FR 11/6/1995

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NOTICE (95-)

National Environmental Policy Act; Shuttle Laser Altimeter

AGENCY: National Aeronautics and Space Administration (NASA).

ACTION: Finding of no significant impact.

SUMMARY: Pursuant to the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.), the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508), and NASA policy and procedures (14 CFR Part 1216 Subpart 3), NASA has made a finding of no significant impact (FONSI) with respect to the proposed Shuttle Laser Altimeter (SLA) to be constructed at the Goddard Space Flight Center, in Greenbelt, Maryland. SLA involves the precise global measurement of the topography of the distance from the Earth's surface with respect to the Space Shuttle.

DATE: Comments in response to this notice must be provided in writing to NASA on or before (insert date 30 days from publication in the Federal Register).

ADDRESSES: Comments should be addressed to Dr. Jack L. Bufton, Associate Chief for Sensor Physics, Laboratory for Terrestrial Physics, Code 920, NASA Goddard Space Flight Center, Greenbelt, MD 20771. The Environmental Assessment (EA) prepared for the proposed SLA which supports this FONSI may be reviewed at:

(a) Prince George's County Memorial Library System - Bowie Branch, 15210 Annapolis Rd., Bowie, Maryland.

(b) NASA Headquarters Information Center, Room 1H23, 300 E. Street S.W.,Washington, DC.

(c) NASA, Ames Research Center, Moffet Field, CA 94035 (415-604-4191).

(d) NASA, Dryden Flight Research Center, Edwards, CA 93523 (805-258-3047).

(e) NASA, Goddard Space Flight Center, Greenbelt, MD 20771 (301-286-7216).

(f) Jet Propulsion Laboratory, Visitors Lobby, Building 49, 4800 Oak Grove Drive, Pasadena, CA 91109 (818-354-5011).

(g) NASA, Johnson Space Center, Houston, TX 77058 (713-483-8612).

(h) NASA, Langley Research Center, Hampton, VA 23665 (804-864-6125).

(i) NASA, Kennedy Space Center, FL 32899 (407-867-2622).

(j) NASA, Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135 (215-433-2902).

(k) NASA, Marshall Space Flight Center, AL 35812 (205-544-5252).

(l) NASA, Stennis Space Center, MS 39529 (601-688-2164).

A limited number of copies of the EA are available by contacting Jack L. Bufton, NASA Goddard Space Flight Center, Greenbelt, MD 20771, telephone 301-286-8591.

FOR FURTHER INFORMATION CONTACT: Dr. Jack L. Bufton, 301-286-8591.

SUPPLEMENTARY INFORMATION: NASA has reviewed the EA prepared for the proposed SLA and has determined that it represents an accurate and adequate analysis of the scope and level of its associated environmental impacts. The EA, including the "Shuttle Laser Altimeter Ground Observer Eye Safety Analysis", is incorporated by reference in this FONSI.

NASA is proposing to test a low power laser altimeter instrument in space as a pathfinder instrument for global measurement of the topography of the Earth's land surface. Laser altimeter instruments have been in use for several decades from airborne instrument platforms for the purpose of terrain mapping and previous laser altimeters have flown in space. Research results from these earlier programs indicate the advantages of a space-based global observations of Earth land surface topography using the high spatial resolution and vertical precision offered by the laser altimeter technique. Accurate topographic information on the Earth's landforms is essential in a wide variety of Earth science disciplines, agriculture, land-use studies, and natural masses crossed will be Africa, most of Latin America, Southland Southeast Asia, and much of Australia. Consequently, no SLA operations will be conducted over the continental US north of Cape Canaveral, Florida.

The proposed action and the no-action alternative were considered in this Environmental Assessment (EA). The no-action alternative will not fulfill the objective of advancing the Nation's topographic measurement capability. Under the No-Action alternative, it will not be possible to fully develop or space test the laser altimeter instrument technology for an operational space-based topography system. It will then be necessary to rely on existing photogrammetric and radar mapping instruments which have limitations in accuracy and in interpretation of topography data.

A review by the North American Defense Command and United States Space Command SPADOC Laser Clearinghouse found that the SLA laser transmitter does not produce sufficient laser energy to exceed their damage threshold and, therefore, does not require clearinghouse screening.

The only potential source of environmental impact from the proposed action is the portion of the laser pulse energy which will pass through the Earth's atmosphere and reach the surface. The SLA laser energy is negligible compared to natural sources of optical radiation. A ground observer safety analysis was performed for the SLA experiment and found no substantial risk of human eye or skin injury from operation of the SLA instrument within the range of possible Shuttle orbital altitudes.

No other environmental impacts have been identified as a result of the EA. On the basis of the SLA EA and underlying reference documents, NASA has determined that the environmental impacts associated with this project will not individually or cumulatively have a significant effect on the quality of the environment. NASA will take no final action prior to the expiration of the 30-day comment period.

W. F. Townsend

William F. Townsend
Deputy Associate Administrator for
Mission to Planet Earth

Environmental Assessment

Shuttle Laser Altimeter Experiment

Goddard Space Flight Center
Greenbelt, MD

August 1995

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ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
ASC	Altimeter Support Canister
CFR	Code of Federal Regulations
cm	centimeter
EA	Environmental Assessment
ft	foot
FWHM	full width at half maximum
GSFC	Goddard Space Flight Center
HMDA	Hitchhiker motorized door assembly
in	inch
J/cm^2	Joule per centimeter squared
km	kilometer
km/sec	kilometer per second
LAC	Laser Altimeter Canister
m	meter
m/sec	meter per second
mJ	millijoule
mm	millimeter
MPE	Maximum Permissible Exposure
mph	miles per hour
mrad	milliradian
MW	megaWatt
NASA	National; Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NHB	NASA Handbook
nm	nanometer
NM	nautical mile
NOHD	Nominal Ocular Hazard Distance
nsec	nanosec
pps	pulses per second
RE	maximum Radiant Exposure
STS	Space Transportation System
W	Watt
W/m^2	Watts per meter squared
ZLV	Z axis aligned with the local vertical

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1.0 Summary and Conclusions

NASA is proposing to test a laser altimeter instrument in space as a pathfinder instrument for global measurement of the topography of the Earth's land surface. Laser altimeter instruments have been in use for several decades from airborne instrument platforms for this purpose of terrain mapping and previous laser altimeters have flown in space. Research results from these earlier programs indicate the advantages of a space-based global observations of Earth land surface topography using the high spatial resolution and vertical precision offered by the laser altimeter technique. Accurate topographic information on the Earth's landforms is essential in a wide variety of Earth science disciplines, agriculture, land-use studies, and natural disaster (e.g. floods, erosion, land-slides, volcanoes, earthquakes) mitigation.

