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SPARTAN

HIGH RESOLUTION SOLAR STUDIES

FINAL CONTRACT REPORT

Contract NAS5-29739

Period of Performance
21 May, 1987 through 31 October, 1993

M. E. Bruner
Principal Investigator

Solar & Astrophysics Laboratory
Lockheed Research & Development Division
Organization 91-30, Building 252
3251 Hanover Street
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(NASA-CR-189340) SPARTAN HIGH RESOLUTION SOLAR STUDIES Final Report, 21 May 1987 - 31 Oct. 1993 (Lockheed Missiles and Space Co.) 24 p

N94-34944

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Lockheed Missiles & Space Company, Inc.

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1 INTRODUCTION

The subject of this investigation is the study of the physics of the Solar Corona through the use of high resolution soft x-ray spectroscopy and high resolution ultraviolet and soft x-ray imagery. This investigation is the continuation of earlier work performed under contracts NAS2-9181 and NAS5-25727. Work on the present contract was started in the summer of 1987, and represents the activity proposed in LMSC-DO88449 (2 July, 1984) for a SPARTAN investigation. Subsequent to our selection, the Challenger disaster effectively forced the indefinite suspension of SPARTAN flights. In discussions with the current discipline chief, Dr. J. D. Bohlin and this deputy Dr. H. S. Ahluwalia, we agreed to revise our plans for the SPARTAN hardware such that the equipment could be flown on sounding rockets, pending the availability of a long duration flight opportunity. This agreement was documented in our letter of August, 1987 to Dr. Ahluwalia. The name of the program was changed in 1989, when the NASA Space Physics Division's Sub-orbital Program was reviewed and re-competed. The new name, Solar Plasma Diagnostics Experiment (SPDE), emphasized the essence of the physics investigation, rather than the program identification.

1.1 Program Overview

The objective of the Lockheed Solar SPARTAN (SPDE) Program is the study of the physics of the solar corona and the underlying chromosphere using the techniques of high resolution imagery and spectroscopy in the ultraviolet and soft X-ray regions of the spectrum. The thrust of the investigation is twofold. First is an exploratory phase in which we study the sun with new, state of the art instrumentation, to see what discoveries may be made when we open our eyes in new ways. In the second phase we seek to interpret the data in terms of physical processes and conditions in the regions that we observe. The emphasis in the first phase has been on high resolution spectroscopic observations in the soft x-ray region and on high resolution imaging in the ultraviolet. Beginning in 1985, we introduced the use of multilayer mirrors to both image the sun in soft x-rays (44 Å) and to limit the spectral bandpass to a single, narrow band of ionization temperatures.

Our primary tool in the second phase of the investigation is diagnostic spectroscopy applied to the UV and soft x-ray spectra, guided by analysis of the UV and soft x-ray images which give both geometric and radiometric boundary conditions. The essence of the analysis is quite simple. From the intensities of allowed transitions, we derive the emission measure, defined as the integral of the square of the electron density over the emitting volume. There are also a number of lines that are density sensitive in the sense that their intensities are not directly proportional to the emission measure, but have some other dependence. Intensity ratios among lines of differing density dependence can be used to infer the electron density of the emitting region. Both the emission measure and the electron density can be determined as functions of temperature by selecting appropriate ions. By combining the emission measure found in each temperature interval with the electron density determined for the same intervals, we can derive the volume of the plasma that lies within each interval. This, together with the geometry, forms a fairly complete physical description of the plasma that can be compared with theoretical predictions.

The scope of the investigation includes the development of a sounding rocket payload (Figure 1), launch support activities for acquiring solar data relevant to the investigation, analysis of the flight data, and publication of the results in the open scientific literature. Deliverables under the contract include semi-annual Progress Reports, developed during the course of the work, and this Final Report.

The majority of the effort under contract NAS5-29739 went into the development of the new sounding rocket payload and its operating system. This new payload is revolutionary in that it represents a complete system for doing experiments in space, rather than the simple implementation of a particular experiment. The payload is re-configurable, and can be quickly modified to perform a wide variety of experiments. More detail will be given in a later section of this report. The payload has been flown once during the course of the contract, and will be re-flown in 1994 under a follow-on contract. Scientifically, the first flight was very rewarding, yielding several discoveries about the spatial relationships between coronal and transition zone structures. A number of papers have been published or presented at scientific meetings.

Program activities and accomplishments have been documented in semi-annual reports that have been submitted during the course of the contract. The remainder of this Final Report consists of a description of the sounding rocket payload hardware, a guide to the contents of the semi-annual reports, a report on the 1993 work, and a bibliography.

