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FLIGHT DEMONSTRATION OF FLIGHT TERMINATION SYSTEM AND SOLID ROCKET MOTOR IGNITION USING SEMICONDUCTOR LASER INITIATED ORDNANCE

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ABSTRACT

Solid State Laser Initiated Ordnance (LIO) offers new technology having potential for enhanced safety, reduced costs, and improved operational efficiency. Concerns over the absence of programmatic applications of the technology, which has prevented acceptance by flight programs, should be abated since LIO has now been operationally implemented by the *Laser Initiated Ordnance Sounding Rocket Demonstration (LOSRD) Program.* The first launch of solid state laser diode LIO at the NASA Wallops Flight Facility (WFF) occurred on March 15, 1995 with all mission objectives accomplished. This project, Phase 3 of a series of three NASA Headquarters LIO demonstration initiatives, accomplished its objective by the flight of a dedicated, all-LIO sounding rocket mission using a two-stage Nike-Orion launch vehicle. LIO flight hardware, made by The Ensign-Bickford Company under NASA's first *Cooperative Agreement with Profit Making Organizations*, safely initiated three demanding pyrotechnic sequence events, namely, solid rocket motor ignition from the ground and in flight, and flight termination, i.e., as a Flight Termination System (FTS). A flight LIO system was designed, built, tested, and flown to support the objectives of quickly and inexpensively putting LIO through ground and flight operational paces. The hardware was fully qualified for this mission, including component testing as well as a full-scale system test. The launch accomplished all mission objectives in less than 11 months from proposal receipt. This paper concentrates on accomplishments of the ordnance aspects of the program and on the program's implementation and results.

While this program does not generically qualify LIO for all applications, it demonstrated the safety, technical, and operational feasibility of those two most demanding applications, using an all solid state safe and arm system in critical flight applications.

ACRONOMYNS

ARC	Atlantic Research Corporation
DoD	Department of Defense
DoE	Department of Energy
EBCo	The Ensign-Bickford Company
ETS	Energy Transfer System
FCDCA	Flexible Confined Detonating Cord Assembly
FTS	Flight Termination System
GSFC	Goddard Space Flight Center
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LDFU	Laser Diode Firing Unit
LID	Laser Initiated Detonators
LIO	Solid State Laser Initiated Ordnance
LOSRD	Laser Initiated Ordnance Sounding Rocket Demonstration Program
MMC	The Martin Marietta Company (now Lockheed Martin)
OSC	Orbital Sciences Corporation
OTA	Ordnance Transmission Assembly
Q	Vehicle dynamic pressure (pounds per square foot)
SNL	Sandia National Laboratory
TBI	Through Bulkhead Initiators
WFF	NASA Wallops Flight Facility

1.0 PROGRAM DESCRIPTION

Background

Laser Initiated Ordnance has for many years been claimed to offer advantages to the launch industry and for payloads. But due to lack of operational use, it has not been employed. Thus, a flight demonstration became important to the aerospace industry in order to provide that key operational experience and the critical flight test data to surmount a major hurdle of LIO acceptance by flight programs. One concern may be attributed to the uncertainties associated with defining safety requirements, including range safety. Without the need established by a specific mission tied into an actual flight LIO system, the generation of safety requirements has been difficult.

As a means to counter those problems, the initial thought for this demonstration program was conceived by the NASA Headquarters author. The NASA Sounding Rocket Program appeared ideally suited to carry out such a mission. The launch vehicle had to expose a LIO payload to a rigorous launch flight environment at very low cost. Further, program activity had to be maintained at a high level of quality and technical rigor. The focus of the organization performing the program had to be one having technology transition interests in order for the program to receive the required priority and detailed attention.

The NASA Sounding Rocket Program at the Wallops Flight Facility had the unique capability of launching a payload into the desired environment at a very low cost, making it ideally suited to this mission; and, hence, it was pursued. While the Sounding Rocket Program is predominantly associated with serving the scientific research community at the present time, in the early years of NASA, and in the NACA before then, it served mainly NASA's aeronautics programs. Further, sounding rocket vehicles have been used to demonstrate and flight qualify new technologies many times; but this involvement in a technology transfer program expands that activity in a relatively new role.

The initial Headquarters suggestion was formally made on September 1, 1993 when discussions were held at the NASA Wallops Flight Facility to explore concept feasibility. The conclusion was that the demonstration project would be important in bringing forth the technology and would be feasible for a sounding rocket flight. On October 21, 1993 a follow-up meeting was held at the Wallops Flight Facility to advance program definition. Then, it was concluded that a dedicated two-stage vehicle, the Nike-Orion, would be the best choice for meeting program objectives and that the availability of telemetry was important. NASA would provide a platform(s) for mounting the required LIO hardware. On January 5, 1994 a Pre-Project Initiation Meeting was held at the WFF to accomplish initial planning. The conclusion was that the desired quick, low-cost LIO motor ignition and flight termination system flight demonstration goal would be feasible, and WFF committed to performing the mission.

Definition

"Laser Initiated Ordnance," that is, "LIO," as defined in this program, uses laser light energy to replace electrical energy for initiation of ordnance and uses all solid state electronic components throughout, including the safe and arm system. The other aspect of laser initiated ordnance, distinguishing it from conventional ordnance systems in general, is that a fiber optic cable replaces the ordnance cord to transfer energy.

Two laser technologies have been developed, rod and diode. Rod laser ordnance ignition has been previously demonstrated on the Small ICBM Program. With the rod laser ordnance initiation experience behind us, the laser choice for this NASA flight demonstration program was, thus, the laser diode. In this program we refer to "LIO" strictly as solid state laser diode technology, unless otherwise specially noted.

Objectives

In order for this to a be quick, results-oriented program and one performed at low cost, it was designed to be highly focused, that is, a program to resolve the key issue of demonstrating the programmatic feasibility of all solid state LIO.

A high risk, i.e., non-redundant, LIO flight system design approach was not only considered acceptable but even essential to prove operational functionality. While the quantity of test hardware was statistically low, the test program was carefully designed to minimize technical risks. Operational goals that closely simulate this technology's claimed functional advantages of electromagnetic insensitivity were to be incorporated into the program's operations, within program safety and cost constraints. It was not intended to address all LIO-related issues, but within programmatic limitations the results were to have widest applicability. Finally, we desired to rapidly transfer results to industry.

In view of the above program philosophy, the program staff established the following flight test objectives. The primary LOSRD Program success criteria were based upon (1) the safe use of LIO and (2) the operation of laser actuated detonators from the ground and in flight for the most critical flight vehicle applications. As a secondary objective, the program used this unique opportunity to gain data from thrust termination using an ordnance design which ports motor chamber pressure from the head end of a solid rocket motor, the subject of a separate report.

Several mechanisms were provided to verify program objectives. LIO safety was particularly important because safety has been stated to be a key LIO technology feature. Further, it is clearly one feature required to make possible the practical implementation of LIO. Confirmation that the detonators have fired was to be determined by visual aids, radar, or accelerometer data telemetered back to WFF. Adequate flight data from the mission was necessary to transition the results of this flight to industry.

Program Implementation

The program management approach was key to our success with accomplishing the tough program objectives. It was decided that to be successful this program must use a highly leveraged technical and programmatic approach if we were to effect realistic results with the cost, performance, and schedule constraints.

Hence, relevant hardware pedigree was essential, requiring the use of existing designs. Ordnance interfaces had to be maintained; otherwise an unaffordable qualification program would become necessary. A management oversight and advisory approach was needed to provide the best possible expertise to prevent costly errors. To that end a government-industry team was organized comprising several NASA centers (Wallops Flight Facility, Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Goddard Space Flight Center) (GSFC) plus the Department of Defense (The Aerospace Corporation), Department of Energy (Sandia National Laboratory), range safety staff (Wallops Flight Facility, eastern, and western ranges), The Ensign-Bickford Company (EBCo), The Martin Marietta Company (now Lockheed Martin), Orbital Sciences Corporation (OSC), and NASA/DoD/DoE Aerospace Pyrotechnics Systems Steering Committee. That advisory group was referred to as the *NASA/DoD/DoE/Industry Laser Ordnance Team*. For assuring success, it was determined at program onset that the conduct of critical program reviews, namely, the Initiation, Design, Full Scale Pre-test Readiness, and Flight Readiness Reviews, were all essential.

Implementation Instrument. A new contractual instrument was the most important ingredient at the beginning of this program to accommodate a rapid program implementation. To that end NASA announced in the second NASA Pyrotechnics Systems Workshop, held at the Sandia National Laboratory on February 7, 1994 that this program was being proposed for consideration. The NASA *Cooperative Agreement for Profit Making Organizations* was the instrument planned, the first such having been implemented successfully for the initial use of LIO on-board the Pegasus® launch vehicle.

Among the criteria for a *Cooperative Agreement for Profit Making Organizations* is government participation. Each participating organization brings forth an element for the common benefit of the technology to industry. Both parties agree to share an active role in implementing project objectives. These are non-fee bearing instruments. The program content must have general relevance and benefit to industry. No hardware is delivered to NASA.

This is the manner by which the LOSRD Program was accomplished. From the government's contributions, NASA Headquarters provided the overall program management. NASA's Wallops Flight Facility provided the project management for this flight mission, as well as the payload team and project support personnel. WFF's responsibilities included the design, fabrication, assembly, integration, and testing of the payload systems. WFF provided the instrumentation for facilitating and verifying LIO functions, such as the onboard monitors, power supplies, timing devices, and transmitter as well as the data receiving station, RF tracking and photographic coverage, the preflight performance analysis, and analysis of test and flight data. NASA provided a dedicated Nike-Orion launch vehicle and facilities, a mounting platform for installation of the laser ordnance hardware, the vehicle flight dynamics analysis, 3-axis accelerometer, FM-FM transmitter, flight system build, flight system integration, and the flight performance analysis. WFF specified standards of workmanship and safety throughout all phases of the project. They coordinated and conducted all launch operations. Finally, Headquarters was to assure the rapid transfer of the technology.

The Ensign-Bickford Company (EBCo) provided the laser ordnance system and the support necessary for integration of the ordnance onto the sounding rocket which was based upon an extensive base in those areas. This included the laser firing unit, the fiber optic cable, connectors, detonators, initiators, and shaped charge. The Ensign-Bickford Company developed the firing system's ground support checkout equipment, provided the ordnance procedures, and installed the ordnance. The ordnance quality program was at their discretion. NASA requested that the LIO be demonstrated to meet vehicle operational and safety requirements and that The Ensign-Bickford Company should establish ordnance test requirements. Testing was to be performed to demonstrate compatibility and functional performance of laser initiation with the current motor ignition system.

