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**Space Applications Industrial Laser System (SAILS)<sup>1</sup>**

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**ABSTRACT**

A program is under way to develop a YAG laser based materials processing workstation to fly in the cargo bay of the Space Shuttle. This workstation, called Space Applications Industrial Laser System (SAILS), will be capable of cutting and welding steel, aluminum and Inconel alloys of the type planned for use in constructing the Space Station Freedom. As well as demonstrating the ability of a YAG laser to perform remote (fiber-optic delivered) repair and fabrication operations in space, fundamental data will be collected on these interactions for comparison with terrestrial data and models.

The flight system, scheduled to fly in 1996, will be constructed as three modules using standard Get-Away-Special (GAS) canisters. The first module holds the laser head and cooling system, while the second contains a high peak power electrical supply. The third module houses the materials processing workstation and the command and data acquisition subsystems. The laser head and workstation canisters are linked by a fiber-optic cable to transmit the laser light.

The team assembled to carry out this project includes Lumonics Industrial Products (laser), Tennessee Technological University (structural analysis and fabrication), Auburn University Center for Space Power (electrical engineering), University of Waterloo (low-g laser process consulting), and CSTAR/UTSI (data acquisition, control, software, integration, experiment design).

This report describes the SAILS program and highlights recent activities undertaken at CSTAR.

**INTRODUCTION**

The UT-Calspan Center for Space Transportation and Applied Research (CSTAR) is one of 17 NASA Centers for the Commercial Development of Space (CCDS). The mission of CSTAR is to team with industry and academia in the development of new and innovation space technologies.

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The SAILS program has been developed under this mission because of its broad potential to benefit industry, academia, and government through advanced laser materials processing technology.

The project team consists of five organizations, headed by Professors Dwayne and Mary Helen McCay of CSTAR and the UTSI Center for Laser Applications, Professor Walt Duley of the University of Waterloo, Steve Llewellyn of Lumonics Corporation, Professor Richard Houghton of Tennessee Technological University, and Professor Ray Askew of Auburn University. Brice Bible of CSTAR is the program manager and Susan Olden of the Goddard Space Flight Center (GSFC) is the mission manager.

The long term space missions planned by NASA will require some form of machining and repair capability. The SAILS experiment will act as the proof-of-concept to firmly establish the YAG laser as a viable materials processing tool for space applications. Follow on phases to the program will develop the infrastructure necessary for implementation on long term space structures by the end of the century.

As the lifetime and complexity of space structures increase, our ability to construct, maintain and repair these structures in space must also be improved. The industrial laser represents a possible solution to the problem of conducting multiple task manufacturing and repair operations at remote, hostile locations such as an orbiting platform.

The purpose of the SAILS project is to demonstrate the capability to employ a YAG laser processing facility in space and to perform practical laser materials processing operations under microgravity conditions. The objectives of this project may be grouped under the following categories:

Science: Determine the effects of gravity on welding, drilling, cutting, brazing, and soldering. Compare experimental results with models to improve predictions of process behavior in 1 and 0 g.

Space Engineering: Demonstrate the viability of laser technology to perform repair and fabrication type operations in space. Applications include a laser repair kit for Space Station, manned Mars missions, a Moon base, and a laser-based factory in space.

Laser Engineering: Design refinement and demonstration of the industrial YAG laser to show that it has become a simple, compact, efficient and rugged tool capable of operating in any environment. It is of particular importance to show the advantages of fiber optic beam delivery, including ruggedness and the ability to operate in remote and harsh environments.

The 1996 flight, designated SAILS-01, is the first in a series of experiments designed to validate the YAG laser as a viable multipurpose energy workstation for space. Interest by the NASA Code C CCDS community as well as other industry, academia, and government organizations has resulted in plans for at least two follow-on flights. Figure 1 indicates the current flight strategy for the SAILS facility.

