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## Paper Session I-A - Starlab Overview

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**STARLAB OVERVIEW**  
**LTC Randall G. Oliver, SDIO<sup>o</sup>**  
**Mr. John E. Moye, TASC<sup>o</sup>**

**Abstract**

Starlab, a test bed designed to be flown on NASA's Space Shuttle, will be used to conduct a series of acquisition, tracking, and pointing (ATP) experiments that are relevant to the Strategic Defense Initiative (SDI) Mission. In the primary experiment, Starlab will acquire, track, and precisely point a laser beam at an instrumented 4-stage booster rocket known as Starbird. Simultaneously, booster plume data will be collected at a variety of wavelengths and at resolutions never before achieved in space. Starlab will also be used to demonstrate advanced adaptive optics techniques using a booster plume source, rapid optical retargeting, and laser communications from space to below the ocean's surface. In addition, Starlab will be used to collect data on earth-space backgrounds and on adaptive optics systems used to compensate for atmospheric turbulence.

**Introduction**

The Starlab mission, planned for launch in late 1991, will be used to conduct acquisition, tracking, and pointing (ATP) experiments from NASA's space shuttle. The purpose of the experiments is to resolve critical technology issues associated with the development of space-based weapons for strategic defense against nuclear-tipped warheads. Although technology issues associated with both directed energy weapons (laser and particle beams) and kinetic energy weapons (interceptors) will be addressed by Starlab, the emphasis is on directed energy weapons.

The principal requirement for a space-based ATP platform is to determine a target's position, velocity, acceleration, and orientation with sufficient accuracy to engage and destroy the target. This information is critical for any space-based strategic weapon to be effective. In addition, a directed energy weapon must be capable of very precise pointing accuracies to stabilize the beam onto the target's vulnerable aimpoint. These requirements result in a variety of technology issues that are addressed by the Starlab mission. Starlab will:

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- Demonstrate the ability to detect and optically track a booster using the booster plume radiation.
- Demonstrate the ability to locate the booster hardbody using information derived from the hardbody plume.
- Demonstrate the ability to optically track the booster when it is illuminated with a laser.
- Demonstrate the ability to precisely point and stabilize a low-power scoring laser at a specific aimpoint on the booster.
- Demonstrate the ability to use booster plume radiation to correct the optical distortions in the beam train in order to increase the laser intensity at the aimpoint.
- Demonstrate the ability to rapidly and precisely repoint an optical sensor and a low-power scoring laser from one target to another.
- Collect data that will improve our understanding of plume characteristics for both solid and liquid boosters.
- Collect data that will improve our understanding of the earth and space backgrounds to improve future sensor designs.
- Characterize the performance of an advanced adaptive optics system that compensates for adverse atmospheric effects on the laser beam.

Starlab will engage a 4-stage solid fueled test booster (Starbird) equipped with a laser scoreboard to demonstrate the acquisition, tracking, and pointing functions and to demonstrate the adaptive optics system that compensates for optical distortions. The Starbird booster, and a booster with a liquid stage, will be used to collect plume data. Space test objects, deployed from the shuttle during the mission, will be used to demonstrate the precision repointing function. Background measurements will be taken of the earth limb and at nadir for a variety of lighting conditions and earth locations. The performance of an adaptive optics system used to compensate for atmospheric distortions will be characterized using the Short Wavelength Adaptive Technology (SWAT) experiment based at Maui, Hawaii. A variety of other tests with stars, planets, the space test objects, and ground sites are planned to characterize the Starlab system on orbit. An experiment of opportunity will be conducted to demonstrate laser communication from space to submerged sensors.

### **Starlab Mission**

As currently defined, the Starlab mission will last seven days. The mission configuration consists of a Spacelab double module and pallet

(Figure 1). It will be launched from KSC aboard a dedicated shuttle in late 1991 and will land at Edwards AFB in California. The crew will be made up of two Payload Specialists intimately familiar with the experiments as well as five NASA astronauts. The mission will be flown at an altitude of 330.4 KM (178.4 NM) and an inclination of 33.4 degrees. The Payload Operations Control Center (POCC) and Science Operations Area (SOA) will be located at the Marshall Space Flight Center in Huntsville, Alabama. The booster targets, or Starbirds, will be launched out of Wake Island (Peacock Point) and Complex 20 at Cape Canaveral Air Force Station in Florida. Six Starbird booster launches are planned during the mission.

