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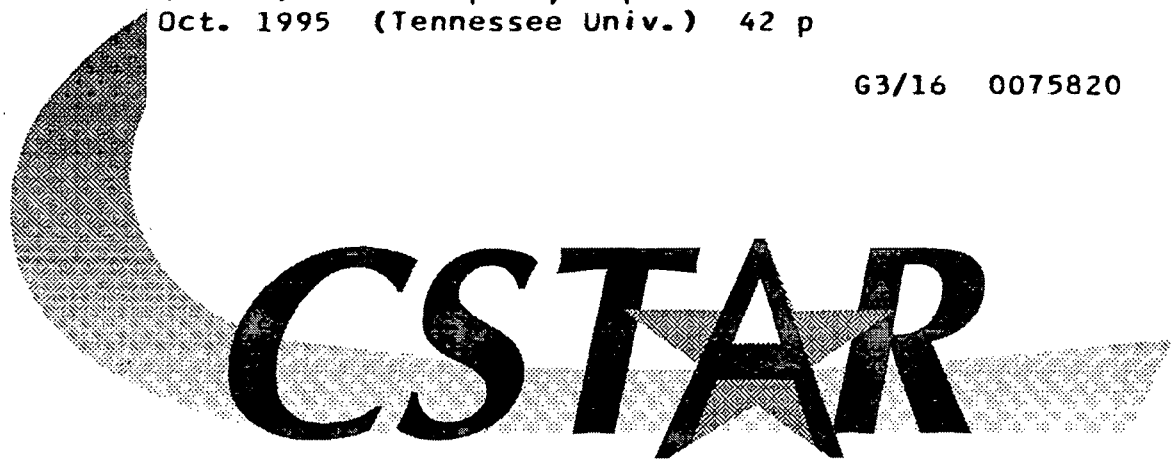
Center for the Commercial Development of Space

NAGW - 1195

FINAL REPORT

September 1987 through October 1995



GRANTEE:

University of Tennessee
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OCTOBER 1995

FINAL REPORT

ATTACHMENTS

A. Grant NAGW-1195 and Supplements 1-19
B. WCSC Final Report
C. CASP Annual Report , October 1, 1987 thru October 30, 1988, NAGW-1195
D. CASP Annual Report, November 1, 1988 thru October 31, 1989, NAGW-1195
E. CASP Technical Symposium, October 1989
F. CASP Second Annual Technical Symposium, November 1990
G. CSTAR Third Annual Technical Symposium, January 1992
H. CSTAR Fourth Annual Technical Symposium, November 1992
I. CSTAR Fifth Annual Technical Symposium, November 1993
J. CSTAR 1993 Annual Report December 1993
K. EER/CSTAR agreement to drop lawsuit

University of Tennessee Center for Space Transportation and Applied Research (CSTAR®)
NAGW-1195 FINAL REPORT
October 1995

1. OVERVIEW

NASA advised CSTAR® by a letter signed by Mr. Gregory M. Reck on December 20, 1993: "I regret to inform you that your Center for Space Transportation and Applied Research (CSTAR®) will be phased out beginning this quarter." The letter further requested a phase out proposal, and advised that decisions relative to the COMET Program were under study.

CSTAR® submitted a plan to meet the NASA objectives; unfortunately, NASA did not fund all the requirements. A far less ambitious plan was directed by NASA, and the phase out began. Because of a lengthy dispute with one of the COMET contractors, the final close-out activities were delayed well into the second half of Grant FY-95.

This report addresses the status of all projects at the time of close-out notification, December 1993, and the close out activities of each. Some issues, not normally included in a technical report will be included here as a convenience to the NASA Technical Representative as well as to others concerned with completeness of the close out package.

Because of the size of the COMET program a separate section has been dedicated to that report. Even so, where appropriate COMET will be discussed in the other sections.

2. HISTORY

NAGW-1195, entitled "Center for the Commercial Development of Space," was issued to the University of Tennessee - Calspan Center for Aerospace Research (CAR), September 10, 1987. At that time Dr. John William Davis was the Principal Investigator. There have been nineteen supplements to the basic Grant, to fund the COMET, EPOP, SAILS, and WCSC programs - as well as administrative no-cost Grant Supplements. The table on the following page identifies the Grant Supplement, date issued, funding distribution, and title. A copy of the Grant NAGW-1195 and each of its supplements is provided as Attachment A to this report. With the issuance of Supplement 3 in October 19, 1988, Dr. Edward M. Kraft was the designated Principal Investigator. Dr. Davis remained a member of the Board of Directors. Demands on Dr. Kraft by his parent organization required him to step down as Executive Director of CSTAR®. At that time Dr. George Garrison became Executive Director and with Supplement 5 dated February 5, 1991 was also the designated Principal Investigator. He has remained Principal Investigator through the close out of the Grant.

It was at about this time the organization was renamed, University of Tennessee Center for Space Transportation and Applied Research or simply CSTAR®.

NAGW-1195 SUMMARY FUNDING

#	Date	Base Grant	COMET	Other	Total	Comment
B	10/15/87	$500,000			$500,000	CCDS Dtd April 1987
1	4/13/88				$0	Admin 5 wk extension
2	6/6/88	$583,300			$583,300	CCDS
3	10/19/88	$1,000,000			$1,000,000	CASP at UTSI-Calspan
4	1/24/90	$1,000,000			$1,000,000	CASP at UTSI-Calspan
5	2/5/91	$1,055,000	$45,000		$1,100,000	CASP at UTSI-Calspan
6	3/28/91	$45,000	$6,000,000		$645,000	COMET
7	4/19/91		$9,000,000		$9,000,000	COMET
8	1/9/92	$1,000,000	$17,500,000	$250,000	$18,750,000	COMET: Base 1M, EPOP 200k, SAILS 50k, COMET mgt 600k, and Ks 1.85M.
9	12/7/92	$1,000,000	$22,050,000	$400,000	$23,450,000	COMET: Base 1M, EPOP 250k, SAILS 150k, COMET mgt 600k, and 21.45M.
10	12/14/92				$0	Administrative
11	6/8/93			$165,676	$165,676	NASA CCDS -- WCSC
12	1/12/94	$200,000			$200,000	NASA CCDS (Operational Expenses only)
13	2/8/94		$5,000,000		$5,000,000	NASA CCDS
14	4/11/94	$560,000			$560,000	NASA CCDS
15	4/25/94		$2,304,100		$2,304,100	NASA CCDS
16	10/27/94		$391,479		$391,479	NASA CCDS
17	11/16/94				$0	Administrative change
18	11/17/94				$0	Administrative Change
19	5/18/95				$0	Administrative Change
TOTALS		$6,943,300	$56,890,579	$815,676	$64,649,555	

It is essential to note that the COMET Program was an attempt by NASA to develop a commercial launch infrastructure. **CSTAR®** was the NASA instrument to accomplish that mission. There was no additional industrial contribution expected under this program beyond that which the major contractor team members chose to contribute in that commercialization effort. Other than providing a technical and financial monitoring function, on behalf of NASA, **CSTAR®** had no leverage to force the achievement of program goals. It was believed that the incentive of owning the first infrastructure for low earth orbit flights would entice the Contractor Team to excel, to finance self enhancing portions of the program, and to vigorously market the capability. NASA and **CSTAR®** overestimated the value of this incentive, and the program faltered; eventually NASA elected to cease funding the program through the CCDS in early 1994 and contracted directly with EER Systems to complete the program.

Other major programs funded by supplements 8, 9, and 11 were the Electric Propulsion Experimental Platform (EPOP), Space Applications for Industrial Laser Systems (SAILS), and Western Space Commercialization Center Infrastructure Study (WCSC). Each of these programs are addressed in significant detail later in Section III. WCSC was concluded with a final report, Attachment B, while the other two programs were essentially in early stages of development. It should be noted that both EPOP and SAILS had significant participation and contribution by our industrial partners.

A myriad of lesser programs were started and completed over the seven plus years of the Grant along with a number of programs that were currently underway at the time of termination. These programs were reported on a regular basis the **CSTAR®** Quarterly reports and the Annual Symposium Reports and, when appropriate, highlighted in Quarterly CCDS Director meetings and called meetings at NASA Headquarters. NASA Code C agreed, early in the CCDS program, that this reporting mechanism met NASA's reporting requirements. The attached five Annual Symposium Reports provide the technical baseline for this final report, Attachments C through J.

CSTAR® had enjoyed very positive feedback from the NASA Technical Office overseeing this Grant for six consecutive years. We had endeavored to meet the objectives of the NASA CCDS program and sought ways to meet and exceed those objectives. On October 26, 1993, **CSTAR®** received a NASA letter authorizing Pre-grant Costs for FY 94. This in itself was viewed as an administrative expediency, since NASA traditionally funded the Grant two to five months after the beginning of the Grant year (see the dates on the supplements in the matrix above).

