SHUTTLE LASER ALTIMETER
A Pathfinder for Space-Based Laser Altimetry & Lidar

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INTRODUCTION

The Shuttle Laser Altimeter (SLA) is a small, secondary Shuttle payload that was completed in June 1995 and is now being integrated for a first flight as part of the STS-72 Mission in January 1996. The primary payload for STS-72 is the retrieval of the Japanese Space Flyer Unit (SFU). After SFU retrieval the Shuttle Endeavor will descend to a 305 km orbit for the remainder of the mission during which there are plans for 104 hours of SLA operations. The SLA Instrument was developed at the GSFC by a small team of engineers and technicians from a mixture of space flight spare parts and assemblies, an airborne optical system, and commercial electronics. The Hitchhiker Carrier was used for its standard interfaces to Shuttle payload mounting, power, command, and telemetry. Together the SLA Instrument and the Hitchhiker Carrier constitute a low-cost experiment payload capable of topography and lidar measurements from Earth orbit. On orbit operations of SLA are illustrated in Fig. 1 where a series of sensor footprints stretch in a measurement profile along the nadir track of the Shuttle. Full interpretation of the SLA distance measurement data set in terms of Earth surface topography also requires meter-level knowledge of the Shuttle trajectory and better than 0.1° knowledge of Shuttle pointing angle. These ancillary data sets will be acquired with an on-board Global Positioning System receiver, S-band and K-band range and range-rate tracking of the Shuttle, and use of Shuttle gyroscopes and star trackers.

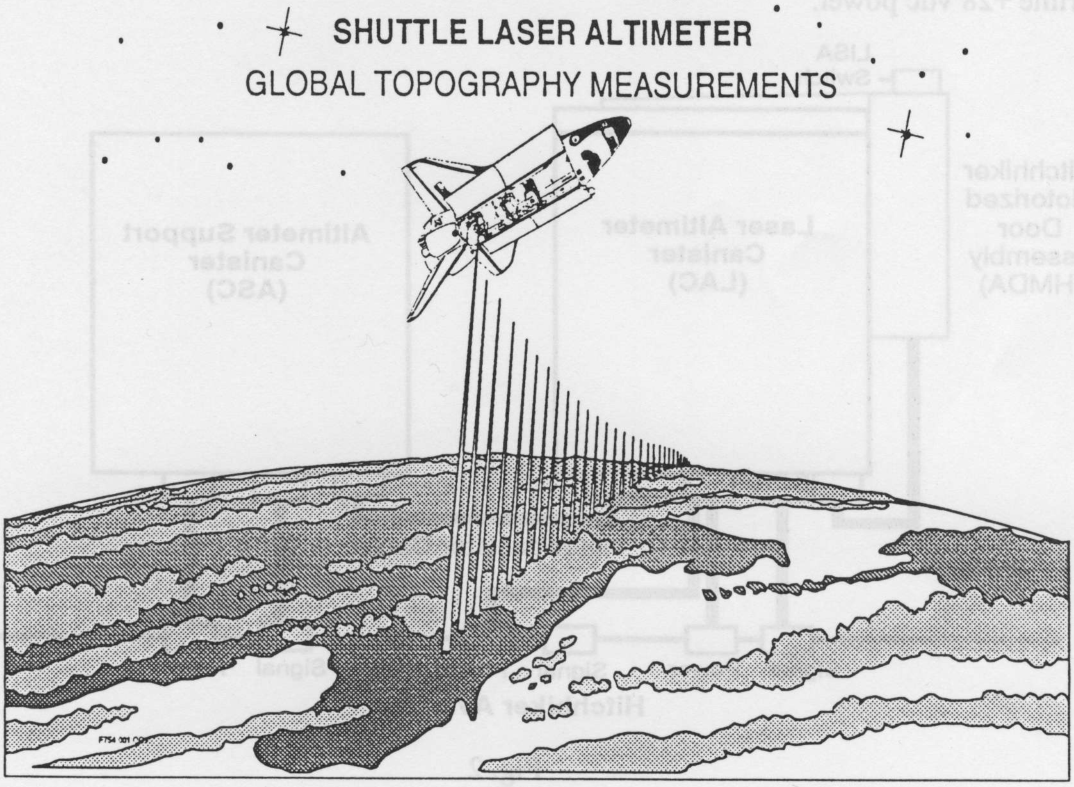

Fig. 1

The laser pulse reflected from the Earth surface is spread in time from its initial value to several tens-of-nsec as a result of non-normal incidence angles, rough surfaces, vegetation, and surface slopes inside the laser footprint. In cloudy conditions the laser pulse is scattered, attenuated, and further broadened in time. The SLA detection and analysis electronics for these weak and broadened pulses consist of: (1) time interval measurements (i.e. range data) and (2) waveform digitization measurements that record the temporal shape of the laser echo. It is waveform digitization that enables a lidar measurement relevant to both the surface and the atmosphere. In the case of surface lidar, for example, tree height can be determined by measuring the characteristic double-pulse signature that results from a separation in time of laser backscatter from tree canopies and the underlying ground. The SLA data system makes the pulse time interval measurement to a precision of about 5 nsec, while the pulse waveform digitizer samples the detector output with an adjustable resolution of 2 nsec or wider intervals in a 100 sample window centered on the return pulse echo. Used at this full resolution, the digitizer configures SLA into a high resolution surface lidar sensor. Used at lower resolution (20-to-100 nsec samples) SLA can function as a cloud lidar sensor.

INSTRUMENT DESCRIPTION

The SLA Instrument design requires the use of two adjacent, Hitchhiker instrument canisters that are connected by a 41-conductor cable for data transmission between the canisters as illustrated in Fig. 2. The two assemblies are the Laser Altimeter Canister (LAC) and the Altimeter Support Canister (ASC), each of which is separately connected to the Hitchhiker avionics through signal and power ports. The transmitter and receiver sub-assemblies of the laser altimeter instrument are located in the LAC canister which is equipped with a Hitchhiker motorized door assembly and a 1 inch (25.4 mm) thick optical window for operation of the laser altimeter instrument in a pressurized environment at the full, clear aperture size of 15.375 inch (390 mm) diam. Both canisters are pressurized at one atmosphere of dry nitrogen. The instrument content of each SLA Hitchhiker canister has a mass of about 100 lbs. (45 kg) and each canister consumes about 30 W of prime +28 vdc power.