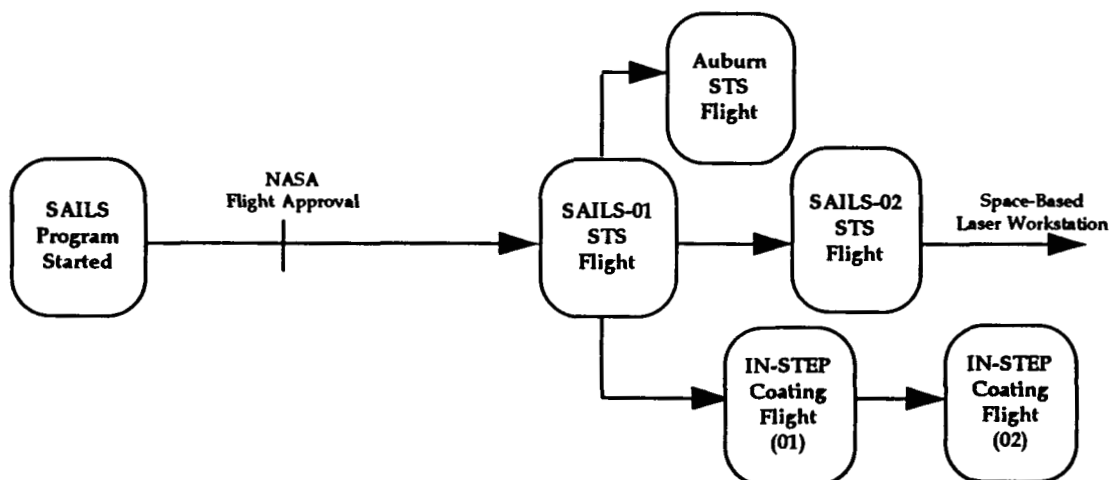


Figure 1 SAILS Facility Flight Plans

### SAILS EXPERIMENT SELECTION

As the SAILS experiment is designed to demonstrate the viability and practicality of laser materials processing in space, the processes to be tested and the materials used should have some application in space systems. After initial trials to show that the materials could be processed with the laser power anticipated for the flight system, the materials and processes were selected as shown in Table 1.

Table 1. Materials and Processes Selected for Testing in the SAILS Experiment.

Material	Spot/Seam Weld	Drill/Cut	Braze	Solder
316L Stainless	✓	✓	✓	
2219 Aluminum	✓	✓		
6061 Aluminum	✓	✓		
Inconel 718	✓	✓		
Copper				✓
Kapton		✓		
Lead/Tin	✓			

The processes all have obvious practical applications, in space or on earth. Structural joining operations (welding and brazing) will be needed in the assembly and repair of man-rated habitats. Cutting will be required for removing damaged components for repair and in the recycling of space debris. Soldering of electrical and electronic components could be accomplished remotely using a dexterous manipulator and a fiber delivered laser beam, with much less heat input to nearby components than with a conventional solder iron.

### GROUND EXPERIMENTATION

Preliminary studies were carried out during 1991-92 using a 400 W Lumonics JK701 YAG laser to show that the materials and processes under consideration could be processed with a relatively low power laser. Since that time, the operating characteristics of the flight laser have been made available with the introduction of the LUXSTAR laser by Lumonics Corporation, the industrial sponsor for the program (see Table 2). Detailed experiment studies will be completed in late 1993 at CSTAR using the LUXSTAR laser to produce the precise processing conditions anticipated for each of the flight experiment samples. As well as finding workable combinations of processing parameters, this study will determine scaling relationships (depth and width of weld vs power, metal structure) between the flight power level and presently available ground-based laser power levels. This will allow us to predict the performance of higher power lasers operating under space conditions.

Table 2. Flight Laser Operating Characteristics

Parameter	Value
Average power	50 W
Peak optical power	3000 W
Pulse length	0.5 - 20 ms
Pulsing rate	to 100 Hz
Pulse energy	to 30 J [10 J]
Fiber core diameter	400 $\mu$ m
Minimum spot size	200 $\mu$ m
Dimensions (Industrial unit)	86.5x56.5x77.5 cm
Weight (Industrial unit)	200 kg
Input voltage	200-240 VAC [28 VDC]
Output voltage to Flashlamp	660 V pulses
Power Consumption	5.5 kW

### FLIGHT HARDWARE DESIGN

The SAILS flight experiment will be housed in three Get-Away-Special (GAS) canisters mounted on the HitchHiker cross bay carrier. These canisters will be interconnected via the top plates for experiment control and distribution of power and laser energy. Figure 1 shows this three-canister configuration and the major components in each module.

The first canister, CAN 1, will contain the laser head, output module (capacitor bank), and cooling system for generation of the laser energy necessary to conduct the experiments. The laser head and output module will be acquired and repackaged from the LUXSTAR Nd:YAG 50 W laser system, a new commercial product manufactured by Lumonics. The cooling system, consisting of a pump and heat exchanger, will be fabricated at CSTAR to provide transfer of the heat generated in the laser cavity

during processing.