On December 20, 1993, Mr. Gregory M. Reck of NASA, Code C, rendered the totally unexpected news by letter to Dr. George Garrison stating; "I regret to inform you that your Center for Space Transportation and Applied Research **CSTAR®** will be phased out beginning this quarter." While **CSTAR®** was braced for a budget cut, because it was well known that the CCDS budgets would be reduced in this year, the letter was received with total disbelief by **CSTAR®** management and staff alike.

While the loss of the Grant may well cause the "Phase Out of the Center for Space Transportation and Applied Research" Mr. Reck should have recognized that he was only phasing out the CCDS located at CSTAR.

The rationale used to justify the action had never been presented to **CSTAR®** for comment nor had CSTAR® been provided an opportunity to offer mitigating material in its defense. Neither was the one year "cure period" allowed as previously promised the CCD's. After years of receiving positive feedback from NASA, the allegations were totally unexpected and, in most cases, unfounded. The 1992 evaluation by NASA had ranked CSTAR® as one of the top four CCDSs in terms of its performance.

CSTAR® immediately commenced formulating a phase out plan, and submitted it to NASA in January 1994. The initial plan designed to support those elements NASA deemed essential required $1.6M. On February 17, 1994, **CSTAR®** was issued $760K with directions to *"protect as much as possible the commitments to students under the CCDS Program; we hope you will work with the students associated with the CCDS Program so that the promised resources for the current academic year is secure. To accommodate the student research, it is suggested that those projects involving students (9008 - Oxygen-Rich Gas Generator; 9011 - SAILS; 9130 - Parallel Computing Initiative; 9206 - Laser Industrial Partnership; 9301 - Evaluation of 3-Grid Ion Thrusters; 9304 - Laser Welding of Reflective Dissimilar Alloys; and 9324 - Hybrid Propulsion) receive priority of the allocated funds. The other projects should be closed out in an orderly but expeditious manner."* This directive ignored the fact that four months into a fiscal year budgeted at $2.4M, **CSTAR®** had already spent over $450K. NASA did not seem to recognize that with only $310K remaining that very few objectives could be supported and at the same time conduct a phase-out.

After scrubbing the requirements, and immediately announcing a lay off, **CSTAR®** advised NASA that of the remaining funds, there was only funding to bring the remaining projects to an orderly but immediate close. We were fortunate that in the case of Parallel Computing, LWDRA, Knowledge Based Systems, and Laser Projects, we had some continuing commitments by our industrial partners to ease the burden of terminating these projects. The details of these project close-outs are provided in Section III.

The one year allowed for contractors to prepare and submit claims on terminated contracts has significantly delayed **CSTAR®**'s ability to accumulate and compile the close-out package. In addition, the EER lawsuit necessarily required a considerable amount of time and Grant resources to resolve the dispute. **CSTAR®** was defending, on behalf of NASA, a significant claim against the Grant (**NASA**). **CSTAR®** has successfully settled the lawsuit brought by EER; with no additional cost impact other than the attendant delay in closing out the Grant. The agreement settling the lawsuit is attached as Attachment K, and further discussed in the section dedicated to the COMET Program.

CSTAR® was able to assist in the transition for some of the CSTAR® staff to other employment. Some were able to find work within the parent company organizations. The organizational cost of this transition was minimal, and was constrained to the close-out budget provided by NASA and unemployment claims paid by the University of Tennessee.

At the submission of this report (or soon thereafter), NASA has under consideration the final claim under this Grant. It includes termination costs for CSTAR® one of the CCDS Monitors, TEES; and a termination claim by EER. CSTAR® requests that its claim and the claim by TEES be accepted; they are allowable, allocable, actual, and certainly reasonable. The EER claim is far too complex to comment on here; however, the details are provided in that subcontractor termination claim submission.

3. PROGRAM STATUS AT CLOSEOUT

The Center for Space Transportation and Applied Research had projects with space applications in six major emphasis areas:

- Laser Materials Processing
- Artificial Intelligence/Expert Systems
- Space Transportation
- Computational Methods
- Chemical Propulsion
- Electric Propulsion

The CSTAR® Fifth Annual Technical Symposium, Attachment G, included as part of this final report, provides an in depth technical report on each of the projects active at the time of Grant termination. The following sections will briefly describe the close out activities and final status of the projects in each of the emphasis areas.

3.1 LASER MATERIALS PROCESSING

There were three significant projects in this emphasis area:

Space Applications of Industrial Lasers (SAILS)
Laser Industrial Partnership Program (LIPP)
Laser Welding of Dissimilar Reflective Alloys

3.1.1 Space Applications of Industrial Laser Systems (SAILS)

OVERVIEW AND FINAL STATUS

The objective of the SAILS program was to develop a YAG laser based materials processing workstation to fly in the cargo bay of the Space Shuttle. The workstation was designed to have the capability for laser brazing, cutting, welding, drilling, and surface treating various materials proposed for use on the Space Station. As well as demonstrating the ability of a YAG

laser to perform remote (fiber optic delivered) repair and fabrication in space, fundamental data was to be collected on these processes for comparison with terrestrial data and models.

The preliminary design for the SAILS flight experiment was completed. The experiment was to be housed in three Get-Away Special Canisters (GAS CAN) mounted on a HITCHHIKER cross-bay carrier. The canisters were to be interconnected via the top plates for experiment control and distribution of power and laser energy.

The participants in the program included the Industrial Products Division of the LUMONICS, Inc., Tennessee Technological University, Auburn University, University of Waterloo, UT Space Institute and CSTAR®.

Upon notice of Grant termination, all work was halted and outstanding contracts were terminated. All staff were transferred to other positions or terminated. The graduate students were supported through the end of the on-going academic year. LUMONICS, the industrial partner on this project, requested that the laser and supporting systems be returned to the Company. After some negotiations, UTSI purchased the YAG laser from them and installed it in the CLA Laboratory.

All work on this project was stopped upon termination of the CCDS Grant. After several attempts to find funding from other sources inside and outside NASA, all efforts directed toward continuing the SAILS project have been abandoned.

SUBCONTRACTS

At project termination the only active subcontract was with The Tennessee Technological University. This contract had been approved as part of the original SAILS project plan. The subcontract has been closed and no outstanding claims exist.

PROCURED HARDWARE

Any hardware procured under the NASA Grant for the SAILS project was included and identified with the project on the master Procured Hardware list reported separately to NASA for disposition instructions.

INVENTIONS AND PATENTS

No inventions were developed nor patents filed as a result of the SAILS program.

3.1.2 Laser Industrial Partnership Program

OVERVIEW AND FINAL STATUS

CSTAR® joined with the UT Space Institute's Center for Laser Applications to develop the Laser Industrial Partnership Program (LIPP). LIPP is a technology transfer program for applying

laser materials processing technology to solve U.S. Industry problems. This is accomplished by providing a multi-disciplinary group of scientist and engineers with state-of-the-art laser and diagnostic facilities for evaluation and implementation of laser material applications into manufacturing applications. Specifically LIPP provided the following services to industry:

- On-site visits to identify potential laser applications
- Laboratory experimentation to establish feasibility
- Detailed parametric studies to optimize the laser process
- Development of prototype components for evaluation
- Design of new products and/or services
- Technical and economic appraisal of proposed laser processes

A comprehensive laser laboratory facility was developed by combining the resources of CSTAR® and its industrial partners with the Center for Laser Applications capability. Laser applications were investigated, demonstrated and prototyped for numerous industrial applications with clients such as:

- Robert Shaw Industries
- Bendix Atlantic Inflator Company
- A Medical Prosthesis Mfg.
- ROCKETDYNE, Huntsville
- Alabama Laser Technologies
- Lukens Medical Corporation

Since its inception at CLA (prior to the NASA Grant), the industrial outreach program has assisted in the selection and installation of lasers in thirteen U.S. Industries.

A significant portion of LIPP direct labor was covered by industry support while a majority of the marketing and administration was being supported by the CSTAR® overhead. After the Grant was terminated, the program has continued through the CLA although at a significantly lower level and without CSTAR support. Without the SAILS project to provide continuous work and support, one staff member and support for several students was terminated.

SUBCONTRACTS

All outstanding subcontracts have been closed and no outstanding claims exist.

PROCURED HARDWARE

NASA Grant funds were not used to procure hardware for this project.

INVENTIONS AND PATENTS

No inventions or patents were developed as a result of NASA funding.

The work under this project was funded by industry, CSTAR® overhead and the University. One invention for a laser drilling anti-spatter process resulted from this effort. Grant Funding was not used to perform the development of this invention. All rights to this invention have been returned to the inventors. Filing for the patent is in the final stages and should be issued within the next six months.

