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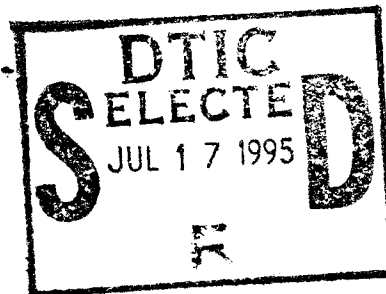
Summary Report: AEDC Hypersonics T&E Workshop



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Micro Craft Technology/AEDC Operations

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Final Report for Period April 6-8, 1994



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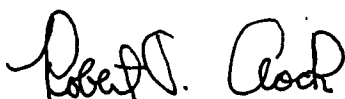
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1.0 INTRODUCTION

On April 6 – 8, 1994, a Hypersonics Test and Evaluation (T&E) Workshop was held at Arnold Engineering Development Center (AEDC). This workshop was sponsored by Dr. Leonidas Sakell of the Air Force Office of Scientific Research (AFOSR). The organizers of the workshop were Maj. M. Briski for the AEDC Air Force and R. K. Matthews for Micro Craft Technology, support contractor for aerodynamic testing at AEDC. A list of the workshop participants is included in Appendix A. Prepared presentations by two of the participants are included as Appendices B and C.

During the original planning for this workshop, two goals were set:

1. Define methodology as it applies to development of hypersonic flight systems.
2. Develop methodologies for two specific technology areas in hypersonics: aerodynamics and aerothermal.

As the meeting progressed, it seemed there were broader concerns that should be addressed. Consequently, the goals shifted somewhat to encompass two major subjects:

1. Define an integrated hypersonic T&E methodology, and
2. Describe an optimum plan for using the existing national assets in ground test, flight test, and computational capability.

In a period of declining budgets, it is imperative that the hypersonics test community provide the best possible support to system developers. This will require that we extract the maximum value from existing test and analysis capabilities, and determine how best to use the limited resources available for research on new facilities and technologies.

The approach taken in organizing the workshop was to invite a group of hypersonics experts to attend the three day gathering and provide an open forum for them to voice their opinions. The goal was to collect their individual ideas and then attempt to reach consensus on integrated research requirements and recommend improvements to the T&E infrastructure. There was some urgency felt in preparing this workshop since it was recognized that many key participants in the various disciplines involved in hypersonics have been active for 25 years or more, and are likely to be retiring in the next few years. The current economic environment, which features large cuts in funding for programs in hypersonics and a consequent drawdown in activity in this area, will likely exacerbate the retirement situation. The situation today is such that these retirees are not being

replaced, so there is an overall reduction in the number of people working in the various areas of hypersonics. This reduction can be tolerated as long as some expertise and capability are maintained in every critical technology area. The problem here is that currently activity in hypersonics is broken into many small parts scattered around the country. A unifying plan is needed.

Another reason for the urgency felt by the group is the result of an individual and collective sense of foreboding about the future of hypersonics in this country. In the present uncertain climate where the absence of a single, dedicated military adversary has required significant restructuring of the nation's DoD R&D capability, this group of testing professionals felt it desirable to assess the current state of hypersonic simulation and experimental techniques. This action is required in order to most efficiently use the present resources and direct planned improvements into the areas where the investment will produce the most return in establishing the best technology base.

It is the fear of serious erosion of the technical base established since World War II, which is required for the development of high-speed flight vehicles, both rocket and air-breathing, for earth and space applications, that prompted this study at this time. Without a planned effort to continue the development and utilization of the technical base, it is likely to be lost through the piecemeal dissolution of its critical elements.

Much of the discussion and deliberation during the course of the workshop was based on the following four basic postulates and assumptions:

1. Progress in hypersonic flight system development is technically very challenging and will become, within the next twenty years, a critical national priority due to military necessity and /or commercial economic needs.
2. The nation's existing methodology for hypersonics T&E is inadequate to support a major new hypersonic flight system development program. A prime example of this problem is the NASP program.
3. Based on a realistic view of economic and political factors, it is not likely that the hypersonics T&E deficiency will be resolved in the foreseeable future (next five to ten years). There are no plans for making major investments in new, more capable hypersonic ground test facilities.
4. Significant improvements to the nation's hypersonics T&E methodology can be achieved by making modest, intelligent investments in :

- a. development of a new methodology for hypersonics based on a synergistic combination of facilities, diagnostics, and computations;
- b. upgrades to existing ground test facilities, and
- c. research in advanced diagnostics capabilities.

The participants in this workshop are convinced that there will be missions in the future for hypersonic flight systems. We can envision critical missions for both military and commercial economic reasons. It is very short-sighted to think that this nation will never again need hypersonics. We are just as certain that investment in T&E must lead system development. NASP proved that it is not possible to develop T&E and a vehicle at the same time; T&E capability drives feasibility, not the other way around.

Development of the workshop was started by sending invitations to a large number of aerospace professionals who have through the years acquired a reputation for expertise in the disciplines of hypersonics. These individuals were given a brief statement of the objective, proposed approach, and potential product of the workshop, as shown in Fig. 1. They were also asked to give an indication of their thoughts about the importance of various topics related to the development of future hypersonic flight vehicles. To do this, they were provided with a chart listing several technical areas relating to hypersonics, with space included to rate each topic as to its importance for different classes of vehicles. The ratings were on a scale of 1 to 5, with 5 being the most important. The results of the survey are given in Fig 2. The numbers in each area for each vehicle class represent an average of the ratings from the respondents.

A quick review of the survey results illustrates the magnitude of the task that was undertaken in trying to define an integrated hypersonics test methodology. Note the wide variety of technical areas that are considered critical, or at least very important, for the various vehicle classes. Each of these areas will have its champion in the industry, and each will have its own slightly different approach to the T&E problem.

2.0 MISSIONS AND REQUIREMENTS

2.1 FUTURE MISSION REQUIREMENTS

Although, as has been mentioned, it is difficult to identify specific vehicles that are likely to be built in the future, it is possible to describe generic flight systems and their major characteristics, and from this, discover facility requirements that must be addressed regardless of the details of the vehicles. Figure 3 lists such generic systems along with the technical requirements relative to ground test facilities. Consider the needs for some of these systems.

Although the new world geopolitical situation may have reduced the prospect for a major world war, it is even more likely that regional conflicts will continue to occur. The U. S. will no doubt become involved in some of these, particularly with our air power. Thus, there will be an obvious need for defensive and offensive missiles with which to arm our aircraft. Some of the missiles currently in our inventory are already being surpassed in capability by Russian and Israeli missiles. Countries like Iran and Iraq have, or likely will have, these missiles. This puts the U. S. air forces at risk of losing aircraft. To avoid this we must keep advancing our missile technology.

As part of the global restructuring of the U. S. Military, bases outside the country are being scaled back or eliminated. If the military is to retain the capability for rapid global response, some way must be found to compensate for the longer distances that will be involved in launching a response from within the continental U. S. instead of from forward bases. One way to accomplish this is to develop faster (hypersonic) aircraft.

There has been much talk in recent years about developing a new space launch system in the U. S. The country currently lacks reliable launchers, which limits military responsiveness and erodes our share of the commercial market in space. The U. S. has already lost a significant portion of the satellite launch business. As commercialization of space continues to grow, in such areas as satellite imagery and the global positioning system just to mention two examples, we need to develop a low cost, dependable means of access to space in order to regain our position as a leader in this area, and incidentally boost our economy by regaining our share of the market.

Also listed in Fig. 3 are potential facilities to meet some of these needs for the near term and for the long term. In Fig. 4 some of the characteristics of these facilities are presented. Noting that this is by no means a complete list of all the potential needs for ground test facilities, and observing the extreme conditions which characterize these facilities, it becomes obvious that inadequacies in ground test capabilities mean that future hypersonic flight systems will of necessity be flown in a less developed state than desired. This then is the reasoning behind the earlier statement that flight testing in the future will entail greater risks.

2.2 T&E REQUIREMENTS FOR FUTURE MISSIONS

Even without a great deal of specific information about the details of future requirements, it should be possible to predict some of the T&E requirements that will be seen with the development of future flight systems. This is the approach that was taken during the 1940s and 1950s with the Unitary Wind Tunnel Plan and the establishment of AEDC. The details of the flight systems which would need these facilities were not known, but it was straightforward to predict enough of the characteristics of the systems to determine what ground test capabilities would be needed. This knowledge, coupled with a national will to meet the challenge, produced the transonic and

supersonic ground test facilities which have served this country well for 30 to 40 years, and kept U. S. aerospace technology far ahead of our competitors. In recent years the U. S. has begun to lose this competitive edge, as witnessed by the loss of market share in various areas of the commercial aerospace business.

