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(NASA-TM-111118) LASER INITIATED
ORDNANCE (LIO) ACTIVITIES IN NASA
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LASER INITIATED ORDNANCE (LIO) ACTIVITIES IN NASA

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NASA Headquarters

Second NASA Aerospace Pyrotechnic Systems Workshop

Sandia National Laboratory

Albuquerque, NM

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*NASA
111118-TM*

LASER INITIATED ORDNANCE BENEFITS

[GOALS FOR ANY PROGRAM]

- **GREATER RELIABILITY**
- **ENHANCED SAFETY**
- **LIGHTER WEIGHT**
- **LESS COSTLY PRODUCTS**
- **IMPROVEMENTS IN DESIGN LEADING TO HIGHER OPERATIONAL EFFICIENCY**

APPLICATIONS

- **INITIATION OF SEQUENCING FUNCTIONS**
- **FLIGHT TERMINATION**
- **PROGRAM APPLICATIONS**
 - new launch vehicles
 - selected use on existing fleet designs
 - spacecraft
- **LASERS HAVE LONG DEVELOPMENTAL HISTORY BUT LACK OPERATIONAL PEDIGREE**
 - ~15+ years
 - small ICBM rod lasers, first laser ordnance flight test

ADVANTAGES OF LASER ORDNANCE

- **PHYSICS OF PHOTON NOT SUSCEPTIBLE TO HAZARDS OF ELECTRON:
ELECTROSTATICS, EMI, RF**
- **LASER DIODES HAVE THE POTENTIAL FOR DESIGN OF ALL SOLID STATE
SYSTEM**
- **POTENTIAL FOR BUILT-IN-TEST (BIT)**
- **PERMITS LESS SENSITIVE INITIATION ORDNANCE**
- **ELIMINATES POSSIBLE HAZARD TO ELECTRONIC EQUIPMENT FROM
FIRING OF HOT BRIDGEWIRE CARTRIDGE**
 - Mars Observer failure option
 - Magellan
- **BOTTOM LINE: THE ABOVE FEATURES, WE SAY, FOR LASER DIODES
EQUATE TO IMPROVEMENTS IN SAFETY, RELIABILITY, OPERATIONS,
COST, POWER, MASS**

- **CONCLUSION: ADDRESS LASER DIODE ORDNANCE
DEVELOPMENT FOR OPERATIONAL FEASIBILITY**

DISADVANTAGES OF LASER DIODE INITIATED ORDNANCE

- **TECHNICAL**

- Low voltage to activate laser
 - concern over electronics setting off laser accidentally
- BIT not proven
 - development of requirements necessary

- **MANAGERIAL:**

- Hardware not proven with operational experience
 - application not mandatory for program success
 - new programs wait for others to “break the ice” to reduce risks with cost, performance, schedule
- Incomplete understanding of requirements

IN THE BEGINNING

PAS PROGRAM PLAN

LIO PROGRAMS

2.4 NASA STANDARD LASER DIODE SAFE AND ARM

2.5.1 NASA STANDARD LASER DETONATOR

3.4 LASER DIODE SAFE/ARM PERFORMANCE

PAS PROGRAM PLAN FOR LIO

2.4 NASA STANDARD LASER DIODE SAFE AND ARM

Project Mgr: B. Wittschen, Johnson Space Center

- Develop, qualify, and demonstrate in flight a standardizable solid state laser safe and arm system
 - Flight demonstration – TBD
 - Joint HQS. activity with JSC
- Determine criteria for what constitutes an acceptable S&A
 - Closely involve range safety in the design and testing
 - Place operational considerations up front in the design
- Enhance safety and reduce risk
 - Enhance functional reliability
 - Simplify design
 - Eliminate problems with current electromechanical designs
- Reduce power, explosive containment, and costs
- Make design more easy to manufacture/checkout
- Products:
 - Flight performance demonstration-TBD
 - Guidelines for incorporating features into flight units
 - Design specification for standard safe/arm devices