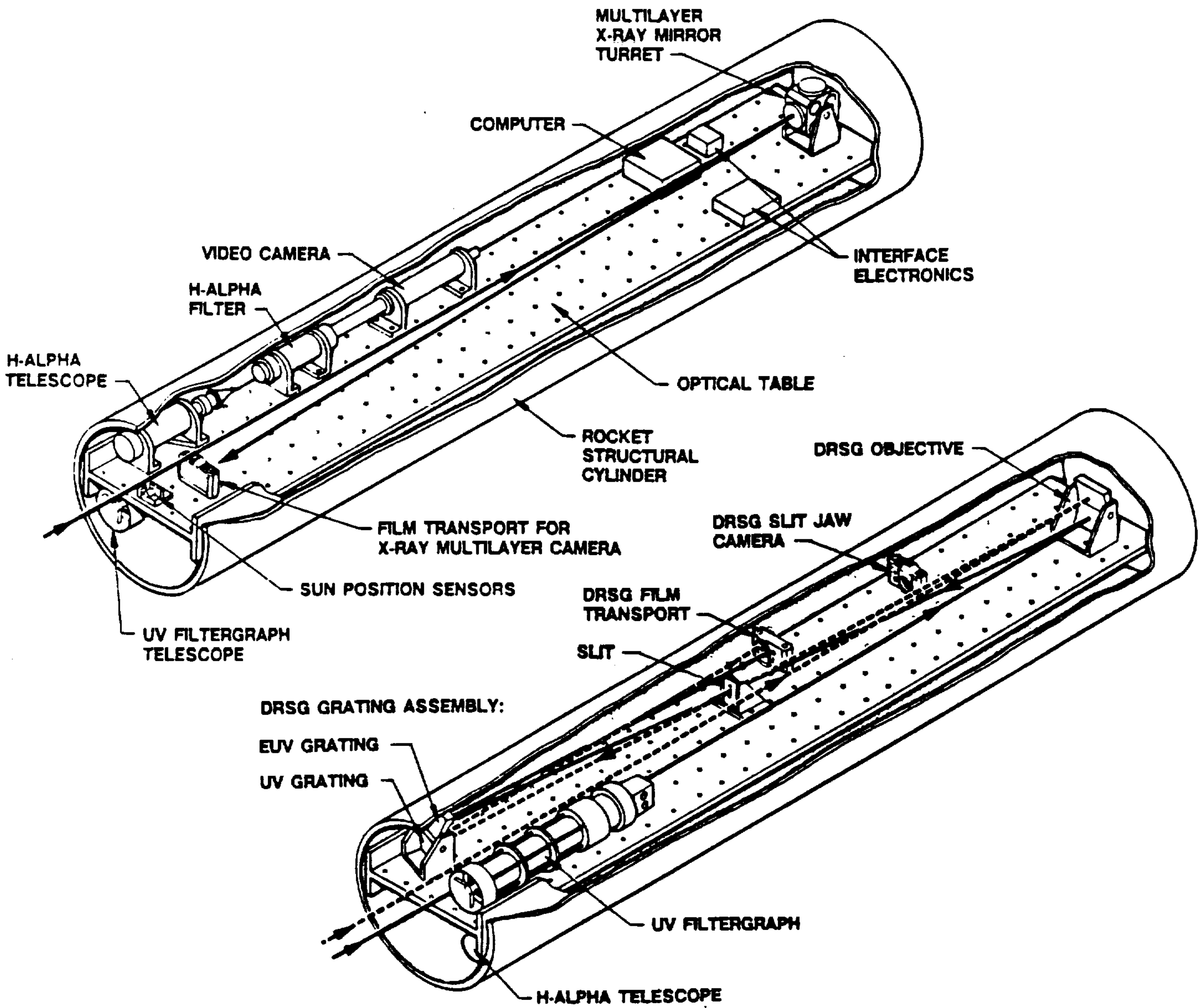

Figure 1: The Solar Plasma Diagnostics Experiment (SPDE) Payload

2 SOUNDING ROCKET PAYLOAD

The SPARTAN / SPDE payload is a suite of complementary instruments carried on a common support structure. The instruments are modular; the payload is re-configurable and can be readily augmented or modified to accommodate changing scientific objectives and different phases of the solar cycle. The instruments in the suite have been chosen to acquire the data needed for a complete diagnosis of the physical state of the matter in the selected region of the solar atmosphere and the geometry of the magnetic field in which it is found. Modules currently installed include a Dual Range Spectrograph (DRSG), a Normal Incidence X-ray Imager (NIXI), an Ultraviolet Imager (UVI), and an H-α telescope. Each of these modules is discussed in the material to follow.

2.1 Optical Table System

The heart of the payload is the Lockheed Optical Table System (LOTS), a rigid, temperature compensated optical support structure carried within the experiment compartment of the launch vehicle (Figure 2). Each side of the LOTS table is fitted with a grid of threaded metal inserts for mounting instrument components to it. An instrument is created by fastening its optical elements, stops, baffles and detectors to the table at appropriate locations just as optical "breadboarding" is done in the laboratory. The rigidity and stability of the table ensures that all modules of the SPDE payload will remain in alignment and focus throughout the test and launch environments.

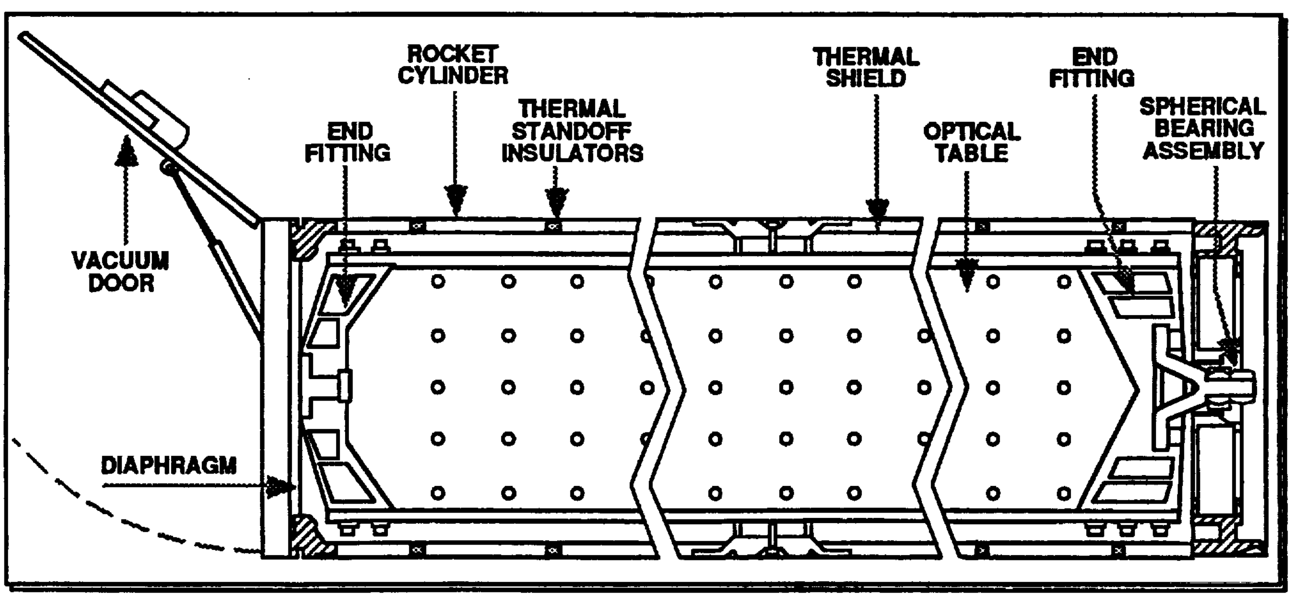

Figure 2: The Lockheed Optical Table System (LOTS) is a versatile platform that serves as a "flying optics laboratory". Instruments are created by attaching optical components to the table at appropriate locations via a series of threaded inserts.

