ADVANCED RESEARCH AND TECHNOLOGY FLIGHT PROJECT
MANAGEMENT PHILOSOPHY
USING PROJECT FIRE AS AN EXAMPLE

INTRODUCTION

This is in response to the request of the Associate Administrator as stated in the minutes of the August Monthly Program Review "Using the Fire flight program results and the related ground-based reentry physics research program as a prime example, write a management-oriented paper documenting the philosophy and techniques employed by NASA to develop experimental bench marks against which ground-based theory can be evaluated and extended."

In each of the five major sections of this document, CART philosophy and techniques are discussed first in a general manner followed by the specific actions and techniques of Project Fire. The five major sections are:

- Project Matched to Ground-Based Research and to Important Space Flight Missions NASA Intends to Accomplish
- Project at Center with Competence in Breadth and Depth
- Strong Advisory Groups Under Both Headquarters and Center
- Adequate Funding Under Direct Control of Cognizant Headquarters Office and Center
- Headquarters Program Management and Center Project Management Responsibilities Clearly Defined and Cooperatively Executed

There is a brief concluding section on Impact of Project Fire.
This general objectivity is basic to the OART charter of providing advanced research and technology as compared to the conduct of space science and applications flight missions (OSSA) or the conduct of manned space flight missions (OMSF). The backbone of the advanced research and technology programs will always be ground-based research, both experimental and theoretical. All major advanced research and flight projects must, therefore, have the general support and approval of OART and Research Center management as well as organizational elements at both locations primarily dedicated to accomplishing everything possible in ground-based research within the resources, talent and facility capability available on the national scene. Because of the fierce competition for OART R&D dollars and Research Center manpower, this almost automatically assures that major flight projects seriously proposed for approval will have been critically reviewed by many anti-flight individuals and organizational NASA elements, and determined to be solidly required for anchor point data where large uncertainties or voids exist in laboratory research information due to basic physical constraints in ground-based experimental facilities. The same types of individuals and organizational elements are likewise directed to, and have a natural inclination to be very critical of whether sound design concepts and measurement techniques are incorporated in the project as proposed and developed.
Of course, most ground-based research and technology is geared to some immediate or long-term objective relating to important space missions NASA intends to accomplish. This is a firm requirement for expensive advanced research and technology flight projects.

The critical matching of the project to ground-based research and important NASA space flight missions must be a dynamic process continuing throughout the life of a project. It is an advanced research and technology project and must, therefore, be periodically reviewed from a technical standpoint considering advances in research and technology as well as problems uncovered in research or in mission oriented project developments. This emphasizes the desirability of the project being designed to gather a broad spectrum of information and to have some flexibility in the research measurements that can be exercised during the project execution, considered, of course, in light of overall impact on reliability, cost and schedule.

Project Fire, as an example, met the test of the project principle discussed in this section. It was conceived and executed as a sophisticated investigation of the heating environment of an Apollo-type body during actual reentry flight conditions at speeds approaching 38,000 feet per second. At the time it was conceived in 1961 there was gross uncertainty regarding the radiative heating, particularly non-equilibrium radiative heating, for a body like Apollo, and some uncertainty regarding convective heating. There was expectation among researchers and designers
that the state of uncertainty would improve from ground-based experi-
mental and theoretical research, but not to the degree required for
certain prediction of the heating environment of the large Apollo
vehicle at reentry speeds where both dissociation and ionization
would occur in the flow.

For example, at the time of Fire approval, the uncertainty of radiative
heating input varied from a $V^{12}$ to a $V^{24}$ relationship, where $V$ is reentry
velocity. The uncertainties stemmed from the proper gas dynamics ingredi-
ants to use in theories. Basically, the problems of predicting the radiant
heat input are as follows:

1. Equilibrium radiant heating is directly proportional to the
nose radius, and hence the shock stand-off distance.

2. The factors affecting the absorptivity characteristics of
the radiant gas, and the interplay of the gas dynamic properties with
respect to the shock stand-off distance.

The models used for experimental tests in ground facilities are usually very
small, which means small shock stand-off distances with attendant difficulties
in measuring radiant heating. Furthermore, simulation of the hyperbolic ve-
locities in ground facilities usually means the physical characteristics of
the gas constituents are not exactly like those experienced during actual
reentry or are not in the same thermal-fluid scale as in reentry.

The mechanism of convective heating is better understood than radi-
ant heating. However, large scale tests are required to confirm that at
hyperbolic velocities the convective heating continues to be inversely pro-
portional to the square root of the nose radius, and that it increases in
direct proportion to approximately the square of the velocity as predicted
by theory.
A great deal of study and critical review by many elements of NASA went into the determination that the required advance in technology could not be attained except by a complex, expensive flight flight project like Fire to provide anchor point data at large scale in the actual reentry environment. With the flight data in hand new empirical theories could be devised which could mathematically simulate the right conditions. Similarly, the anchor point data would establish what makes up the correct gas-flow simulation in ground facilities, or the correct interpretation of results from ground facilities.

The Fire Project was an outgrowth of extensive study effort lasting well over a year before formulation of the project, and which drew heavily on past experience with flight projects and ground-based research programs. While there were a modest number of key people in this effort, it was a genuine team effort aimed toward formulation of a flight and ground test program of which the Fire-Flight Project itself was only a single element. This extensive study included the determination of what technical information was needed; the degree to which the information could be obtained on the ground, both immediately and in the near future, and where flight experiments were mandatory; the instrumentation required to make the flight experiments; the ancillary instrumentation both on the spacecraft and on the ground required for a flight test such as that required to determine body motions and spacecraft trajectory; the size and layout of the spacecraft which would perform the required functions; the mission profile required to obtain the desired reentry environments;
and the launch vehicle system which would be required to boost the spacecraft to the proper position and velocity. These considerations were all interacting and required many iterative cycles both in broad outline and in fine detail.

The choice of the general Apollo shape was deliberate both from the standpoint of greatest value in anchor point data for ground-based research and of support to Apollo. A large reservoir of ground-based experimental data was in hand at the time of project proposal, and considerable further testing was definitely planned. This averted the need for a special extensive ground-based research program except for such unique tests as those to prove the Fire heat shield ejection system. The blunt configuration minimized angle-of-attack affects and thereby enhanced the assurance of obtaining valid-flight data. The design was such that the configuration was especially similar to the Apollo shape at the time of peak heating, thereby increasing its direct application to Apollo technology needs.

As a result of the extensive and intensive study period, the main pattern of the Fire Project was drawn, major problem areas were identified, and solutions or approaches to solutions were defined prior to actual steps taken to implement the project.

There were reentry heating technology changes during the course of Project Fire implementation. For example, fairly early in the project development, laboratory research indicated more conclusively
than anticipated at the time of project approval that non-equilibrium radiative heating was relatively unimportant in an Apollo-type reentry, due primarily to flow processes known as collision limiting and truncation. The Fire flight data conclusively proved the point. Later during the project development, controversy arose among ground-based researchers as to whether convective heating might be twice as great as earlier predicted for an Apollo reentry. This was largely dispelled by the time of Fire flight, and the extensive total heating measurements of Fire essentially validated the large bulk of ground-based data for blunt reentry bodies. Shortly before Fire I flight, considerable uncertainty arose among researchers over the phenomena and impact on Fire or Apollo-type reentry of what has become known as radiative heating in the hard ultraviolet. Although the Fire on-board radiometers were developed to make highly accurate and sophisticated measurements of both the level and character of radiative heating for an important radiative energy range, and a highly specialized ground-based telespectrograph was built to extend the energy range of measurements, there was no way of making direct separate measurement of this type of radiative energy through the spacecraft radiometer windows or through the Earth's atmosphere. Langley and the Fire Project Office immediately took steps, contractually and in-house, to accurately assess the mechanisms and extent to which such radiative heating would be incurred in the total...
heating measurements by the beryllium calorimeters. Furthermore, contracts were let with three leading industrial companies in the reentry technology area to predict the flow fields and heating for Fire I prior to availability of the flight results. The wide range of predictions indicated the large degree of uncertainty at the time concerning radiative heating in the hard ultraviolet, and positively attested the fact that foresight in a complex technology investigation is not nearly as definite as hindsight.

As is known, the Fire total heating measurements did record a substantial contribution attributed to radiant energy in the hard ultraviolet. This is serving as a tremendous catalyst and guide in current expanded ground-based research which is actively seeking positive insight into the nature and effects of the phenomena. Thus, Fire has had a very significant impact on reentry research and technology that will be felt for years to come.