STATUS:

- Project has been terminated

2.5.1 NASA STANDARD LASER DETONATOR

Phase I – Developmental Investigations

Project Mgr: B. Wittschen, Johnson Space Center

- Advance pyrotechnic technology - develop laser detonators
 - Supports Project 2.4, NASA Standard Laser Diode Safe and Arm
 - Conduct off-limits testing of developmental hardware
 - Phase II task qualifies a NASA Standard Laser Detonator
- Goals include optimizing optical interface between the fiber and the pyrotechnic charge, publishing a specification, and the procurement and test of devices to provide a data base
- Products: Qualified NASA Standard Laser Detonator and design/test specification

STATUS:

- Project has been terminated

3.4 LASER DIODE SAFE/ARM PERFORMANCE

Project Mgr: B. Wittschen, Johnson Space Center

- Develop test procedures
- Quantify performance
- Confirm specification performance
- Demonstrate safe/arm devices for flight
- Update design and test specifications
- Products:
 - Publish test specification for use by programs
 - Prepare qualification report

STATUS:

- Project has been terminated

THEN

RE-EVALUATE

IMPLEMENTATION of a FEASIBILITY APPROACH: - BACKGROUND-

- **EVALUATED BY STEERING COMMITTEE FOR MANY YEARS**
 - concern about maturity
- **AUGUST 1991: OSC/EBCO UNSOLICITED PROPOSAL TO CONDUCT DEMONSTRATION ABOARD PEGASUS**
 - NASA performs one-time mission demonstration for a complete vehicle ordnance change
 - OSC performs fleet change
- **OBJECTIVE WAS “QUICK DEMONSTRATION” USING AVAILABLE TECHNOLOGY**
 - delayed for two years
 - Pegasus vehicle contracted under services contract, not R&D
 - lacked clear contractual means to conduct a technology demonstration

IMPLEMENTATION APPROACH

- **MANAGERIAL ASPECTS OF LIO INITIATION POINTED TOWARD:**
 - lack of technical requirements for LIO systems
 - no practical operational experience
 - lack of quick, simple, contractual instrument to implement new technology

- **MANAGERIAL SOLUTION NECESSARY TO PURSUE TECHNICAL ISSUES**

- **ABOVE ANALYSIS POINTED NEED FOR NEW LIO PROGRAMMATIC PATH**

STEPS REQUIRED FOR LIO IMPLEMENTATION

1. VALIDATE FEASIBILITY

a. ARE THE TECHNOLOGY CLAIMS CORRECT?

b. WHAT ARE THE SAFETY, RELIABILITY PROGRAMMATIC DESIGN REQUIREMENTS TO FLY LASER ORDNANCE?

IF FEASIBLE WITHIN COST COMPETITION OF EXISTING ELECTROMECHANICAL SYSTEMS, THEN ADDRESS THE:

2. IMPLEMENTATION OF LIO INTO OPERATIONS

A. VALIDATE LIO FEASIBILITY:

« REDUCE THE RISK «

1. PERFORM FLIGHT DEMONSTRATIONS

PHILOSOPHY:

a. TAKE THE MANAGERIAL APPROACH OF COMMENCING WITH A MINIMUM SAFETY IMPACT PROJECT – THEN PROGRESS TO THE MOST DEMANDING:

- low hazard level in a controllable application, but safety impact exists and is such that the LIO hazard must be controlled
- LIO serves an active function in flight - not along just for the ride
- ultimate application range is from unmanned to manned applications
- ultimate system range is from flight sequencing to flight termination

b. PERFORM SIMPLE, QUICK, DO-ABLE PROJECTS, ADDRESSING ISSUES AS PROGRESSION OCCURS

2. DEVELOP REQUIREMENTS

a. PREPARE SPECIFICATION REQUIREMENTS

b. DEVELOP RANGE REQUIREMENTS

B. OPERATIONAL IMPLEMENTATION

« REMOVE THE RISK «

1. DEVELOP A “STANDARD”

- discussions held with Aerospace/Air Force:
- definition of “Standard” – build to print or to performance specification