The LOTS table is constructed of carbon fiber / epoxy composite face sheets bonded to a vented aluminum honeycomb core in the shape of an "H" beam. The lay-up of the face sheets is designed for a zero coefficient of thermal expansion, and they are made with a special hydrophobic resin that does not form hydrogen bonds with water vapor. The resulting structure is dimensionally stable and is insensitive both to temperature and to moisture content.

The table is supported at its ends via aluminum fittings that are both bonded and bolted to it. The end fitting farthest from the aperture is attached to the rocket structure via a steel shaft and spherical bearing assembly that supports lateral and thrust loads but isolates the table from torsional loads and bending moments. The end fitting at the aperture is supported laterally and in torsion by a steel diaphragm that is fastened at its perimeter to the rocket skin. Longitudinal strain due to thermal expansion of the rocket experiment compartment is absorbed by flexing of this diaphragm. This design provides a very robust, but completely strain-free support for the optical table.

The experiment compartment is evacuated prior to launch; a mechanized door at the aperture end opens after the payload leaves the atmosphere, and closes prior to re-entry. Radiation shields on the interior walls of the payload compartment protect the instrument assembly from the effects of aerodynamic heating of the rocket skins during the ascent phase. These shields are fitted with heaters and temperature sensors for use in pre- conditioning the payload temperature for launch.

Control and sequencing of the SPDE instrument suite is performed by an on-board microcomputer based on the Harris 80C86 processor. Operation of the flight computer is directed by a PC based ground terminal via an RS-232 link, which also returns status information to the terminal. The RS-232 signals are carried by a hard-wire cable for laboratory work, and by a full- duplex telemetry link for flight. Operation of the system is identical in both environments. There is also a bi-directional link between the LOTS ground terminal and the ground support console for the rocket attitude control system. With the aid of this link and appropriate software, it is possible for the flight computer to interactively control the pointing of the rocket.

It is clear from the above that the Lockheed Optical Table System is a very versatile "flying optics laboratory", suitable for a wide range of applications. Its central role in the SPDE payload is illustrated in the following sections.

2.2 Dual Range Spectrograph (DRSG)

The DRSG (Figure 3) consists of an off-axis parabola operating as a prime focus telescope, a slit assembly, a toroidal grating assembly, and a film camera. Functionally, the DRSG operates as a co-aligned pair of stigmatic spectrographs. The grating assembly contains two toroidal gratings, one optimized for the 120 - 160 nm region and the other for the 26 - 31 nm region. The rectangular primary mirror has a 1.8 m focal length, and carries two different coatings, one appropriate to the range of each grating. Light entering the instrument strikes the primary mirror which forms an inverted image of the sun on the entrance slit. The slit serves as a field stop, and defines a segment of a chord on the solar disk that will be sampled by the spectrograph sections. Light passing the slit illuminates the two gratings which disperse the spectrum, and form images of the two spectral ranges on the film. Visible light is excluded from the EUV section of the DRSG by a thin aluminum filter

