities, and was used to develop the TWINS Phase B/C/D cost estimates.

7.1.3 Workforce Staffing Plan

A workforce staffing plan for Phase B/C/D is shown in Table 7.3. This plan gives the time commitments of each hardware institution for each WBS element as a percent of time per month by fiscal year. Time commitments for individual persons are not shown in this chart, but can be found in Table 5.2 of Section 5.1.2, which shows the Phase B/C/D time commitments of key personnel at each hardware institution as a percent of time per month by fiscal year.

7.1.4 Proposal Pricing Technique

Initial Phase B/C/D cost estimates were obtained using a "bottom up" approach. A work breakdown structure (WBS) was developed, iterated with the development team members, and checked for thoroughness. The top level of the WBS is product based, and we were able to describe the project components very well using this method. At the same time, a top level schedule was developed, indicating deliverables and milestones. Next, the purchases and activities needed to provide the WBS products were estimated and checked. At this level all labor and purchases were identified. The appropriate team member institution cost factors were applied to the labor and purchase items and the cost structure was completed. The bottoms-up cost estimate was then compared to known costs of similar projects just completed or in progress at LANL, Aerospace, and SwRI.

We believe the TWINS cost estimate to have a high degree of accuracy due to several factors: 1) LANL is presently developing the MENA instruments, which are identical to the sensor heads used for TWINS, 2) SwRI is currently developing the same front end electronics for the MENA instrument that will be used on TWINS, and 3) Aerospace has just completed development of the DPU for the LENA-P project involving the same S/C host interfaces and a similar neutral atom imaging instrument as planned for TWINS.

During Phase A, providers of large cost items were contacted and prices were rechecked. As a result, we have found that the costs of several key items have increased since the proposal was developed: 1) the cost of S/C contractor support has increased from \$1.0M to \$1.5M, 2) the cost of the gold transmission gratings has increased from $220K to $550K. The S/C activities cost increase occurred as our relationship with the host and contractor and the effort required to accommodate the TWINS instruments on the host spacecraft were better defined. Although the cost to TWINS has increased, it is still nowhere near the actual cost of S/C integration, and the host has agreed to the $1.5M (see Appendix 3, the top-level mission requirements agreement, which will be signed by the mission sponsor as well as by NASA and TWINS personnel). The gratings vendor has completed all other funded projects and requires several equipment repairs and upgrades in order to produce the gratings needed for TWINS. The actuators were initially costed as off the shelf heritage items from the Cassini project. As the TWINS design developed, a need for possible modifications to accommodate interface configurations was identified and associated costs were added to the original estimate. These cost increases may be reduced during Phase B, through trade studies to determine the final actuator specifications, or by negotiating a different spare philosophy with the vendor.

These cost increases have been minimized by funding the TWINS Co-Investigator institutions directly by NASA or through Aerospace. This funding scheme minimizes the amount of pass-through fees, saving a significant portion of the budget. The total cost estimate for Phase B/C/D has increased from $9,980K to $11,610, an increase of 16%, which is well within the cost guideline of a 20% maximum increase during any phase stated in the SMEX AO under which TWINS was selected.

All costs associated with the launch vehicle and launch support will be provided by the host mission. In addition, Mission Operations and Ground Support will be also be provided by host mission, which will bear the associated costs. Although the associated cost for this support is not available, we can make a comparison to a similar NASA mission. Based on the NASA Image mission, the launch costs for the TWINS instruments are approximately $14.5 M (FY97$) and the cost of mission operations is $5.0 M (FY97$); the equivalent of this support will be provided by the TWINS host mission sponsor. Because the host mission lifetime is longer than the TWINS proposed 4 year lifetime, it is probable that an extended TWINS mission can be supported with no financial impact to NASA for mission operations.

Outreach has been planned at 2% of total funding (less the S/C contractor fees), this remains the same as planned during the proposal phase. Contingency has been lowered from 15% to 12%. This reduction is due to the solution during Phase A of the major TWINS cost issues. We feel that the cost estimates for TWINS at this stage are very accurate, due to the high degree of heritage in the design, and thus a 12% contingency is sufficient at this stage in the development process.

Attached is summary of total mission cost phased by fiscal year. Contributed costs were based on an estimate from University of Bonn for the Ly-a detector involvement and on S/C integration, launch, and mission operations estimates modeled after the IMAGE program.

The cost estimate uses the LANL approved contract inflation rate of 4% per year.

The cost estimates include all taxes, burdens, and contract fees.

7.1.5 Phase B/C/D Time-Phased Cost Summary

Table 7.4 is a Phase B/C/D time phased cost breakdown for each work breakdown structure element. As described above, the Phase B/C/D pricing technique is a bottoms-up analysis based on very similar project cost histories at all major development team institutions. Costs are given by month in real year dollars. For a given fiscal year, monthly costs are expected to be the same in each month, so the monthly cost is shown only once for each year of the project. The totals in the right-most column are cumulative totals for all 12 months of each year (6 months each of FY98 and FY04). The total cost to NASA for Phase B/C/D, including 12% reserves, is $12.9 M (RY$), and contributed costs are estimated at $19.0 M (RY$).

7.1.6 Cost Elements Breakdown

Labor

Labor hour estimates are based on years of experience at costing projects and have been checked against previous similar projects which the TWINS team members are involved in or have recently completed. Labor is classified into two types - *STAFF* and *OTHER* - and the cost for each type used as a base cost rate from which the cost estimates are determined.

Labor work hours per month vary depending on the number of holidays, number of days in the month, and the day the month starts on. The average number of working hours per month is 145. It is not LANL policy to disclose labor rates or other labor costing policies to outside agencies; however, due to the fact that LANL is a DOE facility, the labor costing policies have been reviewed and approved by the government.

Materials and equipment

A summary of major material, major parts, and equipment costs (Unburdened FY97$) for Phase B/C/D follows. This cost category also includes a budget for incidental materials and services and the cost is based on a percentage of labor costs.

ITEM	COST	WBS element
Actuators	800K	11
Gratings	550K	6
EEE Parts	200K	7
EEE Parts	150K	9
Micro-channel plates	30K	6
Thin foils	8K	6
Machine shop parts	115K	6
Machine shop parts	85K	9
Computers	90K	10

Subcontracts

The TWINS project will have no subcontracts per se. In order to cut costs we plan to avoid passing contracts through LANL whenever possible due to the very high pass-through burden. On the other hand, Aerospace has a very reasonable pass-through burden, and they have agreed to handle most of the contracts for the TWINS Co-Investigator institutions. Furthermore NASA has agreed to fund the host spacecraft agency directly. The funding plan breaks down as follows:

LANL	to be funded by NASA
Aerospace	to be funded by NASA
S/C	to be funded by NASA
APL	to be funded by NASA
SwRI	to be funded by Aerospace
USC	to be funded by Aerospace
WVU	to be funded by Aerospace

These contracts, with the exception of the S/C agency, are all for TWINS project Co-Investigators. The total amount of the contract for each Co-I institution can be found in the Total Mission Cost Funding Profile, Table 7.9. The relationship between each Co-I institution and the WBS elements can be found the workforce staffing plan (Table 7.3) and in the key personnel time commitments (Table 5.2).

Other direct costs

TRAVEL (#1 and #2 refer to the two TWINS spacecraft):

FY98 28 trips x $2.0K = $56K; PDR, #1 Team meeting, Engineering meetings.

FY99 40 trips x $2.0K = $80K; CDR, #1 Team meeting, Eng. meetings.

FY00 42 trips x $2.2K = $92K; #1 PER, Team meeting, Eng. meeting, System integration; #2 testing

FY01 56 trips x $2.2K = $123K: #1 PSR, Test, Cal, Delivery; #2 PER, PSR, integration/testing.

FY02 26 trips x $2.4K = $62K; #1 FRR, Refurb., L+30 activities; #2 slack

FY03 8 trips x $2.4K = $19K; #2 Delivery, Testing

FY04 18 trips x $2.4K = $43K; #2 FRR, Refurb, L+30 activities

COMPUTERS:

Computers are listed under material and equipment.

SUPPORT:

Support costs are costs for administrative and other services that are directly related labor or materials. This cost is estimated by taking a percentage of direct costs.

INSTITUTIONAL SUPPORT (G&A):

This is the indirect burden cost and is estimated as a percent of sub-total cost. This category also includes the pass through tax on contracts to others going through Aerospace and LANL.

7.2 Phase E cost proposal

7.2.1 Work Breakdown Structure

A work breakdown structure for Phase E is given in Table 7.5. This WBS was used to estimate the Phase E costs shown in Section 7.2.4. Since mission operations and data receiving will be provided by the mission sponsor, the Phase E WBS consists mainly of science activities, including data processing, data analysis, and scientific publications.

7.2.2 Cost Estimating Technique

Initial Phase E cost estimates were obtained using a "bottom up" approach. The work breakdown structure (WBS) and schedule were developed, iterated with the team members, and checked for thoroughness. The WBS for Phase E is much simpler than that for the other phases, with most of the emphasis placed on science activities. Next, the purchases and activities needed to provide the WBS products were estimated and checked. The bottoms-up cost estimate was then compared to similar projects just completed or in progress at TWINS team member organizations.

We believe the TWINS Phase E cost estimate to have a high degree of accuracy due to the very low technical risk nature of the phase and the extensive experience of the TWINS team members in data processing, data analysis, and mission operations for similar space physics missions. LANL is presently performing data processing and analysis and mission operations on 12-15 different instruments on 4-5 separate projects, including Ulysses/SWOOPS, ACE/SWEPAM, and the forerunner of the TWINS Mission, LENA-P. Aerospace developed the DPU for the LENA-P instrument, and is now performing data transfer and processing functions similar to those that will be required for TWINS. SwRI is currently in the data analysis phase of the Cassini and POLAR missions, and APL in the data analysis phase of the Cassini, Geotail, and Ulysses missions.

Since the mission sponsor will provide mission operations for TWINS, no contingency has been included in the Phase E budget for these activities. However, an overall 10% contingency, front-phased, has been added to account for data analysis needs such as having to develop the stereo data analysis, processing and transfer systems early to take advantage of a possible IMAGE stereo mission opportunity.

As in Phase B/C/D, 2% of all Phase E funds has been committed for TWINS education and outreach activities.

The cost estimate uses the LANL approved contract inflation rate of 4% per year.

Contributed costs during Phase E include Ly-a data analysis costs, which will be provided by the University of Bonn, and mission operations and data receiving costs, to be provided by the TWINS mission sponsor. Mission operations costs are based on estimates for the IMAGE program, and University of Bonn costs on data analysis costs from similar programs. As discussed in Section 7.1.4, mission operations costs are estimated to be $5.0 M (FY97$) during the TWINS Phase E.

The same plan used in Phase B/C/D to fund TWINS Co-Investigator institutions will also be used in Phase E.

Major procurements during Phase E are limited to 3 workstations, with an estimated cost of $120K.

Travel for Phase E will consist of science team meetings each year.

FY02 10 trips x $2.4K = $24K
FY03 10 trips x $2.4K = $24K
FY04 10 trips x $2.4K = $24K
FY05 20 trips x $2.6K = $52K
FY06 20 trips x $2.6K = $53K
FY07 10 trips x $2.6K = $27K

7.2.3 Workforce Staffing Plan

A workforce staffing plan for Phase E is given in Table 7.6. This plan gives time commitments by the TWINS team for each WBS element as a percent of time per month by fiscal year. Table 7.7 lists the time commitments for key personnel, as known, during Phase E. Again, commitments are listed as a percent per month by fiscal year.

7.2.4 Phase E Time-Phased Cost Summary

Table 7.8 gives a time phased cost breakdown for each work breakdown structure element in Phase E. This table shows the TWINS Phase E costs by fiscal year in real year dollars. Since mission operations will be provided by the mission sponsor, the majority of TWINS costs during Phase E are for science activities. Total Phase E costs to NASA, include 10% reserves, are $7.1M (RY$), and contributed costs from the spacecraft agency and the University of Bonn are $6.3 M (RY$).

7.3 Total mission cost estimate

Table 7.9 summarizes the total costs for the TWINS mission. Both the cost to NASA and contributed costs by the mission sponsor and the foreign Co-Investigator are included. All costs are given in real year dollars, except the last column, which gives the totals in FY97 dollars.

The total cost to NASA for the TWINS mission is $16.9 M (FY97$): $11.6 M for Phase B/C/D, and $5.3 M for Phase E. The total mission cost also includes contributed costs estimated at $20 M (FY97$), including $720 K from the University of Bonn, Germany, for the Ly-a detectors and $19.5 M from the mission sponsor.

The TWINS team has allocated 2% of the budget during all mission Phases, excluding contingency funds and spacecraft agency fees, for Educational and Outreach activities. This corresponds to $177 K in Phase B/C/D and $94 K in Phase E, for a total of $271 K (FY97$).

The host spacecraft, launch vehicles, launch services, and receiving of data on the ground will all be provided by the mission sponsor at no cost to NASA. Estimates for these services based on the costs for the IMAGE mission are included in the contributed costs section, and the estimation method is discussed above, in Section 7.1.4.

As noted in Section 7.1.4, it is probable that an extended TWINS mission could be supported with no financial impact to NASA for mission operations, since the lifetime of the host spacecraft (7 years) is considerably longer than the planned TWINS mission lifetime (4 years).

APPENDIX 1. RESUMES

PHILIP L. BARKER

Mr. Philip Barker received a B A degree in Management Science from the University of South Florida. He transferred to the Los Alamos National Laboratory in 1980 from private industry and has since been involved in all aspects of space flight hardware development. He has been a Mechanical Technician, Assistant Group Leader for a space instrument engineering group, and Section Leader for instrument build-up, instrument integration and testing, and printed circuit board development.

Mr. Barker has been a member of the LANL Space Physics Team since 1991 and is the Instrument Manager, Project Manager, Deputy Project Leader, and R&QA Officer for the teams' major instrument projects including the Cassini CAPS, the Geosynchronous Orbit Satellite Systems' Magnetospheric Plasma Analyzers, the ACE SWEPAM, the Lunar Prospector GRS/APS/NS, and the IMAGE MENA instrument. He has worked as Project Coordinator for the TWINS Principal Investigator for seven years.

Mr. Barker has many years experience working with the GSFC Explorer Office, the Aerospace and SwRI space instrumentation departments, and the other TWINS Co-I institutions. He has experience working with the Finnish and MIT laboratories that are providing the actuators and gratings. Mr. Barker also has an excellent working relationship with LANL budget, purchasing, and QA personnel, as well as the DOE/AL (LANL's primary funding and controlling organization) contracts and QA representatives.

J. BERNARD BLAKE

J. B. Blake received a B.S. Degree in Engineering Physics in 1957, a M.S. Degree in Physics in 1958, and a Ph.D. in Physics in 1962 from the University of Illinois. He held industrial fellowships from Raytheon and Texas Instruments.

Dr. Blake was a Research Associate at the University of Illinois from January 1962 to September 1962 when he joined the Space Sciences Laboratory of The Aerospace Corporation as a Member of the Technical Staff. He is presently Director of the Space Sciences Department.

Dr. Blake has been an investigator on many satellite missions, beginning in 1963, including ATS-1, ATS-6, OV3-3, S3-3, VIKING, CRRES, SCATHA, ULYSSES, and POLAR, He also has been an investigator on over a dozen USAF missions.

Professional activity has included research in beta decay, the Mossbauer effect, magnetospheric, auroral and cosmic-ray physics, and nuclear astrophysics. Applied work has been concerned with space weather, the effects of nuclear weapons upon ground and space systems, the interaction of the space environment with satellite systems, radiation damage effects, single-particle phenomena, anomaly analyses of various satellite subsystems, and related work.

Professional affiliations include membership in the American Astronomical Society, the American Geophysical Union, and Sigma Xi. He is a Fellow of the American Physical Society. He was awarded the Aerospace Trustees Award in 1986.

He has approximately 200 scientific publications.

J. B. Blake, M. D. Looper, D. N. Baker, R. Nakamure, B. Klecker, and D. Hovestadt, New High Temporal and Spatial Resolution Measurements by SAMPEX of the Precipitation of Relativistic Electrons, *Adv. Space Res., 18,* 171, 1996.

E. Keppler, B. Drolias, M. Fraenz, A. Korth, M. K. Reuss, J. B. Blake, and J. J. Quenby, The High Latitude Pass of ULYSSES: Energetic Particle Observations with EPAC, *Astronomy & Astrophysics, 316,* 464, 1996.

M. D. Looper, J. B. Blake, J. R. Cummings, and R. A. Mewaldt, SAMPEX observations of energetic hydrogen isotopes in the inner zone, *Radiation Measurements, 26*, 67, 1996.

Xinlin Li, D. N. Baker, M. Temerin, D. Larson, R. P. Lin, G. D. Reeves, M. D. Looper, S. G. Kanekal, and R. A. Mewaldt, Are energetic electrons in the solar wind the source of the outer radiation belt?, *GRL, 24*, 923, 1997.

T. I. Pulkkinen, D. N. Baker, N. E. Turner, H. J. Singer, L. A. Frank, J. B. Sigwarth, J. Scudder, R. Anderson, S. Kokubun, R. Nakamura, T. Mukai, J. B. Blake, C. T. Russell, H. Kawano, F. S. Mozer, and J. A. Slavin, Solar wind-magnetosphere coupling during an isolated substorm event: a multispacecraft ISTP study, *GRL, 24*, 983, 1997.

B. Wilken, W. I. Axford, I. Daglis, P. Daly, W Güttler, W. H. Ip, A. Korth, G. Kremser, S. Livi, V. M. Vasyliunas, J. Woch, D. N. Baker, R. D. Belian, J. B. Blake, J. F. Fennell, L. R. Lyons, H. Borg, T. A. Fritz, F. Gliem, R. Rathje, M. Grande, D. Hall, K. Kecsueméty, S. McKenna-Lawlor, K. Mursula, P. Tanskanen, Z. Pu, I. Sandahl, E. T. Sarris, M Scholer, M. Schulz, F. Sørass, and S. Ullaland, RAPID - The imaging energetic particle spectrometer on CLUSTER, *Sp. Sci. Reviews, 79*, 399, 1997.

J. B. Blake, M. D. Looper, E. Keppler, B. Heber, H. Kunow, and J. J. Quenby, Ulysses observations of short-period (<30 days) modulation of the galactic cosmic rays, *GRL, 24*, 671, 1997.

J. B. Blake, D. N. Baker, N. Turner, K. W. Ogilvie, and R. P. Lepping, Correlation of changes in the outer-zone relativistic-electron population with upstream solar wind and magnetic field measurements, *GRL, 24,* 927, 1997.

J. F. Fennell, J. B. Blake, J. L. Roeder, R. Sheldon, and H. E. Spence, Tail lobe and open field line region entries at mid to high latitudes, *Adv. Sp. Res.*, in press, 1997.

M. Grande, J. F. Fennell, S. Livi, B. Kellett, C. Perry, P. Anderson, J. L. Roeder, H. E. Spence, T. Fritz, and B. Wilken, First POLAR and 1995-034 observations of the mid altitude cusp during a persistent northward IMF condition, *GRL*, in press (15 June issue), 1997.

Baker, D.N., X. Li, J.B. Blake, and S. Kanekal, Strong electron acceleration in the Earth's magnetosphere, *Adv. Space Res.*, in press, 1997.

Baker, D.N., X. Li, N. Turner, J.H. Allen, J.B. Blake, R.B. Sheldon, H.E. Spence, R.D. Belian, G.D. Reeves, S.G. Kanekal, B. Klecker, R.P. Lepping, K. Ogilvie, R.A. Mewaldt, T. Onsager, H.J. Singer, and G. Rostoker, Recurrent geomagnetic storms and relativistic electron enhancements in the outer magnetosphere: ISTP coordinated measurements, *J. Geophys. Res.*, in press, 1997.

P. C. Anderson, I. W. McCrea, D. J. Strickland, J. B. Blake, and M. D. Looper, Coordinated EISCAT/DMSP measurements of electron density and energetic electron precipitation, *J. Geophys. Res., 102*, 7421, 1997.

JAMES L. BURCH

Dr. James L. Burch is Vice-President of the Instrumentation and Space Research Division at Southwest Research Institute in San Antonio, TX. He received his B.S. in Physics in 1964 from St. Mary's University of Texas and his Ph.D. in Space Science from Rice University in 1968. Dr. Burch is a fellow of the AGU and a Corresponding Member of the International Academy of Astronautics. Dr. Burch has served as a member of the NASA Space Science and Applications Advisory Committee (1990-1993), the Space Physics Subcommittee (1991-1994), and currently chairs the Sun-Earth Connection Strategic Planning Integration Team. He is also the current president of the Space Physics and Aeronomy Section of the American Geophysical Union. Dr. Burch has served as Associate Editor, Editor, and Editor-in-Chief of Geophysical Research Letters and is currently serving his third term as an Associate Editor of the Journal of Geophysical Research. Dr. Burch was Principal Investigator for the Dynamics Explorer 1 High-Altitude Plasma Instrument and the ATLAS-1 Space Experiments with Particle Accelerators (SEPAC). Currently he is principal investigator for the Ion and Electron Sensor for the European Space Agency ROSETTA comet orbiter and for the first NASA Middle Class Explorer (MIDEX) mission. The MIDEX mission, Imager for Magnetopause to Aurora Global Exploration (IMAGE) will employ neutral atom, ultraviolet and radio plasma imaging techniques to investigate the dynamics of the global magnetosphere. Dr. Burch has published over 150 papers in refereed journals and books.

Selected Recent Publications

Burch, J. L., C. Gurgiolo, and J. D. Menietti, The Electron Signature of Parallel Electric Fields, *Geophys. Res. Lett., 17,* 2329-2332, 1990.

Marshall, J. A., J. L. Burch, J. R. Kan, P. H. Reiff, and J. A. Slavin, Sources of Field-Aligned Current in the Auroral Plasma, *Geophys. Res. Lett., 18,* 45-48, 1991.

Burch, J. L., Diagnosis of Auroral Acceleration Mechanisms by Particle Measurements, in *Auroral Physics,* ed. by C.-I. Meng, M. Rycroft, and L. A. Frank, Cambridge University Press, 97-108, 1991.

Burch, J. L., N. A. Saflekos, D. A. Gurnett, J. D. Craven, and L. A. Frank, The Quiet-Time Polar Cap: DE-1 Observations and Conceptual Model, *J. Geophys. Res., 97,* 19,403-19, 412, 1992.

Menietti, J. D., J. L. Burch, R. M. Winglee, and D. A. Gurnett, DE-1 Particle and Wave Observations in Auroral Kilometric Radiation (AKR) Source Regions, *J. Geophys. Res., 98,* 5865-5880, 1993.

Winglee, R. M., J. D. Menietti, W. K. Peterson, J. L. Burch, J. H. Waite, Jr., and G. Giles Magnetosheath-Ionospheric Plasma Interactions in the Cusp/Cleft, 1, Observations of Modulated Injections and Upwelling Ion Fluxes, *J. Geophys. Res., 98,* 19,315-19,330, 1993.

Burch, J.L., Micro/Mesoscale Coupling in the Auroral Region: Observations, in *Cross-scale Coupling in Space Plasmas,* edited by J.L. Horwitz, N. Singh, and J.L. Burch, 87-96, Geophysical Monograph No. 93, American Geophysical Union, Washington, D.C., 1995.

Burch, J.L., and J.H. Waite, Jr., ed., *Solar System Plasmas in Space and Time,* Geophysical Monograph No. 84, American Geophysical Union, Washington, D.C., 1994.

Delcourt, D. C., J. A. Savaud, O. L. Vaisberg, L. A. Avanov, J. L. Burch, and J. H. Waite, Jr., Signatures of Impulsive Convection in the Magnetospheric Lobes, *Geophys. Res. Lett., 23,* 129-132, 1996.

WILLIAM R. CRAIN, JR.

W. R. Crain received a BS in Electrical Engineering in 1991 from the University of California, Los Angeles. He joined The Aerospace Corporation in 1991 as a Member of the Technical Staff in the Space Sciences Department and is presently Senior Member of the Technical Staff, Space Instrumentation Department, Space and Environment Technology Center (SETC). Mr. Crain has been involved in the design, development, test, and integration of spaceflight instruments since joining SETC. He was a design engineer for the CAMMICE (NASA POLAR) HIT and MICS Data Processing Units (DPU), and later became the Lead Engineer during instrument calibration, delivery and integration with the POLAR spacecraft. Mr. Crain also designed, tested and delivered the Charged Particle Telescope for the CLEMENTINE mission during the CAMMICE era.

Mr. Crain was responsible for Aerospace's Modular DPU design which is presently providing on-orbit support to the MCP/LENA-P and CPT instruments. A derivative of the Modular DPU is under development as Aerospace's contribution to the GUVI experiment for the NASA TIMED mission. The Modular DPU is the heritage design for the TWINS mission DPU.

In addition to his work as a design engineer, Mr. Crain has extensive experience in SETC's Single Event Effects test program for determining the susceptibility of electronics components to the space radiation environment, and experience with detector system design and calibration. Mr. Crain is presently Project Engineer/Manager for the Aerospace GUVI effort.

Mr. Crain is a member of the IEEE.

JAMES P. CRAVENS

Principal areas of specialization are Project/Instrument Management, systems design, particle detector design and testing, visible and UV imaging detector design and testing, calibration of science instruments, integration of instruments and spacecraft, radiation issues related to parts usage, and processes related to fabrication of scientific flight instrumentation.

Highlights of experience in these areas of specialization over the last twenty years include the following successful programs:

Currently: Performing Instrument Manager duties for the IMAGE Mission MENA instrument, and Project Management duties for the Southwest Research Institute efforts with the TWINS project.

