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Aerothermodynamic Analysis of the Project FIRE II Afterbody Flow

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Introduction

35 years later, the Project FIRE II ballistic reentry to Earth at a nominal velocity of 11.4 km/s remains one of the best sources of heating data for the design of sample return capsules. The data from this flight experiment[1-3] encompass both the thermochemical non-equilibrium and equilibrium flow regimes and include measurements of both radiative and total heating on the forebody and afterbody. Because of this, a number of researchers have performed computational fluid dynamics (CFD) simulations of the forebody of the FIRE II entry vehicle,[4-7] with generally good results. In particular, Olynick *et.al.*[5] coupled a Navier-Stokes solver (GIANTS) with a radiation code (NOVAR) and showed excellent agreement in surface heat transfer over the FIRE II trajectory between 1634 and 1651 seconds (77 km to 37 km). However, in most cases the primary motivation of the previous work was to understand and model the coupling between shock layer radiation and aerothermodynamics, and thus the simulations concentrated on the forebody flow only. To our knowledge there have been no prior published attempts to reproduce the afterbody heating data presented in Ref. 2. However, an understanding of this data is critical to our efforts to design the next generation of Earth and planetary entry vehicles and to assess our need for additional flight data.

Reentry Package

Figure 1, taken from Ref. 3, is a schematic of the FIRE II reentry package, showing the sensor locations on both the forebody and afterbody. FIRE II was constructed with a layered forebody consisting of three separate beryllium calorimeters interspersed with phenolic-asbestos heat shields. Each calorimeter was designed to be ejected at the onset of severe melting, resulting in three separate data-gathering windows during reentry. Forebody instrumentation also included stagnation point and off-axis radiometers, which measured total incident radiation between 0.2 and 4.0 microns.

The conical afterbody was constructed of a fiberglass and phenolic-asbestos shell coated with a silicon elastomer protective material. A symmetrical array of 12 gold calorimeters was placed on the afterbody shell, as shown in Fig. 1. All 12 calorimeters appeared to work perfectly during the flight. A sample temperature time history from one of the calorimeters is shown in Fig. 2. The data are well behaved, with the exception of small jumps near the times of forebody calorimeter

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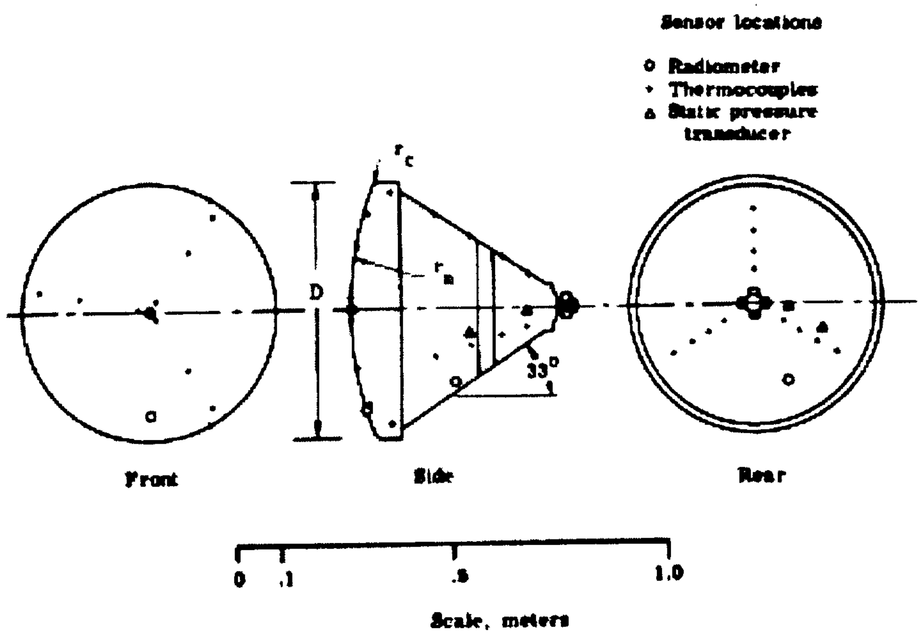

Figure 1 Schematic of the FIRE II instrument package (taken from Ref. 3)

