# THE REENTRY SYSTEMS APPLICATION PROGRAM (RSAP)

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## ABSTRACT

In this age of reductions in strategic nuclear forces and decreasing defense budgets, economics has forced the refurbishing of currently deployed systems and the extension of their operational life expectancies, rather than the building of new systems. The issue of greatly extending the useful age of components and material systems beyond their design lives, from approximately 20 years to as much as 60 years, is a problem that the reentry system industrial base has not faced in the past. Congress has funded the Reentry Systems Application Program (RSAP) with the objectives of providing the technology to maintain the currently deployed reentry systems beyond their original design lives. Topics covered in this paper include: a brief history of the genesis of the program, an overview of the objective and approach to conducting the program, a discussion of a recently conducted reentry industrial base survey, and the results of a ground test program evaluating potential replacement candidate heatshield materials. The reentry system industrial base is found to be undergoing significant erosion. The reentry system heatshield is identified as a component which the industrial base no longer supports and which has the potential for age-related performance degradation. Arc heater tests and high-temperature thermomechanical properties characterization experiments show the potential for the development of a replacement heatshield material.

## BACKGROUND

In his National Security Policy Statement (July 1994), the President outlined rationale for the maintenance of nuclear forces with the following policy statements: "Even with the Cold War over, our nation must maintain military forces that are sufficient to deter diverse threats ... We will retain strategic nuclear forces sufficient to deter any future hostile foreign leadership with access to strategic nuclear forces from acting against our vital interest and to convince it that seeking a nuclear advantage would be futile. Therefore we will continue to maintain nuclear forces of sufficient size and capability to hold at risk a broad range of assets valued by such political and military leaders .... A critical priority for the United States is to stem the proliferation of nuclear weapons and other weapons of mass destruction and their missile delivery systems." In response to this policy, the Department of Defense (DoD) undertook, for the first time in 15 years, a comprehensive review of U.S. nuclear forces by establishing the Nuclear Posture Review (NPR).

### Nuclear Posture Review

The DoD faced a series of new environments as the NPR was initiated. The security environment had undergone rapid and dramatic change. There was a reduction in the conventional threat in Europe. The threat posed by Russia was also reduced and was significantly changed as driven by continuing political and economic reform in the Former Soviet Union (FSU). Regional threats had become more important than ever before. The economic environment was paced by budget constraints which were more severe than at any time during the existence of U.S. Strategic Forces. Substantial reductions in U.S. Strategic Forces were planned and underway. For the first time since the deployment of U.S. Strategic Forces, there was no active or planned program for the development of strategic weapons. These new environments created a need for stock-taking; for rebalancing the Strategic Forces infrastructure, industrial base and technology base; and for developing a plan to retain quality people.

### Results of NPR

The NPR set out military requirements for U.S. Strategic Forces based on projections through the year 2003. Full implementation of START I and START II was assumed. Capabilities of the FSU remained the primary concern. Russia (or anyone else) was not to be targeted today, but U.S. Strategic Forces were directed to be prepared for the possible emergence of hostile governments in Russia or for the failure of the arms control process in the FSU. Preparedness was to take the form of a "warhead upload hedge" which would preserve options for uploading or reconstituting U.S. Strategic Forces in response to changes for the worse in political relations with Russia or to the failure to fully implement START I or START II. Options for

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making faster, deeper force reductions were also to be kept open in the event that new strategic arms reductions agreements could be negotiated.

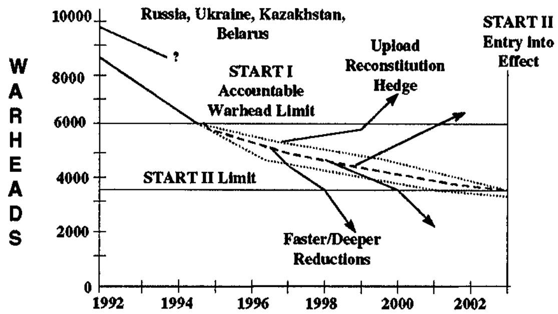



Figure 1. Force Structure Paths

Figure 1 illustrates the warhead upload hedge. The top curve of Figure 1 depicts the reductions toward START I limits accomplished by the FSU before economics brought them to a halt. The bottom curve shows the corresponding U.S. reductions, which met START I levels in 1994 and are on a path to meet START II levels by 2003. Up and down ramps below the "START I Accountable Warhead Limit" line illustrate potential upload/reconstitution hedges as well as potential faster/deeper reductions. Infrastructure requirements identified by the NPR as necessary to support the upgrade/reconstitution hedge included replacement of the guidance systems and re-motoring of the propulsion systems on Minuteman III, continued production of the Trident II D-5 missile body beyond 1995 to maintain the missile industrial base, funding of the sustainment of strategic missile guidance systems, and maintenance of the reentry system industrial base.

SAG Industrial Base Study

In parallel with the NPR, the U.S. Strategic Command (USSTRATCOM) Strategic Advisory Group (SAG) studied the Submarine Launched Ballistic Missile (SLBM) and Intercontinental Ballistic Missile (ICBM) industrial bases. The purposes of the SAG study were to identify those management assurances necessary for USSTRATCOM to retain confidence in the dependability of SLBMs and ICBMs for the next period of years, to determine subsystem areas where special actions would be needed to assure performance, and to define those measures necessary to assure special action subsystems. For the purpose of the study, the SLBM and ICBM industrial bases were defined as the combination of U.S. Government System Program Offices (SPOs), dedicated industrial companies (primes, subs and associate contractors), and the system depots and service/national laboratories necessary to perform all of the acquisition and support functions, from research and development (R&D) to operations and maintenance (O&M)/ modification, for a fielded SLBM or ICBM weapon system. Key industrial base assumptions for the study were: (1) No new weapon system acquisitions would be conducted for an extended period of years. (2) No, or very few, new weapon system performance requirements would be issued for an extended period of years. (3) Severe limits would exist on money and people resources (Government and industry) supporting SLBMs and ICBMs. (4) company CEOs would make SLBM and ICBM industrial base decisions, with or without DoD input.

The study found that the ballistic missile life cycle had been broken. Since the initial deployment of U.S. SLBMs and ICBMs over 40 years ago, there had always been a ballistic missile acquisition industrial base in place to aid in O&M problem solution. Historically, when a ballistic missile weapon system reached operational phase and modifications were required, a new system configuration was started. Based on the NPR plan, for the first time in 40 years, no new SLBM or ICBM systems were planned. In response, prime and subsystem contractors were rapidly downsizing, and suppliers were getting out of the ballistic missile business.

The reentry system industrial base was also assessed. Adequate reentry bodies for NPR requirements existed and had been delivered to the Government. Reentry system production was over, and no new requirements were being worked. As a result, key people were being reassigned or were retiring, and the technical capability to fix unforeseen problems was found to be rapidly eroding. The study found that, without an adequate reentry system industrial base technology program, no materials or expertise would be available to maintain the existing fleet. The study also found that reentry systems must have a meaningful project to sustain an adequate engineering base, and low production rates were not found to be a solution.

The SAG Industrial Base Study made a series of recommendations, including the establishment of a reentry system advanced technology demonstration program. Such a program was required to enable solutions to unknown problems which would develop with the life extension of the ballistic missile fleet. The creation of a reentry system advanced technology demonstration program was also seen to offer the possibility of reentry system technology insertion when needed and to assure the availability of critical test facilities such as the AEDC Plasma Jet Arc Heater.

## REENTRY SYSTEMS APPLICATION PROGRAM (RSAP)

The reentry system industrial base recommendations from the NPR and from the SAG Industrial Base Study were addressed when the DoD proposed and Congress funded the Reentry Systems Application Program (NAVY) and the Reentry Vehicle Applications Program (RVAP, Air Force). RSAP and RVAP are cooperative programs whose objectives are to provide the technology necessary to maintain U.S. reentry systems beyond their original design lives, to maintain the minimum essential capability necessary to address reentry system aging phenomena, and to maintain the minimum essential technologies necessary to address future requirements of in-service SLBM and ICBM reentry systems. RSAP and RVAP are planned and conducted to take advantage of economic and technical synergies between the programs. The RSAP/RVAP coordination process is schematically depicted in Figure 2. Coordination is also regularly conducted among RSAP/RVAP, the Research and Technology Development (6.1/6.2) community, and the Small Business Independent Research Program in order to eliminate duplication of effort and to leverage DoD technology investments. The unique set of weapon

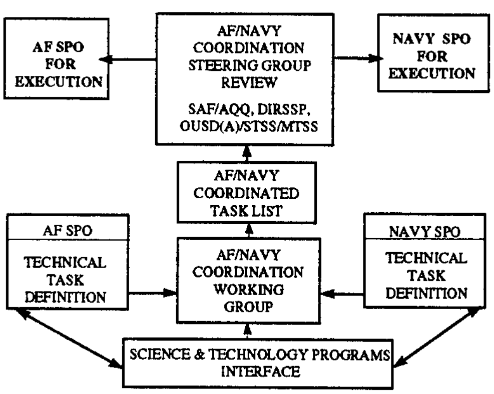



Figure 2. RSAP/RVAP Coordination

requirements applicable to reentry systems are the most severe of all the strategic weapon subsystems requirements. These requirements, as given in Figure 3, mandate the focusing of supporting technologies to the extent that leveraging of other weapons technology for reentry applications is not possible. This also explains the need for a stand-alone reentry systems advanced technology demonstration program as called for by both the SAG Industrial Base Study and the NPR.

<u>MISSION</u>: HOLD STRATEGIC TARGETS AT RISK VIA SAFE, RELIABLE, AND ACCURATE WARHEAD DELIVERY AND DETONATION AT INTERCONTINENTAL RANGES WITHIN 30 MINUTES AND AFTER 15 YEARS DORMANCY

<u>REQUIREMENTS</u>:HIGH LEAKAGE AGAINST TERMINAL DEFENSE
HIGH KILL PROBABILITY, ACCURACY, AND RELIABILITY
SEVERE WEIGHT AND MASS PROPERTY CONTROL
DORMANT FOR 15 YEARS (DESIGN), 23 YEARS TO DATE ON MK12
OPERATIONAL READINESS IN LESS THAN 30 SECONDS
NUCLEAR SAFETY: INADVERTENT DETONATION PROBABILITY $< 1.0 \times 10^{-9}$

<u>ENVIRONMENTS</u>: ASCENT HEATING AND DUST/DEBRIS EROSION
NUCLEAR ENCOUNTERS (HUNDREDS OF ENCOUNTERS)
ENDO AND EXO-ATMOSPHERIC MECHANICAL & ELECTRICAL EFFECTS 10-20 TIMES HIGHER THAN BOOSTER LEVELS
SHOCK LOADS BOOST, DEPLOYMENT AND REENTRY UP TO 200 G's IN REENTRY 34 G (RMS) INTERNAL COMPONENT VIBRATION
REENTRY THERMAL LOADS185 ATMOSPHERES PRESSURE
TEMPERATURES WOULD MELT UNPROTECTED ALUMINUM IN LESS THAN 1 MSEC

Figure 3. Unique Reentry Requirements

RSAP was implemented in FY 95. Three programmatic tasks were to be completed and reported to Congressional Staff before the initiation of technical program activity. These tasks included a Reentry System Industrial Base Assessment, to provide a detailed report on the erosion of the reentry system industrial base; a Reentry System Technology State-of-the-Art Assessment, to identify any emerging technologies which would support the life extension of reentry systems; and a Technical Program Plan, to provide details of the technical tasks that would be accomplished under RSAP.