The principal components of a laser altimeter system are the laser transmitter, optical receiver, and data system. The laser transmitter sends a pulsed laser beam of 1064 nm wavelength radiation through the Earth's atmosphere toward the Earth's surface. Each laser pulse has a temporal duration of 10 nsec and forms a spot of approximately 100 meter diameter on the Earth's surface. Reflection of laser radiation from this spot is detected at the laser altimeter instrument by the combination of an optical telescope and detector that constitute the optical receiver package and convert the optical pulse into an electronic pulse. The laser pulse time-of-flight over the round-trip from the laser altimeter instrument to the Earth's surface and return is measured and is used to compute distance between the instrument and the Earth's surface. The data system performs the computation of distance form pulse time-of-flight and communicates the altimeter data to external systems and on-board data recorders. For laser altimeter operations the instrument must be pointed perpendicular to the Earth's surface in order to make accurate distance measurements. The optical receiver is quite sensitive, since most of the pulsed laser radiation is scattered in the reflection of light from the spot on the Earth's surface or scattered and absorbed in the Earth's atmosphere. By using pulsed laser energy to make a series of distance measurements (profiles) along the ground track of a spacecraft, a laser altimeter instrument can build up a global grid of accurate surface topography.

The proposed Shuttle Laser Altimeter (SLA) Experiment will entail flying a laser altimeter instrument as a small attached payload on the Space Shuttle. The first flight is scheduled for November 1995 and will be a nine-day mission to gain experience in operating a laser altimeter in the space environment, and to evaluate the sensitivity of the laser altimeter instrument for performing the surface elevation measurement mission. The current flight plan calls for seven operational periods of approximately 10 to 15 hours duration each during which the SLA will continuously profile the Earth and ocean surface topography along the ground track (nadir track) of the Shuttle. The SLA instrument operates continuously at 10 pps during each period. This results in a continuous profile of 120 m diameter optical spots (i.e. altimeter sensor footprints) that are separated by approximately 740 m along the ground-track of the Space Shuttle. At least one SLA operational period is scheduled on each Shuttle flight day after flight day 2. The planned orbit for these SLA operations is a 300 km (160 NM) circular orbit at 28.5° inclination. The ground track area that is covered by such an orbit is illustrated in Fig. 1. The ground tracks cover the equatorial regions of the globe between 28.5° North latitude and 28.5° South latitude.

The proposed Action and No-Action alternatives were considered in this Environmental Assessment (EA). The No-Action alternative will not fulfill NASA's objective to advance the Nation's topographic measurement capability. Under the No-Action alternative it will not be possible to fully develop or space test the laser altimeter instrument technology for an operational space-based topography system. It will then be necessary to rely on existing photogrammetric and radar mapping instruments which have limitations in accuracy and in interpretation of topography data.

A review conducted on 05 June 95 by Jeff Jordan, LT, USN Orbital Safety Officer from the US. Space Command Laser Clearinghouse found that the SLA laser transmitter does not produce sufficient laser energy to exceed their damage threshold and therefore does not require clearinghouse screening. The only potential source of environmental impact from the proposed action is the portion of the laser pulse energy which will pass through the Earth's atmosphere and reach the surface. The SLA laser energy is negligible compared to natural sources of optical radiation. A Ground Observer Eye Safety Analysis was performed on 21 July 94 by Jack L. Bufton from NASA'S Goddard Space Flight Center for the SLA experiment and found no significant risk of human eye or skin injury from operation of the SLA instrument within the range of possible Shuttle orbital altitudes. No other potential environmental impacts were identified. Based on this analysis it appears that the proposed SLA Experiment will not have a significant impact on the environment.