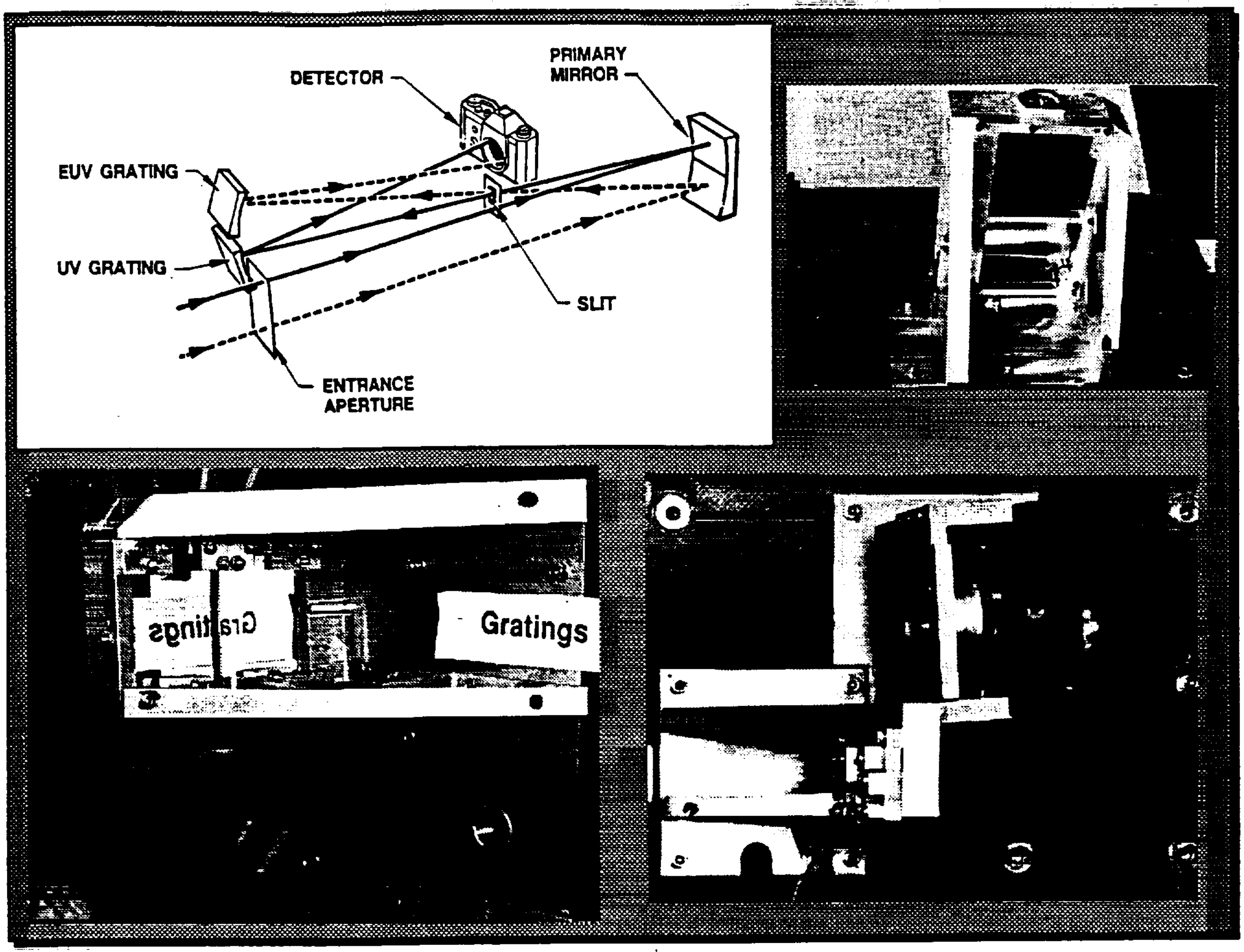

Figure 3: The Dual Range Spectrograph. Upper left: optical schematic. Upper right: primary mirror and mount. Lower left: the two diffraction gratings in their mount. Lower right: slit assembly and Canon T-70 film camera.

just in front of the focal plane. Attenuation of near UV radiation is provided by a "black mirror" coating on the telescope primary. Optically, the DRSG spectrographs are similar to the SERTS spectrograph developed by GSFC. We are pleased to acknowledge the assistance of Dr. Roger Thomas of the GSFC with the optical design.

Since both spectrographs are stigmatic, there is a one to one mapping of points along the sampled chord of the solar disk onto points along the length of the image of each spectral line. The use of a common primary mirror for the telescope ensures that the two sections of the spectrograph sample exactly the same field on the sun. For a given setting of the rocket orientation, the instrument simultaneously observes both the UV and the EUV spectra of about 500 spatial elements on the solar disk.

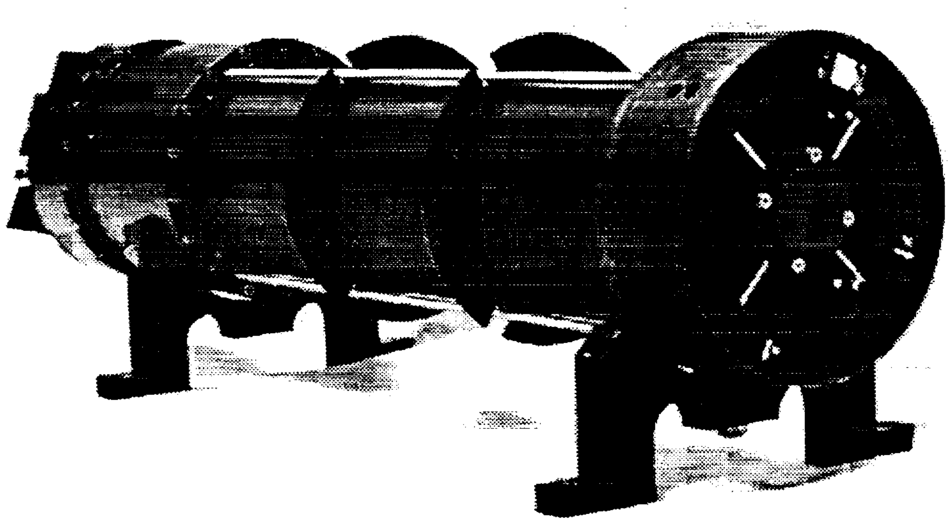

Figure 4: The Ultraviolet Filtergraph (UVF), developed in France, consists of a normal incidence cassegrain telescope, a filter wheel, a shutter mechanism, and a film transport. It has been flown on several Lockheed sounding rockets, including the 12 May, 1992 flight.

2.3 Normal Incidence X-ray Imager (NIXI)

The NIXI is a very simple instrument that uses a series of four multi-layer mirrors to record soft X-ray and EUV images in selected narrow bands between 171 and 304 Å. The four spherical mirrors are mounted on a turret mechanism that rotates each mirror in turn into position as the primary mirror of a Herschelian telescope. Images are recorded on Kodak T-max 100 film carried in a Canon Model T-70 camera body. The NIXI turret and camera are illustrated in Figure 1, presented earlier. Visible light is excluded from the interior of the camera by a thin aluminum film supported on nickel mesh. The focal length of each mirror is 250 *cm*, giving a plate scale of 12 *m/arcsec*. The 7.6 *cm* diameter mirrors each have a geometric collecting area of 45 cm^2. Aberrations are well controlled; the resolution of the system is expected to be about 1 *arcsec* when used with the high resolution T-max 100 tabular grain emulsion. Although the NIXI was carried on the 1992 flight, the data were lost due to a defective aluminum filter. A protective cover for the filter, being added for the next flight, will eliminate this problem in future SPDE missions.

2.4 Ultraviolet Imager (UVI)

The UV Imager (Figure 4) has produced a wealth of data on several previous Lockheed sounding rockets. Originally developed in France under the direction of R. M. Bonnet, the UVI has an aperture of 12 *cm*, an effective focal length of 2 *m*, and a field of view of 40 *arcmin*. A four position filter wheel selects the wavelength range to be observed, and images are recorded on film. The cassegrain optics are very well corrected; the telescope has achieved spatial resolution better than 1 *arcsec* on previous flights.

