AD NUMBER
AD804003
LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; DEC 1966. Other requests shall be referred to Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH 45433. This document contains export-controlled technical data.

AUTHORITY
AFFDL ltr, 21 Oct 1974

AERODYNAMIC CHARACTERISTICS OF BASIC AND MODIFIED ARAPAHO "C" TEST VEHICLE CONFIGURATIONS AT MACH NUMBERS FROM 2.5 TO 5

A. W. Myers

ARO, Inc.

December 1966

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

AERODYNAMIC CHARACTERISTICS OF
BASIC AND MODIFIED ARAPAHO "C"
TEST VEHICLE CONFIGURATIONS
AT MACH NUMBERS FROM 2.5 TO 5

A. W. Myers

ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), for the Goodyear Aerospace Corporation, Akron, Ohio, under Program Element 62405364, Project 6065.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from June 9 to 13, 1966, under ARO Project No. VT0626, and the manuscript was submitted for publication on October 20, 1966.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of the Air Force Flight Dynamics Laboratory (FDFR), or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

James N. McCready
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on 0.182-scale models of basic and modified configurations of the Arapaho "C" test vehicle. Static stability and drag characteristics data were obtained at Mach numbers from 2.5 to 5 at angles of attack from -5 to 15 deg. Reynolds number, based on the basic Arapaho "C" model length of 15.56 in., ranged from 0.59×10^6 to 7.96×10^6. Selected results are presented showing the effects of Mach number and Reynolds number on the vehicle static stability and drag characteristics.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Reference area (cross-sectional area of model centerbody), 3.142 in.^{2}
A_b	Base area (see Fig. 1)
C_A	Forebody axial-force coefficient, $C_{A_t} - C_{A_b}$
C_{A_b}	Base axial-force coefficient, $(p_\infty - p_b)A_b/q_\infty A$
C_{A_t}	Total axial-force coefficient, total axial force/$q_\infty A$
C_ℓ	Rolling-moment coefficient, rolling moment/$q_\infty A d$
C_m	Pitching-moment coefficient, pitching moment/$q_\infty A d$
C_{m_α}	Initial slope of pitching-moment curve, per deg
C_N	Normal-force coefficient, normal force/$q_\infty A$
C_{N_α}	Initial slope of normal-force curve, per deg
C_n	Yawing-moment coefficient, yawing moment/$q_\infty A d$
C_Y	Side-force coefficient, side force/$q_\infty A$
d	Reference length (centerbody diameter), 2.000 in.
M_∞	Free-stream Mach number
p_b	Base pressure, psia
p_o	Stilling chamber pressure, psia
p_∞	Free-stream static pressure, psia
q_∞	Free-stream dynamic pressure, psia
Re_d	Reynolds number based on model diameter
T_o	Tunnel stilling chamber temperature, °F
α	Angle of attack, deg
ϕ	Model roll attitude, deg

SECTION I

INTRODUCTION

Tests were conducted in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) of the von Kármán Gas Dynamics Facility (VKF), AEDC, to determine the static stability and drag characteristics of basic and modified configurations of the Arapaho "C", a vehicle used primarily as a forebody for testing supersonic decelerators. The tests were made in support of the EUREKA (Establishment of an Unsymmetrical Wake Test Capability for Aerodynamic Decelerators) program. Later tests in this program include flow surveys in the wake and parachute deployments behind strut-mounted models of these Arapaho configurations.

Data were obtained at Mach numbers 2.5, 3, 4, and 5 at Reynolds numbers based on model diameter which ranged from 0.072×10^6 to 1.026×10^6, and at angles of attack from -5 to 15 deg. An unsymmetrical flare configuration was tested at roll attitudes of 0, 22.5, 45, and 90 deg. A summary of the test conditions is presented in Table I.

Selected typical results are presented showing the effects of Mach number and Reynolds number on the vehicle static stability and drag characteristics.

SECTION II

APPARATUS

2.1 WIND TUNNEL

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum at each Mach number. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook.*

---

*Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

2.2 MODELS

The 0.182-scale model of the basic Arapaho "C" consists of a cylindrical centerbody with a symmetrical flare afterbody and a probe nose. Two variations in the basic configuration were obtained by replacing the probe nose with a blunted nose cone (configuration 2), and by adding an elliptical flare afterbody as well as the nose cone (configuration 3). Details of the three configurations are shown in Fig. 1, and a photograph of configuration 3 installed in the tunnel is shown in Fig. 2.

2.3 INSTRUMENTATION

Model force measurements were made with a six-component, moment-type, strain-gage balance supplied and calibrated by VKF. Before the test, loadings in a single plane and combined static loadings were applied to the balance which simulated the range of model loadings anticipated for the test. The range of uncertainties listed below corresponds to the difference between the applied loads and the values calculated with the balance equations used in the final data reduction. The minimum uncertainties given are for loads up to about 10 percent of the maximum applied and are for loadings on the particular component only (no combined loading interaction effects). The maximum uncertainties are for combined loadings.

Balance Component	Design Load	Range of Static Loadings	Range of Uncertainties
Normal force, lb	150	±2 to ±60	±0.03 to ±0.12
Pitching moment, in.-lb	690	±10 to ±150	±0.20 to ±0.60
Side force, lb	75	±2 to ±39	±0.03 to ±0.18
Yawing moment, in.-lb	345	±5 to ±80	±0.20 to ±0.90
Rolling moment, in.-lb	60	±24 to ±48	±0.05 to ±0.10
Axial force, lb	75	5 to 25	±0.07 to ±0.12

Model base pressures were measured with 1-, 5-, and 15-psid transducers, referenced to a near vacuum, which are considered accurate to within 0.30 percent of the transducer capacity.

From calibration results, the maximum variation of tunnel centerline Mach number is about ±0.5 percent, and the angle-of-attack setting is considered accurate to within ±0.1 deg.

SECTION III
RESULTS AND DISCUSSION

Normal-force, axial-force, and pitching-moment coefficients for the three configurations are shown plotted against angle of attack in Fig. 3. Data are presented for M_∞ = 2.5 and 5 for the minimum and maximum Reynolds number condition. For the selected moment reference location, configurations 1 and 3 were statically stable at both Mach numbers, whereas configuration 2 was statically unstable at M_∞ = 2.5 for the maximum Reynolds number and stable for the minimum Reynolds number condition for a limited angle-of-attack range. The curves of Fig. 4 show that configurations 1 and 3 were also stable at the intermediate Mach numbers whereas configuration 2 becomes stable for the high Reynolds number, between Mach numbers 3 and 4. This figure also shows a notable decrease in axial force with Mach number increase for all configurations, and further, that although C_{N_α} for configuration 2 increased markedly with Mach number for M_∞ > 3, C_{N_α} for configurations 1 and 3 was essentially constant with Mach number.

Shadowgraph pictures of configuration 2, presented in Fig. 5, show the separated flow regions ahead of the flare at Mach numbers 2.5 and 5. At M_∞ = 2.5, the flow is clearly attached at the maximum Reynolds number condition, but separation is evident at the lower Reynolds number (Re_d = 0.56 x 10^6). At M_∞ = 5, the flow is separated over most of the body, even at the maximum Reynolds number. The Reynolds number effects on the stability of configuration 2 at M_∞ = 2.5, noted earlier in Fig. 3, are clearly a result of the flow separation at the minimum Reynolds number. Figure 6 shows that the axial force at zero angle of attack for configuration 2 is also strongly dependent on Reynolds number at all Mach numbers tested except at M_∞ = 5, where, as mentioned previously, the flow is separated over most of the body.

The static force characteristics of the elliptical flare configuration 3, when pitched for roll attitudes of 0, 22.5, 45, and 90 deg, are shown in Fig. 7 for Mach numbers 2.5 and 5. The data show that the effects of model roll attitude decrease with Mach number increase, and that at M_∞ = 5, vehicle static longitudinal stability differs only slightly for all model roll attitudes. This result is attributed to the large regions of flow separation which essentially blank out the flare contribution to vehicle stability. Axial force showed little or no variation with roll attitude and is not presented. It should be noted here that because of small asymmetries in the large elliptical flare of this configuration, the intercept of the force and moment curves is not always zero at α = 0. This can be seen also in Fig. 3 for this model.

3

APPENDIX I
ILLUSTRATIONS

Fig. 1 Model Details

Moment Reference

2.000

3.190

9.250

13.360

18.760

Configuration 3

A_b = 14.120 in.^{2}

5.600

3.210

Elliptical Flare
Coordinates

Z	Y
0.000	2.800
0.400	2.712
0.650	2.560
0.900	2.318
1.200	1.859
1.400	1.369
1.550	0.727
1.605	0.000

0.125

1.930
1.181

2.573
2.925
4.370
0.070
0.216

Section B-B

Nose Common for
Configurations 2 and 3

0.363R

12.5 deg

18.5 deg

9.250

13.360

15.180

15.900

3.218

Configuration 2

A_b = 8.133 in.^{2}

0.740R

120 deg (Typ)

Section A-A

All Dimensions in Inches

B

Centerbody Common for
All Configurations

Common for
Configurations 1 and 2

0.454

A

A

8.910

13.020

14.840

15.560

A_b = 8.133 in.^{2}

Configuration 1

7

AEDC
13725-66

Fig. 2 Configuration 3 Installed in Tunnel A
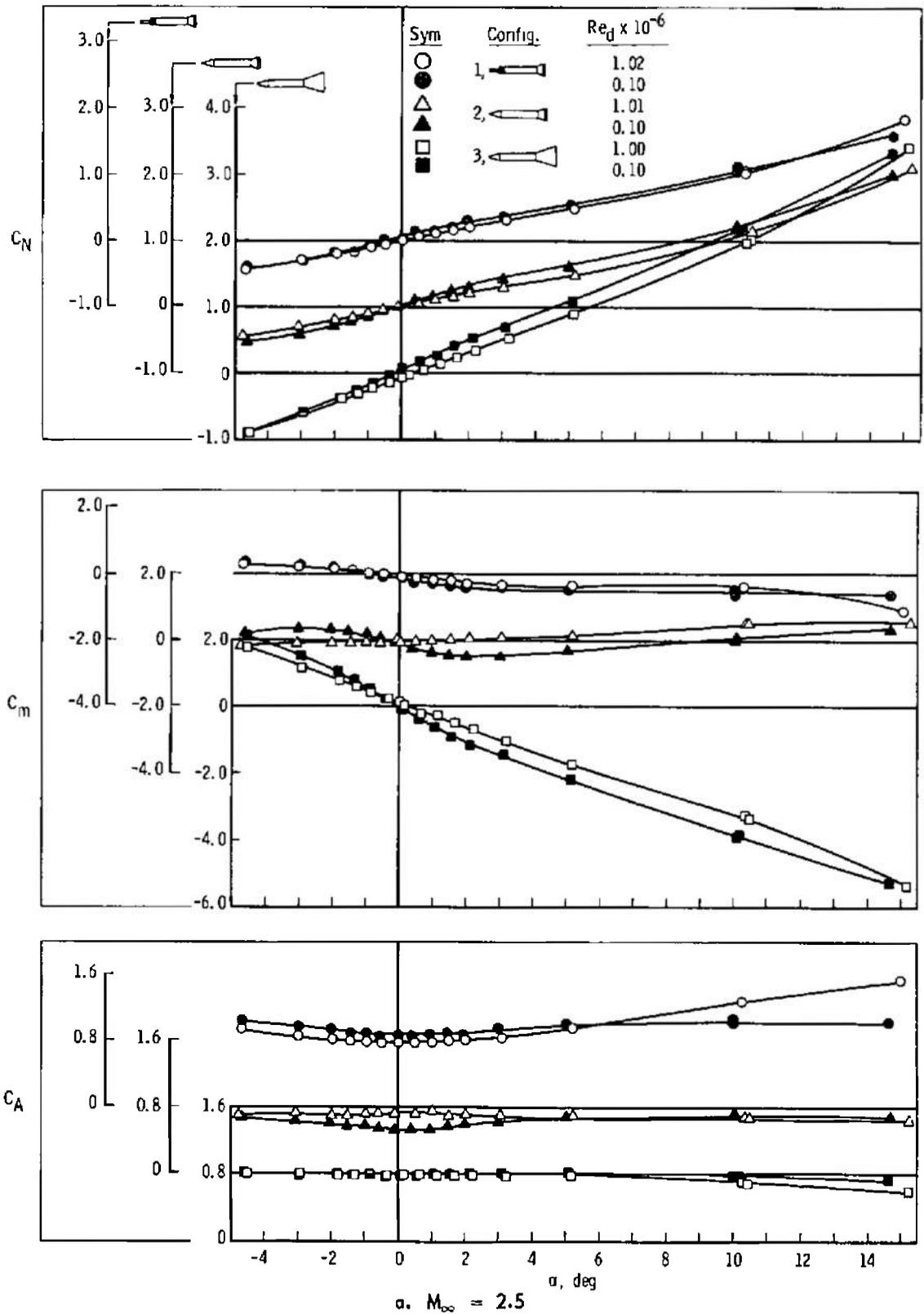
a. $M_\infty = 2.5$

Fig. 3 Effect of Reynolds Number on Longitudinal Static Stability and Axial Force
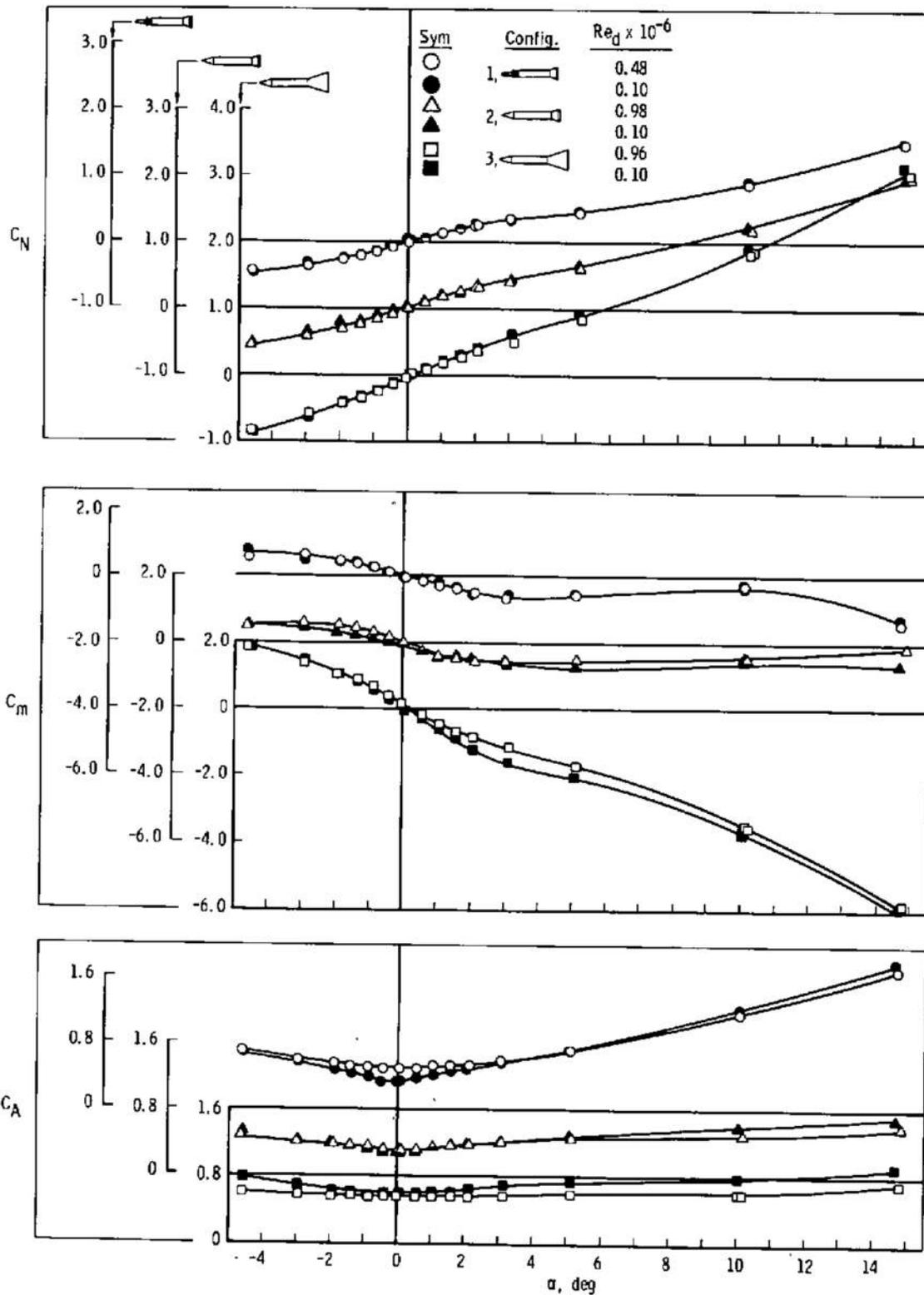
b. $M_\infty = 5.0$
Fig. 3 Concluded
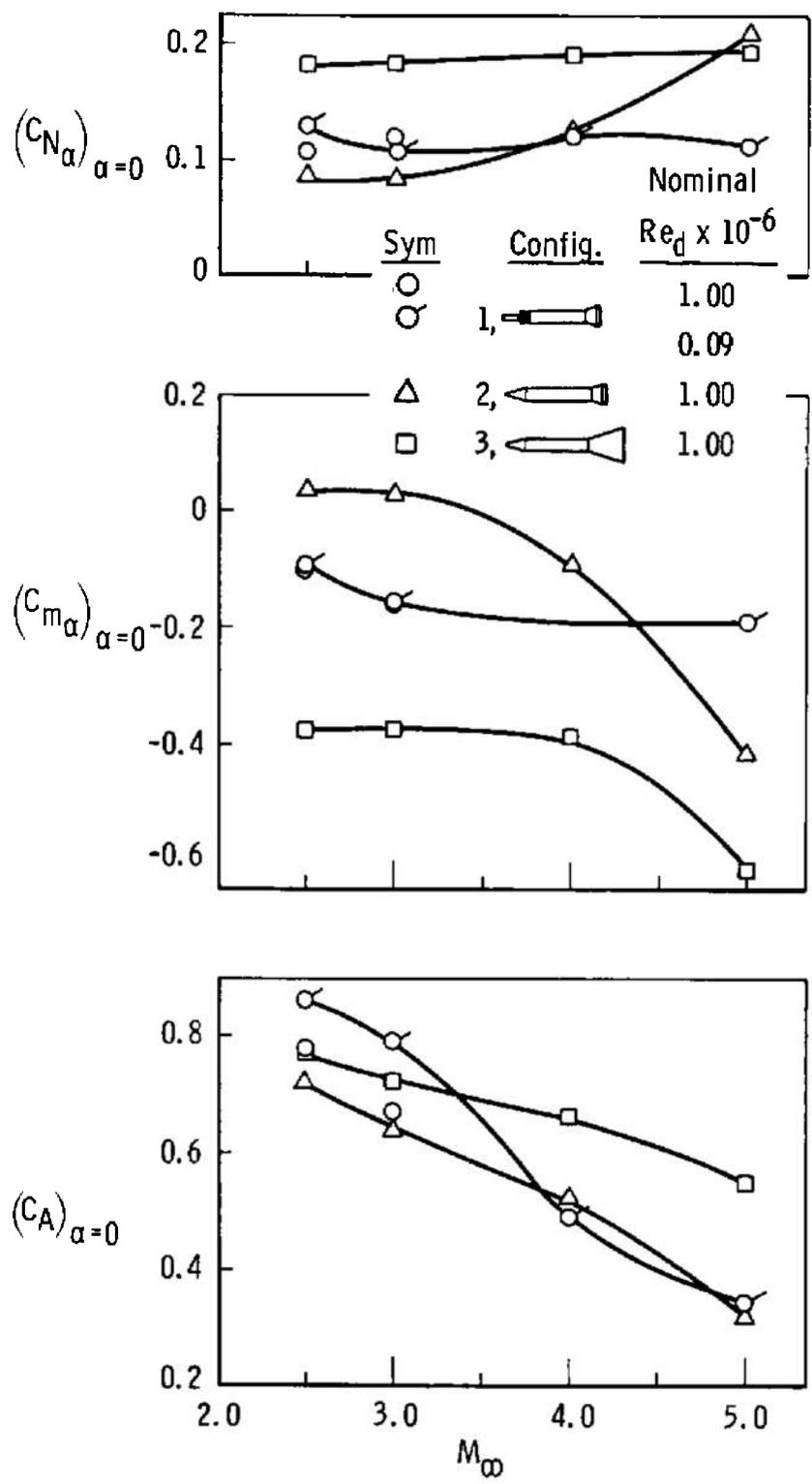
Fig. 4 Effect of Mach Number on C_{N_α}, C_{m_α}, and $C_{A_{\alpha=0}}$

$Re_d = 1.02 \times 10^6$

$Re_d = 0.56 \times 10^6$

a. $M_\infty = 2.5$

$Re_d = 1.10 \times 10^6$

$Re_d = 0.66 \times 10^6$
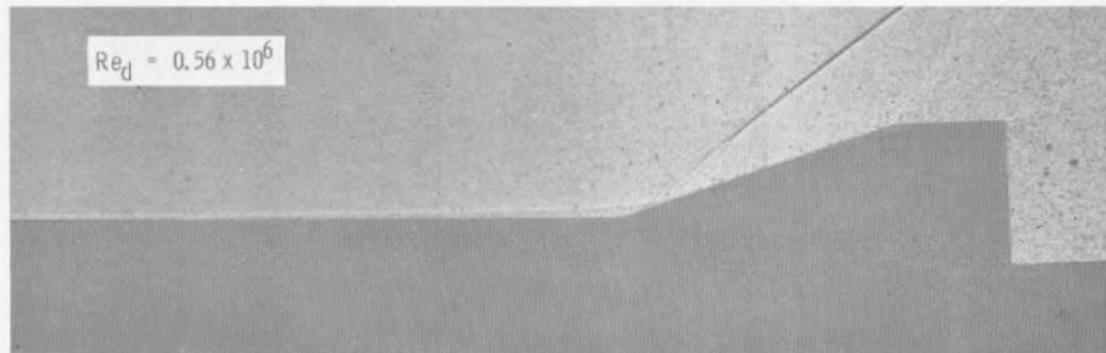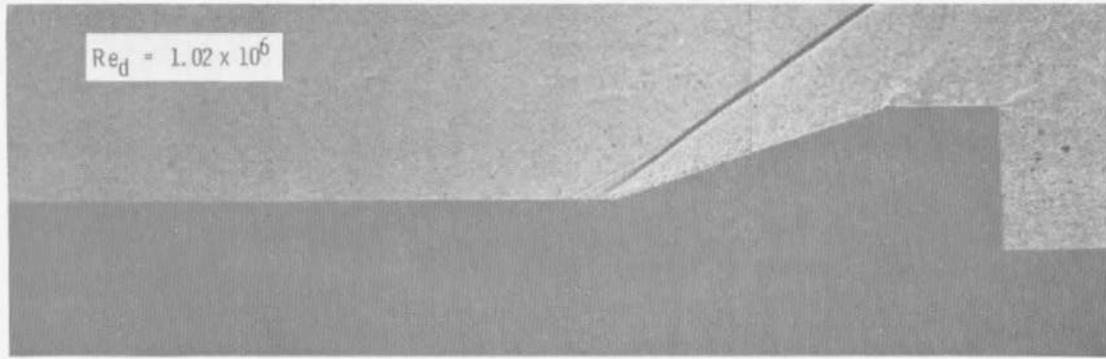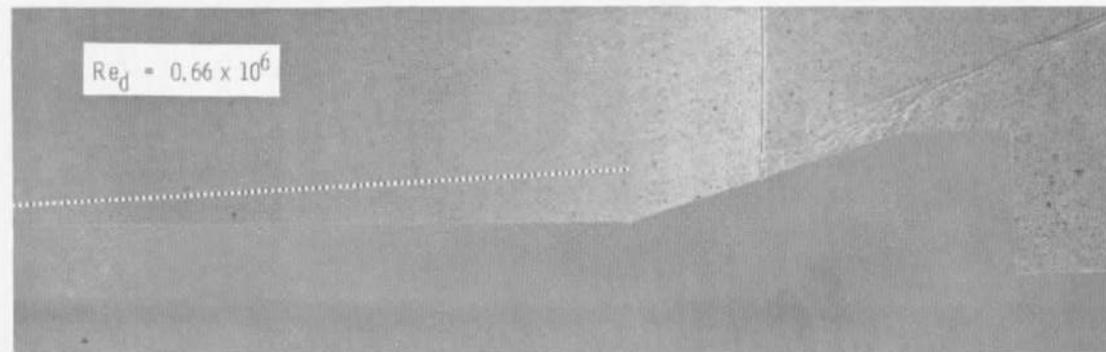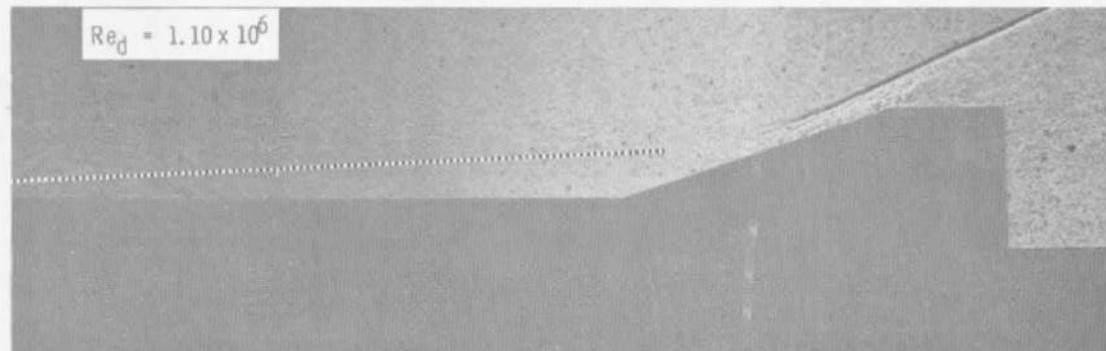
b. $M_\infty = 5.0$

Fig. 5 Typical Shadowgraphs, Configuration 2
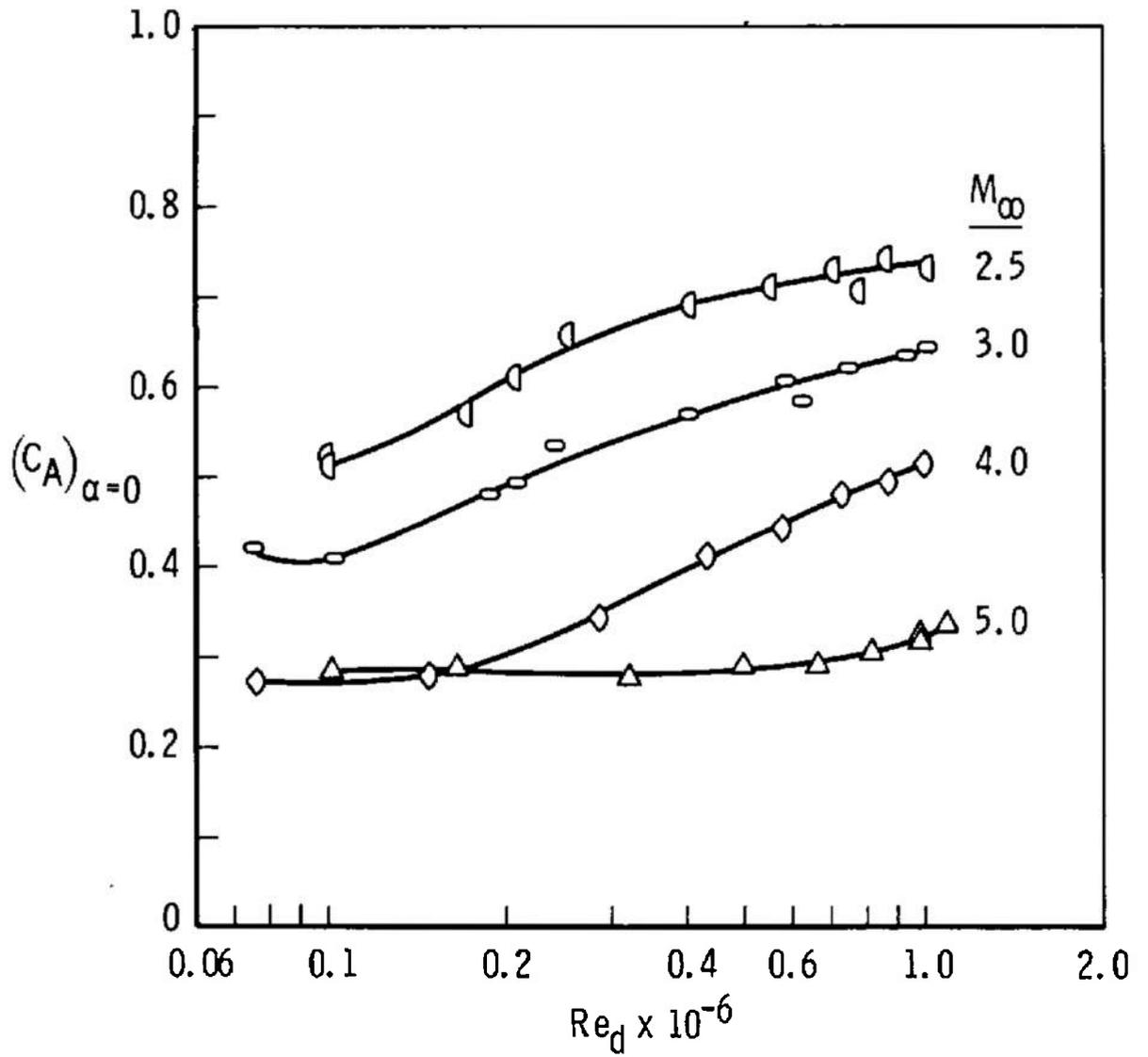
Fig. 6 Variation with Reynolds Number of the Zero-Lift Axial Force, Configuration 2
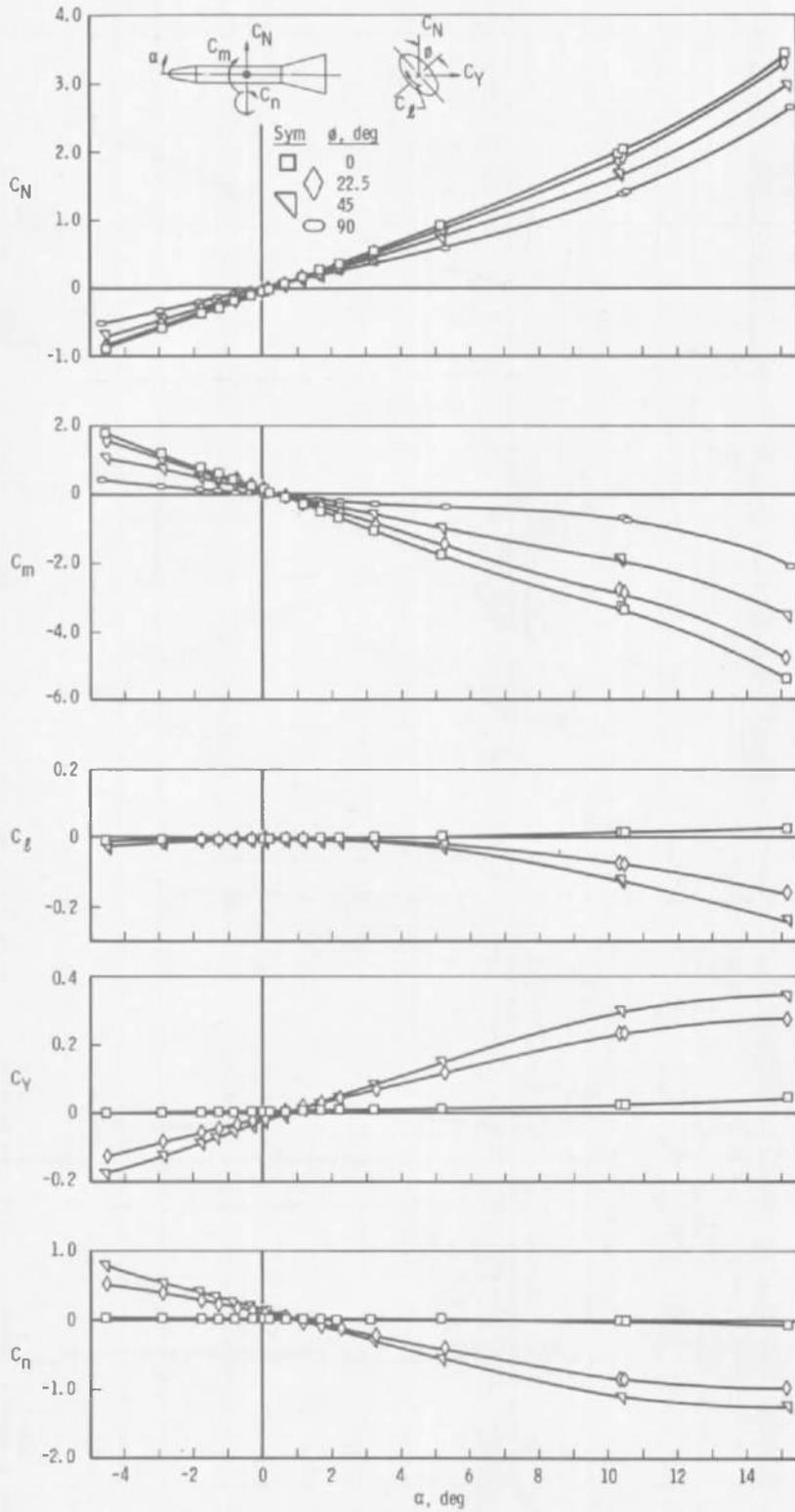
a. $M_\infty = 2.5$, $Re_d = 1.0 \times 10^6$

Fig. 7 Static Stability and Axial-Force Characteristics, Configuration 3
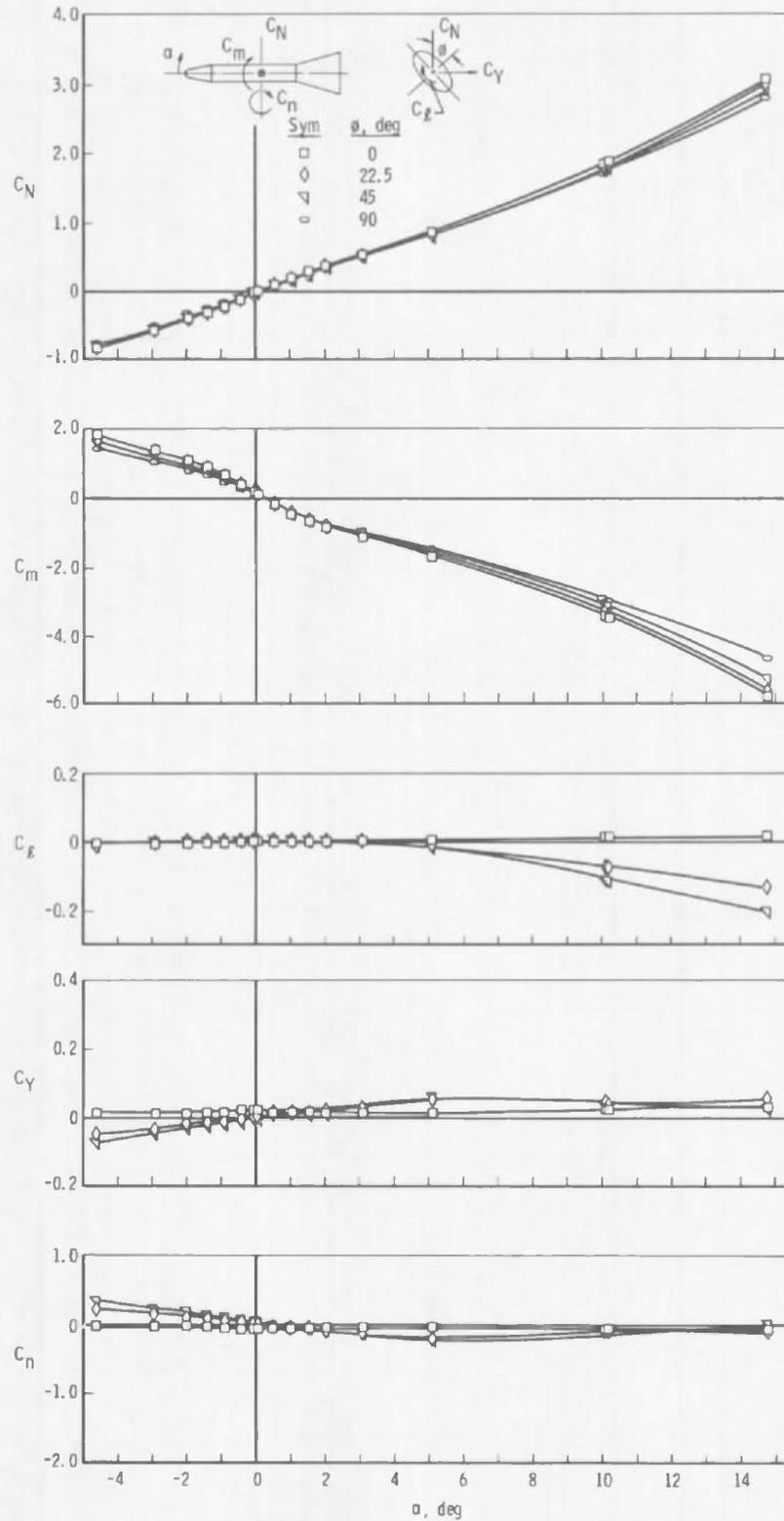
Fig. 7 Concluded

b. $M_\infty = 5.0$, $Re_d = 1.0 \times 10^6$

APPENDIX II
TABLE

TABLE I

TEST SUMMARY

Configuration	Nominal Mach Number	Calibrated Mach Number	α, deg	ϕ, deg	p_o, psia	T_o, °F	$Re_d \times 10^{-6}$
1	2.5	2.49	-5→15	0	3.0	105	0.096
		2.49			18.5	114	0.590
		2.50			33.8	120	1.026
	3.0	2.98			3.3	118	0.078
		2.99			25.4	121	0.596
		3.00			44.0	123	1.018
	4.0	3.98			5.8	119	0.080
		4.02			30.8	126	0.414
		4.02			58.0	94	0.850
	5.0	5.04			12.5	127	0.102
		5.03			20.7	120	0.174
		5.06			59.1	126	0.480
2	2.5	2.49			3.2	116	0.100
		2.50			20.8	114	0.640
		2.50			33.4	119	1.018
	3.0	2.98			3.2	118	0.076
		2.98			9.0	122	0.208
		2.99			26.8	123	0.624
		3.00			43.5	120	1.016
	4.0	3.98			5.3	111	0.076
		4.02			69.4	100	1.002
	5.0	5.02			12.3	122	0.102
		5.06			118.9	120	0.980
3	2.5	2.49		0, 22.5, 45, 90	3.1	92	0.100
		2.50			33.6	118	1.024
	3.0	2.98			3.1	120	0.072
		3.00			43.7	123	1.010
	4.0	3.98			5.3	117	0.074
		4.02			70.2	102	1.008
	5.0	5.02			12.4	120	0.102
		5.06			119.5	126	0.970

Note: Several intermediate Reynolds numbers were obtained for
configuration 2, $\alpha = 0$.

DOCUMENT CONTROL DATA - R&D
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	UNCLASSIFIED
	2b GROUP N/A

3 REPORT TITLE

AERODYNAMIC CHARACTERISTICS OF BASIC AND MODIFIED ARAPAHO "C" TEST VEHICLE CONFIGURATIONS AT MACH NUMBERS FROM 2.5 TO 5

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5 AUTHOR(S) (Last name, first name, initial)

Myers, A. W., ARO, Inc.

6 REPORT DATE	7a TOTAL NO. OF PAGES	7b NO. OF REFS
December 1966	25	1

8a CONTRACT OR GRANT NO. AF 40(600)-1200	9a ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO 6065	AEDC-TR-66-229
c. Program Element 62405364	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d	N/A

10 AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force*

11 SUPPLEMENTARY NOTES Available in DDC.	12 SPONSORING MILITARY ACTIVITY Air Force Flight Dynamics Laboratory Air Force Systems Command Wright-Patterson AFB, Ohio

13 ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on 0.182-scale models of basic and modified configurations of the Arapaho "C" test vehicle. Static stability and drag characteristics data were obtained at Mach numbers from 2.5 to 5 at angles of attack from -5 to 15 deg. Reynolds number, based on the basic Arapaho "C" model length of 15.56 in., ranged from 0.59×10^6 to 7.96×10^6. Selected results are presented showing the effects of Mach number and Reynolds number on the vehicle static stability and drag characteristics.

* Flight Dynamics Laboratory (FDFR).

DD FORM 1473 1 JAN 64

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Arapaho "C" supersonic flow static stability tests drag measurements wind tunnel testing						

2. Missiles -- Drag
3. " -- Stability
4. EUREKA program
5. Decelerators

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

   (1) "Qualified requesters may obtain copies of this report from DDC."

   (2) "Foreign announcement and dissemination of this report by DDC is not authorized."

   (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

      _____ ."

   (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

      _____ ."

   (5) "All distribution of this report is controlled. Qualified DDC users shall request through

      _____ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C),* or *(U).*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.