<u>Reentry System Industrial Base Assessment</u>

The objective of the Reentry Industrial Base Assessment was to evaluate existing and far term capabilities of the reentry industrial base to support reentry system design, development, manufacturing and in-service operations. The approach to conducting the assessment included identification of all prime contractors, suppliers, test facilities, etc. which make-up the reentry system industrial base; ranking of the criticality of the particular expertise which was so identified; and defining critical areas in which technical tasks must be performed to prevent further erosion of critical elements of the reentry system industrial base. The identification of the critical elements of the reentry system industrial base was accomplished by constructing detailed "technical task trees" for the design, development, manufacture and in-service support of each reentry system component. Output from the Reentry System Industrial Base Assessment included lists of reentry system industrial base critical capabilities, critical reentry system industrial base capabilities which are at risk or no longer exist, and recommended reentry system capabilities requiring sustainment.

The status of the critical reentry system capabilities, as determined by the Reentry System Industrial Base Assessment, was much the same as that projected by the SAG Industrial Base Survey. Figure 4 presents an example of the diminishing reentry system industrial base capability. The number of reentry system industrial base employees, as a percentage, is presented for years from 1990 to 1996. The percentage is established relative to the number of employees in the reentry industrial base in 1990 when the Trident II Mark 5 Reentry System was operationally deployed. The trend represented in Figure 4 shows a steady decline to 6 percent in 1996. This trend was also found to exist for reentry ground test experimental facilities.

One of the reentry system capabilities which was identified as critical and requiring sustainment was ability to manufacture the afterbody heatshield subsystem. Major elements of the development and manufacturing "task trees" for the heatshield material had disappeared, and other ballistic missile system components made of the same material had begun to show age-related material demise. As a result, an RSAP task was initiated to develop the technology necessary for the design and manufacture of a "replacement" heatshield system.

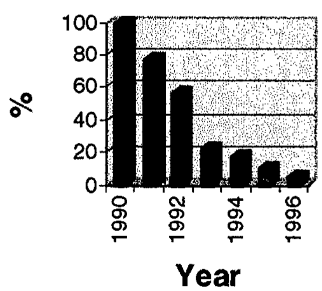



Figure 4. Example of diminishing Reentry System Industrial Base Reentry System Employees

HEATSHIELD DEVELOPMENT

Current Navy reentry body heatshields are made of a rayon-fiber-based carbon phenolic material. The rayon fiber used in the Navy heatshields was produced by AVTEX Corporation. This fiber has not been manufactured since 1986 as a result of the closure of the manufacturing facility and demise of the company.

The goals of the Navy RSAP Heatshield Task are twofold. The first goal is to demonstrate the capability of material vendors to manufacture acceptable heatshield material, to existing heatshield specifications, utilizing the remaining stocks of AVTEX rayon fiber. The second goal, in light of the fact that AVTEX rayon fiber is no longer produced, is to identify alternate-fiber-based carbon phenolic materials that could replace the current AVTEX rayon-fiber-based system.

Alternate rayon fiber development is being pursued by the Air Force under the RVAP Program. Navy/Air Force development activities are coordinated through the RVAP/RSAP AF/Navy Coordination Working Group.

The Navy RSAP Heatshield Task is taking the following approach: (1) Transition replacement fibers from technology development programs and contractor IRAD programs to advanced development. (2) Manufacture replacement heatshield materials. (3) Evaluate materials in ground-test and flight-test environments.

Within the Navy, the RSAP Heatshield Task is a coordinated effort between the Strategic Systems Programs and the Navy 6.2 Strategic and Spacecraft Weapons Materials Program, directed by the Naval Surface Warfare Center, Dahlgren Division. During FY 95 and 96, potential candidate non-rayon-fiber-based replacement heatshield materials were developed and subsequently evaluated to determine their performance.

The performance of the heatshield materials was assessed by plasma arcjet ablation ground tests and thermomechanical material characterization measurements. Performance was judged relative to the performance of AVTEX rayon-fiber-based heatshield materials.

<u>Carbon Phenolic Material Test Specimens</u>

Carbon phenolic composite materials are characterized by the type of fiber and type of resin infiltration process used in their manufacture. All material samples investigated to date were tape-wrapped carbon phenolic composites based on three different precursor fiber types. AVTEX rayon-fiber-based (Navy reference heatshield fiber), pitch-fiber-based, and polyacrylonitrile or PAN-fiber-based materials were tested. There were two AVTEX rayon-fiber-based materials. The Navy reference material was constructed with the resin impregnation process, while the material designated HM Reference was constructed using an alternate resin impregnation process identified as the hot-melt process. The high-strength, high-modulus T350 PAN-fiber-based materials, designated 23-XAB and 25-XAB, and the pitch-fiber-based materials, designated A and A-100, were all constructed using the hot-melt process.

Carbon phenolic materials received from the manufacturer were subjected to a variety of tests to characterize them, in a non-destructive manner, and to determine their thermomechanical properties. The Southern Research Institute (SoRI), Birmingham, AL, performed all of the material characterizations. Non-destructive tests included visual inspection, a check for delaminations using edge X-rays, and measurements of density, porosity, and ultrasonic velocity. These measurements aided in the preparation of test specimens for ablation screening tests and for thermomechanical characterization tests.

## HEATSHIELD PLASMA ARCJET ABLATION SCREENING TESTS

### Test Facility

The AEDC High Enthalpy Ablation Test Unit (HEAT) H1 Facility at Tullahoma, TN is a continuous-flow, electric-arc-heated facility. Air is used as the working fluid. An axisymmetric expansion nozzle provides a supersonic free jet that discharges into the atmospheric environment of the test building. A schematic of the facility and supporting elements is shown in Figure 5.

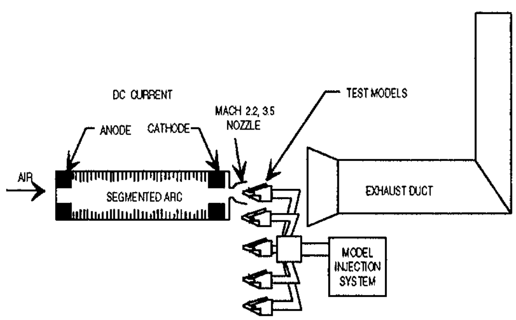



Figure 5. AEDC HEAT facility

A rotary model injection system with eight model mounting positions is used. This system can be programmed to inject test models at various axial stations, advance or retract axially, and expose the models to the flow for various intervals of time. A maximum of seven models can be tested in a single run, as one position is left vacant for heater start-up and shut-down. Diagnostic probes, such as a pitot pressure probe or a calorimeter, may be used to characterize the flowfield; however, there is a one-to-one substitution between probes and models for each probe used in a run. Additional details of this facility may be found in Reference 1.

### Test Instrumentation

Instrumentation used in the testing of heatshield material specimens permitted standard HEAT facility measurements of quantities such as pressure, temperature, water flow rate, current, and voltage. Wedge and null point calorimeter probes were swept through the flow to measure heat flux profiles. Heat flux profiles, along with chamber pressure measurements, were used to generate inferred enthalpy profiles.

Pyrometry was employed to measure the surface temperatures of ablating heatshield materials. Pyrometers were focused at locations on the heatshield surface that corresponded to the positioning of back-face thermocouples.

The Laser Wedge Recession (LWR) system was used to measure the ablation of the candidate heatshield materials as a function of time. A laser was used to project light onto the surface of the sample at a 45-degree angle relative to the surface normal. The reflection of the laser light was picked up by a receiver located 90 degrees from the light source. As the test material receded (ablated) normal to the surface, the laser beam appeared to be displaced along the surface plane of the material. The amount of displacement of the light was directly proportional to the amount of recession. A detailed description of this technique may be found in Reference 2.

Motion picture cameras were used to provide surveillance and to record catastrophic failures if they occurred. These cameras were not relied upon to record data when testing heatshield material specimens.

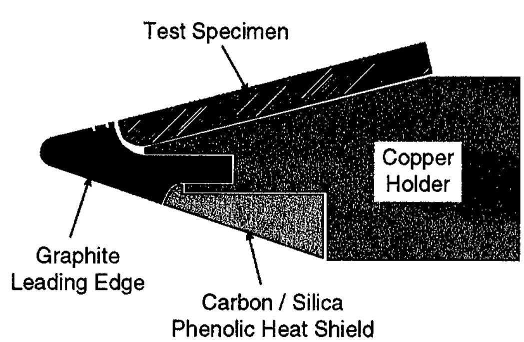
Each model was instrumented with K-type thermocouples bonded to the back face of the material specimen. The measured data from these thermocouples were used to evaluate the relative insulation performance of the candidate materials used in the tests. Thermocouple locations coincided with the thermocouple locations on the wedge calorimeter to ensure that the heating environment was known.

### Test Description

**Test Conditions**: For the tests described in this paper, a Mach 3.5 contoured nozzle having a throat diameter of 0.9 inch and an exit diameter of 3.00 inches was used. The facility operating conditions were adjusted to produce a desired heat transfer rate of 1065 BTU/ft$^2$sec on the model at an axial location 2.00 inches from the leading edge of the model (chamber pressure of 105 Atm, inferred enthalpy of 6200 BTU/lbm).

**Models**: Each material test specimen was machined to a length of 0.9 inch, a width of 3.0 inches, and a thickness of 0.375 inch. Model thickness was selected such that it was sufficiently thick to preclude burn-through yet thin enough to provide sufficient heat transfer to the back face in a reasonable amount of time. The length and width of the test material specimens were dictated by the size of the standard holders used at the AEDC facility. The models were secured to the holders with a graphite clamp arrangement.

**Holders**: The test materials were mounted on heatshield wedge holders. A schematic of the model holder is shown in Figure 6. A single heatshield-material test specimen was attached to each holder. The upper surface of the holder, to which the test material specimen was attached, was inclined at a fixed angle of 15 degrees to the flow. The holder was made of copper, with additional thermal protection afforded by a leading edge of bulk graphite and by a generic carbon/silica phenolic insulator on the underside of the holder. This arrangement allowed the holders to be reusable.




Holder Assembly (Not to Scale)
Figure 6. Schematic of Model Holder

## Test Procedure

The heater was started and allowed to run for six seconds prior to the sweep of the calorimeters through the flow. This six second interval allowed the arc flowfield conditions to stabilize. After the calorimeter sweep, a one second elapsed time was allowed prior to model insertion. Models were introduced into the flow at a location where the leading edge of the model holder was 0.1 inch from the nozzle exit and were held there for seven seconds. After the last model exited the flow, the heater was shut down, and recording of recession data and pyrometer data was stopped. Back-face thermocouple data were recorded for another 40 seconds after heater shutdown.

## Ablation Test Results

The total recession data of pitch and PAN-fiber-based carbon phenolic composite material are shown in Figure 7, along with data for the rayon fiber-based carbon phenolic Navy reference material. These data were taken at a location on the centerline of the model 1.25 inches downstream of the leading edge at a time of seven seconds, corresponding to the end of the test. These results indicated that both pitch and PAN-fiber-based carbon phenolic materials exhibited ablation performance that was generally as good as the rayon-fiber-based materials.

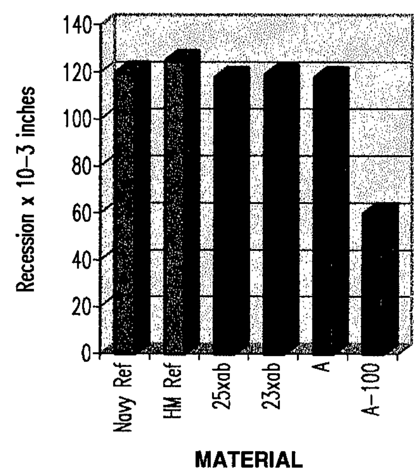



Figure 7. Recession Data

The centerline back-face thermocouple data at a location 2.00 inches downstream of the leading edge, and at a time 20 seconds after the model entered the plasma arcjet flowfield, are shown in Figure 8. The pitch- and PAN-fiber-based composites exhibited back-face temperatures near that of the reference material, indicative of thermal insulation performance as good as that of the reference material.