2. QUALIFY FOR TOTAL OPERATIONAL ENVIRONMENTAL SPECTRUM: – CAPTURE MARKET

3. HAVE A PRODUCT READY FOR PROGRAMMATIC USE, ACCEPTED BY THE PYRO TECHNICAL COMMUNITY

4. MAINTAIN TWO QUALIFIED SOURCES AS A MINIMUM—NO SFP’S

STATUS:

**THIS IS WHAT WE DID AND ARE DOING WITH
REGARD TO THE ABOVE PROCESS**

1. PERFORM FLIGHT DEMONSTRATIONS

a. DEVELOP A NEW PROCUREMENT PROCESS:

COOPERATIVE AGREEMENT

WITH PROFIT MAKING ORGANIZATIONS

b. IMPLEMENT VIA QUICK, CHEAP FLIGHT DEMONSTRATION PROGRAM

COOPERATIVE AGREEMENT WITH PROFIT MAKING ORGANIZATIONS (CAWPMO)

- **NEW PROCUREMENT PROCESS**
 - grants normally performed with universities
 - cooperative agreement previously limited by policy to non-profit organizations e.g. think-tanks, universities, etc.
- **CAWPMO: FROM FIRST THOUGHT UNTIL SIGNATURE = 2 MONTHS**
- **FROM: RECEIPT OF PROPOSAL UNTIL SIGNATURE = 1 MONTH**
- **THIS INSTRUMENT IS BASICALLY A PARTNERSHIP WITH BOTH GRANTEE WITH GOVERNMENT HAVING ACTIVE ROLES**
- **COOPERATIVE AGREEMENT ACCOMPLISHES COMMON BENEFIT**
- **NO HARDWARE IS DELIVERED**
- **NO FEE**
- **INTERNAL COMPANY FUNDING HELPS BUT NOT REQUIRED**
- **RED TAPE REDUCED**

PROJECTS

A. PEGASUS EXPERIMENT

B. SOUNDING ROCKET FTS DEMONSTRATION

C. SHUTTLE

EFFORTS AIMED AT THE DEVELOPMENT OF REQUIREMENTS:

- Specification
- Range Safety

A. PEGASUS EXPERIMENT

TWO TESTS OF LIO CONDUCTED DURING ORBCOMM MISSION:

- **CONDUCT A FLIGHT SEQUENCING FUNCTION: IGNITE TWO OF THE NINE FIN ROCKET MOTORS USING LIO**

- safety hazard to operational personnel: accidental motor ignition. Control by design and procedure
- not mission success dependent. Fin rocket motors not required for mission success
- qualitative information. Go-no go information.

- **FIRE LIO INTO A CLOSED BOMB**

- not a safety hazard. Accidental ignition pressurizes a metal container designed to take the load
- not mission success dependent. Separate experiment
- quantitative information. Pressure measurements performed during flight with be compared with ground test data.

- **FLY ABOARD COMMERCIAL MISSION**

- current date is June 1994

ENSIGN BICKFORD COMPANY TASKS:

1. Conduct necessary design and research to demonstrate feasibility of LIO
2. Manufacture equipment
3. Perform testing in coordination with NASA testing
4. Conduct analyses
5. Coordinate program activities closely with NASA
6. Conduct program tasks per E-B Proposal

NASA TASKS:

As necessary:

1. Perform technical review, analyses, and test support
2. Involve Range Safety Offices
3. Conduct off-limits/overstress tests & evaluations to support Range Safety objectives
4. Establish requirements for NASA-wide application
5. Provide test equipment support such as OTDR
6. Provide overall planning for incorporation of LIO into flight programs
7. Conduct analyses sneak circuit analyses
8. Conduct validation testing of sneak circuit analysis
9. Perform FMEA, safety, and reliability analyses
10. Conduct evaluations of program test planning
11. Conduct safety and reliability ordnance initiation evaluations
12. Provide consultation regarding operational processes
13. Provide guidance on generic flight operational procedures
14. Assist in technology transfer