Perhaps the above technical discussion is somewhat out of place in a management oriented document, but is included to underlie the very important management philosophy or principle that a major advanced research and technology flight project must and can be matched effectively to ground-based research throughout the life of the project.
PROJECT AT CENTER WITH COMPETENCE IN BREADTH AND DEPTH:

This is so obvious as to perhaps go without saying, but so important as to require elaboration. The best considered and documented technical and management plans are needed for an advanced research and technology flight project, but are largely for naught unless the project is managed by a center having a great deal of competence and experience in all the many facets including ground-based facilities and programs in the research and technology areas of the project; advanced instrumentation including tracking and data acquisition; flight hardware design, fabrication, qualification and use; flight project operations and overall systems integration; and procurement and budgetary practices in large, multi-contract projects.

Naturally, it is difficult always to find the desired degree of competence and experience which can be applied in a given center being in a position to initiate and undertake a crucial flight project as an integral part of an overall research and technology program. Some trade-offs are usually required in each individual case. The center does not need to be the recognized leader in the country or even within NASA in the technology area of the project, but it must have a sound foundation of ground-based research activity and open mindedness in actively seeking and cooperatively considering the support and advice of other NASA Centers and industry. The center must be willing to marshall its resources of experience and competence in an effective manner on the project.
The Langley Research Center was uniquely suited to conceive and manage Project Fire. Langley has a long background of research on re-entry heating, and has always worked cooperatively with the Ames Research Center, industry and universities having some specialized skills and facilities not available at Langley. Langley has maintained strong ties with and technical support to Apollo and the Manned Spacecraft Center (which was the Space Task Group located at Langley at the time of Fire approval). By deliberate policy, Langley has undertaken research projects in a wide variety of areas. Hence at the time Fire was initiated, there was available at Langley a good proficiency in almost every technical discipline involved with Fire. Although Langley had not managed a flight project of the magnitude of Fire, it had much experience in managing equally complex flight projects (some in the reentry area) and experience in managing research facility development and procurement of comparable complexity and magnitude as Fire. Langley had vast experience in advanced instrumentation, measurement techniques, and electronics.

Because of the long history of involvement with broad classes of research projects, Langley had a reservoir of personnel who had been trained through experience in making technical management decisions and judgments. These people had learned how to accept technical advice and consultation from experts in a technical area and how to filter and use this advice. They had learned how to proceed when the technical status of a project was "good enough" instead of "perfect", and when to hold
back in an area when there were problems. They had learned to balance
the often conflicting requirements of technical objectives, cost and
schedules in order to maximize the attainment of the objectives while
maintaining a reasonable cost-time relationship.

Langley effectively utilized its broad experience in the general
manner depicted in figure 1. A Project Fire Office was established (dis-
cussed in more detail later in this document) having permanently assigned
personnel with experience in all the general areas mentioned in the first
paragraph of this section. All the key managers (including system and
subsystem managers) in this office had broad technical background and
previous experience in management. While the experience of some of these
personnel was not directly involved with flight projects, they had had
experience in making decisions and judgments of the type that would be
required in Project Fire. All the personnel for the Project Fire Office
were carefully selected by Langley management as persons with a high
capability for execution of responsibilities and with ability to work
well as a team and for complementation of weak points of some individuals
with corresponding strong points of other individuals. The nucleus of
the Project Office was kept small, eighteen to twenty-three persons. How-
ever, the resources of the line organizations of the laboratory were made
available to this group in the manner shown on figure 1 through specific
assignment of responsibilities for consultation, review, or solution of
specific technical problems. Technical specialists, experience on experi-
mental techniques and supporting tests were supplied by the various
Research Divisions within Langley. Likewise additional experienced personnel on engineering, quality assurance, procurement and administrative services were effectively brought to bear from the Engineering and Technical Services and Administrative Services Divisions. Considerable support in analytical studies and ground facility research was obtained from the Ames Research Center. Thus the project was executed with minimum disruption of other Langley research programs and with maximum utilization of specialized personnel in providing support at critical times and with maximum utilization of such Langley centralized functions as budgeting and procurement.

Originally the Project Fire Office reported directly to the Office of the Director until an Assistant Director for Flight Projects was established. Project Fire was reviewed in monthly Langley division chief meetings, in periodic department meetings, in many special meetings or conferences as deemed desirable, and frequently in a special Langley Reentry Science Program Steering Committee discussed in the next section of this document.
STRONG ADVISORY GROUPS UNDER BOTH HEADQUARTERS AND CENTER:

Of course, it is the responsibility of the Office of Advanced Research and Technology in concert with its centers conducting the overall research and technology programs to formulate, guide and conduct such critical flight projects as are required in the national interest to support both ground-based investigations and major space flight projects being developed or planned. In an area as broad and complex as reentry, the requirements for the many specific elements of research in both ground-based facilities and in flight, as well as the experience, competence, facilities and desire to accomplish the research are vested in a very large number of organizations within the government, within industry and universities, within NASA and indeed within any particular NASA Center or Program Office.

Consequently, OART has constituted a number of Research Advisory Committees reporting directly to the Associate Administrator for Advanced Research and Technology. The committees have membership from NASA Centers, NASA Headquarters, DOD, industry and universities. The committees principally review the requirements, objectives, adequacy and general accomplishments of research and technology on a national scale within their assigned areas and make recommendations as appropriate. They generally do not make detailed recommendations on how research should be done in either ground-based facilities or in associated flight
experiments or projects. In some areas, such as meteoroid technology, working groups are formed with membership from various concerned NASA Headquarters Program Offices and Centers which do become involved in the detailed planning of both ground-based research and flight projects or experiments.

Likewise, Research Centers appoint steering committees or other organizational groups as appropriate to review the soundness and adequacy of research in a broad area being conducted by several divisions within the center. The membership is generally composed of key technical personnel who have many years of sound research experience and who supervise large technical elements of the Center that bear importantly on the role of the steering committee or group. The members in their line positions within the Center are responsible almost solely for managing ground-based research and therefore critically review any proposed flight experiments to assure (1) firm justification to augment and enhance ground-based research and/or to support major NASA space flight projects in a strong manner, (2) sound conception to accomplish their objectives from an overall mission point-of-view as well as from the standpoints of basic design approach and measurement techniques, (3) periodic technical review during their implementation to maintain maximum value in light of technology advances and evolving problems, and (4) accurate analysis and expeditious dissemination of data.

The primary role of two important advisory and steering committees on reentry aerodynamics and consequently Project Fire is depicted in
figure 2. They are the NASA Research Advisory Committee on Space Vehicle Aerodynamics (named the Committee on Missile and Space Vehicle Aerodynamics at the time Fire was initiated) and the Langley Reentry Science Program Steering Committee. The membership of these committees at the time Fire was initiated in FY 1962 is listed in figures 3 and 4. All of the members of the Space Vehicle Aerodynamics Committee are readily recognized as men of outstanding prominence in the national aerospace community. Of course, there has been some change of membership through the years, but the same high caliber of membership has been maintained. Dr. Mao Adams has been Chairman from FY 1963 until he came to NASA as Associate Administrator for Advanced Research and Technology in late 1965. The Langley line positions of the members on the Reentry Science Program Steering Committee speak for the caliber of that Committee. Again there has been some change in membership. For example, Brown became an Assistant Director before he left Langley and Mr. A. Swanson of the Office of Assistant Director for Flight Projects was named to the Committee. Mr. H. Wilson, initial Fire Project Manager became a member when he assumed the position formerly held by Mr. J. Shortal. Mr. Anderson has become Assistant Chief of the Structures Division. Although not members, either the Project Fire Manager or Assistant Manager have attended most of the meetings.

The Space Vehicle Aerodynamics Committee, reporting to the Associate Administrator for Advanced Research and Technology through the OART Office of Space Vehicle Research and Technology, meets twice a year to assess
research programs and technology requirements on a national scale. Its primary concern has been laboratory research programs, but its assessment of the urgent requirement for a major reentry flight project to augment and enhance the ground-based research led it to persist in strong recommendations as will be quoted subsequently in this document.