## HEATSHIELD MATERIAL CHARACTERIZATION TESTING

Southern Research Institute is a not-for-profit, contract research organization located in

Birmingham, AL. The Engineering Division of Southern Research Institute has conducted characterizations for high-temperature materials used for Navy and Air Force since the early 1960's. Southern has developed many facilities and techniques for measuring the mechanical and thermal properties of materials at temperatures from cryogenic to 5500 °F.

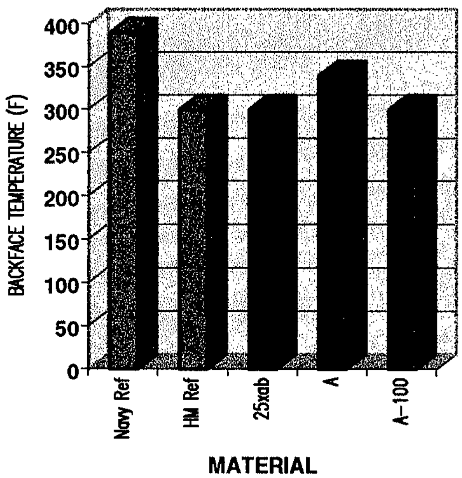



Figure 8. Back-face Temperature

Tensile Strength and Elastic Modulus

Tensile strength and elastic modulus were measured in a gas-bearing tensile test facility developed by Southern Research to evaluate the tensile properties of materials from ambient temperature to high temperatures. Coupon specimens contained in a furnace were loaded in tension to failure. Tensile load and tensile strain were continuously recorded during the test. Tensile strength was calculated from measured load at failure, and elastic modulus was calculated from the slope of the load-strain curve recorded during the initial part of the test. Quartz lamp furnaces were used for temperatures from ambient to ~1200 °F; graphite furnaces were used for temperatures from 1200 °F to 5500 °F. Strain measurements were made with high temperature clip-on extensometers. Load-time data were recorded for load rate control, load-strain data were recorded for preparation of stress-stain curves, and temperature-time data were recorded for low temperature evaluations where heating rate was an important parameter. Ultimate tensile strength, elastic modulus, and strain-to-failure were calculated from the measured load-strain curve; each specimen was inspected for proper failure mode. Data tables, stress-strain curves and summary graphs were reported.

Thermal Expansion

Thermal expansion was measured using dilatometers to record length changes of coupon specimens during heating. For temperatures up to 1500 °F, quartz dilatometers were used; for temperatures up to 5500 °F, graphite dilatometers were used. The dilatometers were calibrated on a regular schedule using NIST fused silica standard for the quartz dilatometers and in-house developed ATJ graphite standards for the graphite dilatometers. For the carbon phenolic materials used in reentry body heatshields, heating rate is an important parameter at low temperatures. For the low-temperature runs with controlled heating rates, length changes were measured during continuous heating with linear variable differential transformers. Thermal expansion was calculated from the change in length that occurred from initial temperature to each temperature (final length - initial length); calculated expansion values were plotted versus temperature to create a thermal expansion curve. Values of instantaneous or secant coefficient of thermal expansion could be calculated from the thermal expansion curve.

Thermal Conductivity

The thermal conductivity was measured in the Comparative Rod Apparatus (CRA) which is used for temperatures up to ~2000 °F. Measured thermal conductivity of carbon phenolic materials is dependent on thermal preconditioning, so that care must be given to describing the conditions of the material before the test and the actual conditions during the test.

The CRA used a "guarded" column containing two test specimens and two reference specimens. Heat flow was measured into and out of the column using the reference specimens and temperatures were measured along the column. Thermal conductivity was calculated from the known heat flows and the measured temperature gradients in the specimens. The specimen column was "guarded" with temperature profiles that matched those in the column to insure that heat flow was one dimensional along the length of the column. Reference materials included copper, Armco iron, 316 stainless steel, and Pyroceram. References were selected to match the thermal conductivity of the material being tested. Test method measurement uncertainties were on the order of 5 percent.

Thermomechanical Test Results

Properties of the candidate heatshield materials were measured. Tests performed included tension at room and elevated temperatures, thermal expansion to 5000 °F, and thermal conductivity to 600 °F. Results of some of the tests are presented in Figures 9, 10, 11, and 12. Figures 9 and 10 show, as expected, that the high-strength, high-modulus, T350 - 23 XAB and T350 - 25 XAB used in the PAN candidates produced the highest strength and highest modulus composites. These low-temperature-fired PAN fibers also yielded a lower thermal conductivity composite, as shown in Figure 10. The PAN conductivity characteristics showed little temperature variation between room temperature and 600 °F. This behavior is desirable from a design standpoint. The pitch candidates also outperformed the Navy Reference material with respect to thermal conductivity, which showed little variation with temperature. The pitch-fiber-based candidates did not perform as well as the PAN candidates with respect to tensile strength and modulus, but they were comparable to the Navy Reference material. In the thermal expansion tests, all of the replacement material candidates performed better (expanded less) than the Navy Reference material.

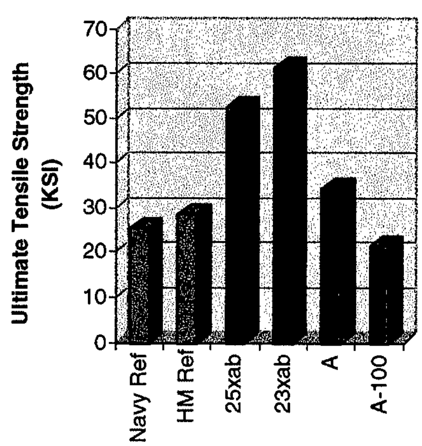



Figure 9. Room Temperature Tensile Strength

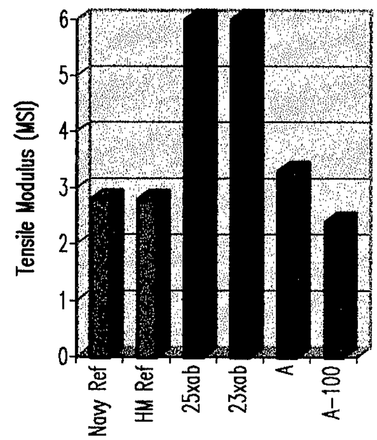



Figure 10. Room Temperature Tensile Modulus

CANDIDATE HEATSHIELD MATERIAL

Test Conclusions

The results of the plasma arcjet ablation testing and the thermomechanical screening and characterization of alternate fiber carbon phenolic heatshield materials indicated that the ablation performance and thermomechanical properties of these materials were as good as or better than those of the AVTEX rayon-fiber-based material, the Navy reference material. All candidates are undergoing

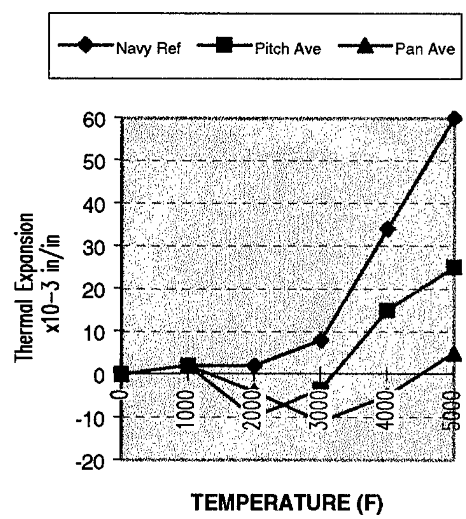



Figure 11. Thermal Expansion

further evaluation. The use of ground-test facilities and material characterization measurements is an effective means for screening alternative materials relative to the existing reference material. Ultimately, the overall performance of any replacement material must be determined in full-scale flight tests.

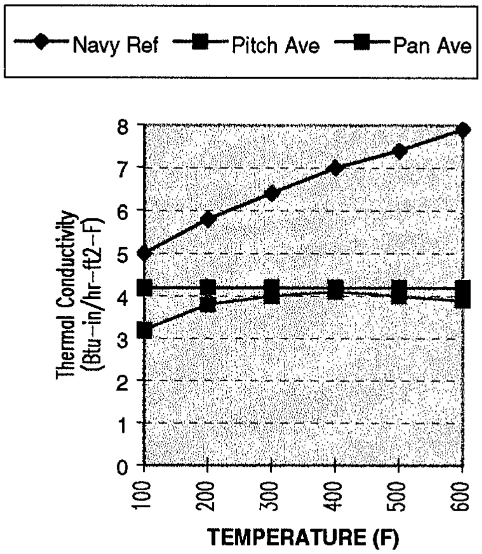



Figure 12. Thermal Conductivity

In the decision-making process associated with the choice of a replacement material, factors and issues in-addition to material performance must also be considered. Many new, alternate replacement fibers were in the realm of R&D. The availability of such fibers is questionable from the standpoint of the ability to produce quantities necessary for component fabrication at an affordable cost. Replacement components must have a capability to meet mission requirements equivalent to the components of the existing systems. In addition, a replacement component must have minimal impact on the overall system, and that impact must be understood. A link must exist between the replacement component and current, existing ground-test and flight-test databases. The replacement component must be affordable. Reductions in the cost of replacement components by a factor of two may be a required reality in the future. In an era with little or no new system production, manufacturers will not operate facilities in a continuous manner. The consistency of replacement components must be ensured and must not be subject to the start-up and shut-down cycles inherent in intermittent operation of material processing facilities.

Future Plans

Additional candidate materials have been identified, and test specimens will be produced, screened, and tested as appropriate. Testing similar to that described will take place on each of the candidate materials. Since many new materials are expected to be available for testing, productivity enhancements in the test procedures are being pursued. One such productivity enhancement is the development and use of a model holder to accommodate two material specimens on each model mount position. A double-wedge configuration with material specimens on both the top and bottom surfaces, is planned to be utilized in future testing. A schematic of this arrangement is shown in Figure 13. A result of preliminary testing of a double-wedge calorimeter configuration, which mirrors the material test model, is shown in Figure 14. Gardon gages were mounted on the top and bottom of the double wedge configuration at various locations to measure the heat flux to the calorimeter. The results of this test indicated that the plasma arcjet flowfield environment was uniform and symmetrical and suitable for testing materials in a double wedge model test configuration.

Ablation testing of actual heatshield materials, excised from conical frusta, is planned to assess the effects of aging on the ablation performance of these materials. To test these specimens in the present test setup would require the machining of the curved specimens into flat samples. Removal of stock from the inner and outer surfaces of the curved specimens may not be desirable, since the thickness of the flat specimen would be reduced from that of the curved specimen, and the stock removal process may alter the state of the "aged" material. A curved model holder, also shown schematically in Figure 13, has been designed, as has a curved calorimeter model. These items should allow the excised heatshield materials to be successfully tested in an ablative environment.

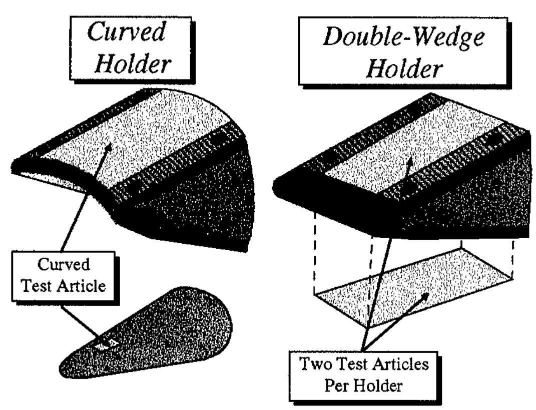



Figure 13 Schematic of Model Holder

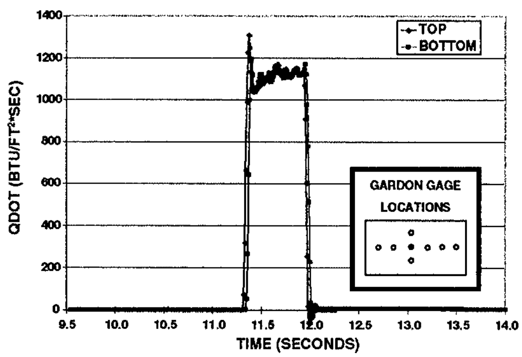



Figure 14 Gardon Gage Heat Transfer Results

Investigations are also planned to produce a simulated trajectory environment in the plasma arcjet. A wedge model with the ability to change its angle relative to the flow and to move toward the nozzle exit may be able to simulate conditions of increasing pressure and heating associated with reentry in the earth's atmosphere.