3.1.3 Laser Welding of Dissimilar Reflective Alloys

OVERVIEW AND STATUS

This project, jointly sponsored by ROCKETDYNE and CSTAR®, involves the development of laser joining of materials which have heretofore been impractical to bond. Of particular interest are joints between stainless steel and copper and also aluminum 6061 to aluminum 2219. Initial results using the pulse tailored laser welding technique developed in CLA for joining crack sensitive materials have proven promising for the aluminum joints based upon metallurgical and electronic microprobe analysis. Declaration of success requires additional mechanical testing. A CW technique has been applied to the stainless -copper joining with some preliminary success. These joints are of significant interest for aeronautics and rocket propulsion applications.

Upon termination of the Grant, this project was brought to a close. However, the research is continuing at a reduced level using funding from other sources.

SUBCONTRACTS

CSTAR® completed the work under a contract with Rocketdyne, the invoices have been paid, and the contract has been closed out.

PROCURED HARDWARE

Procured hardware, if any, for this project will appear on the Grant provided hardware list submitted separately.

INVENTIONS AND PATENTS

Prior to the project inception and under CLA funding, one invention, a process for laser welding of Dissimilar reflective alloys, was developed. All intellectual rights for the invention are the property of the inventor. Filing for the patent is in progress.

3.2 ARTIFICIAL INTELLIGENCE/EXPERT SYSTEMS

There were three projects in this emphasis area:

* Neural Network Analysis on SSME Vibration Simulation Data
* A Knowledge Based System Developer for Aerospace Applications
* SSME Propellant Path Leak Detection

3.2.1 Neural Network Analysis on SSME Vibration Simulation Data

OVERVIEW AND STATUS

This effort was funded wholly by a NASA MSFC Grant. The neural network method is applied to investigate the feasibility in detecting anomalies in turbo-pump vibration of SSME to supplement the statistical method utilized in the prototype system. The investigation of neural networks analysis is conducted using SSME vibration data from a NASA developed numerical simulator. The limited application of neural networks to the HPFTP has also shown the effectiveness in diagnosing the anomalies of turbo-pump vibrations.

NASA Grant NAGW - 1195 funds were not used for this project.
The project has been completed and a final report was written and submitted.

3.2.2 A Knowledge-based System Developer for Aerospace Applications

OVERVIEW AND STATUS

This project was jointly funded by the NASA Grant and by a small business, ERC, Inc. A prototype Knowledge-Based System Developer (KBSD) was developed for aerospace applications by utilizing artificial intelligence technology. The KBSD directly acquires knowledge from domain experts through a graphical interface then builds expert systems from that knowledge. This raises the state of the art of knowledge acquisition to a new level thus reducing the need for skilled knowledge engineers. The feasibility, applicability, and efficiency of the proposed concept was established. A full scale general purpose knowledge-based system developer will result from the successful prototype. The KBSD has significant commercial capability since it will minimize the need for knowledge engineers and increases productivity in the work place.

After the CCDS Grant was terminated, the project has been continued with 100% industry funding albeit at a lower level.

SUBCONTRACTS

There were no outstanding subcontracts.

PROCURED HARDWARE

No hardware was procured for this project.

INVENTIONS AND PATENTS

No patentable inventions resulted from this work.

3.2.3 SSME Propellant Path Leak Detection

OVERVIEW AND STATUS

This project was funded by NASA MSFC. Initial research established that the occurrence of a leak in the power head of the Space Shuttle Main Engine(SSME) is accompanied by sudden, but sustained, change in intensity in a given region of an image. Based upon this, temporal processing of infrared spectrum video images on a frame by frame basis has been used to detect leaks within a given field of view. A leak detection algorithm was developed that consists of a digital highpass filter cascaded with a moving average filter applied at each point in the image field. An extensive amount of data provided by NASA MSFC was used to verify the leak detection system performance. The leak detection algorithm was then applied to anomaly detection in the SSME exhaust by means of three channel color processing as opposed to single channel monochrome processing. An experimental system was constructed on site at MSFC for demonstration during an SSME firing.

This project has been completed and a final report submitted to MSFC.

PROCURED HARDWARE

No hardware was procured under the NASA NAGW-1195 grant.

SUBCONTRACTS

There were no subcontracts.

INVENTIONS AND PATENTS

There were no patentable inventions.

3.3 SPACE TRANSPORTATION

The projects that were included in this emphasis area included:

* Commercial Launch Voucher Program
* WCSC Environmental Process Improvement Study and Demonstration Program
* COMET

3.3.1 Commercial Launch Voucher Program

OVERVIEW AND STATUS

CSTAR® was asked to participate with NASA in the deliberations concerning the Launch Voucher Demonstration Program because of CSTAR's COMET experience and knowledge of the CCDS payload and transportation planning, budgeting and contract management process. CSTAR® was assigned the interface responsibility and provided information and input on an as needed basis.

The support effort was conducted without the use of subcontractors. No inventions or patents resulted from this effort.

3.3.2 WCSC Environmental Process Improvement Study and Demonstration Program

The goal of this project is to simplify the environmental assessment, approval and licensing process for commercial users.

This project was completed on cost and on schedule with final reports distributed to NASA Headquarters and D.C.C.

INVENTIONS AND PATENTS

No patentable inventions resulted from this work.

WCSC subclosed

3.3.3 Commercial Experiment Transporter (COMET)

Overview

The COMmercial Experiment Transporter (COMET) was a spaceflight program administered by CSTAR and supported by five other Centers for the Commercial Development of Space (CCDS's) and three contractors. The program was funded by NASA Headquarters and administered by the Office of Commercial Programs (Mail Code C, later designated as Mail Code X), as an augmentation to CSTAR's grant NAGW-1195.

COMET's goal was to establish a commercial spaceflight system for servicing the needs of the emerging commercial experimenters. The unmanned system would consist of all spaceflight and support efforts necessary to satisfy experiment needs, including Systems Engineering, Payload Integration, Launch, Orbital Operations, and the spaceflight hardware necessary to support on-orbit operations and land recovery. To "prime the pump", three missions (with two options) were to be flown to support experiments by the CCDS's and their commercial partners.

The objectives of COMET focused on contracting for the necessary services from commercial contractors to support experiments provided by the CCDS's and their commercial

partners. The first mission was to be flown 18 months from contract signing and another during each of the two subsequent years. These mission support services were viewed somewhat like commodities since the spaceflight industry had evolved over almost 30 years to a point where space hardware was advertised as "immediately available" at both the sub-system and system level. All industry waited for were enterprising experimenters, funded sufficiently to take the first flights.

COMET was this country's most recent attempt to establish a commercial capability to provide the entire complement of spaceflight services and infrastructure. The capability was seen as necessary to satisfy a growing demand to fly and recover commercially funded experiments. These experiments would prove the fiscal value of space as both a laboratory and a production location. Since the target market for an industry led follow-on to COMET centered on commercial experiments, the commercial experimenter requirements became COMET requirements: easy payload access, late access during countdown, on-orbit data available at the experimenters office, orbits structured to commercial need, and rapid access to the recovered experiments. Land recovery was deemed a necessity since the history of spaceflight proved that ocean recovery is expensive and does not routinely allow experimenters rapid access to their hardware.

Licensing of both launch and recovery operations was to be accomplished by the Department of Transportation in accordance with commercial launch policies and directives. While payloads were to be provided by NASA CCDS's and their commercial partners, COMET was to be a commercial program, one in which the commercial sector drove design, fabrication, integration, testing, and operation. Truly a chance for industry to shuck the burdens of tight controls, military or NASA standards, specifications, and burdensome bureaucracy.

COMET failed to fully meet its goal and many of its objectives. COMET did put an infrastructure to accommodate commercial and CCDS experiments in place. That infrastructure turned out to be a high priced, unmanned competitor to Shuttle. Because of current pricing policy, it appears most users would rather fly on Shuttle for "free" than to pay about $100,000 per pound to fly on a commercial version of COMET. Additionally, the euphoric view of commercial potential of space diminished greatly during the course of the COMET program. This changed business climate led the three COMET contractors to re-evaluate the business potential of commercial space and determine it to be an unlikely place to invest their corporate funds.

At the completion of the COMET grant, a sizable amount of space and ground hardware had been assembled to support the program. This is documented in Appendix A in the form of photos of each system component at the time the program was terminated. These systems, except for the "stacked" launch vehicle, had been integrated, electrically mated, had transferred data from the experiments to the Commercial Payload Operations Control Center (COMPOCC) where the data was received, forwarded to experimenters via modem, displayed, and analyzed. Those tests proved the end to end compatibility of COMET, from experiment to control of the vehicle(s) and experiments, to data gathering and report generation.

COMET, Program History

COMET was initiated in the spring of 1990 when Mr. J. Rose, Assistant Administrator of NASA's Code C authorized CSTAR (then CAR) to implement the COMET Plan. Shortly afterward, Statements of Work were prepared, notices posted in Aerospace Daily, Space News, and Aviation Week, a pre-proposal conference was held in the summer of 1990 and, in late summer, an RFP was formulated and disseminated to prospective suppliers. The system concept is described completely in the minutes of the CSTAR technical symposium which is enclosed with this final report.