### **Management**

The Starlab management structure is shown in Figure 2. SDIO has responsibility as the Mission Director. Within SDIO, the program is managed out of the Directed Energy Directorate. The key participants are Air Force Space Systems Division (AFSSD), responsible for experiment development; U.S. Army Strategic Defense Command (USASDC), responsible for (Starbird) booster and launch site development; and NASA, responsible for mission integration and operations. The prime experiment developers for the mission are Lockheed Missiles and Space Company (LMSC), responsible for the Payload Experiment Package (PEP); Kaman Aerospace (KAMAN), responsible for the Wavefront Control Experiment (WCE); and Space Data Corporation (SDC), responsible for Starbird Booster Development and launch services.

## **STARLAB EXPERIMENT OVERVIEWS**

### **Booster Experiment**

In the primary experiment Starlab, acquires, tracks, and points a laser to an aimpoint on a target booster hardbody. The target booster (Starbird) is a four-stage vehicle with solid rocket motors. This experiment is depicted in Figure 3. The engagement begins by pointing the Starlab optical system, which includes a large 1.55M pointing mirror and 80cm diameter telescope combination at the booster launch site (Wake Island or Cape Canaveral).

The Starlab tracker acquires the booster plume and tracks the booster passively using plume radiation. When the booster comes within the range of an active illuminator laser tracker (Neodymium doped Yttrium Aluminum Garnet Nd:YAG), the booster hardbody will be acquired and actively tracked. A shroud, covering a target board attached to the booster fourth stage, is released within 10 seconds of third-stage ignition. The target board is used to score the pointing accuracy and jitter achieved by the Starlab system. During the booster engagement, plume imagery is taken at a variety of wavelengths. The sensors used to track the booster and to collect the plume data, as well as background data, are listed in Table 1. A typical engagement process follows.

Starlab Sensor Characteristics

SENSOR	WAVELENGTHS Micrometer	FIELD OF VIEW MRAD	COLLECTING AREA (CM)
Visible Acquisition	.35 - 0.7	80 x 63	6.4
Visible Coarse	.35 - 0.7	2 x 1.6	80
Visible Fine	.5321	0.2 x 0.16	80
SWIR	2.7/4.3	80 x 63	3.2
MWIR	2.9/4.3	2 x 1.6	80
UV	0.20-0.32	4.8 x 3.8	20

TABLE 1

**Acquisition** - The acquisition process begins with the shuttle orbiter performing a maneuver to orient itself so that the orbiter bay is pointed toward the booster launch site as it comes up over the horizon. The orbiter is given a slow, 0.7 degree/sec pitch rotation to keep the booster in the Starlab pointing mirror field of regard.

Most Starlab engagements are planned to occur before dawn to improve data quality. If the launch site is not obscured by clouds the Starbird launch site will use a searchlight-type beacon pointed toward the orbiter to assist acquisition. This beacon is extinguished just prior to first-stage ignition.

Acquisition is accomplished by imaging the target on the visible acquisition camera (an intensified CCD video camera). Camera gain and threshold control ensures acquisition of the brightest object in its field of view. The visible acquisition camera is backed up by the infrared camera in its wide field of view mode. Since sunlit clouds are brighter than the visible plume radiation at long slant ranges (the plume could not be acquired by the visible acquisition camera) hence the infrared acquisition is the primary acquisition mode for the one daylight Starbird booster launch .

In a typical engagement the Starlab flight software computes the correct orientation of the pointing mirror using the orbiter ephemeris and Starbird inertial gyro measurements which were previously calibrated by tracking stars. This is followed by flight software computation of the predicted Starbird booster trajectory and the required pointing rate of the large pointing mirror. This computation and servo control assists acquisition of the booster above clouds and the acquisition of the upper stages after the long second-stage coast duration.

**Coarse Tracking** - After the booster is acquired, a rapid slew of the pointing mirror places the plume image near the center of the acquisition camera's field of view so that tracking can begin. When the image appears in the much smaller field of view of the coarse tracker, it acquires the target and provides a tracking

error signal to the pointing mirror control system. The coarse tracker may either be a visible intensified CCD camera, an intensified high-bandwidth quadrant detector, or the narrow field of view mode of the infrared camera.