The Reentry Science Program Steering Committee was formed in May of 1961 and reports to the Office of the Director of Langley. It has met as frequently as three times a week with an average of perhaps twice a month. It has periodically surveyed the total Langley research effort on reentry aerodynamics, heating, heat protection techniques, and communication in great depth. To assist in its responsibilities, it established ad hoc panels of research specialists on Mars Atmosphere Probes (which has subsequently become an independent steering committee), on Entry Heating, on Entry Materials, on Entry Communications, and on Flight Program Formulation. Although the Committee and panels are predominantly constituted of members dedicated to ground-based research, they spend a large part of their time in critically assessing the justification of proposed flight experiments, the matching of such experiments to the real needs of (ground-based research) and the design concepts of proposed experiments, particularly in regard to instrumentation accuracy and sound concepts for acquiring, reducing and interpreting data. The committee does not become involved with instrument design details for example, but does suggest measurement approaches and instrument types. In the case of Project Fire, the Steering Committee worked with many key Langley elements involved in
ground-based research and flight projects both before and after the formulation of a Project Fire Office in establishing the mission goals and the general flight concepts. For example, it suggested the unique "layer-cake" calorimeter-neat shield measurement concept used so effectively by Fire.

It is significant to note that the Chairman of the Langley Reentry Science Program Steering Committee was also the Langley member on the NASA Space Vehicle Aerodynamics Committee. Therefore, there was strong interplay between the Committees. In order to exemplify the strong role of these committees in the initiation and successful accomplishment of an important advanced research and technology flight project, it is important to review some of their recorded actions.

The Aerodynamics Committee at its November 3-4, 1959, meeting spent most of a day reviewing ground-based research and flight experience on reentry and formed the following resolution:

"Lifting reentry vehicles appear extremely attractive for civilian and military space missions. Extensive theoretical and experimental studies by the NASA, universities and industry indicate lifting vehicles provide lateral range and maneuverability for control of landing area, significant enlargement of guidance tolerances and reduced deceleration loads. These capabilities cannot be provided by ballistic vehicles."
While existing ground facilities have provided valuable design data, it is not possible to simulate all the important characteristics of flight environment. An urgent need exists for a timely flight test program on lifting vehicles to provide basic information on aerodynamic characteristics, heat shield systems and control and guidance problems in the actual environment. It is important to correlate these data with data obtained from ground facilities.

Background information now exists to plan and execute an unmanned lifting entry research flight test program at reasonable cost. The NASA Research Advisory Committee on Missile and Spacecraft Aerodynamics strongly recommends that such a program be initiated as soon as practicable in close cooperation with the DOD as a logical and timely step in space vehicle development.

In response NASA planned a reentry flight program using Scout and as "piggyback" experiments on DOD launch vehicles. The following is an excerpt from the summary minutes of the May 11-12, 1960, meeting of the Aerodynamics Committee:

"It was reported that the NASA is beginning to explore the possibilities of reentry experiments in the Air Force Atlas-boosted "piggyback" RVX-2 program having much greater payload capability than the Scout vehicle. The Committee discussed interesting recent results from reentry flight tests..."
with ballistic missile vehicles, the attractiveness of the Air Force "piggyback" and "hitch hike" programs for conducting a large number of reentry flight test programs with big payloads, and concluded that the NASA should make every effort to participate in the Air Force programs. The following recommendation was passed:

"The Committee recommends that NASA now formulate a program of reentry research flights for aerodynamic purposes beginning with earth atmospheric flights and including eventually probing flights of Venusian and Martian atmospheres. Reentry research in the flight program is not receiving enough attention relative to other research.

"The Committee does not believe that a few NASA reentry flights with Scouts is adequate for this program over the next few years. It recommends that NASA participate in and help support the Department of Defense reentry program, and use the Air Force-stabilized Scout-vehicle and other reentry test vehicles. Particularly, the "piggyback" flights on Air Force ballistic missiles such as the RVX-2A and the "hitch hiking" scheme may afford great economies.

"The Committee is setting up a Working Group to list the research results to be sought, as well as proposed methods of getting these results."
The Working Group met on June 20 and July 22, 1960, the latter part
time with Mr. Abbott and Dr. Dryden of NASA Headquarters. The actions
and recommendations of the Working Group were so significant that the
minutes of the two meetings together with a summary report to the Aero-
dynamics Committee are appended as attachments A and B to this document.
At that time the best prospects for expeditious implementation of needed
large elements of reentry research in flight appeared to be via the "piggy-
back" route utilizing DOD ICBM development launch vehicles. Langley ex-
pended considerable effort in conceiving a sound multi-experiment flight
project in this vein including a sizable contracted preliminary design. Both
Langley and Headquarters took many steps in attempting to establish such a
joint project with DOD. Also a predecessor Langley committee to the
Reentry Sciences Program Steering Committee considered an expanded flight
program involving in addition experiments flown on Scout and smaller ve-
hicles, as well as on Atlas-Agena, the latter being known later as Project
Calorie.

The Aerodynamics Committee on October 12-13, 1960, reviewed the
above activity and passed the following recommendations:

"Subsatellite speeds - A certain amount of information on
lifting body aerodynamics and heat transfer has been accumu-
lated in recent years in ground-based facilities. Several
large-scale Air Force development programs in this speed range
are already in the initial phases, and these programs urgently
need additional laboratory data and flight test confirmation
of such data. The flight research program presented to this
Committee by the Langley Research Center recognizes this need."
A specific augmented program of this type must be funded at the required level, and carried out at the earliest possible date.

"Supersatellite speeds - NASA has the full responsibility for successful recovery of a manned lunar mission vehicle and for planetary probes. The entry phase involves flight in a planetary atmosphere at speeds of the order of escape speed, where the most serious gaps in our present knowledge exist. NASA must initiate a comprehensive research program in this speed range well in advance of large-scale development programs, such as Apollo. Such research should include not only flight tests, but also analytical work and tests in ground-based facilities. This Committee would be pleased to hear an outline of such a program at its next meeting."

In the following months, the prospects of initiating a major inter-agency flight research project with DOD became increasingly dim. Emphasis in NASA planning was, therefore, shifted to Project Calorie, an Apollo shaped recoverable vehicle to be flown on Atlas-Agena to investigate both heating environment and ablation materials behavior at lunar return speeds and 45,000 feet per second.

On Jan. 30-31, 1961, the Aerodynamics Committee adopted the following recommendation:
"The Committee endorses the type of general reentry flight test program at supersatellite speed presented at the meeting as proposed by the Langley Research Center. Furthermore, the Committee strongly urges the NASA to plan, budget and conduct reentry experiments in flight at supersatellite speeds specifically to provide advance data in support of the Apollo program. This flight research is needed to conduct critical experiments on such problems as radiative heat transfer from hot gas layers as well as the response of materials to the radiation, and also to provide information to confirm and correct hypervelocity ground facility data now beginning to become available."

Project Calorie was approved under the Office of Advanced Research Programs, managed by Langley in concert with the Space Task Group, and funded by the Office of Manned Flight Programs as an Apollo support item. In September 1961, largely because of Manned Flight funding problems, Project Calorie was cancelled. At the same time, however, NASA management encouraged the initiation of a reentry flight project that could be solidly justified and funded on its research and technology merits without being attached to a mission project.

On the day following cancellation of Project Calorie, the Langley Reentry Science Program Steering Committee began an intense planning effort which was the actual beginning of Project Fire.
The following is an excerpt from a statement adopted by the Aerodynamics Committee on October 3-4, 1961:

"The Committee is now informed that the proposed program (Project Calorie) has been cancelled because of its great expense (budgets ranging from about $55M to $65M have been quoted for four Atlas-Agena shots to begin in July 1963), and because those responsible for Project Apollo say these tests cannot get data in time for the Apollo vehicle design.

"The Committee still believes that a reentry flight test program at an early date is needed. There has been no flight verification of aerodynamic phenomena in this supersatellite speed region, although some significant progress has been made in laboratory work. If the tests cannot be conducted in time for the early designs of the Apollo, they may well be needed for design modification to Apollo in its later stages. In any case, they are needed for the long term space program.

"The Committee understands that beginning in October 1963, there are possibilities that reentry testing on Saturn C-1 flights can be conducted. The Committee is not sure that reentry flight tests in the supersatellite speed region can be achieved for less expense than by use of the Atlas-Agena vehicle.

"In view of all the above, the Committee recommends that NASA make a study of several things - First of a reduced Atlas-Agena program in order to get started quickly, second of a Saturn C-1 as a later substitute for the Atlas-Agena. When such
a study is completed, the Committee or a sub-group of it will be glad to sit with the technical people to determine its adequacy in our opinion."