Through a competitive procurement process, that included intense technical evaluation, three contractors were selected to provide the required services: EER/Systems was to furnish Launch Services, Space Industries, Inc., was to supply Payload Integration, Orbital Operations, and the Recovery Services, while Westinghouse Corp. rendered the Service Module and System Integration elements.

Contract signing was delayed since the price proposed by the three contractors was greater than NASA would fund and the phasing of the funds were not in concert with the NASA budget for Code C's Transportation line item. Meetings with the NASA senior staff, chaired by the Deputy Administrator, set the final amount and phasing of funds that could be accommodated by NASA. The contractors then attempted to fit their programs into this reduced funding level. The resulting program decreased the required funding by $12M and slipped the second and third missions.

After agreeing to the funding levels and phasing established by NASA, three contracts were signed between CSTAR and SII, WEC, and EER. These were commercial contracts for services and were written under the laws and commercial statutes of the State of Tennessee Code. These contracts would be funded by CSTAR using monies provided by NASA under the existing CSTAR CCDS grant (NAGW-1195). CSTAR would be guided by the NASA Grant and Cooperative Agreements Handbook and Circulars from the Office of Management and Budget (OMB) in administering these contracts.

Preliminary Design Reviews, and Final Design Reviews were conducted for each of the six work elements and, by January, 1992 these were completed and WEC and SII ordered most long lead hardware. EER made a major change to system configuration and settled on their 1620 vehicle in March, 1992, thus delaying ordering of long lead items and detailed design by well over 6 months from the schedule which was necessary to meet the October, 1992 launch date.

Cost overruns accrued early when the Westinghouse provided flight computer was deemed unacceptable by EER. This was followed by other change proposals which showed that most systems were being built from scratch instead of "purchased off the shelf" as anticipated in the contract solicitations. Such an approach reflected the propensity of the contractors to treat COMET as if it were another, typical aerospace program.

At NASA's request, Mr. C. Gunn, conducted a "Non-Advocate Review" of COMET at Code C's Crystal City location. Each COMET system, including program management topics, was

reviewed in detail and a number of program modifications, were recommended, each of which was accommodated. Based on the data provided and actions taken by the COMET team, the Non-Advocate Review recommended continuation of the program.

It was agreed, early in the program that contingency funds would be maintained by NASA's Office of Commercial Programs. Therefore, CSTAR had no access to funds with which to accommodate a number of EER Design Change Proposals which began to creep into the program, even if CSTAR had agreed with the contractor. The unwillingness of CSTAR to fund changes, many of which were not allowable under the contract, led EER to seek arbitration in May, 1992. EER's demand for arbitration was withdrawn later in the summer; however, these proposals along with those from WEC (most deemed unallowable) continued to sit in the background as the program progressed. It was EER's un-programmed expenditures and similar claims from Westinghouse and Space Industries which led CSTAR to meet with NASA's Acting Assistant Administrator for the Office of Commercial Programs and his Deputy on June 24, 1992, to discuss the potential for increased program funding. That meeting confirmed that NASA was not maintaining any contingency for the COMET program. Recognizing that expanded funding would be virtually impossible to obtain, CSTAR worked with the contractors to devise methods by which the available funding could be re-allocated and new commercial funds could be found for the program. Most promising was the possibility of "selling" additional payload capability on the open market. This approach was accepted by the contractors who believed that $5M of space might be sold over the three flight program. This approach was eventually abandoned when lower than planned launch vehicle performance and service module weight increases would not allow the system to support an extra pound of weight and still achieve an altitude which would result in an accurate re-entry and recovery.

Hardware continued to be fabricated and, at the end of 1992 all systems, including the CCDS experiments were brought together at Space Industries, Inc. to complete systems integration and testing. These tests successfully demonstrated the ability of the COMercial Payload Operations Control Center (COMPOCC) to command, control and display data from the assembled experiments, recovery system, and the service module. In short, that these could function as a total system. Since the launch system was to be brought together at the launch site for the first time, and EER was far behind schedule with their interface equipment, there was no "all systems test" which included the launch vehicle systems that could be accomplished at the time the spaceflight hardware completed its initial systems integration and test.

Recovery system licensing proved to be a quagmire of bureaucracy. While DOT initially believed itself to be responsible for setting the minimum level of liability insurance for recovering spacecraft, Congress ruled that DOT did not have the right to indemnify for loss above those levels. Thus, the Recovery System (R/S) contractor was to assume unlimited liability for damages caused by the R/S, and still satisfy a NEVER defined set of criteria necessary for "licensing." While the lack of an insurance "safety net" was troublesome to the R/S contractor, more distracting and costly were the numerous reviews and requests made by DOT as they attempted to define their criteria and requirements while validating the landing footprint and damage potential of the 1000 pound R/S. It was evident that DOT was not able to establish the licensing criteria to be met by a space vehicle

which would land within the United States, and was certainly not empowered to indemnify the insured owners of those re-entering systems.

For almost a year, work on all COMET systems continued under a veil of uncertainty while the contractors and CSTAR continued to develop approaches to launch the first mission. During this period, the contractors interfaced often with their Senate and Congressional contacts in an attempt to add more funding to the program. Such efforts did much to assure funding to the programmed amount but were unsuccessful at adding more funds to the program. Finally, faced with ever increasing un-approved contract over-runs and uncertainty of funding, the contractors reported that they issued stop work notices to their subcontractors. CSTAR then issued Cure notices to WEC, SII, and EER in April, 1993 in an effort to continue toward the agreed upon launch date.

During the entire COMET program CSTAR had kept NASA's Office of Commercial Programs advised of program status and challenges, at least on a weekly basis and often on a daily or even hourly basis. In light of a large unworkable, potential program over-run, CSTAR requested a meeting with the NASA Administrator in April, 1993. This meeting was requested in an attempt to define a way to restructure COMET in a manner agreeable to NASA. In May, 1993, the Acting NASA Deputy Administrator and some of the senior NASA staff met with CSTAR. Program status, problem areas, and the options available for program continuation or cessation were presented. In conclusion, CSTAR proposed that a select NASA Technical Team review the program and make an independent assessment of technical worth and the cost to completion. If the program had technical merit and worth to the Agency, then the Agency would be in a position to better determine if funding should be added or the program canceled. The NASA group declined to discuss the CSTAR approach or alternatives/modifications which might be acceptable. Three weeks later a letter informed CSTAR that NASA would neither review the program nor add more funding.

Finally, due to the contractors inability to meet the cost and schedule required by the program, and technical inadequacies (Service Module weight increases, Launch Vehicle redesigns, and Recovery System over expenditures, among others), and NASA's unwillingness to fund program growth, on June 18, 1993 CSTAR requested the Federal Court to determine CSTAR's rights should the three contractors be terminated for default.

Shortly afterward, and at the urging of NASA, CSTAR and the three contractors provided a plan for a single, somewhat degraded mission, in lieu of the three mission program. This plan proposed that the single flight would be funded at the level of the original three flight program. CSTAR did not favor the plan but the contractors would not agree to lower their costs nor would they increase their corporate funding support. As a result of the inability of the program to move forward, the contractors issued stop work orders. COMET was at a point where work was to be stopped due to the contractors inability to complete the program within the contracted cost.

On January 7, 1994, NASA notified CSTAR that it had reviewed and would not approve funding of the single mission plan. The letter continued:

> " Instead, NASA has decided that it would be prudent to conduct a thorough review of the COMET program to determine what is feasible

and will provide a reasonable return on investment for both NASA and the taxpayers. This review, which will be conducted in early 1994, will determine the current technical and financial status of the COMET program, assess the contractor's plans to achieve a successful first mission, and identify any additional work that will be required to ensure that event."

This was precisely the same review requested by CSTAR in April of the prior year! Based on that assessment, NASA would decide if $14M of allocated 1994 funding would be applied to COMET. The COMET team agreed, and, after partial funding was released, the contractors and CSTAR supported the review and subsequent integration tests at Goddard Space Flight Center.

This NASA review was chaired by Mr. T. Cochran and a team of NASA technical experts who reviewed the entire program including technical, contracting, funding, and cost control. By mid March, 1994, their review completed, the Cochran headed team released a report which **found no technical reason why the mission should not be flown.** However, on May 5, 1994 a letter from Mr. Gregory Reck, Acting Assistant Administrator for Commercial Space, advised CSTAR that NASA would not accept the single mission plan of CSTAR and the three contractors due to an undefined risk which the Agency would be taking. Based on that rejection and the diminished possibility of funding, EER filed suit in Federal Court against CSTAR.

Shortly afterward, NASA approached the three contractors and offered to write a sole source contract to fly the COMET mission. In the winter of 1994, NASA posted such a notice in the Commerce Business Daily and, shortly thereafter signed a contract with EER for a single mission. NASA subsequently renamed the mission METEOR, seized the COMET flight assets from the EER COMET contract and provided them back to EER under the METEOR Program as GFM, thus denying CSTAR the only leverage it had to settle the EER law suit.