2.5 Electronics System

Figure 5 is a simplified block diagram of the SPDE electronic system. As discussed in Section 4.1, the control system is built around a microprocessor system, interfaces, and an appropriate software package, all of which were developed during prior phases of this investigation. Each instrument module has a unique electrical interface unit that decodes and accepts commands from the computer's parallel I/O bus. Most of these interface units are simple relays that actuate the remote shutter controls of the Canon T-70 cameras. More complex units are needed for the NIXI turret, the UVI mechanisms, the etalon control electronics, and the CCD cameras. A junction box distributes system power, ground and control signals to the interface units, and also serves as a termination and routing point for cables to the rocket instrumentation and instrument umbilical connectors. Control of the operating mode of the electronic system is directed from the ground via an RS- 232 command link to the flight computer. The link is also used to return on-board software status to the ground terminal during the pre-launch and flight phases of each mission. All elements of the system performed flawlessly during the 1992 flight.

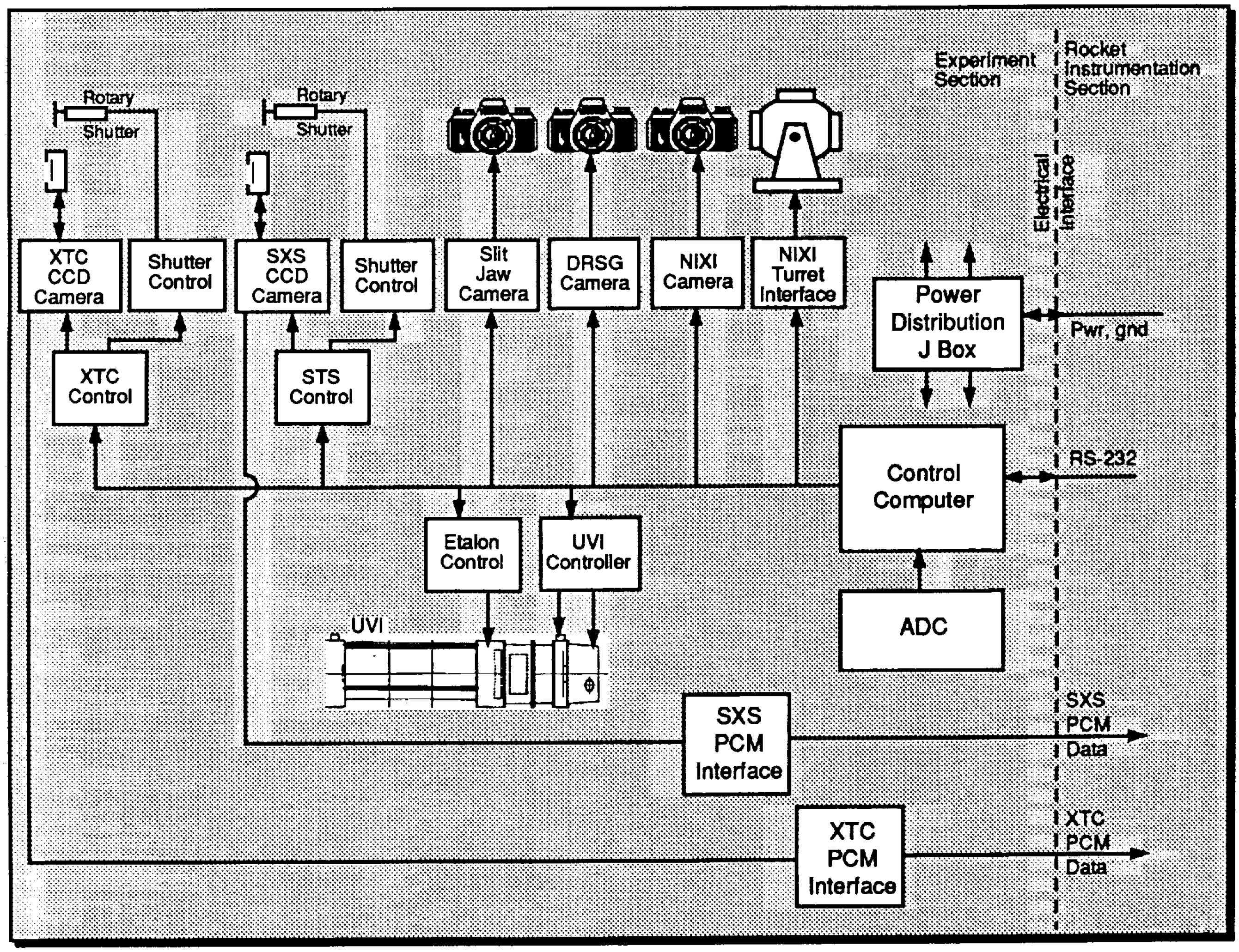

Figure 5: The instruments in the SPDE payload are controlled by an on-board computer and a sequencing software package. Operation of the computer is directed by a full duplex RS-232 link to the experimenter's console on the ground. With the aid of appropriate links between Ground Support Equipment computers, it is possible for the flight computer to interactively control the pointing of the payload. All parts of this system performed flawlessly during the 12 May, 1992 flight.

3 GUIDE TO PROGRESS REPORTS

The material in this section is an extended table of contents to the semi-annual reports that have been prepared and submitted during the course of the contract. It is intended to serve as a guide for the reader to the major project activities and accomplishments. For details of these activities, the reader is referred to the individual reports.

3.1 1 July, 1987 – 29 February, 1988

This is the initial report prepared under the contract. In addition to descriptions of the progress during the reporting period, it contains an overview of the program and a brief history of the accomplishments and work performed during the prior investigations that led to this contract.