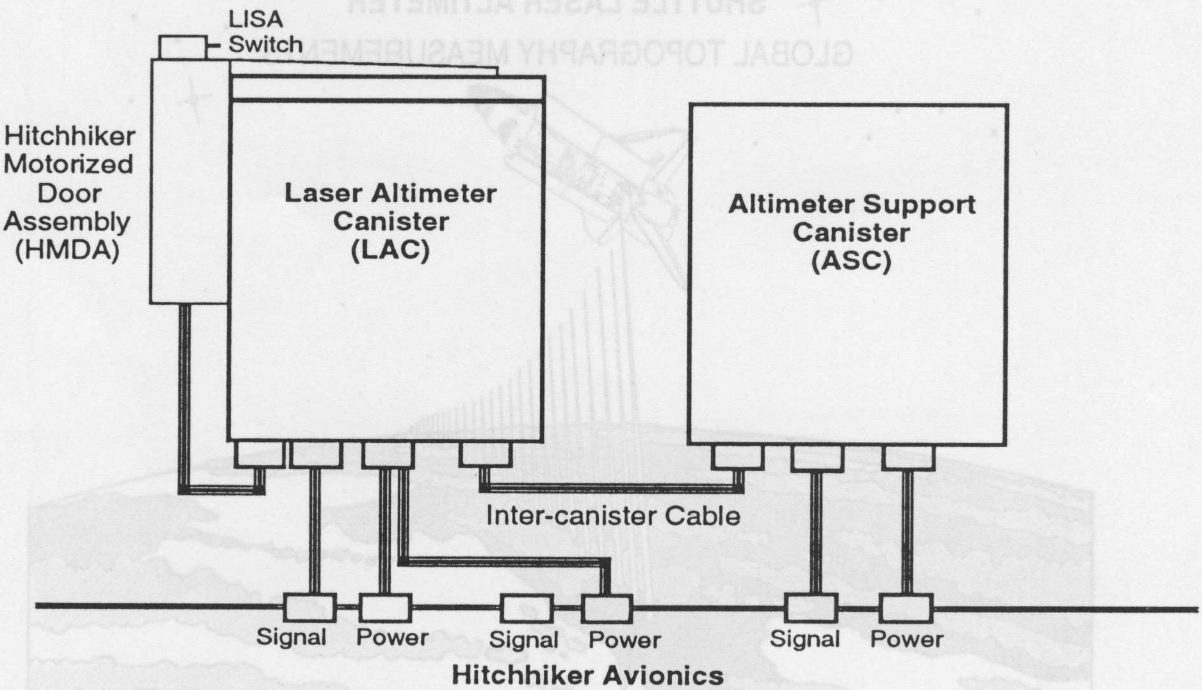

Fig. 2
Shuttle Laser Altimeter Dual Canister Configuration

The SLA works by transmission of short (~ 10 nsec duration) laser pulses at a 1064 nm near-infrared wavelength from the Shuttle and reception of weak backscattered laser radiation from the Earth. A functional block diagram of the SLA payload appears in Fig. 3. The laser source is a diode-pumped Nd:YAG that pulses at a fixed, continuous rate of 10 pps throughout the SLA operational periods. A silicon PIN diode receives ~ 1% of the outgoing laser pulse and provides a "START" signal for the pulse timing and data acquisition. The outgoing laser pulse is turned 90° at the output after emerging from the laser source and passes through a Risley prism pair that is adjusted to align the laser beam to the fixed pointing receiver telescope. The SLA telescope is a gold-plated aluminum, parabolic mirror with a 0.38 m diam. aperture. Some twelve orders-of-magnitude separate the received signal (~femtojoule) from the initial laser pulse energy (~ 40 millijoule). A sensitive silicon avalanche photodiode (APD) with 40% quantum efficiency at 1064 nm is used to detect this weak laser pulse at the telescope mirror prime focus and produce an electronic "STOP" signal. A 2.2 nm wide optical bandpass filter and focusing lenses in the mirror focal plane assist the detector by reducing broadband optical noise due to daytime solar illumination and reducing the size of the image spot to fit it on the 0.8 mm APD.

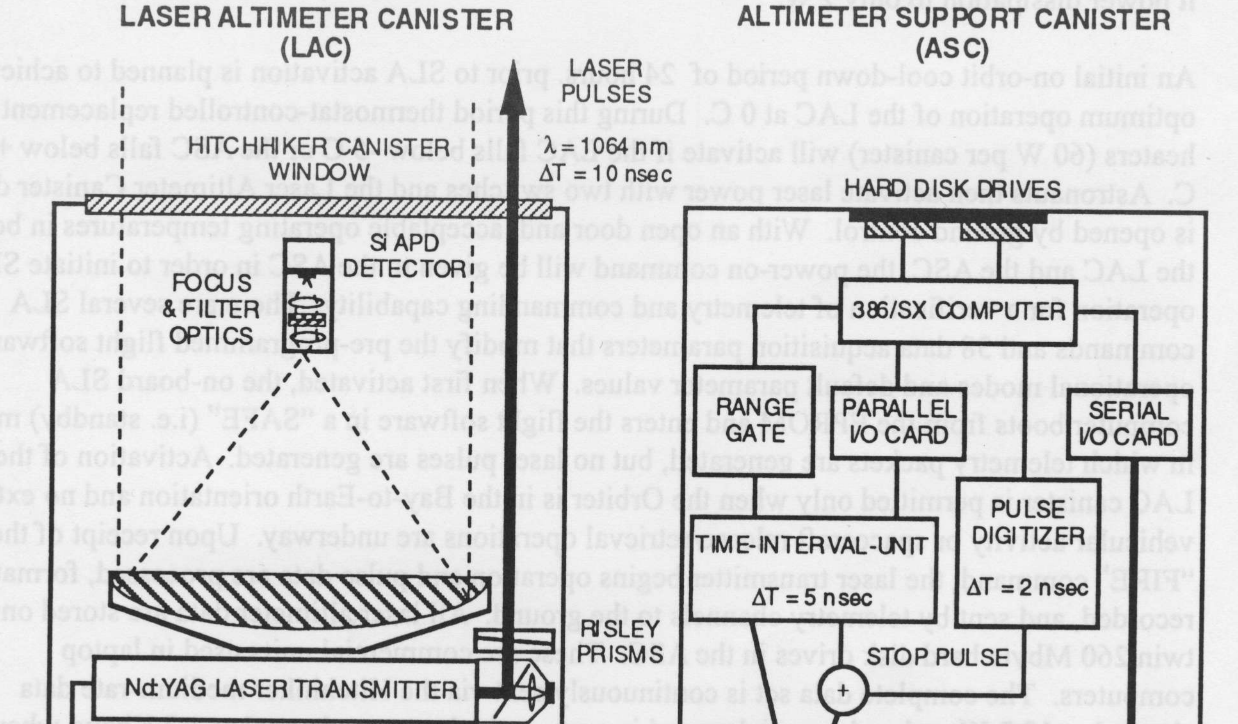

Fig. 3
Shuttle Laser Altimeter Functional Block Diagram

The time-interval-unit, digitizer, and computer data system are the principal data acquisition electronics in the ASC. The time-interval-unit design is based on a 4-channel matched-filter and discriminator bank that precedes a 100 MHz counter. Matched filters, originally developed for the Mars laser altimeter instrument, are optimized for best signal-to-noise ratio in detection of 20 nsec, 60 nsec, 180 nsec, and 540 nsec wide pulses; a range of values that encompasses the expected pulse spreading from the surface and atmosphere. The SLA data acquisition algorithm can accommodate a variable noise level by an automatic threshold tracking loop. In this loop the continuous monitoring of APD detector noise level in a noise pulse counter is used to adjust a voltage threshold up or down to "track" the once-per-sec noise count. This loop provides a stable false-alarm-pulse-rate and maximizes the probability-of-detection of the weak laser pulses that are returned from the surface; hence maximizing the Earth surface data. Performance testing of this loop in space is a key engineering objective of the STS-72 Mission opportunity for SLA. The payload computer, a 386/SX is a single board device with a single 512 Kbyte EPROM and 2 Kbyte of RAM. The computer bus, a ribbon cable, extends to three expander cards necessary for pulse waveform digitization, parallel I/O operations with the altimetry electronics, and the serial I/O communication connections to the Hitchhiker electronics for commands and data. A key innovation of the SLA Instrument design is power cycling of the waveform digitizer that reduces it power dissipation to only 2 W.

An initial on-orbit cool-down period of 24 hours. prior to SLA activation is planned to achieve optimum operation of the LAC at 0 C. During this period thermostat-controlled replacement heaters (60 W per canister) will activate if the LAC falls below -5 C or the ASC falls below +5 C. Astronauts then activate laser power with two switches and the Laser Altimeter Canister door is opened by ground control. With an open door and acceptable operating temperatures in both the LAC and the ASC, the power-on command will be given to the ASC in order to initiate SLA operation for a verification of telemetry and commanding capability. There are several SLA commands and 38 data acquisition parameters that modify the pre-programmed flight software operational modes and default parameter values. When first activated, the on-board SLA computer boots from the EPROM and enters the flight software in a "SAFE" (i.e. standby) mode in which telemetry packets are generated, but no laser pulses are generated. Activation of the LAC canister is permitted only when the Orbiter is in the Bay-to-Earth orientation and no extra vehicular activity or spacecraft release/retrieval operations are underway. Upon receipt of the "FIRE" command, the laser transmitter begins operation and pulse data are processed, formatted, recorded, and sent by telemetry channels to the ground. All laser altimeter data are stored on the twin 260 Mbyte hard disk drives in the ASC. These are commercial units used in laptop computers. The complete data set is continuously sent via the Hitchhiker medium-rate data channel at 19.2 Kbaud and a partial record is sent via the low-rate channel at 1.2 Kbaud when those links are available. The LAC operates continuously until the "SAFE" (i.e. laser off) command is issued. The SLA payload operations will typically continue for 10 to 15 hours during crew rest and sleep periods for a total of about 100 hours per mission. After laser transmitter operation is secured and SLA payload power is removed, the LAC door is closed to complete payload operations.

FUTURE MISSIONS

Four Shuttle flights of the SLA are planned at a rate of about a flight every 18 months. They are aimed at the transition of the Goddard Space Flight Center airborne laser altimeter and lidar technology to low Earth orbit as a pathfinder for operational space-based laser remote sensing devices. Future laser altimeter sensors such as the Geoscience Laser Altimeter System (GLAS), an Earth Observing System facility instrument, and the Multi-Beam Laser Altimeter (MBLA), the land and vegetation laser altimeter for the NASA TOPSAT (Topography Satellite) Mission, will utilize systems and approaches being tested with SLA. The direction of future SLA missions and the instrument complement to be flown in them will of course depend to a great extent on the lessons learned from SLA-01. Planned improvements to the laser transmitter sub-assembly are now underway. These include improvements in laser pulse rate, beam quality, pulsewidth, and laser pulse energy. The eventual goal is a device capable of at least 100 mjoule per pulse energy at 1064 nm, an increase in laser repetition-rate to approximately 50 pps in a single mode (Gaussian) far-field pattern, and the addition of photon counting detection. This more than one-order-of-magnitude increase in sensor performance is driven by the desire to produce contiguous, multi-beam measurements of Earth surface topography with a 30 m diam. sensor footprint. This will permit laser altimetry data to work in synergism with space-based radar and photographic topography sensors. Improvements are also needed in both GPS and pointing attitude data sets to achieve an operational "scientific" level-of-performance in geo-referenced surface elevation data sets. The Shuttle Laser Altimeter is currently manifested on STS-85 permitting us to begin these upgrades.