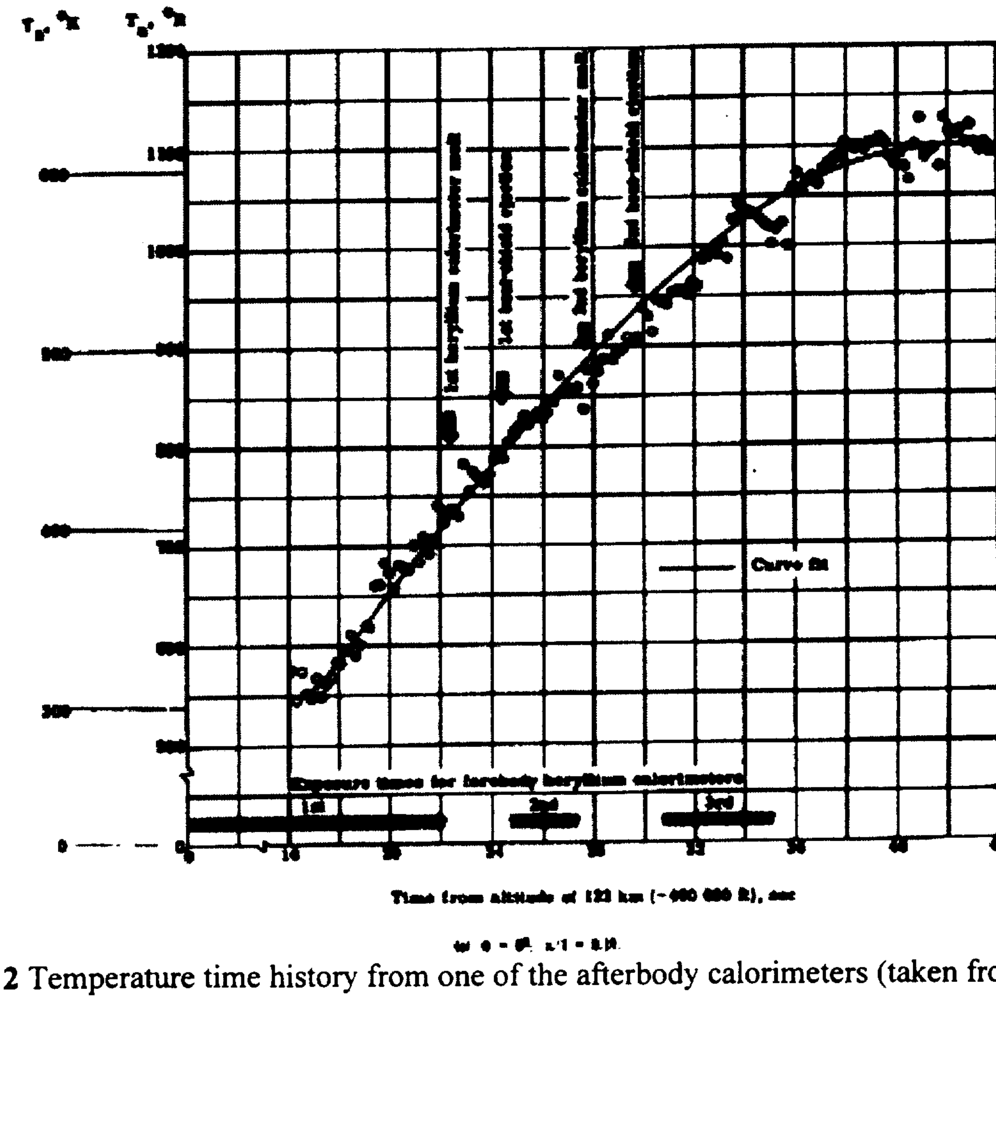

Figure 2 Temperature time history from one of the afterbody calorimeters (taken from Ref. 2)

melting and heat shield ejection (indicated on the figure). The maximum heating rates indicated by the calorimeter measurements ranged between 17.8 and 14.5 W/cm^2. In addition, a single pressure transducer and radiometer were included, as shown in Fig. 1. The afterbody radiometer indicated zero incident radiation during the entire descent, with the exception of a single flash associated with a forebody heatshield ejection. This indicates that the afterbody radiation was less than the 1 W/cm^2 threshold intensity of the radiometer.

Methodology

The FIRE II afterbody flowfield will be examined using a methodology based on earlier work by Olynick *et.al.*[5] This technique has been applied previously to other afterbody analysis, including the Stardust sample return vehicle.[8] The DPLR[9] code, which is based on the same physical and numerical modeling used in GIANTS, will be used to simulate the flowfield. Areas that will be explored include the following:

- Although the onboard radiometer indicated that afterbody radiation was negligible, there may be coupling effects between the forebody radiation and the afterbody flowfield, especially in the shoulder region where the separation shear layer forms.

- Earlier work by Olynick indicates that, although beryllium is nominally highly catalytic to reactions, the presence of atomic oxygen in the flow would quickly oxidize the forebody heatshield, rendering it non-catalytic to neutral species. However, the protective coating on the afterbody may be catalytic.

- Turbulence, which was not a factor on the forebody near the peak heating point, may become important in the wake flow. Proper turbulence modeling is necessary to properly capture the separation point and the shear layer spreading rate, which has a first order effect on the base region.

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