

AD A118876

BMO-TR-82-15

SAI DOCUMENT NO. 067-82R-004

# MANEUVERING AEROTHERMAL TECHNOLOGY (MAT) PROGRAM

## DATA BIBLIOGRAPHY

SCIENCE APPLICATIONS, INC.  
APPLIED MECHANICS OPERATION  
WAYNE, PENNSYLVANIA 19087

MARCH 1981

INTERIM REPORT FOR THE PERIOD MAY 1980 - MARCH 1981

CONTRACT NO. F04701-80-C-0033

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This Final Report was submitted by Science Applications, Inc.,  
994 Old Eagle School Rd., Valley Forge, PA 19087 under Contract Number  
F04701-80-C-0033 with the Ballistic Missile Office, AFSC, Norton AFB,  
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER BMO-TR-82-15	2. GOVT ACCESSION NO. ADA118 876	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Maneuvering Aerothermal Technology (MAT) Data Bibliography (Task 2)		5. TYPE OF REPORT & PERIOD COVERED Interim Report May 1980 - March 1981
		6. PERFORMING ORG. REPORT NUMBER SAI-067-82R-004
7. AUTHOR(s) A. Martellucci S. Weinberg A. Page		8. CONTRACT OR GRANT NUMBER(s) F04701-80-C-0033 CDRL Item No. A003
9. PERFORMING ORGANIZATION NAME AND ADDRESS Science Applications, Inc. 994 Old Eagle School Road, Suite 1018 Wayne, Pennsylvania 19087		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS  Tasks 2.1 and 2.2
11. CONTROLLING OFFICE NAME AND ADDRESS Ballistic Missile Office Norton Air Force Base, California 92409		12. REPORT DATE 24 March 1981
		13. NUMBER OF PAGES 158
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)  Same as Above		15. SECURITY CLASS. (of this report)  Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for Public Release; Distribution Unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Reentry, Maneuvering, Lifting Body, Hypersonic, Supersonic, Ground Test, Flight Test		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report presents an extensive bibliography of experimental ground and flight test data primarily for strategic maneuvering reentry vehicles. The compil- ation and review of pertinent data sources was performed as a part of the Maneuver- ing Aerothermal Technology (MAT) program. The overall objective of the MAT pro- gram is to assess and extend the current state-of-the-art of technology for pre- dicting MaRV aerothermal performance for current and next generation vehicles in flight regimes characteristic of future mission requirements. The specific ob- jective of this data search and review task was to: (1) assemble a compendium (over)		

## 19. KEY WORDS (Continued)

## 20. ABSTRACT (Continued)

of MaRV aerothermodynamic data sources, (2) review data sources to identify data of specific benefit for validation of analytic/numerical codes (including the 3-D Parabolized Navier-Stokes (PNS) codes, the 3-D coupled inviscid-viscid codes, and the general empirical design codes), (3) critique data sources to identify technology data deficiencies, and (4) document results of prominent data sources by configuration/test condition/data obtained.

The results are presented herein and, in addition to fulfilling the aforementioned objectives, provide information for use in the selection of advanced MaRV configurations which meet the MAT program Technical Requirements Document (TRD) performance goals. The results of this task also provide a basis for assisting in the definition of the MAT program experimental ground test plan.

FOREWORD

This report presents a bibliography of data references concerned with maneuvering reentry vehicles. This bibliography was compiled as part of Task 2 of Contract F04701-80-C-0033 entitled the "Maneuvering Aerothermal Technology (MAT)" program. The study is being conducted by personnel of Science Applications, Inc., Valley Forge, Pennsylvania for the Ballistic Missile Office, Norton Air Force Base, California. The project officer for this effort is Captain John Keese, BMO/MNRTE.

This report is submitted in partial fulfillment of the requirements for Task 2 - Technology Base, specifically Task 2.1 - Configuration Review and Task 2.2 - MaRV Flight Data Review (CDRL - A003). The review of empirical techniques and correlations, also required as part of Tasks 2.1 and 2.2 will be provided in a separate document.

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## TERMINOLOGY AND NOMENCLATURE

For reference purposes, the terminology and nomenclature utilized in Section 4 is summarized as follows:

<u>NOSETIP</u>	A	Asymmetric geometry
	G	Gasjet
	S	Symmetric geometry
	TC	Transpiration cooled
<u>CONTROL</u>	DSN	Double swivel nose
	EB	External burning
	F	Flap
	JI	Jet interaction
	MF	Multiple flaps
	SN	Swivel nose
<u>FACILITY</u>	AEDC	Arnold Engineering Development Center von Karman Gas Dynamic Facility
	AEDC-A	Supersonic Wind Tunnel
	AEDC-B	Hypersonic Wind Tunnel
	AEDC-C	Hypersonic Wind Tunnel
	AEDC-E	Blowdown Hypersonic Wind Tunnel
	AEDC-F	Hotshot Hypervelocity Wind Tunnel
	AEDC-G	Hypervelocity Range
	ARL	Air Force Wright Aeronautical Lab (AFWAL) 20" Hypersonic Wind Tunnel
	CAL	CALSPAN Hypervelocity Shock Tunnel
	MDAC	McDonnell-Douglas Trisonic Wind Tunnel
	NASA/LaRC	NASA Langley Research Center Continuous Flow Hypersonic Tunnel (CFHT)
	NSWC	Naval Surface Weapons Center
	NSWC-2	Blowdown Supersonic Tunnel No. 2
	NSWC-8A	Blowdown Hypervelocity Research Tunnel
	NSWC-9	Blowdown Hypersonic Tunnel
	PIBAL	Polytechnic Institute of Brooklyn Blowdown Tunnel
	RPL	Rocket Propulsion Laboratory
	5MW	AEDC HEAT Arc Facility
	50MW	AFWAL RENT Arc Facility

TERMINOLOGY AND NOMENCLATURE (Cont'd)

ANGLE OF ATTACK  
RANGE

0 indicates a ballistic vehicle (small  $\alpha$ ); otherwise the maximum value of  $\alpha$  is specified. If sideslip data is involved, the maximum value of  $\beta$  is specified (e.g., B10 if  $\beta_{\max} = 10^\circ$ ).

DATA TYPE

F&M	Force and moment
LTA	Low temperature ablator
P	Surface pressure
$\dot{q}$	Heat transfer

SECTION 1  
INTRODUCTION AND SUMMARY

## INTRODUCTION AND SUMMARY

This report presents an extensive bibliography of experimental ground and flight test data primarily for strategic maneuvering reentry vehicles. The compilation and review of pertinent data sources was performed as a part of the Maneuvering Aerothermal Technology (MAT) program. The overall objective of the MAT program is to assess and extend the current state-of-the-art of technology for predicting MaRV aerothermal performance for current and next generation vehicles in flight regimes characteristic of future mission requirements. The specific objective of this data search and review task was to:

- (1) assemble a compendium of MaRV aerothermodynamic data sources
- (2) review data sources to identify data of specific benefit for validation of analytic/numerical codes (including the 3-D Parabolized Navier Stoke (PNS) codes, the 3-D coupled inviscid-viscid codes, and the general empirical design codes)
- (3) critique data sources to identify technology data deficiencies
- (4) document results of prominent data sources by configuration/test condition/data obtained.

The results are presented herein and, in addition to fulfilling the aforementioned objectives, provide information for use in the selection of advanced MaRV configurations which meet the MAT program Technical Requirements Document (TRD) performance goals. The results of this task also provide a basis for assisting in the definition of the MAT program experimental ground test plan.

This report is organized in five major sections as follows:

- General bibliography
- Major systems programs Bibliography
- Bibliography cross reference by data category
- Tables of data summaries for a limited set of references
- Detailed review/critique of the MAT related significant data sources

The data reports cited in the bibliographies were obtained from searches conducted through the Defense Technology Information Center (DTIC), the National Technical Information Services (NTIS), the Air Force Wright Aeronautical Laboratories (AFWAL), the Arnold Engineering Development Center (AEDC), McDonnell-Douglas Corporation (MDAC), General Electric Re-entry Systems Division (GE-RSD), TRW, Aerospace Corporation, and the Lockheed Missiles and Space Company (LMSC).

The search was restricted to data sources for configurations of interest to BMO. Consequently, manned lifting bodies, blunt lifting bodies (i.e., those with low L/D potential), and configurations with slender wings were excluded a priori. Even with this restriction, data on MaRV type configurations have been obtained over several decades and as a result the compilation has been organized chronologically in Section 2 by year and month, with the oldest references listed first.

There have been some specific systems programs which have generated large quantities of data for configuration definition and to fulfill specific systems requirements. The most notable of these are the Air Force's Maneuvering Ballistic Reentry Vehicle (MBRV), Advanced Control Experiment (ACE), Advanced Maneuvering Reentry Vehicle (AMaRV), and the Navy MK 500. The aerodynamic and aerothermodynamic data generated under the auspices of these programs are presented chronologically, by subsets, in Section 3. Also provided for the user is a cross reference of data by category or data type. The specific categories cross referenced in Section 4 are:

- Sharp and Blunted Bicones
- Sliced Cones/Bicones
- Elliptic Cross Section Cones
- Bent Axis Configurations
- Asymmetric/Nonspherical Noses
- Transpiration Cooled Nosetips (TCNT)
- Jet Interaction (JI) and External Burning (EB)
- Configuration with Shock Layer Surveys
- Mass Transfer/Roughness Effects
- Dynamic Stability
- Flight Data

It should be noted that a large portion of the data cited, especially those for specific systems programs, are classified. Where the specific classification is known it is so noted on the reference. From some of the data retrieval sources the only information available was that the report was classified but the level was not given; these are so noted in the compilation as Classified. In addition certain of the CONFIDENTIAL reports may have been downgraded since they were published and the current listing may not be correct in this regard.

It should further be noted that Science Applications, Inc. (SAI) does not possess many of the documents referenced in this bibliography. Those reports which appeared to be of specific interest to the MAT program were reviewed at the data source and summary information is listed in the tables of Section 5. Those that would potentially be useful in aerothermal technique validation were then reviewed in some detail and critiqued. This information is contained in Section 6.

#### GENERAL SUMMARY AND OBSERVATIONS

It is evident from this search that a wealth of data exist for high performance lifting reentry bodies. Approximately six hundred reference sources of data or comparisons of data with theory were found. The preponderance of the references contain total configuration force and moment data. The next major source of data are for surface pressure, followed by heat transfer. In general there is a paucity of dynamic stability and shock/boundary layer survey data. Relatively few sources contain complete sets of data (i.e., force and moment, surface and shock layer properties) which could be used by analysts for diagnostic checks on the accuracy of prediction techniques. The limited data sets are useful for ascertaining the accuracy of a "working" code but do not provide sufficient information to pinpoint the source of problem when agreement is not good in a developmental code. For example some reports define detailed maps of surface heating but do not define the complementary surface pressure field. Thus if agreement with data is poor, it may not be evident whether the boundary layer method is lacking or whether the pressure field prediction is inaccurate.

Ground test data are generally obtained for flow conditions far short of those expected in the flight environment of BRVs and MaRVs. Thus viscous effects evident in ground test are different than those in flight for comparable Mach numbers. Two sources of ground test data for  $M > 8$  that were extensively used in the past were the AEDC VKF Tunnels C and F. Care must be exercised in the use of some of the older test data (i.e., nominally before 1975) for two primary reasons. In Tunnel C data were reported to be obtained at Mach 12 whereas it was later discovered that condensation effects were present such that the true Mach number was actually closer to 10. In Tunnel F the use of conical nozzles produced axial pressure gradients in the tunnel flow, and caused the data to be different from those which would have been measured at the same stated Mach number in a contoured nozzle flow. Because of the significant usage of these facilities these results were resolved, documented and later circumvented. The basic question is what is the quality of the data from tunnels which are only infrequently used or not calibrated. In this regard, the data users must be cautious.

A major test series was sponsored by BMO and run at AEDC/VKF primarily to provide a complete diagnostic set of ground test data to validate the HYTAC parabolized Navier-Stokes (PNS) code. The configurations tested were sharp and blunt cones, blunt bicones and bicones with slices. Data were obtained under laminar and turbulent flow conditions. The data obtained were force and moment, surface pressure and heating, and shock layer surveys where total temperature, Pitot pressure, Preston tube, and Mach/flow angularity were measured. These data, although limited in Mach number range, provide an extremely useful set to assist the analyst in code development. Data sets such as this are not generally available. The first MAT program test will augment these data by providing measurements on a sliced bicone under turbulent flow conditions to angles of attack of  $20^\circ$  including data on a flap. These data provide information on a configuration which is locally non-circular in cross-section.

Data obtained on configurations with general non-circular cross-sections are primarily for force and moment. In certain cases limited pressure and surface heating (usually the windward ray centerline of symmetry) also were obtained. For codes which are being developed to compute the flow field details on these 3-D bodies the available data are generally not sufficient to check out the code. The myriad of data obtained on the Space Shuttle configuration (not included here for reasons cited earlier in this report) is one exception. One other notable exception is for the data obtained on the AFWAL X-24C configuration. This configuration, strictly speaking, does not fit into the current study since it represents a manned configuration. It is included because it is a relatively sharp body {compared to the Shuttle) and does provide a useful data set for code validation and configuration performance. However, the detailed check out of computational tools such as the parabolized Navier Stokes (PNS) codes, with complex body transformation potential, requires a more diversified data set before one can generalize on its computational ability, accuracy, and efficiency. These data are lacking.

The increased cost of acquiring experimental data requires that maximum utility be made of (1) the existing data and of (2) the recent advances made in computational fluid dynamics (CFD) to assist in vehicle design. Detailed computational tools such as the PNS solutions or the inviscid flow field codes can be utilized to provide accurate numerical results which will reduce the need for wind tunnel testing. However this requires that the computer codes be validated against sufficient data so that the accuracy and limitations of the codes can be ascertained. As stated earlier, force and moment data do provide a check on the integrated accuracy of a computer tool but do not provide the diagnostic data required to check a computer code where agreement is unsatisfactory. For this purpose surface pressure, heat transfer and flow survey measurements can be used to pinpoint where problems exist and provide a quantitative basis for assessment of code improvements. Data for these diagnostic purposes are clearly lacking.

Flight test provides data for the total environment (i.e., Mach number/Reynolds number) including the effects of real gas, mass transfer, surface roughness, and shape change. The difficulty here is that all of these effects occur simultaneously and consequently it is difficult to interpret each of them independently. Select flights such as AMaRV-1 where some of these influences were minimized does provide some insight and consequently is extremely useful for ascertaining total code predictive capability for a select configuration. Flight test with adequate measurements, when coupled with a complete ground test data set does provide an unsurpassed source of information for configuration performance and computer code validation. For complex configurations of future interest, a complete set of ground test must suffice for code validation. In this regard the Aerodynamically Configured Maneuvering Reentry Vehicle (ACMRV) wind tunnel tests to be performed as a part of the MAT test program will provide the necessary diagnostic ground test data to establish system performance and to check and validate prediction techniques.

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SECTION 4  
BIBLIOGRAPHY CROSS REFERENCE  
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- SHARP AND BLUNTED BICONES
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- ACE Advanced Control Experiment (Complete Listing).
- AMaRV Advanced Maneuvering Reentry Vehicle (Complete Listing).
- MK500 MK500 (Complete Listing).

SECTION 5  
DATA SUMMARY OVERVIEWS

## DATA SUMMARY OVERVIEWS

Summarized in the following tables are highlights of the ground or flight test data contained in select reports that, during the review cycle of this effort, were thought to contain information that potentially would be of specific interest to analysts for computer code validation. A general description of the geometry, the test conditions and facility, and the data obtained are presented. From this cursory review, the data reports that contain a sizeable quantity of data or data of special interest for detailed code validation (e.g., shock layer profile data) are reviewed, summarized, and critiqued in Section 5.

REFERENCE	CONFIGURATION		FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE		CONTROL	M <sub>∞</sub>		
59-1	Elliptic Cone	S	--	PIBAL	3, 6	20°	P Sharp nose configurations. a/b = 1.78, 1.39. Plots of results.
63-1	Elliptic Cone Half Cone	S	--	AEDC-B AEDC-E	8	30° 815°	F&M Plots of data.
63-19	Elliptic Cone	S	--	AEDC-C	10	60°	P Plots of results. Oil flow and schlieren data. Poor flow in Tunnel C (condensation).
64-1	Half-Cone	S	--	AEDC-B	8	100°	F&M 3 different cross-sections. Plots of results
64-4	Elliptic Cone	S	--	AEDC-C	10	60°	q Sharp and blunt noses. a/b = 2.00, 1.43. Limited plots of results.
64-6	Cone	S	--	AEDC-A AEDC-C	1.5 to 10	15°	F&M BGRV Flare angle and fineness ratio variations. Limited plots of results.
64-11	Cone with Slice	S	MF	AEDC-F	19	15°	F&M Conical nozzle. Flap effectiveness tests. Limited plots of data -- roll control data.
64-17	Cone	S TC	--	AEDC-C	10	20°	q BGRV Effects of transpiration on down- stream q. Limited data presented.

REFERENCE	CONFIGURATION		FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE		CONTROL	M <sub>∞</sub>		
64-20	Cone Tricone	S	--	AEDC-A AEDC-C	5 10	14°	P BGRV. Variations in flare angle.
55-18	Cone	S	F	AEDC-A AEDC-C	5 10	25°	F&M Biconic nose. Base domes (2 versions). 90 cone.
65-19	Cone	S TC	--	AEDC-C	10	20°	q BGRV. Effects of transpiration on down- stream q. Plots of results.
65-25	Tricone	S	--	AEDC-B	8	20°	F&M BGRV. Variation in flare angle. Limited plots of results.
66-2	Cone with Slice	S	MF	AEDC-C	10	20° 85°	F&M P Effects of flats and control size on static stability. Flap pressures. Some plots of results.
66-5	Cone Half Cone Delta Wing	S	--	AEDC-L	10	30°	F&M Viscous interaction effects. Transition flow regime. Some plots of results.
66-10	Cone	S	JI	AEDC-B AEDC-C	6,10	30°	F&M P MARCAS II. Tripped turbulent flow. Variations in nose bluntness. Limited plots of data.
67-28 (Vol. I)	Bicone with Slice	TC	MF	--	--	--	-- Maneuvering RV concepts study. Glide LLRI MRV design. No Data - studies only.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>0</sub>	$\alpha$		
67-28 (Vol. II)	Bicone with Slice	TC	MF	--	--	--	--	Maneuvering RV concepts study. Design summary. No data.
67-29	Cone Cone with Slice	S	MF	AEDC-B	8	20°	F&M	Tripped turbulent flow. Trailing controls. Roll control studied. RN variations. Limited plots of results.
67-42	Tricone	S	--	AEDC-G	7 to 16	0°	F&M	BGRV flared tricone. Ballistic range test. Plots and tabulation of results.
67-43	Bicone with Slice	TC	MF	--	--	--	--	Maneuvering RV concepts study. Final report. Low level run-in concept. No data.
67-44	Cone	S	JI	AEDC-B AEDC-C	6 10	27°	q	MARCAS III. q for JI induced separated flow regions. Sharp and blunt noses.
68-14	Bicone	TC	Flare JI	CAL AEDC-C	6 to 10	20°	q	Methods for evaluating aero heating data on BGRV. Some ground, flight data on heating. Brief flight summaries.
68-20 (Vol. I)	Bicone	TC	Flare JI	--	--	--	--	BGRV final report - test program. Ground, flight test descriptions. No data.
68-20 (Vol. II)	Bicone	TC	Flare JI	AEDC-A AEDC-C MDAC CAL	4 to 10	20°	F&M P	BGRV final report - analysis. Some ground test data presented.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
69-9	Elliptic Cone	S	--	AEDC-A	3-6	16°	F&M	UpStage. a/b = 1.85. Limited plots of results.
69-13	Cone with Double Slice	S	SWF	AEDC-A AEDC-B	2,4,6	28°	F&M	Tripped Turbulent flow. Trailing control hinge moments measured. Different afterbodies. Rounded base.
69-14	Cone	S	JI	--	--	--	--	MARGAS III final report. 2 vehicles flown. Flight data and very limited ground data.
69-18	Sharp Cone	--	--	NSWC-2	5	only 24°	P, Survey	Sharp cone tested at α = 24° Leeside shock layer surveyed in separated flow region.
70-1	Cone	S	--	AEDC-B	8	14° 86°	F&M P, q	Bent-nosed cones (δN = 6°) Sharp biconic nosetips with varying bluntness.
70-11	Canted-base cone	S TC	FBN	AEDC-B AEDC-C AEDC-F	6 to 21	25°	F&M	Bluntness & cant angle variations. Base pressure data. Plots of results. Conical nozzle (Tunnel F)
71-1	Cone with Slice	S	SWF MF RAKE	AEDC-A AEDC-B AEDC-F	2 to 12	27° 86°	F&M	Plots of results. Conical nozzle (Tunnel F)
71-4	Cone with Double Slice	S	F	AEDC-F	12	25°	F&M	Tripped turbulent flow. Conical nozzle. Static stability with various control deflections. Rounded base shoulder. Plots and data tabulations.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
71-9	Cone with Slice	S,A	SMF MF	AEDC-A AEDC-B AEDC-C	10.6	25° 86°	F&M	Tripped turbulent flow. Trailing controls. Various RN, biconic & ablated noses. Plots and results.
72-3	Cone with Slice Cone with Double Slice	S	SMF	AEDC-A AEDC-B	2 to 8	24° 85°	F&M	Tripped turbulent flow. Variations in forecone, RN, cuts, δF; static stability data for biased- based vehicles with controls.
72-5	Cone with Double Slice	S	SMF	AEDC-F	12 16	20° 85°	F&M	Conical nozzle. Variable split control deflections. Pitch stability, roll control, limited plots. Data summary (corrected for source flow).
72-8	Cone Bicone	S	RAKE	AEDC-A AEDC-B	2 4 8	24° 84°	F&M q	Tripped turbulent flow. Aft leeside rake. Variations in RN, Rake geometry q from paint; LTA test for nose, rake Plots of results.
72-13	Elliptic Cone	S	EB JI	AEDC-A MDAC	3 to 8	30°	F&M	UPSTAGE final report, a/b = 1.83. Summary of tests (basic body & controls). Some thermal tests (RENT, CAL).
72-14	Bicone Bicone with Slice	S,A	SN	AEDC-A AEDC-B	2 to 8	24° 82°	F&M p q	Variation of forecone angles, blunt- ness, nose shape. Nose slice, deflection variations. Plots of data.
72-19	Bicone	S	--	AEDC-F	10 to 19	20°	F&M	Conical nozzle. Paint for transition data. Viscous effects (laminar & turbulent) found to be significant. Plots of results.
72-20	Bicone Bicone with Slice Bicone with Double Slice	S	F	AEDC-C	10	20° 85°	F&M	Trailing controls (wind and lee). Plots of results.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
72-22	Bicone	S	SWF	AEDC-A AEDC-B	3,5, 8	25°	F&M	SEV Fnl Rpt-Vol. IV-other volumes not of interest. Analyses-aero.flt. mechs., controls; Data presented. Non circ.x-sections.
73-4	Cone Cone with Slice Cone with Double Slice	S,A	F	AEDC-A AEDC-B AEDC-C	3 to 10	24° 86°	F&M P q	Tripped turbulent flow. Parametric geometry variations. Lee & wind slices. Plots of data - <u>SEV</u>
73-18	Cone with Double Slice	S	F	AEDC-G	~12	10°	F&M	Effects of forecone angle on $x_{cp}, \alpha_T$ . <u>Plots and summaries of results.</u> SEV
73-19 Vol. I	Bicone	S	DSN	--	--	--	--	SEE-design & development. Control system design, traj., flight mech.
73-19 Vol. II	Bicone	S	DSN	AEDC-B AEDC-F	8 12	20°	F&M q	SEE-design & development. Configuration aero. Ground test summary (aero & thermo). Refs. for data.
75-12	Flat Plate	--	F	5MW 50MW	--	--	LTA Ablation	Analyses & experiments for nosetip ablation at high α; analysis of flap ablation. ATJ and C/C materials.
76-2 Vol. I	Bicone	S TC	FBN MF SWF JI DSN	--	--	--	--	GE PGRV SDR-Studies and analysis only Various controls analyzed. No data.
76-2 Vol. II	Bicone	--	FBN MF SWF JI DSN	--	--	--	--	GE PGRV SDR-OPV analysis & studies. Aero & traj. analyses.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
76-2 Vol. III	Bicone with Slice	S	MF	--	--	--	--	GE PGRV flight test vehicle SDR.
76-2 Vol. IV	Bicone with Slice	S	MF	--	--	--	--	GE PGRV SDR - flight test planning. Instrumentation, safety, etc. Def'n of flight test objectives.
76-4	Bicone	S, A TC	FYS MF SWF	AEDC-A AEDC-B AEDC-F, G CAL NSWC-9	3.5 8 12 12	25°	F&M P	MDAC final studies for PGRV Limited tests.
78-3	Cone	S	J1 EB	CAL	7.0 to 13.7	20° 812°	P, q	Interaction controls effectiveness. Forces from pressure integration. Data evaluation and application to advanced interceptors.
78-13	Nosetip Only	TC	--	AEDC-G	16000 fps	0	Dust Erosion	TCNT tests in range/Track G. Dust tests.
79-2	Nosetip Only	6	--	5MW 50MW NASA/LARC Martin	2 to 10	0	P, q	Dust test failed. Plasma tests & wind tunnel tests. Flight tests on SAMS/TATER, FLAME, MSV-ATHENA.
79-9	Bicone w/slice ("HYTAC" model)	S	--	AEDC-C	10	14°	F&M, q, P, survey	Complete data set for laminar flow conditions on a blunted bicone. Suitable for computer code validation.
79-11	X-24C Config'n	S	--	AEDC-B	6	6°	Survey	Local Mach number and flow angle survey within bowshock. Data at one model station only.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
79-16	Cone	S	--	AEDC-G	14	0°	F&M	Ballistic range tests. Real gas effects on stability. Plots of results.
80-6	Cone	S	--	AEDC-G	14	0°	F&M	Ballistic range tests. Real gas effects on stability. Plots of results.
80-7	Cone and Bicone	S	--	AEDC-B	8	10°	F&M, q, P, and Surveys	Obtain turbulent flow data base on sharp and blunt cone, and blunt bicones-b.l. trips used.
80-8	X-24C Config'n	S	--	AEDC-B	6	20°	Flow Survey	Local Mach number & flow angle. Survey within bow shock. Data at 2 model stations.
80-9	Bicone	S	SN	NSWC-9 RPL	14, ~3	30° (β <sup>0</sup> )	F&M Ablation	GE Nose Control study. Analysis and wind tunnel data.
80-10	Flat Plate	--	F	NASA/LaRC	10	0°	P, q	Finite span trailing flaps. Turbulent flow. Chord-and spanwise data at δf=0°-15° Plots of results.
80-13	Flat Plate	--	F	NASA/LaRC	10	0°	P, q	Finite span trailing flaps. Turbulent flow. Chord-and spanwise data at δf=0°-15° Plots of results.
80-14	Cone Bicone	S	--	AEDC-B	6	0°	P, q, BL Survey	Turbulent boundary layer measurements Surface data and mean flow profiles. Sharp and blunt noses. Extensive data plots and tabulations.

REFERENCE	CONFIGURATION		FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE		CONTROL	M <sub>∞</sub>		
MBRV-2	Cone with Slice	S	MF	AEDC-B AEDC-C	8 10	27° 810°	F&M  Laminar & turbulent flow. Flap effectiveness. Variations in control geometries and bluntness. Some plots of data - Tunnel C data bad (condensation).
MBRV-3	Cone with Slice	S	MF	AEDC-B AEDC-C	8 10	15°	P  Variations in bluntness, δf. Boundary layer surveys. Oil flow to define separation regions. Tunnel C data bad (condensation).
MBRV-8	Cone with Slice	S	MF	AEDC-A AEDC-C	2,6 10	18°	F&M  Nose bluntness, roll control tests. Limited plots of data. Tunnel C data bad (condensation).
MBRV-10	Cone Cone with Slice	S	MF	AEDC-F	19	15°	F&M  Conical nozzle; w & w/o flaps. Limited plots of results.
MBRV-12	Cone with Slice	S	MF	AEDC-F	19	15°	F&M  Conical nozzle. δf variations for trailing flap. Limited plots of results.
MBRV-15	Cone with Slice	S	MF	AEDC-C	10	~0°	Dynamic Stability  Forced oscillation tests. Tunnel C data bad (condensation).
MBRV-16	Cone with Slice	S	MF	AEDC-C	10	20° 85°	F&M  "Ablated" frustum and contoured controls. Limited plots of results. Tunnel C data bad (condensation).
MBRV-22	Cone with Slice	S	MF	AEDC-F	15	30°	P  Conical nozzle. Limited body and flap data.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
MBRV-28	Cone with Slice	S	MF	AEDC-C	10	15°	F&M	Stability and control with m through porous frustum. Limited plots of results. Tunnel C data bad (condensation).
MBRV-31	Cone with Slice	S	MF	AEDC-A AEDC-B AEDC-C	5 8 12	27° β15°	F&M p, q B.L. Survey	Plots of results from many tests, including hinge moments, boundary layer surveys. Tunnel C data bad (condensation).
MBRV-34	Cone with Slice	S	MF	AEDC-A AEDC-C	2 5 10	18° β10°	F&M	Trapezoidal and rectangular Flaps. Tunnel C data bad (condensation).
MBRV-35	Cone with Slice	S	MF	AEDC-F	2 6 10	12° β10°	F&M	Differential control deflections for roll control on FTV configurations. Plots of results. <u>Conical Nozzle</u> .
MBRV-60 Vol. I	Cone with Slice	S	MF	--	--	--	p F&M	MBRV flight test program. Introduction and summary. Limited flight test data.
MBRV-60 Vol. II	Cone with Slice	S	MF	--	--	--	--	MBRV flight test program. Flight test vehicle design. No data.
MBRV-60 Vol. III	Cone with Slice	S	MF	AEDC-A AEDC-B AEDC-C AEDC-F	2 6 10 20	20°	F&M p, q B.L. Survey	MBRV flight test program. Analytical & ground studies. Summary of ground test data. Also thermo tests. (5MW, MALTA).
MBRV-60 Vol. IV	Cone with Slice	S	MF	--	--	--	--	MBRV flight test summary. Emphasis on FTV-602, 603 (w/maneuvers) Flight test data included.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
ACE-1	Cone with Slice Cone with Double Slice	S,A	F	AEDC-A AEDC-B	2 to 8	24° 33°	F&M	Static stability. Variations in nosetip, slices, split controls. Plots of results.
ACE-2	Cone with Slice Cone with Double Slice	S	F	AEDC-A AEDC-B	2 to 8	24° 81°	F&M	Trip effects on stability. Pitch and yaw stability with differing control deflections. Plots of results.
ACE-3	Cone with Slice Cone with Double Slice	S	--	AEDC-F	12 15 16	25° 83°	F&M	Conical nozzle. Effects of lee slice on pitch and yaw stability. Plots and tabulations of results.
ACE-4	Cone with Slice Cone with Double Slice	S	F	AEDC-B AEDC-F	8 11 14.5	20°	p, q	Tripped turbulent flow. Conical nozzle in F, p, q on controls (nominal and contoured). Paint for leeside heating. Plots of results.
ACE-5	Cone with Double Slice	S	F	AEDC-F	7.5 11 14	20°	p, q	Tripped turbulent flow. Contoured nozzle. Paint used on control box. Goal: q near SWF; ablated controls tested. Plots of data.
ACE-6	Cone with Double Slice	S	F	AEDC-F	16 19	25° 83°	F&M	Laminar flow, conical nozzle. Lateral stability w/different control deflec- tions. Plots and summary of data.
ACE-9	Bicone with Double Slice	S	F	AEDC-F	16	20° 82.5°	F&M	Conical nozzle. Pitch and yaw stability at low α; 2 forecone angles. Limited conical deflections. Limited plots of data.
ACE-10	Cone with Double Slice		F	AEDC-F	8 12 14	10°	p, q	Turbulent flow. Some paint data. Contoured nozzle M <sub>∞</sub> = 8, conical nozzle (M <sub>∞</sub> = 12, 14). Rectangular and trapezoidal controls.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
ACE-11	Cone with Double Slice	S,A	F	AEDC-A AEDC-B AEDC-C	3 to 10	24° B6	F&M	Geometric variations: (R/R <sub>B</sub> , θ), nose cant effects. Elliptic & super-circle flares. Plots of data.
ACE-14	Cone with Slice	S	F	AEDC-B	8		P, q Survey	Sharp & blunt 7° cone. Phase change point for q pitot pressure probe. Some data included.
ACE-15	Cone with Slice	S	F	AEDC-B	8	20°	P, q Survey	Analysis & experiments on slice & flap. Plots of data.
ACE-20	Cone with Slice	S	F	AEDC-F	10.5	20°	P, q	Tripped turbulent flow. Conical nozzle. R <sub>n</sub> & δf variations. Thermocouples & paint for q. Plots of data.
ACE-22 (Vol. I)	Cone with Slice Cone with Double Slice	S TC	F	--	--	--	--	ACE final report - summary. 3 flight tests; some flight data. Ground tests on TCNT.
ACE-22 (Vol. II)	Cone with Slice Cone with Double Slice Bicone with Slice Bicone with Double Slice	S TC	F	--	--	--	--	ACE final report-program description. Summary of flight, ground tests. Summary of biconic stuides.
ACE-22 (Vol. III)	Cone with Slice	S	F	--	--	--	--	ACE Final Report. Flight test summary FTV-1,2,3.
ACE-25 (Vol. II)	Bicone with Double Slice	A	F	AEDC-B AEDC-F	8	20°	F&M, P,q	ACE-Bicone Aero Study. Thermo control & traj. analyses. Control predictions & data. Rect. & trapezoidal flaps.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	RODY	NOSE	CONTROL		M <sub>∞</sub>	α		
ACE-25 (Vol. I)	Bicone with Double Slice	S	F	AEDC-B	8	20°	F&M	ACE Bicone Aero Study. Aero design, limited data shown.
ACE-25 (Vol. III)	Bicone with Double Slice	S	F	ARL NSWC-9 AEDC-B AEDC-F	3 to 18	20°	F&M	ACE Biconic Aero Study, Describes wind tunnel tests. Contains limited data.
ACE-28	Cone with Slice Cone with Double Slice	S	F	AEDC-F	16 19	25° 85°	F&M	Conical nozzle. Viscous and M <sub>∞</sub> effects on lateral stability. Plots of results.
ACE-30	Bicone with Double Slice	S	F	AEDC-F	8 12	25° 84°	F&M	Contoured nozzles (quoted M <sub>∞</sub> , Re <sub>∞</sub> (incorrect). Data with & w/o slice, flap. Some plots (also limited data from A, B, C).
ACE-31	Bicone with Double Slice	A	F	AEDC-G	12 14	~0°	F&M	α <sub>T</sub> = 0°. Some nosetip asymmetry de- veloped in one shot. 2 control de- flections tested.
ACE-32	Cone with Slice Cone with Double Slice	S	F	AEDC-A AEDC-B AEDC-C AEDC-F	3 to 18	30° 83°	F&M	Viscous effects on ACE FTV wind tun- nel data. Examination of viscous effects on data Some data presented.
ACE-33	Bicone	S,A	F	--	--	--	--	3DOF, 6DOF, aero estimates based on documentation wind tunnel tests. Uncertainty analysis.

REFERENCE	CONFIGURATION		FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE		CONTROL	M <sub>∞</sub>		
AMaRV-4	Bicone with Double Slice	S,A	FYS F	AEDC-B AEDC-F NSWC-8A NSWC-9	--	--	AMaRV test plan-parametric & config. refinement w.t. test series. No data.
AMaRV-10	Bicone with Double Slice	S,A	FYS F	AEDC-B	8	27° 824°	Configuration variations. FYS, ablated control contours, cut modifications, "ablated" forecone. Nosetip. RN variations.
AMaRV-12	Bicone with Double Slice	S,A	FYS F	AEDC-F	12.5	10°	Tripped turbulent flow. Contoured nozzle. Control surface effects. Various FYS, controls & nosetips.
AMaRV-20	Bicone	S,A	FYS F	AEDC-A AEDC-B	3.5 5 8	27° 810°	Tripped turbulent flow. Controls, FYS, w&w/o slices. Nosetips rolled 0°, 90°, 180°, 270°. Sample data only. Two balances (high, low α) for accurate $\gamma_{app}$ .
AMaRV-24	Bicone with Double Slice	S,A	FYS F	AEDC-A AEDC-B AEDC-F NSWC-9	3.5 to 14	25°	AMaRV aero analyses. Ground test summary; Predictions & results prior to CDR.
AMaRV-26	Bicone with Double Slice	S,A	FYS F	--	--	--	AMaRV aero thermal analyses at CDR (iterim rpt). Analyses for thermal protection system.
AMaRV-31	Bicone with Double Slice	S,A	FYS F	AEDC-F	12.8	20° 82.5°	Turbulent flow. Contoured nozzle. FTV configuration. Control effectiveness with ablated nosetips (N/A, rolled 0°, 160°), controls, w&w/o FYS.
AMaRV-35	Bicone with Double Slice	S	FYS F	AEDC-A AEDC-B	3.5 5 8	25°	AMaRV aero analyses. Aero analyses since CDR. Comparisons to data for control effectiveness.

REFERENCE	CONFIGURATION		FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE		CONTROL	M <sub>∞</sub>		
AMaRV-38	Bicone with Double Slice	S	FYS F	AEDC-F	9 13	25° 85°	P, q Tripped turbulent flow. Contoured nozzle: 8% & 15% blunt. Unablated & ablated FYS, controls. Sample data only.
AMaRV-39	Bicone with Double Slice	S,A	FYS F	--	--	25°	AMaRV aerothermo analysis. Final report. Analyses for thermal protection system.
AMaRV-43	Bicone with Double Slice	S,A	FYS F	--	--	-25°	AMaRV aero analysis. Aero analysis for FTV-3. Increased control ablation assumed for FTV-3. No explicit data.
AMaRV-48 Vol. I	Bicone with Double Slice	S	FYS F	FLIGHT	Var.	35°	AMaRV post-flight report. Introduction & aero. comparisons to predictions.
AMaRV-48 Vol. II	Bicone with Double Slice	S	FYS F	FLIGHT	Var.	35°	AMaRV-1 Post-Flight report. Thermo and loads data.

REFERENCE	CONFIGURATION			FACILITY	TEST CONDITIONS		DATA TYPE	COMMENTS & KEY WORDS
	BODY	NOSE	CONTROL		M <sub>∞</sub>	α		
MK500-2	Bicone	S,A	FBN	AEDC-A AEDC-B	5,8	14°	Dynamic Stability	Forced oscillation tests for pitch and yaw damping. Most tests at αT. Various nosetips, δN, cone angles. Plots of results.
MK500-11	Bicone	S,A	FBN	AEDC-A AEDC-B AEDC-C	5,8, 10	24° 810°	F&M P	Mostly laminar, some trips. Ablated nosetips. Variations in δN. Plots of data.

SECTION 6  
DETAILED DATA SUMMARY, REVIEW,  
AND CRITIQUE

## DETAILED DATA SUMMARY, REVIEW, AND CRITIQUE

This section contains the detailed data summary review and critique of those sources that contain information that are useful for detailed computer code validation. The objective of this review is to provide the user with sufficient information as to data type and content so that a judgement can be made whether the report contains the information desired for the specified use. The information contained includes the basic test objective, a description of the geometry, a detailed description of the data obtained, and some comments on the data utility and limitations relative to the MAT program objectives. It should be noted that the data itself are not contained, the reader is referred to the original sources for these details.

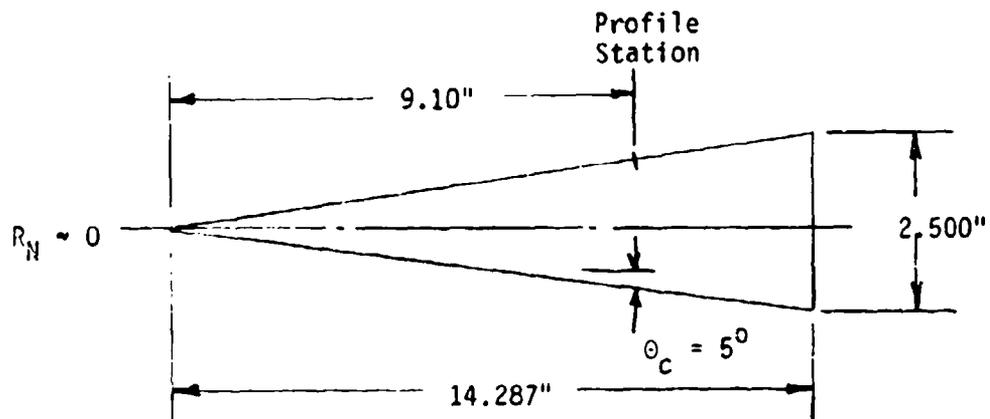
GROUND TEST DATA

DATA REVIEW

REFERENCE: 69-18 (NOLTR 69-187)

TEST OBJECTIVE: Probe the leeside flow field of a yawed sharp cone at large angle-of-attack

CONFIGURATION:



FACILITY: NSWC - TUNNEL 2 -  $M_\infty = 5.07$

ANGLE OF ATTACK:  $24^\circ$

DATA: SURFACE PRESSURE  
FLOW FIELD SURVEY (Leaside only)  
FIVE HOLE CONE PROBE ----> M  
PITOT PRESSURE,  $P_t$  ----> P,  $P_0$   
EQUIL. TOTAL TEMP. ----> T,  $T_0$   
SCHLIEREN PHOTOS

TEST SUMMARY:

<u>Type of Measurement</u>	<u>Re<sub>∞</sub>/FT</u>	<u>Azimuth Angle, φ</u>
<u>SURFACE PRESSURE</u>	2.2 x 10 <sup>6</sup>	0° and 180°
	4.4 x 10 <sup>6</sup>	0° through 180°
<u>FLOW-FIELD SURVEY</u>		
<u>Pitot Tube</u>	2.2 x 10 <sup>6</sup>	180° (leeside)
	4.4 x 10 <sup>6</sup>	135°, 150°, 160°, 165°, 180°
<u>Five-Hole Cone Probe</u>	2.2 x 10 <sup>6</sup>	180°
	4.4 x 10 <sup>6</sup>	130°, 140°, 150°, 160°, 165°, 170°, 180°
<u>Temperature Probe</u>	2.2 x 10 <sup>6</sup>	180°
	4.4 x 10 <sup>6</sup>	180°
<u>SCHLIEREN PHOTOGRAPHS</u>	4.4 x 10 <sup>6</sup>	--

DATA UTILITY:

Data could be utilized to evaluate PNS code prediction capability on a sharp circular cone -- specifically on the leeside flow field where extensive cross flow separation has occurred.

LIMITATIONS:

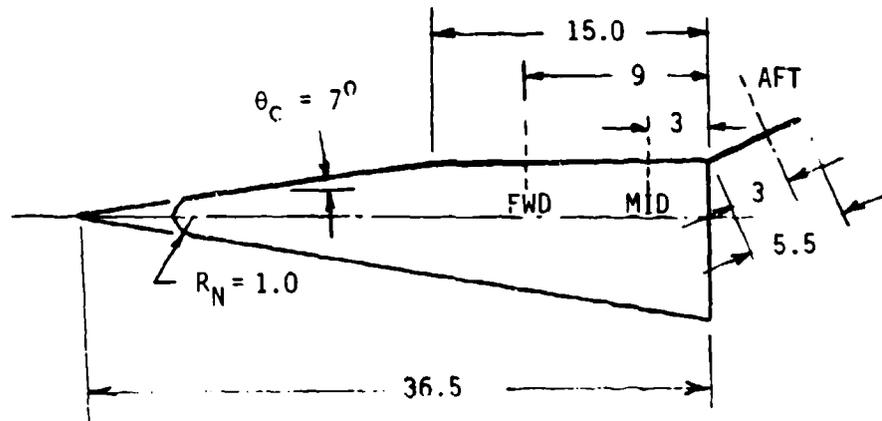
Only leeside shock layer data were obtained at a fixed axial station for a laminar boundary layer flow. Therefore if PNS code agreement with data is poor, there are not enough other diagnostic measurements to establish cause.

## DATA REVIEW

REFERENCE: 74-6 (AFFDL-TR-74-79)

TEST OBJECTIVE: Determine the heating and pressure distributions, and shock layer surveys in the vicinity of the control element for a sharp and blunt nosed slender reentry body.

CONFIGURATION:



----- → survey stations

- 3 models were fabricated
  - one of stainless steel for pressure and survey measurements
  - two of RTV rubber for heat transfer
- spherical trips were used to promote turbulence

FACILITY: AEDC VKF Tunnel B Mach 8

DATA: Surface pressure (115 orifices)  
Heat transfer via phase change paint data  
Shock layer surveys

- Pitot pressure
- Shielded total temperature probe

Oil Flow - (surface streamlines)  
Vapor Screen - (shock shape)  
Schlieren and shadowgraphs

TEST SUMMARY:  $M_\infty = 8$   $Re_\infty/ft = 3.7 \times 10^6$

Phase Change Paint Data (heat transfer)

- Angle of Attack - 0, 3°, 6°, 10°, 20°
- Flap deflections - 0 → 40° in 5° increments.  
(including some split flap data)
- Sharp and blunt configuration

Static Pressure

- Angle of Attack - 0, 3°, 6°, 10°, 20°
- Flap deflections - 0 → 40° in 5° increments.  
(including some split flap data)
- Sharp and blunt configuration

Shock Layer Survey

Sharp Nose

$\delta_F$	Angle of Attack and Stations							
	$\alpha = 0$ deg			$\alpha = 10$ deg			$\alpha = 20$ deg	
	Fwd	Mid	Aft	Fwd	Mid	Aft	Fwd	Mid
0	X	X	X	X	X	X	X	X
10			X		X	X		
20		X	X					

Blunt Nose ( $R_n = 1$  in.)

0	X	X	X	X	X	X	X	X
10			X		X	X		
20		X	X					
40	X	X						

#### DATA UTILITY:

The data contained in this report are useful for evaluating flap effectiveness on conical bodies with and without vortical flow (i.e., nose bluntness) effects. In addition, data of sufficient detail were obtained, over a large range of angle of attack and flap deflection angle, which makes this a useful source for detailed code validation. This is especially true for flow field codes such as the parabolized Navier Stokes and inviscid solutions of the Euler equations.

#### DATA LIMITATIONS:

Data were obtained with boundary layer trips, which at angle of attack could compromise the data reliability. That is, not enough effort was devoted to insure that the trips did not produce disturbances outside of the boundary layer. The data are further limited to one Mach number and Reynolds number.

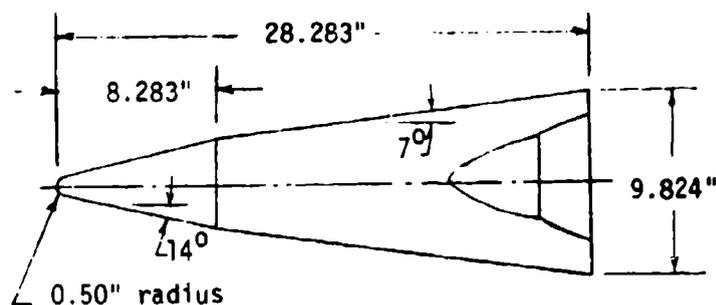
## DATA REVIEW

REFERENCE: 79-9 (AEDC-TSR-79-V36)

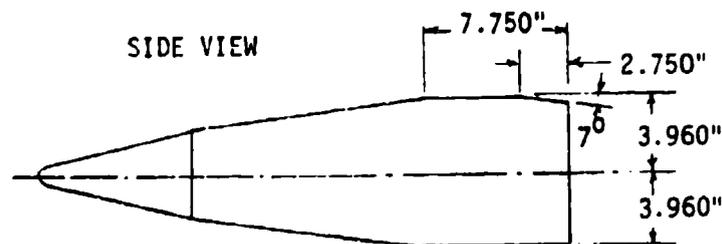
TEST OBJECTIVE: Provide a laminar flow data base for developing and validating analytical codes for predicting hypersonic aerodynamic characteristics of biconic bodies with single and multiple flat surfaces (slices)

CONFIGURATION:

TOP VIEW



SIDE VIEW



FACILITY: AEDC TUNNEL C -  $M_\infty = 10$

DATA: SURFACE HEAT TRANSFER  
SURFACE PRESSURE  
SURFACE TEMPERATURE  
FLOW FIELD SURVEY  
MACH/FLOW ANGULARITY PROBE  
PITOT PROBE  
SHIELDED TOTAL TEMPERATURE PROBE

TEST SUMMARY:

HEAT TRANSFER

$Re_{\infty}/FT$	Angle of Attack, $\alpha$	Azimuth Angle, $\phi$
$1.0 \times 10^6$	$0 \rightarrow 14^\circ$ in $1^\circ$ increments	$0^\circ \rightarrow 40^\circ$ $5^\circ$ increments $40^\circ \rightarrow 150^\circ$ $10^\circ$ increments $150^\circ \rightarrow 180^\circ$ $5^\circ$ increments
$0.55 \times 10^6$	$0, 2^\circ, 5^\circ, 7^\circ, 10^\circ, 14^\circ$	$0, 180^\circ$

SURFACE PRESSURE -  $Re_{\infty} = 1.0 \times 10^6 \text{ ft}^{-1}$

$\alpha = 2^\circ, 10^\circ$

$\phi = 0, 180^\circ$

FLOW FIELD SURVEY -  $Re_{\infty} = 1.0 \times 10^6 \text{ ft}^{-1}$

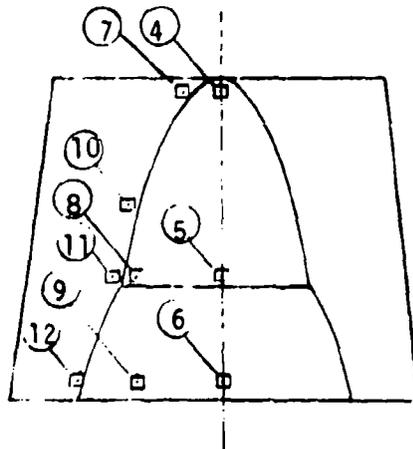
FORECONE - 1 AXIAL STATION

AFTCONE - 1 AXIAL STATION

}  $\alpha = \pm 2^\circ, \pm 10^\circ$

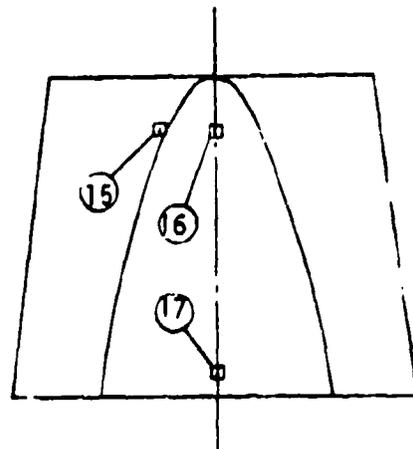
WINDWARD SLICE

$\alpha = -2^\circ, -10^\circ$



LEEWARD SLICE

$\alpha = 2^\circ, 10^\circ$



DATA UTILITY:

Data could be used to evaluate flow field code prediction capability, for laminar flow, on a blunted bicone with localized departure from a circular cross section (i.e. windward slice/cut and leeward slice). For the  $10^{\circ}$  case, leeside flow is separated - good data for PNS code validation.

LIMITATIONS:

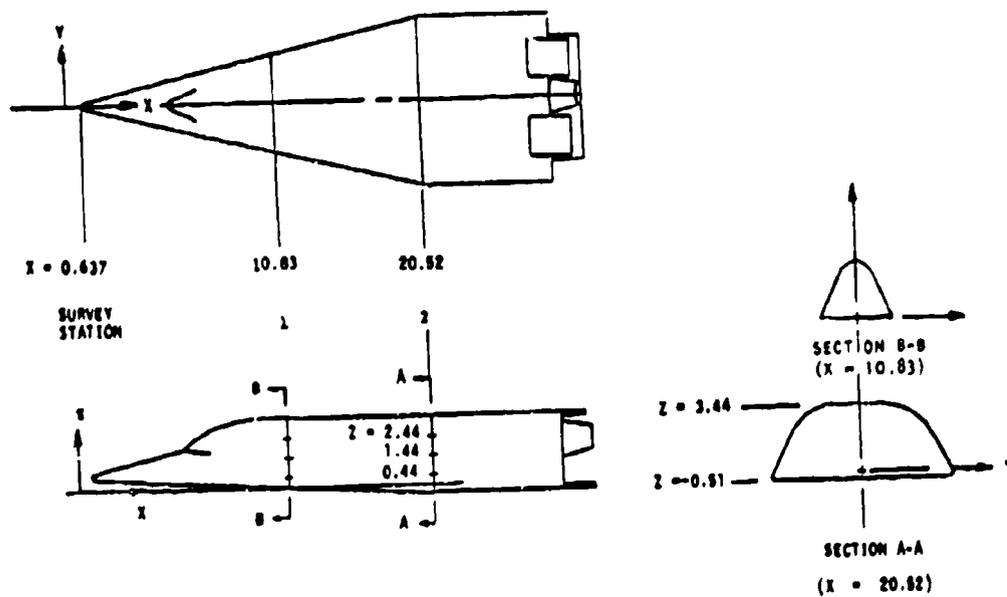
Laminar data taken with  $\alpha_{\max} = 10^{\circ}$ . It would be desirable to have data with  $\alpha \rightarrow 20^{\circ}$ . Data not useful for testing real gas capability of codes.

## DATA REVIEW

REFERENCES: 79-11 (AEDC-TSR-79-V47)  
80-8 (AEDC-TSR-80-V22)

TEST OBJECTIVE: Define the local Mach number and flow angle within the bow shock of the X-24C configuration to provide a data base for use in validating flow field codes.

CONFIGURATION: X-24C (FOREBODY)



FACILITY: AEDC VKF TUNNEL B  
DATA: MACH/FLOW ANGULARITY SURVEY  
Shadowgraphs

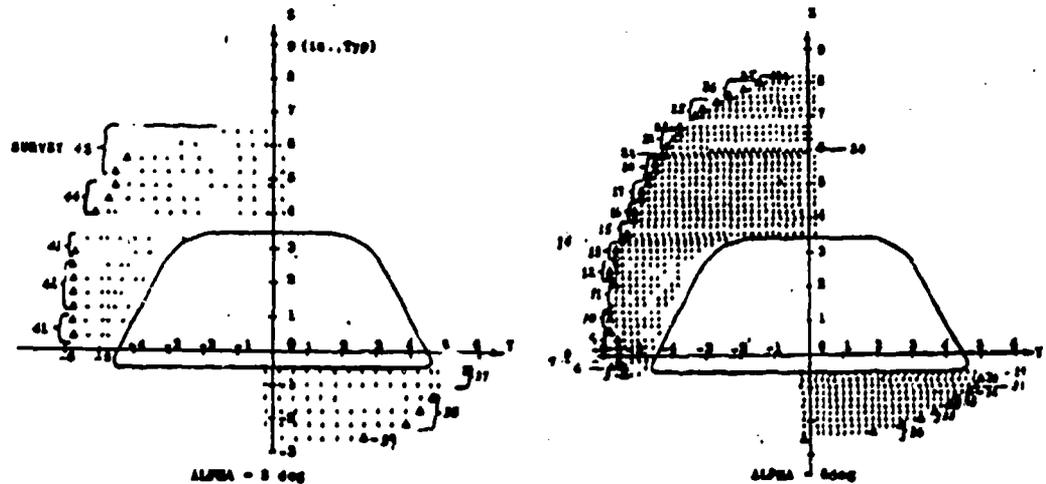
TEST SUMMARY:  $M_\infty = 6$

$Re_\infty/ft = 3.08 \times 10^6$

Mach/Flow Angularity

<u>Survey Sta. (X)</u>	<u><math>\alpha</math></u>	<u>Azimuth Angle, <math>\phi</math></u>
20.52	$2^\circ, 6^\circ, 12^\circ, 20^\circ$	$0^\circ \rightarrow 180^\circ$
10.83	$6^\circ, 20^\circ$	$0^\circ \rightarrow 180^\circ$

For illustrative purposes only, the sketch below defines the data density at the survey station  $X = 20.52$



DATA UTILITY:

The data obtained are extremely useful for evaluating flow field code prediction capability for a non-circular cross-section lifting body.

LIMITATIONS:

In these reports, only Mach/Flow angularity data were obtained. Although these data are a useful diagnostic tool for technique validation it is not sufficient for a total technique evaluation. It would be desirable to have total temperature, Pitot pressure and surface Preston tube data as well. It should also be recognized that these data are for one specific non-circular cross section configuration and consequently is therefore limited in its utility.

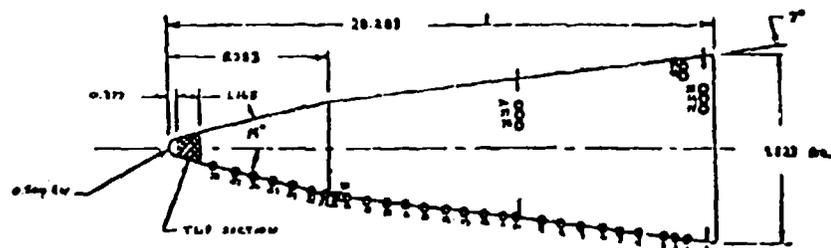
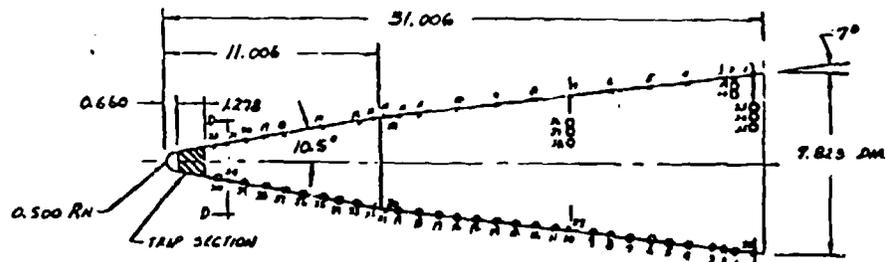
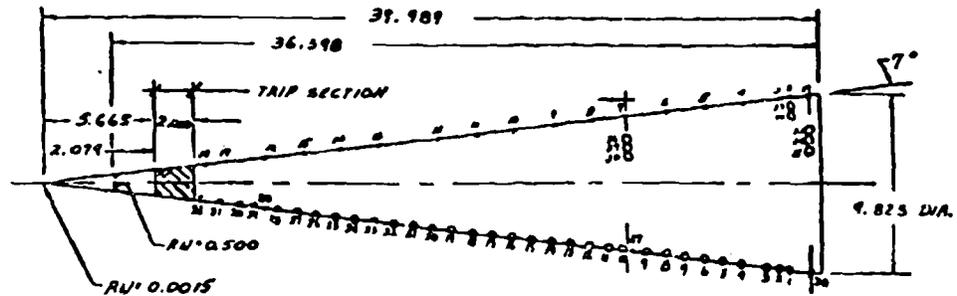
## DATA REVIEW

REFERENCE: 80-7 (AEDC-TSR-80-V14)

TEST OBJECTIVE: Provide a turbulent flow data base for sharp cones and blunt cones and bicones which could be used to validate analytic codes.

CONFIGURATION: (B. L. TRIP 0.060" height machined V GROOVE)

x PRESSURE ORIFICES      o HEAT TRANSFER GAGES



FACILITY: AEDC VKF TUNNEL B -  $M_{\infty} = 8$

DATA: SURFACE HEAT TRANSFER  
SURFACE PRESSURE  
FLOW FIELD SURVEY  
MACH/FLOW ANGULARITY PROBE  
PITOT PROBE  
SHIELDED TOTAL TEMPERATURE PROBE  
PRESTON TUBE

TEST SUMMARY: (NOTE - All Tests w/trips unless otherwise noted)

HEAT TRANSFER

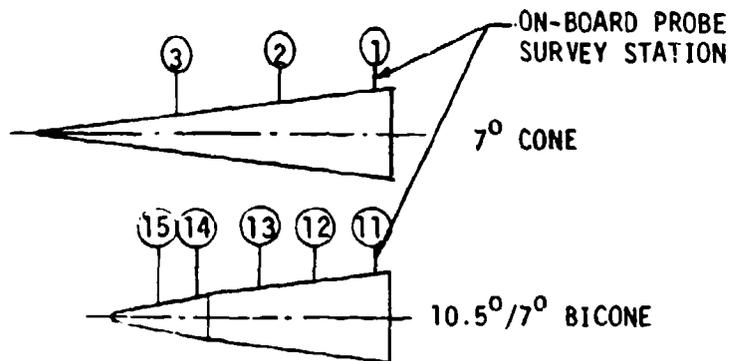
Geometry	$Re_{\infty}/ft \times 10^{-6}$	$\alpha$	Azimuth Angle, $\phi$
7° Sharp Cone	0.6, 1.0 1.0, 2.5, 3.7	0, 7°, 10° 0, 2°, 4°, 7°, 10°	180° (w/o trips) 0→180° in 45° increments
0.5" Blunt Cone	1.0 1.0, 1.5, 2.5, 3.7	0 0, 4°, 7°, 10°	180° (w/o trips) 0→180° in 45° increments
0.5" Blunt 10.5°/7° Bicone	3.7	0, 4°, 7°, 10°	0→180° in 45° increments
0.5" Blunt 14°/7° Bicone	3.7	0, 4°, 7°, 10°	0→180° in 45° increments

SURFACE PRESSURE AND PRESTON TUBE

Geometry	$Re_{\infty}/ft \times 10^{-6}$	$\alpha$	Azimuth Angle, $\phi$
7° Sharp Cone	3.7	0, 4°	0, 40°, 80°, 130°, 180°
0.5" Blunt Cone	3.7	0, 4°, 10°	0, 20, 40, 60, 80, 105, 130, 180°
0.5 Blunt 10.5°/7° Bicone	3.7	0, 4°, 10°	0, 40°, 80°, 130°, 180°

FLOW FIELD SURVEY -  $Re_{\infty} = 3.7 \times 10^6 \text{ ft}^{-1}$

SURVEY STATIONS  
(OVERHEAD PROBE)



Geometry	$\alpha$	Azimuth Angle, $\phi$	
		Overhead Probe	Onboard Probe
7° Sharp Cone	0, $\pm 4^\circ$ , $\pm 10^\circ$	180°	--
	0, $4^\circ$	--	10°-120°
0.5" Blunt Cone	0, $\pm 4^\circ$ , $\pm 10^\circ$	180°	--
	$4^\circ$ , $10^\circ$	--	10°-120°
0.5 Blunt 10.5°/7° Bicone	0, $\pm 4^\circ$ , $\pm 20^\circ$	180°	--
	$4^\circ$ , $10^\circ$	--	30°-120°

DATA UTILITY:

Data would be useful for evaluating flow field code prediction capability, for turbulent flow, on a sharp circular cone and blunted circular cone and bicones. At  $\alpha = 10^\circ$  leeside separation should be present -- good data for PNS code validation.

LIMITATIONS:

The maximum angle of attack for which data were taken was  $10^\circ$  -- it would have been useful to provide data for  $\alpha/\theta_c \approx 3$ . For the blunted cases, turbulent flow conditions were achieved by 60 mil machined roughness grooves. The effect these have on the surface and profile data quality, especially at angle of attack, is not known. Relative to these tests,

the diagnostic information for boundary layer trip effects on the data quality were performed over an angle of attack range using surface heat transfer, and at zero angle of attack only using the shock layer probe data. This information may be found in AEDC-TSR-78-V24 and V25 (August 1978 and April 1978, respectively).

DATA REVIEW  
ELLIPTIC CROSS-SECTION CONES

The documents that contain experimental aerodynamic and aerothermodynamic ground test results for elliptic cross-section cone configurations are collectively reviewed and summarized in the table below.

REF.	A/B	NOSE SHAPE		$r_{n0}$	$\alpha$	DATA TYPE			$R_w / r_0$ $\times 10^{-4}$	LA (in.)	REMARKS
		SHARP	BLUNT			F $\dot{m}$	P	q			
58-1	1.5 3.0 6.0	X	-	1.97 2.94	16°	X	X	-	9.7	9.9	EXCELLENT BASIC REPORT ON LOW M RESULTS
59-1	1.39 1.78	X	-	3.09 6.0	20°	-	X	-	0.30 0.05	4.5	LIMITED DATA BASE
59-2 61-4	2.0	X	-	5.8	14° #10°	-	X	-	0.02	4.2	LIMITED DATA BASE
59-3	1.39 1.78 3.68	X	-	3.09 5.94	15°	-	X	-	0.30 0.05	4.5	LIMITED DATA BASE
64-4	1.43 2.0	X	- X	10	60°	-	-	X	0.5 1.10 2.58	16.0	TUNNEL CONDENSATION EFFECTS COMPROMISE DATA
64-28	1.46	-	X	0.6 to 1.4 2.3, 4, 5, 8, 10	30° #10°	X	-	-	1.65 TO 3.54	8.0 13.5	LARGE DATA BASE FOR BLUNTED CONES
65-7	1.22	-	X	8	90°	X	X	-	1.81	18.0	BLUNTED HALF-CONE DATA OVER WIDE # RANGE
65-14	1.43 1.50 2.0	X	X	10 14	60°	-	X	X	0.06 TO 2.5	11.1 14.3 16.0	LARGE $\dot{q}$ DATA BASE LIMITED PRESSURE DATA
69-9	1.85	X	-	3.0 TO 6.0	16°	X	-	-	1.12 2.99 4.67	25.7	LIMITED DATA BASE FOR UPSTAGE CONFIGURATION
73-2	2.25	X	X	8	60°	-	-	X	2.0 TO 3.7	30.0	PAINT DATA EVALUATION OF BOUNDARY LAYER TRANSITION

DATA UTILITY:

These references collectively provide a variety of force and moment, pressure and heat transfer data for bodies with elliptic cross section that could be used to assess the validity of flow field prediction codes.

LIMITATIONS:

A complete data set (force and moment, pressure, heat transfer) does not exist for any combination of configuration and test condition. Also, no diagnostic shock layer data are available.

## DATA REVIEW

### ADVANCED CONTROL EXPERIMENT (ACE) PROGRAM

The documents that define the experimental aerodynamic and thermodynamic test results for the BMO ACE program are collectively reviewed and summarized below. Reports in this series are, in general, classified SECRET and can be obtained through DTIC with BMO approval. ARV (Pre-ACE) testing is not included because thermal deformations of the models, as a result of the pitch-pause run mode, were later determined to substantially influence the measured aerodynamic forces and moments. In addition, the data taken in the AEDC Tunnel F facility should be viewed with caution since a conical nozzle was employed. This nozzle provided a source flow and consequently affected the measured forces and moments. Analytic studies performed circa 1973 indicated that at Mach 16, for an  $8^\circ/6^\circ$  biconic with  $R_n/R_B = 0.1$ , the error in  $x_{cp}$  between source flow and uniform flow results were 1/2 to 1% of  $L_A$ .

### AEROTHERMODYNAMIC WIND TUNNEL TEST SUMMARY

#### OVERALL TEST OBJECTIVE:

To provide aerothermodynamic data on the ACE configuration for use in design and to support preflight predictions.

#### CONFIGURATION:

The configuration is classified SECRET. A description of the geometry and the tests may be found in the ACE Program Final Report Volume I (Ref. ACE-22). Volume III (Ref. ACE-22) presents a summary of the data analysis and comparison with flight data. More thorough discussions of the data analysis are available in miscellaneous other ACE references. These are summarized below:

## ACE PROGRAM AERODYNAMIC TESTS

1. TEST OBJECTIVES:

To provide control effectiveness data to verify FTV-3 predictions.

MODEL DESCRIPTION:

ACE configuration with 2 cuts and deflectable controls and with 2 interchangeable forecones (different angles).

$$D_{\text{BASE}} = 6.3 \text{ IN.}$$

$$L = 24 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

FACILITY

$M_{\infty}$

$Re_{\infty}/FT$

AEDC F

12

$5.5 \times 10^6$

Note: Conical nozzle was used.

INSTRUMENTATION:

Surface pressure and heat transfer rate measurements.

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

ACE Reentry Vehicle High Mach Number Flap Effectiveness Wind Tunnel Test, (Ref. ACE-19).

FACILITY REPORTS:

Pressure and Heat Transfer Tests on the SAMS0/McDonnell Douglas Advanced Control Experiment (ACE) Vehicle at Mach Number 12, (Ref. ACE-12).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

2. TEST OBJECTIVES.

To evaluate viscous interaction effects on pitch and yaw stability and drag at high angles of attack.

MODEL DESCRIPTION:

ACE configuration with 2 cuts and deflectable controls.

$$D_{\text{BASE}} = 4 \text{ IN.}$$

$$L = 16 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u>M<sub>∞</sub></u>	<u>Re<sub>∞</sub>/FT</u>
AEDC F	16	0.2 - 0.7 x 10 <sup>6</sup>
	19	0.1 - 0.6 x 10 <sup>6</sup>

Note: Conical nozzle was used.

INSTRUMENTATION:

6-component balance = 2 base pressures ( + 1 control surface pressure and 2 surface heat transfer rate measurements for selected runs).

DOCUMENTATION:

TEST RESULTS AND ANALYSIS: Examination of Viscous Effects in ACE High-Angle-of-Attack Directional-Stability Wind Tunnel Data, (Ref. ACE-18).

FACILITY REPORTS:

Lateral Static Stability Tests of the Advanced Control Experiment (ACE) Vehicle at High Angle of Attack and Mach Numbers 16 and 19, (Ref. ACE-16).

Lateral Static Stability Tests of the Advanced Control Experiment (ACE) Vehicle at High Angle of Attack and Mach Numbers 15 and 20, (Ref. ACE-17).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

3. TEST OBJECTIVES: To obtain basic stability and control effectiveness data for various biconic configurations.

MODEL DESCRIPTION: Biconic with various noses (8 spherical and 8 ablated), 4 different forcone angles, 3 different biconic juncture stations, 6 different cut configurations, 6 different control geometries, and flared and skirted configurations for yaw stability enhancement.

$$D_{\text{BASE}} = 8 \text{ IN.} \quad L = 32 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	$M_{\infty}$	$Re_{\infty}/FT$
AEDC A	3 & 5	$4.2 \times 10^6$ $6.5 \times 10^6$
AEDC B	8	$3.5 \times 10^6$
AEDC C	10	$2.2 \times 10^6$

INSTRUMENTATION: 6-Component Balance

DOCUMENTATION:

TEST RESULTS: ACE Biconic Configuration Refinement Aerodynamics Testing at Low Hypersonic Mach Numbers (Ref. ACE-24).

DATA ANALYSIS: ACE Biconic Aerodynamics and Requirements Study, Final Report, Volume 1 (Ref. ACE-25).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

4. TEST OBJECTIVES: To provide parametric data on biconic configurations and to provide parallel flow data to evaluate the source flow corrections made to the AEDC Tunnel F data.

MODEL DESCRIPTION: Bicone with 2 different forecones and 5 different nose tips (1 spherical and 4 ablated shapes) capable of being tested with or without a single cut/control geometry.

$$D_{\text{BASE}} = 3 \text{ IN.}$$

$$L = 12 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	$M_{\infty}$	$Re_{\infty}/FT$
ARL 20" TUNNEL	14.2	$0.6 \times 10^6$

INSTRUMENTATION: 3-component balance (for first 2 entries),  
5-component balance (for second 2 entries).

DOCUMENTATION:

TEST RESULTS: ACE Biconic Configuration Refinement Aerodynamic Testing in the ARL 20 Inch Hypersonic Wind Tunnel, (Ref. ACE-23).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

5. TEST OBJECTIVES:

To provide an independent source of data for establishing uncertainties in hypersonic tunnel data and to develop methods for applying ballistic range to MRV testing.

MODEL DESCRIPTIONS:

Blunt bicones with windward cuts and with fixed controls set to trim at  $\alpha \approx 0$ .

$$D_{\text{BASE}} = 1.0 \text{ IN.} \quad L = 4 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC RANGE G	12-14	$3.6 - 30 \times 10^6$

INSTRUMENTATION:

Position - attitude - time measurements from shadowgraph photos.

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

ACE Biconic Aerodynamics and Requirements Study, Final Report, Volume III, (Ref. ACE-25).

FACILITY REPORTS:

Free Flight Investigation of the Aerodynamic Characteristics of the Small Evader Vehicle, (Ref. 73-16).

Free Flight Range Tests of an ACE Biconic Configuration at Mach Numbers of 11.9 to 14.3, (Ref. ACE-31).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

6. TEST OBJECTIVES:

To verify accuracy of predictions, to determine viscous effects on stability, and to evaluate accuracy and credibility of data from various facilities.

MODEL DESCRIPTION:

Blunt bicone tested with a single nose bluntness, with and without a single windward and leeward cut geometry, and two separate control configurations (one with trapezoidal edges).

$$D_{\text{BASE}} = 8 \text{ IN.} \quad L = 32 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u>M<sub>∞</sub></u>	<u>Re<sub>∞</sub>/FT</u>
AEDC A	3	$4 \times 10^6$
AEDC A	5	$1-6.5 \times 10^6$
AEDC B	8	$1-4 \times 10^6$

INSTRUMENTATION:

6-component balance = 4 base pressures + cut surface pressures (M<sub>∞</sub> = 5 only).

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

ACE Biconic Aerodynamics and Requirements Study, Final Report, Volume III, (Ref. ACE-25).

FACILITY REPORTS:

Static - Stability Characteristics of the Advanced Control Experiment (ACE) Biconic - Phase II Vehicle at Mach Number from 3 to 10, (Ref. ACE-13).

ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

7. TEST OBJECTIVES:

To verify accuracy of predictions, to determine viscous effects on stability, and to evaluate accuracy and credibility of data from various facilities.

MODEL DESCRIPTION:

Blunt bicone with a single nose bluntness capable of being tested with or without a single cut configuration and control geometry. (Same model was tested in NSWC tunnel 8a and in ARL 20" tunnel.)

$$D_{\text{BASE}} = 3 \text{ IN.} \quad L = 12 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/\text{FT}</math></u>
AEDC B	8	$0.6-3.5 \times 10^6$
ARL 20"	14	$0.6 \times 10^6$
NSWC 8a	18	$0.6 \times 10^6$

INSTRUMENTATION:

6-component balance + 4 base pressures (AEDC B and ARL 20"), 4-component balance + 2 base pressures (NSWC 8a), + 2 cut surface pressures and 6 surface heat transfer rate measurements (AEDC B only).

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

ACE Biconic Aerodynamics and Requirements Study, Final Report, Volume III, (Ref. ACE-25).

## ACE PROGRAM AERODYNAMIC TESTS (CONT'D)

### 8. TEST OBJECTIVES:

To verify accuracy of predictions, to determine viscous effects on stability, and to evaluate accuracy and credibility of data from various facilities.

### MODEL DESCRIPTION:

Blunt bicone with single nose bluntness capable of being tested with and without a single cut configuration and control geometry.  $M_\infty = 12$  testing was initially begun with balsa wood core model covered with a thin magnesium skin (Designed for  $M_\infty = 16$  load conditions) but this model deformed excessively during higher load conditions and was replaced with the solid magnesium model.

$$D_{\text{BASE}} = 4 \text{ IN.} \quad L = 16 \text{ IN.}$$

(Also, a  $7^\circ$  sharp cone was tested for diagnostic purposes)

### FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_\infty</math></u>	<u><math>Re_\infty/FT</math></u>
AEDC F	8	$10-40 \times 10^6$
	12	$5.8 \times 10^6$

### INSTRUMENTATION:

6-component balance + 4 base pressure, stagnation pressure, and 3 surface heat transfer rate measurements.

### DOCUMENTATION:

#### TEST RESULTS AND ANALYSIS:

ACE Biconic Aerodynamics and Requirements Study, Final Report, Volume III, (Ref. ACE-25).

## ACE PROGRAM THERMODYNAMIC TESTS

### 1. TEST OBJECTIVE:

To provide thermal mapping of all exposed surfaces and assist placement of discrete sensors in subsequent tests.

### MODEL DESCRIPTION:

30% scale model with changeable flap deflection angles of  $4^{\circ}$ ,  $8^{\circ}$ ,  $12^{\circ}$ ,  $16^{\circ}$

$D_{\text{BASE}} = 6.28 \text{ IN.}$        $L = 23.9 \text{ IN.}$

### FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/\text{FT}</math></u>
KMS	7.6	---

### INSTRUMENTATION:

Paint

### DOCUMENTATION:

### TEST RESULTS:

"Wind Tunnel Measurements of Aeroheating and Pressure for a 30% Model of the ACE Vehicle at Mach Numbers of 8, 11, and 14, Volume I," Part 1, (Ref. ACE-8).

ACE PROGRAM THERMODYNAMIC TESTS (CONT'D)

2. TEST OBJECTIVE:

To obtain control surface pressure and heating data prior to start of the principal thermodynamic test program.

MODEL DESCRIPTION:

Modified 37.5% aerodynamic model with changeable flap angles of  $5^{\circ}$ ,  $7.5^{\circ}$ ,  $10^{\circ}$ ,  $15^{\circ}$

$D_{BASE} = 7.85$  IN.       $L = 29.9$  IN.

FACILITY DESCRIPTION:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC B	8	$3.6 \times 10^6$

INSTRUMENTATION:

Pressure and heat sensors on the flaps only. Heat sensors were 0.25 inch Gardon gages.

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

"Wind Tunnel Measurements of Aeroheating and Pressure for a 30% Model of the ACE Vehicle at Mach Number 8, 11, and 14, Volume I," Part 2, (Ref. ACE-8).

ACE PROGRAM THERMODYNAMIC TESTS (CONT'D)

3. TEST OBJECTIVES:

To provide detailed pressure and heating data over the entire model, with particular emphasis on the submerged surfaces of the flap assembly.

TEST BACKGROUND:

This test program evolved into five series of tests. Each new series was conducted to provide an expanded investigation of some problem detected in an earlier series. Most of these problems involved some portion of the flap assembly.

MODEL DESCRIPTION:

30% scale model with three sets of flaps representing different stages of ablated surface geometry, and changeable flap angles of  $4^{\circ}$ ,  $8^{\circ}$ ,  $10^{\circ}$ ,  $12^{\circ}$ ,  $16^{\circ}$ ,  $20^{\circ}$ .

$$D_{\text{BASE}} = 6.28 \text{ IN.}$$

$$L = 23.9 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

	<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
1)	AEDC F	11	$10 \times 10^6$
		14	$3 \times 10^6$
2)	AEDC F	11	$10 \times 10^6$
		8	$30 \times 10^6$
3)	AEDC F	11	$10 \times 10^6$
		14	$3 \times 10^6$
4)	AEDC F	11	$10 \times 10^6$
		14	$3 \times 10^6$
5)	AEDC F	8	$30 \times 10^6$
		11	$10 \times 10^6$

Note: conical nozzle used

INSTRUMENTATION:

Pressure, heating rate, and temperature sensitive phosphor paint. Heat sensors were sizes of RT and coax gages.

ACE PROGRAM THERMODYNAMIC TESTS (CONT'D)

DOCUMENTATION:

TEST RESULTS AND  
ANALYSIS:

"Wind Tunnel Measurements of Aeroheating and Pressure for a 30% Model of the ACE Vehicle at Mach Numbers of 8, 11, and 14, Volume I, "  
(Ref. ACE-8).

TABULATED DATA  
AND PHOTOS:

"Wind Tunnel Measurements of Aeroheating and Pressure for a 30% Model of the ACE Vehicle at Mach Numbers of 8, 11, and 14, Volume II,"  
(Ref. ACE-8).

ACE PROGRAM THERMODYNAMIC TESTS (CONT'D)

4. TEST OBJECTIVES:

To determine bluntness and biconic configuration effects on frustum and control surface thermal environment.

MODEL DESCRIPTION:

Biconic with alternate 15% and 20% blunt nose tips and changeable flap angles of 5°, 7.5°, 10°, 15°.

$D_{BASE} = 8 \text{ IN.}$

$L = 32.2 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

FACILITY

$M_{\infty}$

$Re_{\infty}/FT$

AEDC B

8

$3.5 \times 10^6$

INSTRUMENTATION:

Pressure and heating rate (Gardon gages)

DOCUMENTATION:

TESTS RESULTS AND ANALYSIS:

"Ace Biconic Aerodynamics and Requirements Study, Final Report - Volume II," (Ref. ACE-25).

FACILITY REPORT:

"SAMSO - MDAC/SEV Tunnel B Heat Transfer and Pressure Data," (Ref. 72-15).

ACE PROGRAM THERMODYNAMIC TESTS (CONT'D)

5. TEST OBJECTIVES:

To support thermal prediction methodology development for the ACE biconic configuration, with particular emphasis on the control surfaces.

MODEL DESCRIPTION:

Biconic with changeable flap angles of  $-15^{\circ}$ ,  $10^{\circ}$ ,  $15^{\circ}$ ,  $20^{\circ}$  and one alternate trapezoidal planform configuration.

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC F	8	$50 \times 10^6$
	12	$10 \times 10^6$
	14	$8 \times 10^6$

Note: Conical nozzle used.

INSTRUMENTATION:

Pressure, heating rate, and temperature sensitive phosphor paint. Heat sensors were RT and coax gages.

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

"Biconic Reentry Vehicle Flap Effectiveness Tests at Mach Number of 8, 12 and 14," (Ref. ACE-26).

FACILITY REPORT

"Pressure and Heat Transfer Rate Test Results on the SAMSO/McDonnell Douglas Advanced Control Experiment (ACE) Vehicle at Mach Numbers 8, 12 and 14," (Ref. ACE-10).

DATA ANALYSES:

"Ace Biconic Aerodynamics and Requirements Study, Final Report - Volume II," (Ref. ACE-25).

## ACE TEST PROGRAM SUMMARY

### DATA UTILITY:

The data obtained under the auspices of the BMO/ACE program provides a formidable data set for blunted cones and bicones with slices - cuts - and flaps. These data were obtained over a wide range of Mach numbers from 3 to 19 for laminar and turbulent boundary layer flows. Surface pressure, heat transfer, and force and moment data were obtained. Effects of nose tip bluntness on the local flow properties and aerodynamic coefficients are available for spherical, non-spherical axisymmetric, and asymmetric nosetip geometries. These data were useful not only in providing assistance in the design of the ACE vehicles but also provide a useful library of information with which to evaluate the accuracy of predictive aerothermodynamic tools.

### LIMITATIONS:

Although the data were obtained over a wide range of Mach numbers, the data obtained in Tunnel F were obtained in the conical nozzles ( $M = 8 \rightarrow 19$ ). These data suffer from the axial pressure gradients associated with the source flow present in these nozzles.

For this entire test series, only surface properties were measured, consequently if predictive techniques disagree with the measurements, there is insufficient diagnostic flow properties available to ascertain the error source. This is especially true for the flow in the slice-flap regions of the body. Furthermore, real gas effects which are present in flight for  $M \gtrsim 10$  are not simulated in the tunnels, therefore these data cannot be directly scaled (e.g. by Reynolds number) to the flight case.

## ADVANCED MANEUVERING REENTRY VEHICLE (AMaRV) PROGRAM

Similar to the summary for the ACE program, the documents that define the experimental aerodynamic and thermodynamic test results for the BMO/AMaRV program will be collectively reviewed and summarized. All reports in this series are classified SECRET and can be obtained through DTIC with BMO approval. Contrary to the ACE program tests, the AMaRV program utilized the AEDC Tunnel F when contoured nozzles were available and consequently the acquired data do not suffer the deficiencies discussed for the conical nozzle (source flow) cases.

### OVERALL TEST OBJECTIVE:

To provide aerothermodynamic data on the AMaRV configuration for use in design and to validate pretest (ground and flight) prediction capabilities.

### CONFIGURATION:

The configuration is classified SECRET. A description of the geometry and the overall aerodynamic test summaries may be found in References (AMaRV-24, 36, and 41). More thorough discussions of the data analysis are available in the several other AMaRV references, highlights of which are summarized below:

## AMaRV AEROTHERMODYNAMIC TESTS

1. TEST OBJECTIVE:

To provide data on stability and control effectiveness in a high Mach number laminar separated flow environment.

MODEL DESCRIPTION:

Bicone AMaRV configuration with interchangeable noeses (3), and a single set of cut, flap, and stabilizer geometries.

$$D_{\text{BASE}} = 4 \text{ IN.}$$

$$L = 14 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
NSWC 8a	18	$0.6 \times 10^6$

INSTRUMENTATION:

4-component balance

DOCUMENTATION:

TEST RESULTS:

AMaRV Aerodynamics Testing Report, Parametric Test Phase, (Ref. - AMaRV-15).

FACILITY TEST REPORT:

Parametric Tests of the AMaRV Configuration at Mach 18 in NSWC/WOL Tunnel 8a, (Ref. AMaRV-8).

DATA ANALYSIS:

AMaRV Aerodynamic Analyses,

(Book I AMaRV-24)

(Book II AMaRV-36)

(Book III AMaRV-43)

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

2. TEST OBJECTIVE: To provide data on body stability and control, and stabilizer effectiveness for environments best simulating the critical design conditions.

MODEL DESCRIPTION: Bicone AMaRV configuration with interchangeable noses (5), 2 different cut geometries, and a single control and stabilizer geometry.

$D_{\text{BASE}} = 15 \text{ IN.}$        $L = 53 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/\text{FT}</math></u>
NSWC 9	14	$0.9 - 4.0 \times 10^6$

INSTRUMENTATION:

4-component balance + 92 pressure and heat transfer rate transducers concentrated in control and stabilizer regions.

DOCUMENTATION:

TEST RESULTS: AMaRV Aerodynamics Testing Report, Parametric Test Phase, (Ref. AMaRV-15).

FACILITY TEST REPORT: Parametric Tests of the AMaRV at  $M_{\infty} = 14$  in the NSWC/WOL Hypervelocity Tunnel 9, (Ref. AMaRV-13).

DATA ANALYSIS: AMaRV Aerodynamic Analyses, (same as for #1 Test Objective).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

3. TEST OBJECTIVE:

To provide parametric configuration data to support the AMaRV configuration design task.

MODEL DESCRIPTION:

Bicone AMaRV configuration with interchangeable noses (10), 3 different control/cut geometries, 2 ablated forecone geometries, and 6 pairs of yaw stabilizers.

$D_{BASE} = 8 \text{ IN.}$

$L = 28 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC B	8	$3.5 \times 10^6$

INSTRUMENTATION:

6-component balance + 2 base pressures.

DOCUMENTATION:

TESTS RESULTS:

AMaRV Aerodynamics Testing Report, Parametric Test Phase, (Ref. AMaRV-15).

FACILITY TEST REPORT:

Static-Stability Characteristics of the AMaRV Prototype at Mach Number 8, (AMaRV-10).

DATA ANALYSIS:

AMaRV Aerodynamic Analyses, (same as for #1 Test Objective).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

4. TEST OBJECTIVE: To provide design verification data necessary to support final definition of the AMaRV baseline configuration.

MODEL DESCRIPTION: Bicone AMaRV configuration with interchangeable noses, capable of being tested with and without cut, with and without controls set at various deflections, and with and without yaw stabilizers.

$D_{BASE} = 15 \text{ IN.}$                        $L = 53 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	$M_{\infty}$	$Re_{\infty}/FT$
NSWC 9	14	$4.0 \times 10^6$

INSTRUMENTATION:

4-component balance + stagnation pressure measurement.

DOCUMENTATION:

FACILITY TEST REPORT:

Documentation Tests of the AMaRV at  $M_{\infty} = 14$  in the NSWC/WOL Hypervelocity Tunnel 9, (Ref. AMaRV-32)

DATA ANALYSIS:

AMaRV Aerodynamic Analysis, (Ref. AMaRV-24). Supplement (Ref. AMaRV-36).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

5. TEST OBJECTIVE:

To provide design verification data necessary to support final definition of the AMaRV baseline configuration.

MODEL DESCRIPTION:

Bicone AMaRV configuration with interchangeable noses, capable of being tested with and without cut, with and without controls set at various deflections, and with and without yaw stabilizers.

$$D_{\text{BASE}} = 8 \text{ IN.}$$

$$L = 28 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC A	3.5	$4.1 \times 10^6$
AEDC A	5	$5.6 \times 10^6$
AEDC B	8	$3.5 \times 10^6$

INSTRUMENTATION:

6-component balance + 2 base pressure measurements.

DOCUMENTATION:

TEST RESULTS:

AMaRV Aerodynamics Testing, Report, Documentation Test Phase (Ref. AMaRV-32).

FACILITY TEST REPORT:

Documentation Test Results for the AMaRV Prototype at Mach numbers 3, 5, 5.0 and 8.0, (Ref. AMaRV-20).

DATA ANALYSIS:

AMaRV Aerodynamic Analysis,

(Book I - Ref. AMaRV-24)

(Book II - Ref. AMaRV-36)

(Book III - Ref. AMaRV-43)

AMaRV Aerodynamic Characteristics, Aerospace Corporation Report (Ref. AMaRV-41).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

A Summary of the AMaRV Pitch Plane Wind Tunnel Data and Comparison with Theory, (Ref. AMaRV-37).

An Analysis of AMaRV Control Surface Characteristics in Turbulent flow, (Ref. AMaRV-40).

Longitudinal Stability of AMaRV Under Tunnel and Flight Conditions in Turbulent Flow, (Ref. AMaRV-46).

Test Plan for AMaRV Parametric and Configuration Refinement Wind Tunnel Test Series, (Ref. AMaRV-4).

Note: Data analysis reports from AEDC and SAMSO document independent analyses that were performed to check MDAC's aerodynamic estimates (i.e., independent interpretation of wind tunnel test results).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

6. TEST OBJECTIVE:

To provide design verification data necessary to support final definition of the AMaRV baseline configuration.

MODEL DESCRIPTION:

Bicone AMaRV configuration with interchangeable noses, capable of being tested with and without cut, with and without controls set at various deflections, and with and without yaw stabilizers.

$$D_{\text{BASE}} = 12 \text{ IN.}$$

$$L = 43 \text{ IN.}$$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u>M<sub>∞</sub></u>	<u>Re<sub>∞</sub>/FT</u>
AEDC F	12.5	4.0 x 10 <sup>6</sup>

INSTRUMENTATION:

6-component balance + 4 model surface pressure, nose stagnation pressure, 2 base pressure and 2 surface heat transfer measurements.

DOCUMENTATION:

TEST RESULTS:

AMaRV Aerodynamics Testing Report, Documentation Test Phase, (AMaRV-32).

FACILITY TEST REPORT:

Test Results on the AMaRV at Mach 12.8, (Ref. AMaRV-31).

DATA ANALYSIS:

AMaRV Aerodynamic Analysis,

(Book I - Ref. AMaRV-24)

(Book II - Ref. AMaRV-36)

(Book III - Ref. AMaRV-43)

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

7. TEST OBJECTIVE:

To provide pressure data for correlation with control and yaw stabilizer analytic predictions and to verify NSWC Tunnel 9 results for conditions near the critical flight environments.

MODEL DESCRIPTION:

Bicone AMaRV configuration with interchangeable noses (3), a single cut configuration, 3 different control geometries including 2 ablated shapes, and 4 separate stabilizer geometries.

$D_{BASE} = 15 \text{ IN.}$

$L = 53 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC F	12.5	$4.0 \times 10^5$

INSTRUMENTATION:

92 surface pressure and 8 heat transfer rate transducers with pressure measurements concentrated on control and stabilizer surfaces.

DOCUMENTATION:

TEST RESULTS:

AMaRV Aerodynamics Testing Report, Parametric Test Phase, (Ref. AMaRV-15).

FACILITY TEST REPORT:

Pressure Test Results on the Advanced Maneuvering Reentry Vehicle (AMaRV) at Mach 13, (Ref. AMaRV-12).

DATA ANALYSIS:

AMaRV Aerodynamic Analyses, (Ref. AMaRV-14).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

8. TEST OBJECTIVE:

To obtain substantiation of ablated flap contours and heating distributions for subsequent aerodynamic force tests.

MODEL DESCRIPTION:

Modified aero force model with both planar and contoured flaps and three alternate yaw stabilizers with angles of  $10^\circ$ ,  $15^\circ$ , and  $20^\circ$ . All control surfaces were made of RTV-60, silicon rubber, to comply with IR heat survey requirements.

$D_{BASE} = 8.0$  IN.

$L = 27.9$  IN.

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_\infty</math></u>	<u><math>Re_\infty/FT</math></u>
AEDC B	8	$3.5 \times 10^6$

INSTRUMENTATION:

Heating rate determined from surface IR radiation scans, (RTV-60 surface coating used on flaps).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

9. TEST OBJECTIVE:

To survey heating rate distribution over all exposed surfaces of the AMaRV vehicle.

MODEL DESCRIPTION:

48% scale model of the AMaRV vehicle with interchangeable nose tips and flaps representing nominal and ablated surface contours. Flap angles were changeable at 0°, 4°, 8°, 12°, 16°, 20°, 24°, and yaw stabilizer angles were 10°, 15°, and 20°.

$D_{BASE} = 11.0 \text{ IN.}$

$L = 38.4 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_{\infty}</math></u>	<u><math>Re_{\infty}/FT</math></u>
AEDC B	8	$3.5 \times 10^6$

INSTRUMENTATION:

Heating rate determined from surface IR radiations scans (RTV-60 surface coating).

DOUCMENTATION:

TEST RESULTS AND ANALYSIS:

"Post Test Report - AEDC/VKF Tunnel B, AMaRV Thermodynamic Survey Wind Tunnel Tests 1B1 and Piggyback," (Ref. AMaRV-17).

AMaRV AEROTHERMODYNAMIC TESTS (CONT'D)

10. TEST OBJECTIVES:

To obtain pressure and heating data on all external surfaces in order to substantiate or develop appropriate design methodology. Particular emphasis was given to the controls region.

MODEL DESCRIPTION:

52% model of the AMaRV FTV with alternate nose tips, flaps, flap box walls, and yaw stabilizers to permit evaluation of nominal and ablated surface contours. Flap deflection angles were changeable at  $0^\circ$ ,  $4^\circ$ ,  $8^\circ$ ,  $12^\circ$ ,  $16^\circ$ , and  $20^\circ$ .

$D_{BASE} = 12 \text{ IN.}$

$L = 42.7 \text{ IN.}$

FACILITY AND TEST CONDITIONS:

<u>FACILITY</u>	<u><math>M_\infty</math></u>	<u><math>Re_\infty / \text{FT}</math></u>
AEDC F	9	$15 \times 10^6$
	13	$4 \times 10^6$

INSTRUMENTATION:

Pressure and heating rate sensors, using both RT and coax gages. Also used temperature sensitive phosphor paint on control surfaces.

DOCUMENTATION:

TEST RESULTS AND ANALYSIS:

"Wind Tunnel Measurements of Aeroheating and Pressure for a 52% Model of the AMaRV Vehicle at Mach Numbers of 9 and 13," (Ref. AMaRV-1).

FACILITY REPORT:

"Heat Transfer and Pressure Test Results on the AMaRV Configuration at Mach 9 and 13," (Ref. AMaRV-38).

## AMaRV TEST PROGRAM SUMMARY

### DATA UTILITY:

The configuration and data obtained for the BMO/AMaRV program are similar to those of the ACE program, consequently there is some overlap in results from an analysis, or code validation, point of view. Programatically these data were obtained specifically to assist in the design and validation of the vehicle system and also to provide confidence in the computer code predictions of vehicle aerodynamics. Where these data clearly augment those for the ACE program are in the areas of; flap effectiveness as affected by ablation of the flap surface, ablated nosetip effects on vehicle aerodynamics, and stability data as affected by FYS.

### LIMITATIONS:

It should be noted that, contrary to the ACE program, the Tunnel F tests at AEDC were conducted in contoured nozzles therefore the deficiencies noted before are not present here. Again, only surface characteristics were measured (i.e., pressure, heat transfer, and configuration force and moment) - no inflow measurements were made.

In general, turbulent boundary layer flow properties on the scaled (blunted) configurations were obtained by providing boundary layer trips. Consequently, the surface properties which depend on the boundary layer state (e.g., the heat transfer) are viewed by viscous flow analysts with some trepidation. This is especially true for the case where the symmetric trips were sized to provide turbulent flow at zero angle of attack and are directly used for the large angle of attack cases (i.e.  $\alpha > 10^\circ$ ).

FLIGHT TEST DATA

DATA REVIEW  
MBRV FLIGHT TEST

REFERENCE: MBRV-60 (SAMSO-TR-68-60)

TEST OBJECTIVE: Flight tests of the MBRV system

CONFIGURATION: Cone with flap control

DATA: Flight measurements and derived quantities include:

- Force and Moment Coefficients ( $C_D$ ,  $C_m$ ,  $C_N$ )
- Control Effectiveness (hinge moment,  $C_{m\delta}$ )
- Surface Pressure (frustum and base)
- Surface Heat Transfer (frustum)
- Recession and In-Depth Temperature (frustum and flap)
- Boundary Layer Transition

DATA UTILITY:

These tests provide data over a wide range of Mach number and angle of attack, and include the effects of real gas chemistry, high Reynolds number, mass addition, and ablation shape change. They provide data on a configuration with a multi flap control. However, data appear to be of only minimal use for flow field code comparisons and validation.

LIMITATIONS:

Large data tolerances preclude use of hinge moment data for prediction comparisons. Only limited force and moment as heat transfer data are presented.

DATA REVIEW  
MARCAS III FLIGHT TEST

REFERENCE: 69-14 (SAMS0-TR-69-308)

TEST OBJECTIVE: Flight test of MARCAS III vehicles

CONFIGURATION: Cone with JI control

DATA:

- JI Control Effectiveness (moment amplification factor)
- Static Margin
- Surface Pressure (JI region)
- Recession and In-Depth Temperature (frustum and J<sup>\*</sup> region)
- Boundary Layer Transition (acoustic sensors)

DATA UTILITY:

Provides data for JI performance in high M, high Re flight environment. Provides bases for comparisons with prediction techniques and ground test data.

LIMITATIONS:

Minimal pressure and temperature data in vicinity of JI control.

DATA REVIEW

UPSTAGE FLIGHT TEST

REFERENCES: 72-13 (MDC G3263)  
72-9 (MDC G3232)

TEST OBJECTIVE: Flight Test of Upstage Vehicles

CONFIGURATIONS: Elliptic Cone with EB Control  
Elliptic Cone with JI Control

DATA:

- JI Control Effectiveness (moment amplification factor)
- EB Control Effectiveness (specific impulse)
- g and Stability ( $C_A$ ,  $X_{CP}$ )
- base Pressure

DATA UTILITY:

Provides data for JI and EB performance in flight environment. Also includes a summary of ground test JI and EB data. Provides basis for comparisons with prediction technique and ground test data.

LIMITATIONS:

Absence of diagnostic surface pressure and temperature data for modeling detailed control interaction effects.

DATA REVIEW  
ACE FLIGHT TEST

REFERENCE: ACE-22 (SAMS0-TR-75-23)

TEST OBJECTIVE: Flight Tests of ACE FTV-1, FTV-2, and FTV-3

CONFIGURATION: Cone with Flap Control

DATA: Flight measurements and derived quantities include:

- Force and Moment Coefficients ( $C_x$ ,  $C_N$ ,  $C_m$ ,  $x_{cp}$ )
- Control Effectiveness (hinge moment,  $x_{cpF}$ ,  $\Delta C_{mF}$ )
- Surface Pressure (flap, frustum, base)
- Surface Temperature (flap, frustum)
- Recession and In-Depth Temperature (flap, frustum)
- Boundary Layer Transition

DATA UTILITY:

Provides data over wide range of Mach number and angle of attack at high Reynolds number real gas flow conditions not attainable in ground test facilities. These data could be used to check the validity of flow field codes for predicting total vehicle and flap aerodynamic characteristics.

LIMITATIONS:

Data scatter precludes use for detailed assessments of prediction code accuracy. Also, the effects of flap and frustum heatshield recession and mass addition are implicit in the data.

## DATA REVIEW

### AMaRV FLIGHT TEST

REFERENCE: AMaRV-48 (BMO-TR-80-14)

TEST OBJECTIVE: Flight test of AMaRV FTV-1

CONFIGURATION: Bicone with flap control

DATA: Flight measurements and derived quantities include

- Force and Moment Coefficients ( $C_x$ ,  $C_N$ ,  $C_D$ ,  $C_L$ ,  $L/D$ ,  $C_L$ ,  $C_m$ ,  $C_y$ ,  $C_n$ ,  $X_{cp}$ )
- Stability Derivatives ( $X_{cp}$ ,  $C_{y\beta}$ ,  $C_{n\beta}$ )
- Control Effectiveness (flap load, hinge moment, flap deflection,  $C_{NF}$ ,  $X_{CPF}$ ,  $C_{m\delta}$ )
- Nosetip Force and Moment Coefficients ( $C_x$ ,  $C_N$ ,  $C_m$ ,  $C_y$ ,  $C_n$ )
- Nosetip Recession and Shape
- Surface Temperature (frustum, flap, base)
- Surface Pressure (frustum, flap, base)
- Recession and In-Depth Temperature (frustum, flap)
- Acoustic Pressure (frustum)
- Vibration (frustum and flap)
- Boundary Layer Transition (from temperature response)

#### DATA UTILITY:

This flight provides benchmark MaRV aerodynamic and aerothermodynamic performance data over a wide range of Mach numbers and angle of attack, and includes the effects of real gas chemistry, high Reynolds number, boundary layer mass addition, and ablation shape change. These data could be used to validate flow field codes at conditions of interest not achievable in ground test facilities. The particular trajectory flown by this vehicle resulted in minimal shape change thus providing useful aerodynamic coefficient data over a wide range in Mach number and angle of attack. The additional acquisition of nosetip and flap control component force and moment measurements further enhances the appropriateness of this data for code validation.

LIMITATIONS:

It is frequently not possible to isolate the effect of any one factor (e.g., shape change, real gas flow, mass addition, etc.) from the flight data since all can contribute to the measured vehicle performance. However this vehicle does not suffer significantly from these problems. Furthermore, data measurement accuracies (especially for derived parameters such as aero coefficients and stability derivatives) are lower, in some parts of the flight spectrum, than desired for use in code assessment and validation.

## DATA REVIEW

### MK 500 FLIGHT TEST

- REFERENCE: (None Available)
- TEST OBJECTIVE: Flight test of MK 500 vehicles
- CONFIGURATION: Bicone with nose control
- DATA: Flight measurements and derived quantities include
- Force and Moment Coefficients ( $C_A$ ,  $C_N$ , L/D,  $C_Y$ ,  $C_n$ )
  - Stability Derivatives ( $C_{m\alpha}$ ,  $C_{N\alpha}$ ,  $C_{n\beta}$ ,  $C_{Y\beta}$ ,  $X_{cp}$ )
  - Surface Pressure (frustum, base)
  - Nosetip recession
  - Frustum Recession and In-Depth Temperature
  - Boundary Layer Transition (from temperature response)

#### DATA UTILITY:

MK 500 flight results provide aerodynamic and aerothermodynamic performance data over a wide range of Mach number and angle of attack, and include the effects of real gas chemistry, high Reynolds number, boundary layer mass addition and ablation shape change. These data could be used to check the validity of flow field codes for a nose controlled vehicle for predicting vehicle aerodynamic and aerothermodynamic performance.

#### LIMITATIONS:

Data measurement accuracy limits the extent to which these data can be used for code validation but can be used as a benchmark for prediction accuracy. Also the effects of parameters such as mass addition and recession can not be isolated from the flight data.

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