## SUMMARY

U.S. strategic policy has established a continuing need for U.S. nuclear Strategic Forces. The NPR has set forth a strategy that preserves options for ramp up to a reconstitution hedge or ramp down to deep cuts from our current strategic reduction plan. Various studies have determined that the strategic industrial base is rapidly eroding due to an absence of ballistic missile development or production programs. RSAP has been established to maintain SLBM reentry systems beyond original design life and to maintain essential capability necessary to address aging phenomena and future requirements for in-service SLBM reentry systems. Results from a Reentry Systems Industrial Base Survey indicated that the reentry industrial base has undergone significant erosion. The reentry system afterbody heatshield was identified as a critical component which can no longer be manufactured and which is subject to aging effects. RSAP has established technical tasks to develop the technology necessary to support the replacement of operational heatshield systems. The results of plasma arcjet heater experiments and high-temperature mechanical properties characterization experiments have been presented which show the potential for the development of a non-rayon-fiber-based, tape-wrapped heatshield material system. Results obtained from the RSAP program to date have indicated that the basic approach holds promise for providing the technical and industrial foundation necessary to support the life extension of SLBM reentry systems.

## REFERENCES


1. Test Facilities Handbook, Volume 1 and Volume 3, May 1992, Arnold Engineering Development Center, Arnold Air Force Base, Tennessee.
2. Sherrouse, P. And Carver, D., "Demonstrated Real-Time Recession Measurements of Flat Materials During Testing in High-Enthalpy Flows," AIAA Paper No. 92-0765, 1992.

# REENTRY SYSTEMS APPLICATION PROGRAM

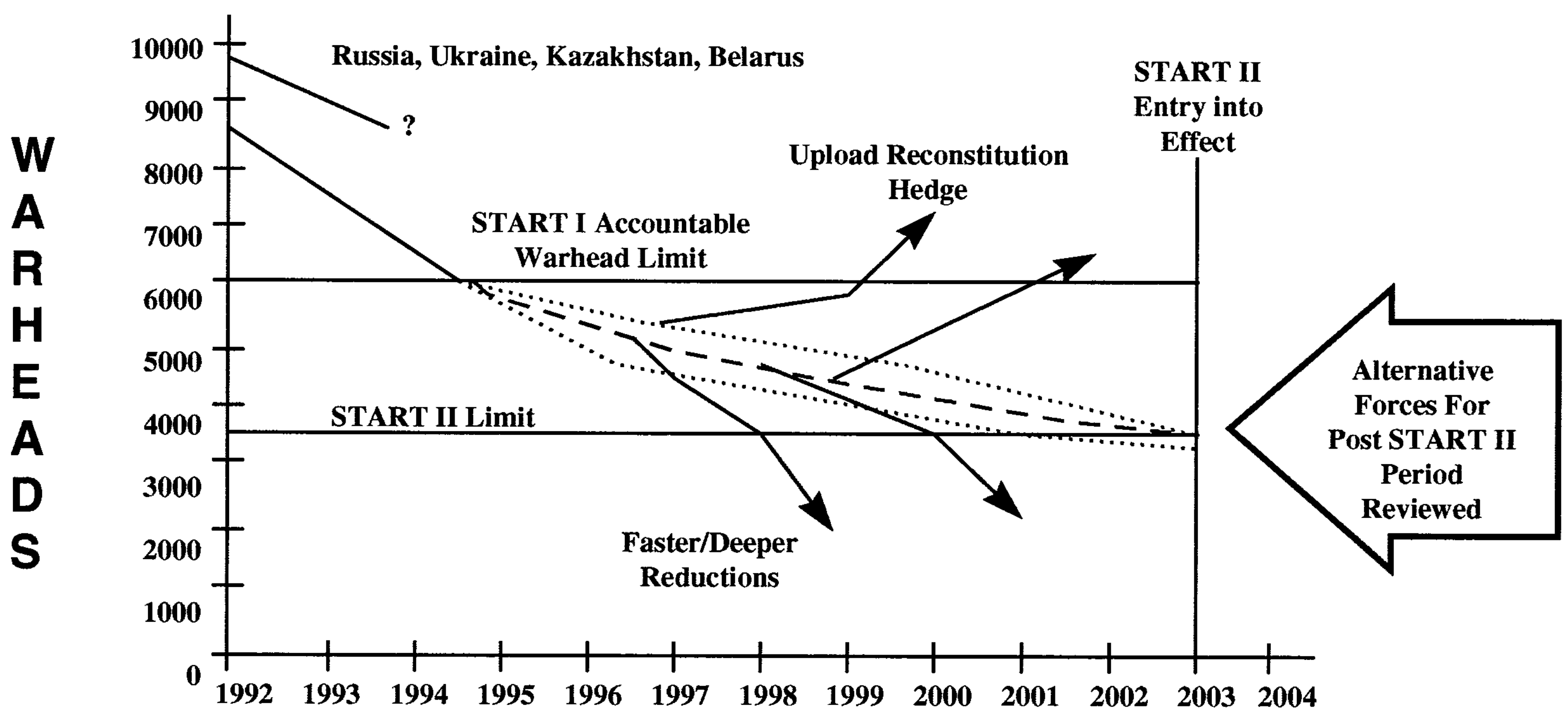
Dr. Alfred M. Morrison
Dr. John S. Vamos
Naval Surface Warfare Center - Dahlgren Division

# PRESENTATION OUTLINE

- Background
- Reentry Systems Application Package (RSAP)
- RSAP Heatshield Materials Development
- Critical Issues
- Conclusions

# FROM DR. DEUTCH'S NPR PRESENTATION TO HASC & SASC

## Force Structure Paths:
### Protecting Options In An Uncertain World



***FROM DR. DEUTCH'S NPR PRESENTATION TO HASC & SASC***

# Main Results of the NPR(Cont)

- **Safety, Security, and Use Control**
  - **Equip all US nuclear weapons systems, including submarines, with coded control devices or PAL by 1997**
  - **Upgrade coded control locking devices on Minuteman III ICBMs and B-52 bombers**
  - **Conduct regular NCA procedural exercises**
- **Infrastructure**
  - **Stockpile stewardship "customer plan" for DoE**
  - **Sustain ballistic missile industrial base by Minuteman III sustainment and D-5 production**
  - **Sustain reentry vehicle and guidance system industrial base**
- **Command, Control, Communications, & Intelligence and Operations**
  - **Continue adjustments to post-Cold War alert/operational requirements**
  - **Support selected C3I programs for assured NCA survivability and continuity**
- **Threat Reduction and Proliferation**
  - **Support Cooperative Threat Reduction program to promote steps to prevent unauthorized/accidental use or diversion of weapons or materials from/within the FSU**
  - **Support counterproliferation initiative to provide conventional responses to use of WMD in regional conflict**

# CURRENT INDUSTRIAL BASE STATUS

- NO NEW RB DESIGN OR PRODUCTION IS PLANNED
  - FOR THE FIRST TIME SINCE THE INITIATION OF REENTRY SYSTEMS (LATE 1950'S) NO DEVELOPMENT OR TECHNOLOGY EFFORT IS ON-GOING
- OVER 3 DECADES OF INDUSTRY UNIQUE RB TECHNOLOGY AND DESIGN METHODOLOGY IS BEING LOST
  - RB ENVIRONMENT PLACES UNIQUE DEMANDS ON ENGINEERING
  - LACK OF ANY PROGRAM (ACTUAL OR PLANNED) IS CAUSING LAYOFFS AND FORCED RETIREMENTS OF ENGINEERS AND SUPPORTING PERSONNEL
  - SUPPLIERS AND CRITICAL FACILITIES ARE BEING LOST OR DISMANTLED

# WHAT MAKES A REENTRY SYSTEM UNIQUE?

**MISSION:**

HOLD STRATEGIC TARGETS AT RISK VIA SAFE, RELIABLE, AND ACCURATE WARHEAD DELIVERY AND DETONATION AT INTERCONTINENTAL RANGES WITHIN 30 MINUTES AND AFTER 15 YEARS DORMANCY

**REQUIREMENTS:**

- HIGH LEAKAGE AGAINST TERMINAL DEFENSE
- HIGH KILL PROBABILITY, ACCURACY, AND RELIABILITY
- SEVERE WEIGHT AND MASS PROPERTY CONTROL
- DORMANT FOR 15 YEARS (DESIGN), 23 YEARS TO DATE ON MK12
- OPERATIONAL READINESS IN LESS THAN 30 SECONDS
- NUCLEAR SAFETY: INADVERTENT DETONATION PROBABILITY $< 1.0 \times 10^{-9}$

**ENVIRONMENTS:**

- ASCENT HEATING AND DUST/DEBRIS EROSION
- NUCLEAR ENCOUNTERS
  - ENDO AND EXO-ATMOSPHERIC MECHANICAL & ELECTRICAL EFFECTS
  - 10-20 TIMES HIGHER THAN BOOSTER LEVELS
  - SURVIVABILITY AND ACCURACY (HUNDREDS OF ENCOUNTERS)
- SHOCK LOADS
  - BOOST, DEPLOYMENT AND REENTRY
  - UP TO 200 G's IN REENTRY
  - 34 G (RMS) INTERNAL COMPONENT VIBRATION
- REENTRY THERMAL LOADS
  - 185 ATMOSPHERES PRESSURE
  - TEMPERATURES WOULD MELT UNPROTECTED ALUMINUM IN LESS THAN 1 MSEC

**RB REQUIREMENTS ARE THE MOST SEVERE OF ALL STRATEGIC WEAPON SUBSYSTEMS**

# FBM REENTRY BODY EXTENDED SERVICE LIFE

## RB SERVICE LIFE & EXTENSION

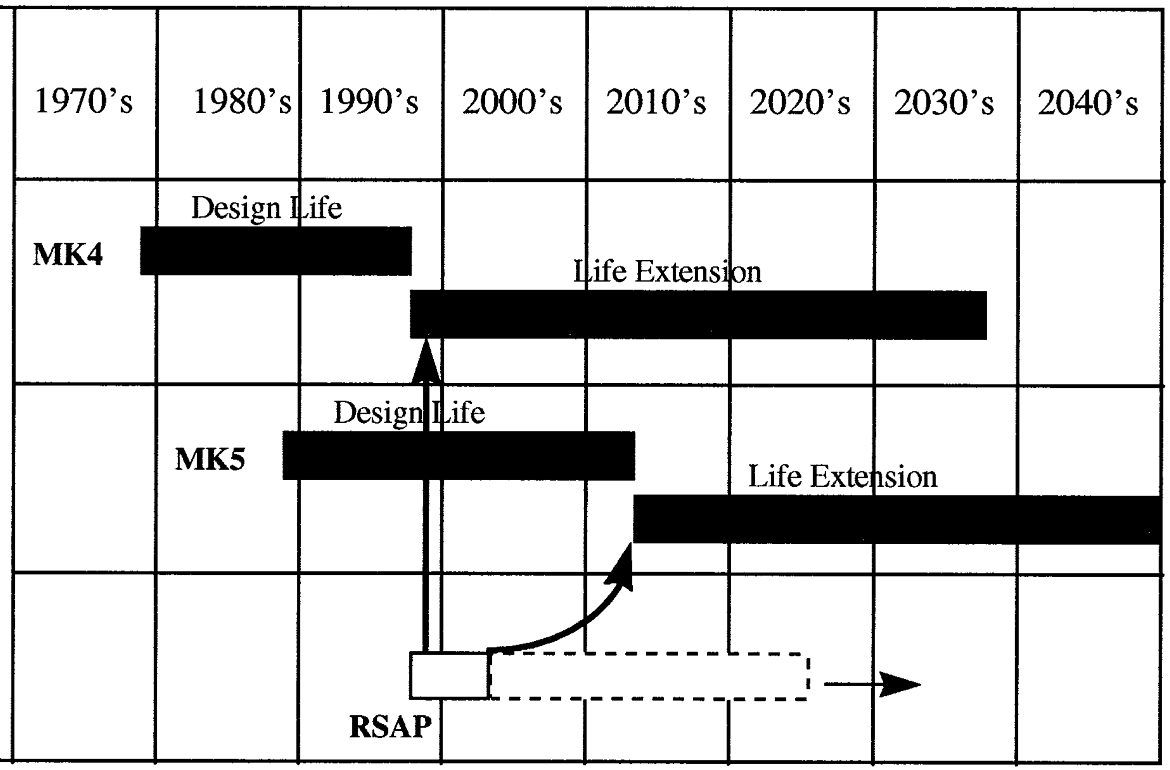
**OBJECTIVE:**
MAINTAIN Mk4 & Mk5 RB PERFORMANCE CAPABILITY BEYOND ORIGINAL DESIGN LIFE:

- **SAFETY**
- **RELIABILITY**
- **ACCURACY**

**APPROACH:**

- **SERVICE LIFE EXTENSION**

**CAPABILITY MAINTENANCE:**
MAINTAIN CRITICAL ELEMENTS OF RB INDUSTRIAL BASE WITH TASKS ASSOCIATED WITH POSSIBLE REFURBISHMENT

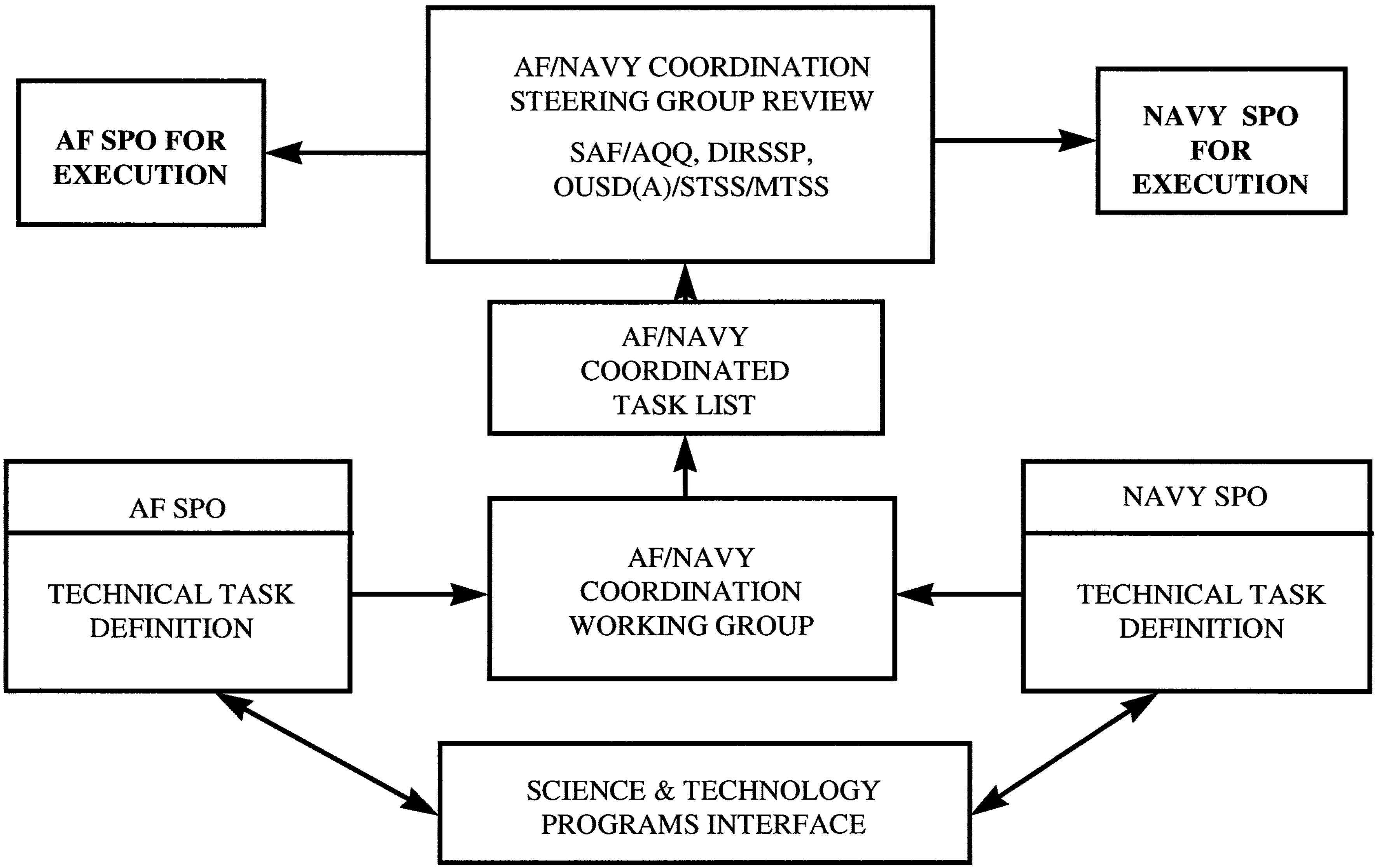


# REENTRY SYSTEM APPLICATION PROGRAM (RSAP)

## PROGRAM OBJECTIVES

- Provide the technology to maintain reentry systems beyond original design life
- Maintain minimum essential capability necessary to address aging phenomena & future requirements for in-service SLBM reentry systems

# RSAP COORDINATION



# RSAP FY ‘95 & ‘96

- **FY ‘95 ACTIVITIES**
  - Industrial Base Assessment
  - State-of-the-Art Assessment
  - Technical Program Plan

**Assessment & Task Planning**

- **FY ‘96 ACTIVITIES**
  - Trade Studies/Requirements Definition
  - Materials/Sensor Development
  - Plasma Arc Jet Test
  - Methodologies Development
  - Hardware Designs
    - Wind Tunnel Test

**Execution of Tasks**

# RSAP HEATSHIELD DEVELOPMENT

**GOAL:**

Identify Pitch (or Pan)-Based Carbon Phenolic Heatshield Materials which could replace the current AVTEX Rayon (no longer available)-Based System.

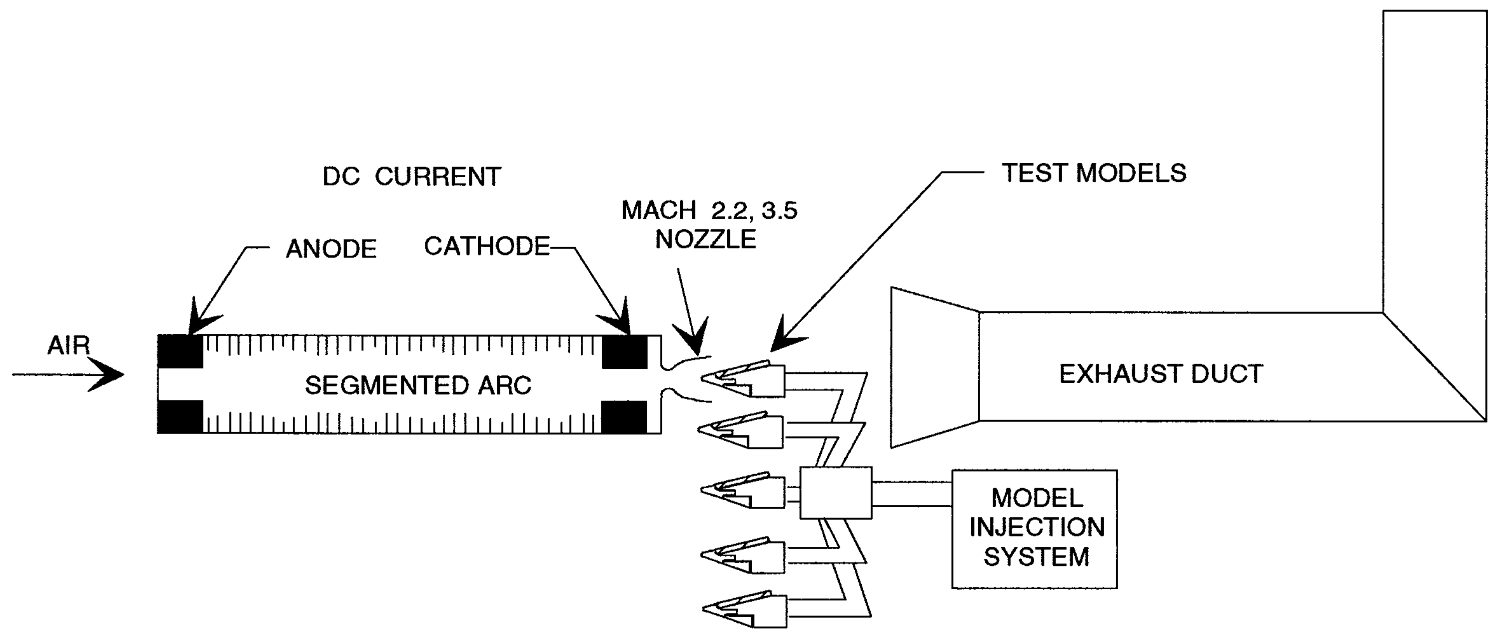
**APPROACH:**

- Demonstrate ability of material vendor to manufacture acceptable Heatshield Material to existing Heatshield Specifications
- Transition replacement fibers from Technology Development Programs and Contractor IRAD
- Manufacture replacement Heatshield Materials
- Evaluate Materials in Ground Test and Flight Test Environments

# CANDIDATE HEATSHIELD MATERIALS

- **RAYON**
  - Navy Reference
  - Hot Melt Reference
- **PAN**
  - 23-XAB
  - 25-XAB
- **PITCH**
  - A
  - A-100

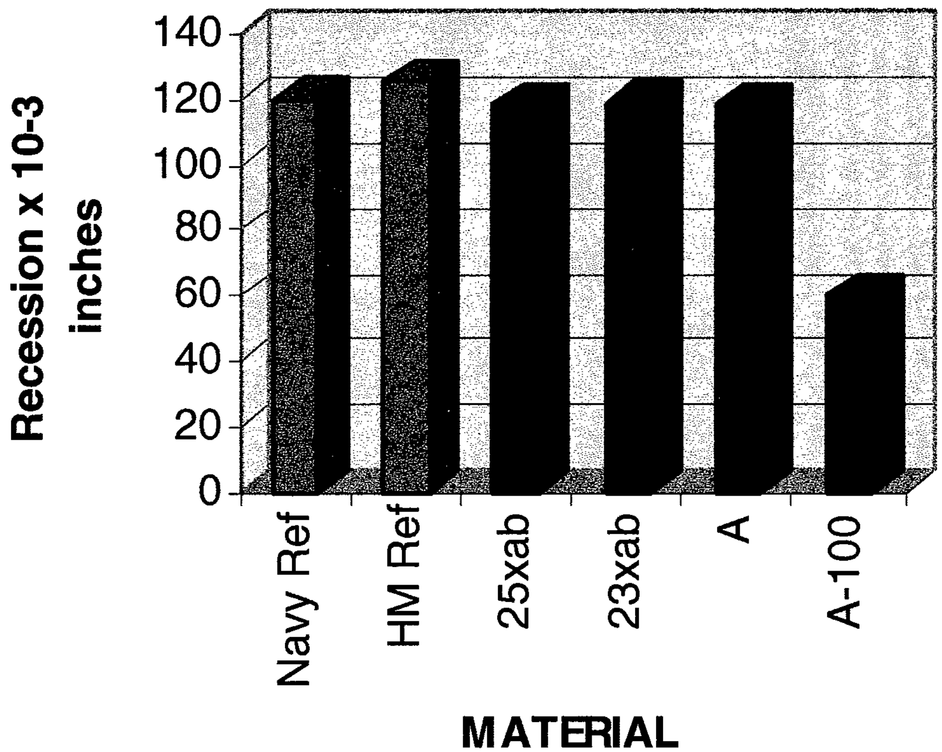
# SCHEMATIC OF AEDC HEAT FACILITY



# RSAP AEDC ARC PLASMA JET WEDGE TEST

- Instrumentation:
  - Laser Wedge Recession System
  - 3 Thermocouples (backface temperature)
  - 3 Pyrometers (surface temperature)
  - 2 Motion Picture Cameras (surveillance)
- Laser & Pyrometer Date Recorded for 7 Seconds
- Thermocouple Data Recorded for 30 - 80 Seconds

