Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Aeroassisted Flight Experiment Aerodynamic Characteristics at Flight Conditions

K. James Weilmuenster* and Peter A. Gnoffo*
NASA Langley Research Center, Hampton, Virginia 23665

Introduction

AEROASSISTED space transfer vehicles[1] use aerodynamic forces during hypersonic aerobraking maneuvers in the upper layers of planetary atmospheres to circularize high-energy, entry trajectories. In order to better understand the flight environment of such a vehicle, a flight experiment has been proposed by research organizations within NASA and is called the Aeroassisted Flight Experiment (AFE).[2]

The success of the AFE project will depend in part on the proper placement of instrumentation on the vehicle surface and on the ability of the vehicle to fly the maximum science payload weight. Both of these factors are impacted by the accuracy to which the trim angle of attack (stagnation-point location) and the pitching-moment characteristics (sizing of the active control system) of the vehicle can be predicted. The initial aerodynamic data base was established using wind-tunnel data where appropriate and computational fluid dynamics (CFD) analysis where the influence of real-gas effects precluded the use of information obtained in ground-based facilities. The initial CFD computations were made using an inviscid code and an equilibrium air-chemistry package and included only the forebody portion of the vehicle.

More recently, a viscous, thermochemical nonequilibrium flow analysis about the complete vehicle, including the wake, has been applied to update the vehicle aerodynamic data base. These two data sets are presented and discussed below.

Geometry

The AFE vehicle shape is shown in a symmetry plane view in Fig. 1. The vehicle is constructed using a 60-deg elliptic cone of ellipticity 2.0 that has been raked off at a 73-deg angle. The nose is an ellipsoid that is tangent to the cone at all intersection points. At the aft end of the cone, a circular arc, which is tangent to the cone in any meridinal plane, is appended to the body. This configuration has been defined mathematically in Ref. 3. In addition, a hexagonal shroud has been appended to the base to provide protection for the science payload.

Received Feb. 11, 1990; revision received and accepted for publication March 8, 1990.

*Senior Research Engineer, Aerothermodynamics Branch, Space Systems Division. Senior Member AIAA.

Computational Codes

High Alpha Inviscid Solution

The inviscid equilibrium air-chemistry computations were made using the High Alpha Inviscid Solution[4] (HALIS) code and employing the equilibrium air curve fits of Tannehill et al.[5] Briefly, the HALIS code generates time-asymptotic solutions of the three-dimensional Euler equations utilizing an unsplit MacCormak differencing scheme. The solution space is the volume between the bow shock wave, which is treated as a time-dependent boundary, and the body surface. This leads to a coordinate system defined by the position of the bow shock and body as well as the spatial derivatives along these surfaces.

Langley Aerothermodynamic Upwind Relaxation Algorithm

Program LAURA[6] (Langley Aerothermodynamic Upwind Relaxation Algorithm) is an upwind-biased, point-implicit relaxation algorithm for obtaining the numerical solution for the governing equations for three-dimensional, viscous, hypersonic flows in chemical and thermal nonequilibrium. The algorithm is derived using a finite-volume formulation in which the inviscid components of flux across cell walls are described with Roe's averaging and Harten's entropy fix with second-order corrections based on Yee's Symmetric Total Variation Diminishing scheme. Because of the point-implicit relaxation strategy, the algorithm remains stable at large Courant numbers without the necessity of solving large, block tridiagonal systems.

Data Points

Initially, for the purposes of consistency, three points along the nominal AFE trajectory were designed as the points at which all CFD computations would be made. They consisted of a point on the entry portion of the trajectory, a point at the maximum penetration of the atmosphere, and a point on the exit portion of the trajectory. Because of the substantial changes to the nominal trajectory, the addition of a fourth CFD

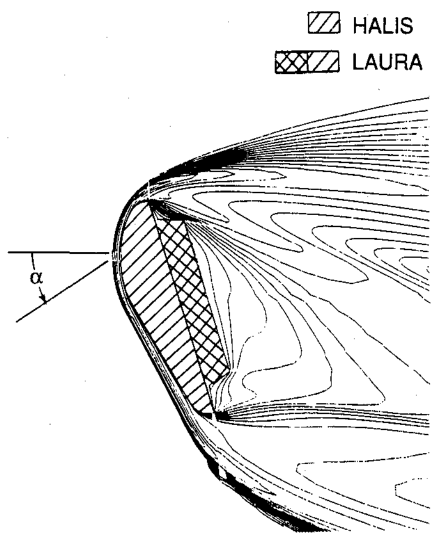

Fig. 1 AFE symmetry plane geometry and vibrational temperature contours (α = −5 deg).

point that corresponds to the point of peak heating on the trajectory for a heavier vehicle was included. The freestream conditions for each of the CFD points are given in Table 1.

Results and Discussion

In Ref. 7, extensive comparisons were made between aerodynamic coefficients derived from HALIS computations and those measured in ground-based facilities. These included data taken in the 31-in. Mach 10 facility at Langley Research Center where the flow could be modeled as a perfect gas and in

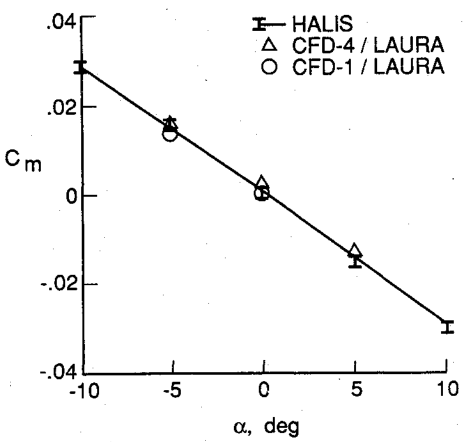

Fig. 2 Comparison of HALIS (forebody) and LAURA (full configuration) AFE pitching-moment characteristics.

Table 1 CFD[a] point freestream conditions

CFD[a] point	V_∞, km/s	P_∞, kg/m^3	T_∞, K	h, km	M_∞
1	9.863	5.682×10^{-6}	189.0	87.3	35.70
2	8.914	2.787×10^{-5}	197.0	77.9	31.67
3	7.711	6.080×10^{-6}	190.3	86.9	27.88
4	9.326	4.293×10^{-5}	200.0	75.2	32.88

[a]Computational fluid dynamics.

Table 2 Aeroassisted Flight Experiment aerodynamic coefficients

CFD[a] point	α, deg	C_N	C_A	C_m	Comments
1	0	0.3783	1.349	0.00112	HALIS—inviscid
1	0	0.3840	1.350	0.00125	LAURA—forebody, pressure only
1	0	0.3680	1.382	−0.00078	LAURA—forebody only, pressure + viscous
1	0	0.3650	1.374	0.00100	LAURA—fullbody, pressure + viscous
1	−5	0.3060	1.298	0.01236	LAURA—fullbody, pressure + viscous
2	0	0.3807	1.355	0.00041	HALIS—inviscid
2	0	0.3830	1.340	0.00035	LAURA—forebody only, pressure only
2	0	0.3752	1.342	0.00205	LAURA—fullbody, pressure + viscous
4	0	0.3760	1.334	0.00208	LAURA—fullbody, pressure + viscous
4	−5	0.3213	1.254	0.01517	LAURA—fullbody, pressure + viscous
4	−5	0.3280	1.250	0.01460	LAURA—forebody only, pressure only
4	−5	0.3225	1.258	0.01467	LAURA—forebody only, pressure + viscous
4	−5	0.0012	−0.003	0.00050	LAURA—afterbody only, pressure + viscous
4	5	0.4256	1.402	0.01318	LAURA—fullbody, pressure + viscous

[a]Computational fluid dynamics.

the Langley CF_4 facility where the flow had to be modeled as a real gas. For those comparisons, both the wind-tunnel and computational models were for the forebody portion of the vehicle as shown in Fig. 1 by the shaded area. These comparisons showed that the HALIS code did an excellent job of predicting the vehicle aerodynamics for either a perfect or real gas flow model. Also in Ref. 7, equilibrium air solutions at the various CFD points were made and the resultant aerodynamics compared with the available computational and experimentally derived data base. This comparison indicated that real-gas chemistry has a significant impact on the aerodynamics of the vehicle. In addition Gnoffo and McCandless,[8] using the AFE forebody configuration, predicted the HALIS-generated aerodynamics for a Mach 10, perfect gas flow.

Yet to be determined were the effects of viscosity, base flow, and thermochemical nonequilibrium flow on the vehicle aerodynamics. All of these phenomena are modeled by the current version of the LAURA code, which used the complete configuration shown in Fig. 1 in the computations. The aerodynamic coefficients derived using the HALIS and LAURA codes are compiled in Table 2 for three of the four CFD points. The viscous and thermochemical nonequilibrium chemistry effects on the aerodynamics should be most prominent at CFD point 1, which corresponds to the highest altitude and Mach number conditions being addressed. In Table 2, the first four lines compare the HALIS inviscid aerodynamics at CFD point 1 with those derived from LAURA solutions. When comparing lines 1 and 2, where only pressure is considered over the forebody, HALIS and LAURA aerodynamics are essentially the same. However, inclusion of the viscous forces (line 3, Table 2) has only a small effect as expected for blunt-body flow. Addition of forces on the base of the vehicle (line 4, Table 2) effectively leaves the aerodynamics of the vehicle unchanged. A comparison of the aerodynamics for the CFD point 2 (lines 6–8, Table 2), which is 10 km deeper in the atmosphere than CFD point 1, shows virtually no difference between the HALIS and LAURA results. Also, LAURA results at CFD point 4 (line 9, Table 2), which is at an even lower altitude, are the same as those at CFD point 2.

In Fig. 1, the vibrational temperature contours serve to illustrate the structure of the external flow about the vehicle. For this −5-deg angle of attack, CFD point 4, part of the free shear layer in the upper symmetry plane impinges on the science payload shroud. A decomposition of the LAURA-derived vehicle aerodynamics is given for those conditions in Table 2, lines 10–13. The contribution of forces acting on the base of the vehicle (Table 2, line 13) are seen to be negligible.

These results indicate that the effects of viscosity, thermochemical nonequilibrium chemistry, and base flow on the vehicle aerodynamics are small with any significant changes being limited to flight at the highest altitude. A composite of the pitch and trim characteristics of the vehicle derived from the HALIS and LAURA computations is shown in Fig. 2. The solid line indicates an average pitching moment C_m derived from the HALIS results while the bars indicate the spread of C_m over the first three CFD points at each angle of attack. Also shown are values of C_m derived from LAURA solutions at CFD points 1 and 4. As this figure indicates, across the altitude and Mach number range covered by this study, there is little change in the trim angle of attack and slope of the pitch curve; and the addition of viscous, thermochemical nonequilibrium and base flow effects have had little effect on the vehicle aerodynamics derived from a forebody-only, inviscid, equilibrium chemistry analysis.

References

[1]Walberg, G. D., "A Survey of Aeroassisted Orbit Transfer," *Journal of Spacecraft and Rockets*, Vol. 22, No. 1, 1985, pp. 3–18.

[2]Jones, J. J., "The Rationale for an Aeroassisted Flight Experiment," AIAA Paper 87-1508, June 1987.

[3]Cheatwood, M. F., DeJarnette, F. R., and Hamilton, H. H., II, "Geometrical Description for a Proposed Aeroassisted Flight Experiment Vehicle," NASA TM-87714, March 1986.

[4]Weilmuenster, K. J., and Hamilton, H. H., II, "Calculations of Inviscid Flow Over Shuttle-Like Vehicles at High Angles of Attack and Comparisons with Experimental Data," NASA TP-2103, May 1983.

[5]Srinivasan, S., Tannehill, J. C., and Weilmuenster, K. J., "Simplified Curve Fits for the Thermodynamics Properties of Equilibrium Air," NASA RP-1181, Aug. 1987.

[6]Gnoffo, P. A., "Upwind-Biased, Point-Implicit Relaxation Strategies for Viscous, Hypersonic Flows," AIAA Paper 89-1972, June 1989.

[7]Weilmuenster, K. J., and Hamilton, H. H., II, "Comparison of Computed and Measured Aerodynamic Characteristics of a Proposed Aeroassisted Flight Experiment Configuration," AIAA Paper 86-1366, June 1986.

[8]Gnoffo, P. A., and McCandless, R. S., "Enhancements to Program LAURA for Computation of Three-Dimensional Hypersonic Flow," AIAA Paper 87-0280, Jan. 1987.

Clark H. Lewis
Associate Editor

U.S. Postal Service

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION

Required by 39 U.S.C. 3685)

1A. Title of Publication: Journal of Spacecraft and Rockets	1B. PUBLICATION NO.: 2 8 2 9 4 0	2. Date of Filing: 11/2/90
3. Frequency of Issue: Bi-monthly	3A. No. of Issues Published Annually: 6	3B. Annual Subscription Price: $26.00

4. Complete Mailing Address of Known Office of Publication *(Street, City, County, State and ZIP+4 Code) (Not printers)*

370 L'Enfant Promenade S.W., Washington, D.C. 20024

5. Complete Mailing Address of the Headquarters of General Business Offices of the Publisher *(Not printer)*

Same as above.

6. Full Names and Complete Mailing Address of Publisher, Editor, and Managing Editor *(This item MUST NOT be blank)*

Publisher *(Name and Complete Mailing Address)*

American Institute of Aeronautics and Astronautics, Inc. Same as above.

Editor *(Name and Complete Mailing Address)*

Clark H. Lewis -- Same as above

Managing Editor *(Name and Complete Mailing Address)*

Heather Brennan -- Same as above.

7. Owner *(If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding 1 percent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a partnership or other unincorporated firm, its name and address, as well as that of each individual must be given. If the publication is published by a nonprofit organization, its name and address must be stated.) (Item must be completed.)*

Full Name	Complete Mailing Address
American Institute of Aeronautics and Astronautics, Inc.	Same as above.

8. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages or Other Securities *(If there are none, so state)*

Full Name	Complete Mailing Address
None.	

9. For Completion by Nonprofit Organizations Authorized To Mail at Special Rates *(DMM Section 423.12 only)*
The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes *(Check one)*

(1) [X] Has Not Changed During Preceding 12 Months
(2) [ ] Has Changed During Preceding 12 Months
(If changed, publisher must submit explanation of change with this statement.)

10. Extent and Nature of Circulation *(See instructions on reverse side)*	Average No. Copies Each Issue During Preceding 12 Months	Actual No. Copies of Single Issue Published Nearest to Filing Date
A. Total No. Copies *(Net Press Run)*	3,618	3,600
B. Paid and/or Requested Circulation 1. Sales through dealers and carriers, street vendors and counter sales	-----	-----
2. Mail Subscription *(Paid and/or requested)*	3,040	3,037
C. Total Paid and/or Requested Circulation *(Sum or 10B1 and 10B2)*	3,040	3,037
D. Free Distribution by Mail, Carrier or Other Means Samples, Complimentary, and Other Free Copies	133	133
E. Total Distribution *(Sum of C and D)*	3,173	3,170
F. Copies Not Distributed 1. Office use, left over, unaccounted, spoiled after printing	445	430
2. Return from News Agents	-----	-----
G. TOTAL *(Sum of E, F1 and 2—should equal net press run shown in A)*	3,618	3,600

11. **I certify that the statements made by me above are correct and complete**

Signature and Title of Editor, Publisher, Business Manager, or Owner

David Quackenbush, Controller

1990 *Journal of Spacecraft and Rockets* Index

How to Use the Index

In the Subject Index, pages 688–691, each technical paper is listed under a maximum of three appropriate headings. Note the number in boldface type following each paper title, and use that number to locate the paper in the Chronological Index. The Author Index, page 692, lists all authors associated with a given technical paper. The locating numbers are identical to those in the Subject Index. The Chronological Index, pages 693–696, lists all papers by their unique code numbers. This listing contains titles, authors and their affiliations, and volume, issue number, and page where the paper appeared. It also gives the AIAA paper number, if any, on which the article was based, as well as the "CP" or conference volume number if the paper was published in a bound collection of meetings papers. Comments, Replies, and Errata are listed directly beneath the paper to which they refer. If the paper to which they refer was published prior to 1990, that paper also will appear in both the Subject and Chronological Indexes. Authors of Comments also are listed in the Author Index.