**Plume Pointing and Passive Plume Signatures** - While each stage of the booster is being "coarse" tracked to very high accuracy, phenomenology data on plume signatures is recorded. Sensor data is obtained from each of the coarse tracking sensors listed above plus the ultraviolet camera and the fine tracker. Spatial resolution, bandwidth and sensitivity of the sensors simultaneously record plume data will provide calibrated plume data of significantly higher quality in many respects than previously collected above the atmosphere.

The fine tracker is used to collect laser radar reflectance of the plume at 531 nanometers wavelength. An on-board laser illuminator, pulsing at 20 pulses/second, is used to paint the plume, and the reflected signal is detected by the fine tracker.

**Hard-Body Handover and Active Tracking** - A tracking handover occurs from plume tracking to "active" tracking of the booster hardbody shroud at the end of second-stage burn, and to active tracking of a scoreboard (after the shroud is removed) during third and fourth-stage burn. Active tracking is accomplished by illuminating the hard body with the laser illuminator beam and tracking the reflected return on the fine tracker. The fine tracker is a viable intensified CCD sensor which has a time window or gate during which it accepts signals. A laser ranger sensor ranges upon the target based on the illuminator laser pulse time of flight, and then sets the time delay for this time gate. The time gate improves the sensitivity of active tracking by effectively making the sensor insensitive to passive visible signals from the plume or from sunlit clouds.

Handover from passive plume tracking to active tracking involves computation and setting of the point-ahead or lead angle of the laser illuminator to account for the finite speed of light; the offset angle from the plume to the hard body location; and the offset angle to account for parallax of the illuminator beam which is displaced on the Starlab equipment from the tracking telescope. A smooth transition from plume tracking to active tracking is made after the fine tracker acquires the target.

**Marker Pointing** - The ultimate demonstration of the performance of the Starlab pointing system is accomplished by directing a low-power helium neon marker laser beam to the Starbird scoreboard with extremely high accuracy and low beam jitter. A complex internal alignment and active optical beam stabilization subsystem is used to obtain the desired accuracy and stabilization. The marker laser beam is preboresighted to the fine tracking focal plane using the Space Test Object (STO) as the target. This target (FIG 6) has optical corner cube reflectors which not only assist active tracking, but also provide a signal return when illuminated by the marker laser beam. The returned signal is used to boresight the transmitted marker and illuminator beams.

While the Starbird scoreboard is being actively tracked, the internal boresight and alignment subsystem is expected to be stable enough to point the marker beam to the center of the scoreboard. Mechanical vibration of Starlab optics due to orbiter disturbances are sensed by both inertial and optical sensors and are greatly attenuated by fast steering mirrors in the servo control system.

**Scoring of Performance** - The performance of the Starlab pointing system is primarily measured by scoring of the marker position on the Starbird scoreboard using optical sensors. This data is included in the Starbird booster telemetry stream. Additional on-board Starlab scoring will be accomplished by conical scanning the marker beam direction toward a corner cube reflector in the center of the scoreboard, and detecting the signal return on a Starlab sensor. This scoreboard reflector has a strong attenuator for the illuminator tracking laser wavelength, so it does not aid active tracking.

During selected portions of the engagement, the Wavefront Control Experiment (WCE) is used to control a deformable mirror which will improve the optical quality of the system. The WCE will also measure plume jitter at high bandwidths.

In addition to the Starbird targets, the Starlab will take plume data on a dedicated liquid plume target. The signatures from liquid propellants are significantly different from solid propellants and are generally more stressing to the tracker.

The booster engagement has been designed to ensure the absolute safety of the shuttle. The design criteria defines an exclusion zone around the shuttle (depicted in Figure 4). The safety analysis implies that there is less than one chance in a million that any booster stage or any debris could reach the orbiter exclusion zone even if the booster exploded during any portion of the flight. Additional attention is being given to all laser engagements. Although both the illuminator and marker lasers are considered to be operationally harmless to the unaided eye when observed from the ground, extreme caution will be exercised during each laser activation to ensure there will be no possibility of danger to the flight crew or ground personnel in the vicinity of the target areas.

### **Wavefront Control Experiment**

The Wavefront Control Experiment (WCE) will be a demonstration of adaptive technologies used for correcting optical aberrations in a space-based optical system. The operation of the WCE is simple in principle in that a processor monitors wavefront sensors and calculates how to warp deformable mirrors to correct for the optical aberrations experienced. The WCE is in fact a complex system using interacting computers, sensor mirrors and electro mechanical actuators. Because of the complexity involved, the WCE was

designed so that any experiment anomaly would not impact other Starlab experiments.