Schedule Milestones.

The target time for the conduct of this demonstration was to be within approximately 6 months from go-ahead, with a report to follow. The actual time from completion of the program initiation meeting to launch was only 6 months, two weeks. The total time from receipt of The Ensign-Bickford Company's unsolicited proposal until launch was 10 months, 19 days. Table 1 presents specific program milestones.

Table 1. Program Milestones.

1994	
Feb. 7	Announcement of intent: NASA Pyrotechnic Systems Workshop
April 26	Receipt of unsolicited proposal to change the original cooperative agreement
May 3	Evaluation team established; proposal review initiated
June 14	Change request package submitted to procurement
Aug. 19	Negotiations/clarifications. Change approved by HQS.
Aug. 30	WFF Project Initiation Meeting
Nov. 14	Design Review
1995	
Jan. 3	Flight hardware build-up complete
Jan. 18	Qualification testing complete
Feb. 7	Pre-Test Readiness Review; Full-Scale System Test conducted
March 7	Mission Readiness Review
March 15	Launch
Apr. 25-26	Laser User-technologist Workshop at GSFC

LOSRD Cost

Demonstrations of this type can be inexpensive to implement using the above management/team approach. The cost of the agreement was $134.5K. The role of the WFF was key to implementing a low cost, highly reliable program quickly.

2.0 PROGRAM DESIGN AND TEST APPROACH

Requirements

Whereas programs normally seek minimum stress levels, the requirements for this program were the opposite. Subjection of the LIO hardware to the greatest flight stress was the goal. Thus, the minimum payload mass, consistent with flight stability, was designed. To achieve the maximum dynamic flight environmental exposure to demonstrate LIO FTS, thrust termination was planned at or near Max-Q. The minimum necessary flight instrumentation to provide useful engineering data was requested. Once the design was completed and determined to meet the mission objectives, no new goals or "improvements" that would cause hardware changes were permitted unless safety were affected.

Safety and Mission Assurance Considerations

For safety, a three failure tolerant (man-safe) design of critical safety-related events was established.

The lowest program cost could only be accomplished by the use of off-the-shelf hardware to the fullest, even if a non-optimal LIO design resulted. Refer to Table 8 for the list of actual hardware and pedigree. Simply stated, we used what in essence amounted to a "standard concept" in order to accomplish the program quickly, cheaply, reliably, and safely: Previously flown hardware was either used within prior operational constraints, or it was retested.

It was important to keep the vehicle simple; and, consequently, no RF command up-link was requested. An all solid state firing/safing system was to be utilized, i.e., no fiber optic line barriers were allowed, requiring an electronic safe and arm system.

Hardware redundancy was excluded except for the altitude switch, a mechanical device safety interlock, which safes the system from inadvertent ignition at altitudes below 5,000 feet. Thus, from that non-redundant hardware approach, initiation events would unquestionably verify LIO operation. This single string design was intended to be a high risk design approach, but one with risk mitigated by a strong qualification test program, including an integrated ground systems test.

Design

The Nike-Orion was selected as a suitable high performance launch vehicle capable of meeting the program's schedule. The redundant motor initiators normally used were changed to a single initiator. High quality parts were used. Key flight events, were monitored via 19 channels of flight data: 3-axis accelerometer, commands, arm status, battery current, and laser voltage. That instrumentation was considered sufficient for safety status determinations, engineering evaluations, and mission success information. Backup flight data, if necessary, were to have been provided by camera and radar coverage.

While there were 23 critical single failure points that could cause loss of mission, the safety reviews identified no single safety critical failure. The key safety features of verifiable, three-inhibit levels for FTS activation and motor ignition system were determined to have been met when reviewed by the *NASA/DoD/DoE/Industry Laser Ordnance Team.* Many of these 23 single failure points were necessary in this ordnance system to maintain low costs that resulted from not requalifying hardware. Hence, that number would be less in a flight system designed specifically for LIO.

Testing

A typical programmatic test approach was selected; that is, the normal acceptance and qualification testing was performed. The greatest quantity of hardware consistent with program funding constraints was tested to the most demanding environmental test levels necessary for meeting mission success. Rigorous component level testing was first conducted on new or modified designs prior to their incorporation into the payload. The complete payload was then tested for the new flight environment in its final configuration. Critical system functions were verified during and after environmental testing. Tests were performed on new or on modified designs and on prior hardware designs used in a new operational environment. Component tests, integration tests, and a full-scale system test were all conducted. The full-scale integrated ground system test was critical to the program, the success of which was established as a launch constraint. Testing was accomplished at various locations: The Ensign-Bickford Company, Wallops Flight Facility, Johnson Space Center, and the Orbital Sciences Corporation.

The wisdom of the test approach was verified when the only failure which occurred was due to an inadequate solder joint that failed in the laser firing unit during vibration acceptance testing. This failure was detectable only by monitoring performance status during environmental testing. Had it remained undetected, the flight termination event would not have occurred.

3.0 VEHICLE DESCRIPTION

Launch Vehicle

A standard Nike-Orion launch vehicle, figure 1, was selected to perform this mission's objectives. It offered the high accelerations that were required to meet mission objectives. Transient ignition accelerations during lift-off can be on the order of ±50 g's, with a second peak of approximately ±30 g's occurring at second stage ignition.

The Nike-Orion launch is a two stage, unguided, spin stabilized rocket which uses Army surplus motors. This vehicle has been a mainstay of the NASA Sounding Rocket Program for many years, and the LIO flight project was its 106th sounding rocket mission. The

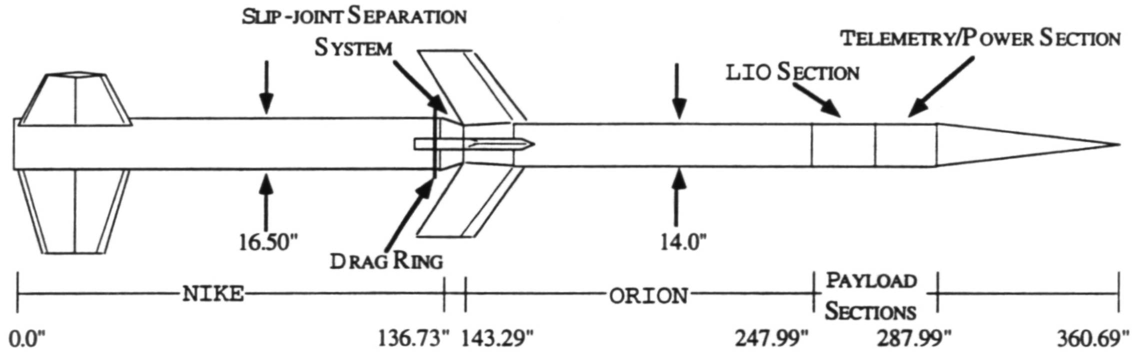

Figure 1. Nike-Orion launch vehicle configuration.

Nike-Orion can carry a 150 pound payload to 190 kilometers, or a 450 pound payload to 90 kilometers at an 85° launch elevation (Figure 2). Care had to be exercised with the use of higher elevations to assure ocean impact of the debris after FTS activation.

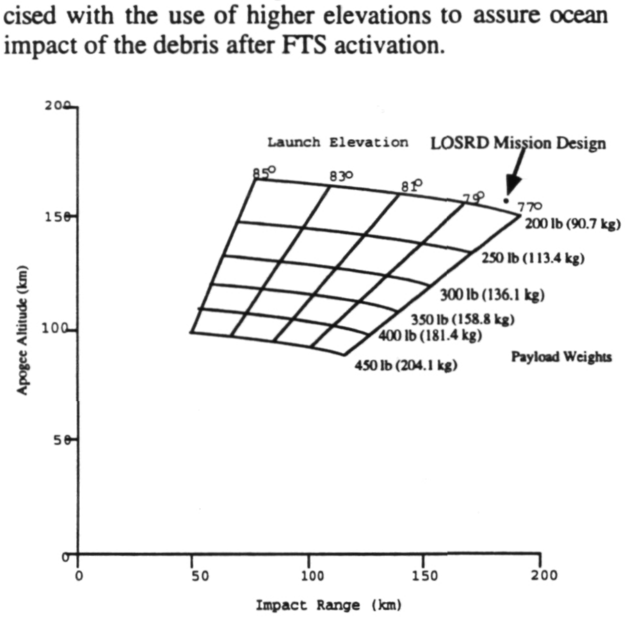

Figure 2. Nike-Orion launch vehicle performance.

The LIO mission was launched from the Pad 2 ARC (Atlantic Research Corporation) launcher on the NASA Wallops Island Launch Facility at a 78° elevation and a 145° azimuth with a 185.75 pound payload. As can be noted from figure 2, this mission was designed to extract the highest level of performance from this launch vehicle as intended by mission objectives.

The M88 M5-E1 Nike Hercules first stage booster has been in operational use for more than 30 years. The head end-type ignitor contains A2 black powder, and the double-base, solid propellant grain has a concentric ring configuration. Burning for a nominal 3.2 seconds, the Nike motor provides an average rated thrust of 42,782 lbf. and specific impulse of 195 lbf-sec/lbm at 60° F. When used as a first stage booster, the Nike motor has three 4.8 ft^2 Nike-Ajax fins. A 69 in^2 concentric drag plate was added for this mission to maximize separation from the Orion motor prior to second stage ignition.

The XM 22E8 Orion (Hawk) dual thrust second stage sustainer was first produced in 1960 for Army surface-to-air tactical missiles applications. The center-type ignitor contains $Al/KClO_4$ and 5A black powder. The two types of composite, solid propellant grains, cast into a concentric-cloverleaf configuration, provide two distinct thrusting modes. The thrust-time history of the motor is one that becomes highly regressive at approximately 5.5 seconds into the burn at a 60°F reference temperature. The first mode is the "boost mode" which operates at a chamber pressure of 1070 psig to produce an average thrust of 13,000 pounds at a specific impulse of 235 lbf-sec/lbm. This is followed immediately by the "sustain mode," which has a 26 second burn duration, at a very low chamber pressure of 190 psig, producing 1740 pounds of average thrust at a specific impulse of 204 lbf-sec/lbm. The desire to reduce the debris pattern, by maximizing the destruction of the payload, prompted the decision to initiate the FTS event 3.5 seconds after Orion ignition, during the higher motor chamber pressure of the boost phase. The motor utilizes 4 fins.