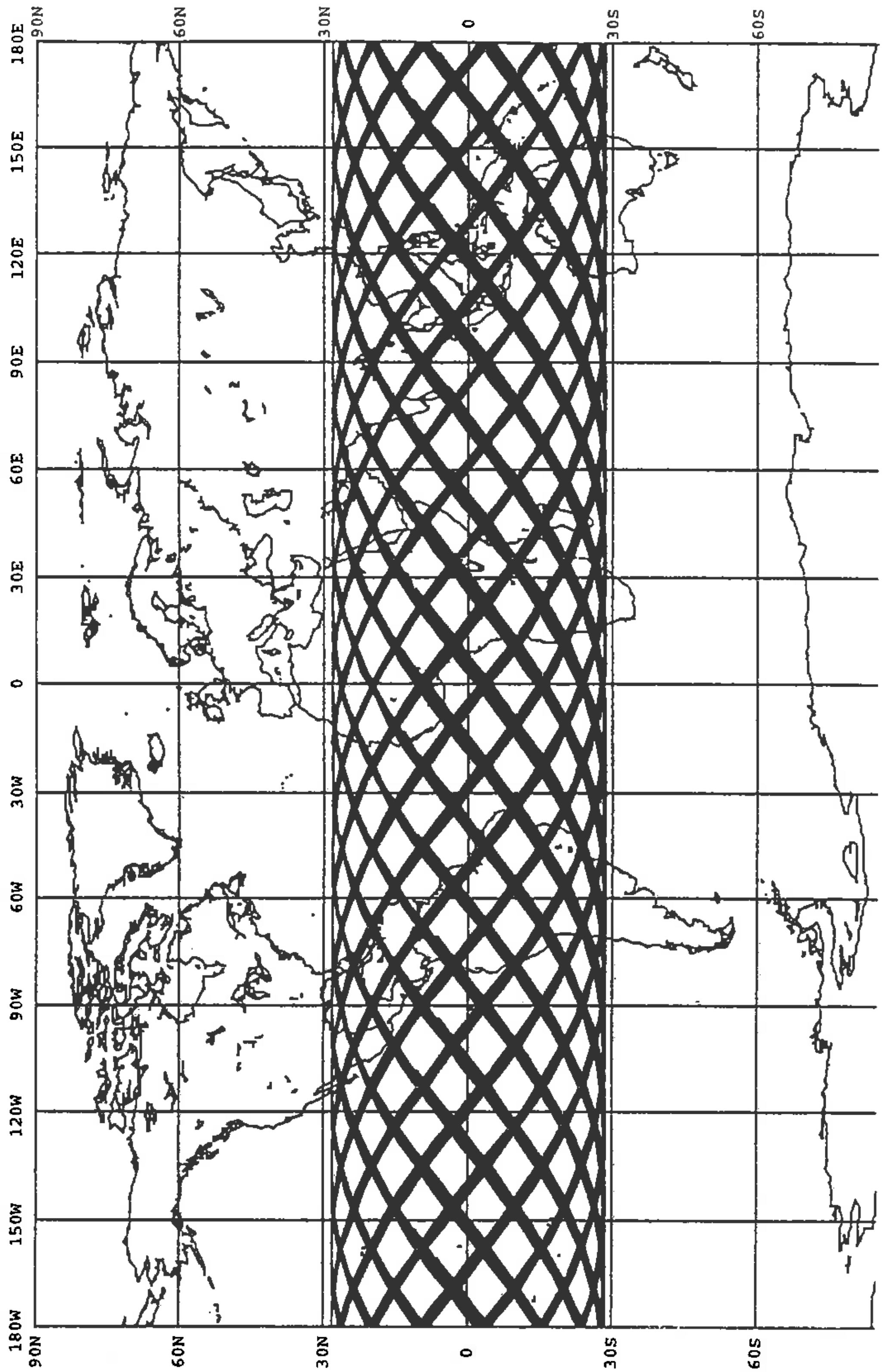


Fig. 1
Ground Tracks for Shuttle Orbit of 28.5° Inclination

2.0. Purpose and Need

2.1 Experiment Background

The first demonstration of pulsed laser sources occurred in the 1960's in laboratory experiments. Thereafter, pulsed lasers quickly found application in remote sensing of the Earth's atmosphere, land surface, and ocean. Laser altimeter instruments have been used since the 1970's to measure distance between airborne platforms and the Earth's land and ocean surface. These devices work by simple time-of-flight measurement of laser pulses for the round trip between the altimeter platform and the Earth's surface. Laser altimeters contain a pulsed laser transmitter, optical telescope, detector package, and an electronic data system that measures the time separation between laser pulse emission from the source and detection of the weak laser radiation backscattered from the surface and then converts these data into distance, i.e. range measurements, and communicates and records the results. This principle of operation is exactly analogous to the conventional radar altimeter that is in operation in many aerospace applications. In contrast to the radar altimeter, however, the laser altimeter offers increased spatial and temporal resolution due to short pulse operation, the tightly confined nature of its beam of optical radiation, and the relatively small optical footprint that is produced on the Earth's surface. These advantages have been demonstrated in numerous airborne measurement campaigns of a research and development nature over the past decade that have used airborne laser altimetry to monitor land surface shape (i.e. topography) for a variety of land-use applications.

The advantage of space-based laser altimeter instruments over the airborne implementations is the opportunity to expand the scope of high-precision topography measurements to the global scale and to tie topography data base information of the separate continents into a common, Earth-center-of-mass-referenced global grid (Bufton, 1989). The goal of this effort is a global grid of topography where the vertical control (i.e. accuracy of surface height at each grid point) is at the meter level. This unprecedented level of topography information would enable multiple scientific, land-use management, and commercial applications. Key applications include flood plain mapping, assessment of volcanic and seismic activity, coastal erosion studies, measurement of the size and shape of the polar ice sheets and accompanying sea ice, agricultural and vegetation assessment, and natural disaster mitigation. The full potential of space-based laser altimetry will require an advanced, operational laser instrument in a polar orbit. This eventuality must be proceeded by testing of laser altimeter instrument components, systems, and data acquisition procedures.

The Shuttle Laser Altimeter (SLA) Instrument is being developed by the Goddard Space Flight Center (GSFC) as a pathfinder for operational laser altimeters planned for space flight in the 1999 - to - 2003 time frame. The SLA is a small, secondary Shuttle payload that is flown on the Hitchhiker carrier as an attached Shuttle payload. It will derive electrical power from the Shuttle, convert some of this power into laser pulses, transmit these pulses toward the Earth, and detect the weak backscatter of laser radiation from the Earth and its atmosphere. Primary data of SLA will be obtained on the laser pulse time-of-flight and the spreading of the laser pulse by Earth surface and atmospheric layers. Measurable backscatter is expected from land surfaces, vegetation, ocean surfaces, cloud-tops, and aerosol layers. All data operations will require Shuttle operation in the Earth-viewing mode with nominal orientation at local nadir.

Four flight missions of SLA are planned. The first of these is a flight on board STS-72, the November 1995 flight of the Space Shuttle Endeavor. Subsequent missions are planned on approximately 18 month intervals. In all these missions the SLA device will make continuous measurements along the nadir track of the Orbiter at a rate of 10 pps. Since Orbiter velocity is approximately 7.4 km/sec the SLA measurements will be spaced at approximately 740 m. Each SLA measurement will be made for a 120 m diameter laser spot on the Earth's surface. This latter dimension is the result of the 0.4 mrad laser source divergence and the 300 km circular orbit of the Space Shuttle.

2.2 Laser Altimeter System

The SLA works by generation of short (~ 10 nsec duration) laser pulses at 1064 nm wavelength from a Nd:YAG laser at a rate of 10 pps from the Shuttle and reception of weak backscattered laser radiation from the Earth. The principal instrument components in addition to the pulsed laser source are a 0.38 m diam. telescope, silicon avalanche photodiode detector, and a computerized data system for pulse timing, pulse waveform digitization, command reception, telemetry, and data recording. The SLA optical receiver collects a small portion of the echo or backscatter of laser pulse radiation from the Earth's surface or atmosphere. In the optically clear atmosphere essentially all the initial laser pulse energy reaches the surface where it is spread into a 100 m diameter spot. Reflection from this spot is diffuse which results in spreading of the incident laser light into a hemisphere. As a result only a very small fraction of the incident laser pulse can be collected by the SLA receiver telescope. Some twelve orders-of-magnitude separate the received signal (femtojoules) from the initial laser pulse energy (millijoules). In the hazy or cloudy atmosphere the laser pulse is scattered before reaching the Earth's surface and the laser altimeter measurement may be triggered by the top surface of the cloud, haze, or aerosol layer. Under these conditions very little laser pulse energy reaches the surface in the form of a laser spot. Instead, the laser light is scattered throughout the atmosphere. Actual operations of the SLA in space will encounter a continuum of atmospheric conditions ranging from the extremes of cloudy to clear. Pointing control for SLA is required to be within ± 5° (3 sigma in roll & pitch) with respect to the Orbiter local nadir (-ZLV) for successful payload operation. Data quality for the SLA Experiment is highly dependent on nominal (full power) operation of the pulsed laser transmitter and maintenance of a clear, unobstructed line-of-sight for the SLA telescope aperture.

2.3 Experiment Objective

The primary scientific objective of the Shuttle laser Altimeter (SLA) on the STS-72 Space Shuttle mission of November 1995 is the precise measurement of distance to the Earth's surface from the Space Shuttle. The specific goal of range measurement precision, approximately 1 m, is dependent on timing of laser pulse propagation to a precision of 7 nsec. Laser range data will be combined with GPS measurements and microwave tracking of the Space Shuttle to derive a 1 m quality orbit for the Shuttle. Laser pointing data from the on-board inertial measurement gyroscopes and star trackers will be needed to interpret these laser and orbit data and derive the final data products on Earth surface elevation. Engineering objectives for this flight mission are concerned with determination of the sensitivity of laser altimeter transmitter alignment and receiver detection of the weak backscattered laser pulses. The major piece of data system technology in this flight is the pulse waveform digitization electronics which captures a 100 sample digital record of each detected laser pulse.

2.4 Scope of the Environmental Assessment

This Environmental Assessment (EA) addresses the environmental issues related to operation of the SLA Experiment. This EA was prepared in accordance with the Council of Environmental Quality Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (NEPA) (40 CFR Parts 1500 - 1508) and NASA policy and regulations (14 CFR 1216.3).