B. SOUNDING ROCKET FTS DEMONSTRATION

- **OBJECTIVE: TAKE THE NEXT STEP WITH UNDERSTANDING REQUIREMENTS AND GAINING CONFIDENCE**
- **INSTALL A FLIGHT TERMINATION SYSTEM ABOARD A TWO STAGE SOUNDING ROCKET AND DESTRUCT DURING THRUST**
 - Nike Orion - second stage destruct flown out of Wallops
- **IGNITE FIRST AND SECOND STAGES USING LIO**
 - maximize experience
- **ACTIVATE FTS BY TIMER-THIS DEMONSTRATION NOT A TEST TO VALIDATE NEW RF COMMAND SYSTEM**
- **HIGHER LEVEL OF SAFETY REQUIRED BEYOND PEGASUS**
- **6 MONTH PROGRAM**
- **AWAIT UNSOLICITED PROPOSAL FOR CAWPMO**

COMPANY TASKS:

1. Design and manufacture termination ordnance
2. Provide LIO ignition for Nike and Orion motors
3. Provide laser firing unit, the fiber optic cable, connectors, detonators, and initiators
4. Perform testing in coordination with NASA testing
5. Conduct analyses
6. Install ordnance and integrate FTS/payload into launch vehicle
7. Participate in flight operations and post flight analysis
8. Testing at company's discretion but expected for demonstrating compatibility of laser initiation with current motor ignition system

NASA TASKS:

1. Launch vehicle: Nike-Orion
2. Vehicle drawings
3. Provide environmental test requirements and WFF range safety requirements
4. Pyro interface such as mounting platform for LIO electronics
5. Instrumentation defining key events and body accelerations
6. 3-axis accelerometer
7. FTS activation timer
8. FM-FM transmitter
9. Build-up and integration of the motor and stage assembly
10. Flight performance analysis
11. Radar coverage
12. Launch operations
13. Post flight analysis support
14. Photographic coverage

C. SHUTTLE

- Payload (Solar Exposure to Laser Ordnance Device)
 - LIO opens shutter in space
 - Exposure of LIDS and LIS:
 - 4 different initiators
 - 2 different detonators
 - 2 different laser firing units
 - Exposure to solar radiation:
 - direct exposure to sun
 - 10:1 magnified exposure to sun
 - no exposure to sun
 - LIO subjected to Shuttle payload safety review process

- STS Equipment (potential project not started - hazardous gas detection bottles)
 - Will subject LIO to Shuttle vehicle safety review process

EFFORTS AIMED AT THE DEVELOPMENT OF REQUIREMENTS:

- **SPECIFICATION: UNFUNDED IN-HOUSE ACTIVITY**
- **COORDINATION WITH RANGE SAFETY STAFF**
 - preliminary set of requirements developed
 - work continues

PRELIMINARY

RANGE REQUIREMENTS FOR LIOS:

GENERAL CATEGORY "A" REQUIREMENTS:

System Level Requirements:

1. Single fault tolerant (two independent safeties) before and after installation of SAFE/ARM type connectors
Cleared pad during power switching, power-on, and RF radiation operations
To allow operations during these conditions, LIOS must be at least two-fault tolerant and meet the Man-Rated design requirements defined in RSM-93 Paragraph 5.3.4.4.5
2. At least one of safety controllable from pad
3. Design to allow power-control operations remotely from blockhouse
4. Component (if electrical type) adjacent to the laser system must be single/double fault tolerant
5. Component adjacent to the lasing device (either in the power or return leg of electrical circuit), shall not be activated until programmed initiation event
6. LIOS must not be susceptible to external energy sources, such as stray light energy, static and RF
7. Design to preclude inadvertent initiation due to singular energy sources, such as unplanned energy in power leg of circuit or due to short circuits or ground loops.
8. Design to allow for ordnance connection at the latest possible time in the countdown process