Ensign-Bickford Through Bulkhead Initiators (TBI) replaced the Holex 3300 Ignition cartridges which are typically used for the ignition of both motors. A slip joint separation system provided the means for staging. The 22.5° fiber-glass nose-cone had a ballast weight of approximately 60 lbs. added to provide vehicle flight stability.

Payload Design, Manufacture, and Testing

The payload hardware was located on 4 decks. Those were mounted in two separate payload sections called the Telemetry/power Section and the Laser Initiated Ordnance, LIO Section, each 20 inches in length and 14 inches in diameter. Those two sections plus a nose cone with ballast comprised the payload assembly. The payload was designed, fabricated, assembled, wired, and tested at the Wallops Flight Facility. In late August 1994, the WFF staff began to design the payload.

The Telemetry/power Section housed NASA's flight support equipment, e.g., batteries, timer, accelerometers, telemetry system, etc. on decks #1 and #2, figure 3.

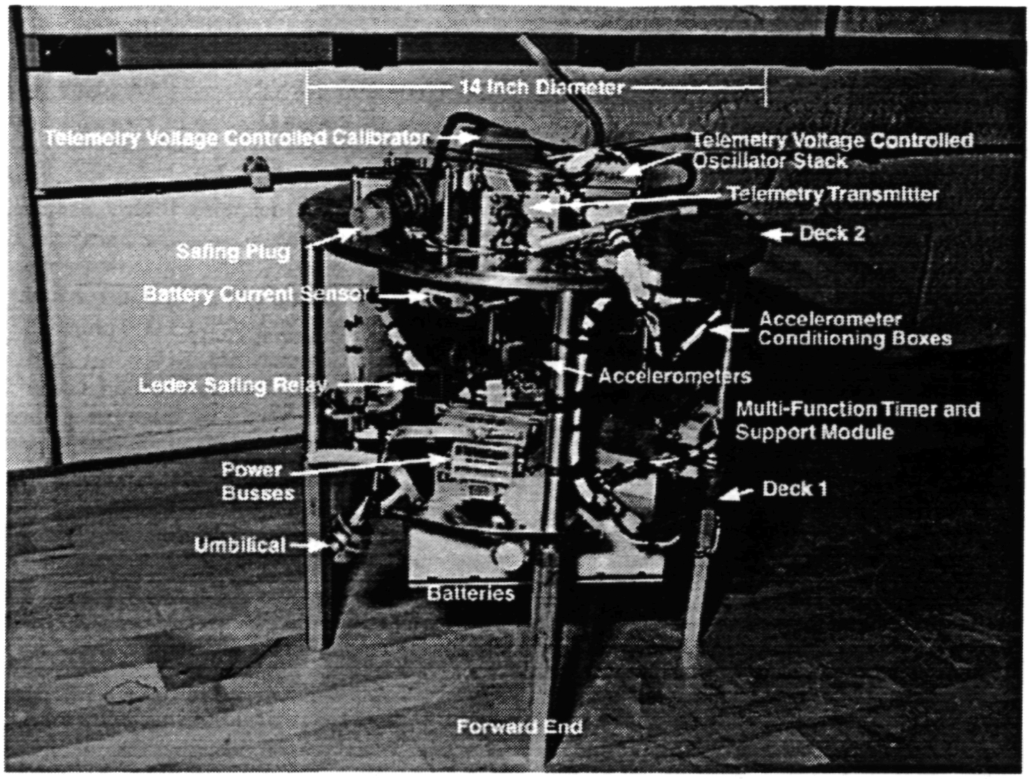

Figure 3. LOSRD Payload, Telemetry/power Section.

Power for the LDFU was provided from two on-board silver-zinc batteries on deck #1. Safe and arm commands for the LDFU were provided by a control panel in the blockhouse. The pre-programmed Multi-function Timer, located on deck #1, provided the fire commands for the two stage events. The timer was started by a lanyard as the rocket cleared the launcher. The timer provided a fire command at T+8.0 seconds for stage 2 ignition and a second fire command at T+11.5 seconds for stage 2 flight termination. An FM-FM telemetry system, deck #2, operating at 2269.5 MHz, provided accelerometer and LIO system status data during flight.

Two decks were provided for installation of the laser initiated ordnance payload equipment, decks #3 and #4 which respectively contained the ordnance and the LDFU laser firing system.

The breakdown of the payload weight assembly is shown in Table 2.

Table 2. Payload weight summary.

Assembly	Weight, lbs.
LIO Components/ordnance	12
Electrical, electronic, telemetry, power, wiring, instrumentation	32
Payload structure	55.3
Nose-cone	28
Ballast	58.5
Total	185.8

To accomplish the primary goal of exposing LIO hardware to the most extreme dynamic environment, a minimum flight vehicle weight maximized the effect of this vehicle's nominally turbulent performance characteristics. Flight system design complexity was minimized, and onboard instrumentation was limited to monitoring of only those functions most critical to the verification of programmatic success and as needed for safety. All design work was completed in early November. The LIO Flight Vehicle Design Review was held at WFF on November 14, 1994. Fabrication of the hardware began immediately thereafter, and this hardware development phase of the program was completed by the end of January 1995.

The payload's LIO Section, which housed the bulk of the laser initiated ordnance system, including most of the devices required to initiate second stage ignition and flight termination, was located at the aft end of the payload and was mated directly to the forward end of the Orion motor. A standard WFF electronic safe and arm (Ledex) switch was incorporated into the flight system as one of three safety inhibits.

The Telemetry/power Section was located just forward of the LIO Section. The WFF wraparound S-band telemetry antenna was mounted externally on this section, figure 5, as was the lanyard-type lift off switch which would start the second stage ignition and FTS timer at first motion. Mounted inside the cylindrical structure were decks #1 and #2, to which most of the WFF payload components were attached. These included the battery pack power supplies and the timers, as well as the redundant altitude switches which would prevent a premature second stage ordnance ignition in the event of an accidental lanyard deploy prior to the launch. The 2 watt TM downlink RF transmitter, also mounted in this section, provided 19 FM/FM channels of data. This was used to transmit monitored data for flight events which were used to verify mission success in lieu of sufficient corroborating evidence from optical and radar tracking. The data to be provided by this on-board system included the output of a 3-axis accelerometer, laser arming status, as well as power supply current and voltage data. Payload power was supplied by 2 silver zinc batteries. An 11-degree, 14-inch diameter asbestos phenolic nose cone was mounted at the forward end of the telemetry section of the payload.

Combined System Level Testing

The laser hardware testing at the component level began in mid January and was completed by the end of the month. The Ensign-Bickford and NASA/WFF payload systems were then brought together in an integrated assembly for the Full-scale Integrated Ground System Test which was performed successfully on February 7, 1995. The overall test set-up is shown in figure 4.

This test utilized the actual flight hardware as much as possible. Expended Nike and Orion motor casings were substituted for the rocket motors. The shaped charge and TBI's were from the same manufacturing lots as the flight items. The payload was suspended in order to limit dampening of structural harmonics during firing of the Laser Initiated Detonators (LID). The overall ground test configuration inclusive of the payload is shown in figure 5.

The program success criteria was LID detonation. Hence, an important objective of this test was the acquisition of the LID firing signature within the environment of the payload flight configuration. This was necessary in order to ensure that a successful LID actuation could be verified even in the event of an unlikely subsequent disruption of the explosive train during the flight test. During this ground test, the onboard accelerometer data clearly indicated a ringing of the payload structure each time a LID functioned. Refer to figure 20 for a description of the dynamics (~1200 Hz ringing) of the FTS event in flight. Subsequent comparisons with flight test data from other programs confirmed that, in lieu of other corroborating evidence, this method would be sufficient for verification of any successful LID event.

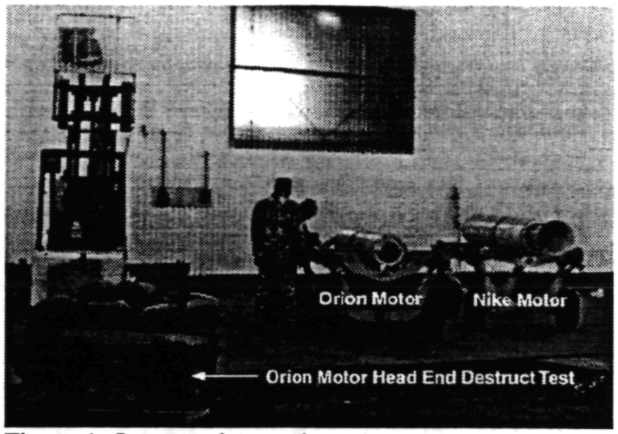

Figure 4. Integrated ground test set-up.

After the integrated ground system test, both payload system sections and the complete flight assembly were subjected to the comprehensive environmental testing procedures which have been developed by the NASA Sounding Rocket Program as the standard payload test series (Table 3[1]).