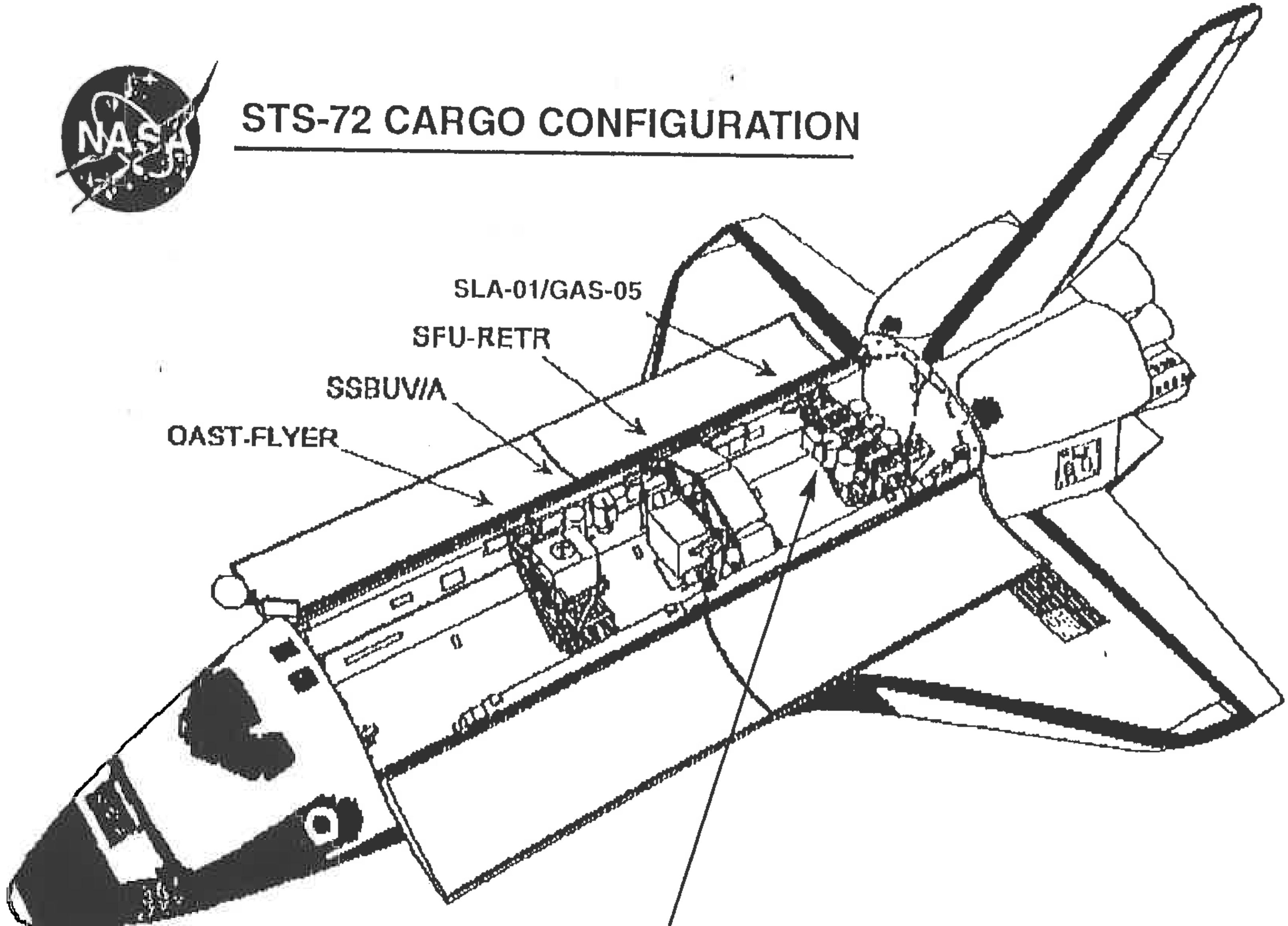
3.0 Description of Proposed Action and Alternatives

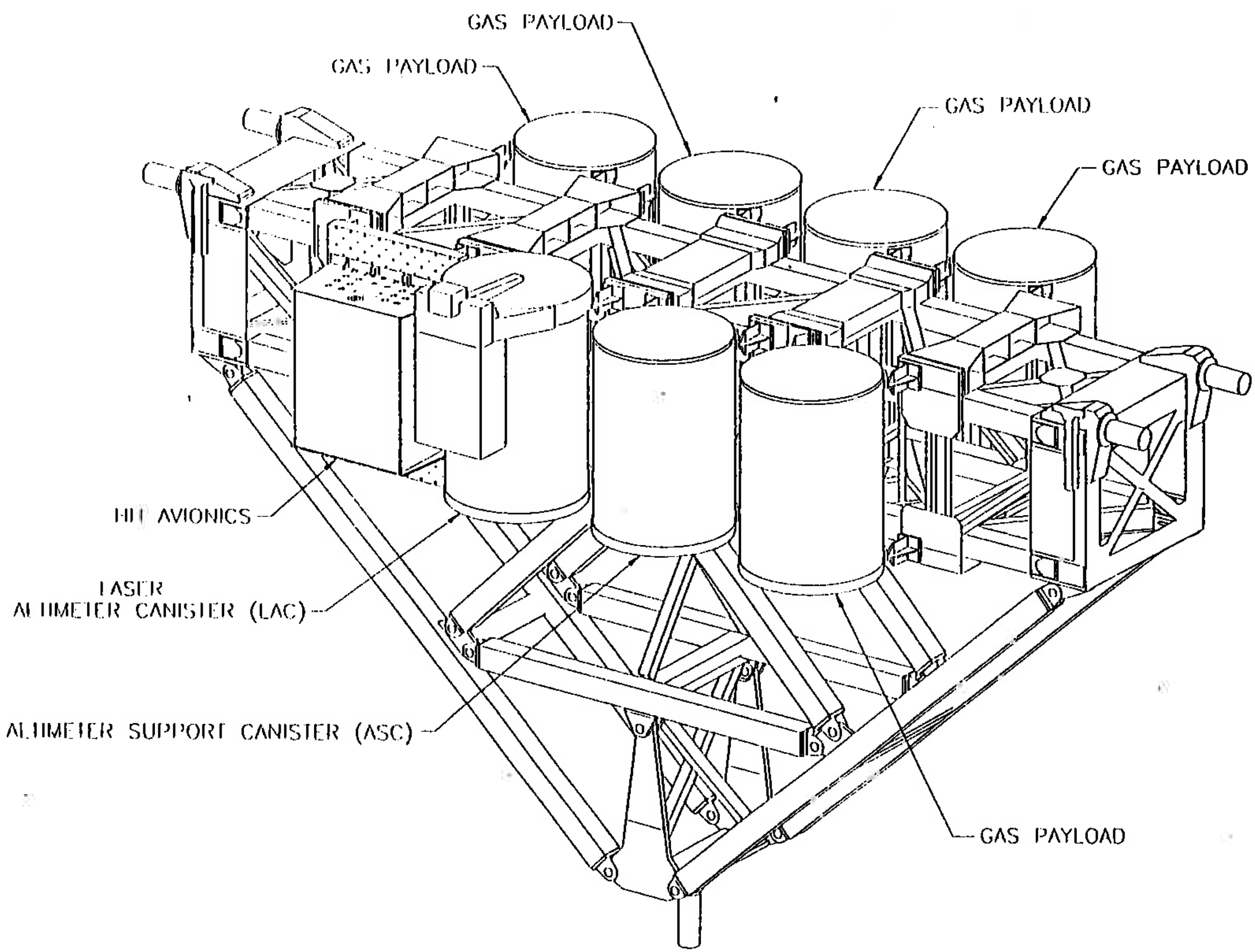
3.1 Proposed Action

3.1.1 Shuttle Laser Altimeter Instrument

The SLA instrumentation is contained within two Hitchhiker canisters which are in turn mounted on a bridge assembly on the Space Shuttle as depicted in Figs. 1 and 2. Figure 1 shows the bridge assembly near the aft portion of the Space Shuttle bay as configured for the STS-72 Mission. Figure 2 is a more detailed view of the forward portion of the bridge assembly that contains both the SLA Instrument and five Get Away Special experiment canisters. Both canisters of the SLA-01 Instrument are right circular cylinders 0.8 m (32 in.) long and 0.6 m (24 in.) in diameter. One of these canisters is equipped with a motorized door assembly as illustrated in Fig. 2. The motor assembly and door is noted as the housing near the top surface of the canister. Detailed 3-dimensional views of the SLA