The METEOR mission's recent launch at Wallops Island failed. CSTAR is not a participant in the METEOR program. Based on the distinct possibility of CSTAR's imminent bankruptcy, EER dropped their suit against CSTAR and, under the terms of the CSTAR/EER contract, EER has filed a termination claim for the costs they could not recover during performance.

COMET Accomplishments

A narrative of technical accomplishments are included as a part of the CSTAR Technical Symposium Reports attached to this document.

Attachment A to this section includes a pictorial description of the status of each of the five hardware elements of the COMET program at the time of NASA's termination of funding. Title to this hardware remained with the contractors until completion of the contract termination process at which time disposition instructions were to be issued by the CSTAR Business Office as directed by NASA Headquarters. Since NASA seized many of the assets of the program, the results of that disposition are not available to CSTAR.

The following table describes the goals (G), and objectives(O) of, and approaches(A) to the COMET program and reviews the program's success. The data for this table are taken from the 1990 "Commercial Experiment Transporter (COMET), A Plan for an Integrated Approach to Satisfying Commercial Needs in Space", the advocacy briefings presented to the NASA Administrator & staff, and the Senate Science and Technology Committee briefing.

GOAL/OBJECTIVE/APPROACH	LEVEL OF ACHIEVEMENT	COMMENTS
Support Establishment of a Commercial Space Infrastructure (G)	Accomplished	At the end of CSTAR's involvement, an entire infrastructure had been put in place.
Match CCDS Experiment Needs (O)	Mostly Accomplished	Unable to accommodate Autonomous Rendezvous and Docking Experiment
Minimize Cost through Competition and Innovation (O)	Questionably Accomplished	Competition brought forth low bids & innovation was evident, but neither resulted in anticipated low program cost.
Provide Late Access To Experimenters (O)	Accomplished	Access was allowed as late as 2 hours prior to launch.
Provide Rapid Access To Recovered Experiments (O)	Accomplished	Experimenters would have experiments delivered to them at the Utah Test and Training Range in less than 2 hours from landing.
Purchase Services (S)	Accomplished	Service contracts were written by CSTAR with the three COMET contractors.
Maximize use of Developed Systems (S)	Somewhat Accomplished	Industry used some developed systems and subsystems but often reverted to in-house development.
Modularize Added Capability (S)	Not Accomplished	Added capability was not pursued.
Accommodate Growth (S)	Partially Accomplished	Service Module and Recovery System volume were greater than required by the SOW.
Institute Aggressive Scheduling to Lower Costs (S)	Partially Accomplished	COMET was ready for first integrated testing less than two years from program approval. Lack of contractor cost control allowed costs to grow without regard to schedule or accomplishments.
Make CCDS's Responsible for Program Success (S)	Accomplished	CCDS's : Provided SOW's & Evaluation Guides Evaluated Proposals Monitored Contractor Technical Performance
Use Best Commercial in Lieu of Specs (A)	Somewhat Accomplished	Often Aerospace Contractors elected to operate in a Govt. Spec. or Standards environment.
Eliminate Man Rated Requirements and Philosophy (A)	Accomplished	

GOAL/OBJECTIVE/APPROACH	LEVEL OF ACHIEVEMENT	COMMENTS
Use Competitive Procurements (A)	Accomplished	EER/SII/WEC all responded to RFP's with detailed SOW's. Source Selection process successfully followed.
Use Grant Funding to Eliminate Bureaucracy (A)	Accomplished	
Disallow Contractor's Development Costs. (A)	Partially Accomplished	Contracts did not allow development costs, some were charged as part of the cost plus contracts, EER attempted to recover development costs. Issue is not yet resolved.
Recognize DOT's Role. (A)	Accomplished	DOT's lack of a defined process and criteria for licensing re-entry systems led to numerous meetings and data needs. This was a major contributor to the recovery system cost over-run.
Establish an Experiment Selection Process (A)	Accomplished	Experiments were screened by a COMET payload review team who provided technical inputs to the Code C Payload Selection Committee.

Synopsis of CSTAR Goals, Objectives, and Approaches for the COMET program.

Management

Management of the COMET program was based on the assumption that the contractors had, at the minimum, existing designs for each of the five hardware work elements. Based on that condition, it was not deemed necessary to manage or monitor closely, the contractor's design efforts. From a top management view, the functions of contract monitoring and technical performance validation would be accomplished by a small CSTAR team assisted by "Monitors" from five other CCDS's. Each Monitor was assigned one of the six work elements and tracked it's performance and cost against the plan as stated in the contract as modified by approved changes. This approach supported the NASA stated mission of developing an infrastructure to support commercial space missions. This approach was evaluated by NASA management who specifically approved this management concept.

CSTAR provided all contract administration, contract funding, top level system design, furnished the Monitor for the Systems Engineering work element, and was the sole contact with NASA Headquarters for the conduct of the program. The Program Manager briefed program status, accomplishments, and challenges to NASA Code C representatives and the CCDS Directors at Quarterly CCDS Meetings. Additionally, the Program Manager was a member of the COMET Senior Management Council - comprised of an official from each contractor and CSTAR, who reviewed overall progress, determined problem areas, and developed approaches to solve program schedule and cost anomalies.

Hardware and software integration was accomplished through a well designed set of interface specifications which were delineated by the Systems Engineering contractor. These were the guidance documents for system level interface testing. Subsystem specifications were, with rare

exception, left to the contractor except where a subsystem interfaced across contractor boundaries. In such instances, interface specifications were defined.

Configuration control was the responsibility of each contractor but a system of drawing control and system specs was defined and monitored by the Systems Engineering contractor. In short, everything possible was done to place the potential for mission success squarely on WEC, SII, and EER. The CCDS's, including CSTAR, monitored performance, assured contract compliance, assisted where possible in the resolution of deficiencies, and interfaced with NASA Headquarters for program direction, information, funding requests, public affairs, and staff assistance.

Late in the program, the contractors elected to establish a Contractor's COMET Program Manager. This individual was empowered to enhance contractor interfaces by establishing contractor schedules for integrated testing and launch processing, and directing accomplishment of those activities.

In the end, the management philosophies and approach used by CSTAR were unsuccessful. While each person performed admirably, there was an incipient flaw in the basic assumption of COMET - the contractors had to desire COMET success enough that they would put their energies into accomplishing the program within it's defined cost and schedule, or fund the variances themselves. In his report, Mr. T. Cochran noted that the management approach taken by CSTAR for COMET was appropriate for the program as it was originally structured, but the program did not develop as anticipated and, in the light of contractor actions, cost and schedule control were not possible.

Financial Control

Each of the six work elements had a cost and schedule associated with its performance. These were baselined in the proposals and approved during contract negotiations. Each work element provided a monthly cost, status, and narrative summary of the efforts expended during the month and, when appropriate, an invoice for work accomplished or milestones met. CSTAR provided these and an analysis of the financial information to the Monitors for their review, validation, and possibly, action. When the COMET Financial Manager at CSTAR was satisfied with the cost data provided by the contractor, a request for payment was processed by the CSTAR Program Manager and the Business Office. The Business Office made the appropriate draw against the Grant and paid the approved invoices.

CSTAR prepared the necessary performance reports for NASA based on these monthly contractor reports and the observations of the Monitors. The detailed contractor monthly reports were archived at CSTAR after Monitor inputs were received.

Conclusion

As a result of COMET, this nation has a commercially operated, full service, space access and recovery system in place. The vision is completed however, the cost of completion was too

high and that cost did not result in a validation, through flight, of the commercial viability of such a service.

SUBCONTRACTS

Subcontracts for services were let to:

* EER/Systems, Vienna VA for Launch Services
* Westinghouse Inc., Baltimore, MD for Systems Engineering and Service Module
* Space Industries, Inc., Clearlake, TX, for Orbital Operations, Recovery System and Payload Integration.

PURCHASED HARDWARE

Only services were purchased under this project.