The notable efforts of the Steering Committee and other organizational elements under the guidance of Langley management and OART and with strong support by the Ames Research Center and Jet Propulsion Laboratory led to the rapid formulation of Project Fire including a Project Development Plan which was reviewed by existing Headquarters procedures at the time. A delegation of the Aerodynamics Committee met in Headquarters on December 19, 1961, the date Project Fire was approved for reentry flight tests at 37,000 feet per second. The second phase of testing proposed at higher speeds was not approved.

The support of the two Committees did not terminate with Project Fire approval. The Aerodynamics Committee periodically reviewed the supporting ground-based research and technology, progress of the project development, and preliminary flight results. As noted earlier, the Steering Committee maintained a major sustaining role in guiding technical aspects of the project design, supporting research, execution and data analysis.

The purpose of the foregoing is not to belabor the historical evolution of Project Fire, but rather to portray conclusively and as a matter of record the vital role of sound, influential advisory groups who persist in their well considered convictions that certain research must and can be accomplished despite obstacles from budgetary constraints, adverse management
decisions, technical problems and so forth. The foregoing historical background also brings out factors supporting the next section of this document.

ADEQUATE FUNDING UNDER DIRECT CONTROL OF COGNIZANT HEADQUARTERS OFFICE AND CENTER:

The two false starts mentioned in the previous section in attempting to undertake major advanced research and technology flight projects with interagency or inter-NASA Headquarters Program Office funding control reflect the serious expenditures of time, effort and dollars that can be wasted due to such a management arrangement. Of course, fund transfers can be readily accommodated as long as the funding control remains with the Headquarters office and Center responsible for the project. This was done on Scout Reentry R IV. Likewise, it is possible to have interagency funding control of a major project (as has been the case with the X-15) or inter-NASA Program Office funding control (as was somewhat the case with Pegasus) as long as there is fairly unanimous agreement in detail concerning the objectives and conduct of the project. Such arrangements generally are undesirable, however, because all of the major funding, technical and managerial problems cannot be foreseen at the outset, causing steps for accommodating such problems to be rather cumbersome and frustrating for both Headquarters and the Center managing the project. The arrangement is conducive to serious delays or oversights in various phases of a project.
A more important basic reason for advanced research and technology flight projects to be totally funded by OART is to force them to be truly an integral part of an overall research and technology program. This makes them almost totally competitive with ground-based research for R&D funds and has a strong influence in their being conceived and executed in a manner to obtain data that are indeed most urgently required to augment ground-based research. Often advanced research and technology flight research projects serve as a catalyst or focal point for greatly strengthening the ground-based research. The turbulent heating flight experiment under the Scout Reentry Project is a good example of this. When the funding control of an advanced research and technology flight project is under the basic control of an OART division having program and funding responsibility for the prime technology area the project supports, both Headquarters and the Center managing the project have a natural tendency to place funding requirements for both ground-based and flight experiment elements of research in a proper perspective. Both NASA elements have a common basis for expeditiously augmenting various SRT activities on problems areas which may be uncovered by the project.

Of course, the Center managing the project must have the day-by-day responsibility for monitoring construction activities and expenditures to live within funds available and to forecast funding changes which may be required. The Headquarters Program Office likewise needs to keep in close touch with the general performance and expenditures of the Center and
contractors to develop an independent feel of how the project is progressing from a funding point of view, and how adequate the funding projections are.

As far as providing adequate funds is concerned, there is no substitute for experience and competence on the part of both the Center and Headquarters in assessing the magnitude of the job to be done, in specifying the contracted work to the maximum degree possible at the outset, and in close monitoring of the contractors.

In the case of Fire, OART did provide adequate funds each year and Langley did a remarkable job of financial management. There were overruns due primarily to unforeseen technical problems, schedule extensions, and some justified changes of scope. There was close liaison between Langley and OART by various routes on financial matters and there were no major sudden financial surprises which could not be accommodated. In some cases OART exerted pressure to squeeze expenditures, and in FY 64 OART budgeted $1.0M more than Langley requested based on OART's independent evaluation of what would actually be required. That money was indeed required by the project. It is a tribute to Langley that in FY 1965 $1.0M of Fire funds became available to reprogram into SRT.
HEADQUARTERS PROGRAM MANAGEMENT AND CENTER PROJECT MANAGEMENT RESPONSIBILITIES CLEARLY DEFINED AND COOPERATIVELY EXECUTED:

The roles of program management at Headquarters and project management at the Center must be mutually understood, respected and supported. Headquarters must recognize that the responsibilities for day-by-day management, line authority in monitoring and directing contractors, and the actual execution of the project are vested in the Center managing the project and other NASA centers managing systems or subsystems such as the launch vehicle, launch operations, etc. The Center must recognize, on the other hand, that the Headquarters office having program management responsibility for the particular project has responsibility for the total spectrum of SRT programs and perhaps other flight experiments in the technology area of the particular flight project. A major advanced research and technology flight project represents a large part of an overall program in a given area as regards technology advancement, manpower usage and financial requirements. The Headquarters Program Office, therefore, has a very important role in assuring that the project objectives and experiment concepts are kept in line with the overall technology needs; in cooperatively planning the various phases of the project (including establishing a sound project organization at the Center, lining up project and SRT support from other NASA Centers and DOD, and selecting contractors); in keeping abreast of the progress of the project in some detail throughout its life (on such matters as design, fabrication, qualification, systems integration, procurement, financial expenditures, budgeting, launch operations, and data analysis); and in expeditiously
making the flight results available to ground-based researchers and spacecraft designers.

The position and prestige of both the Headquarters office and Center are equally at stake in the successful attainment of data from a flight project, and they must work cooperatively as a team. Although the Headquarters has office/authority for project direction, it should very seldom have to issue directives, but should primarily offer leadership and guidance to a project managed by a competent and responsive Center.

The provisions of NASA Management Instruction 4-1-1 are excellent guides for general organization and basic procedures in Center management of a project, and every attempt should be made to implement them effectively and expeditiously. The Center should establish a Project Office having primarily management functions, but with permanent or ad hoc specialists as required and with strong support from the research, technical services and administrative organizations of the Center. Careful selection of key personnel by the Center management cannot be over emphasized. Responsibilities within the Center and especially within the Project Office must be clearly defined and delegated to the lowest possible management level including managers of all systems, major subsystems, system integration, operations, support activities and mission technical functions. Management assignments along the lines specified in 4-1-1 should be cooperatively prepared and approved early to establish the overall management agreements of Headquarters, the project management center and other NASA centers or DOD agencies importantly
involved in the execution of the project. Also, under the direction of the Center management, early management agreements should be instituted to establish direct communication, responsibility and action arrangements at working levels within the Center, and among other NASA centers or DOD agencies supporting the project.

The same general rules apply to the Headquarters organization involved with the project in regard to clear definition of responsibility, delegation of authority to the lowest reasonable level, and judicious utilization of personnel. Considerable flexibility can be used from project to project in performing the Headquarters functions; however, there are some general policies that have proven desirable on advanced research and technology flight projects. One desirable policy is to have Headquarters personnel intimately involved in the project throughout its life who also have important experience and responsibility in Headquarters management of associated SRT programs. This greatly helps to protect Headquarters concerns over the project being conceived and executed to support ground-based research in the most effective and timely manner.

Another policy is that at least one Headquarters individual of respected stature should devote a major part of his time to the project during its development and flight accomplishment. He in essence operates as a member of the Center Project Office Team. There is no adequate substitute for actively participating in many planning activities and meetings, in contractor source selection boards, in center technical, managerial, and financial reviews, in contractor design and performance reviews and in launch
operation exercises to enable Headquarters to be adequately informed to make sound independent judgments of the true status of a project, of the likely impact of daily problems which arise, of steps Headquarters might consider to assist in the project and of projected schedules and budgetary requirements. The Center has a legitimate fear that Headquarters awareness of a recently uncovered problem on a project may lead to its being blown all out of proportion before all the factors are gathered and evaluated. If a capable Headquarters individual spends enough time on the project to be fully acquainted with all the background, and if he is an individual the Center trusts to accurately present the views of the Center or the pertinent Center personnel on the issue regardless of whether he personally agrees, then there is no barrier to open communication between the Center and Headquarters. Such an individual may sometimes be accused by his Headquarters supervisors of working for the Center instead of Headquarters, but this is a healthy sign.

On the other hand, Headquarters needs a third type of individual more concerned with administrative procedures and requirements, cost effectiveness, scheduling, reliability assessment, performance trends, formal review and reporting, and so forth who exert appropriate pressure on the Center and the Headquarters individuals really monitoring the project.