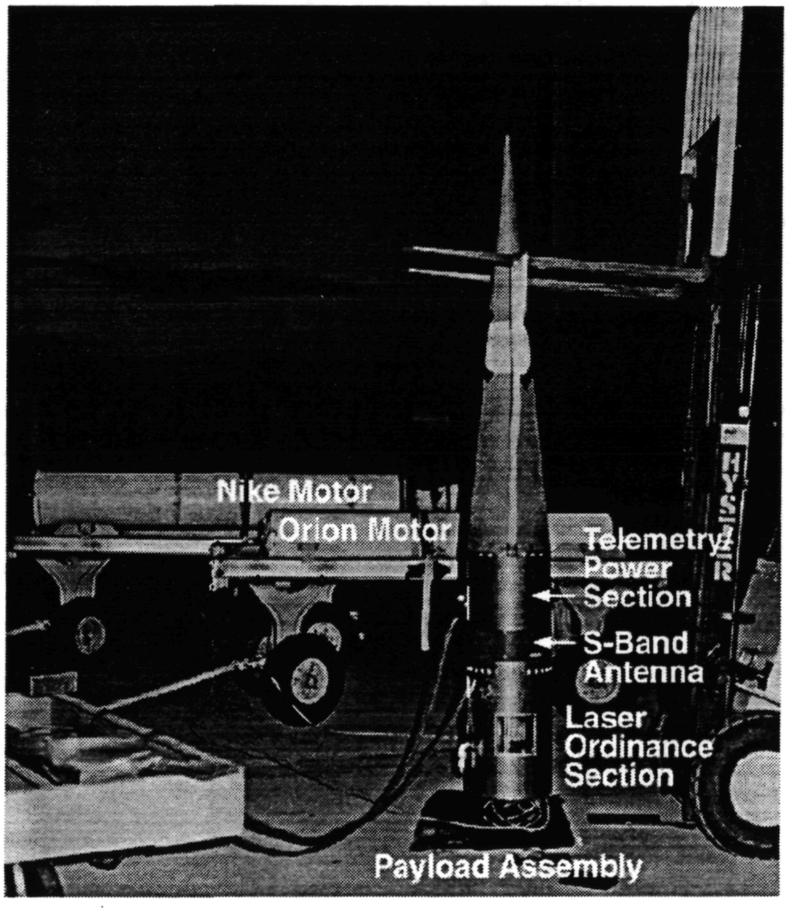

Figure 5. Suspension of payload assembly for the integrated ground test.

Table 3. Payload Test Series.

Test	Predicted flight levels	Qualification test levels
Thump test	Not applicable	55 Hz natural frequency
Sine sweep vibration	Not applicable	7.3 in/s 5-89 Hz, 10.5g 89-800 Hz, 15.0g 800-2000 Hz
Random vibration	8g RMS, 11.5 seconds	20g RMS, 20 sec/axis, 3 axes
Bend test	58,000 in-lbs	48,000 in-lbs at payload base at a 3° angle of attack

During this payload test series, a problem was encountered with the telemetry system which resulted in the change-out of the telemetry calibrator.

Those tests were conducted at the telemetry ground station and the environmental test lab of the WFF Technical Support Branch. Before they could begin, a delay of several days was required for resolving a noise problem in the on-board telemetry system. First detected during the full scale integrated ground test, it was determined to be the result of faulty signal conditioning circuit. The problem was corrected, and the payload test regime commenced with the standard telemetry system checkout which was completed without incident.

After post-ground test refurbishment, such as ordnance replacement, the WFF and Ensign-Bickford payload systems were integrated as planned. Pre-vibration sequence testing verified that all systems were performing to the overall payload design specifications. Systems which were specifically verified to be fully functional included those of the prelaunch power and arm commands, the launch abort disarming sequence, the timed flight events, as well as the power status and the current consumption during all events. All payload hardware demonstrated nominal performance, including the on-board timers and relays, and the on-board monitors for each component or system.

Once we had verified that all payload systems were fully operational, the complete assembled payload in its flight configuration was then subjected to the environmental testing requirements. In this sequence of tests the payload physical properties were measured and dynamically spin balanced. Then it was subjected to stresses comparable to the aerodynamic loads predicted to occur in the flight environment. Those loads were applied in the form of a bend test, in which the payload was flexed to simulate the worst case aeroelastic reaction of that particular payload configuration to the opposing forces of thrust and drag; and a vibration sequence was applied which simulates or exceeds the type of random agitation that normally occurs during motor burn. Payload functions were monitored during the vibration tests, and experiment functions were also monitored before and after each of them. Finally, after all environmental testing had been completed, a repeat of the operational sequence test verified that the payload systems and hardware had indeed survived intact. Armed with the confidence of having seen this payload survive such a rigorous ordeal, we proceeded to the Pad 2 launch rail for final vehicle staging with the actual flight motors, and we prepared for the launch of the LIO demonstration flight.

Predicted Flight Performance

As mentioned, the vehicle mass had been minimized to expose LIO to the worst case flight dynamic environment. The specific loads which that philosophy produced, one may clearly observe from the predicted accelerations for the LIO hardware which are shown in figure 6.

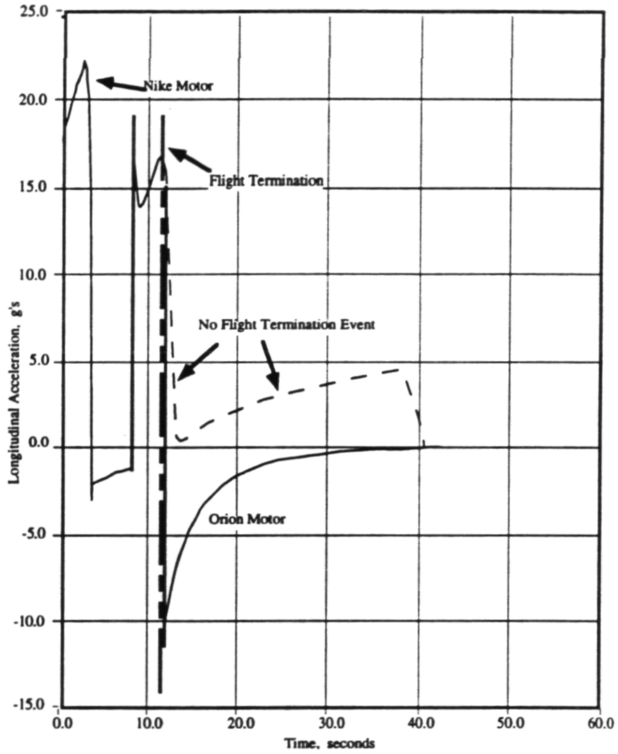

Figure 6. Vehicle acceleration time history.

The flight termination sequence was originally planned at max Q which occurs on this vehicle in this mission at 12.5 seconds. Those loads on this vehicle, when flown to this mission profile, produce the dynamic pressure (Q) time history as shown in Figure 7.

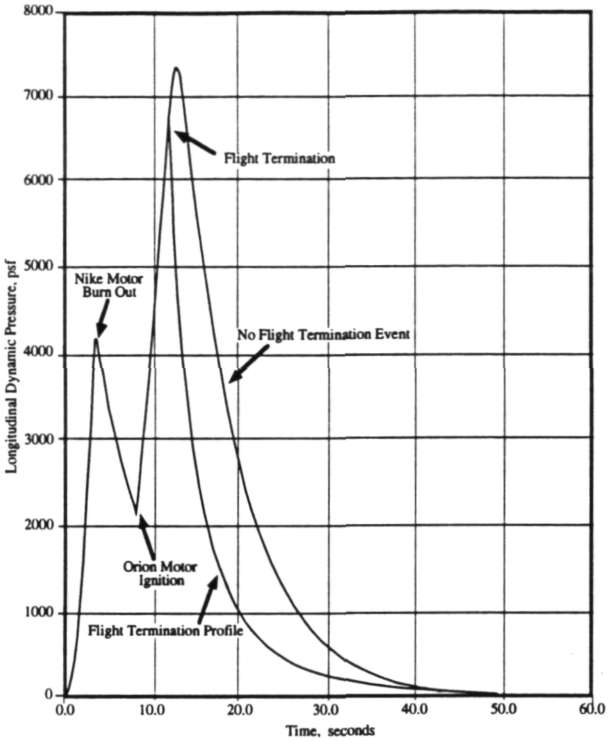

Figure 7. Vehicle dynamic pressure.

Key flight parameters for the flight events are provided in table 4.

Table 4. Predicted flight dynamic environment.

Event	Time, seconds	Altitude, ft	Range, ft	Velocity, fps
Nike Ignition	0	0	0	0
Nike burn out	3.54	3699	840	1964
Orion Ignition	8.00	11332	2725	1595
FTS	11.5	19398	4800	3223

But later, near the date of launch, there was a concern by the range safety office whether the vehicle might not remain sufficiently intact that flight debris generation/dispersions would be less than desired, so the ROM timing chip processor was reprogrammed only two days before launch in order to relieve motor chamber pressure at maximum chamber pressure, this motor having a highly regressive grain design, which corresponded to the flight time of T = 11.5 seconds. This modification set a record for the completion of such a significant change at a time so near launch!

The launch vehicle used standard flight control hardware consisting of a three-fin Nike design and four-fin Orion design (figure 1) which spin stabilized the vehicle at 7 revolutions per second. The components and their weights used for mission performance analysis are summarized in table 5.

Table 5. Vehicle mass summary.

Sub-assembly.	Weight, lbs.
Payload	185.8
Orion	931.7
Nike plus Interstage adapter/drag plate	1320.9
Total	2438.4

4.0 LASER INITIATED ORDNANCE AND FIRING CIRCUIT

Design/pedigree

The design of the ordnance system was based on a laser diode ordnance system previously designed for the Naval Research Laboratory's Advanced Release Techniques experiment[2]. The flight ordnance system for the Nike-Orion launch vehicle comprised a two-output Laser Diode Firing Unit (LDFU), a two-channel Energy Transfer System (ETS), and Laser Initiated Detonators (LID). This two-channel system is identical to the hardware previously qualified for the Pegasus® laser ordnance flight experiment[3]. The LDFU is an electronic safe and arm device containing high power laser diodes controlled by solid state transistor switches. The ETS is a two-channel fiber optic cable assembly used to transfer the laser light from the LDFU to the LID. The LID is an all-secondary detonator with an output which duplicates a standard 1 grain HNS detonating cord output.

Ordnance system layout. The LIO ordnance system initiated three key mission events:

- stage 1 ignition,
- stage 2 ignition, and
- stage 2 thrust termination.

Stage 1 was ignited by the LDFU mounted on the back side of the launcher. (See figure 14.) The stage 2 events were initiated from the second LDFU located in the Telemetry/power Section of stage 2. As mentioned, the ordnance system was specifically designed to be single string with no redundancy. While this provided a riskier mission than using redundancy, it provided an unqualified demonstration of success.

Stage 1 ordnance system. A schematic of the Nike stage 1 ordnance system is shown in figure 8. It comprised an LDFU controlled from the blockhouse, ETS, LID, manifold, self-separating Flexible Confined Detonating Cord Assembly (FCDCA), and Through Bulkhead Initiator (TBI).