STS-72 CARGO CONFIGURATION



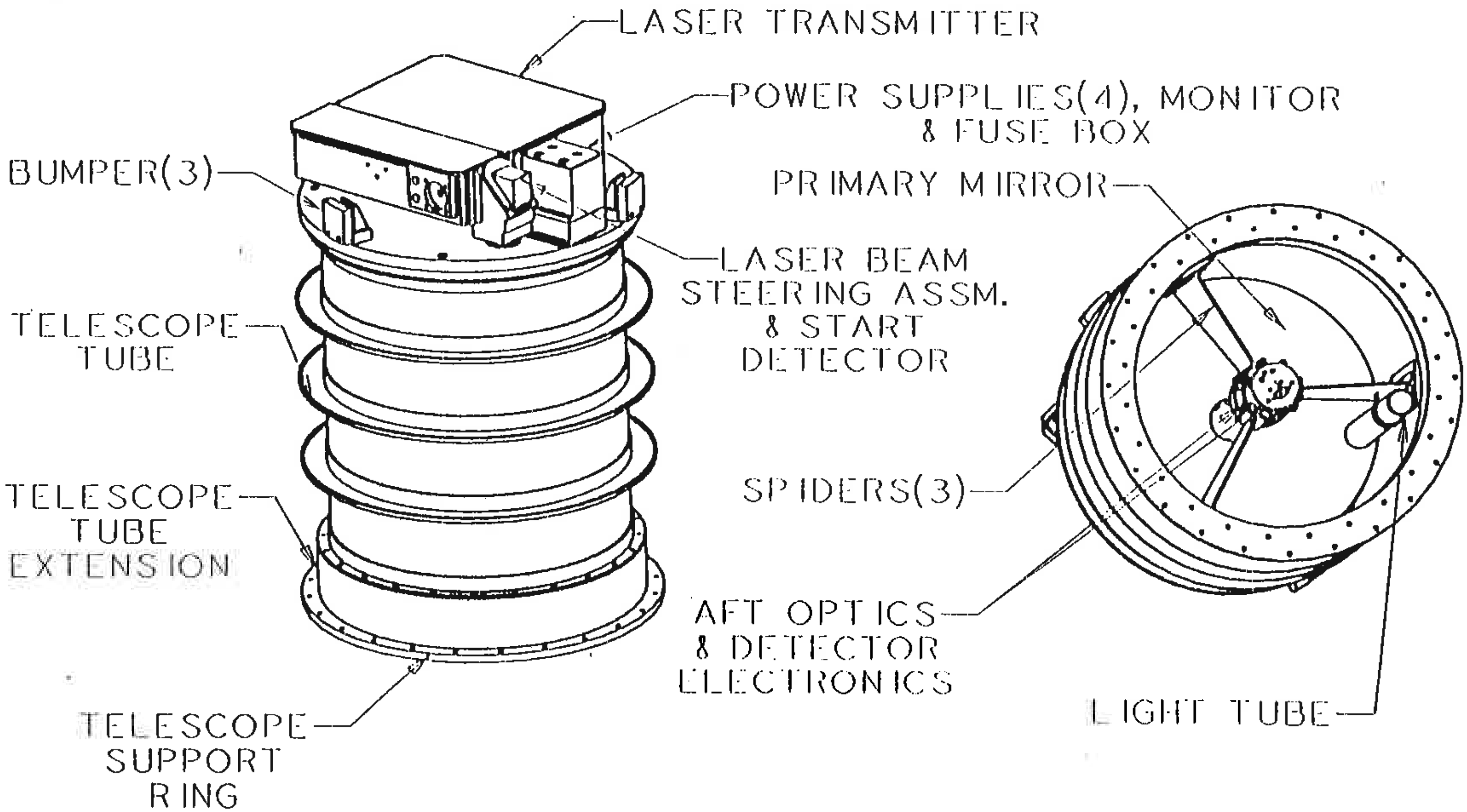


SLA-01/GAS(5) PAYLOAD
FWD VIEW

instrument assemblies contained in these canisters are shown in Figs. 3 and 4. The SLA laser transmitter is packaged inside a Hitchhiker canister that is equipped with a motorized door assembly. This canister is designated the Laser Altimeter Canister (LAC) and is one of the two canisters comprising the SLA payload. The other canister is the Altimeter Support Canister (ASC) which contains the data system for the SLA payload. The laser transmitter and receiver assemblies of the SLA payload are contained in the LAC canister behind a large optical window that maintains a sealed atmosphere of nitrogen (nominal 1/2 atmosphere pressure) while maximizing the receiver aperture size at 0.38 m (15.375 in.) diameter. The laser transmitter beam is totally enclosed inside the LAC up to the point where it exits a light tube at the interior surface of the LAC optical window. At that point the SLA laser output pulse (AKA. the laser beam) is propagating perpendicular to the LAC optical window and collinear with the longitudinal axis of the LAC toward the Earth's surface at the local nadir of the Space Shuttle.

The SLA laser transmitter is a purchased assembly that was developed under NASA Contract NAS5-30542 by McDonnell Douglas Aerospace, Laser and Electro-Optics Systems, St. Louis, MO. The SLA laser transmitter, depicted in Figure 3, is composed of electronics and optical sub-assemblies. They are mounted together in an aluminum laser case that is visible in Fig. 3. The laser is a pulsed Nd:YAG capable of operation only at a fixed laser firing rate of 10 pps and the fixed, single laser wavelength of 1064 nm. Maximum laser output optical energy for each pulse is 40 mJ for a transmitted optical power of 0.4 watt. The laser output optical pulse is controlled by an intracavity optical Q-switch that causes concentration of the 40 mJ of laser output pulse energy into a pulse of ~ 10 nsec full-width at-half-maximum (FWHM). As a result the peak optical power in the pulse is ~ 4 Mwatt. Each SLA laser transmitter pulse is 20 mm square in cross-section at the SLA output port and has a divergence of 0.4 mrad. Both beam cross-section and beam divergence are specified at the transverse dimension that contains 90% of the beam energy. The SLA laser transmitter employs a slab laser crystal design that results in a multi-transverse mode structure for the output laser beam. The multi-mode nature of this beam cross-section can produce peak laser irradiance values that are a factor-of-two greater than the average beam irradiance due to constructive interference. As a result the laser safety calculations for the SLA laser transmitter will assume a 2 times greater laser energy density that has its maximum at 2×10^{-4} J/cm^2 at the laser output and decreases with distance as controlled by the 0.4 mrad laser beam divergence. A summary of SLA laser transmitter optical performance is given in Table 1.