Despite their critical role, none of the Headquarters personnel mentioned so far need to have any line authority over the Center or Project. Program responsibility for the project should rest with the Director of the CART
Division who supports the primary technology area of the project. He of course, must be responsible to the Associate Administrator for Advanced Research and Technology or higher NASA management and refer really major matters to them as may be required once in awhile. The first type of Headquarters staff individual described should always report directly to him. The Headquarters staff responsible for Headquarters flight project administrative management can report to the program manager, to another sister CART division having a Vehicle Technology Flight Experiments Branch, or to a completely separate centralized CART flight project administrative group. The Headquarters Division having program management responsibility should accomplish the day-by-day Headquarters monitoring, but if the Headquarters flight administration group is in another Headquarters Division it will also do a certain amount of frequent monitoring causing some extra work and frustration for the Center.

Documented project plans and reports are also important in managing a project but are of lesser importance than the foregoing factors. A PDP should be prepared early in the project and revised periodically. The PERT system is an effective management tool, especially if it is utilized in a manner helpful to the working level in the Project Office and contractors' work force. Performance and schedule trend charts are useful to Center and Headquarters management. A detailed project integrated qualification and flight test plan periodically up-dated is of great value.

Project Fire is considered to have been well managed from a project point-of-view at Langley and a program point-of-view at Headquarters. Langley management established a strong Project Office with carefully selected personnel
along the lines indicated in Figure 5. As can be seen from the chart, Fire was a complex project involving three prime contractors, Lewis Research Center (initially Marshall Space Flight Center), the United States Air Force, the Goddard Space Flight Center (also Kennedy Space Center to some extent on Fire II) and OSSA in addition to Langley and OART. Great care went into preparation of the overall Langley and Marshall management assignments which were signed by the Acting Director of OART on 5/22/62. (These were later promptly revised when the Agena Project was shifted to Lewis.) Langley management assigned responsibility for execution of the Project Fire to the Project Manager. He in turn assigned responsibility to the various systems, subsystems and other managers shown in Figure 5. This could be referred to as the "capitalistic approach" in that the concept was "produce or be replaced". This approach with carefully selected personnel did, however, produce a tremendous espirit-de-cors that led to the successful accomplishment of Project Fire. The Project Manager and his assistant were strong experienced motivators, trainers and supervisors. In dealing with non-Langley elements supporting the project they repeatedly explained the objectives and importance of the project to the country, which contributed to the excellent support to the project by all parties involved.

The functions of most of the elements of the Project Office (formally named Flight Reentry Program Office) shown in Figure 5 are readily evident and do not require elaboration here. On this project the systems integration contract was under the direct control of the Project Office rather than the
Launch Vehicle System. This enabled the contractor to assist in overall project formal documentation, and to serve as an independent source of talent and manpower for reviewing spacecraft design, development, qualification, reliability assessment and launch operations to a degree that would not have been utilized from a systems integration contract under the direct control of the Project Office rather than the Launch Vehicle System. This activity was very valuable to Fire. The support program manager was largely responsible for the support testing at Langley and Ames in the project development and for establishment of procedures and reduction of flight data to engineering units. The mission technical staff served a very vital role in strengthening the technical capabilities of the flight experiment as reentry heating technology evolved during the course of the project and as certain instrumentation technical problems were encountered. The staff was the Project Office primary interface with ground-based researchers on reentry heating. It had the responsibility for reducing the flight data to the form used by researchers and designers with proper assessment of its accuracy and significance. Finally, the Project Office centralized a great deal of overall project operations because of its organizational complexity. This helped all operations aspects of the project to move very smoothly. There were some changes in personnel between Fire I and II, resulting in well-trained assistants moving up the ladder.

The OART Project Fire organization, as it existed throughout most of the project life, is shown in Figure 6. The project was a part of the
program of the Space Vehicles Research and Technology Division. The Division Director was the OART Project Director. The Division had a Vehicle Technology Flight Experiments Branch responsible for Headquarters administration of all OART flight projects excepting those involving nuclear energy. The chief of that branch played a vital role throughout the project and during the project appointed a member of his staff to serve as the Fire Flight Project Officer. The Project Director appointed his Chief of Environmental Effects and Aerodynamics Programs as the Fire Program Chief. This individual had long association with reentry programs and in fact has served as executive secretary of the Research Advisory Committee on Space Vehicle Aerodynamics throughout its existence. He relinquished a great many of his line duties to direct handling by the Division Director and Deputy. This enabled him to devote the major part of his time to day-by-day Headquarters monitoring of the project in a close two-way association with the Vehicle Technology Flight Experiments Branch. He did a great deal of traveling and participated in most of the major meetings and activities in project planning, contractor selection, design reviews, contractor performance reviews, launch operations, and data review. He enjoyed the full respect and cooperation of Langley management, the Fire Project Office, the Langley Reentry Science Program Steering Committee, and all organizational elements supporting the project. He was the Headquarters representative in the Mission Control Center at Cape Kennedy during the launches and kept the Headquarters Project Director informed of key developments during the launch operations, who in turn referred certain matters to the Associate Administrator
for Advanced Research and Technology and the NASA Associate Administrator. In the latter phases of the project the OART Fire Flight Project Officer became of increasing assistance in some of the project monitoring:

The Project Manager, Langley management and Headquarters management did provide for review of progress and problems on the project. However, this review was kept as informal as practicable and the detail of review in general varied inversely with the management level of the reviewer, with flexibility as required to understand problem areas and/or to form a proper base for management decisions. The detailed execution of the project was left to the lower levels of management. These levels were, in turn, charged with responsibility for bringing problems to the attention of higher levels and to call attention to problems before they became major ones so that proper action could be brought to bear or, as appropriate, to agree that satisfactory approaches to solutions were under way. While higher management levels were kept generally informed as to project progress, main decision functions involved at Center and Headquarters top management levels involved major funding problems and the major trade-offs between funding, schedules, and technical objectives. These levels also conducted general reviews prior to launch to insure general readiness to proceed with final launch preparations. However, the detailed determination of flight readiness was left to the Project Manager; this determination included a responsibility to bring significant problems to the attention of higher levels and to indicate proper close-out of such action items as the general review generated.
Formal procedures and reports were used as tools in management of Project Fire. A preliminary PDP existed at the time of project approval December 18, 1961, and subsequent revisions were issued in February 1962, July 1962, March 1964, and April 1965. Extensive use was made of the PERT system as a part of the project management information system. Performance trend charts were used during certain critical phases of the project. Brief bi-weekly written reports were submitted from the Langley Director to the Associate Administrator for Advanced Research and Technology for a period preceding the first flight. However, the primary key to success was not procedures, paperwork and formal methodology, but rather in the achievement of men, acting together as a team, executing individual initiative through assigned responsibilities with broad policy guidance and review by and a minimum of interference and detailed direction from higher management levels.

A review of the management within the contractor organizations is not included in this document. The launch vehicle was procured through existing procedures with OSSA. The other three primary contracts were CPFF, although the Republic Aviation Corporation contract for the reentry package had a cost sharing provision which deserves some attention in this management document. This basic contract was for $5.0M, exclusive of spares. The contractor agreed to assume 50% of unanticipated additional costs up to $5.5M and 75% of all additional unanticipated costs in the conduct of the contract. This resulted in the contractor spending approximately $3.25M of
his own money, which can be considered as a saving to the government. On the other hand, this was the cause of much trouble and delay in managing and executing the project. Substantial overruns became evident fairly early in the contract and this seriously affected his effective response to Langley technical direction and his effective handling of problems with critical subcontractors and vendors. It caused Langley to expend undue effort in technical and business management. Cheap fixes and short cuts in an attempt to reduce expenses generally resulted in retracing many steps with time delays and net cost increases. Particularly late in the project, it resulted in changes of scope being in essence negotiated on a fixed price basis, with attendant time delays and large expenditures of effort on the part of Langley technical and business personnel.

Since this is primarily a project management philosophy document rather than a case history record, no attempt is made to record the technical or business milestone performance of Project Fire. As a matter of information, the dates of some project approval and contractual events are listed in Attachment C.
IMPACT OF PROJECT FIRE:

It is obviously difficult to separate opinion from facts on this matter, and consequently only a few remarks will be made. All of the tremendous effort over a period of years in surveying the ground-based research and reentry flight technology requirements to determine the need for an advanced research and technology flight project like Fire naturally had a strong influence on bolstering the ground-based research to the extent possible. An advanced research and technology flight project during its active development normally provides a great deal of impetus for directly associated ground-based research, but during the time span of Fire active development, Apollo itself was probably a greater motivating factor.