Waiting for detailed specification of mission requirements can be very dangerous. There has been very little real development of hypersonic facilities in this country since the late 1960s. This has resulted from the practice of tying facility development to system development. The new hypersonic facilities that are needed tend to be large and complex, and have a development cycle time on the order of ten to fifteen years. Typical flight systems on the other hand may have development times on the order of five to ten years. Even worse, the testing requirements, and thus the test facility needs, for the flight system are often not defined until well into the system development cycle. It is immediately obvious that tying new facilities to the systems that need them is a self-defeating tactic.

Another problem that has obstructed the development of new facilities is a tendency on the part of many of us in the industry to try to produce the ultimate, do everything facility. This has led to insupportable claims about the state of readiness of some technologies and a consequent loss of credibility with budget planners and other non-technical groups. The industry needs to admit that facilities to match hypersonic flight will never happen. We need to concentrate on the physical attributes of flight which can be tested on the ground in a way that can be extrapolated to flight. We might then be able to determine what facilities can reasonably be built, what they will do for us, and build them without worrying about the requirements for a specific flight system. That, of course, is how the facilities of the late 1950s and early 1960s, such as those at AEDC, came into being. That approach served us well then, and we need to somehow recapture that kind of visionary approach.

There has been no shortage of studies to address future T&E needs in hypersonics. The Buchanan study in 1988 identified hypersonic facility and research needs but had no plan for meeting these needs. The Hillaker report identified materials, propulsion, and test facilities as three critical technology areas for hypersonics. In 1991 and 1992 the Hypersonic Test Investment Plan (HTIP) Working Group looked specifically at facility shortfalls. As the HTIP report was being prepared, NASA initiated the National Facilities Study; later broadened to include DoD participation. The report from this study includes a two-phase plan for facility acquisition in hypersonics over a twenty-year period. All of these studies have produced forward-looking plans, but all have lacked funding authority. However, it can be seen that there has been a large amount of work done previously that can be used to establish the generic requirements which ground test facilities must meet in the future.

3.0 METHODOLOGY

3.1 DEFINITION

Webster defines methodology as a body of methods, rules, and postulates employed by a discipline; a particular procedure or set of procedures; or alternatively, the analysis of the principles or procedures of inquiry in a particular field. As noted above, one goal of the workshop was to establish a methodology for integrated T&E in hypersonics. In the opening session the entire group debated this concept. After extensive discussions, the definition shown in Fig. 5 was established. It will be seen that the definition is still very generic. As is very often the case, stating a definition is relatively straightforward, but agreeing on just exactly what the definition means is not as simple. Thus the characteristics of the methodology are important to a complete understanding of the meaning of the concept. The final summary statement in Fig. 5 contains several key words: well-defined, systematic, available, low-risk. These are critical parts of a successful methodology.

The generic methodology for development of a hypersonic flight system is shown in flow chart form in Fig. 6. The goal of this methodology is to certify (design, build, and test) a flight system. At some point fairly early in the process, one must establish the feasibility of the system. In doing this it is necessary to view the total environment, including life cycle issues. The mission requirements provide the specifications for the system. All of the blocks on the chart, except for the two design blocks, represent the tools that are available for developing a final system which will meet the specifications laid out by the mission requirements. The process seems to be relatively straightforward. The difficulties occur in determining the details inside each block, and establishing what must happen to the system as it passes through each block. The major problem is that ground simulation of the hypersonic flight environment is poor at best, and therefore an improved method for making the ground-to-flight link inside each box is needed. This method must be technically achievable, affordable, and timely. Complicating the problem of defining a methodology is the fact that each flight system will have different problems and issues. It is often difficult to clearly understand the differences between vehicle-specific issues and generic issues, and how to translate from generic to vehicle-specific.

Consider, for example, the process for developing one particular subsystem for a hypersonic flight vehicle, the material for the thermal protection system. The outline of this methodology is shown in Fig. 7, and additional details are illustrated in Figs. 8 and 9. The process might be considered as encompassing two phases. Phase 1 consists of the first step of the complete process: defining the thermal environment.

Step 1. Define the requirements.

This includes establishing the geometry of the thermal protection system and the operating conditions it will experience. This step may well require both analysis and experiments to satisfactorily define the environment in which the system will operate.

In Phase 2 a viable protection system is demonstrated. The system may include hardware and a flight control system if active cooling is involved. It consists of three steps:

Step 2. Select material(s).

Here candidate material screening is done, which will involve the use of historical data about various materials and analysis of their potential performance in the new system.

Step 3. Test structural designs.

Screening tests of the most promising candidate materials are done, using ground and/or flight test techniques as appropriate. From these tests select one or more materials for use in the preliminary design of the system components. This is the iterative component testing part of the methodology. From this emerges the developed design.

Step 4. Flight hardware verification.

The developed design is subjected to another iterative test process from which the final design is determined.

Problems in each step soon become apparent. As shown in Fig. 8, a variety of analytical and experimental tools will be available. However, none of these may satisfactorily simulate the total environment the system will experience.

One problem that often occurs, but never appears in the above discussion is a cultural one, i.e., the frequent lack of communication among the various technical specialties or disciplines, which are of necessity involved in the development of any component or subsystem of a hypersonic flight system. Each of the individual disciplines needed for a complete T&E methodology in hypersonics is strongly challenged by its own particular problems. This results in a natural tendency to concentrate on individual pieces of the problem. A synergistic combination of test

facilities, diagnostics, and computational capabilities is thus inhibited. This separation occurs professionally, organizationally, fiscally, and politically. If we are to make real progress with existing tools and within limited budgets, a cultural change that will foster, rather than inhibit, this synergy is needed.

3.2 COMPONENTS

Integration of technologies to develop flight systems has often been illustrated by a triad consisting of ground test, flight test, and Computational Fluid Dynamics (CFD). In the development of hypersonic flight systems, each of these components falls short of providing the needed information, so the process requires additional support, as illustrated by the five-legged stool in Fig. 10.

The integrating methodology leg is the most difficult to define, and this was of course the motivation behind this workshop. Not surprisingly, it is not possible to discuss this particular subject without becoming involved in discussions of the other four technology areas. This adds to the difficulty of establishing a common understanding and agreement about the definition of a hypersonic system development methodology.

Hypersonic design problems should be approached by identifying the important physical phenomena and appropriate simulation parameters, and then establishing a development program using available tools. These tools include, for example, CFD and ground and flight test facilities. One must prioritize the simulation parameters and the range of interest for each. Then each solution or approach to solving the problem must be evaluated for the cost/risk balance.

3.2.1 Short Term

One point that developed out of the discussions was the need in the short term for immediate attention to the ground test component of the hypersonic flight system development process. The decline in activity in hypersonics has endangered the existing facility infrastructure. Many facilities have been put in a mothballed status, or even shut down. This has greatly hampered the ability to respond to program needs when a clear mission is identified and testing of a proposed vehicle or components is needed. Reactivation of facilities is costly in terms of both resources and time. This is one of the technical problems that plagued the NASP program. Needed facilities were not available on a timely basis, and bringing them to operational status consumed valuable resources and delayed key technology development.

If ground testing is to be a viable component of an integrated methodology in the future, steps must be taken to stop the decay of the facility infrastructure and to repair the damage that has already occurred. The manner in which this can best be accomplished is as always subject to considerable discussion. However, the solution to this problem must be broader based than just funding one or two major new facilities. Most would agree that a reasonable first step in a recovery plan for hypersonic ground test facilities is to define the facility tools that will be required in the development of future flight systems. This would be followed by a complete evaluation of the most efficient, effective, and intelligent use of the existing facilities to determine those which should be preserved and upgraded to meet the needs of the future. The difference between the required facilities, and potential use of (upgraded) existing facilities, will show the need for new facilities which must be developed. Such a program will reveal that it is essential to advance the state-of-the-art in facility technology on a number of key fronts in order to provide flexibility to respond to challenges both in mission requirements and in facility capabilities. To be successful, the program must engage a wide spectrum of the hypersonics community. The most difficult challenge for this activity will be to maintain fiscal realism in the face of a drastic drop in political and monetary support for hypersonics.

3.2.1.1 Characterization of Facilities

Stepping to one lower level of activity, evaluation of existing facilities will require that current characterizations of these facilities be reviewed to determine where information about facility capabilities is inadequate. This will then identify facility characterizations that are required in the near term. A plan must be developed to accomplish this work facility by facility on a prioritized basis. The characterization features for each facility must be chosen based on a long-term strategy for the use of the facility to solve specific problems or develop specific technologies in hypersonics. This means that the requirements for facility characterization depend on what mission requirements are envisioned, and on how the facility will be used in addressing the development of a flight system to accomplish that mission. This will involve the use of the generic T&E requirements that were discussed above. The plan should specify which facilities need attention, what it is about each facility that needs attention, and how well (in terms of measurement accuracy, level of detail, and range of conditions) each facility must be characterized. The guidelines that are established must state clearly the requirements and standards for facility characterization. Uniform techniques and procedures must be developed and used so that comparisons between facilities can be meaningfully done.