SLA LASER ALTIMETER CAN



SLA ALTIMETRY SUPPORT CAN

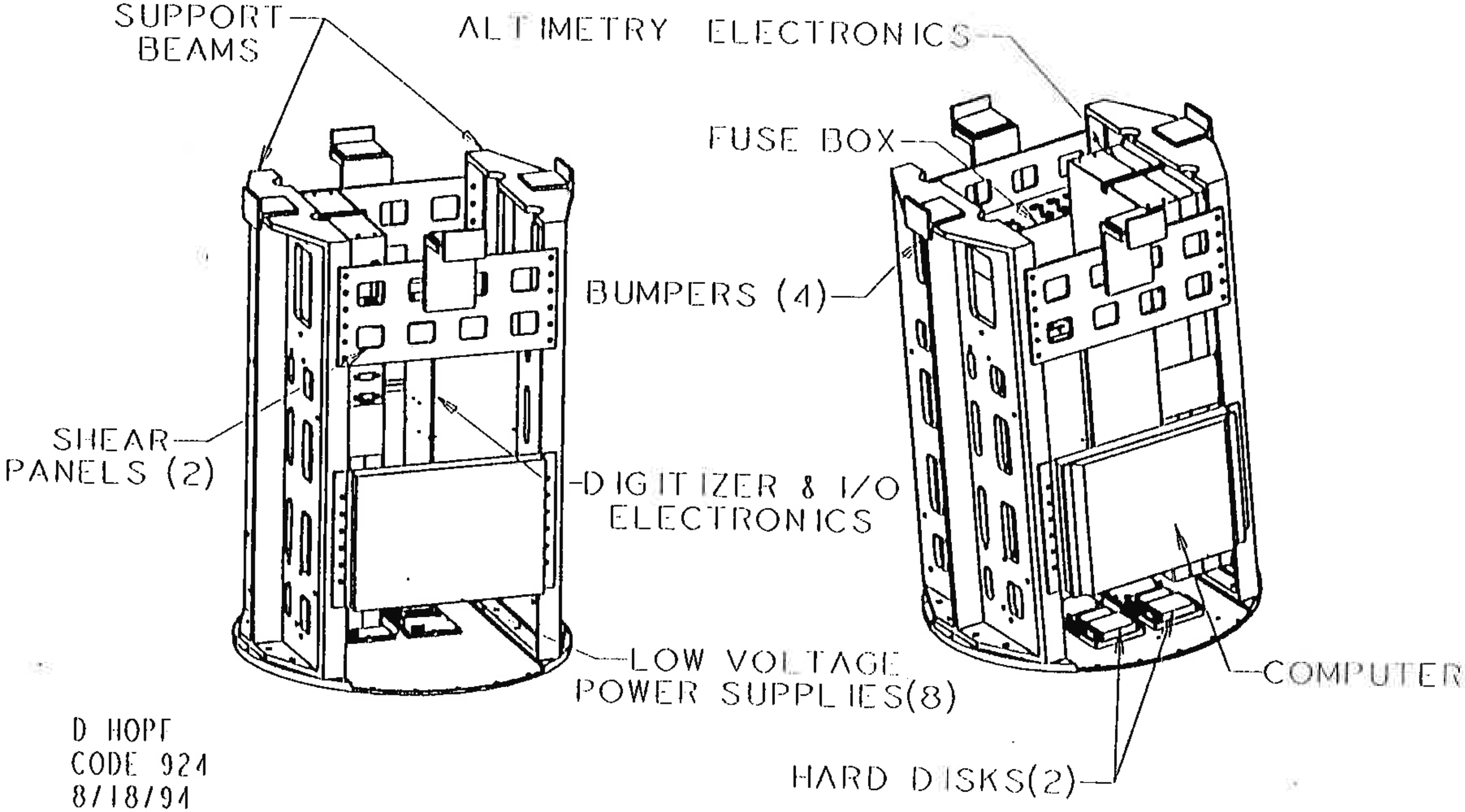


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Table 1

SLA Laser Transmitter Optical Performance Specifications

laser wavelength	1064 nm
pulse energy:	40 mJ/pulse maximum
pulse rate:	10 pulses per sec
average optical output power:	0.4 W maximum
pulse length (FWHM):	10 nsec nominal (8 nsec minimum)
laser beam output cross-section ($1/e^2$):	20 mm by 20 mm square
laser beam divergence ($1/e^2$):	0.4 mrad
transverse mode pattern:	high-order multi-mode
peak beam energy density:	$2X10^{-4}$ J/cm^2 at the laser output port

3.1.2 SLA Space Shuttle Mission Operations

The SLA Instrument will be operated for approximately 100 hours during the STS-72 Mission. Operations will commence at some point after mission day 2 on a non-interference basis when all retrievals of satellites are complete. The first step in activation of the SLA occurs when the astronauts enable the laser payload from the interior of the Shuttle crew cabin. Then the Hitchhiker motorized door assembly (HMDA) for the Laser Altimeter Canister (LAC) is opened. After the door is open and when acceptable operating temperatures in both the LAC and the ASC assemblies have been achieved, the power-on (activation) command will be given to the ASC in order to initiate SLA operation. Separate commands will be used to activate the ASC, activate the LAC, and enable laser transmitter operation. SLA operations require that the Shuttle Z axis be controlled to within ± 5° of nadir in an Earth-viewing orientation (-ZLV). LAC activation will be controlled by the following: an electrical interlock on the HMDA door; manual commands sent from the ground; and by crew procedures. During operations the laser transmitter pulses at 10 pulses per sec, pulse data from laser radiation backscattered by the Earth's surface are collected and processed, and the altimetry and housekeeping data are formatted and recorded. The ASC payload data system computer program operates the laser altimeter instrument continuously until the standby or power-off commands are issued.

The SLA payload operations will be continuous during seven operational cycles of 10-to-15 hours each as part of the STS-72 mission. During each SLA operational cycle a continuous series of laser spots (footprints) will occur on the Earth's surface or atmospheric cloud layer along the ground track of the Shuttle. This pattern is illustrated in Fig. 5. The characteristic linear dimension (diameter) of these spots which contains 90% of the incident laser pulse energy is 120 m (394 ft.). This dimension applies to the nominal orbital altitude of 300 km (160 NM) and the nominal laser beam divergence of 0.4 mrad. Each spot exists for approximately 10 nsec and has monochromatic laser radiation of a maximum of 40 mjoule at a wavelength of 1064 nm. The distance between spots is a result of the laser pulse rate of 10 pps and the Shuttle orbital velocity of 7.4 km/sec. As a result, the spot separation is 740 m (2,428 ft.), and consecutive laser spots do not overlap. This situation is illustrated in Fig. 5. Thus a location or individual on the Earth's surface or aircraft in the Earth's atmosphere can only be illuminated by a single laser spot.

3.2 Alternatives

The alternatives considered in this EA are the proposed action described in the preceding section and the No-Action alternative. The No-Action alternative provides the benchmark against which the proposed action is evaluated. Under the No-Action alternative there will be no SLA flight mission and thus no laser altimeter testing for future space-based operational laser altimeters. Earth surface landform topography will continue to be observed by photogrammetric, radar, and laser mapping from aircraft platforms as well as space-based photogrammetric and radar altimeter mapping.