The second canister, CAN 2, contains the electrical power supply for providing the high peak power necessary to generate the laser energy in CAN 1. This can will consist of Silver-Zinc battery cells housed in a vented container (power source), a DC-DC convertor for electrical power conditioning, and the laser control module. The DC-DC convertor will condition the battery energy to the proper voltage for transfer to the capacitors in CAN 1. The Auburn University Center for Space Power will design and fabricate the power conditioning system in this canister and the power source will be provided by CSTAR. Use of orbiter power was considered as an alternative to the batteries for laser power. However, the peak power requirements for the experiment is approximately 5 kW, which is greater than the maximum of 3.5 kW available to a HitchHiker customer.

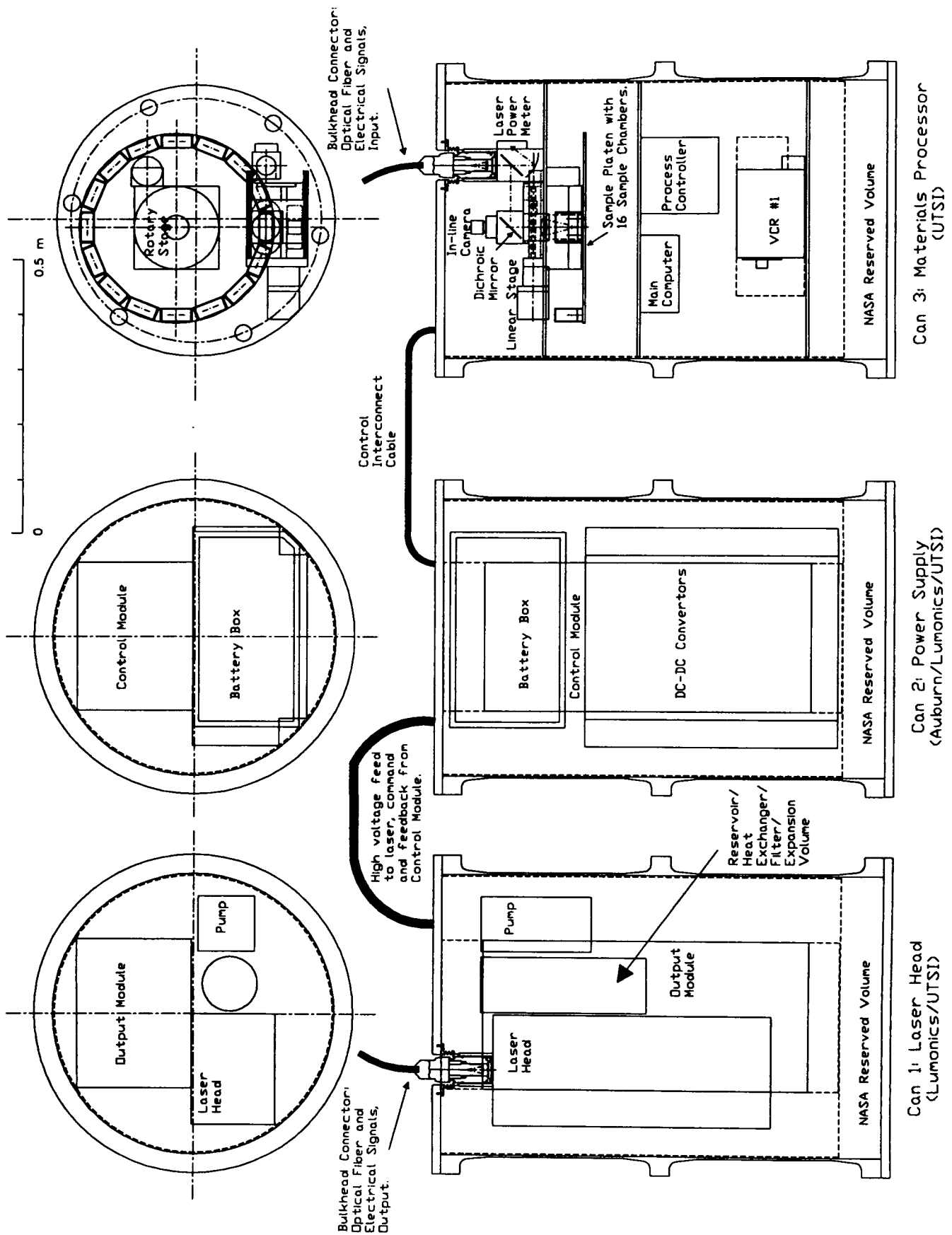
CAN 1 and CAN 2 will be connected via an electrical cable for transfer of the high voltage battery power from the power supply to the laser head. The connectors, cable support structure, and canister modifications will be provided by GSFC and are currently under development. CSTAR will provide the electrical cable.