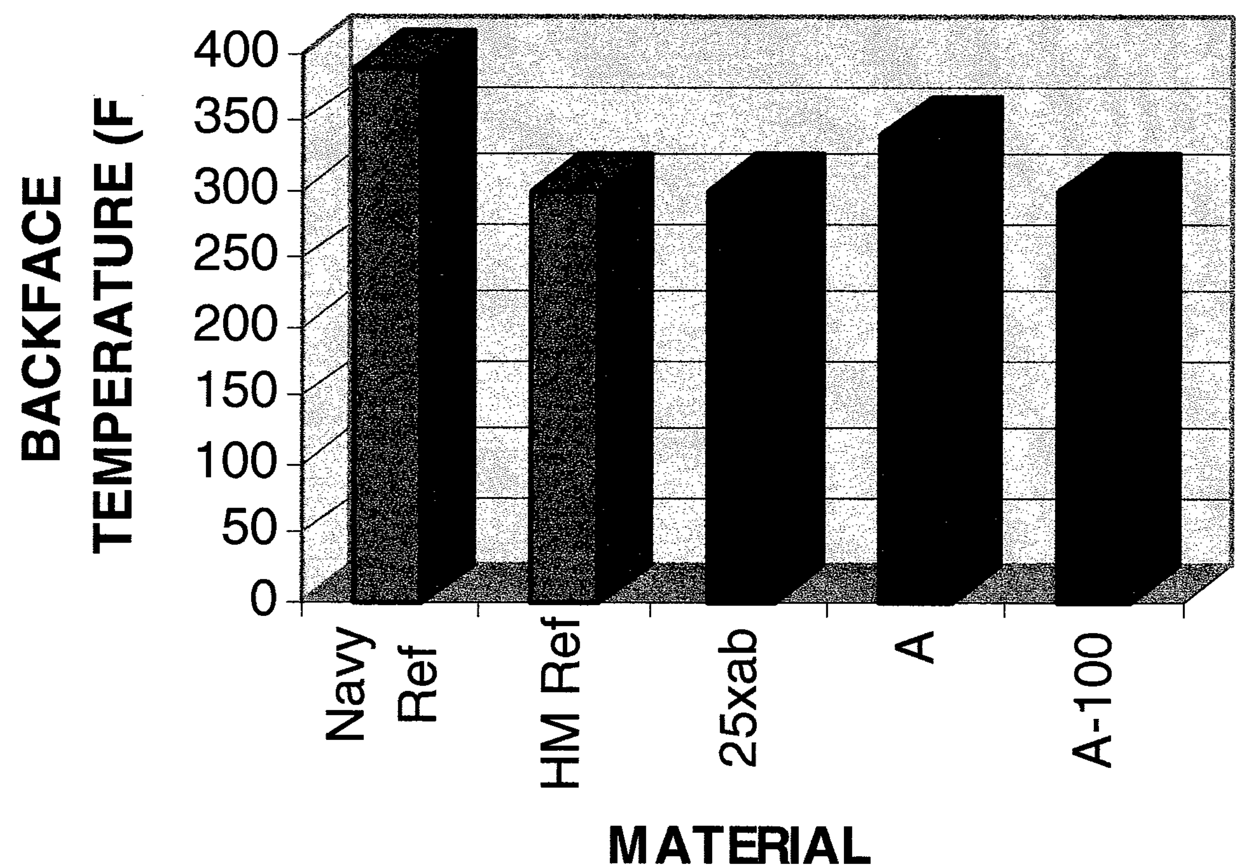
## RSAP ARC PLASMA JET WEDGE TEST RECESSION RESULTS (7 seconds)



# RSAP AEDC ARC PLASMA JET WEDGE TEST
## Performance Relative to Reference

| Material | Relative Ablation | Relative Insulation |
|---|---|---|
| Rayon Navy Reference | 0 | 0 |
| Hot Melt Rayon Reference | 0 | + |
| PAN VCX-14 | ++ | -- |
| PAN 23-XAB | 0 | + |
| PAN 25-XAB | 0 | + |
| Pitch A | 0 | 0 |
| Pitch A-50 | + | + |
| Pitch A-100 | ++ | + |

# RSAP AEDC ARC PLASMA TEST WEDGE TEST
## (Centerline 20 seconds)

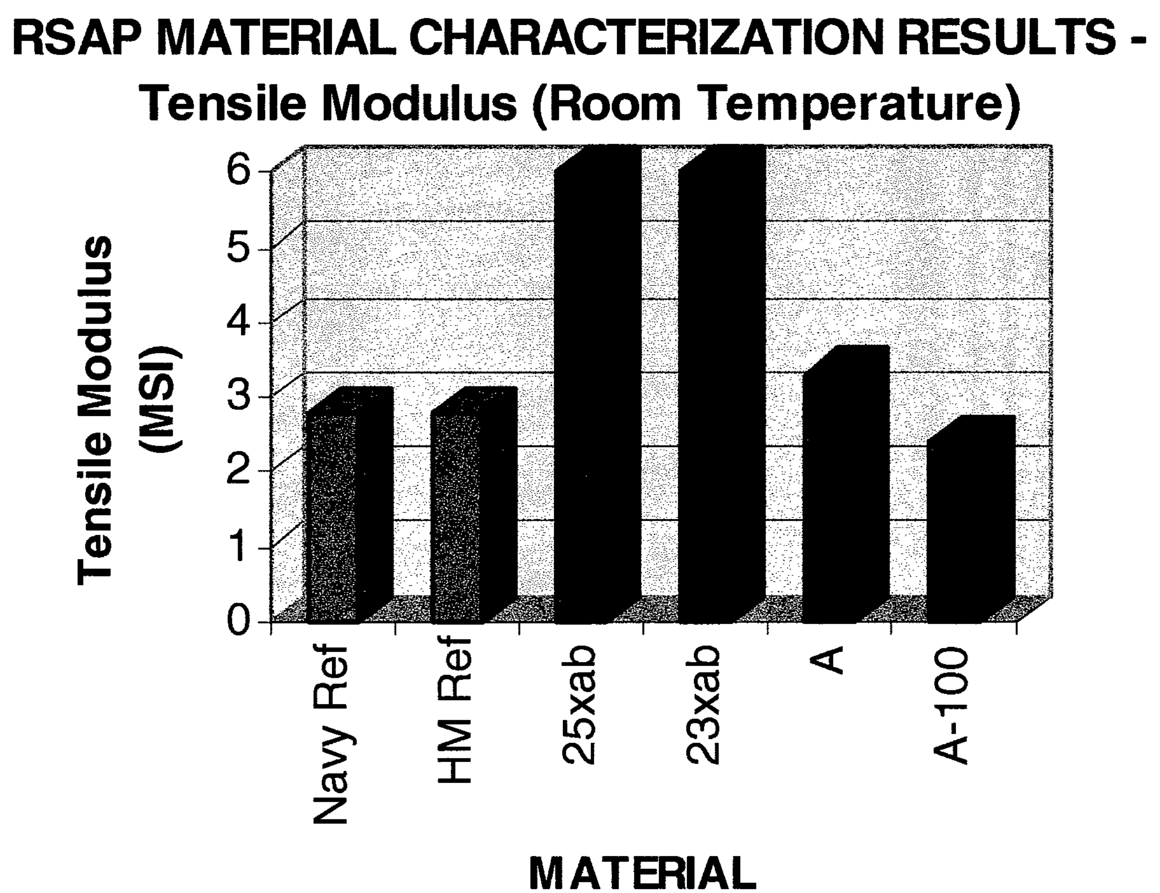


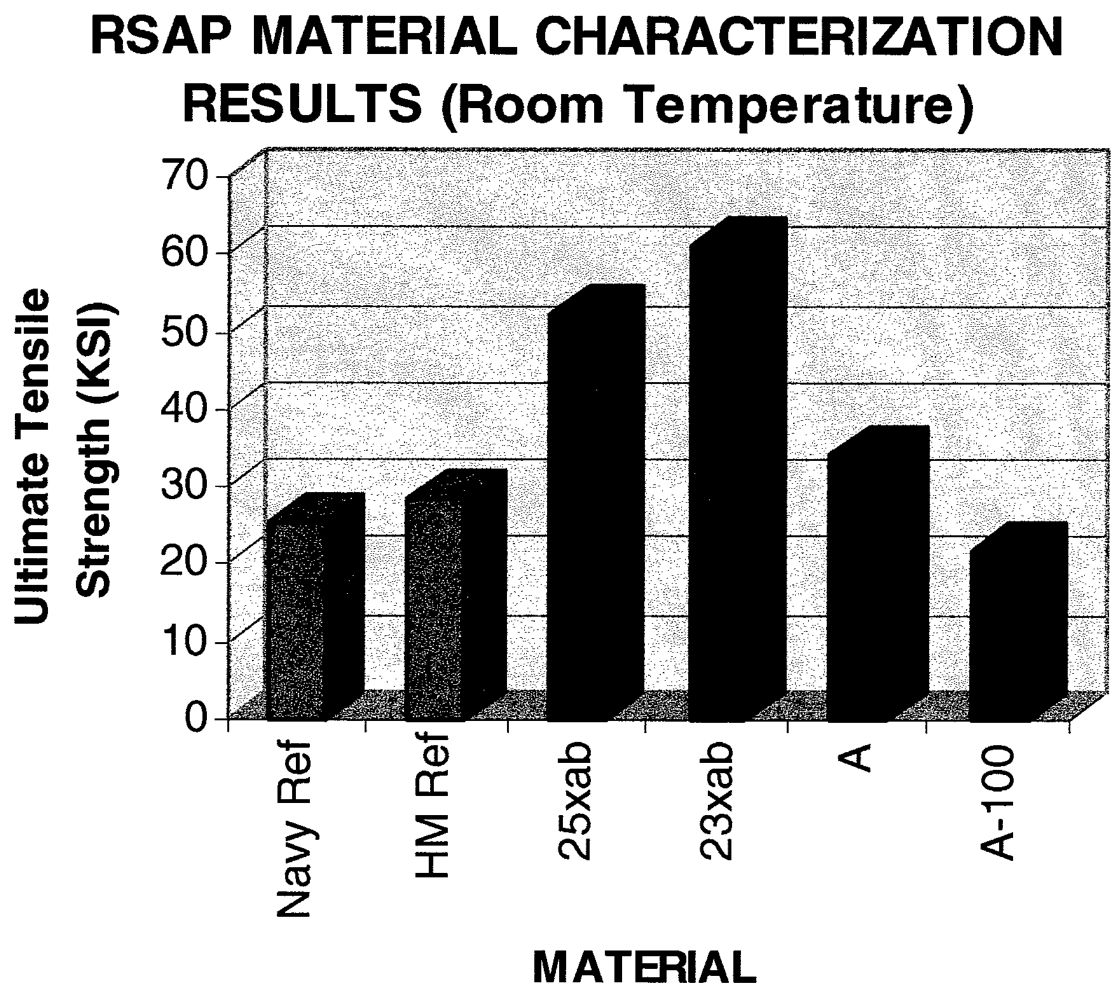
# SOUTHERN RESEARCH INSTITUTE MATERIAL CHARACTERIZATION & SCREENING MATRIX

- Tension (70°F, 2500°F)
- Interlaminar Shear (70°F)
- Thermal Expansion (70-5000°F)
- Thermal Conductivity (700-1800°F)
- Heat Deflection (70-900°F)
- Thermal Response (70-1800°F)
- Thermogravimetric Analysis (70-1700°F)

