The Office of Advanced Research and Technology has the requirement of preparing a management-oriented paper which documents the philosophy and techniques employed by NASA to develop experimental bench marks against which ground-based theory can be evaluated and extended. The following material was prepared from the Fire program experience at the Langley Research Center.

I. TECHNICAL REASONS FOR DEVELOPING EXPERIMENTAL BENCH MARKS AGAINST WHICH GROUND BASED THEORY AND FACILITIES CAN BE EVALUATED AND EXTENDED

When Project Fire was in the planning stages, heating transfer theory stated that above 34,000 fps the stagnation radiant heating input was proportional to the velocity to the twelftth power, or possibly to the twenty-fourth power. At about summer of 1953 comparisons of the best available theoretical radiant heating input calculated for 37,000 fps showed them to differ by factors of 2, 4 and 9. At the time of the Project Fire flights the best available radiant heating input theories calculated for 37,000 fps still had large factors of variance, for example, 2, 3 and 6. This indicates that the ingredients used in the recipe for the theory was still unknown as to what is important to emphasize in the mathematical model of the gas dynamics.

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 velocities 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 radiant heating. However, large scale tests are required to confirm that at hyperbolic velocities the convective heating continues to be inversely proportional 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.

Consequently it can be recognized that actual flight tests in the reentry conditions at large scale would be required to provide anchor point data; thereby, with this 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.

II. MANAGEMENT EVENTS LEADING TO FORMULATION OF FLIGHT PROGRAM.- In February 1960 the NASA advisory committee on the Aerodynamics of Missiles and Spacecraft advised NASA to implement the ground facility research with flight tests in the actual reentry environment. Specifically this advice was for flight tests for lifting reentry at orbital velocities and ballistic reentries at super-orbital velocities. In the spring of 1960 a committee was formed at the Langley Research Center to formulate a program for high-speed reentries utilizing vehicles then known to be available -- RVX-2, Atlas Agena, and "Hitchhike or Piggy-back" payloads on development Atlases. During June 1960 this LRC committee canvassed the industry concerned with reentry technology (G. E., AVCO, SII, Lockheed) along with cognizant government agencies (USAF-SSD, LRC, ARC). A report was made to NASA Headquarters (specifically to office headed by I. H. Abbott) in July 1960 showing how a program could be built using the vehicles that were then available and recommending Atlas-Agena for tests at 36,000 fps. In a memo to the Director of LRC by John V. Becker dated July 20, 1960, a NASA Reentry Flight Test Program was proposed. This program had the support of the Langley Committee and all those at LRC concerned with reentry technology. The program proposed had these main divisions of flight tests:

- RVX-2 on Atlas for lifting body studies in support of Dyna Soar
- Advanced structures and materials on Scout vehicle
- Data transmission - 3 Argo D8 and 2 Atlas E vehicles
- Booster dynamics - 2 Atlas E vehicles
- Heat transfer and advanced materials at 30,000 fps - 3 5-stage Scout vehicles
- Aerodynamics, heat transfer, and advanced materials at 36,000 fps - 2 Atlas-Agena vehicles.
On August 20, 1960 by direction of F. L. Thompson the Langley Research Center began the organization of an LRC program of Flight Reentry Studies with J. V. Becker overall chairman. This program organization consisted of the following panels:

- Panel A: Atlas RVX-2 lifting body studies
- Panel B: Advanced Structures and Materials
- Panel C: Data Transmission
- Panel D: Supercircular Velocity
- Panel E: Vehicle Systems

A report was made by Langley on the activities in formulating a Flight Reentry Test Program to the NASA Committee on Aerodynamics of Missiles and Spacecraft at their meeting on October 11-12, 1960. The committee expressed support and expedition of the Langley program.

On January 6, 1961 E. C. Draley in a visit to NASA Headquarters discussed the flight reentry test program, in particular Headquarters' concern over the funding of such a program. The point was made that this program was expensive and if NASA was to be the leader in reentry technology the program must be funded.

As a result of this panel organization activity through late 1960 and early 1961, the following Flight Reentry Projects came into being:

1. Lifting body reentry flight tests utilizing the RVX-2 on an Atlas. This project was terminated by Langley after informal discussions in NASA Headquarters in late summer of 1962.

2. Five-stage reentry Scout project for supercircular velocity environment and advanced materials.

3. Project RAM radio attenuation measurements.

4. Flight reentry project utilizing the Atlas-Agena B vehicle for the flight investigation of the Apollo reentry environment at 36,000 fps (later named Calorie).

III. EVENTS LEADING TO THE CONCEPT AND ORGANIZATION OF PROJECT FIRE. On May 28, 1961 F. L. Thompson, Director of Langley Research Center, ordered the following changes and implementation of the Flight reentry program:  

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From Mgr, FRPO

to Assoc Dir

1. Rescinded the panel activity and organization setting up to plan the program because the planning job was now complete.