Previously: Provided programmatic and radiation consulting services to Southwest Research Institute for the ACE project; Provided detector design, systems engineering and programmatic support for the ACE Mission SEPICA Instrument at the University of New Hampshire; Provided image intensifier, systems engineering and programmatic support for the ACE Mission SOFT instrument at Washington University at St. Louis; Provided systems engineering and spacecraft integration support for the ACE Mission Project Office at the California Institute of Technology; Project Manager and Senior Engineer for the Polar Mission Visible Imaging System at the University of Iowa; Deputy Project Manager and Senior Engineer for the GEOTAIL Mission Comprehensive Plasma Instrumentation at the University of Iowa; Senior Engineer for the Galileo Mission Plasma Instrument at the University of Iowa; Project Manager for the Plasma Diagnostics Package LEPEDEA Instrument flown on Space Shuttle Mission 51F, Space Lab 2 at the University of Iowa; Team member serving in various capacities for Ulysses, Galileo, Long Duration Effects Facility, Super Fluid Helium Experiment and other instruments at the Jet Propulsion Laboratory.

HANS J. FAHR, *Professor*
Institute for Astrophysics and Extraterrestrial Research
University of Bonn
D-53121 BONN (Germany)

H.J. Fahr was graduated (Physics Diploma, 1964) at the Institute for Theoretical Physics of the University of Bonn and received his Ph.D. in theoretical plasma physics in 1966 at the same institute. In 1968 he was nominated an Assistant Professor at the Institute for Astrophysics of the University of Bonn. In June, 1971 he made his habilitation at the same institute and became an Associate Professor in July, 1973. Since 1980 he is a Full Professor at the Institute for Astrophysics of the University of Bonn. Since 1988, Fahr is a member of the board of Directors of this institute, with his own distinct share of the budget of this institute; he directs his own research group (about 10 persons).

Honorary Positions:

- 1979-1982: President of Commission 49 (Heliosphere) of the International Astronomical Union (IAU)
- 1978-1984: President of the Section "Extraterrestrial Physics" of the German Physical Society (DPG)
- 1980-1984: Member of the Advisory Board "Astrophysics" of DARA (German NASA)
- 1987-1995: Member of the National COSPAR committee
- 1988: Member of the Program Committee of the COSPAR Colloquium "The three-dimensional heliosphere", Warsaw (Poland), 1989
- 1995-now: Member of the Advisory Board of the Max Planck Institute for Aeronomy (MPAe) in Lindau (Harz/Germany)

H.J. Fahr is the responsible leader of scientific cooperations sponsored by the German Ministry of Science and Technology and the Deutsche Forschungsgemeinschaft (DFG) with:

- Institute for Problems in Mechanics of the Russian Academy of Sciences at Moscow (Russia)
- Space Research Center of the Polish Academy of Sciences, Warsaw (Poland)
- Department of Astronomy and Physics, University of Calgary, Calgary/Alberta/Canada

H.J. Fahr was Principal Investigator of the following scientific sounding rocket projects:

- ASTRO-6 (A and B): EUV spectroscopy of geocoronal and interplanetary glows
- ASTRO-HEL: EUV observations of HeI/II resonance glows
- INTERZODIAK: Plasma-Dust interactions near the Sun seen in HI Ly-α
- GEO-SOLLY (I and II): High resolution spectroscopy of the solar emission Ly-α line

H.J. Fahr was Project Leader of the following DFG-sponsored projects: Intersol, TRISOL, HELIOPAUSE, TERREXO, HELIOSHOCK, HALOWIND. He led the joint European-American Medium Class Satellite Proposal HELEX to ESA in 1993.

H.J. Fahr has more than 200 publications with relevance to the scientific objectives of TWINS.

LYNN M. FRIESEN

L. M. Friesen received a BS degree in Information and Computer Science in 1971 from the University of California, Irvine. She joined The Aerospace Corporation in 1971 and has worked there for more than 26 years. Ms. Friesen presently holds the position of Director of the Space Instrumentation Department, in the Space and Environment Technology Center (SETC). The Space Instrumentation Department, comprised of electrical and mechanical design engineers, software engineers, and technical support staff, is the single organization within Aerospace responsible for designing and building spaceflight hardware.

Ms. Friesen has been involved in all phases of spaceflight and ground based experiments, including data processing and analysis; system design, test and integration; requirements definition; and system engineering. She has designed and implemented real-time data acquisition systems to support SETC's Single Event Effects program and has extensive experience designing software systems as ground support equipment (GSE) for spaceflight instrument development. She has participated in numerous satellite programs, including OV1-21, SCATHA, CRRES, and ULYSSES, in various capacities. Most recently, Ms. Friesen was GSE Engineer for the CEPPAD instrument on the NASA POLAR mission, and provided GSE for Aerospace-developed spaceflight instruments delivered to the US government. In addition to her line management and technical role in SETC, Ms. Friesen has almost 10 years of experience as System Integration Manager and Project Manager for three recent missions similar to the TWINS mission of opportunity. In these positions, she has worked extensively with government and contractor personnel.

Ms. Friesen is a member of the American Geophysical Union and the Association of Computing Machinery.

HERBERT O. FUNSTEN

1993-present	Technical Staff Member, Space and Atmospheric Sciences Group, LANL
1990-1993	Post-doctoral Fellow, Space and Atmospheric Sciences Group, LANL
1990	Ph.D. Engineering Physics, University of Virginia

Dr. Funsten is in charge of the Space and Atmospheric Sciences Group's Instrument Calibration Facility, which includes a Class 100 clean room, a 0.5-60 keV/q ion accelerator and associated equipment and electronics for full assembly, test, and calibration of space flight instrumentation. He is currently involved with the instrumentation development and calibration of the Ion Mass Spectrometer (IMS) on the CASSINI mission, the Plasma Experiment for Planetary Exploration (PEPE) mass spectrometer on the New Millennium DS-1 mission, and the Medium Energy Neutral Atom (MENA) Imager on the IMAGE mission. He has successfully led development a compact hydrogen isotope (H, D, and T) mass spectrometer that utilizes ultrathin foil physics (U.S. Patent No. 5,545,894) and a high-sensitivity explosives residue detector (US patent allowed, Sept. 1996). He is also leading development of a highly miniaturized space plasma spectrometer, a new class of time-of-flight mass spectrometer, microchannel plate-based night vision detector technology development, and solid state detector development for detection of low energy plasma particles. His other scientific research interests include analysis of ULYSSES plasma data and ion and electron beam interactions with solids. He is the author or co-author of over 44 scientific papers and has two patents.

SELECTED REFEREED PUBLICATIONS:

H.O. Funsten and D.J. McComas, Limited Resource plasma analyzers: Miniaturization concepts, *AGU Monograph: Measurement Techniques for Space Plasmas,* Eds. J. Borovsky, R. Pfaff, and D.T. Young, *in press*, 1997.

H.O. Funsten, D.J. McComas, and M.E. Gruntman, Mechanisms for neutral atom imaging, *AGU Monograph: Measurement Techniques for Space Plasmas,* Eds. J. Borovsky, R. Pfaff, and D.T. Young, *in press*, 1997.

H.O. Funsten and M. Shappirio, Sputtering of thin carbon foils by 20 keV and 40 keV Ar^+ bombardment, *Nucl. Instrum. and Meth. B*, in press, 1997.

H.O. Funsten, D.J. McComas, and E.E. Scime, E||B energy-mass spectrograph for measurement of ions and neutral atoms, *Rev. Sci. Instrum.,* **68,** 292-295, 1997.

H.O. Funsten, D.J. Suszcynsky, R.W. Harper, J.E. Nordholt, and B.L. Barraclough, Effect of local electric fields on microchannel plate detection and spatial resolution, *Rev. Sci. Instrum,.* **67,** 145-154, 1996.

H.O. Funsten, Formation and survival of H^- and C^- ions transiting ultrathin carbon foils at keV energies, *Phys. Rev., B* **52,** R8703-R8706, 1995.

H.O. Funsten, D.J. McComas, and E.E. Scime, Low energy neutral atom imaging for remote observations of the magnetosphere, *J. Spacecraft and Rockets*, **32,** 899-904, 1995.

H.O. Funsten, D.J. McComas, K.R. Moore, E.E. Scime, and M.F. Thomsen, Imaging of magnetospheric dynamics using low energy neutral atom detection, *AGU Monograph No. 84: Solar System Plasma Physics: Resolution Processes in Space and Time*, eds. J.L. Burch and J.H. Waite, Jr., American Geophysical Union, Washington, 275-282, 1994.

H.O. Funsten, B.L. Barraclough, and D.J. McComas, Interactions of slow H, H_2, and H_3 with thin carbon foils, *Nucl. Instr. and Meth., B* **90**, 24-28, 1994.

H.O. Funsten, D.J. McComas, and E.E. Scime, Comparative study of low energy neutral atom imaging techniques, *Optical Engineering,* **33**, 349-356, 1994.

H.O. Funsten, B.L. Barraclough, and D.J. McComas, Shell effects observed in exit charge state distributions of 1-30 keV atomic projectiles transiting ultra-thin foils, *Nucl. Instrum. and Meth., B* **80/81**, 49-52, 1993.

H.O. Funsten, D.J. McComas, and B.L. Barraclough, Ultrathin foils used for low energy neutral atom imaging of planetary magnetospheres, *Optical Engineering,* **32**, 3090-3095, 1993.

H.O. Funsten, B.L. Barraclough, and D.J. McComas, Pinhole detection in thin foils used in space plasma diagnostic instrumentation, *Rev. Sci. Instrum.,* **63**, 4741-4743, 1992.

H.O. Funsten, D.J. McComas, and B.L. Barraclough, Thickness uniformity and pinhole density analysis of thin carbon foils using keV ions, *Nucl. Instrum. and Meth., B* **66**, 470-478, 1992.

R.C. Elphic, H.O. Funsten, B.L. Barraclough, D.J. McComas, M.T. Paffett, D.T. Vaniman, and G. Heiken. Lunar surface composition and solar wind-induced secondary ion mass spectrometry, *Geophys. Res. Lett.,* **18**, 2165-2168, 1991.

D.J. McComas, B.L. Barraclough, R.C. Elphic, H.O. Funsten, and M.F. Thomsen, Magnetospheric imaging with low-energy neutral atoms, *Proc. Natl. Acad. Sci. USA,* **88**, 9598-9602, 1991.

MIKE GRUNTMAN
Associate Professor
Department of Aerospace Engineering
University of Southern California
Los Angeles, California 90089-1191

Gruntman was graduated (M.S., 1977) at the Department of the Aerophysics and Space Research of the Moscow Physical-Technical Institute and received his Ph.D. in experimental physics from the Space Research Institute (IKI) of the USSR Academy of Sciences in 1984. He actively worked on the development of the novel instrumentation for laboratory and space application and conducted research in experimental and space physics. He has been active also in the development of plasma analyzers and imaging photon-counting detectors for ground (6 meter) and space telescopes. He acted in the capacity of Co-PI in the experiment to study the neutral component of the solar wind and energetic neutral atoms born in the magnetosphere of the Earth. He was a visiting scientist at the FOM-Institute for Atomic and Molecular Physics in Amsterdam, the Netherlands.

In 1990 Gruntman joined University of Southern California (USC) where he was initially involved in reduction and evaluation of the data from Pioneer 10/11 spacecraft and participated in the sounding rocket and space instrument development programs. He worked on the sounding rocket payload integration and testing at White Sands Missile Range.

Gruntman is currently PI and Co-I in several experimental and theoretical programs funded by NASA. His general interests include diagnostics of space plasmas, in particular imaging the heliosphere and planetary magnetospheres in energetic neutral atom fluxes, interplanetary EUV/UV glow, local interstellar medium and global heliosphere, development of particle and photon analyzers and detector systems, position-sensitive detectors, mass spectrometry, EUV diffraction filtering, ion and neutral particle beams, atomic collisions, interactions of particles with surfaces, astronautics, space mission and spacecraft design and spacecraft propulsion.

Gruntman authored and co-authored more than 125 publications. He is teaching courses in astronautics, space sciences, and space instrumentation; he directs development of the USC student microsatellite. He is a Vice Chair for Education of the Los Angeles Section of the American Institute of Astronautics and Aeronautics (AIAA).

REPRESENTATIVE PUBLICATIONS:

M.A. Gruntman and V.A. Morozov, H atom detection and energy analysis by use of thin foils and TOF technique, *J. Phys. E, 15,* 1356-1358, 1982.

M.A. Gruntman, Identification of ions by their masses in multichannel energy analyzers, *Instrum. Exp. Techn., 26,* 943-945, 1983.

M.A. Gruntman, Position-sensitive detectors based on microchannel plates, *Instrum. Exp. Techn., 27,* 1-19, 1984.

M.A. Gruntman, MASTIF: Mass Analysis of Secondaries by Time-of-Flight Technique. New Approach to Secondary Ion Mass Spectrometry, *Rev. Sci. Instrum., 60,* 3188-3196, 1989.

M.A. Gruntman et al., Multielectron secondary emission from thin foils bombarded by accelerated beams of atoms, *JETP Lett., 51,* 22-25, 1990.

M.A. Gruntman, Anisotropy of the ENA Flux in the Heliosphere, *Planet. Space Sci., 40,* 439-445, 1992.

M.A. Gruntman, Charge-exchange born He^+ ions in the solar wind, *Geophys. Res. Lett., 19,* 1323-1326, 1992.

M.A. Gruntman, A new technique for *in situ* measurement of the composition of interstellar gas in the heliosphere, *Planet. Space Sci., 41,* 307-319, 1993.

M.A. Gruntman, A new collimator design for ENA instruments, *Rev. Sci. Instrum., 65,* 758-759, 1994.

M.A. Gruntman, Neutral solar wind properties: advance warning of major geomagnetic storms, *J. Geophys. Res., 99,* 19213-19227, 1994.

E.E. Scime, H.O. Funsten, D.J. McComas, K.R. Moore, and M.A. Gruntman, Novel low-energy neutral atom imaging technique, *Optical Engineering, 33,* 357-361, 1994.

M.D. Daybell, M.A. Gruntman, D.L. Judge, and J.A.R. Samson, A rare gas optics-free stable extreme-ultraviolet photon spectrometer for solar system studies, *Optical Engineering, v.33,* 445-450, 1994.

M.A. Gruntman, EUV radiation filtering by freestanding transmission gratings, *Appl. Opt., 34,* 5732-5737, 1995.

M.A. Gruntman, H_2^+ pickup ions in the solar wind. Outgassing of interplanetary dust, *J. Geophys. Res., 101,* 15555-15568, 1996.

M.A. Gruntman, Transmission grating filtering of 52-140 nm radiation, *Appl. Optics, 36,* 2203-2205, 1997.

DAN J. MABRY

D. J. Mabry received a BS in Electrical Engineering in 1985 from the University of California, Los Angles, and a MS in Electrical Engineering in 1990, from the University of Southern California. He joined the Space and Environment Technology Center (SETC) of The Aerospace Corporation as a Member of the Technical Staff in 1985. Mr. Mabry is presently a Section Manager in the Space Instrumentation Department, SETC, where he has line management responsibility for nine engineers.

Mr. Mabry has 13 years experience designing software and hardware for spaceflight scientific applications beginning with CRRES in the late '80s. He was Project Manager/Flight Software Engineer for the Aerospace Data Processing Unit (DPU) development for NASA's first small explorer mission, SAMPEX; Project Manager/Flight Software Engineer for the CEPPAD instrument on the NASA POLAR mission; and Flight Software Engineer for the LENA-P and CPT DPUs. Mr. Mabry is presently Project Engineer/Manager for Aerospace's ICO Dosimeter Project (Hughes Space and Com), and is providing the flight code GUVI.

Mr. Mabry is a member of the IEEE.

DAVID J. MCCOMAS

David J. McComas is the Group Leader for Space and Atmospheric Sciences (NIS-1) in the Nonproliferation and International Security Division at Los Alamos National Laboratory. Dr. McComas joined the Laboratory in 1980 after receiving his B.S. Degree in Physics from MIT. He was awarded a Ph.D. in Geophysics and Space Physics from UCLA in 1986. Dr. McComas is a Fellow of the American Geophysical Union (AGU) and a recipient of the AGU's 1993 James B. Macelwane Award; he also received Los Alamos National Laboratory Distinguished Performance Awards in 1989, 1990, and 1995 as well as numerous NASA and Los Alamos achievement awards. Dr. McComas is the Principal Investigator for the Ulysses Solar Wind Over the Poles of the Sun (SWOOPS) Experiment and DOE's series of 10 Magnetospheric Plasma Analyzer (MPA) instruments at geosynchronous orbit; he is the Co-Investigator responsible for leading Solar Wind Electron Proton Alpha Monitor (SWEPAM) instrument on the Advanced Composition Explorer (ACE) and the Los Alamos contributions to the plasma instrument for the Cassini mission to Saturn (CAPS). He is also a Co-Investigator on IMAGE, the ISTP Polar spacecraft's Thermal Ion Dynamics Experiment (TIDE), the Cluster plasma electron instrument (PEACE), and is a team member on the New Millennium Plasma Experiment for Planetary Exploration (Pepe'). Dr. McComas presently serves on NASA's Sun-Earth Connections Subcommittee, the Integration Team for NASA's Sun-Earth Connections Strategic Planning, the AGU's *Journal of Geophysical Research (JGR)-Space Physics* Direction and Review Committee, the AGU's James B. Macelwane Medal Committee, and the University of California President's Office Quinquennial Review Committee of the Institute on Geophysics and Planetary Physics. He is also presently Vice Chairman of Nonproliferation and International Security Leadership Council (NIS-LC) and the J. Robert Oppenheimer Memorial Committee and is Chairman of the NIS-LC Steering Committee . He has previously served on numerous committees and panels for the National Academy of Science's National Research Council, the National Aeronautics and Space Administration, the American Geophysical Union, Los Alamos National Laboratory, and the State of New Mexico. Dr. McComas has been an Associate Editor for *JGR-Space Physics*, and is an author of over 200 scientific papers on topics ranging from space instrument design to solar wind, magnetospheric, cometary and planetary physics.

McComas, D.J. and S.J. Bame, Channel Multiplier Compatible Materials and Lifetime Tests, *Rev. Sci. Inst.*, *55*, 463-467, 1984.

McComas, D.J., C.T. Russell, R.C. Elphic, and S.J. Bame, The Near-Earth Cross-Tail Current Sheet: Detailed ISEE 1 and 2 Case Studies, *J. Geophys. Res.*, *91*, 4287-4301, 1986.

McComas, D.J., J.T. Gosling, C.T. Russell, and J.A. Slavin, Magnetotails at Unmagnetized Bodies: Comparison of Comet Giacobini-Zinner and Venus, *J. Geophys. Res.*, *92*, 10111-10117, 1987.

McComas, D.J., J.R. Baldonado, S.J. Bame, and B.L. Barraclough, Channel Electron Multiplier Compatibility with Viton and Apiezon-L Vacuum Grease, *Rev. Sci. Inst.*, *58*, 2331-2332, 1987.

McComas, David J., Jane E. Nordholt, Samuel J. Bame, Bruce L. Barraclough, and John T. Gosling, Linear Electric Field Mass Analysis: A Technique for Three-Dimensional High Mass Resolution Space Plasma Composition Measurements, *Proc. Nat. Acad. Sci., USA*, *87*, 5925-5929, 1990.

McComas, David J. and Jane E. Nordholt, A New Approach to 3-D, High Sensitivity, High Mass Resolution Space Plasma Composition Measurements, *Rev. Sci. Inst.*, *61*, 3095-3097, 1990.

McComas, D.J., B.L. Barraclough, R.C. Elphic, H.O. Funsten III, and M.F. Thomsen, Magnetospheric Imaging with Low Energy Neutral Atoms, *Proc. Nati. Acad. Sci., USA, 88*, 9589-9602, 1991.

McComas, D.J., H.O. Funsten, J.T. Gosling, K.R. Moore, and M.F. Thomsen, Low energy neutral atom imaging, *Instrumentation for Magnetospheric Imagery, SPIE Proc., V. 1744*, 40-50, 1992.

McComas, D.J., S.J. Bame, B.L. Barraclough, J.R. Donart, R.C Elphic, J.T. Gosling, M.B. Moldwin, K.R. Moore, and M.F. Thomsen, Magnetospheric Plasma Analyzer (MPA): Initial three-spacecraft observations from geosynchronous orbit, *J. Geophys. Res.*, *98*, 13453-13465, 1993.

McComas, D.J., H.O. Funsten, J.T. Gosling, K.R. Moore, E.E. Scime, and M.F. Thomsen, Fundamentals of low energy neutral atom imaging, *Optical Eng.*, *33*, 335-341, 1994.

McComas, D.J., R.C. Elphic, M.B. Moldwin, and M.F. Thomsen, Plasma observations of magnetopause crossings at geosynchronous orbit, *J. Geophys. Res.*, *99*, 21249-21255, 1994.

McComas, D.J., H.O. Funsten, and E.E. Scime, Advances in low energy neutral atom imaging, in press in *Measurement Techniques for Space Plasmas, AGU monograph series*, 1996.

McComas, D.J., B.L. Barraclough, R.W. Moses, R.C. Wiens, L. Adamic, D. Burnett, and M. Neugebauer, Solar Wind Concentrator, in press in *Measurement Techniques for Space Plasmas, AGU monograph series*, 1996.

McComas, D.J., J.E. Nordholt, J.-J. Berthelier, J.-M. Illiano, and D.T. Young, The Cassini ion mass spectrometer, in press in *Measurement Techniques for Space Plasmas, AGU monograph series*, 1996.

McComas, D.J., S.J. Bame, P. Barker, W.C. Feldman, J.L. Phillips, P. Riley and J.W. Griffee, Solar wind electron proton alpha monitor (SWEPAM) for the Advanced Composition Explorer", submitted to *Space Science Reviews - special issue on the ACE mission*, 1997.

DONALD G. MITCHELL

Dr. Mitchell is a Principal Professional Staff Physicist at the Johns Hopkins University Applied Physics Laboratory. He received a B.A. in physics from the University of Michigan in 1971, and a Ph.D. in physics in 1975 from the University of New Hampshire. Dr. Mitchell's research interests have included radio astronomy, solar flares, solar wind, and various terrestrial and planetary magnetospheric topics. He is presently focusing on the magnetospheric physics of the Earth and of Saturn. He is or has been the Project Manager for several NASA and NSF analysis grants and contracts, and is involved in the design of a new generation of space instrumentation for the imaging of planetary magnetospheric energetic plasmas, in particular as Instrument Scientist for the Magnetospheric Imaging Instrument on the NASA Saturn mission, Cassini, and as the Lead Investigator for the HENA instrument on the NASA IMAGE Mission. He has also designed miniaturized instrumentation for ion mass and energy analysis in space. He serves on the National Research Council Committee on International Programs, and has served other NRC and NASA committees. He has lectured in the Johns Hopkins University Whiting School of Engineering, Space Systems Course at APL since 1990. On the TWINS Mission Dr. Mitchell will participate in the design of the MENA instrument, and will participate in data interpretation and public outreach efforts.

Recent relevant publications:

Mitchell, D.G., S. M. Krimigis, A. F. Cheng, S. E. Jaskulek, E. P. Keath, B. H. Mauk, R. W. McEntire, E. C. Roelof, C. E. Schlemm, B. E. Tossman, and D. J. Williams, The Imaging Neutral Camera (INCA) for the NASA Cassini Mission to Saturn and Titan, and Possibilities for the Future, *Measurement Techniques for Space Plasmas, Chapman Conference*, Santa Fe, NM, April 3-7, AGU Monograph, 1996.

D. G. Mitchell, S. M. Krimigis, A. F. Cheng, K. C. Hsieh, S. E. Jaskulek, E. P. Keath, B. H. Mauk, R. W. McEntire, E. C. Roelof, C. E. Schlemm, B. E. Tossman, and D. J. Williams, The Imaging Neutral Camera (INCA) for the NASA Cassini Mission to Saturn and Titan, *Proceeding SPIE 2803-16*, Denver CO, August, 1996.

D. G. Mitchell, S. E. Jaskulek, E. P. Keath, S. M . Krimigis, B. H. Mauk, E. C. Roelof, C. E. Schlemm, The Cassini Mimi Ion And Neutral Camera (INCA): Performance Characteristics And Anticipated Magnetospheric Imaging Results At Saturn, *Proceedings COSPAR*, Birmingham, UK, July, 1996.

Angelopoulos, V., D.G. Mitchell, R.W. McEntire, D.J. Williams, A.T.Y. Lui, S.M. Krimigis, R.B. Decker, S.P. Christon, S. Kokubun, T. Yamamoto, Y. Saito, T. Mulai, F.S. Mozer, K. Tsuruda, G. Reeves, W.J. Hughes, E. O. Troshichev, Tailward Progression of Magnetotail Acceleration Centers: Relationship to Substorm Current Wedge, *J. Geophys. Res., 101,* 24599, 1996.

Zhou, X.-Y, C. T. Russell, and D. G. Mitchell, Three Spacecraft Observations of the Geomagnetic Tail During Moderately Disturbed Conditions: Global Perspective, *J. Geophys. Res.*, 1996.

Nakamura, R., D. N. Baker, D. H. Fairfield, D. G. Mitchell, R. L. McPherron, and E. W. Hones, Plasma flow and magnetic field characteristics near the midtail neutral sheet, *J. Geophys. Res., 99,* 23591, 1994.

Mitchell, D. G., A. F. Cheng, S. M. Krimigis, E. P. Keath, S. E. Jaskulek, B. H. Mauk, R. W. McEntire, E. C. Roelof, D. J. Williams, INCA, the ion neutral camera for energetic neutral atom imaging of the Saturnian magnetosphere, *IEEE Optical Engineering, 32,* 3096, 1993.

Mitchell, D. G., Particle observations in the plasma sheet during cross-tail current sheet disruptions, *Proceedings of the Second International Conference on Substorms*, Alaska, March, 1994.

