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N93-20138

Small ICBM Laser Firing Unit (LFU)

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HISTORY/SCHEDULE

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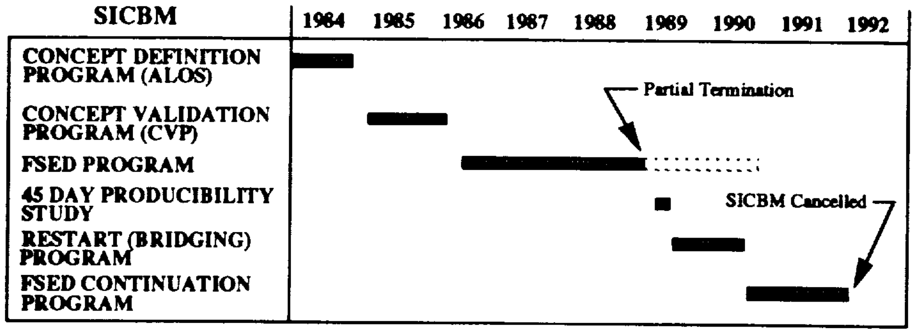

- FLIGHTWEIGHT DEMONSTRATION MAY 1986
  COMPLETE ENVIRONMENTAL EVALUATION TEST SERIES
- FIRST FLIGHT TEST MAY 1989
- SECOND FLIGHT TEST APR 1991

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Teamed with Hercules Inc. of Magna, Utah, SBRC was responsible for the design concept, design, development, qualification and testing of the Laser Firing Unit for Small ICBM. In 1984 the team members shared the cost of building an Advance Laser Ordnance System (ALOS) and demonstrating the concept to the Air Force in preparation for the Air Force funded Concept Validation Program. ALOS was a brassboard laser firing unit made up primarily of M1 tank laser rangefinder parts and a new 24 event optical sequencer. Also demonstrated were the optical fibers and laser initiated detonators.

The Concept Validation Program (CVP) was a competition between the laser system offered by the SBRC / Hercules team and an exploding bridgewire system promoted by others. The CVP program resulted in an eighteen event flightweight laser firing unit, fiber optic cables and laser initiated detonators that successfully completed series of simulated flight environmental tests.

The laser system was selected for full scale engineering development in July 1986. Deliveries of missile test support hardware including mass simulators and developmental firing unit models were required within the first 8 months of the program. Later in 1987 and 1988 ten engineering units were built, tested and delivered to support program milestones. By 1989 seven flight units had been manufactured and delivered and the first missile was launch in May 1989 using the system. Although the missile had other problems the laser ordnance system operated successfully under very abnormally severe conditions. In April 1989 word came that the program was partially terminated for the convenience of the government. A total of 19 operating units were built before the program ended. Later in 1989, anticipating the restart of the program a producibility study was funded by the Air Force to improve the flow through the factory. This 45 day study resulted in about 150 changes to the design to improve producibility.

By October of 1989 the Air Force kicked off a bridging contract to implement the design improvements into the engineering documentation in preparation for a full restart in October 1990. The following year the continuation program for full scale development was started. A new engineering model was built and tested through all required environments successful. Production of another 13 flight units had begun when the President announced that SICBM would be cancelled as part of recent defense cuts.

LFU DEVELOPMENT HARDWARE

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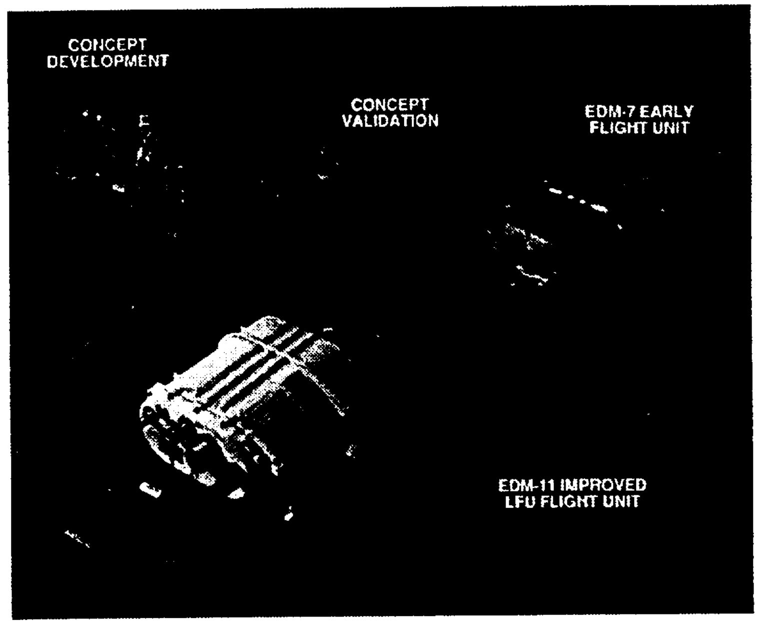

