ASE 396 Current Systems Analysis: AEROASSIST FLIGHT EXPERIMENT

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November 2, 1992

[This systems analysis draws upon a briefing given by Michael Ruiz of NASA/JSC, Navigation Analysis Section, on February 28, 1990, entitled "Aeroassist Flight Experiment: Mission Overview," and on the author's own experiences while working on validation of some aspects of this mission's navigation system design.]

The Aeroassist Flight Experiment (AFE) is a spacecraft whose mission is to study aerobraking technology by performing an aeroassisted orbit change maneuver. It is an autonomous, free-flying vehicle, intended to be deployed and recovered by the Space Shuttle. The mission was cancelled in 1991, just prior to moving into Phase C of its design process, the detailed development phase. Thus, its design is quite mature, and, given the general interest of the aerospace community in aeroassist/aerobrake technology, an examination of the state of its systems just prior to its cancellation can provide a good deal of insight for the spacecraft designer. Furthermore, efforts are underway to revive the program (possibly under another name) within the next several years.

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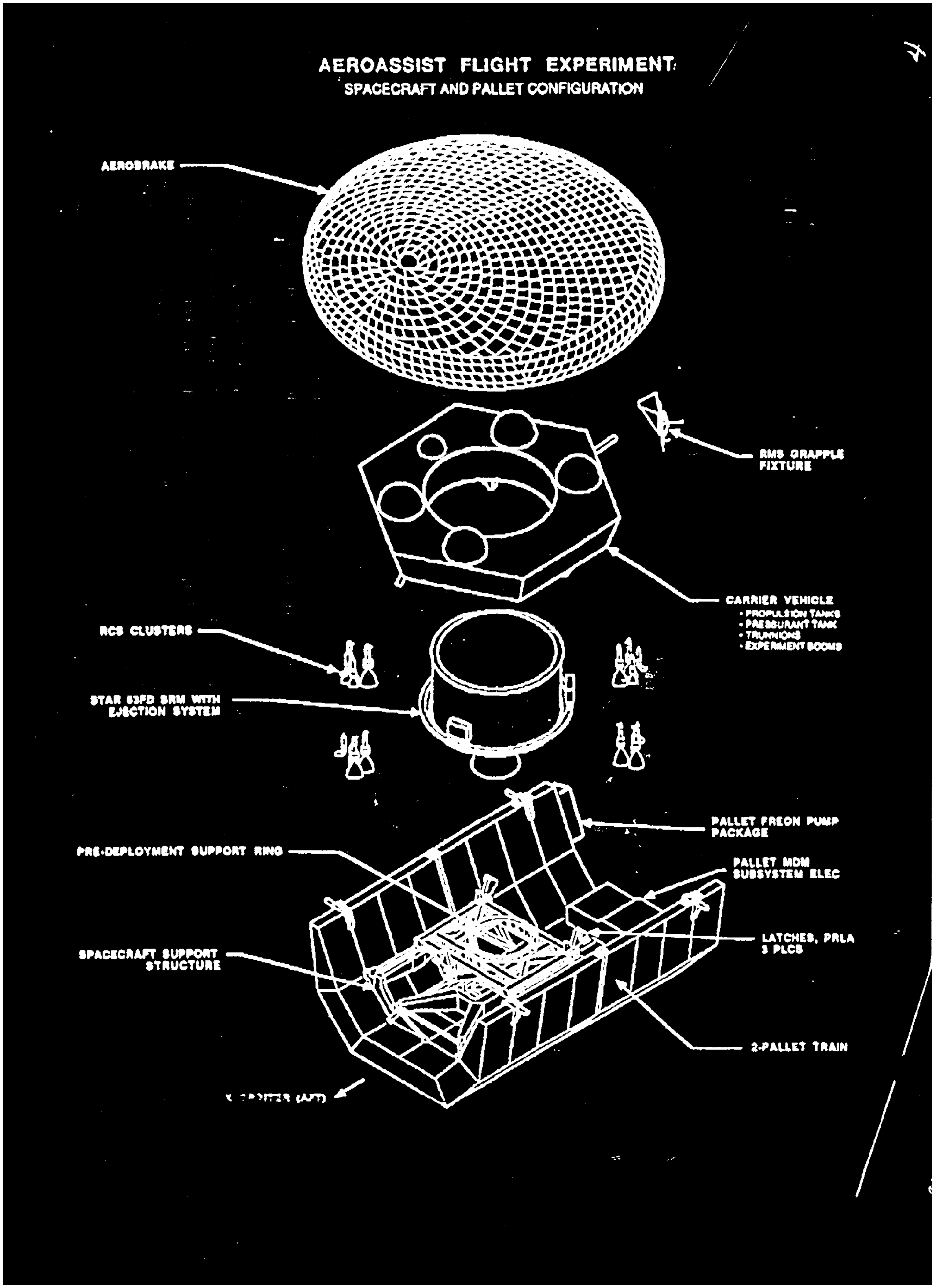