4.0 <u>Environmental Impacts</u>

4.1 Proposed Action

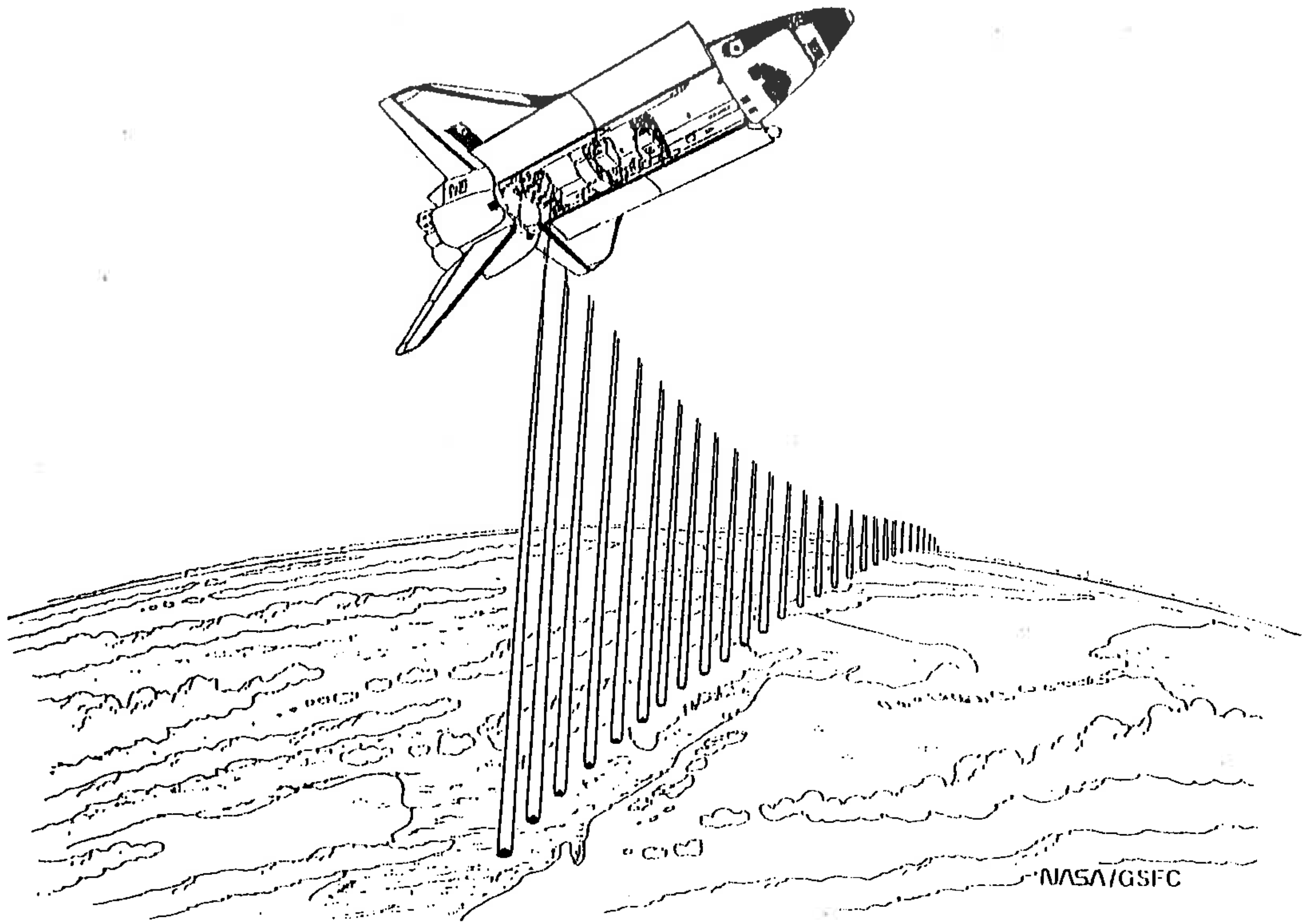
4.1.1 Potential Source of Impact

The proposed action evaluated in this EA is the normal operation of the SLA Instrument within the Space Shuttle cargo bay . The environmental impacts of the Space Shuttle have been addressed in existing NASA NEPA documentation for the Space Shuttle Program (NASA, 1978).

All electrical operating power for the SLA Instrument will be drawn from the Space Shuttle fuel cells. All heat generated by the SLA operation will be dissipated by conduction to the Space Shuttle structure and by radiation from the SLA canisters. The LAC canister will dissipate 80 W and the ASC will dissipate 95 W for an SLA total dissipation of 175 W. These totals include instrument operating power

SHUTTLE LASER ALTIMETER

GLOBAL TOPOGRAPHY MEASUREMENTS



and make-up heater power and are average power values. The majority of this power will be transferred to the Space Shuttle cargo bay by conduction or radiation. The total power dissipated by the SLA is negligible compared to the kilowatts of power dissipated by the Orbiter. The Orbiter attitude control system will provide the pointing control of the laser beam. The SLA payload does not have any built-in pointing control or propulsion system. It is designed to remain in the Orbiter bay at all times and to function as an attached payload. The SLA payload will not produce any emission or effluents other than the transmitted laser beam and the radiation/conduction of waste heat due to dissipation of electrical power. All data acquired during SLA operations will be stored on board in the ASC canister and sent by telemetry to the ground station network as part of the standard Hitchhiker low-rate and medium-rate telemetry stream. The only potential source of environmental impact by normal SLA operations is the emission of the laser pulses toward the Earth's surface.

4.1.2 Biological Effects

The SLA laser transmitter produces a beam of radiation with an average power of 0.4 W, a value that is derived from the product of its pulse energy of 40 mJ and its repetition rate of 10 pps. However, a spot on the Earth's surface will receive the power of only one SLA pulse due to the orbital motion of the Space Shuttle at 7.4 km/sec and the non-overlap of successive SLA pulse spots. Furthermore, the thermal power associated with one SLA pulse is 0.04 W, even though the peak pulse power is 4 MW for 10 nsec, and this power is spread over a dimension of approximately 11,300 m^2 (i.e. the area of a 120 m diameter spot) for a maximum incident irradiance (power density) on the Earth's surface of 3.5 microwatts/m^2. It is not possible for this small value of power density to burn plants or vegetation on the Earth's surface. This average power density is far exceeded (with a factor of > 10^8) by solar radiation which has a nominal value of 1,400 W/m^2 at the Earth's surface.

The potential effect of exposure to SLA laser radiation must also be examined for human beings and animal life. Skin exposure and eye exposure are the two effects that must be considered. A Ground Observer Eye Safety Analysis performed on 21 July 94 by Jack L. Bufton from NASA'S Goddard Space Flight Center has considered these effects is some detail. A summary of the findings will be presented here. This analysis was subject to independent critical reviews by the Space Shuttle flight safety review team at the Johnson Space Center. The SLA Ground observer Eye Safety Analysis (Bufton, 1994) as well as this SLA Environmental assessment have also been prepared using the methodology and approach of earlier documentation (Couch and Climolino, 1992 and Ebasco Services, Inc., 1993) prepared for the Lidar-in Space Technology Experiment (LITE) which flew on the Space Shuttle in September 1994 during STS-64.