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Trigger Circuit Requirements

9. Design such that voltage required to initiate laser is at least 4 times the VCC of solid state logic circuits
10. Design to output energy after application of a 20 ms pulse

Monitor and Test Capability:

11. Provide circuits to allow for remote control and monitor of all components in the Category "A" system. Application of $\pm 35V$ in the monitor circuit shall not affect the Category "A" circuit
12. Recommend Built-in-Test (BIT)

Allow remote testing at energy levels of 10^{-2} below no fire for both normal and failure modes. Use different wavelength than main firing laser, separated by at least 100 nm

13. Design to allow for "no-stray energy" type of tests prior to performing ordnance connection
14. Employ pulse catcher system to detect inadvertent actuation of laser prior to ordnance connection
Monitor 1/100 no-fire and be capable of determining a valid all-fire (power, energy density, frequency, pulse-width)

Laser Output Requirements:

15. Energy delivered to LID shall be 2x all-fire

Ordnance Requirements:

16. All ordnance used with LIOS must be secondary explosive.

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Power Supply Requirements:

17. Install charged ("Hot") batteries into Category "A" circuits only if at least one of the following design approaches is utilized. Otherwise, charge battery at latest feasible point in countdown process with no personnel in danger area
 - 17.1 Electromechanical device utilized which mechanically misalign ordnance train
 - 17.2 Optical barriers utilized which mechanically misalign initiation power from either LID or laser
 - 17.3 Capacitive Discharge Ignition (CDI) system used meeting circuit criteria in RSM-93 Paragraph 5.3.4.4.4
 - 17.4 Designed to be Man-Rated and meets circuit requirements in RSM-93 Paragraph 5.3.4.4.5

PRELIMINARY

SPECIFIC CATEGORY "A" REQUIREMENTS (PARTIAL LIST):

1. Shielding for electrical firing circuits shall meet:
 - 1.1 Minimum of 20 dB safety margin below minimum rated function current to initiate laser and provide a minimum of 85% optical coverage. (A solid shield = 100% optical coverage)
 - 1.2 Shielding shall be continuous and terminated to the shell of connectors and/or components. Electrically join shield to shell of connector/component around 360° of shield. Shell of connectors/components shall provide attenuation at least equal to that of shield
 - 1.3 Shield should be grounded to a single point ground at power source
 - 1.4 Otherwise, employ static bleed resistors to drain all RF power on shield
2. Wires should be capable of handling 150% of design load. Design shall assure that latched command will remain latched with a 50 ms dropout pulse
3. Bent pin analysis shall be performed to assure no failure modes
4. Analysis/Testing shall be performed to determine debris contamination for blind connection sensitivity on optical connectors
5. All components in the Category "A" initiation system shall be sealed to 10^{-6} cc/sec

PRELIMINARY

FTS REQUIREMENTS:

1. FTS circuit must meet all requirements defined under Category "A" requirements
2. Circuit must requirements in RCC STANDARD-319-92, FTS Commonalty Standard, Chapters 1, 2, 3, and 4
3. All LIOS components must meet test requirements in RCC STANDARD-31992, FTS Commonalty Standard, Chapters 5.1 and S.2
4. Meet design requirements specified in WRR-127.1 (June 30, 1993) Chapter 4:
 - a. Circuit requirements in Sections 4.6.7.4.5, 4.6.7.4.8, and 4.6.7.4.9
 - b. Optical connector requirements in Section 4.7.5.2
 - c. LFU requirements in Section 4.7.7.4.1
 - d. LID requirements in Section 4.7.8.3
5. System must meet test requirements specified in WRR-127.1 (June 30, 1993) Chapter 4:
 - a. Appendix 4A.7: LFU Acceptance testing
 - b. Appendix 4A.7: LFU Qualification testing
 - c. Appendix 4A.7: Fiber Optic Cable Assembly Lot Acceptance Testing
 - d. Appendix 4A.7: Fiber Optic Cable Assembly Qualification Testing
 - e. Appendix 4A.7: LID Lot Acceptance Testing
 - f. Appendix 4A.7- LID Qualification; Testing (need to revise numbers)
 - g. Appendix 4A.7: LID Aging Surveillance Test
 - h. Appendix 4B: Common Tests Requirement