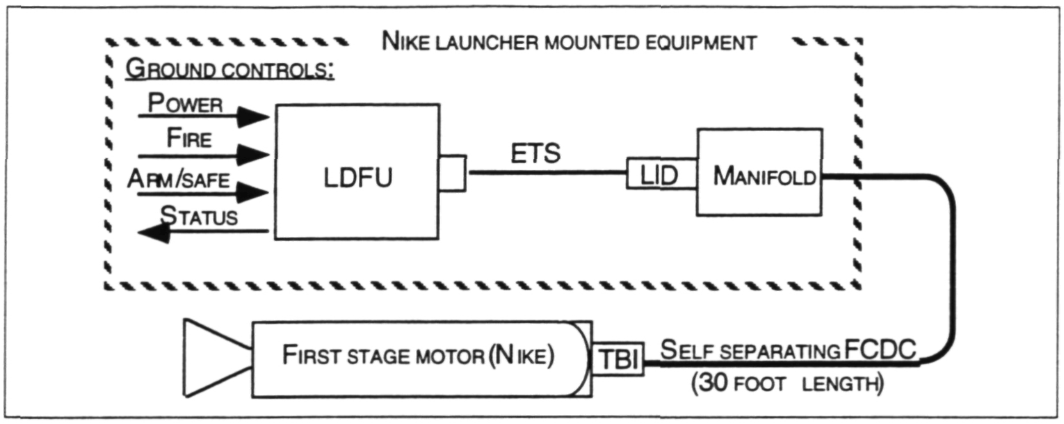

Figure 8. Stage 1 Ground Ordnance System.

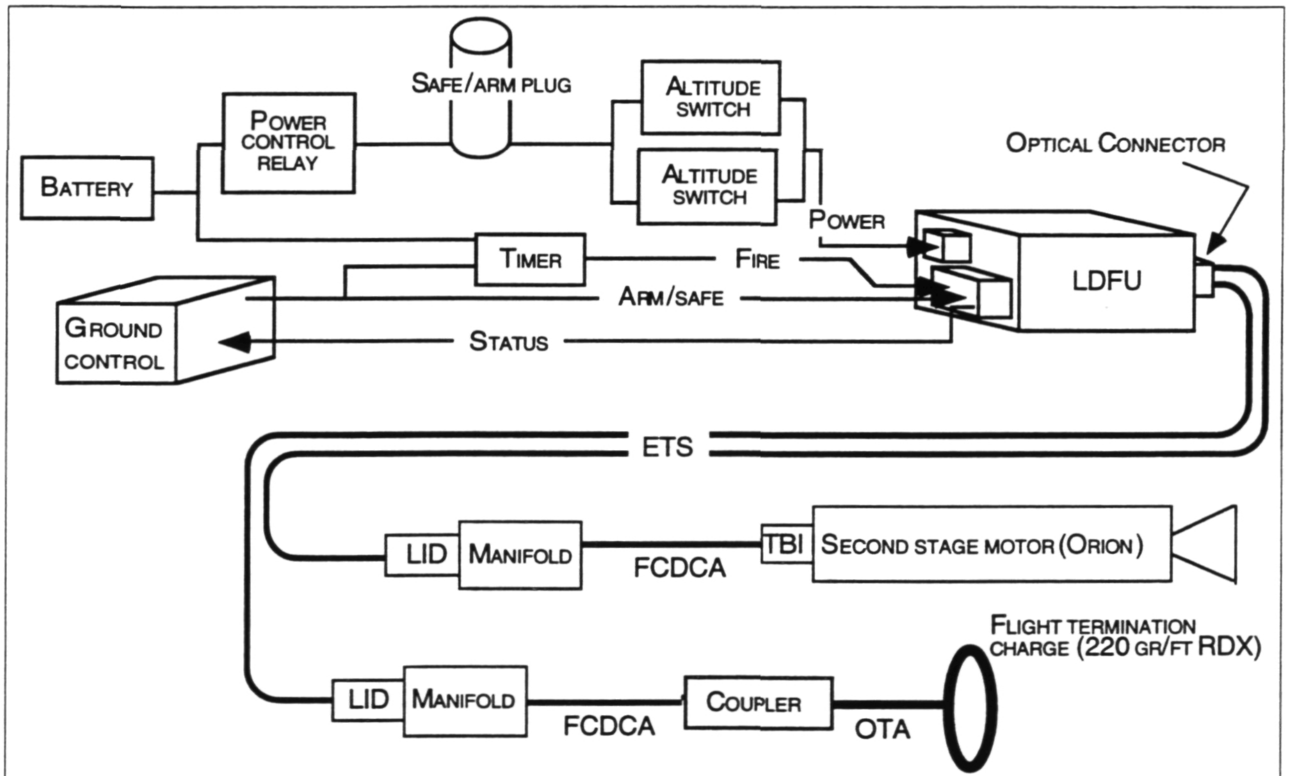

Figure 9. Stage 2 Ordnance System

Power for the LDFU was provided by a 28 VDC power supply located in a mini-blockhouse near the launcher. This power supply and the LDFU arm and fire commands were controlled from the blockhouse. The LDFU was located on the back of the launcher to be protected from the stage 1 launch blast. The laser output of the LDFU was connected to the ETS, then to the LID. A three-port manifold, with one port plugged, provided the interface between the LID and the FCDC. The FCDCA was laid alongside the launcher to the interstage adapter and into the TBI. The separation joint of the FCDCA was located just outside the interstage adapter between the Nike and the Orion. The TBI screwed directly into the Nike ignitor which replaced the normal Nike ignitor cartridge.

Stage 2 ordnance system. The stage 2 Orion ordnance system comprised an LDFU, ETS, LIDs, manifolds, FCDCA, Ordnance Transmission Assembly (OTA), TBI, and destruct charge. A schematic of the Orion ordnance system is shown in figure 9.

The Orion's LIO hardware was mounted on the WFF provided platforms, decks #3 and #4. Ordnance was mounted on deck #3. That consisted of LIDs, manifolds, and FCDCA's. Deck #4 contained the LDFU and ETS. Arm and safe commands for the LDFU were provided by a control panel in the blockhouse. A view of the deck #4 component installation is given in figure 10.

The flight LDFU was armed and safed from the blockhouse and fired from the Nike-Orion's onboard timer, the LDFU fire commands from a preprogrammed timer on deck #3. The laser outputs of the LDFU were connected to the ETS, then to the LIDs. The stage 2 ignition LID interfaced to the FCDCA using an existing three-port manifold with one port plugged. The FCDCA continued to the TBI which was screwed directly into the stage 2 ignitor replacing the normal Orion ignitor cartridge. A manifold connected the destruct LID to an FCDCA. The FCDCA connected to an OTA which provided the necessary physical and explosive output to initiate the destruct charge. The destruct charge was a modified version of the destruct system used on the Pegasus® and Taurus® solid rocket motors. The destruct charge was an eight inch diameter, linear shaped charge ring of 220 grains per foot RDX.

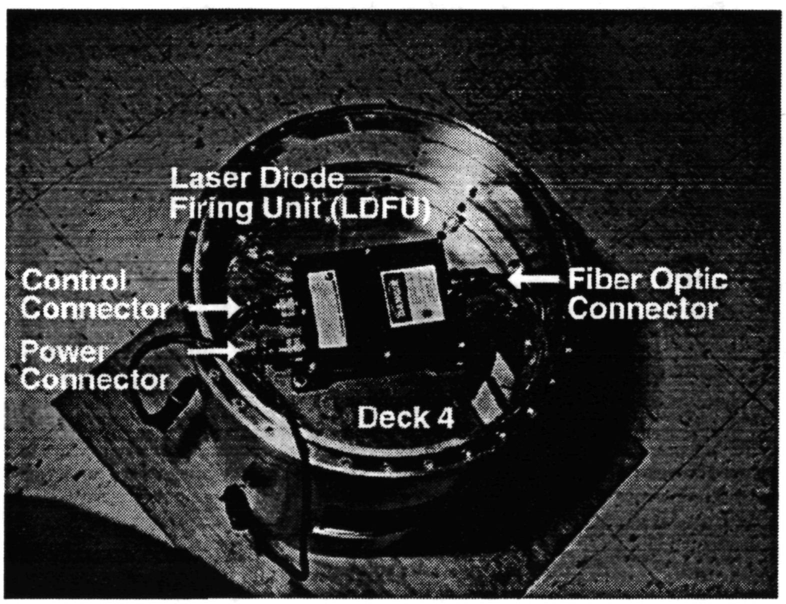

Figure 10. LOSRD Payload, LIO Section.

While this ordnance system is more complex than what would be optimally used, it was designed from only those qualified components with flight pedigree. This approach was chosen to provide the greatest probability of mission success without designing and qualifying any new hardware.

Manufacturing. All the components of the ordnance system were manufactured by The Ensign-Bickford Company using standard management tasks/processes including non-destructive testing (x-ray and n-ray) and lot acceptance testing. Manufacturing processes and procedures were the same as those used for any deliverable product for flight. Each critical step received an independent verification check of the data, the results of which were recorded.

Test Program Description

To insure a successful mission, a two-part test program - component and system - was undertaken to test the laser ordnance system for use in the sounding rocket environments as discussed. Since only one LDFU was fabricated for this program, the decision was made to fly the hardware that had been subjected to the qualification test program. Four separate test series were performed for this program: 1) a test series for the LDFU and ETS components, 2) a test series for the LID, and 3) an all-up integrated system level ground test, and 4) an integrated payload assembly test series. The test program verified components and the system to at least the flight levels or higher as presented in the procedures description discussion below.

The LDFU test series, table 6, exposed the LDFU and ETS to environmental levels at least twice that anticipated in flight. The actual test series was a combination of the standard sounding rocket test series and typical MIL-STD-1540 test levels. The second random vibration test, shown in table 6, was an additional test performed based on the Pegasus® qualification program[3]. During the Pegasus® qualification, the vibration table was

Table 6. LDFU/ETS Test Series.

Test	Predicted flight levels	Qualification test levels
Thermal cycle	10°C to 40°C	-24°C/+61°C, 8 cycles
Sine sweep vibration	Not applicable	7.3 in/s 5-89 Hz, 10.5g 89-800 Hz, 15.0g 800-2000 Hz
Random vibration	8g RMS, 11.5 seconds	1.) 20g RMS, 20 sec/axis, 3 axes 2.) 24.6g RMS, 4 min/axis, 3 axes
Acceleration	25g maximum	60g, 1 min, 3 axes
Shock	Launch and flight shocks encompassed by the vibration spectrum	20g half sine, 11 ms, 1 shock each direction of each axis 80g half sine, 3 ms, 1 shock each direction of each axis

unable to achieve the desired 24.6g RMS due to vibration table limitations. The LDFU and ETS used for this flight are identical to the ones used for the Pegasus® flight. This additional qualification test was performed at WFF.