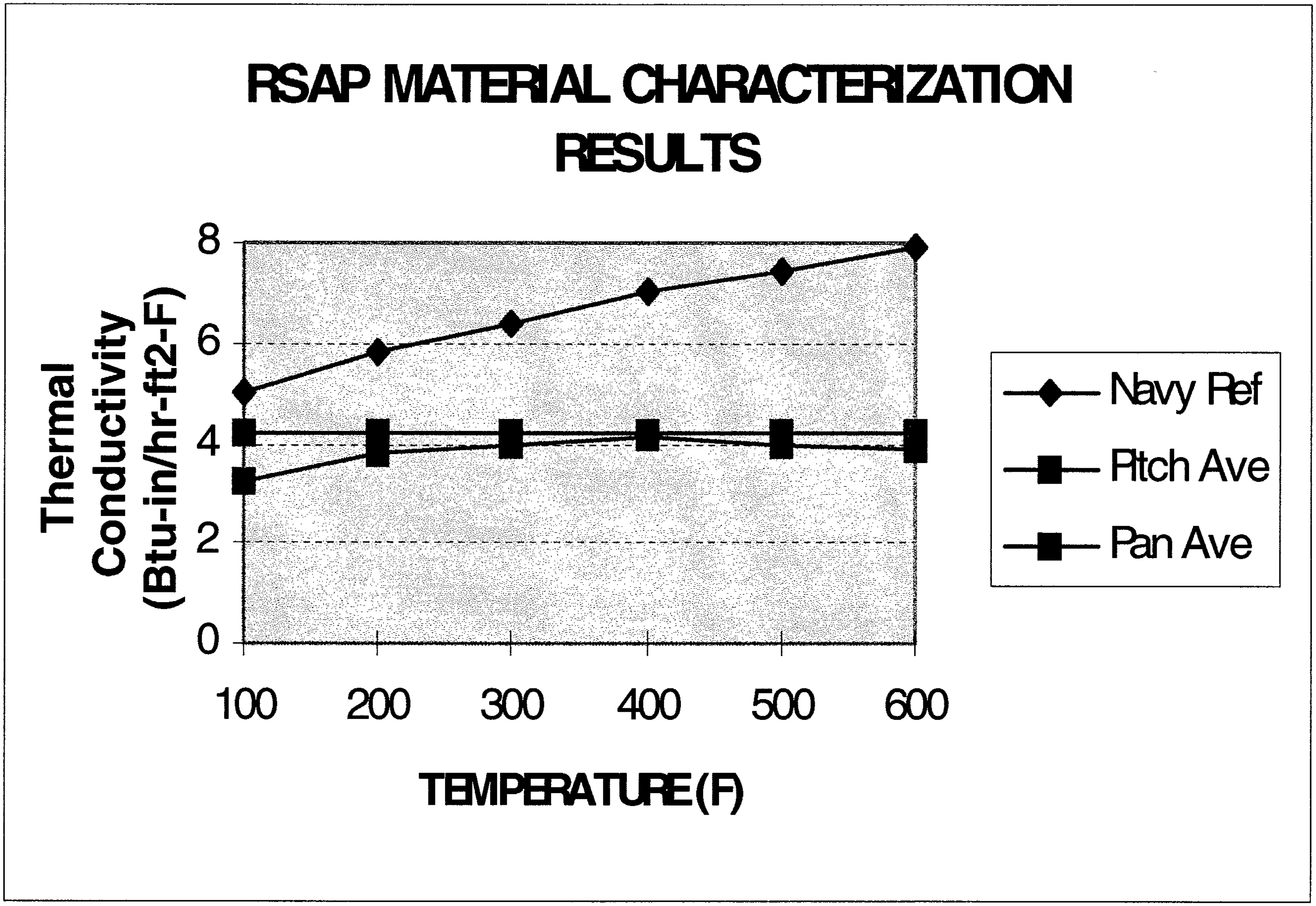
# SCREENING MATRIX (Phase II)

- Compression (70°F)
- Interlaminar Shear (approx. 300°F)
- Permeability (70°F)
- Ply lift (70°F)

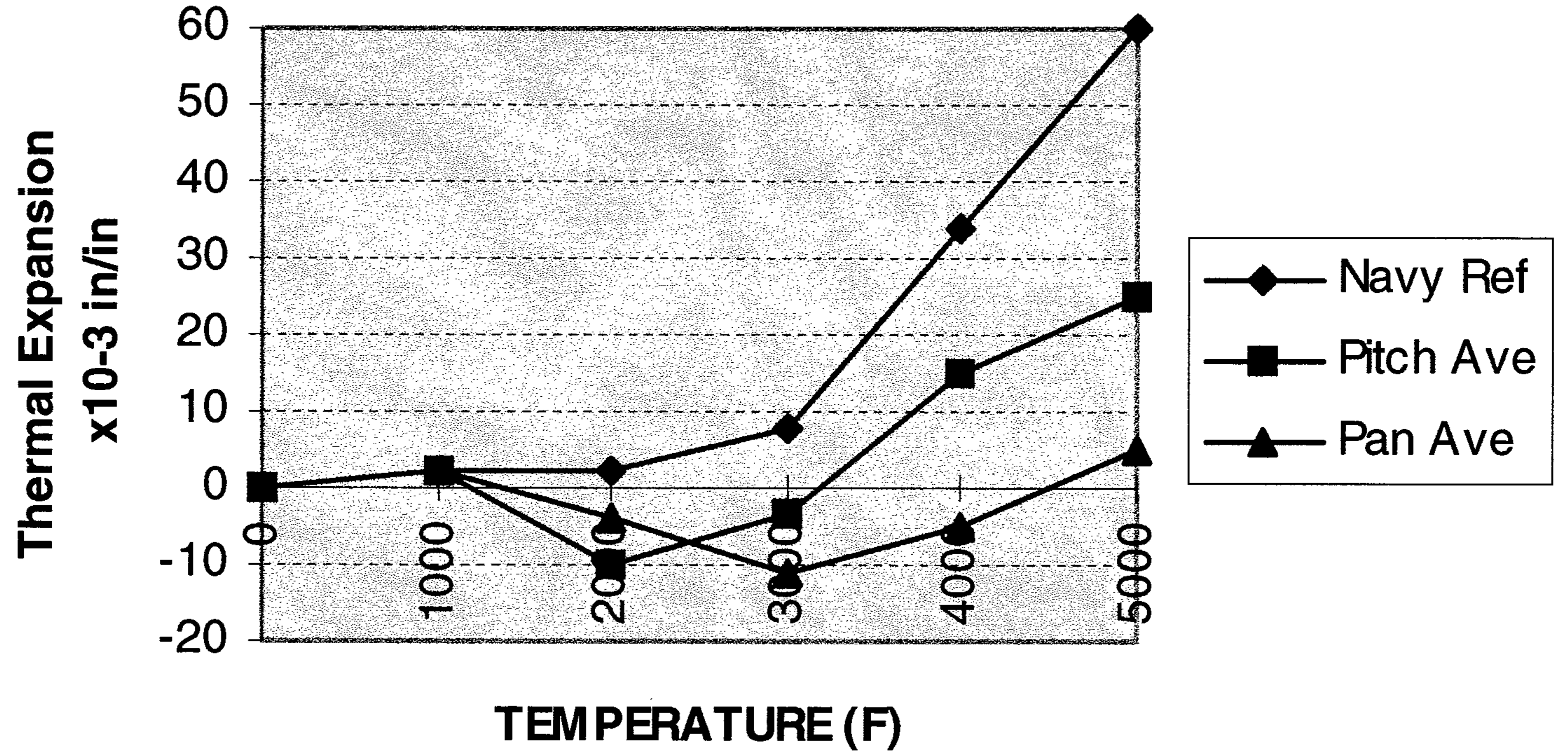

RSAP MATERIAL CHARACTERIZATION RESULTS -
Tensile Modulus (Room Temperature)
Tensile Modulus (MSI)
6
5
4
3
2
1
0
Navy Ref
HM Ref
25xab
23xab
A
A-100
MATERIAL



RSAP MATERIAL CHARACTERIZATION
RESULTS (Room Temperature)
Ultimate Tensile
Strength (KSI)
70
60
50
40
30
20
10
0
Navy Ref
HM Ref
25xab
23xab
A
A-100
MATERIAL

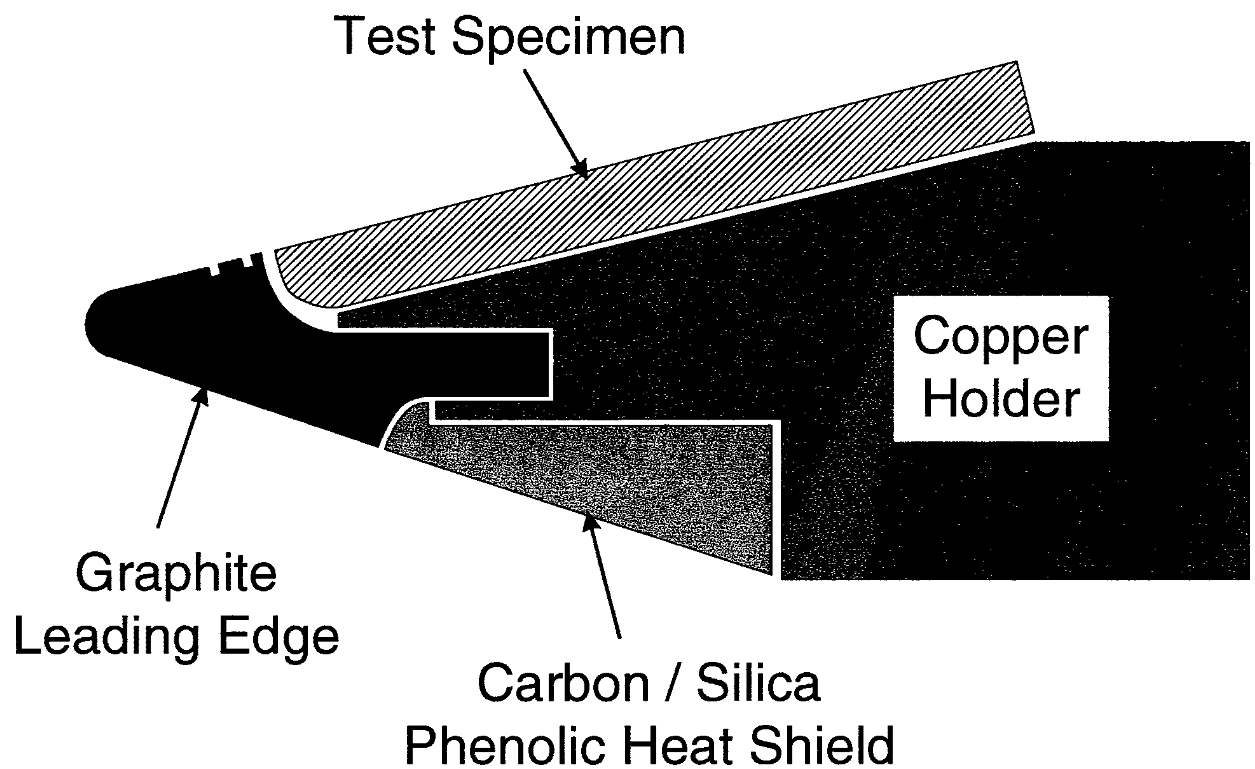

RSAP MATERIAL CHARACTERIZATION
RESULTS
Thermal
Conductivity
(Btu-in/hr-ft2-F)
8
6
4
2
0
100
200
300
400
500
600
TEMPERATURE (F)
Navy Ref
Pitch Ave
Pan Ave