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The AFE mission has the primary objective of simulating the transfer of a satellite from geosynchronous Earth orbit (GEO) to low Earth orbit (LEO) by means of an aerobraking maneuver. This will allow scientists to gather data about the upper atmosphere, and its interaction with a vehicle flying at high Mach numbers, through eleven experiments carried by the vehicle. The mission will also enhance the state of the art in aeroassisted orbit transfer guidance and control technology. Through recovery and inspection of the vehicle, data will be collected concerning the performance of the spacecraft thermal protection system, which will advance the knowledge base in this field as well. Major systems of the AFE include

- the science experiments,
- the aerobrake / thermal protection / structure,
- guidance, navigation, control, and communications,
- propulsion,
- trajectory,
- airborne support equipment (a structure in the Shuttle payload bay to which AFE is berthed),
- power, and
- thermal control.

Each of these systems will be characterized below, and the flow across their interfaces will be discussed, where applicable.

There are eleven science experiments onboard the AFE. Although a detailed description of each is beyond the scope of this document, they are listed below, along with the name of the NASA center at which each is managed (ARC - Ames Research Center, LaRC - Langley Research Center, JSC - Johnson Space Center). Requests for more information about the experiments can be addressed to the Principal Investigator for each experiment, care of the NASA center listed with it.

1. Radiative Heating Experiment (ARC)
2. Wall Catalysis Experiment (ARC)
3. Aerodynamic Performance Experiment (JSC)
4. Pressure Distribution/Air Data System (LaRC)
5. Forebody Aerothermal Characterization Experiment (LaRC)
6. Rarefied-Flow Aerodynamics Measurement Expermeint (LaRC)

7. Heat Shield Performance Experiment (ARC)
8. Base Flow and Heating Experiment (JSC)
9. Afterbody Radiometry Experiment (ARC)
10. Alternate Thermal Protection Measurement (ARC)
11. Microwave Reflectometer Ionization Sensor (LaRC)

These experiments typically have power and thermal control requirements which the spacecraft must satisfy. In addition, some require communications before, after, and/or during the atmospheric passage (“aeropass”). The latter adds significant complexity to the mission in terms of designing antenna pointing algorithms, which must interact with the attitude control software. Some experiments require post-flight inspections and/or analysis on the ground, which drives the requirement for recovery by Shuttle. A final significant driver to mission complexity are those experiments which require a “quiescent period” during the aeropass, in which no attitude control jets may be fired. Based on the author’s experience with this mission, those experiments which make special requirements during the aeropass, such as for communications and/or a quiescent period, significantly increase the cost and complexity of the mission, and reduce its probability of success.

The aerobrake consists of an aluminum skin and stringer structure, covered with Space Shuttle Orbiter thermal protection system tiles (FRCI 12 and LI-2200). It is 14 feet in diameter, and has a “raked-cone” design. Other, deployable, designs were considered including gas bags (“ballutes”), and an umbrella-type mechanical structure. However, the rigid structure was selected since it produces a trim angle of attack, allowing lift vector modulation (e.g. banking) to be used as a trajectory control mechanism during the aeropass. Also, the rigid structure produces a lower heating rate, and is simpler and therefore less risky. The weight of this design however, is higher than that of a deployable system. The AFE afterbody, which carries the bulk of the spacecraft systems, is a simple aluminum spaceframe structure, with additional thermal protection provided by another type of ceramic tile (AFRSI/LI900) and MLI insulation.