More knowledge of the test environment produced in the existing facilities will make it possible to extract more and better information from them. This should lead to a better understanding of the test results and minimize misinterpretation or over-confidence in applying the results. More thorough documentation of the facility characteristics will facilitate use of the test data by a wider audience.

Discussions of these topics lead into considerations of what technologies are most in need of development in the near term. When this point is reached, it becomes very difficult to maintain focus, and a workshop such as this tends to become fragmented as individuals eagerly leap to address their particular areas of interest. Since this is almost impossible to prevent, and since it is not an entirely bad thing, the participants in this workshop engaged in spirited discussions of various enabling technologies for hypersonics. One in particular which was discussed was boundary-layer transition, discussed later in this report.

3.2.1.2 Development of Diagnostics

A major problem in hypersonic ground test facilities is the inability to measure the parameters of interest. Because of the extreme conditions encountered, traditional measurement techniques and transducers often will not survive in the test environment. This has led to extensive research in the field of nonintrusive diagnostics. In addition, because of the high enthalpy involved, the test medium can no longer be considered either thermally or calorically perfect. Thus additional measurements, which are not needed in lower speed testing, are now required to characterize the test medium and the flow field about the test article.

Because of the inherent limitations of ground test facilities to reproduce hypersonic flight test conditions, much of the development of hypersonic flight systems will depend on the use of CFD. Before the complex CFD codes can be used, they must be validated. This requires a carefully designed experiment and very detailed information about the test medium, the free-stream conditions, and the test article flow field. This has placed an added burden on the diagnostician. The established techniques of placing probes in the flow field and transducers on the test article not only are restricted by the issue of survivability, but they frequently cannot provide the density of information needed by the codes.

To characterize the test medium, either in the free stream or in the flow field about the test article, requires that two independent thermodynamic properties plus the chemical composition be known, along with a parameter such as velocity to determine the total energy of the flow. Just to make the problem interesting, spatial and temporal variations of these parameters must also be measured.

In recent years a great deal of progress has been made in developing the technology of a nonintrusive technique known as laser induced fluorescence (LIF) and a variation of this technique called planar LIF (PLIF). In these techniques, a laser beam is the energy source used to excite molecules or atoms in the flow field, and the resultant radiation is measured and analyzed to determine the properties. The theoretical foundation for these techniques is fairly well established, and much progress has been made in developing the hardware required to make the measurements.

However, the technique is by no means developed to the point of routine application in a wind tunnel or other ground test facility setting. Much remains to be done also in developing the procedures and algorithms for processing and analyzing the large amounts of information obtained with this technique.

There are several other nonintrusive techniques that have been under development in recent years. At this point it is not appropriate to try to select one particular technique and eliminate research on the others. Rather there should be a careful assessment of the anticipated information needs in order to first establish what measurements will be required. Then realistic goals for the development of diagnostics should be defined; these goals can then guide the continuing research.

In many ways the measurement of test article data can present more problems than measuring flow-field parameters. Accurate measurement of the pressure at enough locations to adequately define the pressure distribution around a complex vehicle shape at hypersonic speeds is very difficult. But this information is vital to the structural design of the vehicle and to the analysis of the vehicle flight mechanics. New, innovative methods of measuring, in the hypersonic environment, parameters such as pressure, heat transfer, and skin friction, to name a few, are required. Thus, along with a plan for new facilities there should be a program for continuing to advance the state-of-the-art in diagnostics. The steps in this program should be prioritized based on a long-term strategy which matches that of facility and methodology development.

3.2.1.3 Databasing

One of the new supporting technology legs shown in Fig. 10 is labeled Database. This is the sum of the information that has been developed through the years by previous workers in the field. An extensive database in hypersonics exists from the work done in the 1960s and 1970s. There are unfortunately at least two problems with this database. One is that it is fragmented, with bits and pieces scattered among various laboratories, test centers, and contractors around the country. A second problem is that the database is not used as effectively as it should be because the new generation of workers in hypersonics is not aware of the extent of information that is available, or is not able to access the information. Archiving all the information available would be a difficult task. However, a great deal could probably be done in this area. Additionally, for information that is known to exist, but that cannot, for one reason or another, be archived, it might be feasible to prepare bibliographic documents which would aid future workers in obtaining the information they need. Even this would be a major task, requiring extensive resources, which is difficult in the current economic environment. However, with modern capabilities for processing and storage of information, such a goal might be within reach. The need for such a database is recognized globally, the Europeans are establishing such a system, and there are plans for an international meeting in Houston, TX in May of 1995.

The first requirement is the establishment of an archiving institution. Since the data have been generated by a variety of contractors and laboratories, and since much of it is classified, a neutral third party location equipped for providing a secure environment will be required. Typically this would indicate the use of a government organization.

In addition to being an archive, the databasing institution should provide an interactive system with which a user can access the information and manipulate it in many different formats. The Plume Data Center (PDC) at AEDC provides a good example of what can now be done in this area. Established in 1990, the PDC has been funded at the level of about \$2.5M per year through 1994. It has developed to a core staff of 20 people housed in its own building within the AEDC security perimeter, with access to the AEDC support infrastructure. An archival process has been developed in which data are received and reviewed by personnel with expertise in the appropriate discipline, a bar code is applied, the information is copied to the appropriate media, and filed in a high-density storage system. The staff has developed an inexpensive, high-density, rapid access system with a current on-line capacity of 1.2 terabytes, and a total data center capacity of 10.2 terabytes. It is a hierarchical system with three levels of storage. The "hot" or on-line storage with access rates in terms of milliseconds costs \$0.50/MB. The "warm" or near-line storage is available in seconds and costs \$0.25/MB. "Cold" storage information can be accessed in minutes and costs \$0.001/MB. A workstation network with the necessary peripheral equipment allows ready access and utilization of the data. A variety of analysis tools, appropriate to the different types of data, is also available for the convenience of the user. Since much of the information that is of interest to the PDC user is optical, extensive image enhancement and analysis capability, plus state-of-the-art video production equipment, has been acquired. The PDC thus provides an excellent model for a national hypersonics database organization.

3.2.2 Long Term

In the long term it will be necessary to develop a methodology which accounts for our inability to ever duplicate the hypersonic flight environment in full scale except with an actual flight vehicle. The best that can be done is to use the proper selection of what might be called building block experiments to develop as much of the necessary technology as possible, and then extend the technology through the use of some kind of flight platform. Again in choosing these experiments, reference must be made to the generic T&E requirements which will be discussed below.

3.2.2.1 Building Block Experiments

Design and development of hypersonic flight systems require the same suite of technologies as does any other flight regime, i.e., flight mechanics, aerothermal, structures, propulsion, etc. In each of these areas some technology exists, but in all of them there are deficiencies. The details of

the deficiency depend on the particular mission requirements of the flight system under consideration. In each case the deficiencies that are preventing the development of the system must be identified. Then a series of experiments must be devised to obtain the information needed to attack the deficiencies. This process is illustrated in Fig. 11. To see how this occurs, consider Fig. 12, which shows more details of the process from Fig. 11. Four major technology areas are listed. Each of these may require information about one or more of the several development parameters shown at the next level. Obtaining the needed data may involve one or more of the building block experiments shown. For each building block experiment, there are options for facility choices. There is also the option for using CFD alone or in conjunction with experiments. New knowledge is often developed by starting from a baseline (derived from previous studies and preserved in the database) and adding to it incrementally to produce the information needed to feed back to the mission planners.

The logic behind the use of building block experiments is the belief that a dramatic improvement in our understanding of hypersonic flight system design and performance can be achieved through the application of existing capabilities in a more fundamental way. By using a strategic combination of facilities, computations, and diagnostics to attack fundamental problems of hypersonic flight within envelopes dictated by mission requirements, many of the deficiencies which are plaguing us today can be minimized or removed. Too many of the recent T&E efforts have been directed toward solving macro system problems, and therefore little fundamental advancement has occurred.