## RSAP MATERIAL CHARACTERIZATION RESULTS

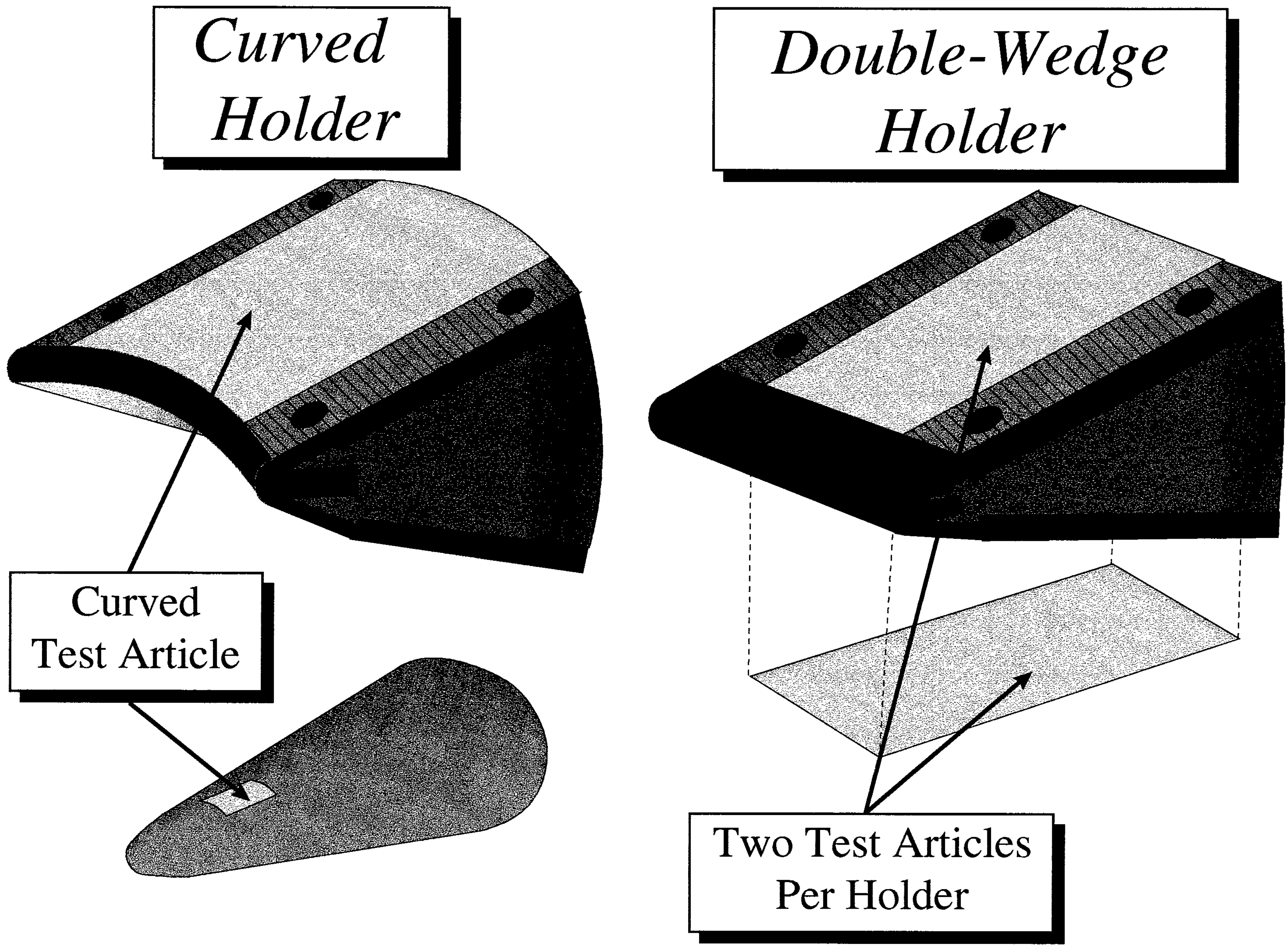


# HEATSHIELD MATERIAL CANDIDATE SUMMARY

- Thermomechanical performance of Pitch and Pan materials is as good or better than the Navy reference Rayon material
- Additional candidate materials have been identified
- All candidates undergoing further evaluation
- Availability of R&D candidate fibers questionable
- Overall heatshield material performance must be determined in full-scale flight test

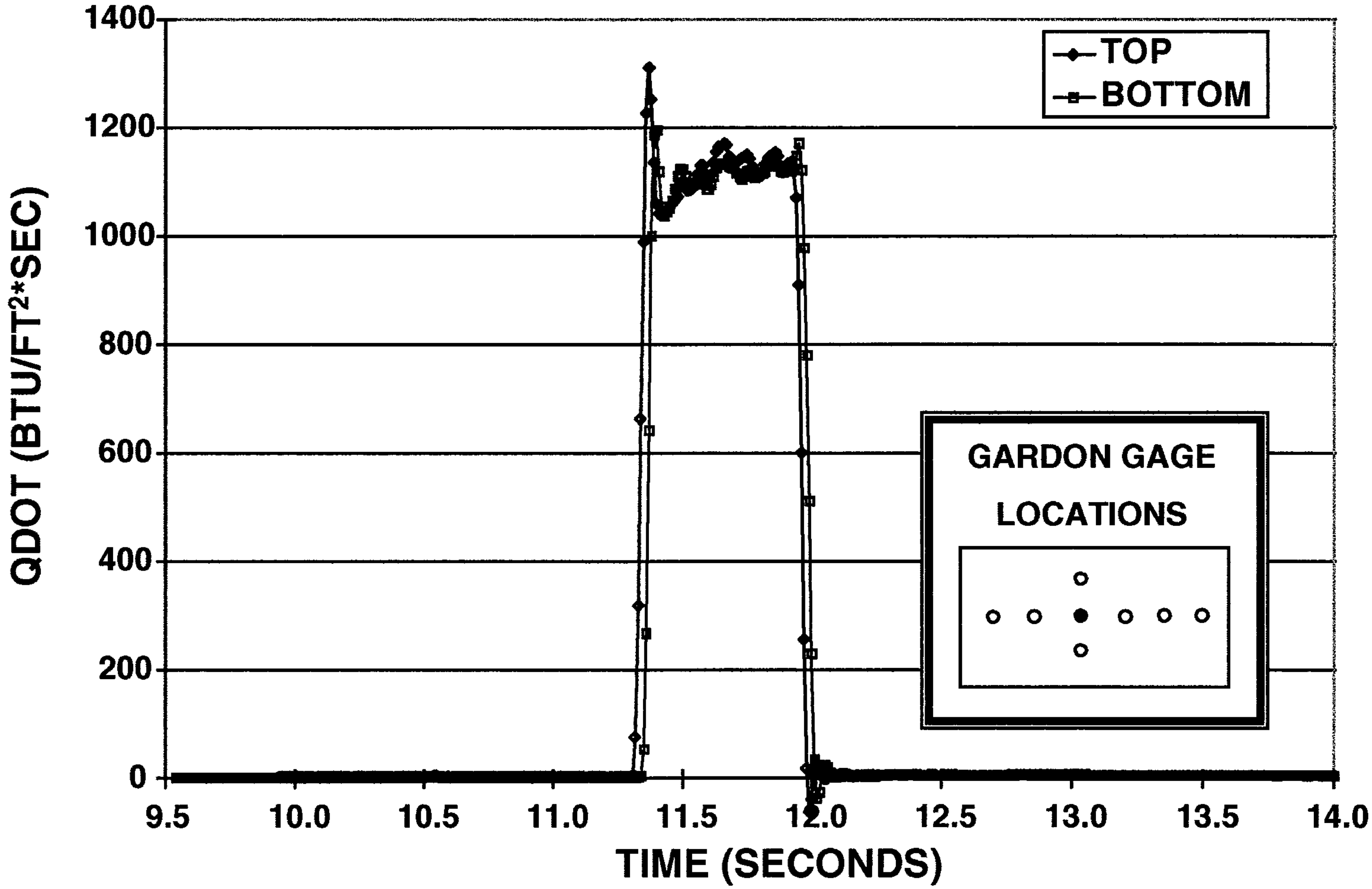



Holder Assembly (Not to Scale)


Curved Holder
Double-Wedge Holder
Curved Test Article
Two Test Articles Per Holder

# DOUBLE WEDGE CALORIMETER

## GARDON GAGE HEAT TRANSFER RESULTS



# CRITICAL ISSUES

- Replacing aging components must consider factors other than measured performance
  - Component must have equivalent mission capability as existing systems
  - Must have minimal system impact
  - Must link with current ground & test flight test databases
  - Must be an affordable component (factor of two cost reduction)
  - intermittent use of manufacturing facilities should not cause changes in the product
- Development of replacement components should provide the opportunity for incorporating features that will augment future mission flexibility at an affordable cost

# CONCLUSIONS

- A program has been established to provide the technology to extend reentry systems and to maintain the minimum essential capability necessary to address aging phenomena and future requirements for in-service reentry systems.
- Promising material candidates have been identified to replace components which can no longer be manufactured.
- Even in light of the Reentry Systems Application Program, the unique reentry industrial base continues to erode.
- Investments in large scale hypersonics development programs will be required to advance the state of the unique reentry industrial base.

**LOCKHEED MARTIN**

1 October 1996

A. Morrison
NSWC, Dahlgren Division
10901 New Hampshire ave.
Silver Springs, MD 20903-5640 Code K07

Dear Mr. Morrison,

Thank you for submitting your technical paper and presentation to our sponsor, Strategic Systems Programs (SSP), for review and approval. As you know, the clock is running and we have milestones to meet in order to stay on schedule. After notification of approval by SSP, arrange to provide copies of your material to the Missile sciences Conference (MSC) General Chairman and myself. These arrangements should be made as soon as possible.

Two (2) copies of your material is to be sent to the MSC General Chairman, Mr. Larry B. Bassham. One (1) copy is to be sent to me. The addresses are listed below.

I would like to mention that the conference schedule that appeared in the September *Aerospace America* contained many errors. Several of our presenters were inadvertently omitted, other sessions papers listed with ours and misspelled words. One notable error that needs correcting is the listing of RADM George P. Nanos as the plenary speaker and session chairman. The correction will state that RADM Nanos will represent our session and speak at the plenary. However, the chairman of our session is Captain John Stillwell. All errors will be corrected in the final program that will be distributed at the conference.

Thank you again for your prompt attention. I will stay in touch and keep you informed of any details you need to be aware of as we approach the conference date.

B D Richter

Sincerely,
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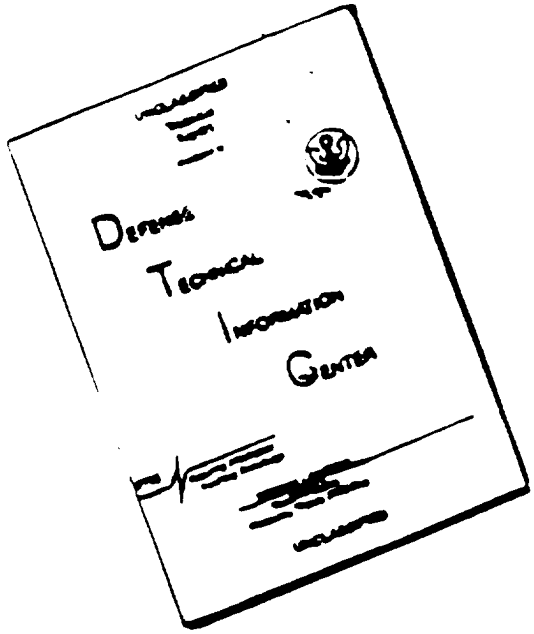

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