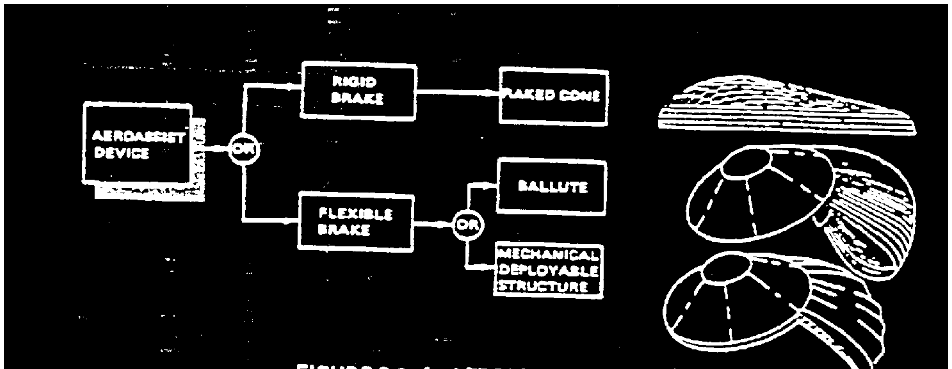


FIGURE 3.1–1 AEROBRAKE OPTIONS

The guidance, navigation, and control systems rely as much as possible on existing hardware and technology, to drive down cost and complexity. Due to limitations of the thermal protection and thermal control systems, an extremely narrow range of atmospheric entry flight path angles is allowable (~ 0.05° tolerance). Therefore, a three-axis stabilized control system is required. This system consists of hydrazine-fueled reaction control system (RCS) jets for main maneuvering actuators, with Helium cold gas thrusters for maneuvering in the vicinity of the Space Shuttle, and a ring-laser gyro inertial measurement unit (IMU) as the only sensor. All computations are performed in a space-rated, Intel-80386-chip-based flight computer. The system is single string, and requires initialization from the Space Shuttle. Although the GN&C system allows the AFE to be autonomous throughout its free-flight phase, relying on the Space Shuttle for initialization requires a significant dose of unnecessary design complexity. In particular, initializing the IMU with an onboard star tracker would provide greater accuracy and more mission flexibility, at a small weight and cost penalty in comparison with the complexity of Shuttle-based attitude initialization.

As just mentioned, part of the propulsion system consists of hydrazine and cold-gas thrusters. The remainder of the system is a Thiokol Star 63F solid rocket motor (SRM), which is used to inject the AFE onto a trajectory which mimics a transfer from GEO. Other systems which were considered included several liquid-fueled boosters, and the PAM-D and -S systems. The system selected was the only one capable of meeting accuracy, safety, and thrust requirements of the mission.

The mission trajectory is a direct insertion from a Shuttle-class LEO orbit (~185 nautical mile (nmi) altitude circular) onto the descending leg of a 19323 x 41 altitude elliptical orbit. The SRM casing will then be ejected, and burn up in the atmosphere. The subsequent maneuvers during aeropass will transfer the AFE onto a 184 x 30 nmi ellipse, and after the aeropass, the RCS jets will be fired to circularize the orbit at 166 x 166 nmi for recovery by the Shuttle. This trajectory was chosen over a “lob-class,” two-burn trajectory, in which the AFE would be inserted first onto the ascending leg of a transfer orbit with a somewhat lower apogee, then a second burn performed on the descending leg to bring the entry velocity up to specifications. This trajectory would require either a re-startable, liquid-fueled booster, or a two-stage solid rocket booster system, increasing the propulsion system complexity. Also, such a trajectory would increase the mission duration, placing greater requirements on the spacecraft power system.