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Pictured is the Small ICBM Laser firing unit hardware in various stages of development. Also shown is the location of the firing unit in the SICBM. It is located in the post boost vehicle (PBV) and has a fiber optic cable harness which extends down an internal raceway to the various ordnance locations along the missile.

SPECIFICATIONS /FEATURES

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NUCLEAR HARDNESS AND SURVIVABLILTY

ENVIRONMENT	OPERATING	NON-OPERATING
TEMPERATURE (°F)	45 TO 110	-37 TO 140
ACCELERATION	15 g	4 g
VIBRATION	18.7 g RMS	3.2 g RMS

MISSION RELIABILTY

>.999 REQUIRED >.99997 ACTUAL

BUILT IN TEST (BIT)

CONTINUITY OF OPTICAL PATH FROM LASER TO INITIATOR

TEST FIRE THE ORDNANCE LASER

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The LFU was required to function during and after exposure to a nuclear environment. The system was tested to the temperature, acceleration vibration and shock environments shown in a series of evaluation and flight proof tests. Mission reliability was specified to be greater than .999 and was calculated to be greater than .99997. The calculation included a monthly built in test operation that verified proper output of the ordnance laser and continuity from the laser to each initiator.

SPECIFICATIONS /FEATURES (CONT'D)

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SEQUENCED OPERATION	11 SEQUENCIAL EVENTS (ORDER OF EVENTS FIXED)
SIZE	10" X 12" X 5" (APPROXIMATELY)
WEIGHT	30 LBS
SIMULTANEOUS INITIATIONS	2 (ELIMINATED IN LATER DESIGN)
MARGIN ABOVE ALL-FIRE	> 30X SINGLE EVENTS > 15X DUAL EVENTS

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The LFU has 11 operational events that occurred in a known order and with a separation in time of no less than 1 second. Size and weight are as shown. There were 2 simultaneous inititations for some events. Simultaneity was accomplished using a single beamsplitter placed in the converging beam just in front of the optical fiber. All flight tests were conducted using this optical splitting approach. The optical splitting was later dropped during the producibility study.

Margin above all-fire level is approximately 30 times under best case conditons (no nuclear event) for a single event and 15 times for the deleted dual events. During a nuclear event margin drops significantly.

SPECIFICATIONS /FEATURES (CONT'D)

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EVENTS PERFORMED

STAGE SEPARATION	LAUNCH EJECT
VALVE ACTUATION	FLIGHT BATTERY
MOTOR IGNITION	CABLE CUTTER

REDUNDANCY

- EACH EVENT - 2 INITIATORS, 2 FIBER OPTIC LINES, 2 LASERS, 1 LFU

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The LFU performed all operational functions of the missile except release and initiation of the warhead. A single LFU has two redundant sides which resulted in a single initiation event being actuated by 2 discrete lasers firing down 2 discrete optical fibers to 2 discrete initiators.

COMPONENTS

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ORDNANCE LASER	FLASHLAMP-PUMPED Nd:GSGG
	400 MILLIJOULES
	180 MICROSECONDS
FIBER	400 MICRON POLYMER-CLAD GLASS
SEQUENCER	STEPPING SOLENOID ACTUATED RHOMBOID PRISM
INITIATOR	WAVELENGTH SENSITIVE COATED WINDOW
	SINGLE FIBER PIGTAIL
	CP
	10 MILLIJOULE ALL-FIRE
BIT SOURCE	LASER DIODE

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The ordnance laser is a flashlamp pumped Neodymium doped Gadolinium Scandium Gallium Garnet crystal (Nd:GSGG) rod laser. It is a derivative of the M1 laser rangefinder laser which was also designed and built by Hughes. GSGG was chosen over a less expensive material such as Yttrium Aluminum Garnet (YAG) due mainly to nuclear hardness requirements. The laser operated about 400 millijoules in a 180 microsecond pulse. This is just over 2 kilowatts.