It is illuminating here to use one of the building block experiments as an example to illustrate the complexity of the issues involved in developing a hypersonic T&E methodology. Consider, for example, the matter of boundary-layer transition. Everyone agrees that this a technology area that is key to the design of future hypersonic flight systems, and that much work needs to be done in this area. But the discussions here raised many questions about what should be done. Should flight experiments be designed to study transition? Flight data can be very difficult to understand, as witness the ambiguity in the data from the Shuttle Orbiter Experiments. Many wind tunnel studies of transition have been done over the years. Are these data reliable? What are the facility effects hidden within the transition study results? Do we need new, "quiet" facilities for transition work? What is a quiet facility? How is it characterized? Suppose transition is an unsteady phenomenon, requiring a statistical approach. One of the attendees, eminently qualified in this area, admitted to confusion as to what measurements should be used to study transition. Another suggested that the spectrum, amplitude vs frequency, of a parameter such as heat transfer would be appropriate. This brings up the question of whether or not the frequency response of the available instrumentation is adequate. Of course, the ultimate goal is to have a CFD code to predict transition on any vehicle. Thus we see that in just this one specialized area we get caught in a circle involving facility characterization, facility upgrades or new facility development, CFD code validation, and use and

reliability of previous data (database), all of which must be integrated somehow into a consistent, organized plan of attack. This workshop did have two recommendations concerning future work in boundary-layer transition. One is to evaluate in a consistent manner the Reynolds number capability and noise levels of existing wind tunnels. The other is to continue support of the Transition Study Group and use them for review of proposed transition experiments.

3.2.2.2 Flight Platform

Ground test facilities that are visualized to correct the current deficiencies and provide test conditions that approach flight conditions are increasingly complex. A point is soon reached where it is reasonable to question whether or not it might be possible to provide a flight test platform which would produce a more economical solution and still be technically acceptable. In devising such a flight test platform, it is crucial that the temptation to develop a do-it-all system be avoided. If we try to build one system that will answer all questions, it will quickly become as complex and cumbersome as the ground test facilities. Since we are discussing a test platform with which to do building block experiments, a simple approach will have a much greater chance of success. The basic flight system should be simple and inexpensive, while at the same time it should provide flexibility to allow adaptation to a variety of experiments. It must also again be designed as part of a synergism with diagnostics, computations, and ground test facilities to resolve particular deficiencies.

A key issue in developing such a flight platform, and comparing it with ground test facilities, is the issue of what type of measurements can reasonably be made, and how much information can be gained from each flight. Flight test instrumentation makes different demands on the instrumentation engineers than does ground test. Since it is proposed to use the flight test platform for building block experiments, many flights will probably be needed to provide the necessary information. This means that the platform must be relatively inexpensive to operate. The test range support infrastructure, including safety and environmental aspects, is also an important consideration. There are several current examples of such flight test platforms which were designed for limited application to a specific problem. The experience gained with these should be very valuable in devising a hypersonic flight test platform.

4.0 INTEGRATED T&E PLAN

4.1 NATIONAL STRATEGY

It should be clear by this point that there is no shortage of ideas about specific tasks to be done to promote the study of hypersonics, and there are advocates for each task. It is equally obvious that there is significant doubt as to whether a unified group can be formed from NASA,

DoD, and industry for a really coordinated approach to developing a national program in hypersonics. The problem here is that in order to succeed in a cooperative approach, there will have to be selected groups which specialize in particular areas for the good of all. This is, of course, contrary to the established way of doing business, in which each entity involved in hypersonics, e.g., contractor, NASA Center, or DoD Laboratory, has felt it necessary to have skills and capabilities in all areas required to design, build, and fly a vehicle. There are those who would contend that this means there will always be a selfish character associated with the business of hypersonics. The current economic situation, in which all contractors and now all government agencies compete with each other for the meager resources available, easily tends to foster such chauvinistic attitudes, to the detriment of each individual group and of the industry as a whole.

A national strategy should be established, one based on an assessment of mission requirements as we now know them and on a coherent, integrated methodology for development of the hypersonic flight systems needed to meet these requirements. The immediate goal of this strategy must be to protect a well-defined national core capability and infrastructure, which exists as a result of previous investments in hypersonic programs. Care must be taken to present the strategy as a total vision for hypersonics. Often in the past, studies and reports on needs in hypersonics have been perceived as simply another wish list of facilities. This, of course, produces a credibility problem. From this standpoint it would be advantageous if the group that develops this strategy is clearly seen as totally unbiased and objective. This might imply that we should make use of the knowledge and experience of some of the older workers in the field, such as some of the attendees at this workshop, who are no longer so concerned about career advancement, or even holding a position against the tide of reductions in hypersonics activities, but who are solely concerned with preserving and advancing the technology of hypersonics for future mission planners and flight system designers.

The development of a new national strategy will obviously be a difficult task, which will take some time to accomplish and possibly even longer to implement. As an initial step toward meeting this ambitious goal, an integrated methodology, using existing facilities and infrastructure, would help to maintain direction for the country in the advancement of hypersonics technologies.

In the long term, what is needed is a national program to accomplish two major tasks. First is to maintain and enhance the infrastructure. This includes all the hardware, such as wind tunnels, engine test cells, computer centers, etc. This will require a long range plan, with adequate resources, to preserve existing capabilities, upgrade where appropriate, and acquire new capabilities in a reasoned, logical manner. The technology does not now exist to build a 10-ft-diam, Mach 0 to 25, continuous flow, true enthalpy facility with a real air test medium. It is important that we establish what can be done now with existing technology and engineering skills, and what will be of value for the future, and begin work on these facilities. At the same time there must be

a reasoned program of research to develop new facility technology and thus extend ground test capabilities toward an advanced, but still practical, goal. Practical means that we must recognize that the ultimate flight duplication test facility will likely never be feasible. This is what makes an integrated methodology vital for the future of hypersonic flight.

The second task is to preserve and extend the skills to effectively work within the infrastructure. Engineering education programs must be evaluated to ensure a proper balance of theoretical and practical training. There has been a concern in recent years that many graduates are computer whiz kids, but are lacking in the skills to effectively run a wind tunnel test and do not have a natural intuitive feel for the hands-on work. There must also be some way to ensure that jobs are available to encourage talented students to take on the challenges in hypersonics. A mentor program to enhance on the job training would aid in developing those skills which cannot be taught in an academic setting, but which must be learned through experience.

One possible technique of retaining for the future the knowledge of the experienced people would be to hold short courses where they could pass on to the younger workers the special tricks of the trade they have learned. A difficulty here is that it is hard to relay this type of information without being in an actual hands-on environment. The new people need to be participants, not observers. University Centers of Excellence might be useful for certain areas of theoretical activity, but they would suffer from limited opportunities for working with hardware on a realistic scale. Also note that both of these ideas require for success a job base of reasonable size. A third technique would be to designate Centers of Hypersonic Expertise, e.g., NASA Langley or AEDC. Each Center would require a carefully crafted mission statement. Because this is proposed as a response to a situation of limited resources, there would have to be a minimum amount of duplication and overlap among the various centers. Each Center would have an area or areas of expertise and maintain a minimum capability in related areas. This, of course, would require a sea change in the current philosophy of operation throughout the industry. Some existing organizations that might participate in this process would be required to surrender some of their present structures and capabilities. There could be significant short-term disruptions of personnel. In the long run, however, such a cooperative program would likely prove less painful to the majority of those concerned with the future progress of hypersonics.

4.2 INVESTMENT STRATEGY

The development of an investment strategy is very difficult in these times of economic pressure. The resource requirements are so large that no single industrial firm, or any reasonable combination of firms, can support more than a small segment of the needs. Only the government has the resources required to adequately address the problems. However, even the government capabilities are declining, and these dwindling resources are being sought by a multitude of other

programs with ever increasing needs of their own. Even within the aerospace industry as a whole, hypersonics represents only a small fraction of the programs fighting for more resources. Even worse, it is at this point a relatively uneconomical fraction over the near term. This makes it a prime candidate for cutting by budget-reviewing accountants in both industry and government.

The current fiscal situation, of course, makes it even more imperative that an organized, coordinated approach to investment in hypersonics activities be developed in order not to waste any of the very scarce resources. All industry and government organizations with an interest in hypersonics must cooperate to apply nationwide resources and expertise to the solution of the problem. A first step in approaching the problem might be to convene an investment workshop. Attendees should include not only technical experts in hypersonics, but also policy makers who provide guidance in fitting the needs of those who are trying to maintain the U. S. position in hypersonics with the needs in other areas of the aerospace industry and with the needs of society as a whole. One goal of this workshop might be to identify national core capabilities around which to structure the future direction of hypersonics activities.

Given the competitive situation in which we now find ourselves, and the nearly universal human instinct towards a chauvinistic attitude in such a situation, it will probably be necessary to establish an independent government task force who will develop a national strategy for hypersonics and will report directly to either the executive or legislative branch of the government. Some way must be found to insulate the members of this group from the pull of existing loyalties to specific groups or ideas. This may be more difficult than solving all the technical problems of hypersonics. Another activity of the investment workshop might be to recommend the structure of this task force. Once a national strategy is in place, the task force would continue to monitor activities and review the investment and implement adjustments as necessary. Hopefully, such adjustments will be minor, and in this way we can free ourselves from the fractured and compartmentalized funding approach that has served us so poorly in the past.