Both the Fire I and Fire II flight results have been widely sought by researchers and those concerned with Apollo reentry. The Fire I results were a primary factor in the AIAA holding an Entry Technology Specialists Conference at Williamsburg and Langley in October 1964. The Research Advisory Committee on Space Vehicle Aerodynamics in November 1964 called in many leading scientists of the country on reentry heating to thoroughly review radiative heating in light of the Fire I results. The Research Advisory Committee on Fluid Mechanics has likewise reviewed such research. There is no question but what research on radiative heating in the hard ultraviolet has been greatly expanded since the Fire flights. The OART Research Division also has sponsored two very profitable meetings of NASA reentry heating
scientists as well as scientists engaged in reentry heating research under
NASA contract to review current research results and to form the basis for
building a stronger ground-based research effort. In summary, there is no
way of absolutely measuring the impact of Project Fire results, but it has
been very great.
MAJOR TECHNICAL ADVISORY AND STEERING COMMITTEES
INVOLVED IN PROJECT FIRE

ASSOCIATE ADMINISTRATOR

OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY

RESEARCH ADVISORY COMMITTEE ON SPACE VEHICLE AERODYNAMICS

Requirements for National Space Program

REENTRY SCIENCE PROGRAM STEERING COMMITTEE

Mission Goals & Concepts

REENTRY FLIGHT TEST

PROJECT FIRE

Figure 2
NASA RESEARCH ADVISORY COMMITTEE on MISSILE AND SPACE VEHICLE AERODYNAMICS

Membership FY 1962

H. G. Stever, MIT (Chairman)  H. Allen, ARC
Mac Adams, AVCO                  H. Drake, FRC
S. Bogdonoff, Princeton          M. Faget, STG
K. Bossart, GD/A                 E. Geissler, MSFC
R. Hildebrand, Boeing            E. Love, LRC
M. Hunter, Douglas               R. Luidens, LeRC
O. Klima, GE                     H. Schurmeir, JPL
L. Lees, Cal Tech                R. May, Hqtrs. (Secretary)
R. Pepping, McDonnell            W. Lamar, USAF
R. Smelt, Lockheed                J. Martin, USAF
G. Solomon, STL                  J. Fagan, USA
                                    R. Freitag, USN
                                    R. Wilson, USN

Figure 3
LANGLEY REENTRY SCIENCE PROGRAM STEERING COMMITTEE

Membership FY 1962

E. S. Love (Chairman), Assistant Chief, Aero-Physics Division
R. A. Anderson, Branch Head, Structures Division
J. V. Becker, Chief, Aero-Physics Division
C. E. Brown, Chief, Theoretical Mechanics Division
H. B. Edwards, Assistant Chief, Instrumentation Research Division
C. L. Gillis, Branch Head, Applied Materials and Physics Division
E. C. Kilgore, Chief, Flight Vehicle and Systems Division
J. A. Shortal, Chief, Applied Materials and Physics Division
R. L. Trimpi, Branch Head, Aero-Physics Division

(Project Fire Manager or Assistant Manager participated in most meetings.)

Figure 4
MINUTES OF MEETING
OF
WORKING GROUP ON
REENTRY FLIGHT TEST PROGRAMS

COMMITTEE ON MISSILE AND SPACECRAFT AERODYNAMICS

California Institute of Technology
Los Angeles, California

June 20, 1960

Present:
Prof. Lester Lees, Chairman
Dr. Mac C. Adams
Prof. S. M. Bogdonoff
Mr. Robert B. Hildebrand
Mr. Otto Klima, Jr. (late arrival)
Mr. Ralph W. May, Jr., Secretary

and on invitation:
Mr. R. B. Chamberlain, GE
Mr. A. E. Flathers, GE
Mr. David G. Stone, Langley

FLIGHT TEST PROGRAM OBJECTIVES

Prof. Lees - Prof. Lees suggested the following outline of a program objective:

I. Basic Aerodynamic Information
   A. Blunt-nosed slender bodies and lifting surfaces with blunt leading edges
      1. Static pressure distributions
      2. Heat transfer rates with and without ablation
      3. Effects of sweep and correlation with unswept body
      4. Sweep plus angle-of-attack effects
   B. Control surface aerodynamics
      1. Lateral extent of low total head gas behind bow shock
      2. Shock-induced boundary layer separation and three-dimensional relieving effects
3. Pressure distribution and heat transfer rates on typical hypersonic control surfaces

II. Heat Protection Schemes
   A. Stagnation point ejection
   B. Annular slots downstream of stagnation point
   C. Shower-head or porous plug
   D. Water (steam) versus helium
   E. Effects of angle of attack and spin rates around body axis

Mr. Hildebrand - He outlined the most important basic problem areas to be investigated in flight as

I. Heating
   A. Convective, \( V > 20,000 \text{ fps} \) - blunt and slender areas
   B. Convective at angle of attack \( V \leq 10,000 \text{ fps} \)
   C. Radiative, \( V > 25,000 \text{ fps} \)
   D. Materials development

II. Flow Field and Pressure Distribution
   A. Slender areas at angle of attack
   B. Electron density

III. Stability and Control
   A. Control effectiveness at high Mach and low Reynolds number
   B. Stability characteristics of shapes over wide range of angle of attack

Emphasis must be given to improving data collection and assessing accuracy. Recovery should be achieved if at all possible.

Mr. Stone - He described the major reentry flight test programs Langley is presently considering for possible inclusion on Atlas-boosted RVX-2 vehicles. They were
1. Aerodynamic investigation of basic shapes mounted on stings at the rear of the RVX-2. Shapes include delta wings at different angles of attack, wedges, blunt-nosed cylinders and blunt lifting bodies. The primary objective is to get flight pressure, heating, force and moment data on basic shapes that have been or will be investigated thoroughly in laboratory facilities to enable a correlation of flight and laboratory data and enhance greater confidence in the latter. Two shapes will be included to study real gas and boundary-layer displacement effects. This program has much flexibility and room for expansion as the flight laboratory test system is developed.

The Working Group thought this scheme to be particularly attractive for reentry flight testing.

2. Transpiration cooling--transmission experiment. As currently conceived a self contained sharp-nosed transpiration cooled cone would be mounted ahead of the present RVX-2 rounded nose. A cylindrical shape of ablation material would be mounted at the cone tip for stagnation heat protection. Heat transfer measurements would be made as well as antenna transmission measurements to determine whether cooling the boundary layer has any effect on improving transmission.

The Working Group saw merit in transpiration cooling for heat protection but not for improving data transmission. The hot ionized layer causing telemeter blackout is the bow shock wave, and boundary layer cooling should have no important effect on this. Furthermore the ablation material ahead of the proposed transpiration cooled area would interfere with the transpiration experiment. Members felt nose coolant ejection was more interesting for a flight test experiment to determine if stagnation area cooling could weaken the ionization in the bow shock and thereby relieve transmission blackout. Considerable gas would be required--more than could be stored ahead of the present RVX-2 nose. Dr. Adams felt that transpiration cooling was reasonably well understood for the leading-edge problem and its use is essentially a development rather than a research problem. Mach number is not a primary factor in its effectiveness, which can be studied adequately in ground facilities where enthalpy is duplicated.

3. Dynamic and acoustical loads on Atlas booster. This is not a reentry flight test program but is felt to be needed for manned flight use of Atlas and requires space in the reentry flight test nose for data recording equipment that can be recovered or played back in the over-the-top part of the missile trajectory.

4. Super satellite speed reentry experiments. The most important flight test requirement is to investigate heating, especially for the radiative input, and high-temperature materials
at these speeds. Langley's thinking is in the early stages as to what such experiments should be and how they should be carried out. Some consideration has been given to mounting the upper two stages of Scout on top of Atlas for an initial preliminary heating experiment.

The Working Group agreed that this is a top priority research problem requiring flight research although flight tests on problems of lunar return flight at satellite speeds are also very important. The capabilities of various vehicles for this research were discussed. Dr. Adams mentioned that AVCO is building a shock tube for laboratory research at 40,000 fps. He felt as much ground testing as possible was required to determine configurations for hypervelocity reentry flight tests. Chemical as well as aerodynamic scaling must be considered in a reentry flight test program at these speeds. Prof. Lees and Bogdonoff suggested that it would be particularly interesting to fly 3 or more bodies with different nose radii in one reentry flight test at 30,000 to 40,000 fps to evaluate the radiant heating problem at these speeds.