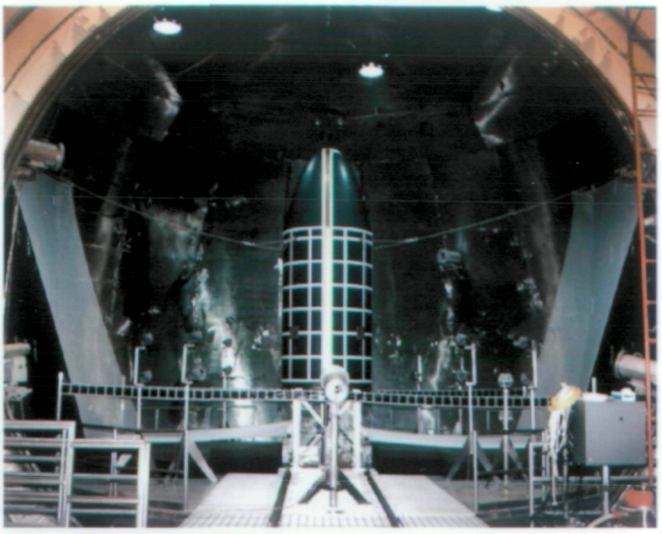
INVENTIONS AND PATENTS

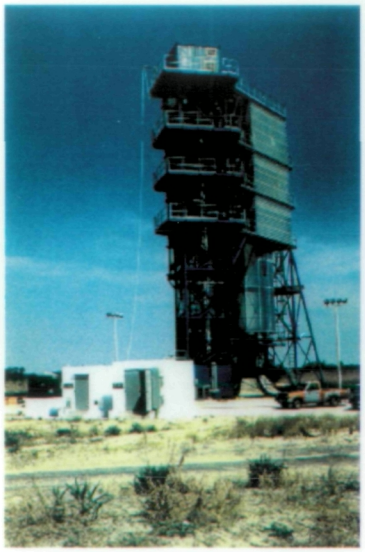
No inventions or patents resulted from this project.

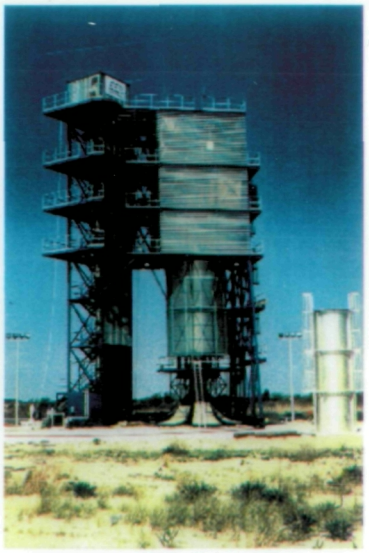
ATTACHMENT A

LAUNCH VEHICLE

Testing of the Launch Vehicle Fairing at White Sands, New Mexico.

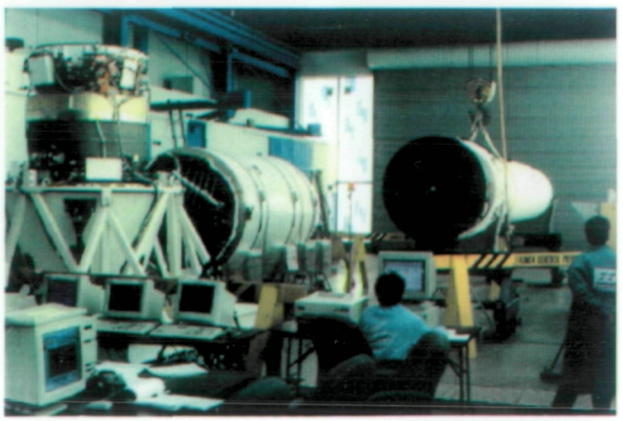






Conestoga Launch System Portable Service Tower.

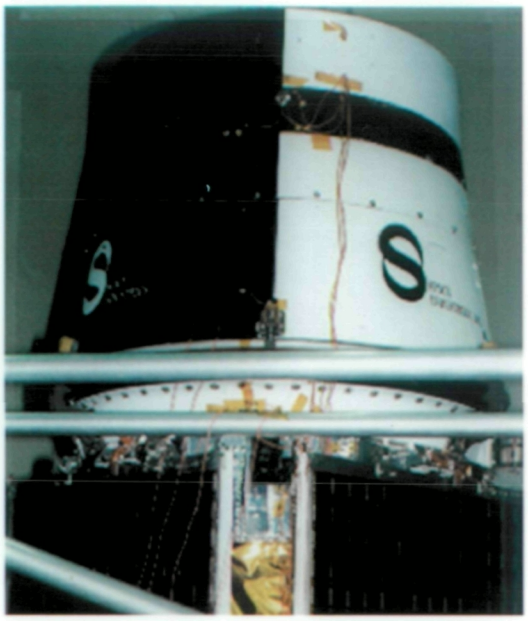
Integrated Testing of CASTOR IVB Thrust Vector Control (TVC) Systems with Conestoga 1620 Upper Stage at Wallops Flight Facility.



ATTACHMENT A

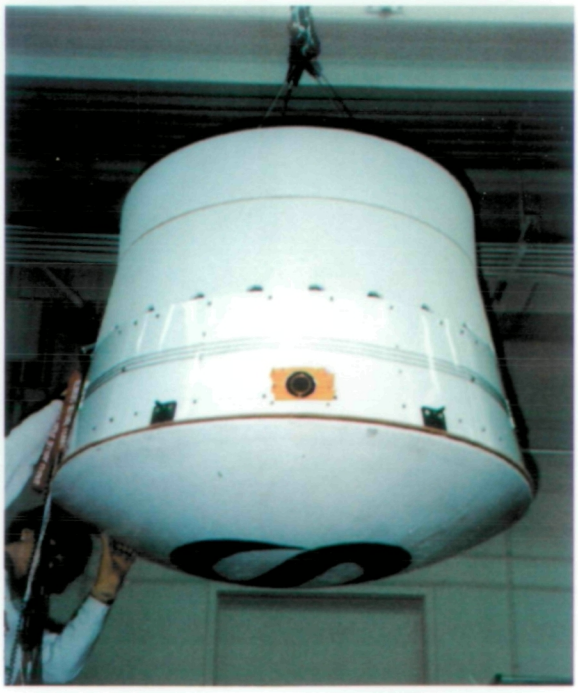
RECOVERY SYSTEM

Integration of the Recovery System to the Service Module.



The Recovery System at Acoustics Testing.

Recovery System and Deployed Main Chute During Reentry Verification Testing.



The Recovery Capsule After Completion.

ATTACHMENT A

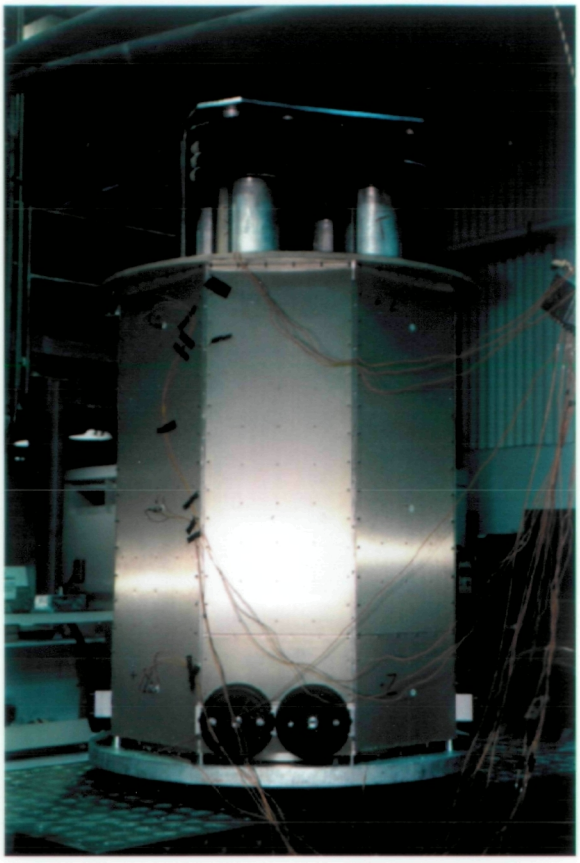
COMMERCIAL PAYLOAD OPERATIONS CONTROL CENTER

COMPOCC Operational.

Orbital Operations Tracking & Communications Antennea at SII, League City, Texas.