4.3 WORKSHOP FOLLOW-UP

At the conclusion of the workshop, the participants drafted some specific plans for follow-on activity. These might be viewed as initial steps in developing a new national strategy for hypersonics. One of the suggestions is that there be annual investment coordination among AFOSR, the Air Force Laboratories and Test Centers, and the NASA Research Centers. This should help all the organizations to better allocate and utilize their scarce resources. A second proposal is that a study be funded for a detailed effort to define the parts of a hypersonics T&E methodology for one particular mission requirement to illustrate the process, identify deficiencies, and provide a beginning for integrated investment planning. An example of such a pathfinder study for a tactical missile interceptor is shown in Fig. 13. Here the activities that would be included in

such a study are presented, along with resource estimates to accomplish the work. A final proposal from the workshop is the convening of a similar gathering to develop an advocacy plan for the conclusions of this workshop and to start the process of developing and implementing new national strategies for hypersonics.

5.0 SUMMARY

The workshop participants recognize that the U. S. is at a critical juncture in aerospace in general and in hypersonics in particular. There is an opportunity to develop a new national vision for hypersonics test and evaluation and the development of future hypersonic flight systems. But with much of the collective wisdom and experience in this area poised for retirement, this window of opportunity will not remain open very long. A workshop such as this one is a reasonable first step towards establishing a new national policy. However, there must be effective follow-through or all the previous efforts will be for naught. The key element of this new vision must be an emphasis on continuity in national hypersonics activities. This is essential if we are to be able to address problems in the development of new hypersonic systems as they occur, at any arbitrary time. This is one lesson that can be learned from the recently deceased NASP program. Because of the nearly 20-year hiatus in activity in hypersonics, the program experienced significant delays while attempts were made to recapture capabilities which had been long dormant or had even totally disappeared.

A key component of a new national vision for hypersonics is effective advocacy. In order to be effective there need to be specific recommendations in a total plan for hypersonics. The problem is that we are trying to advocate a major infrastructure sustainment and upgrade program for which there is currently no clearly identifiable strong customer. No service will state that there is a hypersonic mission that is critically related to the national defense. This means that effective advocacy must convince the highest levels of government of the urgent necessity for creating and supporting this national vision for hypersonics. In environments such as we now find ourselves, it is not likely that this can be accomplished by advocating just from the standpoint of advancing the science and technology of hypersonics. It is true that the loss of infrastructure is reaching a critical point. Retirement of the skill base and the decline in facility capabilities means that there will be a long recovery period when the need for hypersonic systems appears in the future. The potential for foreign competition adds to the criticality. A major factor contributing to the decline in both of these areas is the unstructured reduction in activity in all areas of hypersonics. This drawdown is occurring as a result of economic pressure and the lack of a coordinated national plan to respond to this pressure. Unfortunately, budget makers are typically not impressed with infrastructure arguments. However, it should be possible to reason from the position of support to potential missions which, while they are not now clearly definable, will surely appear in the future. These potential missions will have identifiable needs.

It should then be possible to show that without the proposed investments, it will not be possible to meet certain projected systems requirements.

Another threat is that of foreign competition, which could ultimately undermine the previously dominant U. S. position in aerospace technology. To counter these threats will require the development of a deliberate strategy to maintain the technology base and to continue to push back the frontiers of knowledge in hypersonics. This can only be accomplished through the application of national resources and expertise. It will require total cooperation between all industry and government organizations with interest and capabilities in hypersonics. To generate this cooperation it may be necessary to establish a national task force with responsibility, authority, and adequate resources to attack the problem. Lacking such a broad-based national approach, we may well look forward to the continued decline of our capabilities and influence in this important area of technology for the future.

HYPERSONICS T&E WORKSHOP

- OBJECTIVE:** The objective of this workshop is to define Hypersonic Test and Evaluation (T&E) methodologies and identify research requirements and improvements to the T&E infrastructure.
- APPROACH:** The approach is to invite a select group of hypersonic experts and provide an open forum to collect their individual ideas plus attempt to reach consensus on integrated research requirements and recommend improvements to the T&E infrastructure.
- PRODUCT:** The product will be the proceedings of the Workshop published as an AEDC-TR and sent to all participants plus others.

Figure 1. Workshop objective.

**HYPERSONICS WORKSHOP
AERODYNAMICS SURVEY SUMMARY**

	AIR-BREATHING TRANSATMOSPHERIC	ROCKET-POWERED TRANSATMOSPHERIC	ENDOATMOSPHERIC INTERCEPTORS	UNPOWERED HIGH L/D	BALLISTIC LOW L/D
AERO-COEFFICIENTS					
- B.L. STATE	4	3	2	3	3
- LOW DENSITY	3	2	2	3	2
- REAL GAS	5	3	3	4	3
- DYNAMIC STABILITY	3	2	2	3	3
- BASE DRAG	3	2	2	3	3
- PROPULSION SYSTEM EFFECTS	5	3	1	2	1
- PLUME EFFECTS	3	3	2	1	1
- LEE-SIDE EFFECTS	3	2	2	3	2
AERO-CONTROL SYSTEM					
- FLAPS/SLICES	3	2	3	3	2
- JET INTERACTION	3	3	3	3	2
STAGING					
	2	2	2	1	1
SHROUD/WEAPONS/PAYLOAD SEPARATION					
	2	1	3	1	1
AIR-BREATHING PROPULSION INTEGRATION					
- LOW-SPEED SYSTEM	5	1	1	0	0
- B.L. BLEED					
- NOISE					
- EMISSIONS					
- UNSTEADY EFFECTS IN INLET/COMBUSTOR					
- UNSTEADY INLET-AIRFRAME INTEGRATION (UNSTART)					

Figure 2. Survey.

**HYPERSONICS WORKSHOP
AERODYNAMICS SURVEY SUMMARY**

	AIR-BREATHING TRANSATMOSPHERIC	ROCKET-POWERED TRANSATMOSPHERIC	ENDOATMOSPHERIC INTERCEPTORS	UNPOWERED HIGH L/D	BALLISTIC LOW L/D
Define Thermal Environment					
Boundary-layer state	5	3	4	4	3
Protuberances	3	4	4	3	3
Hot spots	4	4	4	3	3
Shock interactions	5	3	4	3	2
Mass transfer	3	2	3	3	3
Real gas effects	4	3	4	4	4
Viscous effects	4	2	4	3	3
Separated flow	4	3	4	4	3
Low density	3	2	3	3	3
Control jets	2	3	4	2	2
Screen Candidate Materials					
	4	3	4	3	3
Design Thermal Protection System					
Passive system	5	4	4	4	4
Reusable	5	3	0	2	1
Catalytic/noncatalytic wall	4	3	2	3	3
Ablation	3	3	4	3	4
Erosion	4	3	4	3	3
Active Cooling					
Transpiration	3	2	4	2	2
Back-side cooling	4	2	2	2	1
TPS Verification					
	4	4	3	4	4
Electromagnetic Windows					
	3	2	5	3	3

Figure 2. Concluded.

SYSTEM	MAX MACH NO.	KEY TECHNICAL REQUIREMENTS	PHASE I TEST FACILITY	PHASE II TEST FACILITY
Space Launch and Rescue	25 - 30	<ul style="list-style-type: none"> • Mach 12-24 Air-Breathing Propulsion • Real Gas Aerodynamics • Hot Primary Structure 	<ul style="list-style-type: none"> • High Energy Expansion Tube/Tunnel, M = 14-35 • Liquid H₂ Structures Test Facility 	<ul style="list-style-type: none"> • Liquid Air Arc/Direct Energy Addition • PGU Multi-Shock • Large Structures/Airframe Test Facility
Cruise Aircraft	8 - 10	<ul style="list-style-type: none"> • Mach 4-10 Air-Breathing Propulsion • Durable Airframe/Propulsion System 	<ul style="list-style-type: none"> • Mach 3-9 Clean Air T&E Facility • Liquid H₂ structures test facility 	<ul style="list-style-type: none"> • Mach 3-8 Certification Facility • Large Structures/Airframe Test Facility
Interceptors	15 - 30	<ul style="list-style-type: none"> • Real Gas Aero/Control • Thermal Protection • Sensor Performance/Life 	<ul style="list-style-type: none"> • High energy expansion tube/tunnel, M = 14-35 	<ul style="list-style-type: none"> • PGU-Multi-Shock • Advanced Arc Heater • Large Ballistic Range • Liquid Air Arc/Direct Energy
Missiles	10 - 30	<ul style="list-style-type: none"> • Sensor Performance/Life • Thermal Protection • Real Gas Aero/Control 	<ul style="list-style-type: none"> • High Energy Expansion Tube/Tunnel, M = 14-35 	<ul style="list-style-type: none"> • Large Ballistic Range • Liquid Air Arc/Direct Energy • Advanced Arc Heater • PGU Multi-Shock
Planetary Entry Probe	30 - 50	<ul style="list-style-type: none"> • Thermal Protection • Planetary Gases • Sensor Performance/Life 	<ul style="list-style-type: none"> • High Energy Expansion Tube/Tunnel, M = 14-35 	<ul style="list-style-type: none"> • Large Ballistic Range • Liquid Air Arc/Direct Energy • Advanced Arc Heater

Figure 3. Summary of generic systems and facility requirements.