The LID's used for this mission were fabricated in the same lot as the LIDs for the Pegasus® mission. This testing comprised helium leak, x-ray, n-ray, random vibration, thermal cycle, and hot, cold, and ambient function[3].

No additional testing was performed on the balance of the ordnance hardware since this hardware has been previously qualified on other launch vehicle programs to levels far exceeding the levels of the Nike-Orion.

Ground Test. All ordnance interfaces except the TBI to motor ignitor interface had been previously qualified. The TBI's have extensive qualification and flight pedigree with pyrogen ignitors. The Nike motor, however, uses a black powder ignitor, and the Orion ignitor has a pyrogen ignitor of an older design. To validate these interfaces, an integrated ground test program was performed. The first test was for the ignition of a Nike ignitor which had been mounted into an empty motor case to validate the TBI to Nike ignitor performance. The second test sequence first ignited the Orion pyrogen mounted in an empty Orion motor case and then ignited the destruct charge mounted onto an empty Orion motor dome. The second test verified the TBI to Orion ignitor interface and the ability of the destruct charge to cut the motor case in the flight configuration. The test configuration is presented in figure 11.

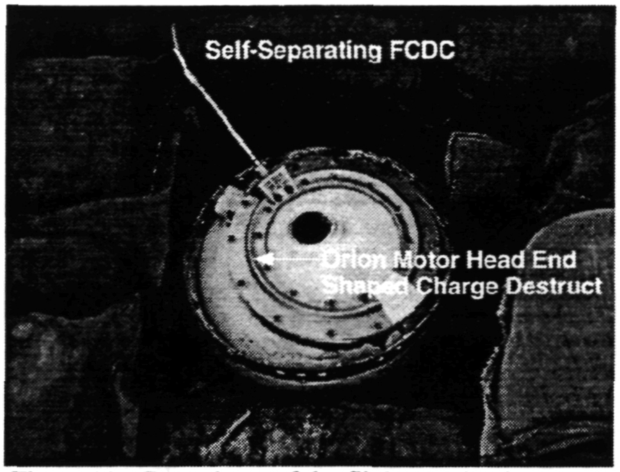

Figure 11. Ground test of the flight termination system for the Orion motor.

The test included a check of the self-separating FCDC which can be observed in the upper left corner of figure 11. Each test was configured as closely as possible to the flight configuration, the only difference being the use of longer detonating cord to reach the ignitors and destruct charge.

Based on the results of a potential failure analysis, it was decided to perform this test with active telemetry and with the stage 2 payload section suspended to simulate flight conditions. Since the system utilized a single string system, a failure in flight downstream of the LID could potentially be attributed to the LID, ETS, or LDFU. The purpose of the active telemetry for the ground test was to determine the signature of the three axis accelerometer for detecting the initiation of the LID, thereby providing a positive indication of LID initiation.

Test Program Results

Procedures. To ensure a quality program, formal written procedures were created for fabrication of the components into a system. These procedure incorporated all the checks and testing to be performed during the build-up of the vehicle. This same procedure was used during the ground test to provide a prelaunch dry-run of the flight launch procedures.

Component Test Results. Only one minor problem was encountered during the component testing. During the LDFU acceptance vibration testing, a tented solder joint broke causing a malfunction of the LDFU. This was repaired, and the test series was successfully completed.

Ground Test Results. The ground test was performed approximately one month prior to launch. This was a very useful test since it was performed on the same pad, using the same cables, interface boxes, and procedures to be used for the launch.

During system build, optical pulse catchers were used to perform a stray light test, which is equivalent to a stray voltage test, and to measure the laser power and pulse width output of each channel of the LDFU. This was the same procedure to be used for the launch. The ambient temperature was 26°F at test time which worked in our favor since it was desirable to test the TBI to ignitor interfaces at a temperature colder than that expected on launch day!

The Nike ignitor was successfully initiated by the stage 1 LDFU from the blockhouse firing command. That was followed by the stage 2 test during which the LIO successfully ignited the Orion motor's pyrogen, followed by the timer-initiated destruct charge which successfully and cleanly cut the motor head end cap as intended. The result of the testing can be viewed in figure 12.

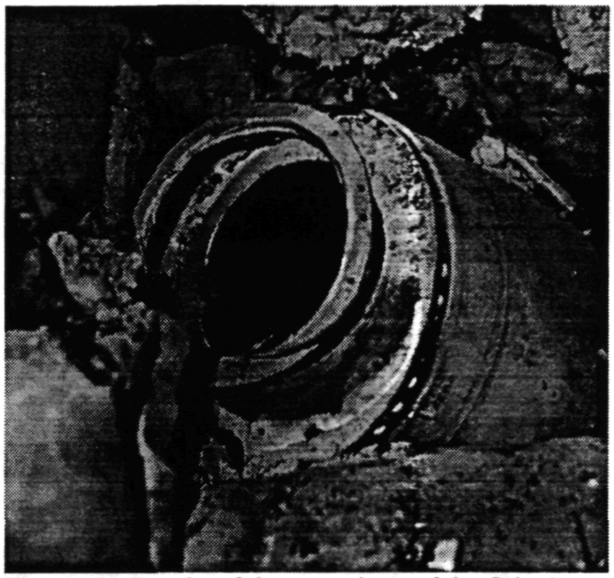

Figure 12. Results of the ground test of the Orion's flight termination system.

5.0 PROGRAM SAFETY

Safety played a major part of this program. The system was designed to meet man safety standards. Further, ground safety was extremely important. Safety personnel made program inputs commencing with the design of the system, the results of which are shown on the current system schematic.

To support the design, a series of analyses were performed including a system hazard analysis and justification for the use of hot batteries. Further, the Failure Modes, Effects, and Criticality Analysis and Sneak Circuit Analysis, performed respectively by Sandia National Laboratories and The Aerospace Corporation as part of the Pegasus® program, were also applied to this system since the LDFU, ETS, and LID are identical. In support of mission success, a potential failure analysis was performed by EBCo to identify if the system, as designed, was capable of isolating any failure to a particular component. This analysis resulted in modifications of the telemetry points and the inclusion of live telemetry during the system ground test. Then, in addition, the range safety staff performed their own independent analyses.

One of the results of the various safety reviews was the addition of the safe and arm plug. The WFF range safety staff had requested that a physical, visible means be provided to assure that power was not being applied unintentionally to the ordnance system. The program's response was to add the safing plug which physically maintains an open circuit and which can be simply viewed by ground works crews. See figure 13 for a view of the installation.

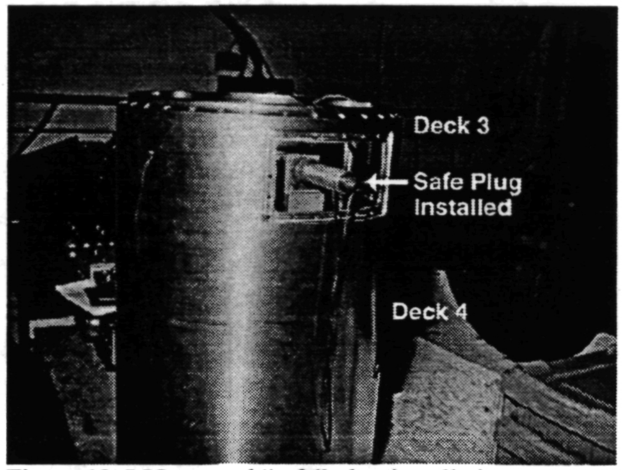

Figure 13. LIO ground "safe" plug installation.

6.0 PRE-FLIGHT ACTIVITIES

Ordnance Installation, Launch Vehicle Assembly, and Pad Checkout

One week prior to launch, the destruct charge was bonded to the head end cap of the Orion motor. Once that bond had cured, the fins were attached to the Orion motor and aligned.

The Nike was mounted on the launcher on March 10, 1995. With the Nike motor on the launch rail, the Nike TBI and ordnance lines were installed. The payload was changed at T-2 days to reprogram the revised vehicle flight termination time at the request of the range in order to assure break-up of the payload. Two days prior to launch, the Orion motor's TBI was installed; the payload was mated to the Orion motor; and the ordnance lines were connected from the manifolds to the Orion TBI and destruct charge. The first stage laser firing controls were mounted to the back side of the launcher where the equipment would be protected from the launch environment (figure 14).

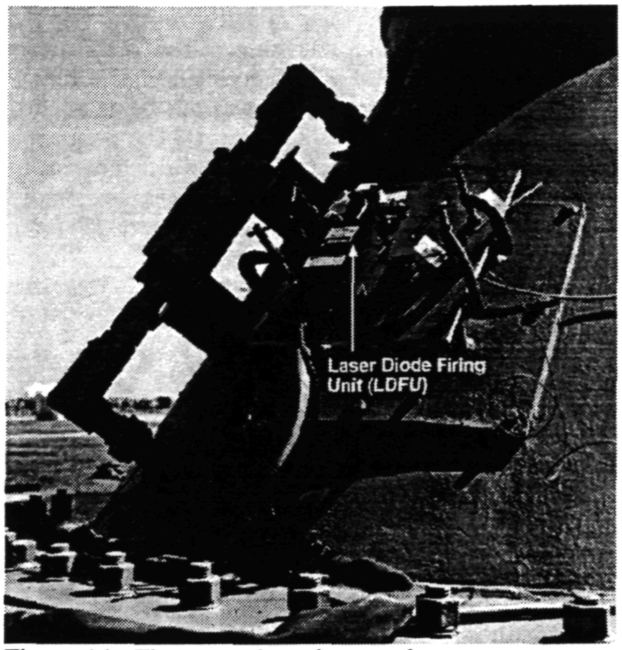

Figure 14. First stage launch controls.

After the Orion motor and payload were mated to the Nike, a final check of the stage 1 and stage 2 LDFUs was performed with each channel fired into a laser pulse catcher and the laser power and pulse width measured. Following completion of this test, the detonators were installed but left optically disconnected from the Energy Transfer System (ETS).

Since the LID's are immune from EMI, RF silence was not required for the installation of the detonators. In fact, telemetry was operating as well as the facility radars during the Orion ignitor and shaped charge ordnance installations.