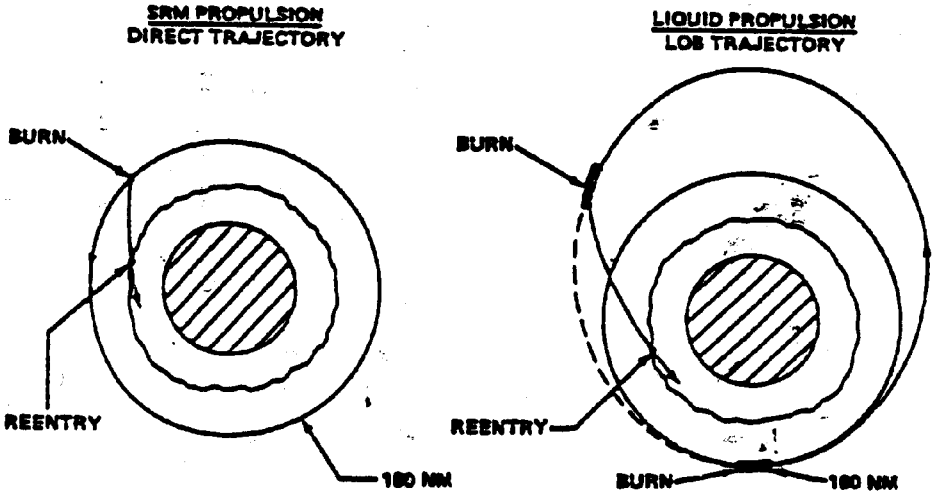
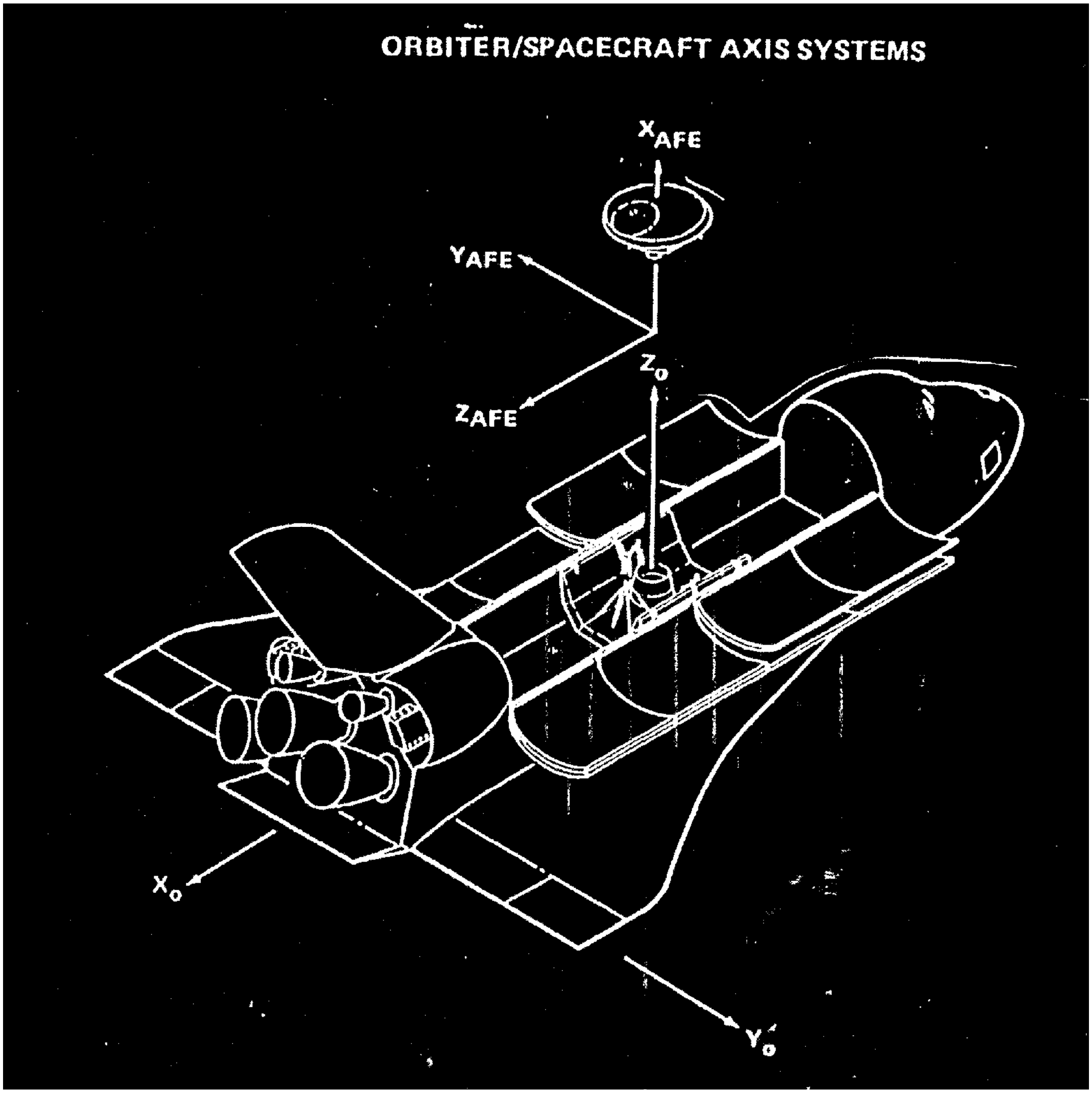


FIGURE 3.4 –1 TRAJECTORY PROFILE OPTIONS

The Airborne Support Equipment provides a berth for the AFE in the Shuttle Orbiter payload bay, which allows for deployment, retrieval, and data transfer. A modified version of the pallet used for Spacelab missions is used. This system is the only existing system meets the aforementioned requirements, is compatible with the AFE design, and is “Shuttle-proven.” Additionally, its cost and weight are low in comparison with other competing systems, such as those used for PAM-A or -D.



Power for the AFE is provided by silver zinc batteries, which are simple, inexpensive, and provide adequate power for the mission. However, the short lifetime of these batteries significantly affect the mission profile and abort modes of the mission. Other systems, such as deployable solar cell arrays and RTGs, were eliminated as design choices, presumably due to cost and complexity.

Thermal control systems are required to dissipate heat during the aeropass, and to keep the electronics warm during dark portions of the mission. Simple passive radiators are used for the former, and heaters are used for the latter.

Although this overview of the AFE systems is necessarily sketchy, a fairly good idea of the complexities and interactions among the variety of subsystems in a mature spacecraft design has been presented. In particular, I have tried to show how a few shortcomings in some systems of an overall design which is very good have had implications which affected the cost and complexity of the entire mission, and in some measure, led to its eventual cancellation. If this mission is ever successfully re-initiated, it may in large part be due to re-considering some the design choices presented here, with an eye to eliminating the problems which we encountered.