FACILITY	RUN TIME	TEST SIZE	STAGNATION PRESSURE	TEMPERATURE	VELOCITY
High Energy Expansion Tube/Tunnel	Milliseconds	5 ft	> 100,000 atm	>24,000°R (Equivalent)	>24,000 fps
PGU/Multi-Shock Facility (Mach 10 - 16)	Seconds	5 ft	Up to > 10,000 atm	Up to 14,000°R	Up to 13,000 fps
Liquid Air Arc/Direct Energy Addition (Mach 10-30)	Minutes	10 ft	> 60,000 atm (Equivalent)	>18,000°R (Equivalent)	>20,000 fps
Mach 3 - 8 Clean Air (Mach 3 - 8)	Minutes	10 ft 4 ft	100 - 200 atm	1,200 - 4,500°R	3,000 - 8,000 fps
Arc Heater (Mach 6 - 12)	Minutes	3 ft	Up to 400 atm	Up to 10,000°R	Up to 12,000 fps
Structure/ Airframe Test Facility (Mach 0)	Hours	250 x 125 ft x 100 ft	Ambient	Heat Load: 50 - 2,500 Btu/ft ² sec	----
Large Ballistic Range	Milliseconds	10-in. diam	Planetary Entry Conditions		45,000 fps

Figure 4. Test facility characteristics.

HYPERSONICS METHODOLOGY

LONG DEFINITION

The systematic application of available knowledge to design and develop a specific aspect of a hypersonic vehicle.

SHORT VERSION

Rules & Tools for developing vehicles

METHODOLOGY CHARACTERISTICS

- Clearly defined vehicle technical issues (e.g., design thermal protection system)
- Important simulation issues identified (e. g., wall temp, heating rate)
- Available tools identified (e.g., codes, ground test, existing data, etc.)

⇒ Well-defined approach that systematically integrates available tools to produce a low risk solution

Figure 5. Methodology definition.

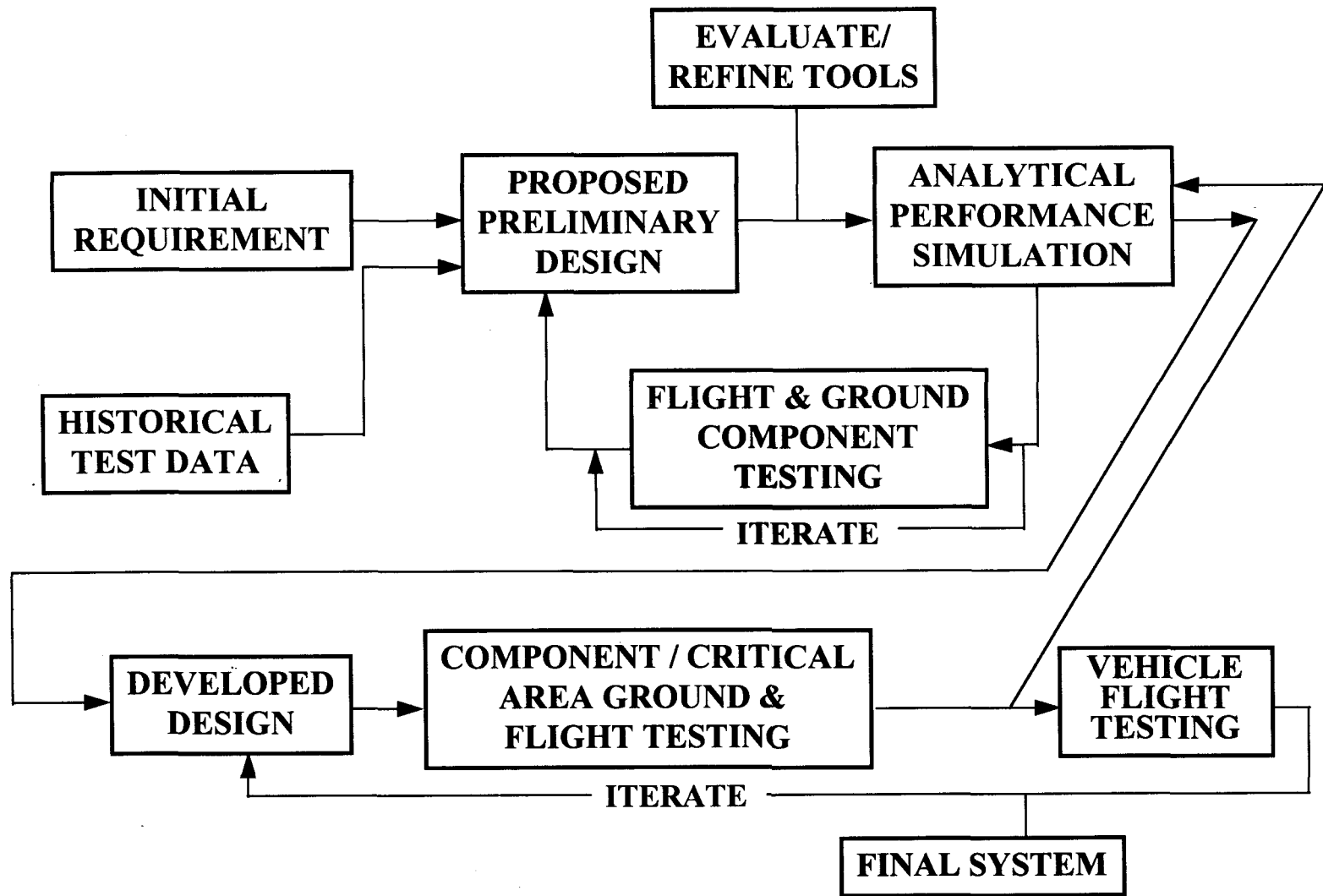
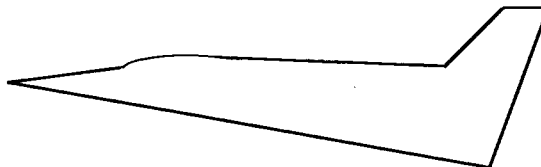


Figure 6. Generic methodology flow chart.

PHASE 1 - DEFINING THERMAL ENVIRONMENTS (STEP 1)

- SCALE MODELS IN WIND TUNNELS
- HEAT-TRANSFER TEST TECHNIQUE



PROVIDES:

- CODE VERIFICATION ⇒ EXTRAP. TO FLT.
- HEATING INPUTS (q)
- THERMAL ENVIRONMENT

PHASE 2 - DEMONSTRATE HARDWARE SURVIVABILITY (STEPS 2, 3, 4)

**MATERIAL TEST
(SAMPLES)**

**STRUCTURAL CONCEPT
TEST
(COMPONENTS)**

**FLIGHT HARDWARE
DEMO TEST
(COMPONENTS)**

- DUPLICATE LOCAL ENVIRONMENT
(i.e., $q_{LOCAL} \approx q_{FLT}$)

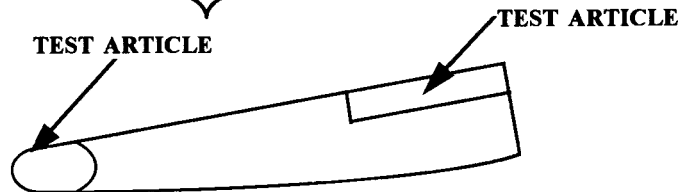


Figure 7. Methodology for aerothermal structures/materials development.

PHASE 1 - DEFINE ENVIRONMENT

STEP (1)

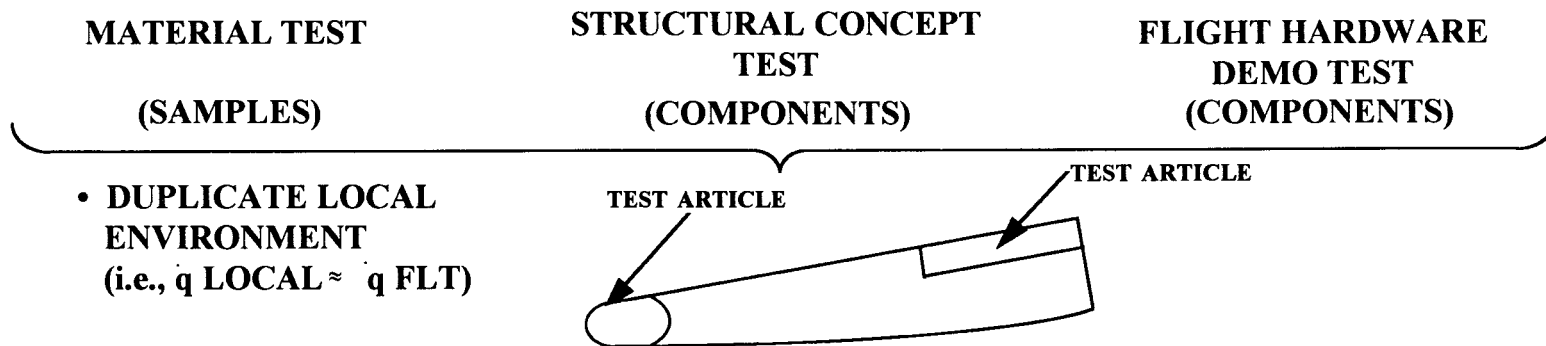
DEFINING THERMAL ENVIRONMENTS (i. e. , WHAT HEATING RATES/TEMPERATURES ARE ENCOUNTERED IN FLIGHT?)