Mr. Klima - Messrs. Chamberlain and Flathers discussed for Mr. Klima the general requirements for reentry flight testing, the limitations of laboratory facility test conditions and the general characteristics of several vehicles for reentry flight testing. The objectives enumerated were similar to those discussed earlier in the meeting.

Considerable discussion ensued regarding the accuracy that could be achieved in reentry flight testing, for example in measuring very low pressures at high altitudes. Mr. Flathers felt the accuracy would be within 20 percent initially and would improve with time. As far as heat transfer is concerned, Prof. Bogdonoff thought it might be better to measure it by direct means rather than through temperature measurements. He reported good repeatability in temperature measurements in the 3,000 to 4,000°F range using zirconium thermocouples. The group as a whole felt that proper and accurate instrumentation must always be a basic consideration in determining the worthwhileness of flight test research.

**SUMMARY RECOMMENDATIONS**

**Space Flight Missions Requiring Reentry Flight Test Research** - The Group felt that the manned lunar mission had the most important research requirements not only at super orbital speeds but at satellite speeds as well. Fundamental flight test research for such a mission would also be pertinent to other important space flight missions such as the 24-hour satellite, recoverable probes, Dyna Soar type vehicles and recovery from low altitude orbits—Project Mercury follow on.
Research Results to be Sought with Particular Application to the Lunar Mission and Recoverable Probes

I. Research Results Required Throughout Speed Range to Escape Speed

A. Heating

1. Local $q$ over surfaces of simple blunt-nosed slender shapes such as blunt-nosed cones and cone cylinders, blunt leading-edge swept and unswept wings, half cones, control surfaces, and wing-body configurations from low to high angle of attack

2. Surface temperature distribution on surfaces of I A 1, especially time histories

3. Ablation rates and material behavior as differentiated from fluid mechanics

4. Cooling systems such as transpiration, nose coolant ejection, etc.

B. Pressure distributions on surfaces of I A 1 over angle-of-attack range

C. Control surface effectiveness

1. Flares, fins, flaps, elevons

2. Shock interaction effects, pressure distributions and forces

3. Measurements for range of $\alpha$ and $\delta$

D. Force and moment measurements for bodies of I A 1

E. Ionization and blackout

1. Effects of nose sharpness

2. Use of different radar frequencies

II. Research Results Particularly Required at Super Satellite Speeds

A. Total heating over wide range

B. Radiant heat transfer
1. Scaling laws
2. Nonequilibrium phenomena
3. Spectrographic characteristics

C. Convective heat transfer
   1. Conduction effects
   2. Dissociation effects
   3. Ionization effects

D. Behavior of materials under high radiant heating

E. Ionization and blackout at super orbital speeds

Means of Accomplishing Integrated Flight Test Laboratory Reentry Research Program

I. Ground Tests and Analysis

   A. NASA
   B. Industry and Universities where NASA facilities not adequate

II. Scout (Air Force Stabilized Version)

   A. Too little payload too late for important use in reentry testing
   B. Extremely marginal performance at super orbital speeds
   C. Could be of some interest in reentry probe shots at 19,000 to 20,000 fps as will be used for Dyna Soar testing

III. Hitch Hike - 500# Payload on Side of Atlas Missile with Operational Nose Cone

   A. Not too interesting for reentry aerodynamic flight testing unless attitude control and recovery systems are incorporated

   B. Warrants possible study in adding propulsion to package for boost to super orbital speeds (Information obtained since the meeting on the size of the package--70" x 28" x 28"--makes this doubtful.)
IV. Piggyback—3000-4000# Payloads Possibly Utilizing RVX-2 Type Vehicles on Missiles in Atlas R&D Program

A. Particularly attractive for reentry testing at orbital and suborbital speeds because of

1. Probable availability of Atlas boosters at no cost for such a program

2. Large payload capacity enables the testing of several aerodynamic and other experiments in a single flight under same flight conditions

3. Basic RVX-2 vehicle and recovery systems are developed articles although admittedly major changes would be involved in a reentry flight test program as envisioned by the Working Group

B. Possibilities exist for adding rockets to boost a reentry payload to escape speeds

C. The Working Group recommends a NASA-DOD program using 8 to 10 Atlas R&D missiles with nose cones of the RVX-2 concept modified as necessary to fulfill research objectives—the tests should be conducted within 18 months and include 2 or more flight tests at super orbital speeds

V. Atlas Able, Atlas Agena, etc. for Super Orbital Speed Flight Tests

A. Ultimately desirable

B. Working Group did not consider these vehicles to any extent at this time because they would be much more expensive (Atlas would have to be bought) than piggy back or hitch hike experiments for initial reentry flight test programs

COURSE OF ACTION

Aside from the country's dire need for generalized reentry flight test information of the type outlined, the Working Group felt that the NASA Research Centers must become active in such endeavor to uncover unforeseen problems in flight, to provide basic flight research information vitally needed in both NASA and DOD development programs, and most importantly, to give direction to and confidence in laboratory research programs using new facilities and techniques for accumulating data at hypervelocities. The Group, therefore, felt strongly that rapid steps must be taken'
to initiate a flight test program. BMD has funded 3 RVX-2A reentry flight test vehicles for materials testing and numerous piggyback experiments. BMD efforts to expand this program have not been successful in obtaining funds partially because of the basic research nature of the program as compared to developing specific military flight systems. Clearly the basic flight research program needed is of the type the NASA should prosecute in support of both NASA and military needs, the latter including needs of advanced ballistic missile as well as military space systems. It does not appear feasible for the NASA Research Centers to undertake such a program alone including purchase of boost vehicles in the time period required and consequently some sort of joint NASA-DOD program seems most practical with the DOD furnishing missiles in the Atlas R&D program for boost vehicles. No suggestions were made as to arrangements for a joint effort but the Group felt the NASA should fund a significant amount for technical direction of the test programs as well as analysis and publication of results.

Time did not permit writing and approval of the Group's summary recommendations at the meeting. The Chairman, therefore, agreed to prepare a statement for circulation to the membership for comment. The Chairman and Secretary will then prepare a summary statement for presentation to the parent Committee's Chairman, Dr. Stever. The summary recommendations appearing in these minutes were prepared by the Secretary based on his interpretation of the meeting and do not represent mutually agreed to recommendations. The Group felt that the NASA should not wait for the Committee to meet and consider its recommendations but rather that Lees and Stever should present the Working Group's recommendations to Mr. Abbott as well as Dr. Dryden and/or Dr. Glennan as soon as possible. Some members offered to solicit Air Force and DOD support at a high level should the NASA so desire. In the meantime the NASA Research Centers should proceed with high priority in laying out specific integrated laboratory-flight test experiments.

Respectfully submitted:

[Signature]

Secretary
ATTACHMENT B

MINUTES OF MEETING
OF
WORKING GROUP ON
REENTRY FLIGHT TEST PROGRAMS

COMMITTEE ON MISSILE AND SPACECRAFT AERODYNAMICS

NASA Headquarters Office
Washington, D. C.

July 22, 1960

Present:
Prof. Seymour M. Bogdonoff, Chairman pro tem
Dr. Mac C. Adams
Mr. Otto Klima, Jr.
Mr. Ralph W. May, Jr., Secretary

Absent:
Prof. Lester Lees
Mr. Robert B. Hildebrand

RESUME OF ACTIONS TAKEN SINCE FIRST MEETING OF WORKING GROUP

As agreed at the June 20, 1960 meeting of the Working Group, Prof. Lees drafted a report of the Group which he circulated to the membership and Dr. Stever for comment along with minutes of the June meeting. During the course of several telephone conversations and visits among the members it was agreed that Prof. Lees' draft was basically as desired with the exception that more emphasis should be placed on orbital and suborbital flight testing. Since Dr. Stever and Prof. Lees could not be available for a second meeting of the Working Group and discussion with Mr. Abbott and Dr. Dryden until mid August, they asked that the Group meet in their absence with Prof. Bogdonoff as Chairman pro tem to formulate a summary report and discuss it with Mr. Abbott and Dr. Dryden. It was agreed in these discussions that the summary report should not be concerned with program or vehicle details as they should be left to the NASA in its negotiations with the Air Force or DOD.