### **Background Data**

The Starlab background data experiment is designed to obtain background data in the infrared and ultraviolet spectral regions while staring at selected NADIR and limb locations. The wide field of view infrared sensor and the ultraviolet sensor described in table 1, are used with a large combination of spectral filters to obtain this data base.

### **Shortwave Adaptive Technology Experiment (SWAT)**

The SWAT experiment is a test of an adaptive optics system used to compensate for atmospheric effects on a laser. The experiment will be done using the Air Force Maui Optical Station (AMOS) located on Maui, Hawaii to acquire, track and point a laser at the shuttle and then the Starlab to acquire, track and point a laser at AMOS. Several lasers of different operating frequencies will be used during the experiment.

The AMOS blue laser is pointed at the shuttle and reflected back by use of a shuttle mounted corner reflector. By use of adaptive optics, this blue laser return is used to compensate a green (argon ion) laser which is also directed at the shuttle where its characteristics are measured. These characteristics include the position of the AMOS beam on the Starlab mirror (indicating the pointing accuracy of AMOS), the beam shape distribution on the Starlab mirror (indicating the quality of atmospheric distortion compensation), and the angle arrival of the beam on Starlab (as an aid to AMOS focus). The Starlab modulates its red (helium neon) laser beam with a coded message and directs it to an AMOS sensor which decodes and uses the data to correct its pointing direction. This experiment is shown in Figure 5.

### **Rapid Retargeting**

In an operational scenario, a space-based weapons platform must be able to engage numerous targets in minimum time. The problem in retargeting a directed energy beam is to destroy a target and move to a new target and stabilize (minimum overshoot and jitter) in an extremely short period of time. This experiment will be run against two Space Test Objects (STO) deployed from the shuttle. The targets (Figure 6) are 18.5 inch diameter diffuse white spheres which reflect sunlight to aid in their acquisition. As the spheres move away from Starlab, they will be tracked, illuminated, and designated. This sequence will be repeated a number of times at various distances as the spheres drift farther apart for rapid retargeting and boresighting.



## **Data Collection**

Communication of experimental data will be primarily via the NASA Tracking and Data Relay Satellite (TDRS) to the White Sands Ground Station and then via DOMSAT to JSC and MSFC (Figure 7). There are nine ground sites which must be coordinated during the mission. Digital science data and video data will be encrypted prior to being downlinked. The primary users of the science will be in the Payload Operations Control Center (POCC) located at MSFC. All data will be recorded on the ground and eventually archived at various locations. It is expected that a "quick look" science report will be issued within 30 days after mission completion and a more comprehensive report written about 6 months later.

## **Data Analysis**

Data Analysis for Starlab will be accomplished in three phases:

- Hardware System Tests prior to launch
- During the Actual Mission (quick look)
- Post mission

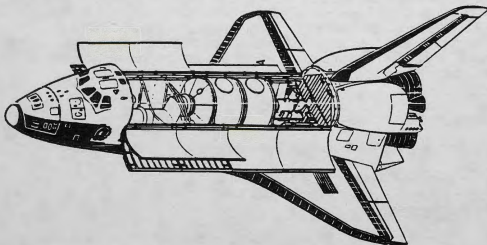
The most intensive analysis will be conducted during the mission using equipment in the POCC and Science Operations Area (SOA) at MSFC. Most of this analysis will be for quick look performance evaluation and problem solving. This same hardware will be also used for post mission analysis. All data will be calibrated during post mission processing and put in a standard format before being archived for future analysis. To aid in both real-time and post mission data analysis, a high fidelity simulation program (MATRIX X) is being developed. This model will be hosted on the computer facilities within the National Test Facility at Falcon Air Force Base, Colorado.

## **Summary**

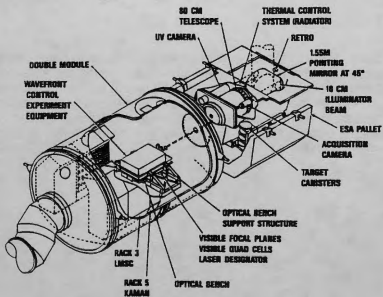
One of the most complex space shuttle experiments to date, Starlab will involve a diverse field of experts in the area of electro optics, sensors, control systems and sensor analysis. The mission will present both technical and operational challenges that must be resolved real-time to ensure mission success. The data obtained in the areas of missile acquisition tracking and pointing will be the basis for designing future space-based weapons systems as well as surveillance platforms.