The fiber used was a 400 micron core polymer clad glass fiber. The sequencing mechanism was a stepping solenoid actuated rhomboid sequencer. The rhomboid was used because of its unique properties as an alignment tool. It displaces a collimated beam in translation only while retaining the input angle. An in depth discussion of this property was made at the workshop at Aerospace corporation in October 1990. Copies of the materials presented can be obtained from the author (J.Aloise).

The detonator was packed with CP and had a 10 millijoule all-fire level as determined by Bruceton testing. The interface was a fiber optic pigtail attached to a window with a wavelength sensitive coating.

OPTICAL LAYOUT-ARM

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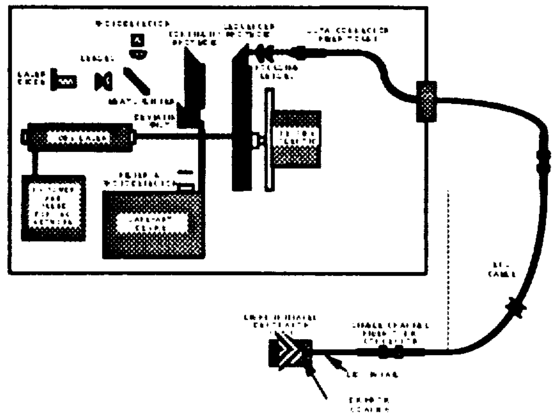

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The light from the ordnance laser enters the input facet of the sequencing rhombold and after traversing the two internal facets, it exits at the same angle it entered. The beam is brought to focus by a lens whose focal plane is just beyond the fiber face. Placing the fiber slightly displaced from the focal plane reduces the energy density at the fiber face which reduces damage.

The light travels down the optical fiber to the initiator and travels uninhibited into the pyrotechnic material igniting it. The rhombold sequencer is stepped to the next location and the laser is fired again at the appropriate moment in the timeline.

OPTICAL LAYOUT-SAFE

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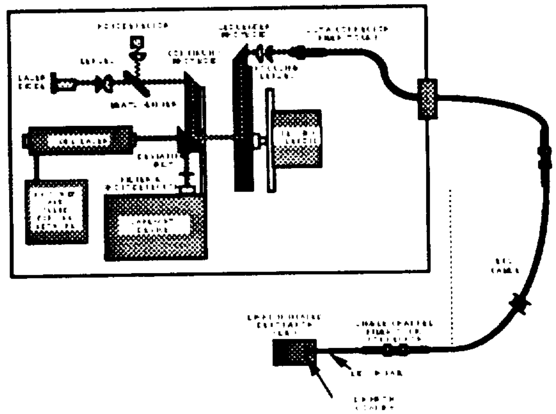

Prior to launch and once a month the system is tested internally. There are two parts to this operation. First, the ordnance laser is safely test fired by blocking its path to the initiator and firing it through an optical filter into a detector. The filter is used to reduce the energy seen by the detector. The beam is interupted by using a prism that deflects it 90 degrees.

At the same time the deviating prism is inserted into the optical path, a second rhombold (as opposed to the one used for sequencing) is inserted. It is used to fold the optical path of the continuity test laser source into the main path to the initiators. Light from a laser diode is collimated and directed through a beamsplitter, the BIT rhombold and the sequencing rhombold. As in the case of the ordnance laser, the light then travels down the fiber to the initiator but is now reflected by the wavelength sensitive coating. The returned energy retraces the entire path and upon reflection off the beamsplitter near the source, is collected by a detector and its level compared to a preset threshold that determines the integrity of the optical path.

BUILT IN TEST

CONTINUITY TEST

- SIMPLER THAN NARROW PULSE
- RETURNED ENERGY FROM ALL REFLECTIONS INTEGRATED
- THRESHOLD DEPENDENT UPON NUMBER OF CONNECTORS AND OTHER OPTICAL ELEMENTS
- INCREASING NUMBER OF CONNECTORS INCREASES PROBABILITY OF INCORRECT CINTINUITY EVALUATION
- VARIATIONS DUE TO MANUFACTURING TOLERANCES AS WELL AS CHANGES OVER LIFETIME MUST BE CONSIDERED

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The continuity test uses a fairly short (approximately 20 nanoseconds) but not ultra-short laser pulse. A very short pulse could be used to detect individual surface reflections and the return from the initiator window. This optical time domain reflectometry-type operation is less susceptible to variations in number of connectors and other effects that get buried in the return with a longer pulse.