The maximum radiant exposure (RE) to which a person on the ground inside one SLA laser spot would be exposed can be computed from the laser pulse energy of 40 millijoules, the laser beam divergence of

0.4 mrad, and the 300 km (160 NM) distance from the Space Shuttle orbit to the Earth's surface. The result is a value of 3.5×10^{-10} J/cm^2 which must then be compared with standard limits for eye and skin exposure to see if a hazardous condition exists. The Maximum Permissible Exposure (MPE) limits for intrabeam viewing (i.e. looking directly at the emission port of a laser from a point within the limits of the laser beam) of laser radiation have been established for the United States by the American National Standards Institute (ANSI) and are widely accepted worldwide by both civilian and military organizations as applicable for human exposure. These standards and relevant laser beam computational procedures are set forward in the publication by the American National Standards Institute (ANSI-Z136.1, revised January 1993). The ANSI-Z136.1-1993 laser safety standard sets forth a definition of laser classes and the applicable MPE values for pulsed and cw laser operation in these various classes. The SLA transmitter is an ANSI-Z136.1-1993 Class 3b pulsed laser operating at 1064 nm wavelength with a minimum 8 nsec pulsewidth. As such it has an MPE of $5X10^{-6}$ J/cm^2 for ocular exposure under the conditions of intrabeam viewing to a single pulse of its radiation. This limit is some 4 orders of magnitude higher than the RE at the Earth surface due to the SLA laser pulse and we conclude that no ocular hazard exists to the unaided human eye. The SLA Ground Observer Eye Safety Analysis also shows that SLA laser radiation does not pose a hazard even when observed with the aided eye, e.g. 50 mm binoculars or a 20 in. diameter telescope. The skin exposure MPE for SLA laser radiation is 5 orders-of-magnitude higher than the ocular exposure MPE at a value of 0.1 J/cm^2. Thus we believe that skin exposure is not a sensible hazard for SLA operations since it is some 9 orders of magnitude less than the MPE for skin exposure.

The only sensible hazard concept for a ground-based observer of SLA laser transmitter operation on the Shuttle is ocular damage caused by a single pulse of 1064 nm laser radiation observed with a very large telescope. The use of larger telescopes for observation of the Space Shuttle is thought to be extremely rare, since it requires a high speed tracking mount capable of tracking through zenith and able to keep up with high angular rates of the Shuttle orbit as observed from the Earth's surface. More importantly, the only time an SLA pulse could enter a telescope is when the telescope is aligned collinear to the SLA laser transmitter's optical axis within the limits of the telescope's mrad-level field-of-view. Furthermore, there are additional factors-of-safety built into the ANSI standard. As a result, it is believed that there is a minimal risk of eye injury for observation of the SLA laser radiation pulse by a ground observer with an unaided eye, binoculars or with a telescope.

4.1.3 Effects on Aircraft, Communications, and Space Systems

The RE level for SLA laser pulse radiation on aircraft is nearly identical to the case of the ground observer with an unaided human eye. For example, an aircraft operating at 45,000 ft altitude is ~ 14 km closer to the Space Shuttle than a ground-based observer. This results in a increase in RE by a factor of (300 km /286 km)^2 or 1.1 to a level of 3.9×10^{-10} J/cm^2, a value still well below the MPE of 5×10^{-6} J/cm^2.

There is no known effect that would permit SLA laser operations to adversely affect or interfere with microwave, very-high-frequency, or ultra-high-frequency communications. This is primarily a result of the optical frequency nature of the SLA radiation which has a carrier frequency of 10^{15} Hz vs. the 10^6 to 10^{12} Hz carrier frequency regime of communications. In addition, the SLA laser radiation is dominated by natural sources of near infrared light (e.g. solar radiation) at its 1064 nm wavelength and thus has no effect more disruptive on terrestrial communications than does the presence of daylight. Finally, the SLA laser operation is compliant with military standards for conducted and radiated emissions as must be the case for instrument operation in the Space Shuttle environment. As a result it does not interfere with any communications originating or arriving at the Space Shuttle.

The SLA laser pulse radiation is also not capable of damaging space systems that are looking at the Earth. This is primarily the result of SLA operation only in the nadir direction which would require a reflection of laser pulse from the Earth's atmosphere or surface for observation by a space system or sensor. Such reflections are at the femtojoule level of pulse energy and at the nanowatt level of peak power when observed in space. These very low values of pulse energy and pulse peak power are well below the damage thresholds of detector systems. A review by the US. Space Command Laser Clearinghouse found that the SLA laser transmitter does not produce sufficient laser energy to exceed their damage threshold and therefore does not require clearinghouse screening. This review is documented in a letter dated 05 June 95 from NORAD and the US. Space Command to the STS-72 Flight Dynamics Officer at Johnson Space Center (Appendix A).

4.2 No-Action Alternative

The No-Action alternative will not fulfill NASA's objective to advance the Nation's topographic measurement capability. Under the No-Action alternative it will not be possible to fully develop or space test the laser altimeter instrument technology for an operational space-based topography system. It will then be necessary to rely on existing photogrammetric and radar mapping instruments which have limitations in accuracy and in interpretation of topography data.

5.0 References

American National Standards Institute, January 1993. "American National Standard for Safe Use of Lasers" ANSI-Z136.1.

Bufton, J.L., "Laser Altimetry Measurements from Aircraft and Spacecraft", Proc. of the IEEE, Vol. 77, No. 3, pages 463-477.

Bufton, J.L., "Shuttle Laser Altimeter, Ground Observer Eye Safety Analysis", Goddard Space Flight Center, Greenbelt, MD, July 21, 1994.

Couch, R.H. and M.C. Cimolino, 1992. "Revised Ground Observer Eye Safety Analysis for the Lidar In-space Technology Experiment (LITE)". NASA Langley Research Center, Hampton, VA. LITE-02-1-03-01, Rev. A.

Ebasco Services, Inc., December 1993. "Environmental Assessment Lidar In-Space Technology Experiment, NASA Langley Research Center, Hampton, VA.

Jordan, Jeff, LT. USN, Orbital Safety Officer, North American Aerospace Defense Command and United States Space Command Laser Clearinghouse Waiver Response, June 5, 1995.

NASA, April 1978. Final Environmental Impact Statement, Space Shuttle Program.

6.0 Agencies Receiving a Copy of the Environmental Assessment

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NORTH AMERICAN AEROSPACE DEFENSE COMMAND
AND
UNITED STATES SPACE COMMAND

05 June 95

FROM: CMOC/J3OCY
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Cheyenne Mountain AFS, CO 80914-6020

SUBJ: SPADOC Laser Clearinghouse (LCH) Waiver Response

TO: Richard Theis
STS-72 FDO, Code DM42
NASA/Johnson Space Center
Houston, TX 77058

1. I have evaluated the laser from your request of 05 June 95. This configuration does not exceed our damage threshold and will not require laser clearinghouse screening.

2. Let me know if you need anything else. I can be reached at AV)268-4450 or commercial 719-474-4450.

Jeff Jordan, LT, USN
Orbital Safety Officer

Appendix A