National Aeronautics and
Space Administration

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250

COMPUTER GRAPHIC FORMAT

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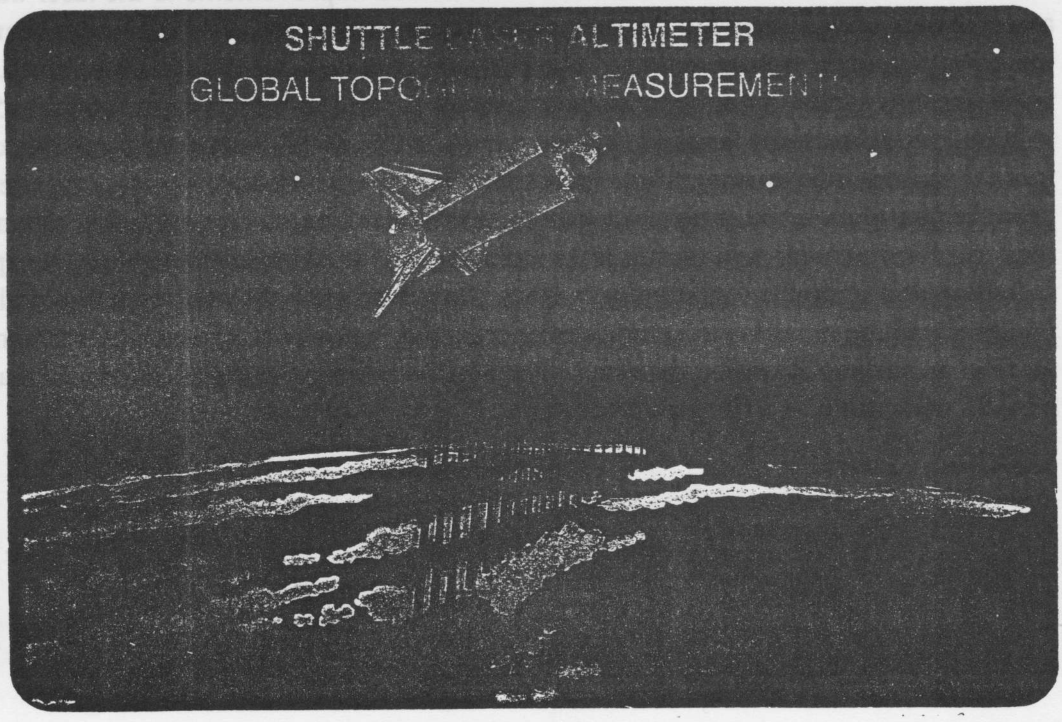
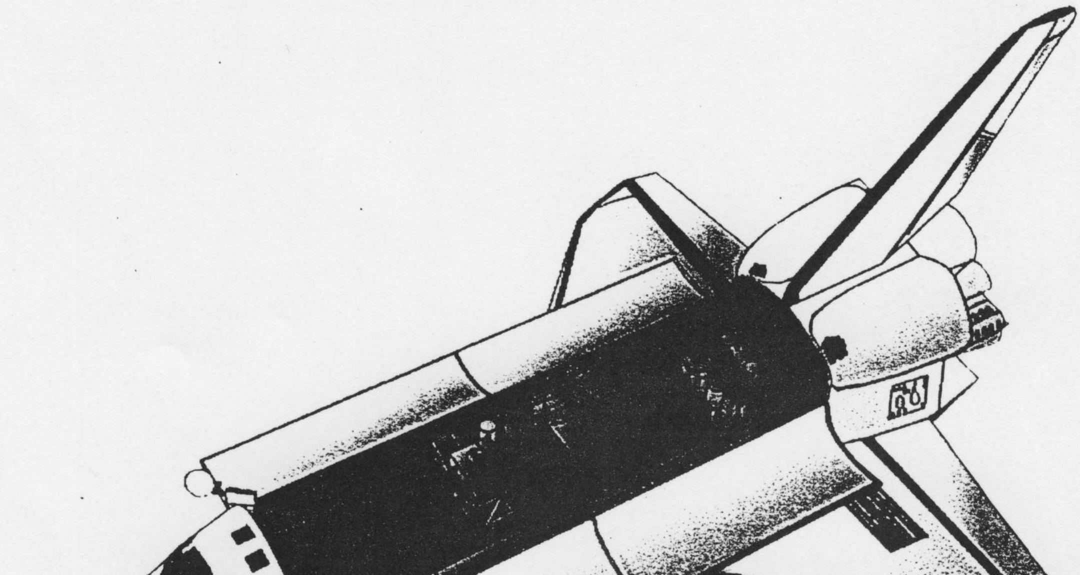
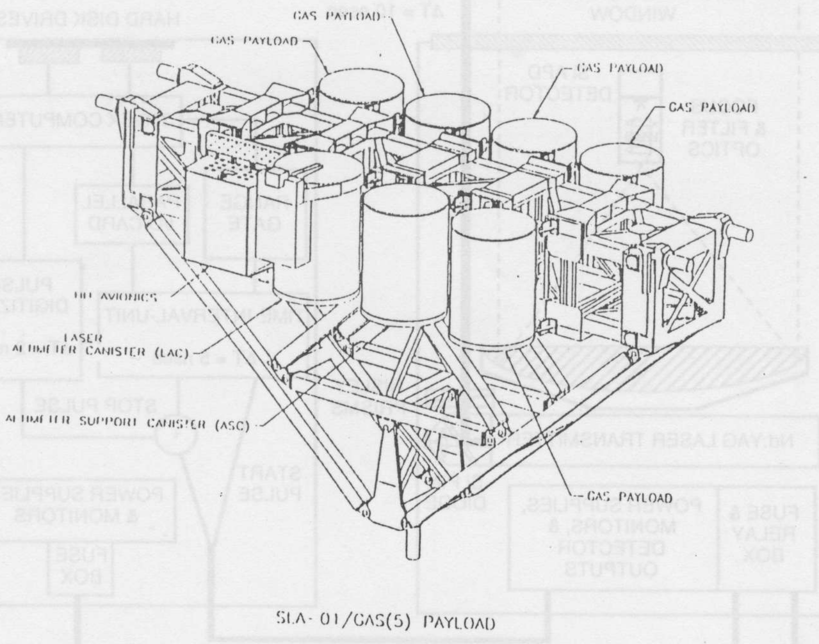
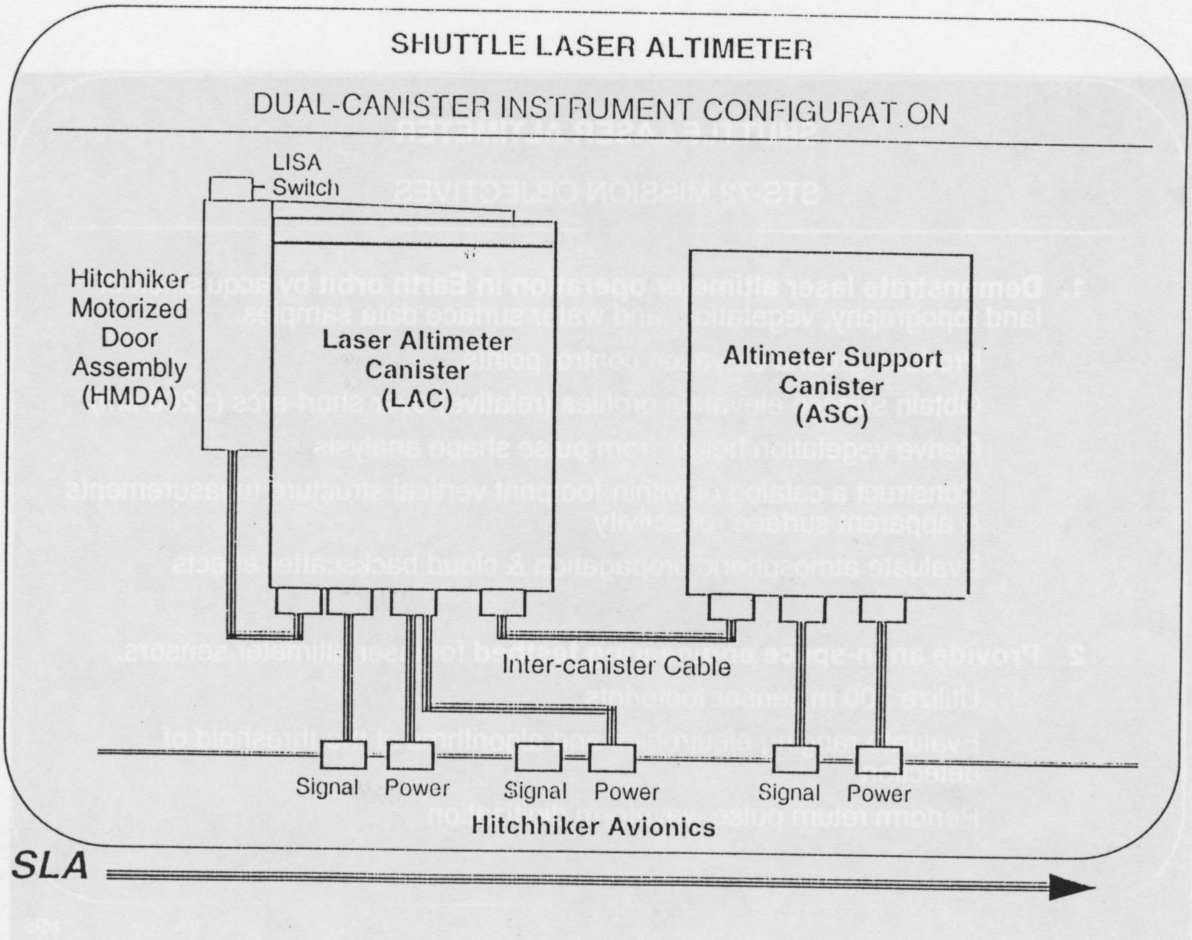