Activities during the reporting period:

- The Optical Table System design was defined.
- Flat Field Spectrograph (FFSG) ray trace was performed on the S. Mrowka design. (A design prepared during an earlier contract.)
- Preliminary optical design and system layout of Dual Range Spectrograph (DRSG) was completed.
- The Normal Incidence X-ray Imager (NIXI) turret mechanism assembled.
- A preliminary camera mount design for the NIXI was completed.
- One paper was published and two others were in preparation. (Note: all papers published, submitted, or prepared during the course of the contract are listed in the Bibliography at the end of this report.)

3.2 1 March, 1988 – 30 May, 1988

Activities during the reporting period:

- The detailed design of the Optical Table completed.
- The DRSG optical design was reviewed. A Revised optical layout was prepared. Diffraction grating sources were investigated.
- The detailed design of the NIXI camera mount was completed.
- A Project Initiation Conference for the initial flight of the new payload was held at the NASA Wallops Island Flight Facility (WFF).
- One previous publication was cited.

3.3 1 December, 1988 – 31 May, 1989

Activities during the reporting period:

- The Optical Table was ordered from Fibertek. The structural system detailed design work was largely completed.
- The gratings for the DRSG were ordered.
- The detailed design of the NIXI was completed. Most mechanical parts were fabricated.
- The system electronic design was completed. The flight computer was received. Computer housing design was started. Interface circuit printed circuit board layouts were completed.
- One invited paper on SPDE payload was prepared for the August, 1989 SPIE meeting in San Diego, CA. A preprint of the paper is appended to the report.

3.4 1 June, 1989 – 28 February, 1990

A significant event during this reporting period was the occurrence of a major earthquake on October 17th, 1989. The earthquake severely damaged Lockheed laboratory building 255, in which the work on this contract was being performed. The building could not be occupied for many months. The payload equipment, though undamaged, was packed and moved several times in the following months, causing substantial program delays and resulting in a considerable amount of lost effort.

Activities during the reporting period:

- The Optical Table Assembly was delivered. Initial mechanical integration was completed.
- The payload electrical wiring was completed and checked out.
- The flight software package was written and checked.
- All optics except for the two DRSG diffraction gratings were delivered.
- The Ultraviolet Filtergraph (UVF) arrived from France, and was integrated with the payload. The mechanical interface arrangement was modified and re-manufactured at the request of the UVF field engineer.
- The central mounting ring of the rocket structure was received from WFF and fit-checked with the optical table assembly.
- The DRSG gratings and slit components were received. Canon T-70 film cameras to support the first flight were loaned to us by Professor A. Walker at Stanford University.
- The H-α system from our previous rocket payload was re-packaged and installed.
- Electronic system manufacture and integration was completed. The flight software was tested and debugged.

3.5 1 March, 1990 – 30 September, 1990

Delays related to the aftermath of the October 17, 1989 earthquake continued through this period. A number of small payload parts could not be located and had to be re-manufactured. A large surface plate, used for optical alignment, was restored to service in Lockheed Building 255. Although building 255 re-construction work was still in progress, critical laboratory areas were approved for occupancy. Personnel were required to wear hard hats, and much of the building was contaminated with dust and construction debris. Working conditions were difficult, at best.

Activities during the reporting period:

- The rocket structural cylinders were received, fit checked, and returned to WFF for the installation of heaters.
- Payload handling equipment was designed and fabricated.
- A UV collimator design approach was developed. A mirror for the collimator (purchased by Lockheed) was received.
- The DRSG primary mirror mount was re-designed to improve its strength and stability under vibration.
- Two of the NIXI mirrors were coated with silicon-molybdenum multilayers.
- Extended tests of the electronic system revealed some minor problems.

3.6 1 October, 1990 – 31 March 1991

Repairs to Lockheed laboratory building 255 were completed, and the building was re-occupied.

Activities during the reporting period:

- The rocket structural cylinder was received and vacuum tested.
- Mechanical work on the vacuum UV collimator was completed.
- The DRSG primary mirror mount was re-built, improving its strength and rigidity. The grating mount was modified.
- Mechanical problems requiring re-work were found with the NIXI turret mechanism. A third NIXI mirror was coated. Preliminary optical alignment was completed.
- Work on the vacuum collimator was nearing completion. A new EUV source (purchased with Lockheed funds) was received.

3.7 1 April, 1990 – 30 November, 1991

Special Contract Report

This narrative report was prepared at the request of NASA Headquarters as part of a comprehensive review of the NASA Sub-orbital Program. Although it overlaps with the two previous reports, it also contains a synopsis of the performance evaluation activities, including sample UV and EUV spectra and photographs of the hardware. The need to eventually replace the Schumann emulsion film is discussed. This film is used in the DRSG, UVF and in the planned FFSG, and is no longer available from any source. Testing of the existing filters for the French UVF showed that they had deteriorated since the last flight in 1985 and would need to be replaced at a cost of $10,000. Delivery was projected for February, 1992. Two papers were presented at the Katsuo Tanaka Memorial Symposium in Tokyo. A synopsis of the second paper is given in the report.

3.8 1 December, 1991 – 31 March, 1992

This report discusses the final pre-launch preparations of the payload and the field activities for mission NASA 36.048. The launch took place at the White Sands Missile Range on 12 May, 1992. Results are summarized in the report.

Activities during the reporting period:

- We discovered and corrected a roll orientation problem.
- We designed and installed a secondary light baffle system in the DRSG.
- The NIXI turret mechanism was modified to increase the strength of the Geneva drive mechanism. Mirror retaining springs were modified to eliminate a mirror distortion problem.
- The UVF film camera spring retractor mechanism was modified to correct a design problem. The film transport motor failed in test and was replaced. The shutter solenoids, which had been damaged in test, were re-worked to eliminate sticking. The shutter drive circuits were modified to include overload protection.
- A vacuum leak in the H-α video camera was found and repaired.
- The new payload was successfully launched and recovered on 12 May.
- A coordinated co-observing campaign was conducted in support of the 12 May launch.
- Microdensitometry of the UVF films were performed in France. Portions of the data set were transmitted to Palo Alto via computer networks.