Dry-run Countdown

At T-1 day, a series of dry run countdowns were performed. The dry run was performed in the horizontal position and another after the launcher had been raised into launch position. During these dry runs the LDFUs were powered on and armed but not fired. Launch abort procedures were also performed. Also, on T-1 day a range safety review was held. A "GO" for launch was given.

Final Countdown

The final countdown started four hours prior to launch and began with the final connection of the LID to the ETS. During this installation, the pulse catchers were used to verify the absence of stray light similar to a stray voltage test performed prior to connecting hot bridgewire devices. RF silence was not required for the stage 2 connections. However, due to uncontrolled shielding of the ground command signals to the stage 1 LDFU, RF silence was imposed for the stage 1 LID connection.

The launch was planned for 1:00 pm to allow for good lighting coverage. A launch hold from that target was necessary to allow clearing of a very localized fog, as good camera coverage was a launch constraint. Ultimately, the weather improved. Power was applied to stage 1 and stage 2 LDFUs at approximately T-2.5 minutes. The LDFU's were armed at T-1.5 minutes.

7.0 FLIGHT RESULTS

Flight Performance: On March 15, 1995, 3:20 pm EST, the first stage was ignited by the Stage 1 LDFU. The LDFU was commanded to fire by the WFF Pad 2 booster firing circuit fire command which started the pyro chain to fire the TBI. The initial command was given by the Wallops programmer. With that chain of events, we thereby successfully ignited the stage 1 Nike motor, the first flight application of solid state laser diode flight event sequencing, Figure 15.

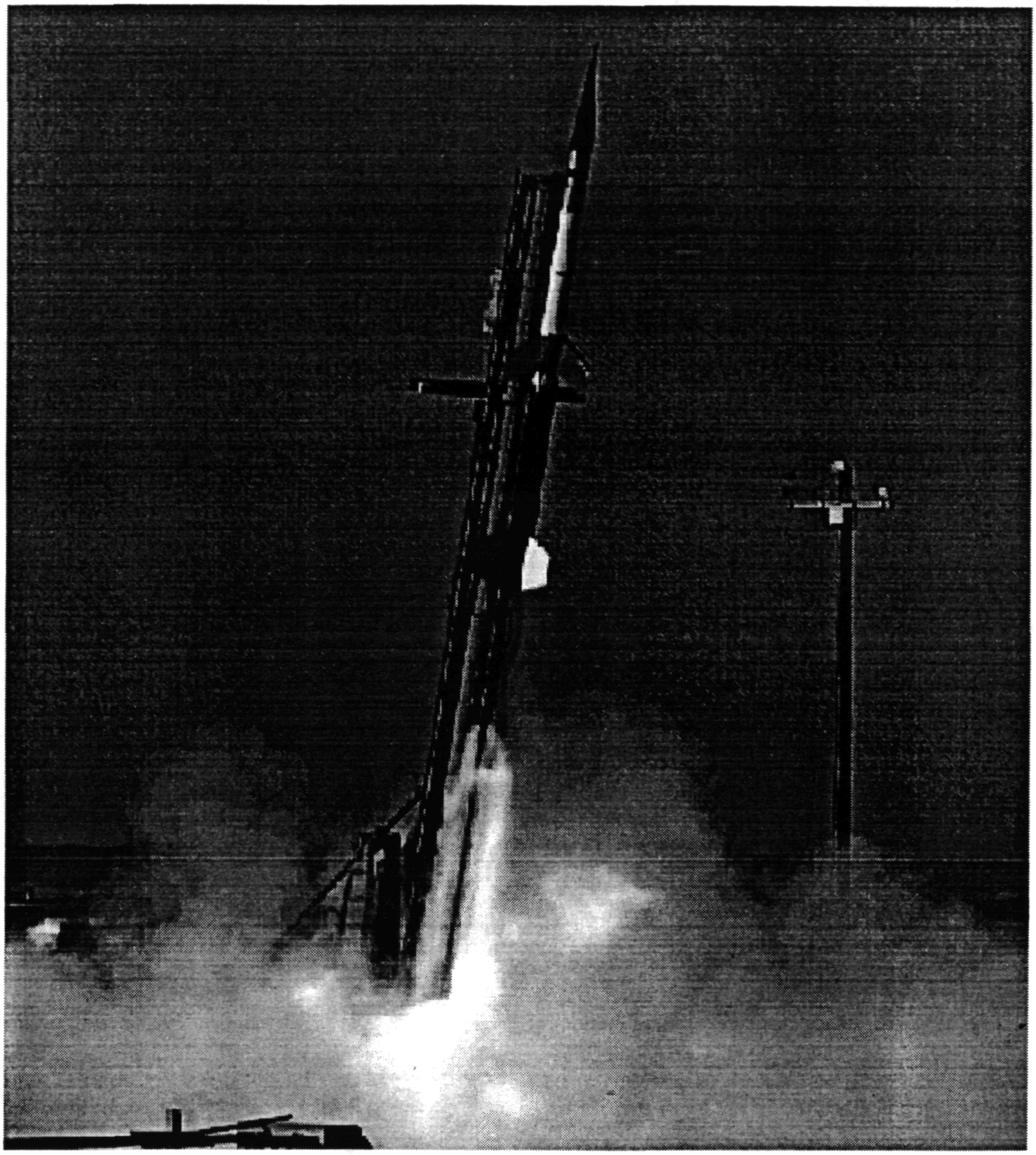

Figure 15. Nike, first stage, LIO ignition, 70 mm pad camera.

The Nike-Orion successfully cleared the launcher accelerating at approximately 25 g's. Nike burnout occurred at approximately T+3.5 seconds followed by successful ignition of the Orion motor at T+8.0 seconds by the second stage fire command which came from channel one of the flight LDFU signal, supplied by the WFF Multifunction Timer, figure 16.

The second channel of the flight LDFU then fired the destruct charge successfully at T+11.7 seconds (similarly multifunction timer initiated). The result was a benign shutdown of motor thrust which was achieved by venting the 1070 psi chamber pressure through the Orion motor's head end cap. The

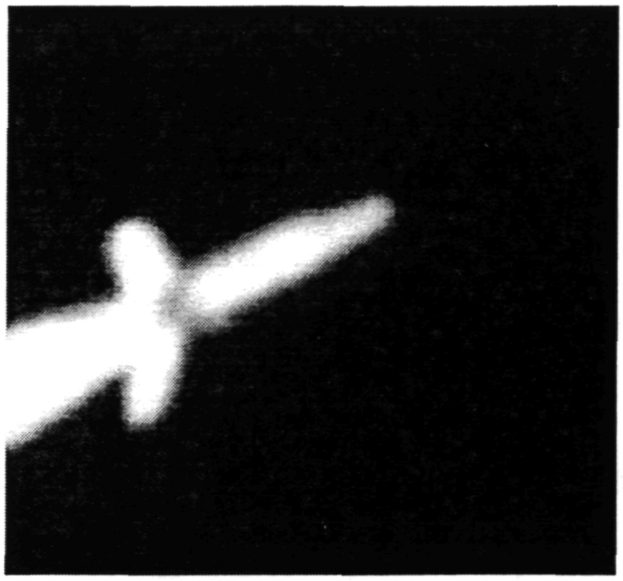

Figure 16. Orion, second stage, ignition, 80 inch lens, 16 mm camera, 128 frames/second.

flight termination sequence is presented in figures 17 and 18.

Figure 17 shows the last frame of the vehicle taken by a

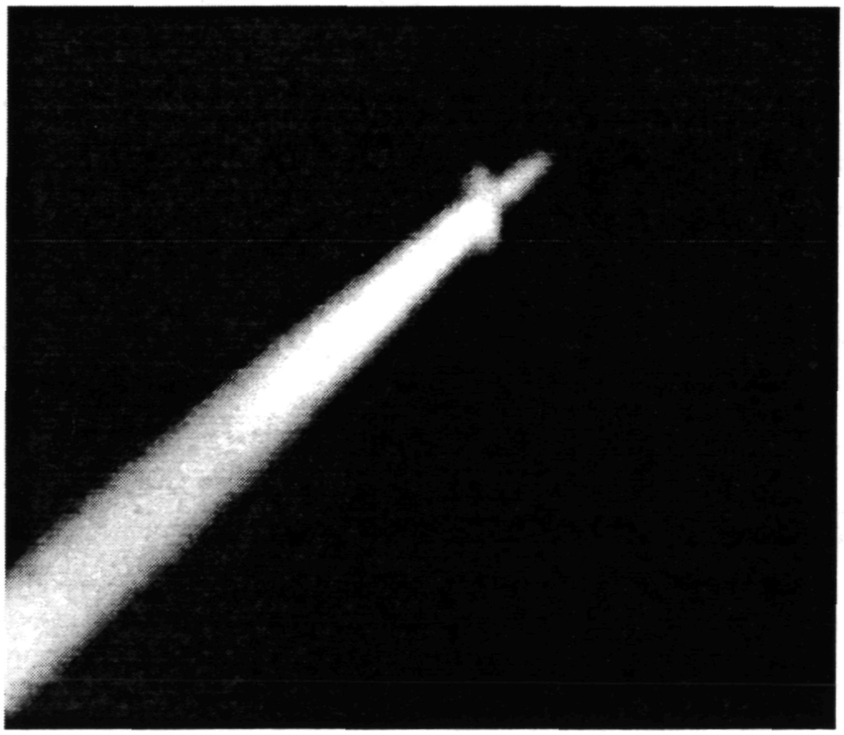

Figure 17. Orion motor thrusting immediately before flight termination.

16 mm camera before the flight termination event. The camera operated at 128 frames per second showing the progression of the termination event in less than less than 0.0078 second after application of the termination signal.

After activation of the FTS, we lost track of the payload but continued to observe and track the Orion which went up another 10,700 feet.

Figure 18. Flight termination event (0.0078 seconds after figure 17).

All flight events occurred as planned, table 7, a table of predicted and actual flight environments. Note that the predicted values for the stage 2 ignition and termination transients are based upon the ground test data. Also, the values shown are only those to first peak, and one should be made aware that the maximum values are considerably higher. Further, the transients above the nominal are shown, that is, we note particularly that the actual values in flight for stage two termination were the levels above/below 14 g's.

Table 7. Flight predictions versus actual.