Angelopoulos, V., V. A. Sergeev, D. N. Baker, D. G. Mitchell, G. D. Reeves, C. T. Russell, H. J. Singer, Multi-point study of bursty bulk flow events during a sequence of small substorms, in *Substorms-2*, Proceedings of the Second International Conference on Substorms, (ICS-2), AGU publication, 1994.

Traver, D. P., D. G. Mitchell, and D. J. Williams, A statistical study of the late substorm recovery phase and quiet time plasma sheet based on ISEE-1 ~30 keV ion observations, *J. Geophys. Res., 99,* 10981, 1994.

Pulkkinen, T. I., D. N. Baker, D. G. Mitchell, R. L. McPherron, C. Y. Huang, and L. A. Frank, Thin current sheets in the magnetotail during substorms: CDAW-6 revisited, *J. Geophys. Res., 99,* 5793, 1994.

Sergeev, V. A., D. G. Mitchell, C. T. Russell, and D. J. Williams, Structure of the tail plasma/current sheet at ~11Re and its changes in the course of a substorm, *J. Geophys. Res., 98,* 17345, 1993.

Williams, D. J., E. C. Roelof, and D. G. Mitchell, Global magnetospheric imaging, *Rev. Geophys., 30,* 183, August, 1992.

E. C. Roelof, D. G. Mitchell, and D. J. Williams, Energetic neutral atoms (E~50 keV) from the ring current: IMP 7/8 and ISEE-1, *J. Geophys. Res., 90,* 10991-11008, 1985.

E. P., Keath, G. B. Andrews, A. F. Cheng, S. M. Krimigis, B. H. Mauk, D. G. Mitchell and D. J. Williams, Instrumentation for energetic neutral atom imaging of magnetospheres, in *Solar System Plasma Physics,* Geophysical Monograph 54, J. H. Waite, Jr., J. L. Burch, and R. L. Moore, Ed., 165-170, American Geophysical Union, 1989.

R. W. McEntire, and D. G. Mitchell, Instrumentation for global magnetospheric imaging via energetic neutral atoms, in *Solar System Plasma Physics*, Geophysical Monograph 54, J. H. Waite, Jr., J. L. Burch, and R. L. Moore, Ed., 69, American Geophysical Union, 1989.

CRAIG JAMES POLLOCK

Personal Information

Date of Birth:	[redacted]
Place of Birth:	[redacted]
Social Security Number:	[redacted]
Home Address:	[redacted]
Marital Status:	Married
Military Service:	United States Air Force (1971-1975) Honorable Discharge

Education

Undergraduate:	Hudson Valley Community College, Troy, NY A.A. (Liberal Arts): 1977
	Siena College, Loudonville, NY B.A. (Physics): 1980, cum laude
Graduate:	University of New Hampshire, Durham, NH Ph.D. (Physics): 1987
Dissertation:	"Rocket-Borne Low Energy Ion Measurements in Space"

Professional Employment

1980-82	Teaching Assistant, U. New Hampshire
1983-87	Research Associate, U. New Hampshire
1987-89	NRC Research Associate, MSFC/NASA
1989-96	Space Plasma Physicist, Space Sciences Laboratory, NASA/MSFC
1996-present	Principal Scientist, Instrm. and Sp. Res. Div., Southwest Research Institute

Positions of Responsibility

<u>Co-Investigator</u>: Ambient Ionospheric Heating: 3D Core Plasma Measurements for TOPAZ3; 1990-1992. Funded by NASA Office of Space Science.

<u>Co-Investigator</u>: Magnetospheric Role of Ionospheric Plasma; 1990-1992. Funded by NASA Office of Space Science.

<u>Experiment Scientist</u>: Thermal Ion Dynamics Experiments / ISTP GGS Polar Spacecraft. Funded by NASA Office of Space Science.

<u>Principal Investigator</u>: Induced Ionospheric Heating: Low Energy Electron Measurements for the CRRES AA-4 sounding rocket; 1990-1992. Funded by NASA Office of Space Science.

<u>Principal Investigator</u>: A Channel Electron Multiplier Processing Facility for Use in Development of Charged Particle Detector Systems. Funded by MSFC Center Director's Discretionary Fund.

Principal Investigator: Low Energy Electron and Ion Measurements for 'Sounding of the Cleft Ion Fountain Energization Region'. Funded by NASA Office of Space Science.
Principal Investigator: Low Energy Electron and Ion Measurements for 'Cleft Accelerated Plasma Experiment Rocket' (CAPER). Funded by NASA Office of Space Science.
Lead Co-Investigator: Medium Energy Neutral Atom (MENA) imager, to be flown on the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission, to be launched in January, 2000. Funded by NASA Office of Space Science.

Selected Publications

Pollock, C. J., M. O. Chandler, T. E. Moore, J. H. Waite, Jr., C. R. Chappell, and D. A. Gurnett, A Survey of Upwelling Ion Event Characteristics, *J. Geophys. Res., 95,* 18969-18980, 1990.

Moore, T. E., C. R. Chappell, M. O. Chandler, S. A. Fields, C. J. Pollock, D. L. Reasoner, D. T. Young, J. L. Burch, N. Baker, J. H. Waite, Jr., D. J. McComas, J. E. Nordholdt, M. F. Thomsen, J. J. Berthelier, and R. Robson, The Thermal Ion Dynamics Experiment and Plasma Source Instrument, *Sp. Sci. Rev., 71,* 409-458, 1995.

Pollock, C. J., T. E. Moore, M. L. Adrian, P. M. Kintner, and R. L. Arnoldy, SCIFER - Cleft Region Thermal Electron Distribution Functions, *Geophys. Res. Lett., 23,* 1881, 1996.

Pollock, C. J., V. N. Coffey, J. D. England, N. G. Martinez, T. E. Moore, and M. L. Adrian, Thermal Electron Capped Hemisphere Spectrometer (TECHS) for Ionospheric Studies, *AGU Monograph on Measurement Techniques for Space Plasmas,* in press, 1997.

Coffey, V. N., T. E. Moore, and C. J. Pollock, The Scanning Ion Composition Spectrometer (STICS), *AGU Monograph on Measurement Techniques for Space Plasmas,* in press, 1997.

Moore, T. E., C. J. Pollock, and D. T. Young, Kinetic Core Plasma Diagnostics, *AGU Monograph on Measurement Techniques for Space Plasmas,* in press, 1997.

Memberships and Professional Affiliations

American Geophysical Union
Sigma Pi Sigma
Sigma Xi

SUSAN E. POPE
Engineer
Department of Space Science
Instrumentation and Space Research Division

B.S., Mechanical Engineering, The University of Texas at Austin, 1996

While at The University of Texas at Austin, Mrs. Pope participated in the cooperative educational program with Applied Research Laboratories (ARL) in Austin. Assignments as a co-op engineer/student included design of sonar equipment used on Navy submarines. She designed and produced detailed drawings for a switch box used with a sonar system. Also, she worked with Mechanical and Electrical engineers in the design of an outboard sonar system consisting of a hydrophone, projector, and receivers. Mrs. Pope produced the detailed drawings for the housings and other parts for both the hydrophone and projector.

Mrs. Pope accepted employment with Southwest Research Institute in San Antonio, Texas after graduation in December of 1996. She began work in January of 1997. Since starting work, she has used Pro/Engineer to do mechanical design for a cusp ion and a cusp electron detector (CID and CED), an instrument on a rocket payload in the Svalbard Cusp Transient Features Campaign. The Rocket was launched successfully from Svalbard in November of 1997, and the data from CID and CED are currently undergoing analysis. Mrs. Pope is also participating in the development of the TICHS and TECHS instruments that will be part of the CAPER sounding rocket mission. She has finished the detail design of the flight unit for the data processing unit on the Medium Energy Neutral Atom Imager, a part of the Imager for Magnetopause-to-Aurora mission (IMAGE). Recently, she has started working on the detail design of the ALICE instrument that will be part of the Rosetta mission.

PROFESSIONAL CHRONOLOGY: 1994-1996 Co-op Engineer with Applied Research Laboratories; 1997-present Engineer, Southwest Research Institute.

EDMOND C. ROELOF

Born: October 2, 1937 - Evanston, Illinois. **Education:** A. B. (Physics), University of California (Los Angeles), 1959; Ph.D., University of California, Berkeley, 1966.
Positions Held: *1974-Present:* Principal Professional Staff (1978-Present), The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland; *1969-74:* Assistant Professor of Physics (1971-1974), University of New Hampshire, Durham, New Hampshire; *1967-69:* NAS/NASA Postdoctoral Research Associate, Goddard Space Flight Center, Greenbelt, Maryland; *1964-67:* Staff Member, Boeing Scientific Research Laboratories, Seattle, Washington.
NASA Missions Co-Investigator: *Pioneer 10/11:* Cosmic Ray Energy Spectra Experiment; *Galileo Jupiter Orbiter:* Energetic Particles Detector; *Ulysses:* Spectral, Composition, and Anisotropy Measurements of Charged Particles at Low Energies; *International Solar Terrestrial Physics (Geotail):* Energetic Particle and Ion Composition; *Cassini Saturn Orbiter:* Magnetospheric Imaging Instrument.
Non-U.S. Missions Co-Investigator: *Astrid*--Swedish Institute of Space Physics: Energetic neutral atom imager; *SAC-B*--Argentina: Energetic neutral atom imager.
Referee: Astrophysical Journal, Geophysical Research Letters, Journal of Geophysical Research, Optical Engineering, Physical Review, Remote Sensing Reviews, Reviews of Geophysics, Solar Physics, Journal of Geophysics, Pure and Applied Geophysics. *Editor's Citation for Excellence in Refereeing:* Geophysical Research Letters (1987).
Professional Societies: *American Geophysical Union* (joined 1962): Secretary, Cosmic-Ray Subsection (1970-74), Honors Committee, Solar-Planetary Relationships Section (1990-92); Secretary, Solar-Heliospheric Subsection (1994-1998); *American Astronomical Society* (joined 1969); *SPIE* (joined 1991), Co-Chair, Special Sessions.
Recent Relevant Publications (Magnetospheric Imaging): (Selected from 130 in terrestrial and planetary magnetospheric, interplanetary, solar, heliospheric, and cosmic ray physics)

Roelof, E. C., Energetic neutral atom imaging of magnetospheric ions from high- and low-altitude spacecraft, *Adv. Space Res.,* Paper D0.5-0008, *in press,* April, 1997.

Chase, C. J., and E. C. Roelof, Computer simulations of energetic neutral atom imaging from low and high altitude spacecraft, *Adv. Space Res.,* Paper D0.5-0050, *in press,* 1997.

Roelof, E. C., ENA emission from nearly-mirroring magnetospheric ions interacting with the exosphere, *Adv. Space Res.,* Paper D0.5-0051, *in press,* 1997.

Lui, A. T. Y., D. J. Williams, E. C. Roelof, R. W. McEntire, and D. G. Mitchell, Observations of energetic neutral atoms by the EPIC instrument - first result on the composition, *Adv. Space Res.,*. paper D0.1-0040, *in press,* 1997.

Barabash, S., and E. C. Roelof, Energetic neutral atom imaging in the Earth's magnetosphere, *Adv. Space Res.,* Paper D0.1-0057, *in press,* 1997.

C:son Brandt, P., S. Barabash, O. Norberg, R. Lundin, E. C. Roelof, C. J. Chase, B. H. Mauk, and M. Thomsen, ENA imaging from the Swedish micro-satellite Astrid during the magnetic storm of 8 February, 1995, *Adv. Space Res.,* Paper D0.1-0103, *in press,* 1997.

Barabash, S., O. Norgerg, R. Lundin, S. Olsen, K. Lundin, P. Cson Brandt, E. C. Roelof, C. J. Chase, and B. H. Mauk, Energetic neutral atom imager on the Swedish microsatellite Astrid, *AGU Monograph, Proc. Santa Fe Conf. on Instrumentation, in press*, 1997.

Hesse, M., D. Mitchell, E. Roelof, B. Mauk, D. McComas, H. Funsten, and J. Birn, Neutral atom imaging of the plasma sheet: Measurement predictions, *Geophys. Res. Lett.,* **24**, *in press,* 1997.

Amsif, A., J. Dandouras, and E. C. Roelof, Modeling the production and imaging of energetic neutral atoms in Titan's exosphere, *J. Geophys. Res.,* **102**, *in press,* 1997.

Lui, A. T. Y., D. J. Williams, E. C. Roelof, R. W. McEntire, and D. G. Mitchell, First composition measurements of energetic neutral atoms, *Geophys. Res. Lett.,* **23**, 2461-2464, 1996.

Chase, C. J., and E. C. Roelof, Extracting evolving structures from global magnetospheric images via model fitting and video visualization, *Johns Hopkins APL Tech. Dig.*, **16**, (2), 111-122, 1995.

Norberg, O., S. Barabash, I. Sandahl, R. Lundin, H. Lauche, H. Koskinen, P. C:son Brandt, E. Roelof, L. Andersson, U. Eklund, H. Borg, J. Gimholt, K. Lundin, J. Ryno, and S. Olsen, The microsatellite Astrid, *Proc. 12th ESA Symposium on Rocket and Balloon Programmes & Related Research,* Lillehammer, Norway, **ESA SP-370**, 273-277, 1995.

Frank, L. A., J. B. Sigwarth, D. J. Williams, E. C. Roelof, D. G. Mitchell, R. E. Gold, E. P. Keath, B. H. Mauk, C.-I. Meng, D. L. Carpenter, B. K. Hultqvist, R. N. Lundin, G. L. Siscoe, R. A. Wolf, D. J. Gorney, M. Schulz, D. J. McComas, H. O. Funsten, K. R. Moore, B. W. Smith, J. D. Craven, Y. T. Chiu, R. R. Meier, and J. F. Seely, Imagers for the magnetosphere, aurora, and plasmasphere, *Optical Engr.,* **33**, 391-408, 1994.

Mitchell, D. G., A. F. Cheng, S. M. Krimigis, E. P. Keath, S. E. Jaskulek, B. H. Mauk, R. W. McEntire, E. C. Roelof, D. J. Williams, K. C. Hsieh, and V. A. Drake, INCA, the ion neutral camera for energetic neutral atom imaging of the Saturnian magnetosphere, *Optical Engr.*, **32**, 3096-3101, 1993.

Cheng, A. F., E. P. Keath, S. M. Krimigis, B. H. Mauk, R. W. McEntire, D. G. Mitchell, E. C. Roelof, and D. J. Williams, Imaging neutral particle detector, *Remote Sensing Rev.,* **8**, 101-145, 1993.

Roelof, E. C., B. H. Mauk, R. R. Meier, K. R. Moore, and R. A. Wolf, Simulations of EUV and ENA magnetospheric images based on the Rice Convection Model, in *Instrumentation for Magnetospheric Imagery II,* ed. S. Chakrabarti, *Proc. SPIE,* **2008**, 202-213, 1993.

Roelof, E. C., B. H. Mauk, and R. R. Meier, Instrument requirements for imaging the ultraviolet and energetic neutral atoms derived from computer-simulated images, in *Instrumentation for Magnetospheric Imagery,* ed. S. Chakrabarti, *Proc. SPIE,* **1744**, 19-30, 1992.

Williams, D. J., E. C. Roelof, and D. G. Mitchell, Global magnetospheric imaging, *Rev. Geophys.*, **30**, 183-208, 1992.

Roelof, E. C., Imaging heliospheric shocks using energetic neutral atoms, *Solar Wind Seven,* (Proc. 3rd COSPAR Colloquium), eds. E. Marsch and R. Schwenn, Pergamon Press (Oxford), 385-390, 1992.

Roelof, E. C., Remote sensing of the ring current using energetic neutral atoms, *Adv. Space Res.*, **9**, (12)195-(12)203, 1989.

Roelof, E. C., Energetic neutral atom image of a storm-time ring current, *Geophys. Res. Lett.*, **14**, 652-655, 1987.

Roelof, E. C., D. G. Mitchell, and D. J. Williams, Energetic neutral atoms (E~50 keV) from the ring current: IMP 7/8 and ISEE 1, *J. Geophys. Res.,* **90**, 10991-11008. 1985.

EARL E. SCIME
Assistant Professor
Department of Physics
West Virginia University
Morgantown, WV 26506

Earl Scime receive his B.S. degrees in Physics and Applied Mathematics from Florida State University in 1987 and his Ph.D. in Plasma Physics from the University of Wisconsin-Madison in 1992. He became a Director's Postdoctoral Fellow at Los Alamos National Laboratory in 1992 and a Department of Energy Distinguished Postdoctoral Fellow in 1993. Since 1995 he has been an assistant professor of physics at West Virginia University. Prof. Scime's research activities include: the development of novel techniques for imaging low energy neutrals from space and laboratory plasmas, space plasma instrument design, the development of algorithms to correct for spacecraft charging effects on the Ulysses spacecraft, and studies of radial evolution of the solar wind electron heat flux. At West Virginia University he has constructed the world's largest steady-state, high beta laboratory plasma source and has begun experimental investigations of high beta, electron and ion, plasma instabilities under space-relevant conditions. He is the author or co-author of over 49 scientific publications.

RECENT REFEREED PUBLICATIONS

Keiter, A., E. E. Scime and M. Balkey, 'Frequency Dependent Effects in Helicon Plasmas,' *Phys. Plasmas*, in press (1997).

Pierre F., J. Solomon, N. Cornilleau-Wehrlin, P. Canu, E. E. Scime, A. Balogh, and R.J. Forsyth, 'Oblique Emission of Whistler-Mode Waves Around Interplanetary Shocks,' *Solar Physics*, in press (1997).

Lin, N., P.J. Kellogg, R.J. MacDowall, E.E. Scime, J.L. Phillips, A. Balogh, and R.J. Forsyth, 'Low frequency plasma waves in the solar wind: From ecliptic plane to the solar polar region,' *Advances in Space Research,* in press (1997).

Scime, Earl, 'How to Really Measure Electron Distributions in Space,' *AGU Monograph - Measurement Techniques for Space Plasmas*, Santa Fe, NM, in press (1997).

McComas, D.J., H.O. Funsten, and E.E. Scime, 'Advances in Low Energy Neutral Atom Imaging,' *AGU Monograph - Measurement Techniques for Space Plasmas*, Santa Fe, NM, in press (1997).

Scime Earl, and Paul Keiter, 'A Mass Resolving Neutral Atom Imager,' *Rev. Sci. Instrum.,* **68**, 292 (1997).

Funsten, H.O., D.J. McComas, and E.E. Scime, 'Precision Energy-Mass Spectrometer for Ions and Neutrals,' *Rev. Sci. Instrum.*, **68**, 296 (1997).

Pierre F., J. Solomon, N. Cornilleau-Wehrlin, P. Canu, E. E. Scime, J.L. Phillips, A. Balogh, and R.J. Forsyth, 'Whistler-mode Waves in the Solar Wind,' Proceedings of the Eighth International Solar Wind Conference (AIP Press, New York), 389 (1996).

Scime, Earl E., S. Peter Gary, Jacques Solomon, and Nicole Cornilleau-Wehrlin, 'Electron Energy Balance in the Solar Wind,' Proceedings of the Eighth International Solar Wind Conference (AIP Press, New York), 211 (1996).

Phillips, J. L., S. J. Bame, W. C. Feldman, B.E. Goldstein, J.T. Gosling, C.M. Hammond, D.J. McComas, M. Neugebauer, E.E. Scime, S.T. Suess, 'Ulysses Solar Wind Plasma Observations at High Southerly Latitudes,' *Science,* **268**, 1030 (1995).

Funsten, H.O., D. J. McComas, K. R. Moore, E. E. Scime, 'Low Energy Neutral Atom Imaging Techniques for Remote Observations of the Magnetosphere,' *J. Spacecraft and Rockets*, **32**, 899 (1995).

Pierre, F., J. Solomon, N. Cornilleau-Wehrlin, P. Canu, E. E. Scime, J.L. Phillips, A. Balogh, and R.J. Forsyth, 'Whistler-mode Wave Generation around Interplanetary Shocks In and Out of the Ecliptic Plane,' *Geophys. Res. Lett.*, **22**, 3425 (1995).

Moldwin, M. B., J. L. Phillips, J. T. Gosling, E. E. Scime, D. J. McComas, S. J. Bame, A. Balogh, and R. Forsyth, 'Ulysses observation of a non-coronal mass ejection flux rope: Evidence of interplanetary magnetic reconnection,' *J. Geophys. Res.*, **100**, 19,903 (1995).

Scime, Earl E., Erik H. Anderson, David J. McComas, and Mark L. Schattenburg, 'Extreme Ultraviolet Polarization and Filtering with Gold Transmission Gratings,' *Applied Optics*, **34**, 648 (1995).

Phillips, J. L., W. C. Feldman, J. T. Gosling and E. E. Scime, 'Solar Wind Plasma Electron Parameters Based on Aligned Observations by ISEE-3 and Ulysses,' *Advances in Space Research,* **16**, 95 (1995).

Scime, Earl E., Herbert O. Funsten, and David J. McComas, 'Three dimensional neutral atom imaging of tokamak plasmas,' *Rev. Sci. Instrum.*, **66**, 336 (1995).

Scime, Earl E., Andre Balogh, Samuel J. Bame, and John L. Phillips, 'Latitudinal Variations in the Solar Wind Electron Heat Flux,' *Space Sci. Rev.*, **72**, 105 (1995).

Phillips, J. L., S. J. Bame, S. P. Gary, J. T. Gosling E. E. Scime, 'Radial and Meridional Trends in Solar Wind Thermal Electron Temperature and Anisotropy,' *Space Sci. Rev.*, **72**, 109 (1995).

Riley, P., C. P. Sonnett, A. Balogh, R. J. Forsyth, E. E. Scime, W. C. Feldman, 'Alfvenic fluctuations in the solar wind: A case study using Ulysses measurements,' *Space Sci. Rev.*, **72**, 197 (1995).

Solomon, J., N. Cornilleau-Wehrlin, D. Lengyel-Frey, S. J. Bame, and E. E. Scime, 'Interaction Between Whistler-Mode Waves and Electrons in the Vicinity of Interplanetary Shocks as Seen by Ulysses: A Preliminary Study,' *Space Sci. Rev.*, **72**, 181 (1995).

Gary, S. Peter, Earl E. Scime, John L. Phillips, and William C. Feldman, 'The Whistler Heat Flux Instability: Threshold Conditions in the Solar Wind,' *J. Geophys. Res.*, **99**, 23,391 (1994).

Scime, Earl E., S. Peter Gary, John L. Phillips, Andre Balogh, Samuel J. Bame, and William C. Feldman, 'Regulation of the Solar Wind Heat Flux from 1 to 5 AU: Ulysses Observations,' *J. Geophys. Res.*, **99**, 23,401 (1994).

Gosling, J. T., S. J. Bame, D. J. McComas, J. L. Phillips, E. E. Scime, V. J. Pizzo, B. E. Goldstein, and A. Balogh, 'A Forward-Reverse Shock Pair in the Solar Wind Driven by Over-Expansion of a Coronal Mass Ejection: Ulysses Observations,' *Geophys. Res. Lett.*, **21**, 237 (1994).

Scime, Earl E., John L. Phillips and Samuel J. Bame, 'Effects of Spacecraft Potential on Three-Dimensional Electron Measurements in the Solar Wind,' *J. Geophys. Res.*, **99,** 14769 (1994).

Scime, Earl E., Herbert O. Funsten, Michael Gruntman, David J. McComas, 'A Novel Low Energy Neutral Atom Imaging Technique,' *Opt. Eng.*, **33**, 357 (1994).

Moore, Kurt R., Earl E. Scime, Herbert O. Funsten, David J. McComas, Michelle F. Thomsen, 'Low Energy Neutral Atom Emission from the Earth's Magnetosphere,' *Opt. Eng.*, **33**, 342 (1994).

McComas, D. J., H. O. Funsten, J. T. Gosling, K. R. Moore, E. E. Scime, and M. F. Thomsen, 'Fundamentals of low energy neutral atom imaging', *Opt. Eng.*, **33**, 335 (1994).

Funsten, Herbert O., David J. McComas, Earl E. Scime, 'Comparative Study of Low Energy Neutral Atom Imaging Techniques,' *Opt. Eng.*, **33**, 349 (1994).

Moldwin, Mark B., Earl E. Scime, Samuel J. Bame, John T. Gosling, and John L. Phillips, 'Electron Plasma Signatures of Magnetic Connection to the Jovian Bow Shock: Ulysses Observations,' *Planetary and Space Science*, **41**, 795 (1993).

Hokin, Samuel, A. Almagri, M. Cekic, B. Chapman, N. Crocker, D. J. Den Hartog, G. Fiksel, J. Henry, H. Ji, S. Prager, J. Sarff, E. Scime, W. Shen, M. Stoneking, and C. Watts, 'Reversed Field Pinch Studies in the Madison Symmetric Torus,' *J. of Fusion Energy* **12**, 281 (1993).

Funsten, Herbert O., D. J. McComas, K. R. Moore and E. E. Scime, 'Imaging of Magnetospheric Dynamics Using Low Energy Neutral Atom Detection,' in *AGU Monograph - Solar System Plasma Physics: Resolution of Processes in Space and Time*, Yosemite, CA, (1993).

RUTH M. SKOUG

Dr. Ruth Skoug is a technical staff member in the Space and Atmospheric Sciences group at Los Alamos National Laboratory. She received a B.A. in physics and mathematics from St. Olaf College in 1989, and an M.S. in physics in 1991 and a Ph.D. in physics in 1995 from the University of Washington. Her graduate work was supported by a NASA Graduate Student Researchers Program fellowship. From 1995–1997, she was a postdoctoral research associate at the University of Washington. She has participated in two sounding rocket projects, and developed and built a search coil antenna to detect very-low-frequency waves from a sounding rocket platform. Dr. Skoug was Project Scientist for a 1997 NASA sounding rocket experiment to study pulsating auroras, and was responsible for managing the design, development, and launch of the payload complement of energetic particle and wave detectors. From 1993–1997, she was involved with the Washington NASA Space Grant program, serving as a mentor and supervisor for undergraduate research students. She has also participated in the analysis of election and ion data from the 3DP instrument on the WIND spacecraft.