APPROACH:

- | Analysis | Experiments |
|---|--|
| <ul style="list-style-type: none">• Estimate Heating Distribution<ul style="list-style-type: none">• Engineering Codes• CFD• Extrapolate Data to Flight• Thermal Response Calculation | <ul style="list-style-type: none">• Scale Model Tests/Simulated Mach and Reynolds Number<ul style="list-style-type: none">• AEDC Tunnels B & C• NSWC Tunnel 9• Calspan Shock Tunnels• AMES 3.5-ft Tunnel• LaRC Tunnels |

Figure 8. Aerothermal methodology—Phase 1.

PHASE 2 - DEMONSTRATE HARDWARE SURVIVABILITY (STEPS 2, 3, 4)



STEPS

- (2) **SELECT MATERIAL**
- (3) **TEST STRUCTURAL DESIGNS**
- (4) **PERFORM FLIGHT HARDWARE VERIFICATION TESTS**

Figure 9. Aerothermal methodology—Phase 2.

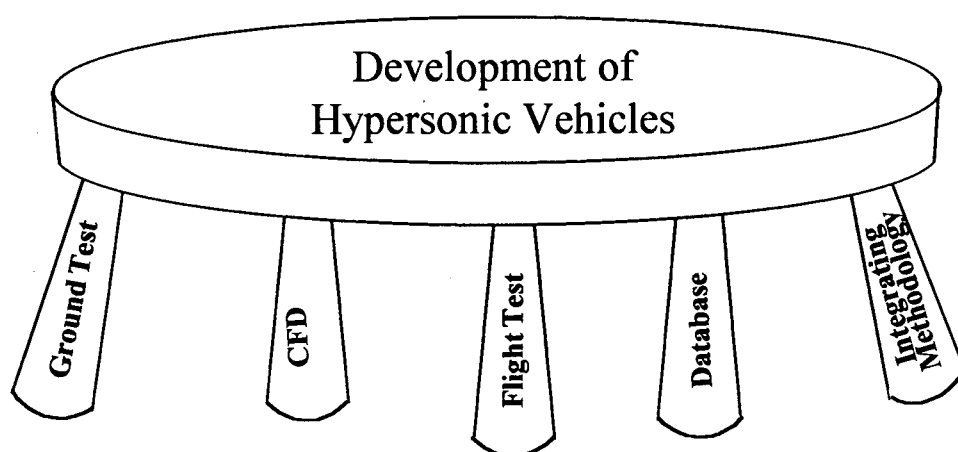


Figure 10. The five supporting technologies.

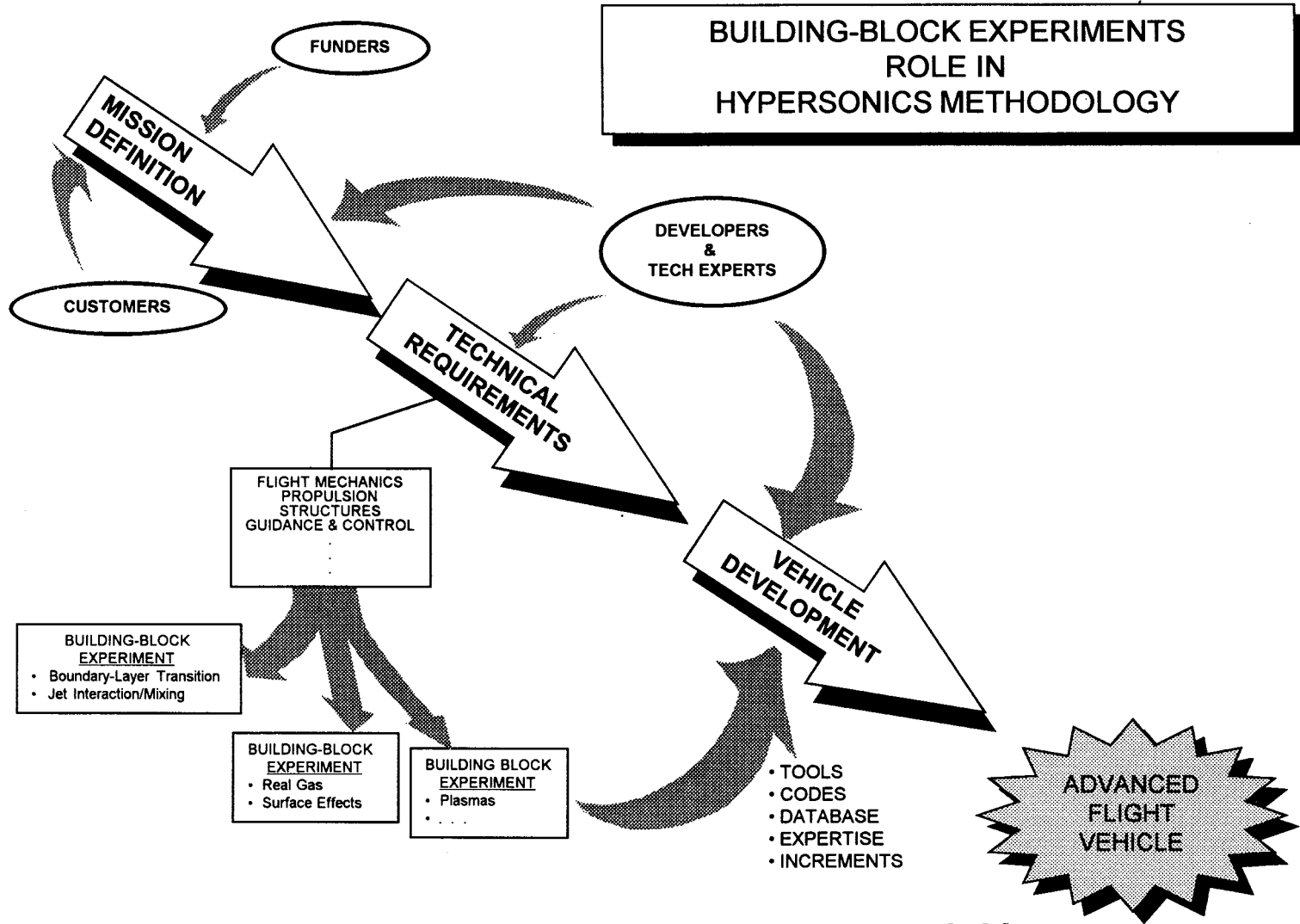


Figure 11. Role of building-block experiments in hypersonics methodology.