The combination of CAN 1, CAN 2, and the voltage interconnection produce a complete, self-contained, ruggedized Nd:YAG laser system for delivery of laser energy to the experiment workstation, CAN 3.

The third canister, CAN 3, contains the workstation for conducting the SAILS experiments. This canister consists of the experiment samples, workhandling, and command and data acquisition systems. The sixteen samples (2.5 cm X 5.5 cm each) will be rotated on a platen and located under the laser beam for processing. A given sample will be processed for approximately 15 seconds, followed by a monitoring period to allow each critical subsystem to return to the appropriate operating conditions before moving to the next sample. This will continue until all 16 samples have been processed. The internal laser beam will be delivered as a free-space beam with moving optics. This configuration mimics current industrial laser practice of using a moving optics end effector to achieve more motion flexibility. The data acquisition systems will include video storage of the actual process (coaxially and along the sample), recording of the environmental conditions before and during each process, and monitoring of the laser process parameters (pulse length, energy, and duration) for each sample.

CAN 3 will be linked to CAN 1 via a fiberoptic cable for delivery of the laser energy to the workstation. This cable will consist of a 400 micron fiber surrounded by a copper shield and control/continuity data lines all encompassed in a nylon outer cover. The connectors will be designed for a hermetic seal at the canister with lid modifications to be provided by GSFC and the fiber/connectors to be provided by CSTAR.

Each of the three canisters will be filled with Argon gas pressurized to one atmosphere and filled with inert gas. CAN 1 and CAN 2 will use dry N<sub>2</sub> while CAN 3 will use Argon to provide enhanced processing conditions for the flight hardware components.



#### **PROGRESS TO DATE**

The SAILS program was proposed to NASA Code C in 1990 with funding and payload approval received in 1991. As described above, work through FY92 focussed primarily on establishing the operating envelope necessary to accomplish the experiment objectives of the program. FY93 has centered on design and development of the flight hardware required to accomplish these objectives. To date, the following activities either have been completed or are underway:

- Completion of preliminary design of the components in each of the three canisters, including the interconnecting fiberoptic and electrical systems.
- Candidate hardware systems for many of the components in the sample workstation canister, CAN 3, have been identified and several components have been procured. The computer/control, VCR, and camera systems have been purchased and are currently under development and integration at CSTAR. TTU has completed preliminary design of the internal experiment structure and a prototype test frame has been fabricated for vibrational testing.
- The Lumonics LUXSTAR laser, CAN 1, has been installed at CSTAR and is currently undergoing operations testing. A prototype cooling system has been developed and will be tested with the laser in early FY94.
- The electrical and fiberoptic interconnection systems have been discussed with GSFC. Design and fabrication of the external mounting hardware will be provided by GSFC and development of the cables will be provided by CSTAR.
- The Carrier Payload Requirements (CPR) document has been submitted to the GSFC Small Payloads Office with final approval anticipated by September 1993. The Safety Data Package has been initiated with the potential hazards identified in the Payload Safety Requirements Matrix. Submittal of the package to JSC for the Phase 0/1 safety review is expected shortly after the CPR is approved.

#### **FY94 ACTIVITIES**

Activities in FY94 will focus on continued development of the flight hardware with completion of procurement and fabrication of the sample workstation canister (CAN 3) modules and most of the laser (CAN 1) and power (CAN 2) canister components anticipated. Some of the major milestones planned for FY94 include:

- Procurement/fabrication of the experiment motion system, internal optics, sample carrier, and internal frame for CAN 3 will be completed. Integration and testing of the canister will be initiated.
- Development of the power supply, cooling system, batteries, and internal frames for CAN 1 and CAN 2 as well as integration of these modules into the LUXSTAR laser for operational tests will be initiated.
- Design of the fiber, voltage, and control interconnects will be completed and fabrication will be initiated.

- Identification of the payload safety-critical items and safety verification procedures will be completed. The Phase 0/1 safety review will be completed and the Phase 2 review process will be initiated.

The SAILS Program Schedule is shown on Figure 3 and illustrates the overall timetable planned to achieve the FY96 shuttle flight.

#### CONCLUSION

A program is well underway to develop the first laser materials processing workstation for use in space. As well as providing fundamental information on several laser-material interactions, this program will demonstrate the ability of laser processing to perform useful repair and fabrication operations in space.



# SPACE APPLICATIONS INDUSTRIAL LASER SYSTEM (SAILS)

## PROGRAM SCHEDULE

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