3.9 1 July, 1992 – 30 September, 1992

This report discusses the preliminary data evaluation. Sample data are presented, including a UV spectrum from the DRSG, and a C IV image from the French UVF. The limb brightening that characterizes solar C IV images is clearly visible, as are the chromospheric network, several active regions, and a number of coronal bright points. Simultaneous data from the Yohkoh Soft X- ray Telescope, (SXT), the Very Large Antenna Array radiotelescope (VLA), and a magnetogram from the Lockheed tunable filter at La Palma are also presented. An appendix contains a partial UV line list from the DRSG. The C IV image was discussed in an informal presentation at the American Astronomical Society meeting in Columbus, Ohio.

Most of the FY 1992 funding was expended in the final preparations of the payload and in support of the launch operations at White Sands. The remaining balance of the FY 1992 funds were used in the microdensitometry of the flight films and in related preliminary data analysis activities.

4 1993 PROGRESS REPORT

Work performed on the contract during the final two reporting periods is discussed in this section of the final report. The scope of this work is substantially lower than originally planned for this period, as the NASA WFF contracting office decided to transfer part of the scope of work to a new contract. Approximately $60,000 of FY 1993 funding was made available to this contract to continue the data analysis and to prepare a final report. The planned second launch of the rocket payload in 1993 was eliminated, and will be conducted under follow-on contract NAS5-32147.

4.1 1 October, 1992 – 30 April, 1993

The activity level during this reporting period was very low due to a delay in the arrival of the FY 1993 funding, and no formal report was submitted. Most of the funds were used in support of the continuing data analysis effort. New microdensitometry of the UV spectra from the DRSG was performed, using a new laboratory CCD camera. (The camera was acquired by Lockheed as a fixed asset, and made available at no cost to this contract.) These microdensitometer results and the data from the C IV images were transferred electronically to the Yohkoh control center in Japan for detailed comparison with the SXT images. Preliminary co-alignment of the X-ray and UV images revealed an arcade of X-ray loops overlying a filament channel that was visible in the C IV image.

Some effort was devoted to the preparation of figures for and final revisions to a paper on the interpretation of the flare spectrum obtained during our 13 July, 1982 sounding rocket flight. We also prepared figures and final revisions to a paper on scale heights observed in C IV images taken during the SMM era.

4.2 1 May, 1993 – 31 October, 1993

The comparison of SXT and C IV images continued at the Institute for Aeronautical and Astronautical Sciences in (ISAS) Japan. Codes were written to re-scale and rotate the C IV images such that they matched the soft X-ray images. Initial matching was done at the limb, and final scaling and matching were done on coronal bright points that were visible in both the C IV and SXT images. Once co-alignment was complete, a blink comparison technique was used to identify the UV counterparts of the soft x- ray images. The comparisons were striking, and resulted in several new discoveries as follows:

UV / Soft X-Ray Study Results

- The footpoints of most soft x-ray loops are bright in C IV.
- X-ray Bright Points typically show pairs of footpoints in C IV.
- A filament channel appears dark in C IV, presumably due to absorption in the Balmer continuum.

- Bright C IV loops are associated, but not coincident with soft x-ray loops over the emerging flux region.
- At least one soft x-ray active region loop appears to coincide with one end of a C IV loop, suggesting the existence of a longitudinal temperature gradient in the loop.

The central result is illustrated in Figure 6, which illustrates an active region near the center of the solar disk in both C IV and soft x-rays. The figure is presented as a composite, consisting of a C IV image, shown in shades of red, and a transparent overlay on which the soft x-ray image is printed in shades of blue. Both images are negatives; that is, higher degrees of color saturation represent higher intensities. North is at the top and West is on the right side of the figure. Viewing the figure while raising and lowering the overlay dramatically illustrates our finding that bright C IV emission is found at the footpoints of the soft x-ray loops.

A paper discussing these results was presented at the July, 1993 meeting of the Solar Physics Division of the American Astronomical Society at Stanford University. A more extended paper on the results is currently in preparation for submission to the Astrophysical Journal. An abstract of the latter is found at the end of this section.

Other activities during this reporting period included submission of the manuscript of the 13 July, 1982 flare paper, arrangements for disposition of the residual government property assigned to this contract, and preparation of this final report. The residual accountable property has been transferred to the follow-on contract, NAS5-32147.

Figure 6: Comparison of soft x-ray and C IV images of a solar active region observed on 12 May, 1992. The C IV image, observed with the rocket Ultraviolet Filtergraph is shown in shades of red, while the soft x-ray image taken by the Yohkoh Soft X-ray Telescope is shown on an overlay in shades of blue. Both are negative images; increasing saturation of red and blue represent increased intensity in the C IV and soft x-ray images, respectively. Lifting the overlay clearly illustrates the correspondence between the footpoints of the coronal loops seen in soft x-rays and bright emission in the transition zone as seen in the C IV image.

The Corona – Transition Zone Interface

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J. R. Lemen M. Morrison K. T. Strong

July 10, 1993

Abstract

We report on simultaneous imaging of the solar corona and transition region made with the *Yohkoh* Soft X-ray Telescope (SXT) and the Ultraviolet Imager (UVI) on a Lockheed sounding rocket payload. The observations were carried out during the 12 May, 1993 flight of the Solar Plasma Diagnostic Experiment (SPDE), a new sounding rocket payload for solar studies. The UVI recorded images dominated by the C IV doublet at 1548, 1550 Å, the H-lyman α line at 1216 Å, and the continuum near 1700 Å. Both instruments had fields of view large enough to include all or most of the solar disk. Co alignment of the C IV and soft X-ray images was done by matching coronal bright points seen in both. We found intense C IV emission at the footpoints of most X-ray loops. X-ray bright points were correlated with pairs of UV bright points, indicating that the X-rays were confined to a loop (as expected) and that the transition zone was brightest at its footpoints. Larger X-ray loops that had simple dipole-like structures were associated with bright C IV areas at each end. X-ray loops that were highly sheared appeared to correlate with C IV bright points that were separated from the apparent ends of the X-ray features, suggesting the existence of a region of substantial size at intermediate temperatures.