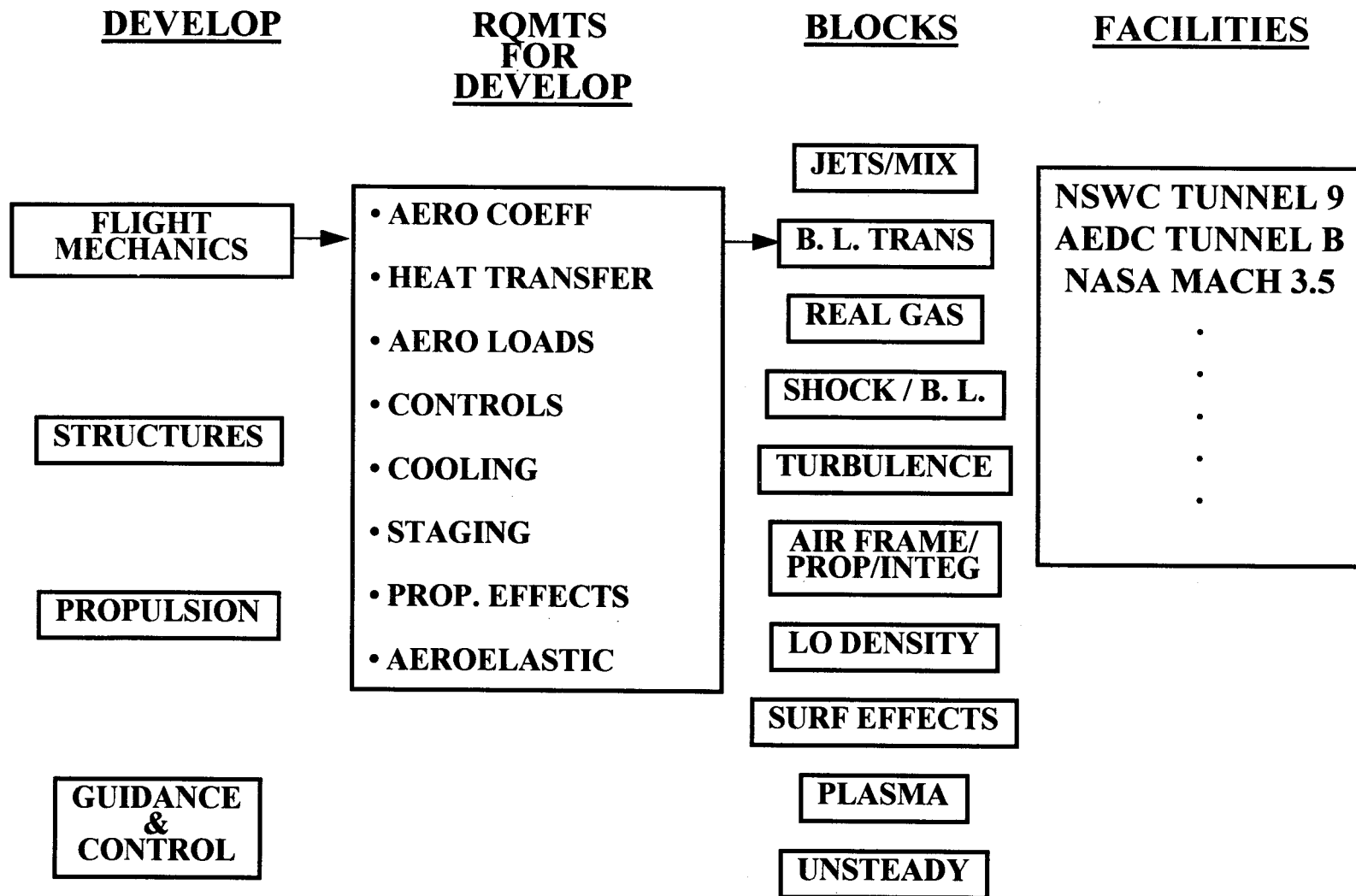


Figure 12. Details of building block process.

Pathfinder Roadmap => Hypersonics T&E Methodology

(BOOST-PHASE INTERCEPTOR)

	MHRS	TRAVEL \$,K	TOTAL \$,K																
				OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP				
DRAFT STAGE: - Assemble Existing Mission Info & Summarize - Draft T&E Requirements Based on Mission Info - Draft Facility Selection, Characterization, Diagnostics Requirements - Draft Building-Block Experiment Requirements Based on Above - Draft Flight Platform Requirements Based on Above	280	0	17	90	50	50	60	40											
FEED-BACK & Critique - Visit Program Offices & Contractors -- Review, Critique, Input - Revise Draft - Mail to Workshop Attendees - Receive Comments	220	4	13					40	50	20	50	20	20						
FINAL REPORT - Assemble Critiques, Reviews, etc. - Draft Final Report - Mail to Attendees for Comment - Establish Review Session at National Meeting - Receive Final Comments - Write Final Report	400	6	24									40	40	80	20	60	60	20	80
	900	10	54	60	60	60	60	80	80	80	100	80	80	80	80	80	80		

Figure 13. Pathfinder roadmap=>hypersonics T&E methodology.

**APPENDIX A
WORKSHOP PARTICIPANTS**

**Hypersonics T&E Workshop
April 6, 7, 8, 1994**

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**Hypersonics T&E Workshop
April 6, 7, 8, 1994**

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APPENDIX B
PRESENTATION BY C. H. LEWIS

The problem statement by Clark Lewis is a succinct summation of the concerns felt by many of the participants and by many others in the industry. Lewis makes some very good points about things to avoid and things to do. A key recommendation is to retain the hypersonics infrastructure. That, of course, is one of the major concerns of the workshop. It is very difficult to accomplish today because of the cost involved. While it is difficult to be optimistic, we can hope that Lewis' prediction for the future will not come to pass.

**AS WE LOOK TO THE FUTURE, LET US NOT
FORGET THE PAST**

**Clark H. Lewis
President
VRA, Inc.
Blacksburg, VA**

**AEDC Hypersonics T & E Workshop
April 6-8, 1994**

THE PROBLEM

- **The Technology base for R&D in hypersonics is rapidly disintegrating.**
- **There appears to be no MISSION.**
- **Without a MISSION there is no SUPPORT.**
- **Without SUPPORT, experienced personnel are retiring or being laid off at an alarming rate.**

A BIT OF HISTORY

- **Threat and mission produced R&D in 1950s and 1960s.**
- **After APPOLLO, we had the 1970s.**
- **Then the Reagan years of the 1980s.**
- **Berlin Wall fell.**
- **The 1990s without a threat or mission.**

SOME THINGS TO AVOID

- **Effects of the de-emphasis of hypersonics in 1970s.**
 - **College education and training declined.**
 - **Much R&D of 1960s not transferred to young engineers.**
- **Effects on programs in 1980s.**
 - **Many young technology managers without 1960s experience or training.**
 - **For example, NASP.**

SOME THINGS TO DO

- **Retain hypersonics R&D base personnel, database of knowledge experience, and facilities.**
- **Define a mission such as validation of CFD predictions from ground test to flight conditions.**
- **Make the process OPEN to all, not just one (or a few) company (ies) and facility (ies).**
- **Put hypersonics back into the DoD and NASA SBIR program.**
- **Clearly define R&D areas to support system design needs--eg., accurate rapid predictions.**

PREDICTION FOR THE FUTURE

If an R&D program (mission and support) is not developed in hypersonics, within 5-10 years we will not have the capability within U.S. industry to develop and deploy a new reentry system.

APPENDIX C
PRESENTATION BY C. W. HALDEMAN

Haldeman reiterates the points about uncertain program needs and the expense of providing facilities to meet the potential needs. The key issue here is that it is difficult to interest Congressional Committees in a hypersonics program that does not address a specific mission for one of the Services. Another major problem is endemic in the budgeting process used in this country. Multi-year funding for a program to extend through the life of the program is typically never available. Instead, program funding is reviewed, and usually changed, every year. Thus a great deal of effort must be spent in re-planning programs to fit new resource constraints. Haldeman also makes another important point that flight testing will involve higher risks, and the industry and the nation need to be aware of and plan for this eventuality.

HYPERSONICS T&E WORKSHOP

**AERO THERMAL TESTING -
METHODOLOGY
AND REQUIREMENTS**

6-8 APRIL 1994

**C.W. HALDEMAN
MIT LINCOLN LABORATORY**

WHAT WILL TAKE PLACE?

- **NEW FACILITIES ARE EXPENSIVE AND LONG LEAD TIME**
- **PRESENT PROGRAM NEEDS ARE UNCERTAIN**
- **INCREASING RELIANCE WILL BE MADE ON “DATA IN EXISTENCE”**
- **HIGHER RISK FLIGHT TESTS**
 - **EXPECT SURPRISES**
 - **ALLOW TIME AND FUNDS TO ITERATE ON FLIGHT TEST**

**CRITICAL AREAS
EXAMPLES - ACTIVE DECOY
PLASMA EFFECT DECOY**

UNCERTAIN AREA

METHOD TO RESOLVE

NOSETIP SURVIVAL

ARC TESTING AEDC H-1

SHAPE CHANGE - STABILITY

**AERO FORCE TESTING
TUNNEL C
TUNNEL 9
96-IN. SHOCK TUNNEL**

EFFECTS OF ABLATION ON STABILITY

**FORCE ABLATION TESTING
AMES 20 MW**

NOSETIP PLASMA GENERATION

PLASMA TESTING AEDC H-1

FUTURE REQUIREMENTS - UNCERTAIN

PROBLEM

**OPTICAL/MICROWAVE WINDOW
HEATING INTERCEPTORS & MaRVs**

**PERFORMANCE OF IMPROVED ABLATORS
AND LO THERMAL PROTECTION**

SUPERSONIC COMBUSTORS

HIGH RADIATION LOAD ABLATORS

TEST NEEDED

**HIGH RATE HEATING WITH
COOLING AND OPTICAL ERROR
MEASUREMENT**

**LOW NOISE AERODYNAMIC HEATING
FACILITY WITH OPTICAL/RADAR
MEASUREMENT**

**GOOD HIGH ENTHALPY, HIGH Re
AERODYNAMIC FACILITY**

EVEN HIGHER