Publications:

S. Datta, R.M. Skoug, M.P. McCarthy, G.K. Parks, Modeling of microburst electron precipitation using pitch-angle diffusion theory, *J. Geophys. Res.*, **102,** 17325, 1997.

G.K. Parks, R.M. Skoug, S.L. Spencer, M.P. McCarthy, R.P. Lin, D. Larson, J. McFadden, H. Reme, T. R. Sanderson, Ion beams observed in the near Earth plasma sheet region on May 10, 1996, *Geophys. Res. Lett.*, **24**, 975, 1997.

R.M. Winglee, R.M. Skoug, R.K. Elsen, M. Wilber, R.P. Lin, R.L. Lepping, T. Mukai, S. Kokubun, H. Reme, T. Sanderson, IMF induced changes to the nightside magnetotail: A comparison between WIND/GEOTAIL/IMP 8 observations and modeling, *Geophys. Res. Lett.*, **24**, 947, 1997.

A.A. Reinard, R.M. Skoug, S. Datta, G.K. Parks, Energy spectral characteristics of auroral electron microburst precipitation, *Geophys. Res. Lett.*, **24**, 611, 1997.

R.M. Skoug, S. Datta, M.P. McCarthy, G.K. Parks, A cyclotron resonance model of VLF chorus emissions detected during electron microburst precipitation, *J. Geophys. Res.*, **101**, 21481, 1996.

S. Datta, R.M. Skoug, M.P. McCarthy, G.K. Parks, Analysis and modeling of microburst electron precipitation, *Geophys. Res. Lett.*, **23**, 1729, 1996.

R.M. Winglee, R.M. Skoug, M.P. McCarthy, G.K. Parks, R.P. Lin, K.A. Anderson, C. Carlson, R. Ergun, D. Larson, J. McFadden, R.P. Lepping, A. Szabo, H. Reme, J. Bosqued, C. d'Uston, T.R. Sanderson, K.-P. Wenzel, Modeling of upstream energetic particle events observed by WIND, *Geophys. Res. Lett.*, **23**, 1227, 1996.

R.M. Skoug, R.M. Winglee, M.P. McCarthy, G.K. Parks, R.P. Lin, K.A. Anderson, C. Carlson, R. Ergun, D. Larson, J. McFadden, H. Reme, J. Bosqued, C. d'Uston, T.R. Sanderson, K.-P. Wenzel, R.P. Lepping, A. Szabo, Upstream and magnetosheath energetic ions with energies to 2 MeV, *Geophys. Res. Lett.*, **23**, 1223, 1996.

T.R. Sanderson, J.P.G. Henrion, K.-P. Wenzel, R.P. Lin, K.A. Anderson, S. Ashford, C. Carlson, D. Curtis, R. Ergun, D. Larson, J. McFadden, H. Reme, J. Bosqued, J. Coutlier, F. Cotin, N. Lormant, C. d'Uston, G.K. Parks, M.P. McCarthy, R.M. Skoug, R.M. Winglee, WIND observations of energetic ions far upstream of the Earth's bow shock, *Geophys. Res. Lett.*, **23**, 1215, 1996.

WILLIAM L. SPURGEON
Electronic Technician VI
Los Alamos National Laboratory
Space and Atmospheric Physics Group

B.S., Electrical Engineering, University of New Mexico, 1989

William (Bill) Spurgeon has worked at Los Alamos for approximately 17 years, and is currently an electrical engineer in the Space and Atmospheric Physics Group. In this position, he held a lead design role in the development of the LENA Prototype instrument, which was launched in mid-1997, and is currently in orbit and collecting data. He developed this neutral atom imager together with the Aerospace Corporation and the Southwest Research Institute.

Bill is also the lead electrical engineer for the LANL portion of the MENA imager for the IMAGE spacecraft. He is responsible for MENA testing and calibration activities performed at LANL.

Bill has also worked on numerous other ground-based and space-based instruments. He established two ground-based transmitter stations, one in Kauai and one in Los Alamos, for the BLACKBEARD project (a subsystem of the ALEXIS satellite), and worked with a team of scientists to re-establish contact with the satellite after it suffered a catastrophic failure on launch.

Previously, Bill worked in the Geothermal Research and Hydrodynamics Test groups at Los Alamos, designing, operating, and maintaining a wide variety of laboratory test equipment, including high speed data acquisition systems, high vacuum control systems, power supplies, and equipment interfaces.

Bill began his electronics career in the military as an Electronics Warfare Technician. His duties included the repair, maintenance, and operation of passive and active electronic surveillance equipment, including narrow-band receivers and associated directional finding antennas.

STEVEN A. STORMS

Steven Storms is an Aerospace Engineer with Comforce Technical Services Inc. working under contract with Los Alamos National Laboratory's Space and Atmospheric Sciences group. He received a B.S. in Mechanical Engineering from New Mexico State University in 1989, and a M.S. in Aerospace Engineering from the University of Colorado in 1992.

Prior to attending the University of Colorado he worked as a Mechanical Engineer at EMI Technologies Inc. While at EMI he designed instrumented vans and trailers, including the complete structural design for an over-sized/over-weight seven axle instrumented trailer for the Army's Pulsed LASER Vulnerability Test System.

From 1992-1995 he was a Research Associate in the Department of Aerospace Engineering at the University of Colorado, studying unsteady atmospheric mountain flows and the hazards they pose to aircraft. He also developed laboratory teaching modules for the College of Engineering's Integrated Teaching Laboratory.

From 1995-1997 he was a Staff Research Assistant with Los Alamos National Laboratory's Space and Atmospheric Sciences group. In this position he functioned as the mechanical engineer, designer, and draftsman for three instruments flown on NASA's Lunar Prospector mission: the Neutron Spectrometer, the Alpha Particle Spectrometer, and the Gamma-Ray Spectrometer. He also helped develop the Low Energy Neutral Atom (LENA) imager prototype which has successfully flown.

In 1997 he became a contract engineer at Los Alamos. Mr. Storms is currently working on the Neutron Spectrometer for MARS 2001 Surveyor, the Medium Energy Neutral Atom (MENA) imager for IMAGE, the Time-of-Flight module in the Plasma Experiment for Planetary Environments (PEPE) for New Millennium DS-1, and the Solar Wind Concentrator for Genesis.

SCOTT E. WEIDNER
Senior Research Engineer
Department of Space Sciences
Instrumentation and Space Research Division

B.S. in Computer and Electrical Engineering, University of Michigan, 1982
M.S. in Electrical Engineering, Purdue University, 1991

As a senior research engineer at Southwest Research Institute, Mr. Weidner has been responsible for designing electronic systems for a wide variety of instrumentation projects. He has designed, delivered, and supported field inservice inspection (ISI) equipment around the world. Mr. Weidner designed the digital circuitry for the AUG-EDAS™ channel card which integrates an analog ultrasonic instrument with 50-Mhz digital processing and control circuits on a VME bus card. He also designed the 50-Mhz wave term average card which averages ultrasonic signals in real time using ECL logic, yielding an increased signal-to-noise ratio.

Previously Mr. Weidner served as an engineer at the McDonnell Douglas Corporation in St. Louis, where he managed projects and designed systems to inspect aircraft components. He led a research and development team to develop a robotic infrared inspection system to evaluate titanium diffusion bonded structures.

He also engineered subsystems for the following programs: AUS V, a nine-axis ultrasonic inspection system to rapidly inspect large composite wing skins on the factory floor; MAUS, a portable ultrasonic system to inspect composite aircraft structures in service; and ADIS, a general-purpose ultrasonic data acquisition system.

Mr. Weidner currently serves as the lead Electrical Engineer in the development of the Medium Energy Neutral Atom (MENA) imager, being developed at Southwest Research Institute for flight on NASA's Imager from Magnetopause to Aurora for Global Exploration (IMAGE) mission. He has primary responsibility for development of the Front End Electronics, Data Processing Unit, and Instrument Controller for the MENA imager. Mr. Weidner also serves as the lead Electrical Engineer for development of the electronics systems for the Thermal Electron Capped Hemisphere Spectrometer (TECHS) and the Thermal Ion Capped Hemisphere Spectrometer (TICHS) being developed at Southwest Research Institute for flight on NASA's Cleft Accelerated Plasma Experiment Rocket (CAPER) scheduled for launch aboard a BB XII sounding rocket from Andoya Norway in January, 1998.

PROFESSIONAL CHRONOLOGY: McDonnell Douglas Corporation, 1983-90 (engineer, 1983-85; senior engineer, 1985-88; lead engineer, 1988-90); Southwest Research Institute (senior research engineer, Nondestructive Evaluation Science and Technology Division, 1992-96; Instrumentation and Space Research Division, senior research engineer, 1996-present).

APPENDIX 2. LETTERS OF ENDORSEMENT

NATIONAL RECONNAISSANCE OFFICE
14675 Lee Road
Chantilly, VA 20151-1715

6 June 97

Dr. David J. McComas
Space and Atmospheric Sciences Group, NIS-1
MS D466 Los Alamos National Laboratory
Los Alamos, NM 87545

Dear Dr. McComas:

I enthusiastically support your Mission of Opportunity proposal to NASA (TWINS) that involves flying a secondary space science payload aboard our new satellites.

As you know, we are currently flying science payloads supplied by one of your proposal Co-Investigators, Dr. J. B. Blake of The Aerospace Corporation, and by you at Los Alamos. My interest in current and future space science payloads is in their applications to improving space weather capabilities, for spacecraft anomaly resolution, and for better definition of the space environment.

I have funded our contractor to do an integration feasibility study. Although integration will begin in 2001, the definition process must begin this year.

I look forward to this joint endeavor.

JOHN D. CUNNINGHAM, Colonel, USAF
System Program Director for Multiple Classified Programs

Los Alamos
NATIONAL LABORATORY

Space & Atmospheric Sciences Group, Mail Stop D466
Los Alamos, New Mexico 87545
(505) 667-3807/ FAX (505) 665-3332
e-mail: pgary@lanl.gov
Web site: http://nis-www.lanl.gov/~pgary/

Date: June 10, 1997
Refer to: NIS-1:97-240

Small Explorer 1997 Support Office
Jorge Scientific Corporation
400 Virginia Avenue SW, Suite 700
Washington, DC 20024

SUBJECT: Los Alamos Proposal R-1906-97-0, "TWINS: Two Wide-Angle Imaging Neutral Atom Spectrometers"

Ladies and Gentlemen,

The subject proposal has been approved by appropriate Los Alamos National Laboratory officials. This letter certifies that, if NASA provides sufficient funding, Laboratory personnel will carry out the proposed work with the full support and sponsorship of the Laboratory. This letter also certifies that the Laboratory provides full concurrence to the management and financial parts of this proposal.

Los Alamos National Laboratory is a Federally Funded Research and Development Center (FFRDC) and, as such, is exempt from providing certifications regarding Drug Free Workplace, Debarment and Suspension, and Lobbying.

Sincerely,

S. Peter Gary

S. Peter Gary
Laboratory Coordinator for NASA Programs

SPG:ko

Cy: File

THE AEROSPACE CORPORATION

2 June 1997

Dr. David J. McComas
Space and Atmospheric Sciences Group, NIS-1
MS D466 Los Alamos National Laboratory
Los Alamos, NM 87545

Dear Dr. McComas:

The Aerospace Corporation enthusiastically endorses participation in the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) Mission of Opportunity. We look forward to taking part in this exciting scientific investigation. This letter certifies that, if the project is selected and funded by NASA, Aerospace is committed to carry out the work assigned to Aerospace as described in this Proposal according the stated budget and schedule.

Sincerely,

Dr. A. B. Christensen
Principal Director
The Space and Environment Technology Center
The Aerospace Corporation

rporate Offices: 2350 East El Segundo Blvd., El Segundo, CA 90245-4691/Mail: P. O. Box 92957, Los Angeles, CA 90009-2957/Phone: (310) 336-5000

The Johns Hopkins University

Applied Physics Laboratory

Please refer to:
AC-23684

June 12, 1997

NASA Space Physics Program Office
AO-97-OSS-03, Suite 810
400 Virginia Avenue, SW
Washington, DC 20024

Attention: Dr. George L. Withbroe, Office of Space Science

Subject: Proposal in Response to AO-97-OSS-03, "TWINS"

Reference: "Announcement of Opportunity – Small Explorer Program and Missions of Opportunity (SMEX)," NASA AO 97-OSS-03, dated April 14, 1997

Enclosure: (1) JHU/APL Cost
(2) Statement of Work

Dear Dr. Withbroe:

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is pleased to provide the enclosed grant proposal to support the efforts of Drs. E. C. Roelof and D. G. Mitchell as Co-Investigators in the data analysis, modeling, and science planning efforts associated with the TWINS program, Dr. David J. McComas of Los Alamos National Laboratories, Principal Investigator. The total cost of this proposal for the period October 1, 1997 to September 30, 2004 is $474,043.

This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed, in whole or in part, for any purpose other than to evaluate this proposal. If, however, a contract is awarded to JHU/APL as a result of, or in connection with, the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the resulting grant. This restriction does not limit the Government's right to use information contained in this data if it is obtained from another source without restriction.

JHU/APL's budget for the participation of Dr. E. C. Roelof and Dr. D. G. Mitchell in the TWINS mission is included. If additional technical information is required, please contact Dr. Donald G. Mitchell, at (301) 953-5981. Questions regarding financial information may be addressed to Mr. Barry R. Handloff at (301) 953-6156.

Very truly yours,

S. M. Krimigis

S. M. Krimigis
Head, Space Department

G. L. Smith
Director

GLS/SMK/CIM/DGM

Astronomische Institute
der Universität Bonn
Auf dem Hügel 71
D 53121 Bonn
Fax +49 228 733672

Astronomische Institute der Universität Bonn

Dr. David J. McComas
Space and Atmospheric Sciences Group, NIS-1
D466, Los Alamos National Laboratory
Los Alamos, NM 87545
USA

98-03-06

Re: TWINS endorsement

Dear Dr. McComas:

TWINS-Lyman-Alpha, the subproject of developing, qualifying and supporting Lyman-alpha-detectors for the upcoming TWINS Small Explorer Mission has been studied and approved by Dr. Max Roemer, chairman, joint directorate of Bonn University Astronomical Institutes.

This letter certifies that we will carry out the proposed work with the full support and sponsorship of the Institut für Astrophysik und Extraterrestrische Forschung, Astronomische Institute and Rheinische-Friedrich-Wilhelms-Universität Bonn.

We look forward to participating in the TWINS project with you.

Sincerely

Dr. Hans J. Fahr
Professor of Astrophysics
Co-Investigator

Dr. Max Roemer
Professor of Astrophysics and Space Science
chairman, joint directorate

SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846

INSTRUMENTATION AND SPACE RESEARCH DIVISION • FAX: (210) 520-9935

June 4, 1997

Dr. David J. McComas
Space and Atmospheric Sciences Group, NIS-1
MS D466, Los Alamos National Laboratory
Los Alamos, NM 87545

Dear Dr. McComas,

The attached proposal has been approved by the appropriate Southwest Research Institute officials. This letter certifies that, if the project is selected and corresponding funding is provided, we will carry out the proposed work with the full support and sponsorship of Southwest Research Institute. This letter also Certifies that Southwest Research Institute is in full concurrence to the management and financial plans of this proposal.

We look forward to participating in the project if it is selected.

Sincerely,

Craig J. Pollock
Co-Investigator

J. L. Burch
Co-Investigator

J. L. Burch, Vice President
Instrumentation and Space Research Division

:ew

USC
UNIVERSITY
OF SOUTHERN
CALIFORNIA

May 23, 1997

Dr. David J. McComas
Space and Atmospheric Sciences Group, NIS-1,D466
Los Alamos National Laboratory
Los Alamos, NM 87545

Department of
Contracts and Grants

Subject:	Subcontract Proposal in Response to NASA AO-97-OSS-03
	Entitled: *Two Wide-Angle Imaging Neutral Atom Spectrometers (TWINS)*
	Principal Investigator: Michael Gruntman
	Total Amount Requested (Years 1 and 2): $48,524.00
	Total Project Period: 10/01/97 - 09/30/07
	Number of Copies: Original

The subject proposal has been approved by the appropriate University of Southern California (USC) officials. This letter certifies that, if the project is selected and corresponding funding is provided, we will carry out the proposed work with the full support and sponsorship of USC. This letter also certifies that USC is in full concurrence to the management and financial plans of this proposal.

We look forward to participating in the project if it is selected.

Should you have any questions of a technical nature regarding this proposal, please contact the Principal Investigator. Information of a business or administrative nature should be directed to my attention at the address below or by e-mail at dsteele@bcf.usc.edu.

Sincerely,

Dorothy A. Steele
Contract and Grant Administrator

Co-Principal Investigator :

Michael Gruntman
Associate Professor

Approved on behalf of the University:

Lloyd Armstrong, Jr., Provost and Senior
Vice President, Academic Affairs

cc: Principal Investigator
Stacy Esposito, USC School of Engineering

University of
Southern California
Los Angeles,
California 90089-1147
Tel 213 740 7762
Fax 213 740 6070
Web page
http://www.usc.edu/
dept/contracts/

Department of Physics
West Virginia University
Eberly College of Arts and Sciences

June 4, 1997

Dr. David J. McComas
Space and Atmospheric Sciences Group
'NIS-1
MS D466
Los Alamos National Laboratory
Los Alamos, NM 87545

Dear Dr. McComas:

This letter certifies that, if the project is selected and corresponding funding is provided, we will carry out our portion the proposed work, the space plasma physics group at West Virginia University is in full concurrence to the management and financial plans of this proposal.

We look forward to participating in the project as a co-investigator if it is selected.

Sincerely,

Earl Scime
Assistant Professor of Physics
West Virginia University
Morgantown, WV 26506

APPENDIX 3. MISSION DEFINITION AND REQUIREMENTS AGREEMENT

Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS)

Program Requirements Document

INTRODUCTION

This document identifies the mission, science and programmatic (funding and schedule) requirements imposed on the Explorer Program Lead Development Center (GSFC) and the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) Principal Investigator for the development and operation of the TWINS investigation.

This document also serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

The TWINS Principal Investigator (P.I.) has the overall responsibility for meeting the mission, science, cost and schedule requirements contained in this document. Additionally, the P.I. will be responsible for all hardware development, mission planning, mission operations, and data analysis tasks and will coordinate the work of all TWINS Co-investigators. The P.I. is also responsible for implementing the TWINS project using the set of approved Co-investigators reflected in the proposal including any approved changes.

Changes to information and requirements contained in this document require approval by the TWINS P.I., the Associated Administrator, Office Of Space Science (AA, OSS), NASA Headquarters, and the Mission Sponsor, SAF/ST. This document will be reviewed periodically and updated as needed. In case of a dispute which cannot be resolved among the signatories, higher level management from each organization will meet to resolve the difference.

PROGRAM REQUIREMENTS

1. Provide stereo neutral atom imaging of the magnetosphere.

2. Address the fundamental questions relative to the science objectives outlined in the proposal. These objectives address, on the time scale of substorms and storms, the global connectivities and causal relationships between processes in different regions of the magnetosphere, including the structure and evolution of the magnetosphere and the sources, energization, transport, and sinks of magnetospheric plasma populations.

3. Develop a Neutral Atom Imager to obtain neutral atom composition and energy resolved images meeting the following critical measurement requirements:

FOV:	90° x 90° (image ring current at apogee).
Energy Range:	1–50 keV (H)
Composition:	Measure H, He, and O with some discrimination
Image Time:	5 minutes (resolve substorm development).

Angular and Energy Resolution: shall be sufficient to resolve the development of storms and substorms and shall be appropriate for the neutral atom energy and species being measured.

4. Assure no less than a minimum science mission by adhering to the following instrument constraints:

• TWINS shall require the Neutral Atom Imagers on both spacecraft to function properly and meet all critical measurement requirements.

5. Scope reductions that may be required to maintain the program cost and schedule constraints (Program Requirements 8 & 9) shall be limited to the "Scope Reduction Plan" approved as an integral part of the NASA Headquarters, Office of Space Science (OSS) Confirmation Review.

• Significant changes in capability must be justified by the P.I. and concurred in by GSFC and NASA Headquarters even if the proposed change results in a mission above the minimum success level.

6. Develop TWINS instrumentation that meets the critical measurement requirements and provides a reliable two-year stereo imaging mission. This includes the development of a TWINS science data handling program for acquisition, processing, and distribution of TWINS data in accord with an open data policy.

7. Develop and execute an aggressive public outreach and education program consistent with information provided as a part of the NASA Headquarters, Office of Space Science (OSS) Confirmation Review.

8. The TWINS instruments shall be launched on two Mission of Opportunity spacecraft. Delivery of the TWINS instruments to the two spacecraft shall occur in approximately mid-2001 and mid-2003. Each spacecraft shall be launched into a Molniya orbit of approximately 500 km perigee by 7.2 Earth radii apogee.

9. TWINS funding to the P.I. and Co-I. institutions is capped at a cost of $10.1 M (FY97$) for all Phase B/C/D activities, excluding the launch vehicle integration costs and project management oversight. Integration costs of $1.5 M (FY97$) to cover the cost of integrating the TWINS instruments to the launch vehicle will be transferred directly from NASA to the mission sponsor. Mission Operations and Data Analysis (MO&DA, Phase E) activities are capped at $5.3 M (FY97$).

_______________________ Date:______

Dr. George L. Withbroe
Science Program Director
Sun-Earth Connection
NASA Headquarters

_______________________ Date:______

K. W. Ledbetter, Director
Mission and Payload Development
NASA Headquarters

_______________________ Date:______

Dr. David J. McComas
TWINS Principal Investigator
Los Alamos National Laboratory

_______________________ Date:______

James S. Barrowman
Explorers Project Manager
Goddard Space Flight Center

_______________________ Date:______

Colonel John D. Cunningham
System Program Director for Multiple
Classified Programs
SAF/ST

APPENDIX 4. STATEMENTS OF WORK

The Space Physics Team at the Los Alamos National Laboratory, in collaboration with five other institutions, proposes to design, develop, deploy, and operate two neutral atom imaging instruments for the purpose of collecting and analyzing data to conduct a scientific investigation of the earth's magnetosphere. This, the TWINS project, will provide the first stereo investigation of the magnetosphere, contributing new insight into its make-up and processes.

With the study and preliminary design phases occurring in FY1998, and development phases in FY1999-2002, the project will launch the first instrument aboard a non-NASA U.S. government opportunity mission in FY2002. This instrument will have a minimum lifetime of four years. The second instrument will follow on a sister mission in FY2004 with a nominal lifetime of two years, thereby providing a stereo investigation during the second half of FY2004, all of FY2005 and the first half of FY2006.

LANL will have overall responsibility for the TWINS project. This includes the coordination of: project management and administrative support, reliability, quality assurance, and safety activities, science support, systems support (including reviews and interface definition), overall design and mission planning, system integration, testing and calibration, and data analysis system design and planning, In addition, specific LANL hardware tasks include development of the sensor housing, collimators, re-closable door assembly, gratings, start foil assembly, actuators, and geocoronal imager, and sub-system integration.

The effort will include collaboration of five other development teams from the following institutions: the Aerospace Corporation, providing DPU and ground support test equipment development, and S/C system integration; the Southwest Research Institute, providing detector, high voltage power supply, and front end electronics development; and the Applied Physics Laboratory, the University of Southern California, and West Virginia University teams providing UV filtering, neutral atom imaging, and charged particle rejection expertise. All institutions will play a role in the data analysis and science portion of the investigation.

The instrument development effort will use the technologies presently being developed by SwRI, LANL, USC, and WVU for the MIDEX IMAGE/MENA instrument and the similar S/C systems coordination experience gleaned from the LANL/Aerospace Corp. collaboration on the LENA Prototype project.

TWINS PROJECT PHASE B STATEMENT OF WORK
April 1, 1998 - Sept. 30, 1998

LANL

LANL has overall responsibility for technical and administrative management oversight of the project, progress and cost reporting, and preparation for the Preliminary Design Review. During Phase B, LANL will work out the details of the LANL/NASA Phase C/D contract with NASA and take the lead in getting the various other contracts processed: NASA/Aerospace, Aerospace/SwRI, NASA/APL, Aerospace/WVU, and Aerospace/USC. The TWINS project QA plan will be finalized and a draft verification plan will be composed. The TWINS Level 1 Requirements document will be completed and signed by the appropriate NASA, TWINS, and Mission Sponsor personnel. In addition, LANL will be responsible for and chair weekly telecons, periodic team meetings and project reviews, and will lead education and outreach program activities.

At the sub-system level, LANL will refine the sensor head/front-end electronics package interface and modify the sensor head conceptual designs and drawings to reflect necessary changes. We will also perform mass and radiation shielding analysis to ensure that the instrument specs are within guidelines.

On the systems level, LANL will further refine the overall TWINS system development plan. This will include leading the development of the mechanical and electrical Interface Control Documents (ICD), and working with Aerospace in the development of a radiation shielding plan. Another task will be leading the effort in planning the Ly-α detector and actuator development. For Phase B, this involves setting up and testing the existing actuator (engineering model from the Cassini project is available) for EMI compatibility with the S/C, and refining the Ly-α design and interfaces. LANL will also take the lead in developing the purchase requests for the actuators and gratings and prepare the international agreement with the University of Bonn for acquiring the Ly-α detectors. In addition, LANL will coordinate and correlate material for the Phase C/D plan.