The longer pulse system is a bit simpler however. The integrated energy from all reflections is compared to a preset threshold for a go - no go decision. The optimum threshold is dependent on many factors including number of connectors and optical elements as well as circuit characteristics and mechanical tolerances. The most significant effect is adding a connector to the path. When analyzing the optimum threshold for good vs. bad fiber it is important to go beyond a simple analysis using nominal values. Also, variations due to degredation and drift over time and temperature must be considered.

BUILT IN TEST (CONT'D)

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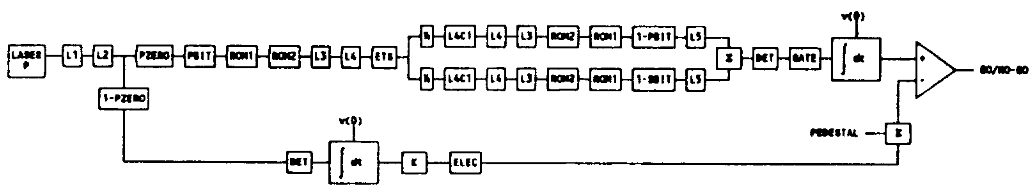

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Shown is one of the analytical models used to determine probabilities of rejecting a good fiber as bad or declaring a bad fiber good. Optical elements and phenomenon (vignetting, for example), electronics stability, etc. were each given nominal values and some tolerance. The tolerances were uniform, gaussian, beta, and zero distributions around nominal as appropriate. Such models were used to produce histograms as seen on the following slide.

Some abreviations: lenses (L), Energy Transfer Lines (ETS), Rhombold (ROM) and vignetting (C1).

BUILT IN TEST (CONT'D)

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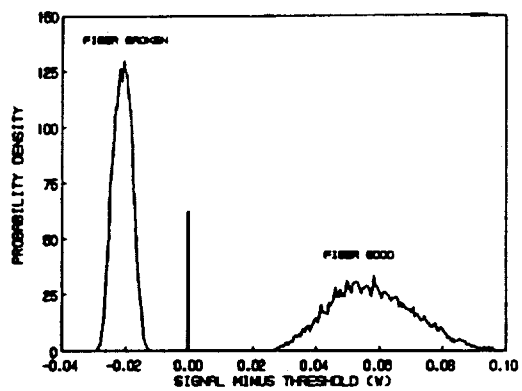

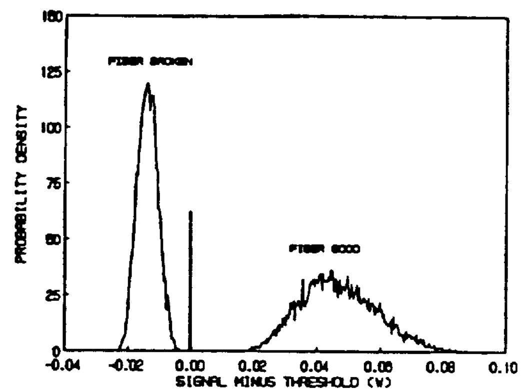

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The histograms show the probablity density functions of the signal produced by a good fiber versus a bad fiber. The numbers are represented by a relative factor in that the difference between actual signal and threshold are plotted. The graphs show several phenomena. First, it can be seen that the relative width of the bad fiber density function is much smaller than that for a good fiber. This means that the optimum location for threshold in terms of simultaneously reducing the probability of judging a good fiber as bad or a bad fiber as good is somewhere other than the center of the peaks of the two curves. Second, it can be seen that the adding of an additional connector to an otherwise unchanged optical system moves the probability density functions closer requiring a new optimal threshold setting. Adding additional connectors moves the functions closer and closer until the overlap is unacceptable.

The graphs were obtained using a Monte Carlo analysis of the appropriate parameters of mechanical, optical and electronic elements. Each parameter was defined to have a nominal value with some allowable variation due to manufacturing tolerances, degradation and drift with time. The LFU was required to function for up to 15 years.