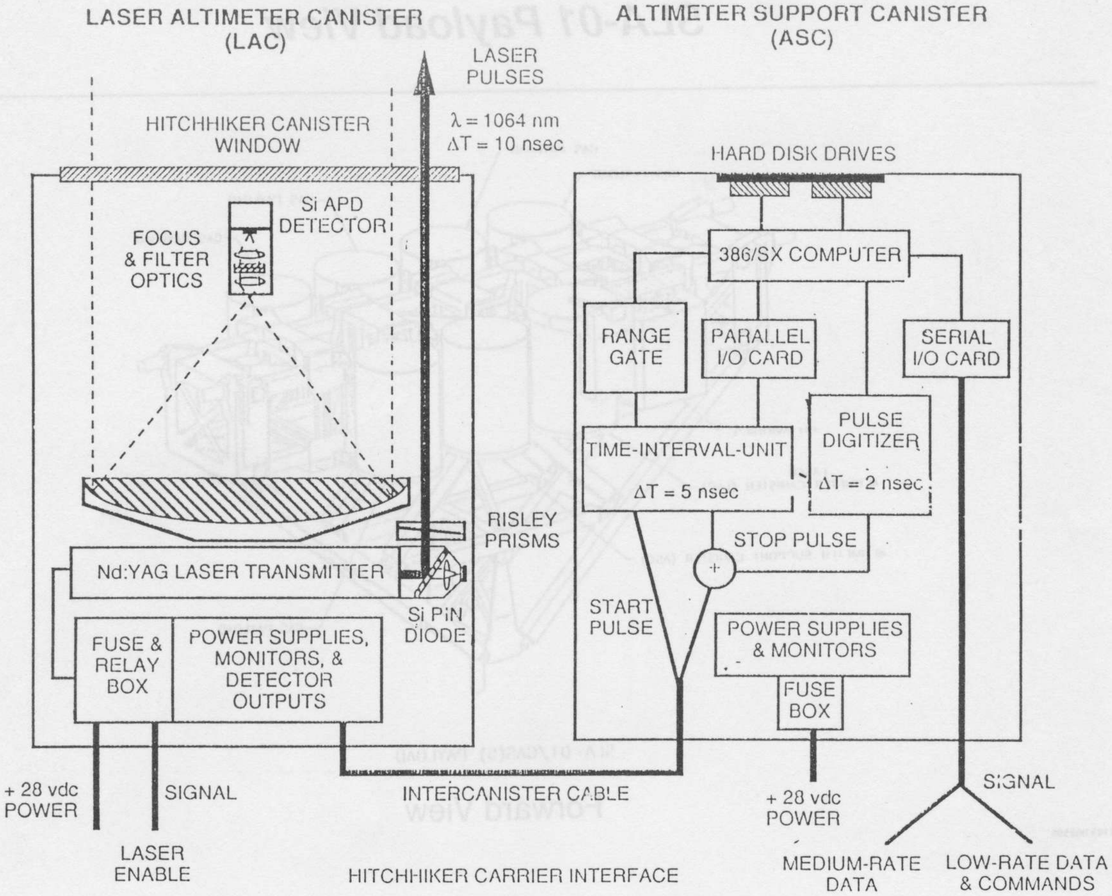


SLA-01 Payload View



Forward View





SHUTTLE LASER ALTIMETER

STS-72 MISSION OBJECTIVES

1. **Demonstrate laser altimeter operation in Earth orbit** by acquisition of land topography, vegetation, and water surface data samples.
   - Produce ground elevation control points.
   - Obtain surface elevation profiles (relative) over short-arcs (~200 km)
   - Derive vegetation height from pulse shape analysis
   - Construct a catalog of within-footprint vertical structure measurements & apparent surface reflectivity
   - Evaluate atmospheric propagation & cloud backscatter effects

2. **Provide an in-space engineering testbed** for laser altimeter sensors.
   - Utilize 100 m sensor footprints
   - Evaluate ranging electronics and algorithms at the threshold of detection
   - Perform return pulse waveform digitization