EVENT	PRE-FLIGHT	FLIGHT
Stage 1 ignition, seconds	T = 0	T = 0
Longitudinal Acceleration, g's:		
Stage 1 (max)	22.3	24.5
Stage 2 (max)	20.0	16.2
Stage 1 burn out, seconds	T= 3.5	T = 3.4
Stage 2 ignition time, seconds	T = 8.0	T = 8.0
Stage 2 ignition acceleration transients, 1st peak, g's:		
Z axis	+0.4 to -0.2	+3 to -2.5
Y axis	+0.2 to -0.3	+1.7 to -2.6
X axis	+0.2 to -0.1	+0.9 to -1.7
Stage 2 termination time, seconds	T = 11.5	T= 11.6
Stage 2 termination accelerations, 1st peak, g's:		
Z axis	+1 to -0.7	+5 to -5
X axis	+1.1 to -1.5	+2.5 to -1.8
Y axis	+3.1 to -2.6	+2.8 to -3.6

Thrust termination dynamics from the Orion Z-axis acceleration profile can be observed in figure 19.

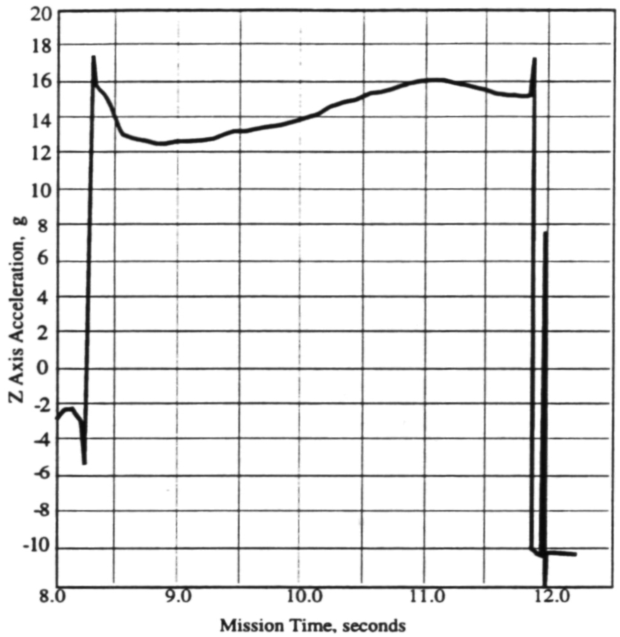

Figure 19. Flight dynamics of the Orion, Z-axis, g's acceleration.

During the activation of the shaped charge, the system was exposed to a very severe operational environment for this mission. The thrust termination duration was approximately 0.028 seconds. Refer to figure 20 which shows the results of the longitudinal (Z-axis) accelerometer data during this phase of the mission.

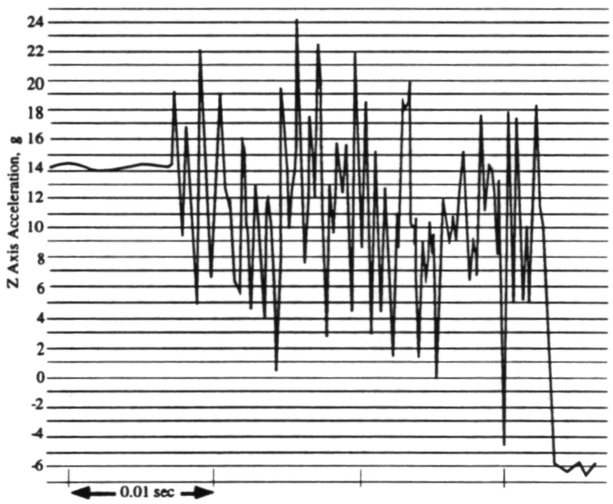

Figure 20. Flight termination dynamics, Z-axis, g's acceleration.

The flight dynamics of the vehicle was well within preflight predications. The range-altitude track is shown in figure 21 commencing with radar skin tracking data. Launch parameters had been selected with mission objectives in mind, as well as range safety, time of launch winds, and coverage by the radar and cameras. These all converged well for the flight. For example, it was not completely clear prelaunch that the radar which would have a good skin track in sufficient time to acquire a good signal before mission termination. The launch time change from 12.5 seconds to 11.5 worked negatively too, unfortunately. But the results were good as shown by figure 21.

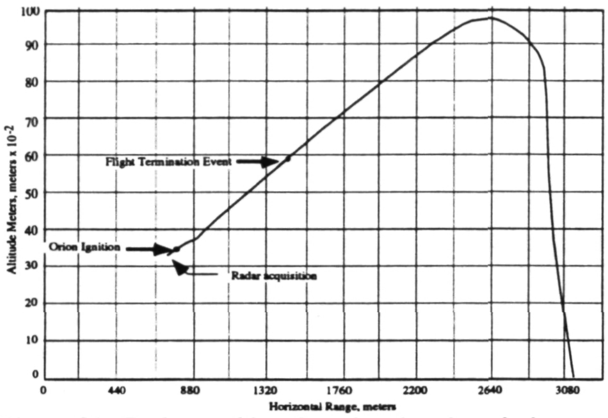

Figure 21. Radar tracking data showing the mission flight profile of altitude versus range.

Details of the motor termination are to be the subject of another report since this is intended to discuss the laser initiated ordnance technology aspects. It was interesting to note that the telemetry continued to function, at least in part, until water impact. The latter event occurred 94 seconds after launch.

8.0 LOSRD HARDWARE DATA BASE

One of the conditions of the NASA cooperative agreement is to conduct cooperative work for the benefit of industry. As part of the agreement we provide the start of a LIO data base. Thus, a summary of the hardware manufactured or procured for this program and its use is shown in Table 8.

Table 8. Hardware Manufactured for the LIOSVP Program.

PART	QTY. MFG.	USE
Laser Diode Firing Unit	2	1 - Stage 1 ignition* 1 - Flight unit
Energy Transfer System	2	1 - Stage 1 ignition* 1 - Flight unit
Laser Initiated Detonator	13	3 - Ground test units 3 - Flight units 7 - Spare units
Manifold	11	3 - Transfer verification test units 3 - Ground test units 3 - Flight units 2 - Spare units
Flexible Confined Detonating Cord Assembly	14	6 - Manifold transfer verification test units† 2 - Ground test units 2 - Flight units 2 - Lot acceptance test units 2 - Spare units
Self Separating Flexible Confined Detonating Cord Assembly	4	1 - Ground test unit 1 - Flight unit 1 - Lot acceptance test unit 1 - Spare
Ordnance Transmission Assembly	3†	1 - Ground test unit 1 - Flight unit 1 - Spare
Through Bulkhead Initiator	5†	2 - Ground test units 2 - Flight units 1 - Spare
Flexible Confined Detonating Cord Assembly Coupler	2†	1 - Ground test unit 1 - Flight unit
Ordnance Checkout Control Equipment	1	1 - Used to checkout readiness of system for flight and for ground test.
Destruct Charge	2	1 - Ground test unit 1 - Flight unit
Pulse catcher	2*	2 - ground test equipment

* Also used on Pegasus®

† These items were obtained from EBCo stock and not specifically manufactured for this program.

9.0 SUMMARY

A new technology capability has been demonstrated by NASA under the LOSRD Program to help make LIO technology available to industry. NASA, working cooperatively with The Ensign-Bickford Company via its first *Cooperative Agreement with Profit Making Organizations* and using the Nike-Orion sounding rocket as a demonstration test bed, has developed, built, and qualified a LIO ordnance system to meet 2 different demanding program applications, namely, solid rocket motor ignition and solid rocket motor flight termination. A high risk, non-redundant design approach, implemented via a quick turn around program was successfully accomplished. The program validated flight and ground operational procedures for using LIO, thereby removing the major impediment for the flight application of LIO. All program safety objectives were fully accomplished. Safety of an all solid state safe and arm, without physical barriers installed in the fiber optic line, has been proven with ordnance installation occurring in an active RF environment. The Sounding Rocket Program at the Wallops Flight Facility has, once again, proven itself to be a worthy instrument for providing new technology demonstrations in flight on a quick turn-around basis at very low cost. The new NASA *Cooperative Agreement with Profit Making Organizations* has been proven as an excellent instrument to accomplish technology demonstrations. These important technology flight demonstrations, as managed herein, can be very inexpensive and serve a very useful applied technology role in which researched hardware is taken to the operational state of readiness.

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[1] NASA Wallops Sounding Rocket User's Handbook, September 1988, Section 7.

[2] *Laser Ordnance System for NRL's ARTS Program*, B. Purdy, M. Fratta, C. Boucher, AIAA 93-2361

[3] *Flight Demonstration of Laser Diode Initiated Ordnance*, C. Boucher, N. Schulze, AIAA 95-2982

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13. ABSTRACT ***(Maximum 200 words)***
Solid State Laser Initiated Ordnance (LIO) offers new technology having potential for enhanced safety, reduced costs, and improved operational efficiency. Concerns over the absence of programmatic applications of the technology, which has prevented acceptance by flight programs, should be abated since LIO has now been operationally implemented by the *Laser Initiated Ordnance Sounding Rocket Demonstration (LOSRD) Program*. The first launch of solid state laser diode LIO at the NASA Wallops Flight Facility (WFF) occurred on March 15, 1995 with all mission objectives accomplished. This project, Phase 3 of a series of three NASA Headquarters LIO demonstration initiatives, accomplished its objective by the flight of a dedicated, all-LIO sounding rocket mission using a two-stage Nike-Orion launch vehicle. LIO flight hardware, made by The Ensign-Bickford Company under NASA's first *Cooperative Agreement with Profit Making Organizations*, safely initiated three demanding pyrotechnic sequence events, namely, solid rocket motor ignition from the ground and in flight, and flight termination, i.e., as a Flight Termination System (FTS). A flight LIO system was designed, built, tested, and flown to support the objectives of quickly and inexpensively putting LIO through ground and flight operational paces. The hardware was fully qualified for this mission, including component testing as well as a full-scale system test. The launch accomplished all mission objectives in less than 11 months from proposal receipt. This paper concentrates on accomplishments of the ordnance aspects of the program and on the program's implementation and results.
While this program does not generically qualify LIO for all applications, it demonstrated the safety, technical, and operational feasibility of those two most demanding applications, using an all solid state safe and arm system in critical flight applications.

14. SUBJECT TERMS
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