Aerospace

For Phase B, Aerospace will refine the preliminary design for the data processing unit (DPU) and flight firmware, firm up all S/C interfaces, and prepare for the Preliminary Design Review. Refining the DPU designs will involve completing trade studies on the actuator/DPU functional and interface issues, planning development of a DPU GSE and a S/C simulator, and performing preliminary thermal and structural analyses. They will also collaborate on the command and data format/processing plan and incorporate this into the DPU C&DH planning. Aerospace will develop, in conjunction with LANL, a plan for radiation shielding.

Aerospace has overall responsibility for interfacing with the mission sponsor and Host contractor. As part of its responsibility, Aerospace will develop three project documents during Phase B: the TWINS/Host Interface Control Document (ICD); a draft Integration and Test Plan for Host integration; and a draft Concept of Operations (CONOPS) plan.

Aerospace will perform an analysis to determine the predicted exposure of the foil to atomic oxygen over the mission life. This information can be used with H. Funsten's analysis of foil degradation as a function of exposure time to determine whether a door or other protective mechanism is required.

Aerospace will also develop a detailed plan for Phase C/D, finalize its portion of the QA plan, and prepare the NASA/Aerospace contract. Aerospace, along with help from LANL, will also prepare the Aerospace/SwRI, Aerospace/USC, and Aerospace/WVU contracts. They will participate in science collaborations, education and outreach activities, team meetings, and reviews.

SwRI

For Phase B, the Southwest Research Institute will refine the preliminary design for the front-end electronics (FEE) and the detector. This will involve firming up all FEE/DPU, FEE/sensor head, and detector/sensor head interfaces. It will also involve structural and thermal analysis and radiation shielding input to the project system analysis effort. This information will be correlated and presented at the PDR. SwRI will collaborate in the C&DH and data format planning and incorporate this into the FEE.

SwRI will assist in preparation of the Aerospace/SwRI contract and develop a detailed plan for Phase C/D. SwRI will also finalize their portion of the QA plan, Interface Control Documents, and draft software, FEE, and GSE development functional verification plans. They will participate in science collaborations, education and outreach activities, team meetings, and reviews.

APL

APL will continue development of the image inversion model and software required for analysis of TWINS image data, and will provide this information to the TWINS science team and the TWINS web page. They will also participate in science collaborations, education and outreach activities, team meetings, and reviews, and will prepare the NASA/APL contract for Phase C/D.

USC

USC will collaborate in planning the development and testing of the Ly-α detector and the gold transmission gratings, and participate in science collaborations, education and outreach activities, team meetings, and reviews. They will assist in preparation of the Aerospace/USC Phase C/D contract.

WVU

WVU will collaborate in planning the development and testing of the gold transmission gratings. They will also participate in science collaborations, education and outreach activities, team meetings, and reviews. They will assist in preparation of the Aerospace/WVU Phase C/D contract.

PHASE B DELIVERABLES/MILESTONES

Item	To	From	Date Due
Actuator EMI test results	S/C	Aerospace/LANL	5/15/98
QA plans finalized	NASA	LANL/Aerospace/SWRI	7/15/98
Interface information	LANL	ALL	8/15/98
Radiation shielding analysis		LANL/Aerospace	8/15/98
Prelim. Thermal/struct. anal.	LANL	ALL	8/15/98
Interface control documents		LANL/Aerospace	9/1/98
Phase C/D contract info	NASA	ALL	9/1/98
Level 1 Req document	NASA	LANL	9/15/98
PDR material	NASA	LANL (ALL)	9/15/98
PDR			10/1/98

TWINS PROJECT PHASE C/D STATEMENT OF WORK
OCT 1, 1998 - APR 1, 2004

LANL

LANL will provide overall project oversight for the TWINS Project. This will involve (on a monthly basis) collating schedule, cost, technical, QA and safety information from project members, reviewing this material, and reporting to the Explorer Office. In addition, LANL will be responsible for and chair weekly telecons, periodic team meetings and project reviews. LANL will be responsible for leading education and outreach activities.

LANL will develop the sensor head flight models (FM) to project specifications. This will include the collimators, door assembly, sensor housing, gold transmission gratings, entrance foil/grid assembly, and the detector and the detector/FEE interface. This will involve purchasing, screening and integrating the gold transmission gratings into the sub-system and also involve receiving the detector from SwRI and integrating it into the sub-system. LANL will also be responsible for procuring the actuator platform.

LANL will provide systems management and engineering leadership, and support the integrated project. LANL will be responsible for the integration, functional testing, environmental testing, and calibration of the TWINS system consisting of the sensor heads (SH), front-end electronics (FEE). data processing unit (DPU), the actuator (ACT), and the Ly-α detectors (LYAD).

LANL will also be responsible for refurbishment of the sensor heads before launch, and re-integration and testing. LANL will be responsible for launch preparation support and launch+30 days instrument activation and tuning.

LANL will set up a data ground station and develop Level 1 and 2 data processing capabilities. LANL will develop web site tools for data distribution to team and outreach members. LANL will develop a system to archive the TWINS data. LANL will take the lead role in planing Phase E activities and placing the Phase E contract for the project and for LANL.

Aerospace

Aerospace will develop the DPU flight models (FM) to project specifications. This will include the development of an electrical test unit (GSE) and a S/C simulator. Aerospace is also responsible for all S/C interface and compatibility issues and will serve as liaison between the S/C contractor and the TWINS Team. Aerospace will support all team telecons, team meetings and reviews, and education and outreach activities.

Aerospace will oversee the integration of the TWINS system with the spacecraft and subsequent environmental testing. Aerospace will develop a command and data handling system for the TWINS project. Aerospace will develop a ground data link with the S/C telemetry agency and provide Level 0 processing of TWINS data. The Level 0 data will then be transferred to LANL for Level 1 and 2 processing. Aerospace will plan Phase E activities and prepare the NASA/Aerospace contract. Aerospace, along with help from LANL, will also prepare the Aerospace/SwRI, Aerospace/USC, and Aerospace/WVU contracts.

SwRI

SwRI will develop the FEE and detector flight models (FM) to project specifications. This will include the FEE (consisting of the high voltage power supplies and TOF and PHA electronics), the detectors and charge amplifiers, a GSE, and data processing software. This will involve purchasing, screening and integrating the micro-channel-plates (MCPs) into the detector sub-system.

SwRI will support all team telecons, team meetings and reviews, and education and outreach activities. SwRI will also plan Phase E activities and assist in preparation of the Phase E Aerospace/SwRI contract.

APL

APL will support the science and technical development process as needed. Specifically, APL will participate in the development of TWINS science and data processing tools, and will continue the development of image inversion models. APL will support team telecons, team meetings, reviews, and education and outreach activities. APL will also plan Phase E activities and prepare the NASA/APL Phase E contract.

USC

USC will support the science and technical development process as needed. Specifically, USC will support the development, testing, and characterization of the gold transmission gratings and the Ly-α detector. USC will support team telecons, team meetings, reviews, and education and outreach activities. USC will also will plan Phase E activities and assist in preparation of the Phase E Aerospace/USC contract.

WVU

WVU will support the science and technical development process as needed. Specifically, WVU will support the development, testing, and characterization of the gold transmission gratings. WVU will support team telecons, team meetings, review, and education and outreach activities. WVU will also will plan Phase E activities and assist in preparation of the Phase E Aerospace/WVU contract.

PHASE C/D DELIVERABLES AND MILESTONES

Item	To	From	Date Due
Critical Design Review			3/99
	(PM/FM#1 Development)		
PM Detector	LANL	SwRI	6/99
PM Development/testing completed	ALL		2/00
PM Subsystems (integration)	LANL	Aerospace/SwRI/Bonn	2/00
FM#1 Pre-Environmental Review	ALL		4/00
	(PM Environmental testing)		
	(Refurb PM into FM#1)		
FM#1 Subsystems (integration)	LANL	Aerospace/SwRI/Bonn	10/00
FM#1 Pre-Ship Review			1/01
FM#1 Delivery to S/C	S/C	Aerospace	8/01
FM#1 Flight Readiness Review			2/02
	(FM#2 Development)		
FM#2 Detector	LANL	SwRI	12/99
FM#2 Subsystems (integration)	LANL	Aerospace/SwRI/Bonn	10/00
FM#2 Pre-Environmental Review	ALL		4/01
	(FM#2 Environmental testing)		
FM#2 Pre-Ship Review	ALL		10/01
FM#2 Delivery to S/C	S/C	Aerospace	8/03
FM#2 Flight Readiness Review	ALL		2/04

TWINS PROJECT PHASE E STATEMENT OF WORK
APR. 1, 2002 - MAR. 31, 2007

LANL

LANL will have overall responsibility for the project as described in the Phase B and C/D SOWs. LANL will direct the mission operations, instrument operations, data processing, and data analysis tasks needed for Phase E, and will continue to lead the education and outreach program.

LANL will receive the Level 0 data from Aerospace, monitor the instrument state-of-health and perform de-convolution functions to develop a Level 1 processed data set (format to be defined in Phase C/D). The Level 1 format data will be disseminated to the TWINS science team. TWINS images and other derived quantities will be displayed on the TWINS website.

LANL will be responsible for integrating the stereo data once the second TWINS unit is operating. LANL will also be responsible for archiving the data and making data available to outreach team members.

Aerospace

Due to the nature of the primary mission and the relationship between Aerospace and the S/C sponsor, Aerospace will be the point of contact for the initial data. Aerospace will receive the data from the S/C agencies and perform Level 0 data processing. This consists of converting the data stream from S/C format into TWINS data transmission format (to be defined in Phase C/D), sorting out the instrument state-of-health data, time tagging the data, and incorporating spacecraft attitude information. At this point the data will be transmitted to LANL.

Aerospace will participate in data analysis and generation of scientific publications and other presentations, and will support the education and outreach activities.

SwRI, APL, USC, and WVU

During Phase E, the Co-Investigator institutions will participate in data analysis and generation of scientific publications and other presentations, and will continue to support the education and outreach activities.

PHASE E DELIVERABLES

Item	Agency	Date
Level 0 Data	Aerospace	Beginning 10 days after start of phase, and ongoing through Phase E
Level 1 Data	LANL	Beginning 30 days after start of phase, and ongoing through Phase E
Instrument Description	ALL	120 days into Phase E
Science products	ALL	ongoing
Science publications	ALL	ongoing

APPENDIX 5. INCENTIVE PLAN

The major team members are non-profit institutions, and therefore contract incentives in the normal sense are not applicable. However, as a suggestion to the Explorer Office, unused contingency at the end of Phase B/C/D could be used by team members to enhance outreach activities, upgrade data analysis equipment, or be used in other areas to further promote the project.

The ACE project, for example, offered excess Phase C/D funds to boost team member outreach programs. As a result, LANL was able to initiate a much more substantial outreach program than the nominal 2% of project budget would have allowed.

APPENDIX 6. RELEVANT EXPERIENCE AND PAST PERFORMANCE

6.1 Los Alamos National Laboratory

The Space Physics team at Los Alamos National Laboratory has extensive experience in the development of space instrumentation, and in particular is used to working on defense sponsored projects where schedule overruns are simply not permitted. In addition, LANL is a non-profit institution and therefore does not stand to gain from cost overruns. The motivation behind instrument development at LANL is science and reputation among peers in the science community and sponsors of space exploration projects. Cost overruns are considered one of the strongest factors in ruining a good performance reputation.

The LANL team has a great deal of experience in managing space hardware development projects. The instrument team has been developing satellite borne instruments since 1962 and has successfully deployed over 100 instruments for over 30 different NASA and DOE projects. Instruments developed within the last 10 years include Ulysses, ACE, Cassini, New Millennium DS-1, Lunar Prospector, Genesis, Mars 2001 and the forerunners of TWINS; the LENA-P and MENA projects. None of these projects have had any significant schedule or budget problems which affected delivery schedules or costs. These projects were all managed by the same personnel who are responsible for TWINS.

Ulysses and ACE are Solar Wind science missions for which LANL developed a pair of ion and electron mass spectrometers. These Ulysses instruments have been working for 7 1/2 years and the ACE instruments for six months. For Cassini, the LANL team collaborated with SwRI and other institutions on the development of a new instrument (patented by the LANL team), the linear electric field, 3-D ion mass spectrometer.

The LENA-P project is the first neutral atom imager in the world designed and developed for operation in space. It has been operating on the order of three months and is functioning as designed. The IMAGE MENA project is half-way through Phase C/D and is within schedule and cost predictions.

The Point of Contact for project management at LANL is:

Mr. Phil Barker
MS D466
Los Alamos National Laboratory
Los Alamos, NM 87545
Phone: 505-667-0057
Fax: 505-665-7395
email: pbarker@lanl.gov

6.2. The Aerospace Corporation

The Aerospace organization (SETC) has a long history of successfully carrying out space plasma physics research dating back to the early 1960s. Three particularly relevant efforts in the last ten years are:

1. SAMPEX

Aerospace had a Co-Investigator role on SAMPEX, the first of the small explorers, and were responsible for the DPU that services all experiments and built a significant part of one of the four instruments. The Aerospace hardware continues to function in a nominal manner after almost six years of continuous orbital operation the Web address for SAMPEX is http://lepsam.gsfc.nasa.gov/www/sampex.html.

2. POLAR

Aerospace is heavily involved in three of the eleven POLAR science investigations: Ceppad, Cammice, and Pixie. This involvement included a major hardware involvement in all three. Two years after the POLAR launch, all of the Aerospace hardware continues nominal performance and are returning excellent science. Two Web addresses of these investigations are: http://leadbelly.lanl.gov/ccr/CCR.html and http://pixie.space.lockheed.com/. In all cases, Aerospace met the agreed-upon schedule and cost.

3. HEO

Aerospace has been involved in several space science and engineering investigations with the TWINS-spacecraft host organization over the last decade. All Aerospace hardware has maintained nominal performance on-orbit, in some cases over several years, and met schedule and cost constraints. In this work the Aerospace team has been involved with many of the key people in the host organization for the TWINS mission.

The point of contact for these missions at Aerospace is:

Dr. J. B. Blake
Space Sciences Department
The Aerospace Corporation
PO Box 92957
Los Angeles, CA 90009
Phone: 310-336-7078
Fax: 310-336-1636
e-mail: blake@dirac2.span.nasa.gov

6.3 Southwest Research Institute

Southwest Research Institute has been developing, testing and successfully operating space related hardware for more than 20 years. Southwest Research Institute has been the key institution on many space missions. A few of these missions include the following: Dynamics Explorer, the Particle Environment Monitor on the Upper Atmosphere Research Satellite (UARS), The Thermal Ion Dynamics Experiment (TIDE) instrument on POLAR, the Cassini Plasma Spectrometer (CAPS) for the Cassini mission, the Medium Energy Neutral Atom Imager (MENA) for the IMAGE mission and the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) spacecraft and instrument compliment - the first MIDEX mission.

SwRI has considerable experience in the programmatic aspects of instrument development. Included in this experience are schedule development and maintenance, project costing, and WBS development. SwRI is currently managing the IMAGE MIDEX mission. As a part of the IMAGE project management SwRI is charged with the responsibility of managing 19 subcontractors with subcontract values totaling over 40 million dollars. To meet this responsibility SwRI has implemented a number of performance metrics, including a true earned value system, a comprehensive scheduling system, and a risk management system. Using Primavera Project Planner (P3), SwRI has developed a scheduling system employing a master schedule and 8 subproject schedules integrated into a master mission schedule from which SwRI can apply a set of performance metrics.

For IMAGE work performed in house, SwRI performs a true earned value analysis on the value of work performed every four weeks. The eV system provides the best early indicator of cost performance possible. SwRI will apply its experience and expertise in project management to the TWINS project. The same expertise currently used to manage the 82M$ pre-launch cost IMAGE project will be applied to TWINS.

The first step in the development of SwRI instrument cost estimates is the development of a detailed work breakdown structure (WBS). After the project is started, actual costs are entered into P3 for each WBS element for the current four week accounting period. With actual costs entered, P3 calculates the earned value of the work performed and reports the variance in the value of the work performed. With the magnitude of the cost variance known to the instrument manager. corrective action can be taken very early.

A comparable set of schedule performance metrics is used to determine the overall efficiency of the instrument development team. Again, schedule variances are measured every four weeks and corrective actions are taken as needed to maintain an on time delivery.

SwRI instrument management also includes a strong systems engineering component. In a well managed program such as TWINS, the science objectives are used to determine the instrumentation and measurement requirements. From these requirements, specifications are developed and, subsequently, verification procedures. The SwRI systems engineering process will be coordinated with LANL to form a complete TWINS systems engineering process. Other traditional systems engineering activities, such as resource allocations and interface management is also practiced by the SwRI systems engineering team. Close coordination between LANL engineers and SwRI engineers is a given in this project.

In summary, SwRI has the experience, expertise, tools, and commitment to successfully manage the SwRI portion of TWINS just as we have managed numerous other instrument development programs going back to the late 70's.

The point of contact for SwRI is:

Dr. Craig Pollock
Southwest Research Institute
6220 Culebra Rd
San Antonio, TX 78228
Phone: 210-522-3978
Fax: 210-520-9935
email: cpollock@swri.edu

APPENDIX 7. INTERNATIONAL AGREEMENTS

The foreign Co-Investigator agreement with the University of Bonn, Germany (under direction of Dr. Hans Fahr) for the development of the Ly-a detectors will be formalized by a letter of agreement to be developed during Phase B. The agreement will follow the format of the NASA Foreign Co-I Agreement documentation. The agreement will define the instruments and support which the University of Bonn will contribute to the mission and describe the Co-Investigator rights and privileges granted to Dr. Fahr in return.

The University of Bonn has generously agreed to provide the TWINS Ly-α instruments and associated instrument and science support at no charge to the project. At present, we are working together under an endorsement letter sent by Dr. Fahr guaranteeing the support of his institution. This letter is included as part of Appendix 2.

APPENDIX 8. REFERENCES

Funsten, H. O., and M. Shappirio, Sputtering of thin carbon foils by 20 keV and 40 keV Ar^+ bombardment, *Nucl. Instrm. and Meth. B*, **127**, 905, 1997.

Funsten, H. O., B. L. Barraclough, and D. J. McComas, Pinhole detection in thin foils used in space plasma diagnostic instrumentation, *Rev. Sci. Instrum.*, **63**, 4741, 1992a.

Funsten, H. O., D. J. McComas, and B. L. Barraclough, Thickness uniformity and pinhole density analysis of thin carbon foils using incident keV ions, *Nucl. Instrum. and Meth. B*, **66**, 470, 1992b.

Funsten, H. O., D. J. McComas, and B. L. Barraclough, Ultrathin foils used for low energy neutral atom imaging of the terrestrial magnetosphere, *Opt. Eng.*, **32**, 3090, 1993.

Funsten, H. O., D. J. McComas, and E. E. Scime, Low-energy neutral-atom imaging techniques for remote observations of the magnetosphere, *J. Spacecraft and Rockets*, **32**, 899, 1995.

Funsten, H. O., D. M. Suszcynsky, R. W. Harper, J. E. Nordholt, and B. L. Barraclough, Effect of local electric fields on microchannel plate detection of incident 20 keV protons, *Rev. Sci. Instrum.*, **67**, 145, 1996.

Funsten, H. O., D. J. McComas, and M. A. Gruntman, Neutral atom imaging: UV rejection techniques, in *AGU Monograph: Measurement Techniques for Space Plasmas*, Eds. J. Borovsky, R. Pfaff, and D. T. Young, *in press*, 1997.

Gruntman, M. A., Extreme-ultraviolet radiation filtering by freestanding transmission gratings, *Appl. Opt.*, **34**, 5732, 1995.

Gruntman, M. A., Transmission grating filtering of 52-140 nm radiation, *Appl. Opt.*, **36**, 2203, 1997.

Joselyn, J. A., J. B. Anderson, H. Coffey, K. Harvey, D. Hathaway, G. Heckman, E. Hildner, W. Mende, K. Schatten, R. Thompson, A. W. P. Thomson, and O. R. White, Panel achieves consensus prediction of Solar Cycle 23, *EOS, Trans. Amer. Geophys. Union*, **78**, 205, 1997.

McComas, D. J., B. L. Barraclough, R. C. Elphic, H. O. Funsten III, and M. F. Thomsen, Magnetospheric imaging with low-energy neutral atoms, *Proc. Natl. Acad. Sci. USA,* **88**, 9598, 1991.

McComas, D. J., H. O. Funsten, and E. E. Scime, Advances in low energy neutral atom imaging, in *AGU Monograph: Measurement Techniques for Space Plasmas,* Eds. J. Borovsky, R. Pfaff, and D. T. Young, *in press*, 1997.

Meier, R. R., Ultraviolet spectroscopy and remote sensing of the upper atmosphere, *Space Sci. Rev.*, **58**, 1, 1991.

Ngo, T., E. J. Snyder, W. M. Tong, R. S. Williams, and M. S. Anderson, O-atom etching of graphite in low Earth orbit, *Surf. Sci.*, **314**, L817, 1994.

Ogawa, H. S., D. R. McMullin, D. L. Judge, and R. Korde, Normal incidence spectrophotometer with high-density transmission grating technology and high-efficiency silicon photodiodes for absolute solar extreme-ultraviolet irradiance measurements, *Opt. Eng.*, **32**, 3121, 1993.

Ritzau, S. M., Ion induced electron emission from ultra thin carbon foils and nearly free electron metals, Ph.D. Dissertation, University of Virginia, May, 1997.

Schattenburg, M. L., R. J. Aucoin, R. C. Fleming, I. Plotnik, J. Porter, and H. I. Smith, Fabrication of high energy x-ray transmission gratings for AXAF, *Proc. SPIE*, **2280**, 181, 1994.

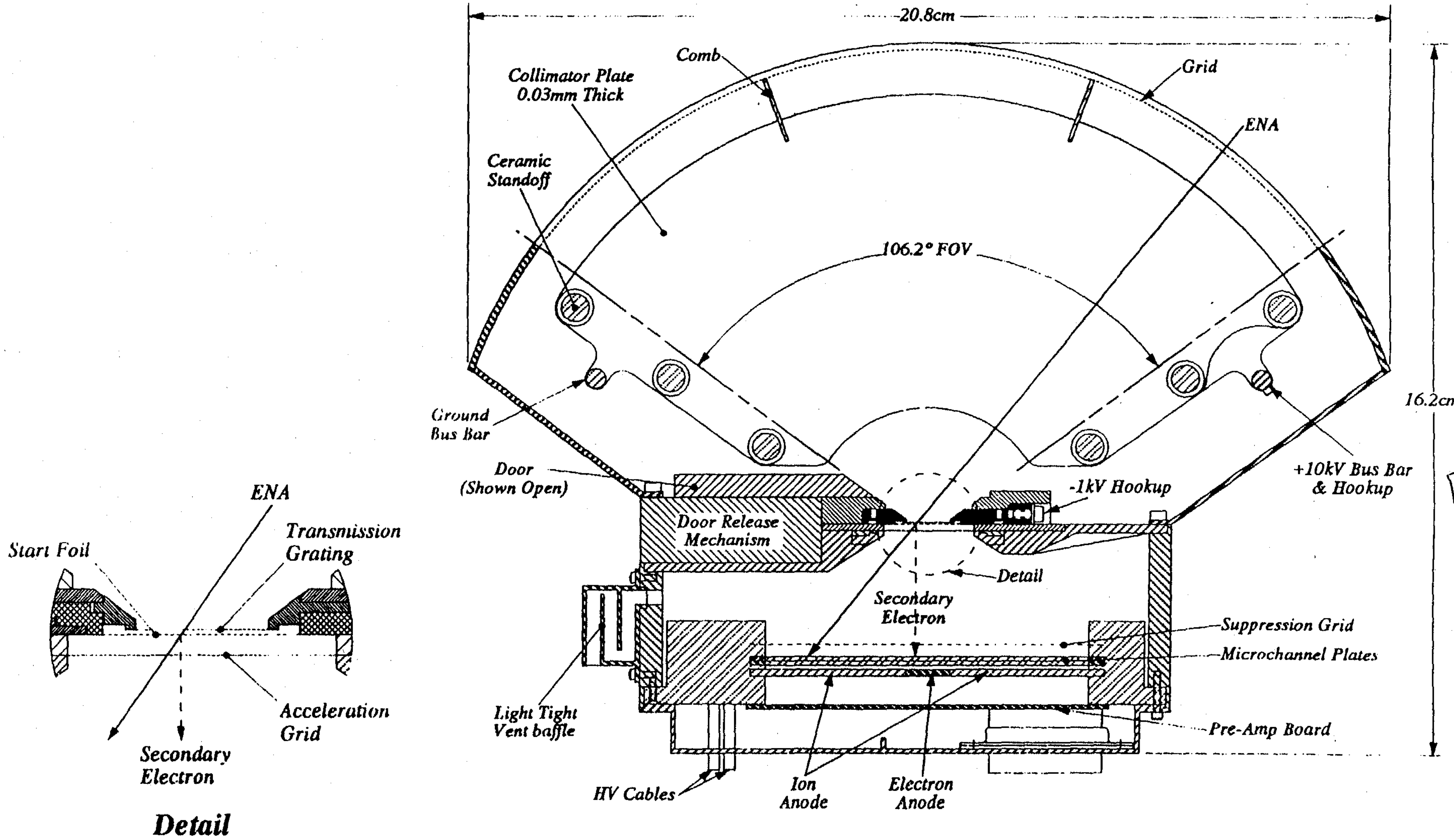
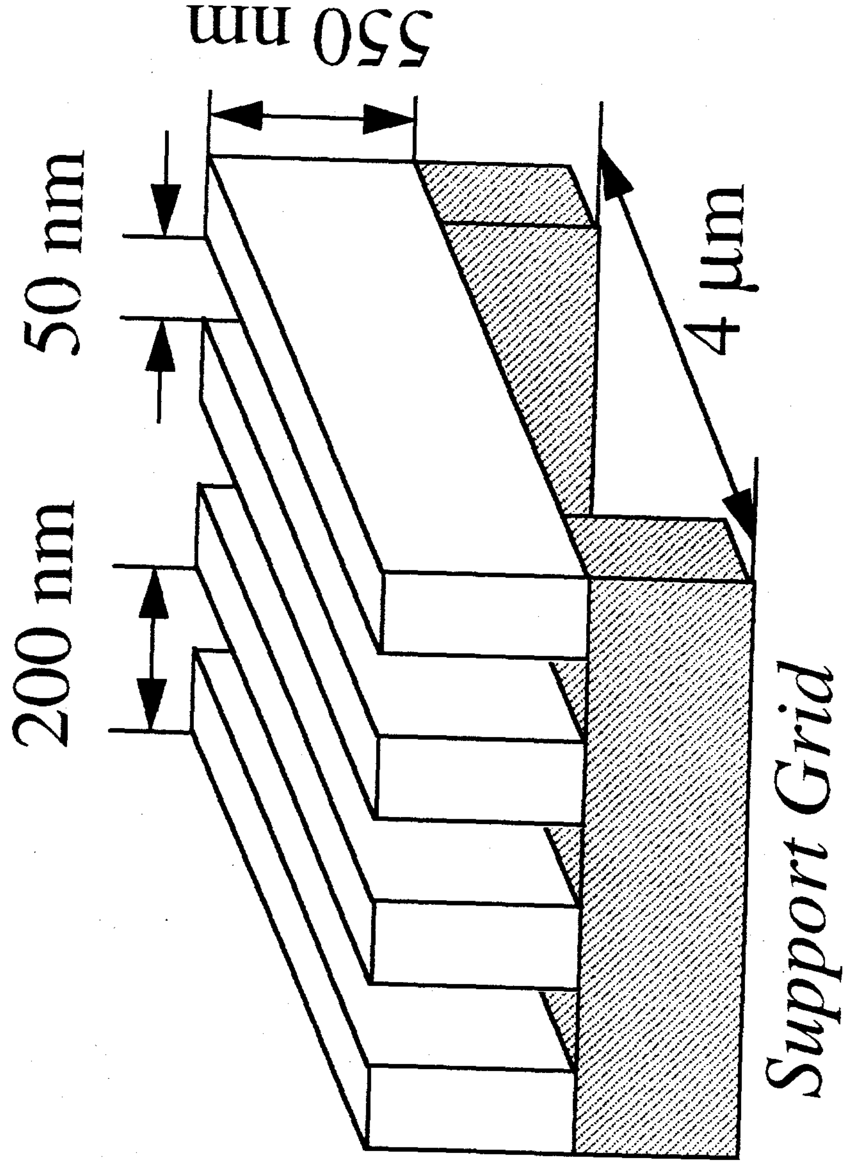