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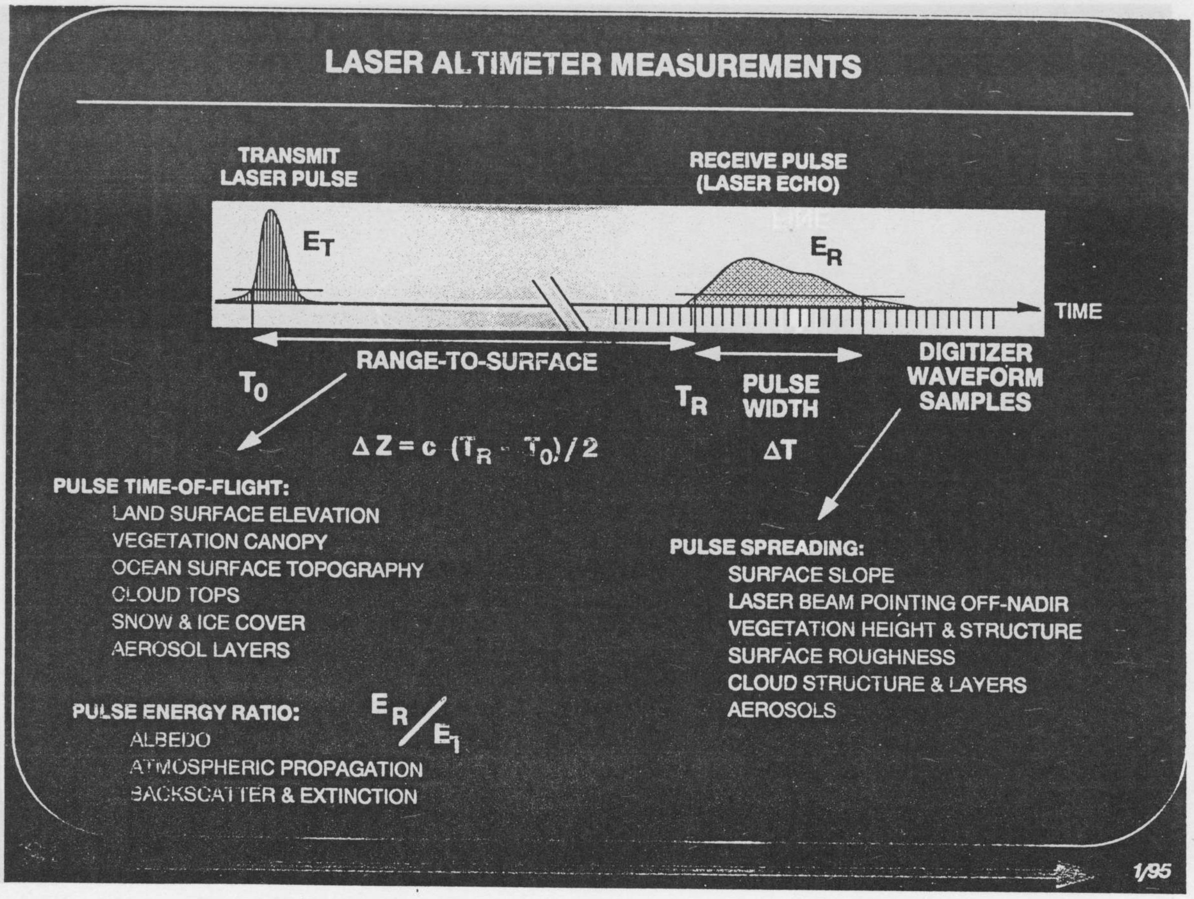
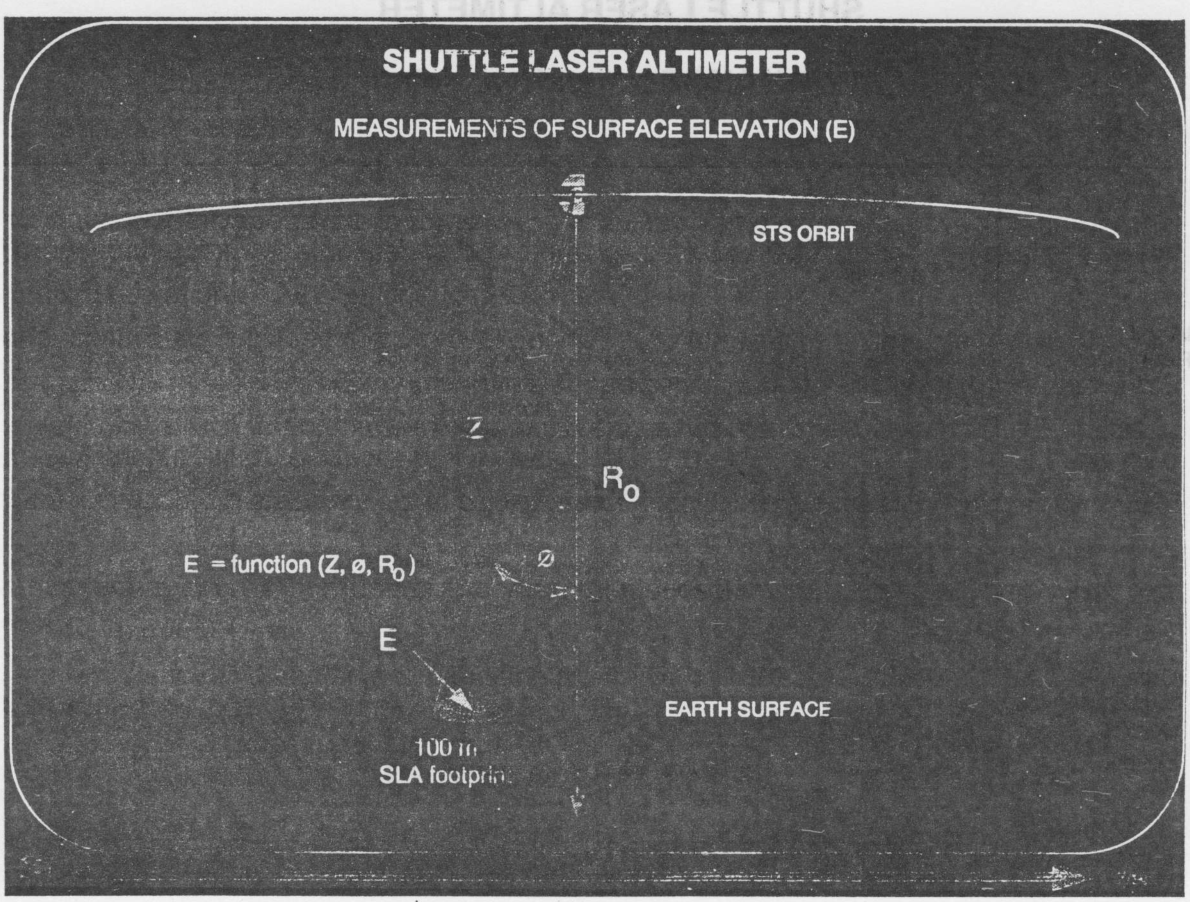
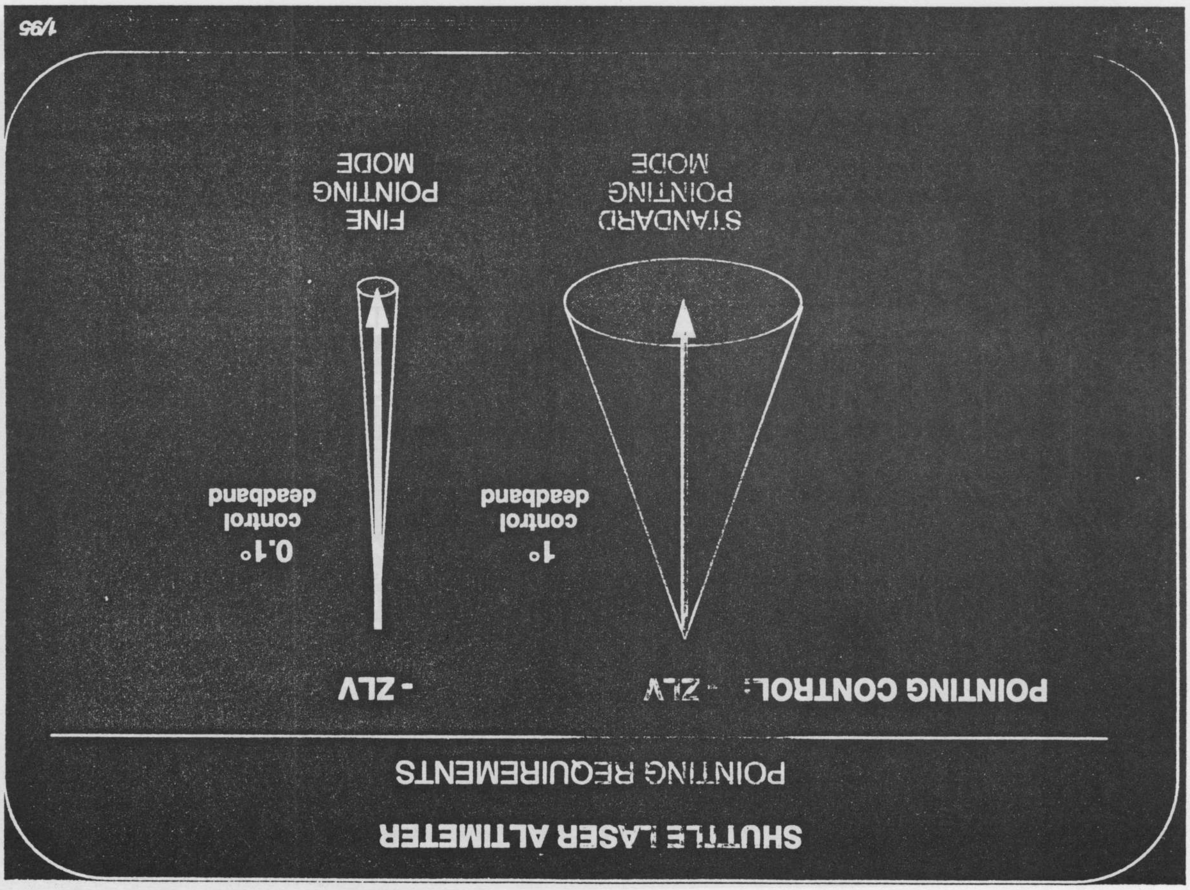
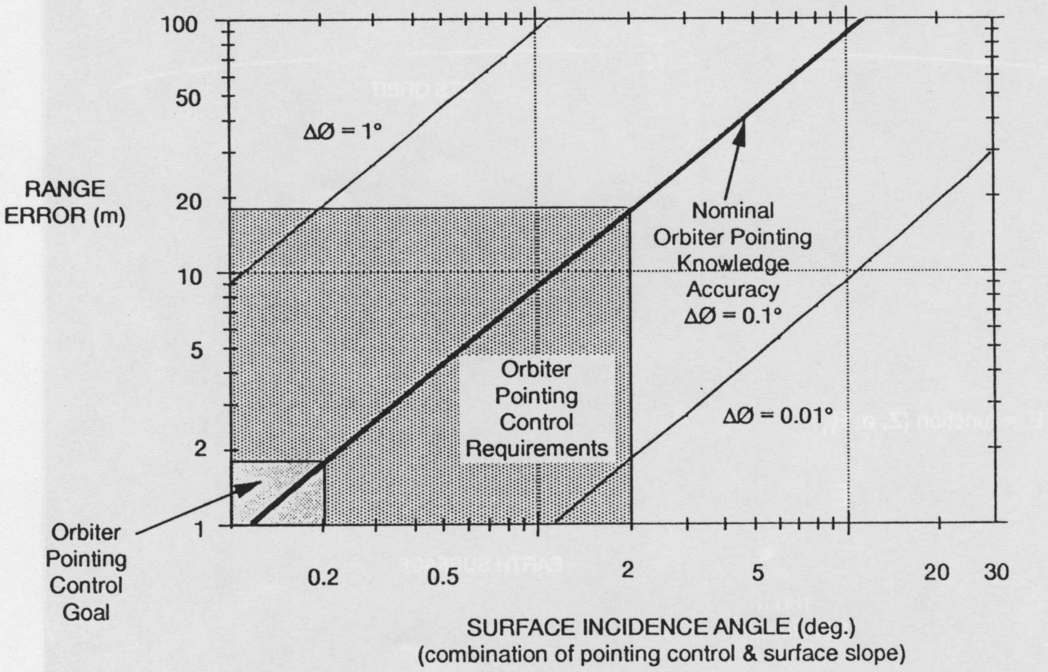