## STARLAB



## STARLAB CONFIGURATION



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FIGURE 1



# Starlab Management Team

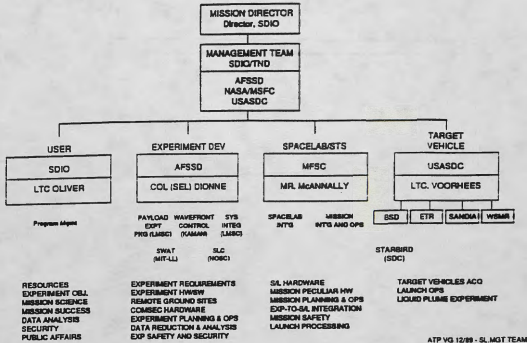
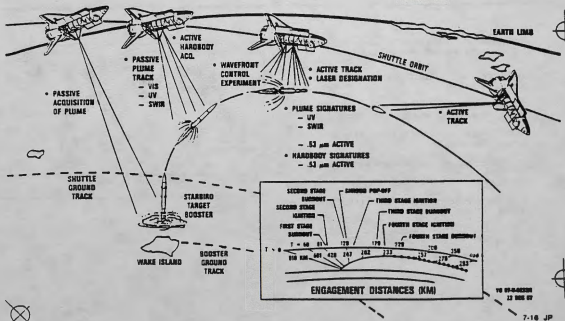


FIGURE 2



## BOOSTER ENGAGEMENT EXPERIMENT



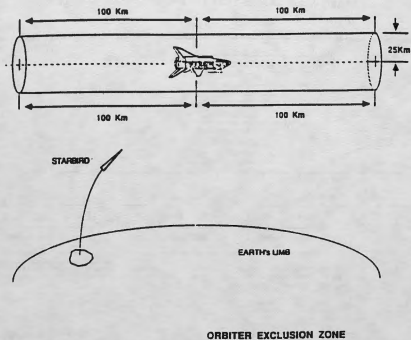


FIGURE 4

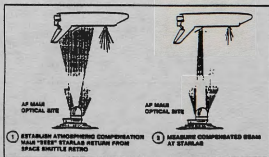
FIGURE 5

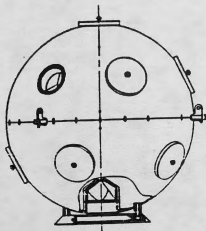


## SWAT EXPERIMENT GENERAL DESCRIPTION

THREE LASERS ARE USED DURING THE SWAT EXPERIMENT;  
TWO FROM AMOS AND ONE FROM STARLAB:

- AMOS TRANSMITS A BLUE BEACON LASER BEAM (4880A ARGON-ION)
  - RETURNS FROM STS RETROREFLECTOR
  - USED TO MEASURE ATMOSPHERIC TURBULENCE
- AMOS TRANSMITS A GREEN BEACON LASER BEAM (5143A ARGON-ION)
  - CORRECTED USING INFORMATION OBTAINED USING BEACON BEAM
  - BEAM CHARACTERISTICS ARE MEASURED BY STARLAB
- STARLAB TRANSMITS A RED MARKER LASER BEAM (6328A HE-NE)
  - USED AS REAL-TIME COMMUNICATION LINK TO AMOS
  - NO MARKER RETURN REQUIRED





- SPHERE  
- 18.5 INCH DIAMETER
- 150 LBS
- OCTANT RADAR RETROS
- 12 SOLID RED RETROS  
- FOR MARKER RETURN
- DIFFUSE WHITE SURFACE  
- FOR ILLUMINATOR  
RETURN

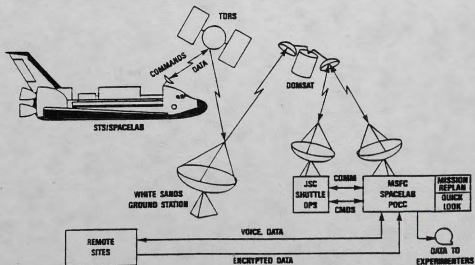
TEST OBJECT

FIGURE 6

FIGURE 7



## EXPERIMENT OPERATIONS CONCEPT



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