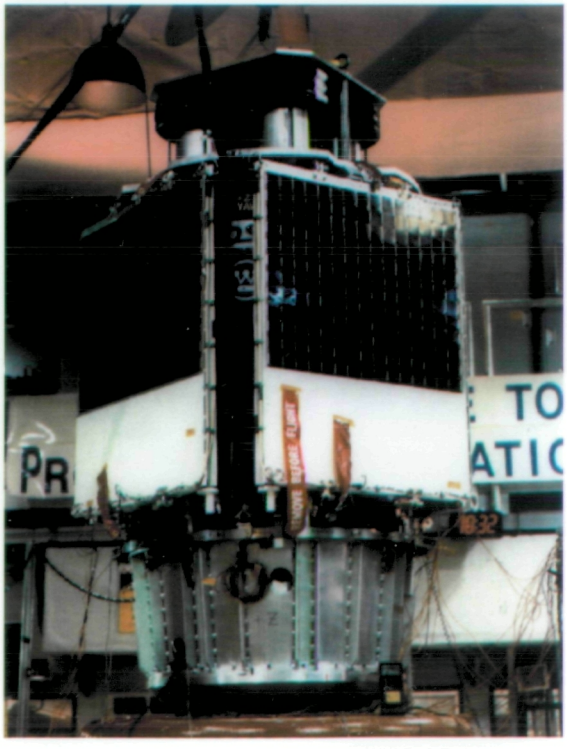
ATTACHMENT A

SERVICE MODULE



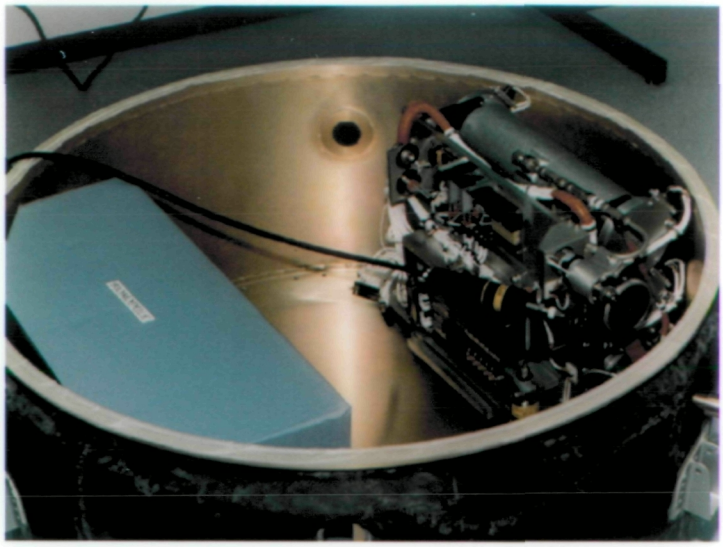
The Service Module Undergoing Modal Frequency Test.

Service Module Post Vibration Test.



ATTACHMENT A

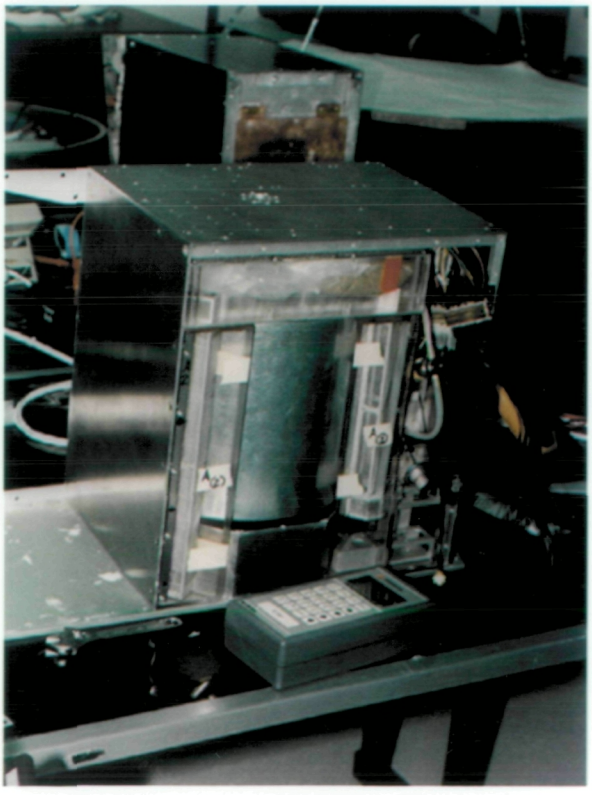
PAYLOAD INTEGRATION



ABOVE: UAH's NLO Experiment Integrated into the Experiment Container Mockup.

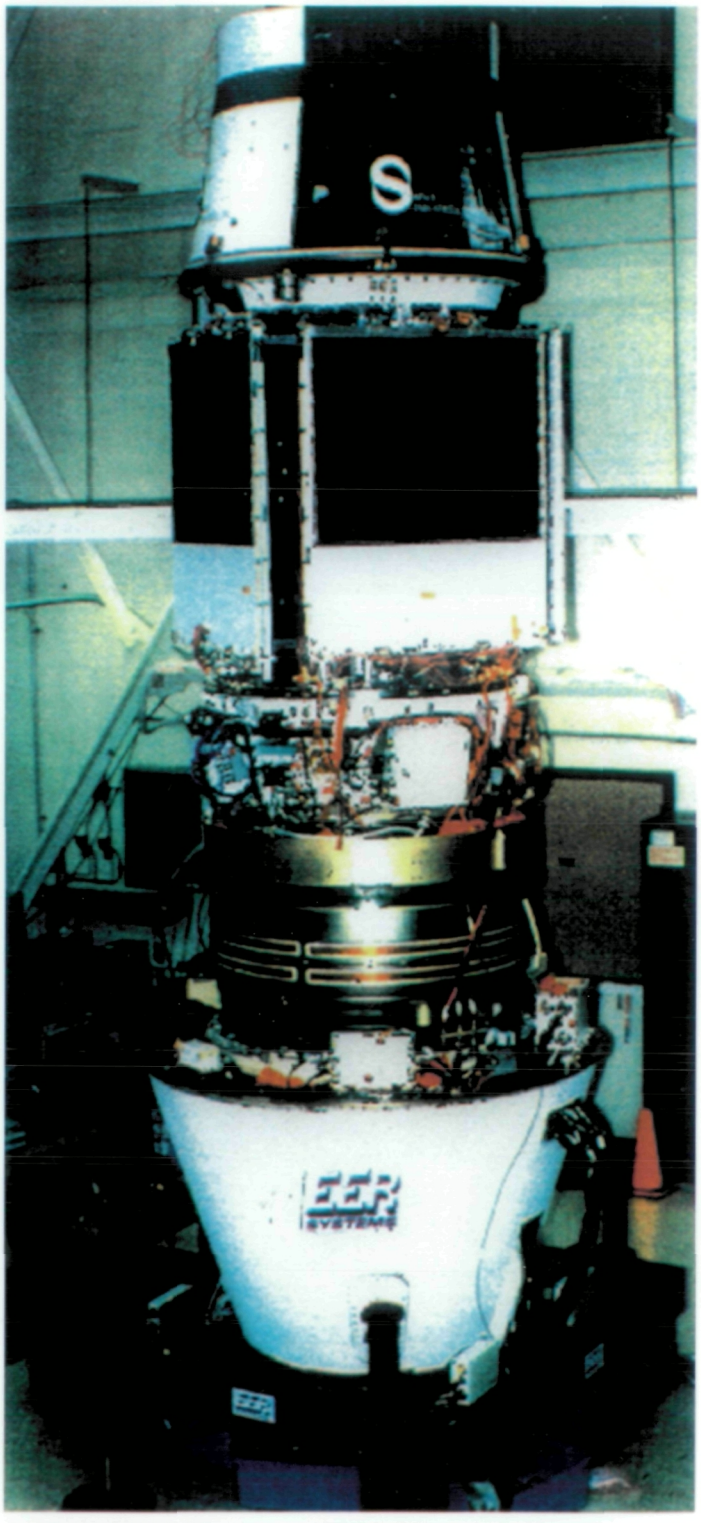
LOWER LEFT: BioServe's Flight Experiment.

LOWER RIGHT: BioServe's Flight Experiment with Experimenter Dr. Steve Simpsky.



ATTACHMENT A

SYSTEMS ENGINEERING



Conestoga Upper Stage, Service Module and Recovery System in GSFC Acoustic Chamber.

3.4 COMPUTATIONAL METHODS/APPLICATIONS

Computational applications include projects that apply or develop computational intensive computer programs. Such programs typically require super computers to obtain solutions in a timely fashion. CSTAR® had two relatively low level efforts in this area; one directed toward developing a Parallel Processing capability and the other related to transferring the CHIMERA technology to U.S. industry. Both of these efforts were brought to an early end before the potential industry partners could see fit to make significant investments.

There were no subcontracts negotiated under this effort.

No inventions or patents resulted from this effort.

No equipment was purchased under this task.

3.5 CHEMICAL PROPULSION

CSTAR® had several projects in the area of Chemical propulsion during the last five years. These were being performed in collaboration with industry and in preparation for teaming with industry on several development contracts. The areas of primary interest were:

Oxygen Rich Combustion
Variable Mixture Ratio Propulsion Systems
Combined Cycle Engine Analysis
Hybrid Engine Development
Premix Injectors

We were in the early phases of developing an industrial team to demonstrate and fly several hybrid rockets when we found ourselves in competition with a Hybrid RFP to be released by MSFC. An example of the right hand not knowing what the left hand is doing. The program was ultimately contracted under the Technology Re-investment Program and our former team members, AMROC and Martin Marietta won. In July 1995, AMROC announced that they would be forced to withdraw from the program because of the inability to raise the matching funds.

3.5.1 Thermally-choked Combustor Technology

OVERVIEW AND STATUS

A theoretical and experimental program was undertaken to demonstrate the practical feasibility of thermally-choked combustor technology with particular emphasis on rocket propulsion applications. Rather than using a converging-diverging nozzle to produce supersonic flow, the goal is to create a thermal throat by adding combustion heat in a diverging nozzle. Such a device would have certain advantages over conventional flow accelerators assuming that the pressure loss due to heat addition does not severely limit the efficiency. As an aid to evaluation, a generalized one-

dimensional compressible flow analysis tool was constructed. Experimental work was also being carried out in an attempt to develop a practical bench-scale demonstration using H2/O2.