20.8cm
16.2cm
Comb
Grid
Collimator Plate
0.03mm Thick
ENA
Ceramic
Standoff
106.2° FOV
Ground
Bus Bar
+10kV Bus Bar
& Hookup
Door
(Shown Open)
-1kV Hookup
Door Release
Mechanism
Detail
Secondary
Electron
Suppression Grid
Microchannel Plates
Light Tight
Vent baffle
Pre-Amp Board
HV Cables
Ion
Anode
Electron
Anode
Start Foil
Transmission
Grating
Acceleration
Grid
Detail

FIGURE 4.1

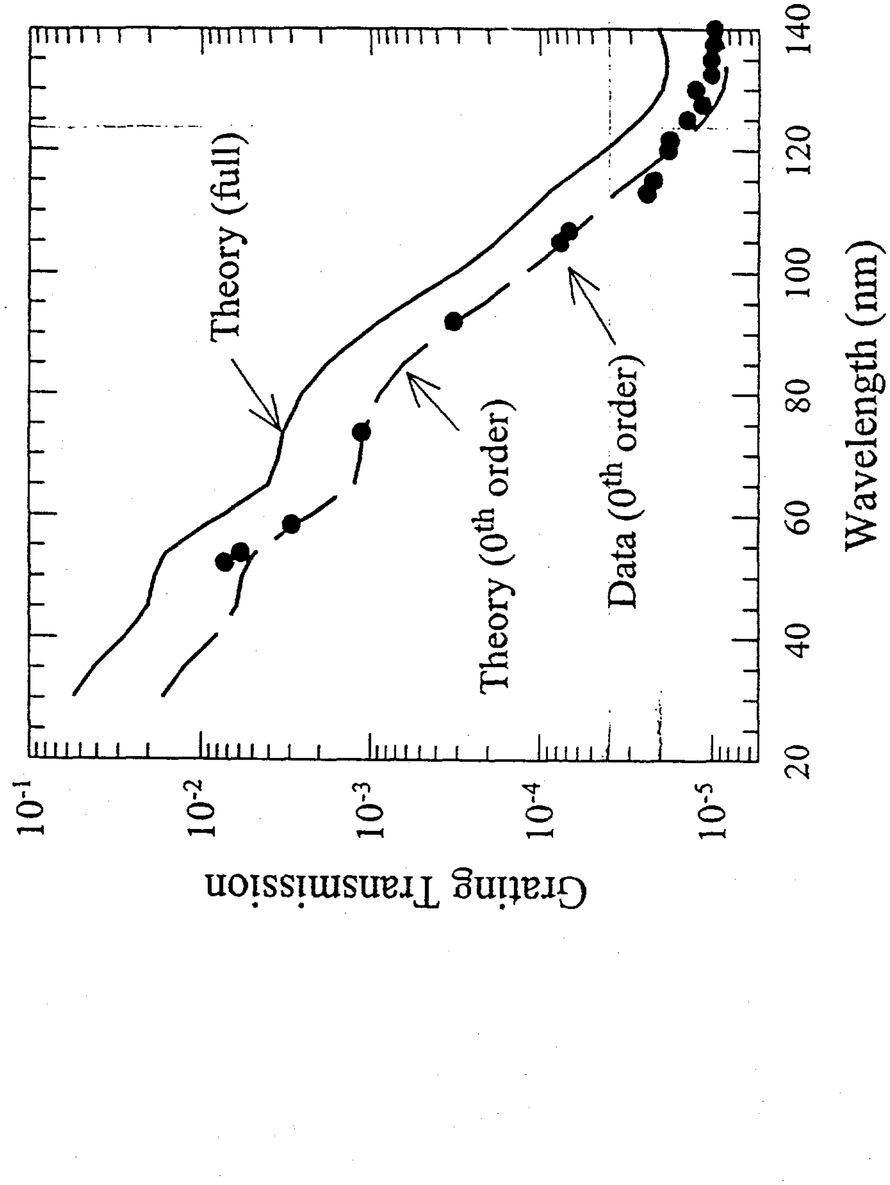
FIGURE 4.2



~~GRATING 2~~

FIGURE 4.3

~~Fig 1.11~~



TWINS TOP LEVEL BLOCK DIAGRAM

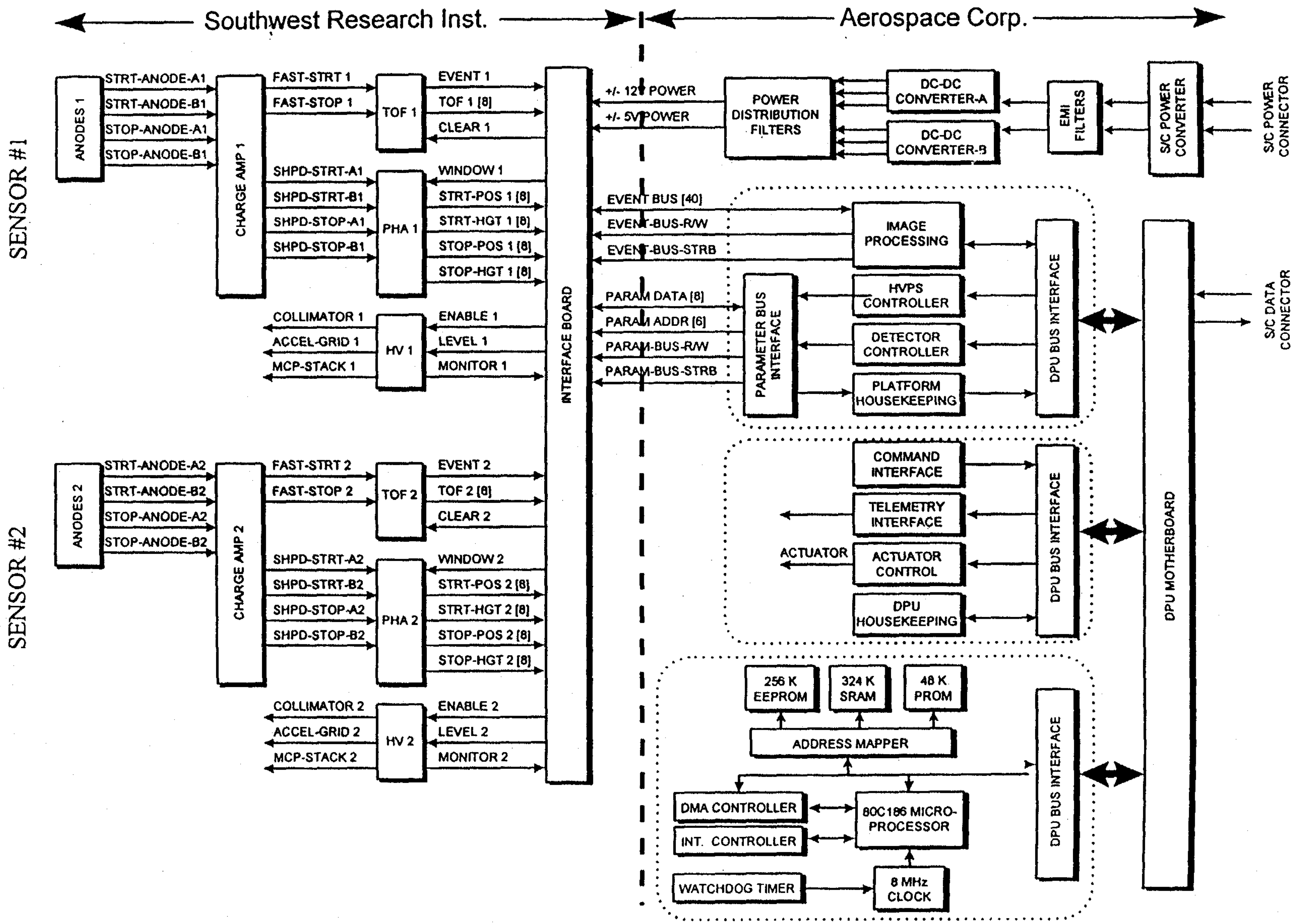
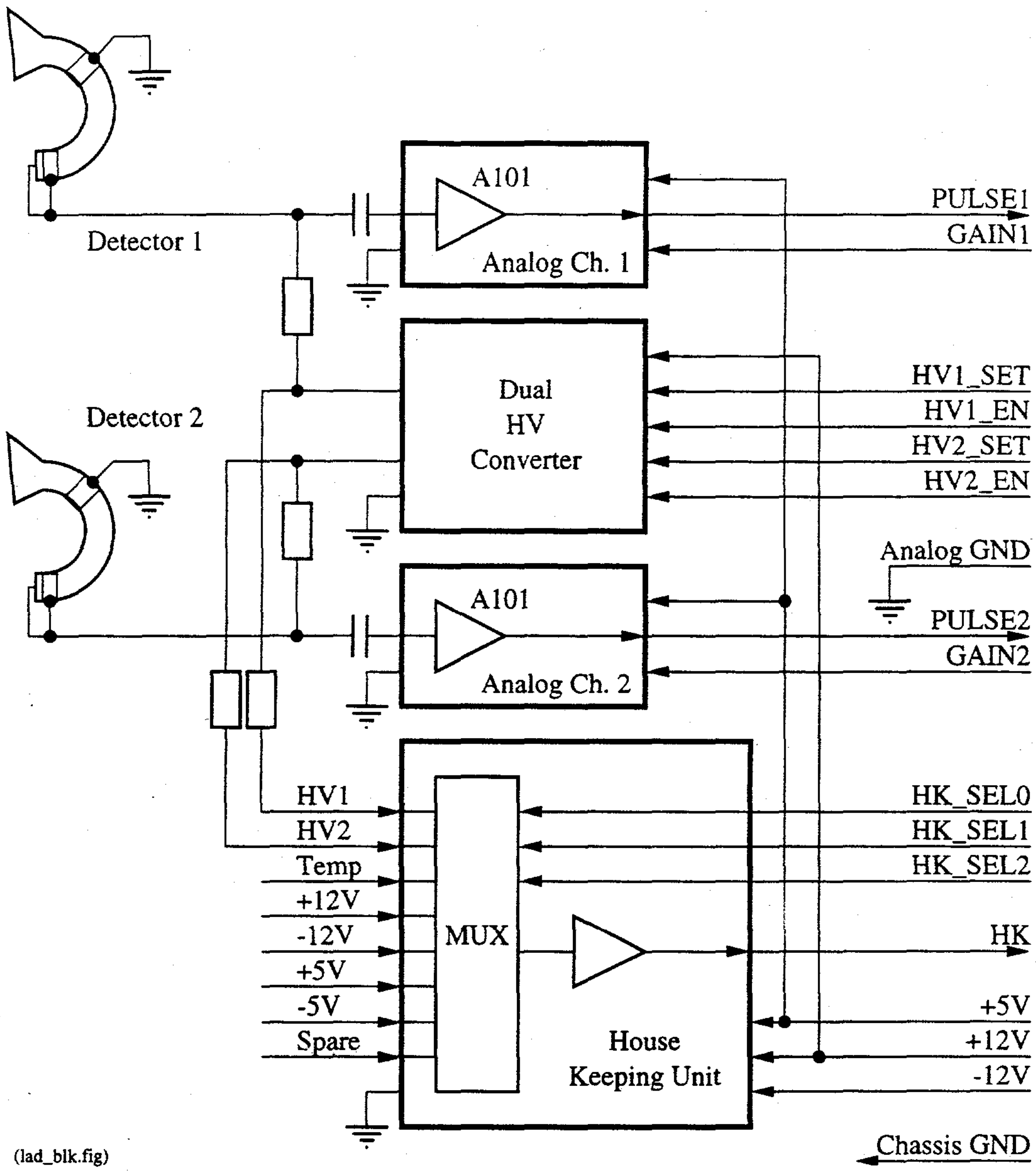


FIGURE 4.4

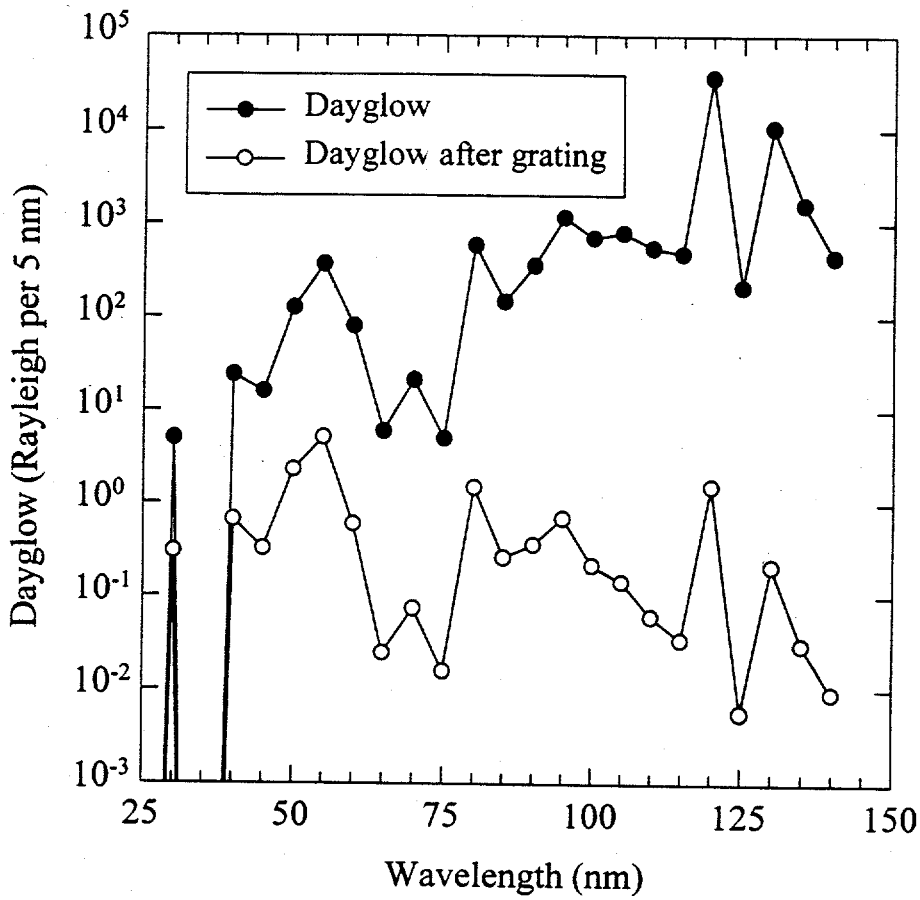
FIGURE 4.5

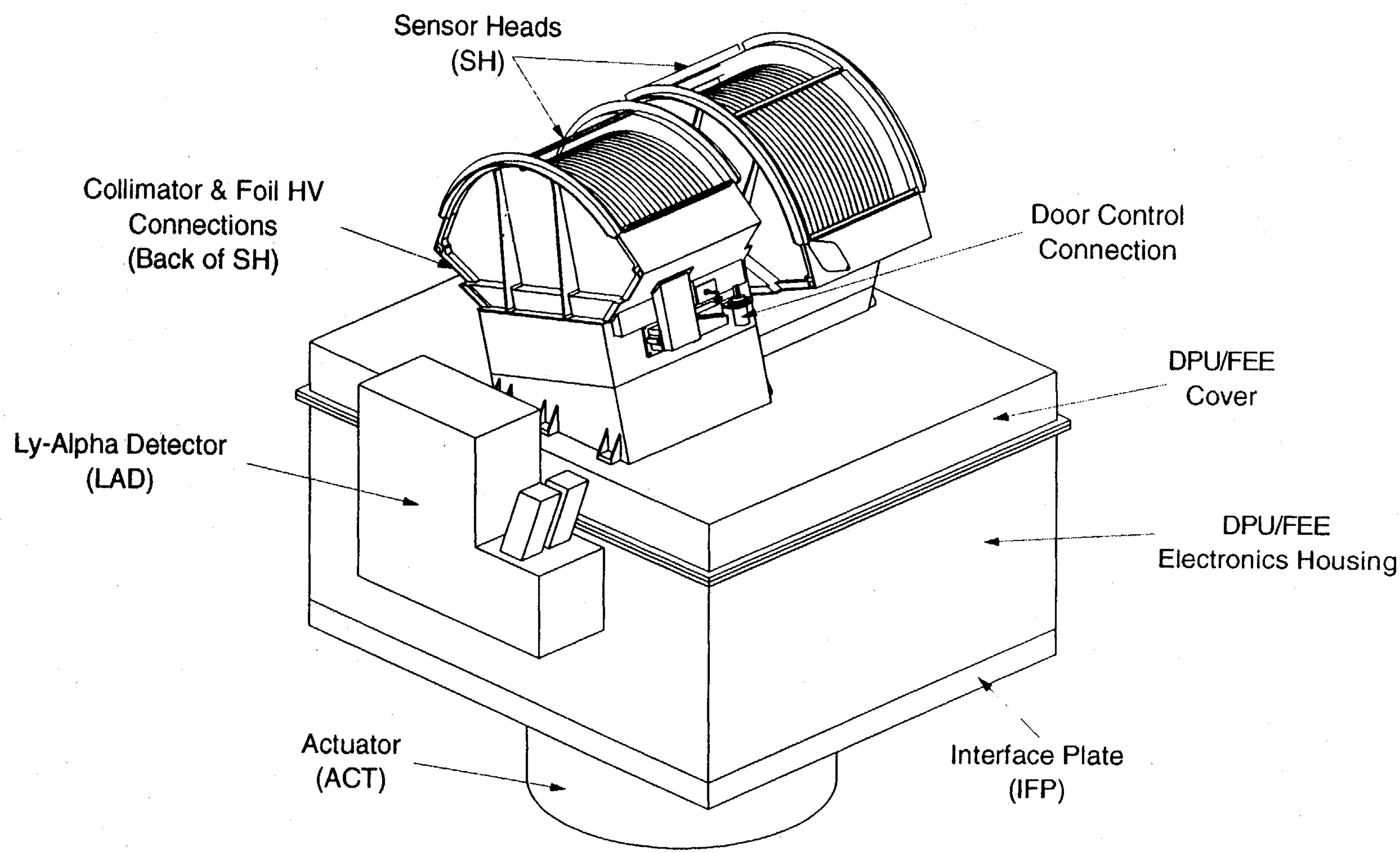


(lad_blk.fig)

~~FIG. 1.2~~

FIGURE 4.6

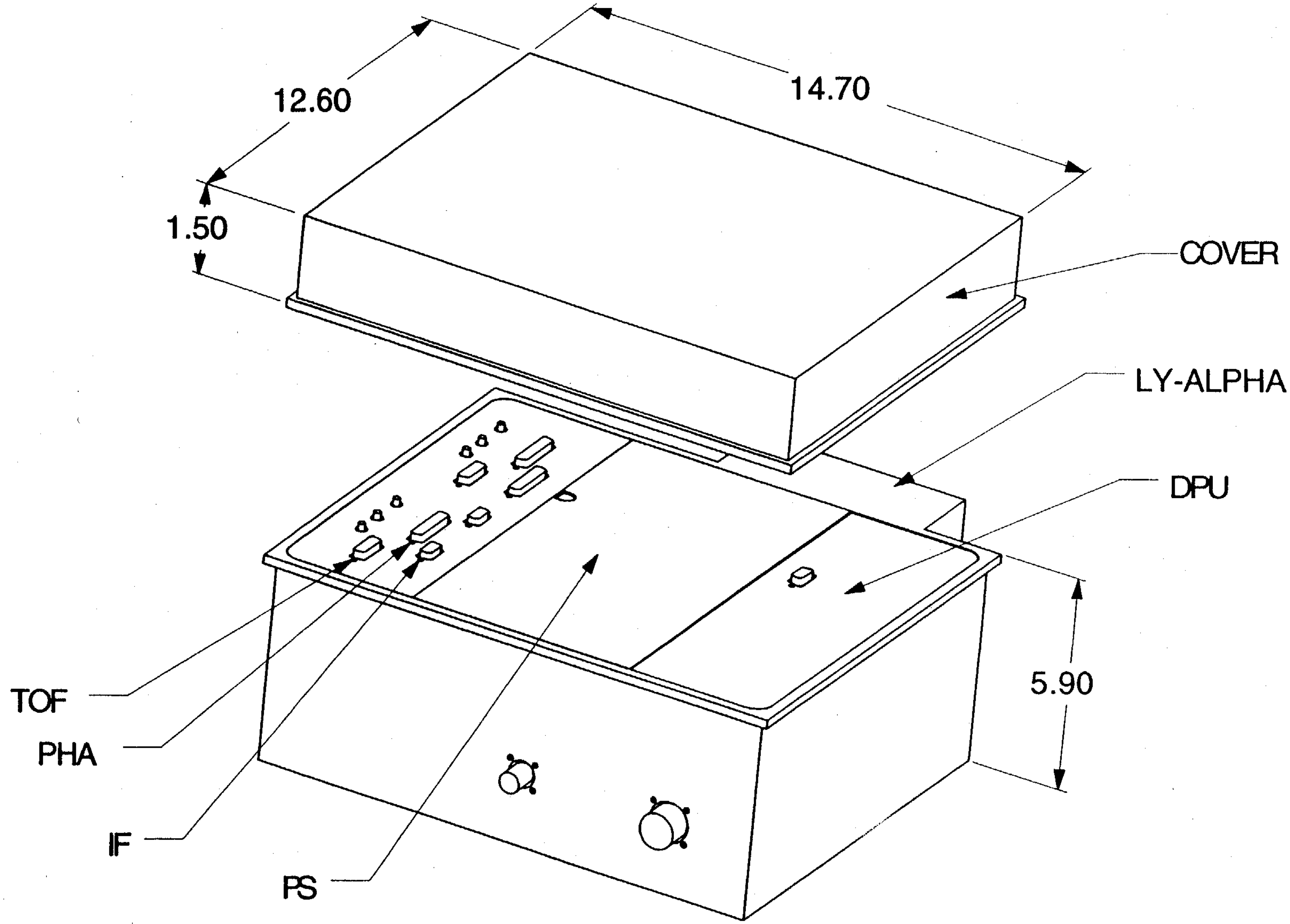




TWINS CONCEPT

3/27/98

FIGURE 4.7



TWINS
DPU/FEE ELECTRONICS HOUSING AND COVER

3/27/98

FIGURE 4.8

TWINS
NTE
OPERATIONAL ENVELOPE

3/27/98

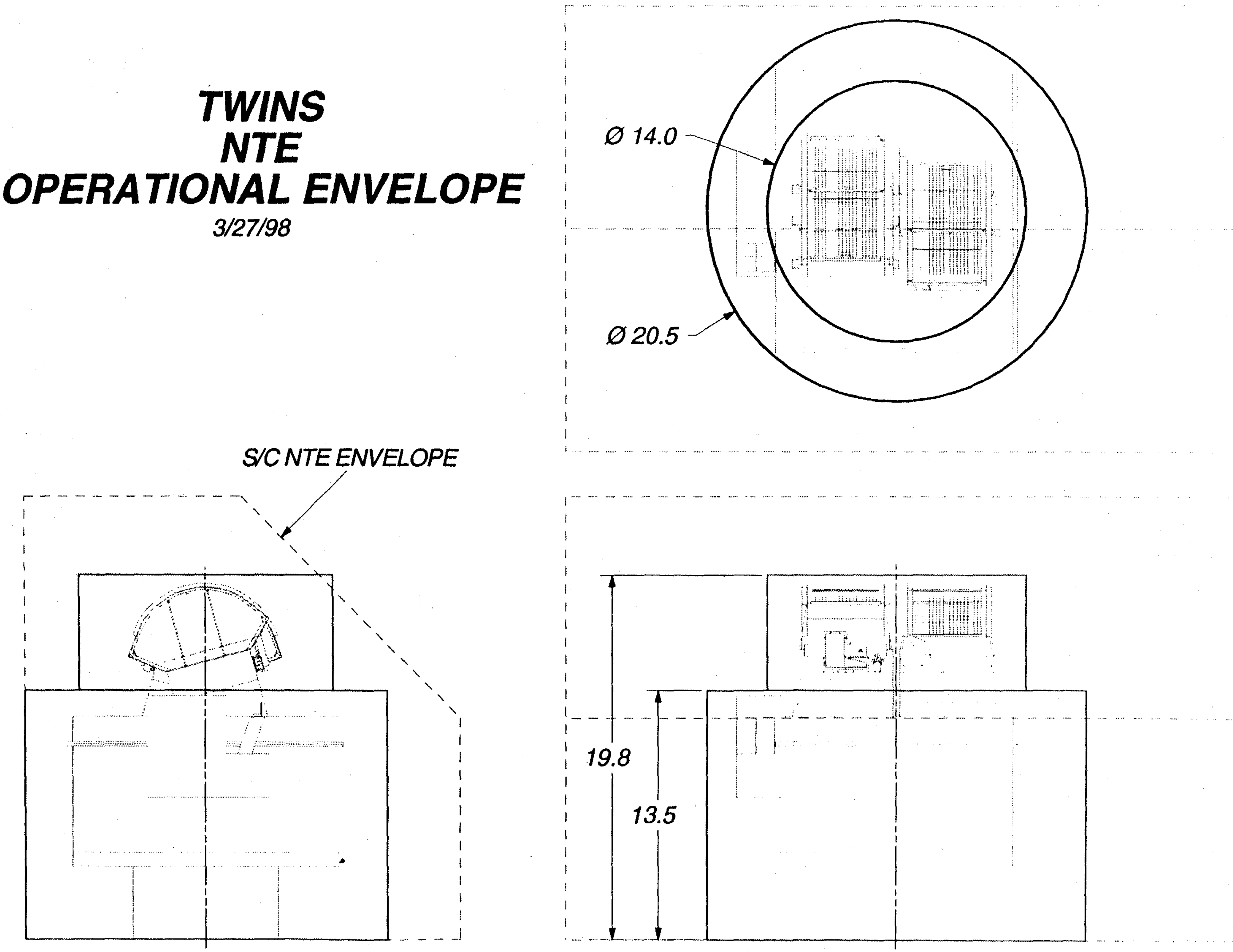
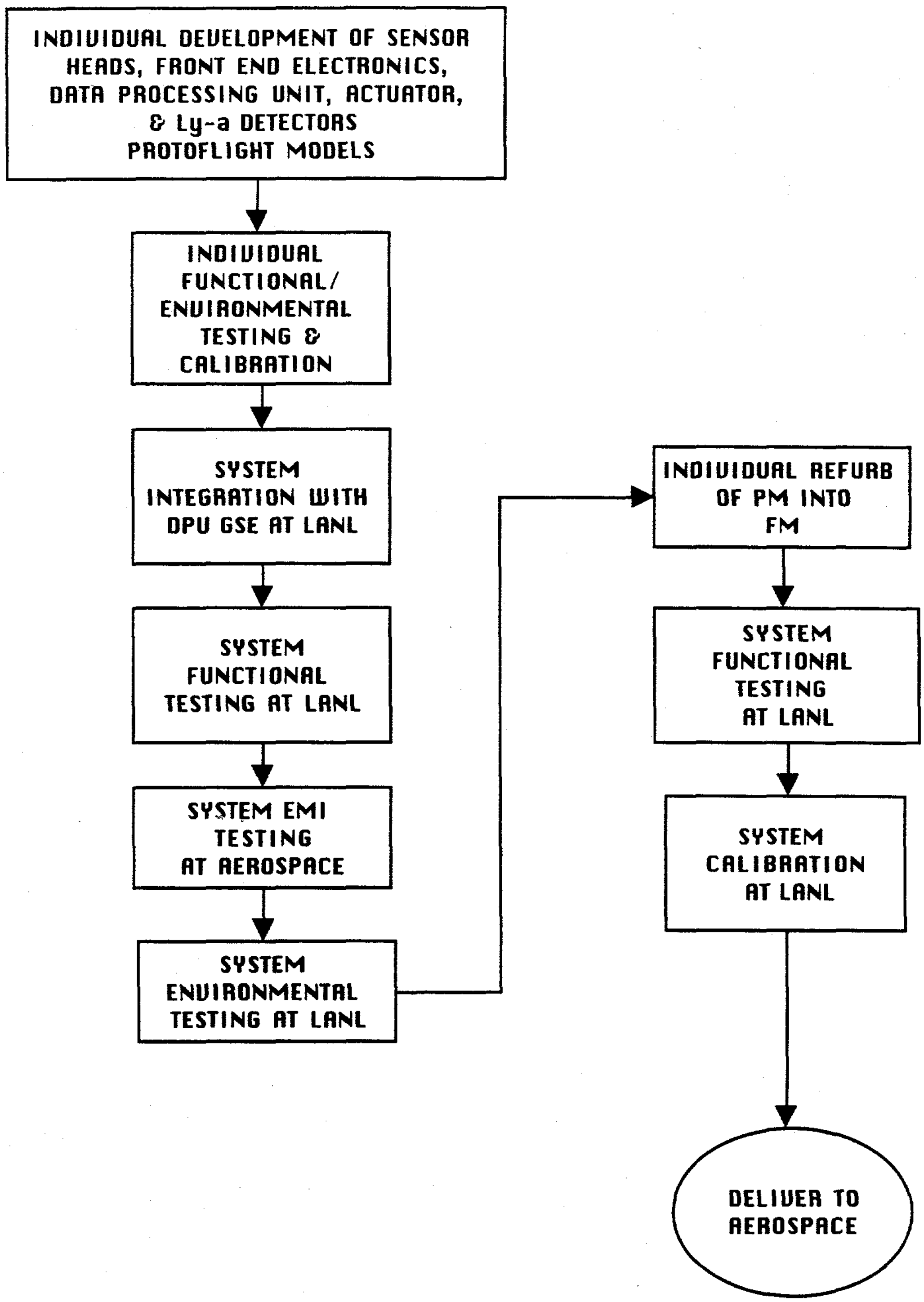


FIGURE 4.9

FIGURE 4.10

TWINS SYSTEM DEVELOPMENT/VERIFICATION PROCESS



TWINS SUB-SYSTEM DEVELOPMENT/VERIFICAION PROCESS

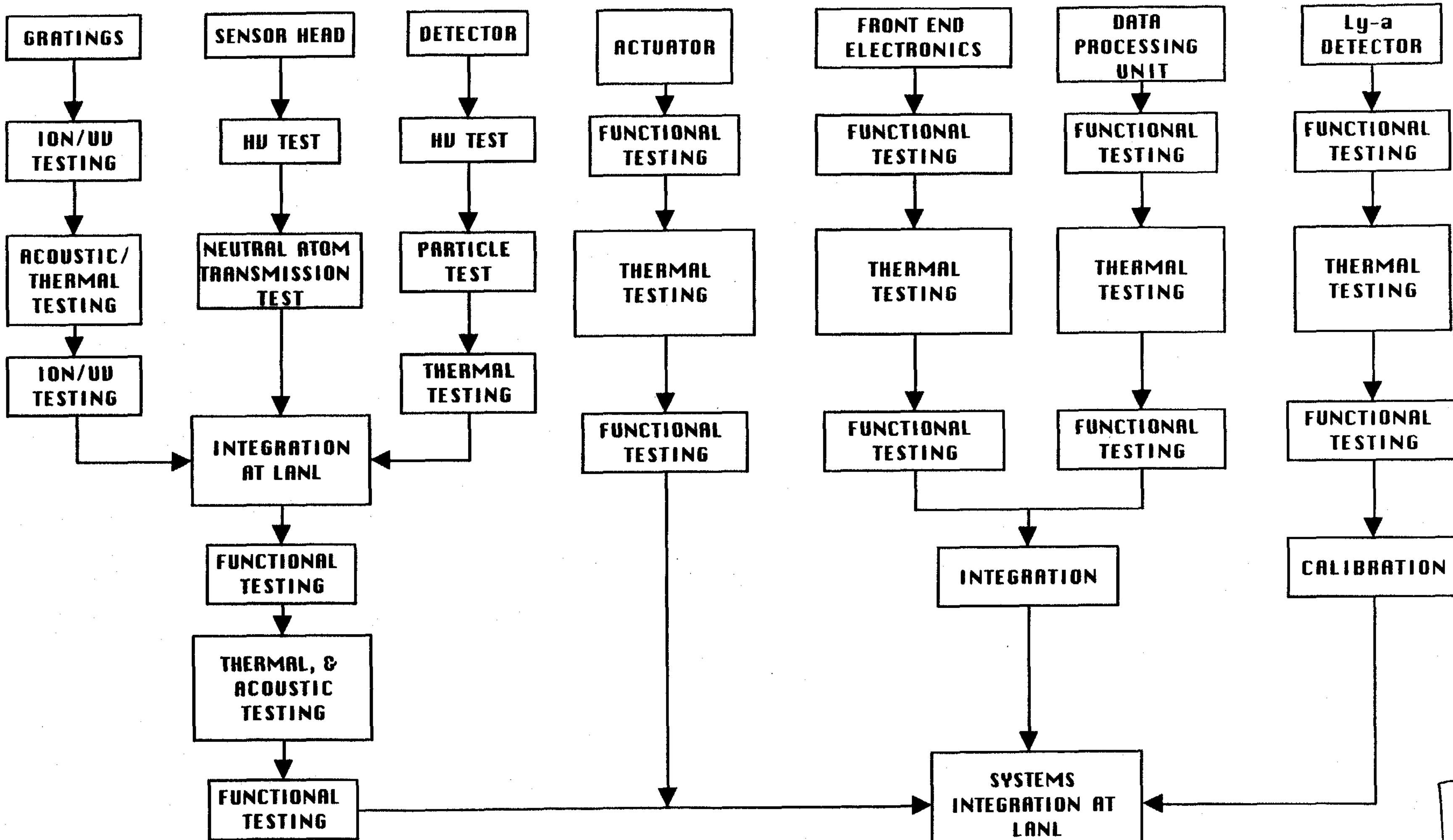


FIGURE 4.11

TWINS DATA SYSTEM

FIGURE 4.12

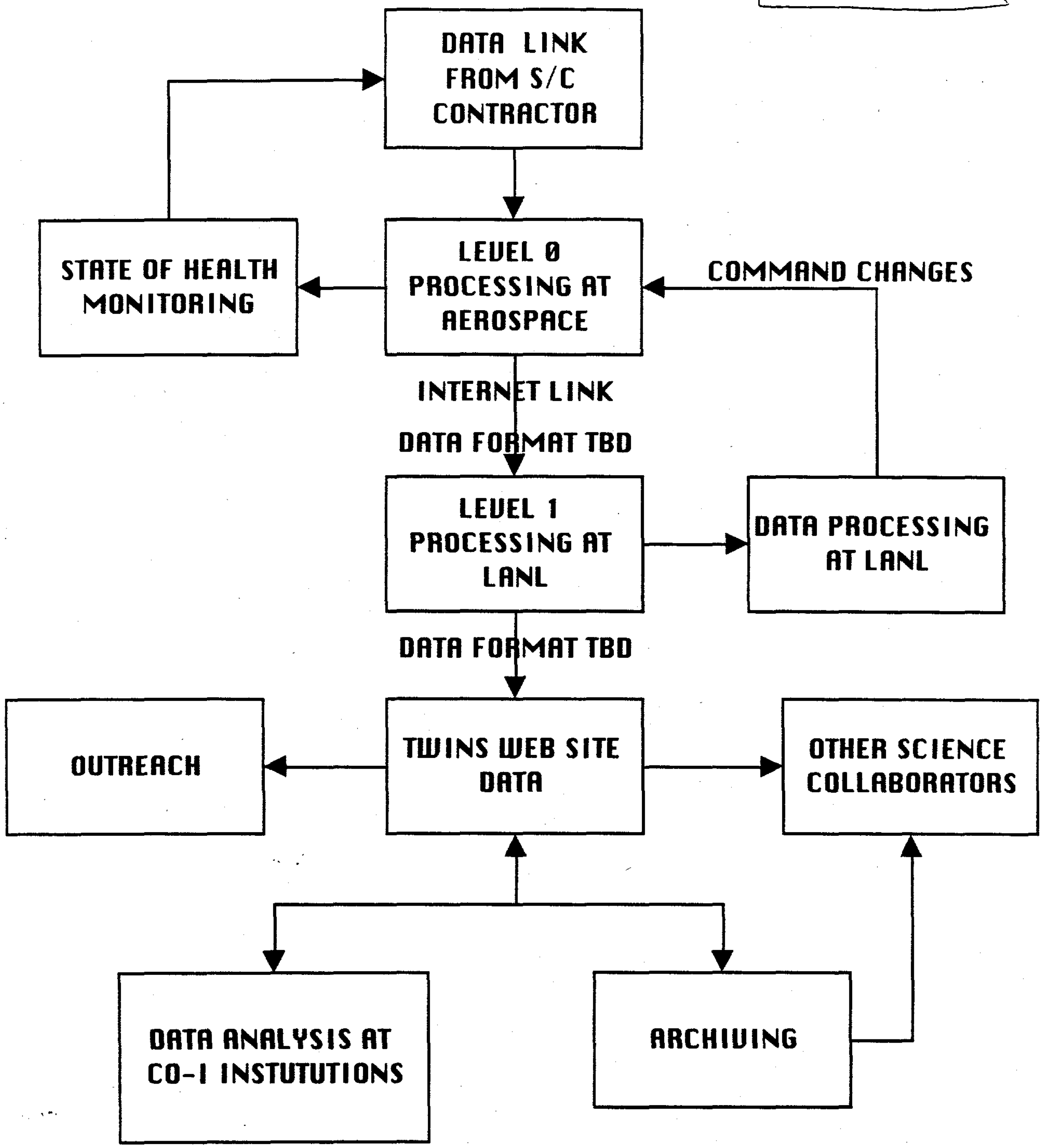
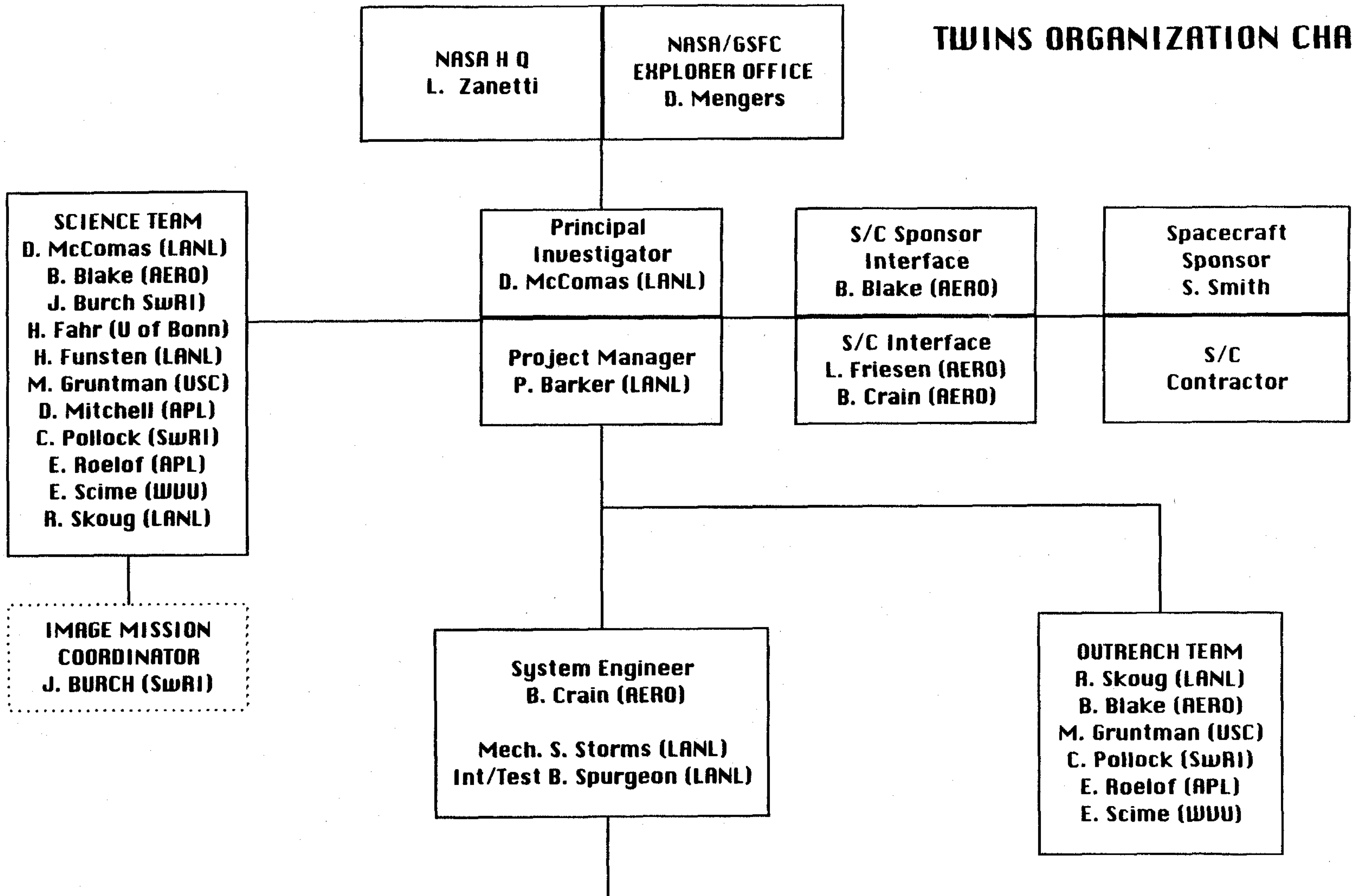


FIGURE 5.1

TWINS ORGANIZATION CHART



INSTRUMENT DEVELOPMENT TEAM

AGENCY	LANL	AEROSPACE	SWRI	U of Bonn	USC	WVU	APL
CO-INVESTIGATOR	H. FUNSTEN	B. BLAKE	C. POLLOCK	H. FAHR	M. GRUNTMAN	E. SCIME	D. MITCHELL
ELECTRICAL ENG.	B. SPURGEON	B. CRAIN	S. WEIDNER	TBD	N/A	N/A	N/A
MECHANICAL ENG.	S. STORMS	M. SIVJEE	S. POPE	TBD	N/A	N/A	N/A
RESPONSIBILITY	SENSOR	DPU	SENSOR ELECT.	Ly-a DETECTOR	Ly-a DETECTOR	GRATINGS	SCIENCE

TABLE 5.1

RESPONSIBILITY	AGENCY	POC
Science	LANL	D. McComas
Project Management	LANL	P. Barker
Systems Manager	LANL	R. Skoug
Sensor Development	LANL	H. Funsten
HV Power Supplies/ Front End Electronics Development	SwRI	S. Weidner
Command and Data Handling System (DPU)	AERO	B. Crain
Flight Software	AERO	D. Mabry
Turntable Control	AERO	B. Crain
GSE Development	AERO	B. Crain
Detector Development	SwRI	C. Pollock
Turntable Development	VTT	P. Stigell
Gratings Development	LANL	H. Funsten
Gratings Manufacture	MIT	P. Hindle
Gratings Characterization	WVU	E. Scime
Ly-a Detector Development	LANL	H. Funsten
Development	U of Bonn	H. Fahr
Collaboration	USC	M. Gruntman
Sensor Integration & Testing	LANL	B. Spurgeon
Sensor Calibration	LANL	R. Skoug
Instrument / Spacecraft Integration	AERO	L. Friesen
Instrument Operations	AERO	B. Blake
Data Processing	LANL	R. Skoug
Level 0	AERO	L. Friesen
Level 1	LANL	R. Skoug
Ly-a Data	U of Bonn	H. Fahr
Data Archiving	LANL	R. Skoug
Data Analysis	LANL	R. Skoug
Image Inversion Development	APL	E. Roelof
Outreach	LANL	R. Skoug
IMAGE Project Coordination	SwRI	J. Burch

TWINS PHASE B/C/D KEY PERSONNEL

TABLE 5.2

		1/2		% OF TIME				1/2	
POSITION	NAME	FY98	FY99	FY00	FY01	FY02	FY03	FY04	TOTAL
LANL									
Project Leader	D. McComas	0.20	0.25	0.25	0.10	0.10	0.05	0.05	1.00
Project Manager	P. Barker	0.60	0.70	0.60	0.50	0.20	0.10	0.10	2.80
Systems Manager	R. Skoug	0.55	0.54	0.20	0.18	0.12	0.02	0.04	1.65
Instrument Scientist	H. Funsten	0.15	0.15	0.20	0.20	0.10	0.05	0.02	0.87
Science	M/F/S/T	0.28	0.28	0.28	0.30	0.20	0.01	0.01	1.36
Mech. Engineer	S. Storms	0.20	0.25	0.08	0.06	0.02	0.02	0.02	0.65
Ele. Engineer	B. Spurgeon	0.20	0.20	0.12	0.20	0.20	0.06	0.04	1.02
Other		0.10	0.66	1.00	1.07	0.40	0.28	0.07	3.58
LANL TOTALS		2.28	3.03	2.73	2.61	1.34	0.59	0.35	12.93
AERO									
Science	B. Blake	0.11	0.11	0.10	0.10	0.03	0.00	0.00	0.45
S/C Integ. Manager	L. Friesen	0.70	0.71	0.34	0.46	0.16	0.06	0.04	2.47
DPU Engineer	B. Crain	0.55	0.97	0.12	0.14	0.13	0.08	0.14	2.13
S/W Engineer	D. Mabry	0.40	0.50	0.00	0.00	0.04	0.04	0.00	0.98
Other		1.20	1.86	0.15	0.21	0.39	0.00	0.00	3.81
AERO TOTALS		2.96	4.15	0.71	0.91	0.75	0.18	0.18	9.84
SWRI									
Science	C. Pollock	0.22	0.38	0.18	0.17	0.02	0.03	0.04	1.04
FEE Manager	J. Cravens	0.35	0.33	0.22	0.24	0.02	0.02	0.03	1.21
FEE Ele. Engineer	S. Weidner	0.20	0.51	0.31	0.15	0.02	0.01	0.03	1.23
FEE Mech. Engineer	S. Pope	0.34	0.32	0.11	0.08	0.01	0.01	0.02	0.89
Other		0.46	1.90	1.23	0.46	0.04	0.05	0.07	4.21
SWRI TOTALS		1.57	3.44	2.05	1.10	0.11	0.12	0.19	8.58
OTHERS	APL,USC,WVU	0.51	0.51	0.51	0.51	0.51	0.51	0.51	3.57
GRAND TOTALS		**7.3**	**11.1**	**6.0**	**5.1**	**2.7**	**1.4**	**1.2**	**34.9**

M/F/S/T = Some combination of McComas, Funsten, Skoug, and Michelle Thomsen

Other = Mech/Ele Technicians. QA/Safety staff, Programmers, Data Technicians.