DISCUSSIONS WITH NASA OFFICIALS

Based on the above discussions, a brief summary report was prepared for discussion first with Messrs. Abbott and Pearson and later with Dr. Dryden present. There was complete agreement on the need of a type of reentry flight test program recommended by the Working Group and of the desirability of working with the Air Force in providing "piggyback" reentry test vehicles to be flown on missiles utilized during ballistic missile R&D programs. Mr. Abbott summarized the NASA financial position as pertinent to
such a flight test program, which would require NASA participation to be more limited than desired by the Working Group in the next two year time period. Nevertheless he pledged his efforts to initiate a substantial reentry flight test program by the NASA Research Centers in cooperation with the Air Force if vehicles in the ballistic missile R&D program can be made available. Langley at this time is working on a definite proposal which he would like to have in hand before approaching the Air Force within a week or ten days. Prof. Bogdonoff suggested, however, that Mr. Abbott's initial approach to the Air Force not be concerned with program details but rather with obtaining high level agreement in principle to the type of joint NASA-DOD reentry flight test program desired. Mr. Abbott concurred, although he felt it desirable to have some type of general NASA proposal in hand that would suggest the general approach to be taken, the level of NASA support and so forth.

In the discussion with Dr. Dryden, he pointed out difficulties in placing "piggyback" experiments aboard Atlas R&D launchings and expressed personal doubt that as many Atlas R&D vehicles could be made available for reentry type testing as envisioned by the Working Group. He stated that the NASA Space Flight Centers are considering some reentry flight tests, although the plans are not at all settled at present. Nevertheless, he welcomed the recommendations of the Working Group and encouraged the Group to be of as much assistance as possible in initiating a joint NASA Research Center-Air Force reentry flight test program using Atlas missiles in the ballistic missile R&D program. He asked Mr. Abbott to approach the Air Force on the matter.

SUMMARY REPORT

Following the above discussions the Working Group prepared the attached summary report for distribution to the parent Committee on Missile and Spacecraft Aerodynamics and for possible use of the NASA in negotiation with the Air Force.

Respectfully submitted:

[Signature]
Secretary
ESTABLISHMENT OF WORKING GROUP ON REENTRY RESEARCH

NASA RESEARCH ADVISORY COMMITTEE ON MISSILE AND SPACE VEHICLE AERODYNAMICS

At a meeting of the full NASA Committee on Missile and Space Vehicle Aerodynamics held May 11-12, 1960, the following recommendation was adopted:

The Committee recommends that NASA now formulate a program of reentry research flights for aerodynamic purposes beginning with earth atmospheric flights and including eventually probing flights of Venusian and Martian atmospheres. Reentry research in the flight program is not receiving enough attention relative to other research.

The Committee does not believe that a few NASA reentry flights with Scouts is adequate for this program over the next few years. It recommends that NASA participate in and help support the Department of Defense reentry program, and use the Air Force stabilized Scout vehicles and other reentry test vehicles. Particularly the "piggy back" flights on Air Force ballistic missiles, such as the RVX-2A, and the "hitch hike" scheme may afford great economies.

The Committee is setting up a Working Group to list the research results to be sought, as well as proposed methods for getting these results.

The Committee Chairman, Dr. H. Guyford Stever, appointed the following Committee members to constitute the Working Group:

Professor Lester Lees, Chairman
Dr. Mac C. Adams
Professor Seymour M. Bogdonoff
Mr. Robert B. Hildebrand
Mr. Otto Klima, Jr.
Mr. Ralph W. May, Jr., Secretary
During the next five to ten years, this country will undertake a whole series of space explorations and experiments, ranging from sub-orbital and orbital programs to lunar and planetary explorations. These efforts are not being supported to a sufficient degree by an integrated basic research program aimed at supplying the required fundamental information. The Working Group feels that the NASA Research Centers must become active in such endeavors to provide basic flight research information vitally needed in both NASA and DOD development programs, and to establish the relationships between flight results, theoretical predictions, and laboratory experimental data.

Although the many research problems are interrelated, actual testing requirements and objectives can be used to delineate three key areas of research:

1. **Super-satellite reentry.** During the next few years one of the most challenging technical problems to be undertaken by the NASA is the launching and successful recovery of a manned lunar mission. The reentry phase involves flight in the earth's atmosphere at super-satellite velocities up to escape speed and over a wide range of flight altitudes, a region in which almost no data are available. A vigorous program of research into the unknowns in this area must be initiated now if the designer is to be supplied with the information he requires in time to be useful to him. Knowledge developed by this research program will also be useful in the design of unmanned, recoverable lunar and planetary instrument carriers, and in recovery from 24-hour orbits.

2. **Verification of laboratory experimental and theoretical results.** No single ground-based facility now known can simultaneously simulate all of the complex phenomena occurring in the satellite and super-satellite speed range. Essential theoretical work, and experimental investigations in such equipment as firing ranges, shock tubes, shock tunnels, "hot shots", helium tunnels, arc tunnels and low-density hypersonic tunnels must be supplemented and supported by flight tests if the laboratory results are to be used with confidence to design advanced vehicles. Our conclusion that flight research is a necessity and not a luxury is strongly supported by several years of practical experience with the ICBM nose cone problem.

3. **Satellite and sub-orbital application.** Any vehicle designed for super-satellite reentry would, of course, also operate in this region during part of its flight program. Current programs of satellite and sub-orbital application still lack fundamental information in many areas.
Particular problems are associated with configuration design and maneuverability in this speed range. Such concepts as Dyna Soar, the satellite "ferry", and advanced ICBMs all depend on fundamental information not currently available in scope and confidence level required to design advanced vehicles.

Although the Working Group realizes that the outline presented represents, in some ways, a National Reentry Flight Program which the NASA cannot support in its entirety, they strongly recommend that the NASA take the initiative in establishing such a program, both in support of its own efforts as well as the nation's as a whole. This Working Group strongly recommends that the NASA take immediate steps to initiate a cooperative NASA-USAF flight research program.

We outline below some of the basic problem areas and factors that should be considered in the formulation of an adequate flight research program.

**Problem Areas**

1. Heat Transfer and Ionization Problems at Super-Satellite Speeds. At super-satellite speeds, radiative heat transfer to the blunt nose of a vehicle can become the dominant mode of energy transfer. Ionization levels in the shock layer are much higher than at ICBM speeds, so that the communications blackout problem becomes even more serious. A research program in this area should include the following studies:

   (a) Total heat transfer rates on some simple shapes, e.g., blunt-nosed conical body at various angles of attack, with various bluntness ratios.

   (b) Radiative heat transfer contribution, including establishment of scaling laws, study of self-absorption, non-equilibrium phenomena and radiation "overshoot", and spectrographic measurements.

   (c) Convective contribution, including effect of ionization on boundary layer heat transfer.

   (d) Behavior of materials under radiant heat input, especially ablating materials. Development of good reflectors over the important portion of the spectrum.

   (e) Cooling systems, including ejection of helium, hydrogen and other gases at blunt nose, or leading edge; and transpiration cooling.

   (f) Ionization and blackout, including study of reflection and absorption of electromagnetic waves over wide range of frequencies from 30 mc./sec. to 100 kmc./sec.

(a) Static pressure distributions over typical blunt-nosed slender bodies, such as blunted cones, unswept and swept wings with rounded leading edges, and simple lifting half-bodies, over a range of angles of attack.

(b) Control surface effectiveness for deflected fins, flares, and flaps, over a range of angles of attack and control surface deflection angles, including static pressure distributions and heat transfer rates.

(c) Measurement of forces and moments on complete configurations.

Basic "Ground Rules" for a Reentry Research Flight Program

1. Test vehicles should utilize existing boosters.

2. Flights should utilize existing range facilities for tracking and reception of telemetered reentry data.

3. A recovery system is necessary to obtain data during "blackout", as a backup for telemetry and as an essential part of the study of materials and behavior of sensors.

4. Attitude control and stabilization is essential during reentry.

5. Each flight may carry many different experiments.

6. Each flight must be closely supported by analytical work and ground-based experiments if the data are to be meaningful.

Possible Means of Obtaining Flight Research Results

It is the understanding of the Working Group that a number of Atlas firings are scheduled by the Air Force over the next two years in order to check out propulsion, guidance, and other components but not the reentry vehicle. On these shots the ICBM nose cone may be replaced by a research vehicle of the RVX-2 type. This vehicle can weigh in excess of 3000 pounds and can be made flexible enough to carry multiple experiments, guidance and stabilization systems, several hundred channels of telemetry, and may include a booster stage for increasing the speed.
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