2. Set up the Reentry Science Program Steering Committee chaired by E. S. Love. This committee to report directly to and to assist the Director in technical management of the program since the program was now in the active stage of implementation.

3. Set up the Flight Reentry Programs Office for the management and implementation of the projects in support of Dyna Soar utilizing the RVX-2 and in defining the reentry environment at 36,000 fps in support of Apollo.

Through the summer of 1961 activities proceeded on plans to implement the Atlas-Agena program at 36,000 fps by means of research and development contracts to industry. A calorimeter approach for direct measurement of the total heating was specified plus a direct measurement of the radiative heating as was being explored by a new instrument, or radiometer, in the Scout reentry program. Considerable support in ground facilities was conducted to support the concepts and to lend assurance to the proposed measurement techniques. This flight program received approval in NASA Headquarters on September 15, 1961 and was funded under Manned Spacecraft resources. At this time the flight reentry project in support of Apollo was named Calorie. Project Calorie had proceeded to the stage where the request for proposals were about to be published when the project was cancelled by the Headquarters of the NASA on September 28, 1961.

With the cancellation of Project Calorie, work proceeded immediately on a new flight reentry test proposal to explore the environment of a vehicle reentering at hyperbolic velocities. The technical need for the flight test was still the basic requirement of providing anchor point data on the convective and radiant components of heat transfer and plasma sheath effects needed to expand the usefulness of ground facility experiments and theoretical investigations. During 1961 considerable knowledge had been gained by the Langley Research Center on just how to measure total heating and radiative heating, and as a consequence the layered calorimeter heat shield approach was proposed. A project development plan was submitted through the Langley Directors to OART-NASA Headquarters in late November 1961 for a new flight reentry project having two flights at 37,000 fps using Atlas plus the solid fuel Antares powered spacecraft, and two flights at 44,000 fps using the Atlas Agena-B.
On December 5, 1961 the Langley Reentry Science Program Steering Committee agreed to the layered heat shield approach recommending beryllium as the calorimeter material. Also, the Committee set the order of priority of the measurements on the flight payload as follows:

1. Radiative and convective heat transfer measurements
2. Materials response
3. Radio attenuation measurements
4. Lifting entry conditions.

In addition, the committee stipulated that the calorimeter experiment as a first-choice should have three beryllium calorimeter layers and make radiation heating measurements at the stagnation point, off center on the face, and on the afterbody. The RSFS committee unanimously endorsed the planned new flight test program.

On December 11, 1961 the project plans were changed to include the 37,000 fps flight tests only at the request of NASA Headquarters and concurrence of the Langley Director. This new flight reentry research project, now named Fire, was approved on December 19, 1961. Cognizance and funding of the Project Fire effort was under the auspices of the Office of Advanced Research and Technology.

During the autumn of 1963 contracts for theoretical predictions of the heat transfer characteristics of the Fire configuration and reentry conditions were let with three different companies (G. E., Philco and Lockheed). This was done to get a measure of several different methods of theoretical prediction prior to and not influenced by the results of the Fire reentry data.

Some milestones which are indicative of the pace and history of Project Fire are as follows:

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<tr>
<th>Date</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>12-19-61</td>
<td>Project approval</td>
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<tr>
<td>1-2-62</td>
<td>Initiate procurement of Atlas launch vehicles</td>
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<tr>
<td>1-30-62</td>
<td>Reentry Package request for proposals mailed to industry</td>
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<tr>
<td>6-13-62</td>
<td>Formal award of Reentry Package contract to Republic Aviation Corporation</td>
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<tr>
<td>7-25-65</td>
<td>Formal award of Velocity Package contract to LTV-Aerospace Corporation</td>
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<tr>
<td>9-30-63</td>
<td>Practice dry run of launching. All systems were ready with the exception of the Reentry Package.</td>
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From Mgr, FRPO to Assoc Dir

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4-14-64 Successful Flight of Fire I
5-22-65 Successful Flight of Fire II

IV. MANAGEMENT OF PROJECT FIRE.—The Flight Reentry Programs Office was
organized by the Director to manage flight reentry projects. This office
reports to an Assistant Director and was staffed with engineers and
scientists of wide experience and competency. Other than the function
of the Mission-Technical Staff of the Office, the function of the Office
was management. The engineering, technical, administrative, and supporting
services were provided by the Langley line divisions. At one time or another
all of the Langley divisions became involved with Project Fire at various
levels of support. Over a three and one-half year period of the project
the number of equivalent full-time Langley personnel varied from a minimum
of 23 to a maximum of 83. The maximum number of people in the project
office was 23. The amount of R and D funds obligated to Project Fire to
date is 20.2 million dollars for spacecraft and support, 9.2 million dollars
for launch vehicles which is a current total obligation of 29.4 million
dollars. The estimated total cost to completion is 29.9 million dollars.

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