LASER ALTIMETER MEASUREMENTS
TRANSMIT LASER PULSE
RECEIVE PULSE (LASER ECHO)
E_T
E_R
TIME
RANGE-TO-SURFACE
T_0
T_R
PULSE WIDTH
DIGITIZER WAVEFORM SAMPLES
$\Delta Z = c\ (T_R - T_0)/2$
ΔT
PULSE TIME-OF-FLIGHT:
LAND SURFACE ELEVATION
VEGETATION CANOPY
OCEAN SURFACE TOPOGRAPHY
CLOUD TOPS
SNOW & ICE COVER
AEROSOL LAYERS
PULSE SPREADING:
SURFACE SLOPE
LASER BEAM POINTING OFF-NADIR
VEGETATION HEIGHT & STRUCTURE
SURFACE ROUGHNESS
CLOUD STRUCTURE & LAYERS
AEROSOLS
PULSE ENERGY RATIO:
E_R / E_T
ALBEDO
ATMOSPHERIC PROPAGATION
BACKSCATTER & EXTINCTION
1/95

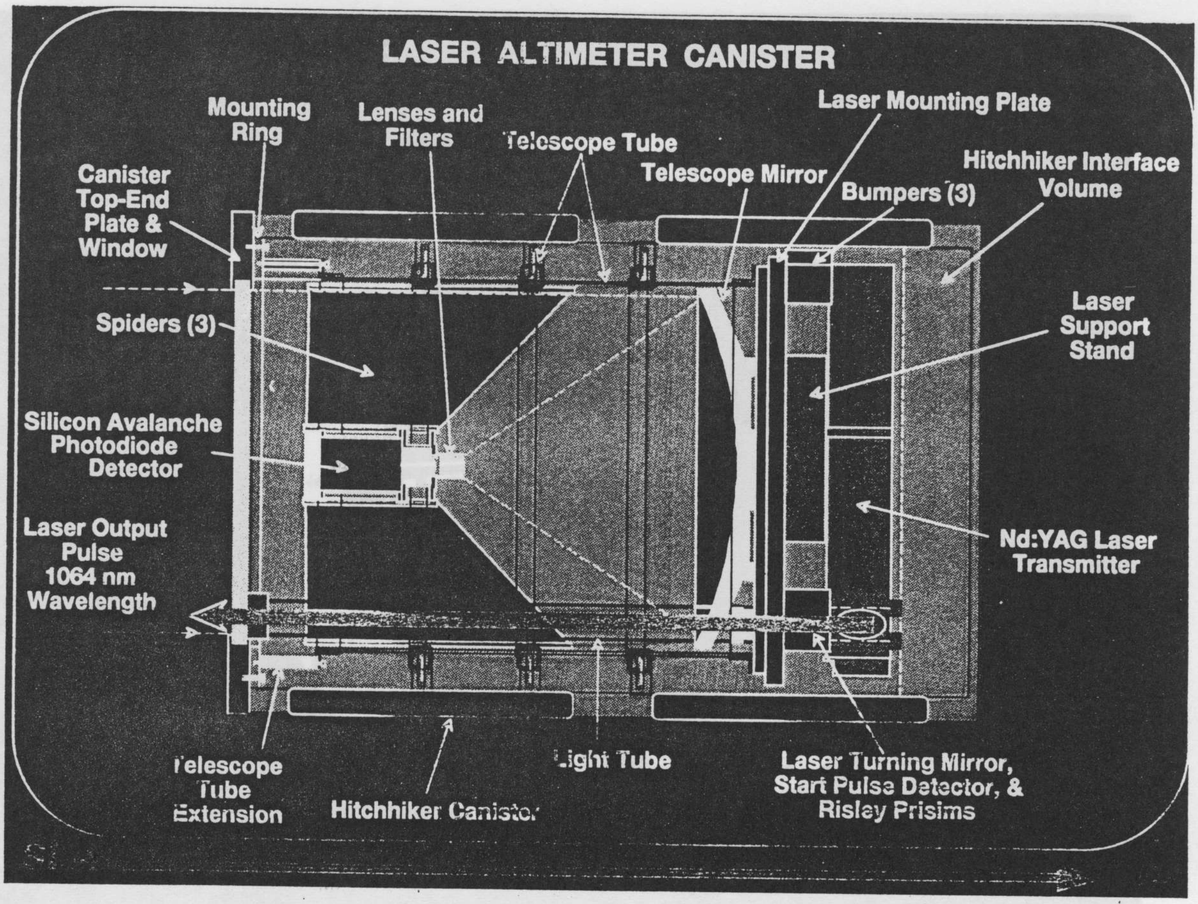

SHUTTLE LASER ALTIMETER
MEASUREMENTS OF SURFACE ELEVATION (E)
STS ORBIT
Z
R_0
E = function (Z, ø, R_0)
ø
E
EARTH SURFACE

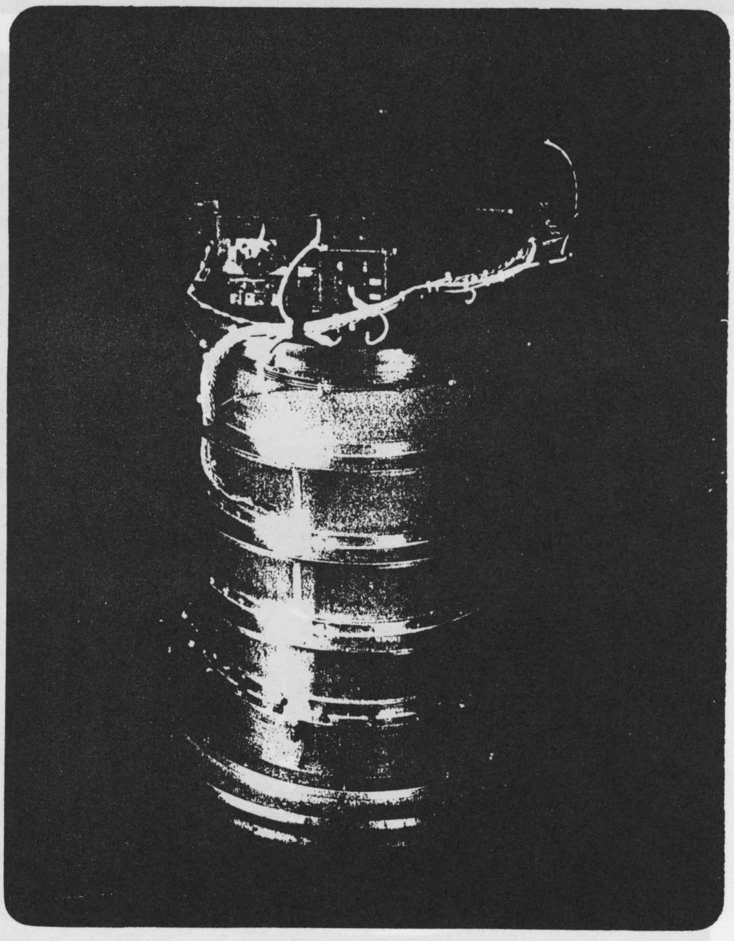


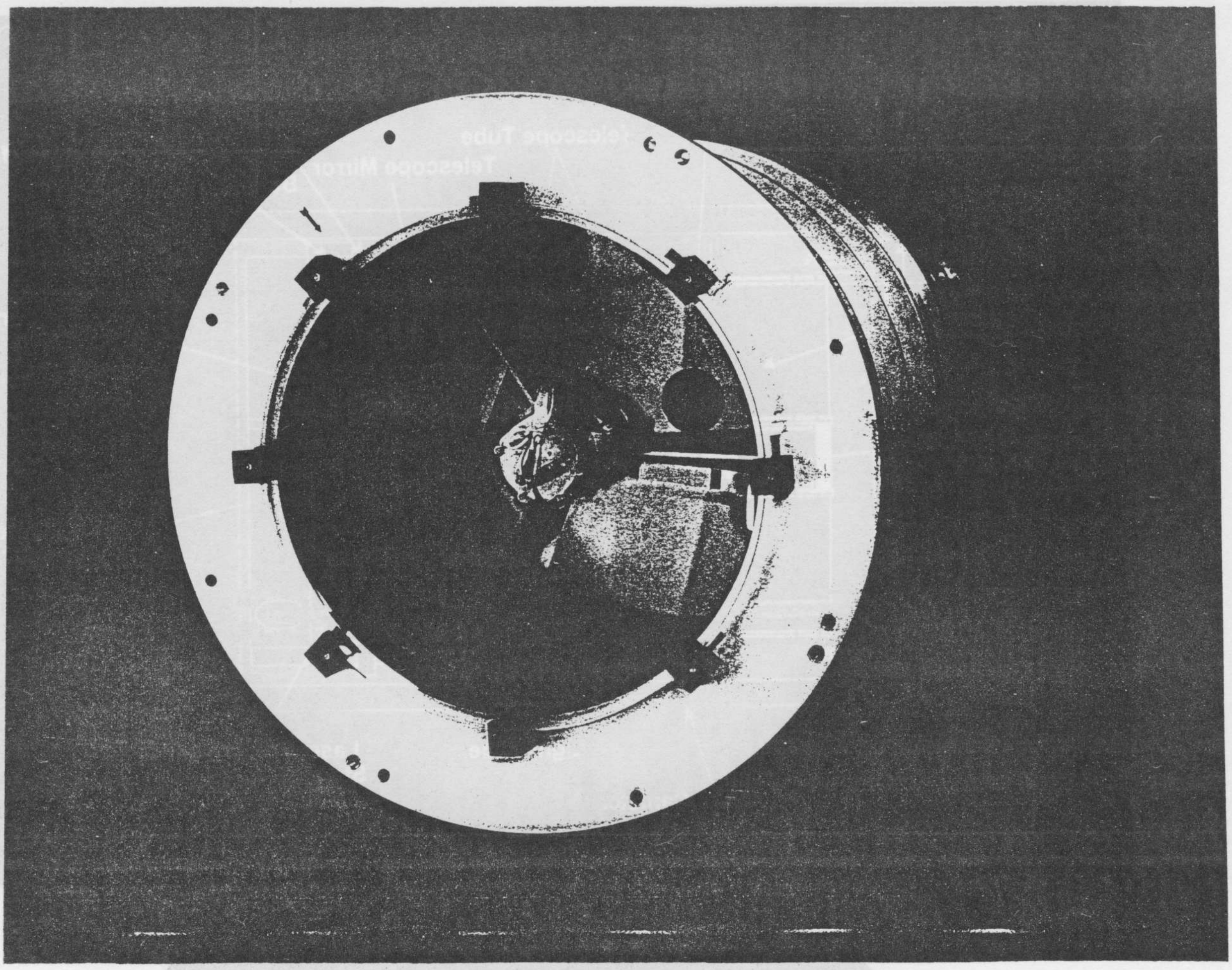
SHUTTLE LASER ALTIMETER

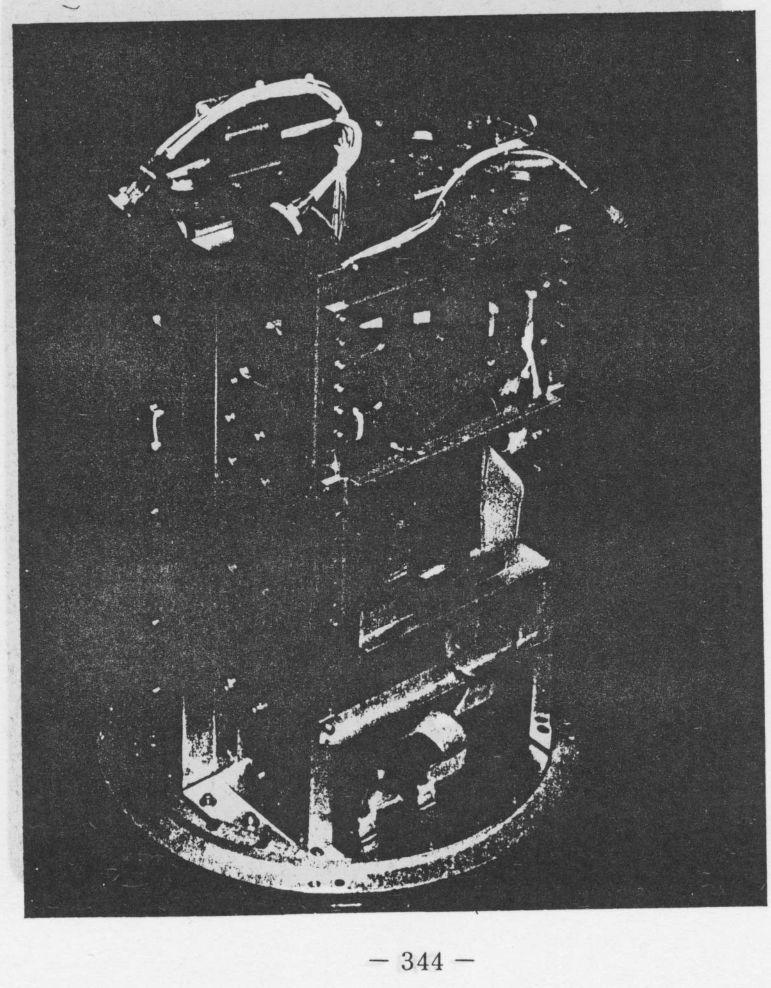
RANGING PERFORMANCE for various pointing errors (ΔØ)