Experience of key personnel can be found in the appendix

FIGURE 5.2

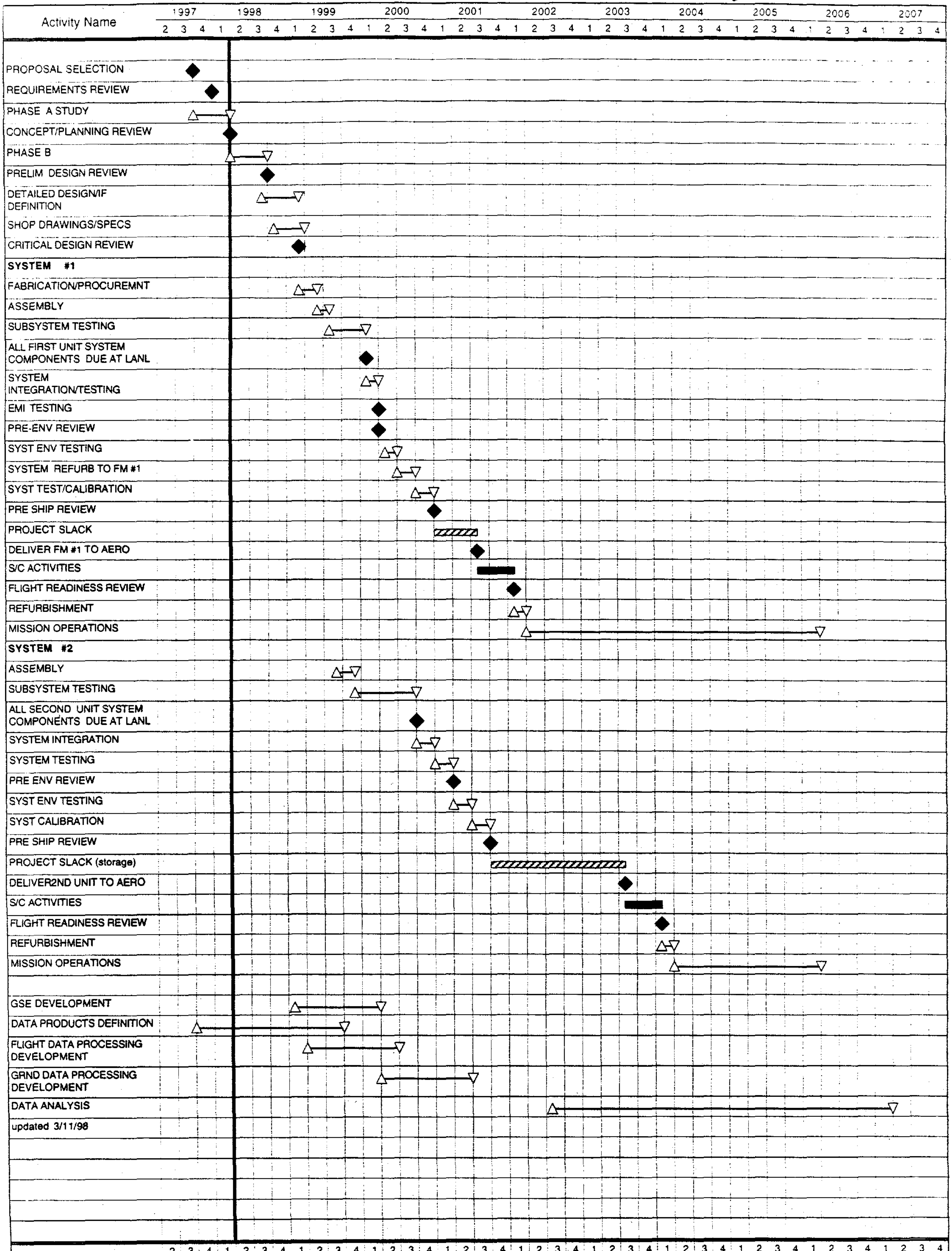

Activity Name
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
PROPOSAL SELECTION
REQUIREMENTS REVIEW
PHASE A STUDY
CONCEPT/PLANNING REVIEW
PHASE B
PRELIM DESIGN REVIEW
DETAILED DESIGN/IF DEFINITION
SHOP DRAWINGS/SPECS
CRITICAL DESIGN REVIEW
SYSTEM #1
FABRICATION/PROCUREMNT
ASSEMBLY
SUBSYSTEM TESTING
ALL FIRST UNIT SYSTEM COMPONENTS DUE AT LANL
SYSTEM INTEGRATION/TESTING
EMI TESTING
PRE-ENV REVIEW
SYST ENV TESTING
SYSTEM REFURB TO FM #1
SYST TEST/CALIBRATION
PRE SHIP REVIEW
PROJECT SLACK
DELIVER FM #1 TO AERO
S/C ACTIVITIES
FLIGHT READINESS REVIEW
REFURBISHMENT
MISSION OPERATIONS
SYSTEM #2
ASSEMBLY
SUBSYSTEM TESTING
ALL SECOND UNIT SYSTEM COMPONENTS DUE AT LANL
SYSTEM INTEGRATION
SYSTEM TESTING
PRE ENV REVIEW
SYST ENV TESTING
SYST CALIBRATION
PRE SHIP REVIEW
PROJECT SLACK (storage)
DELIVER2ND UNIT TO AERO
S/C ACTIVITIES
FLIGHT READINESS REVIEW
REFURBISHMENT
MISSION OPERATIONS
GSE DEVELOPMENT
DATA PRODUCTS DEFINITION
FLIGHT DATA PROCESSING DEVELOPMENT
GRND DATA PROCESSING DEVELOPMENT
DATA ANALYSIS
updated 3/11/98

TABLE 7.2

TWINS Phase B/C/D WBS

1.0 Project Management/Administrative Support
- 1.1 Project Support
- 1.2 *Progress and Budget Reports
- 1.3 Contract Maintenance

2.0 R&QA/Safety Activities
- 2.1 QA Plan development/implementation
- 2.2 QA Systems Reviews/Site Visits
- 2.3 Safety Assessments/Reports
- 2.4 Verification Plan

3.0 Science
- 3.1 Science Support
- 3.2 Data products definition
- 3.3 Derive De-convolution Algorithms
- 3.4 DPU Science Data Handling Support
- 3.5 Instrument Operating Modes Definition
- 3.6 Data Processing Stations
- 3.7 Instrument Activation/Calibration/Tuning Plans

4.0 Systems Support
- 4.1 Mechanical Interface Definition - Development of the *Interface Control Document
- 4.2 Electrical Interface Definition - Development of the *Interface Control Document
- 4.3 Review Support
  - 4.3.1 Requirements Review (semiformal)
  - 4.3.2 Concept Review (semiformal)
  - 4.3.3 Preliminary Design Review (formal)
  - 4.3.4 Critical Design Review (formal)
  - 4.3.5 Pre-environmental Review (formal)
  - 4.3.6 Pre-ship Review (formal)
  - 4.3.7 Flight Readiness Review (formal) (#1 and #2)

5.0 Spacecraft Items **(AERO)**
- 5.1 Thermal Analysis
- 5.2 S/C environmental specifications
- 5.3 S/C Interface
- 5.4 *Low Voltage Power Supply

6.0 *Sensor **(LANL)**
- 6.1 Housing (structure, purge, ele/mech interface)
- 6.2 Collimator (bookends, plates, mesh, HV interface)
- 6.3 *Door Assembly
- 6.4 *Gratings (gratings, holders, grating assemblies, start foil interface, MIT Contract)
- 6.5 *Start Foil Assembly (foils, holders,acceleration grid w/holder, grating mount

interface)

6.6 Sensor System Integration/Test

7.0 *Front End Electronics (FEE) **(SwRI)**

7.1 Time of Flight Electronics
7.2 Time to Digital Converter
7.3 Position Electronics
7.4 Pulse Height Analysis Electronics
7.5 High Voltage Power Supplies
7.6 Mechanical Structure

8.0 *Detector Assembly **(SWRI)**

8.1 Grid/Holder
8.2 Micro Channel Plate Holder
8.3 Anode/Holder
8.4 Charge Amp
8.5 Mech/Ele Interface
8.6 MCP procurement and burn-in

9.0 *Data Processing Unit **(AERO)**

9.1 Command Logics
9.2 Housekeeping Monitors
9.3 High Voltage Controllers
9.4 Modes of Operation
9.5 Flight C & DH software
9.6 Data storage
9.7 Telemetry Interface
9.8 Mechanical Structure
9.9 Actuator Command Electronics

10.0 *Ground Support Equipment

10.1 Sensor GSE (LANL)
10.2 FEE GSE (SwRI)
10.3 DPU GSE (AERO)
10.4 S/C Simulator (AERO)

11.0 *Actuators **(LANL)**

11.1 Actuator components purchases (LANL)
11.2 Actuator system (VTT)
11.3 Actuator purchase contract

12.0 *Ly-a Imagers **(U of Bern)**

12.1 Collimator/filter section
12.2 MCP Section
12.3 Preamp Section
12.4 Mech/Ele Interfaces

13.0 Integration/End-To-End Testing **(LANL)**

13.1 Mechanical Integration

- 13.2 Electrical integration
- 13.3 Functional Testing
- 13.4 HV testing
- 13.5 Mass Properties

14.0 Environmental Testing **(LANL)**
- 14.1 Vibration Testing
- 14.2 Acoustic Testing
- 14.3 Thermal Vacuum Testing
- 14.4 Verification Functional Tests
- 14.5 EMC Testing (AERO)

15.0 Calibration **(LANL)**
- 15.1 Angular (Polar &Azimuthal) Response
- 15.2 Energy/Species Response
- 15.3 Resolution
- 15.4 Geometric Factor Determination

16.0 S/C Integration/Test activities **(AERO)**
- 16.1 S/C System Integration
- 16.2 S/C Level EMC Testing
- 16.3 Environmental testing
- 16.4 Refurbishment (LANL)
- 16.5 Reintegration
- 16.6 Launch preps
- 16.7 L+30 Turn On and Check Out

17.0 Outreach **(LANL)**
- 17.1 Web Site Program
- 17.2 General Public Program
- 17.3 School Programs

* Deliverables

TABLE 7.3

TWINS PHASE B/C/D STAFFING PLAN

WBS ELEMENT	FISCAL YEAR	1/2	PER CENT PER MONTH BY FISCAL YEAR					1/2	
		FY98	FY99	FY00	FY01	FY02	FY03	FY04	TOTAL
1.0 Project Management/Administrative Support									0
LANL		80	95	85	60	30	15	15	380
AERO		19	15	10	10	2	2	2	60
SWRI		25	23	15	15	2	2	3	85
2.0 R&QA/Safety Activities									0
LANL		7	6	6	6	2	2	2	31
AERO		2	2	2	2	6	2	2	18
SWRI		2	19	12	4	1	1	1	40
Other									0
3.0 Science Support									0
LANL		28	33	29	31	24	2	10	157
AERO		15	11	10	10	3			49
SWRI		22	38	18	17	2	3	4	104
WVU		7	2	8	7	12	17	17	70
USC		7	8	8	13	11	17	17	81
APL		14	24	24	24	19	17	17	139
4.0 Systems Support									0
LANL		30	54	20	23	12		4	143
AERO		20	15	10	10	2	2	2	61
SWRI		10	10	7	9				36
Other									0
5.0 Spacecraft Activities									0
LANL		19	4	2	2	2	2	2	33
AERO		46	41	14	16	12	2	2	133
SWRI									0
6.0 Sensor									0
LANL		33	80	48	4		8		173
AERO									0
SWRI									0
WVU		10	10	4	2	2			28
USC		10	5	4	2	2			23
Other									0
7.0 *Front End Electronics									0
LANL		4	4	4					12
AERO									0
SWRI		66	111	71	15	2	1	3	269
Other									0
8.0 *Detector Assembly									0
LANL		4	4	4					12
AERO									0
SWRI		28	92	44	8	1	1	2	176
Other									0
9.0 *Data Processing Unit									0
LANL		4	4	4					12
AERO		180	264	19	9	17			489
SWRI									0
Other									0
10.0 *Ground Support Equipment									0
LANL		4	8	4					16
AERO		14	35	2	0				51
SWRI		2	19	12	4				37
Other									0
11.0 *Actuators									0
LANL		6	6	6					18
AERO									0
SWRI		2	10						12
Other									0
12.0 *Ly-a System									0
LANL		2	2	2	4	2			12
AERO									0
SWRI									0
USC		2	2	2	2	2			10

TWINS PHASE B/C/D STAFFING PLAN

WBS ELEMENT	FISCAL YEAR	1/2 FY98	FY99	FY00	FY01	FY02	FY03	1/2 FY04	TOTAL
		PER CENT PER MONTH BY FISCAL YEAR							
13.0 Inst. Syst. Integ./Test Support									0
LANL		0	0	47	24				71
AERO		0	15	2	6				23
SWRI			15	20	14				49
Other									0
14.0 Environmental Testing									0
LANL		2	2	2	20	20	0	0	46
AERO		0	2	2	6	6	0	0	16
SWRI				2	4				6
Other									0
15.0 Calibration									0
LANL					48	48			96
AERO					10				10
SWRI					10				10
Other									0
16.0 S/C Integration/Test activities									0
LANL					30		30		60
AERO					10	27	10	7	54
SWRI					8	2	4	6	20
Other									0
17.0 Outreach (2% of total)									0
LANL		3	5	4	4	3	1	1	21
AERO		4	8	2	2	2	1	1	20
SWRI		1	7	4	2	1			15
Other		1	1	1	1	1			5
GRAND TOTALS		735	1111	596	508	280	142	120	3492

* Key personnel staffing plan for each institution is attached

TWINS
PHASE B/C/D
COST BREAKDOWN BY WBS
(REAL YEAR DOLLARS)

[TABLE 7.4]

TIME PHASED COST BREAKDOWN BY WBS AND MAJOR COST CATEGORY								PHASE B/C/D
	COST PER MONTH IN REAL YEAR K $S							
WBS/COST CATEGORY DESCRIPTION	FY98	FY99	FY00	FY01	FY02	FY03	FY04	TOTAL
Total Direct Labor Cost	65	90	56	53	32	17	25	339
1.0 Management	11.16	10.00	9.92	8.64	3.60	2.09	3.50	499
2.0 R&QA/Safety	0.99	2.52	1.75	1.22	1.25	0.55	0.57	97
3.0 Science	7.00	8.33	9.25	10.37	7.51	6.16	10.17	603
4.0 Systems Support	5.17	6.50	3.61	4.27	1.48	0.83	2.50	246
5.0 Spacecraft Items	5.67	4.20	1.56	1.83	1.48	0.67	0.46	154
6.0 Sensor	4.67	9.33	5.46	0.81	0.67	0.88	1.00	240
7.0 Front End Electronics	6.00	10.75	7.17	1.53	0.50	0.11	0.34	279
8.0 Detector Assembly	2.88	8.96	4.17	1.25	0.25	0.11	0.23	195
9.0 Data Processing Unit	16.00	16.67	2.08	1.25	1.80	0.00	0.00	358
10.0 Ground Support Equipment	1.80	4.58	1.58	0.41	0.17	0.00	0.00	92
11.0 Actuators	0.72	1.49	0.59	0.00	0.00	0.00	0.00	29
12.0 Ly-a Imagers	0.36	0.37	0.39	0.61	0.42	0.00	0.00	24
13.0 Integration/EtE Testing	0.00	2.80	6.33	4.47	1.58	0.00	0.00	182
14.0 Environmental Testing	0.18	0.37	0.59	3.05	2.75	0.00	0.00	82
15.0 Calibration	0.00	0.00	0.00	6.91	5.08	0.00	0.00	144
16.0 S/C Integration/Test	0.00	0.00	0.00	4.88	3.07	4.84	6.00	189
17.0 Outreach	2.67	3.58	1.67	1.25	0.67	0.42	0.67	111
Total Materials and Equipment Cost	110	102	32	8	2	3	4	2447
1.0 Management	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2.0 R&QA/Safety	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
3.0 Science	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
4.0 Systems Support	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
5.0 Spacecraft Items	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
6.0 Sensor	47.67	24.75	0.00	1.00	0.00	1.17	0.00	609
7.0 Front End Electronics	0.00	19.17	3.08	0.00	0.00	0.00	0.00	267
8.0 Detector Assembly	2.17	4.75	2.25	0.00	0.00	0.00	0.00	97
9.0 Data Processing Unit	2.17	19.67	10.00	5.33	0.00	0.00	0.00	433
10.0 Ground Support Equipment	5.50	6.33	2.25	0.00	0.00	0.00	0.00	136
11.0 Actuators	52.00	27.00	11.17	1.92	2.00	2.08	4.33	868
12.0 Ly-a Imagers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
13.0 Integration/EtE Testing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
14.0 Environmental Testing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
15.0 Calibration	0.00	0.00	3.08	0.00	0.00	0.00	0.00	37
16.0 S/C Integration/Test	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
17.0 Outreach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total Oth Costs(Travel,Support,G&A)	205	203	65	50	27	16	26	5711
1.0 Management	8.93	8.00	7.93	6.91	2.88	1.67	2.80	399
2.0 R&QA/Safety	0.79	2.02	1.40	0.98	1.00	0.44	0.46	77
3.0 Science	4.67	6.67	7.40	8.30	6.01	4.93	8.13	476
4.0 Systems Support	4.13	5.20	2.89	3.42	1.19	0.67	2.00	197
5.0 Spacecraft Items	4.53	3.36	1.25	1.46	1.19	1.25	0.37	131
6.0 Sensor	15.50	24.75	4.37	1.45	0.53	1.64	0.80	491
7.0 Front End Electronics	4.80	27.00	6.50	1.22	0.40	0.09	0.27	453
8.0 Detector Assembly.	4.04	10.97	5.13	1.00	0.20	0.09	0.18	234
9.0 Data Processing Unit	14.53	22.00	9.67	5.27	1.44	0.00	0.00	548
10.0 Ground Support Equipment	4.00	8.73	3.07	0.33	0.33	0.00	0.00	174
11.0 Actuators	0.58	1.75	0.50	0.00	0.00	0.00	3.47	51
12.0 Ly-a Imagers	0.29	0.30	0.31	0.49	0.34	0.00	0.00	19
13.0 Integration/EtE Testing	0.00	2.24	5.07	3.58	1.25	0.00	0.00	146
14.0 Environmental Testing	0.14	0.30	0.92	2.44	2.20	0.00	0.00	71
15.0 Calibration	0.00	0.00	2.47	5.53	4.06	0.00	0.00	145
16.0 S/C Integration/Test	130.0	67.50	0.00	4.58	2.46	3.87	4.80	1750
17.0 Outreach	2.13	2.87	1.33	1.00	0.53	0.33	0.53	89
PASS THROUGH FEES	5.83	9.17	4.58	2.00	1.17	0.75	2.17	260
Total Reserves (12%)	29.33	38.50	18.00	13.00	7.25	4.17	6.50	1186
Total Contract Cost	409	433	171	124	69	40	62	12867
Total Other Costs to NASA	0	0	0	0	0	0	0	0
								0
Total Contributions	17.3	30.6	15.8	12.7	714	22.3	1566	19042
University of Bonn								
12.0 Ly-a Detector	17	26	7	3	2	1	4	593
S/C Agency	0	5	9	10	712	21	1562	18449
Integration and Test								
Launch Services								0
Ground segment								0
								0
TOTAL COST FOR PHASE B/C/D	426	464	187	137	782	62	1629	31909

TWINS PHASE E WBS

TABLE 7.5

1.0 Project Management/Administrative Support
- 1.1 Project Support
- 1.2 *Progress and Budget Reports
- 1.3 Contract Maintenance

2.0 Instrument Operations
- 2.1 Instrument State of Health Monitoring
- 2.2 Instrument Command Coding and Uploading
- 2.3 Troubleshooting and Analysis

3.0 Science
- 3.1 Derive De-convolution Algorithms (APL)
- 3.2 Data Receiving/Level 0 Processing (AERO)
- 3.3 Level 1 Data Processing (LANL)
- 3.4 *Data Distribution & Archiving (LANL)
- 3.5 Data Analysis (ALL)
- 3.6 Science Collaborations
- 3.7 *Scientific Publications & Presentations
- 3.8 Science Team Meetings

4.0 Outreach **(LANL)**
- 4.1 Web Site Program
- 4.2 General Public Program
- 4.3 School Programs

* Deliverables

TABLE 7.6

TWINS PHASE E STAFFING PLAN

WBS ELEMENT / FISCAL YEAR	1/2 FY02	FY03	FY04	FY05	FY06	1/2 FY07	TOTAL
	% PER MONTH BY FISCAL YEAR						
1.0 Project Management/Administrative Support	30	30	50	50	50	30	240
2.0 Instrument Operations	20	20	20	20	20	20	120
3.0 Science	230	230	420	420	420	230	1950
4.0 Outreach	5	5	8	8	8	5	39
GRAND TOTALS	285	285	498	498	498	285	2349

TWINS PHASE E KEY PERSONNEL

TABLE 7.7

		1/2	% PER MONTH PER YEAR				1/2		
POSITION	NAME	FY02	FY03	FY04	FY05	FY06	FY07		TOTAL
Principal Investigator	D. McComas	0.20	0.20	0.40	0.40	0.40	0.20		1.8
Project Manager	P. Barker	0.10	0.10	0.10	0.10	0.10	0.10		0.6
Instrument Operations	AERO	0.20	0.20	0.20	0.20	0.20	0.20		1.2
Science Co-Is	All	1.40	1.40	2.80	2.80	2.80	1.40		12.6
Data Processing	AERO/LANL	0.40	0.40	0.40	0.40	0.40	0.40		2.4
Other Data/Science	All	0.50	0.50	1.00	1.00	1.00	0.50		4.5
Outreach	All	0.05	0.05	0.08	0.08	0.08	0.05		0.4
GRAND TOTALS		**2.85**	**2.85**	**4.98**	**4.98**	**4.98**	**2.85**	**0.00**	**23.5**

TABLE 7.5

TWINS
PHASE E
COST BREAKDOWN BY WBS
(REAL YEAR DOLLARS)

TIME PHASED COST BREAKDOWN BY WBS AND MAJOR COST CATEGORY							
	COSTS IN REAL YEAR K $S						E
WBS/COST CATEGORY DESCRIPTION	FY02	FY03	FY04	FY05	FY06	FY07	TOTAL
Total Direct Labor Cost	152	323	798	866	875	244	3259
1.0 Management	20	41	89	74	77	24	325
2.0 Instrument Operations	13	27	71	59	62	16	249
3.0 Science	115	247	621	715	717	199	2614
4.0 Outreach	4	8	17	18	19	5	71
Total Materials and Equipment Cost	60	63	94	63	117	0	397
1.0 Management							0
2.0 Instrument Operations							0
3.0 Science	60	63	94	63	117		397
4.0 Outreach							0
Total Oth Costs(Travel,Support,G&A)	157	369	694	717	714	204	2854
1.0 Management	16	33	71	59	62	19	260
2.0 Instrument Operations	11	22	57	47	49	13	199
3.0 Science	92	198	497	572	574	159	2091
4.0 Outreach	3	6	14	14	15	4	57
PASS THROUGH FEES	35	110	55	24	14	9	247
Total Reserves (10%)	144	144	144	71	36	36	575
Total Contract Cost	**513**	**899**	**1730**	**1717**	**1741**	**484**	**7085**
Total Other Costs to NASA	0	0	0	0	0	0	0
							0
Total Contributions	646	1257	1256	1257	1256	647	6319
University of Bonn							
12.0 Ly-a Detector	36	37	36	37	36	37	219
S/C Agency	610	1220	1220	1220	1220	610	6100
TOTAL COST FOR PHASE B/C/D	1159	2156	2986	2974	2997	1131	13403.6

TABLE 7.9

TWINS MISSION FUNDING PROFILE
FY97 AND RY DOLLARS

Cost Item	FY98 RYK$	FY99 RYK$	FY00 RYK$	FY01 RYK$	FY02 RYK$	FY03 RYK$	FY04 RYK$	FY05 RYK$	FY06 RYK$	FY07 RYK$	TOTAL RYK$	TOTAL FY97K$
Phase B/C/D												
LANL/nasa2640	327.6	993.6	686.6	638.8	357.5	184.2	85.8				3274.0	2897.0
VTT/aero800	337.0	349.9	145.6	25.7	26.8	27.9	29.0				942.0	866.0
MIT/lanl550	364.0	378.0	0.0	0.0	0.0	0.0	0.0				742.0	700.0
AERO/nasa1700	262.1	932.0	285.6	258.6	91.5	17.8	26.4				1874.0	1700.0
SWRI/aero1955	134.2	1110.2	586.9	289.0	147.6	83.8	130.7				2482.4	2214.0
APL/nasa250	21.8	45.4	47.0	46.8	51.2	53.3	27.7				293.3	250.0
USC/aero130	12.5	24.8	25.8	24.6	28.1	29.2	15.8				160.8	137.0
WVU/aero100	9.4	19.4	20.2	21.1	22.0	22.9	11.9				126.7	108.0
S/C/nasa1,500	780.0	810.0	0.0	0.0	0.0	0.0	0.0				1590.0	1500.0
Contingency 12%	176.2	462.4	215.7	156.5	87.0	50.3	39.3				1187.4	1064.6
Outreach 2%	29.4	77.1	36.0	26.1	14.5	8.4	6.5				197.9	177.4
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0
Total Phase B/C/D	2454.1	5202.9	2049.3	1487.2	826.1	477.8	373.2	0.0	0.0	0.0	12870.5	11614.1
Phase E												
LANL/nasa2525					195.2	381.0	792.0	822.0	852.0	236.8	3279.0	2420.0
AERO/nasa370					28.1	58.4	121.4	126.0	130.6	34.0	498.6	368.0
SWRI/aero709					58.6	120.7	250.8	260.3	269.8	71.0	1031.2	761.0
APL/nasa709					53.7	111.8	232.3	241.1	249.9	65.1	953.9	704.0
USC/aero210					13.4	34.3	79.2	82.2	85.2	16.3	310.6	229.0
WVU/aero210					13.4	34.3	79.2	82.2	85.2	16.3	310.6	229.0
S/C					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contingency 10%					143.7	143.7	143.7	71.1	36.2	36.2	574.7	471.1
Outreach 2%					7.2	14.8	31.1	32.3	33.5	8.8	127.7	94.2
Other					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Phase E	0	0	0	0	513.3	898.9	1729.8	1717.3	1742.4	484.6	7086.3	5276.3
NASA Mission Cost Total	2454.1	5202.9	2049.3	1487.2	1339.4	1376.7	2103	1717.3	1742.4	484.59	19956.8	16890.4
Contributions												
Phase B/C/D												
U of Bonn	104.0	313.2	78.4	35.1	24.4	12.7	26.4				594.2	540.0
S/C*	0.0	54.0	112.0	117.0	8540.0	254.0	9372.0				18449.0	14550.0
Total Phase B/C/D	104.0	367.2	190.4	152.1	8564.4	266.7	9398.4	0.0	0.0	0.0	19043.2	15090.0
Phase E												
U of Bonn					36.6	36.6	36.6	36.6	36.6	36.6	219.6	180.0
S/C*					610.0	1220.0	1220.0	1220.0	1220.0	610.0	6100.0	5000.0
Total Phase E	0.0	0.0	0.0	0.0	646.6	1256.6	1256.6	1256.6	1256.6	50.0	6319.6	5180.0
Contributed Costs Total	104.0	367.2	190.4	152.1	9211.0	1523.3	10655.0	1256.6	1256.6	50.0	25362.8	20270.0
								Mission Totals			45319.6	37160.4

* Rough estimate based on IMAGE s/c and and average cost per system

S/C integration&test estimated at 100/yr

Launch = 50M/7 instruments = 7M

Mission operations = 70M/year/7 = 1000