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6. Incorporate a Built-in-Test (BIT) feature which allow remote testing at energy levels of 10^{-2} below no-fire for both normal and failure modes and must also be at a different wavelength than main firing laser. The wavelengths for the main firing laser and the test laser must be separated by at least 100 nm
7. Piece parts shall be IAW ELV specs
8. All ordnance interfaces shall allow for 4 times (axial, angular max. gap) or 0.15" and 50% minimum design gap
9. Connectors per IAW MIL-C-38999J
10. Perform analysis/design on: LIOS FTS-FMECA, bent-pin analysis, LID heat dissipation due to SPF's

SAFETY POINTS

- **GENERAL REQUIREMENTS:**
 - avoid introduction of new hazards,
 - avoid inadvertent ignition,
 - functions upon demand
- **LOW VOLTAGE FOR DIODE TO LASE CONCERN**
- **POSITIVE CONTROL OF PERSONNEL SAFETY AT PAD ESSENTIAL**
- **RANGE STRAWMAN REQUIREMENTS**

ISSUES TO WORK

- **SAFETY REQUIREMENTS**
- **BUILT-IN-TEST**
- **COSTS**
- **DEMONSTRATED RELIABILITY UNDER VARIETY OF APPLICATIONS AND ENVIRONMENTS**

WHERE DO WE GO FROM HERE?

WORK NEEDED AND NEXT STEPS

- **BUILT-IN-TEST**
- **SPECIFICATION**
- **DEMONSTRATED RELIABILITY UNDER A VARIETY OF APPLICATIONS AND ENVIRONMENTS**
- **STANDARD DESIGN: BUILD TO PRINT VERSUS BUILD TO SPECIFICATION**
- **MARKET ANALYSIS**

SUMMARY

- **PROGRAMS MORE LIKELY TO USE IF CONCEPT IS PROVEN VIA DEMONSTRATION**
- **PROGRAMS WILL USE LIO IF QUALIFIED AND IS COST COMPETITIVE**
- **NO PROGRAM DESIRES TO MAKE USE OF LIO AND PROCEED DOWN THE LEARNING ROAD, UNLESS MANDATORY FOR PROGRAM SUCCESS OR SAFETY**
- **WITHOUT A PROCESS WHEREBY THIS TECHNOLOGY IS DEMONSTRATED AND COST FACTORS VERIFIED, THERE IS NOT ANTICIPATED TO BE A DEMAND**

CONCLUDING THOUGHTS

- **A TECHNICAL COMMUNITY NOT UNITED IS NOT ANTICIPATED TO MEET WITH THE SUCCESS NECESSARY FOR LIO IMPLEMENTATION ON A REASONABLE TIME FRAME.**
- **A WELL-COORDINATED, JOINTLY-CONDUCTED, AND CO-FUNDED INITIATIVE BETWEEN GOVERNMENT AND INDUSTRY OFFERS THE BEST OPPORTUNITY FOR TECHNOLOGY IMPLEMENTATION.**
 - One example is the Pegasus demonstration.
 - Another is laser gyro demonstration.
- **THERE ARE ISSUES TO BE WORKED WITH SUCH AN APPROACH SUCH AS: PROPRIETARY INFORMATION, DEGREE OF FUNDING PARTICIPATION VERSUS RETURN EXPECTED, WHO DOES WHAT, GETTING AGREEMENT ON TECHNICAL ISSUES, ETC.**
- **BUT THESE MUST BE CONSIDERED WORKABLE WHEN VIEWED FROM THE PERSPECTIVE OF THE VALUE OF THE EFFORT AND THE IMPACT OF SUCCESS.**

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