Figure 7: Abstract of Paper in progress.

5 SUMMARY AND RECOMMENDATIONS

The bulk of the effort during the phase of the SPARTAN / SPDE investigation covered by this contract has been directed toward the development, qualification, calibration and flight of a new sounding rocket payload. This new payload represents a major step in the technology of rapid response low-cost optical instrumentation. By basing the structure on a re-configurable optical table, we have created a "flying optics laboratory" that is capable of addressing a wide range of diverse experimental objectives requiring access to space. Its utility is certainly not limited to solar physics experiments, or even to optical instruments. The Lockheed Optical Table System (LOTS) is well suited to the application of high precision mechanical metrology techniques to alignment (and co-alignment) of the various optical systems that make up the SPDE payload. Our experience with the build-up of the SPDE instruments as modules on the LOTS has confirmed our expectations that the approach would work well. We recommend the use of the LOTS as a cost-effective approach to the rapid flight qualification of new instrument and flight subsystem technology.

In keeping with its heritage in the SPARTAN program, we have designed the SPDE payload for compatibility with the SPARTAN carrier and the mechanical envelope of the Space Shuttle. In addition to preconditioning the payload and protecting it from contamination, the vacuum canister serves as a containment vessel meeting key safety requirements in the Shuttle environment. The thermal design of the payload includes radiation shields, structure heaters, and temperature sensors as well as a temperature compensated optical structure; the major elements needed for thermal control in orbit are already installed. Thus, the SPDE payload is ideally suited for flight on a SPARTAN. Such a flight would enormously increase the value of this scientific investigation, and we strongly recommend that the SPDE payload be considered for a SPARTAN flight at the earliest opportunity.

Two new instrument modules were developed during the contract, the Normal Incidence X-Ray Imager (NIXI) and the Dual Range Spectrograph (DRSG). The NIXI is a normal incidence herschelian telescope that uses multilayer mirrors to both enhance the soft x-ray reflectivity and to define the narrow bandpasses needed to isolate different coronal temperature ranges. It is based on a turret mechanism that was developed during a previous contract. The turret carries four different mirrors, allowing the instrument to isolate four different temperature ranges. Although the turret mechanism and film transport functioned nominally during the 1992 flight, the data were spoiled by a damaged thin aluminum filter. A protective door for the filter is being designed for use in future flights.

The DRSG is the first implementation of an idea developed by M. Bruner with the assistance of Dr. R. Thomas of GSFC for use in studying solar flares. The DRSG was originally part of the SHAPE experiment proposed for the Max-91 mission. The instrument consists of two stigmatic grating spectrographs fed by a single telescope arranged such that the fields sampled by the spectrographs are strictly co-aligned. One spectrograph is sensitive to plasmas formed primarily in the corona, while the other is sensitive to emission arising in the transition zone, chromosphere, and temperature minimum region. Results of the first flight demonstrated the basic soundness of the design and produced a useful spectrum that is now being analyzed. Performance of the UV section demonstrated very high sensitivity. Aperture reduction can be used to balance sensitivity with the EUV section for future flights.

Minor design changes have been identified to improve scattered light control and relative sensitivity of the two spectrograph sections.

The ruling of two new diffraction grating masters was commissioned during the development of the DRSG. These grating masters remain available so that the production of replica gratings will be available at low cost for reproducing the DRSG design in the future. The DRSG has been identified as a possible candidate for the HESP mission, now in the planning phase.

We draw attention to the fact that the special films used by both of these instruments are no longer being manufactured, and that existing supplies will soon be exhausted. We strongly recommend that the film cameras be replaced with CCD detectors at the earliest opportunity.

Continuing analysis of data acquired during previous rocket flights has resulted in a number of papers and presentations during the period of performance. Two papers and one presentation were based on the analysis of the x-ray flare spectrum obtained during our 13 July 1982 flight. The shell model of post-flare loops, postulated to explain these data, is beginning to gain acceptance in the solar physics community as other investigators find that it also is useful in interpreting their data. A number of papers on the instrumentation have also been published.

The most significant finding to date from the 12 May, 1992 flight is the correspondence between footpoints of coronal x-ray loops and bright emission in the C IV line. Although this relationship is expected on theoretical grounds, these data are to the best of our knowledge, the most convincing demonstration of the effect. Bright C IV emission at the bases of loops is expected as a consequence of heating of the upper chromosphere by thermal conduction from the million degree plasma found in the loops. The heating is expected to be localized because of the effect of the magnetic field, which reduces the mobility of electrons (and hence the thermal conductivity) across field lines with respect to that along the field. A paper on this result was presented at the July, 1993 meeting of the AAS Solar Physics Division; a more extended version of the paper is in preparation for submission to the Astrophysical Journal.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1993

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
SPARTAN High-Resolution Solar Studies
Final Contract Report

5. FUNDING NUMBERS
NAS5-29739

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lockheed Research and Development Division
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Palo Alto, CA 94304

8. PERFORMING ORGANIZATION REPORT NUMBER
Org. 91-30

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
CR-189340

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category 92

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report summarizes the work performed on Contract NAS5-29739, a sub-orbital research program directed toward the study of the geometry of and physical conditions in matter found in the upper layers of the solar atmosphere. The report describes a new sounding rocket payload developed under the contract, presents a guide to the contents of semi-annual reports submitted during the contract, dicusses the results of the first flight of the payload and the progress on scientific analysis. A bibliography of papers and publications is included.

14. SUBJECT TERMS
sun, corona, chromosphere, transition region, ultraviolet, x-rays, images, spectra, sounding rocket, sub-orbital

15. NUMBER OF PAGES
22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)