PRODUCIBILITY ISSUES

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45 DAY PRODUCIBILITY STUDY

- NO MAJOR DESIGN CHANGES RECOMMENDED
- MANY MINOR CHANGES SUGGESTED
- EXAMPLE
  - BEAMSPLITTER REQUIREMENTS
  - EXOTIC LIGHTWEIGHT MATERIALS
  - STANDARDIZE COMPONENTS
  - CAST VS MACHINE STRUCTURES
  - HANDLING FIXTURES
- EFFECT
  - APPROXIMATELY 3 % INCREASE IN WEIGHT
  - APPROXIMATELY 20 % SAVINGS ON RECURRING COSTS

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During the 45 day study in 1989 many aspects of the LFU were examined in the context of improving producibity. No major design changes were recommended. Many minor changes such as accesibility to certain locations or material changeouts were recommended. An example follows related to the ability of manufacturers to meet tolerances and schedules.

The use of an optical splitter to achive simultaneous intitiations was dropped due to qualified suppliers inability to meet a high enough production rate with the tight tolerances specified. The beamsplitters had reflectance requirements that were related to both wavelength and polarization. Although it was not necessary to determine which of the two paths were bad (only if one or both were), it was necessary to isolate the return signal from one versus the return signal from the other. This was accomplished by using BIT lasers with orthogonal polariztions. The beamsplitter would send one polarization down one path and the other polarization down the other path. The result was a beamsplitter that was 50 % reflective and not polarization sensitive at 1.06 microns and highly reflective in one polarization and highly transmissive in the other at .85 microns. In addition the coating is required to meet a high laser damage threshold. The resulting beamsplitter design was sensitive to moisture, requiring special handling during unit assembly and supplier yields were less than 30%.

Incorporating the suggested changes resulted in a 3% increase in weight and a 20% reduction in cost.

PRODUCIBILITY ISSUES
(cont'd)

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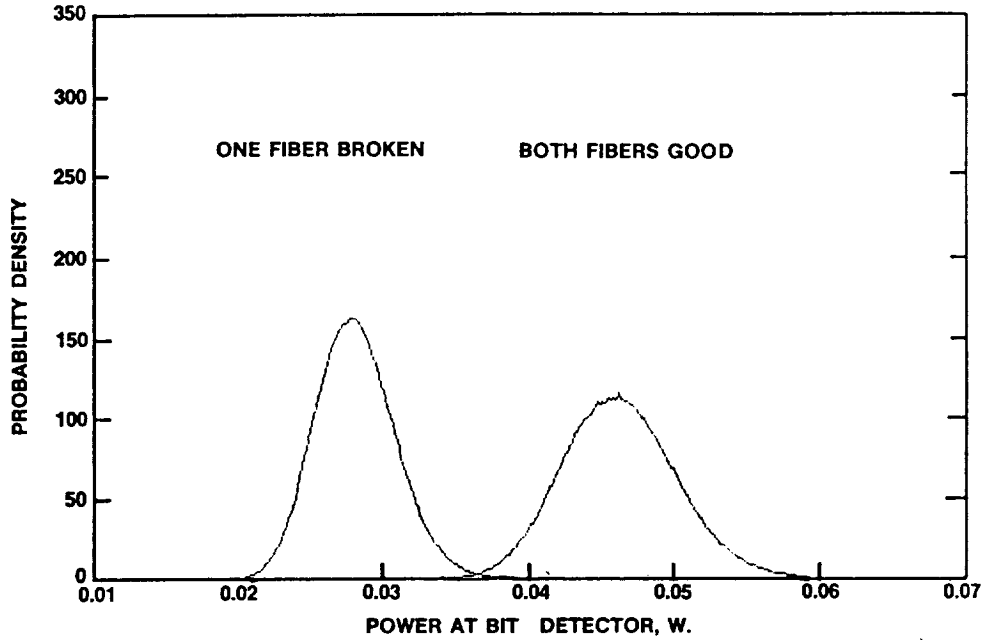

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The graph shows the type of results that occurred when all variables were modeled to their full tolerance distribution expectations in a dual channel path. It can be seen that a dual event path presented an unacceptably high probability of rejecting a good fiber as bad or finding a bad fiber to be good. The model included additional polarization sensitive elements such as quarter wave plates and compensators.

By simply matching continuity test hybrids to a particular beamsplitter, for example, the types of well separated distributions shown on the earlier slide can be achieved. Addressed from a producibility standpoint, the recommendation was made to eliminate optical splitting rather than proceed with matching components.