The results from the one-dimensional model indicate that a thermally choked combustor is feasible from both a fluid dynamic and thermodynamic standpoint. A bench-scale experiment was designed, fabricated and operated. The testing was in the initial phases and addressing such fundamental issues as flame stabilization and flashback/quenching when the project was terminated. The experimental results at that point were inconclusive as to the feasibility of a thermally choked combustor.

SUBCONTRACTS

There were no subcontracts under this project .

PROCURED HARDWARE

There were no major hardware purchased under this contract.

INVENTIONS AND PATENTS

There were no inventions or patents.

BIBLIOGRAPHY

See the CSTAR® Fifth Annual Symposium for references.

3.5.2 Effect of Strong Vortex Flow on Hybrid Rocket Combustion and Performance

OVERVIEW AND STATUS

An examination of the effect of vortex flow on hybrid rocket combustion and performance was undertaken as part of the CSTAR® effort to support industry in the development and commercialization of hybrid rocket engines. Emphasis was on the response of the fuel regression rate when subjected to vortex flow. A test chamber consisting of two concentric plexiglass cylinders and aluminum end plates was constructed. The inner cylinder is perforated to allow oxygen to be injected tangentially into the combustion chamber. The combustion occurs on the inner surface of the inner cylinder. The flow exits through a converging-diverging nozzle in the center of the lower plate that supports the two concentric cylinders.

The initial experimental results indicate that the tangential flow has a marked effect on the surface erosion pattern inside the cylinder. The project was terminated before extensive runs and measurements could be attempted.

SUBCONTRACTS

There were no subcontracts under to this project.

PROCURED HARDWARE

There were no major hardware purchases under this project.

INVENTIONS AND PATENTS

There were no patents or inventions.

3.6 ELECTRIC PROPULSION

CSTAR® had a very active electric propulsion group with both theoretical and experimental projects and significant industry participation. At the close of the Grant the active projects included:

- Electric Propulsion Orbital Platform
- Emission Spectroscopy and Laser-induced Fluorescence Measurements of the plume from a 1-KW Arcjet
- Charge Exchange Erosion Studies of Accelerator Grids in Ion Thrusters
- Electric Propulsion Technology Applications

The status of these projects at Grant termination will be discussed in the following sections.

3.6.1 Electric Propulsion Orbital Platform (EPOP)

OVERVIEW AND STATUS

The objective of the Electric Propulsion Orbital Platform (EPOP) was to provide an instrumented platform for testing electric propulsion devices in space. The EPOP was to be flown on the Shuttle deployed Wake Shield facility. The first flight was to be a 1.8 KW arcjet system operated on gaseous hydrogen propellant. The objective of EPOP is to develop in space testing capability and in particular on the first flight, to demonstrate a unique hydrogen feed system. Comparisons between the space based and ground based data was to be used to validate the arcjet and its components.

The EPOP consortium consists of CSTAR®, McDonnell Douglas Aerospace, Olin Rocket Research Company and Boeing Defense & Space Group. The Space Vacuum Epitaxy Center at the University of Houston has the responsibility for the Wake Shield Facility.

The EPOP project plan was approved by NASA for funding and the preliminary design for the first flight was completed. Preliminary testing of the 1.8 KW arcjet had been completed at the time the CCDS Grant was terminated. Several efforts were made to acquire funding from other industry and government sources but were unsuccessful.

SUBCONTRACTS

There were subcontracting and letters of agreement in place between the parties involved in EPOP. All of the legal arrangements have been terminated and no additional costs are anticipated.

PROCURED HARDWARE

The hardware purchased under this project was identified in the Grant procured hardware list submitted separately.

INVENTIONS AND PATENTS

There were no inventions or patents resulting from this project.

BIBLIOGRAPHY

See the CSTAR® Fifth Annual Technical Symposium.

3.6.2 Diagnostics for the EPOP

OVERVIEW AND STATUS

The instrumentation and diagnostics for the first flight of the Electric Propulsion Orbital Platform was being developed under this project. The objective was to characterize to the greatest degree possible the in-flight performance of a 1.8 KW hydrogen arcjet. The performance characterization included a space craft to ground communications experiment, probe measurements of the arcjet plume, and spectrally resolved plume imaging measurements of the plume. The communications experiment was designed to measure small noise on the communications link which results from arcjet operation. The other two measurements primarily serve the purpose of characterization of the plume plasma. These measurements were to be compared to similar measurements performed in a vacuum chamber to establish whether significant differences exist between ground-based and space performance of the arcjet system.

The first phase of the preliminary ground testing had been completed when the project was terminated.

SUBCONTRACTS

The subcontract with Rocket Research Company has been closed including all outstanding financial issues.

PROCURED HARDWARE

Any hardware procured under this project was reported separately for disposition instructions.

INVENTIONS AND PATENTS

No inventions or patents resulted from this effort.

3.6.3 Experimental and Analytical Ion Thrusters Research

OVERVIEW AND STATUS

The plume from a 3 cm ion source was studied using spectroscopic techniques. The spectroscopic technique allows measurement of the plasma density near the grids where access by an electrical probe is difficult. The experimental techniques developed can be used to characterize the operating characteristics of a 3-grid, 15 cm diameter ion thruster supplied by NASA JPL. A simple analytical model was developed to calculate the grid impingement current resulting from the charge exchange collisions in the ion thruster plume.

The experimental program was successful and follow-on work looked promising. This effort was jointly funded by Boeing and ERC, Inc. When the Grant was terminated, the CSTAR® support was terminated and the project along with one employee was transferred to ERC, Inc.

SUBCONTRACTS

All subcontracts have been closed and no outstanding obligations exists.

PROCURED HARDWARE

No major hardware was purchased under this project.

INVENTIONS AND PATENTS

There were no inventions or patents resulting from this work.

3.6.4 Emission Spectroscopy and Laser-induced Fluorescence Measurements on the Plume of a 1-KW Arcjet Operating on Simulated Ammonia

OVERVIEW AND STATUS

Spectroscopic and laser-induced fluorescence measurements were performed on the exhaust plume from a 1-KW NASA Lewis arcjet operated on simulated ammonia, In particular, emissions were analyzed from the Balmer lines of atomic hydrogen and from the one of the rotational bands of the NH radical. The laser-induced fluorescence measurement were performed on the Balmer-alpha line of atomic hydrogen. The exit plane temperatures were found to be in the range of 1500 to 3500 K and the electron density upstream of the exit plane is on the order of 1.5x10(14) cm(3). Both emission spectroscopy and laser-induced fluorescence were used to measure the plume velocities of atomic hydrogen. Using either technique, velocities on the order of 4 km/sec were measured at the

exit plane and significant acceleration of the flow was observed in the first 2 mm beyond the exit plane. The result indicates that the arcjet nozzle design is not optimum.

SUBCONTRACTS

There were no subcontracts under this project.

PROCURED HARDWARE

No major hardware was procured under this project.

INVENTIONS AND PATENTS

No patents or inventions resulted from this effort.

3.6.5 Charge-exchange Erosion Studies of Accelerator Grids in ION Thrusters

OVERVIEW AND STATUS

A particle simulation model was developed to study the charge-exchange grid erosion ion thrusters. Since the neutral gas downstream from the accelerator grid is different for space and ground based operations, the charge exchange erosion processes are also different. Based on an assumption of no electric potential hill downstream from the ion thruster, the calculations show that the accelerator grid erosion rate for space operating conditions should be significantly less than the erosion rates experienced observed at NASA Lewis and at NASA Jet Propulsion Laboratory. In order to resolve the erosion issue, the entire electric potential field downstream from the thruster must be measured.

This effort was jointly funded by Boeing. Upon termination of the Grant, the project was terminated and the investigators were laid off.

SUBCONTRACTS

The subcontracts and all financial matters have been closed.

PROCURED HARDWARE

No hardware was purchased under this project.

INVENTIONS AND PATENTS

No patents or inventions resulted from this work.

3.6.6 Electric Propulsion Technology Applications

OVERVIEW AND STATUS

The effort was funded by a Grant from NASA Lewis and industrial funds. The objective was to identify opportunities to apply the expertise and knowledge in electric propulsion to industrial manufacturing applications. The general approach and plan was developed and several opportunities had been identified when the CCDS was terminated. A report of the six month effort has been prepared and submitted to NASA Lewis.

SUBCONTRACTS

There were no subcontracts under this project.

PURCHASED HARDWARE

No major hardware was purchased under this project.

INVENTIONS AND PATENTS

No inventions or patents resulted from this project.

Activities following notice of termination: