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MISSILE MANUFACTURING TECHNOLOGY CONFERENCE HELD AT
HILTON HEAD ISLAND, SOUTH CAROLINA ON
22-26 SEPTEMBER 1975. PANEL PRESENTATIONS: GUIDANCE

Army Materiel Command
Alexandria, Virginia

1975

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MGM-52C LANCE GUIDANCE SET (AN/DJW-84) MANUFACTURING TECHNOLOGY ANALYSIS

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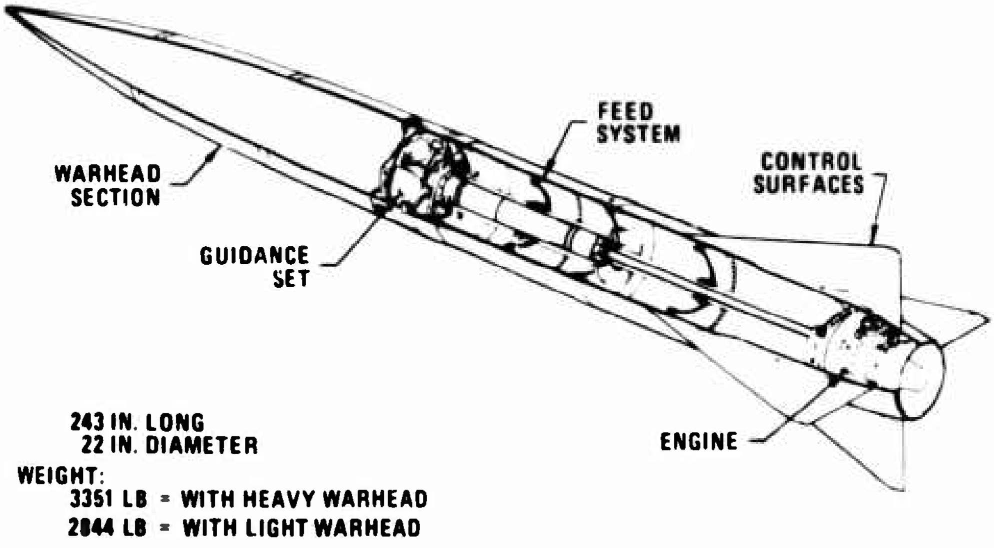
SUMMARY

Review of the LANCE guidance set does not reveal any major cost drivers and tends to indicate that no single manufacturing technology project could produce a significant reduction in cost. There are a number of projects which could reduce the guidance set cost by about 15 percent. In addition, redesign to take advantage of integrated circuit (IC) technology has the potential of increasing the cost reduction to more than 20 percent. The total cost to realize the maximum savings, not including the cost for flight requalification, is estimated to be $2.5-3M. The time for the various projects would take about two years to accomplish.

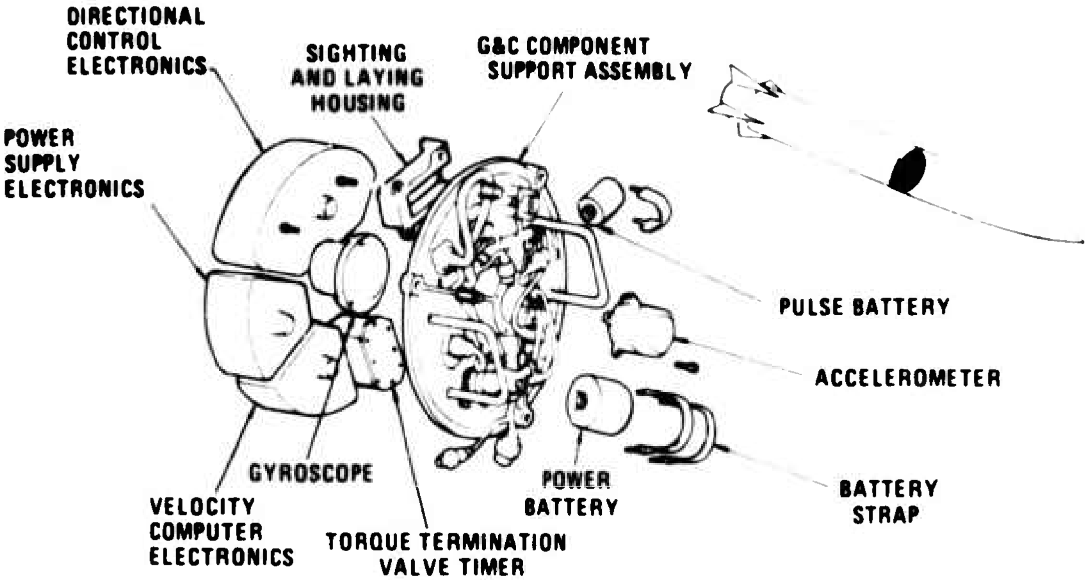
INTRODUCTION

The LANCE missile is about 20 feet long, 22 inches in diameter, and weighs 2,844 pounds when fitted with a nuclear warhead. With a non-nuclear warhead, it weighs 3,351 pounds.



The missile is made primarily of aluminum and has three major sections: warhead, M5 main assemblage, and control surfaces (fins). The main assemblage is used with either warhead, but a set of large control surfaces is required with the 469-pound nuclear warhead, and a set of small control surfaces with the 1,000-pound non-nuclear warhead. The different fin sizes compensate for the shift in missile center-of-gravity, which accompanies a change in warhead selection. Additional details on the missile structures are provided in the paper "Manufacturing Technology Analysis of Lance Missile Structures" by J.J. Ryan.

LANCE utilizes a simplified inertial guidance system that is "body-fixed" to the missile. The guidance set, located in a compartment just aft of the warhead/missile interface, weighs less than 40 pounds. It has handles for ease of handling and installation. The complete assembly is installed in the missile by three mounting surfaces which have been machined to provide the required alignment; therefore, the assembly can be replaced in the field without any special alignment.



The guidance set is made up of three subsystems: the directional control (DC) subsystem, the velocity control (VC) subsystem, and the power supply subsystem.

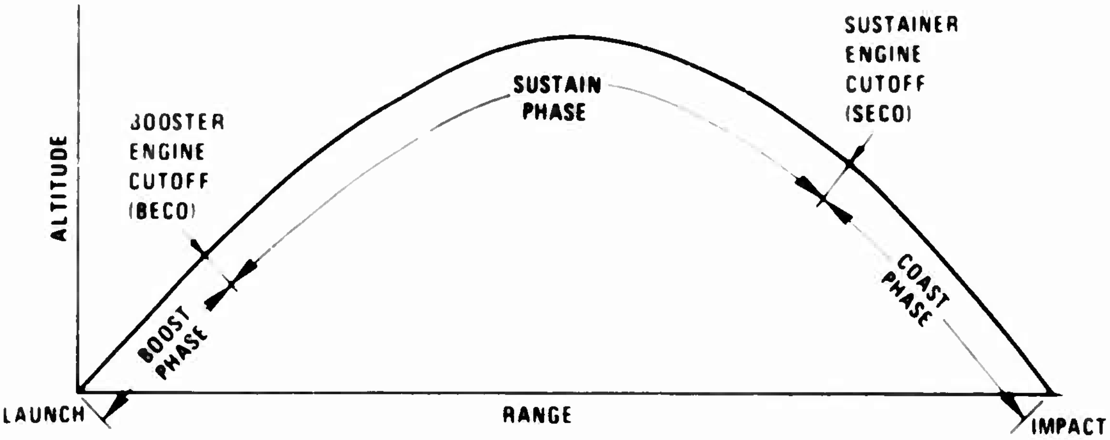
By regulating the four TVC valves, the DC subsystem maintains correct missile attitude about the pitch and yaw axis during the boost portion of flight. The major components of the subsystem are: a two-degree-of-freedom gyroscope and a directional control electronics (DCE) assembly.

The VC system, which contains an accelerometer and a velocity control electronics (VCE) assembly, measures missile velocity and shuts off the booster when engine missile velocity reaches a preset value. After boost termination, the VC subsystem maintains missile thrust equal to drag by controlling sustainer engine operation.

The missile.s operating power is provided by the power supply subsystem, which includes the power supply electronics (PSE) assembly that regulates the supply of power to the guidance components, a power battery that provides power to the PSE, and a pulse battery that provides power for firing the torque termination valve (TTV) and BTV squibs.

The guidance set also includes a timer to fire the squibs that close the torque-termination valve when the desired missile spin rate is achieved. All of the above components are interconnected by the harness.

The LANCE missile is so designed that its trajectory nearly conforms to an ideal ballistic trajectory. Its three phases of flight are:



Boost Phase

The missile is accelerated to the required velocity. The correct heading, set at launch, is maintained by proper directional control.

Sustain Phase

The missile reduces all external forces except gravity to longitudinal drag and provides the proper amount of thrust to cancel it.

Coast Phase

Sustainer engine cutoff (SECO), controlled by a timer to occur prior to propellant depletion, initiates the coast phase. The missile then acts as a free rocket.

By controlling the boost termination velocity (the velocity at the start of ballistic flight) and launching at a known QE, the range can be predetermined, provided that all external forces acting on the missile, except for gravity, can be balanced.

LANCE uses two QE's: 54 degrees for the extremely long ranges (within about ten percent of maximum) and 48 degrees for all other ranges. These high QE's permit LANCE to fly over projecting terrain, even at short ranges.

This paper describes a number of potential manufacturing technology projects which could be employed to reduce the cost of the LANCE guidance set. The assistance of Arma Division of Ambac Industries, Systron Donner Corporation, E-Systems, Inc., and Mr. Ashwani Dhir of Michigan Division, LTV Aerospace Corporation in preparation of this paper is gratefully acknowledged.

I. DETAILED COST INFORMATION

More than 1000 LANCE missiles have been produced. Based on the most recently completed production contract, the actual cost of the LANCE guidance set is distributed among its components as follows:

Gyro	26.4%	Arma
DCE	17.1%	E-Systems
Accelerometer	15.9%	Systron-Donner
VCE	12.7%	Systron-Donner
Harness	10.4%	LTVAC-MD
PSE	10.2%	E-Systems
Integration Hardware & Assembly	7.3%	LTVAC-MD
	100.0%	

Comparison of the average cost for this contract with that for the first production buy shows a reduction of about 30 percent which is equivalent to a pricing slope of about 92 percent, including the effects of design changes and inflation.

Each of the six major components have been analysed in order to show the breakdown into the standard manufacturing cost categories. The result is given below.

	Gyro	DCE	Accel	VCE	Harness	PSE
Material	1.0	3	11	25	7	4
Purchased Parts	24.0	22	42	12	39	27
Fabrication/Processing	18.0	11	2	2	12	11
Assembly	23.0	25	20	43	16	21
Test and Inspection	22.0	14	24	17	3	11
Support	12.0	25	1	1	23	26
	100.0%	100%	100%	100%	100%	100%

When these in turn are related to the total guidance cost and are combined into the standard guidance components, the result is as follows:

			Electronics				
	Gyro	DCE	VCE	PSE	Σ	Accel	Cables
Material	0.3	0.5	3.1	0.4	4.0	1.7	0.7
Purchased Parts	6.3	3.7	1.6	2.7	8.0	6.7	4.1
Fabrication/Processing	4.7	1.9	0.3	1.1	3.3	0.3	1.2
Assembly	6.1	4.3	5.4	2.1	11.8	3.2	1.7
Test and Inspection	5.8	2.4	2.2	1.2	5.8	3.9	0.3
Support	3.2	4.3	0.1	2.7	7.1	0.1	2.4
	26.4	17.1	12.7	10.2	40.0	15.9	10.4

From this summary, it may be seen that no standard manufacturing cost category for any of the six major components of the LANCE guidance set amounts to as much as 7 percent of the total.

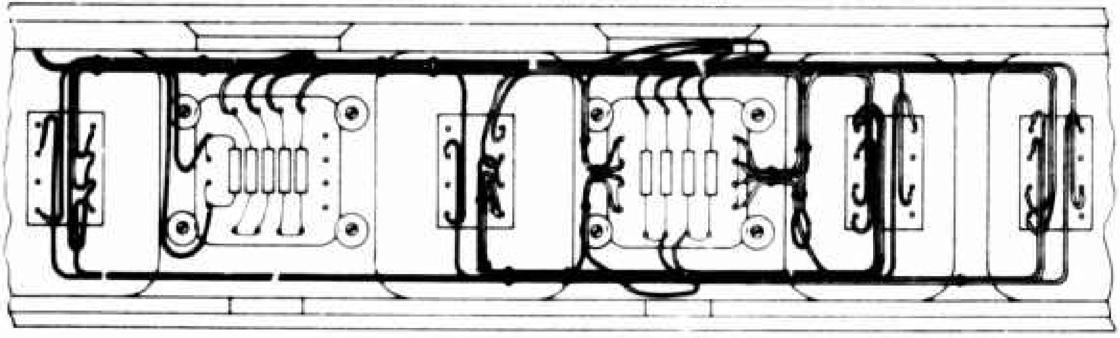
The above summary does not reveal any major cost drivers and tends to indicate that no single manufacturing technology project could produce a significant reduction in the cost of the LANCE guidance set. As a result of this conclusion, specific reviews of each of the six major components were performed. From these it appears that a 15-20 percent cost reduction is possible, principally through redesign of the current individual components to take advantage of integrated circuit (IC) technology. Further as much as a 25 percent reduction might be realized by using IC's and related technology to combine all electronics (DCE, VCE, and PSE)) into one package instead of the current three. Some detail on each component follows.

II. POTENTIAL MANUFACTURING TECHNOLOGY PROJECTS

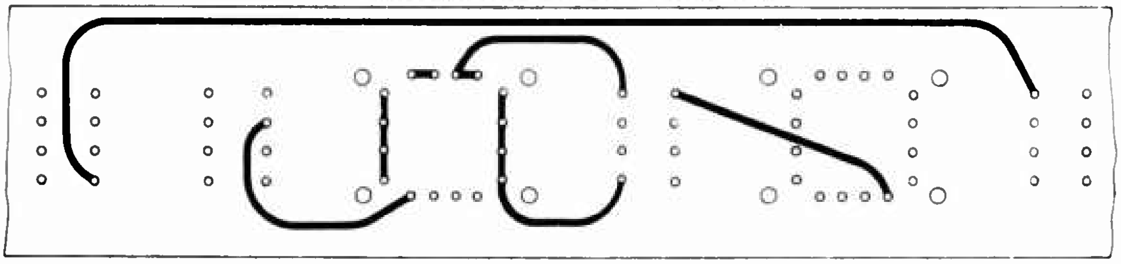
Gyro

Because of the stringent performance (accuracy) and environmental operating requirements (-40° to +200°F), gyro fabrication continues to require a significant amount of hand work and individual testing. Two potential manufacturing technology projects offer a 10 percent cost savings on the gyro (2.5 percent of guidance set cost). The first project (Attachment 1) involves the replacement of the present handwriting with printed circuit cable.

CURRENT HANDWIRED HARNESS



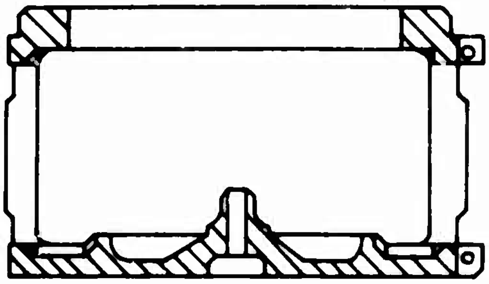
PROPOSED PRINTED CIRCUIT HARNESS



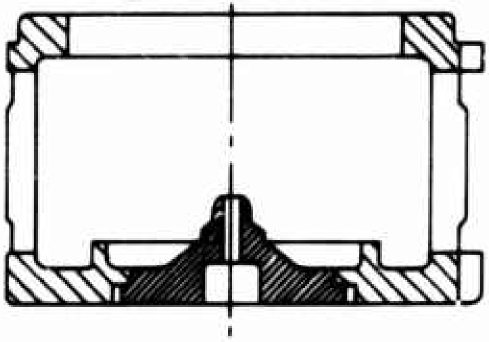
As may be seen, this replacement would reduce wiring costs by eliminating many handwiring steps (select, cut, dress, wrap, route, attach and solder) and by preventing wiring errors and associated trouble shooting and rework. It is estimated that this change would result in a 6 percent reduction in gyro unit cost. A nine-month project costing about $50K would be required, not including the cost of the gyros used for evaluation. In addition any flight requalification costs are not included.

The second project (Attachment 2) involves the redesign of the gyro housing to convert it from a machined and built-up structure to a casting.

CURRENT MACHINED HOUSING



PROPOSED CAST HOUSING



As may be seen, this change would eliminate considerable costly blind precision machining with the accompanying spoilage. It is estimated that this change would result in a 4 percent reduction in gyro unit cost. Again, a nine-month program costing about $50K would be involved. In this case also, the cost of any gyros used for proofing the change plus any flight requalification costs as a result of the change are not included.

Accelerometer

The performance requirements for the LANCE accelerometer are more stringent than for the gyro since it must function accurately at 1 g during presetting before launch, at accelerations up to 30 g's during boost, and at 0 g during sustain phase, and all of this within the environment requirements of -40° to +200°F. Differing from the gyro, the accelerometer does have significant internal electronics. A potential manufacturing technology project (Attachment 3) offers about a 30 percent reduction in instrument unit cost (4.5 percent of guidance set cost). This project would involve three changes: (1) redesigning the electronics to incorporate IC's in order to reduce part costs, simplify set up and eliminate the filter board; (2) changing the sensor material to reduce machining costs; and (3)change the preload set to a bellows arrangment. It is estimated that this change would involve a project costing about $115K and taking six months to complete, not including any flight requalification costs.

VCE

Similar to the accelerometer and the DCE, redesign of the VCE to incorporate current technology in the form of IC's, flatpacks, etc. offers the potential for a significant cost reduction. This potential manufacturing technology project (Attachment 4) offers a VCE unit cost reduction of about 23 percent (3 percent of guidance set cost). It is estimated that the project cost and duration would be about $120K and eight months, not including any flight requalification costs. Another potential manufacturing technology project (Attachment 5) offers a small cost reduction (2 percent) by a change in the method of hermetically sealing the VCE from the current solder seal banding. The cost and duration for this project would be about $50K and eight months.

DCE

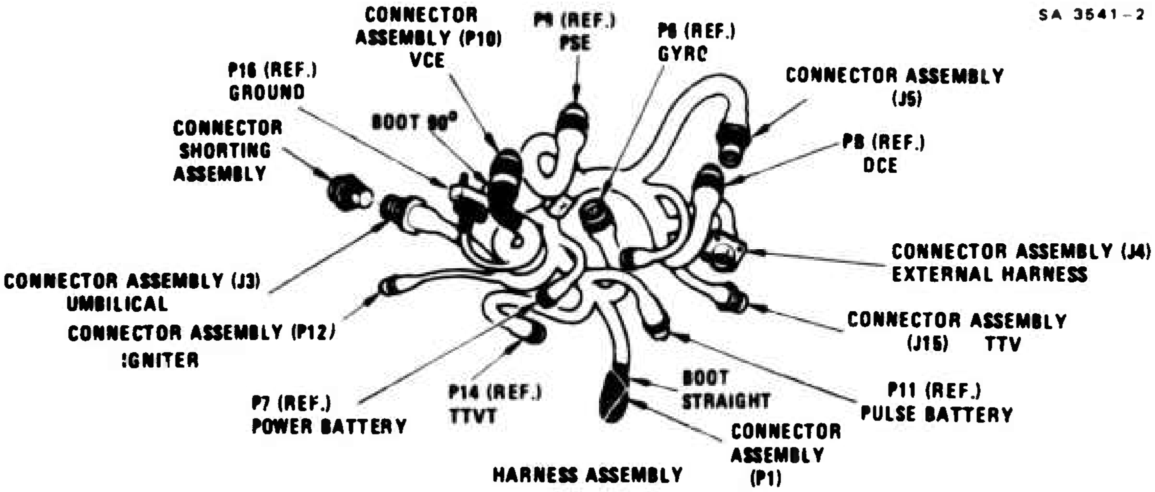
Application of current IC technology to the DCE (see Attachment 4) offers a comparable 25 percent cost savings on the DCE (4 percent of guidance set cost). The project cost and duration for application to the DCE would be comparable - about $125K and nine months. Two other manufacturing technology projects offer some potential cost reduction on the DCE. The first (Attachment 5) involves a change in the means of hermetically sealing the metal package from the current solder seal banding. The potential cost savings on the DCE is about 2 percent (0.3 percent of guidance set cost). The project cost is estimated to be about $100K over a 12-month timeframe. The second project (Attachment 6) involves the development of automated equipment for acceptance testing. Development of such equipment would save time and eliminate human errors. It is estimated these savings would be equivalent to about a 5 percent reduction in unit cost (0.8 percent of guidance set cost). The project cost for automated equipment for both the DCE and PSE would be approximately $1M over an 18-month period.

PSE

Both of the manufacturing technology projects described above (Attachments 5 and 6) are also applicable to the PSE, with essentially equivalent cost reduction potential. Application to the PSE would therefore result in about a 7 percent reduction in unit cost (0.7 percent of guidance set cost). The project cost and timing would be as described above.

Harness

The LANCE guidance set electrical harness depicted below is an intricate cable in order to accomplish all of the required interconnections. The harness cost has been reduced by more than 40 percent during production to date. From the cost summary in section I,it can be seen that the Fabrication/Processing and Assembly of the harness contribute 28 percent of its current cost. The following table shows a breakdown of this cost into the respective operations such as wire cutting, preparation, shielding, routing, etc. Recent developments in electronic packaging and production industry have shown applications of either mechanization or numerical controlled automation in each of these operations. Application of these developments to the harness fabrication/processing and assembly operations to produce an automated line-processing system would produce a substantial improvement in productivity.



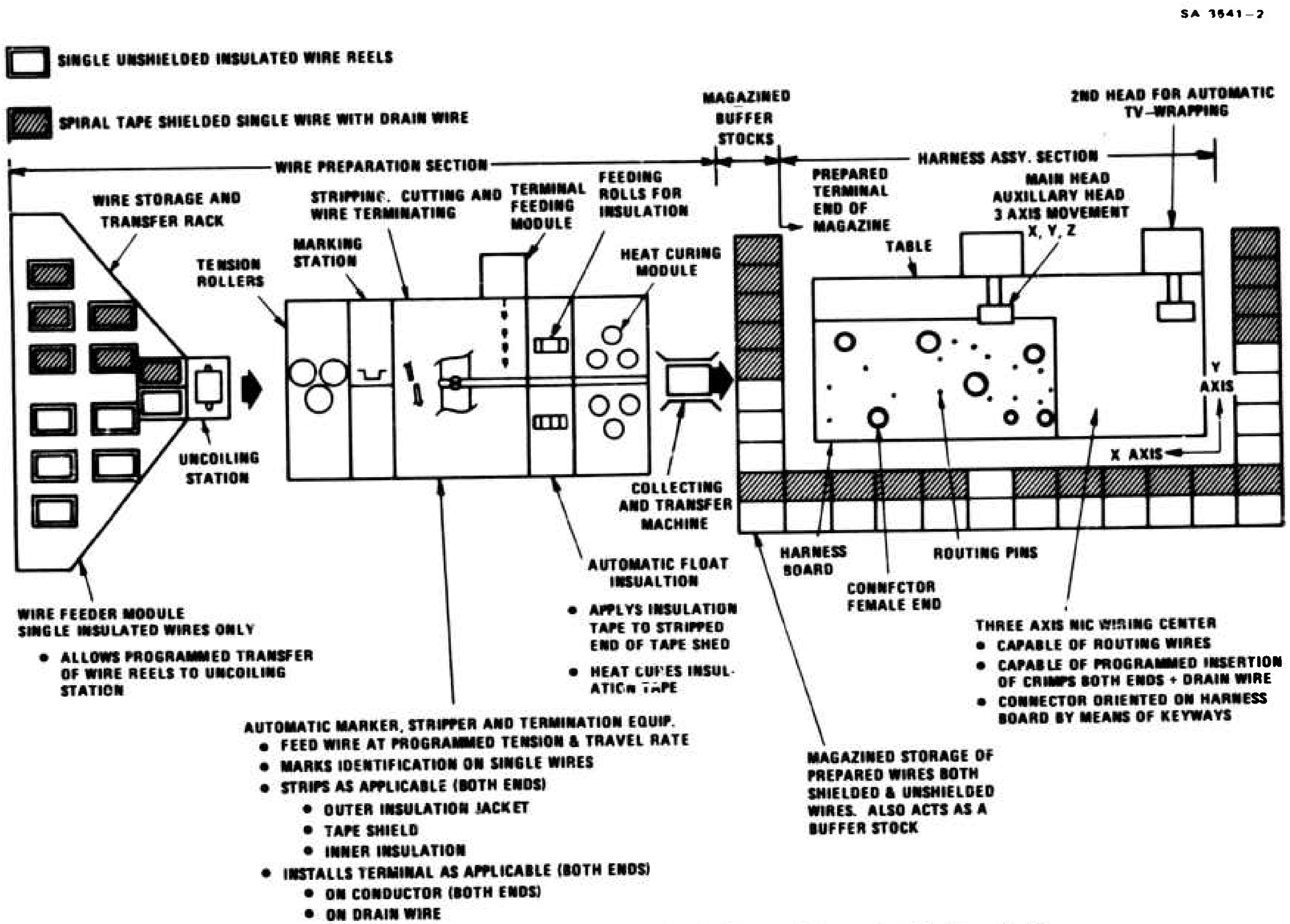
The data on the table show that the costs associated with harness fabrication and assembly can be reduced by 50 percent. This represents a 15 percent reduction in the harness unit cost (1.5 percent of guidance set cost).

The manufacturing technology project (Attachment 7) to accomplish this cost reduction involves the development of the automated and modularized line processing system to fabri-

Operation	Improvement	Work-Content, Units/Assembly			Cost Reduction (%)
		Present	Revised	Reduction	
Gathering parts and wire-cutting, identifying.	Employ magazined handling and transfer of wires/parts.	2.66	2.06	0.60	1.7
Wrapping of RFI shielding and insulation.	Substitute mechanized wrapping and use of zipper tubing.	5.06	3.10	1.96	5.7
Assembling ferrels, contacts, back-shells, etc.	Modify connectors. Eliminate ferrels. Mechanize. Conduct numerical controlled Assembly.	6.20	3.20	3.00	8.7
Solder connectors, cups, wires. Pot connectors.	Substitute crimp connectors. Conduct numerical controlled assembly.	6.17	1.46	4.71	13.7
Spot tying, etc.	Substitute numerical control and ty-wrap automation.	0.98	0.50	0.48	1.4
Wire preparation: strip, pigtail, bin.	Introduce crimped terminals, mechanized shielding, numerical controlled assembly, modified connectors.	11.30	5.65	5.65	16.5
Route wires on harness boards.	Substitiue numerical controlled operation.	1.94	1.00	0.94	2.8
		34.31	16.97	17.34	50.5

cate and assemble electrical cables. The following specific approaches would be involved in this development: (a) use of crimped terminals, (b) elimination of ferrels by modified connector design, (c) use of special taped shielded single wires with drain wire feature, (d) use of zipper type tubing for insulation and shielding of branches, (e) automatic wire identification, cutting, terminating and insulation, plus (f) numerically controlled harness assembly.

A preliminary concept for an automated harness assembly processing line is shown in next figure. A single line is shown to handle both shielded and unshielded wires. The first half of the line may be called the wire-preparation-section. The second half may be called the harness-assembly-section. At the start of the line, various wires are shown stored in a wire storage and transfer rack. Wire is fed into the automatic wire-preparation-center (WPC) from an uncoiling mandrel and through certain tension and guide rollers. In the WPC, the wire is automatically marked, cut to length, stripped and terminated at either end. In case of shielded wire, terminals are crimped onto the drain-wire in addition to the conductor. The exact length of wire to be cut is determined by preceding dry-runs across the numerical controlled harness-assembly-center. After stripping and terminating, shielded wires are shown to automatically receive a tape insulation to protect the



WIRE FEEDER MODULE
SINGLE INSULATED WIRES ONLY
- ALLOWS PROGRAMMED TRANSFER OF WIRE REELS TO UNCOILING STATION

AUTOMATIC FLOAT INSUALTION
- APPLYS INSULATION TAPE TO STRIPPED END OF TAPE SHED
- HEAT CURES INSULATION TAPE

THREE AXIS NIC WIRING CENTER
- CAPABLE OF ROUTING WIRES
- CAPABLE OF PROGRAMMED INSERTION OF CRIMPS BOTH ENDS + DRAIN WIRE
- CONNECTOR ORIENTED ON HARNESS BOARD BY MEANS OF KEYWAYS

AUTOMATIC MARKER, STRIPPER AND TERMINATION EQUIP.
- FEED WIRE AT PROGRAMMED TENSION & TRAVEL RATE
- MARKS IDENTIFICATION ON SINGLE WIRES
- STRIPS AS APPLICABLE (BOTH ENDS)
  - OUTER INSULATION JACKET
  - TAPE SHIELD
  - INNER INSULATION
- INSTALLS TERMINAL AS APPLICABLE (BOTH ENDS)
  - ON CONDUCTOR (BOTH ENDS)
  - ON DRAIN WIRE

MAGAZINED STORAGE OF PREPARED WIRES BOTH SHIELDED & UNSHIELDED WIRES. ALSO ACTS AS A BUFFER STOCK

Figure 7. Preliminary Concept for a Largely Automated Harness Assembly Processing Line

stripped ends of the RFI shield. The heat-shrinkable insulation is cured in line at the exit-end of the equipment. Prepared wire is delivered into a special magazine which allows subsequent automatic retrieval of the wire at the harness-assembly-center. Prepared wire of each specification must be stored in its own magazine at a prescribed storage location.

The complete routing and assembly of wires into connectors and harness is shown to be conducted in the second half of the line in a numerical controlled work center. Prepared wires are retrieved automatically from magazines at programmer locations. The work center has three axis capability and two operating heads. The main head performs the function of routing wires and inserting terminals into connectors. Connectors are prepositioned on harness-board-tooling at specified location and orientation. The routed wires are held in position in special elastic retainers. The auxiliary head is used for tie-wrapping harness automatically at programmed locations.

It may be noted that the basic equipment for automated wire-preparation and for numerical controlled harness assembly are commercially available. The proposed line-processing, however, will demand certain modifications and added features.

The project cost is estimated at about $700,000 as follows:

Prototype equipment, construction for optimization	$225,000
Equipment improvements for optimization	$145,000
Engineering Support and Technical Data	$330,000

The project duration is estimated at 27 months.

INTEGRATED DCE/VCE/PSE

As noted above, redesign to incorporate current electronic technology such as IC's offers significant savings on both the DCE and VCE. Use of this same technology to combine all of the electronic components (DCE, VCE, PSE, and TTV) within one package offers a very significant guidance set cost reduction. Such a change is further supported by current LANCE operational requirements which require removal of the complete guidance set for return to Direct Support wherever fault isolation to the subassembly level is required.

It is estimated that a manufacturing technology project (Attachment 8) to accomplish this repackaging would reduce the cost of the missile guidance set by 15 percent. The approximate cost for this project would be about $0.5M over a duration of 12 months. Flight requalification would probably require about 10-15 flights and take an additional 12 months.

SUMMARY

The potential manufacturing technology projects described above and in the eight attachments offer the following potential reductions in the unit cost of the LANCE Guidance Set:

	Component Cost Reduction	Equivalent Guidance Set Cost Reduction	Cost
Gyro	10%	2.5%	100K
Accelerometer	30%	4.8%	115K
VCE	25%	3.0%	170K
DCE	30%	5.0%	1,225K
PSE	7%	0.7%	---
Harness	15%	1.5%	700K
Total		17.5%	2,310K

or alternatively:

	Component Cost Reduction	Equivalent Guidance Set Cost Reduction	Cost
Combining VCE, DCE, and PSE		15%	530K
Total with Gyro and Accelerometer		22%	

As noted above, the cost for flight requalification is not included in the above figures.

III. GUIDANCE TREND DATA

The impact of LSI (large scale integration) devices such as ROM (read only memory), mircoprocessors, programmable logic arrays, etc., is now being felt in guidance system state-of-the-art. Also, potential further cost reductions with increased memory capacity offered by bubble domain memory and charge coupled devices will further establish trends in this direction. The large memory capacity, high speed, yet low cost and small size of these devices opens up avenues of instrument compensation for multiple, critical parameters and adaptive control techniques not possible or too costly before. The critical parameters of gyro and accelerometer instruments have had to be held tightly over wide ranges of environment. With imbedded microprocessors, it is possible that parameters, once defined, can be placed within the microprocessor memory for proper compensation, without mechanical adjustments or trimming.

Microprocessor capacity also allows sophisticated gain and compensation profiles for autopilots thus providing optimal control over a broad range of vehicle environment. Adaptive control techniques can now be accomplished at low cost.

This trend toward extensive use of microprocessors must be accompanied with new and innovative computer architectural techniques and low cost software management.

Attachment 1

Title: Manufacturing Technology Project to Provide Cost Improvements in the Gyro Pick-off Wiring System

System/session area/component: LANCE Missile/Guidance/Gyro

Problem: The handwiring of the RSG-15 gyro requires skilled personnel following time consuming procedures. The assembly wireperson is required to select, cut, dress, wrap, route, attach, and solder a multitude of individual wires to pickoffs and terminal boards. Errors occur which require wire and test time, troubleshooting and rework.

Proposed solution: Replace the present "handwiring" by printed circuit cable. This custom pre-fabricated cable consists of a flat layer of circuit etched copper conductors bonded between two sheets of flexible insulating sheets. The conductors terminate in eyelets or perforated solder pads which can be pushed down over component terminal pins. The pads provide a bare copper solder area 360 degrees around the pin. A conventional soldering iron can be used to make reliable solder joints.

Project cost and duration: The project costs include the design of the flexible etched circuit, the terminal boards and pick-offs to interface with the flex. Fabrication of new parts and components and installation in gyros. Complete cycle of production testing before and after environmental checks for temperature, vibration, and shock. Production proofing of the changes in a minimum of ten gyros. (Cost of gyros used for evaluation not included in cost.)

Project cost: $43,000

The estimated duration of the project is nine months.

Benefits: Printed circuit cabling reduces wire costs in the following ways:

Material costs less, in quantity, than conventional cable.

Reduced time required for wiring by eliminating the numerous steps of "handwiring" described above. Prevents wiring errors. Eliminates troubleshooting. Eliminates rework due to wiring errors.

Other intangible advantages of printed circuit cable include:

Product uniformity. Increased reliability - there are no "tight" wires overstressed during vibration.

Use of automatic soldering equipment to further reduce wiring costs will be investigated as an alternate to conventional soldering.

Benefits to be derived from this project are a reduction in recurring hardware costs.
Reduction in gyro cost = 6%

Assumptions: The above analysis is based upon a lot quantity of 400 gyros produced at a rate of 45 gyros per month.

Attachment 2

Title: Manufacturing Technology Project to Provide Optimization for Fabrication of Gyro Rotor Housing

System/session area/component: LANCE Missile/Guidance/Gyro

Problem: The rotor housing and stiffening end plate are fabricated from bar stock material requiring machining and assembly. The design requires deep, blind, precision machining operations on inside of housing which supports the rotor through the spherical bearing. Spoilage costs are high because of the complex design which also mounts the electrical pick-off system. The end plate, which mounts to housing using twelve screws, was added to provide axial stiffness to the rotor support plane.

Proposed solution: Design the gyro housing as a cast structure for mounting the pick-offs and terminal boards. The only machining required is to provide mounting interface surfaces for the housing, pick-offs, and terminal boards. The rotor support portion of housing will be designed as a separate piece which can be readily machined as a surface of revolutions and hardened. The two pieces will be mounted together using electron beam techniques. The rigidity of the assembly will equal or exceed the original assembly.

Project cost and duration: The project costs include the design of the new assembly, interchangeable with the old. Fabrication of new parts and assembly in gyros. Complete cycle of production testing before and after environmental checks for temperature, vibration, and shock. Production proofing of the changes in a minimum of ten gyros. (Cost of gyros used for evaluation not included in project cost.)

Project cost: $53,000

Estimated duration of the project is nine months.

Benefits: Benefits to be derived from this project are a reduction in recurring hardware costs. These reductions are as follows:

Reduction in gyro cost = 4%

Assumptions: The above analysis is based upon a lot quantity of 400 gyros produced at the rate of 45 gyros per month.

Attachment 3

Title: Manufacturing Technology Project to Reduce the Cost of the 4841 Accelerometer

System/session area/component: LANCE/Guidance/Accelerometer 4841

Problem: The 4841 currently used in the LANCE G&C package is a major cost driver for the G&C package. Systron-Donner has been investigating ways to improve the performance and reduce the price of the 4841. The modified 4841 would be less expensive because it would have fewer components and lower assembly costs. The problem is to produce prototype 4841's with the design changes contemplated and qual-test the new unit.

Proposed solution: The project would tool up and incorporate those techniques necessary to produce the 4841 modification. This would include design, drafting and testing of the new unit. Primary emphasis would be given to redesigning the electronics to reduce parts cost, simplify set up and eliminate the filter board. The sensor material would be changed to reduce machining costs and the preload set would be changed to a bellows type arrangement.

Project cost and duration: Estimated costs are as follows:

Design Engineering	$ 35,000
Drafting	15,000
Technician	15,000
Manufacturing Engineering	30,000
Q.A. Engineering	5,000
Fixtures	15,000
Total	$115,000

Estimated duration of the project is six months.

Benefits: Benefits to be derived from this project are a reduction in recurring hardware costs. These reductions are as follows:

Reduction in accelerometer unit cost = 30%

Assumptions: The above analysis is based on a lot quantity of 400 accelerometers produced at a rate of 45 per month.

Attachment 4

Title: Manufacturing Technology Project to Reduce the Cost of the VCE

System/session area/components: LANCE/Guidance/Velocity Control Electronics

Problem: The problem is to reduce the cost of the VCE.

Proposed solution: The project would modernize the design of the VCE to 1975 standards. Extensive use of integrated circuits, flatpacks, etc. would be employed.

Project cost and duration: Estimated costs are as follows:

Design Engineer	$ 45,000
Drafting	15,000
Technician	15,000
Manufacturing Engineer	30,000
Q.A. Engineer	5,000
Fixtures	10,000
Total	$120,000

Estimated duration of the project - eight months.

Benefits: Benefits to be derived from this project are a reduction in recurring hardware costs. These reductions are as follows:

Reduction in accelerometer unit cost - 25%

A comparable project is applicable to the DCE with comparable savings potential and cost.

Assumptions: The above analysis is based upon a lot quantity of 400 gyros produced at the rate of 45 gyros per month.

Attachment 5

Title: Manufacturing Technology Project to Accomplish Hermetic Package Sealing other than with a Solder Seal

System/session area/component: LANCE/Guidance/Direction Control Electronics and Power Supply Electronics

Problem: The package for both the PSE and the DCE consists of an aluminum sand casting base and a drawn aluminum cover. Both of these package components are plated to provide solderability during integration. Assembly consists of installation of the connector, electronic modules and interconnecting harness into the base. Final closure consists of installing the cover onto the base and finally providing a hermetic seal by soldering a plated brass band around the perimeter of the completely assembled package at the junction seam between the base and the cover. The original design philosophy behind this packaging approach was to provide a long shelf life for a component assumed to be in the throw-away category. It was also based on the use of hermetic seal materials and methods available during the early 1960's. The primary problems associated with this package concept are as follows:

> The cost value for each of these components (PSE and DCE) is sufficient enough by todays assessment to remove it from a throw-away category in case of an internal failure prior to deployment. As a result, salvage and repair are expensive alternatives with the current package concept.
>
> Solder band and connector installation are time consuming operations which require high skill levels for the operator. This skill level has been demonstrated to require continuous practice by the operator and therefore lends itself to only being performed where the frequency of occurrence for the operation is relatively high (not felt to exist at the normal depot level for maintenance).
>
> Because of its inherent porous nature, the hermetic seal integrity of the sand casting base is primarily a function of the quality of the plated surface. While testing is done on the base prior to implementation, subsequent surface damage can jeopardize future hermetic seal integrity.

Proposed solution: The project would investigate current state-of-the-art packaging methods and to evaluate any improved methods to provide a hermetic seal for components on missile programs which have LANCE similar requirements. Primary emphasis would be to optimize repairability without jeopardizing storage life or operational requirements inherent to LANCE. The end result of this project would be the fabrication of a prototype unit. This unit would be used to evaluate the packaging approach selected when subjected to a step-stress and accelerated life test program which would be developed to demonstrate compliance with the LANCE missile objectives.

Project cost and duration: Estimated cost of the project is anticipated to be $100K over a timeframe of 12 months.

Benefits: Benefits to be derived from this project include the following:

A reduction in recurring hardware cost (2.5% per PSE and 1.5% per DCE).
A reduction in production lead time.
Improve maintainability.
A reduction of the equipment and labor talent requirements at a depot repair facility.

Assumptions: As described above, this project would not provide how to documentation in a format which may be required to satisfy an industry wide production procurement program in a competitive market situation.

Attachment 6

Title: Manufacturing Technology Project to Provide Optimized Production and Acceptance Testing for the LANCE DCE and PSE Components

System/sesseion area/component: LANCE/Guidance/Direction Control Electronics and Power Supply Electronics

Problem: A major cost driver for the subject subsystems is the result of test time required to support both in-line verification and acceptance of hardware. Since all testing is currently accomplished using manual test equipment, the production program would benefit should tests be performed using automated equipment. Besides the recurring cost advantage realized by the reduction in time required for acceptance and verification, other advantages provided by an automated test set would include: elimination of most human failings which can result in testing blunders, the potential (without straining test capability) for expanding parameters to be tested and data recording and storage advantages.

Proposed solution: The scope of the proposed project would encompass the design, fabrication and checkout of an automated test console (including software). In concept, this equipment would provide sequential test commanding which could be accomplished either manually (on test operator command) or automatically by a tape reader or similar sequencing device. Speed of operation in the automatic mode would be dependent only upon setting times required by the UUT (DCE or PSE). Stopping on UUT faults or advancing through to any selected point in the test program would be a project design feature useful for troubleshooting or other in depth investigations. The project would take advantage of experience and existing talent which has been accumulated at E-Systems on similar production programs.

Project cost and duration: Estimated cost of the project is anticipated to be $1,000,000 over a timeframe estimated to be 18 months.

Benefits: Primary benefits to be derived from this project are a reduction in recurring hardware costs. These reductions are anticipated to be as follows:

DCE test reduction	1.5%
DCE Test Support (Engineering) reduction	3.8%
DCE net test reduction	5.3%
PSE test reduction	1.3%
PSE test support (Engineering) reduction	3.7%
PSE net reduction	5.0%

Assumptions: As defined and estimated above, this project would result in an automated test console which would demonstrate the desired test time savings if implemented in the production program. It would not, however, cover or provide for changes to production hardware documentation which would be required to specify the proposed alternate method and equipment for production testing; nor would it develop or provide how to make, how to use or how to calibrate documentation other than that which might be needed to support the E-Systems in-house quality assurance requirement.

Attachment 7

Title: Manufacturing Technology Project for developing an automated assembly line for fabrication and assembly of harnesses for aerospace applications.

System/session area/components: LANCE/Guidance/Harness Assembly

Problem: In the experience gained with the LANCE missile, the harness assembly comprises half of the total inhouse fabrication, processing, assembly, testing and inspection costs of the guidance set. Fabrication and processing of the harness contributes 28 percent of its unit cost.

Proposed solution: The proposed solution is to undertake a development program for application of automated and modularized line-processing techniques to the fabrication and assembly of harnesses. The program objectives would be as follows:

(a) Development of a standardized line-processing equipment concept, which would be capable of application to a majority of current and future missile systems.
(b) Development of a prototype, automated processing line to support the study of alternatives under item (a), above.

In developing the processing line concepts, the utilization of existing, proven processing systems will be maximized. One of the possibilities of such an application is given below:

Operation	Example of Automation
Wire preparation, including stripping, pig tailing, preparing jumpers, cutting and tinning.	Replace all soldered connections with crimped connection.
Solder connectors, cups, wires, etc.	Use Eubanks type Stripper/Terminator, automatic equipment for automatic measurement, cutting, stripping and terminal attachment.
Assemble ferrels, contacts, backshells, etc.	
Route wires on harness boards.	Use Huges wire-center systems including solderless wire-wrapping inter-connection techniques where applicable.
Wrap RFI shield and tape.	Substitute with the use of zipper-type tubing using special semi-automated tools.
Shrink tubing.	
Spot-tie wires.	Substitute TY-WRAP mechanized systems.

Project cost and duration: Estimated costs are as follows:

Prototype equipment, construction and installation	$225,000
Equipment improvements and modifications	145,000
Engineering support and technical data	330,000
Total	$704,000

The estimated duration of the project is 27 months.

Benefits: Benefits to be derived from this project are:

A reduction in recurring hardware cost for harness = 15%.
A standardized automated processing system for fabrication of harness assemblies for aerospace applications.

Attachment 8

Title: Manufacturing Technology Project to provide Reduced Missile Cost by Demodularization and Increased Use of Integrated Circuits

System/session area/component: LANCE/Guidance/Missile Guidance Set

Problem: Study shows that major cost drivers do not exist in the LANCE guidance system; therefore, no single manufacturing technology project could produce a significant cost reduction in the LANCE guidance set. However, four separate subassemblies, each housing different electronic circuits used in the guidance function, are contained within the set. The initial impetus for the individual subassemblies includes both the need for packaging room and modularity for field maintainability. The evaluation of the LANCE operational concepts in which the Guidance Set is removed as an assembly and returned to Direct Support for fault isolation to the subassembly level and consequent replacement has eliminated the need for modularity. Combining the four electronic subassemblies into one larger subassembly will reduce cost of the guidance set by elimination of many individual connectors, harnesses, enclosures, etc.

Proposed solution: The cost of the LANCE missile guidance set can be significantly reduced by repackaging the four electronic subassemblies into one larger unit. Further gains in cost reduction, as well as easing the packaging effort, can be accrued by redesign of current discrete component circuits to make maximum use of integrated circuit (IC) technology. The effort would provide substantial savings by reducing printed circuit board count, component count, connector count, and harness complexity.

Project cost and duration: Estimated costs are as follows:

Circuit redesign and breadboard test	$100,000
Packaging redesign	32,000
Prototype fabrication and test (3 units)	200,000
Technical documentation	200,000

Estimated duration of the project is 12 months.

Benefits. Primary benefit to be derived is a 15 percent reduction in cost of the Missile Guidance Set.

Assumptions: Project cost and duration extensive qualification testing such as EMI, lightning effects, RFI, etc. will not be required.

PERSHING II MISSILE SYSTEM GUIDANCE SUBSYSTEMS

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ABSTRACT

This paper reviews the guidance subsystems of the Pershing II Missile System. This system, which is presently in the Advanced Development Phase, is being monitored for production design and costs as part of the Army Design to Unit Production Cost program. The guidance subsystem cost is furnished for the standardized component categories requested. Cost drivers, and manufacturing technology projects to reduce cost, are identified.

INTRODUCTION

Martin Marietta has been pursuing continuing studies and developments applicable to the Pershing Missile System for the U.S. Army Missile Command. These include improvements in Pershing performance, cost-effectiveness, and flexibility in field operations. For example, the Automatic Reference System (ARS), which evolved from a requirement to automate the azimuth determining and presetting procedures for the Pershing Ia guidance subsystem, is now entering operational service.

The constraint which guides the development of the Pershing Missile System is that it has to be both militarily effective and, because of the necessity for a minimum of collateral damage to civilians, politically acceptable to solve the "Tactical Nuclear Dilemma" arising from the use of tactical nuclear weapons. The Pershing II Missile System provides a solution to this problem with the use of a small nuclear weapon, a short reaction time, low vulnerability, and an order of magnitude improvement in accuracy. Pershing is capable, with present technology, to satisfy the improved accuracy requirements, and already possesses the required reaction time and low vulnerability.

The Pershing II Missile System is now in the Advanced Development (AD) phase. Following successful demonstration in the Terminal Radar Area Correlator Experiment (TRACE), which was a helicopter captive flight test program to prove the feasibility and accuracy of the radar guidance system for a terminally guided reentry vehicle, the guidance subsystem was changed significantly for the Pershing II Missile System. Engineering models of the guidance subsystem equipments have been fabricated and factory acceptance tested. Flight test in helicopter and fixed-wing aircraft is presently in process to simulate portions of missile performance. Prototype equipments are in design/fabrication phases leading to Pershing II missile flights late in 1977. Production designs and costs are being pursued as part of the Army Design to Unit Production Cost (DTUPC) program. Production cost information used in this presentation is obtained from the DTUPC phase of the Pershing II program.

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SYSTEM DESCRIPTION

Pershing II Missile and Reentry Vehicle

Pershing II capability will be provided by a small cost increase over maintaining the present Pershing Ia system. The cost increase is small because the Pershing II Weapon System is a modular improvement to the Pershing Ia system, utilizing the existing PIa first and second stage motors, launcher, and other ground support equipment. The only change to the system is the front end of the missile. The Pershing Ia guidance and control section and reentry vehicle (RV) are replaced with a new RV containing an inertial system for guidance and control throughout missile flight, a radar area correlation terminal guidance and control system, and a warhead. The Pershing II missile is launched, like Pershing Ia, on an inertially guided boost phase trajectory to second stage cutoff and reentry vehicle separation, after which the reentry vehicle proceeds on an attitude controlled ballistic path to the terminal phase. An all-weather radar is activated in the terminal phase to correlate the returns from an area surrounding the target with a prestored reference map of the target area. Several such correlations are obtained during terminal descent to derive position corrections for updating the inertial position of the reentry vehicle. This technique provides an order of magnitude improvement over Pershing Ia in delivery accuracy. Without terminal guidance activation, the Pershing II still achieves the same accuracy as Pershing Ia.

The tactical reentry vehicle shown in Figure 1 contains the complete missile guidance subsystem. Basic guidance is provided by a combination of inputs from the inertial measurement and radar correlator systems. Control is maintained by both reaction jets and air vanes. Guidance commands are given by the Pershing airborne computer which derives its inputs from the inertial measurement unit, rate gyro unit, and the radar correlator system.

The guidance subsystems considered in this paper are the:

Inertial Measurement Unit (IMU)
Pershing Airborne Computer (PAC)
Sensor Correlator System (SCS)
Radome

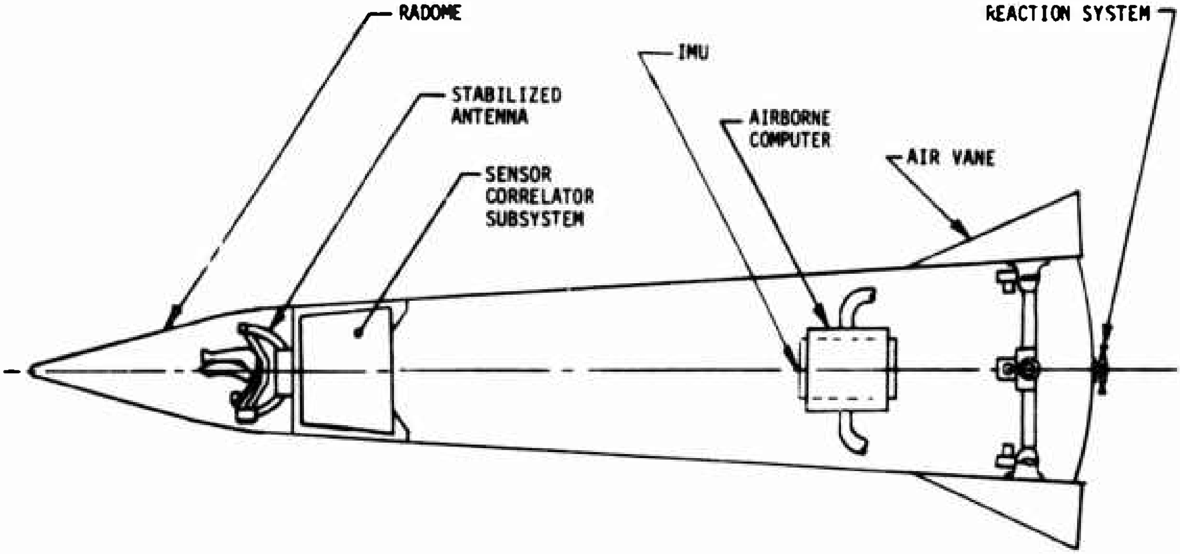

Figure 1. Tactical Reentry Vehicle

Inertial Measurement Unit. The Inertial Measurement Unit (IMU) consists of a 4-gimbal platform which uses gyros as sensing elements for stabilization, and accelerometers for measuring acceleration. During flight, the IMU, in conjunction with the airborne computer, supplies missile guidance and control output functions of navigation and steering, and also stabilizes the radar sensor gimbal during the terminal flight phase. The IMU also, in conjunction with the airborne computer, performs a self-alignment during ground operations without the need for external referencing equipment for determining the azimuth of the IMU with respect to north.

The IMU built by Singer-Kearfott for the Pershing II application uses off-the-shelf hardware and designs from the KT-70 family of Kearfott IMU's, principally from the SRAM missile and A-7 Aircraft IMU. The IMU azimuth cluster, housing the inertial elements (gyros and accelerometers), consists of A-7 components in its entirety. The gimbal system structure also contains A-7 components for the most part. Over 1000 A-7 IMU's have been produced.

The gimbal system is housed in a cylindrical casting mounted through shock isolators (see Figure 2) to a base, one side of which also provides mounting for the shock mounted electronics housing. The electronics components are mounted on five multilayer printed circuit cards measuring 6.6 x 8.6 inches overall with a 6.0 inch radius on one side. The five electronic assemblies are dedicated to the following functions: one for the power supply, one for the X and Y axis digital accelerometer loop, one for the Z axis digital accelerometer loop and the serial core memory, one for sequence and alignment, and one for gimbal control. These cards are mounted on three replaceable subassemblies which are cast frames which provide stiffness as well as cooling (see Figure 2). The parts count for the IMU is detailed in Table I.

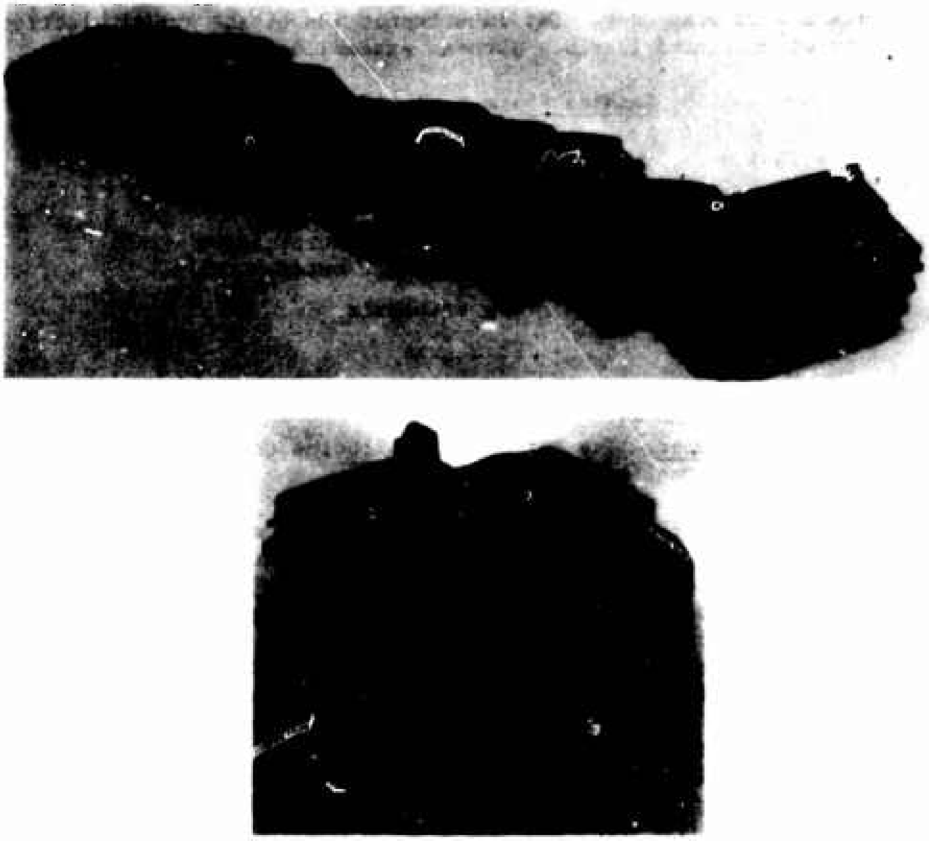

Figure 2. Inertial Measurement Unit

TABLE I

Guidance Parts Count

	IMU Quantity	PAC Quantity	SCS Quantity	Total Quantity
Integrated Circuits	164	681	624	1469
Resistors	852	769	2094	3715
Capacitors	369	774	1025	2168
Diodes	164	120	139	423
Transistors	187	63	230	480
Inductors/Transformers	27	56	50	133
Connectors	5	61	133	199
Printed Circuit Boards	6	23	15	44
Miscellaneous	40	29	42	111
TOTAL	1814	2576	4352	8742

The cooling system is a forced air system in which the air first passes over the gimbal outer housing and then into the electronic section where it passes over fins cast into the module frames. Protection for the electronics as well as the containment and ducting of the cooling air flow is provided by a drawn sheet metal cover. The interconnections of the modules is via a wire wrap tray. The interconnection of the gimbal electronics and the I/O connectors is with printed flexible harness assemblies.

General Characteristics

Weight	32 lb
Size	8.5 x 10.5 x 13 in.
Platform	4 gimbal (azimuth, inner pitch, roll, outer pitch)
Linear acceleration	40g each axis
Vibration	25.3 grms
Shock	2850g peak

Pershing II Airborne Computer. The Pershing II Airborne Computer (PAC), designed by Bendix, consists of four functional areas.

A central processor unit (CPU) performs all the computational, processing, and formatting requirements for the air, ground, and test modes of the Pershing II Missile Weapon System. A memory section provides the required storage of both the program and data for all operational, executive, ground communications, and test programs. In addition, storage is provided to facilitate program loading and computer startup. An Input/Output (I/O) section controls inputting data from and outputting data to the required missile subsystems and ground support system. The fourth function is the power supply section.

The structural and thermal design utilized in the PAC is a direct descendant of the BDX-900 family from these Bendix programs: the B1 Bomber Air Inlet Control System, the B1 Electronic Control Assembly for the attitude reference system, the S3A Aircraft Flight Guidance Computer and Air Data Computer, and the Mark 30 Underwater Vehicle Strapdown Guidance and Control System. The design consists of a brazed aluminum housing which provides two cold walls for the forced air cooling system (see Figure 3). The unit contains twelve plug-in modules and space for one spare card. Nine of these are multilayer printed wiring boards 6 x 6.5 inches in size comprising the following functions: Arithmetic Card (1), Control Card (1), Interrupt Card (1), Serial Data Card (1), A/D-D/A Converter Card (1), Signal Conditioner Card (3), Monitor Card (1). The remaining three modules are the Analog Power Supply (an assembly consisting of two multilayer cards), the Logic Power Supply (an assembly comprised of several small PC cards), and the 16K core memory module. The modules are interconnected by means of a wire wrapped backplane with connections to the I/O connectors by flexible printed circuit harnesses.

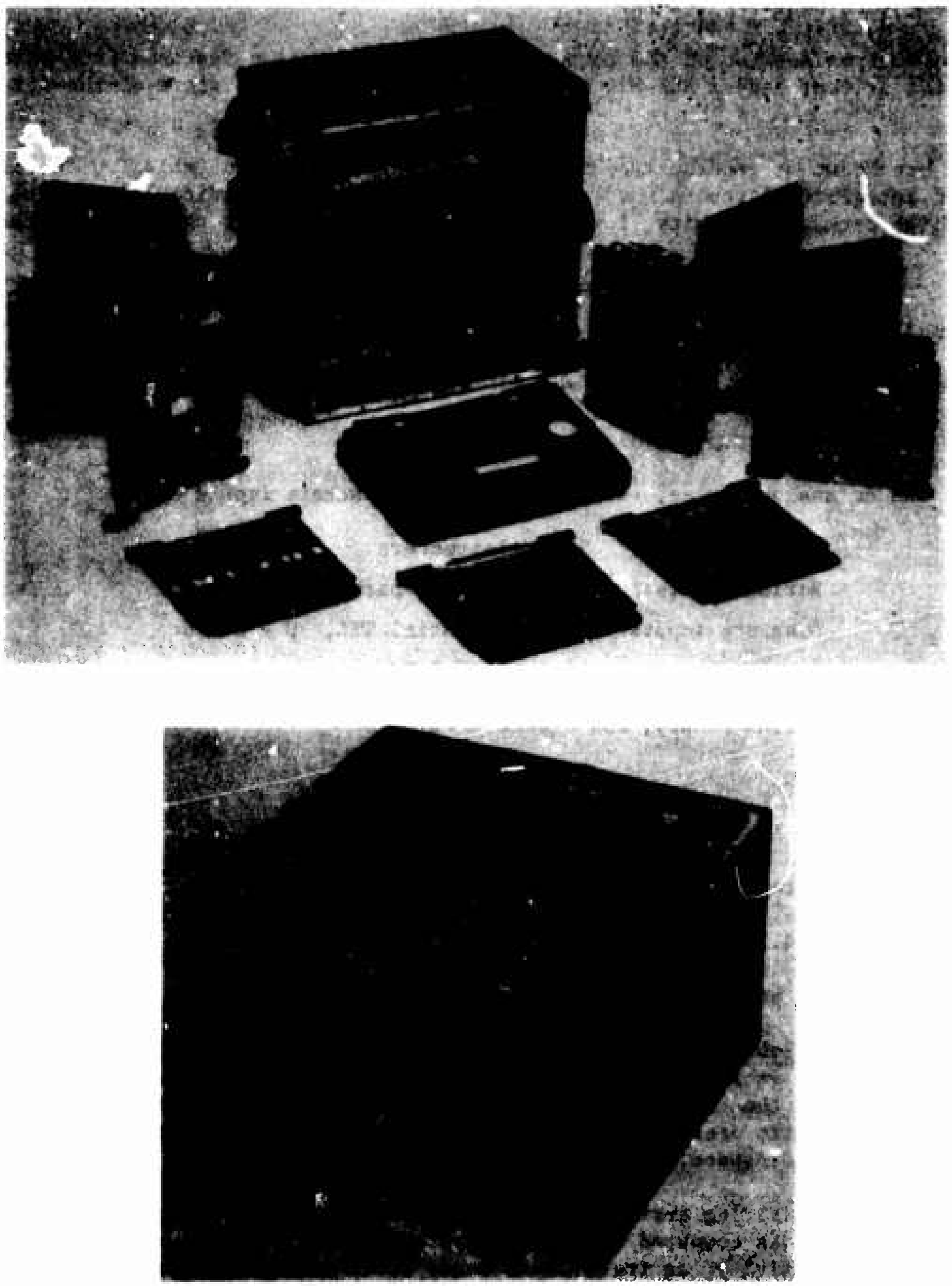

Figure 3. Pershing II Airborne Computer

The Central Processor Unit (CPU) employed in the PAC is identical to that used in the BDX-900 computers with the exception of incorporating components of a low power dissipation, and minimum circuit changes to increase the computational rate; however, the architecture and utility software are identical. It is interesting to note that flight software development time was materially reduced through the use of a BDX-9000 computer, a commercial equivalent of the BDX-900. This allowed software to be developed concurrently with PAC development and manufacturing.

The core memory is a modified electronic memories SEMS 9 16K memory. This memory is a descendant of the 4K SEMS 8 memory used in the MK-30 system and F15 Avionics Intermediate Shop which were both built by Bendix.

The Input/Output section of the computer incorporates design features from both the Mark 30 and the present Bendix BDX-820 computers utilizing present state-of-the-art components.

A parts breakdown by generic type for the computer is shown in Table I. The large proportion of integrated circuits used, many of them MSI and LSI devices, is key to achievement of the high packaging density, low power, and high reliability required for the PAC.

General Characteristics

- Parallel, microprogrammed, 16 bit CPU with 2.4 μs add time
- 16K x 16 bits plus parity RAM and ROM memory with 1.2 μs cycle time
- 13 priority interrupt levels
- ac and dc analog, pulse, serial binary, and discrete inputs

Pulse inputs	3 accelerometers
Serial inputs:	16 bit serial-parallel converter
Discrete inputs:	24 differential TTL, 30 - 28 Vdc
Power input:	25.5 to 32.5 Vdc

- dc analog, serial binary, and discrete outputs
- Weight: 35 lb
- Size: 12.5 x 13.75 x 7.5 in. max
- Linear acceleration: 40g each axis
- Vibration: 24.3g rms max
- Shock: 1550g peak

Sensor Correlator Subsystem. The Sensor Correlator Subsystem (SCS) located within the Pershing II reentry vehicle, provides relative target position information for reentry vehicle guidance during the terminal phase of flight. The SCS is a combination all-weather radar sensor and automatic area correlator integrated as part of the guidance subsystem furnished by Goodyear Aerospace.

Upon a command indicating arrival at the target area, as derived from inertial coordinates, vehicle altitude is computed using the first return signal available. The radar provides terrain reflectivity, as its antenna scans about a vertically stabilized axis from which a Plan Position Indicator (PPI) image is created and stored in the correlator. This image is compared in the correlator with a previously prepared reference image, and signals are generated that indicate missile displacement from the inertially computed position. These signals, along with the altitude error signal, are used to correct the inertial data in the Pershing Airborne Computer (PAC), which, in turn, generates missile steering commands to the air vanes.

The SCS includes the Stabilized Antenna Unit (SAU), Radar Unit (RU), Correlator Unit (CU), and Power Converter Unit (PCU). See Figure 4.

The Stabilized Antenna Unit consists of a three-degree-of-freedom gimbaled antenna with associated drive motor and resolver pickoffs. There is a servo electronics housing containing one double sided printed circuit card holding IC's and discrete components. The SAU utilizes a separate altitude measurement antenna and a terrain mapping antenna with associated wave guide switch, feed horns, rotary wave guide joints and linkage normally associated with antenna systems. This unit is 16 inches high and requires a 16 inch diameter clearance and is mounted forward in the nose of the missile and is covered by the radome.

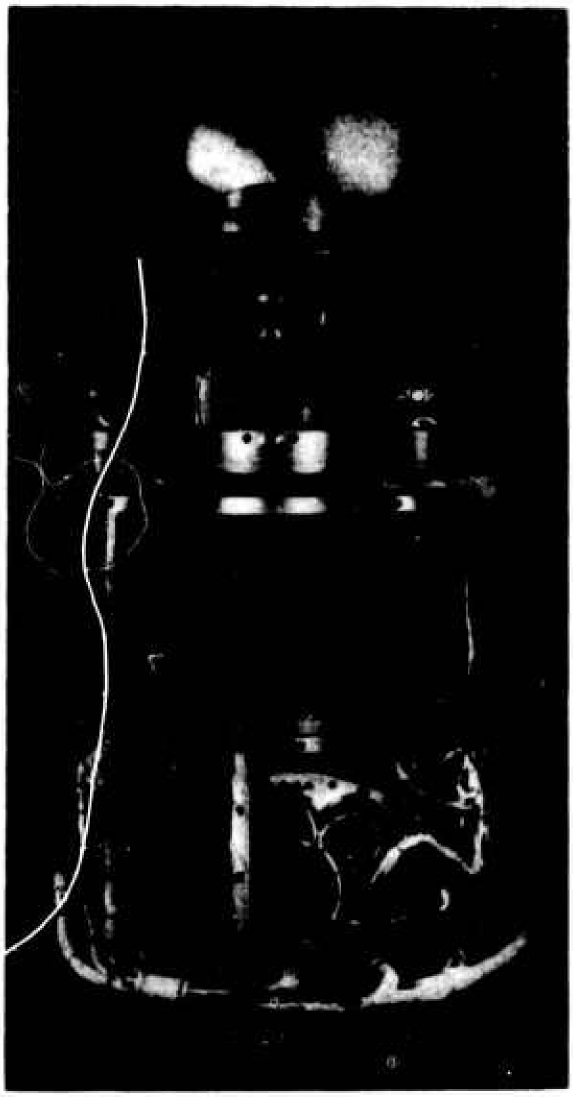

Figure 4. Sensor Correlator Subsystem

The Radar Unit consists of a cast housing containing a tunable frequency agile magnetron, receiver, modulator, tracking local oscillator and associated waveguide and semi-rigid coaxial cable. The housing has a formed cover which provides an RF tight enclosure. The unit contains 12 double sided printed circuit boards which measure 3 x 4 inches and contains IC's and discrete components. The unit measures 14 x 8 x 8 inches and occupies one quadrant of the forward section of the missile just aft of the antenna unit.

The Correlator Unit consists of a cast housing which has a cover which provides an RF tight unit. The unit contains nine multilayer printed circuit assemblies which measure 5 x 10 inches and mount a combination of integrated circuits and discrete components. This unit also houses the correlatron tube and associated hardware which performs the basic comparison function between the incoming live radar PPI image and a self-contained reference. The reference film unit assembly used in loading and holding the reference data is mounted to the outside of the housing. The overall dimensions of the unit are 14-1/2 inches long, 16 inches wide, and it is semicircular in cross section with a taper to fit the forward missile section just aft of the antenna unit mounting bulkhead.

The power converter unit is a purchased assembly which converts battery 28V to 13 regulated output voltages with a peak power output of 2500 watts. The unit measures 14 x 9 x 9 inches and occupies a quadrant of the forward section of the missile just aft of the antenna unit.

Table I shows the parts count for the SCS.

Radome. The Pershing II radome assembly consists of three basic parts: (1) a titanium-zirconium-molybdenum alloy (TZM) nose cap subassembly (including an impact fuze device and an RF energy absorber), (2) a slip-cast fused silica (SCFS) ceramic radome body, and (3) a glass/epoxy attachment ring which is bonded to the base of the ceramic shell, and by means of integral captive nut plates attaches the radome assembly to the RV airframe. See Figure 5.

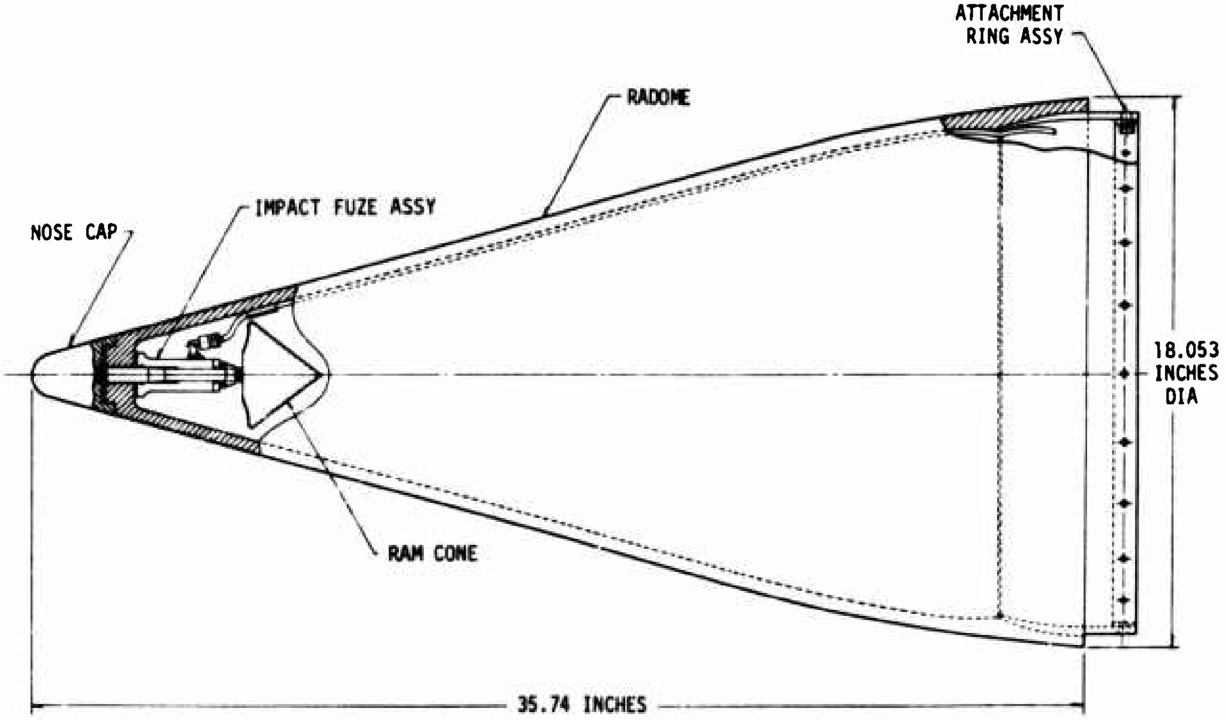

Figure 5. Radome Assembly

GUIDANCE SUBSYSTEM DETAILED COST INFORMATION

Inertial Measurement Unit

The Inertial Measurement Unit cost is apportioned to the standardized component breakdown as shown in Table II. Relative costs for each standard component are then broken down into the standardized cost categories by percent. See Table III.

Using Tables II and III, the total IMU cost breakdown is shown in Table IV.

TABLE II

IMU Component Breakdown

	(Percent)
Electronic Assemblies	35
Major mechanical parts (gimbals, structural member)	37
Gyros	17
Accelerometers	11
TOTAL	100

TABLE III

IMU Cost Categories

Cost Categories	Electronics	Major Mechanical	Gyro	Accelerometer
Material and Purchased Parts	82	50	40	25
Fabrication and Processing	0	0	7	20
Assembly	6	16	35	35
Test and Inspection	4	16	12	14
Support	8	18	6	6
TOTAL (Percent)	100	100	100	100

TABLE IV

IMU Cost Breakdown

Standard Guidance Component		Manufacturing Cost Categories					
		Materials	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support
Electronics	35	-	28.6	-	2.1	1.4	2.8
Major Mechanical	37	-	18.5	-	5.9	5.9	6.7
Gyros	17	-	6.8	1.2	6.0	2.0	1.0
Accelerometers	11	-	2.8	2.2	3.9	1.5	0.7
TOTAL (Percent)	100	-	56.7	3.4	17.9	10.8	11.2

The major cost driver for the Pershing II IMU is purchased parts at 57 percent of the total IMU cost. A further breakdown of this shows that the electronic component purchase is slightly more than 50 percent. The major mechanical area, which includes the resolvers, the gimbals, and slip rings accounts for a little more than 32 percent of the purchased parts costs. The parts purchased for the inertial components (the gyros and accelerometers) account for less than 17 percent. This is no doubt due to the fact that both the gyros and accelerometers are used on many other Kearfott IMU programs and production economy can be achieved.

The next major cost driver for the Pershing II IMU is labor which can be broken down into three subareas of assembly, test and support. It accounts for 43 percent of the total IMU cost. As can be expected in a complex system such as an IMU, the assembly accounts for the major share of the labor costs at approximately 50 percent. Support and test account for approximately 25 percent each. Although complex tests are run on an IMU, the test labor is relatively low because a great many of the tests are run with automatic test equipment under computer control.

The material/labor ratio of 57 percent material/43 percent labor is due to the use of hybrid electronics where possible and, although hybrid components tend to be higher cost components, fewer components are used. In addition, another factor that influences this cost ratio is the automatic testing concept.

Airborne Computer

The Pershing II Airborne Computer is classified under the Electronic Assemblies standardized component heading. The relative costs for the standardized cost categories are shown in Table V.

The primary cost drivers are purchased parts - 50 percent, and assembly - 33 percent. In the purchased parts, the particular costly items are:

1 Core memory (16K words, 17 bits/word)

2 MIL-STD, HI-REL parts

3 High performance linear IC devices and ultra precision resistors.

The core memory accounts for at least 20 percent of the total cost of the computer. Appreciable cost savings should be possible in this area with the availability and application of non-volatile semiconductor memory.

TABLE V

Airborne Computer Cost Categories

Cost Categories	(Percent)
Material and Purchased Parts	50
Fabrication and Processing	8
Assembly	33
Test and Inspection	3
Support	6
TOTAL	100

The use of Military-Standard, HI-REL parts, particularly for integrated circuits, probably accounts for another 15 percent of the total computer cost. While the additional cost of MIL-M-38510 devices may ultimately be reduced, this has to be regarded as a significant cost factor for the foreseeable future.

The use of high performance linear integrated circuits and ultra-precision resistor networks to meet very tight gain stability and linearity requirements in analog channels accounts for an estimated 5 percent of the total cost.

Sensor Correlator Subsystem

The Sensor Correlator Subsystem cost is broken down to the standardized guidance components shown in Table VI.

Relative costs for each standard component are now shown in the standardized manufacturing cost categories of Table VII.

TABLE VI

SCS Component Breakdown

	(Percent)
Electronic Assemblies (Correlator Unit)	40.9
Microwave Devices (Radar Unit)	27.4
Major Mechanical Parts (Stabilized Antenna Unit)	20.1
Cables	4.5
Power Supplies (Power Converter Unit)	7.1
TOTAL	100.0

TABLE VII

SCS Cost Categories

	Electronics	Microwave Devices	Major Mechanical Parts	Cables	Power Supplies
Material	4.5	0.6	1.2	0.1	
Purchased Parts	63.3	78.2	66.0	19.0	100
Fabrication and Processing	10.3	7.5	17.1	1.8	
Assembly	15.8	9.8	7.5	36.2	
Test and Inspection	2.2	1.5	4.8	32.8	
Support	3.9	2.4	3.4	10.1	
TOTAL (Percent)	100.0	100.0	100.0	100.0	100

TABLE VIII

SCS Cost Breakdown

Standard Guidance Component		Manufacturing Cost Categories					
		Materials	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support
Electronics	40.9	1.8	25.9	4.2	6.5	0.9	1.6
Microwave Devices	27.4	0.2	21.4	2.1	2.7	0.4	0.6
Major Mechanical	20.1	0.2	13.3	3.4	1.5	1.0	0.7
Cables	4.5	0	0.9	0.1	1.6	1.5	0.4
Power Supplies	7.1		7.1				
TOTAL	100%	2.2	68.6	9.7	12.3	3.8	3.3

TABLE IX

SCS High Cost Items

	Percentage of SCS Costs
Radar Receiver Front End with Tracking Local Oscillator	10.8
Tunable Magnetron	3.3
Correlatron	3.0

Using Tables VI and VII, the total SCS cost breakdown is shown in Table VIII.

The major cost driver of the SCS is purchased material which accounts for approximately 70 percent of the SCS total cost. Of this 70 percent, 17 percent is in three high cost items of which only one is used per guidance system. See Table IX. Of the total parts count, Table I, the remainder accounts for 50 percent of the SCS costs.

The other cost driver is touch labor which accounts for about 25 percent of the total SCS costs.

Radome

The manufacturing cost category breakdown of the radome is shown in Table X.

TABLE X

Radome Cost Categories

	(Percent)
Materials	12.6
Fabrication and Processing	66.5
Assembly	4.6
Test and Inspection	12.8
Support	3.5
TOTAL	100.0

The cost driver is touch labor. A description of the fabrication process is furnished with references to the effect on cost of the various steps in the fabrication.

The TZM nose cap is conventionally machined from bar stock and is not a major cost contributor to the radome assembly. The attachment ring is fabricated by hand layup of pre-impregnated glass fabric on a mandrel with conventional debulking methods used at intermediate stages of the layup. The completed layup is autoclave cured on the mandrel under elevated pressure and temperature and the cured part is machined to proper external contour while attached to the mandrel. The proper internal contour of the attachment ring is provided by the external shape of the mandrel thus reducing machining time. Fabrication of the attachment ring up to the point of bonding it into the ceramic body represents approximately 13 percent of the end item cost of radome and only 0.6 percent of the guidance system cost; therefore, cannot be considered a major cost driver.

Fabrication of the SCFS ceramic radome body represents approximately 46 percent of the end item cost of a radome assembly (2 percent of guidance system cost) and is considered the major driver of the radome cost. The radome body is produced by slip casting in a plaster mold, firing the resultant "green" casting at elevated temperature to produce a dense, rigid blank and grinding the blank to required dimensions. The starting material, slip, is a slurry of finely divided silica particles suspended in water. The plaster mold is made by allowing plaster of Paris to harden around a model of the shape to be duplicated. The plaster mold together with an internal displacement mandrel (sized to produce the required inner shape of the as-cast blank) is then filled with slip under pressure. The plaster outer-wall of the mold absorbs the water from the slip leaving a filter cake deposit which becomes the desired shape. The thickness of the cast wall is a function of time and typically a Pershing II radome blank requires approximately 6 hours of casting time. Excess slip is then drained from the mold after the desired cast wall thickness is obtained and the cast shape is allowed to partially dry in the mold before removal. The casting is then dried thoroughly in a temperature and humidity controlled environment to remove absorbed moisture before firing in a kiln to develop the desired sintered strength and density (which in turn determines the dielectric constant of the material). A typical firing cycle is six hours at 2200°F in air. It is during the critical casting, drying, and firing cycles that differential shrinkage of the part occurs and if not carefully controlled can result in cracking of the part, rendering it useless. Even with stringent control, a typical yield will be one useful blank for every two cast. During startup of a production run, casting yields are even worse, typically one of three or four until the process "tailoring" phase is complete for the particular part geometry involved. Fortunately, at this point in the process the material and manpower investment is relatively low so that low initial yields do not substantially drive the finished cost of a radome when produced in quantity (100 or more units).

After firing, the casting is thoroughly inspected for cracks, inclusions, and other flaws and then proceeds into the grinding phase which accounts for approximately 88 percent of the finished cost of the ceramic body. Two vertical grinders with diamond wheels are used in the operation, one to form the outside contour of the part and a separate unit to grind the inner contour. Approximately 70 hours of continuous grinding are required to produce a dimensionally acceptable radome body from the as-cast blank. Because of the hardness and brittle nature of SCFS, past attempts to reduce machining time by increasing feeds and speeds has invariably resulted in increased losses (reduced yield) and has proved economically unjustifiable.

After completion of grinding and necessary dimensional inspection, the part is oven dried to remove moisture, sprayed with a sealer of silicone resin, and proceeds to final assembly where the glass/epoxy attachment ring is bonded into the unit and the nose cap assembly is fitted.

Total Guidance Costs

The total Pershing II Guidance Subsystem cost is summarized in Table XI. The cost drivers identified previously in this paper carry over to the total guidance subsystem unchanged. We see that we have approximately 60 percent purchased material and parts versus 40 percent other cost categories - primarily touch labor. The 60 percent purchased material is made up of 30 percent primarily electronic piece parts (except for memory) for the electronic assemblies, and 9 percent for the microwave devices, where the high cost RF components predominate. On the labor category, the assembly category at 10 percent for the electronic assemblies is the only large cost driver.

TABLE XI

Guidance System Cost Breakdown

Standard Guidance Component		Manufacturing Cost Categories					
		Materials	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support
Radome	4.5	0.6	0	2.9	0.2	0.6	0.2
Electronics	49.2	1.0	30.4	3.4	10.2	1.5	2.7
Microwave Devices	11.7	0.1	9.1	0.9	1.1	0.2	0.3
Major Mechanical	20.5	0.1	11.7	1.5	2.5	2.2	2.5
Gyros	5.6	0	2.2	0.4	2.0	0.7	0.3
Accelerometers	3.6	0	0.9	0.7	1.3	0.5	0.2
Cables	1.9	0	0.4	0	0.7	0.6	0.2
Power Supplies	3.0	0	3.0	0	0	0	0
TOTAL	100%	1.8	57.7	9.8	18.0	6.3	6.4

TABLE XII

Project Cost and Potential Guidance System Cost Reductions

	Cost ($)	Potential Cost Reduction of Guidance System Cost (percent)
Production of printed wiring boards using the semi-additive technique	452,200	1.0
Improved production techniques for multilayer rigid-flex printed circuit assemblies	133,000	1.0
Elimination of connectors and reduction of interconnections	205,000	0.1
Printed wiring board cleaning procedures	120,000	0.15
Accelerated cure conformal coating for printed wiring boards	120,000	0.2
Microelectronic packaging utilizing leadless inverted devices (LID's) and chip component technology	65,000	5.0

MANUFACTURING TECHNOLOGY PROJECTS

With the cost drivers identified, the potential manufacturing technology projects submitted are primarily aimed at reducing the fabrication, assembly, and test cost of the electronic assemblies through reducing the cost of the printed wiring board. As a result, these technology projects should have widespread applicability to all electronic systems in which printed wiring boards are used. The microelectronics packaging project is aimed at a method of achieving the cost savings of MSI and LSI techniques, without the large initial investment of time and money, by utilizing component chips in leadless inverted devices that can be mounted directly on printed circuit cards. Table XII contains the proposed manufacturing technology projects together with project cost and potential guidance system cost reductions.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the invaluable assistance obtained in the furnishing of source material and in the preparation of this paper from his co-workers at Martin Marietta Aerospace, and from personnel at Singer Company, Kearfott Divison, Little Falls, New Jersey; Bendix Corporation, Guidance Systems Division, Teterboro, New Jersey; and Goodyear Aerospace Corporation, Akron, Ohio.

REFERENCE

Design to Unit Production Cost, AMC Guide - December 1974

Manufacturing Process for Producing Military Approved Printed Wiring Boards Utilizing the Semiadditive Technique

System/Panel Area/Component. Defense Missile Systems/Guidance Control and Launch/ Printed Wiring Boards (PWB).

Problem. The present Military Specifications preclude the use of a cost saving semiadditive or Thin Copper Foil (TCF) technique for fabrication of PWBs for Military systems. Changing existing specifications and writing new ones, where necessary, could result in considerable savings for the Military, since PWBs often represent 30 to 50 percent of a subsystem control cost, and improve pollution abatement. This process would develop technology for higher density packaging, finer line widths and improved spacings.

Proposed Solution. The processing techniques required to meet the demanding high density packaging requirements would be enhanced and the amount of undesirable effluents reduced. This would require the design, fabrication, installation and checkout of a pilot line. Test specimen fabrication and test data accumulation would be treated as a prime element as backup for Military Specification changes. Some of the more detailed task descriptions are:

1 Determine the affected specifications and the degree of impact.

2 Evaluate the process capability for producing laminations without foil pin holes.

3 Establish and perform test requirements.

4 Establish process control.

5 Develop automatic techniques with adaptive controls.

6 Change Military Specifications.

7 Write new specifications.

8 Acquire specification approval.

Project Cost and Duration. Estimated costs are as follows:

Pilot line design	$ 22,400
Pilot line construction - tank facilities	144,800
Pilot line automation - equipment and controls	112,000
Materials	5,000
Engineering support and tech data	112,000
Specification approval	56,000
	$452,200

Estimated duration of the project is 24 months.

Benefits. Expected benefits to be derived from this project are a reduction in recurring hardware costs for all PWBs produced for the Military and also improved pollution abatement. The reductions are as follows:

Reduction in drilling costs	20%
Reduction in etching costs	80%
Total reduction of a PWB	30%

This results in a 2 percent reduction in electronic assembly costs, and approximately 1 percent potential guidance system cost reduction.

Assumptions. That all branches of the Military are receptive to common specifications.

Improved Production Techniques for Multilayer Rigid-Flex Printed Circuit Assemblies

System/Session Area/Component. Missile/Electronic Controls/Electronics

Problem. Multilayer (M/L) rigid-flex circuits are an effective means of providing the complex interconnections needed for high density advanced design electronic assemblies. Present day techniques and tooling employing bench operations for their manufacture are expensive, and more automated lower cost concepts are required.

Procedures, tooling and bench operations are used to laminate, solder and trim M/L rigid-flex circuits. The following process requirements exemplify the problem areas which will require more mechanization in their fabrication.

Problem

1 Etching thin film laminates.

2 Selective cutouts of prepregnated fabric.

3 Bonding of copper to flexible H-film.

4 Curing of M/L laminated circuits.

5 Drilling, plating and verification of thru-hole connections and circuits.

6 Cutouts of M/L printed circuit board laminates and flexible H-film.

7 Skiving of flexible H-film for soldering branch circuit pads.

8 Soldering of M/L rigid-flex assemblies.

Proposed Solution. This project would center on development of new manufacturing techniques, low cost tooling concepts, mechanized procedures susceptible to automation, and producibility guidelines for production improvements in processing M/L rigid-flex assemblies. Present manual, bench type methods will be replaced with techniques which are inherently less costly by one or two orders of magnitude. The following actions are proposed:

1 Technical survey on M/L rigid-flex applications.

2 Design process and tooling improvements (standardization).

3 Prepare cost tradeoff analysis.

4 Pilot production of work samples.

5 Preproducibility/design guidelines.

6 Technical demonstration of automation.

7 Issue project documentation/reports.

Project Cost and Duration. Estimated costs are as follows:

Manufacturing and engineering effort in information collection, design, and checkout of new techniques	$112,000
Tooling	14,000
Material	6,000
Travel	1,000
	$133,000

Estimated project duration is 14 months.

Benefits. Benefits to be derived are a reduction in recurring hardware costs as follows:

Estimated reduction in manufacturing and quality labor costs of rigid-flex assemblies	80%

This is equivalent to an electronic system cost reduction of 1.8 percent, and approximately 1 percent potential guidance system cost reduction.

Assumptions. That utilization of rigid-flex packaging techniques will continue to be needed in the manufacturing technology applications of the 1980's.

Elimination of Connectors and Reduction of Interconnections

System/Panel Area/Component. Missile/Electronic Controls/Connectors

Problem. The use of connectors for round-to-round, flat-to-flat, and flat-to-round contacts often encounters problems because of hardware availability, hardware cost and system reliability. A standard connection typically requires a minimum of three interconnections to achieve electrical continuity between two electrical conductors.

Proposed Solution. Connectors will be eliminated and the interconnection between electrical conductor and male/female members reduced by joining electrical conductors to each other, thereby effecting only one interconnection instead of the usual three. Joining methods will be developed which are reversible and nonreversible. Nonreversible interconnections may be "broken" by removal of 1/8 inch interconnection area and repreparing adjoining conductor ends for reconnection.

Where testing requires multiple disconnects a temporary mechanical interconnection may be made until final assembly is desired with a reversible or nonreversible direct conductor to conductor interconnection.

Interconnection will be made by mechanical, soldering, or metallurgical hand procedures singly or in combination.

Project Cost and Duration. Estimated costs are as follows.

Manpower requirements	$165,000
Facilities	20,000
Engineering support	20,000
	$205,000

Estimated duration of project is 24 months.

Benefits. Benefits to be derived from this project will reduce project cost for the fabrication of the larger missile systems such as Pershing by approximately 0.1 percent each.

Assumption. The presently conceived and demonstrated interconnection philosophy can be readily advanced to be production worthy and economical.

Fabrication of Lower Cost, Higher Reliability Printed Wiring Boards by Mechanization of Cleaning Procedures

System/Panel Area/Component. Control - autopilot, servos, power supplies, networks, printed circuitry; guidance - electro-optics, printed circuitry, designators, IR devices; test equipment - printed circuitry.

Problem. Recent Military Specification revisions (MIL-P-28809) specify use of Rosin Active (RA) flux for soldering. All traces of rosin must be removed as indicated by ionic contamination measurement. Presently, specified solvents are not bipolar. They remove both polar and nonpolar soil; consequently, flux residue is not effectively removed. The problem calls for development of bipolar technology to meet Military Specification requirements within EPA/OSHA restrictions. PWB module fabrication is now ineffective and costs are prohibitive due to poor ionic/benign soil solvency power and redundant cleaning operations.

Proposed Solution. New solvent systems possess high solvency power for both polar and nonpolar soils. By the use of one of these solvents (35 percent ethanol in freon or water-based solutions) the industry will be able to conform with residual contamination requirements specified in MIL-P-28809 and other documents. In-process control and monitoring technology will be obtained by translation from laboratory measurement instrumentation on-stream feedback control systems.

Selected solvents will supersede nonpolar chlorinated hydrocarbons and become industry standards to conform with OSHA/EPA environmental edicts. Single solvent systems that can remove all soil types will be used to remove soil to the specified, required levels at a substantially lower cost with regard to intrinsic value and process labor. Developed in-line cleaning process would contain self-monitoring of solvent-of-Printed Wiring Board to ensure repetitive process effects automatically.

Project Cost and Duration. Estimated costs are as follows:

Technical survey	$ 5,000
Cleaning system definition	10,000
Pilot line design	15,000
Pilot line construction	25,000
Pilot line demonstration	15,000
Cleaning guideline development	10,000
Engineering and technical support	20,000
Adaptive controls and mechanization	20,000
	$120,000

Estimated duration of this project is 24 months.

Benefits. The benefits to be derived from this project may be applied to all electronic modules included in platforms, microwave devices, power supplies, transmitters, and sensors.

Electronic module cleaning costs for both labor and material can be reduced by a factor of 50 percent over present industry standards, and a potential guidance system cost reduction of 0.15 percent is estimated.

Improved performance and higher acceptance rate in fabrication will result from ability to use more active flux for improved solderability. The reliability/acceptance rate will improve by 20 percent.

An intangible benefit will be derived from the use of OSHA/EPA approved solvent systems and the ability to meet new Military Specification requirements.

<u>Assumptions</u>. The cost and acceptance benefits will be achieved from known tested solvent systems and well-designed, functionally-controlled stock hardware items.

The solvent usage will conform with EPA/OSHA standards as now defined and/or projected for future utilization.

Accelerated Cure Conformal Coating

System/Panel Area/Component. Guidance/Printed Wiring Boards/Connector Potting

Problem. Conformal coating now costs in excess of $10 per printed wiring board. bulk of this cost is from setup and touch labor. To obtain proper material properties, precise two-part weighing is required. Curing is for 4 to 6 hours at elevated temperature, during which time coating is tacky and attracts atmospheric contaminants, causing rework.

The curing cycle is a major manufacturing constraint. When the disadvantages of two part conformal coatings are considered - mixing, application poisonous solvent cleanup for gun and masks, pot life, and energy requirements - single material with indefinite pot life and fast cure (4 to 10 seconds) becomes extremely attractive.

Proposed Solution. Fast cure one-part resin systems are in widespread use in the furniture and printing industries. The material is easily applied by airless spray or curtain coating. The photo-initiator serves as a catalyst causing 100 percent liquid-to-solid conversion in a few seconds when ultraviolet radiation is beamed onto the liquid film. No other energy is required for curing.

Since the new technology is reduced to practice, the success risk is low. What must be developed however is a "curtain" flow of resin to accommodate irregular shapes of Printed Wiring Boards as the present art is for flat surfaces (originally developed for coating wood panels with epoxy at 100 feet per minute).

Preliminary development work shows that certain ultraviolet-cured resin families will meet the stringent requirements of MIL-I-46058C with regard to protective qualities and coating hydrolytic reversion characteristics.

Project Cost and Duration.

Specify coating and curing equipment	$ 30,000
Develop processing technology for regular shapes	30,000
Develop control technology	30,000
Certify process with written process	10,000
Implement process in production	20,000
	$120,000

Project is expected to require 24 months for completion.

Benefits. A cost-effective conformal coating system will be developed which cures in seconds instead of hours. Cost reduction will accrue from curing time factors, mechanized (curtain coating) application, energy savings, and material cost savings (no waste due to pot life).

The benefits derived from line throughput and readily mechanized in-line staging are apparent. Process controls are minimized, and skilled labor requirements reduced substantially.

All factors indicate a conformal coating fabrication cost saving of 60 percent and a potential guidance system cost reduction of 0.2 percent.

Assumption. Modification of QPL list of MIL-I-46058.

Microelectronics Packaging Utilizing Leadless Inverted Devices (LID'S) and Chip Component Technology for High Density Packaging

System/Panel Area/Component. Missile Systems/Guidance and Control/Electronic Assemblies.

Problem. Parts procurement typically accounts for 60 percent of all systems cost and there is a need for high density in many electronic systems. The use of hybrid, MSI and LSI devices during development and for the production of limited quantities results in a high initial parts cost, and an excessive turnaround cycle for incorporating changes. The savings inherent in hybrid, MSI and LSI techniques requires high production to justify the high front end costs.

Proposed Solution. A technology will be developed to utilize component chips and LID's attached directly to printed circuit boards by use of a solder cream or conductive epoxy. Sealing and protection would be provided by a vapor deposition of Parylene. These circuits will approximate the density of hybrids and allow for repair and the incorporation of change during the development phases. This technique also has application to the limited production quantities usually required by an engineering evaluation phase. The mechanical and electrical characteristics are such that they allow conversions to hybrids, MSI or LSI if the quantities of a carry-on production phase warrant a change.

Project Cost and Duration. Estimated costs are as follows:

Engineering and Technical Support	$36,000
Material	7,000
Travel	2,000
Test	20,000
	$65,000

Estimated duration of the project is 12 months.

Benefits. The benefits of this program are development of a system to allow high density packaging during initial development phases at cost in line with discrete component usage, and enhanced ability to convert to hybrid, MSI, and LSI devices during the carry-on production phase.

The use of LSI/MSI in place of discrete parts can result in savings up to 20 percent in electronic assemblies. Since 49.2 percent of guidance system cost is attributed to electronic assemblies, up to 10 percent guidance system cost savings could be achieved. A conservative 5 percent potential savings will be allocated to allow for existing MSI device usage, and for circuits where MSI is not applicable.

Assumptions. The assumptions made were that the trend of LSI costs is downward and that this technique has applications to any program where potential production quantities justify LSI's and where high density/low weight are requirements.

LOW COST INERTIAL GUIDANCE SYSTEM MANUFACTURING TECHNOLOGY FOR THE LONG RANGE GUIDED MISSILE

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INTRODUCTION

In assembling this paper and selecting proposed Manufacturing Technology Projects, Honeywell has attempted to attack the significant cost drivers. We have also directed our efforts along the goals stated by the Honorable W. P. Clements, Jr. in his Memorandum for the Secretaries. Specifically, we have chosen the technology that holds the most potential for advancing low cost, high reliability tactical missile midcourse guidance and control-- the Ring Laser Gyro. We are applying modern manufacturing techniques from the outset of its design (numerically controlled machining, hot pressed processes versus machining, laser beam cutting and welding, etc.) and are exploiting the existing Honeywell owned state of the art capital equipment for maximum producibility and minimum nonrecurring cost to the Army. In addition, we have chosen manufacturing projects that will assist the Army and advance basic manufacturing technology, thus benefiting the DOD requirements in general.

It is with these goals in mind that Honeywell submits these projects to the AMC Conference on Missile Manufacturing Technology.

BACKGROUND

The Long-Range Guided Missile (LRGM) is a tactical surface-to-surface weapon employing a conventional warhead intended for battlefield support missions in 1980. Low cost in volume production is of primary importance for the LRGM. The necessary multiyear development contracts further emphasize the need for innovative manufacturing techniques to counter the effects of inflation.

The Army Missile Command is currently evaluating several candidate concepts for LRGM guidance and control, such as distance-measuring equipment (DME), command guidance, and inertial guidance. Operationally and logistically, the inertial guidance approach has the advantage of being completely self-contained and independent of ground stations and ground or air based data links. It would also utilize elements of the present Lance missile ground-handling equipment (Figure 1).

As defined by the Army for LRGM, the missile guidance and control is performed by a guidance system composed of an Inertial Measuring System (IMS),

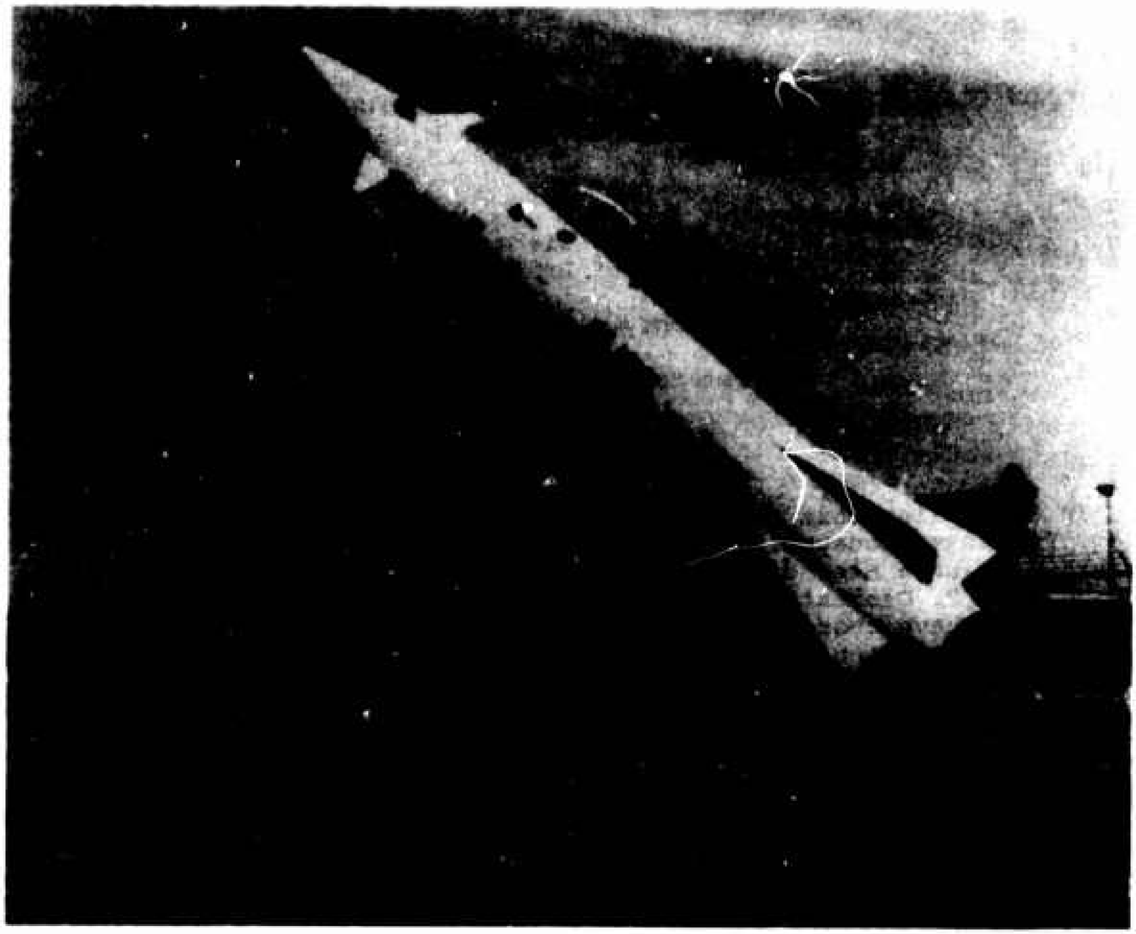


FIGURE 1. LANCE MISSILE ON MOBILE LAUNCHER

Flight Control Computer (FCC), and Unit Power Supply (UPS). In turn, the IMS includes a set of inertial sensors, three rate-integrating or attitude gyroscopes, and three pendulous accelerometers. The IMS senses the specific forces (thrust, lift, drag) and angular rates (pitch, roll, yaw) acting upon the vehicle from initial boost through aerodynamic flight to impact; the FCC processes the measurements to determine the vehicle's position, velocity, and attitude in a navigation reference frame which also contains target coordinates. Using predetermined guidance laws, the FCC then commands the vehicle to steer to the target. Finally, the FCC computes autopilot corrections from rate gyro inputs to maintain the vehicle on a stable path throughout the flight regime.

TECHNICAL APPROACH

The two most common ways to mechanize an inertial system are gimbaled and strapdown. In the gimbaled approach, the accelerometer triad is isolated from vehicle angular motion by gimbals which are stabilized in the navigation reference frame by the gyro triad. A separate body-mounted rate gyro triad is required for the autopilot function. In the strapdown approach, the gyro and accelerometer triads are mounted ("strapped down") to the vehicle body directly. The accelerometer outputs are transformed by the FCC from body to navigation frame by a nine-element direction cosine matrix which is updated by outputs from the gyro triad. This is sometimes referred to as an electronic gimbal.

The Honeywell approach to the design of a low-cost guidance system for LRGM is based on four elements:

a. The strapdown mechanization which eliminates expensive gimbals, torquers, and gimbal pickoffs.

b. Elimination of duplicate sensors and electronics for the autopilot function, a strapdown characteristic.

c. The ring laser gyro for the strapdown attitude sensor with its simple, rugged construction, and lower parts count.

d. Standard, commercially available high volume electronics parts for digital processing, control logic, and memory elements.

These technologies have been developed for the Naval Weapons Center/ China Lake on the Advanced Tactical Inertial Guidance System (ATIGS X-O Experimental Program). The ATIGS X-O (Figure 2) has repeatedly demonstrated two to four nautical miles per hour performance on two and three hour captive flights in an A7E aircraft. Technical and cost goals established in the ATIGS X-O program for the low cost production system, as shown in Table I, have resulted in the design of the modular ATIGS-2 System shown in Figure 3. Engineering development of ATIGS-2 is expected to be complete in 1978 with pilot production in 1979 and full volume production in 1980 to 1981.

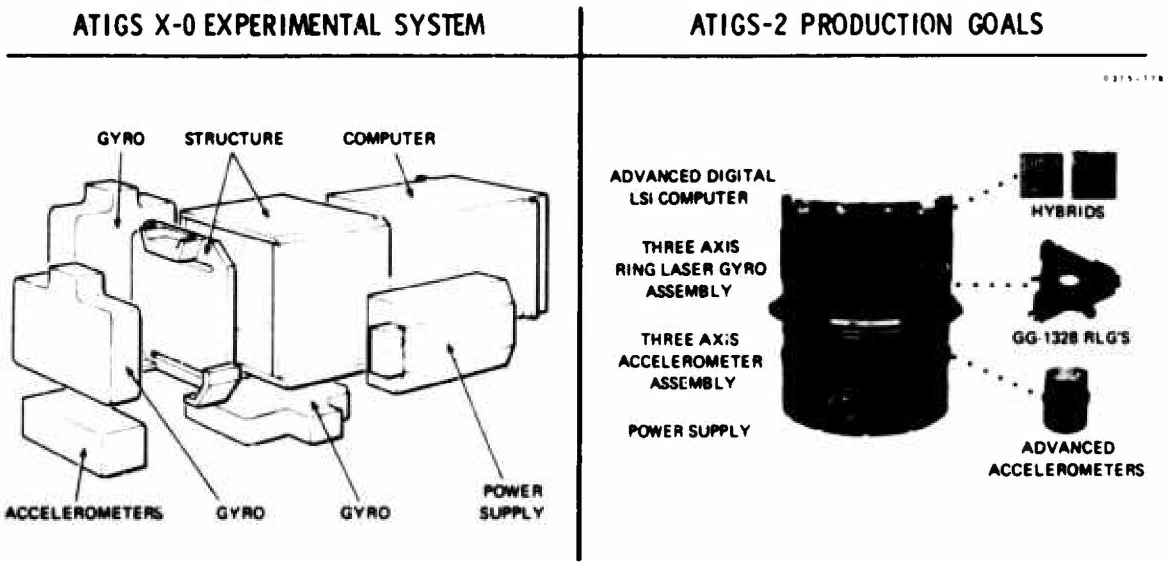


FIGURE 2. ATIGS X-O FUTURE PAYOFF

TABLE I. ATIGS DEVELOPMENT GOALS

Volume	500 Cubic Inches
Weight	25 Pounds
Power	65 Watts
Performance	500 Ft SEP (Missiles

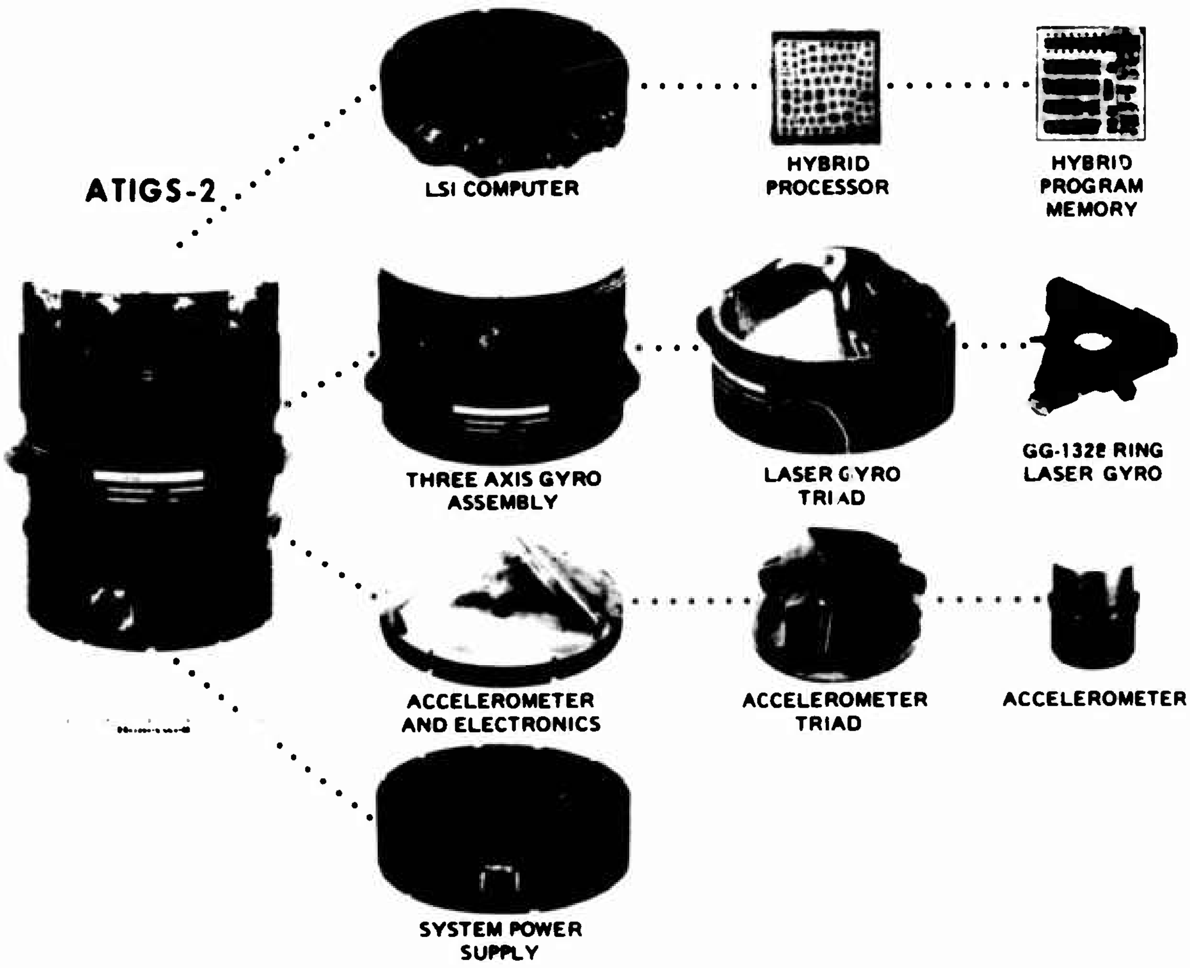


FIGURE 3. MODULAR ATIGS-2 SYSTEM

COST DRIVERS

This orderly development will allow sufficient time to develop the proposed manufacturing techniques to insure the successful attainment of the LRGM production cost goals of the 1980's. In attacking the design to cost and producibility efforts currently in process, we have identified the cost drivers and are systematically attacking each area. This paper, however, has attempted to categorize the drivers per the AMC Conference's format and will address only three areas requiring special Army attention and assistance. We feel these three projects fall into the Manufacturing

Technology charter and the results will be universally useful to the industry.

Several obvious cost drivers can be identified from Table II:

a. The gyro is the single highest cost driver.

b. The second most signifcant cost item is the electronics, and in particular, the digital computer hybrids (see Figures 2 and 3). In Table II, the FCC hybrids are included in purchased parts and comprise 13.7 percent of the total system cost. The benefits of the proposed manufacturing project on hybrids will be even more significant if the decision is made to utilize hybrids in areas other than the computer, such as inertial sensor electronics.

c. The third most significant cost driver is the accelerometers, but since the current plan is to procure these devices, no technology project is proposed at this time. Honeywell, however, has under research a heaterless high-g accelerometer which may be an area for consideration in the future.

Although system level testing does not show in the cost model as a line item, it is a critical event which limits production rate and influences per unit cost. In addition, this testing screen must insure that only "good" hardware reaches the Army or the life cycle cost escalates. In addition, this proposed testing project would allow the Army to make maximum utilization of one of the most advanced inertial guidance test facilities in the industry and is in keeping with the Army's objective of providing incentives "for contractor capital investments in modern, more effective manufacturing facilities" (1). Special emphasis will be assigned therefore, to testing and Honeywell has included a proposed task for this effort.

TABLE II. LRGM/ATIGS ADVANCED TACTICAL GUIDANCE SYSTEM COST BREAKDOWN

Standard Guidance Component		Manufacturing Cost Categories					
		Materials	Purchased Parts	Fabrication & Processing	Assembly	Test & Inspection	Support
Ring Laser Gyros (3)	40.9%	1.3	3.2	$\boxed{13.2}$	9.9	3.9	9.4
Electronics (FCC)	21.8%	---	$\boxed{17.6}$	---	1.6	1.4	1.2
Accelerometers (3)	15.9%	---	$\boxed{15.9}$	---	---	---	---
Unit Power Supply	6.2%	---	2.5	---	2.5	0.5	0.7
Structure	10.1%	3.7	2.4	0.7	1.3	1.2	0.8
Cables & Connectors	5.1%	---	3.3	---	1.2	0.4	0.2
TOTALS	100%	5.0	44.9	13.9	16.5	7.4	12.3

☐ MAJOR COST DRIVERS

The next section delineates manufacturing projects to attack. In order of priority: the Ring Laser Gyro, Hybrid Electronics, and System Test Cost Drivers. Following the technology discussion is the Project Summary for each of these projects.

PROPOSED MANUFACTURING TECHNOLOGY PROJECTS

Manufacturing Technology Project for Optimizing Hybrid Manufacturing for the Computer

Problem. In its final or production form, the ATIGS Advanced Digital Computer Subsystem will be a small, compact, and functionally capable device. It will consist of a circular housing containing two printed wiring boards as shown in Figure 3. Mounted on each circuit board are three thick film hybrid packages, each two inches by two inches. One of these hybrids is a central processor (CPU), one nonvolatile program memory (PM), one scratchpad memory (SPM), and the other three are input/output modules. The integrated circuit chip complement consists of approximately 400 chips for the total computer and represents approximately 22 percent of the total system cost (see Table II and Figure 4).

The costs for the computer are divided into the following major areas: hybrids, circuit boards, and final computer assembly and test. The hybrid costs, including the integrated circuits, mounting labor costs, and the

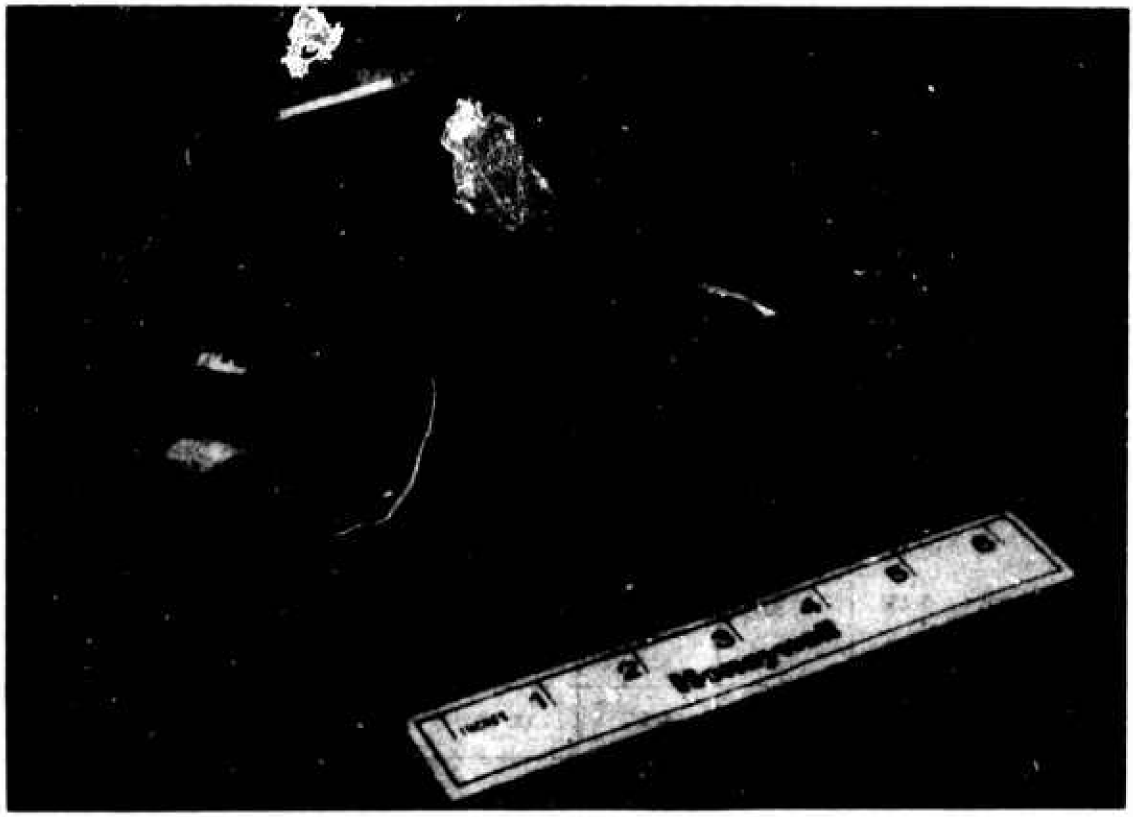


FIGURE 4. ATIGS COMPUTER SHOWING THICK FILM PACKAGES

device test, account for 81 percent of the total computer cost. These costs assume the use of commercial parts screened to Mil-Spec requirements and the bonding of these parts to the substrate by use of flying wire bolts. The wire bonding process has been the industry standard for mounting integrated circuit chips in packages or onto hybrid modules. This technique is time-consuming and costly. Further, the wire interconnects have been recognized as the major source of failures in IC's and hybrids. Several attempts have been made to speed up chip handling processes. Some, like Spider Bonding and Unibond, tried to automate the chip transfer from the wafer to the dual-in-line lead frame. For others, such as beam lead and flip chip processes in which chips were used for multichip applications, modifications in the conventional metallurgy of ICs allowed a collective bonding of all pads on a substrate. For many reasons, such as pad number limitation, limited power dissipation capability, and lack of standardization between manufacturers or cost, none of these techniques has been totally successful in becoming a new industry standard.

Proposed Solution. Preliminary studies have shown that significant cost reductions can be achieved by eliminating the manual bonding of the chip leads. The proposed method for achieving this goal is Tape Automated Bonding (TAB). It derives from the Honeywell Multibond Process and is in preproduction at Honeywell's Computer Facility in Phoenix, Arizona. The process consists of two main operations:

a. IC's are picked up from a sawed wafer and bonded to a 16 mm wide, copper laminated, plastic tape (Figure 5). Accurate chip orientation is preserved during and after bonding.

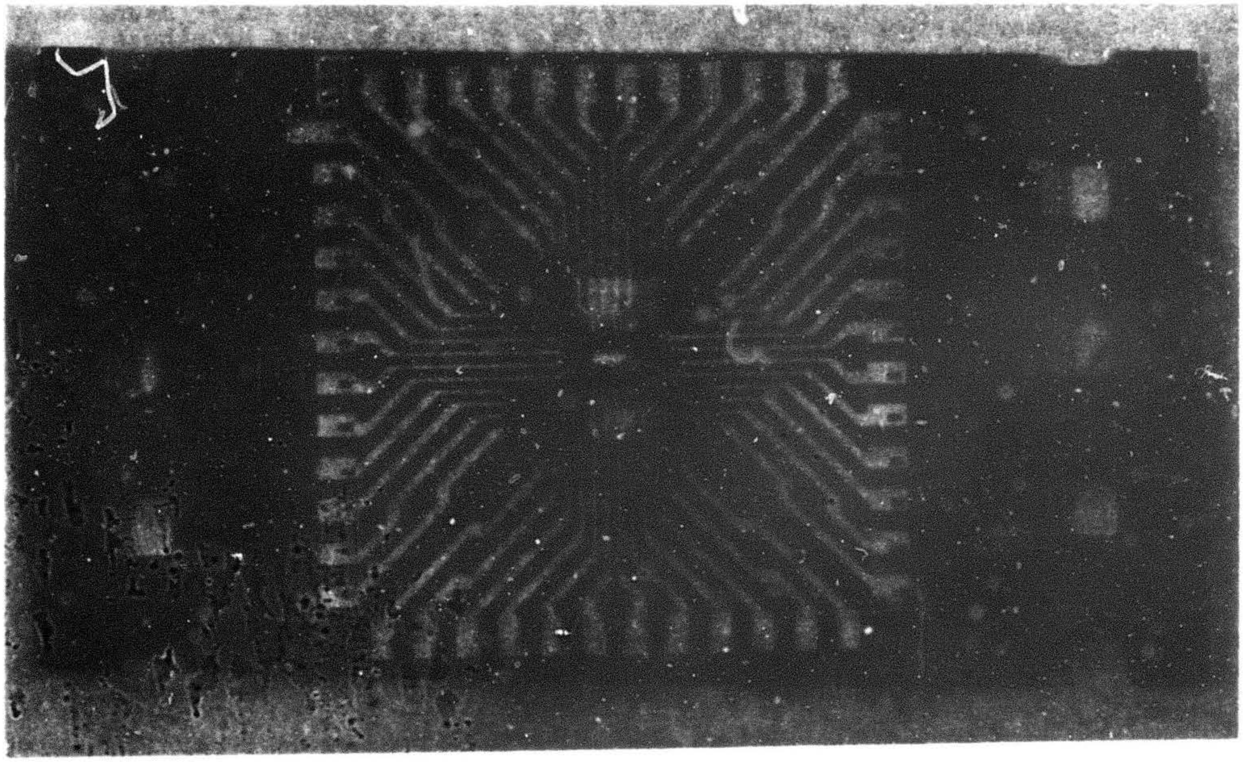


FIGURE 5. TAB TECHNIQUE CHIP SOLDERED TO CARRIER STRIP

b. Depending on the application, this plastic tape is then wound on on a reel, or chips in 35 mm slide frame are used to transfer chips onto the ultimate substrate. In the LRGM computer application, IC's will be bonded onto multilayer ceramic substrates.

TAB, as previously described, is conceptually easy to automate utilizing:

a. A carrier tape (Kapton presently).

b. A wafer sawing machine which preserves chip orientation.

c. A bonder for chip to tape bonding.

d. A bonder for chip to substrate (or lead frame) bonding.

Laminated tape fabrication is not a complicated process. Honeywell has a commercial production line for its tape needs. Several flexible circuit manufacturers can also provide tapes to Honeywell's specifications.

Wafer sawing is the second step which has to be automated. Wire saws have been available for several years. Their major drawback is the kerf between rows of chips which is larger than usual scribe lines.

A new wafer saw using a diamond impregnated blade has recently been introduced on the market. It allows a kerf loss in the range 0.001 to 0.002 inch entirely compatible with standard scribe lines.

To fully demonstrate the feasibility of the TAB concept, three machines have been commercially developed. Two of them are bonders and have been called Inner Lead Bonder (ILB) and Outer Lead Bonder (OLB). The third one is a test adapter for ac and dc testing of IC chips.

Once IC chips have been mounted on tape (ILB), they would be ac (and dc) tested in order to bond only good chips on substrates. The flexibility of performing 100 percent functional testing is one of the main advantages of TAB. Standardization in the location of the outer ends of leads at the tape level (Figure 6) provides this flexibility. The test pattern shown allows use of the same probe head for any chip type provided pin count is at most 24. Other heads are used for higher pin count IC's.

The TAB process just briefly described lends itself to complete automation. It has several advantages over the conventional chip bonding processes:

a. Individual handling of IC chips is completely automated and full advantage is taken of the high accuracy in chip alignment which exists at the wafer level and is preserved throughout the entire process. Without this accurate alignment, complete automation would be practically impossible.

b. Fast, complete dynamic testing is possible once chips (of whatever type) have been bonded on the tape. This step permits only good chips to be bonded onto the substrate and thereby represents a significant increase in module yield.

c. In case of multichip substrate applications, compatibility between equivalent chips of different manufacturers is possible. Only the inexpensive photomask which defines lead etching has

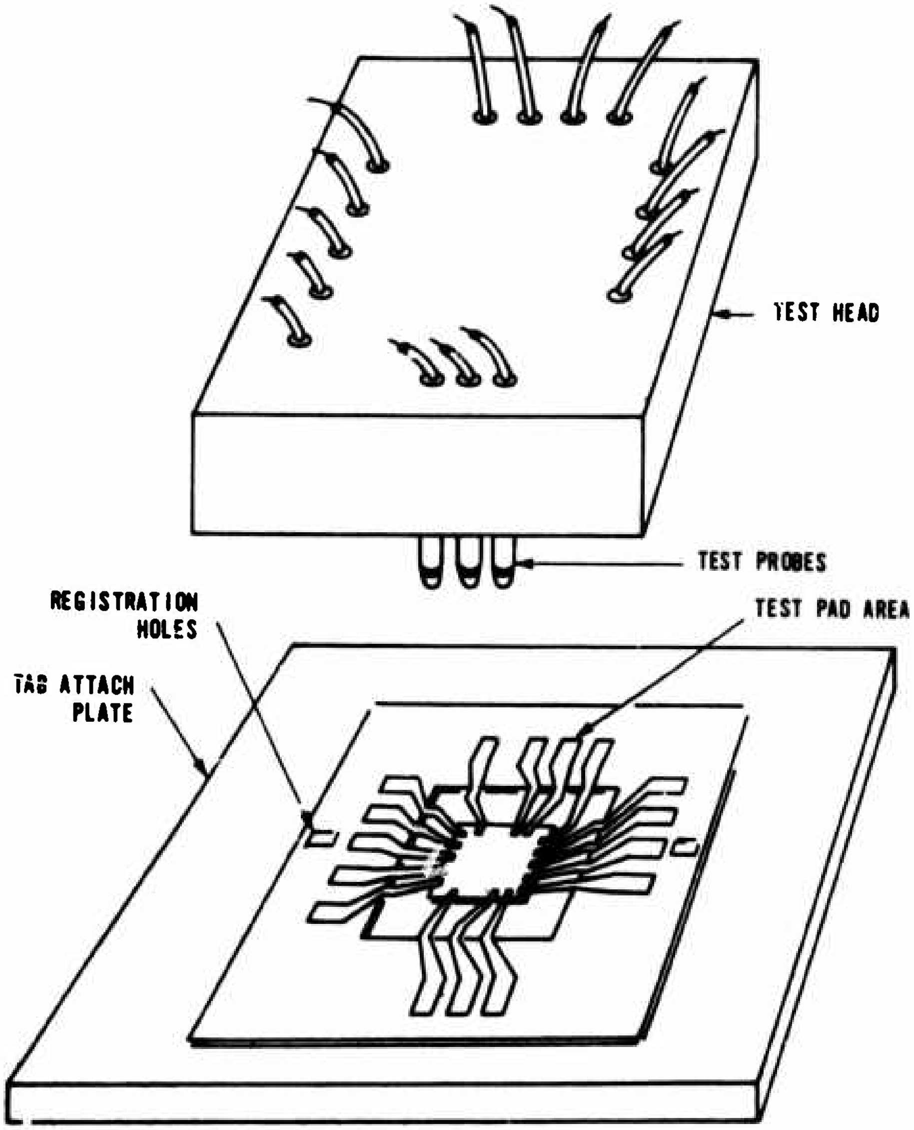
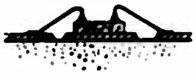


FIGURE 6. RIBBON TEST AREA

to be changed. This compatibility is a significant feature which up to now has been a problem with beam leads and flip-chips. Table III summarizes the various chip attachment procedures and compares them to TAB.

TABLE III. CHIP ATTACHMENT CONVENTIONAL TECHNIQUES VERSUS TAB

0675-305	Compatibility *	Automation Capability	Number of Leads	Connection Length	Heat Transfer Capabilities Rth (J-s)	Dynamic Testing
Die and Wire Bonding 	Good	Poor	High No limitation	0.010" to 0.030"	Good 2 to 10°C/W	Expensive
Beam Lead 	Medium Good	Medium Poor	High 50	0.005" to 0.010"	Poor 50 to 100°C/W	Expensive
Flip Chip 	Poor	Medium Good	Low 30	0.000"	Medium Poor 25 to 75°C/W	Expensive
TAB 	Good	Good	High 72 demonstrated	0.020" to 0.040"	Good 2 to 10°C/W	Inexpensive

*Capability to mount equivalent chips from different manufacturers at same substrate location.

Project Cost and Duration:

•	Assessment and R&D Study of TAB for Military Applications (Go/No-Go decisions on metallization system and approach)	$ 55,000
*•	Production Line Prototype Equipment Development and Evaluation	120,000
•	Test Prototype Equipment Development and Evaluation	80,000
•	Production Line Equipment Fabrication and Installation	100,000
•	Test Equipment Fabrication and Installation	75,000
		$430,000

The duration of this program will be 30 months.

Benefits. This technology and production technique will reduce module test time (all IC's are tested before mounting), assembly time (automated equipment), rework effort (pre-tested piece parts and simple repairs), and will increase yields. Net result is a significant cost reduction and reliability improvement in the missile computer and potentially in other areas of the system.

Reduction in Computer Costs	10 percent
Reduction in System Costs	2.5 percent

Assumptions. The above presentation and figures assumed a delivery rate of 50 systems per month. For that number of systems, the number of IC's in production per month is approximately 25,000.

Manufacturing Technology Project for Adapting Advanced Capital Facilities for High Volume ATIGS Inertial Guidance and Control Testing

Problem. Prototype laser guidance system testing (gyros, accelerometers, and digital computers) has been performed in a manual/semiautomatic mode with high operator interaction and cost. The present test method does not optimize operational confidence because of differences in test versus flight dynamics, nor provide the low cost, high volume test capability to meet tactical missile guidance and control delivery rates and cost goals.

Proposed Solution. During the past two years, Honeywell has acquired and capitalized a state of the art test facility for support of its new products. This facility has just become operational and is now available for application to a wide range of programs and products. The ATIGS hardware approach is an ideal candidate for test in this facility, and adaptation of the guidance system to the facility will be cost effective for Honeywell and the Army LRGM program. It is proposed that we mechanize a

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* This development effort is predicated upon the fact that commercially available materials and processes may not be compatible with the requirements of military hardware.

multiple system calibration and performance test. This test will be computer controlled with no operator intervention on an automatic test table. (See Figure 7.)

This system will consist of a three-axis test table, computer controller, special fixturing, special software package for test and control, and will interface with an existing centralized data management system.

The test system hardware will consist of:

a. An available Goerz Model 551-2 or equivalent test table, four of which are currently in place and operational at Honeywell's Aerospace Division.

b. Special fixturing which will mount four or more guidance systems for concurrent testing and will isolate guidance system mechanical crosstalk.

c. Test computer and interface: H316 minicomputer with special purpose table control and data interface.

The test software will be modular and written in a high level language such as FORTRAN for ease of transfer to other computers. It will include diagnostic capability for the unit under test as well as the test system, and will enable automatic fault isolation to the shop replaceable unit. Software routines will be developed to automate all tests. The advantage of this approach is repeatability of testing and building the engineer's knowledge into the test.

The data analysis will be both real time and batch for history purposes. Real time analysis of critical parameters will be displayed locally and logged automatically for history.

The data package will be printed at the end of each meaningful increment of the guidance system test. Each data package will be stored in a central system for trend analysis and history file.

FIGURE 7. HONEYWELL'S INERTIAL TEST FACILITY

Project Cost and Duration. Estimated costs are as follows:

Analysis	$ 50,000
Interface Hardware Modification	100,000
Software	75,000
Demonstration Test	50,000
	$275,000

Estimated duration of this project is 12 months.

Benefits:

a. Reduction of 12 percent in factory testing cost.

b. Reduction of 1 percent in total guidance system acquisition cost.

c. Test time will be reduced from six hours per unit to one-half hour per unit using the multiple technique described.

d. The proposed method is a dynamic test capable of giving operational confidence at a factory or depot level and will greatly simplify field operational problems and save an intangible, but large amount of money in operational use.

e. The test will be automated and rigorously controlled so that costly human errors will be minimized and will not slip through the manufacturing process to become field problems.

f. Data package will be automated and standardized and will ease the Army inspection task during sell-off of guidance systems from factory to depot.

g. Honeywell has operated such a test system and has capital equipment available to mechanize and demonstrate it.

Manufacturing Technology Project to Optimize Production Processes for Laser Gyros

A labor/material breakdown of current costs of the ring laser gyro is shown below.

	Percent of Current Costs		
	Laser Block	Mirrors	Total
Material	1.9	0.1	3.2
Purchased Parts	---	3.9	7.9
Fabrication and Processing	11.2	6.4	32.2
Assembly	---	---	24.1
Test and Inspection	---	---	9.5
Support	---	---	23.1

Major cost drivers are the laser block and mirrors. These components contribute 23.5 percent to the cost of the gyro directly. Indirectly, through their impact on assembly, test and inspection costs, they contribute approximately another 10 percent. A schematic representation of the block assembly is shown in Figure 8 and a photo description in Figure 9.

Problem. The major cost driver of the ring laser gyro is the fabrication cost of the ring laser block. The block is made of CerVit 101, a stable low expansion but high cost glass ceramic material available only in bulk form. It must be machined to intricate contours and close tolerances. Currently, single spindle, manually controlled ultrasonic diamond milling and drilling machines and single spindle optical polishers are employed. Efforts to reduce laser block costs have focused on a search for alternative lower cost materials having the potential for utilizing lower cost manufacturing processes and on the development of improved machining and polishing technology.

Alternate Material. Contacts with glass and glass ceramic manufacturers have identified a material similar to the CerVit 101, capable of being hot pressed and possessing appropriate physical properties. Hot pressings of this material are currently being used to manufacture a line of commercially available components so that basic technology has been developed and production facilities are existent. Enough progress has been made to date in achieving the required material homogeneity, that is, freedom from entrained air, to warrant consideration of this material for the laser block. Current estimates are that the cost of the final, hot pressed block will be comparable to the raw material cost of the CerVit 101 in production quantities.

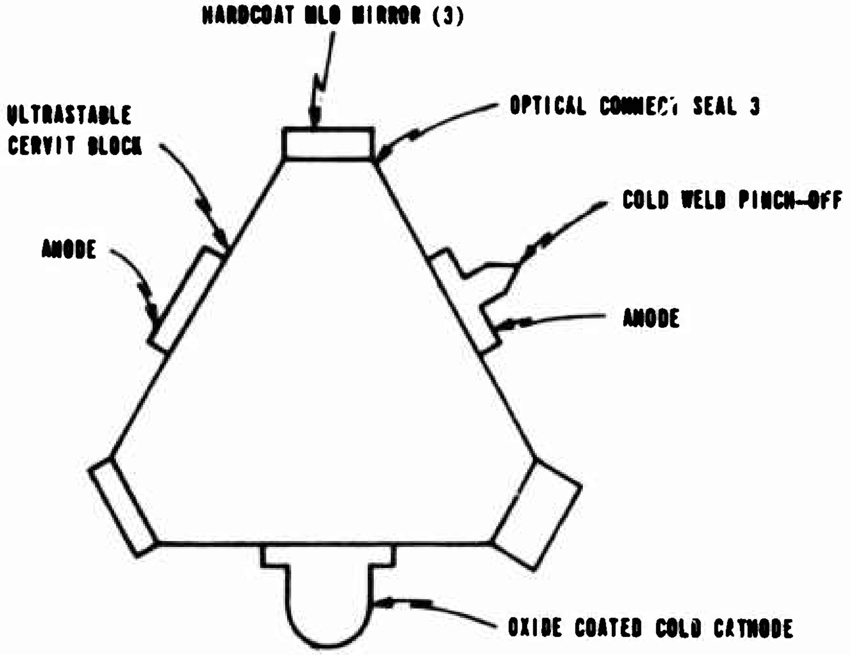

FIGURE 7. HONEYWELL LASER GYRO DESIGN CONCEPT

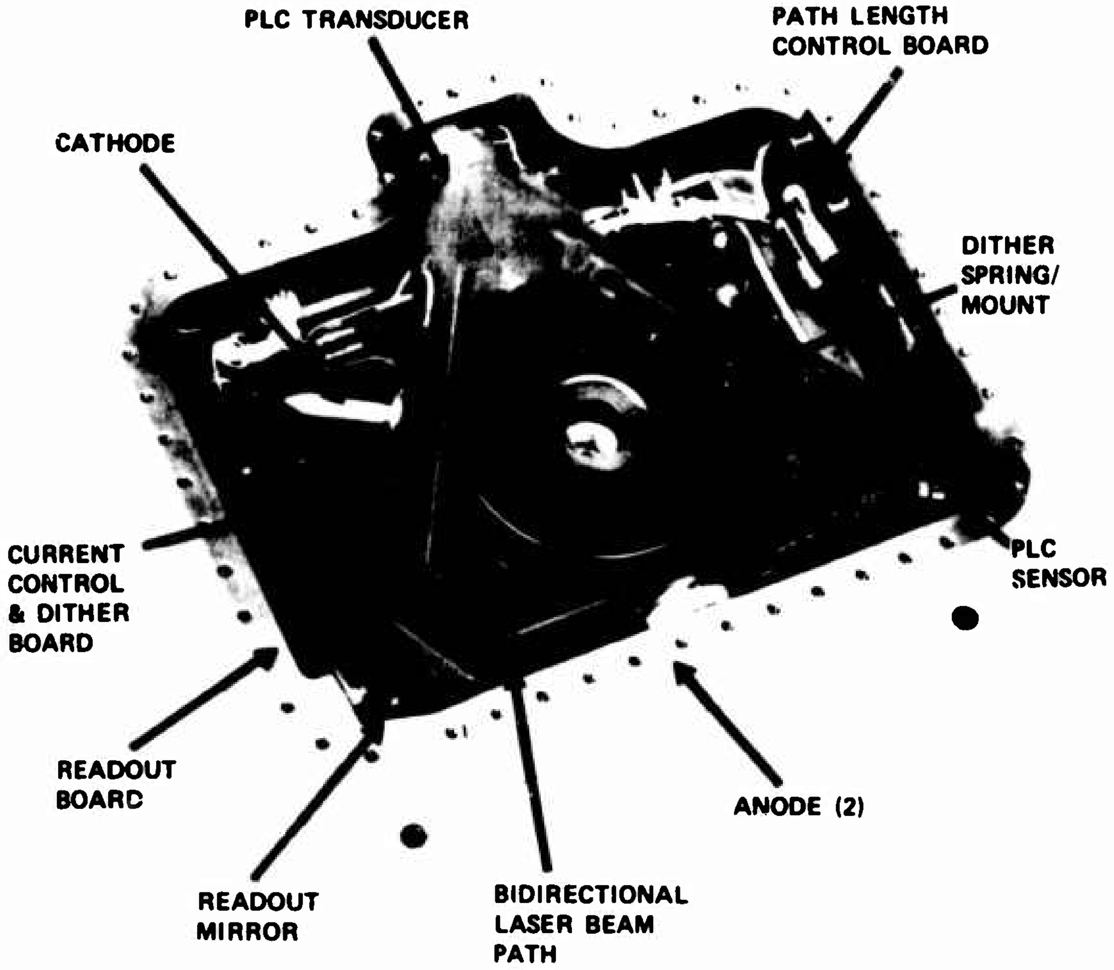

FIGURE 8. RING LASER GYRO

The hot pressing will permit many of the previously machined external features of the block such as the dither mechanism, to be achieved at no additional cost. By the judicious distribution of the block material in stiffening ribs, etc., it will permit a reduction in block weight and inertia and an increase in stiffness at no additional recurring cost. The resultant improvement in performance under dynamic environment reduced dither drive power requirements, and electronics simplification are additional benefits to be realized. Vendor mold and process development and in-house design and development efforts are required to implement both this manufacturing technology development and other modifications designed to eliminate several expensive components by integrating their functions into the laser block.

Machining Technology Development. Block machining costs have been reduced to one-third of their original costs over the last three years using Ultrasonic Diamond Grinding Spindles for milling and drilling operations. These single spindle, operator tended machines are vintage tool room equipment when measured against what is achievable with numerically controlled machines employing these spindles. Machining costs can be reduced 10 percent by the combination of hot pressing, design modification, and the development of an automatic indexing, numerically controlled Ultrasonic Diamond Milling machine and a three spindle Ultrasonic Drilling machine. The latter will permit simultaneous ultrasonic grinding of the three sets of identical internal features and mirror mounting faces. Preliminary studies have established the feasibility of these machines and have identified parameters to be controlled and development effort required. The basic machine tool configuration has been established. The result of the proposed machine tool development effort will be the achievement of a glass ceramic machining capability on a par with contemporary metal working technology and block machining costs consistent with targeted gyro costs.

Machining technology development required includes: developing the optimum spindle speed and transducer parameters, establishing the automatic shutdown criteria, design and fabrication of the machines and application of the machines to the block and mirror substrate fabrication.

Polishing Technology Development. The potential for reducing block polishing costs to less than one-third of their present costs by gang polishing tool development has already been demonstrated. The latter is based on the use of a four-block holding fixture and the simultaneous polishing of four surfaces on conventional polishing equipment.

The comparatively poor surface control resulting from current ultrasonic diamond milling operations in comparison with the precision surface location and flatness control required for the molecular bonded mirrors, necessitates multiple polishing operations with progressively finer polishing compounds. By the implementation of a fine-grinding operation with diamond bonded laps, preparatory to the polishing operation, a high quality surface close to the final surface requirements can be achieved at very low cost. With modern bonded-diamond products, the preparation of optical surfaces for polishing becomes more nearly a machining operation, and considerably less the craftsman's art. It will permit the use of unskilled operators to attend to the loading function.

By eliminating the need for polishing on half of the surfaces now polished, reducing the number of separate polishing operations required on the mirror mounting surfaces, and by gang polishing on several conventional polishing machines tended by a single operator, polishing costs can be cut 5 percent.

The manufacturing technology development required involves refining the gang polishing tooling, applying existing fine grinding equipment and technology, restructuring and refining the polishing operations, and developing the required inspection and metrology.

Mirrors. The mirrors are high cost elements requiring manufacturing technology development to effect the transition from single item fabrication to high yield batch processing. The flat, curved and adjustable mirror substrates require the development of improved manufacturing tools, processes, and controls for fine grinding and polishing and improved polishing materials. The mirror coating processes now employed provide satisfactory mirrors in small lots but at excessive cost and with excessive lot-to-lot variablility. Production equipment and processes and improved process controls identified below will permit the required 5 to 1 reduction in substrate cost and 10 to 1 reduction in mirror coating costs.

Substrate Machining and Polishing. Viable batch processing techniques have been developed for the fabrication of flat mirrors substrates which to date have cut substrate costs to one-fourth of prior costs.

Additional development is required to permit the extension of these techniques to larger production lot sizes with improved controls. Fine grinding will achieve superior surface flatness and finish, and reduce subsequent polishing costs. Application of the above, in conjunction with the numerically controlled ultrasonic machines, will permit low cost fabrication of the adjustable mirror which provides the laser gyro's optical path length control. Modification of the curved mirror design will permit the tooling to be developed for the simultaneous generation of the concave surface on a lot of parts.

Mirror Coating. Multilayer Dielectric mirrors used to form the laser cavity and their interaction with the laser beam determines the performance of the gyro. Establishment of the mirror criteria to be met has not been considered within the scope of the proposed manufacturing technology program but is a necessary precursor effort. The manufacturing technology program will insure that the established mirror criteria are met in a cost effective manner consistent with established targets. The primary objectives will be to establish and meet the required substrate criteria and coating process control. Mirror coating is a batch process with unit cost essentially dependent on the capacity of the deposition chamber once satisfactory substrates have been loaded into the chamber and adequate control of the deposition process insured. CerVit substrate scatter evaluation techniques will be developed. Alternative mirror coatings which may be more susceptible to process control will be sought. Several specific compositions have been investigated and shown to provide significant potential performance benefit. Recent modifications of the standard electron beam evaporation process which shows promise of being able to improve the stability of laser mirror materials will be investigated.

Other Related Manufacturing Technology Development. In addition to the above fabrication and processing cost drivers, there are cost drivers in all the areas tabulated in the labor/material breakdown of the ring laser gyro. In general, these either require longer lead time manufacturing technology development or shorter lead time engineering efforts to achieve the cost targets established. The latter, having less new development content, are not included herein.

The longer lead time manufacturing technology development required include the following:

- Lower cost batch cleaning processes for laser gyro components.
- Lower cost seals for electrodes.
- Multiunit fill station for simultaneous fill, test and pinch off of several laser blocks.
- Mirror-to-block and block-to-case alignment tools and processes.

Typical of the necessary but shorter lead time engineering efforts required but not included are the following:

a. Cost reduction of mechanical hardware by the application of precision casting, deep drawing and powder metallurgy to case, covers, electrodes, brackets, etc.

b. Rationalization and automation of computer assisted gyro calibration, acceptance test and test log preparation.

c. Electronics manufacturing technology development.

REFERENCES

(1) Memorandum signed by W. P. Clements, Jr. for the Secretaries of the Military Departments, Subject: Cost Reduction Initiatives, stamped April 11, 1975.

SAM-D GUIDANCE SYSTEM MANUFACTURING TECHNOLOGY PROJECTS

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ABSTRACT

The SAM-D Air Defense Missile System is currently in the "Proof-of-Principle" guidance-system flight-test program phase. Experience that has been gained in building and testing the first group of the guidance systems has provided insight as to the areas where the development of new manufacturing technology could provide significant production cost reductions for the SAM-D system. About three years are available for the development of new manufacturing technology to permit its application to the SAM-D system during the Producibility Engineering Planning phase. The major cost drivers are the airborne travelling-wave tube, gyros and accelerometers, radome, microcircuit devices, hybrid microcircuit assembly, and the ground-radar array-element support structure. Thirteen manufacturing technology projects are proposed to deal with these and other production problem areas. The cost of these projects is estimated at approximately $10 million, with a potential total production-cost saving of approximately 8 percent of the airborne guidance system cost and approximately 2-1/2 percent of the ground radar unit cost.

INTRODUCTION

The SAM-D Air Defense Missile System is currently in the development phase, and the guidance system is demonstrating its basic performance characteristics in the initial series of guided-missile flight tests designated as the "Proof-of-Principle" flight-test program.

As of the end of August, 1975, five of these flights have been made successfully. More than half of the guidance systems for these flights and several ground-test missiles have been completed and the remainder are in various stages of assembly. This provides some visibility as to the major areas in which design changes are required for producibility and as to the areas in which new production technqiues will be required to handle the unique features of this new design. Some of the problems will be resolved during the normal evolution of the engineering development program. Others will be dealt with during the producibility engineering activities that are a prelude to the first limited production phase. The first stage of this is the Producibility Engineering Planning Phase, which is currently being planned to start in 1978, with low-rate initial production being considered for 1980. Thus, there is a period of several years for the development of new manufacturing technology to be available as the basis for production implementation for SAM-D.

The purpose of this paper is to identify those areas in which the investment of funding well in advance of future production to develop improved manufacturing methods could provide a significant pay-off for reducing the cost of the SAM-D guidance system. Presented herein are thirteen proposed projects which have high potential for production cost reduction. In almost all cases, these developments can also benefit other programs. As background for these proposed projects, a brief description of the SAM-D guidance system is presented, followed by a percentage breakdown of the cost elements of its major components, and a discussion of the projects.

SAM-D GUIDANCE SYSTEM DESCRIPTION

The SAM-D guidance system applies the "target-via-missile" (TVM) concept, wherein a ground-based multifunction phased-array radar and digital computer are used both to track the target and control the missile in flight. The radar tracks the target aircraft and also illuminates it with radiation that, when reflected by the target, is received by the interceptor missile. Information on the target is then relayed from the missile to the ground for instantaneous course correction, if required.

To accomplish the functions described above, the guidance system consists primarily of a seeker and on-board transmitter/receiver system for communication with the ground-based portion of the guidance system. The seeker is comprised of an antenna, inertially stabilized pedestal and gimbal assembly with rate integrating gyros and torquer motors, and various electronics for head control and for processing the received signals. For the purpose of this discussion, the slip-cast fused-silica radome can be considered to be part of the seeker. The uplink/downlink system is comprised of a high-voltage power supply, transmitter with travelling wave tube (TWT), receiver, several antenna horns, and antenna-select switching system. In addition, there are several electronics packages to perform various logic and flight-control functions. The autopilot, consisting of an electronics package and inertial sensors assembly (ISA), which is furnished to Raytheon by the Martin-Marietta Corp., is included herein as part of the guidance system. A single multipurpose battery supplies power to the entire guidance and armament systems. (A separate battery is used to power the motor for the hydraulic pump in the control actuation system.)

The location of these various components is shown in Figure 1. It can be seen that most of the guidance system is packaged compactly into the guidance section, with the seeker antenna projecting forward into the radome. Various elements of the link antenna system are installed in the warhead and control sections, and the inertial sensor assembly, with its three body-mounted rate gyros and linear accelerometers, is mounted at the aft end of the warhead section. The exploded view of the guidance section shows that most of the electronics, including the autopilot electronics package, are assembled in trays which surround the inner structure. The battery and power supply are mounted in the center, with the TWT and transmitter components and the aft end. A cooling system is provided for ground testing. An overall view of the electronics trays and the seeker assembly is given by Figure 2. The TWT is illustrated in Figure 3.

The SAM-D guidance system has been designed to meet stringent performance specifications within very tight constraints of packaging volume. It therefore has the characteristic of being densely packaged and of making use of a number of integrated circuits and hybrid microcircuit assemblies, as illustrated in Figure 4.

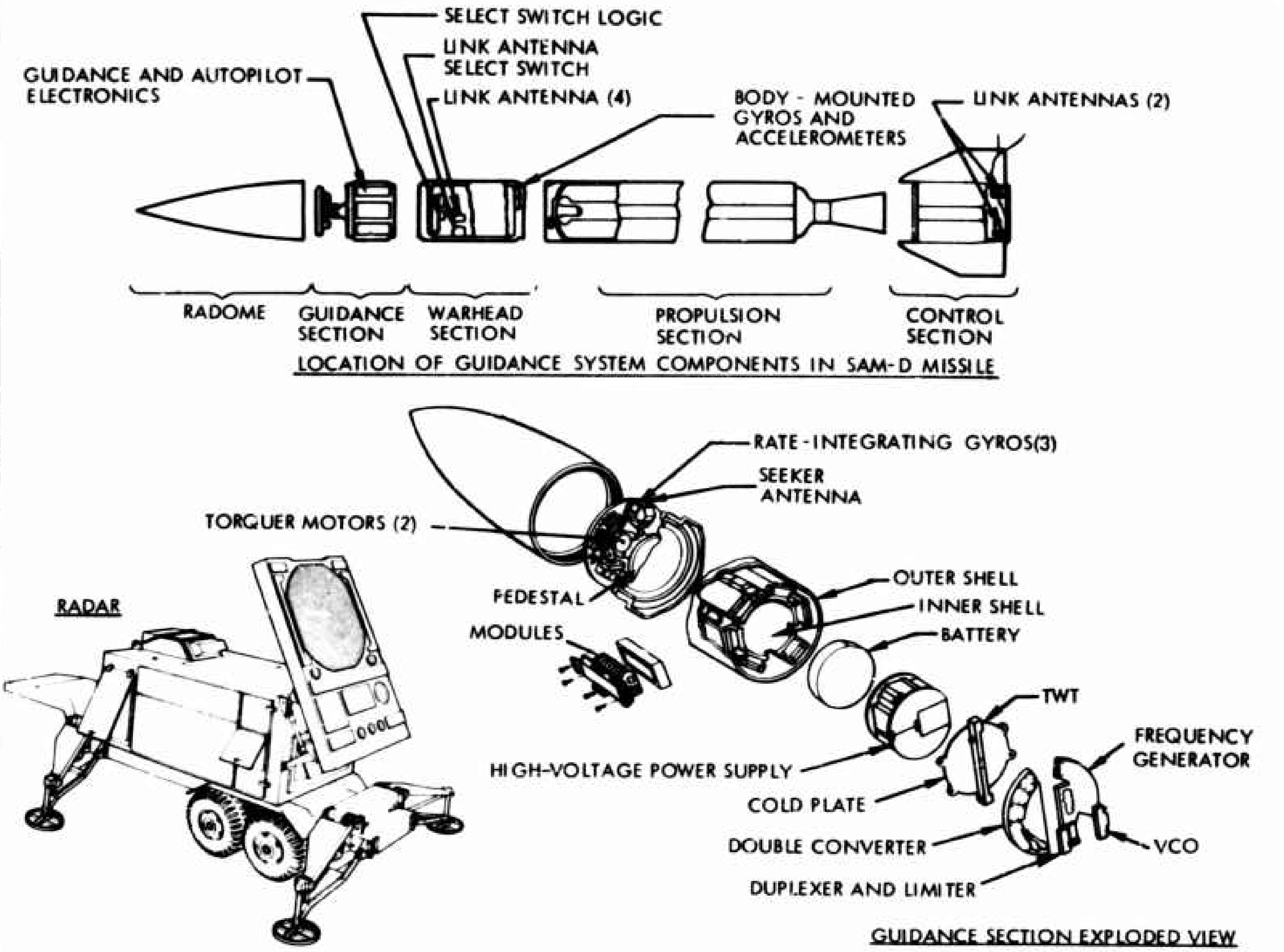

FIG. 1 SAM-D GUIDANCE SYSTEM

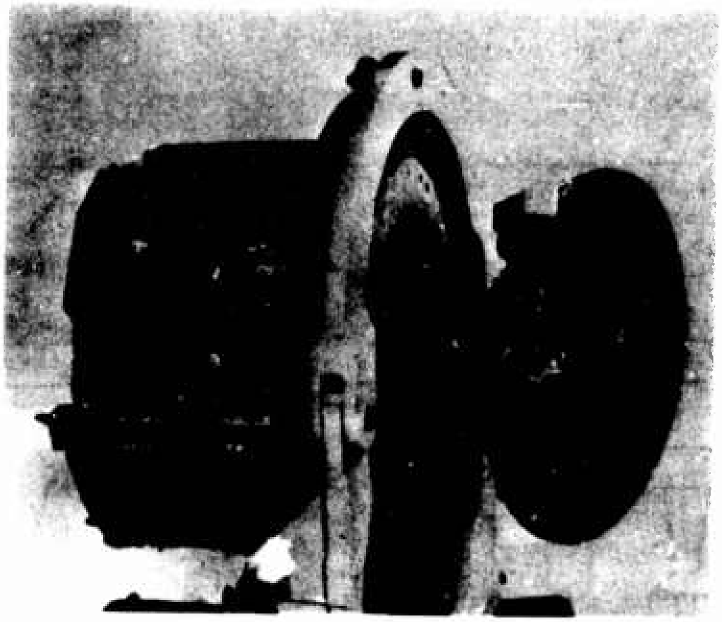

FIGURE 2

SAM-D AIRBORNE GUIDANCE SYSTEM ASSEMBLY

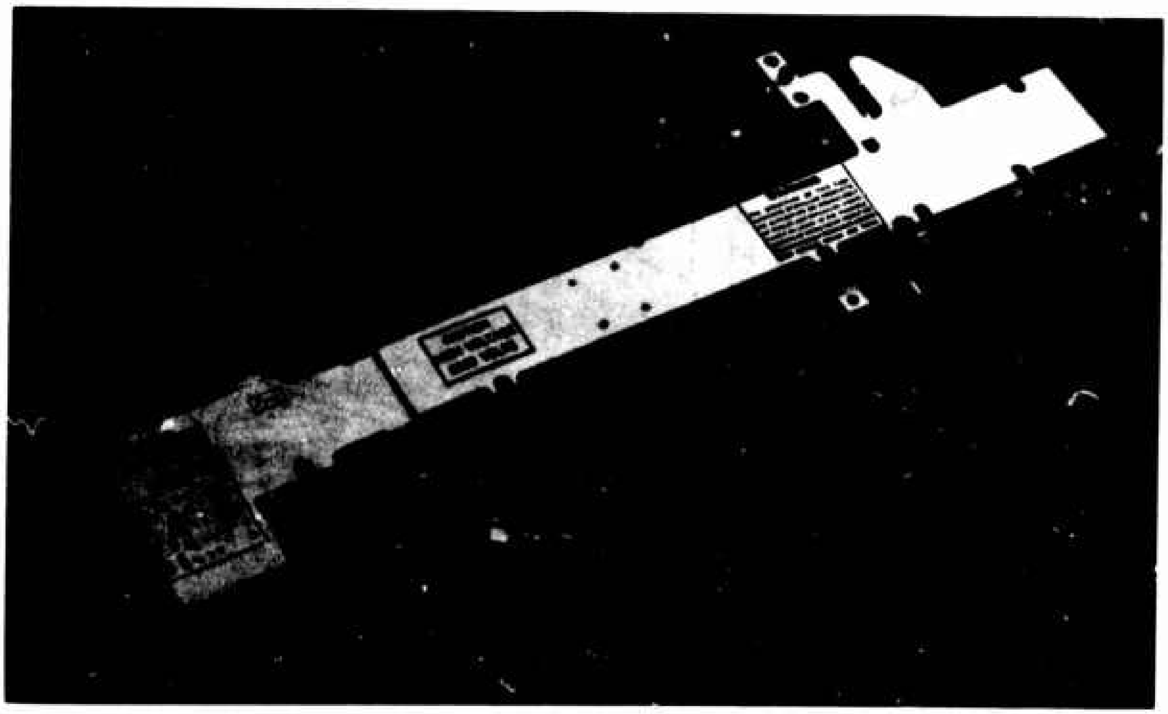

FIGURE 3

SAM-D AIRBORNE GUIDANCE TRAVELLING WAVE TUBE

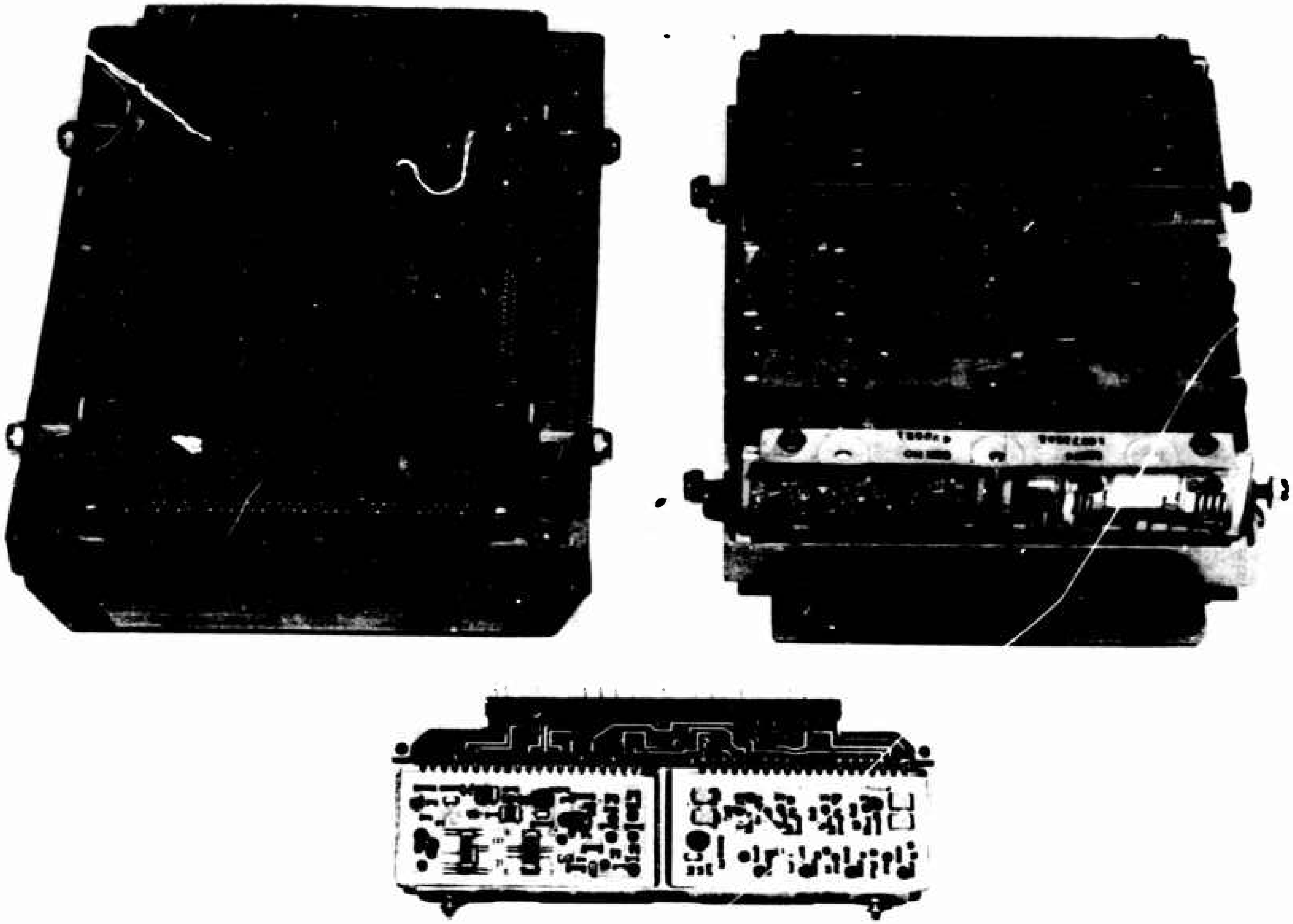

FIGURE 4 TYPICAL TRAY AND HYBRID MICROCIRCUIT ASSEMBLY

The radar unit is also shown as part of the guidance system. In fact, the radar and the weapon control group all play a part in missile guidance, as well as in all of the other functions of the SAM-D system. There is no rational basis for isolating any specific ground hardware as being dedicated to missile guidance; therefore, the entire radar unit (including the shelter, but not including the vehicle on which it is mounted) is also included in this discussion.

SAM-D GUIDANCE COST ELEMENTS

Raytheon's current estimate of production cost of the SAM-D system provides the reference points for the cost percentage breakdown presented in Tables I and II. These reference points assume that none of the proposed MM&T projects have been carried out. Potential savings from any project are assessed against the relevant reference point.

Table I presents a detailed breakdown for the airborne portion of the guidance system with the significant cost drivers encircled. With the cost information that was available, it was not feasible to accurately separate purchased components and purchased material, so these are shown as one category. However, purchased components are clearly the dominant part of this group. It is clear that the cost drivers are almost every category of purchased components plus electronics assembly and test. Support costs tend to run as a percentage of the other labor costs, so they will automatically benefit from any reduction in those costs. By far the largest single cost driver is the category of purchased electronic devices.

It also was not feasible to separate the costs of "Magnetics" and "Connectors". Magnetics are distributed in several other categories, and connectors are shown together with cables. The cost of connectors dominates this category under the heading of "Material and Purchased Parts".

A breakdown of the cost percentages of the components of the SAM-D Radar Unit is shown separately in Table II since there is no rational way to allocate a portion of the multi-function radar costs against each guidance system. A breakdown of these costs into the manufacturing cost elements was not available at the time of this report. However, significant cost drivers of this group are the fabrication and assembly of the antenna system.

On the basis of the foregoing information, a list of promising manufacturing technology projects have been developed, which are discussed in the next section.

TABLE I

SAM-D AIRBORNE GUIDANCE SYSTEM COST ELEMENTS

AIRBORNE GUIDANCE COMPONENTS	% OF TOTAL	PROJECTED MANUFACTURING COST ELEMENTS IN PERCENTAGE				
		MATERIAL & PURCHASED PARTS	FABRICATION AND PROCESSING	ASSEMBLY	TEST AND INSPECTION	SUPPORT
RADOME	4.5	2.8	0.7	-	0.4	0.6
ELECTRONICS	45.5	23.3	1.2	6.8	6.3	7.9
MICROWAVE DEVICES	13.9	9.6	0.7	1.3	0.8	1.5
MAJOR MECHANICAL PARTS	6.5	3.3	0.8	0.6	0.6	1.2
GYROS, ACCELEROMETERS	6.7	6.7	-	-	-	-
CABLES AND CONNECTORS	12.7	10.1	0.2	0.8	0.7	0.9
POWER SUPPLIES	10.2	6.9	0.5	0.9	0.7	1.2
TOTAL	100.0	62.7	4.1	10.4	9.5	13.3

◯ MAJOR COST DRIVERS

TABLE II

SAM-D GROUND-BASED RADAR UNIT PERCENTAGE COST BREAKDOWN

Radar Unit Subsystem	Percent of Total
Antenna Systems Group	32.7
Signal Processor Group	8.3
Control Unit Group	2.7
Transmitter Group	16.1
Receiver	28.2
VRU & Interface Unit	0.7
Shelter and Interconnections	10.0
Integration, Assembly, & Checkout	1.3
Total	100.0

DISCUSSION OF PROPOSED PROJECTS

The projects which are proposed in this paper have been selected primarily with the objective of attacking the cost-driving elements of the SAM-D Guidance System. However, some projects have also been included which require the development of manufacturing methods in order that products with desirable design characteristics can be made producible. Others may not be especially applicable to the system, as now designed, but are aimed at establishing fabrication techniques compatible with future design trends.

The cost of producing a guidance system is driven fundamentally by its design, and most particularly, by the number of discrete parts. Consequently, the most dramatic cost reductions, and reliability improvement, result from the incorporation of new technology through design evolution. The best example of this is the incorporation of integrated circuits to accomplish specified functions with fewer parts. It is to be noted that the largest single SAM-D cost driver is the category of purchased electronic parts, over which the guidance-system manufacturer has little control other than by basic design. Design is also closely interrelated with the normal producibility engineering process and with the application of new manufacturing methods. Therefore, some degree of design development must be involved with some of the proposed projects, although the fundamental objective has been to identify the areas in which new manufacturing technology is needed, with a good probability of successful achievement.

Thirteen projects are proposed for the Army Materiel Command Manufacturing Technology Program. These are summarized in Table III with estimates of project cost and percentage cost reductions of the airborne guidance system or ground-based radar unit. Most of these projects are directly aimed at reducing SAM-D guidance system production costs where new technology is required. Project #3, on the inertial sensors,

TABLE III

SAM-D GUIDANCE SYSTEM MANUFACTURING TECHNOLOGY PROJECTS

PROJECT TITLE	ESTIMATED COST	PERCENTAGE COST REDUCTION	OTHER BENEFITS
AIRBORNE GUIDANCE SYSTEM			
1. TRAVELLING-WAVE TUBE AUTOMATION	$3,350 K	3%	APPLIES TO OTHER TWTs
2. RADOME BILLET CASTING METHODS	650 K	1%	---
3. INERTIAL SENSOR AUTOMATION	1,270 K	2%	IMPROVED RELIABILITY
4. GUIDANCE BATTERY AUTOMATION	583 K	Small	REDUCED LIFE-CYCLE COSTS
5. IMPROVED ADHESIVE BONDING METHODS	200 K	1/2%	---
6. IMPROVED ELECTRICAL BONDING METHODS	350 K	1/2%	---
7. ADVANCED MULTI-LAYER BOARD FABRICATION METHODS	175 K	1/2%	1% OF RU
8. KO-1 ALUMINUM CASTING METHODS	230 K	1/4%	GENERAL APPLICATION
9. ADVANCED COMPOSITE FABRICATION METHODS	350 K	Small	LESS VIBRATION
10. AUTOMATED TESTING OF INERTIAL SENSOR ASSEMBLY	500 K	1/4%	---
GROUND-BASED RADAR UNIT (RU)			
11. AUTOMATION OF DIP ASSEMBLY	450 K	POSSIBLE 1/4% OF RU	FUTURE DESIGN TREND
12. FAB OF ARRAY-ELEMENT SUPPORT PLATES	800 K	1% OF RU	---
13. IMPROVED ARRAY-ELEMENT ASSEMBLY METHODS	625 K	1-1/4% of RU	MORE UNIFORM PERFORMANCE
TOTAL	$9,533 K	8% OF AGS; 2-1/2% OF RU	

primarily the rate-integrating gyro, involves significant detailed redesign in order to make manufacturing improvements feasible. Project #4 on the guidance battery does not appear to provide much cost reduction on initial procurement, but is extremely promising for doubling useful life and, therefore, reducing life-cycle costs. Projects 5 through 7 all deal with improved methods for electronic assembly. Project #8 for improving KO-1 aluminum casting methods has general application. Project #9 on advanced composite fabrication methods also has general application, but is proposed here with respect to a specific structure in the SAM-D guidance system, since it is a good practical example on which to develop new fabrication methods. Project #11, dealing with automated assembly of dual-in-line packages onto printed circuit boards, has primary application to the Radar Unit electronics, and for future new applications, recognizing current design trends. Projects 10, 12, and 13 all involve areas in which development work must be performed to demonstrate that the new methods can be applied to SAM-D production.

In addition to the specific projects proposed herein, there is another area which the Army Missile Command should consider for a broad-scale development program. This is the area of quality-assurance environmental screening tests, including temperature (burn-in), vibration, acceleration, and other tests to identify any inherent defects in the manufacturing process. Very effective methods have been developed and applied to date, as evidenced by the extremely successful SAM-D flight-test program thus far, but these have been developed on an empirical basis. A better fundamental understanding of these methods, in terms of their effectiveness in revealing inherent defects without inducing unacceptable cumulative damage, is sorely needed. This would require a substantial development effort which is recommended for consideration.

Appended hereto are the Project Summary Sheets for each of the thirteen proposed projects.

ACKNOWLEDGEMENT

The efforts and contributions of a large number of people in the Bedford Laboratories and the Andover Production Facility of the Raytheon Missile Systems Division, and also the Microwave and Power Tube Division of Raytheon, are gratefully acknowledged.

SAM-D GUIDANCE PROJECT #1

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to develop automated production methods for traveling wave tubes.

System/Session Area/Component: SAM-D/Guidance/Microwave Devices

Problem: The TWT used in the SAM-D guidance system is a complex electronic microwave device meeting extremely stringent requirements. This device contains 737 parts made from 24 different materials. The SAM-D TWT is the most expensive component in the guidance system and is a significant system cost driver.

The SAM-D TWT has been designed and is manufactured using present-day microwave tube technology and its cost is typical of that technology as practiced throughout the industry. A fundamental change of concept in the manufacturing process is required to reduce the cost of TWT's in general, as well as the SAM-D TWT in particular. A number of operations, for example testing during the aging process, have high labor content. The development of automated methods to reduce labor is required. Also new technology is required to fabricate high-cost component parts.

The tight performance requirements of the SAM-D TWT cause the additional problem that the tube may have performance changes due to subtle differences that inevitably occur as a result of changes in fabrication methods. Thus, a complete evaluation and verification of tube performance from tubes manufactured by the intended final production process is required in advance of a commitment to production.

For the reasons outlined above, a manufacturing technology project for reducing the cost of the SAM-D TWT is required well in advance of any contemplated production procurement.

Proposed Solution: This program would develop automated equipment to perform fabrication processing and test operations that presently require large amounts of labor. These equipments would be evaluated individually. They would then be integrated into a pilot production line and a sample run of SAM-D TWT's would be manufactured. Both the quality and the cost of these tubes would be monitored closely to insure the program objectives are met. Tube quality would be established by a tube qualification test program to assure performance equal to or exceeding that successfully demonstrated in the SAM-D development program. This program would also develop the technology needed to fabricate expensive component tube parts. This would principally involve components in the magnetic circuit and the electron gun. Parts made by this new technology would be evaluated by using them in the same run of tubes manufactured on the pilot production line with parts costs and the quality of the resulting tubes carefully evaluated.

Project #1

At the end of this program, a pilot line employing the newly developed automated equipment would have been set up and a run of 100 SAM-D TWT's would have been manufactured and evaluated. The form, fit and function of these tubes would be identical with TWT's made using present-day technology. This project will be successful if these objectives are met and, in addition, the tube costs are consistent with the estimated cost for anticipated SAM-D production rates.

The amount of equipment used for the pilot line would be the minimum necessary to demonstrate the concept and would not be sufficient to support the planned SAM-D delivery schedule in full production. The additional copies of the equipment that would be required to support the production contract would be procured at that time.

Project Cost and Duration: Estimated Costs are as follows:

Design and Development of Automated Equipment and Tube Component Technology	$1,970,000
Pilot Line Design	50,000
Pilot Line Set-up	400,000
Pilot Line Prove-out	860,000
Production Line Design	70,000
Total	$3,350,000

Estimated duration of the project is 36 months.

Benefits: Benefits to be derived from this project are a reduction in recurring costs for the SAM-D TWT. These reductions are estimated to amount to approximately 3 percent of SAM-D guidance system cost.

The methods and equipment developed would also be applicable to other TWTs.

Assumptions: The stated benefits do not include the costs associated with procuring equipment for and setting up the planned production line. It is further assumed that the tube construction rate would be four per day in full production.

SAM-D GUIDANCE PROJECT #2

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to reduce the finishing cost of slip-cast fused-silica radomes.

System/Session Area/Component: SAM-D/Guidance/Radome.

Problem: The current state-of-the-art of slip casting silica radome billets requires casting to a wall thickness approximately 0.3 inches greater than the final wall thickness in order to allow for thickness variability and distortion during firing and still have sufficient material to grind to the specified shape. This means that a great deal of grinding is generally required afterward. Also, the yield of sound castings is low (about 50%). The keys to reduce radome costs are to improve yield, to cast with thinner walls to reduce grinding, and to develop improved methods for the rough grinding operation.

Proposed Solution: A basic improvement in casting technology is required to enable slip casting to thinner walls with more uniform results. This program would investigate various approaches to "matched casting" wherein a displacement plug is inserted into the mold to form the inside surface of the radome billet, whereas that surface is now formed as the free surface of the slip as it settles under the external pressure forcing water out through the porous mold. The primary problem to be solved is how to extract the displacement plug as the billet shrinks during drying. Since the green casting has very low strength at this stage of the process, it is easily susceptible to shrinkage cracks. Regardless of the outcome of the foregoing task, a second task is to develop methods for casting more uniform billets of reduced wall thickness. It is also necessary to develop new techniques of supporting dried billets during the firing process to minimize distortion, especially for thinner-walled billets. The successful accomplishment of these two tasks requires a careful step-by-step program.

An additional task of the proposed project is to explore automated methods of grinding the rough billet to further reduce the cost of this operation. This task would be initiated approximately six months after the start of the first task to allow time for initial results to become available.

It should be noted that the method of casting discussed herein has not been successfully accomplished heretofore, so that there is some risk of success in this project.

Project #2

Project Cost and Duration: Preliminary estimates are as follows:

Task	Estimated Cost	Duration
1. Matched Casting Investigation (Casting, Holding and Firing)	$200 K	18 months
2. Reduced Wall Thickness Casting	50 K	9 months
3. Automated/Mechanized Machining Studies	400 K	18 months
Total	$650 K	24 months

Benefits: A preliminary estimate of the savings in recurring costs is approximately 1% of the SAM-D guidance system cost.

SAM-D GUIDANCE PROJECT #3

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to Apply Automatic Methods to Inertial Sensor Fabrication

System/Session Area/Component: SAM-D/Guidance/Gyros and Accelerometers

Problem: The performance requirements of the SAM-D missile guidance and control system dictate the use of three precision rate-integrating gyros, three high-performance body-mounted rate gyros, and three body-mounted accelerometers. These instruments are expensive and therefore represent a significant cost driver to the guidance and control system. The integrating gyros have been produced in limited production quantities which has forced the use of precision fabrication and assembly methods involving considerable skilled labor. Several iterations of test, adjustment or rework, and re-test are normally required before reaching specified performance levels. An excessive rate of scrap or rework is inevitably a part of this process. New concepts in the manufacturing process are required to apply increased automation and staged screening tests to reduce labor cost and increase yield. A manufacturing technology project is therefore required to develop new methods and modify design approaches to demonstrate that resulting gyros can be produced in conformance with performance requirements. The same technology improvements can be achieved, to a somewhat lesser degree, with the body-mounted rate gyros and accelerometers.

Proposed Solution: This program would begin by systematically studying each of the fabrication, assembly, test, and rework tasks involved in gyro and accelerometer manufacture that are known to be the most costly. Modifications of design or selections of alternate materials would be identified, where necessary, to permit improved production methods utilizing modern tape-controlled machine tools and advanced metal-forming methods. The criteria for design change should be to reduce manufacturing cost combined with unimpaired performance and reliability. Extensive use of automated techniques for machining and assembly, using self-fixturing parts or carefully designed fixtures, would be applied insofar as practicable to achieve unit-to-unit identity with a minimum of skilled hand labor. Automatic fluid fill stations would then be used for maximum repeatability of results. This would be followed by automatic test stations for processing multiple numbers of units with pre-programmed tests and automatic data printout.

An important aspect of this program would be the development of effective screening techniques for each stage of fabrication, gaging, subassembly and final assembly to assure very high reliability of each subassembly before it goes into the next stage of assembly and test. If this successfully achieves close to 99 percent yield at each of five stages of manufacture, total yield could be between 90 and 95 percent. In this case, the few failures could be scrapped and rework eliminated.

Project #3

This project would include setting up a pilot line to demonstrate the principles employed and to produce a sample run of production gyros and accelerometers. These instruments would be subject to a qualification program to demonstrate that they conformed to the performance requirements established during the SAM-D development program. This type of program must be carried out well in advance of anticipated production procurement for the resulting sensors to be considered for use in production SAM-D missiles.

Project Cost and Duration: Estimated costs are as follows:

Design analysis and optimization	$125,000
Process equipment specification writing	50,000
Modification and expansion of prototyping facilities	100,000
Tool design, fabrication	120,000
Tool design, assembly	200,000
Fabrication of prototypes of fabrication and assembly tools	250,000
Engineering support and data	150,000
Manufacturing qualification units and qual test	75,000
Production Tools and test equipment	200,000
	$1,270,000

Estimated Duration: 24 to 30 months.

Benefits: It is estimated that production costs of gyros and accelerometers could be reduced more than 20 percent, representing a possible saving of approximately 2 percent of the production cost of the SAM-D guidance and control system.

Assumptions: Estimates are based on assumed production rates representative of those required to support current missile systems using similar instruments.

SAM-D GUIDANCE PROJECT #4

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project for Automation of Manufacture and Testing of Guidance Batteries.

System/Session Area/Component: SAM-D/Guidance/Power Supply

Problem: The majority of positive- and negative-plate manufacturing for silver-zinc batteries is still based upon techniques developed twenty years ago. Process control equipment development in the last few years offer a tremendous opportunity to almost all manufacturing companies to update manufacturing technology. However, the initial expenditure for such equipment for military batteries is normally more than one company or one program could support. One such instance is installation of automated battery-plate manufacturing lines, one for positive plates and one for negative plates. These lines would necessarily have to be capable of manufacturing all sizes and types of plates for a variety of batteries, in order to offset the cost of the equipment.

An additional problem is the large number of in-line production and acceptance tests to which the SAM-D guidance battery is subjected during its manufacture prior to being submitted to final acceptance testing. A large majority of these tests are electrical (i.e., continuity, insulation resistance, resistance, voltage, etc.), which could be performed by a computerized test center.

Proposed Solution: It is proposed to undertake a development project to develop techniques for continuous plate manufacture and automatic plate setting of positive and negative plates. This project would set up and prove out automated manufacturing lines utilizing a sensor-based computer as the heart of the process control and monitor system. This system would exert a much greater control over the variables involved and substantially reduce manufacturing cost and time.

A second task of this project would be to install a sensor-based computer with appropriate sensors and to develop a program to test the guidance battery. Subsequent to installation and prove-out, this system would also be incorporated on all DOD programs. A sensor-based computerized test center performing both production and final acceptance tests would increase efficiency and reliability of the testing in that it would take less time to perform the tests and each battery would receive exactly the same test.

Project #4

Project Cost and Duration: Preliminary estimates are as follows:

		Cost	Duration
1.	Automated Plate Manufacture	$485,000	24 months
2.	Computerized Testing	98,000	12 months
	Total	$583,000	24 months

Benefits: The benefits to be derived from this program are estimated to be about 3.4% of the cost of the SAM-D guidance battery, which is a very small saving in terms of the guidance system cost (approximately 0.1%). However, this project is proposed because of its potential saving to all batteries manufactured for defense programs and because of the improved reliability that can be achieved by increased automation. In addition, there can be a real life-cycle cost benefit in the form of increased shelf life and, therefore, a decrease in the number of battery replacements required during the operational life of the missile system. Depending on the decrease in variability among production batteries that is achieved by automated methods, it is estimated that the useful life of the battery might be as much as doubled. The saving in the cost of replacement batteries over the operational life of the SAM-D system could be five to ten percent of the original acquisition cost of SAM-D guidance systems.

Assumptions: Production quantities and rates expected for SAM-D and other missile systems were assumed. The estimate of life-cycle cost benefits, expressed in terms of guidance-system acquisition cost, assume that all costs are in constant 1975 dollars.

SAM-D GUIDANCE PROJECT #5

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project for Improved Methods of Mechanical Bonding

System/Session Area/Component: SAM-D/Guidance/Electronics

Problem: A wide variety of adhesive materials are used extensively throughout the SAM-D guidance system for bonding components, substrates, printed wiring boards, covers on substrates, etc. As a result, many different types of bonding materials must be available at all times. Several factors determine how much material should be purchased and stored: for example, material usage, shelf life, minimum lot size, material packaging.

Each type of material as specific parameters that must be adhered to for maximum effectiveness; for example, mixing ratios, application, bonding pressures and curing temperatures. Some materials have short pot life which requires the mixing of numerous small batches when processing in high volume. These variables which are normal for any one system, when multiplied by several systems, become more complex and operator dependent.

Proposed Solution: A manufacturing technology project for the development of improved methods for handling adhesive materials on a production basis is proposed. A basic goal of this project would be to standardize the use of adhesives, insofar as possible, to minimize the required inventory of adhesive materials, solvents and cleaning compounds, and the number of ovens which must be maintained at different curing temperatures. In addition, the use of premeasured or premixed packages and the use of automated storage, mixing, and dispensing processes would be investigated. This project would include the following tasks:

1. Investigate the properties and manufacturing costs of the various adhesives in current use to establish a reduced number of standard adhesives. Waste due to limited shelf life and normal rework requirements will be considered.

2. Investigate the use of automated equipment for handling and dispensing adhesives.

3. Develop universal type bonding fixtures.

This project would include a tooling prove-out phase to certify that the methods are acceptable for use in production.

Project Cost and Duration: This project is estimated to cost approximately $200,000 and extend over a period of 18 months.

Benefits: It is estimated that this project could result in a saving of approximately 1/2 percent of the guidance system cost. In addition, it is believed that further benefit will be derived from an improvement in long-term reliability.

SAM-D GUIDANCE PROJECT #6

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to Develop Methods for using Conductive Epoxy for Various Types of Electrical Bonded Connections

System/Session Area/Component: SAM-D Guidance Electronics

Problem: It is very difficult to control the flow of solder in a production environment when making soldered electrical connections on high-density packages such as hybrid microcircuits. This may cause electrical shorts or contamination or leaching of adjacent gold leads and connections. Also, if processes are not carefully controlled, soldered connections are subject to fatigue and can cause thermal stresses. Soldering also has the disadvantages of subjecting assemblies to high local heating, requires the use of flux which must be cleaned off, and requires cleaning solvents which may have adverse effects on the devices and assemblies.

Proposed Solution: A project is proposed to investigate and evaluate conductive epoxy materials and application management for use in the fabrication of hybrid thick- and thin-film circuits for military systems. This effort would be comprised of the following tasks -

1. Conduct a vendor survey of the leading conductive epoxy materials and dispensing equipment.
2. Generate a test/reliability program to evaluate the selected materials and processes.
3. Design and generate art work of appropriate test patterns.
4. Investigate and evaluate one-component vs. two-component conductive epoxy systems and method of application. For example: screen printing and dispensing.
5. Investigate and evaluate repair/rework techniques.
6. Generate design/drafting standards for producing art work of circuits utilizing conductive epoxy.
7. Fabricate appropriate test patterns utilizing active and passive devices for evaluation and demonstrate the production methods to be used.
8. Generate cost analysis of conductive epoxy vs. solder attachment of microfilm components.

Project Cost and Duration: The project is estimated to cost approximately $350,000 with an 18-month duration.

Benefits: A potential cost saving of about 1/2 percent of the guidance system cost is anticipated to result from the successful development and application of conductive epoxy to electrical bonded connections.

SAM-D GUIDANCE PROJECT #7

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Advanced Multilayer Board Fabrication Methods

System/Session Area/Component: SAM-D/Guidance/Electronics

Problem: Production of multilayer printed circuit boards (PCB's) using epoxy fiberglass laminates has consistently posed a number of vexing in-process problems for the fabricator. Three of the most serious of these problems are summarized as follows: 1) Epoxy Smears: The detection and removal of epoxy smears, 2) Delamination: Delamination is primarily caused by thermal shock, 3) Discontinuity: Continuity problems in plated-through holes which can be caused by a number of problems, including those described above. Furthermore, there is a need to develop methods for producing multilayer boards of larger size and incorporating transmission lines of controlled impedance.

In addition, the fabrication of multilayer printed circuit boards (PCB's) has traditionally been accomplished by the "subtractive" process wherein etching is employed to obtain the required circuit patterns. This process requires stringent in-process controls and large facilities are needed for high-volume production. More recently, the industry trend has been to supplement the subtractive production facilities with "additive" process facilities which offer a high-volume fabricator many cost saving advantages which cannot be achieved using the traditional subtractive process. PCB's produced by the additive process possess characteristics such as excellent fine lines with straight walls and high-density circuits with landless holes which cannot be achieved otherwise. This process has not been applied and demonstrated for military hardware.

Proposed Solution: A project is proposed to develop the manufacturing technology required to produce PCB's using POLYIMIDE or equivalent materials as a substitute for EPOXY FIBERGLASS laminates. This is based on the following technical considerations which can be related to the three problems addressed in the preceding section. 1) The polyimide system is smear proof - thus eliminating the first problem and associated costs. 2) Polyimides can withstand temperatures up to 260°C as opposed to FR-4 epoxy which is rated at 125°C maximum. 3) Polyimides have a thermal coefficient of expansion in the Z axis of 1.0 X 10^{-5} IN/IN°C as compared to 15 X 10^{-5} IN/IN/°C for FR-4 epoxy fiberglass laminates. This fact will not alleviate the thermal shock problem, but help in the continuity of plated-through holes, since the polyimide system more closely approaches the expansion characteristics of the copper which is deposited in the plated-through holes.

This project would also include a comprehensive review of manufacturing technology and facility requirements associated with the additive process. Emphasis would be placed on identifying areas in which the application of this technology would be most cost-effective and especially as to its applicability for the fabrication of large-size multilayer boards. The proposed project includes the fabrication of sample multilayer boards such as digital or analog (which incorporate stripline circuits with controlled characteristic impedances) utilizing the additive process to demonstrate state-of-the-art circuit and unique network configurations which can be produced.

Project Cost and Duration: This project is estimated to cost approximately $175,000, with a duration of twelve months shown as follows:

	Months after Go-ahead											
Task	1	2	3	4	5	6	7	8	9	10	11	12
Material Procurement	△		△									
Process Development	△				△							
Laboratory Experiments			△			△						
Fabrication - PCB's					△				△			
Test/Evaluation								△			△	
Report											△	△

Benefits: All available data and experience to date indicates that multilayer PCB's fabricated with polyimide glass laminates result in a superior product with respect to dimensional stability, reliability and tolerance of higher maximum service temperature. The proposed solutions are directed toward yield improvement as well as processing cost reduction. It is estimated that a cost saving of more than 20% could be realized in the fabrication of multi-layer boards.

This could mean a saving of about 1/2% of the airborne guidance system cost and up to 1% of the radar unit cost.

Assumptions: The stated benefits assume the successful completion of the tasks described. The implementation of automatic plating-solution monitoring equipment is assumed, along with a volume of multilayer printed-circuit boards in the order of 50,000 per year.

SAM-D GUIDANCE PROJECT #8

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project for Developing Improved Methods for Casting KO-1 Aluminum Alloy

System/Session Area/Component: SAM-D/Guidance/Major Mechanical Parts

Problem: In many cases, aluminum castings are desirable for light weight and for forming complex shapes. Most aluminum casting alloys have considerably lower strength than the wrought alloys, which limits the use of casting for aluminum parts. The aluminum alloy commonly known as KO-1 is a relatively new casting alloy that has higher properties and can be used for high-strength applications. However, it is very difficult to cast this material because it is "hot short" which causes cracking during solidification. Reject rates commonly run from 25 to 45 percent. In addition, this material is not readily weldable by conventional techniques which limits the possibility of repair of defective castings at the foundry and limits broader design applications. A project for developing improved casting and welding methods for KO-1 aluminum is required.

Proposed Solution: It is proposed that a project be undertaken to develop improved casting procedures for KO-1 aluminum for both permanent mold and investment casting. This project would include an investigation of the following factors:

1. Effect of tolerances on chemical composition
2. Mold temperature
3. Methods for controlling solidification on a production basis
4. Effect of pouring with and without screen
5. Techniques for repeatedly achieving fine grain

A parallel program is proposed to develop optimum welding techniques relative to pre-heat, filler wire alloy, composition, post-heat, welding speed, and optimum heat to avoid vaporization.

Project Cost and Duration: A preliminary estimate of the cost of this project is:

	Cost	Duration
A. Casting Investigation	$160,000	12 months
B. Welding Investigation	70,000	6 months
Total	$230,000	12 months

Project #8

Benefits: A significant improvement in the yield of KO-1 castings is estimated to enable a possible saving of about 1/4 percent of the cost of the SAM-D guidance system.

Assumptions: It is assumed that this project would lead to casting yields up to about 85 percent.

SAM-D GUIDANCE PROJECT #9

MANUFACTURING TECHNOLOGY PRODUCT SUMMARY SHEET

Title: Advanced Composite Material for the SAM-D Guidance Inner Shell Support Structure

System/Session Area/Component: SAM-D/Guidance/Major Mechanical Parts

Problem: The SAM-D Missile is a high-performance flight vehicle which is subjected to severe aerodynamic forces and thermal responses. As a result of these external environments, the internal support structures of the guidance system also experience high design environments. These are complex in shape and expensive to fabricate due to limited package volume and critical structural requirements. A high-cost hardware item within the SAM-D guidance system is the inner shell electronic-package support structure.

The current design of the inner shell is of an aluminum casting which is expensive, heavy, of medium strength and stiffness and possesses low structural damping.

Proposed Solution: A method of achieving lower fabrication costs of the inner shell, as well as to gain secondary advantages of weight reduction, increased strength, increased structural damping and the ability to orient fibers to obtain directional strengths and stiffness for uncoupling frequencies, is to consider the utilization of Advanced Composite Materials.

Recent developments in the aircraft, aerospace, industry and leisure product industries have demonstrated that various composite materials have been utilized successfully in the forms of compression molded, injection molded, filament winding, pultrusion and prepreg tape to comprise efficient end items.

The paramount objective of this program will be directed toward low-cost fabrication and will study the Advanced Composite Materials available and the associated manufacturing methods required, both innovative and existing, to achieve a low-cost SAM-D inner shell structure. Currently, the raw costs of composite material is generally higher than metals; however, raw-material cost should decrease in the future as composites come into more general use, and there are other cost advantages and fabrication techniques which can, in many applications, result in competitive final costs, such as

- The ability to orient and position reinformed fibers in specific areas can result in structure of simpler design than those achieved with metals where welding, riveting and bolting is required.
- The use of hybrid materials, such as mixtures of glass and reinforced fibers, will allow improved performance while optimizing the effect of the high-priced material.

Project # 9

- The fabrication technique can be selected to provide the best cost advantage. A combination of techniques may be used to reduce overall costs.
- In many cases the component can be molded or wound to final dimensions, thus eliminating or reducing machining operations.

Specifically the program tasks are as follows:

- The selection, through extensive analytical and fabrication studies, of candidate composite materials.
- Development of cost effective fabrication methods.
- Development of analytical approaches, design criteria and failure criteria required for designing with anisotropic materials.
- Preliminary design and analysis of the inner shell.
- Prototype fabrication.
- Demonstration and engineering testing.
- A meaningful comparison between end products in terms of cost, weight and performance will be made, since dimensional, environmental and system constraints used for this application would be identical to those of the existing component.

Project Costs and Duration:

Material Selection and Development of Manufacturing Methods	$ 80,000
Engineering Design, Analysis and Methods	180,000
Prototype Fabrication	50,000
Engineering Testing	40,000
Total	$350,000

Estimated project duration is 24 months.

Benefits: It is extremely difficult to estimate possible production cost reductions before more detailed studies of the particular application have been made. On a preliminary basis, it is estimated that the production cost of the inner shell could be reduced more than 10% which would be a fractional percent reduction of the guidance system cost. However, there are a number of intangible benefits which should ultimately be reflected in reduced life-cycle costs, namely, greater resistance to fatigue, reduced weight, and reduction of transmissibility of shock and vibration environments to the major part of SAM-D guidance electronics. The results of this project could also be applied to other mechanical parts in the SAM-D guidance system, with the inner shell serving as the most suitable candidate for developing new methods.

SAM-D GUIDANCE PROJECT #10

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to develop semi-automatic testing techniques for acceptance testing of Inertial Sensor Assemblies

System/Session/Component: SAM-D/Guidance/Gyros and Accelerometers

Problem: The body-mounted gyros and accelerometers, which are part of the SAM-D autopilot, are installed in a heated block for mounting in the missile. This assembly is the Inertial Sensor Assembly (ISA) for which a major cost factor is the 24 to 36 hours of testing on each at final acceptance. Each of the three gyros and three accelerometers in the ISA is tested by conventional means during tests of the ISA on a centrifuge and rate table. This procedure is time consuming since the tables must be accurately adjusted for rotational rate and the data recorded manually. The ISA must also be repositioned six times on the centrifuge and three times on the rate table.

Proposed Solution: The project would involve designing and fabricating an automatic testing system. The system would utilize automatic data read and record through the use of a coupler system and a tape punch. A dedicated mini-computer would be integrated into the system for both the testing and data reduction. ISA positioning would be accomplished automatically through the use of a servo controlled positioning device which would be controlled by the computer.

Project Cost and Duration: A preliminary cost estimate for the entire project is approximately $500,000, with a duration of 18 months.

Benefits: It is estimated that this project could achieve a production cost saving of approximately 1/2 percent of the guidance and control system cost.

SAM-D GUIDANCE PROJECT #11

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to Investigate and Evaluate Methods for Automatic Processing and Assembly of Dual-in-line Packages (DIPS) into Printed Circuit/Multilayer Board Type of Electronic Assemblies

System/Session Area/Component: SAM-D/Guidance/Electronics

Problem: In general, conventional military type of electronic modules which employ the use of either flatpack integrated circuits and/or LSI microelectronic devices, are not readily adaptable to automated assembly methods.

This condition is primarily attributed to the configurations of the electrical leads of these types of devices and to a certain extent variations with respect to physical sizes of those components which have been selected to satisfy specific logic functions. Manufacturing processes, methods and technqiues generally associated with these devices require, upon completion of pre-conditioning (burn-in), that the leads of the device be pretinned and formed to a desired configuration. These involve different kinds of operations, depending on the device and the application. The devices must then be precisely oriented and aligned with respect to corresponding pad locations on the PC/MLB. Final assembly of the devices is then completed by using soldering technqiues involving either resistance or infra-red reflow systems.

In order to avoid such problems, as described above, manufacturers of electronic components have developed and produced a variety of dual-in-line packages (DIPs), which are configured to be compatible with automatic insertion equipment. Although these devices are primarily being used in commercial applications, future design trends indicate an increasing utilization of DIPs in both missile airborne guidance and ground systems. Inasmuch as military electronic systems have more stringent requirements in terms of high packaging density, tighter manufacturing tolerances, critical reliability and maintainability factors, etc., a project should be undertaken in order to develop methods, equipments and procedures which will demonstrate the feasibility and reliability of such automated systems for military systems.

Proposed Solution: Initially this project would entail a series of in-depth engineering studies which would include the following:

- Survey and classify the configurations of those DIPs which meet such conditions as performance and producibility which is required for both missile airborne guidance as well as tactical ground systems.

- Survey and evaluate those currently available equipments which indicate a potential capability for reliably processing and assembling DIPs into PC/MLB type of assemblies. These include magazines, sequencers, inserters, and testers.

Project #11

- Evaluate and establish design guidelines for high-density electronic modules which are compatible with automated manufacturing methods and processes.
- Establish criteria for and acquire facilities, tooling, and equipments necessary for pilot line prove-out, and conduct a pilot-production demonstration of the system.
- Prepare and submit final report which would identify all major findings associated with this project plus conslusions and recommendations as to the feasibility for fully automated processing of DIPs through such operations as tinning, sequencing, assembly and soldering.

Project Cost and Duration: A preliminary estimate for this project is as follows:

1.	Survey and classification of DIPs and handling equipments	$30,000
2.	Establish requirements and design standards	50,000
3.	Design representative modules with DIPs for application to SAM-D for pilot-line prove-out	70,000
4.	Acquire and set up pilot line	150,000
5.	Pilot-line prove-out	150,000
	Total	$450,000

The estimated duration of this project is 18 months.

Benefits: If the Radar Unit electronics were redesigned entirely to use DIPs instead of flatpacks, it is estimated that this project could reduce recurring Radar Unit costs approximately 1/4 percent. This method could be applied to the airborne guidance system if it also were redesigned to incorporate DIP-type packages.

Assumptions: The project cost estimate is based on a pilot production run of approximately 100 modules with 20 DIPs per module. Estimates of benefits are based on the assumption that production rates would require that 2600 electronics modules per month be produced.

SAM-D GUIDANCE PROJECT #12

MANUFACTURING TECHNOLOGY PROJECT SUMMARY SHEET

Title: Manufacturing Technology Project to Apply Electro-Discharge Machining for the Fabrication of the Array-Element Mounting Plates of the Radar Antenna

System/Session/Component: SAM-D/Guidance/Radar Illuminator

Problem: The SAM-D phased-array radar antenna is comprised of over 5,000 array elements in the main array. These are mounted in three tiers of plates, which are fabricated in three sections each and joined at two seams on each of the three levels. The total of over 15,000 mounting holes must be in registration within 0.014 inches of true position. The present method of fabrication is to punch the holes and to register the nine plate sections. It has been found during the Engineering Development Phase to be extremely difficult to meet tolerance requirements by this method. Four sets had to be manufactured in order to obtain an acceptable set. Problems encountered during the manufacturing cycle were distortion, twist, work hardening, internal stresses, and unpredictable dimensional growth. Electro-discharge machining is being successfully applied today for forming holes with very tight tolerances, but development is required to apply it to plates of the size required for the SAM-D radar.

Proposed Solution: It is proposed that a project be undertaken to develop the tooling and techniques for forming the holes in full-size array-element support plates by electro-discharge machining. The end result of this project would be the qualification of this manufacturing method for use in the production phase of the SAM-D system. This effort would be performed in five major phases, described as follows:

1. **Study and Evaluation** -
This period will consist of producibility evaluation of detail design relating to electrode-discharge machining. Examples of producibility studies would be dimensional changes necessitated by new locating points and tooling holes. Another example of study during this period would be evaluation of vendor recommendations, power requirements, special designed and extruded shape electrodes, including material selection for electrodes.

2. **Establishment of Requirements** -
A vendor survey will be conducted. Based on results of study phase, detailed requirements will be established related to tolerances, time cycles, power requirements as a function of the number of holes cut simultaneously, electrode material and design, heat dissipation, and pumping, cooling, filtering and flow requirements of the dielectric fluid. Also, preliminary design concepts will be developed for tools and fixtures.

3. **Prototype Test** -
Small -scale prototype tests will be conducted using approximately 10 electrodes, for the following investigations:

    a. Study copper extrusion and molded graphite electrodes

    b. Study finish on piece parts as a function of time cycles

c. Establish wear and length of electrodes

d. Establish flow characteristics and cooling of electrodes

e. Slug removal and electrode flushing

f. Establish number of electrodes possible in one set-up

The results of these will be used to establish the overall size of machine and table and other detail requirements.

4. Acquisition and Set-up of Full-size Machine - A final vendor selction will be made to fabricate a full-size machine suitable for the antenna-plate application. Close monitoring of his efforts throughout construction will be maintained. Test pieces will be run to burn pattern into the locating table. A final test piece will be run and inspected for final acceptance of the machine after installation at Raytheon.

5. Prove-out Phase - Three complete antenna sets (nine plates total) will be electro-discharge machined to qualify this method for SAM-D production. These plates will be submitted to the inspection cycle for all aspects of drawing mandates. These areas will encompass such criteria as:

a. Tolerance, true position, configuration, etc.

b. Flatness

c. Twist

d. Repeatability

e. Surface finish

f. Structural Analysis

g. Analyze after EDM for material degradation

Project Cost and Duration: It is estimated that 36 months would be required to complete this project, with costs estimated as follows:

1.	Study and Evaluation	$ 20,000
2.	Establishment of Requirements	20,000
3.	Prototype Tests	70,000
4.	Acquisition and Set-up of Full-size Machine	450,000

(continued next page)

Project #12

Project Cost and Duration: (continued)

5. Tooling		200,000
6. Prove-out Phase		40,000
	Total	$800,000

Benefits: It is estimated that the increase in yield expected by this method could result in a 75 percent saving in the labor for fabricating these plates, with an overall cost reduction of approximately 1 percent of the Radar Unit cost.

SAM-D GUIDANCE PROJECT #13

MANUFACTURING TECHNOLOGY PRODUCT SUMMARY SHEET

Title: Radar Phased Array Element Fabrication and Assembly Methods

System/Session Area/Component: SAM-D/Guidance/Radar Illuminator

Problem: The SAM-D Array Element in the phased-array radar consists of two major subassemblies: a microwave phase-shifter assembly and an electronic control assembly. The subassemblies must go through many operations and consist of approximately 60 components. Each operation affects the yield of the element and certain critical operations affect the electrical performance.

Proposed Solution: This program would examine all areas of array element fabrication, assembly and test and would develop methods to change the high-labor, low-yield operations to minimize the labor and increase the yield. The main areas of concern are listed below.

Phase Control Assembly: Investigate co-firing the insert and toroid as one unit, in order to eliminate the insertion and curing effort.

Investigate a precision molded insert with wires plated on. This would require a special connector technique which would also be investigated.

R.F. Subassembly: Investigate powdered metal technqiues to eliminate the extrusion and grinding of the waveguide body.

Investigate replacement of beryllia windows with a non-toxic material. This would increase safety and lower cost due to the fact that beryllia requires special handling, special cleaning, and special disposal.

Investigate tooling required to fully automate insertion of all components into the R.F. Subassembly; this would include toroids, inserts, wires, chokes, soldering of wires, insertion and bonding of front and rear radiators.

Rear Radiators: Investigate a precision moldable rear radiator material to eliminate precision machining.

Flex Print, Filter Network, Flux Driver: Investigate alternate methods of interconnections including a single-substrate assembly.

Project Cost and Duration: Estimated cost of this program is $625K spread over 23 months. This effort would include building a small number (300) of array elements utilizing the new manufacturing techniques developed during the first 13 months of the program.

Project #13

Benefits: The benefits of this program will be a higher yield for all aspects of array element fabrication. A more uniform element in terms of RMS phase error is also expected which in turn would further increase yield and improve the radar performance. A 10 to 15% yield increase should easily be achieved which would reduce the cost of the SAM-D Radar Units approximately 1-1/4 percent.

Assumptions: The only assumption here is that the full-up production build would not start until the completion of this manufacturing effort.

BALLISTIC MISSILE DEFENSE SYSTEM GUIDANCE MANUFACTURING TECHNOLOGY

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ABSTRACT

This paper discusses Anti-Ballistic Missile (ABM) guidance technology development in terms of performance, cost, manufacturing technology and the interrelationships of these factors.

Anti-Ballistic Missile (ABM) technology has proceeded from successful development and flight test of the SPRINT I interceptor missile in the 60's to operational status of the present SAFEGUARD System at Grand Forks, North Dakota, in the mid-70's. Development commenced in 1972 on SPRINT II, a less costly and improved performance missile featuring 65 percent component commonality with SPRINT I which was designated for Minutemen Site Defense. In late 1974, technology validation studies of a significantly enhanced performance capability SPRINT derivative, the Improved SPRINT II Missile Subsystem (ISMS) were initiated and continue at this time.

ABM guidance technology development, production, and plans for future production have progressed consistent with the evaluation of the existing manufacturing technology, perceived threats and systems options for effective threat counteraction. SPRINT is required to execute high g (>100) maneuvers - with millisecond response - within a broad range of Mach numbers, dynamic pressures, and angles of attack. It must also survive nuclear radiation and blast effects without structural failure or loss of controllability. Life Cycle cost considerations are impacted by acquisition cost deltas associated with the performance parameters needed to meet the evolving threat plus provisions for 10 year storage life in the readiness state, cell security from sabotage without personnel protection, shock withstanding of free field nuclear effects, and launch, flight, in storage reliability. An overview of the impact interrelationships on guidance design is shown below for the three major configurations of interest:

Missile	Configuration	Performance/Cost Drivers
SPRINT I	Autopilot/Missile Guidance Set	NE, D, A
SPRINT II	Missile Controller Set	NE, D, A, R/
ISMS	Digital Missile Controller Set	NE, D, A, R/, RT, TG

NE - nuclear effects
D - dynamic (shock and vibration)
A - acceleration
R/ - reliability
RT - reaction time
TG - technology growth

Cost Drivers have been quantified in terms of hardware element and function as shown below:

Hardware Element	Percent of Total Cost	Function	Percent of Total Cost
Electronics (modules)	48.6	Purchased parts	41.4
Platforms	13.7	Factory labor	22.6
Microwave devices	12.0	Quality labor	12.4
Major mechanical	7.1	Support	9.2
Gyros	7.0	Test Labor	7.6
Cables	5.2	Material	6.8
Power supply	4.7	Total	100.0
Accelerometers	0.9		
Heat sinks, bkts, etc.	0.5		
Connectors	0.3		
Total	100.0		

Detailed discussion of both design and cost experience associated with ABM guidance is presented in order to provide a base from which proposed manufacturing technology projects which can favorably impact cost for systems in the 1980's may be evaluated and correlated with other Army programs.

Manufacturing Technology projects are identified and described which indicate total cost reduction potential of approximately 38 percent for missile guidance systems.

I. INTRODUCTION

A. BMD Interceptor Evolution

In 1972, a SAFEGUARD SPRINT missile intercepted a Minuteman reentry vehicle high over the Kwajalein Test Range, demonstrating a new breed of missile distinct from previous and concurrent ballistic and space vehicles - the terminal interceptor missile. To achieve this successful milestone, development of new structural concepts and new materials to meet launch shock, acceleration load, and aerodynamic heat and pressure parameters pushed technology thresholds far beyond anything any previous missile had experienced. More than a decade of interceptor research and development enabled the interceptor to accomplish its mission - seeking-out and destroying a reentry vehicle on a one-to-one intercept.

Today, the SAFEGUARD System is installed and operational at the Grand Forks, North Dakota SAFEGUARD Site to protect a portion of our retaliatory forces and to provide the U.S. invaluable experience in operating a deployed Ballistic Missile Defense system.

Shortly after, SPRINT II was conceived to meet a growing and more formidable threat and development was started under the Prototype Demonstration Program. Changed to the Site Defense program in 1973, the purpose was the research and development of BMD components (a radar, interceptor missile, and tactical software) that would form the basis of a second generation system for defense of Minuteman. In 1974, the emphasis was switched from a Site Defense Prototype Demonstration Program to the advanced development of Site Defense components. Development of the SPRINT II missile subsystem was redirected to an Improved SPRINT II Missile Subsystem.

The Improved SPRINT II Missile Subsystem (ISMS) provides an improved configuration of the SPRINT Interceptor missile subsystem used in the Safeguard and Site Defense systems while maintaining the same role of intercepting and destroying incoming RV's.

B. BMD Threat/Mission Evolution

Advances in offense ICBM technology such as chaff, multiple warheads, and decoys made a short-range, very high acceleration missile necessary. Thus, SPRINT, an outgrowth of the Nike-Zeus program, was created as the second line defense to complement the longer range SPARTAN missile, and provide terminal defense. The evolution of the BMD systems has been intended for various levels of deployment from area defense to terminal hard point defense. Although SAFEGUARD uses the major components developed for the Sentinel system (area defense) its limited deployment plan reflects changes of mission from full to light area defense, and more recently, to point defense of Minuteman. SPRINT, through extremely high acceleration and maneuverability, is able to intercept RV's at closer range. Close range intercept is advantageous because atmospheric friction burns up penetration aids such as chaff, decoys, and debris; thus making identification of actual RV's relatively simple.

Looking to the future, we must anticipate the growing threat of independently-targeted reentry vehicles, or closely-spaced in-line reentry vehicles. Mission requirements to counter this threat are more challenging. Engagement problems caused by multiple nuclear blasts within a battle space environment present a formidable challenge to interceptor development. Any of several phenomena resulting from a thermal blast can seriously cripple the missile's effectiveness and most likely prevent it from accomplishing its mission.

As a warhead is intercepted, the first effect is a pulse of prompt nuclear radiation. This pulse can disable adjacent interceptors, a phenomena known as fratricide.

The next disabling effect encountered is the nuclear fireball and its dissipation pattern. With it, as a concomitant effect, is an electromagnetic blackout region which prevents radar detection and microwave guidance signals from reaching interceptors near or behind the fireball.

The last phenomena is a shock wave or blast that can disrupt the interceptor's flight pattern, or even destroy interceptors at high intensities.

Application of the basic technologies in analyzing specific interceptor problems within a thermal environment provide a valuable cross-pollination of technical know-how in continuing to push back the thresholds of interceptor technology development.

In addressing interceptor guidance technology development, it is necessary to summarize the evolution of the guidance systems in SPRINT interceptors of the SAFEGUARD, Site Defense, and Site Defense Technology Programs.

II. INTERCEPTOR GUIDANCE

A. Safeguard Sprint

In the SAFEGUARD mission, the SPRINT interceptor is required to execute high g maneuvers, with millisecond response, over a broad range of Mach number, dynamic pressure, and angle of attack. In addition, it must survive nuclear radiation and blast effects without structural failure or loss of controllability. To accomplish this, a lateral acceleration autopilot and missile guidance set is used with gain scheduling as a function of dynamic pressure via the ground radar and on-board gain optimization using a high gain adaptive control approach. This enables the maneuver response to be nearly optimum in spite of large aerodynamic non-linearities and uncertainties that occur over the broad range of interest. In principle, the adaptive loop functions to maintain as high a gain in the control loops as possible, consistent with acceptable limit cycle amplitudes as determined by hydraulic control system flow capability and endurance.

B. SPRINT II Missile Subsystem

Technical advances that had been used to develop SAFEGUARD SPRINT became part of the basic SPRINT II design. Changes brought about by the Site Defense role of providing low altitude defense of Minuteman sites against an increased ICBM threat included integrating the missile guidance set and autopilot into an integrated circuit Missile Guidance Set (MCS) which would increase reliability and accuracy at a reduced cost. Advances in semiconductor technology made it possible to combine the SPRINT autopilot and missile guidance set into one integrated assembly capable of performing in the SPRINT II environment.

C. Improved SPRINT II Missile Subsystem

The concern over Soviet technology advancements was the driving factor in redirecting the Site Defense Prototype Demonstration Program to a Technology Development Program. Addressing itself to the technologies of ballistic missile defense, BMD technology development lays the basis for future systems efforts by incorporating technologies into components that could be integrated into new systems or be used as adjuncts to SAFEGUARD or Site Defense. The Improved SPRINT II Missile Subsystem (ISMS) provides an improved configuration of the SPRINT interceptor missile subsystem used in the SAFEGUARD and Site Defense systems. The ISMS improvement includes a change from the analog MCS to a digital missile controller set (DMCS). The DMCS yields substantial improvements over the SPRINT II MCS in the areas of radiation order limits and reduced trajectory deviations, digital control circuits, improved circumvention scheme, and limited inertial navigation. This later capability is provided through the strap down inertial system using a laser gyro together with the on-board digital computer. The inertial navigation technique provides a large system benefit via a reduction in radar scheduling. Retention of vital system variables such as gains, steering commands, discretes, missile mode logic, and major filter state variables, enables a major reduction of radiation induced trajectory deviations. Restoration of the DMCS to normal operation is achieved more quickly and completely than in SPRINT II because the DMCS digital circuits have faster recovery times than the SPRINT II analog circuits.

III. MCS COST CONSIDERATIONS

A. MCS Cost Drivers - Background

Three factors predominated in the ultimate considerations which led to the current MCS design, 1) Cost, 2) Reliability, 3) Nuclear Hardness. A summary of each factor and the major design selection and trade study approaches selected is presented below.

1. Cost. The lowest risk, reduced cost development approach was the specific objective. To this end, detailed analyses and trade studies were performed for four basic design concepts: cordwood, hybrid, medium scale integration (MSI), and module.

The evaluation of these concepts, which follows, describes the applicability of their specific attributes to the SPRINT II MCS.

Cordwood - The Cordwood packaging technique is used in SAFEGUARD SPRINT for both the autopilot and missile guidance set. Though this technique affords a high packaging density, it was not chosen for SPRINT II because fabrication complexity and difficulty of maintenance drive the overall cost higher than the module concept.

The cordwood package would have had a failure rate of 14,313 fits, and a 98 percent testability. The package would contain 4,500 autopilot and 5,500 MGS (SAFEGUARD) parts, or approximately 50 percent more electronic components than the module design.

Hybrid - The hybrid technique includes a combination of film (both thin and thick) and monolithic fabrication methods to produce circuit components (resistors, capacitors, diodes, and transistors) interconnected in a complete circuit and assembled in a single package.

Though the hybrid savings were projected to be slightly more than those of several other candidates, the hybrid concept was not chosen for SPRINT II primarily because of the development risk. A dry, hermetically sealed package would have had to be developed to minimize nichrome resistor problems, and thick film resistor tolerances (0.1 percent) would require extensive development to achieve. In addition, analog implementation would be poor, and several of the components (such as tantalum capacitors, coils, filters and delay lines) could not be hybridized. Figure 1 illustrates savings for hybrid versus the cordwood design concept as a function of production quantity. Breakeven was calculated to occur at 65 units.

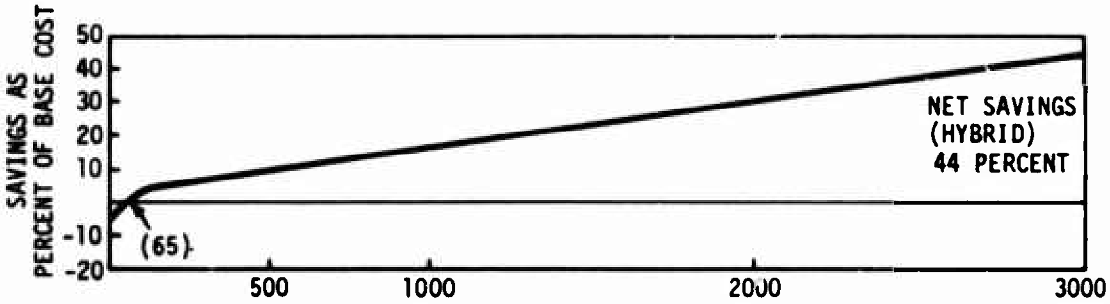

Figure 1. Hybrid versus Cordwood Savings

Although the hybrid technique did not lend itself to wide application in the MCS design, it is being used in the IF amplifier, resulting in a simplified package and a cost savings.

Medium Scale Integration - In the MSI technique a group of solid state monolithic technologies is used in the fabrication of integrated electronic components with circuit complexities in the range of 10 to 100 gates. All circuit elements (active and passive) are simultaneously formed in a single small wafer of silicon by the diffused planar technique.

The MSI design was not chosen because, even though the packaging volume of this design would be small, cost and risk would be high. Many semiconductor devices would have to be developed to meet the nuclear requirements. MOS (metal oxide silicon) technology had not progressed sufficiently for consideration in a design and development application, and there were, and still are, an insufficient number of radiation hard bipolar MSI circuits available in production today. In addition, MSI technology is more readily applied to a digital implementation than to the analog used in the MCS.

Module - The module concept was selected for use in the MCS because it provided increased nuclear hardness to survive the SPRINT II dynamic environment, improved performance, greater reliability, and reduced cost, through the use of semi-automated assembly techniques, i.e., wave soldering, automatic insertion, easy mechanical assembly, and automated test; all within the baseline constraint of minimum departure from the SAFEGUARD SPRINT design.

The module packaging concept is the baseline MCS design (Figure 2). Among its advantages are design simplicity, low cost, and low development risk. This simple printed circuit board concept is easily fabricated, and has automatic insertion and soldering processes. Each module is designed as a functional entity. The result is ease of maintenance and 100 percent testability. Reliability is good, with a failure rate of 10,900 fits (failures per billion hours of use).

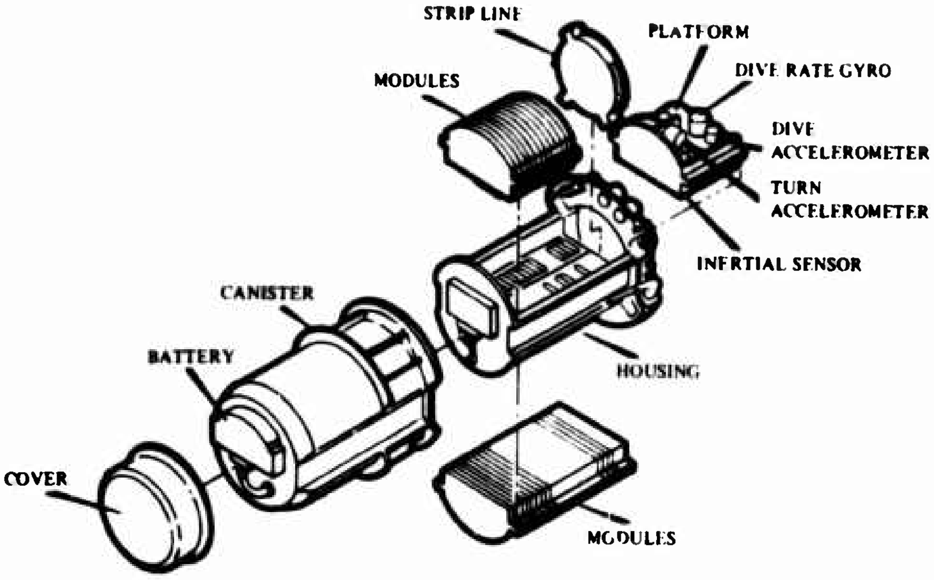

Figure 2. MCS Design Showing Module Packaging Technique

The current MCS design contains 5,408 electronic parts mounted on 26 single-sided modules. This design through the use of integrated circuits and modular packaging allowed a 46 percent reduction in electronic parts.

In order to realize the maximum return from the SAFEGUARD investment, a parts commonality of 85 percent was obtained for the SPRINT II design. By use of integrated circuits, parts count and solder joint connections were substantially reduced(*). The modular baseline MCS design was judged to offer the minimum development risk, the lowest cost, and the most reliable approach which attained nuclear hardness.

2. Reliability. Analytical approaches utilizing reliability mathematical models were developed very early in the SPRINT R&D program. From these models, it was apparent that the following parameters were the most important in achieving the reliability goals:

a. Electronic storage failure rate during a 5 year life (i.e., storage failures)

b. Percent of testability of missile electronics

c. Periodic test interval for missile electronics

d. Severity of inflight environments (acceleration, shock, vibration, and aerodynamic heating).

The development philosophy for SPRINT was "a tactical missile from a tactical silo with the initial design." Although many changes occurred during the 13 year development, the first flight test missile (launched successfully on November 17, 1965) is not greatly different than the 70 that are being deployed at Grand Forks, North Dakota.

At the end of the Reliability Demonstration series (flown at both WSMR and KMR), the SPRINT subsystem had completed 51 flight tests with no electronic failures. Each missile contains about 9,000 electronic piece parts and the Ground Support equipment contains an additional 5,000 parts for a total of just over 700,000 parts tested with no failures. This highly successful flight test series demonstrated the flight reliability of the SPRINT subsystem. The demonstration of the ability to survive long term storage in a controlled environment proved to be somewhat more difficult. In order to facilitate better communications

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*The only components not common to SAFEGUARD in the SPRINT II MCS design are the integrated circuits, six magnetic devices and eight discrete semiconductors.

with customer and management and provide a simple numeric for tracking progress and problems, an average electronic piece part storage failure rate was established. This single value is simply the total system electronic storage failure rate divided by the total number of electronic piece parts in the system. In order to meet the reliability goals established early in the R&D program, it was calculated that an average electronic piece part storage failure rate of 3.05×10^{-9} failures per hour was required. Based on a simple comparison of this single numeric (average part failure rate) it is shown that the fielded system is performing better than predicted.

	Average Electronic Pieces Part Storage Failure Rate
Required to meet specified reliability goals	3.05×10^{-9} failures/hour
Predicted based on failure rate revision of 1969	2.3 failures/hour
Experience to date (all sources)	1.4 failures/hour
Grand Forks only	1.07 failures/hour

As a result of the extensive flight test program and the long term monitoring of storage data, two critical parameters of the SPRINT subsystem have been demonstrated.

1	Overall success ratio	91 percent
2	Storage average part failure rate	1.07×10^{-9} failures/hour

Perception of Reliability impact on cost drivers is aided by a review of the techniques used to achieve these results:

Decision to Use High Reliability Piece Parts - The quality and reliability of the basic building blocks of a complex electronics system is vital to achieving system reliability. The failure rate of high rel parts is roughly one-half of the more commonly used Mil Standard parts. This lower failure rate is achieved by extensive environmental screening and 268 hours (typical) power burn-in on a 100 percent basis. SPRINT parts specification requirements were developed jointly by Martin Marietta Corporation and Bell Telephone Laboratories using the Minuteman I parts spec as a reference.

Derating - A conservative derating policy of 50 percent was established for SPRINT electronics and was confirmed by detailed stress analysis. Of some 14,000 electronic piece parts, only 6 were found to violate this policy, and the majority were even more conservatively derated. Derating tends to drive the operating failure rate in the direction of the much lower storage failure rate.

Testability - In any long life system, the degree to which it can be periodically tested is one of the most important considerations in achieving reliability. Testability is defined as the percentage of the parts that are testable in terms of failure rate. The SPRINT System Missile electronics is greater than 98 percent testable. Testability considerations must also address test frequency. Studies have indicated that one test per day is optimum, however, once per month is sufficient to exceed reliability goals.

Production Environmental Testing (PET) - PET is also an extremely important factor for achieving high reliability. It consists of conducting environmental screening tests on 100 percent of items produced. Testing is done at the assembly or black box level. On SPRINT II, sine vibration, mechanical, and temperature shock are used for PET.

Lot Sampling, Dissection Analysis and Storage - During the production of the 70 SPRINT Subsystems for deployment, a piece part lot sampling program was initiated. In general, 10 samples were selected from each purchased lot of piece parts. Two were dissected and compared to a carefully prepared baseline. The baseline consists of complete characterization of a known good part with respect to parameters and physical characterization including enlarged color photographs. The other 8 samples are placed in storage, and periodically, critical parameters are measured and analyzed for trends.

Certified Lines - The R&D program revealed several very troublesome components which did not entirely respond to normal corrective actions. In order to prevent further problems during production, certified or captive lines were established at 3 vendors covering 4 parts. These certified lines were wholly controlled by MMC, and only SPRINT parts were produced on them. Operation of the lines was supervised by MMC personnel after which no further problems occurred with these 4 parts.

Clean Room Assembly Area - Use of high rel parts alone does not assure reliable assembly level of black box hardware. In order to minimize fabrication errors and contamination, all electronic assemblies were built in a clean room environment. All employees wore smocks and access was limited to the fabrication area. All components were staged and detailed process plans developed. All employees were certified in their particular operation by extensive education courses. The courses emphasized superior fabrication results, acceptable results, and unacceptable results. All tools were calibrated before each shift and for certain operations. Employees were required to fabricate several samples for destruction test prior to starting the shift production run. This technique minimized fabrication errors and improved the production yield.

Reliability Growth Test-Post Flight Analysis of Performance - The WSMR series of 42 flight tests served as an excellent example of reliability growth. Exhaustive analysis, simulation and ground test followed each failure occurrence. Once corrective action was established, the change was fully tested and evaluated before introduction into the next test missile. In most cases this technique solved the problem at first attempt. There were, however, two cases where the cause was not fully understood and near the end of the WSMR series second failures occurred. However, in both cases, the final solution was effective and demonstrated by no reoccurrences during the 34 tests at KMR.

Preflight Management Review and Inspection-Subsystem Managers - Prior to each test flight a thorough review of all discrepancies, failures, test data, changes and risks was conducted by top engineering management (technical director and his staff). These reviews were conducted early enough so that correction of deficiencies could be completed prior to scheduled flight date. The data was presented to management by the subsystem manager of each portion of the system. This approach was unique on SPRINT. Each element of the SPRINT missile, silo, and ground equipment had a key engineer assigned to it. This engineer was responsible for all aspects of his hardware and had reporting to him cognizant experts in Manufacturing, Quality, Procurement, etc.

Production Policy - As production of deployed hardware was beginning, it became evident from the KMR series that the reliability was exceeding goals. Therefore, a "no change" policy was established. In other words, no changes in design, tooling, or procedures were permitted so that degradation in performance would be minimized if not eliminated. Obviously, it was not possible to stop all changes; however, the difficulty in getting a change approved went a long way in eliminating problems that are always evident with wholesale changes. The control over changes was exercised by the "A" Change Board which was chaired by the top executive on the project and manned by his immediate staff.

Other tasks which contributed to the reliability success of the program included:

Failure Modes Effects and Criticality Analysis;

Reliability Design Analysis-Component Stress and End of Life Tolerance;

Laboratory Exposure of all hardware to anticipate flight environment prior to first flight;

Qualification test program which was, in general, conducted at 50 percent overstress in transportation, handling, storage, and flight environments;

Sampling of production line hardware on periodic basis and subject to transportation handling storage and flight environments;

Elaborate system of failure reporting, corrective action, and follow-up.

In conclusion, the results of these techniques are best shown by the success of the Reliability Demonstration - Flight Test Program where a success ratio of over 90 percent was achieved and by the average electronic storage failure rate which at 1.4 x 10^{-9} failures/hour is much less than the required value of 3.05 x 10^{-9} failures/hour. A more subtle but equally important result was the actual deployment operation itself. A total of 70 sets of ground equipment and 69 missiles were installed precisely on schedule with no schedule deviations due to failure of hardware, procedures, or support equipment. This operation was conducted and completed on schedule in the hostile environment of North Dakota's severe winters. In retrospect, it is evident that some cost reduction opportunities could have been incorporated with acceptance of quantifiable degradations in Reliability which continued to meet specified levels.

3. Nuclear Hardness. a. Nuclear Environment - The SPRINT II transient ionizing radiation environment consists of the short duration prompt gamma pulse (experienced within hundreds of nanoseconds after the fratricide burst), and the delayed ionization pulse (experienced within tens of microseconds after the burst) which is caused by neutron interactions with air, neutron interactions with the missile, and decay of fission debris.

The prompt gamma component of the weapon spectrum produces the peak ionization dose rate of the SPRINT II environment in the missile. The neutron component of the weapon spectrum produces the delayed ionization pulse. Weapon yield, missile altitude, and distance from the fratricide burst affect the magnitude of the peak ionization dose rate, the neutron fluence and energy spectrum, the delayed ionization dose rate encountered, and the total dose environment.

Neutron radiation produces delayed ionization transient damage effects in semiconductors (which anneal out in a time interval dependent on the operating condition of the device), and permanent damage in semiconductor devices through displacement of atoms or capture of the neutrons by atoms. Semiconductor photocurrents that result from transient ionizing radiation can cause transient circuit responses, fractional loss of capacitor charges, and alteration of the elctrical properties of dielectric and insulating materials.

Both transient and permanent damage effects of the nuclear radiation environment are dependent upon dose rate, total dose, neutron fluence, circuit configuration, and the type of component device used. These effects can lead to circuit transients and perturbations which degrade the performance, maneuverability, and reaction time of the missile.

b. Source Limitations - The choice of nuclear design approach was also influenced by the difficulties of procurement. Though it was possible to buy standard TTL logic and integrated circuit operational amplifiers in the limited quantities needed, the Texas Instruments 5400 series (which is the basis of the MCS logic) was the only line of hardened integrated circuits available, and even this source was in danger of being closed down because of a lack of volume purchases.

Thus, a major problem was faced in building a hardened system because of existing supplier constraints that appeared likely to become more severe. The Department of Defense no longer occupies a dominant position as a buyer of semiconductors. Present DoD requirements account for only 5 percent of the total integrated circuit market, and the government ranks fifth in dollar expenditures for this item among the following user markets: computer systems, industrial, distributor, consumer, government, and export.

c. **Dynamic Environments** - The SPRINT II MCS must also perform in flight environments exceeding 10,000g's peak acceleration shock at 24 grms random vibration. Comparable levels for the DMCS are 20,000g's and 45 grms.

4. Performance/Cost Driver Summary. An overview of the combined interrelationship of performance/cost drivers is shown in Figure 3 for the three major SPRINT guidance hardware configurations.

Missile	Configuration	Performance/Cost Drivers
SPRINT I	Autopilot/Missile Guidance Set	NE, D, A
SPRINT II	Missile Control System	NE, D, A, R/
ISMS	Digital Missile Controller Set	NE, D, A, R/, RT, TG

NE - nuclear effects
D - dynamic (shock and vibration)
A - acceleration
R/ - reliability
RT - reaction time
TG - technology growth

Figure 3. Performance/Cost Driver Interrelationships

ABM guidance technology development, production, and plans for future production have progressed consistent with the development and application evaluation of the needed manufacturing technology, perceived threats, and systems options for effective threat counteraction. SPRINT is required to execute high g (+100) maneuvers with microsecond responses within a broad range of Mach numbers, dynamic pressures, and angles of attack. It must also survive the nuclear radiation and blast effects without structural failure or loss of controllability. Life Cycle cost considerations are impacted by the performance parameters needed to meet the evolving threat plus provisions for 10 year storage life in the readiness state; cell security from sabotage without personnel protection; shock withstanding of free field nuclear effects; and launch, flight, and in storage reliability.

The SPRINT I analog autopilot was the last major assembly to be qualified for tactical use. Primary factors impacting design schedule and cost were the uncertainties associated with needed interceptor characteristics and the necessary characterization of the nuclear environment. Design objectives for the SPRINT II MCS included improved performance and reliability, increased nuclear hardness, and reduced cost.

B. MCS Design Actions Impacting Cost During Development

1. Initial Concepts. MCS hardware design features incorporated as part of the fundamental concept include: microelectronic hybrids, rigiflex harnesses, cast structure, and packaging methods.

Microelectronic Hybrids - Martin Marietta-developed microelectronic hybrid designs are used in the SPRINT II MCS in place of SAFEGUARD SPRINT thin film IF amplifiers. The hybrid is considerably cheaper and more producible than thin film. These advantages are evident in the resulting replacement of four thin film assemblies with one hybrid.

Rigiflex Harnesses - All internal wiring of the MCS is accomplished with printed circuits, using rigiflex harness interconnections. Figures 4 and 5 illustrate the rigiflex harness designed for the inverter regulator No. 1 module. This approach cuts cost and increases production largely by avoiding the necessity to handle individual wires and by maintaining a constant lead dress.

Cast Structure - The MCS is an all-cast structure (Figure 6). At the time it was the largest investment casting for such an application in the country. Casting provides an integral structure that eliminates fabrication of individual parts, tolerancing problems, and many machining operations.

Figure 4. Multilayer Printed Wiring Rigiflex Harness for Inverter Regulator No. 1

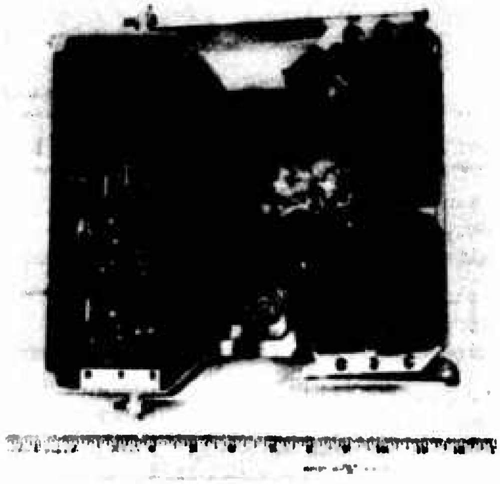

Figure 5. Inverter Regulator No. 1

Figure 6. MCS Cast Structure Showing Equipment Shelf and Canister

Packaging Methods - Although state-of-the-art electronic packaging methods are used throughout the MCS, the modules are basically produced by existing, proven techniques. The 22 thin modules in the system are framed and attached to printed circuit boards (16 double-sided and 5 multilayer), to which the components (discrete, TTL, integrated circuit operational amplifiers, and other subassemblies) are mounted and soldered. Each module is encapsulated in foam and shielded. Each is functionally testable.

This method greatly reduces assembly time by permitting components to be assembled in one flat plane. All modules are designed for automatic component insertion equipment. Accessibility allows repairs to be made quickly and easily. The sacrifice in component density and volume remains well within the volume or weight restrictions of packaging in the missile guidance and control section. Moreover, costs are reduced and producibility enhanced without jeopardy to reliability.

Increased Production Yield - Another advantage of the printed circuit module construction method is that the production yield of the board is high, and the yield increases when comfortable conductor widths and spacings are used. Table I reflects Martin Marietta experience with printed circuit board production. The MCS printed circuit boards are produced using Class I and II tolerances.

TABLE I

Conductor and Spacing Tolerance versus Yield

Fabrication Technique	Class I	Class II	Class III	Class IV	Class V
Print and etch (no overplate) Approximate percent of yield*	+0.006 -0.010 99 percent	+0.004 -0.005 95 percent	+0.002 -0.004 85 percent	+0.001 -0.002 50 percent	+0.001 -0.001 30 percent
Panel plate (no overplate) Approximate percent of yield*	+0.010 -0.015 98 percent	+0.007 -0.010 95 percent	+0.005 -0.008 90 percent	+0.004 -0.006 85 percent	+0.002 -0.003 40 percent
Pattern plate (no overplate) Approximate percent of yield*	+0.015 -0.010 98 percent	+0.010 -0.007 95 percent	+0.008 -0.005 90 percent	+0.006 -0.004 85 percent	+0.003 -0.002 50 percent
*The yield is the approximate number of acceptable boards expected in a quantity of 100. This yield relates to conductor line width and pad sizes. It does not consider other processing deficiencies that may cause rejection.					

2. Cost Targeting (CT) and Design to Cost (DTC). The SPRINT II program established cost targets during the Concept Development (CD) phase which became design-to-requirements in the Prototype Development (PD) phase. Additional emphasis was placed on cost reduction midway in the PD program through introduction of a project wide DTC program.

Cost Targeting is fundamental to the achievement of DTC objectives. Both techniques stimulate favorable attitudes and impetus for manufacturing technology improvements.

Figure 7 illustrates the overall SPRINT II program development cost estimate history for a composite of development program tactical hardware prototypes. Twelve different hardware elements comprising a total of 66 subassemblies are represented. It will be seen that the initial status of 7 percent adverse was impacted by specific development actions to culminate in a final status which was 15 percent favorable. Figure 8 is a corresponding abstract of the SPRINT II history for the MCS.

Table II lists the major development actions which contributed to favorable cost target attainment of 5.5 percent.

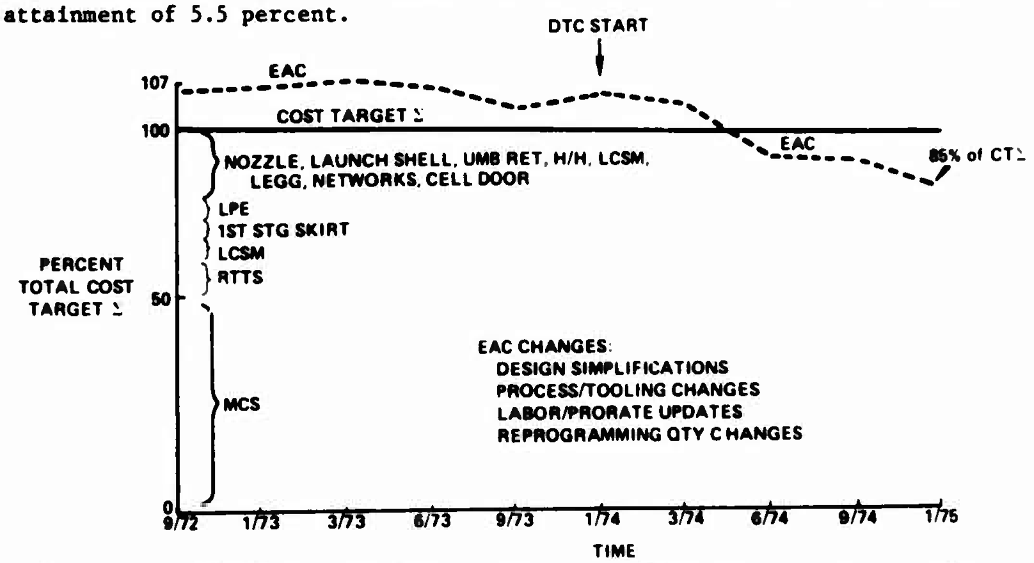

Figure 7. SPRINT II Cost Target (CT) versus Estimate at Complete (EAC)

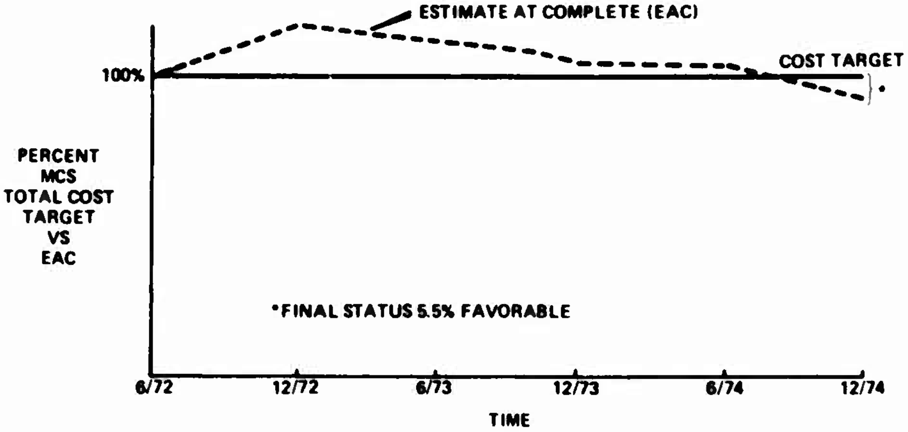

Figure 8. Missile Controller Set (Quantity: 12)

TABLE II

Missile Controller Set Development Actions
Which Favorably Impact EAC

Action	Percent Cost Target Improvement
Eliminate conformal coat (pc cards)	0.60
Remove connector pc card eyelets	0.65
Remove computor designations on pc cards	1.37
Use hybrids	0.15
Stop redundant separation force checks	0.29
Revice MPP's	0.16
Redesign inverter regulator loop	0.26
Delete video processor transistors	0.07
Improved method of RFI module seal	2.06
Others	0.07
Total	5.68

It should be noted that the development of a more effective process for applying an RFI seal to modules constitutes the largest single beneficial cost driver interaction. Additional innovations of note involved design and manufacturing process simplifications. In total, the 5.5 percent favorable cost status of the MCS resulted from design/manufacturing technology actions whose total value was 5.68 percent. Of this total 93 percent resulted from manufacturing cost reduction actions. Cost reductions achieved through use of hybrids did not reach the target levels which had been originally established.

C. MCS Cost Drivers

Table III illustrates the functional cost analysis of the SPRINT guidance system. It should be noted that the electronic modules constitute the largest single guidance cost element and that its value is over 3.5 times the next largest element. Conversely, purchased parts are approximately 2 times the value of factory labor in the functional breakdown.

Figure 9 is an additional illustration of the cost impacts and interrelationships of guidance system hardware elements and functions. This information constitutes the base from which the proposed Manufacturing Technology Projects are constructed.

TABLE III

SPRINT Guidance System Functional Cost Analysis

Guidance Element	Percent of Total Guidance Cost	Purchased		Percent Distribution of Cost Elements				Total
		Parts	Material	Factory Labor	Test Labor	Quality Labor	Support	
Electronics (modules)	48.6	62.1	0.9	16.8	3.3	8.3	8.6	100
Platforms	13.7	6.2	11.5	37.7	12.8	20.6	11.2	100
Microwave devices	12.0	53.4	9.4	12.0	8.2	8.4	8.6	100
Major mechanical	7.1	7.9	23.9	21.2	21.2	17.3	8.5	100
Gyros	7.0	9.9	4.8	39.3	13.3	21.6	11.1	100
Cables	5.2	15.7	9.9	38.3	9.3	19.4	7.4	100
Power supply	4.7	33.6	18.1	20.5	5.8	10.8	11.2	100
Accelerometers	0.9	0.9	16.8	37.6	12.8	20.6	11.3	100
Heat sinks, brkts	0.5	14.1	13.9	46.9	-	17.6	7.5	100
Connectors	0.3	78.4	-	9.6	-	4.7	7.3	100
Total	100.0	41.4	6.8	22.6	7.6	12.4	9.2	100

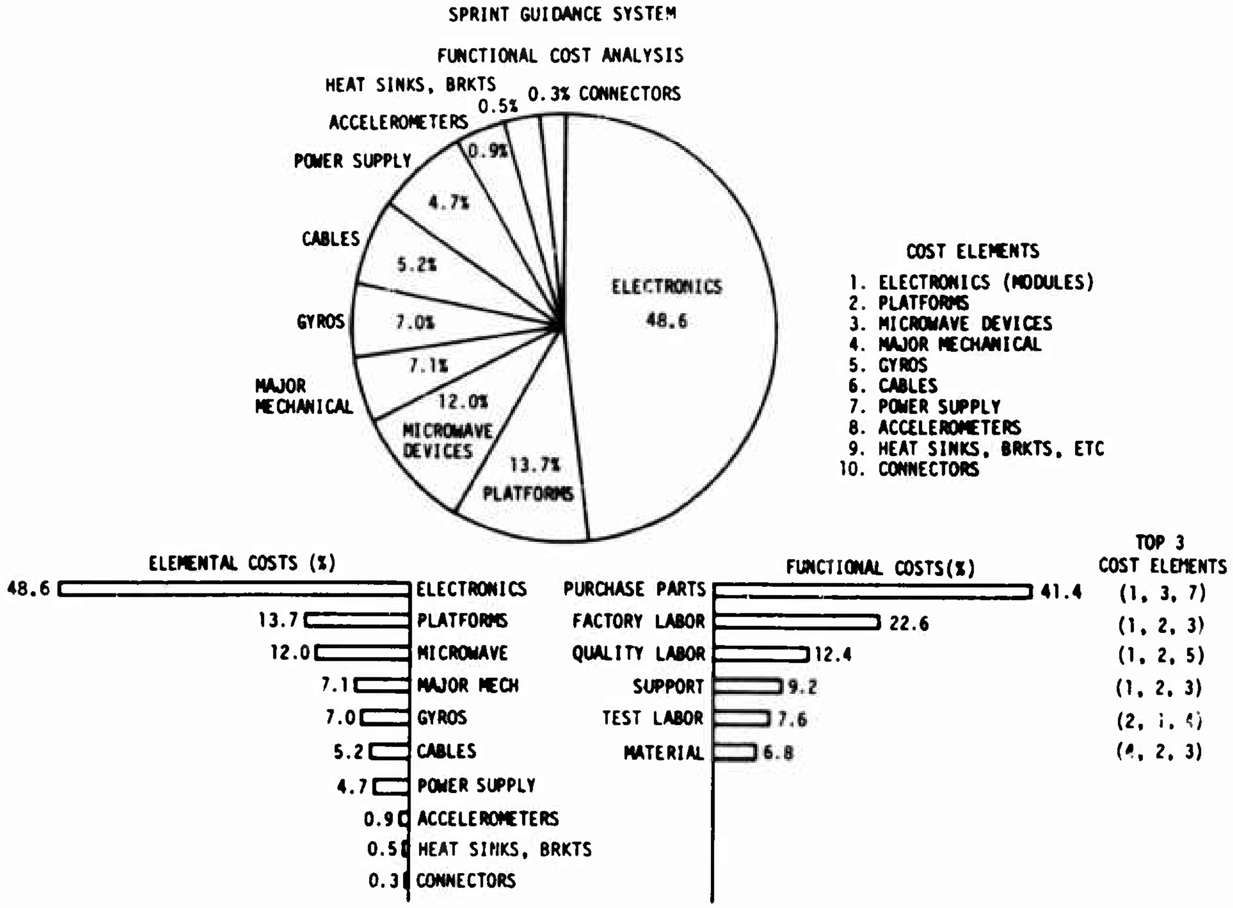

Figure 9. SPRINT Guidance System Functional Cost Analysis

D. Manufacturing Technology Projects

Table IV lists the proposed manufacturing technology projects, the estimated initial cost of development, and indicates the cost reduction potential for each project in terms of percentage of guidance system cost. Detailed additional descriptive information is attached to some of the manufacturing technology projects as amplification of the project objective.

TABLE IV

Proposed Manufacturing Technology Projects, Project Initial Cost, and Potential Guidance System Cost Reductions

	Initial Cost	Potential Cost Reduction of Guidance System Cost (percent)
Comprehensive investigation of part costs	$ 85,000	12.0
Improved selection/application of nuclear hard semiconductors	78,000	10.0
Develop semi-automatic acceptance test techniques for inertial sensor assemblies	157,028	5.0
Exploration of CAD/CAM automated assembly of film hybrid microcircuits	65,000	3.0
Production of PCB's using the semi-additive technique	452,200	2.0
Improved production techniques for multilayer rigid-flex PC assemblies	133,000	1.8
Coaxial cable fabrication	440,000	1.7
Connector/interconnection reductions	205,000	1.2
Laser trimming of star value resistors	194,000	1.1
Optimize production inspection of electronic assemblies	210,000	0.6
Total	$2,019,228	38.4

E. Institutional Cost Drivers

Detailed study and consideration of cost drivers and efforts to conceive alternatives for improvements naturally encounters problems of an institutional or historical nature. Such problems are basically attitudinal. They are impacted by future expectations as well as habitual outlooks and approaches conditioned by experience. Although their influence on cost effectiveness achievement is subtle and difficult to quantify, it is recommended that an attempt be made to obtain the thinking and intuitive feelings of the conference attendees on possible approaches to future improvements. Some items which may profitably be explored are:

1 The applicability of Military Specifications for parts, material, processes, and design/manufacturing control. Could a standardized, simple procedure be devised to take meaningful exceptions? Previous studies strongly indicate significant cost reduction potential. (1.) (2.)

2 The measurement and control of Operations and Maintenance (O&M) cost factors during development. Means for better utilization of contractor organization knowledge and skill to beneficially effect O&M cost and field performance and reliability.

3 Lessons learned from experience in application of additional Design to Cost Emphasis.

4 Functional interface standardization versus detailed specification standardization.

5 Exploration of potential pitfalls and benefits associated with encouraging the use of standardized electronic modules and preferred LSI components. Cost savings potential is considered attractive when applied on a DoD wide basis. (3.)

6 In depth cost effectiveness analysis of quality control techniques and approaches. One analysis indicated as much as 25 percent of missile cost was assignable to procedures derived from MIL-Q-9858. (4.)

IV. CONCLUSION

It is our belief as a result of previous cost reduction efforts and the additional insights gained through the preparation of this paper that concentrated additional study is warranted on both specific manufacturing technology projects and those generalized, procedural aspects of DoD Development and Acquisition which pervade the total cost process.

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(3.) Philip K. Klass, "Avionics - USAF Weighing Standardized Modules," Aviation Week and Space Technology, September 16, 1974, p 51-56

(4.) C. Leatherbury, A. Kresse, C. David Weimer, "Production Cost Reduction Case Studies of Three Tactical Missiles," AD 513090, Institute for Defense Analysis, September 1970, p 37

V. MANUFACTURING TECHNOLOGY PROJECTS

Title: Conduct a Comprehensive Survey/Investigation of Factors Which Comprise Part Costs and Develop Cost Effective Alternative Approaches

System/Panel Area/Component: Missile/Electronic Controls/Purchased Parts

Problem: Purchased parts are the largest single electronics cost driver. Special military requirements impact this cost and present military part cost trends are adverse in view of the decline in proportion of military to commercial business. Analyses of commercial hardware items adapted for military usage typically reveal significant cost advantages when compared to fully militarized designs and have performed adequately in the military application. The attached description contains additional background information on this problem.

Proposed Solution: Identification and thorough analyses of specific case histories of commercial/military product developments can provide a data base from which possible future approaches can be quantified and projected. The data base should be supplemented by a comprehensive survey of all major elements of the military parts selection, specification, purchase and handling process as fulfilled by DoD contractors. In particular, the quantifiable and obscure cost elements of present practices must be definitized and assessed. Performance considerations and risks associated with new approach alternatives should be appraised with a degree of thoroughness comparable to the cost element analysis.

Project Cost and Duration: Estimated costs are as follows:

Develop detailed case histories assessing cost impact of parts	$35,000
Conduct detailed survey of contractor and DoD representatives - parts life cycle cost impact analyses	35,000
Prepare report summarizing findings and recommending approach alternatives	15,000
	$85,000

A follow-on step is recommended in which the project findings are applied and verified to an on-going project. Estimated cost is $250,000. Estimated duration of project is 8 months.

Benefits: Benefits achievable from this project are a reduction in parts life cycle cost as follows: Net reduction in parts costs - 25 percent (savings will approach 50 percent where nuclear hardness is not required). This equates to a 12 percent reduction in guidance system cost.

Assumptions: That effective means can be determined to more closely approximate commercial design practices for parts application in military hardware.

BACKGROUND

Purchased Electronic Parts Life Cycle Cost

The following factors combine and interact to adversely impact the total life cycle cost of purchased electronic parts in military systems:

1. Military Part Specifications/Standardization - considerable effort has been spent recently to achieve better understanding of the cost/performance impact of system and detailed part specification and standardization efforts. The concensus, with some reservations, is that system performance standardization should be more oriented toward function and less dominated by "how to do it" specifications. A recent report concludes "The elimination of the MIL-SPEC burden can substantially reduce the cost of electronic systems" and cites one example in which material cost was 25-50 percent lower than an equivalent military system for an identical environmental application.(1.) Present military part specifications require payment of a purchase price premium which tends to increase in magnitude for areas where commercial technology is rapidly changing. The effects of such a constraint on contractor design and other internal activities is significant but not readily quantifiable without detailed investigation and actual trial study, measurement, and evaluation of alternative approaches. Semiconductor costs in particular are impacted adversely by current trends. Evidence exists that military functions are exploring alternative means of working these problems. In one instance the Army is bypassing its own MIL-S-19500 and MIL-M-38510 specifications to permit a single application of a non-military semiconductor part family.(2.) Purchase cost differentials of 10:1 are not uncommon between military and commercial versions of an equivalent circuit function. These factors suggest that a systematic evaluation and pilot study of alternative approaches is needed with the objective of responding to the AMC Design to Cost Policy statement "An important part of the product we are buying from the contractor is his design creativity and he must be free to use his best judgment in producing his competitive prototype hardware."(3.)

2. Commercial Industry Trends - at one time military purchases represented approximately 80 percent of the semiconductor business. Currently MIL STD IC's are approximately 5 percent of total industry billings and trending downward. The implications for design applications are that measures which more closely approximate effective commercial design practices for fielding workable products under warranty are needed. The key question pertaining to effective reaction to these trends centers on how rather than if and to what extent. A recent article presents data and an approach rationale which asserts that effective part screen testing can be performed in-house or contracted from independent test labs for approximately $0.10 per device at a volume of 150,000 per month.(4.).

   Military product designers with some modification in attitude and approach can determine effective means for making the transition from utilization of military specified parts to commercial parts. An effective investigation technique for identifying and implementing positive actions is to obtain the data necessary for analyzing parts as a systems engineering process which can be optimized in terms of the weapon system life cycle.

3. Design/Manufacturing Technology Trends - The technology demands of the 1980's will encompass greater diversity of part selections and greater inherent complexity in part application than presently exists. To effectively and economically cope with these challenges simplification of all ancillary constraints which effect part documentation, purchase, and design application is necessary. Reliability, availability, and maintainability (RAM) needs must be met more effectively as well. Forseeable actions which impact parts cost from initial purchase throughout the life cycle are:

   a. Selection/Receipt/Screening - limited across the board use of blanket military specifications.

   b. Application - environmental testing at the PCB level prior to subsequent assembly. Reference (1.), p 286 discusses the need for more realism in environmental design.

   c. Test - system/subsystem level testing of the PET and Reliability verification variety.

   d. Product Warranty - greater contractor participation in the diagnostic/repair process at the depot and field maintenance levels.

4. Warranty/Maintainability Trends - A sufficient experience base exists to substantiate the desirability of extending long-term contractor maintenance warranties to military electronics. Properly contracted and administered warranties have resulted in substantial equipment reliability growth early in the acquisition process and significant reductions in maintenance costs.

   The warranty/maintainability process is facilitated by the following techniques:

   a. Contractor cost tradeoffs in component cost, assembly-line quality control and failure rate prediction.

   b. Adequate protection against equipment tampering and misuse.

   c. Contractor visibility and participation in the equipment maintainability process.

An important consideration in meeting cost and performance goals within the provisions of enforceable warranties is recognition of the need to provide sufficient contractor flexibility during development. The lowest cost, adequate, simplified design will frequently not extensively employ military standard parts and may be fabricated by commercially proven processes.

5. Designer/Manufacturing Technologist Interactions - To accomplish these objectives will require closer and more intensive relationships between Manufacturing, Quality, and Engineering technologists than has been typical in the past. A centralized area equipped with a broad complement of part test equipment for screening, PC board fabrication, and subsequent environmental test verification is necessary. Personnel staffing of individuals thoroughly versed in the affected technologies is vital since practical decisions and actions must be made and implemented quickly.

The contractor knows (or will quickly learn) how to manufacture an assembly at the lowest possible cost for a fixed price that will reliably perform as required. The following ideas are suggested for further evaluation:

a. Minimize piece part documentation controls required by military contracts.

b. Allow purchase of commercial type parts to minimal functional and environmental requirements and documentation.

c. Minimize costly receiving inspection and acceptance testing on the part level.

d. Develop more cost effective manufacturing processes and controls.

e. Provide more knowledgeable and experienced personnel to the assembly line to perform tests and quality inspections.

f. Assign qualified engineers to be accessible to evaluate and correct any problem recognized by the testing or inspection personnel.

g. Customer should place emphasis on accepting product on the printed circuit or replaceable assembly level.

h. For maximum benefit, a dollar limit for throwaway level has to be established for individual programs based on technology, complexity, and total quantities.

These objectives will require breaking away from habitual practices of relying on detailed part specifications to provide assurance of a product suitable for the application. They will also require careful, technically mature, and practical judgment of the design application need prior to and during the breadboard stage as well as in fabrication of deliverable products. Product grade level selections equivalent to JAN-TX or MIL-M-38510 will not be avoided if they are purchasable at an affordable price but need not be specified for a given design. Some savings in documentation cost are forecastable from simpler specifications and process documentation but these are nonrecurring.

To compare expected cost savings on a typical assembly the following matrix is offered:

Recurring Cost Matrix

This matrix depicts an electronic assembly using 10 IC circuits, 10 resistors, and 7 capacitors.

	Industrial		**Military**	
(10) 54164 Type IC's	(5.50 ea)	$55.00	(25.00 ea)	$250.00
(10) RCR's Resistors	(0.03 ea)	0.30	(0.04 ea)	0.40
(6) Ceramic CAP	(0.13 ea)	0.78	(16.00 ea)	0.96
(1) TANT CAP	(0.30 ea)	0.30	(0.35 ea)	0.35

	Industrial	Military
Trouble shoot/test and repair assemblies	80 percent yield $7.00	90 percent yield $3.50
Per Assembly	$63.38	$255.21
(1000) Total Cost	$63,380	$255,210

The matrix does not include items that would have approximately the same cost such as lot acceptance testing, assembly fabrication, staging of parts, and stocking of parts.

Basis for Calculations

1. Manufacturing time for working hour = $15.00 hours.

2. Cost to repair and retest failed assemblies = $35.00.

3. 1000 Electronic assemblies to be fabricated.

Title: Improved Selection/Application of Nuclear Hard Semiconductors

System/Panel Area/Component: SPRINT Missile System/Guidance Systems/Semiconductors

Problem: Electronic parts are the major cost driver in guidance system design. Semiconductors are the major electronic part cost element. Nuclear hardened semiconductors are significantly more costly than commerical equivalents by factors which frequently exceed 20:1.

Economy of scale factors are continuing to drive the cost of military electronic parts higher. In particular, upward cost trends for semiconductors can be expected to reflect steadily decreasing trend ratios of military/commercial product mixes experienced in the past decade by part manufacturers. Those design applications requiring nuclear hardness are the most severely impacted since the nuclear characterized parts are an even smaller fraction of the total military part product business and consequently, bear the risk of unavailability for both development and production quantity buys as well as the cost premium associated with technological obsolescence and sporadic development quantity purchases. Recently, such problems have adversely impacted costs for a major DoD program.(5).

Proposed Solution: Conventional solutions to this problem such as captive production lines, clean room assembly areas, precisely specified part selections, etc. have one common feature - high cost. However, the manufacturing technology of the 1980's will continue to require effective part control, reliability and affordable cost. Achievable improvements are dependent upon realistically appraising the response of the parts industry to the major trends of the marketplace and developing cost effective internal techniques for providing the needed part control. This proposed manufacturing technology project impacts the highest cost factor of the highest element of part cost for some military design applications - nuclear hardness. In essence a methodology and pilot equipment configuration is proposed which will provide a cost effective screen and/or characterization test procedure for handling a moderate to large volume of semiconductors. The inherent feasibility of this approach has been demonstrated for small part quantities. Therefore this proposed manufacturing technology project is focused on making an effective transition of the technique to larger quantities on a systematic production line basis.

A key feature to the success of the concept is a cost effective and proven method for assessing piece part suitability in the nuclear environment of interest. Dependent on program design requirements, EMP, neutron damage, prompt gamma burnout or total gamma dose degradation may be the key performance parameters which require test verification.

Conventional methods of screening for the critical environment are costly and time consuming. Typical present methods of screening use either single channel (high speed) oscilloscope photography, single channel data recording or multi-channel recorders. All these methods furnish data which requires further processing to evaluate pass/fail decision parametric values.

Martin Marietta Aerospace studies of this problem for several years have led to the development of a more cost effective test unit to provide necessary decision block interface data. A method of multiple channel data acquisition and analysis in real time has been successfully demonstrated which significantly effects the cost of providing discrete part nuclear hardness assurance. Additional information which describes the technique and present test equipment is attached.

Project Cost and Duration: Estimated costs are as follows:

Purchase parts and materials	$10,000
Part characterization test, irradiation and post irradiation test (includes some outside irradiation facility rental cost)	34,000
Analysis of data and report preparation	12,000
Follow-on application of improved techniques to develop test hardware	12,000
Preparation of detailed final report	10,000
Total	$78,000

Estimated project duration is 12 months.

Benefits: Potential benefits to be derived are a new generation of test fixtures which will enable pass/fail decisions in real time and provide a permanent record of device operation history as described in the attachment.

1. An initial reduction of $3.00/device screened (based on costs of polaroid film lease equipment and manpower to reduce data) through systematic use of the described techniques.
2. 30 percent reduction in records retention and retrieval cost.
3. A potential additional reduction of $3.00/device screened resulting from test optimization of equipment to increase throughput.
4. Fixture standardization which assures that each part screened is subjected to identical predetermined stresses.
5. Increased availability of consistent quality parts because suppliers to the specification can understand the methods, procedures, and fixtures instead of suspecting the screen techniques are inconsistent and arbitrary.

Development and verification of the productionized version technique will potentially lower the net cost of nuclear hard semiconductors by 30 percent. This equates to a 10 percent reduction in guidance system cost where nuclear hardness is required.

Assumptions: The potential benefits are predicated on design applications which require high rel, nuclear hard parts within the discipline of a development philosophy which requires that all tactical requirements be approached concurrently.

Data Acquisition System

Economical data acquisition is accomplished by utilizing a computer controlled single-shot analog to digital converter, programmable multiplexer, fast RAM storage, and a digital demultiplexer. The system is shown in block form in Figure 1 with a photograph of the complete system in Figure 2. The system organization simulates 1, 2, 4, or 8 dual gun oscilloscopes. The selection or channel assignment depends on the type of data to be analyzed, the time rate of response and the spectral characteristics of the environmental simulator.

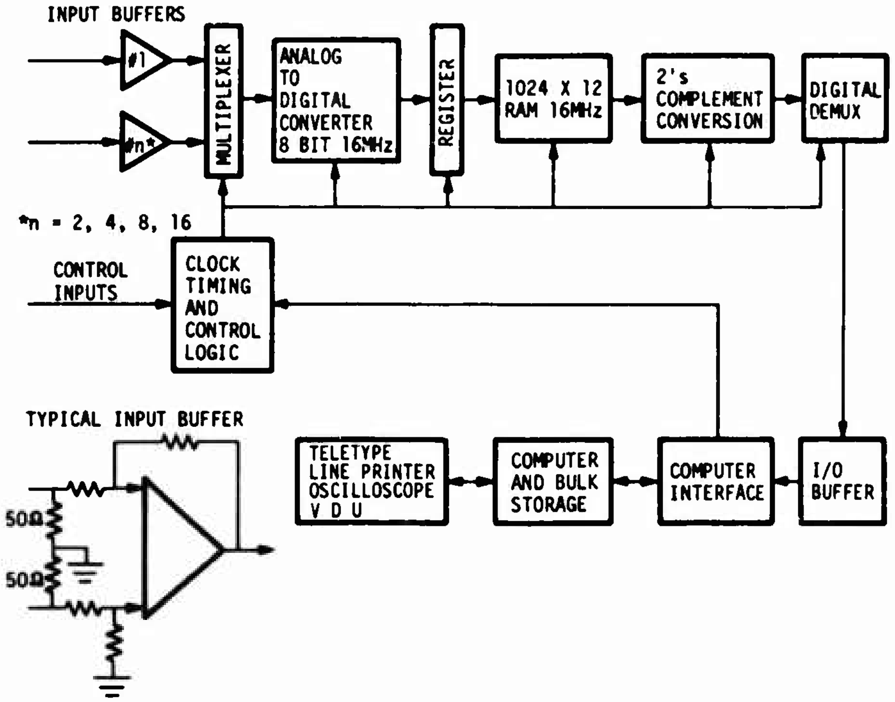


Figure 1. Data Acquisition System Block Diagram

Figure 2. Nuclear Test Data Acquisition System

The data output may be displayed on an oscilloscope, a video display unit, teletypewriter, or line printer. All data is stored on magnetic tape in engineering units for finish formatting after test is completed. Figure 3 shows a typical data pulse printout. This data is for a prompt gamma linac screen of PIN gamma detector diodes. The first row is a printout of dosimetry, rows 2 through 4 are the PIN responses and row 5 the cumulative data output summary including mean and deviation. This data is available on an ASR 33 TTY within one minute of the data pulse. The test throughput rate, including permanent data storage is one linac pulse/minute. This testing was done in parallel with present oscilloscope acquisition methods where two men operated two Tektronix 556 oscilloscopes (lease cost $220/week) and annotated Polaroid film ($165/case). The data system requires one man plus ten reels of 4 inch mag tape/week ($12/reel). The differential devices test cost is $3.00.

```
SET          DOSE RATE          PULSE WIDTH
 +11,  +0.135417E+000    +0.799999E-006    DOSIMETRY MEASUREMENT
 +11,  -0.251923E+000    +0.799999E-006    TEST DEVICE #1
 +11,  -0.239423E+000    +0.533333E-006    TEST DEVICE #2
 +11,  -0.283654E+000    +0.799999E-006    TEST DEVICE #3
 +36,  -0.272344E+000    +0.433810E-001    CUMULATIVE DISTRIBUTION
                ↑                  ↑
               MEAN              SIGMA
```

Figure 3. Typical Data Pulse Printout

This system will operate on neutron data in the same manner. The important difference is that the pulse time in a reactor is one pulse/hour such that all prior data is completely organized and formatted between reactor pulses rather than summarized.

This system will perform detailed neutron circuitry characterization in a similar manner. The important difference is that the typical pulse time from a reactor is one 50 μs pulse/hour. Therefore, all prior data may be completely organized and formatted between reactor pulses rather than summarized for subsequent analysis. This eliminates one or more weeks of turn around time for subsequent data evaluation and possible retest of a modified circuitry configuration. Using this system it is possible to obtain a neutron circuitry characterization, summarize and evaluate the data, make exploratory circuitry modifications, and verify the performance of the altered circuitry configuration within the time availability of the next neutron pulse. The potential reduction in system development and acquisition costs are substantial.

The system is ruggedized for complete air or truck transportability and operates on one phase, 20 ampere service.

The complete success of this unit indicates that substantial savings can be achieved in multi-channel, single-shot or repetitive testing and further development of this technology is warranted.

Title: Development of semi-automatic testing techniques for acceptance testing of Inertial Sensor Assemblies.

System/Panel Area/Component: Missile/Guidance/Electronics Inertial Sensor Assemblies (ISA's)

Problem: A major cost factor for ISA's is the 24 to 36 hours of testing on each assembly at final acceptance. Each gyro (3) and accelerometer (3) is tested by conventional means on a centrifuge and rate table. This procedure is time consuming since the tables must be accurately adjusted for rate/RPM and the data recorded manually. The ISA must also be repositioned six times on the centrifuge and three times on the rate table.

Proposed Solution: Develop and evaluate a mechanical fixture capable of being repositioned automatically into many different precise locations remotely by the operator. The following factors would be evaluated and combined to determine the overall cost savings from implementing this approach.

Servo type drive system - electrical pneumatic, screw, piston, etc.

Position locking device - pin, clamp, wedge, electrical, pneumatic, etc.

Fixture material - aluminum, steel, magnesium, cast.

Producibility - tolerance study, fabrication techniques, calibration.

Interchangeability - shock machine, rate tables, centrifuge table, vibration machine (evaluation of environments fixturing will be subjected to).

Positioning - specified positions, random or sequenced, infinite on demand.

Sub-fixturing - premounting of unit under test prior to submittal to test area.

Physical characteristics - weight, size and center of gravity considerations versus environmental applications.

Develop plan for automating all mechanical and electrical functions: input stimuli, output monitoring and decision making, automatic programming of rate table, centrifuge rpm, and sequencing of fixture positioning through use of a mini-computer and software.

Project Cost and Duration: Estimated costs are as follows:

Design engineering	$90,000
Engineering sketches	10,000
Engineering fixtures, fabrication	20,000
Engineering electronic test equipment, fabrication	20,000
Final report	10,000
Total	$150,000

Material:

Mini-computer PDP-11/05	$4,312
Teletype	1,620
Interface components	316
Connectors	80
Standard accelerometer	700
Total	$7,028
Total manpower	$150,000
Total material	7,028
Total project cost	$157,028

Estimated project duration is 12 months.

Benefits: Test time can be reduced by 16 to 24 hours per unit or approximately 65 percent of test labor effort. Less skilled personnel may be used as test operators. Test results will be more accurate and reliable, eliminating human judgment and error. This equates to a guidance system cost improvement of 5.0 percent.

Assumptions: Representative (SAM-D, SPRINT) ISA's are available for evaluation during this project. SPRINT and SAM-D Manual ISA Test Stations are available for use on this project.

Title: Exploration of CAD/CAM Automated Assembly of Film Hybrid Microcircuits

System/Session Area/Component: SPRINT/Guidance Electronics/Hybrid Microcircuits

Problem: Usage of selected hybrid microcircuits is potentially cost effective in many future electronic system designs. In particular, such circuitry offers the potential for design adaptation of readily available standardized circuitry elements in chip form to the unique requirements of a single system. A customized hybrid microcircuit which performs needed additional signal processing while avoiding a completely new circuit combination for one or more Printed Wiring Boards (PWB) offers potential economies for production of the limited development hardware quantities. Frequently, once the development design is verified it is not cost effective to re-modify for optimization of the ultimate production cost for an additional first run production quantity. Additional background information is attached.

Solution: Appraise and cost the factors which should be assessed in initial design of a hybrid microcircuit which will minimize the constraints on cost effective production of volume quantities. Prepare a set of design guidelines which encompass these factors and fulfill a necessary preliminary step to effective integration of CAD/CAM technology. The logical step which follows is application and perfection of the resulting techniques to an existing design application. The basic objective of this manufacturing technology project is to organize, systematize, and document the essential considerations in practicing what is sometimes called KIS (KEEP IT SIMPLE) in the initial microcircuit design application.(6.) Existing CAD technology will be applied to optimize essential cost/performance parameters such as tolerance, sensitivity, resister ratios, and power dissipation, into a CAM integrated design which optimizes layout, interconnect and crossover topology, processes, and circuit element selection.

Project Cost and Duration: Estimated costs are as follows:

Material	$10,000
Development of model guidelines (fabricate a selected microcircuit)	50,000
Tooling	5,000
Total	$65,000

Estimated project duration is 6 months.

Benefits: Our experience indicates this technique can potentially improve guidance system cost by at least 3.0 percent. Cost reductions will result from the design simplifications and optimizations achieved by harnessing computer capability to perform the multiple calculations involved in ordering and summarizing the separate cost/performance impacts of parameters and circuit element selection options. Potential savings are higher for many electronics systems.

Assumptions: There will be a significant number of cost effective opportunities for future use of hybrid microcircuits.

BACKGROUND

Fabrication and Assembly of Thick Film Hybrid Microcircuits

Definition of Problem and Manufacturing Constraints - Present hybrid circuit designs require eutectic attachment of capacitor chips and active semiconductor devices to thick film circuits which are subsequently soldered to metal package headers and hermetically sealed. While these hybrid circuits meet stringent SPRINT specifications, they require

ROTARY-HEAD LASER STRIPPER IMPROVES REMOVAL OF HIGH-TEMPERATURE-RESISTANT WIRE INSULATION

Laser stripping of wire insulation has eliminated the problem of nicked or cut conductors, often associated with mechanical stripping methods. However, conventional laser stripping machines employ a fixed laser beam and require turning the wire to expose the entire circumference to the laser. This involves mechanical complexity and can be a problem with some wire configurations (e.g., excessive length).

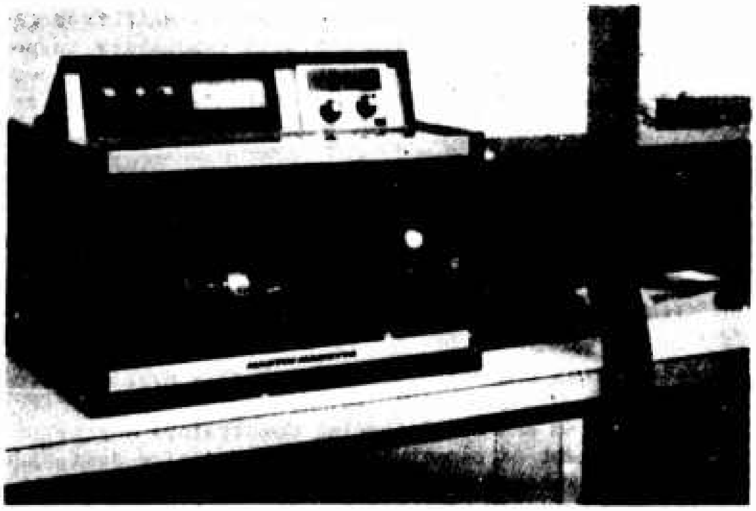
To eliminate the necessity to turn the wire, Martin Marietta's Orlando Division has built a prototype of a patented laser stripper with a rotary laser head, employing a 50-watt CO_2 laser to burn off high-temperature-resistant insulation. Limited tests on 20 types of wires have produced consistent results. The machine strips both single and twisted multiconductor wires having spiral or braided shield. Insulation material in the tests included flourocarbons, FEP, PTFE, polyimides, and fiber glass. The processed wires exhibited no detrimental charring or pitting of the insulation and no damage to shields or conductors.

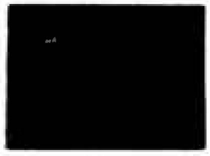
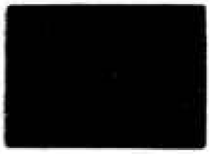
In virtually all cases, the laser beam produced clean cuts in the primary insulation with little or no fraying. The insulated and shielded wires that are especially difficult to strip by mechanical or conventional thermal means (those with polyimide and fiber glass insulations) appear prime candidates for CO_2 laser stripping with the rotary head machine. Specifically, the eight wire types identified in the table have excellent characteristics for use with Martin Marietta's laser stripper. For tests with these wires, laser focus was held constant and the CO_2 laser was operated at 20 watts. The rotary head speed and exposure time were varied to accommodate the different shield types and insulation thicknesses.

In its present developmental configuration, with the range of head rotation speed limited, the machine has restricted versatility. For longitudinal cuts, the operator manually pulls the wire past the laser head, which is fixed for this operation. In tests, longitudinal cutting has caused slight discoloration of the wire jacket at braid openings.

The prototype could be applied to production with moderate additional development. The rotary head concept is proved; however, additional features such as automatic control of timing, shutter operation, lens focus, and longitudinal feed and faster rotary head speeds could be required for a production-capable rotary-head laser wire stripping machine.

As the heat resistance of wire insulation materials increases, so does the applicability of laser wire stripping. Martin Marietta's rotary-head wire stripper, optimized and with production control features added, will solve an increasingly severe problem in wire preparation.



	Wire Type	Mil Spec	Insulation Type	Stripping Time (seconds)	Head Speed (rpm)	Result
	Single conductor, braid shield	MPD-1098[illegible]	Polytetraflouro-ethylene/coated glass	5	50	No marks on jacket under braid
		NAS-702	Nylon over PVC tape resin	1	100	No marks on jacket under braid
	Single conductor, no shield	MIL-W-5080/1	Nylon over glass fiber braid over nylon	30	10	Thick insulation slight char
	Single conductor	MIL-W-22759/2	TFE & TFE coated glass over flouro-polymer	4	50	No marks on conductor
	Twisted pair, braid shield	MIL-C-27500	Extruded clear nylon	5	50	No marks on conductor
	3-wires twisted, braid shield	11181014	Clear nylon Sp. MIL-P-20693 Type III, Grade E	3	100	No marks on jacket/ some under braid
	Solid coaxial, double braid shield	MIL-C-1701/60	PVC Polythylene synthetic rubber glass on teflon	3	100	Clean cut no marks
	Single conductor, no shield	MIL-W-22759/2	Flouropolymer insulated TFE & TFE coated glass	5	100	No marks on wire
	Single conductor, twisted shield	11199791	Polyimide film and FEP tape	5	100	No marks on wire

costly production methods not adaptable to high rate production. Moreover, they require special substrate configuration and hand assembly, are difficult to rework, and can be contaminated with flux during soldering which requires an extensive cleaning operation.

The application of known manufacturing processes and testing of functional circuits fabricated with these processes to prove their application can solve this problem, leading to producible designs and lower cost in production.

1. Objectives and Benefits - Determine cost effective assembly methods for hybrid circuits and provide test data which will verify application of these methods in meeting system specifications. Some processes to be investigated are listed below.

<u>1</u> Elimination of substrates with holes and use of multiple image printing with laser scribe and break.

<u>2</u> Use of silver and/or gold epoxy for chip capacitor and die attachment to substrate.

<u>3</u> Use of ultrasonic high speed gold wire ball bonding to replace present thermo compression pulse bonding.

<u>4</u> Elimination of solder and flux inside package when using hermetically sealed metal package (replace with epoxy and wire bond).

<u>5</u> In-process test and rework prior to header attach (assembly of expensive header package).

<u>6</u> Replacement of present metal hermetic package with ceramic package with soldered lead frame, parylene coating, and transfer molded plastic body or with non-hermetic epoxy attach ceramic lid.

These new techniques and processes can reduce hybrid costs by 25 percent and result in producibility design guidelines for implementation in other programs. A further cost reduction of 10 percent may be realized by potential use of an all plastic hermetic packaging concept.

2. Description of Work - A two part program is proposed to investigate new processes which are applicable to the present hermetic package and to investigate the use of ceramic packages or hermetic plastic molded packages.

Processes

<u>1</u> Multiple image printing, laser scribe, and break.

<u>2</u> Epoxy screen printing for component attach, material selection, bond strength, screenability, rework ability, curing, and handling.

<u>3</u> Attachment of capacitors, active die, and other chip components.

<u>4</u> Bond line (visual) criteria, bond strength, reliability, temperature aging.

<u>5</u> High speed ultrasonic ball bonding, full strength, compatibility with epoxy bonded devices, and elimination of 100 percent ND wire pull testing.

<u>6</u> Substrate to header attach and interconnect.

<u>7</u> Test for part life cycle without deterioration or degradation when using new materials and processes.

Packaging

1 Use of ceramic header with soldered on lead frame, materials, solderability, interaction with other material, components, and processes.

2 Parylene coating for moisture barrier and protection of components when using non-hermetic package.

3 All plastic package - material selection, transfer molding.

4 Test for part life cycle without deterioration or degradation.

Title: Manufacturing Process for Producing Military Approved Printed Wiring Boards Utilizing the Semi-Additive Technique.

System/Panel Area/Component: Defense Missile Systems/Guidance Control and Launch/Printed Wiring Boards (PWB).

Problem: Present Military Specifications preclude the use of a cost saving semi-additive or Thin Copper Foil (TCF) technique for fabrication of PWBs for military systems. Changing existing specifications and writing new ones, where necessary, could result in considerable savings for the military since PWBs often represent 30-50 percent of guidance subsystem base labor cost, and can also improve pollution abatement. This process would develop technology for higher density packaging, finer line widths, and improved spacings.

Proposed Solution: This project will enhance the processing techniques required to meet demanding high density packaging requirements and reduce the amount of undesirable effluents. It will require the design, fabrication, installation, and checkout of a pilot line. Test specimen fabrication and test data accumulation would be useable as a prime back-up element for Military Specification changes. Some of the more detailed task descriptions are:

1 Determine affected specifications and to what degree.

2 Evaluate the process capability for producing laminations without foil pin holes.

3 Establish test requirements and perform same.

4 Establish process controls.

5 Develop automatic techniques with adaptive controls.

6 Identify Military Specifications changes needed to accommodate the semi-additive technique.

7 Write new specification drafts.

8 Obtain specification approvals.

Project Cost and Duration: Estimated costs are as follows:

Pilot line design	$22,400
Pilot line construction - tank facilities	144,800
Pilot line automation - equipment and controls	112,000
Materials	5,000
Engineering support and technical data	112,000
Specification approval	56,000
Total	$452,200

Estimated duration of the project is 24 months.

Benefits: Expected benefits to be derived from this project are a reduction in recurring hardware costs for all PWBs produced for the military and the improvement of pollution abatement. Cost reductions are as follows:

Reduction in drilling costs	20 percent
Reduction in etching costs	80 percent
Total reduction of a PWB preparation cost	30 percent

This equates to a 2 percent reduction in guidance system cost.

Assumptions: That all branches of the military will be receptive to a common specification.

Title: Improved Production Techniques for Multilayer Rigid-Flex Printed Circuit Assemblies

System/Session Area/Component: Missile/Electronic Controls/Electronics

Problem: Multilayer (M/L) rigid-flex circuits are effective means of providing the complex interconnections needed for high density advanced design electronic assemblies. Present day techniques and tooling employing bench operations for their manufacture are expensive and more automated lower cost concepts are required.

Procedures, tooling, and bench operations are used to laminate, solder, and trim M/L rigid-flex circuits. The following process requirements exemplify the problem areas in their fabrication which require more mechanization:

Problem Areas:

1 Etching thin film laminates.

2 Selective cutouts of prepreg fabric.

3 Bonding of copper to flexible H-film.

4 Curing of M/L laminated circuits.

5 Drilling, plating, and verification of thru-hole connections and circuits.

6 Cutouts of M/L printed circuit board laminates and flexible H-film.

7 Skiving of flexible H-film for soldering branch circuit pads.

8 Soldering of M/L rigid-flex assemblies.

Proposed Solution: This project would center on development of new manufacturing techniques, low cost tooling concepts, mechanized procedures susceptible to automation and producibility guidelines for production improvements in processing M/L rigid-flex assemblies. Present manual, bency type methods will be replaced with techniques which are inherently less costly by one or two orders of magnitude. The following actions are proposed:

1 Technical Survey on M/L Rigid-Flex Applications.

2 Design Process and Tooling Improvements (standardization).

3 Prepare Cost Trade-off Analyses.

4 Pilot Production of Work Samples.

5 Prepare Producibility/Design Guidelines.

6 Technical Demonstration of Automation.

7 Issue Project Documentation/Reports.

Project Cost and Duration: Estimated costs are as follows:

Manufacturing and Engineering effort in information collection, design, and checkout of new techniques	$112,000
Tooling	14,000
Material	6,000
Travel	1,000
Total	$133,000

Estimated project duration is 14 months.

Benefits: Benefits to be derived are a reduction in recurring hardware costs as follows:

Estimated reduction in Manufacturing and Quality labor costs of rigid flex assemblies - 80 percent.

This equates to a guidance system cost reduction of 1.8 percent.

Assumptions: That utilization of rigid-flex packaging techniques will continue to be needed in the manufacturing technology applications of the 1980's.

Title: Coaxial Cable Fabrication

System/Panel Area/Component: Missile-GSE/Networks Cables

Problem: Termination of flexible semi-rigid Coaxial Cables represents a significant cost driver for the aerospace industry. The cost impact stems from fabrication and operating problems in achieving consistent VSWR standards.

Proposed Solution: Automatic equipment needs to be designed to cut coax cables to correct length and perform all end-trimming operations. Following these operations the cables should have end terminations automatically installed by crimping, swaging, or induction or resistance soldering. These techniques will require a new family of interconnections for coaxial cables. During research on this problem, possible use of lasers will be explored as a means to trim and strip cables. Currently, an experimental laser stripper equipped with a rotary cutting head shows considerable promise as replacement for mechanical equipment. Laser application in cable preparation will help enhance the reliability of the product and reduce its cost since the machine will be programmed for consistent repeatability and error free performance. A description of the laser stripper is attached.

Project Cost and Duration: Estimated costs are as follows:

Review present type of coax cables	$ 15,000
Survey existing automatic equipment for possible use	15,000
Design new interconnections	100,000
Material costs	10,000
Fabricate samples (soft tools)	20,000
Test samples	20,000
Tradeoff studies (fab cost)	20,000
Design special purpose equipment	200,000
Determine implementation cost	20,000
Final report	20,000
Total	$440,000

Estimated project duration is 30 months.

Benefits: The benefits derived from this project are the reduction in rework and the resulting lowering of recurring labor cost and material savings. Present procedures result in 30-50 percent rework, material waste, and excessive touch labor costs.

Reduction in recurring cable labor	50 percent
Reduction in cable material costs	50 percent
Reduction in cable reject and rework	85 percent
Overall reduction in cable cost	33 percent

This equates to a 1.7 percent reduction in guidance system cost.

Assumptions: The cost reductions indicated apply to the fabrication of large quantities (10,000 and above) of coaxial cables and can be applied to any weapon system.

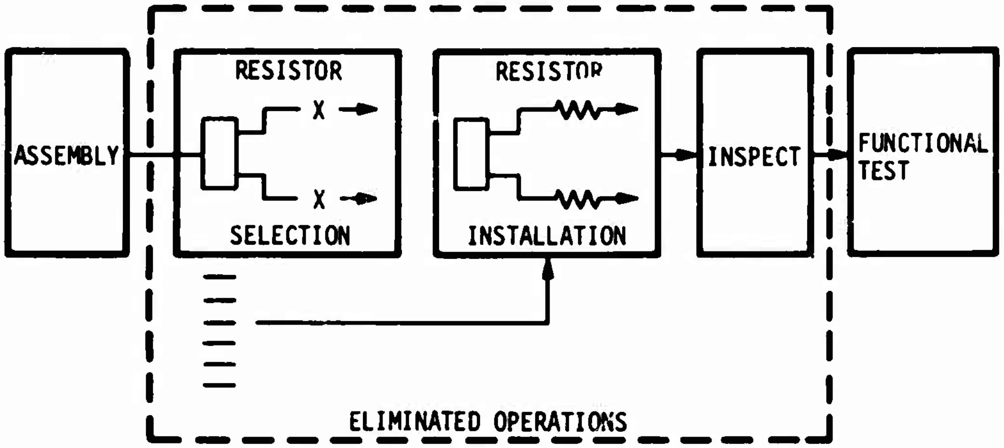
Title: Adjusting Star Value Resistors* by Thick Film Laser Trimming Techniques

System/Panel Area/Component: SPRINT/Electronics Controls/Star Value Resistors

Problem: The costly and time consuming requirement for electronic output balancing of the SPRINT autopilot, the MCS, and the DMCS has proven to be a major cost driving factor throughout the development of these subsystems. Since the flight environment prohibits the use of potentiometers, or other adjustment devices, close-tolerance fixed-value resistors are selected during test to meet precise system balance requirements. In some cases, where balance is quite critical, resistors are installed in series to derive required values.

Since Star Value Resistors cannot be selected from existing stocks, but rather, must be ordered in sets to assure star value balancing, a large inventory of high cost, close-tolerance parts is maintained for each test operation throughout the life of the program. This, in turn, calls for procurement of resistor sets representing the probable balance selection ranges for each test application. When used, however, only one resistor from each set is applicable. This condition entails significant component cost, which, coupled with the added and more significant labor cost involved in the selection, installation, and inspection of each application, represents a sizable factor for each guidance package.

Proposed Solution: Existing commercial technology for laser trimming of thick film circuits can be upgraded to meet the stringent environmental requirements of the missile electronics system. Laser trimming would eliminate at least three costly hand operations plus the waste involved in a requirement to purchase and maintain relatively large stocks of surplus resistor sets.



Project Cost and Duration:

Resistor Network Design and Packaging (approx. 6)	$ 26,000
Equipment and Tooling	20,000
Automatic Test Program	16,000
Engineering Support and Data	72,000
Automatic Packaging	60,000
Total	$194,000

Estimated duration of the project is 18 months.

Benefits: Overall cost reduction can be realized in the assembly, test, and star value resistor selection. The major cost reduction will be in recurring operations. Cost of thick film resistor elements will almost balance the costs involved in discrete resistor acquisition.

Reduction in recurring labor is approximately 11 percent per system. This equates to a 1.1 percent reduction in guidance system cost.

Assumptions: The above benefits are based on the assumption that automatic methods will replace manual operations, and that it will be possible to automate all testing and selection of resistor values and include this function in the overall module test program. An additional assumption is that presently developed potentiometers which can be set and locked are not a viable replacement for star value R's.

*Star Value Resistor - a component whose value can be determined only by testing the module, and is selected to meet certain functional requirements.

Title: Elimination of Connectors and Reduction of Interconnections

System/Panel Area/Component: Missile/Electronic Controls/Connectors

Problem: The use of connectors for round-to-round, flat-to-flat, and flat-to-round contacts often encounters problems because of hardware availability, hardware cost, and system reliability. A standard connection typically requires a minimum of three interconnection actions to achieve electrical continuity between two electrical conductors.

Proposed Solution: Elimination of connectors or reduction of the interconnection labor required to join electrical conductor male/female members to each other by effecting only one interconnection instead of the usual three. Joining methods to be developed will be both reversible and non-reversible. Non-reversible interconnections may still be broken by removal of 1/8 inch interconnection area and repreparing adjoining conductor ends for reconnection. Preliminary investigations of this technique are encouraging.

Where testing or preassembly requires multiple disconnects, a temporary mechanical interconnection can be made. Upon final assembly, the desired reversible or non-reversible direct conductor to conductor interconnection is performed.

Interconnections can be made by mechanical, soldering, or metallurgical hand procedures singly or in combination.

Projected Cost and Duration: Estimated costs are as follows:

Manpower requirements	$165,000
Facilities	20,000
Engineering support	20,000
Total	$205,000

Estimated duration of project is 24 months.

Benefits: Benefits to be derived from this project will be reduced cost for the fabrication of the Electronics modules and other interconnections labor by approximately 70 percent. This equates to an overall guidance system cost reduction of approximately 1.2 percent. At this time material costs appear to be comparable for both techniques.

Assumption: The presently conceived and demonstrated interconnection philosophy can be readily advanced to be production worthy and cost effective.

Title: Functional Examination Measures for Optimizing Production Inspection of Electronic Assemblies

System/Panel Area/Component: Missiles/Electronic Controls/Printed Wiring Board Assemblies

Problem: Visual inspection cost and subsequent cost of reworking rejects by touch-up operations on Printed Wiring Board (PWB) assemblies are two major cost drivers in missile production. Visual inspections which require variances in appearance and subsequent classification as production rejects requiring component replacement or touch-up are due to scratches or pin holes in conductors, spots in plating, shape of solder fillets, measling spots in laminate, and other anomalies.

Specifications for missile electronic controls, MIL-S-45743 and MIL-S-46844A (MI), identify appearance features requiring visual inspection. Quality records accumulated during the production of the SPRINT system have proven that visual inspection to meet these MIL-Specifications for appearance requirements cause rework and are less effective in discovering discrepancies than electrical (environmental) functional testing. Visual inspection without instrument measurement is not effective for microcircuits or in detecting latent component failures.

Proposed Solution: A functional test procedure for electronic assemblies is proposed to detect or induce latent failures as a fault screening system for appearance anomalies that are costly to change. Optimized production inspection cost and reduced touch-up costs will be achieved by extending present experience in production environmental testing (PET) systems to a limited environmental testing (LET) procedure for checking of production anomalies and verification of functional acceptance. In many cases a simple thermal fatigue test will locate latent defects readily.

Using selected electronic PWB assemblies from SPRINT and similar missile control systems, the following comparison will be made to compare PET and LET test methods:

1 Thermal shock at selected levels of time-temperature exposure rates.

2 Vibration at selected ranges of amplitudes and frequencies for cycle-duration exposure rates.

Project Cost and Duration:

Engineering design	$ 30,000
Manufacturing tests	150,000
Test tooling	20,000
Test evaluations and reports	10,000
Total	$210,000

Estimated duration of the project is 18 months.

Benefits: The selected functional test (PET versus LET) procedure will provide the following benefits:

Reduction in rework costs	6 percent of electronics assembly cost
Reduction in inspection costs	3 percent of electronics assembly cost
Net reduction	9 percent of cost of electronic system assembly cost for each missile.

This equates to a 0.6 percent reduction in guidance system cost.

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IMPROVED HAWK MISSILE GUIDANCE MANUFACTURING TECHNOLOGY PROJECTS

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Improved HAWK is a mobile surface-to-air missile system deployed by the U. S. Army. The Improved HAWK program modifies the existing Basic HAWK system by providing a new missile, an automatic data processor, and modifications to ground support equipment. The program is in the production phase at this time.

The purpose of this paper is to discuss current manufacturing technology associated with the missile guidance section and present some proposed production technology improvement studies which have the potential benefits of increased reliability and lower cost.

Figure 1 shows the Improved HAWK guidance and control group. The guidance section component parts are solid state and are designed for fast start capability so that these components are dormant until the missile is commanded to launch. Since the missile is not required to operate until launch, field test and repair are not required. The missiles are accepted in lots of 300 to 500 based on flight testing. This acceptance program coupled with the no field test or repair feature results in a certified round missile.

Manufacturing, lot acceptance, the repairs resulting from sample tests, rebuild and training are the significant cost drivers associated with the guidance section.

The elements which contribute to the cost of manufacture are defined in the matrix in Table 1. Areas where a manufacturing technology project discussed in this paper could result in significant cost reductions are circled in Table 1.

Lot acceptance requires that missiles be flown and a specific number of reliability and lethality successes must occur. As previously stated a lot contains from 300 to 500 missiles of a fixed configuration and can be accepted with as few as six flights or as many as twenty flights. The acceptance program can cost from 6.6 to 20% of the guidance package cost and is directly related to reliability.

After missile deployment, readiness is verified by testing 10% of each lot on an annual basis using a Theater Readiness Monitoring Facility. The acceptance test equipment in this facility is identical to that used in the factory. The average repair costs for a missile which fails this test is equal to 2% of guidance package acquisition cost.

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MISSILE SUB SYSTEMS

SEEKER

- SOLID STATE ELECTRONICS
- PHASED ARRAY – GIMBALLED ANTENNA
- INVERSE RECEIVER
- QUICK START
- SELECTABLE AUTOPILOT TIME CONSTANT

ACTUATOR

- HYDRAULIC ACTUATORS
- TRAILING EDGE ELEVON CONTROL
- LARGE DEFLECTION FOR HIGH MANEUVERABILITY

FIGURE 1
IMPROVED HAWK GUIDANCE AND CONTROL SECTION

IMPROVED HAWK GUIDANCE SECTION

COST ELEMENTS

	% OF TOTAL	MANUFACTURING ELEMENTS IN PERCENTAGES				
		PURC PARTS AND MAT'L	FAB	ASSEMBLY	TEST & INSP	SUPPORT
RADOMES	7	1.6	2.9	0.1	0.8	1.6
ELECTRONICS	37	17.0	2.9	5.3	5.3	6.5
MICROWAVE	7	4.7	0.3	0.3	0.6	1.1
MAJOR MECHANICAL	7	1.8	2.0	0.9	0.7	1.6
CABLE	6	1.6	0.1	2.5	0.4	1.4
POWER SUPPLIES	4	2.0	0.3	0.5	0.2	1.0
MISCELLANEOUS	4	0.2	0.1	0.8	2.0	0.9
GYROS & ACCEL	10	10.0				
CONTROLS	16.5	7.5	3.5	0.6	1.6	3.3
GROUND RADAR	1.5	0.7	0.5	0.2	0.15	0.4

TABLE 1

A continuous training program consisting of Annual Service Practice (ASP) firings is in process. Missile reliability also dictates the number of rounds expended for training.

Table 2 tabulates the proposed manufacturing technology projects, including the project cost, expected cost savings, and the cost drivers addressed by the project. The project cost covers the necessary engineering, qualification test, and demonstration efforts to prove that the task is feasible and achieves the efficiencies that are expected on a pilot basis.

The expected cost saving is expressed as a percentage of guidance section cost and is based solely on the application of these advancements to Improved HAWK production assuming that the production rate remains constant and that these projects prove feasible within their respective schedules. It is estimated that guidance section costs could be reduced by approximately 5% if these projects achieve the efficiencies expected.

Current manufacturing trends show a marked increase in nondestructive test (NDT) facilitization. Instrument and peripheral sales have increased at a rate of 10% per year from a $85M sales in 1970 to a $250M projection in 1980. Currently over 200 manufacturers produce NDT systems, components, auxiliary equipment and supplies. Economic, technical, regulatory, and legal factors influence the expansion of this technology. References 1 through 9 detail this trend and the growth of data processing as an adjunct to nondestructive testing.

The following pages contain the projects and are presented in the format required for this symposium.

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GUIDANCE MANUFACTURING TECHNOLOGY PROJECTS

PROJECT	PROJECT COST	EST. SAVINGS %	COST DRIVER
AUTOMATE COMPONENT PART X-RAY ADD 3D X-RAY CAPABILITY NEUTRON BOMBARDMENT TEST	$ 780,000 220,000	1.25% 0.45%	TEST AND INSPECTION ACCEPTANCE REPAIR
AUTOMATE DEBURRING OPERATIONS	275,000	0.30%	MAJOR MECHANICAL FABRICATION
ADDITIVE PLATING PC BOARD MANUFACTURE	60,000	0.21%	ELECTRONICS FABRICATION
AUTOMATIC INSERTION OF MULTILEADED PARTS	195,000	0.20%	ELECTRONICS ASSEMBLY
FABRICATE PLASTIC SIDE ANTENNA/ RADOME/FAIRING/REPLACE PRECISION WAVEGUIDE WITH HIGH TOLERANCE STRIPLINE	196,000	1.80%	RADOME FABRICATION/ MICROWAVE PURCHASED PARTS
AUTOMATE CABLE LAYOUT, LACING, AND CONNECTOR ASSEMBLY	750,000	1.00%	CABLE ASSEMBLY
TOTAL	$2,476,000	5.21%	

TABLE 2

(11) Richard G. Green, "Burr - Breaker's Guide to Deburring Techniques," Automation, July 1975.

(12) "Reinforced Plastics Bid for Metal Replacement Parts," Product Engineering, August 1975.

PROJECT #1

Title: Automate X-ray Readout and Provide 3D X-ray Capability

System/session area/component: Improved HAWK/guidance/incoming inspection and test, in process inspection, missile lot acceptance, and repair and training after deployment.

Problem: Part and material screening processes were started to eliminate infant mortality failures during manufacture and deployment. These screens include preconditioning at rated power and high temperature, centrifuge tests, and X-ray. Semiconductors are preconditioned on a 100% basis and other components are preconditioned on a sample basis. Improvements in automated assembly line efficiency result from these techniques which are common practice in commercial industry.

Rework costs increase directly with the level of assembly build up so substandard materials and component parts ideally should be eliminated prior to use in higher levels of assembly. Rework of failed assemblies in highly automated manufacturing facilities requires diagnostic equipment and operators with skills greater than those required on the production line.

No screening system is 100% effective, and failures do occur in manufacture, flight acceptance programs, sample electrical test of deployed missiles, training, and rebuild programs. Costs of flight failures include the missile, the test range, and flight analysis. Costs of failures during electrical tests include the cost of missile repair and associated logistic transportation and handling.

X-ray is a key nondestructive tool in a part/material screening program and has a tremendous growth potential. The process costs are low on a per unit basis; permanent records can be kept for reference; and operators can be trained easily. The system is fundamentally flexible, and a new component part type does not require major system changes. Equipment improvements in other diagnostic fields, such as medicine, are directly applicable to the X-ray screening process.

X-ray is now limited to a two dimensional format, and is dependent on the judgement and training of the inspectors.

Six hundred thousand (600,000) components per month are currently X-rayed for the Improved HAWK program, and all of the results are analyzed by operators. A high component reject rate still exists in spite of a four year corrective action program with semiconductor manufacturers.

Figures 1, 2 and 3 show typical failure modes detected by X-ray that would pass electrical tests but contain inherent failure mechanisms such as solder balls, poor bonding or foreign material.

Table 3 tabulates the number of potential failures detected by X-ray during 1975 on a per guidance section basis.

X-ray screening is 14% of the cost of component part screening.

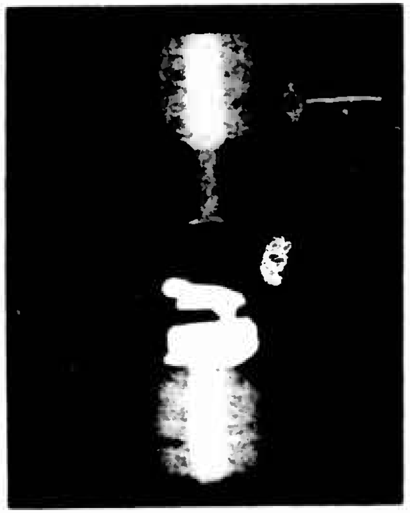

FIGURE 1
DIODE CONTAINING
SOLDER BALLS

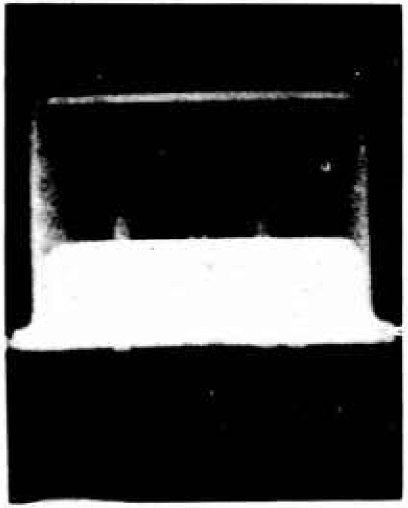

FIGURE 2
BOND DROOP
DETECTED IN A
TRANSISTOR ALLOWS
FOR SHORTS TO TRANSISTOR
METALLIZATION

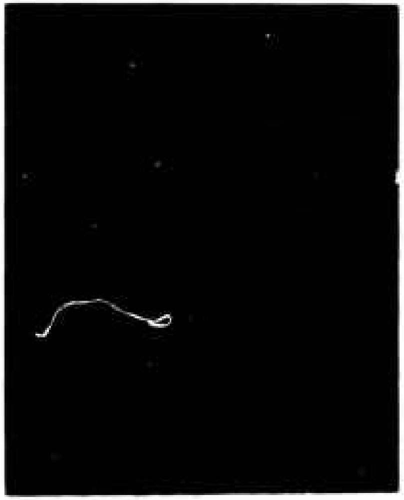

FIGURE 3
FOREIGN MATERIAL
IN A SEALED
INTEGRATED CIRCUIT

TABLE 3

COMPONENT PART TYPE	POTENTIAL FAULTS/ GUIDANCE SECTION
Integrated Circuits	1.6
Diodes	0.7
Transistors	2.8
Other Parts	0.3
TOTAL	5.4

Proposed solution: To improve fault detection efficiency two steps should be taken. The first step is to automate the analysis of X-ray results; the second is to provide a depth perspective by parallax or holographic techniques.

Automated readout would compare the pattern of the device under analysis with a pattern of an acceptable device using a small computer and scanning equipment. This pattern recognition technique has been used in allied fields such as automated semiconductor bonding.(10) It is also feasible that this equipment could evolve so that an intermediate step such as a radiograph would not be necessary.

Parallax X-ray photography will provide a three dimensional image when combined with stereo optical techniques. It may also be feasible to employ zone-plate holographic techniques to achieve the same effect. The software developed in automated readout can be expanded to add the third dimension. Component parts from current production would be used to validate the improved efficiency and fault detection capability.

Project cost and duration:

A) Automated Readout

1. Develop computer readout programs for X-ray analysis - transistors, diodes, integrated circuits and capacitors	$180,000
2. Engineering support to run pilot production runs through automated analysis/compare with manual system	40,000
Total	$220,000

Estimated project duration is 12 months.

B) Add 3 Dimensional Readout Capability

1. Develop stereo X-ray techniques for better fault detection	$305,000
2. Upgrade computer readout to handle stereo X-ray analysis technique, provide necessary engineering support to part screening analysis	255,000
Total	$560,000

Estimated project duration is 30 months.

Estimated combined project cost is $780,000

Benefits: The primary benefit is improved product reliability. Additional benefits include reduced rework at higher levels of assembly. Improvements in reliability will also result in reductions in lot acceptance costs, training costs and sample test and rebuild repair requirements. These benefits are estimated to provide the following savings:

Reduction in screening test touch labor	0.05% of guidance package cost
Reduction in rework costs	0.50% of guidance package cost
Reduction in acceptance test costs	0.20% of guidance package cost
Reduction in field repair costs	0.50% of guidance package cost
Total estimated savings	1.25%

Assumptions: The number of defects found in component parts will remain constant during this time frame and Improved HAWK production will be essentially constant. This type of NDT technology will be applicable to other systems where highly automated manufacturing techniques benefit markedly from reduced rework activity.

PROJECT #2

Title: Neutron Bombardment Nondestructive Testing

System/session area/component: Improved HAWK/guidance/inspection and test.

Problem: Component parts, sealed electromechanical devices, and sealed one shot devices are frequently contaminated with non-metallic foreign material.

Flux and lubricants are contaminants in gyros, accelerometers and potentiometers as well as other solder sealed assemblies. These contaminants frequently jam the instrument or result in erratic operation.

If component parts are suspect, destructive sample tests are usually necessary and in some cases the lot of material is scrapped because the extent of contamination is unknown.

Proposed solution: Neutron bombardment can detect organic contamination in metal sealed devices. Preliminary tests have shown that two drops of flux can be detected using present techniques. The source of the neutron beam is a nuclear power plant.

Neutron bombardment strikes the object under test which in turn impresses a radioactive pattern on indium foil. A film is then exposed to the gamma and beta rays given off by the indium foil to provide a radiograph of the sample. It is also feasible to expose the film directly through gadolinium foil.

The radiograph will show the organic contamination that exists. Compounds which contain good neutron scattering materials such as hydrogen, beryllium, and carbon show up best using this technique.

The project would test components where the common failure mode is caused by organic contamination. Visual aids and enhancement techniques will be explored. Pilot computer programs will be developed to determine whether computer pattern recognition will improve inspection efficiency.

Project cost and duration:

Set up pilot neutron bombardment test station	$110,000
Engineering support, sample setup, review, develop visual aids and enhancement techniques	60,000
Computer software to determine pattern recognition feasibility	50,000
Total poject cost	$220,000

Estimated project duration is 18 months.

Benefits: Better product reliability and reduced rework and scrap at higher levels of assembly.

Improved reliability will result in reduction in lot acceptance costs, training costs, and field repair requirements. These benefits are estimated to yield the following savings:

Reduction in rework and scrap costs	0.15% of guidance section cost
Reduction in acceptance test costs	0.10% of guidance section cost
Reduction in field repair costs	0.20% of guidance section cost
Total estimated savings	0.45%

Assumptions: The number of defects found in component parts will remain constant during the time frame, and Improved HAWK production will be essentially constant during this feasibility study.

PROJECT #3

Title: Automatic Deburring Operation

System/session area/component: Improved HAWK/guidance/major mechanical fabrication

Problem: Fabrication of metal parts requires deburring and breaking sharp edges as part of the standard fabrication requirements. Certain designs require deep intersecting holes which are difficult to deburr and inspect. These tasks are frequently performed by hand and inspection requirements are judgemental and subjective. Various shapes of metal parts and low production runs have restricted the use of automated deburring processes. Improperly deburred hardware can cause difficulties in assembly and metal burrs can result in subsequent electrical or mechanical failures.

Proposed solution: Slurry deburring is one of the current automated deburring processes (11) in which an abrasive suspended in a carrier of hydraulic oil or other medium is pumped through a component to remove burrs, form radii as specified, or improve surface finish on irregularly shaped contours. The suspension moves through the part in both the forward and reverse directions at a predetermined rate of flow and pressure controlled by a special hydraulic pumping unit.

The slurry solution is constantly kept in motion by motor driven paddles which maintain the abrasive in suspension.

This process is presently being used for fine finish deburring on stainless steel hydraulic components. A typical installation is shown in Figure 4. These parts contain a series of cross holes and the operation deburrs both ID and OD.

This system uses very low pressures (as low as 18 PSI) in order to avoid damaging other finished surfaces while removing burrs from cross holes and corners. Since this deburring operation would normally take place when a component has reached its final stages of completion, care must be taken to avoid the possibility of removing material from areas previously finished to size.

A program to apply this method to components of various sizes and other raw materials, primarily aluminum, will consist of:

1. Selecting candidate parts from the Improved HAWK missile system, including valve blocks, cylinder actuator, gimbal block, and rocker arm.

2. Design and manufacture of a pilot slurry deburring unit capable of handling parts with the size limits selected.

3. Determining the best possible abrasives and carrier solutions.

4. Implementing the optimum tool design practices for holding the component while supplying the best access for media to the part.

5. Testing various rates of flow and pressure requirements in order to develop proper cycle times for the operation.

This process is a controlled pumping operation with a fixed time cycle, therefore quality and time expended would be consistent and uniform through

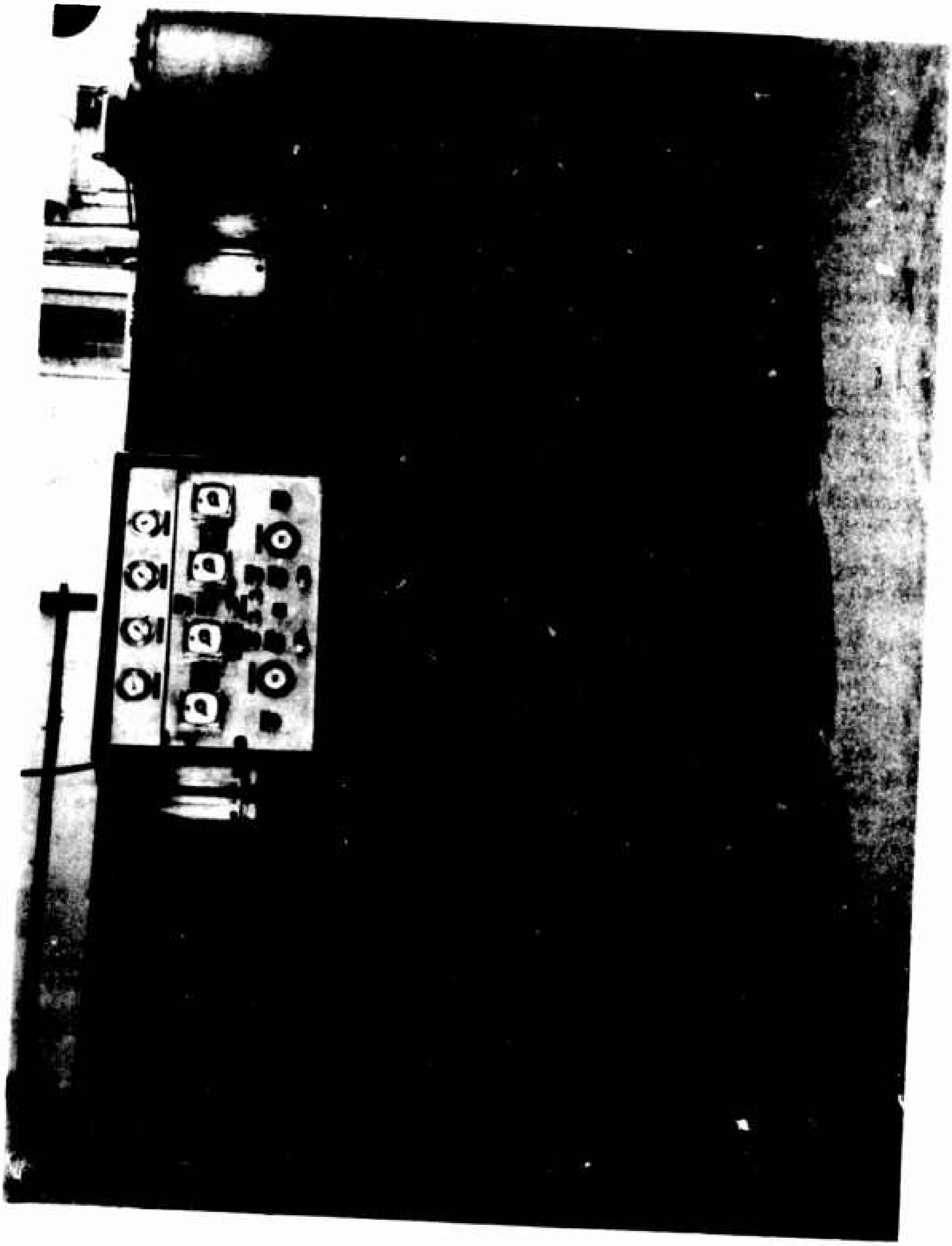

FIGURE 4

any quantity of parts. The consistent quality level attained could not be accomplished by any of the present manual deburring methods.

Project cost and duration:

Set up pilot facilities	$200,000
Engineering support, test and validation	75,000
Total project cost	$275,000

Estimated project duration is 24 months.

Benefits: Parts fabricated using this process require less touch labor and inspection and rework and scrap are reduced, resulting in a reduction in hardware cost.

Reduction in touch labor/inspection	0.15% of guidance section cost
Reduction in scrap/rework	0.15% of guidance section cost
Total estimated savings	0.30%

Assumptions: Improved HAWK guidance section production will remain constant during this time frame. The cost of production equipment will be amortized in the reduction of touch labor and inspection requirements.

PROJECT #4

Title: Printed Circuit Board Fabrication

System/session area/component: Improved HAWK/guidance/electronics fabrication

Problem: The fabrication of printed wiring boards involves removal of a layer of copper clad from all surface areas except where the desired circuit pattern has been protected from the etching process. The present method starts with a thick (one ounce per square foot) copper clad layer, which is drilled, copper plated, masked to protect the desired circuit pattern, and then etched. The thick copper layer reduces drill life, and requires a long etching time which increases etchant consumption and waste treatment costs. Horizontal undercut of the copper circuit pattern which occurs during the long etching time results in poor line definition and restricts allowable line density to approximately a 10 mil spacing.

Proposed solution: This project would show the feasibility of pilot production using a modified fabrication technique that would eliminate the inefficiencies and undesirable technical problems inherent in the present method. The proposed technique would start with an ultra thin (1/8 ounce per square foot) copper clad layer which would then be drilled, plated with a thin copper layer, and then masked to expose only the desired circuit pattern to the next copper plating operation. After the circuit pattern has been plated to achieve the desired thickness, the board will be masked to protect only the circuit pattern and then etched.

The thinner copper clad will result in increased drill life, and the shorter etching time will essentially eliminate undercut and reduce etchant consumption and waste disposal.

Elimination of undercut will result in improved quality and yield, better line definition, and higher allowable line density with spacings as low as 5 mils.

Project cost and duration:

Setup pilot line and fabricate samples	$40,000
Qualification	20,000
Total project cost	$60,000

Estimated project duration is 12 months.

Benefits:

Reduced purchase price of copper clad	0.01% of guidance section cost
Decreased reject (undercut)	0.10% of guidance section cost
Reduced drilling time/increased drill life	0.05% of guidance section cost
Reduced etching time/etchant consumption	0.05% of guidance section cost
Total estimated savings	0.21%

Assumptions: Printed wiring board production will be essentially constant during this development.

PROJECT #5

Title: Automatic Insertion of Multi-Leaded Component Parts

System/session area/component: Improved HAWK/guidance/electronics assembly

Problem: Automatic insertion machinery is used to insert axial lead component parts in a manner similar to a stapling machine. Axial lead parts are mounted on reels, programmed, and inserted into PC boards. This type of machinery cannot handle components with three or more leads such as transistors, filters and certain integrated circuits packaged in metal TO series cans. These components must be hand inserted.

Proposed solution: Develop reels, lead straightening fixtures, and insertion heads to handle multiple lead component parts on automatic insertion machinery. Provide reel sequence check capability for multi-lead component parts as well as electrical test hardware adapters for use with reel mounted multiple lead components.

Project cost and duration:

Design and validate reels, lead straightening fixtures, and insertion heads	$100,000
Engineering support	45,000
Pilot run	50,000
Total project cost	$195,000

Estimated project duration is 15 months.

Benefits: Reduced touch labor and reduced rework where specific part indexing is critical.

Total estimated savings 0.20% of guidance section cost

Assumptions: It is assumed that Improved HAWK production rates will remain at current levels.

PROJECT #6

Title: Replace External Metal Guidance Components with Plastic

System/session area/component: Improved HAWK/guidance radomes

Problem: External guidance components and radomes must meet stringent electrical requirements and structural constraints. Improved HAWK side fuzing antennas are built into the external tunnel fairings which also provide an external cover for hydraulic lines, electrical cables, and rear antenna waveguide. These side antenna assemblies must perform under severe transport and launch dynamic stresses, aerodynamic loads, high wall temperatures during flight, and external storage temperature and humidity extremes. The current fabrication technique uses an aluminum fairing and waveguide with a plastic radome. This process requires precision machining, brazing and sealing to meet all the environmental requirements.

Proposed solution: Mold these fairings from diallyphthalate or epoxy glass resin. (12) These materials can be molded in the proper finishes and have the necessary strength, heat resistance, and weatherability characteristics. The radome can be integral to the mold thereby eliminating a critical seal requirement involving dissimilar materials. Necessary structural attach points can be strengthened with inserts. Waveguide will be replaced with a stripline antenna which would further simplify molding the assembly. Stripline of this length and close tolerance should be feasible for production at this time. Figure 5 shows the current configuration and the recommended material changes.

Project cost and duration:

Tooling to provide pilot fairing mold	$ 16,000
Necessary engineering support, radome RF test, qualification test	80,000
Fabrication of pilot stripline and necessary engineering support	65,000
Complete antenna test/fairing combination, pattern measurement	35,000
Total project cost	$196,000

Estimated project duration is 15 months.

Benefits: Reduced fairing cost, simplified sealant technique, and a 30% weight reduction would result. Touch labor would be reduced by over 50%. Stripline side antennas would reduce critical waveguide machining. Colors can be molded in which will eliminate finish requirements and reduce field maintenance costs.

Molded side antenna fairing	1.0% of guidance section cost
Stripline antenna	0.8% of guidance section cost
Total estimated savings	1.8%

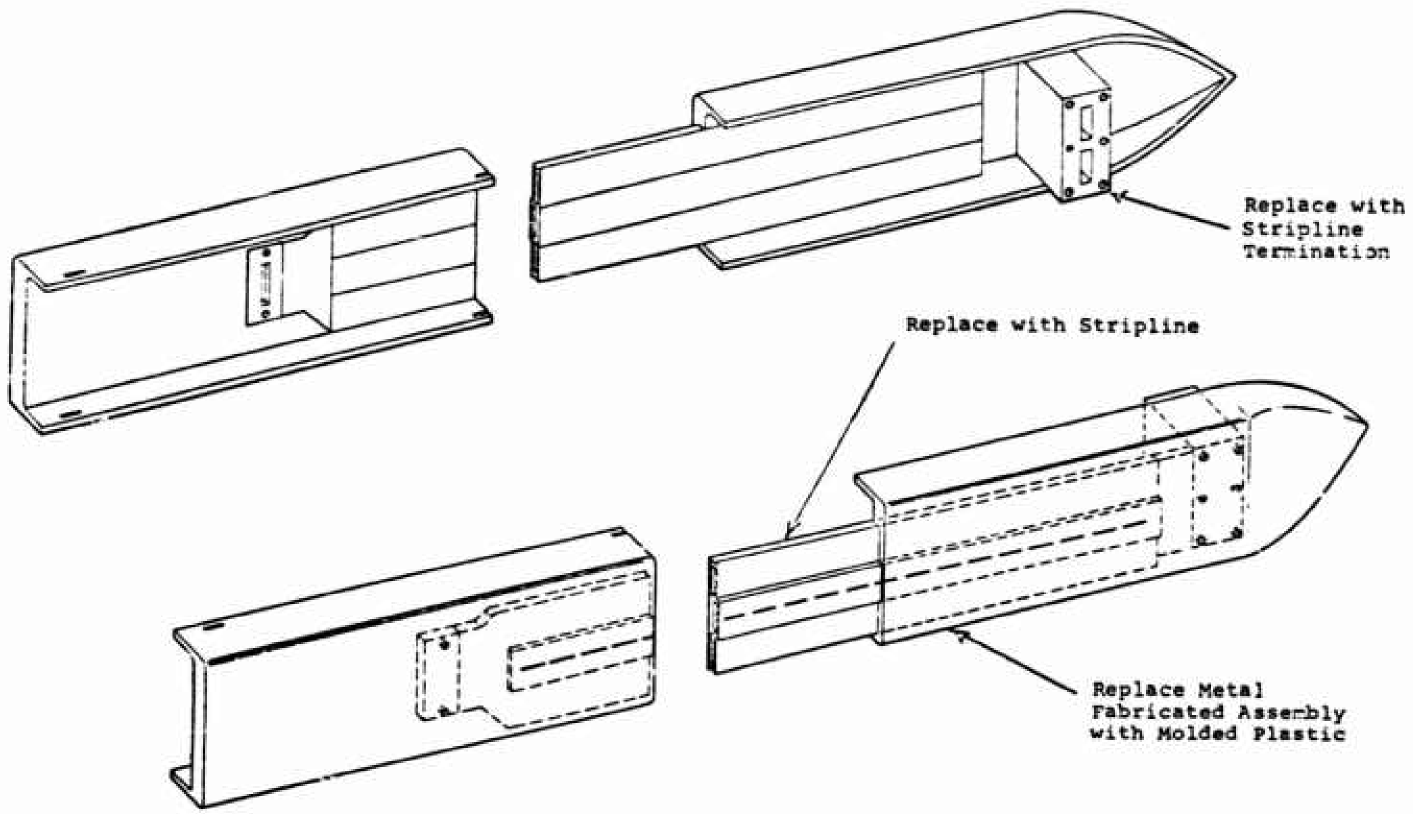

FIGURE 5
REPLACE METAL SIDE ANTENNA FAIRING WITH PLASTIC

PROJECT #7

Title: Fully Automated Harness and Cable Fabrication System

System/session area/component: Improved HAWK/guidance/harness and cable fabrication and in process inspection

Problem: Harness fabrication is essentially an operator function. Interconnecting wire cables cannot be eliminated due to system requirements for specific insulating materials such as teflon, or coax cable requirements, or connector type restraints which do not lend themselves to printed wiring cables.

Harness fabrication consists of four steps, i.e., wire lay-in, wire lacing, wire stripping and wire termination to connectors or terminal strips with associated potting after electrical connections are complete.

Although wire lay-in systems of varying complexity are appearing on the market, all systems presently developed are gated by the need to manually tie the wire bundles together. This allows for 50% efficiency of the harnessing station.

Proposed solution: This project will develop fully automated harness fabrication starting with automatic wire lay in and lacing using a numerically controlled high velocity cable forming and lacing system. The system will consist of a control console, a work table and a dereeling station.

The control console receives the program and provides direction to the head mechanism mounted on the table and to the dereeling and feeding mechanism on the dereeling station.

The work table (see Figure 6) consists of the harnessboard and the head mechanism. The head mechanism will accept a pneumatic drill for automatically drilling all holes for harness post nails, a pneumatic harness post nail positioner and driver, prethreaded wire lay in heads and a pneumatic lacing head (see Figure 7).

The dereeling station consists of stored reels of wire and the dereeling and feeding mechanism that feeds the table head mechanism on command from the control console.

The system will automatically lay in and lace harnesses up to six by twelve feet in size and more than one table can be operated by computer input to the control console.

Since this system is fully automated, in process inspection can be reduced from 100% to a sample inspection after first article verification.

After lay in and lacing, wires would be stripped using a laser beam that would melt through the insulation without damaging the conductor wire. One stripper will handle any size wire without adjustment and will eliminate torn insulation and nicked or broken strands, markedly reducing cable quality defects.

Cable termination to connectors would employ a single type of adaptable strain relief, and after connections to the pins have been terminated, the

WIRE LAYING MACHINE

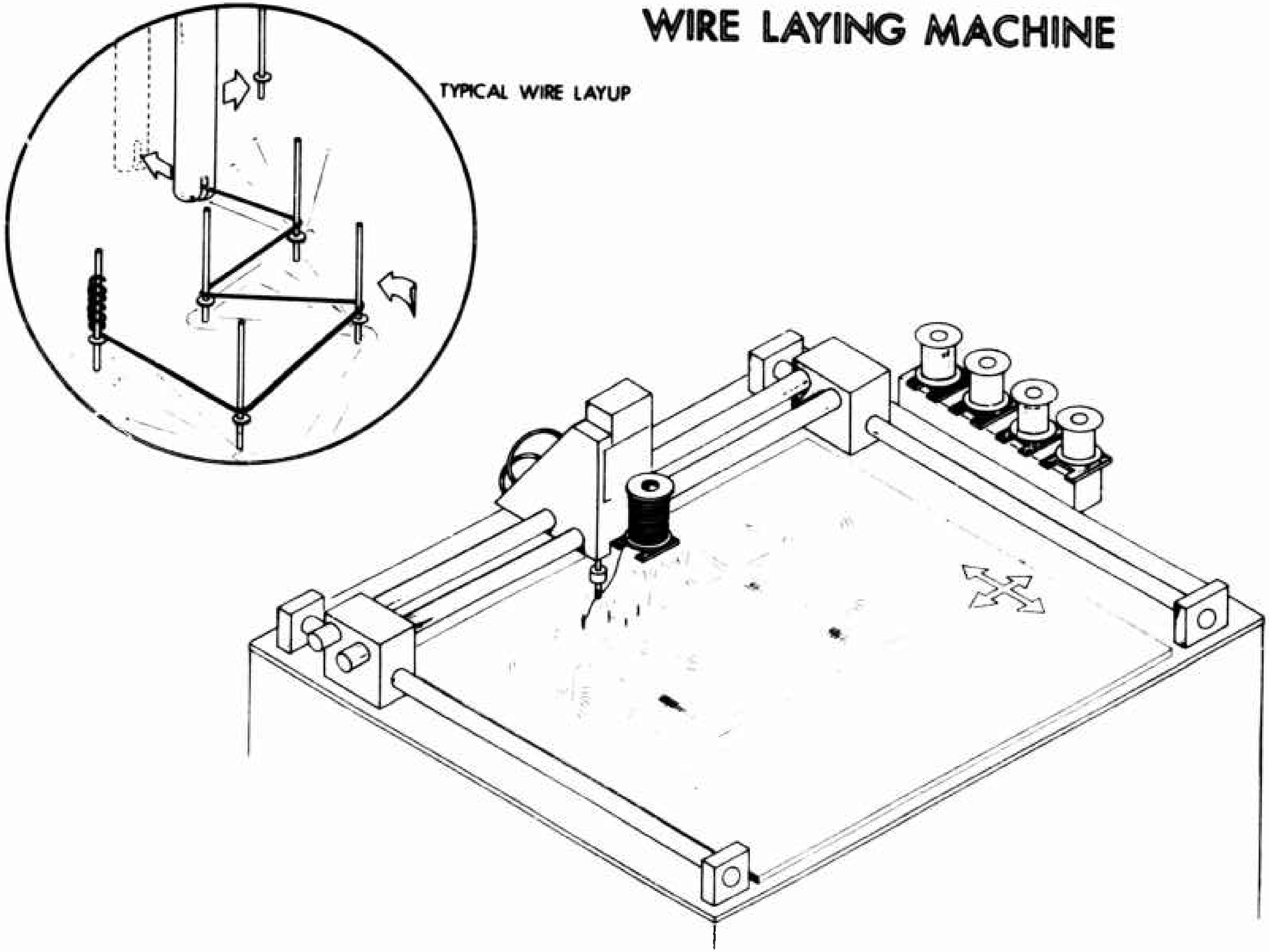

FIGURE 6

AUTOMATIC LACING MACHINE

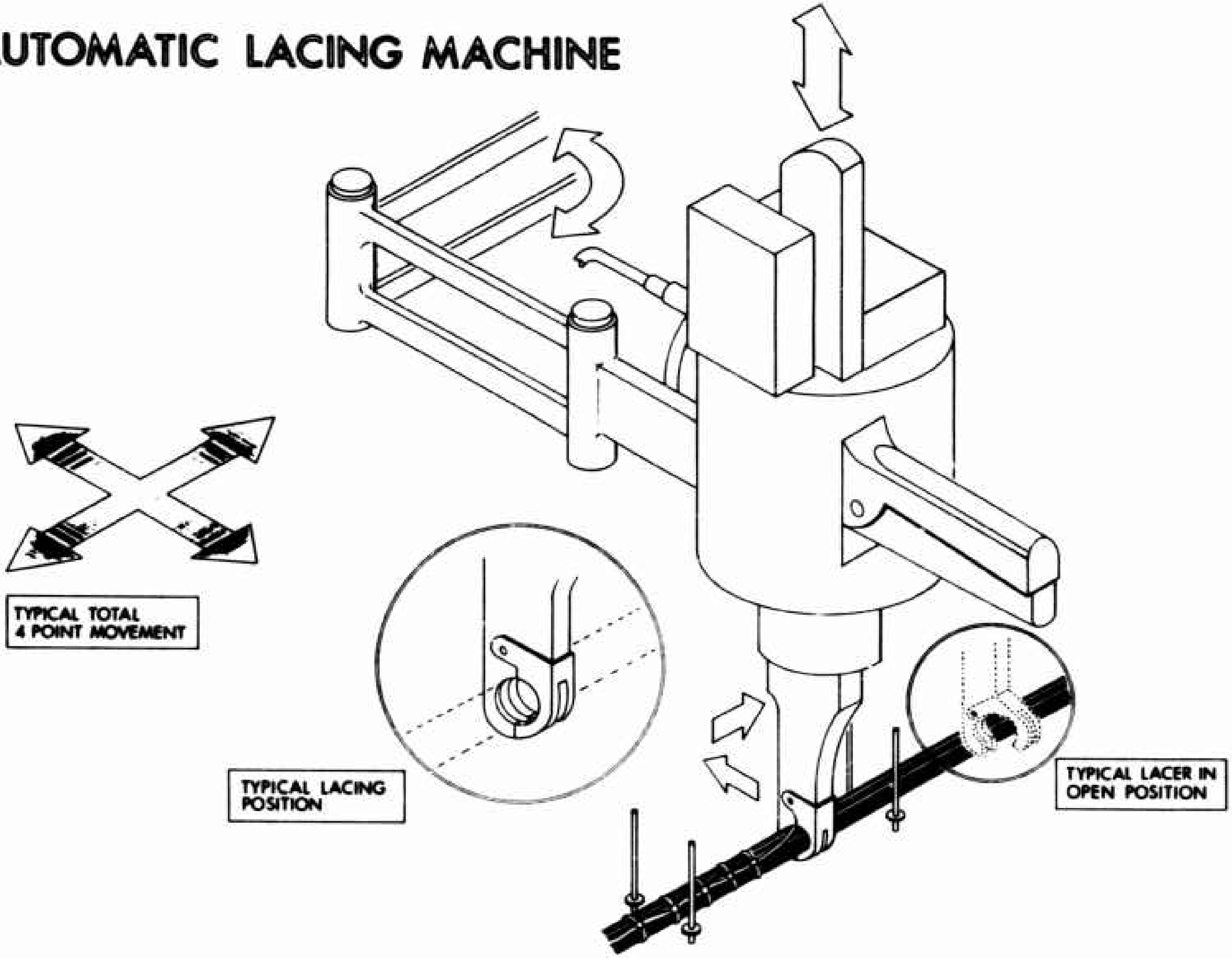

FIGURE 7

connector would be transfer molded in a manner similar to the construction of 110V line cords.

Project cost and duration: Estimated costs are as follows:

Design of pilot facilities for numerically controlled lay in and lacing, laser stripping and cable termination	$150,000
Construction of pilot facilities	325,000
Test and validation of pilot facilities	150,000
Engineering support and technical data	125,000
Total project cost	$750,000

Estimated duration of the project is 24 months to pilot facilities demonstration.

Benefits: This would result in reduced touch labor, scrap, cable rework, and in process inspection costs. Quality improvements include improved cable terminations, and a reduction in nicked and broken wire strands.

Total estimated savings 1.0% of guidance section cost

STINGER GUIDANCE SYSTEM MANUFACTURING TECHNOLOGY PROJECTS

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ABSTRACT

This paper is concerned with the total manufacturing environment in which the STINGER Guidance System is produced, with cost reducing manufacturing technology projects as its paramount theme. The STINGER weapon, its guidance system, and the manufacturing process used to produce the guidance system are described. Relative recurring unit production costs are broken down for each guidance component into standard manufacturing categories and the cost drivers are identified. Relative time based recurring support costs are presented. Manufacturing projects to reduce the manufacturing costs of STINGER are outlined. Trends for future MANPADS guidance systems are discussed and an important manufacturing technology project is presented.

THE STINGER WEAPON SYSTEM

The STINGER Weapon System, which is in Engineering Development at General Dynamics, Pomona Division, is an advanced man portable air defense system (MANPADS) designed to replace the 12 year old REDEYE weapon with performance capabilities to counter the latest known threats. The STINGER weapon shown in Figure 1 provides low altitude air defense to the foot soldier located in remote areas unaccessible to other missile systems. In Figure 2, STINGER intercepts target drone. STINGER continues to provide the same superior "fire and forget" launch policy and the same deadly "bullseye" accuracy inherent to REDEYE, while providing significant and necessary performance improvements. These performance improvements include:

1. Extended acquisition and launch ranges
2. All aspect target detection
3. Higher speed target intercepts
4. Higher maneuvering target intercepts
5. IFF capability
6. Greater countermeasure immunity
7. Greater RFI protection

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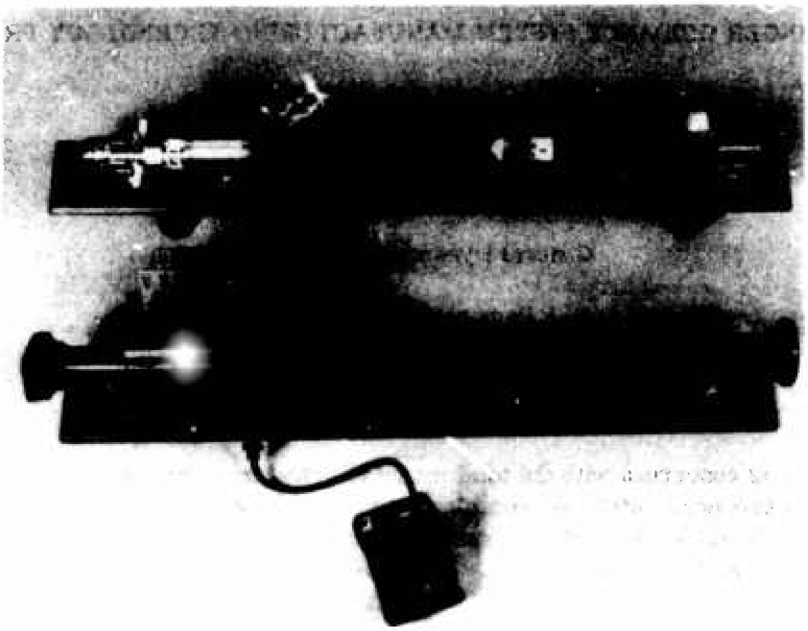


Figure 1. The STINGER Weapon.

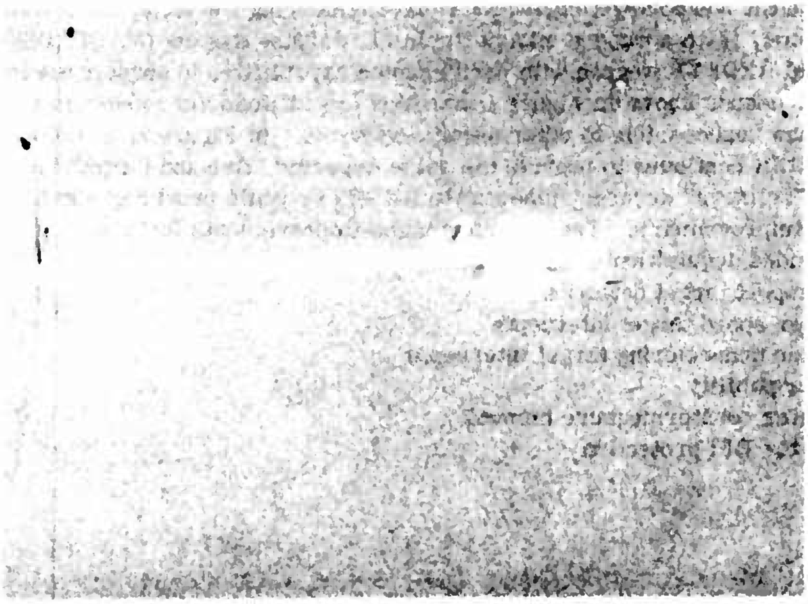


Figure 2. STINGER Hits the Target.

THE STINGER GUIDANCE SYSTEM

The above required weapon performance improvements dictated that the guidance system's functional complexity be increased by approximately two and one-half times REDEYE. This complexity increase was accomplished while maintaining the same volume, weight, and power allocation and while achieving only a modest increase in the constant dollar recurring unit production cost and the same high reliability as the REDEYE guidance system. We can credit much of this accomplishment to the design-to-cost requirement which was held equal in importance to the design-to-performance requirements.

During the present Engineering Development (ED) Phase, the Guidance system's production unit cost has been closely tracked and compared to its design-to-cost requirement. Cost analysis, producibility changes, and redesigns have been performed throughout the ED phase to achieve the design-to-cost requirement. Reliability assessments have been periodically made to measure the reliability growth and to insure the reliability integrity of the lower cost configurations. Figures 3 and 4 present the relative production unit cost history and the reliability growth history of the STINGER guidance system as a function of years after ED contract start. Note that the unit cost is better than its requirement and the reliability is projected to grow above its requirement.

The STINGER guidance system is depicted in Figure 5. Its three major subassemblies are a seeker head, an electronics section, and a cryostat assembly. The seeker head is composed of:

1. An IR dome housing assembly
2. A two degree of freedom gyro
3. An optical/encoding system
4. A head coil assembly
5. An infrared detector assembly

The electronic section consists of:

1. Five analog/logic multilayer circuit card assemblies
2. One power multilayer circuit card assembly
3. A multilayer printed wire distribution board
4. A connector

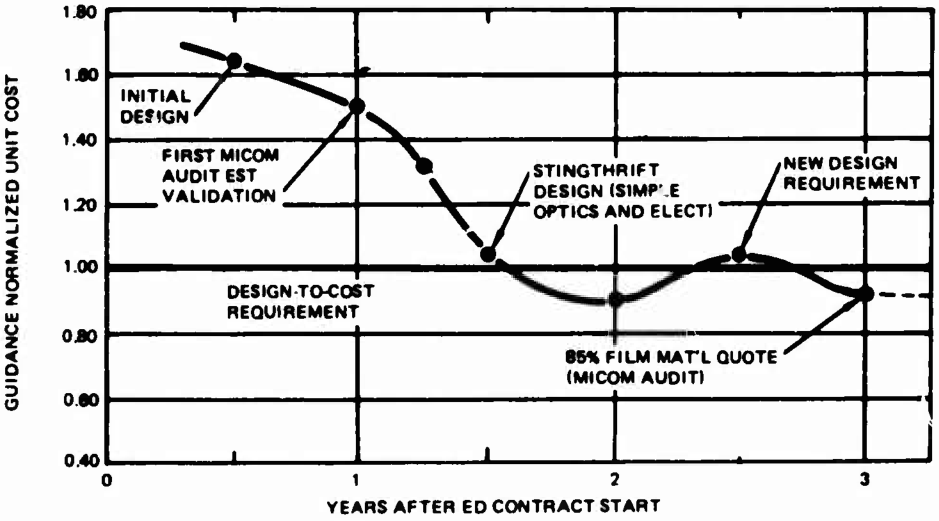


Figure 3. STINGER Guidance Cost History.

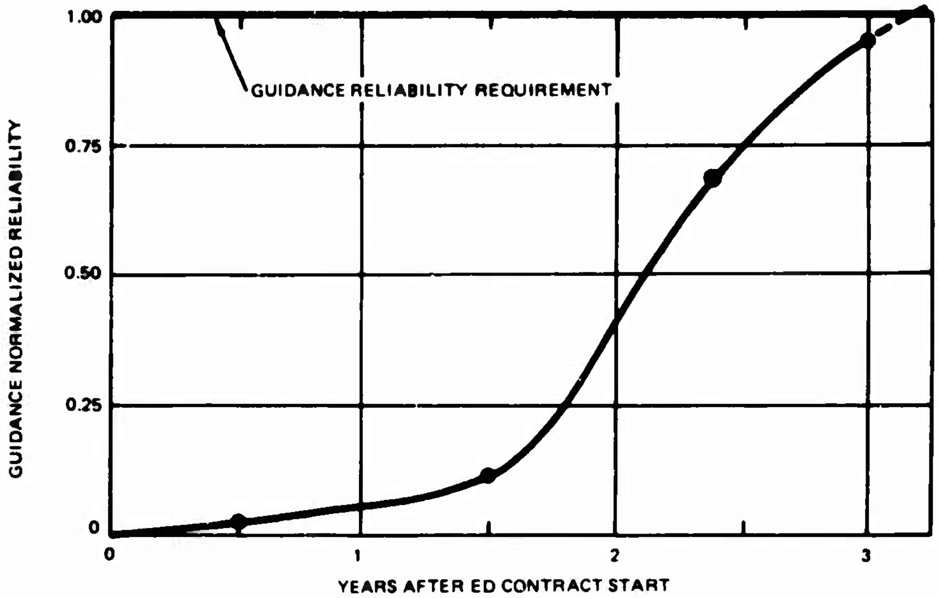


Figure 4. STINGER Guidance Reliability Growth History.

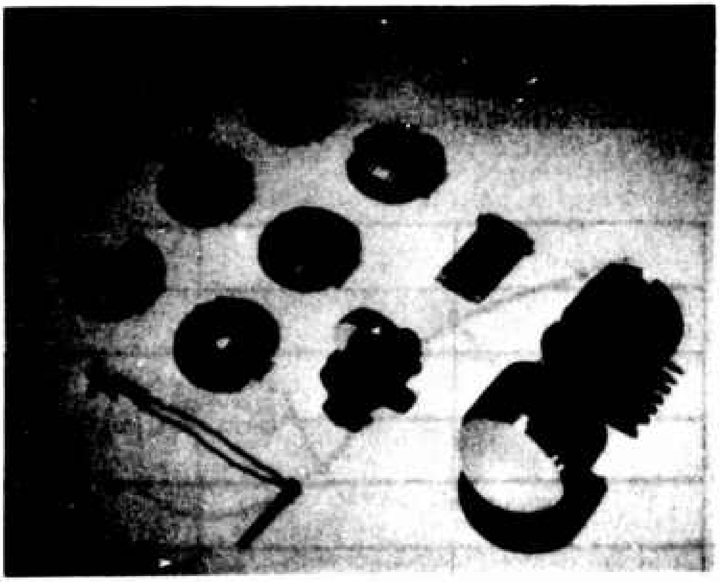


Figure 5. STINGER Guidance System.

The cryostat assembly is made of:

1. A miniature finned coil tube
2. A flexible gas line and connector
3. An inline particle filter

STINGER GUIDANCE MANUFACTURING PROCESS

The manufacturing sequence and flow diagram for the STINGER guidance system of Figure 6 shows that to achieve the guidance system design-to-cost requirement, the latest and most advanced manufacturing technologies are planned and applied for the production of STINGER. These technologies include maximizing the use of castings, numerical control machining, automatic multilayer PWB plating and etching, numerical control drilling, automatic electronic component insertion, wave soldering, automatic electronic testing and fault isolation, and automatic guidance system tailoring and acceptance testing. Figure 7 depicts the various automated processes planned for STINGER. The manufacturing process has been optimized considering the present manufacturing technology state-of-the-art, production rates, total quantity, and the guidance performance requirements.

There are several areas where additional savings can be achieved when advances in the manufacturing technology take place. Five significant areas are:

1. Automatic cryostat fabrication and testing
2. Automatic place and solder of high density flat pack components
3. Automated inspection
4. Numerical control precision machining
5. Automatic assembly of high precision mechanical parts

Of these five, the first three appear to have potential solutions by developing and proofing manufacturing technologies. At the present time the required tolerance constraints of the precision mechanical parts are just within the present state-of-the-art for manual machining and assembly and will require a significant state-of-the-art jump to achieve automation. These areas will be discussed in detail later in this paper.

DETAILED GUIDANCE RECURRING COST

Relative recurring quantity based unit production costs are broken down for each guidance subassembly item into standard manufacturing categories in Table I.

Table I. STINGER Guidance Cost Breakdown

Sub-assembly	Percent of Total	Purchased Material	Piece Parts Fabrication	Assembly & Test	Inspection
Guidance Integration	4.1	--	--	3.5	0.6
Seeker Head	52.9	19.2	$\boxed{9.9}$	$\boxed{16.7}$	7.1
Electronics	38.1	$\boxed{21.0}$	$\boxed{8.3}$	4.3	4.5
Cryostat	4.9	--	0.6	$\boxed{3.6}$	0.7
Totals	100.0	40.2	18.8	24.6	$\boxed{12.9}$

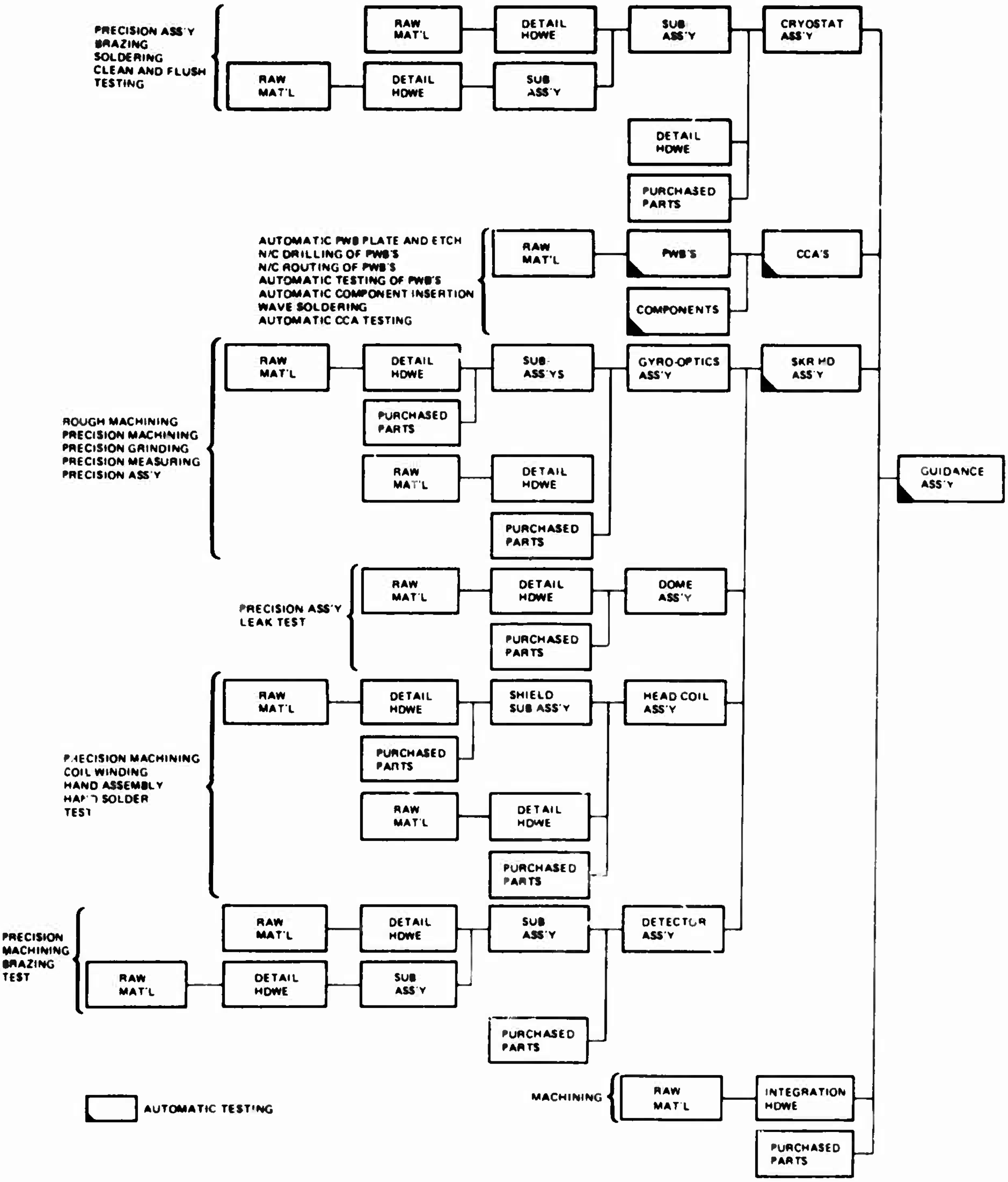
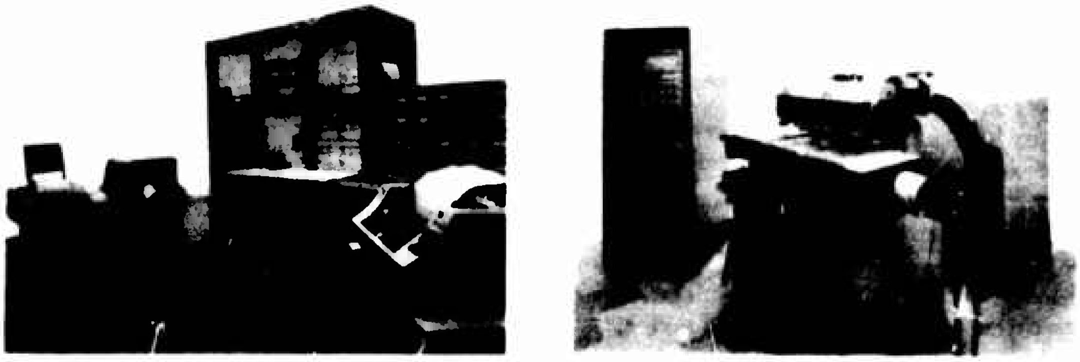
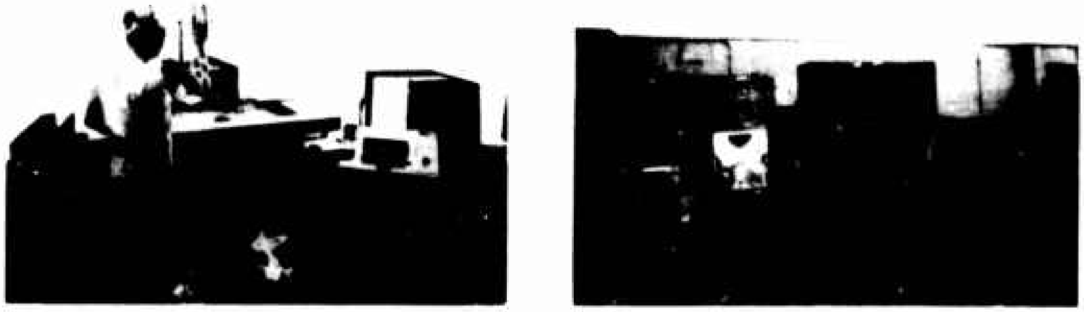


Figure 6. Diagram of Guidance Manufacturing Sequence and Flow.



AUTOMATIC CCA TEST UNIT

N/C CIRCUIT BOARD ROUTER



AUTOMATIC ELECTRONIC COMPONENT INSERTION

AUTOMATIC CIRCUIT ANALYZER

AUTOMATIC GUIDANCE TEST UNIT

INCLINED WAVE SOLDERING

Figure 7. Automatic Processes Used On STINGER Guidance.

Note that 40.2 percent is purchased parts cost, 12.9 percent is inspection costs, and 46.9 percent is the cost for fabrication, assembly, and test. There are six areas which deserve special attention as cost drivers. They are:

1. Seeker head parts fabrication
2. Seeker head assembly and test
3. Electronic purchase parts
4. Electronic parts fabrication
5. Cryostat assembly and test
6. Inspection

Each of these areas will be discussed in detail below with the help of the percent cost versus manufacturing operation bar graph shown in Figure 8.

Seeker Head Part Fabrication

The major source of the seeker head parts fabrication cost is the ultra-high precision machining required to fabricate the gyro gimbal assembly parts. Guidance performance requirements dictate the required precision and tolerance structure. The fabrication task is just within the state-of-the-art for manual lathe and grinding operation and at the present time no known automatic technology is within the reach of the immediate state-of-the-art.

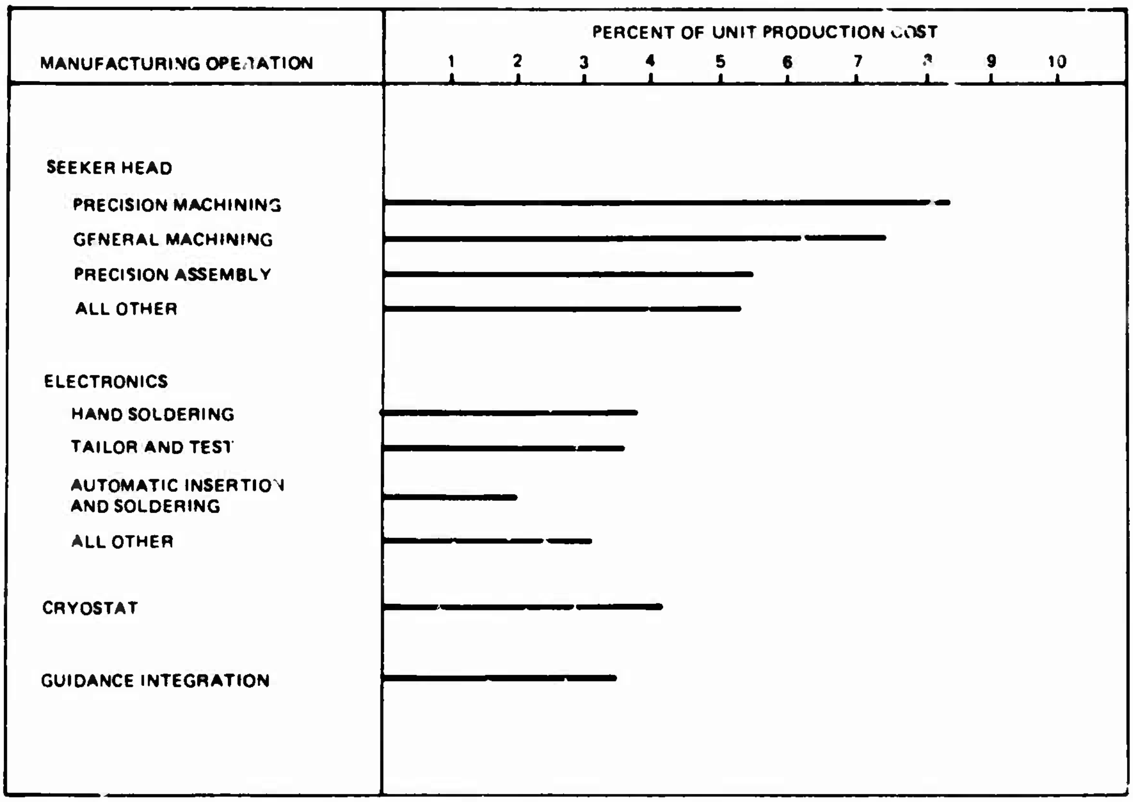


Figure 8. STINGER Guidance System – Percent of Unit Production Cost Versus Manufacturing Operation.

Seeker Head Assembly and Test

The major contributor to the seeker head assembly and test cost is the assembly of the gyro gimbal assembly which requires manual matching, fitting, and adjusting the ultra-precision, tight tolerance gimbals. Here again, no automatic technology is within the immediate state-of-the-art.

Guidance Electronics Purchase Parts

There are two major contributors to the high cost of electronic components. The small packaging volume allocation for the electronics requires miniature size discrete resistors and capacitors. Approximately ten percent of the 21 percent (two percent of total guidance cost) is attributed to miniature size discrete parts. The requirement for HI REL MIL-STANDARD electronic components, rather than MIL-STANDARD electronic components, makes up 28 percent of the 21 percent (six percent of total guidance cost). That is, a six percent reduction in the total guidance cost could be achieved by using MIL-STANDARD electronic components. It is interesting to note that REDEYE uses MIL-STANDARD electronic components and exceeds its guidance reliability requirement.

Electronic Fabrication

Hand soldering of high density flatpack components contributes 30 percent to the eight and one-half percent (two and one-half percent of the total guidance cost). Conventional methods for automatic place and solder of flatpack components is not achievable with the present manufacturing technology with high density components packaged on both sides of the PWB as they are packed in the STINGER electronics. The development of an automatic place and solder technology for STINGER as a project will virtually eliminate this cost.

Cryostat Assembly and Test

Manual assembly and testing drives the cryostat cost approximately 100 percent beyond the predicted cost if the technology were available for automatic assembly and test. A manufacturing technology needs to be developed to automatically manufacture the STINGER cryostat. A two percent reduction in total guidance system cost can be achieved if automation is developed.

Total Inspection Costs

All inspection on STINGER is presently performed manually by visually comparing the item to its drawing. Automatic inspection technologies should be developed with a goal to reduce inspection costs by 35 percent.

STINGER GUIDANCE MANUFACTURING TIME BASED SUPPORT COSTS

Eight years of REDEYE production experience has established an accurate support cost history which can be used to project the STINGER guidance support costs. From this history it is projected that the support costs during initial production will be approximately equal to the quantity based recurring costs. These support tasks include, but are not limited to:

1. Program Management
2. Configuration and Change Control

3. Design Engineering Support
4. Manufacturing Engineering Support
5. Quality Engineering Support
6. Quality Assurance Management
7. Cost and Schedule Tracking (CSMS)
8. Tool Maintenance
9. Test Equipment Maintenance
10. Shipping and Receiving
11. Inventory Control
12. Software Maintenance
13. Periodic Conformance Inspection (periodic environmental testing)
14. Production Planning

Significant cost savings can be realized for approximately 50 percent of the above tasks by developing a Computer Integrated Manufacturing System. This system should:

1. Reduce configuration and change control cost by approximately 50 percent
2. Decrease the span time for change incorporation by approximately 50 percent.
3. Maintain an up-to-date drawing package without CO attachments
4. Reduce planning and replanning costs by a factor of four
5. Provide automatic inventory and routing control of all hardware in the manufacturing process
6. Provide real time schedule and cost tracking data
7. Reduce the amount of paper by 50 percent
8. Reduce quality assurance management costs by providing real time analysis of quality assurance data

A reasonable estimate of the cost savings which can be achieved by implementing the system is approximately 25 to 30 percent of the total STINGER guidance time based support costs.

FUTURE TRENDS IN MANPADS GUIDANCE

General Dynamics, Pomona Division has accumulated more than 25 years of guided missile design and manufacturing experience and more than 16 years of direct experience on MANPADS guidance systems. From this history, future trends can be fairly accurately forecasted. The 1985 threat for the MANPADS weapon system will impose performance requirements which will necessitate an increase in guidance complexity of approximately three times over the complexity of STINGER.

Figure 9 predicts the complexity factor of the future (1982-85) seeker head to be six using the 1959 initial REDEYE guidance system as the unity reference.

Figure 10 forecasts the equivalent discrete circuit element count to be approximately 7,000 in the 1982-85 time frame, four times the circuit element count of STINGER and 30 times the current element count of the initial REDEYE. The use of integrated circuits, operational amplifiers, and resistor arrays has permitted STINGER's actual parts count to remain at a reasonable level as shown in Figure 10.

As the amount of integration has increased the rocket motor and warhead designers have influenced the electronic packaging volume allocation decisions and the available packaging volume has decreased according to the trend curve of Figure 11. From these data electronic packaging density trends are computed for MANPADS guidance and plotted on Figure 12.

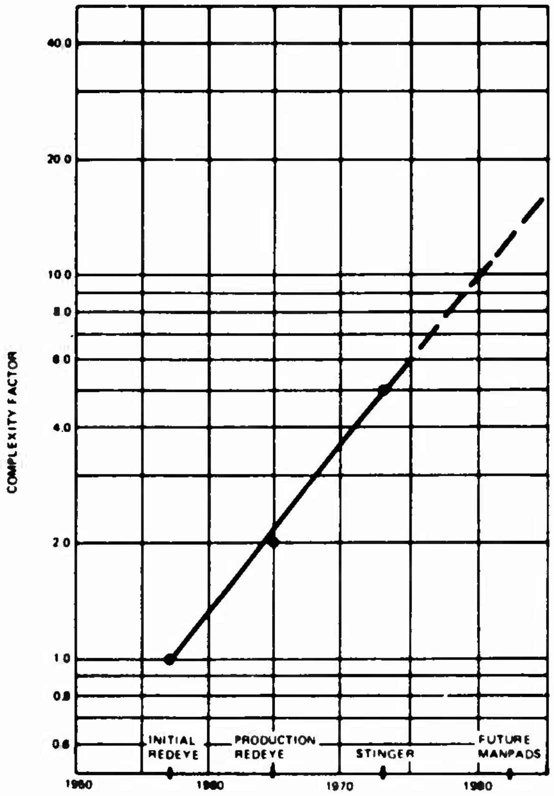


Figure 9. MANPADS Guidance Seeker Head Requirements/Complexity Trend.

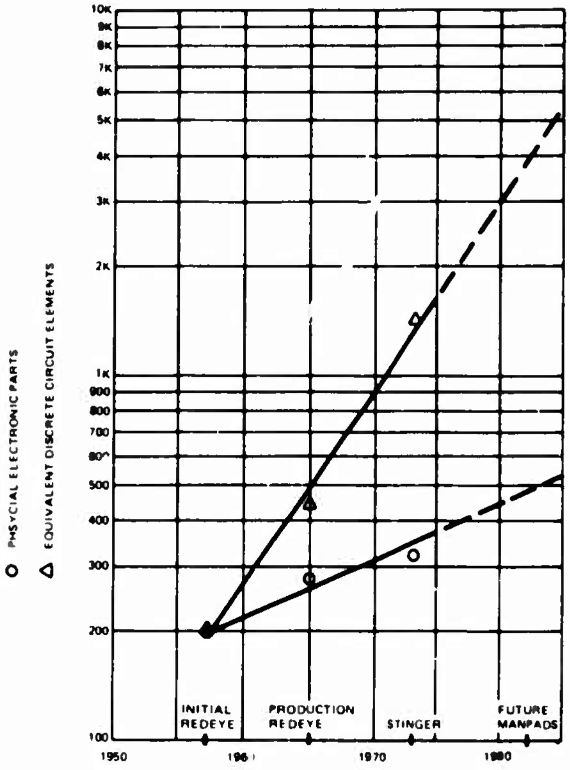


Figure 10. MANPADS Guidance Electric Parts Count Trend.

STINGER has reached the packaging density limit for packaging with multilayer PWBs and off the shelf discrete components. Future packaging density needs require the use of a large scale hybrid (LSH) packaging system. The photograph in Figure 13 shows a typical LSH wafer assembly which must be used for any future MANPADS guidance electronics in order to meet the projected packaging volume and component count. This LSH packaging system is composed of a large ceramic wafer with deposited circuit pads, thin and thick film resistor, chip capacitors and semiconductor components, all connected with wire bonded gold wire. The wafer is hermetically sealed.

The present manufacturing technology for this LSH system requires a significant amount of skilled manual operations, primarily for the placement of chip components and wire bonding the interconnect. Individual semiconductor chips cannot be easily tested prior to placement on the substrate.

Recently several semiconductor houses have developed rolled film/tape carriers for semiconductor chips which permit them to be individually tested and automatically placed on substrates. A manufacturing technology project is needed to evaluate and proof the feasibility of automating this emerging semiconductor carrier system. This new manufacturing technology for automatic LSH electronic assembly has the potential of reducing the cost of hybrid electronics manufacturing to a level equal to or less than the cost of automatic insertion and wave soldering of the multilayer PWB/discrete component packaging system.

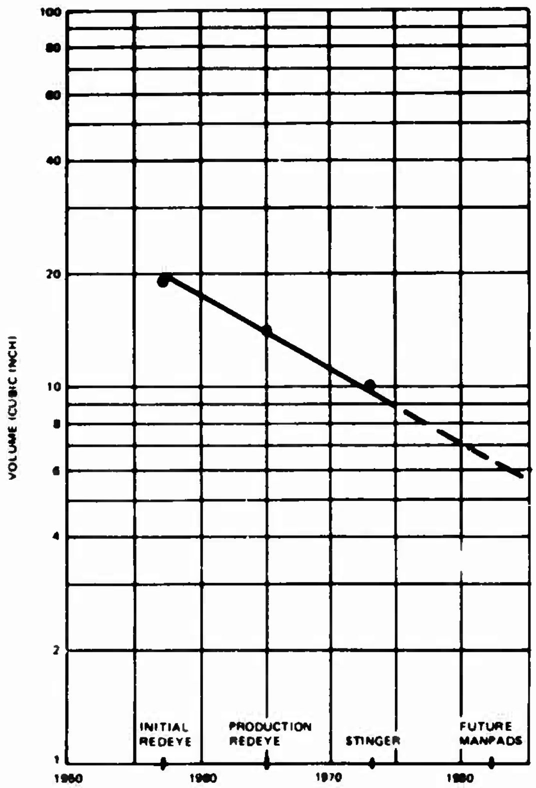


Figure 11. MANPADS Guidance Electronic Packaging Volume Trend.

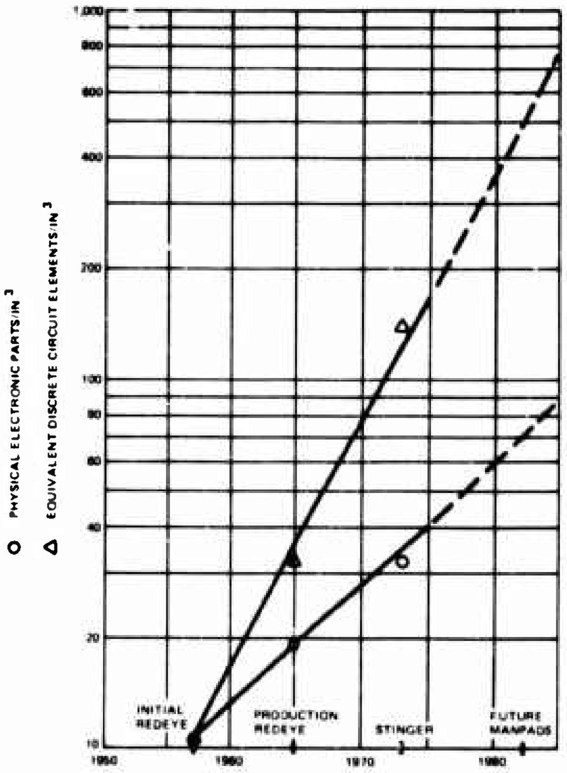


Figure 12. MANPADS Guidance Electronic Packaging Density Trend.

TRENDS IN MANPADS GUIDANCE MANUFACTURING TECHNOLOGY

Figure 14 presents a projection of the manufacturing technology forecast for the 1985 time frame based on REDEYE history and STINGER's present manufacturing technology. This projection is based on the natural growth in manufacturing technology and on an assumption that the manufacturing technology projects of this conference will be funded.

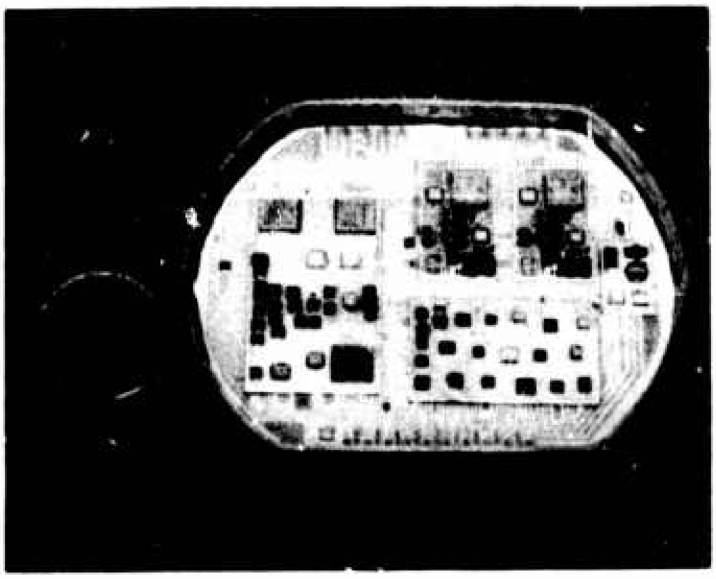


Figure 13. MANPADS Advanced Wafer Assembly.

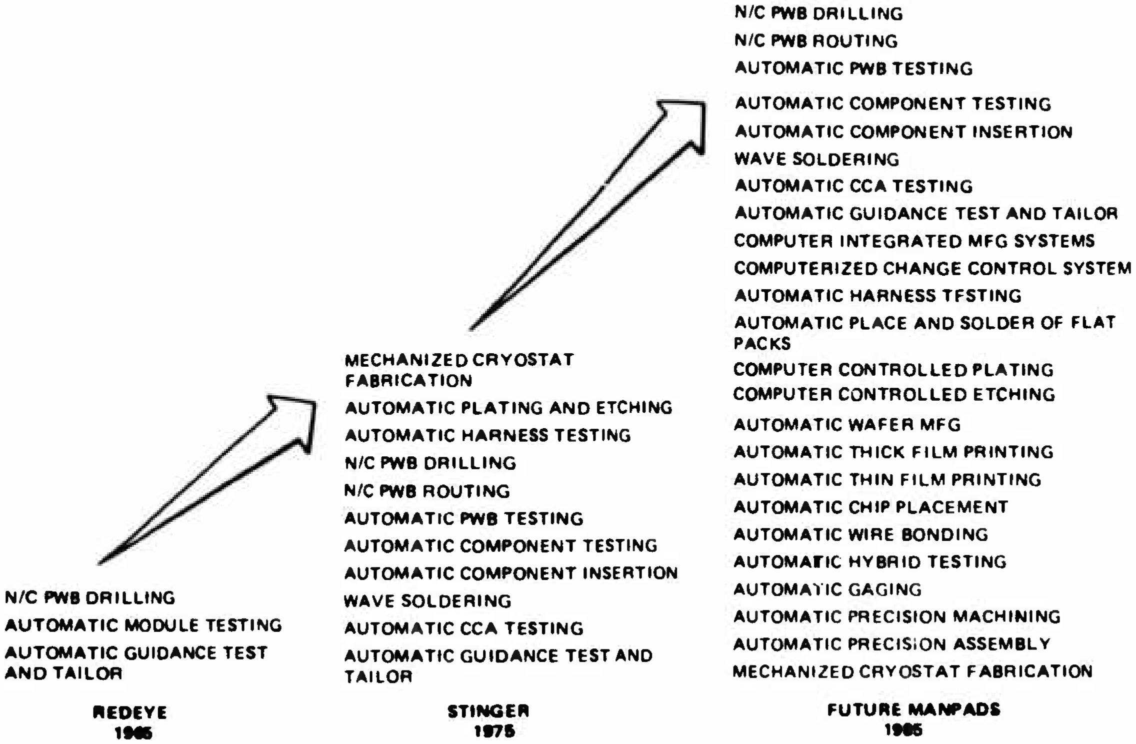


Figure 14. Automation/Mechanization Trend.

The following table summarizes the U.S. Army Materiel Command Missile Manufacturing Technology Conference STINGER Projects.

Project Name	Area	Funding Required	Duration (Months)	Savings
STINGER High Density Flatpack Automatic Place and Solder	STINGER/guidance/ electronics	$ 280,000	12	Two and one-half percent of guidance cost
Low Cost STINGER Cryostat Assembly Technology	STINGER/guidance/ cryostat	$ 133,000	12	Reduce cryostat cost by 50 to 60 percent (two percent of total guidance cost)
CADAM Configuration and Change Control System for STINGER Production	STINGER/guidance/ support	$ 288,000	12	Reduces configuration control cost by 50 percent
Computer Integrated Manufacturing System	STINGER/ structure/ management system	$6,000,000	48	Reduction in design-to-production transition time of 25 percent Reduction in recurring costs: Manufacturing: Existing STINGER Program: 5% Future Program: 50% Support: 50% Reduction in nonrecurring costs: 60% Reduction in paper costs: 50%
STINGER Automated Inspection Technology	STINGER/guidance/ inspection	$ 330,000	18	Reduction of 25 to 35 percent on STINGER guidance inspection (four percent of total guidance cost)
Tape Carrier Micro-Interconnect System for Large Scale Hybrid Electronic	Future MANPADS/ guidance/electronics	$1,650,000	36	Reduces assembly costs by 75 percent
CADAM Control of Chemical Processes for Fabrication of STINGER Printed Circuitry	STINGER/guidance/ electronics	$ 390,000	36	Reduces printed wiring board fabrication cost by 40 percent
Substrate Material Research on Stripline/ Microstrip Circuits	Various/guidance/ stripline-microstrip circuits	$ 75,000	12	Reduction in fabrication and reliability costs

U.S. ARMY MATERIEL COMMAND
MISSILE MANUFACTURING TECHNOLOGY CONFERENCE
STINGER PROJECTS

Title: STINGER High Density Flatpack Automatic Place and Solder

System/session area/component: STINGER/guidance/electronics

Problem: To attain the high packaging density required in the guidance electronics, discrete parts are mounted on both sides of the circuit cards. Through-hole mounted (axial and radial leaded) parts are mounted on one side and flatpack microcircuits are mounted on the opposite side (normally the solder side). In addition, feed-through holes interconnecting the various layers (six) of the printed wiring board must be plugged with solder. To attain high productivity, automated assembly techniques, such as automatic part insertion and wave soldering, are employed. Wave soldering, however, leaves excessive and uncontrolled amounts of solder on the circuit card, thereby obstructing automatic flatpack place and soldering.

Proposed solution: To develop an automatic masking process to preserve the original flatpack footprint solder surface and automate the place and reflow solder operation for attaching the flatpacks on side #2 of each circuit card.

Project cost and duration: Estimated costs are as follows:

Masking process development	$ 50,000
Machine design and specification	80,000
Pilot machine and proofing	150,000
Total	$280,000

Estimated duration of the project is 12 months

Benefits: Reduction in the total STINGER guidance recurring cost by two and one-half percent.

Assumptions: None

Title: Low Cost STINGER Cryostat Assembly Technology

System/session area/component: STINGER/guidance/cryostat

Problem: Present manual methods to manufacture the STINGER cryostat are costly because of the tight tolerances to achieve an insertion force of 0.5 to 3.0 pounds and to cool the IR detector at a specified rate without becoming restricted due to contamination.

Proposed solution: Develop the manufacturing technology, specialized manufacturing equipment, cleaning equipment and test equipment required to decrease the cost of manufacturing the cryostat by 50 - 60 percent.

Project cost and duration:

Equipment design	$ 22,000
Pilot equipment manufacture	71,000
Evaluation and proofing	40,000
Total	$133,000

Estimated duration of the project is 14 months

Benefits: Benefits to be derived from the project are as follows:

1. Reduced cryostat cost by 50 - 60 percent (two percent of total guidance cost).
2. Increased yield.

Assumptions: None

Title: CADAM Configuration and Change Control System for STINGER Production

System/session/area component: STINGER/guidance/support

Problem: Present method to control the configuration is to maintain an approved Form 1 MYLAR hard copy drawing and changes are contained on separate sheets called "Change Orders." The Change Orders are part of the documentation package and are manually incorporated onto the MYLAR hard copy at a later date and a letter change is assigned to the drawing. This sometimes causes confusion and difficulty in tracking and maintaining an up-to-date documentation package for all concerned parties.

Proposed solution: Develop a CADAM configuration data bank which continuously maintains each drawing to its latest configuration. Develop subroutines to retrieve, display and make changes to each displayed drawing instead of preparing Change Orders. Obtain the necessary approval using the display rather than paper, prior to incorporating it in the CADAM configuration data bank. This eliminates the MYLAR hard copy and the Change Order and provides all concerned parties with an on-the-spot latest configuration.

Project cost and duration: Estimated costs are as follows:

Develop interactive graphics software	$210,000
Develop system software	30,000
Evaluate and proof "STINGER" data bank	48,000
Total	$288,000

Estimated duration of the project is 12 months

Benefits: Benefits to be derived from the project are as follows:

1. Eliminates confusion by providing realtime configuration data.
2. Eliminates MYLAR hard copy with attached Change Orders by automatically translating drawings onto microfilm.
3. Reduces configuration control and change incorporation costs by 50 percent

Assumptions: None

Title: Computer Integrated Manufacturing System

System/session/component: STINGER/structures/manufacturing system

Problem: The manufacturing system as we know it today is under heavy pressure to become more productive, flexible and precise and better able to cope with the varying requirements of the military product.

There are currently a variety of approaches to improving efficiency of individual facets of the system; design through synthesis and analysis programs; Documentation through interactive graphics and computer aided drafting; Configuration Control and Manufacturing Control through ports listings and release systems; Material Control through Inventory Management and Procurement Systems; Fabrication control through Planning systems and NC programming systems; Product Quality through automated test and inspection systems with reporting of performance and yield trends; Budget Control via CSMS and on and on.

Little or no system planning has been done to develop a comprehensive system. Gross inefficiencies are caused by the mish mash of small systems designed for specific purposes without the larger needs of the total transition through Design and Production to Product Use.

The evolution of products established in this helter skelter of mismatched design and production systems tends to perpetuate the system inefficiencies because some part of most new products are contained in the existing systems.

Proposed solution: Perform a system design relating the various inputs, outputs, formats, data modification requirements, etc., to meet the requirements of the total design-to-use progression. Develop the requirements for evolving from existing systems where possible and for providing for system growth. Provide for system sizing to maintain economy over a spectrum of applications.

Investigate parts classification systems and develop a system capable of handling the entire spectrum of parts found in tactical missile systems. The system must meet the requirements developed in the total system design of the above paragraph.

Perform programming and implementation of the system design on one computer system.

Project cost and duration: Estimated costs are as follows:

Project Initiation and Review and Preliminary Specification (12 months)	$1,000,000
Preliminary System Design and Final Specification (12 months)	1,500,000
Detail System Design and Development (12 months)	2,000,000
System Programming and Implementation (12 months)	1,500,000
Total	$6,000,000

Estimated duration of the project is 48 months.

Benefits: Benefits to be derived from this project are as follows:

1. A reduction in the design-to-production transition time.
2. A reduction in both recurring and nonrecurring costs.

	Percent of Savings
Design-to-production span reduction	25
Recurring:	
Manufacturing: Existing STINGER Program	5
Manufacturing: Future Program	50
Manufacturing: Support	50
Nonrecurring	60
Paper costs	50

Assumptions: The project cost estimates assume that a totally integrated manufacturing system would be planned, developed and implemented on one host computer system. Modularity of the design would allow for incremental transition from existing subsystems to the integrated system. Use of existing software that would satisfy the preliminary specifications at the end of the first phase would substantially reduce the cost estimates for subsequent phases. Likewise conversion of the system to other computer systems would increase the estimates.

Tasks affected:

1. Process analysis
2. Production planning
3. Shop loading and scheduling (Span and Bank)
4. Tool design
5. Part programming (Fabrication)
6. Assembly system programming
7. Machine control to "on-line"

8. Job and machine status
9. Issuance and control of documents
10. Cost tracking

Group technology (part family coding): Identification of part families permits creation of standard process/assembly plans, or menus, and from the key to retrieval systems.

Common data bank: The common data bank of information being utilized by the manufacturing system, with engineering initiating the file with a geometric part description and other control path. Each subsystem processes this data interactively with the computer. Such a system, besides cutting down on duplications common in today's system, will allow for better control of the total information flow. These files form the basis for creating parts lists and the programming of assembly systems.

Production planning: The production planning system will utilize the "menu" retrieval concept, and will include such automatic subroutines as:

1. Machine utilization and efficiency
2. Cutter selection with speed and feed
3. Time standard calculation
4. Machining data
5. Process/assembly sequence

Tool design: Tool design/drafting utilizing the same basic software developed for engineering design. The common data bank will be accessed for part geometry. Tool design data was captured in the computer and a micro-film produced in lieu of a drawing. One aperture card will be used for configuration control.

Machine/process programming: Automatic generation of the geometric location of each discrete part on the electronic circuit card, or substrate will make for efficient use of assembly systems developed for future packaging concepts.

Title: STINGER Automated Inspection Technology

System/session area/component: STINGER/guidance/inspection

Problem: Present inspection methodology is performed manually and visually by comparing the item's characteristics to the drawing requirements. This is a time consuming and relatively costly process.

Proposed solution: The following areas are to be investigated and evaluated during this project:

1. Automate handling and inspection of printed wiring boards and printed flex cables for dimensional and visual conformance to drawing requirements.
2. Automate gaging methods of complex precision machined parts for dimensional conformance to drawing requirements.
3. Automate gaging methods, on the machine, with feedback to the machine, of numerical control machined parts.
4. Develop methods of determining integrity of soldered connections by other than visual inspection methods.

Project cost and duration: Estimated costs are as follows:

Technology investigation and definition	$ 90,000
Equipment development	150,000
Software and proofing	90,000
Total	$330,000

Estimated duration of the project is 18 months

Benefits: Benefits to be derived from this project are as follows:

1. To achieve 25 to 35 percent cost reduction on STINGER guidance inspection (four percent of total guidance cost).
2. To provide the capability to meet increased production rate and schedule demands.

Assumptions: None

Title: Tape Carrier Micro-Interconnect System for Large Scale Hybrid Electronics

System/session area/component: Future MANPADS/guidance/electronics

Problem: The increased packaging density needed for future MANPADS guidance electronics requires the use of hybrid microelectronic devices packaged on large scale hybrid wafers. Present state-of-the-art of the manufacturing technology for this system requires highly skilled costly labor and future manufacturing costs will be high unless a new manufacturing technology is developed.

Semiconductor elements cannot be individually tested prior to assembly.

Proposed solution: To design a system for automatically transporting and assembling semiconductor devices which are housed on rolled tape carriers. This tape carrier system is presently being introduced into industry by the semiconductor manufacturers.

Project cost and duration: Estimated costs are as follows:

Develop standards for tape carrier	$ 100,000
Develop automatic bonding process	520,000
Develop and proof design standards	150,000
Establish feasibility assembly line	200,000
Optimize fabrication and assembly system	580,000
Total	$1,650,000

Estimated duration of the project is 36 months.

Benefits: Benefits to be derived from this project are as follows:

1. Reduces assembly costs by 75 percent.
2. Permits individual semiconductor testing prior to assembly.
3. Improves reliability (bond strength and size).

Assumptions: None

Title: CADAM Control of Chemical Processes for Fabrication of STINGER Printed Circuitry

System/mission/component: STINGER/guidance/electronics

Problem: Tactical missile systems are calling for highly dense, sophisticated, heterogeneous electronics to be packaged in volumes fixed by existing air frames. This in turn has increased the tolerance and complexity of the printed circuit interconnection substrates for electronic and control guidance tremendously. The numbers of circuit lines per unit area has increased by a factor of two per unit area, the number of layers of circuitry per substrate has increased from two to eight. The chemically plated line widths have been reduced from ±0.025 inch, ±0.005 inch to 0.012 inch, ±0.002 inch. The control of the many step chemical plating and etching processes, which are the heart of the fabrication procedure have become marginally possible to control manually. Scrap and rework as well as excessive manual QA have increased production cost considerably.

Proposed solution: A series of selective ion electrode, photocell and current sensing sensors can be used to monitor critical process operating parameters. Closed loop regulation systems can be established based on these reference sensors. Computer programming can be created to integrate this regulatory system into an overall computer aided manufacturing control network.

Project cost and duration: Estimated costs are as follows:

Identify and demonstrate feasibility of sensor system	$ 65,000
Develop closed loop feedback system	125,000
Proof the concept with hardware	200,000
Total	$390,000

Estimated duration of the project is 36 months.

Benefits: Reduce printed wiring board fabrication cost by 40 percent.

Assumptions: None

Title: Substrate Material Research on Stripline/Microstrip Circuits

System/session area/component: Various/guidance/stripline-microstrip circuits

Problem: Stripline and Microstrip circuits utilize chip capacitors, chip resistors, microcircuits packaged in leadless inverted devices (LIDs) and the like in order to obtain high density packaging. They also use teflon substrates in order to achieve the desired dielectric properties. The thermal coefficient difference between the ceramic components, the teflon substrates, and solder used for joining cause severe fabrication and reliability problems resulting in high costs.

Proposed solution: A basic material evaluation of substrate material, component package material, and joining technique is called for. One possible candidate might include an all polyimide system. Polyimide substrates are beginning to be used for high temperature circuit board substrates. A relatively new system of packaging microcircuit on polyimide tape with printed circuit lead frame interconnects is beginning to emerge. Thermo compression bonding of various metallurgical joining systems are known. A thorough dielectric performance as well as assembly process investigation as a function of potential material systems is called for.

Project cost and duration: Estimated costs are as follows:

To conduct a material and component evaluation and establish a compatible joining process	$75,000

Estimated duration of project is 12 months.

Benefits: Prototype hardware with a reduction in fabrication and reliability cost.

Assumptions: None

STINGER ALTERNATE GUIDANCE SYSTEM

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ABSTRACT

This report contains a discussion of the potential production cost reductions for the Stinger Alternate guidance system if manufacturing technology projects are applied during the development phase. This report describes the Stinger Alternate missile system, identifies the major system cost drivers and recommends three manufacturing technology projects to reduce unit production cost. These projects are for: (1) large scale integration (LSI) of the missile electronics, (2) fluidic rate sensors, and (3) replication of optics. The estimated costs of the manufacturing technology projects versus production costs reduction show a very favorable ratio.

SYSTEM DESCRIPTION AND DESIGN CRITERIA

SYSTEM DESCRIPTION

Stinger Alternate is a man-portable shoulder fired air defense missile system that employs a laser beam riding guidance system and visual target tracking. It is effective against all subsonic low altitude aircraft targets. The total weight of a tactical configuration will be approximately 32.5 pounds.

The major elements of the Stinger Alternate system are shown in Figure 1. They are the missile and its eject motor, the missile launch tube, and the Guidance Unit. The missile, its eject motor, and the thermal battery required to operate this missile during flight are integral to the Launcher Assembly which is a throw-away item. The Guidance Unit, which is attached to the Launcher Assembly prior to use, is reusable.

Missile

The missile airframe is a simple body tail configuration with a maximum diameter of 3.25 inches. In a tactical configuration, the missile will weight approximately 17.0 pounds and have an overall length of 47 inches. The current Advanced Development missile weighs approximately 20.0 pounds and has a length of approximately 52.5 inches.

The airframe is designed to carry the Stinger warhead and fuze, which are mounted in a low drag nose fairing. For the development program, the warhead is replaced by a telemetry unit and its associated signal conditioning circuitry.

Propulsion is provided by the ejector motor (which burns in the launch tube to provide a launch velocity of 60 feet/second) and the flight motor which ignites 20 feet from the launcher and provides a supersonic flight velocity. Both motors are solid propellant boost

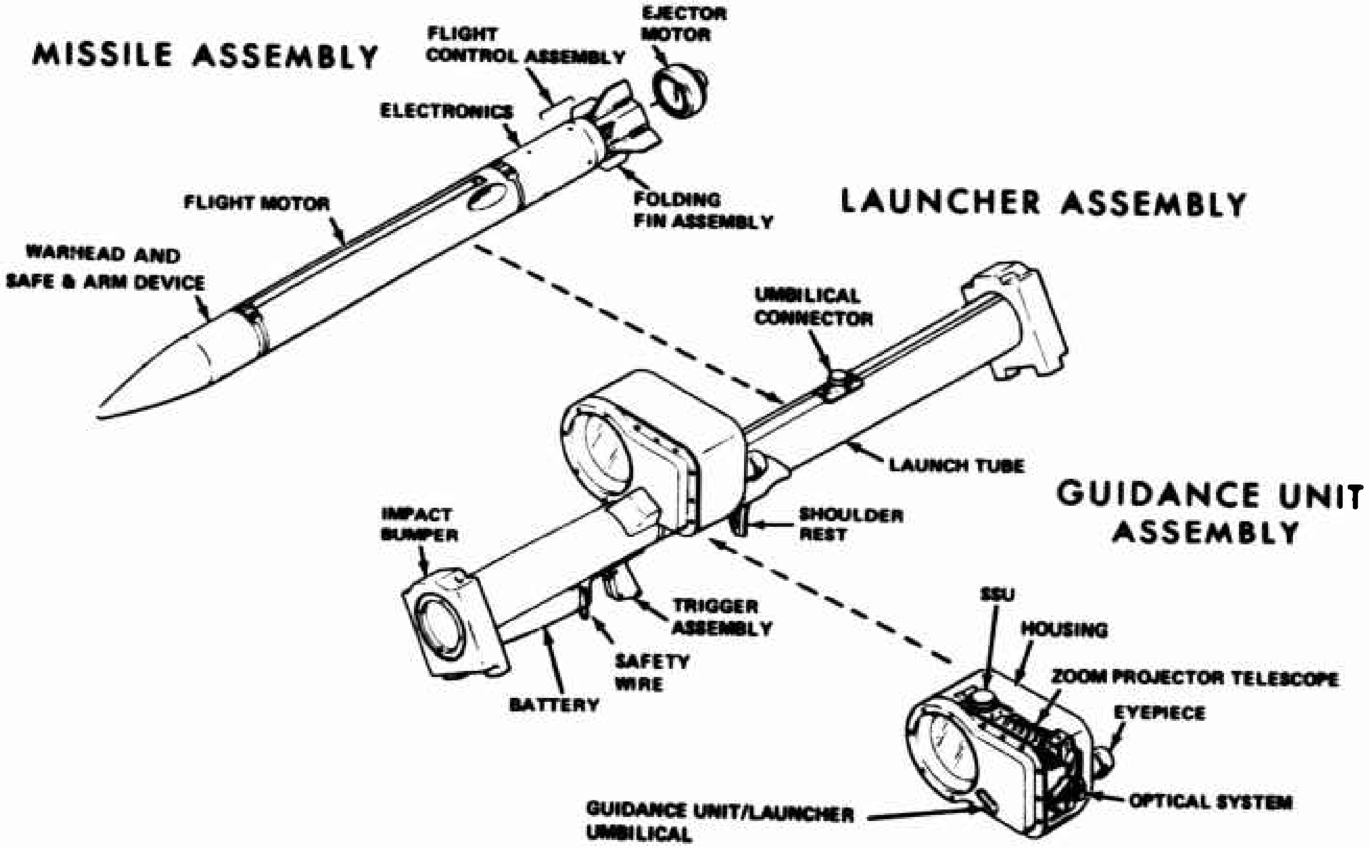

FIGURE 1. STINGER ALTERNATE WEAPON CONFIGURATION

designs which use smokeless double base propellants. The flight motor nozzles are located at the midbody and canted outboard at an angle of 20 degrees.

The flight control system is a 3 axis attitude controlled autopilot which is commanded by guidance error signal derived from the output of the guidance receiver at the rear of the missile. Attitude reference for the autopilot is provided by three rate sensors. Control is accomplished by deflection of the missile tail surfaces, which are independently actuated to provide control of pitch, yaw and roll. During the low speed phase of flight following launch, the effectiveness of the aerodynamic surfaces is augmented by reaction control jets which are activated in parallel with the tail control surfaces.

Guidance Unit Assembly

An assembly view of the Guidance Unit Assembly is shown in Figure 2. The Guidance Unit Assembly consists of the stabilized mirror (SSU), zoom laser beam projector and the gunner's 10X telescope. The guidance beam is generated by a pair of laser diodes. Each diode radiates into a fiber optic, the apertures of which are positioned to form an "L" shaped pattern of the object plane of a zoom lens system. The pattern is continuously focused at the missile during its flight by programmed motion of the zoom lens.

The guidance beam is nutated and the modulation frequency of each diode varied with the phase of the nutation cycle. The missile guidance error components (vertical and lateral deviation from the beam centerline) are determined from the modulation frequency detected by the missile receiver as the image of each diode sweeps by the receiver. The zoom lens program maintains the dimensions of each element of the beam at approximately 1 meter x 6 meters from a range of 120 meters to maximum range. This provides an approximately circular guidance field with a constant diameter of 6 meters.

Target tracking is accomplished visually by the gunner by pointing the launch tube as he would a rifle. Accurate tracking is achieved by means of the Sightline Stabilization Unit (SSU) which stabilizes the field of the gunner's 10X telescope and the projected laser guidance beam.

The SSU was designed to provide an optimum combination of the rapid target acquisition capability of a hand-held weapon with the high tracking accuracy of a stabilized mount. The basic element of the system is a two axis gimballed mirror which is stabilized by a pair of rate gyros. The mirror is dynamically coupled to the launch tube so as to obtain maximum attenuation of the normal extraneous motions of a hand held weapon while providing the control necessary to track rapidly moving targets.

MISSILE DETAIL ASSEMBLY

The Stinger Alternate Missile is shown in Figure 3. Three major sections are defined on the fly-away assembly. An eject rocket motor, which falls away after missile emergence from the launch tube, completes the assembly. The three sections consist of (1) the warhead section which houses the Stinger ordnance or the Stinger telemetry elements, (2) the flight propulsion section, and (3) the flight control section which consists of the flight control servo, electronics, thermal battery, rate sensors, the receiver, and the aerodynamic control fins. Two threaded couplers are used to assemble the three sections. The physical characteristics of the prototype missiles will closely approximate those of the tactical design, with electronics packaging and instrumentation accounting for differences (which will not affect missile performance). Figure 4 is a photograph of the prototype Advanced Development Stinger Alternate missile.

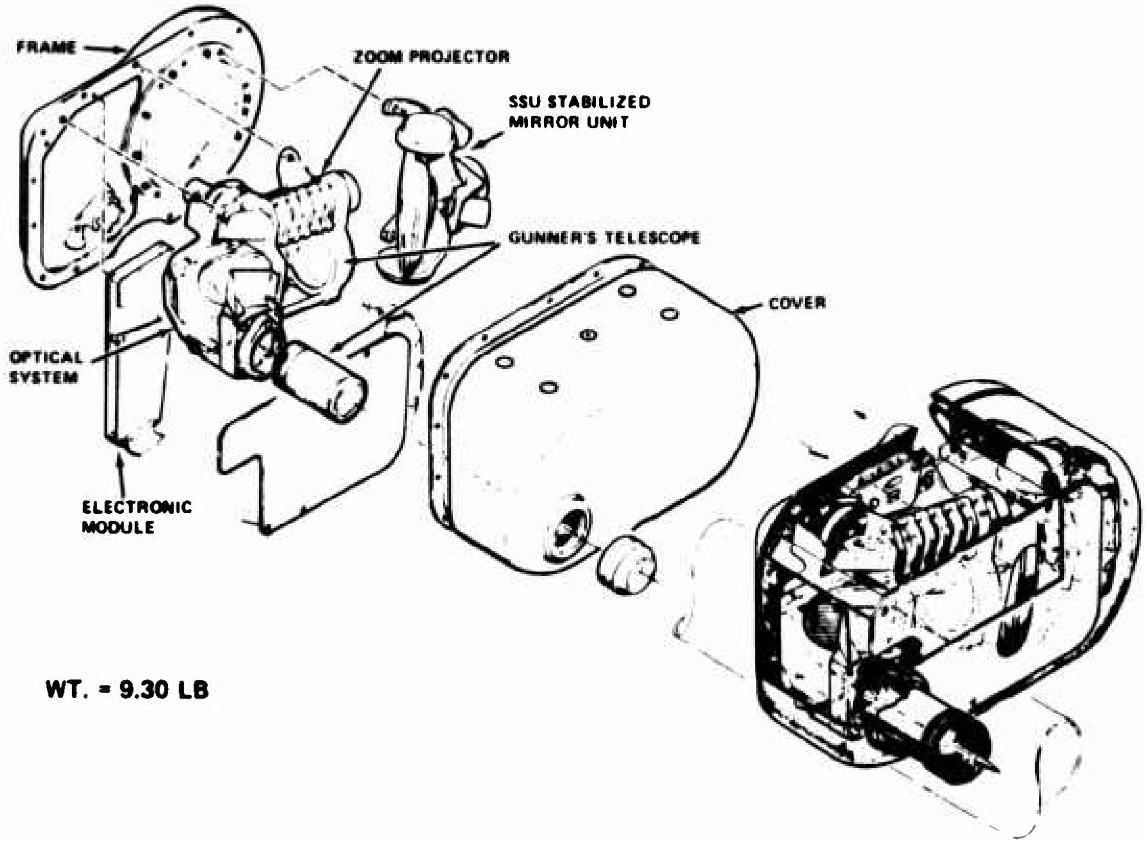

FIGURE 2. GUIDANCE UNIT ASSEMBLY

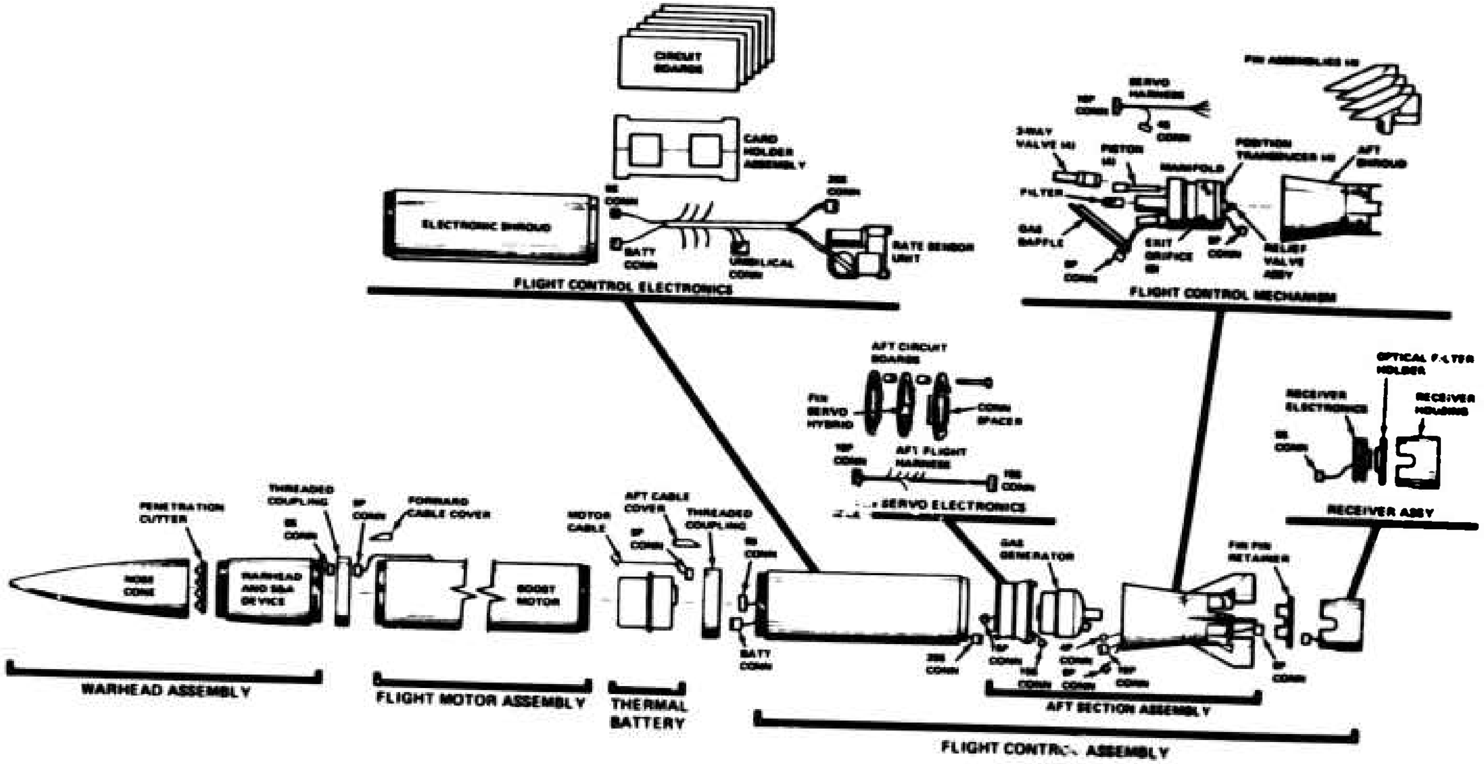

FIGURE 3. MISSILE ASSEMBLY FLOW DIAGRAM

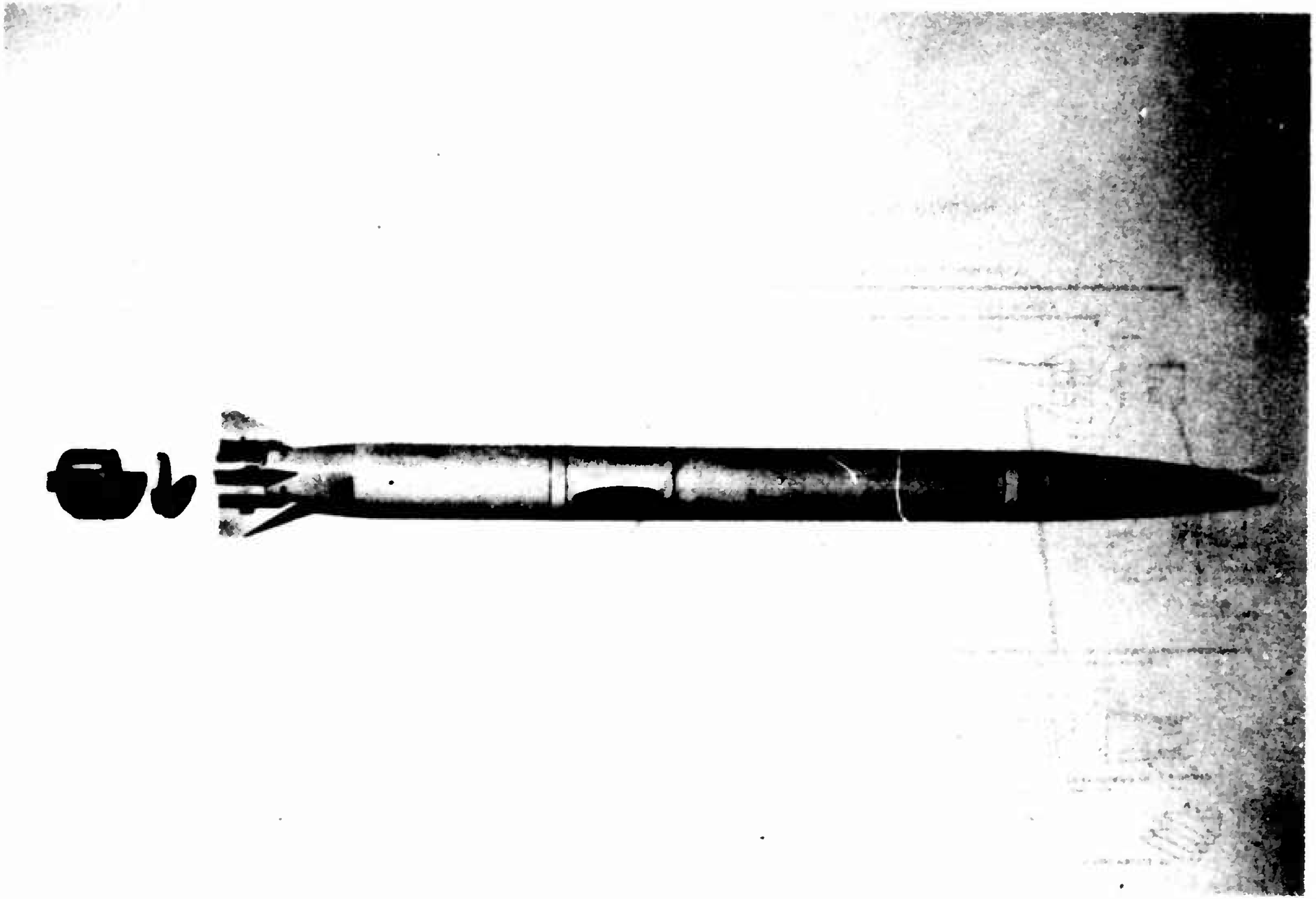

FIGURE 4. STINGER ALTERNATE MISSILE

Airframe

Physical Characteristics. The missile airframe consists of a body configured of an ogival nose and a cylindrical afterbody having a diameter of 3.25 inches. The nose shape is a 3.15 calibre secant-ogive, with a 0.15 inch diameter spherical bluntness. Overall missile length is 47.0 inches, with the eject rocket motor increasing the overall package to 50.4 inches. The last 4.5 inches of the missile body is stepped down to form a sub-calibre multi-sided shroud section over which the aerodynamic control fins fold while in the launcher. The aft region of the shroud is contoured to reduce system drag. The forebody is constructed of thin gauge aluminum alloy, the flight propulsion section is of high strength steel, and the flight control cylindrical shroud is of aluminum alloy. The noncircular flight control servo assembly and the gas manifold are hard anodized aluminum castings. The elements contained in the flight control section are preassembled as a unit and inserted into the aluminum shroud piece, where they are retained by screws installed through the shroud structure. The missile assembly weight buildup is summarized below:

Ordnance Section	2.83	
Flight Motor Section	9.36	
Flight Control Section	4.47	
Assembly Hardware	0.34	
Missile Launch Weight		17.00 pounds
Eject Propulsion	1.00	
Total In-Tube-Weight		18.00 pounds

Structural/Mechanical Design Characteristics. The primary structural/mechanical design characteristics of the missile assembly are established by the need to provide structural integrity under all external and self-induced loading conditions with low cost fabrication and assembly techniques, while attaining the minimum weight characteristics required for a man portable weapon system. To this end, the structural/mechanical design integrates the necessary load carrying structure into the configuration physical characteristics generated by the functional requirements of the major elements of the missile.

1. Design Loading Conditions. The principal external loading for the missile assembly is generated by dynamic response of the missile to shock inputs that may occur during field handling impact conditions when the missile is in the launcher assembly. Since the launcher assembly provides support for the missile and protection from direct impact of sharp objects on the missile external structure, this loading condition is not critical to primary structure design. Internal subassemblies and components of the missile and their attachment structure are designed to withstand the high level, short duration acceleration loads resulting from the impact loading conditions.

   The significant self-induced loading for the missile primary structure is produced by the maximum lateral maneuver acceleration, high dynamic pressure condition that occurs in combination with high axial accelerations during flight motor operation. The maximum expected combined accelerations are 55 g's axial and 45 g's lateral. For these conditions, the missile structure and all subassemblies and components are designed to withstand the distributed shear forces and bending moments resulting from the worst case aerodynamic and inertia loads. Other critical self-induced loading conditions considered in the design include the high temperature, high pressure conditions that exist in the flight propulsion unit, the gas generator pressure vessel, the flight control servo valve and actuator assembly, and the eject motor pressure chamber. The aerodynamic forces and moments generated by the movable control tails are the primary loads considered in the structural design of the tail surfaces and the control tail actuator mechanisms.

Other structural/mechanical design considerations include the requirement to provide control tail panel and actuator mechanism stiffness and mass distribution values necessary to ensure the absence of tail flutter throughout the missile flight regime and to preclude tail/actuator system dynamic coupling with the flight control system frequencies. In addition, the Marman clamps that connect the three major missile subassemblies are designed to provide the required strength as well as the joint stiffnesses necessary to ensure that the significant missile body-bending frequencies will not cause unsatisfactory flight control system performance.

2. Structural Characteristics. The primary structure for the missile consists generally of the external conical or cylindrical shaped thin-walled metal skin that supports the internal subassemblies and components. The external skin structure for the ordnance section and flight control section assemblies utilizes a 6000 series high-strength aluminum alloy chosen to attain a lightweight structure with low fabrication costs. The wall thickness for the ordnance section shroud is 0.010 inch where supported by foam, while the thickness is increased to 0.030 inch in the flight control section shroud. The flight propulsion motor case structure, designed to withstand the high pressure and temperatures induced by propellant burning, utilizes a high temperature maraging steel. The wall thickness for the motor case is 0.025 inch. The structure for the flight control actuator valve/manifold assembly is also primary missile structure in that region and is constructed by precision casting of a high strength castable aluminum alloy, Type 356. The aft shroud structure supporting the receiver and the tail control surfaces is also constructed of 356 aluminum casting.

IDENTIFICATION OF THE MISSILE SYSTEM GUIDANCE ELEMENTS

The Stinger Alternate missile system is different from the Chaparral or Stinger in that part of the guidance system is on the expendable missile and part of it remains with the launch station for reuse. For the purposes of this paper for the Missile Manufacturing Technology Conference, the Stinger Alternate guidance system consists of the entire reusable Guidance Unit Assembly plus the following missile components: (1) laser optical receiver, (2) receiver data processing and autopilot electronics, (3) the three axis rate sensor unit and associated interconnecting harness and support hardware.

The current Design-to-Cost guidelines on Stinger Alternate include the buy of 23,000 missiles at the rate of 275/month with 2020 Guidance Unit assemblies. Thus, the current Design-to-Cost objectives for Stinger Alternate include the flyaway costs of 23,000 weapon rounds (missile plus launcher plus eject motor) plus the costs of 2020 Guidance Unit assemblies. This sum total cost number is then divided by 23,000 to obtain the Unit Procurement Cost (UPC) objective for the missile system.

COST DRIVERS

The major cost elements of the Stinger Alternate guidance system on a generic basis are shown in Table I.

TABLE I.

Guidance Element	% Guidance System Costs
Guidance Unit Assembly (GUA)*	5.0
Laser Optical Receiver	6.5
Receiver Data Processor Electronics	22.0
Autopilot Electronics	24.0

TABLE I. (Continued)

Guidance Element	% Guidance System Costs
Missile 3-axis Rate Sensor	31.0
Harness and Connectors	8.3
Housing and Structures	3.2

*GJA % of total guidance costs is amortized on a $\frac{2020}{23,000}$ basis

The Stinger Alternate guidance system can be identified relative to the Standard Components list as shown in Table II.

TABLE II.

	Standard Components Category	Guidance Component(s)	% of Guidance System Cost
1.0	Protective covers (radomes, irdomes)	None	0
2.0	Electro-optical collectors	(1) Laser Receiver Optical Assembly (2) Zoom beam projector (3) Sightline Stabilization Unit (4) Gunner's Telescope	8.5
3.0	Electronics	(1) Optical Receiver Preamp (2) Receiver data processor (3) Autopilot electronics (4) SSU electronics (5) Transmitter electronics	46.0
4.0	Electro-Optical Detectors	Silicon detector in receiver optics	2.4
5.0	Major mechanical parts	(1) Missile electronics housing (2) SSU gimbals (3) Guidance Unit housing (4) Zoom projector frame (5) Telescope frame	3.8
6.0	Gyros	(1) 2 axis rate sensor for SSU (2) 3 axis missile autopilot rate sensor	31.0
7.0	Cables	(1) Guidance Unit internal harnesses (2) Missile interconnect cables from receiver optics to data processor to autopilot	4.6
8.0	Power Supply	Not unique to guidance - not included	N/A

TABLE II. (Continued)

	Standard Components Category	Guidance Component(s)	% of Guidance System Cost
9.0	Connectors	(1) Interconnect electronic modules in Guidance Unit (2) Interconnectors for electronic boards in missile	3.7

The relative costs for the Guidance System components versus the manufacturing cost categories is summarized in Table III.

TABLE III. GUIDANCE SYSTEM COST BREAKDOWN

		Materials	Purchased Parts	Fab & Proc.	Assy.	Test & Inspect.	Support
Electro-Optical Collectors	8.5%	1.0%	4.0%	1.0%	1.0%	0.5%	1.0%
Electronics	46.0%	2.0%	23.0%	4.0%	9.0%	1.0%	7.0%
Electro-Optical Detectors	2.4%	-	1.8%	-	-	0.3%	0.3%
Major Mechanical Parts	3.8%	0.5%	1.0%	1.0%	0.5%	0.5%	0.3%
Gyros	31.0%	-	29.0%	-	-	1.0%	1.0%
Cables	4.6%	1.0%	2.0%	-	1.0%	-	0.6%
Connectors	3.7%	-	2.7%	1.0%	-	-	-
TOTALS	100.0%	4.5%	63.5%	7.0%	11.5%	3.3%	10.2%

Major Cost Drivers

The laser beamrider Stinger Alternate missile approach is inherently lower cost than the seeker type missile systems such as Chaparral and Stinger since the expensive part of the guidance system is retained at the launch station for reuse with the next missile. Another feature of the missile design is the three section missile assembly approach where the aft flight control section, the mid rocket motor section and the forward ordnance section can be mass produced at different facilities with very minimum interface specifications.

However, in considering all of the guidance components, three (3) areas of the guidance system have good possibility for application of manufacturing technology programs. They are: (1) electronics, (2) rate sensors, and (3) optics representing 46%, 31% and 14% of the guidance system cost respectively.

1. Guidance System Electronics. Electronics represents a major portion of the Stinger Alternate system cost, and the missile electronics alone are 44% of total guidance system cost. The current production baseline for Stinger Alternate includes much digital logic, and further digitization of guidance circuitry is being investigated. It appears the full cost savings potential for digital circuitry can best be realized from utilization of large scale integrated circuits (LSI). These are used extensively in large commercial markets such as pocket calculators and digital watches. However, generally very large non-recurring costs are involved in producing the first article. To minimize the impact of these costs and make the cost savings potential of LSIs available to missile production, a study program is proposed. This program will investigate current and anticipated digital circuitry needs for the missile industry.

Development of industry standard LSIs will be investigated along with direct substitution or ruggedizing of commercially produced digital logic. In particular, adaptation of recent developments in microprocessors and other monolithic integrated circuits should be investigated.

2. Rate Sensors. Rate sensors are required for position reference in both the missile and the guidance unit; a device performing this function will probably always be required in a laser beam-rider system. Fluidic rate sensors are considered the baseline devices for the Stringer Alternate system. They show considerable promise for significantly reducing production costs relative to conventional rate gyros. However, fluidics are still in development and production methods and equipment have yet to be proven. To reap their cost savings potential, a production methods investigation and pilot production program is proposed. This will both substantiate Stinger Alternate production cost estimates and provide production proven, low-cost devices for this and other missile programs.

3. Optics. Optics are required to generate and control the beam for a laser beamrider. Stinger Alternate uses a zoom lens and mirror system for pointing and focusing the beam. The zoom lens in particular is a relatively costly device, and efforts should be directed toward reducing its production cost. A major cost factor is the alignment of the optical elements. Since exotic materials are not required, investigation of molded optics has promise. A development program is proposed to investigate precision molding of lenses, together with their immediate mounting structure. Since the critical alignment is transferred to the supports, concentricity and axial alignment is much easier to obtain.

   For the mirrors, production techniques eliminating the need for polishing individual elements should be investigated. Application of such techniques as replication (transferring of mirrored surface from a master), lamination, and micro machining (use of high-speed diamond lathe - eliminating need for grind or polish) would be a part of the proposed manufacturing technology program. Reduction or elimination of the "edge chip" problem of replication warrants particular investigation. Application of micro machining techniques to zoom lens components would also be studied in an optics cost reduction program.

   It is believed the proposed manufacturing technology programs will even further increase the cost effectiveness of the Stinger Alternate system. They will also provide the necessary background to promote cost reduction of missile systems into the 1980's.

PROPOSED MANUFACTURING TECHNOLOGY PROJECTS

Manufacturing Technology Project to Pilot Produce Fluidic Rate Sensors

System/Session Area/Component: Stinger Alternate/Guidance/Missile Autopilot

Problem: The only developed, environmentally qualified and mass produced rate sensors available for the Stinger Alternate missile autopilot are conventional subminiature rate gyros. Even though these units have been quantity produced, they are relatively expensive for use in a manportable air defense system. Fluidic rate sensors have adequate performance for the Stinger Alternate missile, are simpler and lower cost but are only in the early development phase with no production history.

Proposed Solution: Conduct a manufacturing technology project to do the rate sensor development qualification, production engineering, tooling development and conduct a 1000 unit pilot production run. This will provide substantiation for the current Stinger Alternate UPC numbers and qualified production proven rate sensors for the Stinger Alternate and other direct fire weapon systems such as the Tank Fired Guided Missile (TFGM).

Project Cost and Duration: The estimated project costs and schedule are as follows:

(1)	Rate sensor development qualification	$100,000 - 12 mo.
(2)	Production Engineering Program (PEP)	200,000 - 18 mo.
(3)	Tooling development	75,000 - 6 mo.
(4)	Pilot production run of 1000 units	125,000 - 12 mo.
(5)	Lot sample testing, reliability analysis, and documentation	50,000 - 8 mo.
	Total Costs =	$550,000
	Schedule =	48 mo. assuming some concurrency of activities

Benefits: Based on our work with the fluidic rate sensor suppliers since mid-1973, it can be projected that this manufacturing technology project would result in a 30 percent reduction in the recurring hardware costs of the fluidic rate sensor. This reflects a 30 percent reduction of an item that is a significant part of the total missile system UPC. For a 23,000 missile buy, this will result in a program cost saving of $4.1M. or 2.1 percent. Thus, the fluidic rate sensor Manufacturing Technology Project will result in a $\frac{4.1}{55}$ or 7.5:1 return on investment to the U.S. Army for the Stinger Alternate program above:

Manufacturing Technology Project to Utilize LSI Techniques in the Missile Guidance Electronics

System/Session Area/Component: Stinger Alternate/Guidance/Electronics

Problem: Electronic circuits represent 25 percent of the Stinger Alternate guidance system. The current missile design and the UPC is based on use of hybrid electronic circuits. Most of the missile electronics is already in digital format compatible with LSI techniques. Use of LSI electronics in the missile not only reduces production cost but size and weight on the missile which can be translated to a lighter carry weight for the gunner or increased missile performance for a fixed weight. The design and utilization of LSI electronics in an Advanced Development program is not feasible because of the inability to make quick changes. The basic problem in Engineering Development is the extreme reluctance of the Army project office to authorize changes between A.D. and E.D. for two reasons: (1) don't change anything since it worked in A.D., and (2) the much higher RDT&E costs of initial implementation of the LSI circuits versus hybrid. This is particularly true if the E.D. phase is competitive - no contractor is going to voluntarily bid LSI electronics and price himself out of the program.

Proposed Solution: Conduct a manufacturing technology project for LSI development, qualification, production engineering and pilot production run on the complete Stinger Alternate missile guidance electronics. This includes everything from the output of the receiver optics preamplifier through the autopilot to the value drivers. This would be accomplished at the mid-point of E.D. where the circuit definition in hybrid form was very firm. The complete flight control section would be redesigned to take advantage of the size and weight reduction of the LSI electronics. The missile electronic development and qualification would be completed with actual missile firing tests. The production engineering would be completed, tooling developed and a pilot production run of 200 missile electronic sections made to be ready for quantity production.

Project Cost and Duration: Estimated costs and program schedule are as follows:

(1)	LSI circuit development	$500,000 - 10 mo.
(2)	Missile electronics qualification	500,000 - 18 mo.
(3)	Production Engineering Program	100,000 - 10 mo.

(4)	Pilot Production Run (200 units)	400,000 - 12 mo.
(5)	Lot sample testing, reliability analysis and documentation	50,000 - 8 mo.

Total Costs = $1.55M

Schedule = 51 months with some concurrency

Benefits: Based on our own experience and supplier data, it is estimated that complete digitizing of the missile electronics and making maximum use of LSI techniques will reduce the missile cost by $110 or 3.5%. This includes both a reduction in recurring hardware costs and the non-recurring startup for production. This equates to a $2.53M savings on a 23,000 Stinger Alternate missile buy. This is only a $\frac{2.53}{1.55}$ or 1.5 return on investment for the Army, but it does not account for the operational benefits of a lighter weight or higher performance missile using the LSI missile electronics.

Manufacturing Technology Project to Reduct the Costs of the Guidance System Optical Elements

System/Session Area/Component: Stinger Alternate/Guidance/Optical Elements
Problem: The Stinger Alternate guidance system contains several optical elements such as precision lenses, mirrors, and filters. All the optical components are in the Guidance Unit Assembly except for a filter in the missile receiver The current Advanced Development hardware design reflects high quality conventional optical fabrication techniques which, if carried through E.D. and into production, would reflect low rate higher cost optics. A program is needed to investigate higher rate production techniques such as mirror replication, lamination and micromachining.
Proposed Solution: Conduct a manufacturing technology project to develop and pilot production qualify higher rate, lower cost fabrication of the guidance system optical elements. The objectives of this program would be to reduce the number of optical elements in the design, reduce the tolerances for the optical elements, reduce fabrication and inspection time, and reduce rejection rates in the fabrication process.
Project Cost and Duration:

(1)	Conduct design simplification study	$ 50,000 - 6 mo.
(2)	Redesign and test optical elements	100,000 - 12 mo.
(3)	Complete E.D. quality of new optical design	150,000 - 12 mo.
(4)	Conduct Production Engineering and tooling development	100,000 - 12 mo.
(5)	Conduct Pilct Production Run (100)	100,000 - 12 mo.

Total Cost Estimate = $500,000

Total Schedule = 48 mo. including some concurrency

Benefits: A review of the current optical component costs in the missile system UPC shows a realistic recurring hardware cost reduction potential of $510 or 9.2 percent per Guidance Unit Assembly using replication, lamination and micro-machining techniques. This equates to 2020 x $510.00, or $1,030,200 for the Stinger Alternate production. This reflects a $\frac{1,030,200}{500,000}$ or 2.05:1 return on investment for the U.S. Army.

Summary of Manufacturing Technology Projects Benefits

On a conservative basis of working just the three major cost drivers in the Stinger Alternate guidance system, (1) guidance electronics, (2) missile and guidance unit assembly rate sensors, and (3) guidance unit assembly optical elements, a total program cost saving of $7.66M can be realized at a Manufacturing Technology Project investment of only $2.60M. This represents a return on investment to the Army of 290 percent. In the case of the LSI project it also results in improved system performance. All of the projects, if conducted in parallel with the missile system Engineering Development phase, will reduce production lead time.

TRENDS IN SYSTEM COSTS

There are several trends in the missile development and production cycle that tend to create and lock-in excessive costs. Some of these that pertain to small tactical missiles such as Stinger Alternate are as follows:

1. Source selection procedures still emphasize performance over cost/performance tradeoffs. This causes second priority on Design-to-Cost objectives.

2. Design simplification that is discovered during Advanced Development is not being implemented in the Engineering Development phase, particularly if Engineering Development is determined from competitive approaches. The Army should exercise management maturity to renegotiate the winning Engineering Development contract to include improvements found in Advanced Development.

3. Historically, most Advanced Development programs are extremely competitive, low cost and successful. During Engineering Development, however, the contractor and Army management staffs expand exponentially to satisfy excessive documentation and procedures manuals with often the result excessive costs, marginal performance and schedule delays.

   These same trends of over management and excessive documentation produce high costs in the acquisition phase. These trends can be reversed by using the same procedures in Advanced Development and Engineering Development.

4. A similar trend to (2) is found in the latter phases of Engineering Development. Changes discovered in the latter phase of Engineering Development which could reduce costs with only minimal changes in system performance are not implemented because of the firing test requalification procedures. The procedures could be changed to allow incorporation of the changes on the basis of pre-flight qualification tests only and complete flight test qualification with production hardware.

CHAPARRAL MISSILE GUIDANCE MANUFACTURING TECHNOLOGY PROJECTS

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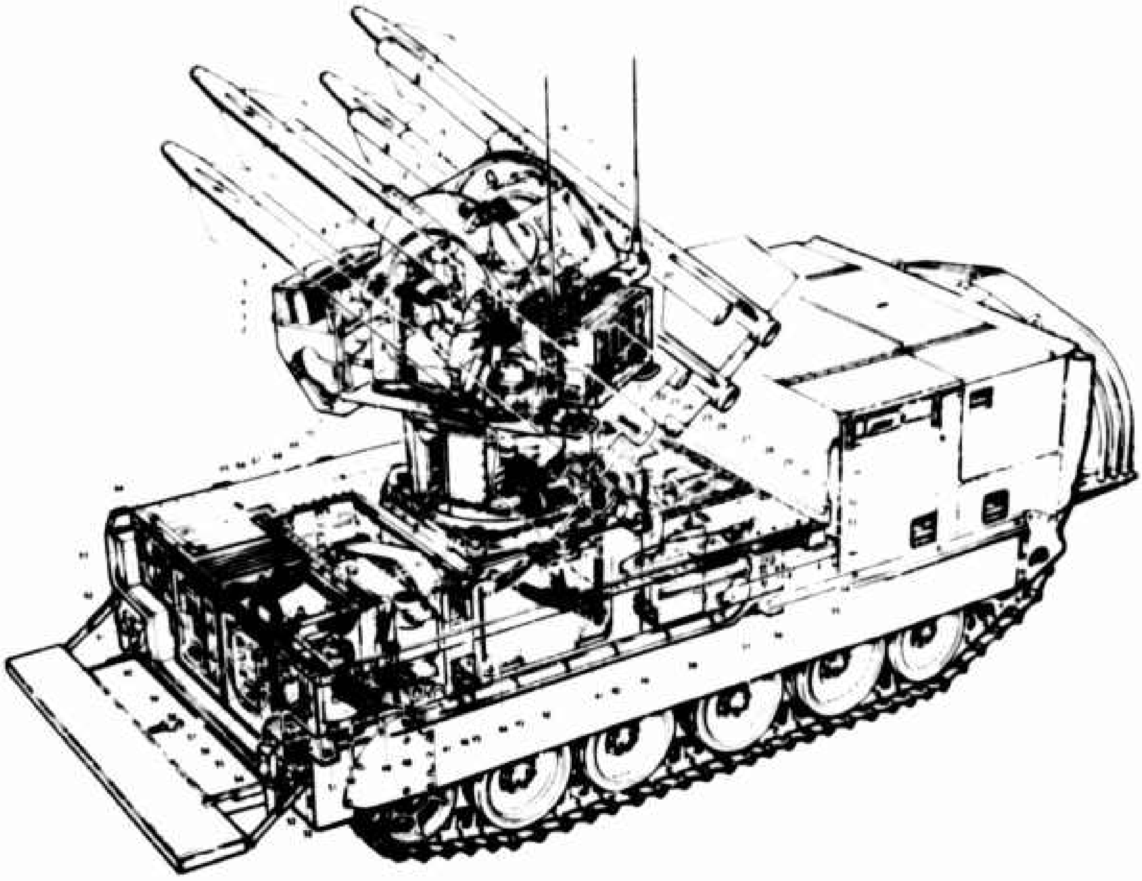
CHAPARRAL SYSTEM DESCRIPTION

The Chaparral Air Defense Guided Missile System (Figure 1) is a versatile weapon system providing effective air defense for Army forward area tactical units. Chaparral can be deployed in any global area as a point defense with the capability of destroying all types of enemy aircraft, including helicopters, flying at low to medium altitudes during visual flight conditions. The capability to meet similar needs of the Navy has been demonstrated by a shipboard adaptation.

FIGURE 1. CHAPARRAL AIR DEFENSE GUIDED MISSILE SYSTEM

The M48 Fire Unit is self-propelled and highly mobile, consisting of the M54 Launching Station mounted on an M730 Tracked Carrier (a slightly modified M548 Cargo Carrier). In alternate versions, the M54 Launching Station may be ground-emplaced or trailer-mounted. Figure 2 shows the major system components.



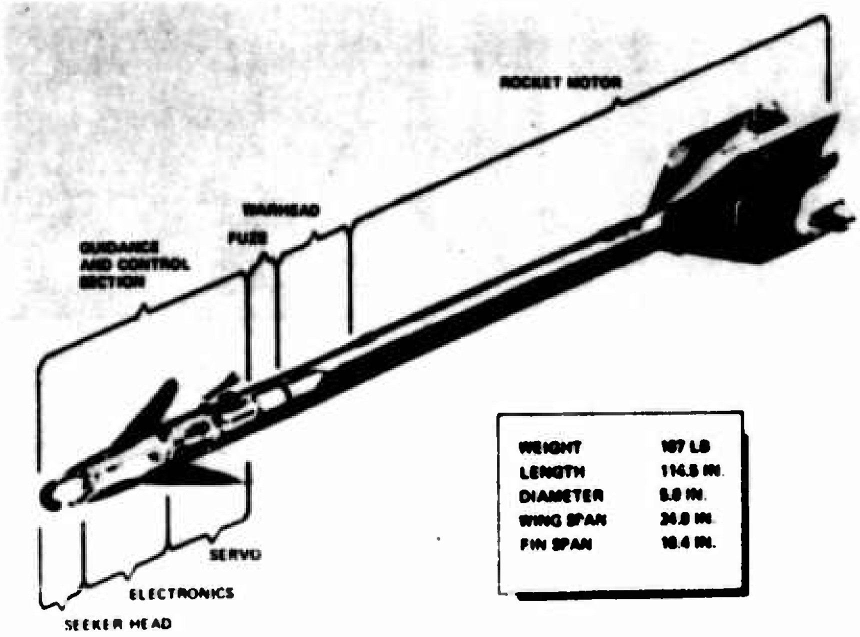
1 CONTROL PANEL L H
2 HEATER UNIT (HINGES UP FOR ACCESS)
3 AIR INLET COVER
4 REGISTER ASSY
5 FILTERS
6 AIR BLOWER
7 COVER (HINGES UP FOR ACCESS)
8 ELECTRICAL HEATER
9 AZIMUTH AND ELEVATION HAND CONTROL
10 CENTER CONTROL PANEL
11 CONTROL PANEL R H
12 OPTICAL SIGHT
13 RETICLE HOUSING AND CONTROL
14 SIGHT SUPPORT (ELEVATES WITH MISSILE)
15 LAUNCH RAIL
16 ANTENNA AT 912 VRC
17 BASE ANTENNA AB-15/GR
18 HYDRAULIC ELEVATION DRIVE UNIT
19 HYDRAULIC FLUID COOLER
20 AIR CONDITIONER
21 HYDRAULIC AZIMUTH DRIVE UNIT
22 MOUNT DRIVE CONTROL BOX
23 MISSILE CONTROL BOX (FAR SIDE)
24 TURRET ERECT RETRACT DRIVE SPROCKET AND CHAIN
25 SLIP RING ATTACHMENT ARM
26 MASTER POWER DISTRIBUTION BOX
27 RECEIVER R 442 VRC
28 CREW EQUIPMENT COMPARTMENT
29 STORAGE BATTERIES (4)
30 TURRET ERECT RETRACT MOTOR
31 BATTERY BOX COVER
32 MISSILE AIR PURIFIER
33 EXTERNAL TELEPHONE AND POWER CABLES TYP BOTH SIDES
34 MISSILE STORAGE COMPARTMENT R H
35 EXTERNAL POWER CONNECTOR TYP BOTH SIDES
36 HEATER AIR DUCT WITH SUMMER WINTER VALVE
37 COMMUNICATIONS PANEL TYP BOTH SIDES
38 CABLE CHANNEL TYP BOTH SIDES
39 TURRET MOUNT ERECT RETRACT HELIX (4)
40 LIMIT SWITCH SYSTEM FOR CONTROL OF ERECT RETRACT MOTOR
41 FUEL TANK AND FILLER TYP BOTH SIDES
42 SLIP RING CONNECTORS TO TURRET ROTATE WITH TURRET
43 SLIP RING BASE ATTACHED TO BASE
44 CABLES AND AIR HOSE FROM BASE TO SLIP RING
45 OPENING FOR MAIN POWER UNIT COOLING AIR TYP BOTH SIDES
46 FUEL LINES FROM ELECTRIC FUEL PUMP
47 ENGINE CARBURETOR AIR INTAKE
48 HEATER
49 AIR INTAKE TO ELECTRICAL COMPARTMENT COOLING FAN
50 AIR COMPRESSOR
51 AUDIO FREQUENCY AMPLIFIER AM-1780 VRC
52 FUEL DRAIN VALVE
53 DRAIN HOSES
54 TRANSCEIVER RT 524 VRC
55 RADIO LOCAL CONTROL UNIT C 2299 GRA 39
56 ELECTRICAL COMPARTMENT ACCESS DOOR
57 MASTER CONTROL INDICATOR PANEL
58 GENERATOR SET CONTROL ASSY
59 CANARD FIN STORAGE
60 FIN STORAGE COMPARTMENT DOOR
61 AFT FIN STORAGE
62 ENGINE COOLING AIR EXHAUST SCREEN
63 MISSILES (4 STOWED EACH SIDE OF BASE)
64 ENGINE EXHAUST L H HEATER EXHAUST R H
65 MAIN POWER UNIT GENERATOR HIDDEN MOUNTED TO LEFT OF ENGINE
66 POWER SUPPLY BOX
67 DISTRIBUTION BOX
68 HYDRAULIC PUMPING UNIT
69 AZIMUTH GEAR
70 COOLING AIR BLOWER
71 MISSILE ELEVATION GEAR AND DRIVE GEAR SIMILAR BOTH SIDES

FIGURE 2. MAJOR COMPONENTS OF CHAPARRAL SYSTEM

The Launching Station can carry four MIM-72 missiles on the launch rails and eight additional missiles in integral stowage compartments. The missiles may be one of three versions:

- o MIM-72A Chaparral Missile
- o MIM-72B Training Missile
- o MIM-72C Improved Chaparral Missile

This presentation will address the MIM-72C Improved Chaparral Missile, which is now ready for full-scale production. The missile is a passive infrared homing supersonic member of the Sidewinder family. Its major components are the AN/DAW-1 Guidance and Control Section (GCS), M817 Target Detecting Device, MK13 Safe/Arm Device, M250 Warhead, MK50 Rocket Motor, movable fins and fixed wings (Figure 3).



WEIGHT	187 LB
LENGTH	114.5 IN.
DIAMETER	5.0 IN.
WING SPAN	24.8 IN.
FIN SPAN	18.4 IN.

FIGURE 3. IMPROVED CHAPARRAL MISSILE,MIM-72C

The AN/DAW-1 GCS is shown in Figure 4 with other members of the Sidewinder family and in Figure 5 in an "exploded" line drawing. For definition purposes in this presentation, the guidance portion of the GCS consists of the seeker head (gyro-optics, refrigerated detector unit, head coil, and dome/housing), four electronics boards with mounting spindle, and interconnecting cables.

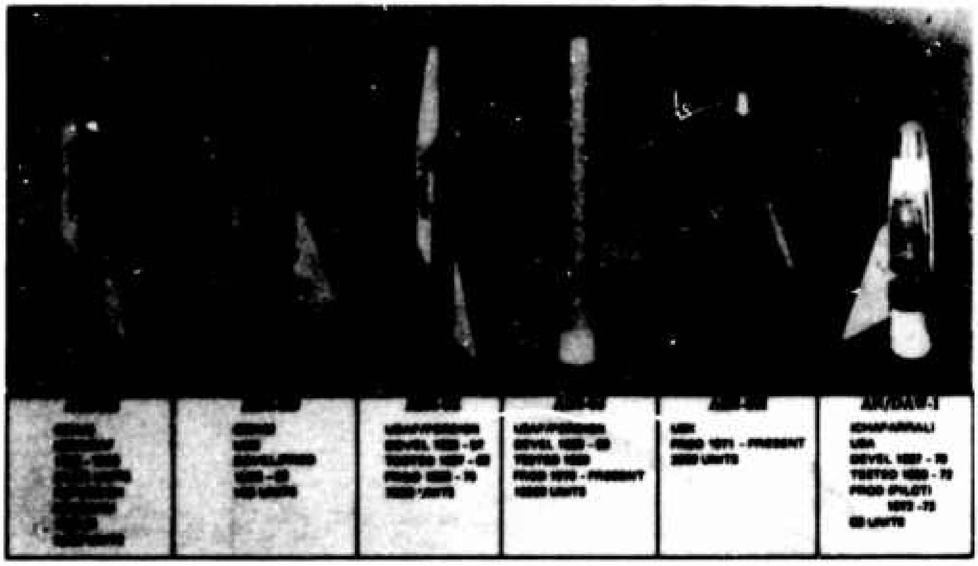


FIGURE 4. SIDEWINDER GUIDANCE FAMILY

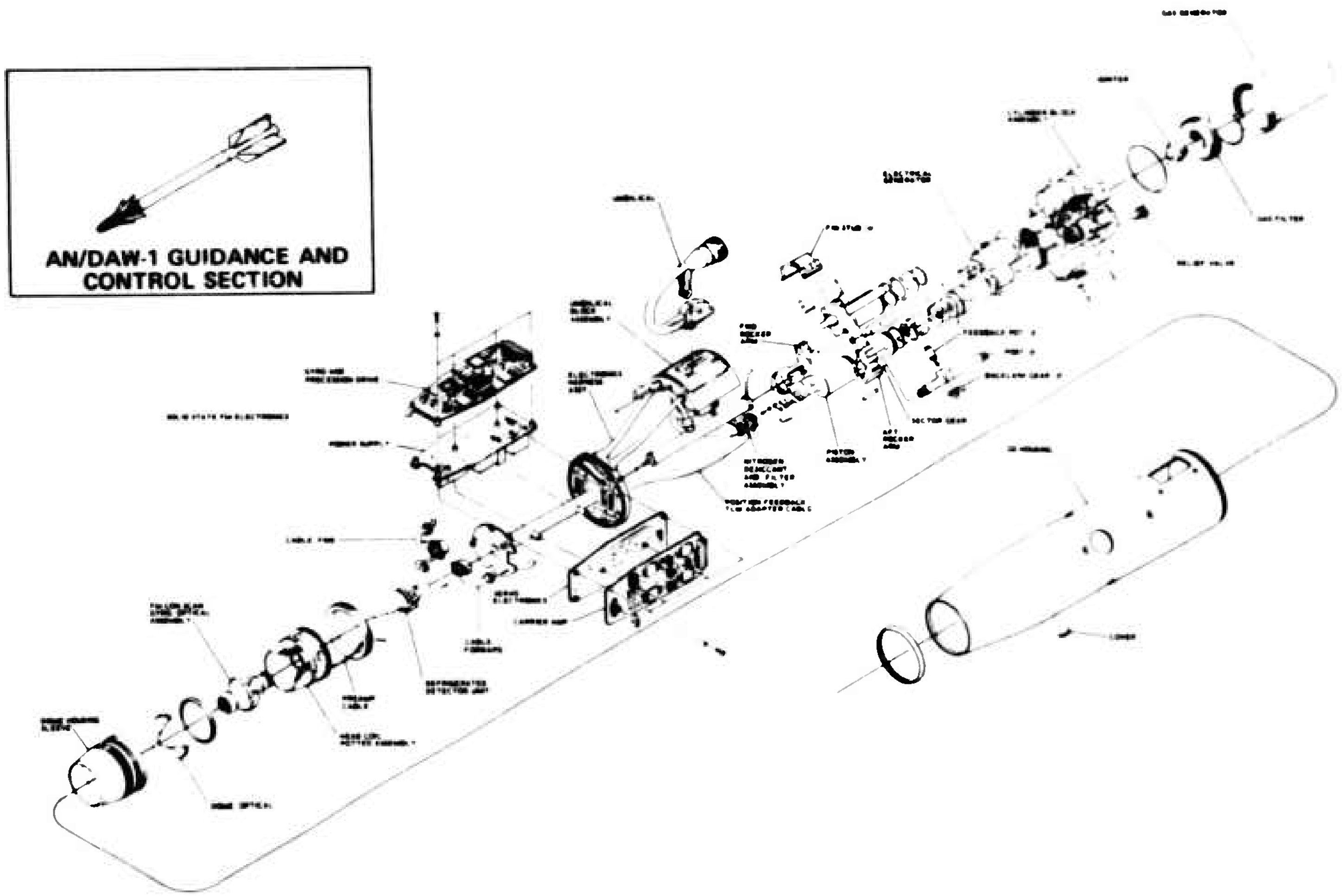


FIGURE 5. IMPROVED MISSILE GUIDANCE AND CONTROL SECTION FOR CHAPARRAL

CHAPARRAL GUIDANCE COST

The cost for Chaparral guidance is portrayed in Figure 6 for the areas of major concern to Aeronutronic Ford from the manufacturing technology viewpoint. The following definitions apply to the cost presented:

- Material---raw material, purchased parts and compounds, and subcontractor items
- Labor---fabrication, assemblage, inspection, quality and manufacturing engineering, production control, and procurement labor.

All costs include burden. However, tooling and test equipment costs have not been included due to the strong influence a procurement quantity assumption would have on cost allocations.

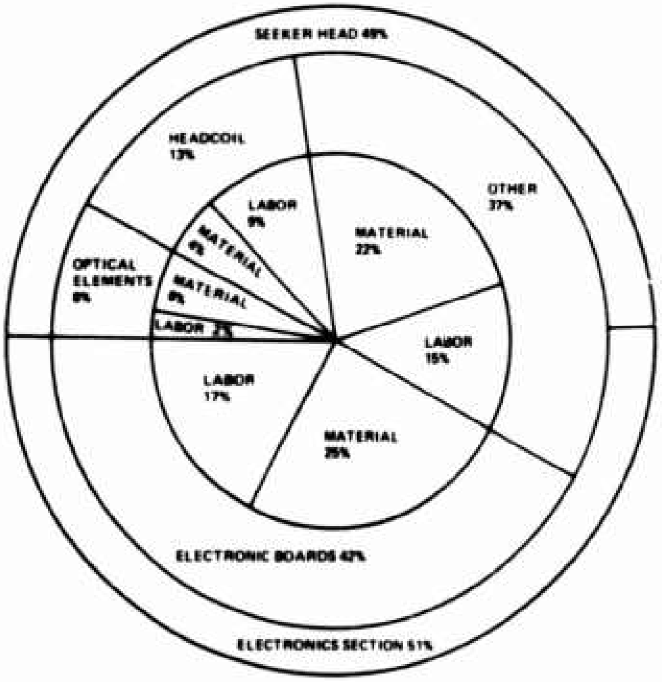


FIGURE 6. CHAPARRAL GU!DANCE COST

One-fourth of the guidance cost is for labor on the head coils and electronic boards. We feel that most of the work elements have been refined and automated to the maximum practicable extent for hardware produced in the 50-500 units per month range. We took different approaches when we were producing Shillelagh missiles at over 2000 per month but the production rates and quantities associated with MIM-72 and related missiles do not justify a greater allocation of resources.

However, a significant portion of the guidance unit labor is incurred in potting the head coil, conformally coating boards, and potting cable connectors -- operations which would benefit from improvements in manufacturing technology. We feel that the use of plastic compounds is one of the least understood and least predictable of the manufacturing processes undertaken on the Sidewinder class of missiles. The portion of our labor which we are devoting to unknowing over-control of elements of the process or expending in solving problems which might have been avoided is not readily determinable but is certainly ill-spent. All too frequently, in our opinion, an innocuous well-intended change made by either our people or a plastics supplier leads to extensive rework or scrap hardware. For example, one batch of a material which we had used successfully for years to pot connectors was actually conductive.

A second area of concern to us, which is based too much on black magic, is the assessment of the adequacy of optical elements, displayed in Figure 7. Due to both a lack of proper emphasis and a lack of viable alternatives during the design phase, the surface qualities of optical elements are normally specified in terms of MIL-0-13830. These criteria actually apply only in the visual spectrum and can be only vaguely correlated with infrared performance. Even then, a considerable amount of subjective judgment is required in application.

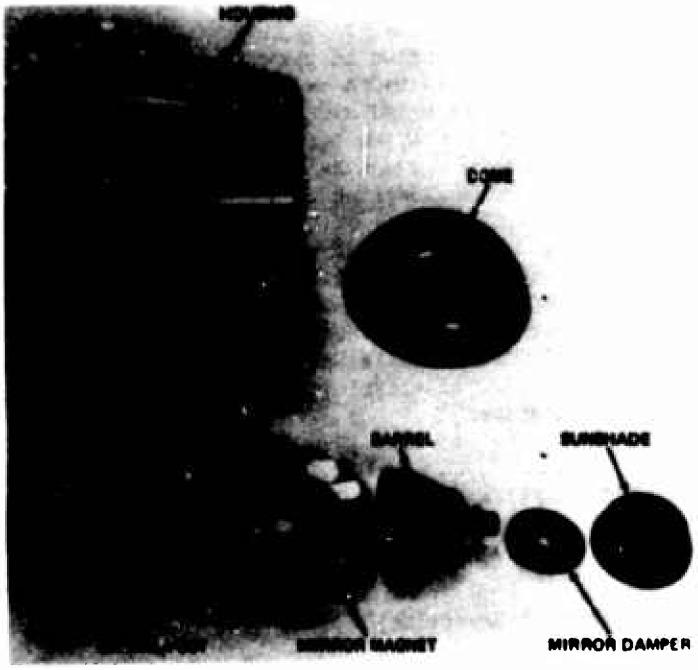


FIGURE 7. AN/DAW-1 SEEKER HEAD

Many of the "optical" defects are only cosmetic at infrared wavelengths. Other defects, or concentrations and arrangements of defects, can be more critical to particular system performance parameters. Aeronutronic Ford and others have engaged in efforts to develop meaningful functional criteria, but further work is required.

A third area in which we recommend a technology study, albeit not directed toward missiles currently in production, is improvement of missile domes, or infrared windows. Currently, all members of the Sidewinder family have magnesium fluoride domes, which is an adequate material for the present application. However, the velocity and guidance requirements of missiles now in the conceptual stage require superior properties. The capability to create hyper-hemispheric or asymmetric shapes would also enhance the performance of the new missiles. Mass production technology for spinel or some similar compound which shows optical, structural and formability potential should be developed.

Following sections of this presentation develop the three problem areas defined above and provide recommended manufacturing technology projects:

SPECIFICATIONS FOR PLASTIC COMPOUNDS

FUNCTIONAL CRITERIA FOR INFRARED OPTICS

IMPROVED INFRARED DOMES

SPECIFICATIONS FOR PLASTIC COMPOUNDS

Although each of our companies continually learns better techniques in utilizing potting and coating compounds, this learning is accomplished on essentially a "cut and try" basis and is usually oriented toward solving problems, not reducing the cost of a successful product/process. We develop a process, and control that process and our suppliers to the degree which appears to be necessary. We all have had occasion to discover that our understanding was not as thorough as we thought when a compound set up too fast or too slow or cracked or was porous.

The compounds we are addressing function to provide protection from hostile environments such as shock, vibration, and humidity or as structural members and sometimes as heat sinks. The designer chooses a material based upon either prior experience with similar hardware or a supplier's offering of a new, better product. The material handling/processing is based on similar tenents and may be frozen into the design or qualified configuration through the success of engineering prototypes.

Table 1 shows cured potting compound specifications for two materials used today. Compound B is used to pot the Chaparral head coil and Compound A is used to pot modules in another member of the Sidewinder family. Compound B is the more fully specified, but even here there is not sufficient information for a designer to be sure that he is not creating a manufacturing problem. For example, shrinkage and coefficient of expansion are only of relative value if modulus of elasticity data is unknown. Also, all of the strength data are at room temperature.

TABLE 1. TYPICAL POTTING COMPOUND SPECIFICATIONS

	Compound A (1)	Compound B(2)
Coefficient of Linear Thermal Expansion,		
in./in./°C(30°C to 90°C)	37 x 1	
in./in./°C(-65°C to 100°C)		35 ±3.5 x 10^{-6}
Compressive Strength, psi	27,000	12,000 min.
Density, lb/cu. in.	0.058	0.057 min.
Filler Content, %	46.7	49 - 54
Flexural Strength, psi	15,000	--
Hardness, Short D	89	92 min.
Linear Shrinkage, %	0.8	0.4 max.
Tensile Strength, psi	5,000	10,000 min.

Notes: (1) Vendor specification, but "Some variation in listed values may occur."

(2) From Specification Control Drawing. Drawing for using assembly specifies cure cycle.

Consider for a moment the manufacturing cycle of a typical potting compound. A supplier formulates his compound from other vendor materials, adjusting the mix as necessary to accommodate material variations to bring the properties of the compound within his advertised range. When you receive the compound, your quality control organization conducts some evaluation tests (probably completely different from the supplier's tests). In use, the compound resin and catalyst are mixed (probably at a controlled temperature) and de-gassed. The compound is then poured into a mold or potting shell and de-gassed (control the temperature again), and oven-cured through some time/temperature cycle. Your hardware is then inspected and, although the inspector does not understand why it is a different color this week, it is hopefully accepted and passes subsequent environmental lot sample tests.

All of us know that certain of the material and process controls must be maintained to avoid trouble but we also know that we have neither cost-optimized nor precluded future problems. Much theoretical work has been accomplished and many application studies have been conducted, resulting in both Government and industry specifications/test standards. However, at least for the Sidewinder missiles, the effort has not been adequately directed toward the specific applications.

Rigid epoxy potting compounds are known to induce large stresses on the internal components which the potting is supposed to be protecting. These stresses are primarily caused by the difference in coefficients of expansion between the individual components and the surrounding potting. Typically, epoxies are cured at elevated temperatures in order to stabilize their electromechanical behavior. This elevated temperature cure causes the potting to compressively load the surrounded components proportionately to the reduction in temperature during cooling to room temperature. If the subassembly is further cooled due to low temperature exposure, compressive loads continue to grow. If the load carrying capability of either the components or the potting is reached, the end result is a failed internal circuit element or a crack in the surface of the subassembly. In production lot acceptance testing, either failure is generally cause for lot rejection.

The mechanical behavior of most potting/conformal coating systems is not readily predictable even at room temperature. Performance information over a reasonable temperature range is practically nonexistent. Most of the potting materials know today exhibit viscoelastic performance over part of the environmental range.

An experimental study was recently performed at Aeronutronic Ford to measure the internal axial loads on typical component sized objects. Strain gauges were attached to a short length of aluminum tubing, calibrated, and then potted in a commonly used rigid epoxy. At that time, the epoxy was being used to pot guidance section circuits (not Chaparral) which were experiencing a high failure rate of specific components during subsequent temperature shock testing. Tantalum capacitors and glass-cased diodes without internal strain reliefs were particularly susceptible to compressive load-induced failures. The transducers fabricated from the aluminum tubing were not intended to determine the loads on specific components but rather the relative loading history during cure, cool-down and subsequent lot acceptance testing. These transducers measured an axial compressive load of 320 pounds at room temperature following cure. Subsequent thermal shock testing, during which the potting and transducer reached -60°C, subjected the transducer to 500 pounds axial compression. Components with a main structural element of glass or ceramic would experience much higher loads due to the smaller coefficient of thermal expansion and greater stiffness as compared to the aluminum transducer.

Additional studies have also proven that compressive loading of components is not the only failure mode that results during temperature cycling. If the ends of component leads are firmly anchored in the potting through connection to other circuit elements (e.g., cordwood style between printed circuit boards), the high compressive loads cause the leads to yield at low temperature. This initial yielding at low temperature presents no immediate problem provided that the potting is not allowed to warm up again. Circuit continuity could be maintained in the leads in either case because most metals have high elongation both in tension and compression. Unfortunately, the interconnections made with the component body do not have this ability. Consequently, certain potted components are not able to withstand the interconnection tensile forces which result after leads have yielded compressively at low temperatures. Those components most susceptible to this type of failure are ceramic resistors and capacitors where most of the tensile load must be carried by a small brazed or diffused metal interconnection with a diameter in the order of twice the lead diameter.

Figure 8 depicts the stress conditions just described for a typical potted assembly. The potting is in tension near potted components and the component leads have yielded in compression upon return to room temperature after potting cure. Low temperature exposure increases the tensile forces in the potting. Assuming that the potting does not crack, return to room temperature results in essentially the initial residual stress level. The component lead, however, continues to yield during the low temperature cycle until warming commences. At this point, return to room temperature results in a tensile load in the lead.

Thorough prototype testing will alleviate a large portion of potential problems, but it will not eliminate them because components and potting compounds periodically undergo subtle changes during an extended manufacturing program. The crux of this issue is the lack of definitive knowledge on the compounds and components that we use. Figure 9 presents a recommended Manufacturing Technology Project to Develop Plastic Compound Standards for Properties and Applications.

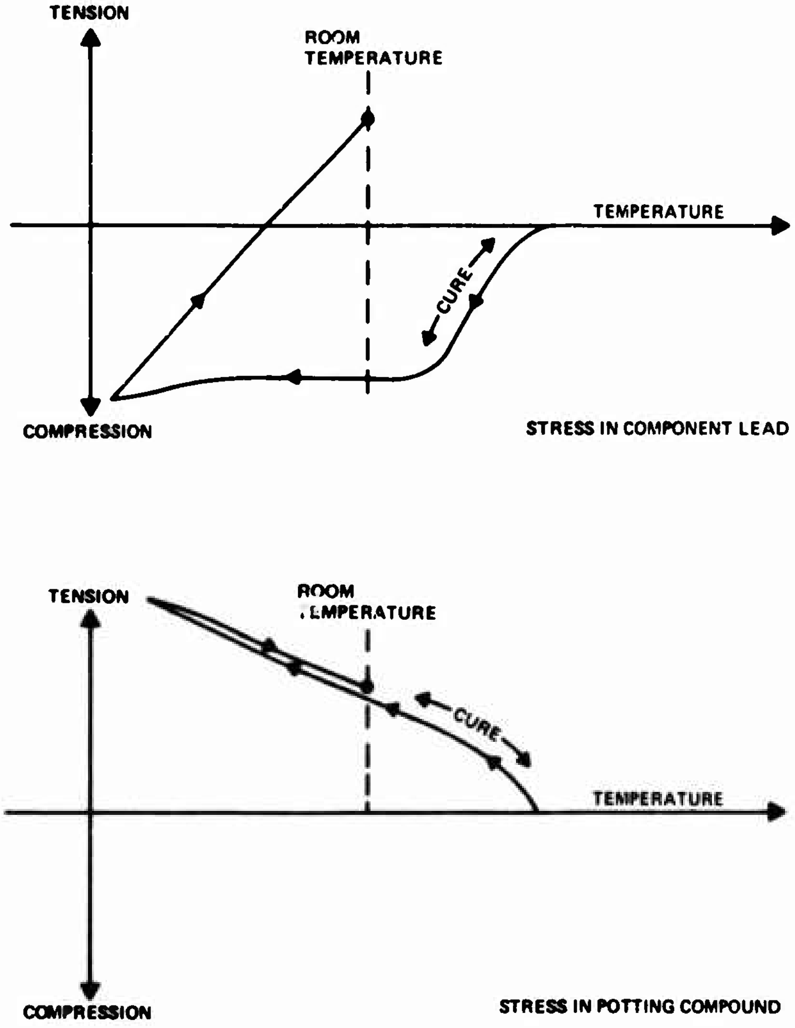


FIGURE 8. POTTING STRESS CHARACTERISTICS

FIGURE 9

TITLE: Manufacturing Technology Project to Develop Plastic Compound Standards for Properties and Applications.

SYSTEM/SESSION AREA/COMPONENT: Chaparral/guidance/plastic compounds

PROBLEM: The mechanical behavior of plastic potting compounds, even at room temperature, is ill-defined and difficult to control. Through the temperature range in which missile products must operate, failure of the potting compound or encapsulated components may occur. Our best efforts to control suppliers and in-house processing are sometimes not sufficient due to a lack of knowledge of the effect of changes in formulation. There is a considerable body of knowledge, theoretical and empirical, which has resulted in both Government and industry specifications/test standards. However, at least for the Sidewinder class of missile, the effort has not been adequately directed toward specific applications.

Qualification tests are imposed on some electronic components, plastic compounds, and hardware items in an attempt to establish an adequate combination of materials and processes. However, surviving qualification tests is no guarantee of continued success. A subtle change in compound formulation or processing can cause marginal success to become failure.

PROPOSED SOLUTION: Effort should be applied to

1. Determine factors influencing the properties of commonly used compounds and the sensitivity of properties to changes in constituents of these compounds; create definitive standard specifications and standard testing methods which directly relate to the end use of these compounds.
2. Evaluate the effect of processing variations on the properties of the selected, definitively specified compounds and publish matrix property data.
3. Evaluate the effect of potting compound internal stress on electronic components and publish expected stress data for common component sizes/mounting techniques.

Availability of this information would permit more cost effective fabrication of existing designs and, more importantly, would provide engineers with the tools to properly select and define the desired compound for new systems.

PROJECT COST AND DURATION: Estimated costs and program duration are

1.	Compound evaluation and quantification of variables	$150,000 - one year
2.	Evaluate processing variations	$100,000 - one year
3.	Evaluate effect of compounds on electronic components	$150,000 - 6 months
4.	Develope, staff and issue standard compound specifications/ tests and component stress data	$100,000 - one year

Total cost would be $500,000 with a probable elapsed time of two years assuming some concurrency of activities.

BENEFITS: The forecast definition would reduce the cost of prototype development, reduce the cost of manufacture by decreasing scrappage and rework, and increase weapon system reliability. Material and process controls could be cost-optimized -- relaxed where proven not critical and tightened where necessary for the particular application. The $500,000 cost of this Technology Project may appear large, but it is less than the cost of solving a serious problem while in production. The direct cost of scrap hardware and effort to solve the problem, plus the cost of schedule delays, can be very large in the typical production program.

The largest portion of the cost savings, and cost avoidance, are of a non-recurring nature. It is difficult to convert these effects into dollars, but it is our opinion that the cost on this project would be less than the savings accured during the life cycle of one missile system.

FUNCTIONAL CRITERIA FOR INFRARED OPTICS

In the specification of optical surface finishes, the criteria have usually been relevant to the optical image received by the human eye even though the infrared (IR) radiation is less susceptible to scattering effects caused by surface imperfection. Due to a lack of specifications and standards dealing with IR performance, it has been the practice to specify the best optical finish affordable, usually in terms of MIL-O-13830.

This "General Specification Governing the Manufacture, Assembly, and Inspection of Optical Components for Fire Control Instruments" has been used for many years to control the quality of optical instruments such as telescopes and range finders. Digs, scratches, and the other controlled defects which adversely affect a visual image are of concern in those applications. It was only natural for our Optical Engineers to continue the use of familiar criteria in their IR system designs. Also, the engineer wants to be sure his design will function as claimed so he specifies the best "optical" quality for components that his budget can afford. If he truly has conceived a "better idea," the demonstration model will be documented and go into production. Forevermore, we get beautiful lenses, mirrors, and domes. The science is furnished and, since we are all bidding to the same criteria, there is little need to critically examine the functional necessity of the dig and scratch requirements.

Aeronutronic Ford has conducted extensive studies, some under contract with the Missile Command, into the correlation between visual defects and IR performance. Our conclusion is that functional test specifications/standards would reduce the cost of optical elements and would also minimize rejections at the system level. One of our studies on seeker domes (IR windows) concluded that the primary effect of poor surface and material quality is a loss of target radiation proportional to the lost surface area. The effect of unwanted radiation that was diffusely scattered-in by visual defects was found to be negligible, because there is a much higher effect from unwanted specular reflections and direct stray radiation, both of which are a function of the optical design. Therefore, the recommended test concept for the systems we studied is to measure the quality of the window by measuring its specular transmittance. Additional criteria would then be imposed only to ensure structural adequacy and to provide an appearance that would maintain customer confidence.

A functional test for an optical element could involve the use of absolute performance criteria or could be a comparison of the test unit with a standard unit (or units). Figure 10 illustrates one concept for a tester suitable for both types of tests for windows and lenses. This tester consists of a double-beam optical system with a single IR source and a single detector. Energy from the source would be alternately transmitted to the reference standard and the test units by the chopper. Similarly, the detector would alternately receive energy from the two beams. Performance criteria could be in terms of the transmittance ratio of the two units or, with the reference standard removed, transmittance relative to air.

Simultaneous testing of the two units and evaluating transmittance ratios would eliminate the effect of variations in source output and detector sensitivity. Reference standards could be chosen on analytical bases or through system evaluation of intentionally degraded units. Figure 11 presents a recommended Manufacturing Technology Project to Develop Standard Specifications and Tests for Infrared System Optical Elements Based on Functional Performance Requirements.

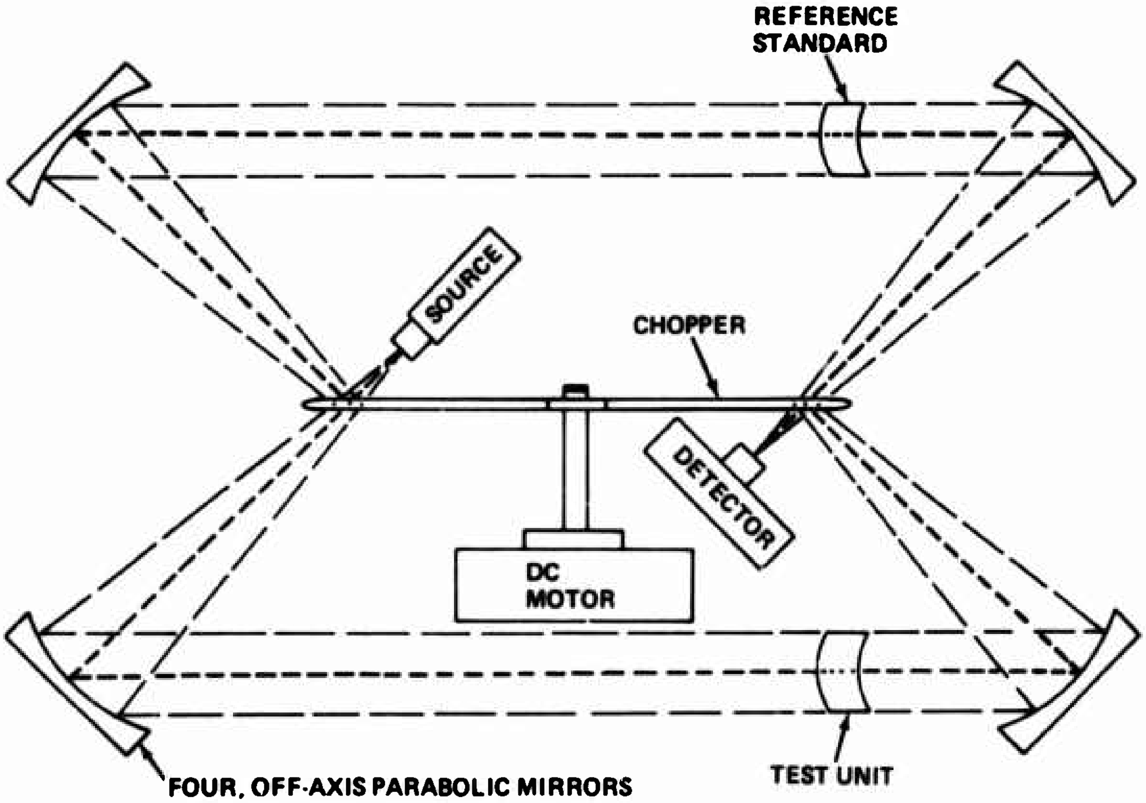


FIGURE 10. FUNCTIONAL TESTER FOR OPTICAL ELEMENTS

FIGURE 11

TITLE: Manufacturing Technology Project to Develop Standard Specifications and Tests for Infrared System Optical Elements Based on Functional Performance Requirements.

SYSTEM/SESSION AREA/COMPONENT: Chaparral/guidance/optical elements

PROBLEM: The surface qualities of IR system optical elements is normally specified in terms of MIL-O-13830, which is really a test of defects of optics used in the visual spectrum, and requires a considerable amount of subjective judgment in application. There is no real correlation between the effect of physical defects on performance of an optical element in the visual wavelengths and performance in the IR range. Many of the "optical" defects are only cosmetic in IR applications. Other defects, or concentrations and arrangements of defects, can be much more critical to particular system performance parameters.

A study by Aeronutronic Ford under contract DAAH01-72-C-0737 has revealed that the measurement of total transmittance is the best parameter for evaluating the quality of the infrared optical windows used in some missile seekers. Other work also indicated MIL-O-13830 is not particularly germaine to IR lenses and mirrors. Improved definition of IR requirements could be pursued on a system by system basis, but without a definitive alternative to MIL-O-13830, results would be fragmentary at best.

PROPOSED SOLUTION: Further verification is required of the efficacy of functional criteria/test of IR optical elements. Test and evaluation of the IR systems now in Army inventory would be necessary. If the hypothesis is substantiated,

1. A supplement or replacement of MIL-O-13830 could be developed,
2. Optical design guidance for the functional test concept could be established, and
3. Standard tests and test equipment could be defined.

Functional tests, if substituted for visual examination, would

1. Reduce inspection costs,
2. Reduce fabrication costs by avoiding nonfunctional and overspecified quality requirements.
3. Reduce rebuild costs by reducing system rejection rates, and
4. Ensure that functional quality requirements are achieved.

PROJECT COST AND DURATION: Estimated costs and program duration are

1. Complete feasibility study	$100,000 - one year
2. Define standard tests and test equipment (build prototypes)	$150,000 - two years
3. Develop, staff, and issue new specification and design guidance	$25,000 - two years

Total cost would be $275,000 with a probable elapsed time of three years assuming some concurrency of activities.

BENEFITS: Based on our experience and comments from our suppliers, we estimate that the cost for IR optical elements could be reduced by 20 percent and system level test failures could be reduced significantly if functional tests are used in lieu of visual criteria. The aggregate savings would be approximately 2 percent of the guidance section cost.

IMPROVED INFRARED DOMES

Currently, all members of the Sidewinder family of missiles have magnesium fluoride IR domes. This material has adequate IR energy transmission and structural properties for the present applications. However, the velocity and guidance requirements of future systems will require superior properties, plus the capability to form the dome in hyper-hemispheric or asymmetric shapes is desirable.

The increasing demand for erosion resistance and refractory thermal shock resistance presents an interesting challenge to the materials technologist. The magnesium fluoride manufacturing process involves mixing, hot pressing to rough shape in refractory metal or graphite dies, and grinding and polishing to final shape. This process limits the dome design to a hemispheric form. The material itself is relatively soft, subject to environmental erosion, and limited in strength at high mach numbers due to thermal effects.

Because polycrystalline materials do not exhibit viscous flow at hot pressing temperatures, the formation of complex shapes, such as a hemisphere, with uniform optical properties is severely limited because of nonuniform pressure distribution in the die cavity. An alternate fabrication technique employing isostatic cold pressing and sintering of optical quality materials has not been successful because of scattering caused by residual pores.

A solution to the problem must evolve from the development of improved fabrication techniques for the manufacture of optical materials and shapes more complex than existing magnesium fluoride domes. Process procedures must be developed for generating uniform optical properties throughout dome cross sections with hard refractory compounds suitable for high temperature erosive environments.

At least two processes appear applicable to the problem. The first is hot gas pressure bonding, pioneered by the Battelle Memorial Institute with various modifications by others. Hot gas pressure bonding has been primarily developed for the fabrication of refractory metals, carbides, borides, and composites from powders with limited control of tolerances and final dimensions. The material to be pressed is placed in an evacuated sealed refractory mental foil, inserted in a high pressure autoclave, and compacted by hot gas at pressures as high as 20,000 psi. This process is limited by dimensional tolerances and the ability to control interface reactions between the encapsulation foil and the pressed compound.

The second process employs chemical vapor deposition of optical quality materials on inert substrates as developed by the Research Division of the Raytheon Company. Results of this work have been very successful for the fabrication of large flat shapes but may pose restraints on product uniformity over many surfaces of variable geometry in a mass production situation. The process is unique for the fabrication of large ports and windows of previously unattainable optical quality.

An investigation of ways to improve these processes separately or in combination with conventional hot pressing and sintering techniques offers a means of advancing the state of the art of IR dome manufacturing methods. Cost effectiveness of a hybrid process employing modifications of existing fabrication methods coupled with dimensional control should be primary objectives.

Material selection and screening should be limited to compounds with cubic crystal structures to minimize anisotropic optical behavior. Other desirable properties would include maximum hardness, good mechanical strength, and, resistance to thermal shock. Table II presents a comparison of the properties of magnesium fluoride, magnesium oxide, and magnesium aluminate (spinel). Magnesium oxide and spinel both have been extensively investigated under Air Force, Army and Navy programs for transparent armor applications. These materials have cubic crystal structures and similar mechanical, thermophysical, and optical properties. Spinel is approximately twice as hard as magnesium fluoride and significantly more resistant to erosion and impact than either magnesium oxide or magnesium fluoride. The high thermal conductivity of magnesium oxide emphasizes its potential superior resistance to thermal shock followed by spinel and magnesium fluoride.

With increasing operational emphasis toward erosion resistance and all-weather capability of air-to-air tactical missiles, the development of advanced IR dome shapes of the harder magnesium aluminate (spinel) appears highly desirable. Figure 12 presents a recommended Manufacturing Technology Project to Develop Improved Infrared Domes.

TABLE II. PROPERTIES OF CANDIDATE IR DOME MATERIALS(1)

	Magnesium Flouride (MgF2)	Magnesium Oxide (MgO)	Magnesium Aluminate (MgAl2O4
Hardness, Knoop	576	640	1,200
Thermal Expansion % @ 400°C	0.44	0.40	0.35
Flexure Strength, RT, psi	22,000	35,000	32,000
Young's Modulus, RT, 10^6 psi	16	44	34
Thermal Conductivity, BTU/HrFt^2°F in. @ RT	80	300	108
Refractive Index	1.36 - 1.24	1.75 - 1.40	1.7
Transmission, µM, 80%	2.0 - 6.5	0.8 - 6.0	0.2 - 5.7
Melting Point, °C	1,255	2,800	2,140

(1) Kodak Irtran Data Sheets
and Engineering Props. of Ceramic Mat'ls, Am. Cer. Soc., 1966

FIGURE 12

TITLE: Manufacturing Technology Project to Develop Improved Infrared Domes

SYSTEM/SESSION AREA/COMPONENT: Chaparral/guidance/IR dome

PROBLEM: Although magnesium flouride IR domes are adequate for currently deployed missiles, the next generation of missiles with higher velocities and more stringent guidance requirements must employ a superior material. Magnesium fluoride will not provide the requisite erosion resistance, thermal shock capacity, and formability in complex shapes.

PROPOSED SOLUTION: Both magnesium oxide (superior thermal conductivity) and magnesium aluminate (superior hardness) offer high potential as IR dome materials if a suitable manufacturing process can be developed. Hot gas pressure bonding or vapor deposition may be feasible, or they possibly could be combined with hot pressing and sintering techniques.

PROJECT COST AND DURATION: Estimated costs and program duration are

1. Evaluate process and material alternatives, select candidate and demonstrate feasibility by fabricating one inch diameter hemispheric optical blank.	$100,000 - one year
2. Develop process and tooling; demonstrate technique by fabricating four inch diameter IR dome (hemisphere)	$200,000 - one year
3. Develop mass production methods and create pilot production line.	$800,000 - two years

Total cost estimate is $1,100,000 with an elapsed time of four years.

BENEFITS: As this project does not apply to current missiles, benefits must be considered in terms of the value of higher performance missiles, with the possible small side benefit of reduced dome maintenance (replacement). It is beyond the scope of this paper to make this evaluation.

HELLFIRE GUIDANCE SYSTEM

MANUFACTURING TECHNOLOGY PROJECTS

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ABSTRACT

The presentation on the HELLFIRE Guidance addresses the Laser HELLFIRE Guidance Module. The HELLFIRE Missile System configuration requirements and its modular elements are briefly described. The major functional elements and the operational characteristics of the HELLFIRE Laser Guidance System are presented. The design and performance requirement features most heavily impacting production costs are discussed. In addition, the close correlation between the functional elements of Laser Guidance Systems and other types of guidance mechanizations such as EO/TV is described. The close similarity between the cost driving elements of the Laser Guidance System and EO/TV guidance mechanizations is discussed. Guidance groups, in general, have the same cost drivers which can be ameliorated by the same or derivative production technology advances. The possibilities of reducing the cost driving factors of other guidance mechanism concepts as a by-product of resolving Laser Guidance System cost drivers is explored.

INTRODUCTION

This paper addresses the HELLFIRE Modular Missile System (HMMS) Laser Guidance production technology and its correlation to Electro-Optical/Television (EO/TV) guidance production technology. The format employed for the presentation is as follows:

Part 1 consists of the following elements:

- Weapon System General Description
    - Program Status
    - System Characteristics
    - System Elements
- Guidance System Description
    - Laser Guidance Module
    - EO/TV Guidance Module
    - Correlation between Laser and EO/TV Guidance Elements
- Cost Analysis
    - Laser Guidance
    - EO/TV Guidance
    - Correlation between Laser and EO/TV Guidance Elements
- Trend Discussion

Part 2 consists of recommended manufacturing technology projects.

PART 1

HELLFIRE WEAPON SYSTEM GENERAL DESCRIPTION

Program Status

The U.S. Army HELLFIRE Modular Missile System (HMMS) has undergone an extensive program of feasibility test and demonstration supported by engineering model hardware designed and fabricated for that purpose. Development of the system has now progressed into Advanced Development (AD) to the degree that second-generation hardware elements have been designed, fabricated, and ground tested. The AD program contract contains "Design-to-Cost" provisions, thus projections of production phase manufacturing costs significantly influenced the system configuration.

The modular missile seekers are being developed independently from the development of the rest of the HMMS missile. A total of four seekers are currently being developed. Three are in exploratory or advanced development, while the laser seeker is currently in the Engineering Development (ED) phase. The modular missile design incorporates form, fit, and functional provisions to permit interface with the specified characteristics of all four seekers.

System Characteristics

The system characteristics provide the capability to defeat armored vehicles and other point targets. The system is configured for effective integration with current and projected attack helicopters; however, consideration has been given to its adaptability to other carriers, both air and ground. High survivability of the system results from several characteristics, including adequate standoff range, launch-and-leave capability, indirect fire capability, and minimal exposure time. Growth potential is assured as a result of the modular missile concept. The system characteristics permit each helicopter to carry and employ a load of missiles with a mix of seekers tailored to the projected operational scenario.

The system configuration permits operation in four basic modes, as follows:

- Semiactive Laser–A pulse laser beam is trained on the target from an Airborne Laser Locator Designator (ALLD) or Ground Laser Locator Designator (GLLD). The target is then acquired by the attack helicopter sensing the reflected laser energy either through use of the Airborne Laser Tracker (ALT) or the laser seeker missile. A laser missile is then launched and homes on the reflected laser energy. The ALLD may be carried by the scout helicopter or the attack helicopter. The GLLD is employed by a forward observer. Alternate methods of employment utilize the lock-on-after-launch capability of the system.

- Passive Optical Contrast–A target is visually identified by the attack helicopter either directly or by reference to the imaging display mounted in the cockpit. The imaging display then provides the basis for designation of the target to an optical contrast EO/TV equipped missile. After launch, the missile operation is completely autonomous.

- Passive Radio Frequency/Infrared (RF/IR)–A radio frequency energy emitting target is acquired by the attack helicopter sensing the RF energy either through use of the Radio Frequency Target Discriminator (RFTD) or the seeker of an RF/IR equipped missile. After launch, the missile homes on the RF energy until the terminal phase, whereupon it can switch to the IR homing mode. After launch, the missile operation is completely autonomous.

- Passive Infrared Imaging–During night operations, a target is identified using the imaging display. The imaging display then provides the basis for designation of the target to a missile equipped with an Infrared Imaging Seeker (IRIS). After launch, the missile operation is completely autonomous.

System Elements

The HELLFIRE Weapon System is comprised of the major elements identified in Figure 1. The set of system elements designated as the HELLFIRE Modular Missile System (HMMS) is contained within an attack helicopter. An attack helicopter with a maximum load of HELLFIRE missiles is shown in Figure 2. The HMMS elements are illustrated in Figure 3 with other primary interfacing elements carried by the helicopter.

The HELLFIRE Modular Missile shown in Figure 4 is an assembly of three major sections designated seeker (guidance), warhead, and airframe and control.

The warhead section is specified as Government Furnished Equipment (GFE).

As previously discussed, guidance modules which use differing sensor and signal processing techniques will be employed. The common primary functions of all of the guidance modules are to:

- Sense the target signal and its orientation relative to the attitude of the missile.
- Process the target signal such as to provide accurate guidance commands to the missile control equipment.

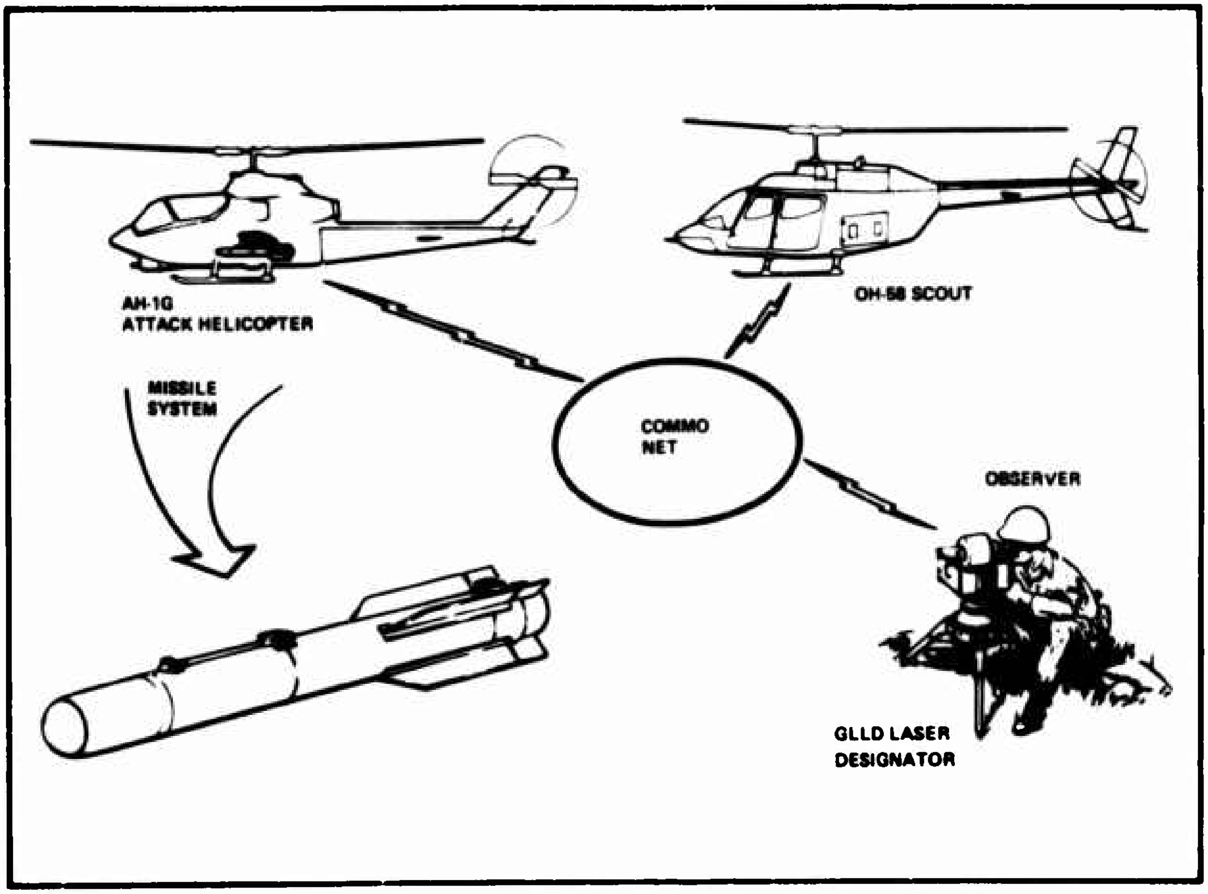

Figure 1. HELLFIRE Weapon System

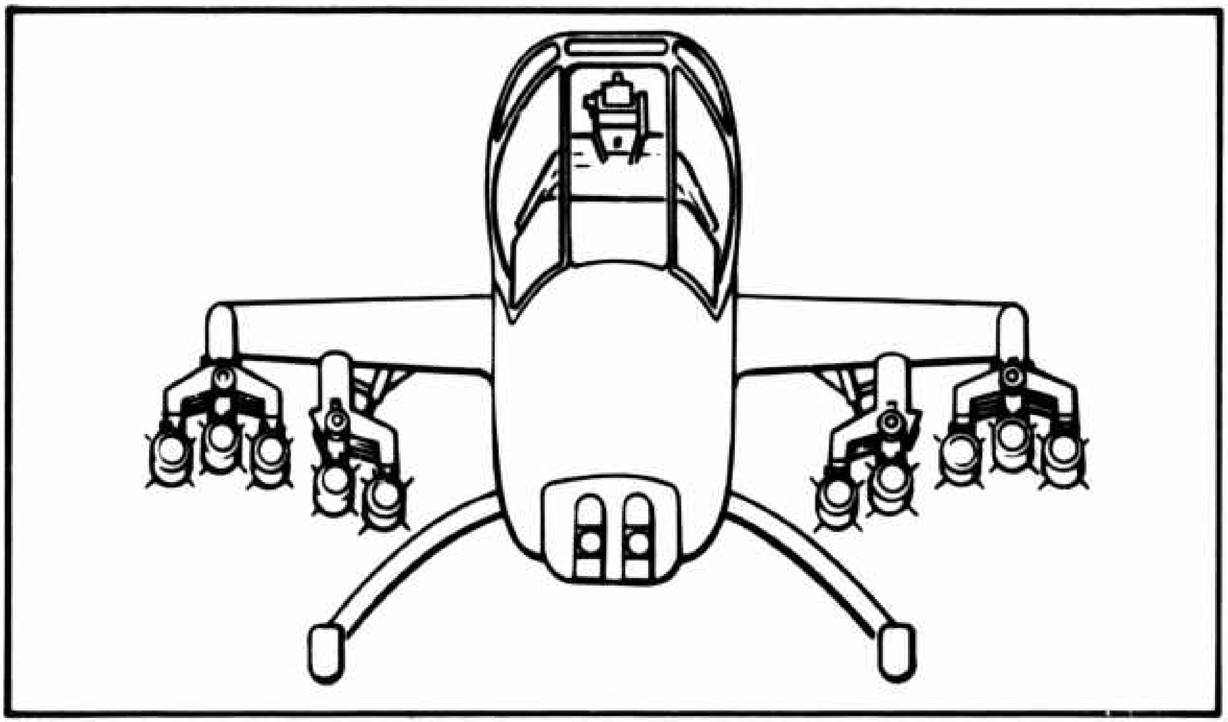

Figure 2. Attack Helicopter with Full Load of Launchers and Missiles

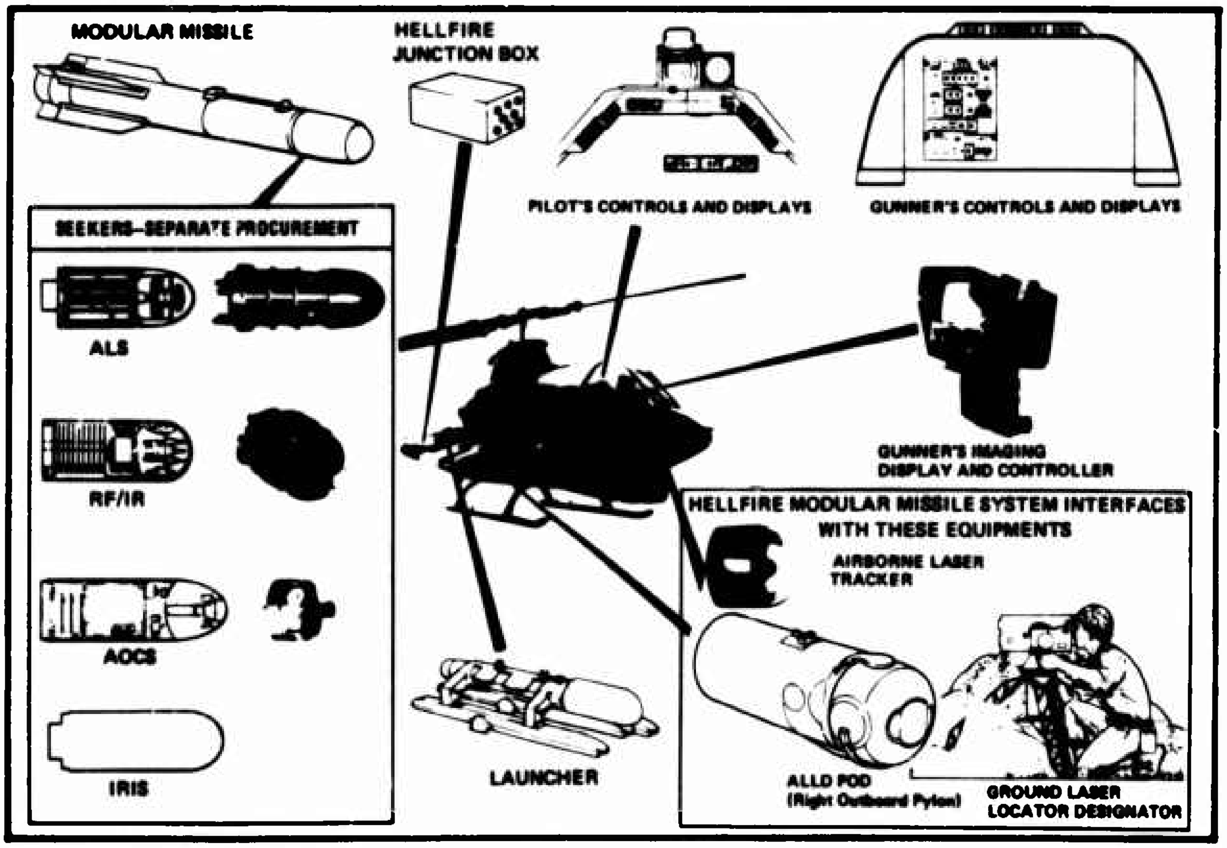

Figure 3. HELLFIRE Modular Missile System Elements

Figure 4. Baseline Modular HELLFIRE Missile

In addition, the guidance module has some important functions in the search, acquisition, and designation phases of the mission. Primary elements of the guidance module are:

- Signal Sensor, including appropriate optics.
- Attitude/Inertial Sensing Device(s).
- Electronics.
- Structure.

While the aforenoted performance capabilities define the functions and functional elements required in the guidance module, the configuration requirements establish the degree of difficulty and cost in achieving the design in these functional elements. Figure 5 presents the configuration requirements for the HELLFIRE guidance modules. The configuration requirements that most seriously impact the design of the HELLFIRE guidance section are the 13-inch maximum length, 6-inch maximum diameter, and 12-pound maximum weight. These requirements create the need for extensive utilization of miniaturized if not microminiaturized technologies.

GUIDANCE SYSTEM DESCRIPTION

Laser Guidance Module

The Laser Guidance Module (LGM) is the modular laser guidance unit configuration to be used on both the Army laser-guided HELLFIRE and the Air Force Laser Maverick missiles. The LGM design described herein fulfills this dual requirement.

The exploded view of the LGM in Figure 6 illustrates the overall simple packaging and assembly concept. The seeker has been designed for economical recurring production cost in high volume production through use of an all-plastic optical system, a gyro designed with few critical tolerance components, structural parts fabricated by injection molding and casting techniques, and a low-cost electronics packaging concept.

The LGM functions as an independent laser guidance unit requiring primary power, mode control signals, coding address signals, and initial gimbal pointing commands. It yields proportional rate guidance signals, gimbal pointing signals, and mode status signals. A LGM functional block diagram is shown in Figure 7.

The gyro platform consists of a combination optical mirror and magnet free to spin about the optical axis supported by an internal ±30-degree gimbal set. The head coils contain a set of motor coils to spin the gyro, a set of reference coils to sense the instantaneous location (phase) of the gyro, a cage coil to sense the gyro gimbal angle, and a precession coil to torque the gyro. Sensing and torquing are accomplished through magnetic coupling between the coils and the rotating gyro magnet. The gyro drive electronics spins up the gyro platform and inertially stabilizes the optical line of sight (LOS). This function is similar to an AC motor drive to spin the rotor and accurately control the spin speed.

The mode logic circuitry controls the seeker operating modes to provide for electrical cage, scan, slave, stare, and track modes. These functions are commanded by external controls.

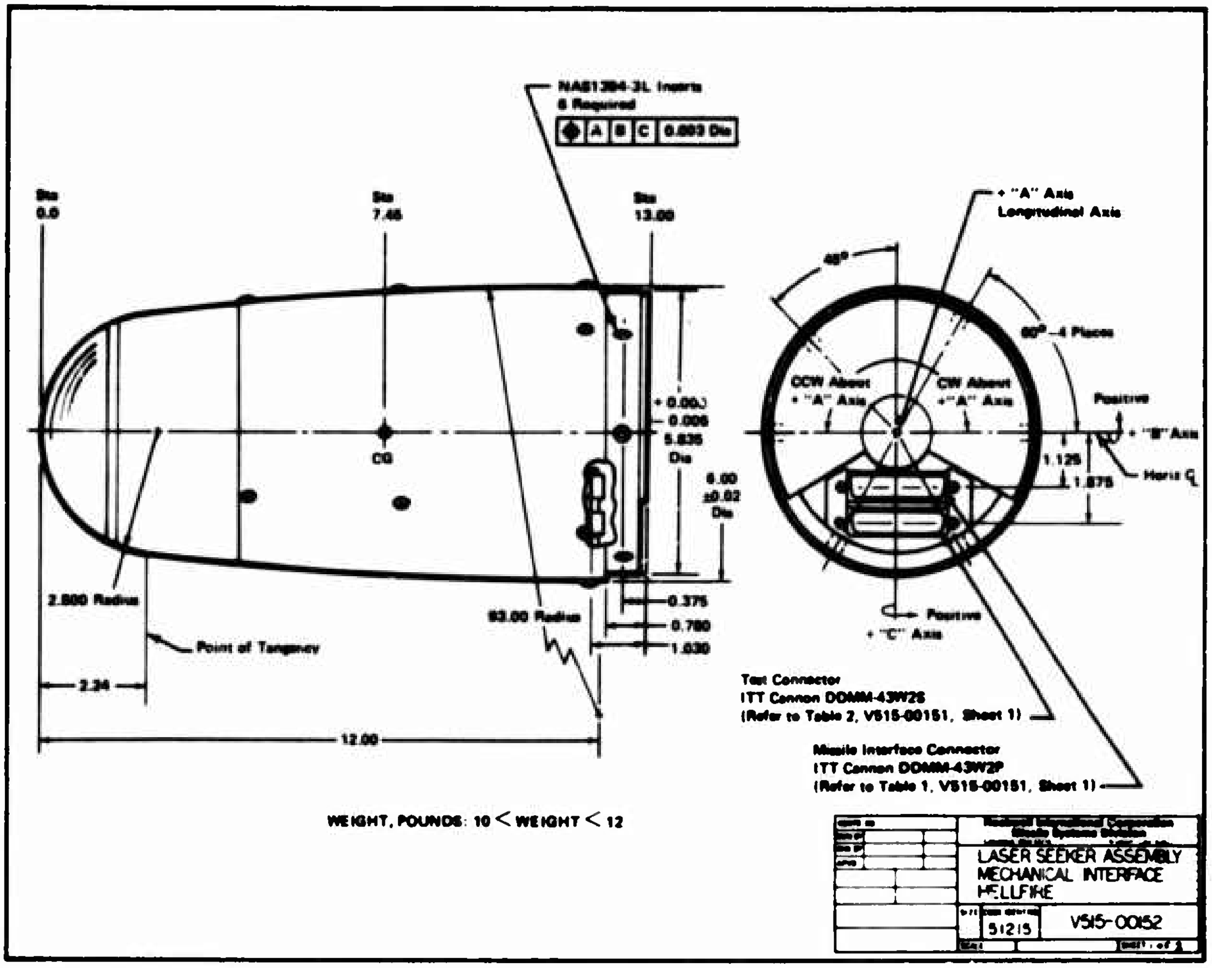

Figure 5. HELLFIRE Guidance Interface Control Drawing

The LGM structure has been designed to meet stringent structural and environmental requirements. The more critical requirements are summarized as follows:

- Temperature.
- Acceleration.
- Shock.
- Sine and random vibration.

Extensive use is made of aluminum and glass-filled polycarbonate to provide adequate structural characteristics, lightweight and simple fabrication procedures. The LGM consists of three principle assemblies:

- Seeker Head Assembly (includes dome, gyro optical assembly, and head assembly).
- Electronics Assembly (includes printed wiring boards, fairing, retainer and support assembly, bulkhead, and interconnect).
- Power Supply.

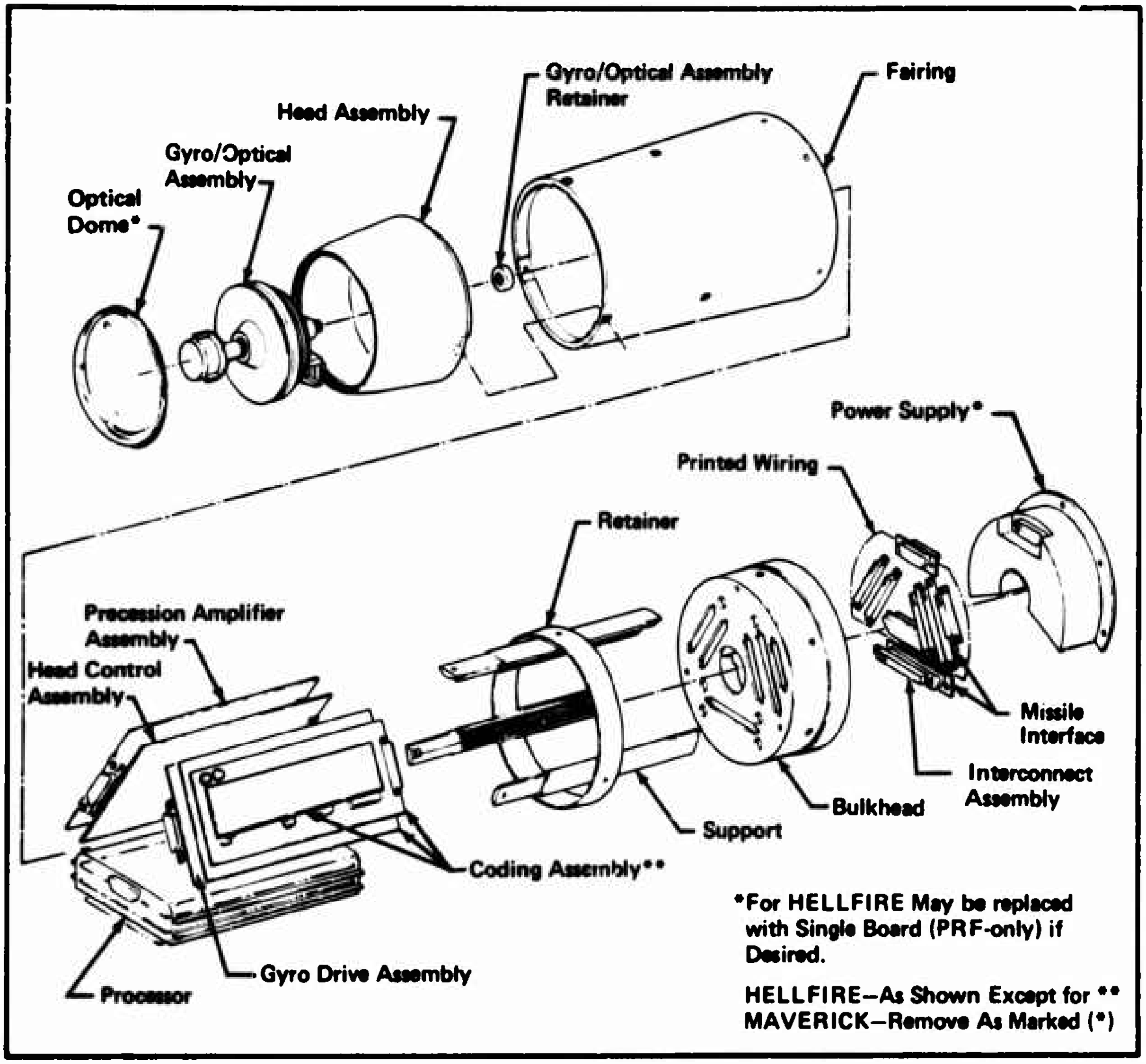

Figure 6. Laser Guidance Module

Seeker Head Assembly. The head assembly is shown in detail in Figure 8. Construction techniques make maximum usage of aluminum in the gyro structure and glass-filled polycarbonate in the coil form.

The gyro design features an internal gimbal system with a soft stop to provide for gimbal limits where contact is made by nonspinning gyro parts. The mirror, magnet, and cager with attached nutation damper are mounted on the optical barrel. A nonspinning detector support assembly is mounted on the spin bearing support shaft.

The head coil features a unitized plastic coil form/desiccant chamber/aft bulkhead which results in significant cost reduction (because it will be injection molded). Hermeticity is maintained. The polycarbonate dome and coil form are not hygroscopic. Seals are incorporated at the dome, connector, gyro post, and desiccant plug to provide sealing on assembly. A moisture indicator strip is visible through the dome.

The optics consist of a dome, aspheric mirror, and narrow bandpass filter, designed by trading performance with cost and producibility. An injection-molded polycarbonate dome is used because of its high temperature and injection molding characteristics. A protective overcoating is applied to the outer surface of the plastic dome to

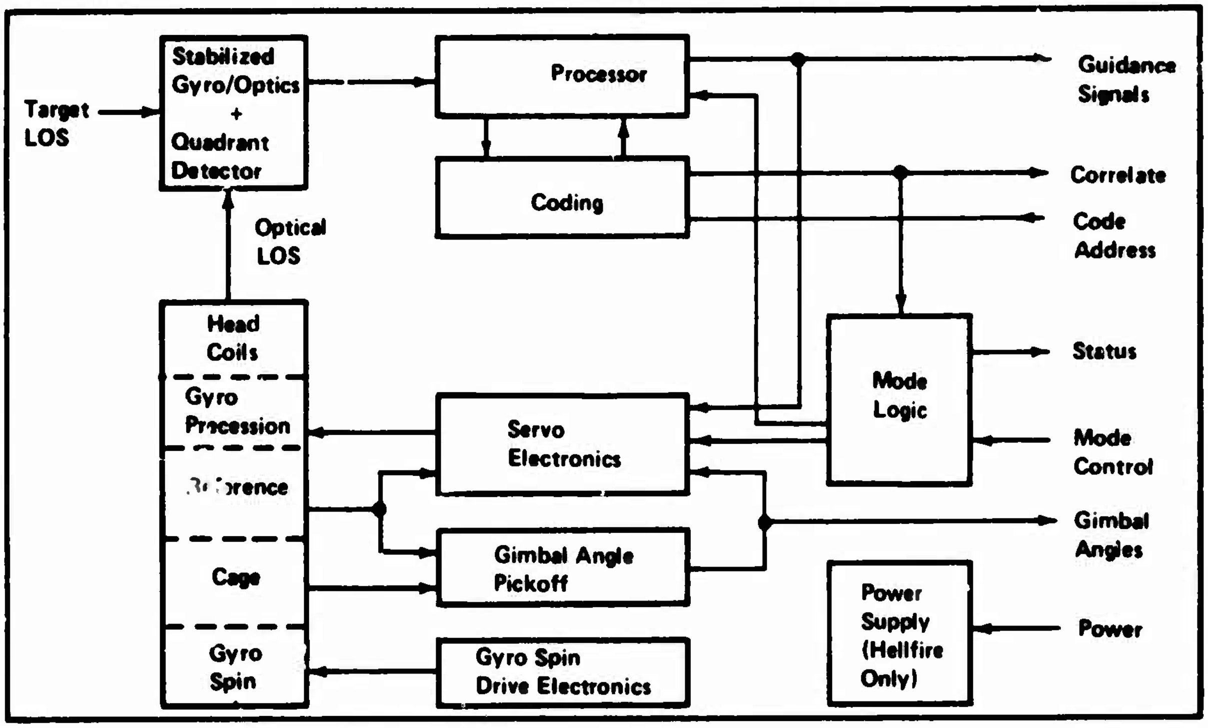

Figure 7. Laser Guidance Module Assembly Block Diagram

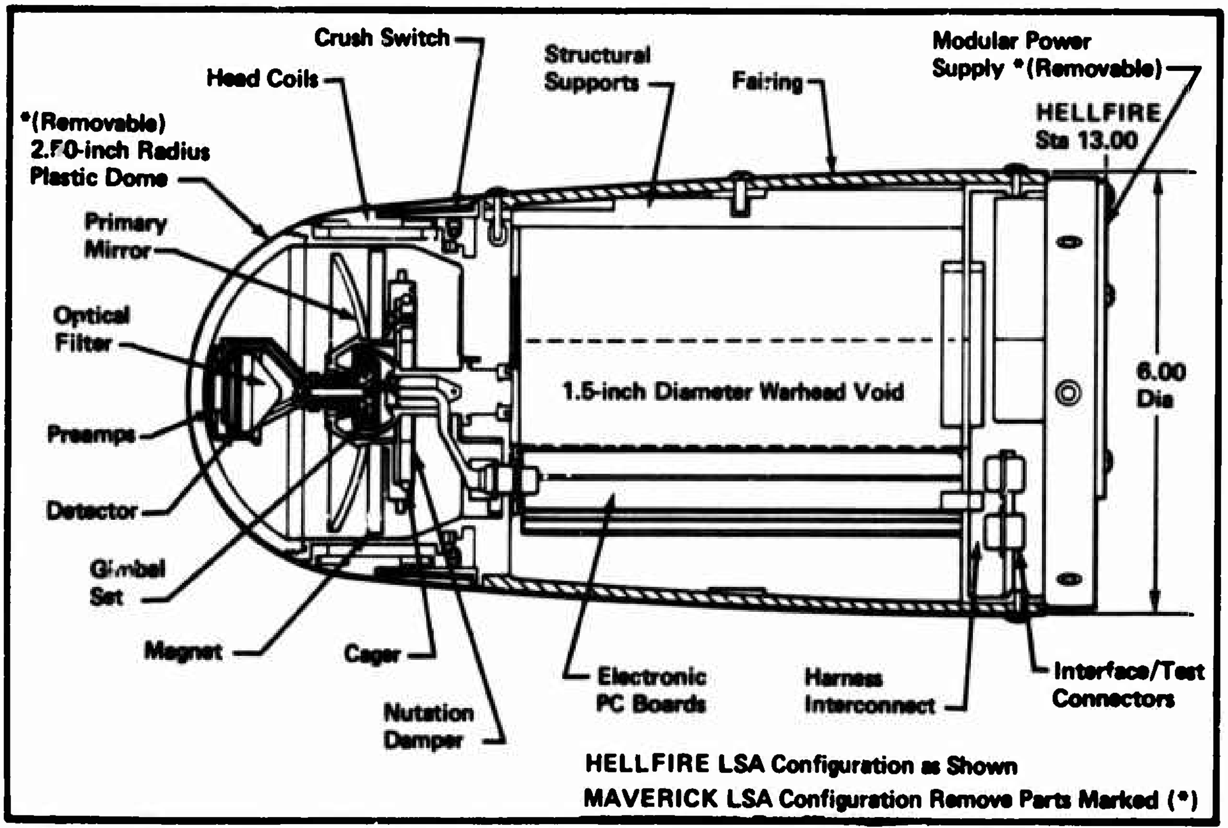

Figure 8. Laser Guidance Module Assembly Configuration

improve scratch resistance. The aspheric mirror is a front surface reflector of injection-molded polycarbonate plastic. Again, significant cost savings and temperature compatibility are realized by using molded plastic. The mirror is gold-coated on the front surface. A narrow bandpass filter is required to limit induced noise into the detector due to solar background levels.

The stabilization system for the LGM contains a gimbaled, momentum-stabilized rotor surrounded by body-fixed torquing and sensing coils. The rotor of the gyro/spin motor is a two-pole permanent magnet to which the mechanical cager and primary mirror are attached. These items rotate together, effectively increasing the spin momentum of the rotor. The laser sensor assembly is attached to the inner gimbal, but does not spin with the rotor.

The mechanical cager is used to keep the spin axis aligned with the longitudinal axis of the LGM when the gyro is at rest. This restrains the gimbaled rotor during shipping and handling, and also maintains the alignment of the magnet rotor during spin-up.

The head coil assembly consists of four gyro drive coils (spin motor), four saturable reactor coils (spin motor rotor position sense), four reference coils (precession rotor position sense), two precession coils (precession torque), one cage coil (polar gimbal angle sense), and two cage compensation coils (polar gimbal angle linearization).

Electronics Assembly. The primary load carrying members of the electronics section are the fairing (glass-filled polycarbonate), chassis (aluminum), and aft bulkhead (aluminum). Seven electronics printed circuit boards (PCBs) are installed into this chassis providing the functions of Signal Processing, Gyro Drive, Head Control, and Coding. In addition, the electronics assembly includes an interconnect.

Power Supply. The HELLFIRE power supply is a plug-in module located at the aft end of the electronic section. The power supply structure is designed to carry only its own load and provide a path for conducting heat from the power components into the aft bulkhead, and thus into the missile structure.

Materials, Processes, and Parts. Selection of materials, processes, and parts is in accordance with MIL-E-5400 and ANA Bulletin 400. All materials used to fabricate and assemble the seeker will be suitably treated to resist corrosion where applicable. Printed wiring boards are to be conformally coated with non-nutrients of fungus per MIL-STD-454. No dissimilar metals are in direct contact. Materials used within the LGM are listed in Table I.

Lubrication of the gyro bearings is an important design consideration to meet five years of maintenance-free storage or a desired shelf life of ten years.

Table I. Material Summary

ITEM	PRIMARY MATERIAL	SELECTION ATTRIBUTES
Seeker Head		
• Head Coil Assembly	Polycarbonate (glass filled) Stycast Encapsulant	Light Weight, Low Cost, and Strength Thermally Compatible with Polycarbonate
• Dome	Polycarbonate	Low Cost Optics, Thermally Stable
• Mirror	Polycarbonate	Low Cost Optics, Thermally Stable
• Magnet	ALNICO V	
• Cages	Polycarbonate (glass filled)	Low Cost, Light Weight
• Sensor Support	Polycarbonate (glass filled)	Low Cost, Light Weight
• Gimbal Structure	2024 Aluminum	Ease of Manufacture, Weight, and Stability
• Impact Sensor	Nylon (glass filled)	Injection Moldable for Low Cost and Reliability
Seeker Electronics		
• Fairing	Polycarbonate (glass filled)	Low Cost, Weight, and Strength
• Support	Aluminum Extrusion	Low Cost, Weight, Thermally Conductive
• Aft Bulkhead	Aluminum	Ease of Manufacture, Weight
Power Supply Housing	Aluminum	East of Manufacture, Weight, Thermally Conductive

EO/TV Guidance Module

The helicopter carriage vibration and launch environment, the small 6-inch diameter by 13-inch long envelope combined with the system requirements of extended launch range, small target signature, and close-in guidance cutoff dictate the design of the HELLFIRE EO/TV seeker. MSD's extensive EO/TV guidance production experience on the Air Force HOBOS and Navy CONDOR programs provides a typical HELLFIRE EO/TV design base for production cost driver correlation to the preceding HELLFIRE laser guidance section. This typical design includes:

- A momentum-stabilized platform for low susceptibility to sight-line jitter and low cost mounted in a vibration isolator to further reduce the effects of the severe vibration environment.
- A high performance vidicon sensor providing maximum utilization of target contrast and haze penetration.
- An in-line optics and sensor package mounted with the sensor on the momentum-stabilized platform.
- The camera and tracker circuitry will probably require hybrid or LSI modules mounted on printed wire boards because of volume limitations. The platform electronics and power conditioner will use a high percentage of discrete components due to the power requirements of these circuits. The camera, tracker, and servo electronics are all contained in the electronics module. The power conditioner is mounted to the rear bulkhead of the guidance section in the same manner as the laser guidance.

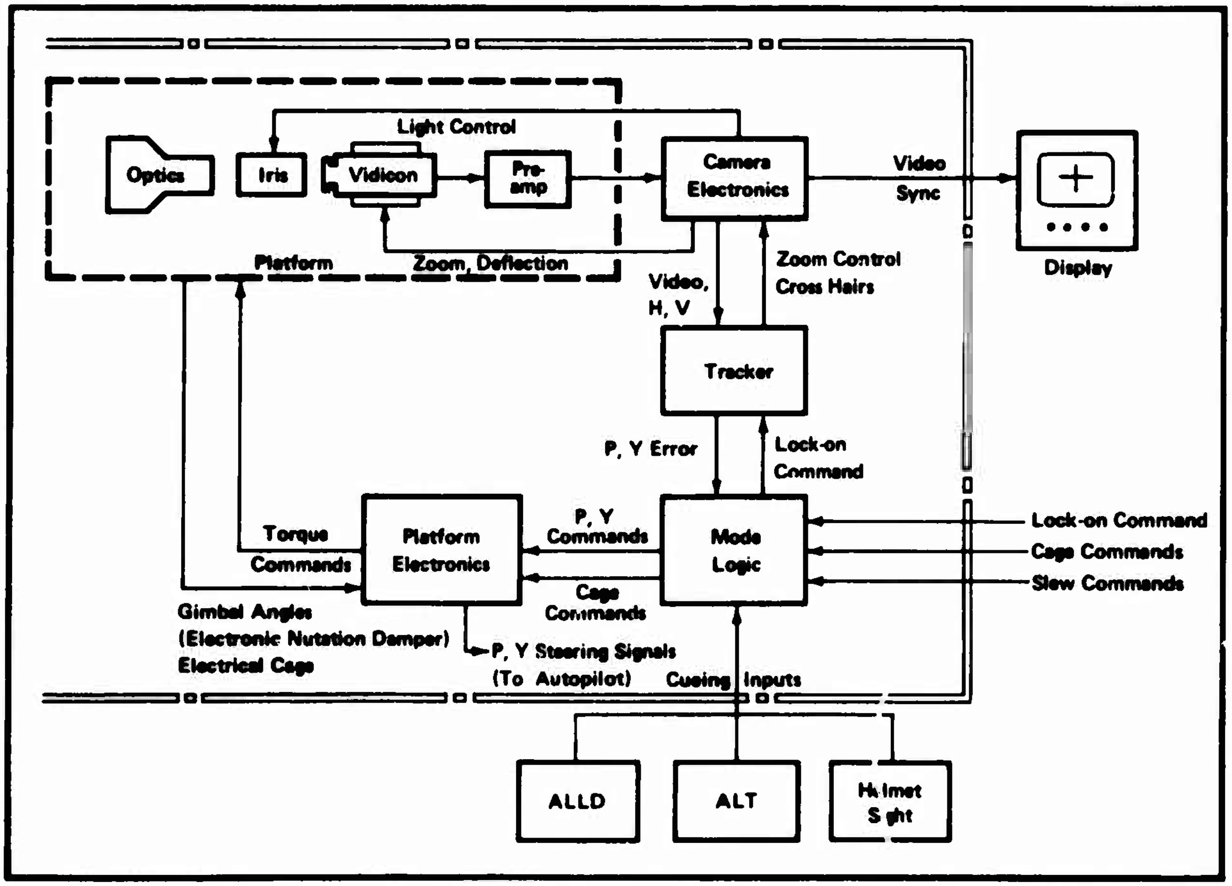

Figure 9. EO/TV Guidance Block Diagram

The guidance module provides a video presentation of the target scene and signal processing functions for: (1) target acquisition and target lock-on, and (2) area and edge mode target tracking and signal generation for use by the missile control elements to direct the weapon to the target after launch. During target acquisition and tracking, the guidance module provides signals for video representation of the target scene for transmission directly to the cockpit. The guidance module provides steering command requirements to the control module. The guidance module includes a dome window in the nose, a gimbal-mounted sensor which senses the target utilizing visual energy, platform control electronics and torque devices, signal processing, and tracking electronics.

The functional flow item diagram for the EO/TV guidance module is shown in Figure 9.

The EO/TV guidance module (Figure 10) primary subassemblies are a seeker head assembly and an electronics bay. The following are the major functional components of the guidance module:

- Guidance Equipment Assembly.
- Guidance Body Assembly.
- TV Sensor (Vidicon).
- Tracker Electronics.
- Video (Camera) Electronics.
- Platform Control Electronics.
- Mode Logic Electronics.
- Power Supply.
- Optics Chain (Dome and Lens).
- Preamplifier Electronics.
- Gimbal Platform Assembly.

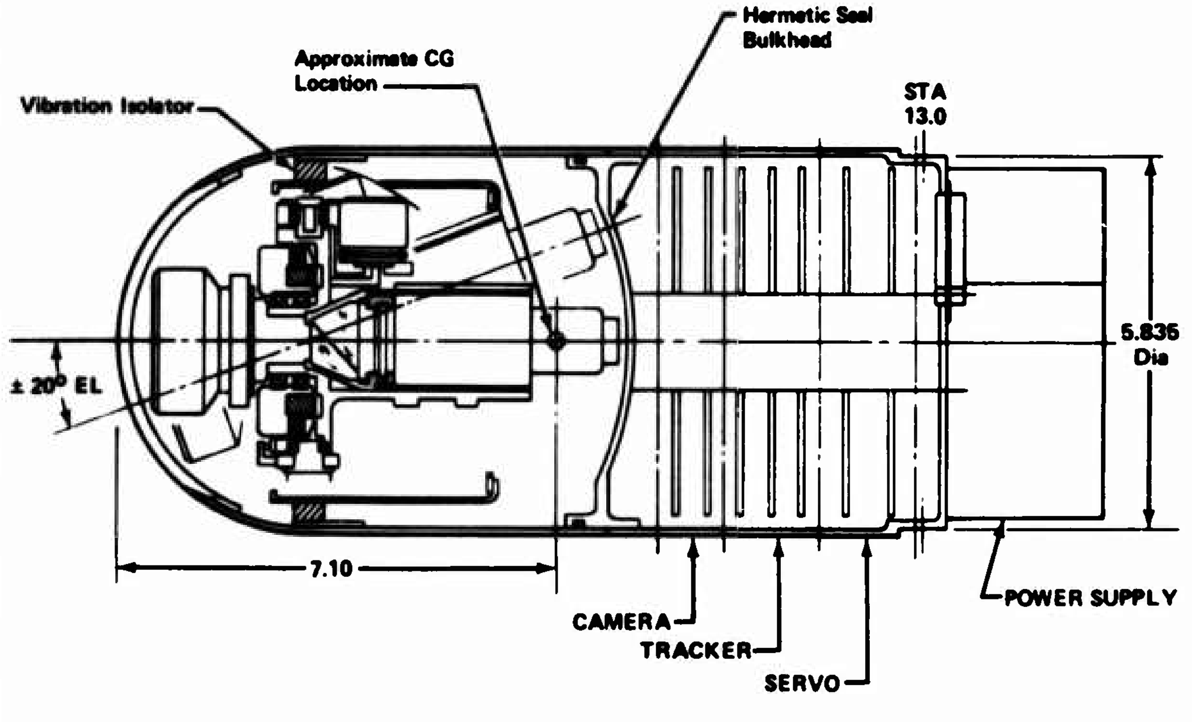

Figure 10. EO/TV Guidance Module

The seeker head assembly is made up of the gimbaled platform payload assembly and dome cover assembly. The payload assembly includes the potted vidicon, lens holder, preamplifier electronic module, and the lens. The dome cover assembly contains the optical dome, retaining ring with ancillary seals and hardware, and a permanent mold cast pressure cover. The payload is inserted in the gimbaled platform and bolted to the inner gimbal. The platform housing includes provisions for attaching and sealing the dome cover assembly. The assembled sealed platform, payload, and dome cover are purged of ambient air and filled with dry nitrogen.

The electronics bay is made up of the electronics bay body assembly, the guidance mounting assembly, and printed circuit board assemblies. The guidance mount assembly includes a structural mounting plate and electronics housing box, a printed wiring interconnect board containing the printed circuit board connectors, and the guidance section connectors.

Correlation Between Laser and EO/TV Guidance Elements

The correlation between laser and EO/TV guidance starts with the functions and the mechanization at the plug-in module level. There is either an analogy or an identicality between almost all of the functional elements in the two guidance mechanizations.

- Optical System–The laser and EO/TV both require precision optical domes and filters with very high transmittance and precise optical characteristics requirements. The laser mirror is analogous to the EO/TV lens system in that both require optical elements with a very high degree of precision.

- Stabilization System–Both laser and EO/TV utilize a momentum stabilization system to maintain LOS between the laser and the target. Both include gimbals, spin bearings, and spinning mass momentum systems. The laser stabilization system spins the magnet while the EO/TV spins the rotor. Both require wire winding and dynamic balancing production technologies. Both include caging mechanisms and nutation dampers.

- Sensor System–The laser silicon detector and the EO/TV vidicon are different in function and operation, but the detail production technology challenges are similar. Both require small precise mechanical parts, hermetic sealing, and a chemical reaction process to create the sensing element (silicon crystal growth/photo conductor deposition). In addition, both require precise miniaturized and generally blind (not accessible to visual inspection) welding and bonding assembly techniques.

- Electronics–While the individual circuits of the laser and EO/TV systems are different, the electronics PCBs are either functionally the same or closely analogous. The laser and EO/TV both have stabilization system drive, control, and position sensing electronics. They both have preamplifiers. The laser signal processor is very analogous to the EO/TV video camera circuit while the laser coding module is analogous to the EO/TV tracker in functions and components required. A comparison of the detailed parts list of electronics components between the two systems shows a very high, 70 to 85 percent, correlation in:

    - Distribution of types of components (resistors, capacitors, integrated circuits, diodes, transistors, etc).
    - Utilization of common part numbers.

COST ANALYSIS

The cost analysis will first treat the laser and EO/TV guidance production cost as separate entities identifying the cost driving elements for each guidance mechanization. A comparison between the laser and EO/TV cost data will show the correlation between the cost-driving elements of both guidance systems. The laser guidance cost analysis is based on the production history of the developmental Army Laser Seeker and projected design-to-cost elements of the production HELLFIRE laser guidance module. The EO/TV guidance cost analysis is based on the production history of over 4000 production HOBOS units built for the U.S. Air Force. By utilizing percentages in lieu of dollars the relative cost elements are independent of outside forcing elements such as inflation, burden rates, etc.

Laser Guidance Cost Elements

The first-level laser guidance cost elements are listed in Table II. The laser guidance module consists of eight major related functional elements of groups of plug-in modules and the guidance module assembly cost. Of these eight elements, as can be seen from Table II, the electronics and stabilization platform are the most significant cost drivers.

Table III presents the second-level cost elements for the laser guidance electronics. For those electronic printed circuit boards which utilize discrete components, one of the cost driving elements is component cost. A prime contributor to escalating the component cost is the Hi-Rel component requirement specified for some of the components. One potentially fruitful area for cost reduction of this element is the possibility of replacing Hi-Rel components with either screening of components or burn-in at the plug-in module or guidance module levels.

Another contributor to the high cost of components is redundant circuitry added for increased mission reliability. In some circuits this could be as much as 15 percent of component cost. Frequently these redundancies are incorporated at the basic design level and are not subject to cost effectivity trade-offs. Unfortunately, currently available increased reliability versus component redundance versus cost effectiveness trade-off criteria are at best ambiguous and argumentative.

Of the eight electronic PCBs used in the laser guidance module, seven have comparable cost elements within two percent. As indicated in Table III, the coding electronics PCB is significantly more expensive than any of the other modules. This board has a component/function density of four to five times that of the other modules. This forces the use of hybrid thick and thin film circuitry with the attendant increase in fabrication, processing, and assembly costs.

The fabrication and processing cost driving element is due primarily to microcircuit fabrication and checkout; while the assembly cost element is driven by alignment of component tolerances, fault isolation, and identification of rework required. Automated fault isolation equipment with computerized rework printout instructions could significantly reduce this cost element. Amortization of the nonrecurring or capital investment for this capability would require justification by very large production quantities.

Table II. First Level Laser Guidance Cost Elements

STANDARD GUIDANCE COMPONENT	MANUFACTURING COST CATEGORIES						
	Material	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support	Total
Optics	–	2%	–	–	–	–	2%
Electronics*	1%	$\boxed{13\%}$	$\boxed{10\%}$	$\boxed{7\%}$	2%	2%	$\boxed{35\%}$
Laser Sensor Assembly	–	$\boxed{9\%}$	1%	1%	1%	–	$\boxed{12\%}$
Stabilization Platform	1%	8%	2%	$\boxed{5\%}$	3%	2%	$\boxed{21\%}$
Power Supply	–	$\boxed{11\%}$	–	–	–	–	$\boxed{11\%}$
Cables/Interconnects	–	2%	1%	1%	1%	–	5%
Structure	–	2%	2%	1%	1%	–	6%
Guidance Module Assembly	1%	–	–	3%	3%	1%	8%
TOTAL	3%	47%	16%	18%	11%	5%	100%

* Does Not Include Power Supply Electronics.

▭ Major Cost Drivers

Table III. Second Level Laser Guidance Cost Elements—Electronics

STANDARD GUIDANCE COMPONENT	**MANUFACTURING COST CATEGORIES**						
	Material	**Purchased Parts**	**Fabrication and Processing**	**Assembly**	**Test and Inspection**	**Support**	**Total**
Preamplifier	–	2.0%	–	5.0%	1.0%	1.0%	9.0%
Signal Processor No. 1	1.0%	4.0%	1.0%	2.0%	0.4%	0.3%	8.7%
Signal Processor No. 2	–	5.0%	0.5%	1.0%	0.3%	0.3%	7.1%
Signal Processor No. 3	1.0%	4.0%	0.5%	2.0%	0.3%	0.4%	8.2%
Gyro Drive	–	5.0%	1.0%	1.0%	1.0%	1.0%	9.0%
Head Control No. 1	1.0%	6.0%	1.0%	2.0%	0.5%	–	10.5%
Head Control No. 2	1.0%	5.0%	1.0%	2.0%	0.5%	–	9.5%
Coding	–	6.0%	$\boxed{21.0\%}$	3.0%	5.0%	3.0%	$\boxed{38.0\%}$
TOTAL	4.0%	37.0%	26.0%	18.0%	9.0%	6.0%	100.0%

▢ **Major Cost Drivers**

The cost driving elements for the stabilization platform are the head coil fabrication, processing and assembly, the procured gimbal, and the gyro optics assembly. The primary contributor to the cost of the head coil is the functional alignment and electrical balancing of the individual coils. An automated alignment, while winding, setup could significantly reduce this cost. The primary contributor to cost of the procured gimbal assembly is the precision machining tolerances and matched assembly requirements.

The gyro optics assembly operation assembles the gimbal, the momentum wheel magnet, the mirror and the optical barrel, sensor/filter assembly. The primary contributor to the cost of this element is the dynamic balancing operation of this gyro assembly. Even when fabricated to extremely tight machining tolerances, the tolerance variation of the assembly will produce instability of the momentum wheel at the required high rotational speeds. Dynamic balancing of the gyro optics assembly is an empirical "cut and try" process requiring frequent disassembly of the momentum wheel (magnet) to add or remove material. An automated computer-aided balance tester utilizing a high energy laser to remove material from the wheel could significantly reduce this cost element.

As indicated in Table II, another cost driver is the laser sensor assembly which contains the laser detector and preamplifier. The primary contributor to the laser sensor assembly cost is the procured laser detector. The laser detector cost is primarily due to process control and yield problems.

The basic building block in the fabrication of the laser detector is the silicon wafer used as the sensing element. An extremely high purity, high resistivity silicon crystal refined to eliminate all impurities is required. From this silicon crystal, thin wafers are sliced to form the basic laser detector element. This wafer is then polished and etched to the final dimensional requirements. At this point, inclusions, voids, or cracks not discernible during the crystal growth and refining process are frequently found.

The next step is a diffusing operation during which dopants such as boron and phosphorus are diffused under controlled conditions in the crystal structure. These dopants form the basic PN junctions required for the low leakage photo-diode mode of operation and the geometric definition of the detector quadrants. Tight process control and cleanliness requirements are mandatory to achieve the correct balancing of diffused dopants into the silicon wafer. The wafer is then passivated.

After the diffusing and passivating operation, gold contacts are plated on the wafer to provide a base for electrical connections. During the gold plating operation, it is mandatory that a noiseless ohmic characteristic is achieved. Once again, tight process control and cleanliness are mandatory for successful completion of the process.

The next step is insertion of the sensor element in the detector package and bonding the leads. Before sealing, an anti-reflective (AR) coating optimized for the silicon material and the operating wavelength, is vacuum deposited on the front surface of the detector element. The package is then hermetically sealed by bonding or welding. Any contamination introduced during the packaging, lead bonding, AR coating or sealing operations will cause functional test failure of the assembly.

The most common rejection causes for laser detectors are:

- Low reverse breakdown voltage. This is established by the reverse biased diode, generally caused by contamination in the fusing process or crystal damage.
- High leakage currents. This is generally caused by contamination during the plating or packaging process or crystal damage.
- Low quantum efficiency. This is generally caused by a bad AR coating, or a bad reflective back surface, or a too thin silicon wafer.
- Operating life degradation. Generally due to contaminants in the sealed package.

The procured power supply package is another cost driver. The power supply contains two transformers, two inductors, two electronics PCBs, heat sinks and interconnects installed in a self-contained package. The major cost contributor is the components and the Hi-Rel requirement.

The other cost driver is the guidance module assembly. This is the collection and mechanical assembly of all the functional elements that make up the guidance module. This functional alignment and system balancing of the functional subassembly tolerances culminates in the final selloff of the guidance module. The primary contributor to the cost of this activity is the alignment of the functional elements, identification of failure causes, fault isolation, and identification of rework required to integrate the guidance module. Automated fault isolation with computerized rework printout instructions could significantly reduce this cost; but the nonrecurring cost for achieving this automated capability presents an amortization problem.

EO/TV Guidance Cost Elements

The first-level EO/TV guidance cost elements are listed in Table IV. As with the preceding laser guidance module, the EO/TV guidance module contains eight major related functional elements or groups of plug-in modules and the guidance module assembly cost. As indicated in Table IV, the EO/TV guidance electronics and stabilization platform are the most significant cost drivers, as they were on the laser guidance module.

Table V presents the second-level cost elements for the EO/TV guidance electronics. The EO/TV guidance electronics utilizes discrete components on all of the PCBs, and therefore variation of the second-level cost elements from PCB to PCB are minimal. The variation in cost from one electronics module to the other (listed in Table V) is directly proportional to the component count. All the boards are not designed to the same component density.

As with the preceding laser guidance electronics, the major cost driving element for the EO/TV electronics is the component cost. Unlike the laser electronics cost where impact was due to Hi-Rel requirements the EO/TV electronics component cost is directly proportional to component count. As with the laser guidance, redundant circuits increase component count and cost.

The assembly operations for the EO/TV guidance PCBs is the same as that for the laser guidance PCBs and the electronics assembly cost element is driven by the same factors; alignment of component tolerances, fault isolation, and identification of rework required. An automated, computerized test, fault isolation, and rework identification capability developed for laser guidance could easily be adapted for use by EO/TV guidance electronics.

Table IV. First Level EO/TV Guidance Cost Elements

STANDARD GUIDANCE COMPONENT	MANUFACTURING COST CATEGORIES						
	Material	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support	Total
Optics	0.3%	4.5%	1.2%	0.7%	0.5%	0.1%	7.2%
Electronics*	–	$\boxed{8.9\%}$	–	4.6%	2.7%	0.5%	$\boxed{16.7\%}$
Detector–Vidicon	–	$\boxed{9.0\%}$	–	–	–	–	$\boxed{9.0\%}$
Stabilization Platform	3.5%	6.2%	$\boxed{14.8\%}$	$\boxed{7.8\%}$	3.8%	1.5%	$\boxed{37.6\%}$
Power Supply	–	3.1%	–	0.8%	0.2%	0.1%	4.2%
Cables and Interconnects	–	2.8%	0.9%	4.7%	0.8%	0.2%	9.5%
Structure	1.2%	0.6%	2.7%	0.6%	0.4%	0.1%	5.6%
Guidance Module Assembly	–	0.2%	–	1.4%	8.2%	0.4%	$\boxed{10.2\%}$
TOTAL	5.0%	35.3%	19.6%	20.6%	16.6%	2.7%	100.0%

* Does Not Include Power Supply Electronics.

▢ Major Cost Drivers

Table V. Second Level EO/TV Guidance Cost Elements–Electronics

STANDARD GUIDANCE COMPONENT	MANUFACTURING COST CATEGORIES						
	Material	Purchased Parts	Fabrication and Processing	Assembly	Test and Inspection	Support	Total
Preamplifier	–	1.7%	0.8%	2.9%	0.5%	0.1%	6.0%
Tracker	–	8.1%	1.2%	4.0%	3.8%	0.5%	17.6%
Demodulator and Rate	–	11.3%	1.0%	2.3%	1.9%	0.5%	17.0%
Relay and Nutation	–	7.9%	0.8%	0.9%	0.8%	0.3%	10.7%
Servoamplifier	–	9.5%	0.8%	2.2%	1.0%	0.5%	14.0%
Sync and Deflection	–	6.7%	1.8%	4.2%	4.2%	0.4%	17.3%
Video	–	7.7%	1.2%	4.0%	3.9%	0.6%	17.4%
TOTAL	–	$\boxed{52.9\%}$	7.6%	$\boxed{20.5\%}$	$\boxed{16.1\%}$	2.9%	100.0%

▢ Major Cost Drivers

The major cost driver for the EO/TV stabilization platform is for the fabrication and processing of the inner gimbal assembly. The EO/TV inner gimbal assembly contains twin spinning motors for momentum stabilization, gimbal bearings, and a gimbal housing. These elements require coil winding, precision machining of detail elements, momentum balancing, etc. These production processes are very similar, and in many cases identical to those required for the similar functioning elements of the laser guidance stabilized platform. The production technology solutions to alleviate the cost drivers on the laser guidance stabilization system such as automated balancing, automated coil winding and alignment, and precision castings or powdered metallurgy will be directly applicable to an EO/TV guidance application.

Correlation of Laser and EO/TV Guidance Cost Elements

A comparison of the laser and EO/TV guidance cost element data from Tables II and IV is depicted in Table VI. As previously noted, Table VI highlights that the major cost drivers for both systems are the electronics and the stabilization platform. Further examination identifies that the detector, structure, and guidance module assembly cost element values are almost identical. There is very little variation between EO/TV and laser guidance in the manufacturing cost categories of material, fabrication and processing, assembly, and support. The minor variations in fabrication and processing, and assembly are related to the variation in purchased parts caused by different manufacture/purchase distributions on the two systems.

The cost percentages for the optics, interconnects, and test and inspection elements of the EO/TV system are higher than those for the laser system. The primary reason for this difference is utilization of improved manufacturing technologies in these areas. Note that the cost data used for the EO/TV system are based on a rate

Table VI. Correlation of Laser and EO/TV Guidance Cost Elements

STANDARD GUIDANCE COMPONENT	LASER	EO/TV
Optics	2.0%	7.2%
Electronics	$\boxed{35.0\%}$	$\boxed{16.7\%}$
Detector	12.0%	9.0%
Stabilization Platform	$\boxed{21.0\%}$	$\boxed{37.6\%}$
Power Supply	11.0%	4.2%
Cables/Interconnects	5.0%	9.5%
Structure	6.0%	5.6%
Guidance Module Assembly	8.0%	10.2%
MANUFACTURING COST CATEGORIES		
Material	3.0%	5.0%
Purchased Parts	47.0%	35.3%
Fabrication and Processing	16.0%	19.6%
Assembly	18.0%	20.6%
Test and Inspection	11.0%	16.6%
Support	5.0%	2.9%
▢ Major Cost Drivers		

production guidance module program which started in production in the early 1970s, while the laser guidance costs are based on the laser HELLFIRE guidance modules currently in Engineering Development. The production technology improvements incorporated in the laser guidance (and now available for the HELLFIRE EO/TV) are:

- Optics–Molded plastic dome and mirror used on laser HELLFIRE in lieu of ground glass dome and lens elements.
- Interconnects–Multi-layer printed circuit boards in lieu of wire harnesses and a build-up motherboard.
- Test and Inspection–Automated computer-aided printed circuit boards and electronics integration test stations in lieu of semiautomated comparitor test stations.

While the electronics and the stabilization platform are the major cost drivers on both the laser and EO/TV systems, their relative positions as shown in Table VI, are reversed. This is caused by two factors:

- Platform complexity for EO/TV.
- Laser electronics components.

The EO/TV platform complexity is greater than that of the laser platform primarily due to the size of the sensor payload to be stabilized. The laser optical mirror is an integral part of the spinning magnet/rotor and thus the payload to be stabilized is the relatively low mass and moment of the laser detector and filter. The EO/TV platform must mount and stabilize an in-line vidicon-lens assembly with significantly increased mass, balance, and momentum requirements. This increases the complexity of the gimbal, bearing, and mechanical caging requirements. Finally, the EO/TV system requires more accurate LOS position information, thereby adding a requirement for a sensitive position pickoff.

While the relative costs within the guidance module are different for the laser and EO/TV stabilization platforms, the manufacturing technology requirements are the same. Both require coil winding, precision mechanical assemblies, and momentum balancing. The production technology solutions to alleviate the cost drivers of one will be directly applicable to the other.

A comparison of the laser and EO/TV electronics cost element data obtained from Tables III and V is listed in Table VII. As can be seen from Table VII, the cost contribution for fabrication and processing (excluding hybrid circuits) and assembly operations is the same for both systems. Test and inspection costs on the EO/TV electronics are higher because, as previously noted, the laser production (taking advantage of five years' advancement in the state-of-the-art) utilizes fully automated, computer-aided printed circuit board testing.

The laser electronics contribution to the laser guidance module cost is inflated over that of the EO/TV electronics to the EO/TV guidance module by two factors:

- The specified Hi-Rel requirements.
- Increased parts count.

The laser guidance module specifies a requirement to use Hi-Rel components. The EO/TV system has no such specified requirement, but rather has a specified system reliability requirement, which was met without resorting to Hi-Rel components.

As can be seen from Table VII, the component count distribution for the types of components (Integrated Circuits, Solid State Devices, Discretes) is approximately the same between the Laser and the EO/TV electronics; yet component cost distribution is different. While the percentage of Integrated Circuits (ICs) used in the laser electronics is about the same as that used in the EO/TV, the cost percentage for the laser ICs is more than twice that of the EO/TV ICs. This cost increase is due to the specified laser guidance requirement to use Hi-Rel integrated circuits.

The other factor contributing to the cost of the laser electronics is the parts count. As indicated in Table VII, the laser electronics parts count is 30 percent higher than that of EO/TV. Included in this higher laser electronics parts count is almost twice the number of integrated circuits.

Table VII. Correlation of Laser and EO/TV Guidance Electronics Cost Elements

	LASER	EO/TV
MANUFACTURING COST CATEGORIES		
Material and Purchased Parts	41.0%	52.9%
Hybrids Fabrication and Processing	19.0%	–
Fabrication and Processing (Less Hybrids)	7.0%	7.6%
Assembly	18.0%	20.5%
Test and Inspection	9.0%	16.1%
Support	6.0%	2.9%
COMPONENT COUNT DISTRIBUTION		
Integrated Circuits and Hybrids	11.0%	7.4%
Solid State Devices	15.6%	18.3%
Discrete Components	73.4%	74.3%
COMPONENT COST DISTRIBUTION		
Integrated Circuits	33.0%	16.0%
Solid State Devices	19.0%	15.0%
Discrete Components	48.0%	69.0%
COMPONENT COUNT		
Integrated Circuits and Hybrids	106*	56
Solid State Devices	155	139
Discrete Components	731	563
TOTAL	996	758

*Includes Four Hybrid Thin/Thick Film Circuits.

TRENDS

Any discussion on guidance manufacturing technology trends must first examine the trends in guidance system requirements; for these are the driving forces creating the need for new and improved manufacturing technologies. The current trends in guidance requirements are:

- Modularity–Self-contained guidance modules interchangeable on the same or different missiles for specific mission and/or functional requirements. Multi-purpose/multi-mode guidance systems are complex, expensive, and difficult to maintain. Interchangeable guidance modules each providing a special capability (i.e., laser, EO/TV, IR, etc) for a specific mission and/or functional requirement appear to be the trend for the immediate future.

- Reliability and Maintenance–The trend in maintainability is for minimal or zero field maintenance–limited to replacement of self-contained sections (i.e., guidance section, control, etc). Coupled with this is a trend for increased "out-of-the-box" reliability requirements at the section level. The Depot level maintenance trend is for replacement of throwaway modules at the printed circuit board level. Implicit in this is the requirement for design of the system into low cost, throwaway modules.

These requirements trends identify the production technology requirements for the next decade:

- Lower cost miniaturized circuitry.
- Lower cost sensor fabrication.
- Higher component reliability at reasonable cost.
- High system reliability.

Part 2 of this paper presents some suggested production technology projects to achieve these goals. Following is a summary of some of the production technology advances and trends currently being pursued in the industry.

Vidicons. The current vidicon assembly process includes matching yoke assemblies and tubes so that the horizontal and vertical scans are interchangeable to permit mounting in either plane. This requirement increases the tube cost because of man-hours used in matching components and a higher rejection rate for both items. Also, the tube performance has been degraded due to compromises necessary in the yoke design to obtain the interchangeability in scan direction. Applications that do not require the scan directions be interchangeable result in a decrease in unit cost due to increased yield and reduction of labor time required. In addition, an optimized yoke design can be used thus improving tube resolution performance.

Current deflection yoke manufacturing techniques are basically hand operations. Several vidicon suppliers are developing a vidicon using "print-on-wall" deflection which has a greater potential for automatic production techniques (present deflections are handmade) and would result in a more rugged tube with improved performance at even lower cost.

Miniaturized Electronics. The trend in requirements for smaller size, higher reliability, lower cost guidance modules has created a need for miniaturized low cost electronics modules. Two answers to this need have emerged:

- Hybrid Thick/Thin Film Circuits.
- Large Scale Integrated (LSI) Circuitry.

Current guidance electronics designs are a mix, in almost equal proportions, of digital and analog circuits. Digital circuits are easier to miniaturize in either the hybrid or LSI mechanization. The trend in circuit design is to replace analog with digital circuit mechanizations wherever possible , i.e., trackers, autopilots, etc.

Digital LSI is one of the most important electronic technology advances, and one of the most powerful tools available for cutting the cost and size of electronic systems. The use of LSI technology makes today's pocket calculator feasible, whereas only a few years ago using non-LSI construction the cost would have been completely prohibitive. Digital LSI technology is capable of constructing several hundred logic gates within a single low-cost unit.

Current analog LSI technology for component count and circuit complexity is not as great as that of digital LSI. Component counts are now approaching 200 per integrated circuit, and the technology continues to improve. Figure 11 shows the trend of monolithic analog component density increase during the past ten years of technical progress in this discipline.

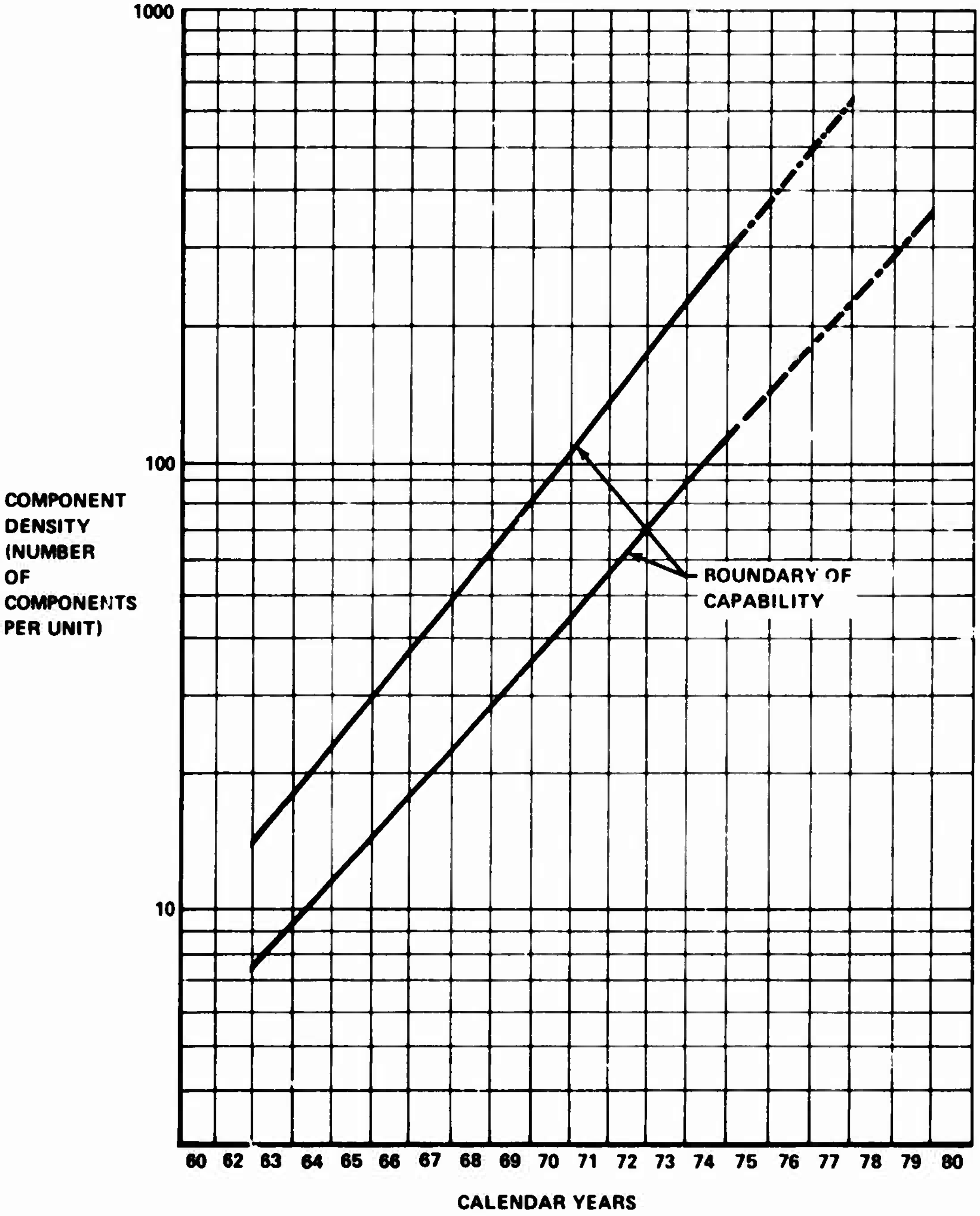

Figure 11. Monolithic Linear Circuit

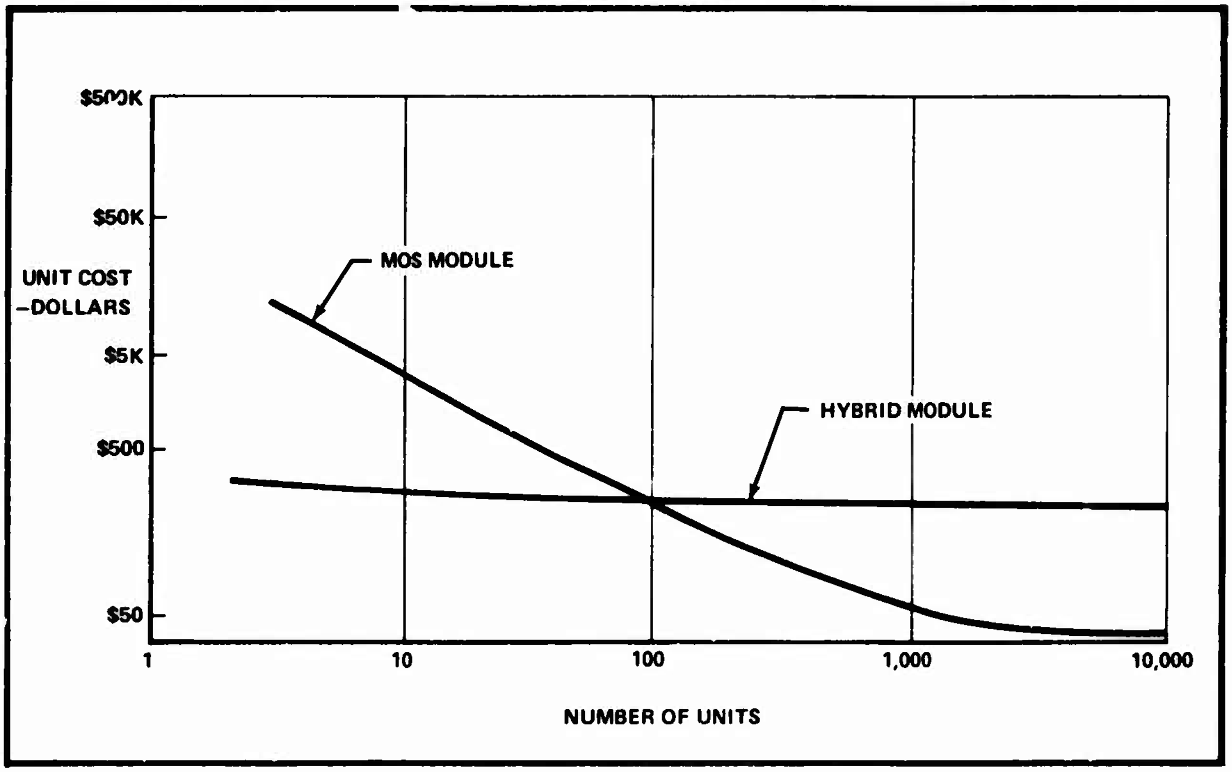

Figure 12. LSI vs. Hybrid Unit Cost Trade-off

While hybrid thick/thin film circuits meet the reduced size and/or volume requirement, they are no more reliable and are more expensive than discrete components on conventional printed circuit boards. Hybrid nonrecurring costs are as high as LSI nonrecurring costs; while hybrid recurring costs are slightly higher than automatically inserted discrete component designs. The cost trade-off between a typical digital circuit in hybrid and LSI mechanization is shown in Figure 12.

Electronic Components Price Trends. One of the largest purchased parts cost elements for both the laser and EO/TV guidance is the electronics components. MSD has conducted a study to evaluate the stability of these prices to establish cost trends. This review utilized recent price trends data of electronic components as depicted in the Bureau of Labor Statistics (BLS) Indices. Also, the subject of cost trends was explored with two well-known electronics firms. The results of the review suggest, in summary, that the typical guidance components (including PWB boards and connectors) will see an increase in cost of approximately 2.7 percent through the 1979 time frame. The BLS Composite Index No. 1178 for electronic components and accessories indicates there has been a 14.3 percent increase in component price from the base year period of 1967 through October 1974 with 11 percent of this occuring during the last two years. We took note that the particular components required by the laser and EO/TV guidance electronics does not, in the main, include those specific components which have contributed heavily to this annual 5.5 percent increase over the last two years.

Integrated circuits, which represent 33 percent of the laser guidance component cost, have actually decreased in cost by approximately six percent over the last two years and by approximately 48.3 percent over the past six years. It appears to be the general consensus that integrated circuits would continue to go down at approximately the same rate as experienced over the last several years due to increased capacity and improved manufacturing techniques; however, this will not apply to TX or Hi-Rel type parts which require more manual testing labor which, in turn, tends to offset efficiencies gained by improved production methods. More specifically, the TX or Hi-Rel, integrated circuits will remain at approximately the present price levels unless costs are severely impacted by significantly higher inflation.

According to the BLS, Solid State Devices, as a family, have increased by 19.4 percent over the last two years but only 5.3 percent since the 1967 base year. Closer scrutiny of the indices shows that the driving force behind these increases may be related to the increased cost of germanium. Since the laser and EO/TV guidance electronics does not require the use of germanium transistors, the data indicates that the price of TX or Hi-Rel transistors and diodes will follow approximately the same path as TX or Hi-Rel integrated circuits; i.e., flat pricing over the next four years.

The BLS Indices covering capacitors, as a family, indicate that the price over the last two years has increased approximately 16 percent. This appears to be attributed mainly to the increased cost of aluminum and other metals. In discussing the question of where capacitors appear to be headed with a major capacitor supplier, they report that they are making the following average unit price projections for the two types of MIL-S capacitors:

	1973	1974	1975	1976	1977	1978
Tantalum	0.207	0.240	0.222	0.208	0.195	0.150
Ceramic	0.182	0.168	0.161	0.156	0.152	0.150

Based on the foregoing, we would expect to see the price of capacitors decreasing by approximately 17 percent below current prices.

The laser and EO/TV guidance utilizes three different types of resistors: metal film, composition, and wire wound. Because of increased industrial usage of metal film resistors, it is expected we will see a five percent or so decrease in the price of this device within the next three to four years. Conversely, the decreasing use of the other two devices is expected to keep the current price relatively flat over the next several years.

A typical manufacturer of connectors believes that the cost will rise at an approximate rate of ten percent per year plus the effect of any increase in the price of gold.

For the inductors and printed wiring boards, an approximately six-percent-per-year increase is estimated.

Precision Casting Trends. As previously noted, precision castings present a potential for some reduction to the high cost of machining the precise gimbal parts. Figure 13 shows the precision casting trends over the past 25 years in three significant parameters:

- Casting size increases.
- Nonrecurring die cost per pound of casting.
- Die cast material allowables.

As shown in Figure 13, the industry capability to accommodate larger precision casting sizes made significant strides during the period from 1950 through 1970. The rate of increase has tapered off since 1970, but the projected trend shows a potential for 10 to 15 percent increase during the period from 1975 through 1980.

Nonrecurring costs, utilizing the parameter of nonrecurring die cost per pound of casting produced showed a significant reduction during the period from 1950 through 1965. Since then, this has stabilized and as can be seen in Figure 13, nonrecurring die costs per pound of castings have held steady in the past ten years while finished casting sizes have increased.

Finally, aluminum precision casting material allowables have shown a steady increase over the past 25 years with no indication of reduction in the rate of improvement over the next five- to ten-year time period.

Nonmetallic Fabrication. Increased utilization of composite nonmetallic materials for structural elements is the trend for the next decade in missile production. Figure 14 illustrates the trend since 1950 of two significant production parameters for both nonmetallic injection and compression molding.

- Improvement of tolerances achievable.
- Increase in size of parts to be molded.

As shown in Figure 14, injection molding has made the most significant improvements in these two parameters with no indication of slacking off in the rate of improvement.

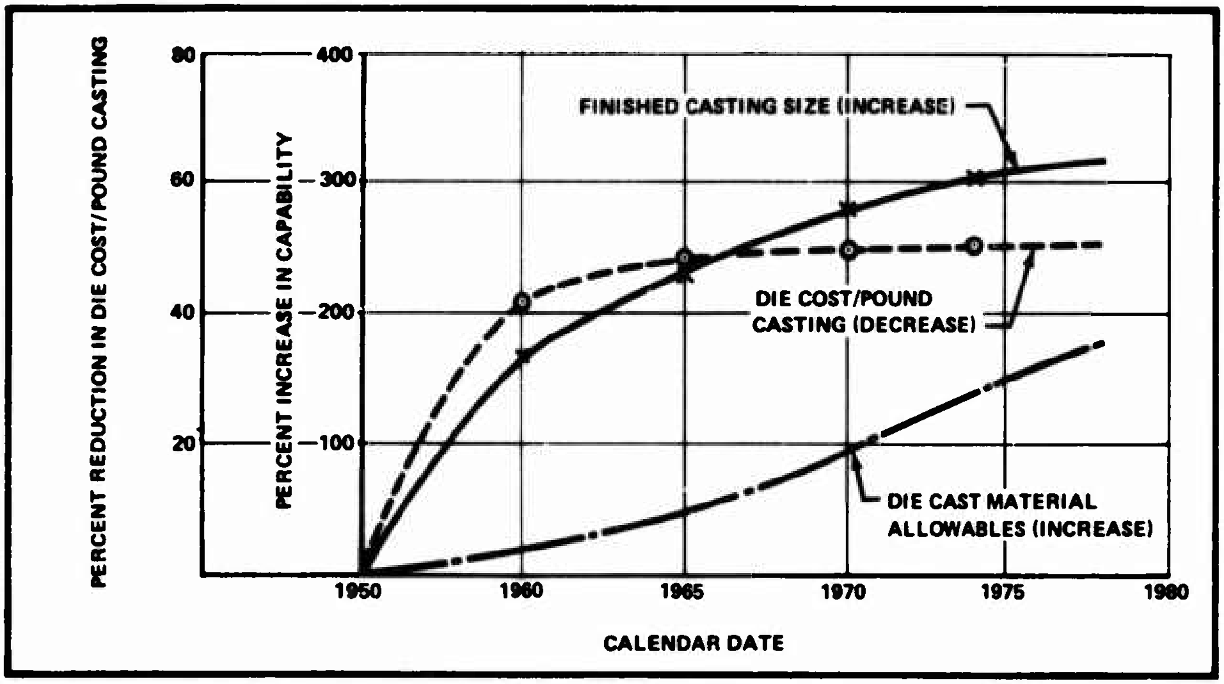

Figure 13. Precision Casting Tr. nds

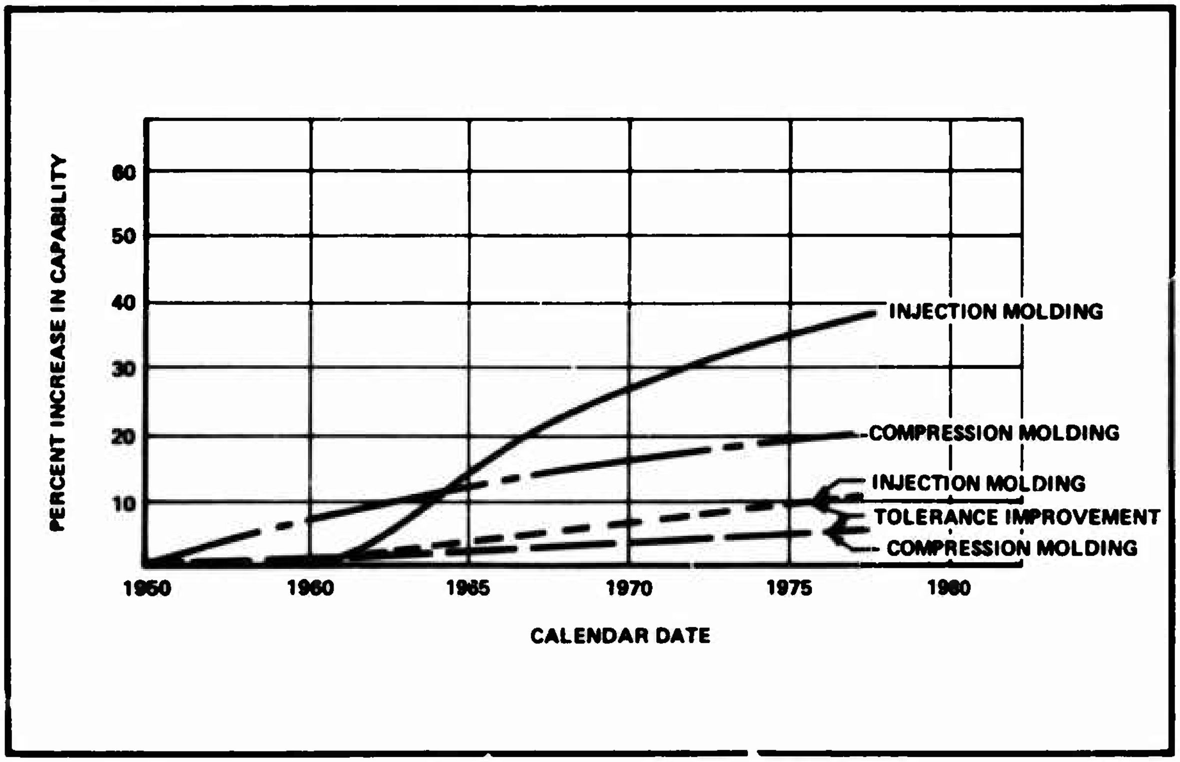

Figure 14. Structural Nonmetallics T. ends

PART II

PROJECT SUMMARIES

PROJECT SUMMARY–1

TITLE: Manufacturing Technology Project to develop economical nonrecurring cost automated failure diagnosis and repair indication.

SYSTEM/SESSION AREA/COMPONENT: HELLFIRE/Guidance/Electronics (testing)

PROBLEM: A major cost driver in Guidance System electronics production testing is the cost of trouble shooting and repair. This is equally true of other missile system electronics (autopilot, power supply, etc). These costs can increase testing time by factors of three to four and repair time by factors of two to three, especially when manual methods are required. Automated equipment having the prime function of verifying acceptable parameters usually provides little information for failure diagnosis and repair. There is also a need for retaining some test measurements for reliability predictions and trend analysis. Incorporation of these facilities into automated production test equipment is an expensive nonrecurring cost that makes it impractical to accomplish separately on different missile programs. A more generalized approach using equipment having application to the general class of missile systems electronics is needed to reduce production testing costs on all programs.

PROPOSED SOLUTION: Develop an approach to trouble shooting, failure diagnosis and test parameter monitoring that utilizes computer-aided automatic equipment to analyze and provide a repair instruction printout for rejected electronics subassemblies. Design and fabricate the necessary testing equipment. Develop the necessary adaptability to make the equipment usable for multiple guidance applications.

PROJECT COST AND DURATION: Estimated costs are as follows:

Develop Approach and Design Equipment	$175,000
Procurement and Fabrication of Test Set	$550,000
System Software	$125,000
Documentation	$ 75,000
Total	$925,000

Estimated duration is 30 months.

BENEFITS: Reduced nonrecurring costs for reject analysis equipment. Reduced recurring costs for reject analysis time by approximately 75 percent, and reduce repair time by 50 percent.

Reduction in reject analysis cost	–	2.11% of missile cost
Reduction in rework costs	–	0.47% of missile cost
Net Reduction		2.58% of missile cost

ASSUMPTIONS:

(1) Labor is 50 percent of missile or guidance module cost.

(2) Based on production histories, 10 percent of missile labor costs are expended in reject analysis (trouble shooting), rework identification and repair. Further, 75 percent of this time is due to electronic subassemblies and systems rejects, and 75 percent of the time is expended on reject analysis.

$\therefore$ 0.10 (0.75) (0.75) = 5.6% of missile labor is electronics and system reject analysis.

0.10 (0.75) (0.25) = 1.9% of missile labor is electronics and system rework.

(3) Project cost is amortized over 25,000 units of laser and EO/TV guided missiles.

PROJECT SUMMARY–2

TITLE: Manufacturing Technology Project to develop automated coil winding fabrication and concurrent electrical alignment and balancing.

SYSTEM/SESSION/COMPONENT: HELLFIRE/Guidance/Stabilization System

PROBLEM: The HELLFIRE Laser Seeker is a high volume guidance module for which fabrication assembly and test of the head coil assembly is a major cost driver in the guidance module. The winding and testing of coils and head coil assembly is labor intensive. The development of an automatic coil winding and testing capability would not only reduce guidance cost but increase unit reliability. In addition, this technology would be adaptable to spin rotor coil winding for other guidance systems.

PROPOSED SOLUTION: The Production Technology project would be to develop equipment tooling, flow processes and techniques to automatically wind and test coils. Included in the project would be the assembly (forming) of gyro drive/reference coils and interconnecting coil assembly as well as potting of the head assembly. A pilot line would be equipped, set up, and proofed out as part of this project.

PROJECT COST AND DURATION: Estimated costs are as follows:

Design Equipment	$ 35,000
Pilot Winding Equipment Procurement and Fabrication	$ 39,000
Pilot Test Equipment Procurement and Fabrication	$ 87,000
Setup and Proof	$ 25,000
Operation Support	$ 15,000
Total	$201,000

Estimated duration is 18 months.

BENEFITS: The basic results would be the reduction of the HELLFIRE guidance coil winding cost by approximately 50 percent, and improve yield by 67 percent.

Reduction in coil winding costs	–	2.31% of guidance cost
Improvement in coil winding yield cost	–	1.41% of guidance cost
Net Reduction		3.72% of guidance cost
		2.23% of missile cost

ASSUMPTIONS:

(1) Project cost is amortized over 15,000 laser guidance systems.

(2) Guidance is 60 percent of missile cost.

PROJECT SUMMARY–3

TITLE: Manufacturing Technology Project to develop economical nonrecurring cost automated electronics alignment and test.

SYSTEM/SESSION/COMPONENT: HELLFIRE/Guidance/(Testing)

PROBLEM: Electronics alignment and testing equipment development represents a large nonrecurring cost, especially affecting development programs and initial production. This cost is incurred on each new design because the equipment and test procedures are oriented to the specific requirements of a given program. Automated, generalized test methods and equipment have been developed for many applications and automated equipment is usually planned for high rate production. The problem is developing the application of automated generalized equipment to the class of guidance system electronics so that the technology can be transferred among programs and designs in the form of directly usable equipment.

PROPOSED SOLUTION: Design, develop, and construct automated alignment and test equipment generally applicable to laser seeker systems electronics. The nature of the test equipment would be to use the comparison method of test which compares production units with working standards with the facility for cross checking with various signal inputs.

PROJECT COST AND DURATION: Estimated costs are as follows:

Design and Development	$100,000
Fabrication and Demonstration	$400,000
System Software Development	$ 50,000
User Documentation	$ 50,000
Total	$600,000

Estimated duration is 24 months.

BENEFITS: Reduced nonrecurring cost for alignment and test of laser seeker system electronics by approximately 30 percent.

PROJECT SUMMARY–4

TITLE: Manufacturing Technology Project for dynamic balancing of momentum stabilization systems through the use of laser balancing or other automated techniques.

SYSTEM/SESSION AREA/COMPONENT: HELLFIRE/Guidance/Gyros

PROBLEM: The HELLFIRE Laser Seeker is a high volume low-cost system in which the balancing of the stabilization system is one of the major cost drivers. The present techniques of balancing in two planes is very expensive and time consuming, requiring balancing in one plane and then balancing in a second plane, rebalance first, etc. Generally, disassembly is required to balance for removal or addition of material for proper balance. Recent developments with high energy lasers indicate the possibility of accurate metal removal using the laser. The primary problems with this technique are that it has not been done in production and the possible effects on mirror, prevention of contamination of optical surfaces or bearings.

PROPOSED SOLUTION: The proposed solution would be the setup of a pilot station for balancing by laser removal of material, including balancing fixtures, shields, and high energy laser. The primary emphasis would be to develop an automated contamination free and cost effective laser material removal balancing system. A computer would be used to measure this imbalance, compute the correction required, the location and amount of material to be removed, and the laser position and duration time.

PROJECT COST AND DURATION: Estimated costs are as follows:

Design and Engineering Support	$ 58,000
Laser and Balance Sensing Equipment	$110,000
Assembly Fixture and Tools	$ 23,000
Procurement (Computer, Etc)	$150,000
Operations Support	$ 28,000
Total	$369,000

Estimated duration of 24 months.

BENEFITS: Reduction of balancing time and improved yield by approximately 50 percent.

Reduction in balancing costs	–	1.61% guidance system cost
Improved yield savings	–	0.16% guidance system cost
Net Reduction		1.77% guidance cost 1.06% missile cost

ASSUMPTIONS:

(1) Project cost is amortized over 25,000 units of laser and EO/TV guided missiles.

(2) Guidance is 60 percent of missile cost.

PROJECT SUMMARY–5

TITLE: Trade-off Study of Hi-Rel Components versus Screening versus Burn-in Techniques

SYSTEM/SESSION AREA/COMPONENT: HELLFIRE/Guidance/Electronic Components

PROBLEM: In accordance with contract specification, the use of Hi-Rel MIL-STD parts is imposed on the HELLFIRE guidance design. The cost of these parts becomes a significant cost driver in the production seeker. This requirement coupled with the increasing emphasis on operational reliability has resulted in ever increasing requirements for testing at all levels of production. This proliferation of testing has increased production tests costs for purchased parts, in-process testing, and acceptance testing, including "burn-in," to cost driver levels. Some observations suggest that corresponding levels of reliability improvement are not being achieved.

PROPOSED SOLUTION: This project would design and conduct a carefully controlled experiment to gather accurate and meaningful data relative to the effectiveness of the various reliability screening tests, that is Hi-Rel components, MIL-STD TX tests, receiving inspection screening, operational burn-in at assembly level, and temperature shock testing at printed circuit board level. Sample parts of real missile hardware would be fabricated and subjected to each of the screening techniques. Hi-Rel components, temperature conditioning tests on various assembly levels, in-process environmental tests, and burn-in would then be inserted and withheld on a controlled basis and the results analyzed.

PROJECT COST AND DURATION: Estimated costs are as follows:

Design and Proceduralize Experiment	$ 75,000
Sample Hardware Procurement and Fabrication	$300,000
Data Collection and Analysis	$220,000
Total	$595,000

Estimated duration is 30 months.

BENEFITS: The benefits from the project are a potential reduction in recurring labor and purchased material cost of as much as 12 percent. However, successful outcome of this project would result in large cost reductions on other system elements and other programs.

Reduction in Electronics Purchased Parts Cost –	3.12% guidance cost
Net Reduction	3.12% missile cost

ASSUMPTIONS:

(1) Project cost is amortized over 25,000 laser and EO/TV guided missiles.

(2) Laser guidance purchased parts impacted by this project is 26 percent of laser guidance cost. This same ratio would apply to other guidance modules and their control sections.

PROJECT SUMMARY–6

TITLE: Manufacturing Technology Project to develop economical heaters for photo detectors.

SYSTEM/SESSION AREA/COMPONENT: HELLFIRE/Guidance/Detector

PROBLEM: Present requirements for laser photo detectors necessitated that heaters be integrated into their packages to offset an otherwise 40 percent degradation in quantum efficiency at ambient operational temperatures of −65°F. The heaters typically are required to raise the silicon temperature from −65° to +60°F in 30 seconds or less with 6 watts input power.

Heaters integrated into this type of photo detector have experienced very low yield. Explanations which have been advanced by the photo detection industry have been that the heaters opened circuit under cycling or that the silicon was heated nonuniformly. Heaters must withstand up to 2000 cycles. Heater designs have been serpentine layouts of thin film nichrome deposited on the back side of the ceramic support for the silicon wafer. A minute fracture of this type of design is generally catastrophic.

PROPOSED SOLUTION: Perform trade studies and build feasibility models of heater designs employing both nichrome and cermet deposition technologies. Technology has evolved in the thermal printer industry yielding ultra thin resistive elements of cermet. Therefore, large area conductive paths are possible which should improve thermal uniformity and reduce the catastrophic effects of fractures under repeated on-off cycling. Select the most reliable heater technology and conduct production optimization studies as to the most cost effective method of manufacture of the heater element (i.e., deposition, sputtering, etc).

PROJECT COST AND DURATION: Estimated costs are as follows:

Engineering Developmental Analysis and Requirements	$45,000
Prototype Fabrication and Test	$35,000
Total	$80,000

Estimated duration is 12 months.

BENEFITS: The cost savings of a successful trade study for the heater would be very significant since its yield improvement is directly related to the yield improvement at the detector level. That is, failure of a heater normally would occur after integration of the heater and silicon into the detector, making the expensive silicon wafer nonrecoverable.

Reduction in Detector Cost	–	0.9% guidance cost
Improvement in Detector Assembly Yield	–	1.2% guidance cost
Net Reduction		2.1% guidance cost
		1.26% missile cost

ASSUMPTIONS:

(1) Project cost is amortized over 15,000 laser guidance units.

(2) Guidance is 60 percent of missile cost.

PROJECT SUMMARY–7

TITLE: Manufacturing Technology Project for reduction of cost for cutting and polishing of high purity silicon detector wafers.

SYSTEM/SESSION AREA/COMPONENT: HELLFIRE/Guidance/Detector

PROBLEM: A number of companies prepare large quantities of small silicon wafers by sawing and polishing. The preparation is equipment intensive and is low cost. Wafers prepared for large area, high performance silicon detectors have additional requirements.

(1) Polished on two sides.
(2) Surface quality, flatness, and parallelism.
(3) High yield.
(4) Minimal surface damage.

The material requirements for the Army and the Air Force over the next five years are 2000 to 2400 kilograms of silicon which corresponds to 1.5 to 1.8 million wafers.

Processing such a large number of wafers, significant cash savings may be realized by addressing each of the requirements previously listed.

PROPOSED SOLUTION: Since both surfaces of the wafers are to be polished, double-face polishing (that is polishing both faces simultaneously) should be explored. The goal would be to minimize machine time required for polishing and to improve flatness and parallelism, as is consistent with yield.

The nature of silicon photo-voltair detectors requires wafers with minimal surface damage which is our source of excess dark currents. The degree of surface damage that is tolerable has not be quantified. A method of evaluating the surface quality of a wafer should be determined. The surface quality required can only be determined by the fabrication and test of satisfactory high performance photo-diodes. Exploration of wafer preparation should be accompanied by a detector fabrication and evaluation activity.

Slicing techniques such as a gang saw using a slurry of grinding compound should be used for time considerations. Possible cooling contamination is a consideration. The silicon material costs on the order of $10/gram and so "kerf" losses should be minimized by using a wire (gang) saw. The cutting abrasive used for sawing should be optimized to give minimum surface damage and to require minimum material removal during the polishing steps.

PROJECT COST AND DURATION: Estimated costs are as follows:

Engineering Design	$ 75,000
Pilot Equipment	$120,000
Setup and Proof	$ 85,000
Production Engineering	$ 50,000
Total	$330,000

Estimated duration is 24 months.

BENEFITS: The benefits of this project are a reduction in cost of up to 25 percent in wafer cost which translates into approximately a 15 percent reduction in detector costs.

Detector Cost Reduction	1.00% guidance costs
Net Reduction	0.06% missile cost

ASSUMPTIONS:

(1) Project cost is amortized over 25,000 laser guidance units.

(2) Guidance cost is 60 percent of missile cost.

COST CONSIDERATION FOR LASER GUIDANCE DESIGNATOR PRODUCTION

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ABSTRACT

Cost-effective production of Laser Guidance Designators is a function of a number of factors. Production costs are directly influenced by the quantity of units to be produced and the manufacturing techniques and processes used in the fabrication and tests of the units. Of equal importance is the requirement that the laser be designed for production to the fullest extent possible. For a minimum-cost, production-engineered system all components should be specified only to the extent absolutely necessary and with as broad a tolerance range as possible. Clearly, simplicity of design and minimization of components also is critical.

Major cost of optical components in a LGD system include the laser rod, Q-switch assembly, resonator optics, collimating optics, and sighting optics. The laser rod is the dominant single-cost element at 8 to 10% of the total system cost. The costs of the various components is a strong function of the performance requirements of the laser. For instance, a laser requiring a low beam divergence will require much more expensive collimating optics than a system with less stringent beam divergence specifications. Tradeoffs between Nd:YAG laser rod sizes and tolerance effects on laser performance and manufacturing techniques are discussed with the intent of ultimately defining laser rod specifications for production systems. This discussion is appropriate because the laser rod is currently the single dominant element of component cost.

Manufacturing methods and technology for LGD are discussed and include: (1) identification of major cost items and tradeoffs in the manufacture of LGD; and (2) a discussion of the optical test requirements of LGD.

INTRODUCTION

Laser development continues to expand not only in technology and reliability, but in the numbers of fielded systems. Within the next few years significant quantities of additional Laser Guidance Designators (LGD) will be produced such as the Ground Laser Locator Designator (GLLD). The need for efficiency in using personnel and material resources expands at a rate equal to or greater than the number of systems produced. This is due both to the extended life over which these systems will be operated and maintained as well

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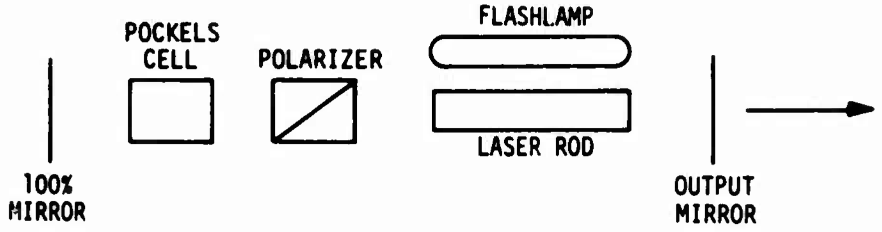
as to the high skill level of the personnel currently required to operate and maintain these systems. Until now, systematic efforts to expand manufacturing technology have not been pursued in depth due to the small number of laser systems produced of any one particular type. To realize the substantial savings which can be expected through improvements in manufacturing technology, this systematic study must be performed prior to the initiation of larger production quantity manufacturing. Cost performance tradeoffs and improved measurement techniques of the LGD as they relate to fabrication and maintenance is a requirement for cost effective production. The U. S. Army Missile Command is currently funding two companies to investigate certain aspects of manufacturing methods and technology for Laser Guidance Designators.

Cost effective production of Laser Guidance Designators is a function of a number of factors. It is clear that production costs are directly influenced by the quantity of units to be produced and the manufacturing techniques and processes used in the fabrication and tests of the units. However, of equal importance is the requirement that the laser be designed for production to the fullest extent possible. For a minimum cost production engineered system all components should be specified only to the extent absolutely necessary and with as broad a tolerance range as possible. Also the laser should be capable of achieving at least 30% greater performance than is required for production acceptance. This paper will discuss the impact of performance specifications upon unit cost and will present tradeoffs for specific components. Clearly, simplicity of design and minimization of components is critical for both lowest initical cost and system maintenance.

Major optical component costs in a LGD system include the laser rod, Q-switch assembly, resonator optics, collimating optics and sighting optics. The cost of the various components is a strong function of the performance requirements of the laser. Of the performance requirements, low beam divergence is the most costly. For example, a laser requiring a low beam divergence will require much more expensive collimating optics than a system with less stringent beam divergence specifications. Also, optical quality specifications will be much tighter, and the cost higher, on all optical elements in the resonator. In addition, a more complex resonator is usually required. Environmental temperature requirements will always impact on system cost but a low beam divergence laser system is especially susceptible to temperature fluctuations. Tradeoffs between Nd:YAG laser rod sizes and tolerance effects on laser performance and manufacturing techniques must be examined with the intent of utlimately defining minimum laser rod specifications for production systems. This tradeoff is required because the laser rod is currently the dominant single component cost element in the laser system with a percentage cost of 8 to 10% of the total materials cost. The next most expensive element is the $LiNbO_3$ Pockels cell which represents approximately 5% of the total materials cost. The substitution of dielectric polarizers for calcite polarizers has resulted in a significant cost reduction with the added bonus of improving some system performance parameters. This paper will discuss only optical resonator components in the belief that improvements in this portion of the laser will have the greatest impact on system costs.

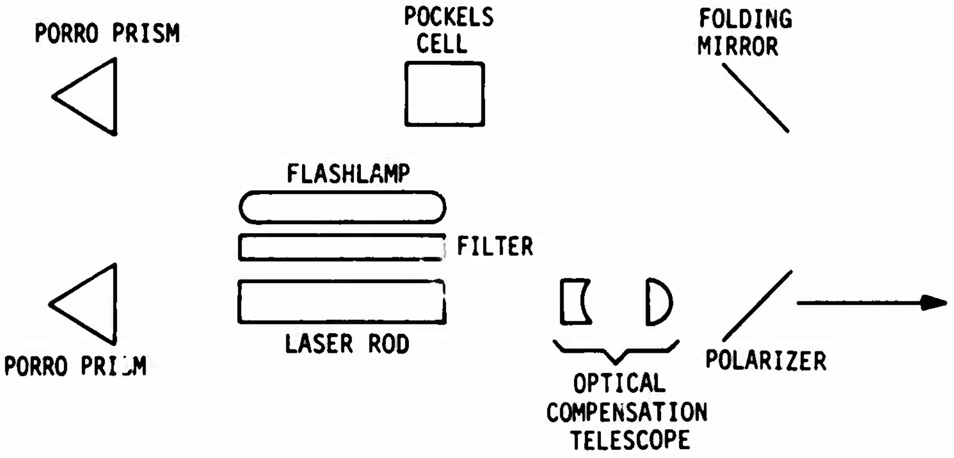
RESONATOR DESIGN CONSIDERATIONS

In Figure 1 are shown the optical schematic of two different types of laser resonators. Type A represents the simplest form of laser resonator feasible for use in a LGD. It consists of a simple Fabry Perot interferometer, the Pockels cell Q-switch and a laser rod, pumped by a flashlamp all in a simple in-line configuration.



SIMPLE Q-SWITCHED LASER RESONATOR

FIG. 1A



ILS HIGH BRIGHTNESS RESONATOR

FIG. 1B

Type B represents an interferometer configuration typically used by International Laser Systems consisting of a folded interferometer with each end of the interferometer terminated by a Porro prism rather than a flat or curved mirror. The energy output of the system is coupled out through a polarizer. It is clear that the Type B resonator is more complex than the Type A resonator. What may not be clear is why the complexity is required.

First let us consider the reason for folding the interferometer. Most laser guided designators require a very small beam divergence. Typically, laser beam divergence and interferometer length is inversely related in that the longer the interferometer length, the smaller the beam divergence. Also of primary consideration is the fact that the system must be reliable and, therefore, the possibility of damage to the laser optics must be reduced to a minimal level. To this end the pulsewidth of the laser designator should be no more narrow than is absolutely necessary. For a given output energy, laser peak power should be as low as possible. Again, this requires a longer resonator, the pulsewidth being directly proportional to resonator length for a given energy output. Another design consideration is that typically the LGD must be as small, compact and lightweight as possible. To this end it is usually not feasible to have a long in-line resonator on the order of 20 to 30 inches. It is preferable to optically fold the interferometer so that small packages on the order of 10 to 15 inches physical length may be achieved. Flat-flat resonators such as shown in Type A are very sensitive to misalignment and very difficult to keep aligned in a severe shock and vibration environment or over temperature extremes. The Porro prisms in Type B are primarily used to make the system more tolerant of severe environmental conditions. The telescope shown in the Type B interferometer is used to compensate for the thermal distortion introduced in the laser rod by the internal temperature gradients generated when the rod is operated at high pulse repetition rates. This lens is required to give the low beam divergence required of the LGD. We see, therefore, that the increased complexity and the increased cost of the Type B resonator over the Type A is a result primarily of the performance specifications and performance requirements of the LGD. The Porro prisms are considerably more expensive than flat mirrors; alternative arrangements are known which make use of less expensive optical components but these designs have not been developed. The optical compensation scope is an additional cost element in the laser resonator but its use is currently required for low beam divergence.

COMPONENT TRADEOFF ANALYSIS

General

Tradeoff analyses are used in relaxing or modifying the specification of laser components to effect reduced costs and/or ease of fabrication. The results of these efforts will be the basis for establishing accept/reject criteria for initial component inspection.

To provide a basis for the tradeoff analysis, a percentage cost breakdown for a laser system is shown in Table 1. This table will vary from manufacturer to manufacturer according to which items are purchased and which are manufactured in-house. Also, the table applies to low volume manufacture and performance testing of the laser only to the poin environmental testing begins. This testing usually represents a significant portion of a system cost but the exact cost is strongly dependent upon the individual system and the specified test requirements. In any event, it is shown that material and labor are divided approximately 50 - 50 for a low volume production. Actual fabrication of the unit including materials (not including test and inspection) represents approximately 80% of the system cost.

Table 1. LASER COST BREAKDOWN

Category	Percent of Manufacturing Costs
Labor	50%
Fabrication	30%
Test & Inspection	20%
Environmental Testing	Not Included
Material	50%
Laser Resonator	20%
Laser Rod	8%
Pockels Cell	4%
Electronics	24%
Cooling System	6%

In a current ILS MM&T program, selected components are installed in a special breadboard laser in direct substitution for a component of known high quality used as a standard of reference. The effect of each component parameter variation is measured on system performance parameters, i.e., energy output, beam divergence, pulsewidth, Q-switch holdoff energy, etc. As each component type is tested over the range of tolerances selected, tabulations and graphical analyses are developed relating optical quality to system performance. A close correlation of system performance with component quality measurements will allow the development of accept/reject criteria based on physical parameter measurements which are generally more easily made than the substitution test in a laser system. If there is less correlation than expected, further analysis must be done on the tolerances and/or the basic parameters which control laser performance of the given component.

It is expected that some components may be of unnecessarily high quality for their intended function in a given system, since some criteria were established on the basis of sufficiency rather than extensive tradeoff tests. It is also possible that a component may be marginally specified for its particular function by the same arguments. Additional folding prisms represent added cost and complexity but their use is necessitated by the desire to achieve a very lightweight, small package. Folding prisms and Porro prisms optical quality are of extreme importance in that their optical quality may effect both laser beam divergence and laser efficiency. Anti-reflection coatings on all optics effect system efficiency and are also critical in an optically folded system.

Laser Rod Performance - Cost Tradeoffs

The requirement for minimum weight in laser guided designators often drives the design toward achieving the maximum possible efficiency without a great deal of concern for specific component costs. The relationship between component cost and efficiency as a function of Nd:YAG rod geometry is indicative of several cost tradeoffs for a LGD.

The LGD energy output requirement may be met by several different sizes of laser rods. The performance of 5 x 75 mm, 0.25 x 3 inch and 0.25 x 4 inch Nd:YAG laser rods is shown in Figures 2, 3, 4 and 5. All of these rods will provide the output requirements for a LGD but with different efficiencies. For instance, in Figure 2 we see that the poorest performance is obtained with a 5 x 75 mm rod and a 25% reflector. Even this combination yields 200 millijoules with a 10 joule pump. Performance data are taken with a Type A interferometer but with no Q-switch in the interferometer. All data is for normal mode only. This represents the most efficient possible operation of the laser system. Any additional component inserted with the resonator will decrease system efficiency. For each size rod, we wee the relationship between the output energy and the input energy from the flashlamp. In all cases we see that efficiency may be increased by increasing the reflectivity of the output mirror. This represents a tradeoff between efficiency and reliability due to the fact that the higher the mirror reflectivity used in the system, the greater the possibility of incurring damage to the laser interferometer as a result of higher power densities in the laser resonator. Each graph in Figures 3, 4 and 5 represents a sample of 6 rods. The variance, the maximum and the minimum lines for each mirror reflectivity, represents the poorest and best performance obtained with the rods within the sample group. It is clear that in all cases the deviation from rod to rod is relatively small. The maximum deviation around the median occurs with a 5 x 75 rod as shown in Figure 5. A 50% reflector is shown to give ±10% deviation in efficiency. This represents a very acceptable tolerance range for production systems and would appear to offer a very low rejection ratio. Figure 6 shows a tradeoff between system efficiency and rod length for rod diameters of 0.25 inches. As shown in the figure, if a 0.25 x 3 inch

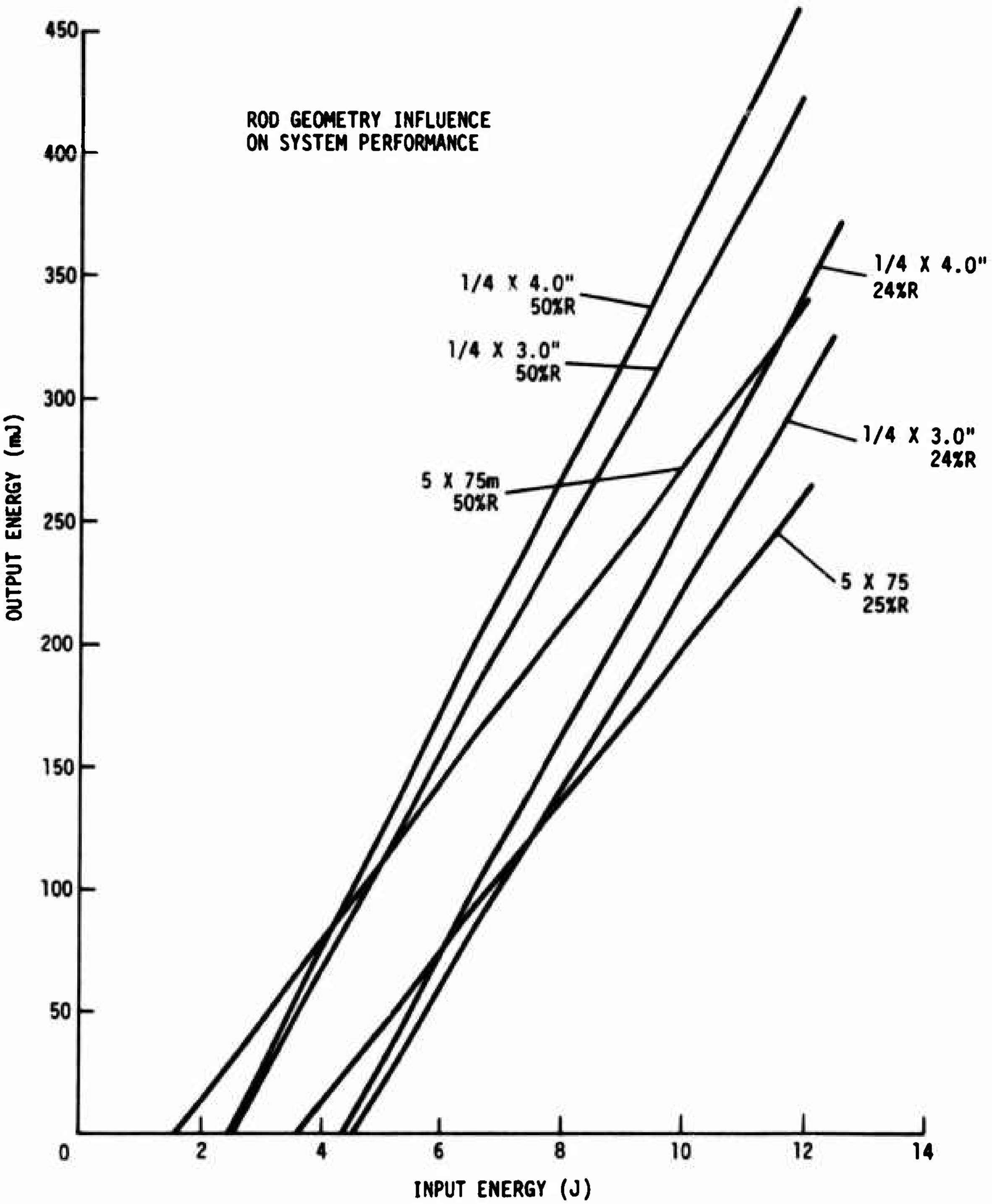

ROD GEOMETRY INFLUENCE
ON SYSTEM PERFORMANCE
1/4 X 4.0"
50%R
1/4 X 3.0"
50%R
5 X 75m
50%R
1/4 X 4.0"
24%R
1/4 X 3.0"
24%R
5 X 75
25%R
OUTPUT ENERGY (mJ)
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
INPUT ENERGY (J)

FIGURE 2

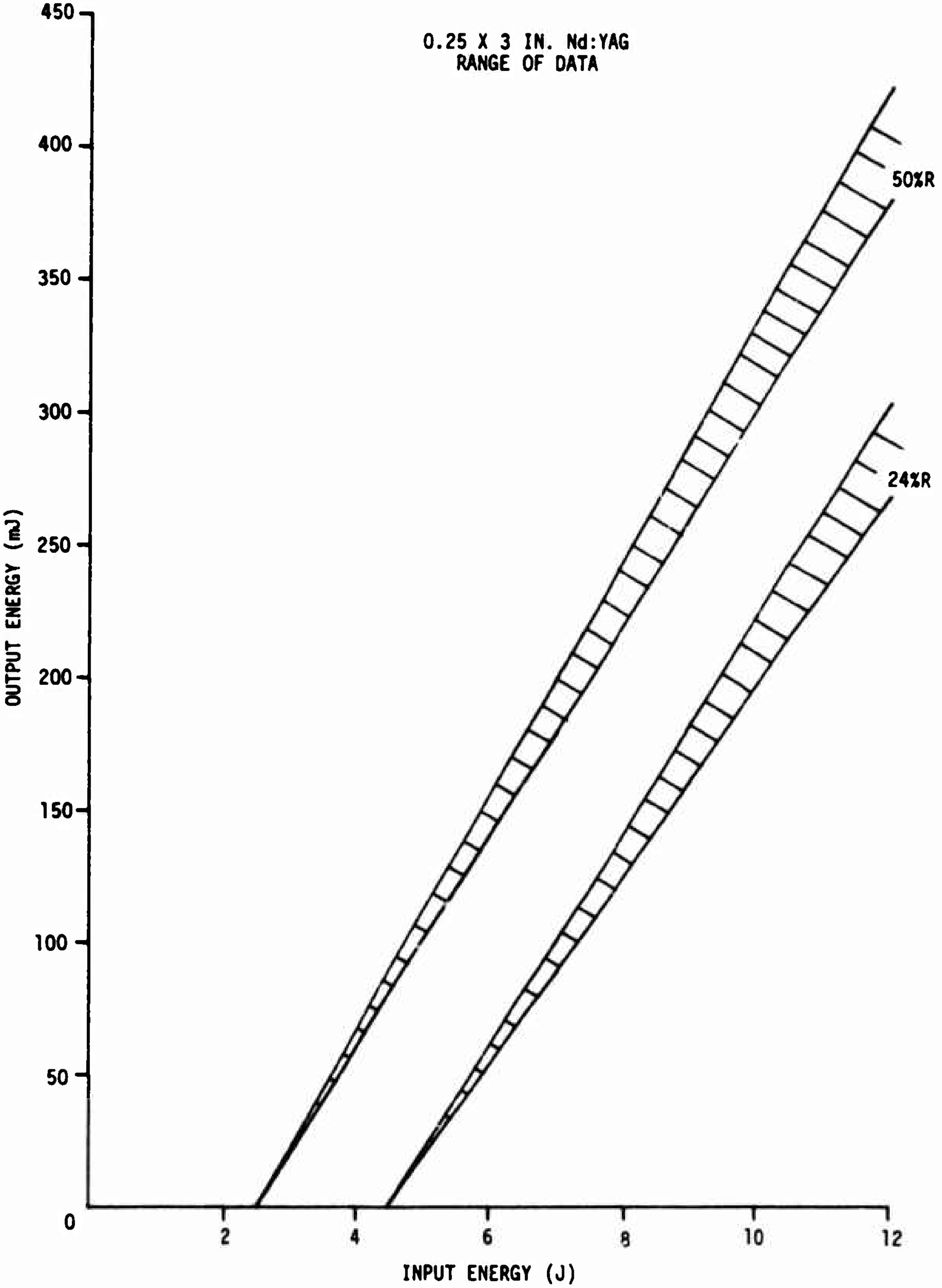
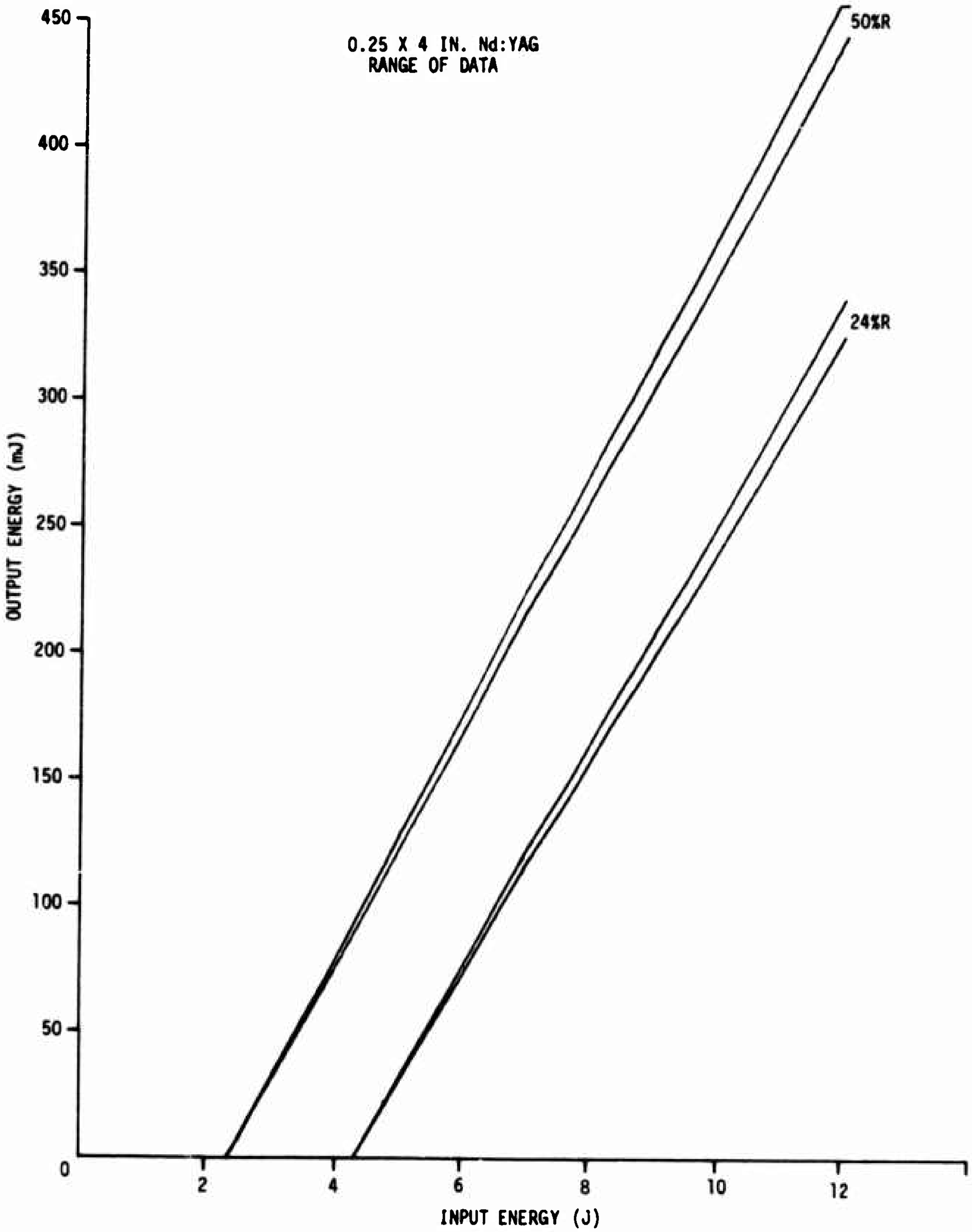

0.25 X 3 IN. Nd:YAG
RANGE OF DATA
50%R
24%R
OUTPUT ENERGY (mJ)
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
INPUT ENERGY (J)

FIGURE 3



0.25 X 4 IN. Nd:YAG
RANGE OF DATA
50%R
24%R
OUTPUT ENERGY (mJ)
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
INPUT ENERGY (J)

FIGURE 4

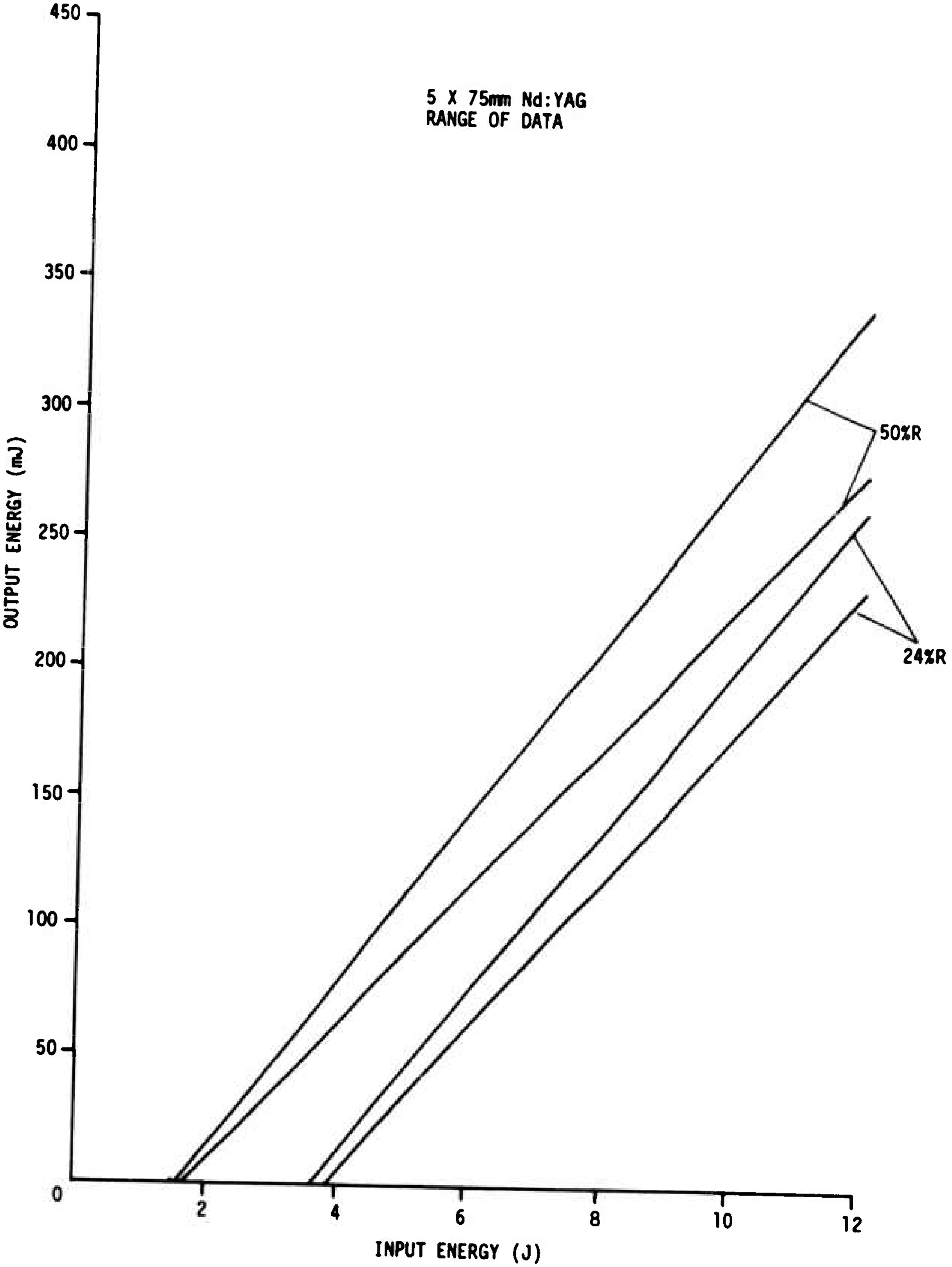

5 X 75mm Nd:YAG
RANGE OF DATA
OUTPUT ENERGY (mJ)
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
INPUT ENERGY (J)
50%R
24%R

FIGURE 5

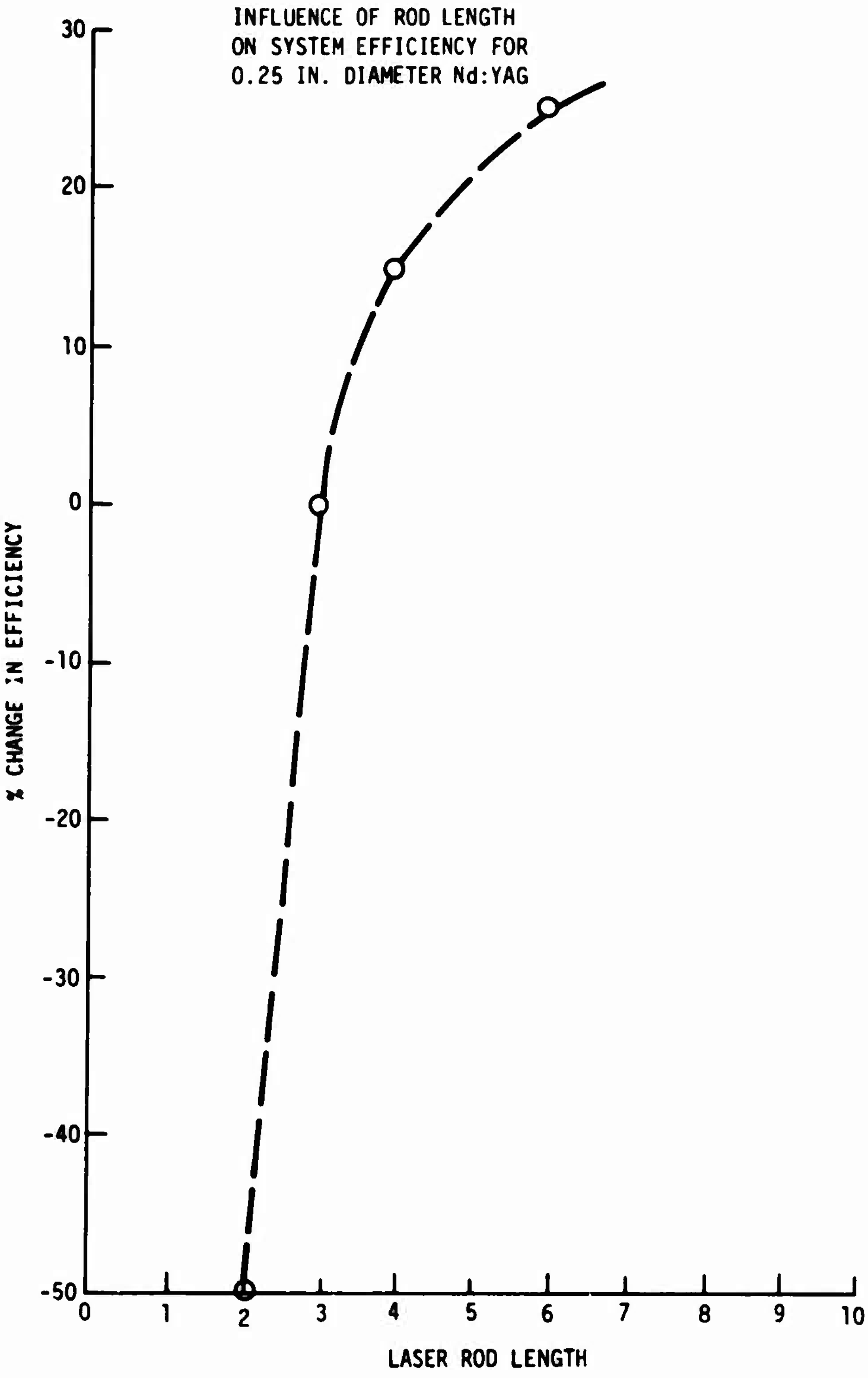

INFLUENCE OF ROD LENGTH
ON SYSTEM EFFICIENCY FOR
0.25 IN. DIAMETER Nd:YAG
% CHANGE IN EFFICIENCY
30
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7
8
9
10
LASER ROD LENGTH

FIGURE 6

rod is used as the norm; only about 15% improvement efficiency may be obtained by using a 0.25 x 4 inch rod. Conversely, if a 0.25 x 2 inch rod is used, system efficiency may drop by 50% from that obtained from the 0.25 x 3 inch rod. This is meaningful if one considers the cost of the various rods. In Figure 7 we see that the 0.25 x 4 inch rod, which costs approximately $780 in quantities of 1000, offers a very small performance advantage over the 0.25 x 3 inch rod costing $630 in quantities of 1000. A 15% increase in performance is obtained with a 24% increase in cost. In contrast, the 0.25 x 2 inch rod offers a 25% cost savings over the 0.25 x 3 inch rod but with a 50% drop in efficiency. If system weight is the dominant criteria, then a 0.25 x 6 inch rod may be required. This rod offers a 25% improvement in efficiency for a 70% cost increase. If weight of the system is not all important, then similar cost versus performance must be generated on the laser power supply and cooling system before the system can be optimized from a cost-performance tradeoff standpoint.

Flashlamp Tradeoff

Flashlamp technology has improved significantly in the last two years. A flashlamp represents approximately 1% of the system material cost. Its replacement is no longer a major item as demonstrated by the following table showing lamp performance at a level compariable with a LGD. The major production effort on lamps at this point in time should be the development of a cost effective technique for detecting early failures. A burn-in procedure is a possible technique.

Table 2. FLASHLAMP SHOTS BEFORE FAILURE (ILS ML-1)

Lamp No.	Date Installed	Date Removed	Shots
1	Unknown Fla.	10/27/74	20,000,000+
2	10/24/74	10/29/74	8,000,000
3	10/29/74	11/18/74 (Broke on removal)	31,002,100
4	11/18/74	12/04/74	13,573,100
5	12/04/74	12/17/74	13,116,900
6	12/17/74	01/09/75	15,195,900
7	01/09/75	01/30/75	32,477,600
8	01/30/75	02/07/75	15,532,200
9	02/07/75	02/17/75	12,698,100
10	02/17/75	02/26/75	13,372,200
11	02/26/75	03/24/75	43,298,800
12	03/24/75	04/08/75	15,480,800
13	04/08/75	04/24/75	19,411,000
14	04/24/75	as of 05/13/75	24,000,000
		Average	18,800,000

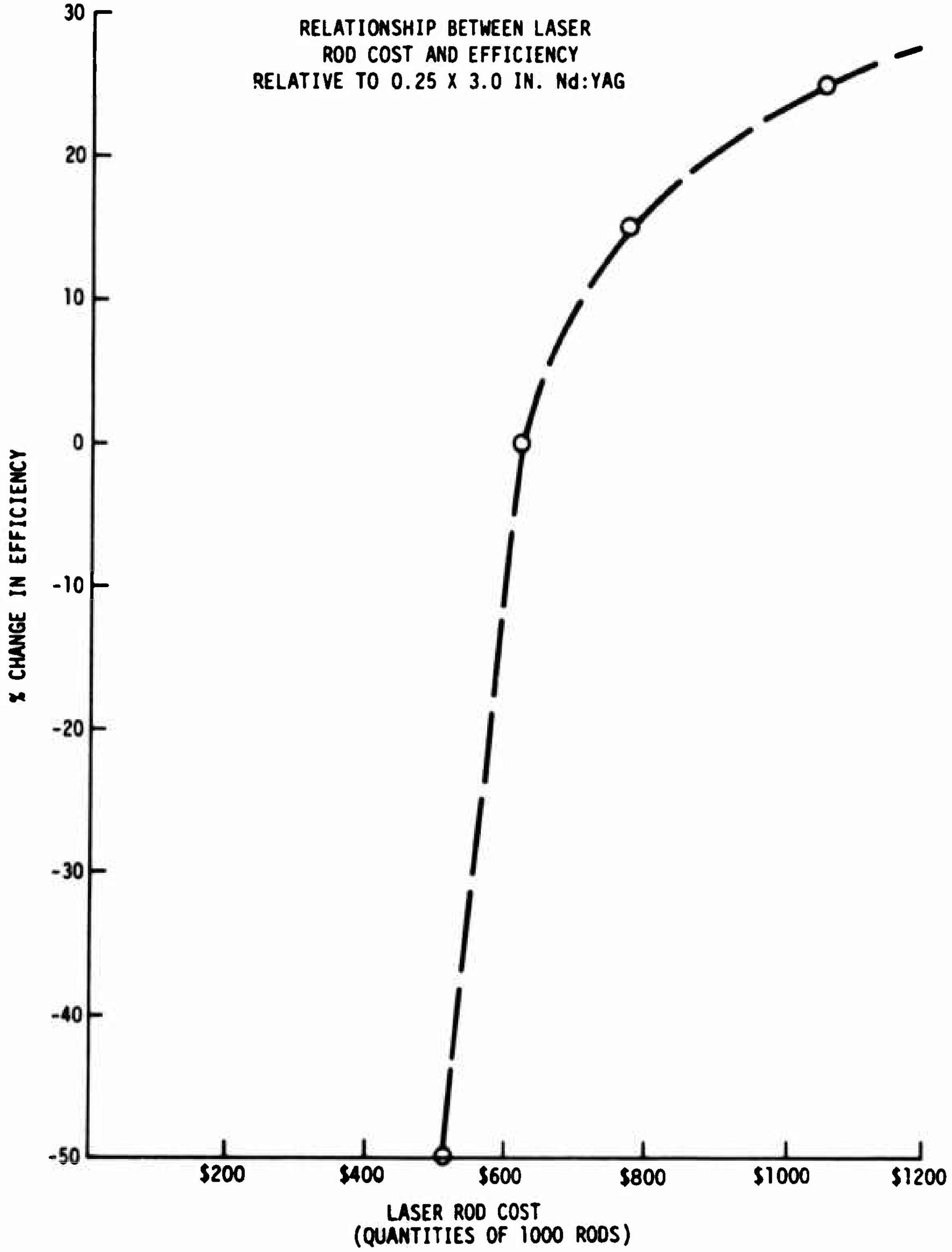

RELATIONSHIP BETWEEN LASER
ROD COST AND EFFICIENCY
RELATIVE TO 0.25 X 3.0 IN. Nd:YAG
30
20
10
0
-10
-20
-30
-40
-50
% CHANGE IN EFFICIENCY
$200
$400
$600
$800
$1000
$1200
LASER ROD COST
(QUANTITIES OF 1000 RODS)

FIGURE 7

Polarizer Tradeoff

A major area of both efficiency and cost improvement in the LGD over older designs is associated with the use of a dielectric polarizer rather than a calcite polarizer in the Pockels cell Q-switch. Prior lasers of this type have all used natural crystalline calcite for the polarizer. Polarizers made from natural calcite suffer from limited availability insofar as their use in production systems is concerned and all attempts to synthesize laser quality calcite have been unsuccessful to date. Also, the cost of calcite remains high because of the requirement for selection of the highest optical quality calcite for laser use as well as the requirement for precision and expensive optical finishing to fabricate a good Glan-laser calcite polarizer.

The cost of a laser quality calcite polarizer will vary from approximately $200 to $700 depending upon the size and type of cut required. In contrast, the dielectric polarizer, which consists of a multilayer dielectric film stack deposited on one side of a quartz or glass substrate, will cost as low as $10 or $15 in production quantities. The dielectric polarizer is oriented at Brewster's angle in the laser resonator under typical conditions and the losses introduced by the uncoated surface of the polarizer plate are minimized at this incidence angle. Thus, in addition to cost, a major advantage of the dielectric polarizer plate is its low insertion loss in the laser resonator.

Dielectric polarizers operating in the reflection mode -- that is using the reflected linearly polarized beam as the resonant beam of the laser interferometer -- have been measured to have insertion losses between 3 and 10%. This is a significant improvement over the 10 to 20% insertion losses typically measured with calcite polarizers. Thus, the use of the low insertion loss dielectric plate polarizer typically offers 10 to 15% improvement in system efficiency over the performance obtainable with a calcite polarizer. The major current difficulty with this polarizer for production use is the lack of repeatability in the incidence angle required for maximum polarization effects.

COMPONENT PARAMETER MEASUREMENTS

Laser component measurements have a major impact on system cost and reliability. The ability to make efficient and meaningful component measurements must be refined to allow initial component inspection to sort and reject components which otherwise would waste valuable assembly and checkout times as well as system failures in the field.

Laser component tests fall into three primary categories; optical, electrical and mechanical. Some fall into more than one category such as the flashlamp which must be accepted on the basis of optical output, electrical triggering stability and mechanical dimensions. Both static and dynamic tests may be required on some components to assure system performance. Dynamic tests refer to tests which are run under actual or simulated operating conditions to measure parameter changes induced by these conditions, such as thermal lensing in laser rods. It has been found that an occasional rod with normal optical quality in a quiescent state may develop severe and unsymetrical optical distortion under conditions where heat is applied to the rod from the pumping flashlamp. Dynamic tests will undoubtedly have to be included in the inspection procedure for some components to effect the necessary rejections of this type abnormality.

Table 3 gives a list of representative laser and receiver system components with the indicated category of testing for each.

Table 3. COMPONENT TEST CATEGORIES

	Optical	Electrical	Mechanical
Rods	S - D		S
Pockels Cell	S - D	S - D	S
Flashlamps	D	D	S
Polarizers	S		S
Mirrors	S		S
Lenses	S		S
Detectors		S - D	S
Filters	S		S
Mounts	S - D		S - D
Prism	S		

S - Static
D - Dynamic

One of the outputs of one current MM&T program is to provide accurate characteristics for a number of each of these types of components. A reasonably broad range of tolerances will be used so that component trade-off analyses can be performed. The accept/reject criteria and the necessity for performing all of the tests indicated in Table 3 will be derived from performance tradeoff studies.

The reduction in component check-out time will come in some measure from the output of tradeoff studies which will allow components to be better specified. It is not expected that all dynamic tests can be eliminated, however, some static tests might be met by a well developed dynamic test. All test procedures must be studied to minimize the number and complexity of the tests performed by streamlining current procedures and by evaluating the cost effectiveness of specialized test equipment.

Optical component parameters currently being measured by ILS for the purpose of establishing specifications are listed as follows:

Laser Rods
  Double pass loss coefficient
  Efficiency
  Optical distortion due to pumping
  Birefringence induced by optical pumping
  Single pass transmission

Pockels Cell (KD*P and Lithium Niobate)
  Contrast ratio
  Extinction ratio
  Single pass transmission

Polarizers (Dielectric)
- Angle for polarization
- Angular sensitivity of the polarization angle
- Single pass transmission of proper polarization
- Single pass reflection of proper polarization
- Extinction ratio of both reflected and transmitted beams

Dielectric Mirrors
- Reflectivity at desired angle
- Depolarization effects of dielectric

TITLE: Manufacturing Technology Project to Provide Cost Effective Production of Laser Guidance Designators (LGD)

SYSTEM/SESSION/COMPONENT: Guidance and Control/Laser Guidance Designator

PROBLEM: LGDs are essential subsystems of all laser terminal homing systems. In most instances the requirements on laser size and weight dominate most performance specifications with the possible exception of laser beam divergence. To achieve the performance and weight specifications the LGD must be extremely efficient and must be manufactured with a minimal power reserve factor. Any laser system required to operate at all times near its peak performance capability requires both high quality optics and electronics with narrow tolerances on all individual component specifications. In addition, labor of a high skill level is required to bring the laser to peak performance on the production line.

Continued effort to develop techniques and equipments for measuring critical parameters of electro-optical materials and components at all stages of production is required. In addition, continued effort on cost and performance as a function of EO tolerance is required to permit production engineers to transform engineering designs to production designs. Improvement of laser efficiency through further improvement in laser coatings, resonator design, optical pumps and laser material would permit manufacture of the LGD with a larger power reserve factor. This would minimize or eliminate the need for engineering level personnel dynamically adjusting each laser to its optimum performance level on the production line.

PROPOSED SOLUTION: This project would develop LGD production design and manufacturing techniques which would result in a low cost LGD for high volume production. Areas of production improvement include increasing the margin between the peak performance capability of a LGD and the required operational performance. This would be achieved through the improvement of laser efficiency through further component optimization such as laser rod geometry, optical pump improvement optimization of laser resonator design. A laser resonator design will be developed which may be statically aligned and requires no dynamic tuning to meet LGD performance specifications. Component cost versus performance tradeoffs will be continued to ensure that cost effective components are used throughout the laser system. To provide control of LGD manufacturing, measurement instrumentation will be developed which will monitor LGD performance parameters on a production line basis with low skill level personnel.

PROJECT COST AND DURATION: Estimated costs are as follows:

Production oriented laser design	$100,000
Production oriented measurement instrumentation	$125,000

Estimated duration of project is 18 months.

BENEFITS: Benefits to be derived from this project are a reduction in recurring hardware costs of approximately 20 to 25% and an increase in field reliability of the system. This represents a savings of approximately 1.25 million dollars on a procurement of 200 units and in excess of 2.5 million on a procurement of 500 units.

DRAGON MISSILE GUIDANCE IMPROVEMENT PROJECTS

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Bedford, Massachusetts 01730

ABSTRACT

Every missile system in production has identifiable high-cost drivers which potentially impact both product performance and cost. The primary purpose of this paper is to identify several technology projects which will ultimately reduce the product and life cycle cost of the Dragon Missile System as much as 9 to 16 percent. In particular, these projects will concentrate on the guidance portion of the system.

The contents of this paper are outlined below.

- System
  - Concept
  - Missile Guidance
  - Tracker
  - Launcher
  - Missile
- Technology Projects
  - New Gyros
  - Optically Polarized Non-Gyro System
  - Optical Data Link
- Summary Cost Impact
  - Cost Matrix
  - Technology Trends
- Appendix: Project Summary Sheets

SYSTEM

Concept

The Dragon Guided Missile is designed to be used against armored vehicles and fortified battlefield emplacements as illustrated in Figure 1. The weapon is portable and is deployed by an infantryman as a medium anti-tank assault weapon. The three major system components are:

1) A Wire-Guided Missile

2) A Disposable Launching Tube

3) A Reusable Optical IR Tracker.

In operation, the gunner maintains alignment by observing the selected target at the center of the telescope's cross hairs. Stadia or surveying lines within the scope indicate whether or not the selected target is within firing range.

The firing sequence is initiated by pressing the trigger on the tracker. A gas generator propellant located in the rear of the launching tube provides the initial thrust of the missile in a recoilless fashion. Continued forward thrust as well as vertical and horizontal flight corrections are accomplished by sequentially firing canted thrusters located at the center of gravity and peripherally around the body of the missile.

Missile Guidance

In flight, the missile's position is provided to the tracker by means of an ECM IR source, called a flare, located in the aft section of the missile. Since the flare's position or axis within the tracker is collimated with the optical axis of the telescope, a resultant flight position error is derived by the tracker's signal comparator electronics in the form of horizontal and vertical correction signals. See Figure 2.

During the missile's flight, the controlling wire plays out from a bobbin also located in the aft section of the missile. This cable receives vertical and horizontal correction signals which emanate from the tracker's electronics and terminate in the missile's flight control computer. Thus, the tracker provides correction signals to maintain the missile's flight toward an impact point at the center of the target while the missile computer calculates the appropriate firing position for its body thrusters as the missile rotates in flight.

Tracker

As shown in Figure 3, the tracker consists of four major assemblies. These are:

1) The Trigger

2) Telescope and Optics

3) Nutator

4) Signal Comparator.

These assemblies are designed as separable units and support the system operations described above.

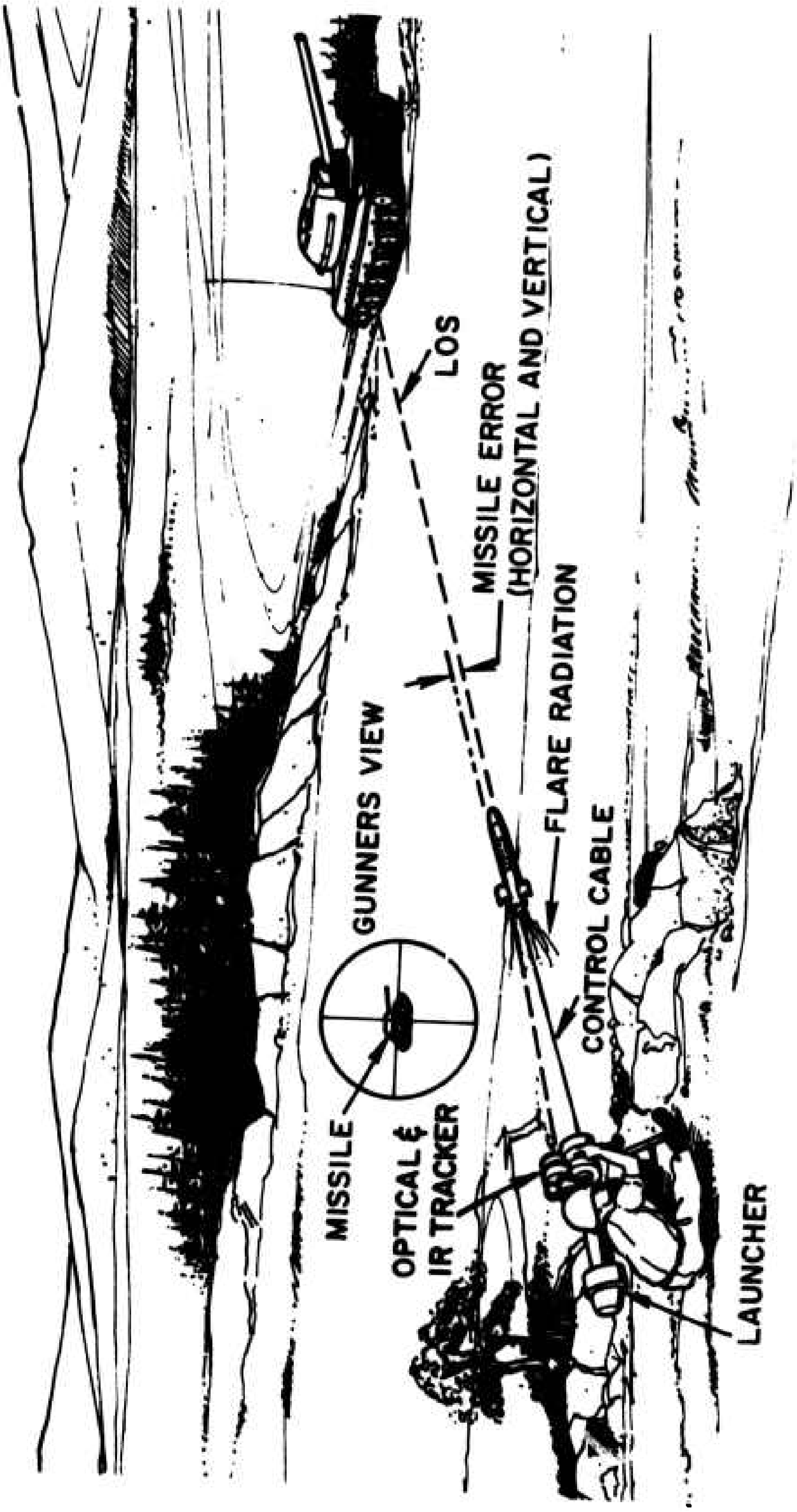

LOS
MISSILE ERROR
(HORIZONTAL AND VERTICAL)
FLARE RADIATION
CONTROL CABLE
LAUNCHER
GUNNERS VIEW
MISSILE
OPTICAL &
IR TRACKER

Figure 1

DRAGON SYSTEM BLOCK DIAGRAM

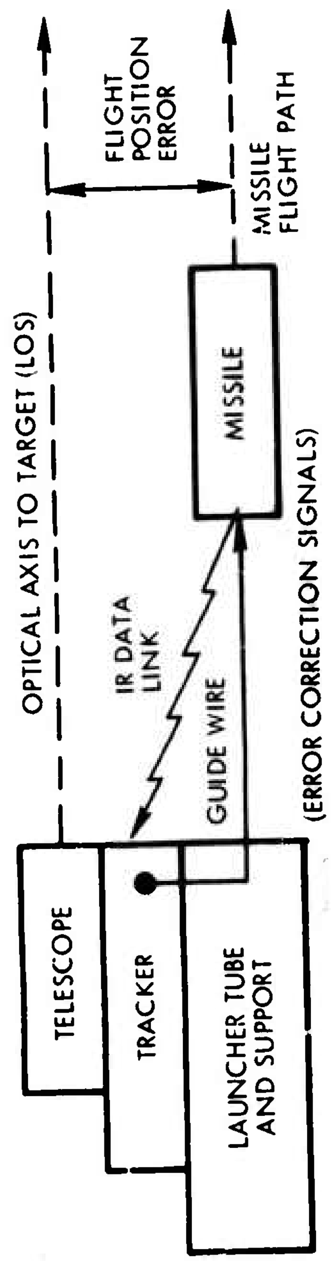


Figure 2

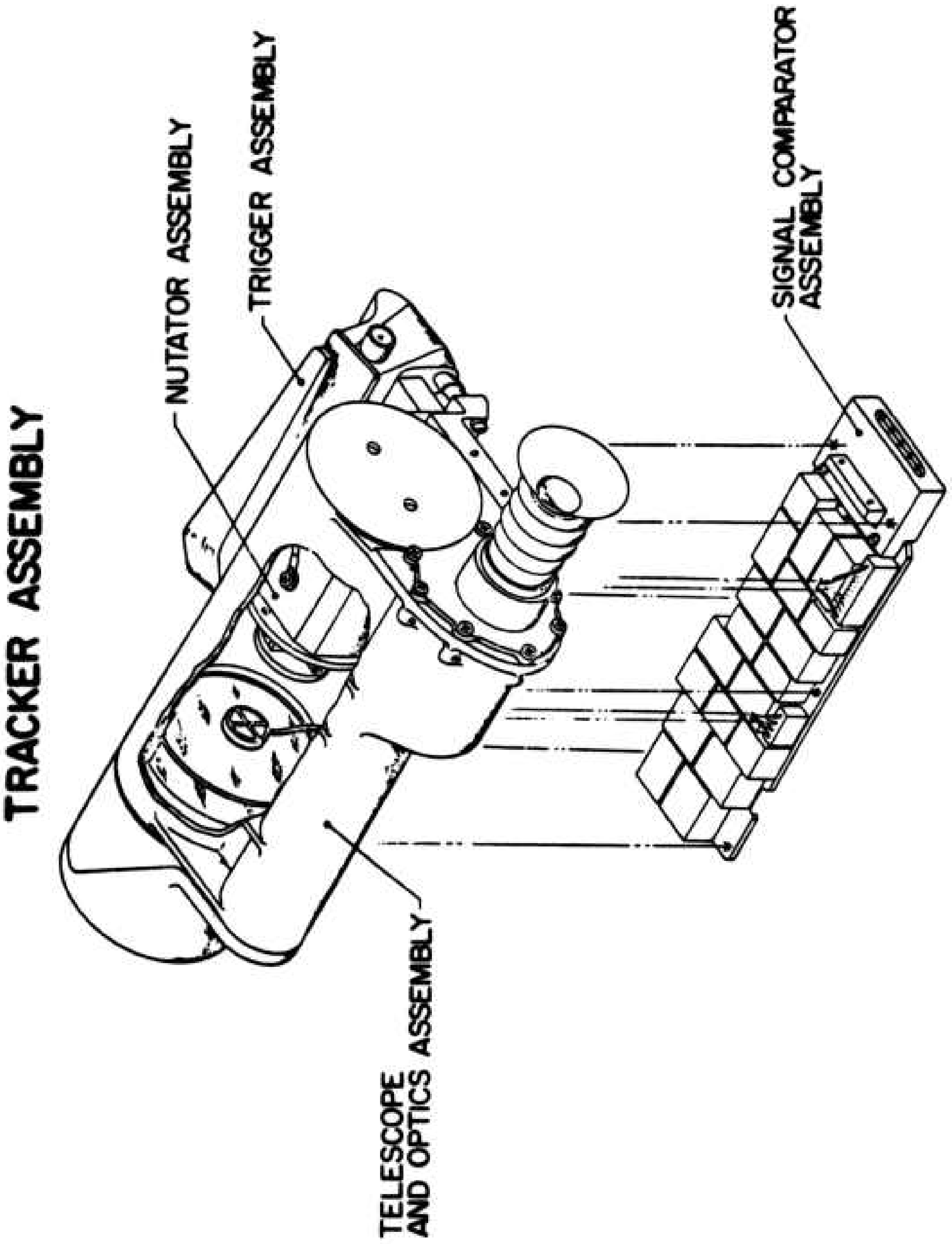

TRACKER ASSEMBLY
NUTATOR ASSEMBLY
TRIGGER ASSEMBLY
SIGNAL COMPARATOR ASSEMBLY
TELESCOPE AND OPTICS ASSEMBLY

Figure 3

Briefly, the trigger activates the missile into flight. The telescope and optics allow the gunner to sight and align the target with the in-flight missile. The nutator establishes the droop axis for the missile. Lastly, the collimated target and missile axis are compared in the tracker's signal comparator and guidance signals are generated and distributed to the missile.

Launcher

The launcher is a filament-wound fiberglass tube 34 inches long by five inches in diameter, Figure 4, in which the missile is secured by shear pins. An adjustable aluminum support stand is attached to the forward end of the tube to provide a steady track of the target. At the rear end of the launching tube, a breech-canister assembly containing the prime propulsion charge propels the missile from the launching tube with a minimum recoil.

Also included as part of the launcher is a connector assembly for attaching the tracker, a thermal battery for tracker power and an interconnecting harness.

Missile

The missile, shown in Figure 5, consists of three major sections. These are:

1) The Warhead

2) The Center Section

3) The Aft Section.

In this paper, most of the product improvements suggested will involve the center and aft sections of the missile.

The center section contains 60 side thrusters divided into three groups equipositioned around the periphery of the missile. Each of the three thruster groups, spaced 60 degrees apart, is connected to a pair of firing circuit boards. The function of these firing boards is to fire pairs of thrusters when commanded by the Control Signal Computer in the aft section. The firing circuit boards are designed such that a maximum of five sequenced firings can be accomplished by each board. The thrusters, located equidistant from the missile's center of gravity, are fired in pairs in order to prevent any pitch misalignment while providing flight path corrections and forward thrust.

The aft section contains:

1) Thermal Battery

2) Gyro

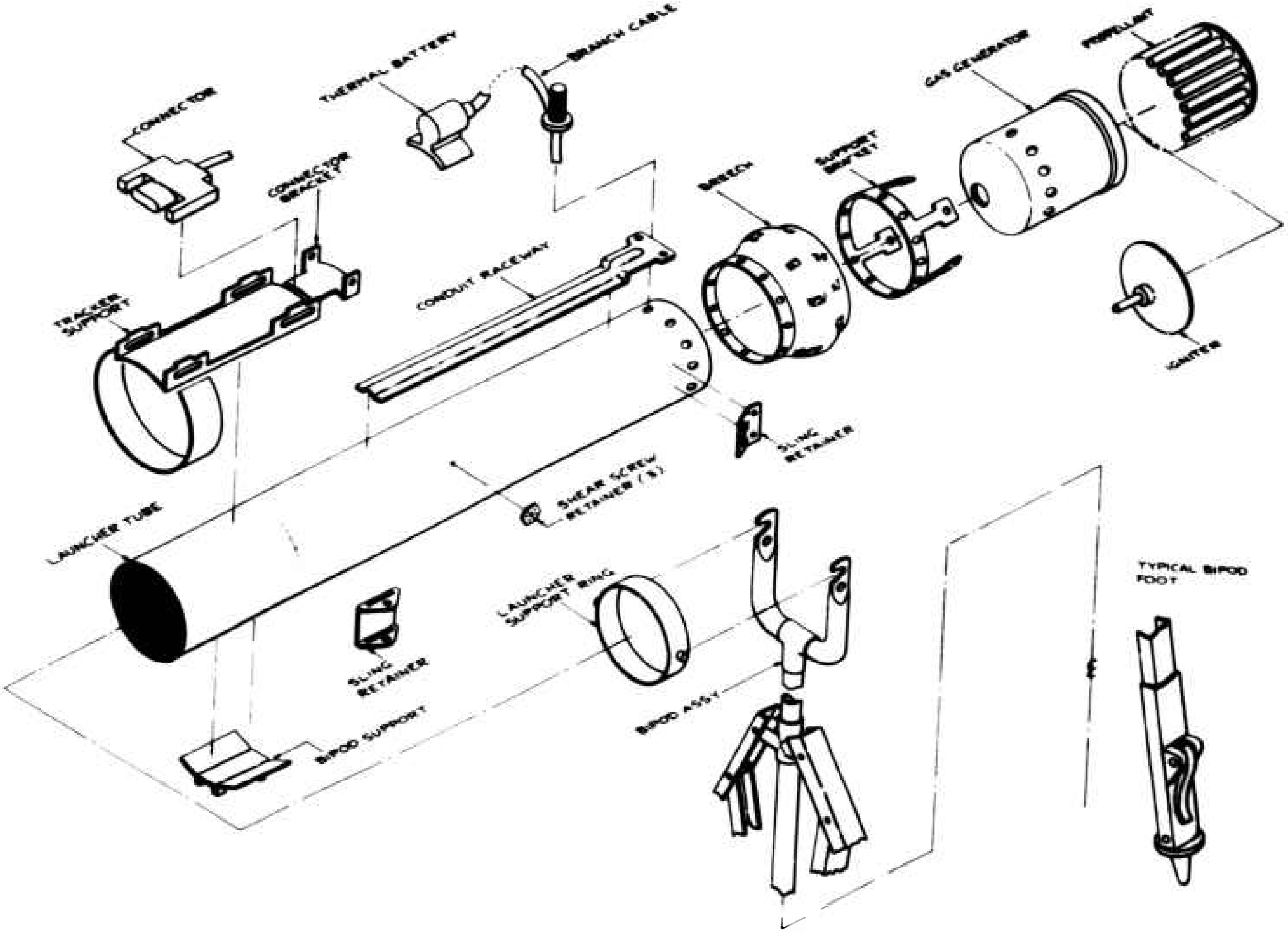
3) Control Signal Computer

4) Flare Assembly

5) Control Bobbin

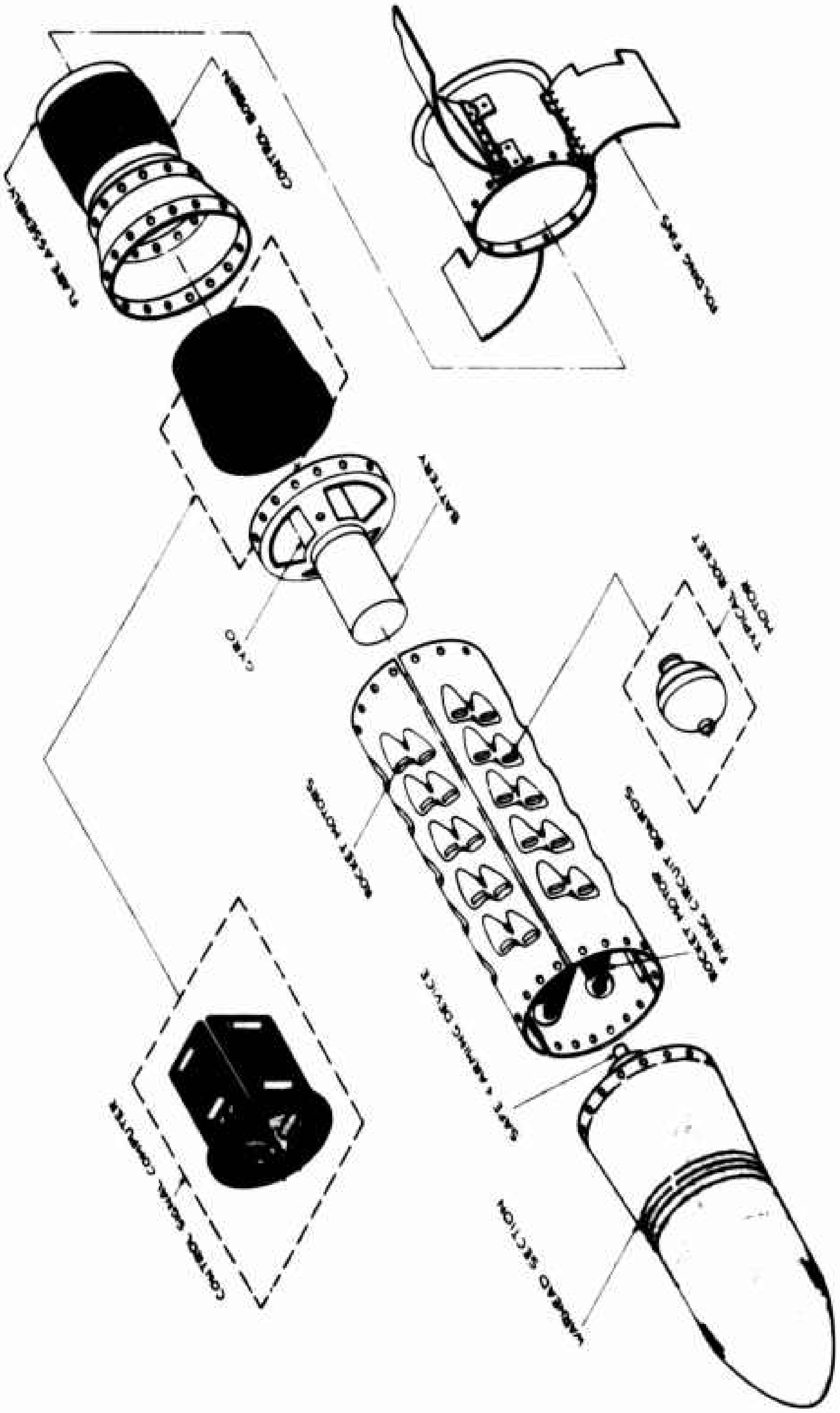
6) Canted Folding Fins.

The battery provides missile power for only the center and aft sections of the missile. The tracker trigger activates this battery and a series of related events.



DRAGON M222 MISSILE LAUNCHER

Figure 4



DRAGON M222 MISSILE

Figure 5

1) Initiates squib firing for gyro run-up

2) Flare motor comes up to speed

3) Power is supplied to electronic circuits

4) Power supplied to safety arming devices

5) Uncaging of the gyro allows power to launch the canister squib

6) After missile launch, a time delayed G and thermal switch provides power to thruster firing circuits.

The gyro provides a stable inertial reference against which the missile computer can determine the appropriate firing position for sequenced thruster pairs. A simplified illustration of this gyro is shown in Figure 6.

The Control System Computer effectively controls the lead angle firing of the side thruster pairs. It accomplishes this by considering the following system parameters:

1) Magnitude left/right error voltage

2) Instantaneous missile roll position (ϕ_a and ϕ_b)

3) Roll rate ($\dot{\phi}_a$ and ϕ_b)

4) Ambient temperature

5) Time change between firing command and last channel fired.

The flare assembly consists of a set of variable intensity lamps, an IR filter, a chopper motor and a reticle modulator disc. As previously mentioned, the flare provides the tracker with unambiguous data which locates the missile's position with respect to the selected target.

The control bobbin contains a three-wire cable which is used to communicate left/right or vertical error information to the missile.

Finally, the canted folding fin assembly provides the missile with a rotating force when the fins are deployed. This occurs as the missile leaves its launching tube.

Many of the units discussed above are good candidates for technology improvement projects.

TECHNOLOGY PROJECTS

In order to determine whether or not a portion of the Dragon Missile System's guidance should be modified, a cost analysis was made to determine major system cost drivers. The summarized results of this analysis are presented in Table I. It should be noted that there is good correlation between the technology projects suggested and the major cost drivers. Potential savings will be analyzed in the Summary Cost Impact section of this paper. However, this section is dedicated to a technical development of the suggested projects.

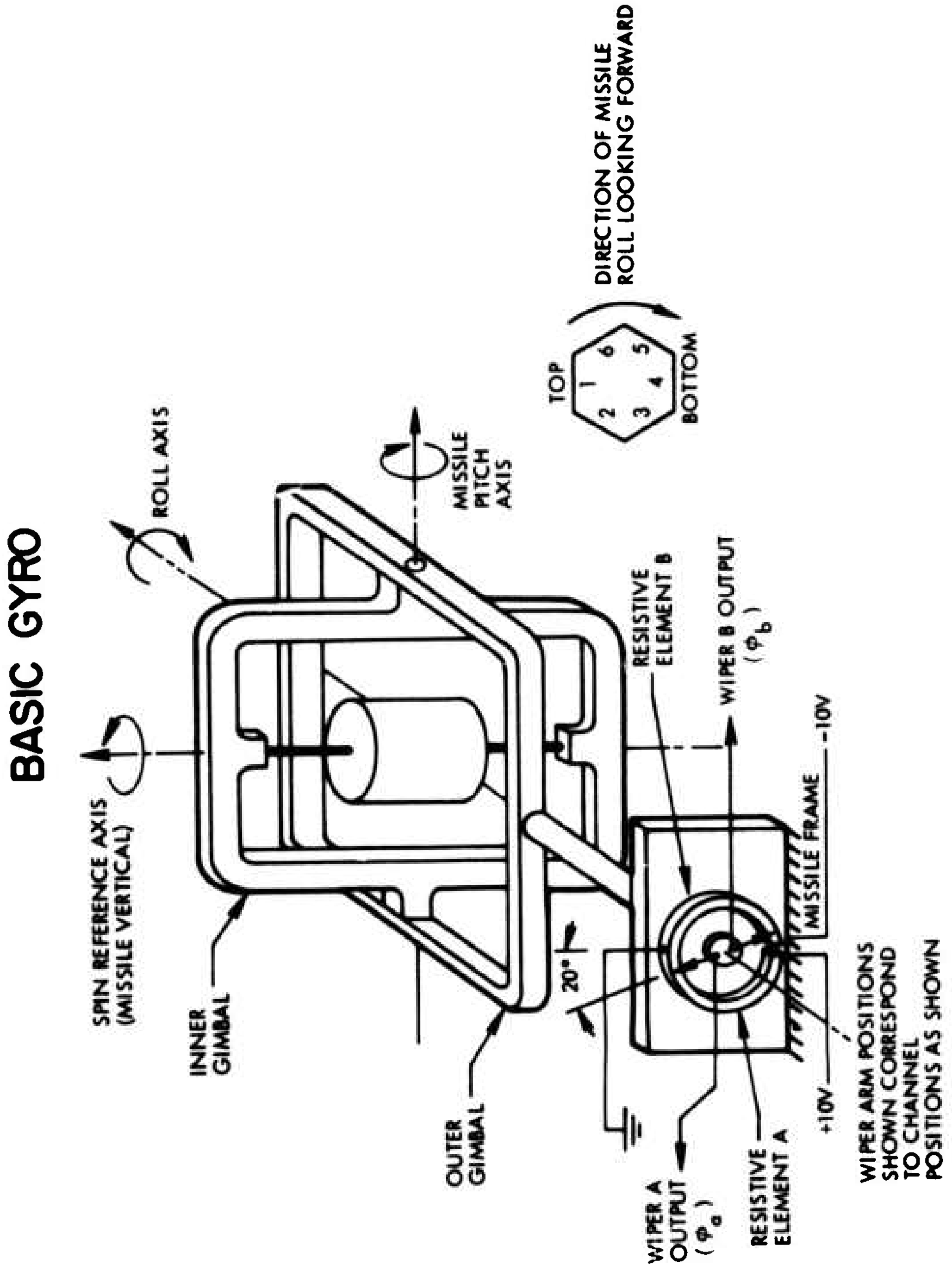

BASIC GYRO
SPIN REFERENCE AXIS (MISSILE VERTICAL)
ROLL AXIS
MISSILE PITCH AXIS
TOP
1
2
3
4
5
6
BOTTOM
DIRECTION OF MISSILE ROLL LOOKING FORWARD
INNER GIMBAL
OUTER GIMBAL
RESISTIVE ELEMENT B
WIPER B OUTPUT (ϕ_b)
-10V
MISSILE FRAME
20°
WIPER A OUTPUT (ϕ_a)
RESISTIVE ELEMENT A
+10V
WIPER ARM POSITIONS SHOWN CORRESPOND TO CHANNEL POSITIONS AS SHOWN

Figure 6

TABLE I

COMPARATIVE ANALYSIS

DESCRIPTION	F/A	I/T	MATERIAL	TOTAL
Computer	19%	3%	78%	13%
Transmitter	8%	1%	91%	18%
Fin Assembly	54%	6%	40%	2%
Bobbin Assembly	35%	6%	59%	8%
Section I Misc. Assembly	86%	4%	10%	2%
Rocket Motor (60 pieces)	17%	3%	80%	15%
Circuit Card - Fire Control Board (6 pieces)	18%	2%	80%	8%
Battery Missile	--	--	100%	8%
Gyro	7%	1%	92%	23%
Section II Misc. Assembly	42%	14%	44%	3%
TOTALS	17%	2%	81%	100%

F/A Fabrication/Assembly
I/T Inspection/Test

New Gyros

From Table I, it can be seen that the missile gyro is the largest cost driver in the missile. Consequently, it is a good candidate for cost savings. The currently employed cold-gas driven gyro is illustrated in Figure 7 and its operation is also summarized in this figure. The gyro is an excellent design. However, an analysis of system accuracies indicates that the performance specification for the required gyro can be relaxed. Consequently, a lower cost design can be developed which potentially can be produced at a substantially reduced cost. One such design is shown in Figure 8. The internal mechanism is very similar to a watch-winding mechanism and its yoke engaging stem assemblies. The case for the new gyro project is summarized below:

Requirements

1) Cold Gas or Spring Powered

2) Activation Less Than 300 msec.

3) Drift Rate Less Than 2 deg./13 sec.

4) Two Channel Pot Output for Timing of Thrusters

Present Gyro

1) Used in Majority of Missiles to Date

2) Performance 5X Better Than Spec.

3) Disadvantage is Cost (because of extra capability designed-in)

Raytheon Proposed Unit

1) Simple Design

2) Performance easily verified by test with minimum tools and preparation

3) Can be re-armed after test without degradation of performance

4) Is spring powered with spring (saving in size and cost)

5) Cost in production estimated 25 to 40 percent less than present cold gas unit

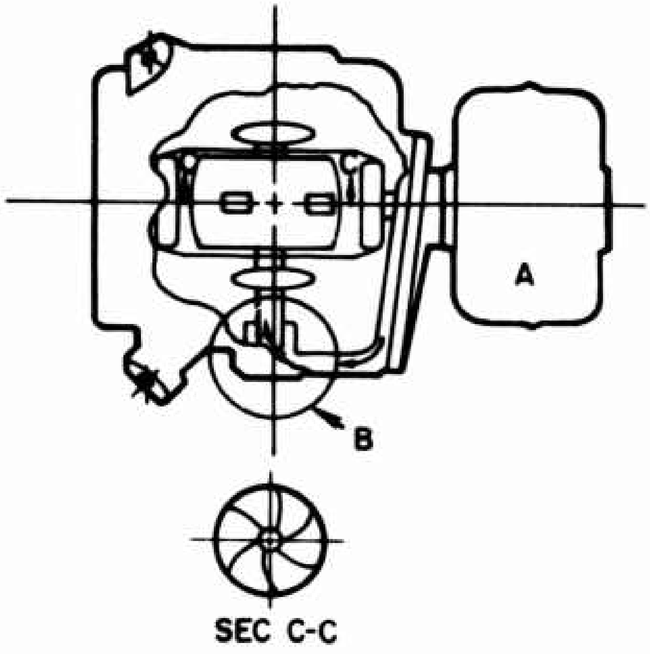
Optically Polarized Gyroless System

Recognizing the fact that the gyro is the largest cost driver, an incentive is provided to not only lower its cost but to the conjecture that it may be possible to eliminate the gyro completely. The proposed project suggests a technique which eliminates all mechanical parts and is a completely optical approach.

Figure 9 illustrates in block diagram form the tracker and missile modifications. The tracker contains an LED transmitting source which radiates through an inexpensive plastic polarizing filter and is then collimated by means of a Fresnel lens. This simple, inexpensive implementation would require a tracker modification.

The missile would require the addition of a polarizing receiver capable of responding to the missile's rotational position. In order to provide a stable angular position

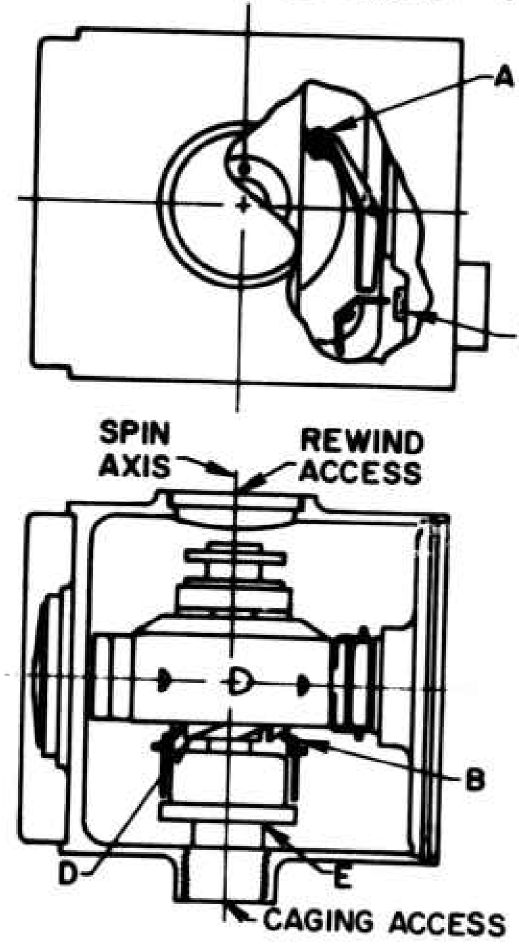
COLD-GAS DRIVEN



1. GAS IS RELEASED FROM CHAMBER "A" ON FIRING OF SQUIB IN CHAMBER.
2. GAS FOLLOWS ARROWS INTO ROTOR SHAFT THROUGH CAGING MECHANISM "B".
3. GAS EXITS TANGENTIALLY FROM SLOTS IN ROTOR, REACTION ACCELERATING WHEEL. DROP IN CASE PRESSURE FOLLOWING RISE UNCAGES GYRO ELEMENT.
4. UNIT REQUIRES CAGING, SEALING AND INSTALLATION OF NEWLY SQUIBBED CHARGED GAS CHAMBER, TO REARM.

Figure 7

PROPOSED RAYTHEON
SPRING- POWERED FREE GYRO



1. ROTOR SPRING IS ARMED BY WINDING ROTOR CLOCKWISE. FORCE IS EXERTED BETWEEN LATCHES "A" ON WHEEL AND "B" ON TOOTHED ARBOR "D."

2. SQUIB "C" TRIGGERS LATCH "A" FREEING ROTOR TO ACCELERATE. WHEN ENERGY IS EXPENDED, TOOTHED ARBOR "D" TURNS CLOCKWISE AND STRIKES LATCH "B" WHICH ACTIVATES UNCAGE MECHANISM "E."

3. GYRO CAN BE REARMED BY RELATCHING, RESQUIBBING, RECAGING AND (I) REWINDING.

Figure 8

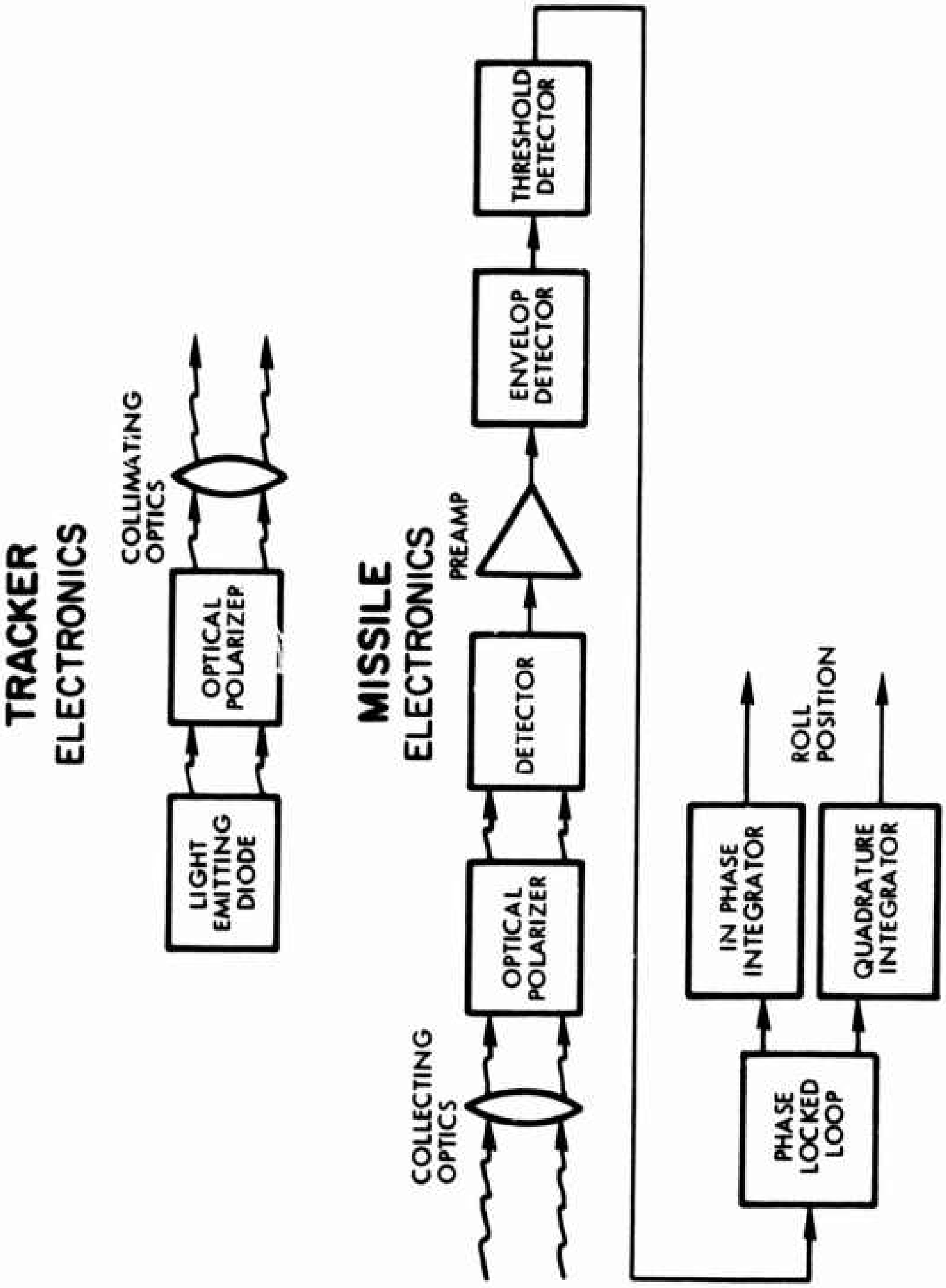

TRACKER ELECTRONICS
LIGHT EMITTING DIODE
OPTICAL POLARIZER
COLLIMATING OPTICS
MISSILE ELECTRONICS
COLLECTING OPTICS
OPTICAL POLARIZER
DETECTOR
PREAMP
ENVELOP DETECTOR
THRESHOLD DETECTOR
PHASE LOCKED LOOP
IN PHASE INTEGRATOR
QUADRATURE INTEGRATOR
ROLL POSITION

Figure 9

reference, a phase-locked loop is added to the IR receiver front end. The waveforms at each stage in the receiver are shown in Figure 10. The advantages of this approach are:

1) Much Lower System Cost
2) Lower System Weight
3) No Mechanical Parts
4) Improved Reliability.

Its disadvantage is that a major modification to both the missile and tracker is required. It should be noted that the cost in production of this approach is likely to be between one quarter to one third of the current gyro unit.

Optical Data Link

A natural adjunct to the polarized gyroless system is an optical data link which would eliminate the necessity for a three-wire bobbin assembly. The modification, Figure 11, to the gyroless system is to modulate the tracker transmitter with the normal left/right and firing control error signals. The missile's front-end receiver would require a small error signal decoder which feeds the missile's computer. The combination of the last two projects affects 31 percent of the missile's cost drivers. An expected reduction of approximately 9 to 16 percent could be realized by implementing the last two projects. The basic advantages and disadvantages are the same listed under the gyroless system.

SUMMARY COST IMPACT

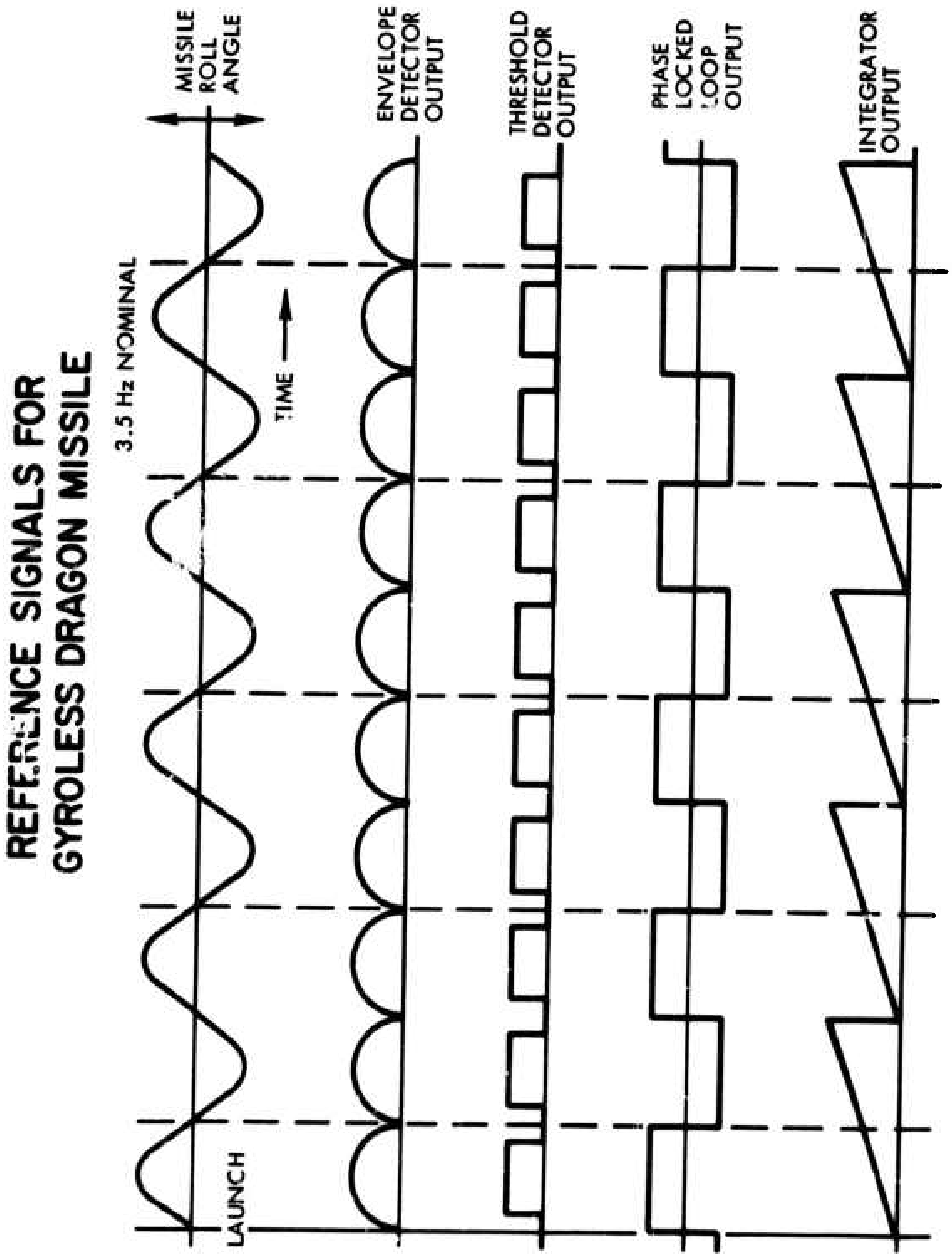
The total potential cost savings is obviously a function of which improvement programs are successfully implemented. Table II indicates the improvement potential of each of the suggested projects.

In the order of their greatest impact, the gyroless optical data system realizes the greatest potential savings. This is consistent with the fact that the gyro is the largest cost driver (Table I). The second most significant reduction, as expected, is produced by changing the gyro to a lower cost unit.

Another method which can be employed to determine each value of improvement projects is to evaluate their return on investment ratio, also indicated in Table II.

It should be noted that these numbers are based upon large production quantities such as 100,000 and that the cost of implementation only includes engineering development prototypes. It does not consider field retrofitting, deployment nor full ordnance documentation. In this respect, the return ratio represents an optimistic but relative value.

The technology trend for the last two projects strongly suggests that they have been made possible by improved semiconductor developments. The gyroless optical system consists of LED and monolithic semiconductor implementations. Thus, the common denominator for most of the technology projects suggested in this paper is state-of-the-art semiconductor technology which can produce as much as a 9 to 16 percent improvement in product cost.



REFERENCE SIGNALS FOR GYROLESS DRAGON MISSILE

Figure 10

WIRELESS CONTROL LINK FOR DRAGON

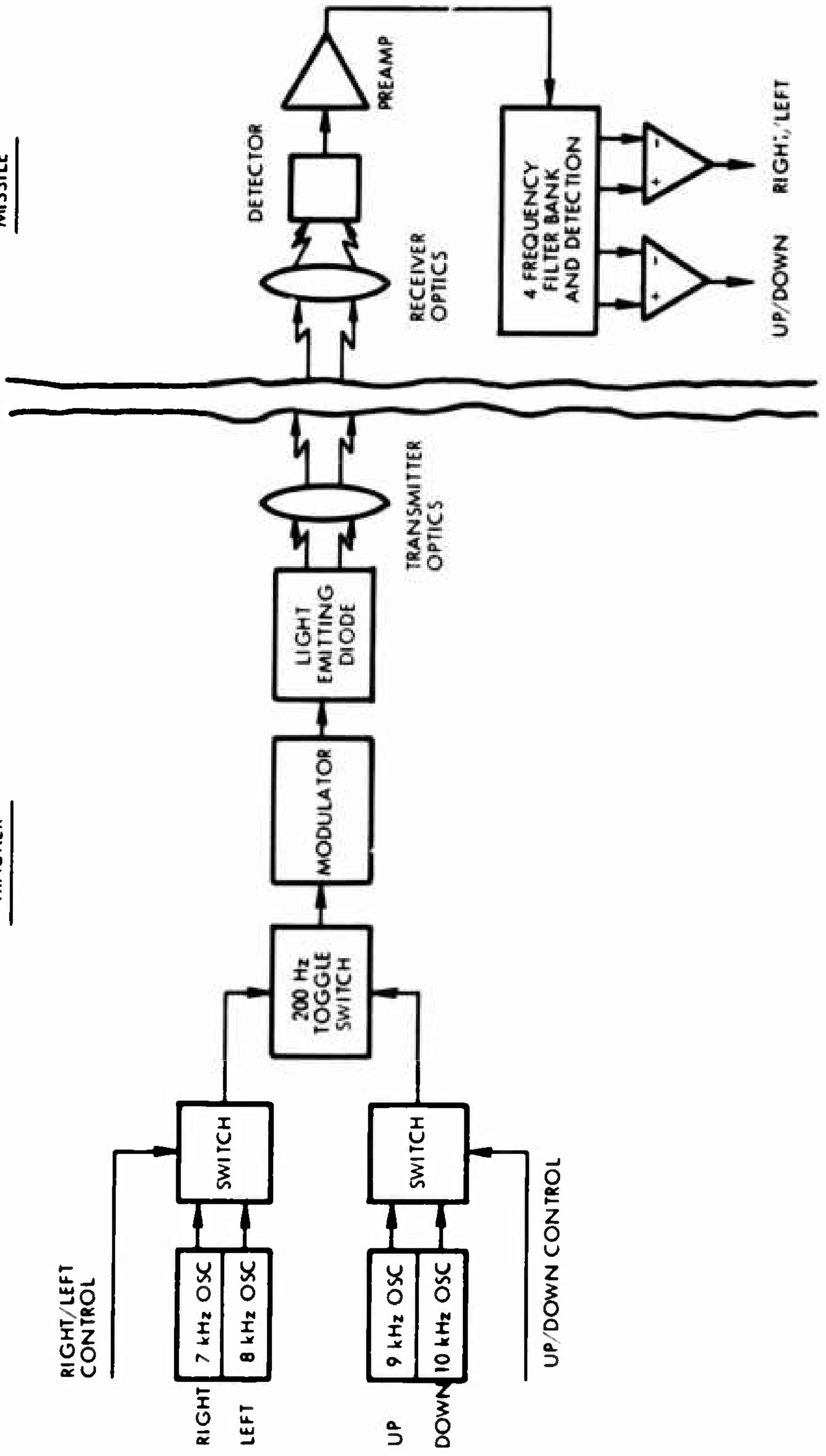


Figure 11

TABLE II

IMPROVEMENT MATRIX

Improvement Project	Assembly Impact	Inverse Improvement Factor	Current Cost %	Projected Cost %	Percent Improvement	Return Ratio**
New Gyro	Gyro	0.75	23	17.3	5.7	15
Gyroless System	Gyro	0.62	23	14.3	8.7	29
Optical Data Link*	Gyro	0.64	23	14.7	8.3	40
	Bobbin	0.0	8	0.0	8.0	

*As part of Gyroless System
**Based on 10^5 units

Title: Manufacturing Technology Project to Replace the Dragon Missile Cold-Gas Driven Gyro with a Spring-Powered Free Gyro.

System/session area/component: Dragon Missile/guidance/gyro.

Problem: The Dragon Missile System is a high-volume, low-cost system for which the Guidance Section, Gyro, is the largest cost driver in the missile. An analysis of the system accuracies indicated that the performance is five times greater than required in the specification. Consequently, a lower cost design can be developed which can be produced at a substantially reduced cost.

Proposed solution: This project will develop a low-cost gyro such as one that would include a watch-winding mechanism and a yoke-engaging stem assembly that would substantially reduce the cost of this large cost driver. This proposed unit would include:

1) Simple design

2) Easily verified performance by test with minimum tools and preparation

3) The capacity to be re-armed after test without degradation of performance

4) A spring-powered device with spring (saving in size and cost)

5) A 25 to 40 percent cost savings in production

Project cost and duration: Estimated costs are as follows:

Tooling	$300,000
Engineering support and technical data	200,000
Total	$500,000

Estimated duration of this project is 18 months.

Benefits: Benefits to be derived are:

Reduction in material parts - 5-9% of total missile cost

Assumptions: The stated benefits assume that the Dragon Missile will be in production for 100,000 units or more and that the cost of implementation only includes engineering development prototypes.

Title: Manufacturing Technology Project to Develop An Optically Polarized Gyroless Guidance System.

System/session area/component: Dragon Missile/guidance/gyro.

Problem: The Dragon Missile is a high-volume, low-cost system for which the Guidance Section, Gyro, is the largest cost driver. The current solution contains mechanically moving parts which are generally less reliable than solid state electronic implementations.

Proposed solution: This project will develop an optically polarized light-emitting diode assembly and its polarized receiver counterpart to replace the existing mechanically driven gyro assembly. The advantages of this approach are:

1) Much lower system cost

2) Lower system weight

3) No mechanical parts

4) Improved reliability

Project cost and duration: Estimated costs are as follows:

Tooling	$300,000
Testing equipment	200,000
Engineering support and technical data	400,000
Total	$900,000

Estimated duration of this project is 18 months.

Benefits: Benefits to be derived are:

Reduction in material	-	6.3%	
Reduction in touch labor	-	2.0%	
Reduction in inspection	-	-0-	
Net reduction		8.3%	of total missile cost

Assumptions: The stated benefits assume that the Dragon Missile will be in production for 100,000 units or more and that the cost of implementation only includes engineering development prototypes.

Title: Manufacturing Technology Project to Add An Optical Data Link and Eliminate the Three-wire Bobbin Assembly.

System/session area/component: Dragon Missile/guidance/bobbin.

Problem: The Dragon Missile System is a high-volume, low-cost system for which the Guidance Section is a major cost driver. This proposal, in conjunction with the Optically Polarized Gyroless System, would eliminate the three-wire bobbin assembly thereby culminating in a cost reduction and a weight, volume and logistics improvement of the missile system.

Proposed solution: A natural adjunct to the polarized gyroless system is an optical data link which would eliminate the necessity for a three-wire bobbin assembly. The modification to the gyroless system is to modulate the tracker transmitter with the normal left/right and firing control error signals. The missile's front-end receiver would require a small error signal decoder which feeds the missile's computer. The advantages to this approach are:

1) Reduction in system cost

2) Reduction in system weight

3) Reduction in system volume

4) Reduction in logistics

Project cost and duration: Estimated costs are as follows:

Tooling	$ 20,000
Test equipment	50,000
Engineering support and technical data	100,000
Total	$170,000

Estimated duration of the project is 12 months.

Benefits: Benefits to be derived are:

Reduction in material parts	- 4.8%	
Reduction in touch labor	- 2.9%	
Reduction in inspection labor	- .3%	
Net reduction	8.0%	of total missile cost

Assumptions: The stated benefits assume that the Dragon Missile will be in production for 100,000 units or more and that the cost of implementation only includes engineering development prototypes.

HYBRID ELECTRONICS APPLICATION AND LOW COST PRODUCTION FOR MISSILE SYSTEMS

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PART I: DETAILED COST INFORMATION

The Tucson Manufacturing Division of Hughes Aircraft Company is currently in high rate production of the TOW Missile along with two other Department of Defense programs at USAF Plant 44. Additionally, this Division is now implementing for production of the US Roland Missile and participating in the development of the Hellfire Missile which, if Hughes is the successful contractor, will also be produced at the Tucson facility. These two programs are also under contract with the U.S. Army Material Command.

TOW is the U.S. Army's heavy assault wire guided missile developed to provide a major increase in fire power for infantry units. It is described as a Tube-launched, Optically-tracked, Wire-guided missile.

With TOW, the gunner trains a telescopic sight on the target, then presses his trigger to launch the missile. In flight, the TOW Missile unreels two hair thin wires from internal bobbins through which steering signals are transmitted. All the gunner has to do is hold the cross hair of his sight on the target and the missile will be automatically steered to impact on the spot where he is sighting. After the missile leaves the launch tube, the optical source in the rear of the missile is energized so that the optical sensor on the launcher, which is bore-sighted with the gunner's telescopic optics, can track the missile along its flight path. The optical source does not distract the gunner, but is sufficiently strong to allow automatic guidance to the maximum range of the missile under all conditions that the target is visible to the gunner.

The gunner's only job is to keep the cross hairs of his optics on the target during missile flight. The radiation of the optical source in the missile is tracked by the optical sensor which measures the angle between the flight direction of the missile and the gunner's line of sight. These displacements are transformed by the computer into guidance commands which are sent to the missile over the two wires. The missile thus flies down an imaginary tunnel which is closely centered around the sight line established by the gunner.

The gunner does not have to estimate range to the target, speed of the target, or the angle between the course of the target and the missile. The weapon system has inherent accuracy that has established an entirely new set of performance standards for anti-tank weapons.

The guidance system of the TOW Missile consists of essentially five elements:

1) Electronics Unit - Processes the guidance signal from the gyro.
2) Gyro - Generates error signals with respect to the target.
3) Optics Assembly - Provides a modulated infrared beacon and is the reference between the launcher and the missile.

4) Modulator - Provides the power to drive the beacon at the correct frequency.
5) Interconnection cables and harnesses.

As a result of the TOW Missile being in high rate production for several years, considerable experience has been gained on the relative cost factors associated with the missile units. The Electronics Unit is the highest percentage cost element in the TOW Missile guidance system.

The current production TOW Missile electronics unit is comprised of seven (7) printed circuit board assemblies which contain three hundred sixty-six (366) discrete electronic components.

The TOW Missile program, though implemented in 1968, has through continuous updating of its manufacturing facilities consistently applied the latest concepts in equipment and techniques to automated electronic assembly methods. It utilizes, to the maximum extent possible, automatic sequencing and insertion of components, continuous conveyorized wave soldering and cleaning systems, and automatic metering, dispensing, and curing equipment in the encapsulation process. In addition, the use of minicomputer process controllers and high speed computer controlled inspection equipment assures minimum production costs compatible with the high degree of reliability demanded on the TOW Missile system.

GUIDANCE SYSTEM COST BREAKDOWN

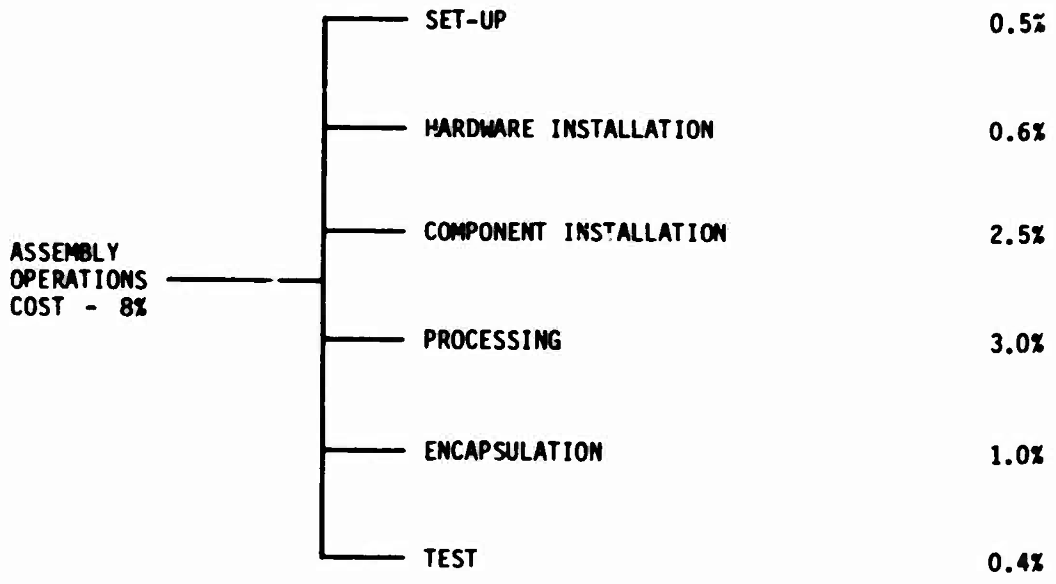
TOW MISSILE

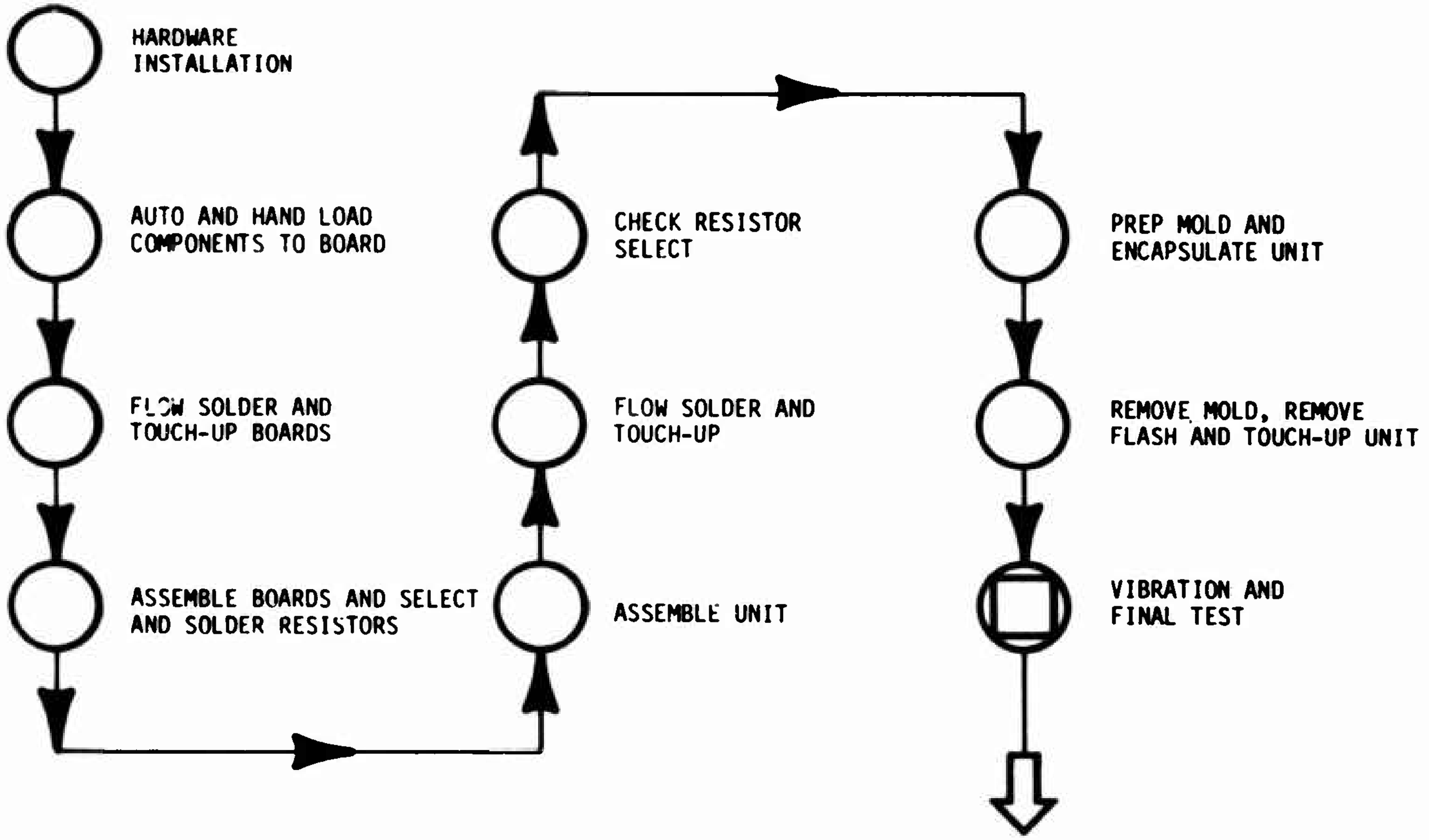
	ELECTRONICS UNIT 40%	OPTICS ASSEMBLY 15%	GYRO 30%	CABLES 9%	MODULATOR 6%
PURCHASED PARTS	27.5%	12.0%	30.0%	7.0%	3.0%
FABRICATION LABOR	2.0%	0.5%	-	-	0.5%
ASSEMBLY LABOR	8.0%	1.0%	-	1.5%	1.5%
TEST LABOR	0.5%	0.5%	-	0.5%	0.5%
RAW MATERIAL	2.0%	1.0%	-	-	0.5%
	40.0%	15.0%	30.0%	9.0%	6.0%

MAJOR COST DRIVERS - ☐

DETAIL ASSEMBLY OPERATIONS COST BREAKDOWN

TOW MISSILE ELECTRONICS UNIT




HARDWARE INSTALLATION
AUTO AND HAND LOAD COMPONENTS TO BOARD
FLOW SOLDER AND TOUCH-UP BOARDS
ASSEMBLE BOARDS AND SELECT AND SOLDER RESISTORS
ASSEMBLE UNIT
FLOW SOLDER AND TOUCH-UP
CHECK RESISTOR SELECT
PREP MOLD AND ENCAPSULATE UNIT
REMOVE MOLD, REMOVE FLASH AND TOUCH-UP UNIT
VIBRATION AND FINAL TEST

GAR SERIES MISSILES - SIMPLE CIRCUIT - 6 CHASSIS - 818 DISCRETE COMPONENTS	GAR-4A GUIDANCE UNIT PREAMP	F4 LAUNCHER - FIRST ALL SEMI-CONDUCTOR/ DISCRETE SYSTEM: AIM-4D AUTO-INSERTION	PHOENIX MISSILE COMPLEX CIRCUIT - HIGH SPEED: TOW SIMPLE CIRCUIT	PHOENIX MISSILE RE-DESIGN FOR AUTO-INSERTION: MAVERICK MISSILE COMPLEX CIRCUIT - 13 CHASSIS 2,034 DISCRETE COMPONENTS: TOW HIGH RATE PRODUCTION IMPLEMENTATION - 7 CIRCUIT CARDS - 366 DISCRETE COMPONENTS	IMPROVED AXIAL LEAD AND DIP DISCRETE AUTO-INSERTION	LARGE SCALE INTEGRATION CIRCUIT: HYBRID SIZE REDUCTION CONTINUES
VACUUM TUBES	SEMI-CONDUCTORS			HYBRIDS	V.C.D-D.I.P. INSERTION	L.S.I.
1952 - 1955	1957	1962	1966	1968	1972	1975

PART II: POTENTIAL MANUFACTURING TECHNOLOGY PROJECTS

Hybrid Electronics Application and Low Cost Production for Missile Systems

System/Session Area/Component. TOW/Guidance/Hybrid Electronics.

Problem. To reduce the cost of producing electronic assemblies for missile systems.

TOW is a high volume, low cost missile system within which discrete components are a major cost factor. High rate, specialized automatic assembly equipment is employed to minimize recurring production labor cost.

The TOW Missile production program was implemented in 1968 with automatic component insertion equipment using minicomputer controllers, automatic feed wave soldering/cleaning system, and numerous methods refinements to ensure minimum production cost with the existing design. However, there remains several lucrative areas that impact present cost. Discrete component cost continues to increase, high reliability component requirements cause shipment delays from suppliers due to test constraints, and various manual operations are subject to workmanship problems.

New missile system designs employ hybrid microcircuits which began to emerge in the early 1960's. Hybrid microcircuits have proven to be cost competitive with discrete configurations. Weight and space requirements are greatly reduced. Reliability is improved as compared to discrete configurations. Raw material requirements are reduced and improved standardization is achieved through use of hybrid microcircuits.

Proposed Solution. It is proposed that a significant decrease in production cost could be realized if the electronics unit is redesigned to allow effective incorporation of hybrid integrated circuits. A preliminary study indicates that this redesign would result in an electronics unit which consists of three (3) etched circuit boards, which mount five (5) custom hybrid modules and some fifty (50) discrete components. The study also pointed out that a cost decrease could not be effected unless the hybrid modules were produced in a highly automated facility with a minimum of manual operations and handling. The proposed project would include the design, implementation, and check-out of a hybrid pilot line that would utilize available automation and would be capable of being scaled-up to a fully automated facility.

The tasks to be accomplished would include:

1) Implement hybrid pilot line facility at Tucson utilizing available automation.
2) Develop state-of-the-art semi-automatic equipment into fully automatic equipment.
3) Advance the technology in handling of chips and substrates.
4) Development of methods criteria and equipment specifications for a fully automated hybrid production line.
5) Develop computer input/output and systems software applications requirements.

Project Cost and Duration. Estimated costs are as follows:

1)	Implement hybrid pilot line facility at Tucson utilizing available automation.	$1,700,000.00
2)	Develop state-of-the-art semi-automatic equipment into fully automatic equipment.	175,000.00
3)	Advance the technology in handling of chips and substrates.	50,000.00
4)	Development of methods criteria and equipment specifications for a fully automated hybrid production line.	75,000.00
5)	Develop computer input/output and systems software applications requirements.	100,000.00
	TOTAL	$2,100,000.00

Estimated project duration is twenty-eight (28) months.

Benefits.

1) A 30% cost reduction in Guidance System Electronics Unit Assembly Labor, thereby reducing labor to 5.6% of Electronics Unit cost.
2) A 30% cost reduction in Guidance System Electronics Unit Purchased Parts, thereby reducing Purchased Parts to 19.25% of Electronics Unit cost.
3) A 10.65% cost reduction in Guidance System as a result of cost reductions in Electronics Unit.
4) Five fold reliability improvement.
5) Three fold increase in circuit speed performance.
6) Four fold decrease in unit weight and volume.

Assumptions. The stated benefits assume that a hybrid pilot line facility will be implemented and amortized in the cost of TOW. We also assume that TOW production rates will continue at present schedule and that the hybrid design would be produced at a 30% savings over present discrete design.

PART III: TREND DATA

Use of Hi-Rel Components

The use of Hi-Rel Components continues to grow rapidly as more new devices are developed and more companies enter this field. The improvement curve continues to be steep (80.5%) as compared to discrete (85%). The savings in cost will become more notable in the very near future by virture of increased application. The average number of discretes replaced per hybrid per system (board) is 49. The cost today becomes equal (per system) at the one hundred twenty-five (125) unit level where as a few years ago it was equal at the one thousand (1,000) unit level.

Components Per Function

Components per function as the result of the inroads by hybrids is as previously stated 49 to 1, however this ratio will vary depending on the type of function being addressed.

Cost Versus Weight

Trade off studies conducted show that the average weight reduction from a discrete design to hybrids is approximately 75%, while the cost reduction for the same studies approaches 30%. Therefore we can safely assume that 25% of the discrete weight in hybrids is equal to a 30% cost reduction.

Cost Versus Number of Components

As the usage of components increases the cost associated with the component decreases. The following four charts show the cost trend for discrete components and hybrid components.

Degree of Miniaturization

In the early 1950's, the vacuum tube was the heart of all missile designs. The missile electronics units were physically large, required high current and voltage power sources and provided slow response time to circuit signals. In the late 1950's the semi-conductor emerged and began to replace the vacuum tube. The earliest semi-conductor forms employed in Hughes Aircraft Company designs were the simple transistor and diode. The integrated circuit was introduced to electronics units shortly thereafter and the overall size of the electronics unit was reduced. Because the semi-conductor requires less power than its predecessor the vacuum tube, the power source was also reduced. Circuit signal speed was increased allowing new generations of guidance systems to evolve.

The first generation of hybrid modules was introduced into the missile electronics units in the mid 1960's. These hybrids used simple transistor and diode chips, integrated circuit chips, and in many instances diodes and resistors in discrete form. The early hybrid reduced the size of circuit cards and the resultant missile electronics units only slightly. However the hybrid began to rapidly reduce in size and increase in complexity as new integrated circuit designs emerged. The early hybrid total circuit content soon became a single component chip as the circuit functions were increased on a single chip, called a Medium Scale Integration (MSI) integrated circuit. By 1972, the hybrid design was able to replace a discrete design and provide a space reduction of 75%.

The prediction for future designs in missile electronics units is that the Large Scale Integration (LSI) integrated circuits will continue to reduce the size required to achieve circuit functions. At present, one hundred fifty-five (155) discrete components required for a tracking function can be replaced by a single LSI chip plus twenty-five (25) discrete components. This provides a 5.1 to 1 size reduction ratio, which is an improvement of an additional 25% over the 1972 achievements of 4.0 to 1 size ratio. At the present pace, a size ratio of 7 to 1 can be expected by the mid 1980's.

Degree of Manufacturing Automation

There is a great contrast between the manual methods of circuit card assembly of the 1950's and the sophisticated automation of the 1970's. In the early 1960's automatic component prepping, handling and insertion were introduced. The early equipment used numerical control systems requiring simple programming, but provided limited flexibility to machine functions and production changes.

The late 1960's began to employ a new evolution in minicomputers, improved mechanical flexibility and computer software that allowed rapid set-up and change. The Variable Center Distance (VCD) axial lead component insertion machine was one of the most important advances in automatic equipment development. The VCD allowed axial lead components of varying sizes and types on different insertion spans to be automatically inserted on a single set-up. This operation, in conjunction with the component prep sequencer, has effected a labor reduction of approximately 7 to 1.

In addition to component insertion, wave soldering using automatic circuit board handling has provided significant improvement over the hand solder techniques used in earlier years.

As missile electronic designs at Hughes Aircraft Company incorporate more and more hybrid modules, the emphasis in automatic assembly equipment must of necessity shift to hybrid manufacturing and handling. The available equipment for hybrid manufacturing is semi-automatic using minicomputer control. A second generation of hybrid equipment is in the conceptual and design stages and will be available in the late 1970's or early 1980's. Automatic substrate and chip handling equipment is available to couple to semi-automatic processing thus making a high degree of automation available now for hybrid processes.

With the existing equipment, hybrids are competitive with circuit boards employing discrete components at a 1 to 1 ratio. However with the evolution of the new generation of hybrid automatic equipment, the ratio will approach a 1.5 to 1 ratio with hybrids being more cost effective.

LSI IMPLEMENTATION OF LOGIC FUNCTIONS PRESENTLY USED IN MISSILE GUIDANCE SYSTEMS

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Bedford, Massachusetts 01730

SYSTEM/SESSION AREA/COMPONENT

All missiles containing digital controls (Pershing, SAM-D, etc.)/ Guidance/Electronics.

PROBLEM

While LSI (large scale integration) has reduced the cost of consumer electronics dramatically, its use in defense systems has been held back by the high development and tooling cost for specific circuit functions which in most military applications cannot be distributed over a sufficiently large production volume.

The new microprocessors alleviate this problem to some extent, but they satisfy at most 20 to 30 percent of all digital logic requirements because of their functional and speed limitations.

If the tooling cost for LSI logic circuits of typically 300 gate complexity could be reduced from the present 100,000 dollar level to a range of $6,000 to $8,000, custom LSI could be utilized for retrofit conversions of present digital systems utilizing SSI/MSI circuits in DIP's or Flatpacks. Such a low-cost LSI manufacturing technology would also facilitate greatly the introduction of digital LSI controls into new missile designs.

PROPOSED SOLUTION

Raytheon has developed both Schottky TTL and SOS (Silicon on Sapphire) logic arrays of 300 gate or greater complexity which utilize standard diffusion patterns at a relatively small penalty in circuit density. These designs are specifically aimed at low tooling and small-volume manufacturing costs through maximum use of computer-aided layout, mask generation and test.

It is proposed to develop a manufacturing system for the low-cost conversion of standard TTL or CMOS SSI/MSI logic into LSI at a cost per LSI part number of about $6,000. This manufacturing system will also provide the efficient low-cost manufacture of small-volume production runs, with a goal of less than 15¢ per gate at the 1,000 device level. This cost will include the cost of computerized testing.

While the proposed LSI manufacturing technology will be of potential benefit to a large variety of military systems, this effort will concentrate on the conversion of missile guidance logic into LSI to achieve reduced cost and power dissipation and increased reliability.

Some of the key details of the proposed approach are:

(a) Schottky TTL Array Specifications

The 300 gate Schottky TTL array is most suitable as the replacement of existing TTL designs using SSI/MSI since it interfaces directly with all TTL circuit families. It has a typical gate delay of 5 nsec and a maximum gate delay-power product of 25 picojoules. It is designed for a two-layer metallization system of Al or Au with a maximum of 64 pads. An extensive library of building block functions and automatic interconnect routing is provided. Either hybrid packaging or the use of 40 lead DIP's is possible.

(b) CMOS/SOS Logic Array

The SOS array is superior with regard to speed (gate delay of 2 to 3 nsec) and power consumption (10 percent of bulk CMOS, 1 percent of Low Power Schottky TTL), but has less drive capability than the TTL array.

(c) Tooling Technology

The generation of the required interconnect masks and test programs is accomplished by use of CAD (computer-aided design). Routing is semi-automatic, utilizing an interactive display. Typical total prototype tooling cycle is 5 to 6 weeks from logic design to tested device, as compared to 8 to 12 months for a conventional custom LSI circuit.

(d) Manufacturing Technology Development

The manufacturing technology project proposed here will provide the following results:

- Pilot plant optimization to increase yield and reduce processing cost.
- Technical data regarding wafer process specifications, mask specifications, device layouts and quality controls.
- Technical data regarding the CAD generation of mask tapes and test programs.
- Conversion of a selected circuit assembly for demonstration purposes.
- Demonstration pilot line runs providing sample circuits as well as actual cost and yield information.
- Analysis of the obtained data to refine the cost saving estimates for specific missile systems.
- Final report.

PROJECTED COST AND DURATION

The proposed project will utilize existing plant facilities at Raytheon Bedford. The estimated costs to obtain a qualified LSI production line with fast turn-around capability are as follows:

Pilot Plant Optimization	$ 60,000
Engineering Support and Technical Data	110,000
Demonstration Pilot Runs	35,000
Total	$205,000

This cost does not include the qualification of the selected device designs. Depending on the number of types implemented, the qualification cost should range from $40,000 to $60,000.

The estimated project duration is 18 months.

BENEFITS

The conversion of digital missile circuitry from SSI/MS devices to LSI will result in a typical manufacturing cost reduction of 30 percent to 50 percent at the digital subsystem level, and a reliability increase by a factor of 2 to 10.

Since electronics represent about 40 percent of guidance systems cost, and digital circuits can reach, in modern guidance designs, as much as 20 percent of the electronics content, a guidance cost reduction of up to 4 percent (0.5 x 0.4 x 0.2) seems feasible by utilizing custom LSI for the guidance control. Additional cost savings are possible, of course, by utilizing the proposed LSI technology in other areas as well.

The reduction in missile life cycle cost due to the improved reliability depends on the level of digital systems implementation, but should yield measurable additional savings.

ASSUMPTIONS

The proposed cost savings are based on a detailed comparison of actual systems in both LSI and SSI/MSI implementation. The $6,000 to $8,000 tooling cost for a complex, high-performance LSI circuit has been demonstrated in a laboratory environment, and its extrapolation to factory tooling should be low-risk. Costs are based on a total annual throughput of only 20,000 LSI circuits per production line.

IMPROVED HYBRID CIRCUIT MANUFACTURING TECHNIQUES

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SYSTEM/SESSION AREA/COMPONENT

Support missiles and high altitude air defense missiles (Pershing, HAWK, SAM-D)/Guidance/Electronics.

PROBLEM

The use of hybrid circuits for missile guidance systems provides the advantage of significant savings in packaging volume and weight. Unfortunately, hybrid circuits have also some disadvantages when compared to conventional electronics utilizing discrete components on P.C. boards. First, assembly cost is higher because chip components must be wire bonded individually. It is true that beam lead devices would alleviate this problem, but their availability is unfortunately restricted. Secondly, the repair rate during assembly is higher, since semiconductor chips cannot be burned-in conveniently. Thirdly, attachment of components to the hybrid circuit substrate is made difficult by the need of mixing different attachment techniques.

Most passive chip components require solder attachment, while semiconductors are wire-bonded. Particularly on thick film circuitry, extended heating cycles during component assembly may lead to solder-leeching of the conductive layer and subsequent weakening of bonds. Lid sealing by soldering, finally, limits yield because it requires the application of temperatures which can potentially weaken internal bonds. In addition, conformal coatings used for the protection of hybrid circuits are often not fully compatible with the total manufacturing cycle.

PROPOSED SOLUTION

Ideally, hybrid circuits could be fabricated cheaper and more reliably by standardizing on a single attachment technique such as ultrasonic or thermocompression bonding of leads for all components, active and passive, as well as for external circuit leads. Since such an approach, however, would require excessive new component developments, it is proposed to conduct a manufacturing technology program which stresses the compatibility and cost reduction of attachment and assembly methods for existing off-the-shelf components. This program encompasses the following tasks:

(a) The adaptation of tape-carrier lead frames for the attachment of chip components to hybrid substrates. The tape carrier technology permits the gang bonding of all chip-to-substrate connections similar to the beam lead technology, but has three important advantages. Firstly, it can be applied to any device designed for conventional wire bonding and eliminates thereby the problem of limited device availability. Secondly, it permits - in contrast to beam lead devices - the right side up bonding of chips to substrates, thereby greatly facilitating quality control inspections. Finally, the tapes can be utilized as a convenient chip transfer and handling medium during the assembly of the hybrid circuits, facilitating automation of the assembly process.
Due to these advantages, tape carrier packaging has an increasing impact on the low-cost assembly of commercial DIP packages. It can be expected that the adaptation of this technology to the manufacture of hybrid circuits for missile systems will lead to an assembly cost reduction of up to 40 percent. This task will develop the required assembly technology to achieve this goal.

(b) Development of a method for the economic burn-in of semiconductor chips. It is being considered to base such a method on the tape supported chip lead frames developed under paragraph (a). Typically 5 percent to 8 percent of IC's are found defective during burn-in. Processes for effective burn-in of chip components will increase reliability of multichip hybrid circuits and reduce rework of circuits for the replacement of defective components.

(c) Development of processes for the attachment of active and passive components to the substrate by use of modern high temperature epoxies. Compatibility will be achieved with ultrasonic and thermocompression wire bonding of leads as well as with tape-carrier lead frame bonding. The epoxy system will permit the replacement of defective chip components at high repair yields.

(d) A compatible low temperature lid sealing technology will be developed, based on either epoxy sealing or welding, or both.

(e) Conformal coatings will be developed which will be compatible with easy repair procedures which will provide maximum protection of all external leads.

(f) Demonstration of a low-cost hybrid circuit manufacturing approach using the following standard missile hybrid circuits as development vehicles:

1) RF and IF Amplifiers
2) RF Switch
3) Voltage Regulators (8 types from -22.5 to +22.5V)

It should be noted that MICOM is supporting a somewhat similar program for digital hybrid circuits used in SAM-D ground equipment. These circuits are, however, technologically simpler than typical missile guidance hybrid circuits, since they contain beam-lead devices only. It is planned to coordinate the proposed project closely with this SAM-D effort.

PROJECT COST AND DURATION

Tape Transfer Chip Attachment	$150,000
Method For Chip Burn-in	70,000
Compatible Chip Attachment Method	50,000
Lid Sealing Method	50,000
Conformal Coating Evaluation	70,000
Fabrication of Standard Missile Circuits	50,000
Total	$440,000

Estimated Duration - 24 months.

BENEFITS

The implementation of this program will lead to a significant cost reduction in the manufacture of hybrid circuits which should reach about 40 percent of assembly and touch labor cost, or about 20 percent of total hybrid circuit cost. For complex guidance systems where the cost of hybrid circuits may reach as much as 10 to 15 percent of the guidance package, the resulting savings could exceed 2 percent of the manufacturing cost of such a system.

In addition to the manufacturing cost savings, a significant increase in reliability should be achieved which would translate into additional life cycle cost savings.

ASSUMPTIONS

The proposal is based on the actual experience in the manufacture of hybrid circuits for missile guidance systems. No additional assumptions based solely on engineering judgement have been made.

COMPOSITE MATERIALS TECHNOLOGY FOR ELECTRONIC SUPPORT STRUCTURES

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SYSTEM/SESSION AREA/COMPONENT

Support missiles and high altitude air defense missiles (Pershing, LRGM, HAWK, SAM-D)/Guidance/Major mechanical parts.

PROBLEM

A missile is exposed to very high accelerations, vibrational levels, and temperatures. As a consequence, not only aerodynamic structures, but even electronic support structures such as inner shells, trays and fixtures are exposed to significant mechanical stresses. This requires the use of expensive high-strength materials for such structures. Their cost is further increased by the generally required high packaging densities and odd form factors, which result in complex structural shapes.

PROPOSED SOLUTION

Today the electronic support structures in missile guidance systems are generally fabricated from brittle aluminum castings which are heavy, of limited strength and medium stiffness, possess low damping and uncontrolled natural frequencies, and are volumetrically inefficient.

It is proposed to utilize instead composite materials of reinforced graphite/epoxy for these structures, or alternatively a substitution of Kevlar-49 or PRD-49 organic fibers for the graphite filaments. These epoxy-based composites will reduce weight, increase reliability and strength, reduce the transmission of shock and vibration, and permit a tailoring of structural stiffness to meet specific requirements. It should be noted that the damping characteristics of graphite/epoxy are outstanding.

Graphite/epoxy composites have also a great potential as a structural material for missile airframes. Here the requirements are somewhat different, however. Thermal stress is larger, and so are strength requirements. This project aims specifically at the development of materials and manufacturing methods optimized for internal structures supporting the guidance electronics. Low cost manufacturing methods such as extruding or molding will thus be emphasized.

During the graphite fiber growth, the planes of the carbon crystallites rotate and shift to acquire a three-dimensional stacking order and interlayer spacing. This order consists of planes of hexagonally arranged atoms stacked in ABAB sequence, where the A planes and the B planes are shifted laterally with respect to each other. Strong, covalent bonds prevail within each layer, but weak van der waals-type forces exist between adjacent layers, the first having energies on the order of 100K cal/mole, the latter only 1.3K cal/mole. Therefore, the individual crystallites are extremely anistropic. Electric resistivity in the vertical direction is about 100 times that of the lateral direction, thermal expansion coefficients exhibit a ratio of 28 to 1, and heat and shock transfer are similarly directional.

Ordinarily, this fiber anisotropy requires the careful orientation of the graphite fiber bundles in the epoxy resin matrix by hand lay-up or other fabrication methods. Extruded bodies, however, show preferred alignment of the fibers in the direction of extrusion, and molded bodies in the direction of pressure application. These phenomena provide the opportunity to achieve the required fiber orientations by the controlled application of relatively simple and inexpensive manufacturing methods.

The project will be structured into the following tasks:

- The development of graphite/epoxies which will be optimized for use in the inner structure of missiles.
- A study of how to manufacture at low cost the typical shapes and piece parts used in supporting electronics such as inner shells, I and H beams, trays, etc. This study will explore such fabrication methods as extruding, molding, layering, machining and bonding.
- The project will emphasize the one-to-one replacement of present metal structures to facilitate the possibility of retrofitting current designs.
- The refinement of present analytical methods to include the treatment of anisotropic materials regarding stresses, deflections and strength.

This program will utilize as its vehicle an existing missile guidance design to provide a meaningful comparison.

PROJECT COST AND DURATION

Guidance and Control Structure Design	$ 90,000
Guidance and Control Structure Fabrication	50,000
Testing and Evaluation	30,000
Development of Manufacturing Methods	80,000
Engineering Support and Test Data	50,000
Total	$300,000

Estimated project duration is 24 months.

BENEFITS

Taking advantage of the unique anisotropic properties of composites in a design, one finds that the component often becomes simpler and, hence, easier to manufacture than its monolithic counterpart. The simplicity of the part coupled with the nature of the material enhances maintainability and reliability, again with cost reductions.

There is no question, however, that the greatest benefit from a utilization of graphite/epoxy composites will be achieved for new missile designs where maximum advantage can be taken of the increased strength, lighter weight and better damping characteristics of the new material. Nevertheless, the benefits should be significant even for retrofits. Aside from a lowering of the component stress, the cost of fabricating and assembling the intricate shapes of electronic support structures should be reduced if extrusion and molding processes can be applied to composites of moderate strength requirements.

The typical cost of electronic support structures for missile guidance systems is about 6.5 percent of the total guidance system cost. Savings due to the use of composites are difficult to estimate at this time. Should they reach 15 percent of the structural cost, total guidance system cost savings would reach about one percent.

ASSUMPTIONS

This proposal is not based on specific assumptions. The advantages of composites in aerostructures have already been demonstrated in numerous applications.

THE REPLACEMENT OF ELECTRONIC WIRING BY OPTICAL FIBER DATA LINKS

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SYSTEM/SESSION AREA/COMPONENT

Long range general support missiles and high altitude air defense missiles (Pershing, LRGM, SAM-D)/Guidance/Cables and connectors.

PROBLEM

Larger missiles require a complex wiring harness which represents not only a significant cost item, but also a potential source of failures. Furthermore, cables limit the EMP and noise immunity of the system. Sensitive cable connections are in particular those between sensors and guidance system on one hand, and between guidance system and rear link antennas on the other.

PROPOSED SOLUTION

Raytheon proposes to develop, in cooperation with Bell-Northern Research, Ottawa, the manufacturing technology for optical data links using fiber optics. These data links will be specifically optimized for missile requirements and environment.

The project will address such questions as the high-density, low-cost packaging of the transmitter/receiver/transducer circuits, the implementation of low-cost connectors, and the splicing of the optical fibers in a factory environment. Factory test procedures for optical links will also be developed.

Preliminary specifications visualize two separate data link designs for analog and digital data. Both will be based on well-proven Bell-Northern designs. The analog link shall provide good linearity with a bandwidth up to 60 MHz, and the digital link shall meet a bit rate specification of at least 15 MHz. The data links will utilize an LED transmitter to achieve the desired linearity, and a PIN photo diode receiver. Low power and packaging volume will be emphasized.

The project will consist of the following tasks:

- Analysis of a typical missile guidance wire harness for simplification by the selective use of fiber optics as interconnection medium.
- Analysis of the potential cost savings by the resultant harness simplification and the concurrent reduction in cross talk problems.
- Development of an analog data link suitable for missile guidance applications.
- Development of a digital data link suitable for missile guidance applications.
- Study of the applicability of these fiber optic data links to other missile system equipment.
- Development of the manufacturing technology for the missile guidance data links, including the techniques required in missile assembly.
- Development of the required repair techniques, including the splicing of optical fibers.

PROJECT COST AND DURATION

The cost of this project, leading to the demonstration of a fiber optics data link in a missile guidance test environment, is estimated at $250,000. The preliminary breakdown of this estimate is as follows:

• Analysis leading to the modification of an existing wire harness	$ 20,000
• Adaptation of analog data link	60,000
• Adaptation of digital data link	50,000
• Development of manufacturing and assembly methods	80,000
• Development of repair methods	40,000
Total	$250,000

The estimated project duration is 18 months.

BENEFITS

The replacement of critical electronic cables by optical data links will result in a simplification of the missile wiring harness, improved reliability, simplified factory testing and an improved missile performance in an ECM environment.

It is estimated that the cost of a complex missile wiring harness might be reduced by 20 percent, and guidance assembly and test cost by 10 percent. Since harness cost and test cost each represent about 4.5 percent of the cost of a guidance system, total savings would amount to 1.3 percent ((0.2 x 0.045) + (0.1 x 0.045)).

ASSUMPTIONS

The actual cost savings will depend to a large extent on the manufacturing costs achievable for the transducer and multiplexor circuits. It is being assumed that this manufacturing technology project will reduce the transducer circuit cost to $30, and that a low-cost multiplexor circuit can also be obtained. These assumptions look reasonable. Furthermore, it is contemplated that all inter-subsystem IF and digital signal paths in the missile will utilize optical data links.

Title: Manufacturing Technology Project to demonstrate the advantages of low cost computer controlled thin film techniques in the manufacture of microcircuits.

System/Panel Area/Component: Guidance - complex solid state circuitry in the guidance and other electronic systems of the missile.

Problem: Considerable costs are incurred in the manufacture of microcircuits for electronic systems of missiles. Major cost contributors are the substrate materials, the complex capital equipment required in the manufacture, the high labor content, the yield level experienced in the manufacturing process and other factors between the points of manufacture and use.

Proposed Solution: The thin film technology permits the use of low cost easily obtainable substrate materials such as metallic (aluminum) or non-metallic film. The required capital equipment is smaller, simpler and less costly than the presently used equipment. The technique employs a continuous process and computer control. One of the main advantages of the system is that because of its small size it can be installed at the point of use, neither skilled technicians nor process engineers are required to keep the equipment in operating condition. The design and construction of a prototype is proposed, dedicated specifically to the manufacture of microcircuits used in missile systems.

Project Cost and Duration: Estimated costs are as follows:

Design and construction of system	$400,000
Manufacture and evaluation of microcircuits	300,000
Total	$700,000

Estimated duration of the project is 24 months.

Benefits: Numerous cost benefits would be derived from the application of this process in the following areas:

- raw material costs
- product costs
- defective material costs
- inventory costs.

The expected cost reductions are between 25% and 75% depending on the complexity of the circuit.

Some concurrent benefits would be:

- less dependence on heavily process oriented materials (substrates)
- higher process yield
- ability to manufacture at the point of use
- shorter delivery cycle
- elimination of strategic threat to present sources of supply through dispersal
- ability to introduce design changes more quickly
- requires low operator skill.

Assumptions: Production requirement is sufficiently large to warrant the investment for the equipment.

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TITLE: Manufacturing Technology Project to develop automatic inspection syetem for printed circuit boards

SYSTEM/PANEL AREA/COMPONENT: All/Guidance/Printed Circuits

PROBLEM: Quality control inspection of printed circuit boards after loading and soldering is presently performed manually. Human operators are subject to moodiness, fatique, and outside pressures, thus giving the possibility of irregularities in the quality of work. Inspection of printed circuit boards can be a monotonous task in which the failure to notice a small deficiency may allow a defective board to be incorporated into the final system. An automatic, printed-circuit board inspection system could be used to advantage on all missile systems having a reasonable production quantity. Soldering quality and parts loading could be examined and verified in a systematic manner based on an approved set of standards.

PROPOSED SOLUTION: Development of an automatic inspection system for printed-circuit boards would require an imaging system, a pattern recognition system, and a precision positioning system for locating the printed circuit board with respect to the imaging system. A method of measuring a pertinent feature for each test to be performed is required. Experimentation to verify the measurement of features would be followed by design of a complete system and construction of a prototype system.

PROJECT COST AND DURATION: Estimated costs for the development are:

Breadboard Verification of Techniques	$ 50,000
Design and Construction of Prototype System	300,000
Test and Optimization of System	100,000
TOTAL	$450,000

Estimated duration of development is 24 months.

BENEFITS: Use of an automatic, printed-circuit board, inspection system would give more reliable, quality hardware at a reduced labor cost by systematically inspecting all points on a printed-circuit board. Part loading as well as soldering quality could be tested in a more thorough manner than possible with human inspectors. Cost savings with automatic inspection is expected to be between two and five percent of the hardware cost for a typical missile system.

ASSUMPTIONS: In order to practically use an automatic inspection system, it will be necessary to have an approved threshold of acceptance for each feature tested by the machine. It will also be necessary to provide numerical coordinates for each point or part to be tested. Reasonable production quantities are assumed in order to make the system cost effective.

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ADDITIVE PROCESS FOR FABRICATION OF PRINTED CIRCUIT BOARDS

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SYSTEM/PANEL AREA/COMPONENT

All Systems/Guidance, Electronics/Printed Circuit Boards

PROBLEM

Plated through hole circuit boards fabricated by normal subtractive processing have limitations in their achievable tolerances. Attainment of very fine lines and spaces is restricted by etching undercut, and the resultant loss of accuracy. Pure additive processing eliminates this and additionally reduces the cost of board fabrication by eliminating etching, and depositing copper uniformly by electroless plating only in the holes and on circuitry where it is desired. However, pure additive processing has disadvantages. Among them are:

(a) the quality of the copper deposited by electroless plating (ductility and strength) is not equivalent to the best that can be obtained by electroplating,

(b) most circuit board manufacturers already have equipment and capability for fabricating boards using subtractive processing and special materials and processes are required to produce boards by additive methods.

For these reasons, additive processing does not seem most desirable for production of boards meeting military spec requirements. A method or technique is needed which will provide the benefits of additive processing, yet be compatible with existing facilities and processes throughout most of industry.

PROPOSED SOLUTION

This problem will be solved by developing processes and qualifying them to MIL-Spec requirements which combine the advantages of normal subtractive and additive processing.

Using recently available thin-clad laminates, almost the entire circuit thickness can be produced by electroplating resulting in maximum possible strength and ductility. Consistently good adhesion is obtained, provided by the initial copper cladding, without the necessity of developing capability for conditioning of unclad epoxy.

The solution will be accomplished by completing the following tasks:

The first task will be to evaluate the available materials to be used as the starting point for the program, and establish their advantages, disadvantages, and physical/chemical properties.

Task 2 will be to develop the process and optimize processing parameters to give the best results.

Task 3 will be to qualify the process to MIL Specs to demonstrates its ability to produce military quality boards.

Task 4 will be to document the qualification results and the process used to obtain the test results.

PROJECT COST AND DURATION

1.	Material evaluation	$ 10K
2.	Develop production process	30K
3.	Optimize process for maximum quality	35K
4.	Conduct qualification	20K
5.	Release final process report, MIL Spec test report, cost evaluation report	5K
	TOTAL	$100K

The estimated duration of the project is 12 months.

BENEFITS

The benefits will be a capability for producing MIL Spec quality circuit boards with the close tolerance control and costs savings possible utilizing modified additive processing.

ASSUMPTIONS

The justification for this program assumes that further miniaturization in electronics packaging is desirable without an increase in cost or decrease in reliability. It further assumes that a process which can be implemented with maximum utilization of existing capital equipment is desirable.

OPTIMIZATION OF PLATED-THROUGH HOLE TUBELETS

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SYSTEM/PANEL AREA/COMPONENT

All/Guidance/Printed Wiring Boards

PROBLEM

In plated-through hole circuit boards, particularly multilayer boards, the process of making a plated-through hole interconnection has not been analyzed and studied in an overall, systematic way to develop a process which maximizes all variables. Drilling, hole treatment, copper plating have been studied separately, generally by Engineers with different backgrounds and objectives, with a view toward solving separate problems. The total system has not been analyzed and studied to optimize all process variables dependently to achieve maximum performance and reliability.

PROPOSED SOLUTION

This program would entail the analysis of material properties, drilling, hole cleaning, metallizing and copper plating as one system and optimize them concurrently, to produce a plated-through hole with substantially longer life and greater reliability.

PROJECTED COST AND DURATION

1.	Develop consistent, thorough evaluation criteria and tests	$ 20,000
2.	Conduct developmental program	75,000
3.	Conduct final tests, document results and process	15,000
	TOTAL	$110,000

The estimated duration of the project is 24 months.

BENEFITS

The benefits would be improved plated-through hole circuit board performance, resulting in longer service life and reduced fabrication cost in electronics.

ASSUMPTIONS

The assumptions underlying this investigation are that increasing electronics miniaturization will place greater reliance on plated-through hole interconnection integrity, as multilayer boards are designed with more layers, and smaller and more plated-through holes.

TIN-LEAD PLATE FUSING CONTROL OF PRINTED CIRCUIT BOARDS

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SYSTEM/PANEL AREA/COMPONENT

All Weapon Systems/Guidance Area/Printed Circuit Board Component

PROBLEM

Circuit board assembly solderability and solder joint reliability is heavily dependent on the solderability of the printed circuit board land areas. Wave soldering techniques require consistent, good solderability to minimize manual solder joint touch-up and reduce costs.

Tin-lead plate followed by IR reflow shows promise of providing a process for depositing a known and closely controlled amount of solder to a board, and reflowing it without significant variation. To realize these advantages and achieve optimum solderability during flow soldering, with the ultimate objective of eliminating hand solder touch-up, the tin-lead plate and IR reflow must be closely controlled. As the processes are interdependent, desired results can best be obtained by evaluating them together.

PROPOSED SOLUTION

The processes for lead-tin plating and IR reflow require optimization of solution concentration, current density, and design density in plating, and heat input and uniformity, conveyor speed and thermal absorption in reflow, and methods developed to monitor them for effective control.

This will be accomplished by working to optimize the following three areas:

The lead-tin plated process will be optimized, and the best value for each operating variable will be established. Control methods to consistently achieve optimum results will be developed.

Circuit board design parameters for uniform circuit density and heat absorption to produce consistent results will be established.

IR reflow process will be optimized, and conditions established for most rapid lead-tin plate reflow.

PROJECTED COST AND DURATION

1.	Optimize solder plating process variables	$ 20K
2.	Optimize IR reflow variables	25K
3.	Develop design standards for maximum plating and heat absorption uniformity	40K
4.	Issue final report and recommendations	15K
	TOTAL	$100K

The estimated duration of the project is 18 months.

BENEFITS

Optimizing and improving the uniformity of the deposit on circuit boards prior to soldering will improve the consistency of soldering and allow establishment of reproducible soldering schedules increasing solder joint quality and reliability. This will permit greater soldering mechanization and could greatly reduce solder joint inspection and touch-up.

ASSUMPTIONS

This program is justified based on the following assumptions:

(a) soldering will remain the prime method of joining components to printed wiring boards.

(b) maximum board solderability contributes to cost effective and reliable soldering.

SPECIAL SURFACE TREATMENTS FOR LAMINATING SURFACE ADHESION

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SYSTEM/PANEL AREA/COMPONENT

All/Guidance, Electronics/Printed Circuit Assemblies

PROBLEM

Delamination of multilayer circuit boards is a problem which is one of the most pervasive throughout the PCB industry. It is not one which is caused bv improper or careless processing, but it is due to the fact that the presently developed surface treatments, the copper to epoxy internal layer bond is marginal when subjected to the 550°F, 10 second solder float test specified in the MIL Specs (MIL-P-55640 and MIL-P-55110) commonly required in Military contracts.

Optimum processes have not yet been developed for improving the copper surface on interior layers of multilayer laminates to increase adhesion so that resistance to thermal shock will be significantly improved.

PROPOSED SOLUTION

The problem will be solved by accomplishing the following four tasks:

Task 1 will be the evaluation of various surface structures produced by different methods of surface treatment and photographed by scanning electron microscope and cross sectioned to determine their topography. These various surfaces will then be evaluated for the quality of their bond, by running various bond strength tests including lap shear and wedge crack extension tests. Thermal stress testing per MIL-Spec)550°F solder float) will also be conducted.

Task 2 will be the investigation of various new surface treatments and the improvement in adhesion they produce in addition to the surface topography.

Task 3 will be to evaluate the effect of various "primers", materials which can be applied to the surface prior to laminating.

Task 4 will be to evaluate laminating methods which exclude oxygen and other gases which may be absorbed on the copper surface prior to bonding and vaporized during thermal shock resulting in extreme pressure, causing rupture of the bond.

PROJECT COST AND DURATION

1. Evaluate surface treatments topographically	$ 20K
2. Evaluate bond strengths	25K
3. Evaluate thermal shock resistance	25K
4. Evaluate new treatments	30K
5. Evaluate effects of primers	25K
6. Determine effect of "gas free" lamination	15K
7. Determine and document optimum process	35K
TOTAL	$175K

The estimated duration of the project is 15 months.

BENEFITS

The improved lamination technique will reduce multilayer circuit board costs by eliminating delamination resulting from thermal shock in normal production.

ASSUMPTIONS

The basic assumption underlying this program is that the MIL-Spec (MIL-P-55640) test and criteria for delamination resistance is valid and that more effective surface preparation for higher bond strength is feasible.

ESTABLISH PRODUCTION CLEANLINESS PROCEDURE FOR PRINTED CIRCUIT BOARDS

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SYSTEM/PANEL AREA/COMPONENT

All/Guidance Electronics/Printed Circuit Assemblies

PROBLEM

Performance of high performance circuit board assemblies operating at high frequencies and incorporating more dense circuitry is dependent on surface cleanliness. Present cleaning methods, however, tend to be empirical and their effectiveness not directly measurable. There is a need for more thorough circuit board cleaning procedures and for quantitative test procedures to measure their effectiveness.

PROPOSED SOLUTION

The solution to this problem is to develop a cleaning procedure or procedures which will produce surfaces of ultimate cleanliness which will yield optimum results in subsequent processing, and will give the maximum end item quality. Accompanying this, a reliable method of evaluating surface cleanliness will be developed.

This effort will be divided into tasks:

Task 1 will be to identify various classes of residues and contaminants which may be found on printed circuit boards and establish analytical methods most suitable for determining their presence. These methods may include electron microprobe, energy dispersive x-ray, chromatography, atomic absorption, and other techniques.

Task 2 will be to establish the optimum cleaning procedure for each of these residues. The cleaning procedure may involve chemical or mechanical cleaning, or a combination of both for contaminant loosening, as well as various rinsing methods for maximum soil removal.

Task 3 will involve establishment of production cleaning methods for removing combinations of contaminants found in production to reduce cost by standardizing cleaning procedures and simplifying equipment required to accomplish cleaning.

Task 4 will be to develop a production testing method for determining the cleanliness of a surface.

PROJECT COST AND DURATION

1.	Identify classes of residues and analytical methods	$ 20K
2.	Determine optimum cleaning procedures	40K
3.	Develop appropriate production cleaning methods	30K
4.	Develop cleanliness testing methods	25K
5.	Report on procedure and recommended equipment for production cleaning	10K
	TOTAL	$125K

The estimated duration of the project is 18 months.

BENEFITS

A consistent level of cleanliness can be obtained that will assure the success of subsequent process to which the cleaning is preliminary, thereby reducing costs by eliminating failure and rework, as well as by permitting construction of optimum cleaning facilities, eliminating duplication and providing efficient equipment utilization.

ASSUMPTIONS

The assumptions underlying this program are that:

(a) increased electronics complexity will require more dense circuitry and more precise operation.

Surface cleanliness of the printed circuit board is essential to successful further processing and performance.

TITLE:

Manufacturing Technology Project to Optimize Assembly Processes for Subminiature Gyros and Accelerometers

SYSTEM/PANEL AREA/COMPONENT:

Various (e.g., HAWK, SAM-D, SHORADS)/Guidance/Gyros, Accelerometers

PROBLEM:

Gyros and accelerometers used for seeker stabilization and autopilot control represent a significant part of missile costs. A major contributor to these component costs is assembly labor, since many operations require operator skill and judgement. A recently developed family of subminiature gyros and accelerometers eliminates much of this costly labor through the use of assembly processes which lend themselves to automation (e.g., precision welding, machine coil winding, etc.). The problem is that the processes have been demonstrated on only small lot sizes and the tools and fixtures required have not been fully evaluated on a production scale.

PROPOSED SOLUTION:

The project would permit evaluation of the assembly processes on a production pilot quantity of units. This would include design and fabrication of special tools and fixtures as required. Primary emphasis would be on adapting the processes to production line requirements. If successful, the project could reduce the cost of gyros and accelerometers by 25%.

PROJECT COST AND DURATION:

Estimated costs are as follows:

Piece parts fabrication/procurement	$ 50,000
Tools and fixtures	200,000
Assembly	75,000
Engineering Support & Technical Data	100,000
TOTAL	$425,000

Estimated duration of the project is 18 months.

BENEFITS:

Benefits to be derived from this project are a reduction in recurring hardware costs amounting to about 2% of guidance system costs for SAM-D and SHORADS and 1% for HAWK.

ASSUMPTIONS:

The estimated benefits assume a production line set-up for instrument manufacture at a minimum rate of 500 units per month.

ADDITIONAL INFORMATION:

A new family of subminiature gyros and accelerometers has been developed which from the outset has stressed low production cost. The design philosophy is based on eliminating the "black art" usually associated with gyro manufacture, such as special fitting and adjustment accomplished by a hand full of highly specialized operators. To accomplish this end, the piece parts have been designed and dimensioned for fabrication by means of high volume, highly repeatable and automatic techniques whereby the precision is imparted by the machines rather than the operator. The configurations of the parts lend themselves to fabrication techniques which achieve final form and dimension with a minimum of machining. A high degree of parts commonality among the various instruments in the family has been achieved which further contributes to low piece-part costs.

The instrument design has also accounted for reduced assembly costs. Once again, the philosophy has been to employ techniques where the precision and consistency are inherent in the process or can be built into the fixturing and tooling. Examples of this are precision welding for effecting hermetic seals (rather than soldering) and machine coil winding to replace earlier manual methods.

The development of the instrument family (a fully floated rate integrating gyro, partially floated rate gyro and pendulous accelerometer) has been completed and prototype units evaluated. The need exists to move to the preproduction phase to investigate and evaluate various areas in the manufacturing technology necessary to effect the projected cost savings.

RAYTHEON COMPANY
Missile Systems Division

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TITLE:

Manufacturing Technology Project to Optimize Fabrication Processes for Subminiature Gyros and Accelerometers

SYSTEM/PANEL AREA/COMPONENT:

Various (e.g., HAWK, SAM-D, SHORADS)/Guidance/Gyros, Accelerometers

PROBLEM:

Gyros and accelerometers for seeker stabilization and autopilot control represent a significant part of missile costs and as such, are continuing subjects for cost reduction efforts. A recently developed subminiature gyro (and companion accelerometer), characterized by a heaterless design and welded construction, is a major step in the direction of reduced cost. However, the full cost potential of these instruments cannot be achieved until certain of the fabrication processes are further developed. This includes the following:

> A means for fabricating gyro gimbal parts in high volume at low cost (minimizing milling and turning operations). A production method for finishing torsion bars with a high yield of acceptable parts. A technique for metallurgically bonding ferrous metals to aluminum (as opposed to cementing or plating/soldering) where a hermetic seal is required, as in the attachment of electrical terminals to the gyro gimbal.

In each of the above instances, a less-than-optimum method is presently in use.

PROPOSED SOLUTION:

The project would permit development and evaluation of alternative fabrication processes in the above three problem areas compatible with high volume, low cost production. Impact extrusion would be investigated for gimbal part fabrication, automatic form centerless grinding and heat treating for torsion bar finishing, and various welding techniques for bonding ferrous parts to aluminum. The processes would be demonstrated through fabrication of a representative quantity of parts and documented for production application.

PROJECTED COST AND DURATION:

Estimated costs are as follows:

Material and parts procurement		$ 50,000
Tooling		125,000
Fabrication		50,000
Engineering Support & Technical Data		75,000
	TOTAL	$300,000

Estimated duration of the project is 1[illegible] months.

BENEFITS:

Benefits to be derived from this project are a reduction in recurring hardware costs amounting to about 1% of guidance system costs for HAWK, SAM-D, and SHORADS.

ASSUMPTIONS:

The estimated benefits assume a production fabrication set-up and a run of about 5000 parts each.

ADDITIONAL INFORMATION:

A new family of subminiature gyros and accelerometers has been developed which from the outset has stressed low production cost. The design philosophy is based on eliminating the "black art" usually associated with gyro manufacture, such as special fitting and adjustment accomplished by a hand full of highly specialized operators. To accomplish this end, the piece parts have been designed and dimensioned for fabrication by means of high volume, highly repeatable and automatic techniques whereby the precision is imparted by the machines rather than the operator. The configurations of the parts lend themselves to fabrication techniques which achieve final form and dimension with a minimum of machining. A high degree of parts commonality among the various instruments in the family has been achieved which further contributes to low piece-part costs.

The instrument design has also accounted for reduced assembly costs. Once again, the philosophy has been to employ techniques where the precision and consistency are inherent in the process or can be built into the fixturing and tooling. Examples of this are precision welding for effecting hermetic seals (rather than soldering) and machine coil winding to replace earlier manual methods.

The development of the instrument family (a fully floated rate integrating gyro, partially floated rate gyro and pendulous accelerometer) has been completed and prototype units evaluated. The need exists to move to the preproduction phase to investigate and evaluate various areas in the manufacturing technology necessary to effect the projected cost savings.

RAYTHEON COMPANY
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TITLE:

Manufacturing Technology Project to Provide Optimized Angle Transducer

SYSTEM/PANEL AREA/COMPONENT:

Various/Guidance/Sensors

PROBLEM:

Angle transducers such as potentiometers and resolvers are used in missile seekers, gyros, and controls. Where precision is required, these devices are relatively costly. In addition, potentiometer wiper friction in some instances places greater constraints on other system elements, which have a negative impact on cost. Potentiometers are also a source of unreliability and often require replacement. The feasibility of angle transducers based on Hall Effect devices has been well proven. Such components can replace potentiometers and resolvers at a fraction of the cost, very often with improved accuracy, and with much greater reliability since they are solid-state and contain no rubbing parts. The problem is that no one has yet devised a productionized component for missile use.

PROPOSED SOLUTION:

The project would establish a production source for Hall Effect angle transducers. This would be accomplished through preparation of production documentation and tooling and demonstrated on a pilot production run of units. Primary emphasis would be on meeting various missile needs with a family of standard components.

PROJECT COST AND DURATION:

Estimated costs are as follows:

Parts fabrication/procurement	$ 25,000
Tooling	75,000
Test Equipment	50,000
Engineering Support & Technical Data	75,000
TOTAL	$225,000

Estimated duration of the project is 12 months.

BENEFITS:

Benefits to be derived from this project are a reduction in recurring hardware costs of 1/2% for a HAWK or SAM-D guidance system. A Hall Effect transducer would be about 1/5 the cost of a comparable resolver and about 40% of a comparable potentiometer. Additional savings would result from the greater reliability. A Hall Effect transducer would also contribute to improved system performance when used in place of a potentiometer.

ASSUMPTIONS:

The estimated benefits assume a production line set-up with a minimum rate of 1000 units per month.

ADDITIONAL INFORMATION:

The Hall Effect angle transducer is a low cost replacement for conventional resolvers. It is the functional equivalent of a resolver and provides accuracy equivalent to a resolver. It has additional advantages in small size, weight, and power consumed. It also provides flexibility in that the input and output can be either ac or dc, sine wave or square wave.

As a replacement for potentiometers, the transducer provides greater accuracy, reliability, and reduced friction (it has no rubbing parts) along with a saving in cost.

The device is based on the Hall Effect principle which states that when a steady current is flowing in a conductor or semiconductor material in a magnetic field, electromotive forces are developed proportional to the product of the control current and the intensity of the magnetic field normal to the face of the conductor. Physically, the transducer consists of a stator which carries a perpendicular pair of Hall Effect cells, a rotor containing two small magnets and, in a self-contained version, a pair of precision instrument bearings.

Prototype transducers have been built and evaluated. However, in order to establish a production source, production documentation and tooling must be prepared and demonstrated on a pilot quantity of units.

RAYTHEON COMPANY
Missile Systems Division

Gerald M. Nearman
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Title: Manufacturing Technology Project to Provide Low Cost Hybrid Microelectronics

Panels/Area/Component: Guidance, Control/Circuit Assemblies/Hybrid Microelectronics

Problem: Hybrid microelectronic circuit assemblies represent a vital part of current and future systems, especially guidance and control. Present technology uses metallurgically bonded, hermetically sealed hybrid microelectronic packages. While performance and reliability characteristics are excellent, costs are high. Recent work suggests that reliable, low cost hybrid microelectronics can be achieved through the use of high performance plastics for such functions as chip bonding, circuit protection, lid sealing and encapsulation. This technology can be combined with standard electronic module (SEM) concepts to achieve major cost improvements through manufacturing technology advancement.

Proposed Solution: The proposed solution to the stated problem is to establish guidelines on use of plastic materials, optimize manufacturing methods and controls for the several areas of greatest potential and develop standards and quality assurance information for providing reproducibility in manufactured products.

Project Cost and Duration: Estimated costs are as follows:

Study to establish guidelines on use of plastic materials	$300,000
Study to optimize manufacturing methods	200,000
Study to develop controls and quality assurance	300,000
Total	$800,000

Estimated duration of this project is 36 months.

Benefits: Benefits to be derived from this project are reduction in recurring hardware costs and reduction in life cycle maintainability and spares costs. These reductions are estimated as follows:

Reduction in circuit assembly hardware costs:	3% of hardware cost
Reduction in maintainability and spares costs:	2% of hardware cost
Net reduction:	5% of hardware cost

Assumptions: The stated benefits assume that study programs will be conducted to establish the manufacturing methods, controls and quality assurance needed to reproducibly manufacture low cost hybrid microelectronic circuit assemblies.

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Participant: Charles A. Harper, MS 465
Westinghouse Electric Corporation
Defense & Electronic Systems Center
Systems Development Division
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Title: Quality Control and Manufacturing Technology Project for controlled, low-cost production of highly reliable thermal batteries.

System/Panel Area/Components: Dragon, Maverick, CLGP, Hellfire, Bulldog, Lance, Shrike, Sidewinder and other Missile and Ordnance Systems/Guidance/Power Sources.

Problem: Most missile systems use the thermal battery as a source of D.C. power for various system functions. The major problems associated with the manufacture of thermal batteries are identification, measurement and control of the critical chemical and thermal characteristics of their components. Experience indicates that the state-of-the-art for present electrochemical systems cannot be significantly advanced by conventional methods but that through improved Quality Control instrumentation and techniques battery performance and reproducibility can be greatly improved.

Proposed Solution: The project would consist of three major tasks:

a. Identification of critical parameters.

b. Determination of the quality control instruments and techniques most suitable for the applications.

c. Implementation of the selected tools and methods and evaluation of their effectiveness by means of pilot runs under various controlled conditions at appropriate intervals.

Existing Quality Control focuses on chemical and physical analyses of components at room ambient temperature - a critical flaw since thermal batteries operate usefully at temperatures in excess of 400°C. It is proposed to use atomic absorbtion spectroscopy and wet chemical analysis in conjunction with differential scanning calorimetry to provide on-line quality information to various production stations. A differential scanning calorimeter provides data on the thermal requirements of a system as it is heated to 700°C and then slowly cooled thereby duplicating the thermal profile of the material under investigation. Preliminary studies have shown that a subtle change in component behavior which led to battery failure could be detected by this instrument even though chemical analysis showed the material to be within specification. This more sophisticated approach would be cost effective since it would (1) reduce engineering development time and material, (2) reduce manufacturing and quality processing time, (3) increase yield of in-process components and finished batteries and (4) assure battery reproducibility.

Project Cost and Duration:

Equipment Cost		$ 30,000.00
Engineering Support		60,000.00
Cost of building and testing experimental batteries		25,000.00
Technical Data		11,000.00
	Total	$126,000.00

<u>Duration of Project</u>: 18 Months

<u>Benefits</u>: The benefits to be derived from this project are reduction in development and production costs of thermal batteries.

Reduction in Development Cost - 20-30%
Reduction in Production Cost - 15-20%

<u>Assumptions</u>: None

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Leonard A. Stein, President

Title: Manufacturing Technology Project to Study the Relationship Between Design Parameters and Fabrication Costs of Printed Wiring Boards

System/Panel Area/Component: Various/Guidance/Printed Wiring Boards

Problem: Problems for the printed wiring board fabricator are often created at the design stage when fine lines and spacings, small diameter holes, too low pad-to-hole ratios, and thick copper are specified sometimes unnecessarily. These kind of requirements are certainly cost drivers to the board fabricator and can also be a factor in board assembly. Often times the designer overdesigns simply because he does not understand the fabrication limitations, and often times other restraints make such designs mandatory. At the present there is very little information available that relates the impact of design on fabrication. The result is that Fabricators are forced to spend additional time and live with high scrap rates when a much more economical solution might be looser designs.

Proposed Solution: This Manufacturing Technology Study proposes to establish definitive cause and effect relations between design requirements and fabrication costs. Various design parameters will be studied and the impact upon fabrication costs and scrap rates determined. Once information is available that relates certain design conditions to cost, minimum design standards will be established; and where the minimum standards are exceeded the costs incurred can be calculated.

Project Cost and Duration: Estimated costs are as follows:

Review of Design Criteria:	$ 20,000
Study of Design vs. Fabrication:	80,000
Minimum Design Levels:	10,000
Analysis of Costs vs. Design:	20,000
Total	$130,000

Estimated duration of the project is 12 months.

Benefits: Benefits to be derived from this study are the establishment of minimum design criteria and reduced costs and scrappage during printed wiring board fabrication. The study will also provide information so that when design is a cost driver, more cost effective trade-offs can be made.

Assumptions: These benefits are based upon the assumption that the trend in military electronics toward increasing density and complexity will continue. This trend will create even greater problems for the designer and the fabricator and will make cost effective trade-offs a necessity or spiraling costs will result.

COMPANY NAME	PARTICIPANTS
McDonnell Douglas Electronics Company	Rose Mayfield P.O. Box #426 St. Charles, MO 63301 (314) 232-0232 (2707)

Title: Manufacturing Technology Project to Develop and Study Metal Core Printed Wiring Boards

System/Panel Area/Component: Various/Guidance/Printed Wiring Boards

Problem: In many guidance electronic systems two problems exist: Space is limited, and circuit/component density results in overheating. Both of these problems place constraints on designers, and the second problem complicates the first in that to achieve necessary heat dissipation, bulky fans and/or more space are often required.

Proposed solution: For applications where space and heat transfer are critical metal core printed wiring boards could be utilized. As the name implies, this type board consists of a metal core, either steel or aluminum, coated with a dielectric material upon which the circuit is developed. Because of its strength a metal core board can be used as a structural member of the equipment, thus reducing the space required. Metal core boards are also excellent heat sinks so that costly design trade-offs and additional heat transfer are not necessary.

This manufacturing technology program would establish fabrication processes for metal core boards, would examine the feasibility of forming boards into various shaped structural members and would study the heat sinking properties of various combinations of core materials, core thicknesses, and dielectric coatings. The end result would be a handbook which would delineate detailed processes to fabricate the boards, and would provide information to designers as to the heat characteristics of a number of standard board types.

Project Cost: The estimated cost of this project would be:

Fabrication Processes	$100,000
Study of Properties	100,000
Preparation of Handbook	20,000
Total	$220,000

The estimated duration of the project would be 18 months.

Benefits: Benefits to be derived from this project are a large reduction in printed wiring board material costs: (metal core material $\approx$ \$.50/Ft.^{2}; Epoxy/Glass$\approx$ \$2.50/Ft.^{2}). Other benefits would be more efficient utilization of space and a solution to problems of heat build-up in electronic assemblies.

Assumptions: These benefits are based upon the assumption that the trend in military electronics toward increasing density and complexity will continue. This technology project is oriented toward fulfilling some of the needs created by the trend.

COMPANY NAME	PARTICIPANTS
McDonnell Douglas Electronics Company	Rose Mayfield P.O. Box #426 St. Charles, MO 63301 (314) 232-0232 (Ext. 2707)

Title: Manufacturing Technology Project to Utilize Thin Foil Copper Clad Laminates for Low Cost Printed Wiring Board Fabrication

System/Panel Area/Component: Various/Guidance/Printed Wiring

Problem: Printed wiring boards, used in large quantities for missile applications, are fabricated from copper clad laminates that are controlled by military specifications which limit the copper foil thickness to 1 ounce (0.0014") or greater. This restriction creates attendant problems of lower yields, quality and production rates in the fabrication of printed wiring boards. The availability of thin copper foil (1/4 ounce) laminates offers significant cost and quality advantages for printed wiring manufacture. The problem is that the military specification restriction has limited the thin foil material to commercial applications.

Proposed Solution: The project would optimize the processing techniques used to fabricate printed wiring boards from thin foil laminates. The impact of thin foil laminates on printed wiring fabrication costs and yields would be documented and compared to those obtained for conventional 1 ounce laminates. The successful completion of this project could result in improved printed wiring board yields of at least 10 to 15%.

Project Cost and Duration: Estimated costs are as follows:

Material Test and Evaluation	$ 50,000
Process Optimization	50,000
Test Specimen Fabrication	50,000
Comparative Testing	50,000
Technical Documentation	25,000
Total	$225,000

Estimated duration of the project is 18 months.

Benefits: Benefits to be derived from this project are a reduction in recurring hardware costs and improved quality. Typical benefits are as follows:

1. Elimination of deburring operations - Sanding and honing
2. 100% increase in drill rates
3. 50% reduction in drill bit usage
4. 300% increase in etching throughput
5. 75% reduction in etching undercut
6. Improved environmental protection - Reduced copper in waste effluent
7. Reduced etching chemicals
8. Increased circuit densities possible

In general, all of these factors should combine to improve printed wiring yields to an estimated 10 to 15%.

Assumptions: The stated benefits assume a change in the military specification for printed wiring laminate to allow thin foil material.

COMPANY NAME	PARTICIPANTS
McDonnell Douglas Electronics Company	Rose Mayfield P.O. Box #426 St. Charles, MO 63301 (314) 232-0232 (2707)

Title: Manufacturing Technology Project to Optimize the Performance of Printed Wiring Boards by Implementation of Polyimide Materials.

System/Panel Area/Component: Various/Guidance/Printed Wiring Boards

Problem: In many guidance systems, printed wiring boards are a major cost driver because of defects that develop in printed wiring boards during assembly, testing, and thermal cycling. A major cause of the defects is related to the properties of the epoxy-glass material commonly used in board fabrication. The coefficient of expansion of epoxy is much greater than that of metals laminated and plated onto the board. This thermal mismatch results in damage to a circuit board any time it is exposed to heat or to wide temperature variations. This damage (in the form of lifted pads, delamination, stress cracking of metals) and related repair result in high life cycle costs for circuit boards.

Proposed Solution: Polyimide/Glass is a new dielectric material which is particularly suited for wiring board fabrication because of its expansion rate which closely matches electroplated copper. This manufacturing technology study would establish optimum fabrication processes for polyimide printed wiring boards and would compare the performance of boards of each type material to determine life cycle costs and the savings which could be realized with a better suited material. The project would include a test vehicle portion to determine relative costs accurately.

Project Cost and Duration:

Estimated Costs of Project:

Establish Fabrication Processes	$200,000
Compare Performance	200,000
Total	$400,000

Estimated duration of project is 18 months.

Benefits: Benefits that would be realized from this project are reduced costs of wiring board repair and scrappage and improved performance coupled with longer life cycle. The test vehicle portion would provide back-up data to justify polyimides to the military.

Assumptions: These benefits are based on the assumption that polyimide boards perform better for a longer period of time than epoxy boards. Based on the preliminary work done at MDEC, this assumption is valid, but more study is necessary.

COMPANY NAME:	**PARTICIPANTS:**
McDonnell Douglas Electronics Company	Rose Mayfield P.O. Box #426 St. Charles, MO 63301 (314) 232-0232 (Ext. 2707)

Title: Manufacturing Technology Project to Provide Cost Effective Processes for Cleaning, Soldering Printed Wiring Board Electronic Assemblies

System/Panel Area/Component: Missile/Guidance/
Printed Wiring Boards/Electronic Assemblies

Problem: The guidance portion for all missile systems includes printed wiring board assemblies. Proper specification and preparation of components as well as control of the soldering process are essential to insure high reliability. The cost of assembly can be reduced by establishing a means of determining the cleanliness level of the final assembly and then determining the incremental cost for each level of cleanliness so that the most cost effective cleaning processes can be selected. The problem is that there is no rapid, inexpensive method that has been accepted by the military and industry of determining the cleanliness level and therefore there is no way to arrive at a cost effective total process.

Proposed Solution: The project will result in an accepted cleaning test and cost effective cleanliness level for specific soldering processes. More sophisticated chemical analysis techniques will be utilized in proving the adequacy of an inexpensive method of measuring cleanliness. Then various combinations of component platings, storage conditions, pre-cleaning, flux activity, solder pot contamination, soldering temperature and speed, and post-solder cleaning will be used in determining the cost of reaching incremental cleanliness levels. The costs will include non-recurring costs as well as recurring costs of the processes taking into account the cost of scrap and rework. The final phase of the project will prove that reliability is not effected by using a lower cost process, and that long term storage does not adversely influence the performance of the printed wiring board assembly.

Project Cost and Duration:

Cost:

Pilot line design		$ 6,000
Pilot line procurement & installation		100,000
Process Optimizations and Materials		405,000
Parts for test assemblies		25,000
Data submittals		50,000
	Total	$586,000

Duration:

Optimization		30 months
Reliability		12 months
	Total	42 months

Benefits: Anticipated reduction in recurring costs are for parts, materials, and labor. Non-recurring costs are saved by elimination of duplicate facilities now needed for approved processes which are less than the state-of-the-art. Reliability may be improved.

Recurring Costs:

Parts and materials	0.5%
Labor (including rework)	2.0%
Net reduction in recurring cost	2.5% of missile such as Dragon
Net reduction in non-recurring cost	$100,000

Assumptions:

1. Maximum monthly production rate of 6000
2. Parts and materials can be obtained in less than 3 months
3. Equipment can be procured and installed within 6 months
4. Non-recurring costs are not amortized in the cost of the Missile.

COMPANY NAME:

McDonnell Douglas Electronics Company

PARTICIPANTS:

Rose Mayfield
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TITLE: MANUFACTURING TECHNOLOGY PROJECT TO DEVELOP AN AUTOMATIC MONITORING AND CONTROL SYSTEM FOR WAVE SOLDERING MACHINES

SYSTEM/PANEL AREA/COMPONENT:

All Guided Missiles/Guidance/Printed Circuits

PROBLEM:

Printed Circuit Boards are common to all guidance systems, yet considerable manufacturing costs are incurred due to required semi-automatic control of the wave soldering process. This involves constant attention by trained operators who are skilled, not only in wave soldering machine operation, but who can quickly observe, evaluate, diagnose and properly correct the machine controls to ensure that properly soldered assemblies result. Automation of this monitoring and control process would reduce manpower costs for machine operation, inspection and board rework; would reduce reject material costs; and would improve product quality, reliability, and process throughput (through reduced downtime).

PROPOSED SOLUTION:

The project will include the design, development and testing of a prototype monitoring and control system, including the interface necessary for adaptation to existing wave soldering machines. The technical approach will include the real-time monitoring of critical process control variables and automatically converting these to output machine controls necessary to adjust or maintain the process. This project, if successful, could provide a means for lower production costs of Printed Circuit Boards by more than 3 per cent. It has been Chrysler's experience on production and/or proposal work on TOW and DRAGON that 95% of their guidance system cost is P.C. boards. This means that 3% cost savings on the indicated guidance systems are possible. It is likely that comparable savings could accrue for other guided missiles (i.e. SAM-D, HELLFIRE, HAWK, SHORADS, etc.) as well.

PROJECT COST AND DURATION:

Estimated costs are as follows:

Prototype hardware/software design	$300,000
Prototype fabrication	250,000
Prototype Test and Optimization	150,000
Final Report	50,000
Total	$750,000

Estimated project duration - 24 months

(continued--)

BENEFITS:

Benefits to be derived from this project are reduction in Printed Circuit Board production cost. These reductions translate to guidance system savings as follows:

Reduction in operator cost	- 1% of system cost
Reduction in inspection/rework manpower cost	- 2% of system cost
Net reduction	3% of cost of Missile Guidance Systems

ASSUMPTIONS:

The stated benefits assume that each flow soldering machine is operated at capacity, approximately 3,000 boards per 8-hour working day, and that one machine operator plus two inspector/repair personnel per line could be eliminated. It is assumed that process control system acquisition and operational costs are more than compensated for by reduced field failures, repair costs and manufacturing scrap costs.

COMPANY	PARTICIPANT
Chrysler Huntsville Electronics Division	Phil T. McCuiston, Jr. 102 Wynn Drive Huntsville, Alabama 35805 205-895-1433

TITLE: MANUFACTURING TECHNOLOGY PROJECT TO DEVELOP AN AUTOMATIC INSPECTION SYSTEM FOR PRINTED CIRCUIT BOARDS

SYSTEM/PANEL AREA/COMPONENT:

All Guided Missiles/Guidance/Printed Circuits

PROBLEM:

Printed Circuit Boards are common to all guidance systems, yet considerable manufacturing costs are incurred in providing visual inspection for defects after components have been soldered in place. This involves constant attention by skilled inspectors (two per line) on the lookout for major defects such as excess or deficiency of solder, solder bridges, missing components, and improper lead cutting and bending. Automation of the inspection process would reduce the cost of circuit board manufacture through subsequent reductions in labor for inspection and would improve product reliability through accurate and repeatable detection and correction of defects.

PROPOSED SOLUTION:

Recent innovations and applications of scanning and pattern recognition techniques suggest the feasibility of an automated inspection system. The project will include the design, development, and testing of a prototype system which can function at points in the assembly process where maximum cost effectiveness can be achieved. The technical approach will incorporate a suitable pattern recognition technique to compare the board being inspected with a reference master board. This will entail optical inspection, converting the optical image to electronic data, and comparing the data to pre-established limits and/or reference images. This project, if successful, could provide a means for lowered production costs of Printed Circuit Boards by at least 2%. It has been Chrysler's experience on production and/or proposal work on TOW and DRAGON that 95% of their guidance system cost is P. C. Boards. This means that 2% cost savings on the indicated guidance systems are possible. It is likely that comparable savings could accrue for other guided missiles (i.e. , SAM-D, HELLFIRE, HAWK, SHORADS, etc.) as well.

(continued--)

PROJECT COST AND DURATION:

Estimated costs are as follows:

Prototype hardware/software design	$200,000
Prototype fabrication	160,000
Prototype Test and Optimization	110,000
Final Report	30,000
Total	$500,000

Estimated project duration - 18 months

BENEFITS:

Benefits to be derived from this project are reductions of 2% in guidance system production cost through the elimination of inspectors.

ASSUMPTIONS:

The stated benefits assume that each automatic inspection station is operated at capacity, approximately 3,000 boards per 8-hour working day and that two inspectors per line could be eliminated. It is assumed that system acquisition, operational, and reprogramming (test criteria for new run of boards) costs are more than compensated for by reduced field failure and repair costs (resulting from human inspection error).

COMPANY	PARTICIPANT
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IMPROVED PRODUCTION PROCESSES FOR SEALING MICROELECTRONICS PACKAGES

V. F. Lardenoit

Hughes Aircraft Company
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SYSTEM/PANEL AREA/COMPONENT

Various/Guidance/Microelectronic Devices.

PROBLEM

Increased usage of microelectronic devices in current and future systems necessitates the development of a processing technique to provide low cost hermetically sealed packages under high production rates. Presently, the final hermetic sealing of microelectronic devices in a protective package is accomplished using conventional soldering or resistance welding. Depending on quantities of parts being manufactured, the specific sealing techniques may be manual, semi-automatic or automatic. Each technique has inherent cost disadvantages associated with the processing variables and metallurgical characteristics of the parts being joined. These disadvantages include high labor cost, potential part damage from high temperatures, potential corrosion problems from inadequate flux removal, formation of brittle intermetallics, and in the case of resistance welding, subsequent repair is not practical due to the permanent nature of the seal.

PROPOSED SOLUTION

An alternative technique for sealing, such as diffusion joining, would alleviate many of the above difficulties. As opposed to diffusion bonding, which entails the use of temperature and pressure to obtain coalescence between two metallic parts, the proposed process utilizes a metallurgically compatible interface material between the parts to be joined which, on melting, alloys with the base metals, thus forming the metallurgical bond. Selection of the interfacial metal is based on its alloying characteristics with the base metals involved and application is usually by electroplating. Proper selection of the combination allows a variety of melting ranges depending on the metals involved and the alloy system's eutectic temperature. An added feature is that, in many cases, the remelt temperature is higher than the original fusion temperature when a third metal is involved.

The project would be divided into two phases. Phase I would be the processes and techniques evaluation phase during which various materials and processes would be studied and those providing the most potential evaluated. Phase II would be the pilot production line implementation and evaluation phase during which a pilot line would be established utilizing the processes and techniques selected in Phase I. Materials, processes and techniques to be investigated would include the following:

Materials: Establish the materials that will provide an optimum combination of characteristics to produce a high reliability metallurgical bond. Characteristics to be evaluated include availability, cost, melting temperature, metallurgical compatibility, wettability and remelt temperature.

Processes: Determine the optimum processing steps for applying the diffusion technique to package sealing. Included would be joint design, method of applying interfacial materials, methods of heating, necessity for fluxing and a cost analysis of the processes.

PROJECT COST AND DURATION

Estimated costs are as follows:

Phase I - Preliminary evaluation	$85,000.00
Phase II - Pilot production line implementation	90,000.00
Total	$175,000.00

Estimated duration of the project is 18 months.

BENEFITS

It is anticipated that $20 per unit will be saved by utilizing advanced joining techniques. Savings for two typical systems would be as follows:

Hellfire - 19 hybrids/system x 200 systems x $20 = $76,000.
Shorads - 5 hybrids/system x 20 systems x $20 = $20,000.

Additional savings would be realized on other missile systems.

PROJECT SUMMARY

Title: Manufacturing Technology Project to Optimize Production Processes for Laser Gyros.

System/Session/Component: Long Range Guided Missile/Guidance/Ring Laser Gyro.

Problem: High cost of laser block machining, mirror fabrication, and gyro assembly.

Proposed Solution: Reduction of laser block machining, mirror polishing and fabrication, and gyro assembly costs by developing:

- A hot pressed glass ceramic block with integral dither springs
- Processes and equipment for the machining and polishing of glass ceramic laser block and mirror substrates
- Improved mirror coating process controls
- Improved assembly procedures.

Project Cost and Duration: Estimated costs are as follows:

• Hot pressed block development	$120,000
• Block machining and polishing development	280,000
• Mirror machining, polishing and coating development	200,000
• Other related development	200,000
	$800,000

Estimated project duration is 24 to 32 months.

Benefits. Benefits to be derived from these projects are:

1. A 20 percent reduction in the guidance system recurring costs.

2. A 49 percent reduction in laser gyro recurring costs when augmented by other elements of planned design-to-cost, producibility and technology development projects, and by normal learning.

3. Completion of the long lead portion of the manufacturing technology development required to assure achievement of the laser gyro's target production cost.

4. Reduced production lead time.

5. Advancement in the state of the art in glass ceramic machining, hot pressing and mirror fabrication technology.

Assumptions: It is assumed that definitive laser gyro mirror criteria and a mirror coating capability will be developed in-house independently of this project. Cost reduction benefits assume a production quantity of of 6,000 units for the before and after comparison.

PROJECT SUMMARY

Title: Manufacturing Technology Project for Method of Optimizing Hybrid Manufacturing for the Computer.

System/Session/Component: ATIGS/Guidance/Computer

Problem: The ATIGS Guidance System is a high volume, low cost system for which assembly of integrated circuits is a major cost driver. The ATIGS computer alone uses 400 integrated circuit chips which must be manually mounted on thick film ceramic substrates. The manual mounting is costly. Automatic mounting processes are being developed at Honeywell for assembly of chips on hybrid modules for use in large scale data processing systems. The TAB (Tape Automated Bonding) process is the principal one. The problem is the end item hardware (hybrid module) is commercial and the TAB process equipment will be used in commercial process lines. It has only been developed for small pilot commercial line operations.

Proposed Solution: The project would evaluate the existing commercial pilot line TAB processing equipment and the resulting hybrid module bonding for application to ATIGS hardware and controlled military processing lines. This would include the design and setting up of a pilot line for prototype ATIGS computer module production. Primary emphasis would be given to the adaptation of the existing commercial TAB processing equipment to ATIGS production. TAB processing, if successful, could lower the cost of the ATIGS computer by 10 percent and the IMS by approximately 2 percent.

Project Cost and Duration. Estimated costs are as follows:

TAB Assessment	$ 55,000
Prototype Assembly Equipment Development	120,000
Prototype Test Equipment Development	80,000
Production Assembly Pilot Line Set Up	100,000
Production Test Pilot Line Set Up	75,000
Total	$430,000

Estimated duration of the project is 30 months.

Benefits: Benefits to be derived from this project are a reduction in recurring computer hardware costs. These reductions are as follows:

Reduction in computer chip assembly and test:	10 percent of Computer cost

Assumptions: The stated benefits assume that the ATIGS computer hardware will be produced at the rate of 50 per month in total quantities of 2,000 or greater.

PROJECT SUMMARY

Title: Manufacturing Technology Project for Adapting Advanced Capital Facilities for High Volume ATIGS Inertial Guidance and Control Testing.

System/Session/Component: LRGM/Guidance/Guidance Systems

Problem: Prototype laser guidance system testing has been performed in a manual/semiautomatic mode with high operator interaction and its resultant cost. The present test method does not optimize operational confidence because of test versus flight dynamics differences nor provide the low cost, high volume test capability to meet LRGM delivery rate and cost goals.

Proposed Solution: Mechanize a fully automatic guidance system test and calibration system based on existing advanced Honeywell capital air bearing test tables and computer facility. Test in multiples of four or more at or near flight dynamic conditions to increase operational confidence and reduce recurring test cost.

Project Cost and Duration. Estimated costs are as follows:

Analysis	$ 50,000
Interface Hardware Modification	100,000
Software	75,000
Pilot-Production Testing	50,000
Total	$275,000

Estimated duration of this project is 12 months.

Benefits. Benefits to be derived from this project are:

1. A reduction in recurring guidance system acquisition costs of 1 percent.
2. A reduction of 12 percent in testing costs.
3. Assure delivery rates of 50 to 60 per month.
4. Increase in operational confidence due to dynamic testing.
5. A reduction in cost of ownership due to reduced field problems.

Assumptions: The stated benefits assume production quantities and a delivery rate of 50 to 60 per month.

HUGHES AIRCRAFT COMPANY, CANOGA PARK, CALIFORNIA
Improved Low Cost Stripline Microwave Component Project

Summary

This project relates to missile guidance system RF components such as antennas, RF feed systems, sum and difference networks, microwave components. Typical applications include SAM-D, Hellfire, PHOENIX, Brazo, ASALM, and SRBDM.

Stripline circuitry has found increasing applications in various microwave type components and antenna systems. As the operational frequency of these devices increased, the difficulties in building good devices has also increased. Fabrication methods being used to manufacture these components become more expensive because of lower yields due to increased complexity and high costs for special dielectric materials.

Nonuniformity in performance is another problem associated with higher frequency applications of stripline microwave component technology. Some of this nonuniformity is due to process variables existing in the raw materials, some is due to process variables in finishing the raw material and the remainder is found in the component fabrication and assembly.

The solution to the problem consists of a modified approach to component design and fabrication by alternate methods. Instead of buying proprietary dielectric material to precise dimensional requirements with laminated copper foil, comparable dielectric material in raw stock form would be used and processed to the required dimensions. Since each element of the component design does not require comparable precision, unnecessary cost is not incurred. The element which makes the use of processed raw material directly at the component size level feasible are the techniques of "plating-on" the circuitry required and monolithic bonding. These not only eliminate the need for a dissimilar dielectric constant adhesive to be introduced into the system but also provides a compatible dielectric constant adhesive which is cured to form the single monolithic assembly. This monolithic assembly of dielectric boards with plated-on microwave circuitry is then shell plated with copper to provide the necessary ground plates on either side of the device. Terminations to the device can be made with conventional termination connectors or by a modified connection system integral with the dielectric board assembly.

Weight is a significant aspect of current stripline components and this proposed method of manufacture substantially reduces its impact on a system. A typical stripline device 100 mm x 128 mm using conventional fabrication techniques would typically be in the region of 16 mm in thickness and weigh > 460 grams. This same component made by the proposed technique would be < 3.2 mm in thickness and weigh ≈ 46.0 grams having equal or better performance.

The advantages that will accrue from this program impact both systems and manufacturing goals. From the systems viewpoint this capability will reduce component size which frequently will result in an RF implementation to meet performance goals that might not otherwise be practical. As missiles utilize higher density electronics packaging, weight becomes more difficult to accommodate. The smaller size also allows for functional integration reducing or eliminating connecting cables which at RF frequencies can represent a major cost contribution.

An advanced guidance system such as the proposed complementary guidance for the SAM-D includes a significant number of RF related components. These include on-gimbal elements such as antenna and feed systems and off-gimbal elements such as RF processing circuits, sum and difference circuits, RF switches, mixers, etc. These components contribute approximately 10% to the cost of the guidance system and the > 80% reduction in fabrication costs predicted for the proposed technique can, together with size and weight reductions indicated, represent a major cost reduction for production systems.

Two programs directed toward proving the feasibility of the concept have been initiated and successfully completed. The first of these which developed the basic stripline board processes was accomplished in various company material and process laboratory and was completed in April 1975. The second program was oriented to implement the documented processes in a single engineering development laboratory and validate the process directives. This effort was completed in August 1975.

Scope of Program

The proposed program scope would include the following tasks:

1. Establish a basic capability to fabricate repetitively X- and Ku-band microwave components.
2. Design, specify and/or fabricate as appropriate any special manufacturing tools required for achieving repetitive results.
3. Perform cost, performance and environmental evaluations.
4. Document equipment and process specifications.

Company

Hughes Aircraft Company
Missile Division
Canoga Park, CA 91304
Fred D. Walton
883-2400, Ext. 2603

SPIRAPHASE PHASED ARRAY ANTENNA DEVELOPMENT

H. R. Phelan

Harris Electronic Systems Division

Melbourne, Florida 32901

PROBLEM

Future missile systems such as SAM-D have as part of the overall guidance subsystem a ground based phased array antenna. Because of the thousands of elements required in a phased array antenna and the high cost of these elements, the phased array antenna has historically been a major cost contributor of the overall missile system.

PROPOSED SOLUTION

The proposed project will fabricate a new phased array antenna element type, called SPIRAPHASE, which has significant potential for reducing the overall cost of phased array antenna systems. The proposed project would consist of construction of an engineering prototype model of such an antenna system for SAM-D and other similar missile systems, in depth system testing of the antenna, and generation of low cost Hybrid Microwave Integrated Circuit and Medium Scale Integrated Circuit fabrication techniques for the elements.

PROJECT COST AND DURATION

The total duration of the program is estimated to be 18 months with total cost under $2 million. These time periods and costs are relatively low, and they have high confidence behind them because they are based on prior development accomplished in the area of SPIRAPHASE antennas funded by the Government. This work was undertaken for White Sands Missile Range and included development of a feasibility model of a C-band SPIRAPHASE antenna.

BENEFITS

The key benefits derived from the SPIRAPHASE antenna approach are lower cost, lower life cycle cost, improved performance, and a lower weight antenna system. Following are some details of these benefits:

Hardware Cost

In depth cost analysis on recent prototype fabrication of hundreds of SPIRAPHASE elements indicate that the overall antenna approach reduces the cost of a phased array by approximately 50 percent.

Life Cycle Cost

Because of the basic simplicity of the SPIRAPHASE antenna elements, the reliability of the elements is high. Recent estimates indicate an

MTBF of approximately 100,000 hours. In addition, the basic phased array approach exhibits a fundamental graceful degradation failure mode so that maintenance costs are low.

Performance

The SPIRAPHASE antenna approach is basically a diode phaseshifting approach which has higher reliability and lower switching speed than the conventional ferrite phase shifter. Although diode phase shifters have historically exhibited higher loss than ferrite, SPIRAPHASE array elements have demonstrated measured insertion loss equal to or less than ferrite types.

Weight

Recent hardware efforts on the SPIRAPHASE antenna approach have shown that the overall weight of the antenna is approximately an order of magnitude lower than conventional phased array approaches. This can be a key benefit in application of the technique to tactical systems such as SAM-D.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975—601-951-36

THE STANDARD ELECTRONIC MODULE PROGRAM

JOHN A. WYATT

Department of the Navy
Naval Electronic Systems Command
Washington, D.C.

BACKGROUND

In our consideration of means whereby we can reduce life-cycle costs, improve system performance, reduce production lead time, conserve scarce resources, or satisfy any of the other goals of MANUFACTURING TECHNOLOGY, it seems that we ought to include the extension of any ongoing programs which offer opportunities to accomplish those goals. One such program which has demonstrated considerable success is the Standard Electronic Module Program. It is, therefore, recommended here for consideration as a Manufacturing Technology project base. Various applications, including test equipment, will likely prove to be desirable candidates for its application.

INTRODUCTION

The purpose of this paper is to describe the Standard Electronic Module Program (SEMP); *what it is, how it works, where it stands now,* and *what the future is likely to hold for it.* In order to address that last question it will first be necessary to consider the achievements and benefits of the program, and, then, to present the prospects for the future in a context of what the other Services are doing and where the Navy stands in the developing Standard Electronic Module Program of the Department of Defense.

WHAT IS IT?

The SEM Program is an electronic module standardization program which is being actively promoted throughout the Navy at the direction of the Chief of Naval Material. The purpose of this program is to provide families of reliable electronic modules that will reduce the cost and facilitate the design, production and logistics support of military electronic systems.

The concept of the SEM Program is based upon the principle of limiting redundant design through the use of standard functions, thus achieving cost benefits through consequent large production volumes and wide competitive availability. As the program continues to gain further acceptance, the cost and performance benefits should become even more significant.

BASIC OBJECTIVES OF THE SEM PROGRAM

- Partition electronic functions in a manner which ensures commonality among a majority of equipment applications.
- Document modules with functional specifications to preclude dependence upon specific vendors' designs or technologies; thereby promote long term availability and cost savings through vendor innovation and competition.
- Achieve high reliability through mandatory quality assurance requirements for module designs and their vendors.

- Achieve replace-upon-failure maintenance policy based on high reliability and low cost.

- Provide flexible mechanical packaging requirements which accommodate various circuit and packaging technologies.

- Ease the logistics support burden on the congested supply system by extensive inter-system commonality of a limited number of module types.

HOW DOES IT WORK?

STANDARDIZATION MEANS MONEY

As we look for a place to concentrate our efforts for reducing electronic systems cost, we had better look to the circuit card or module level, since more than 50% of system procurement costs can be typically attributed to electronic modules. Combine this with the potential discount that can be realized through large production volume procurements and the results are significant. The following table depicts typical discount rates as a function of quantity and applies to all electronic modules.

Table I. Impact of Volume Procurement

No. of Items	0-5	200	500	1000	5000
Discount	0%	10-15%	15-25%	25-35%	35-50%

As indicated in Table I, a production volume of 5,000 units commands discount rates as high as 50%. This is significant; for, without attempting to standardize and create a production base of some consequence, we have been traditionally working at the low end of the curve with the "one of a kinds".

Electronic functions, those common building blocks that are used over and over again in constructing electronic systems, comprise the area where the major pay-off in electronics standardization resides. To be successful, however, we must accommodate common electronic functions at a partitioning level that will achieve high inter-system commonality. It is also necessary to combine the proper functional level with a flexible mechanical packaging concept and electrical interface standards.

The key to a viable electronics module standardization concept is flexibility. It must remain responsive to new requirements developed from an ever-changing state-of-the-art. The SEMP is an example of such a program. It permits the module's physical form factor to expand in standard growth increments, thereby providing for additional circuit area and connector pins as needed. As indicated in Figure 1, this flexibility has enabled the Navy SEM Program to accept increasing functional complexity as demanded by systems' growth and economics.

PROGRAM ORGANIZATION

Under the sponsorship of the Naval Material Command, the program is basically organized as indicated in Figure 2, with the Naval Electronic Systems Command designated as the Technical Management Activity (Program Manager); the Naval Avionics Facility, Indianapolis (NAFI), as the Design Review Activity; and the Fleet Logistics Support Department of the Naval Weapons Support Center (NWSC), (formerly the Naval Ammunition Depot), Crane, Indiana, as the Quality Assurance Activity. In addition, the Naval Air Systems Command and Naval Sea Systems Command, along with laboratories such as the Naval Electronics Laboratory Center, Naval Air Development Center, and Naval Weapons Center assist in the identification and performance of needed studies and program support.

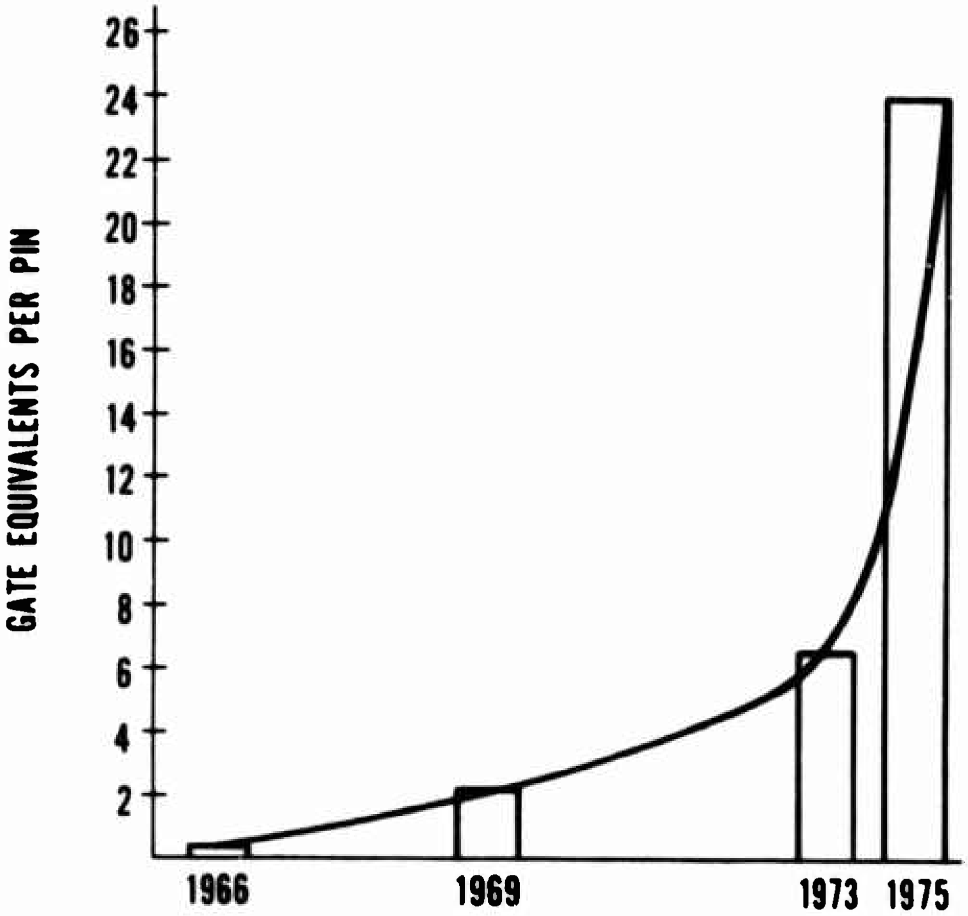

Figure 1. Profile of SEMP Growth in Functional Complexity

The Technical Management Activity is responsible for the operation of the entire SEM Program. Its primary responsibilities are:

- Establishment of SEM Program objectives consistent with Department of Defense and Navy standardization requirements.
- Organization, implementation and control of the characteristics necessary to meet Navy objectives.
- Organization and direction of SEM Program laboratory activities.
- Promotion of the Program within the Navy, and sponsorship of module development activities.
- Coordination of SEM Program with other elements of the Department of Defense.

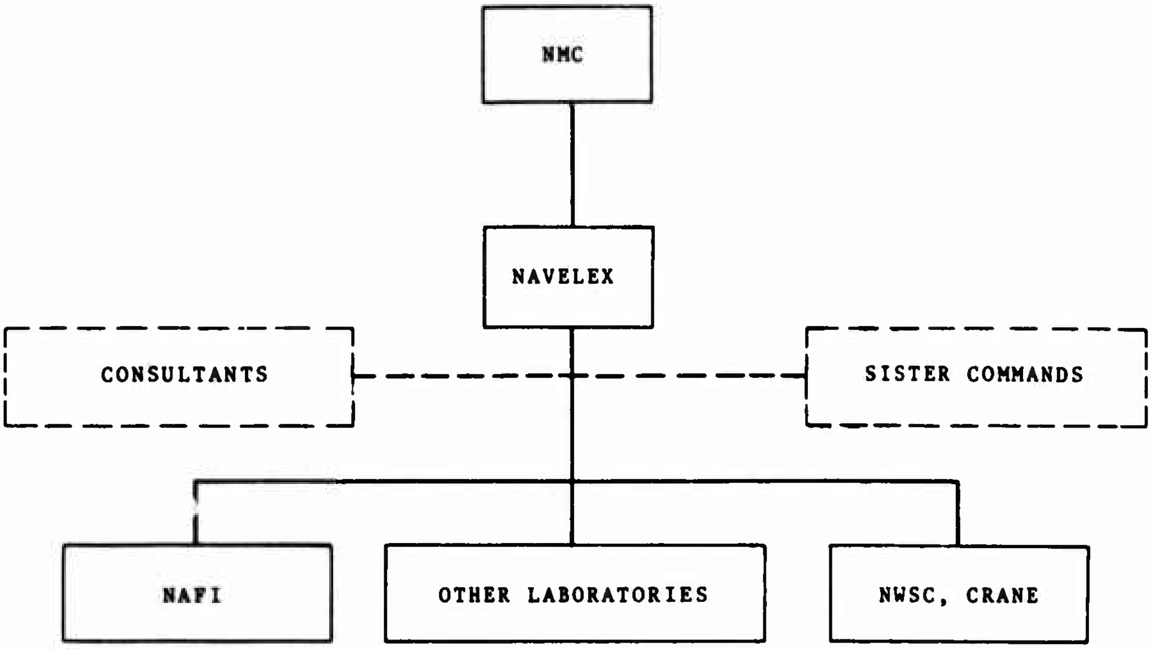

Figure 2. SEM Program Organization

The Design Review Activity has as its primary responsibility the review and classification of each new module proposed for development. As a result, it assigns key codes and specification numbers for new module designs. Also, the Design Review Activity performs studies and provides engineering support to Systems Command program offices, and the SEMP Technical Management Activity.

The Quality Assurance Activity is primarily responsible for the qualification testing of module designs and their vendors. It establishes and maintains SEM Program quality assurance requirements, performs initial and periodic module qualification testing; performs correlation of SEM Program vendor test equipment; performs failure analyses, and compiles SEM Program reliability data. This activity also provides engineering support to Systems Command program offices and to the SEMP Technical Management Activity.

SEM PROGRAM SPECIFICATIONS

The mechanical and environmental requirements for SEM Program modules are given in specifications which describe the electrical, functional and reliability requirements for each module type. These specifications are prepared in accordance with MIL-STD-1378, Requirements for Employing Standard Electronic Modules. The specifications for SEM Program modules are prepared b the original module developer for approval and control within the SEM Program. They specify requirements for form, fit and function rather than detailed design requirements. This documentation technique permits module vendors to produce modules without unnecessary restrictions on components and specific design details, as long as the functional requirements of the specification are met.

Though the details of design are left to the module developer and subsequent vendors, it is essential that interface standards and reliability requirements be observed; therefore, the basic mechanical configurations from which the designer may choose are covered by a design standard; MIL-STD-1389, *Design Requirements for Standard Electronic Modules*. This standard prescribes the design requirements which will enable modules to satisfy the quality assurance requirements specified in MIL-M-28787, *Standard Electronic Modules, General Specification for*.

We all know that it's cheaper to do it right the first time, than to continually apply a series of of "fixes" over the equipment life cycle. Unfortunately, the objectives of those who develop systems and those who support them are driven by the extremes of initial acquisition cost and life cycle cost. The SEM Program, by requiring qualification testing of both the module design and its vendors has achieved reliability results that are at least an order of magnitude better than the traditional approach of QA for printed circuit board assemblies. *SEM Program modules are averaging less than 0.05 failures per million hours*. By this method of specification, the traditional rivalry between standardization and advancing technology is obviated. These two disciplines now complement one another, by providing the natural vehicle for permitting cost reduction innovations derived by advances in the state-of-the-art. Reliability at the module level obviously relates to system reliability, and yes, the major element of life cycle cost - logistics support.

SEM PROGRAM REQUIREMENTS

The basic SEMP module configuration is depicted in Figure 3. The principle dimensions: width, height, and thickness, were derived by consideration of the amount of circuitry required to perform various functions, the maximum number of necessary interface connections, the size of the keying and retaining mechanisms, and the maximum tolerable cost for a "throw-away" module.

The SEM Program further provides for the development of modules of multiple span and thickness. Modules can be increased in span by increments of 3.00 inches and in thickness by increments of 0.300 inch as illustrated in Figure 4.

Figure 5 illustrates an array of various SEM Program module functions, which range from power supplies (top) to digital logic modules, further illustrating the utilization of modular incremental growth.

WHERE DOES IT STAND NOW?

At the present time the specifications and standards covering the design, procurement and application of such modules are being coordinated for interservice use. As a result, it is anticipated that a broader spectrum of functional modules will be developed and documented, thereby leading to an even greater utility of the program's concepts and benefits.

The SEM Program has evolved to where it now comprises more than 250 module types, with a commitment to service of over 3 million modules. These modules include the following families:

a. Digital Logic

    DTL
    TTL
    Low Power TTL
    High Speed TTL
    Schottky TTL
    Low Power Schottky TTL

b. Interface Circuits

c. Converter Modules

d. Analog Modules

e. Power Supply Modules

f. Miscellaneous Digital Modules

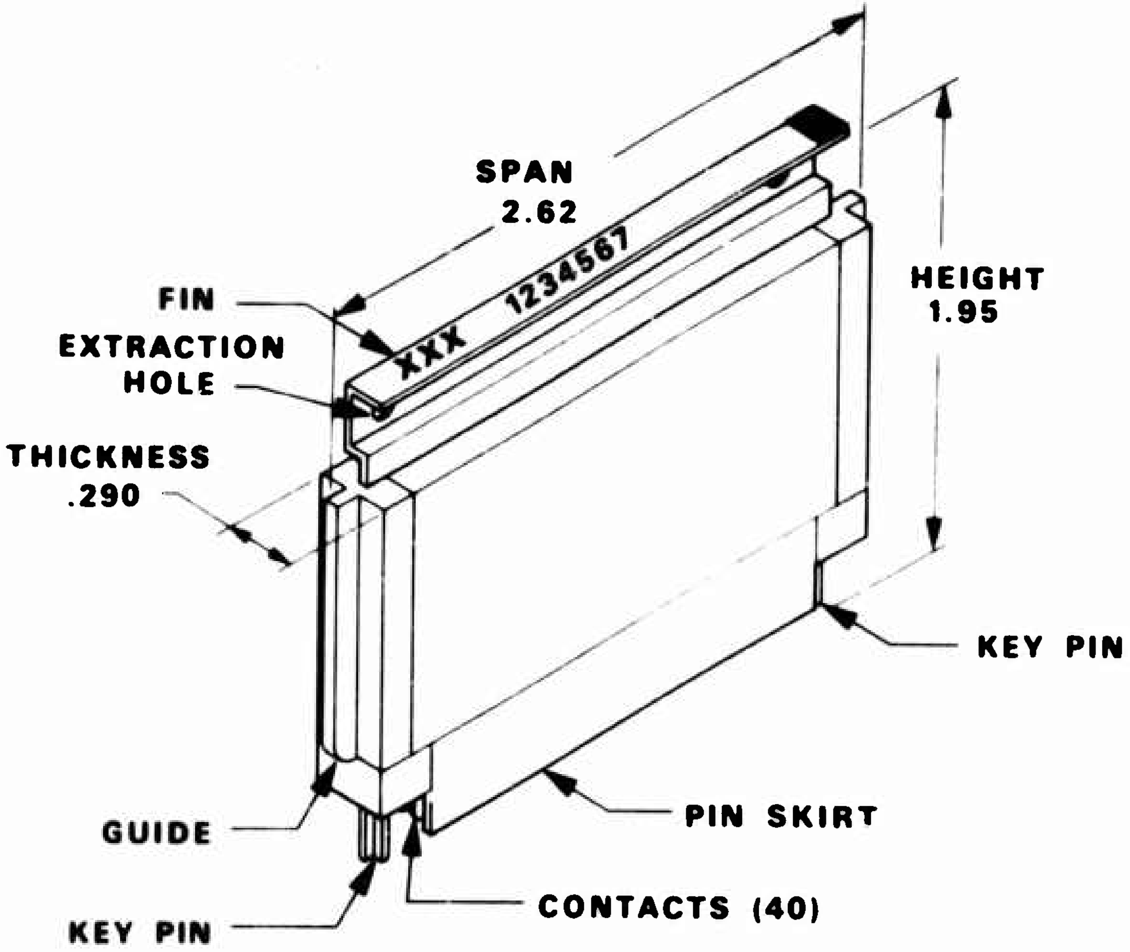

Figure 3. Basic SEM Configuration

To date, SEM Program modules have been used in more than 50 systems spanning virtually every operating environment. The following listing presents a sampling of those system applications:

Mk 88 Mod 0 (POSEIDON) Fire Control System

AN/BQR-21 "DIMUS" Sonar System

AN-BQQ-5 Sonar System

AN/WLR-9 Submarine Acoustic Warfare System

AN/BQN-17 Depth Sounder
Mk 98 Mod 0 (TRIDENT) Fire Control System
AN/BQQ-6 (TRIDENT) Sonar System
AN/BQH-6 Sonar System
"HARPOON" Ground Support Equipment
AN/APN-59B Radar
SA-2011(V)/WQS Standard Scan Switch

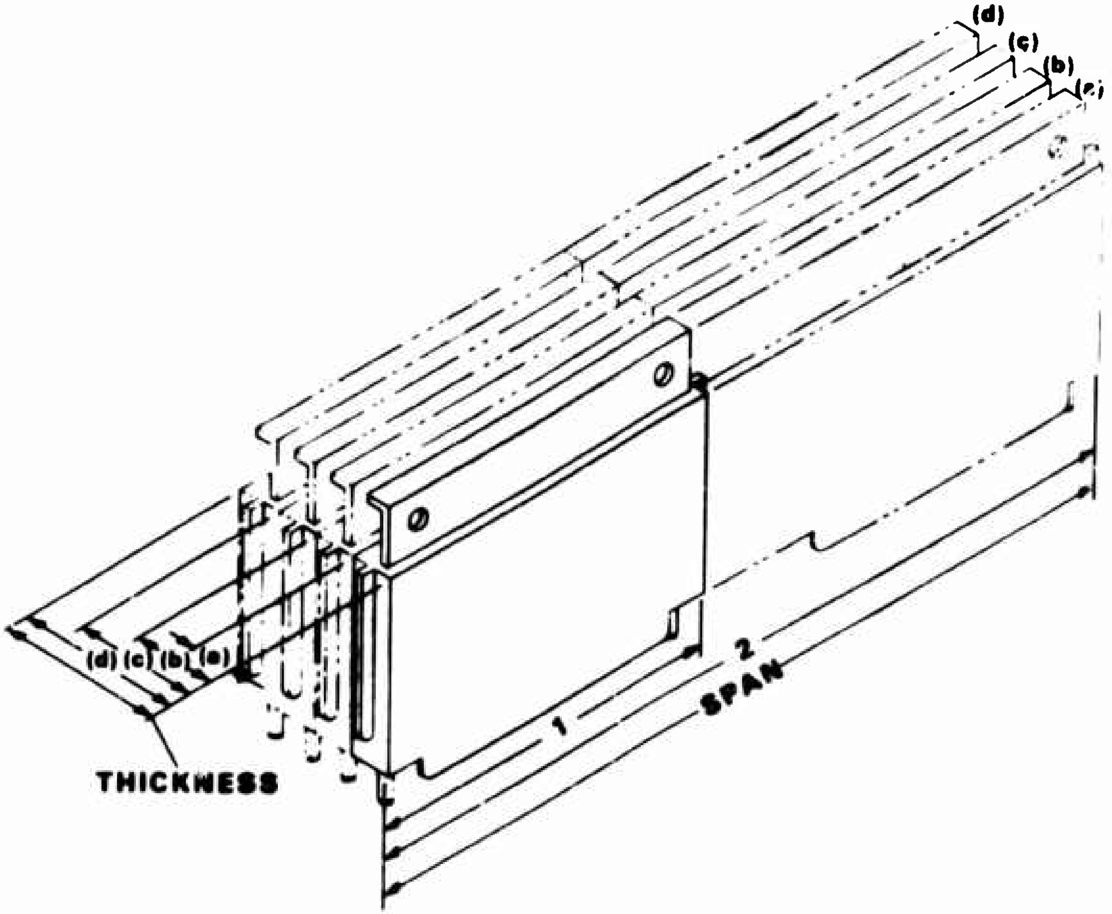

Figure 4. Module Incremental Growth

LIFE CYCLE BENEFITS

The SEM Program is a well conceived approach to instituting a rational discipline for the development and deployment phases of military electronic system life-cycles. By properly applying its principles and requirements, the SEM Program can provide benefits in the following program phases.

DEVELOPMENT PHASE

- <u>Reduced Development Costs</u>. These result from a reduction in the engineering circuit design costs for functional modules, reduction in performance, verification testing at the module level, and a reduction in the documentation required to define and support the overall system.

- Reduced Development Time. Lead time is reduced since complete functional modules and piece-parts are available with adequate documentation. The magnitude of this advantage will obviously depend on how many existing module types can be used, and how many new types are required.
- More Realistic Cost Bids for System R&D. By specifying use of standard functional modules in requests for R&D proposals, the tendency for a contractor to "buy-in" is reduced, since he cannot be assured of winning the follow-on production contract.

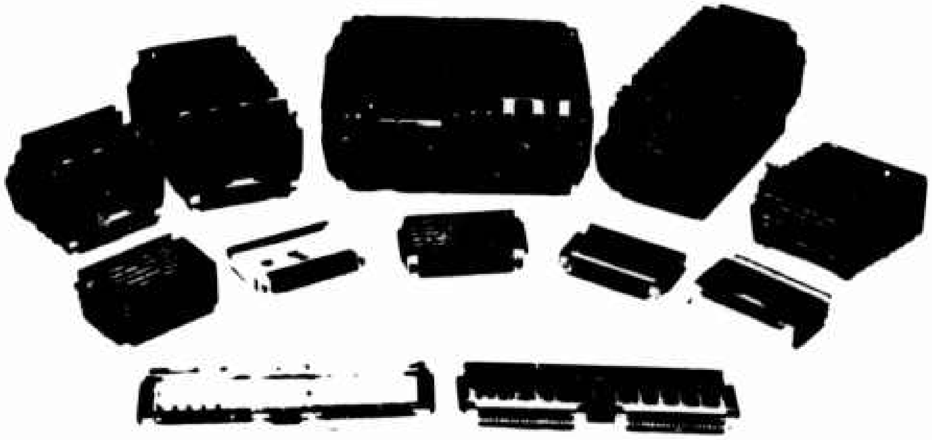

Figure 5. SEM Program Module Array

PRODUCTION PHASE

- Reduced Cost of Test Equipment. The test equipment required to support the system can be used on other functionally independent systems that use common standard modules. This reduces the need for unique test equipment for each separate system.
- Reduced Cost of Production Systems. This occurs through multiple sourcing of standard modules, high volume use, and a higher level of quality control.

- Reduced Time to Volume Production. Ready availability of standard modules is promoted by development of multiple sources and high volume use.

- Aid in Increasing Production Competition. By use of standard modules, functional documentation developed during the R&D phase will stimulate competition in the production phase.

OPERATIONS PHASE

- Increased Savings. By reducing the number of different functional modules between systems, savings will occur in simplified maintenance manuals, module testing procedures, requirements for technician training, and a reduction in required corrective maintenance by an increase in module reliability. The extent of this increase depends on the number of systems utilizing the same functional modules on the same platform (i.e., weapon systems platform).

- Reduced Support Costs. This is probably the greatest advantage of functional standardization. Use of interchangeable modules between systems reduces the number of different spare part and test equipment requirements. The Government is also in a better position to procure nonproprietary replacement modules.

- Improved System Reliability. This is achieved by concentration on systems development effort, extended testing, and quicker direct application of field-gathered reliability data to future system developments. It is enhanced by increased applicability of the standard modules in the system.

ACHIEVEMENTS

The SEM Program has proven successful in meeting its objectives of improving reliability and reducing cost, and the potential of added benefits is increasing rapidly as expanded implementation of the program continues. To illustrate how the SEM Program has benefitted a typical development program, SEM Program costing data has been compiled from the Naval Sea Systems Command AN/BQQ-5 and AN/BQQ-6 (TRIDENT) Sonar programs.

COST

The AN/BQQ-5 Sonar development program was initiated in 1970 and extensively employed SEMP modules. The 16,000 total modules required per system were comprised of 138 module types. Twenty-one SEMP Standards accounted for over 12,000 of the 16,000 module total. As a result of the subsequent AN/BQQ-6 Sonar development program also employing SEMP modules, this program was able to satisfy system requirements almost exclusively with existing modules which are common to the AN/BQQ-5 and other Navy systems. The AN/BQQ-6 Program needed to develop only 30 new Standard module types to fulfill its system requirements. The following chart presents a

360

brief tabulation of the more obvious life cycle cost savings identified on these two sonar programs.

Savings Resulting from SEMP Commonality
BQQ-5 and BQQ-6

Area of Savings	Amount* (Thousands)
Development	$2,580
Volume Procurement/Production	3,069
Residual BQQ-5 Modules	330
Supply Administration	150
Spare Support	1,500
Total Savings Quantified	$7,629

* Savings shown here were based on calculations for 20 BQQ-5 systems and 10 BQQ-6 systems. Actual total savings are significantly greater and relate to the actual number of systems as well as additional savings in the areas of training, testing, support equipment and documentation.

It should be noted, that these factors are only the "tip of the iceberg" relative to life cycle cost savings achievable through the use of the SEMP. Savings should go far beyond what has been identified here, and, if the "obscured" items related to logistics and long term availability can ever be properly quantified, the true life-cycle cost savings for user systems will be tremendous.

RELIABILITY

Because of the large number of modules already committed to use in various systems, the significant growth in module usage in recent months, and favorable projections of future growth of the SEM Program, approximately 15 companies have become qualified as module vendors under the program. They have done so by submitting samples (for each type of module they wish to manufacture) to the SEM Program Quality Assurance Activity for a thorough design review, followed by electrical, mechanical, and environmental tests. This is similar to the normal "QPL" procedure, except that all testing is done at one Navy Laboratory. As with other military components, prime system contractors can competitively purchase SEM Program modules from vendors who are qualified to produce them, or they may become qualified themselves. The modules are not normally handled as "Government Furnished Material".

CURRENT VISIBILITY

Electronics standardization, especially at the module level has finally gained the attention of those in a position to establish the policies that can make it a reality. Although the Navy's Standard Electronic Module Program has been struggling for needed support since 1966, the Chief of Naval

Material in 1971, established the Naval Electronic Systems Command as its agent for implementing the Standard Electronic Module Program throughout the Navy. Consequently, both the Army and Air Force are sponsoring study efforts to evaluate the SEM Program for applicability to their own service requirements. With all this inter-service interest, the Defense Material Specifications and Standards Board (Electronics Panel), a policy making group headed by the Office of the Assistant Secretary of Defense has begun probing the question of module standardization in general, in an effort to establish a consolidated DOD policy. This group consequently chartered two sub-panels: The Standard Modules Sub-Panel, and the Form, Fit and Function Sub-Panel for the purpose of:

a. investigating electronics module requirements across various service platforms and environments

b. identifying existing module programs

c. determining desirability of "black box" standards such as the ARINC concept, and

d. determining the most desirable functional level for achieving maximum standardization.

Efforts are now underway by these two sub-panels to answer these questions through cooperation among various independent and joint Service study efforts.

It should also be noted, that interest in the SEM Program is not restricted to our DOD alone. Presentations have recently been made to NATO delegations concerned with fiscal constraints and the need to improve operational capabilities. It should also be interesting to note, that military equipments constructed of SEMP modules are already being procured by Italy, Spain, Australia and the Netherlands.

FUTURE OF SEMP

The future of the SEMP is dedicated to extending the applicability of the program to a greater number of military systems, for as its applications base broadens, the benefits derived will also increase. As with any standardization effort, however, the SEMP will require an extremely wide base of application before its full benefits can be realized. For this reason, R&D efforts in the area of new module identification and in their application are being continually carried out to make the SEMP responsive to a majority of system needs.