LASER ALTIMETER CANISTER
Mounting Ring
Lenses and Filters
Telescope Tube
Laser Mounting Plate
Canister Top-End Plate & Window
Telescope Mirror
Hitchhiker Interface Volume
Bumpers (3)
Spiders (3)
Laser Support Stand
Silicon Avalanche Photodiode Detector
Laser Output Pulse 1064 nm Wavelength
Nd:YAG Laser Transmitter
Telescope Tube Extension
Light Tube
Laser Turning Mirror, Start Pulse Detector, & Risley Prisims
Hitchhiker Canister







COMMAND & DATA HANDLING

Flight System:

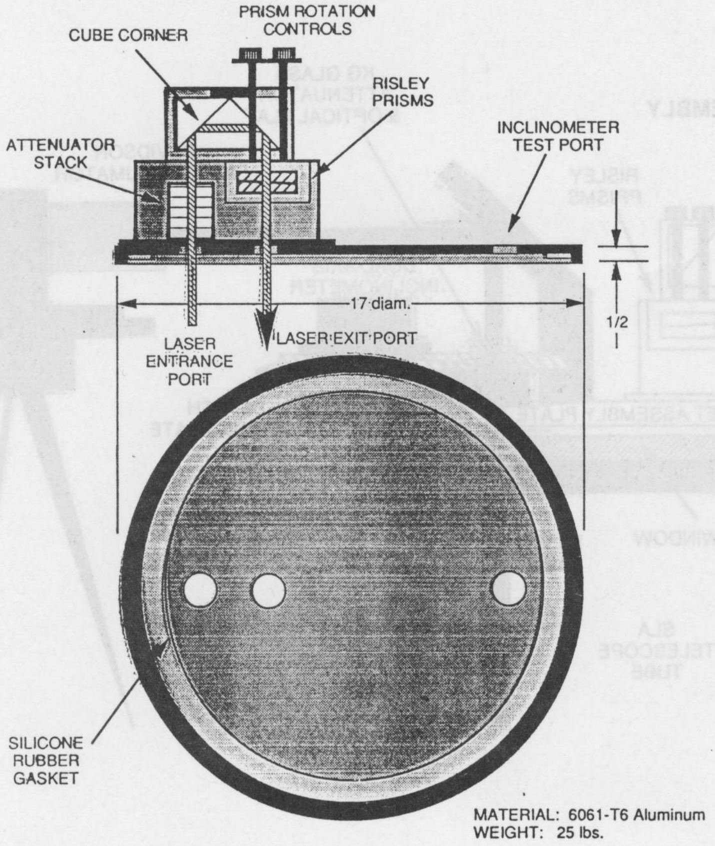
- **Data Volume:** 12 kbps for 104 hours = 562 MByte
- **Housekeeping:** 16 temperatures (8 per canister), voltages, currents, status bits
- **Medium-Rate Telemetry:** all data
- **Low-Rate Telemetry:** samples of all data
- **On-Board Storage:** 520 MByte (2 hard drives)
- **Low-Rate Uplink for Commanding**

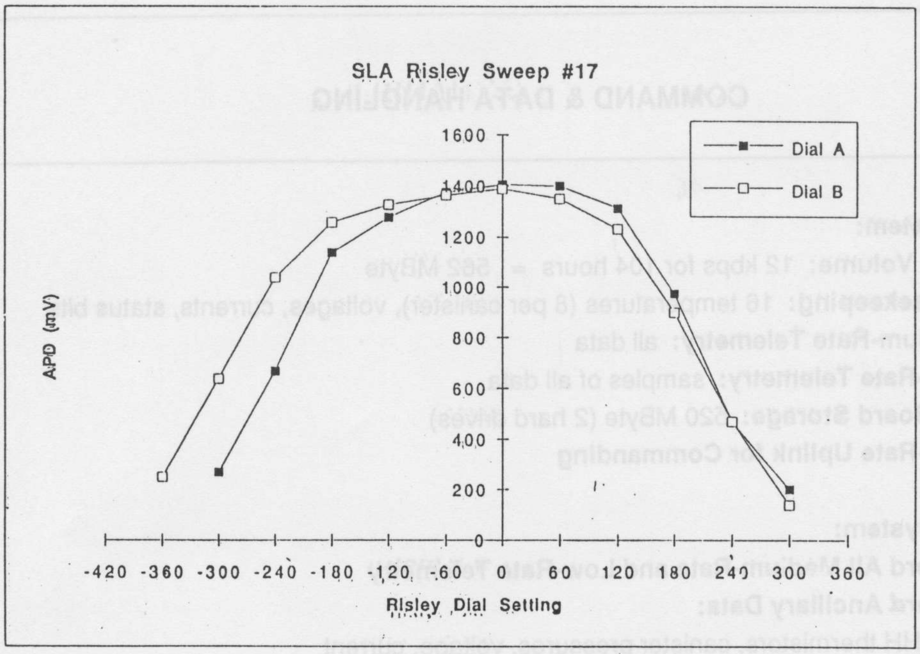
Ground System:

- **Record All Medium-Rate and Low-Rate Telemetry**
- **Record Ancillary Data:**
  - HH thermistors, canister pressures, voltage, current
- **Record Orbiter Real-Time Position & Attitude Data**
- **Commands:**
  - Laser ON/OFF, Hard Drives ON/OFF, Computer Reset, Altimeter Mode Selection, Data Acquisition Parameter Updates: e.g. Range Gate Delay, Range Gate Width

SLA

SLA TARGET ASSEMBLY





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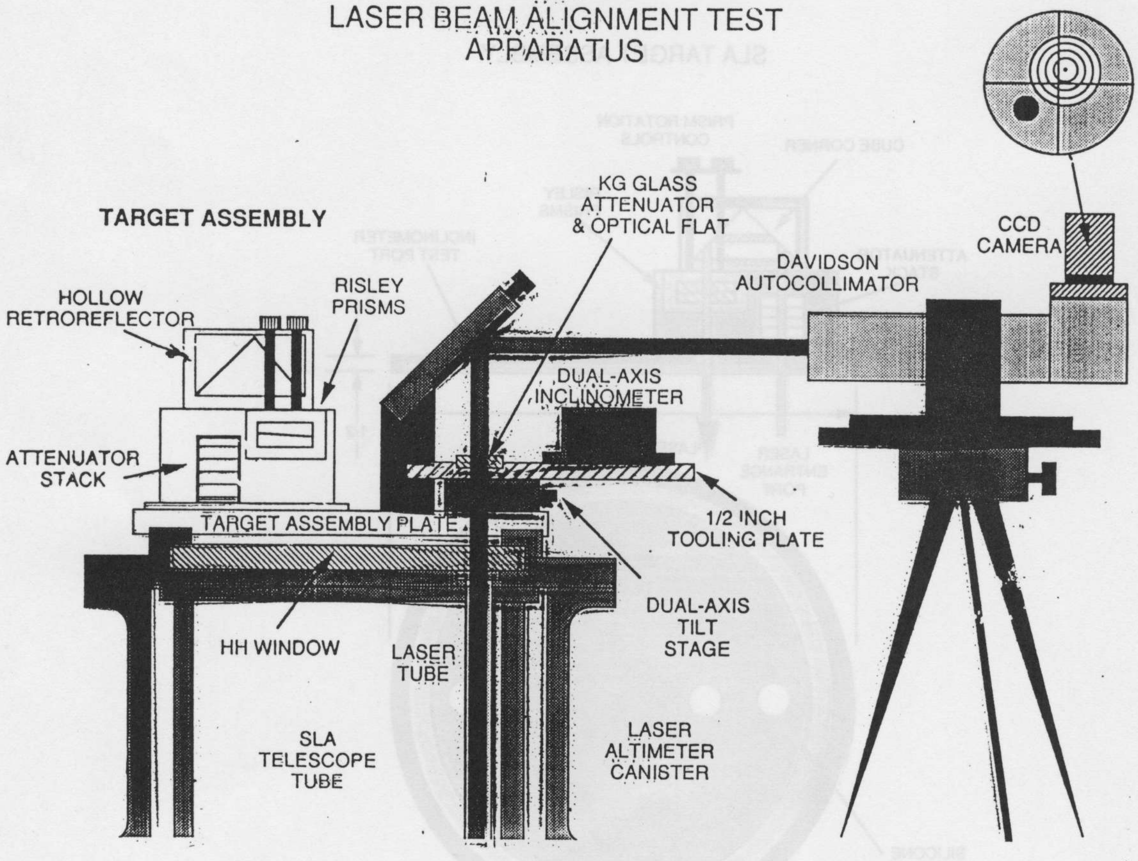
SLA LASER BEAM ALIGNMENT TEST APPARATUS



SHUTTLE LASER ALTIMETER

SUMMARY OF INSTRUMENT STATUS 9/7/95

- **PASSED VIBRATION & EMI/EMC TESTING:**
- **ELECTRICAL INTEGRATION TO HITCHHIKER CARRIER & AVIONICS COMPLETE:**
- **MECHANICAL INTEGRATION TO HITCHHIKER BRIDGE ASSEMBLY COMPLETE:**
- **FLIGHT SOFTWARE: Final as of June 10, 1995 ---- No anomalies in testing.**
- **GSE:**

  Two SLA GSE computer systems and software compete and verified.

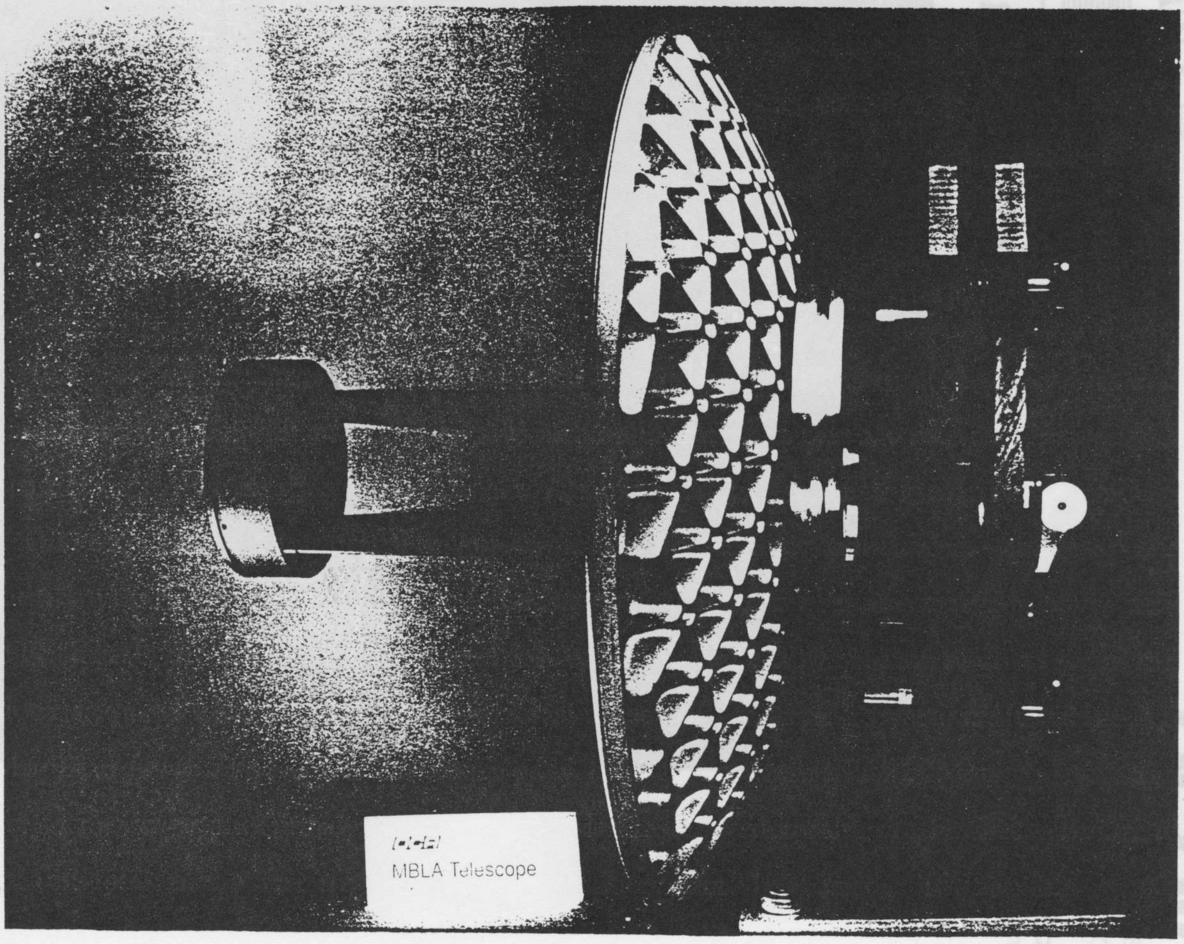
  Target Assembly & laser beam alignment test apparatus complete and verified.
- **OPTICAL ALIGNMENT: Finalized February 8, 1995**

  No adjustment since 2/8/95 and test data over the interim confirms co-boresight is still valid as of 8/31/95.

  No boresight shift greater than 0.2 mrad.
- **ALIGNMENT TESTING WITH RESPECT TO HITCHHIKER BRIDGE TRUNION PLANE:**

  RESULT: Laser beam emitted from LAC is aligned to better than 0.1° with respect to Hitchhiker Bridge roll & pitch axes

SLA



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