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WIND TUNNEL TESTS ON A MODEL OF THE TOMAHAWK SOUNDING ROCKET AT $M_\infty = 5$

J. C. Uselton

ARO, Inc.

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May 1967

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FOREWORD

The work reported herein was done for the Sandia Corporation, contractor for the United States Atomic Energy Commission, under System 921D.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted February 16 and 17, 1967, under ARO Project No. VA1760, and the manuscript was submitted for publication on April 20, 1967.

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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

Force and moment data and vapor-screen photographs were obtained in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on a Tomahawk sounding rocket model. Data were obtained with and without model spin at Mach number 5 at a Reynolds number, based on model length, of 27.3×10^6. Side force and moment data are presented for 0- and 1.5-deg canted fins along with vapor-screen photographs for the zero cant fins. Also, data are presented illustrating the effects of an offset nose.

CONTENTS

APPENDIX
Illustrations

NOMENCLATURE

A	Reference area, 3.1416 in.^{2}
C_n*	Yawing-moment coefficient, yawing moment/$q_\infty Ad$
C_y*	Side-force coefficient, side force/$q_\infty A$
d	Model diameter, 2 in.
ℓ	Model length, 46.758 in.
M_∞	Free-stream Mach number
P*	Model spin rate, rpm
p_o	Tunnel stilling chamber pressure, psia
q_∞	Free-stream dynamic pressure, psia
Re_ℓ	Reynolds number based on model length
T_o	Tunnel stilling chamber temperature, °R
α	Angle of attack, deg
δ	Fin cant angle, deg
ϕ_n*	Nose roll angle, deg

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*See Fig. 1 for indication of positive directions.

SECTION I
INTRODUCTION

In 1966, an extensive wind tunnel test program (Ref. 1) was conducted on a model of the Tomahawk sounding rocket to investigate the Magnus effects which were thought to be contributing to the coning problems encountered on several Tomahawk flights. The data from this investigation indicated that Magnus effects were present and also that unsymmetrical leeside vortices were causing small side loads when the model was not spinning. Another test program was initiated to further study the leeside flow patterns using the vapor-screen technique and also obtain force and moment data. Possible effects of aeroelastic bending which had been analytically investigated by Reis and Sundberg (Ref. 2) were investigated by obtaining data on the model with an offset nose.

Data were obtained in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) of the von Kármán Gas Dynamics Facility (VKF) on the 2/9-scale Tomahawk model at Mach 5 at a Reynolds number of 27.3 x 10^6, based on model length. Force and moment data were obtained at angles of attack from 0 to 15 deg, and vapor-screen photographs were obtained at angles of attack from 0 to 20 deg.

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_∞ = 6). Minimum operating pressures range from about one-tenth to one-twentieth of the maximum pressures. A description of the tunnel and airflow calibration information may be found in Ref. 3.

2.2 MODEL

The 2/9-scale Tomahawk model is an ogive-cylinder with cruciform 45-deg swept fins mounted at the model base and has a fineness ratio of 23.4. Model details are given in Fig. 1, and a photograph of the model installed in Tunnel A is shown in Fig. 2. The model was mounted on two ball bearings with their inner races fixed to an inner shell that was attached to the balance forward taper. The model could be locked with pins fixing the outer shell to the inner shell. Model spin rates were obtained by canting the fins. Also, the model nose could be offset 1 deg, and this offset could be fixed at various roll angles.

2.3 INSTRUMENTATION AND TECHNIQUES

Model force and moment measurements were made with a four-component, moment-type, strain-gage balance supplied and calibrated by the VKF. The balance has small outrigger side beams to obtain the sensitivity required to accurately measure small side loads while maintaining adequate balance stiffness for large pitch loads. Before the tests, a range of static loads was applied to the balance to simulate the model loads anticipated during testing. All balance components were loaded singly and simultaneously, and a range of uncertainties in measurement was determined from the differences between the applied loadings and the values calculated by the balance calibration equations used in the final data reduction. Listed below with the balance design loads are the ranges of static loads applied and the uncertainties for the components loaded singly and simultaneously:

Component	Design Load	Range of Static Loadings	Uncertainties
Normal Force, lb	500	25-150	0.25-0.75
Pitching Moment, in.-lb	2500	75-500	1.00-4.80
Side Force, lb	25	1-6.5	0.01-0.12
Yawing Moment, in.-lb	125	10-40	0.10-0.70

For the zero spin data, the model was locked by pinning the outside shell of the model to the inner shell. When the model was tested with the canted fins, it was allowed to free spin at its steady-state value. Up to seven points were taken at each angle of attack when the model was spinning, whereas two or three data points were usually taken with the model locked (zero spin). The numerous data points were taken to average the scatter encountered because of model vibration and the small magnitude of the side forces. The data points presented in this report are the arithmetic average of all the data points taken at the particular angle of attack. Model spin rates were measured with a high intensity Strobotac® by synchronizing on a fin through the tunnel window. The positive directions for the side loads and spin are given in Fig. 1.

The vapor-screen technique was used to study the leeward flow patterns. Steam was injected into the tunnel upstream of the stilling chamber. Two 20-mw laser light sources were used with their beams being deflected by cylindrical lenses such that they produced a narrow slit of light. The plane of light could be positioned at different stations along the body; thus, the leeward flow field could be traversed.

Force and moment data and vapor-screen photographs were obtained for the model locked (P = 0) with the straight nose and with the nose pitched down 1 deg and rolled ±20 deg. Data were also obtained for the basic model spinning (cant angles of ±1.5 deg). The test conditions were as follows:

M_∞	p_o, psia	T_o, °R	$Re_\ell \times 10^{-6}$
5.01	150	610	27.3

SECTION III
RESULTS AND DISCUSSION

In Fig. 3, the variations of C_Y and C_n with angle of attack are presented for fin cant angles of 0 and ±1.5 deg. As mentioned previously in the Introduction, a thorough treatment of the aerodynamic characteristics of the Tomahawk model, including the effects of spin, is given in Ref. 1. The spin data shown in Fig. 3 for $\delta = \pm 1.5$ deg, $P_{\alpha = 0} = 2850$ rpm repeated the trends of the previous tests. There was only a small variation of spin rate for the angle-of-attack range tested.

The zero spin data, presented in Fig. 3, show, as was determined previously (Ref. 1), that at the higher angles of attack the model begins to experience side loads which are attributed to the leeward vortex pattern becoming asymmetric. This change in the vortex pattern is seen in Fig. 4 where the vapor-screen photographs are presented for the model locked (P = 0). An explanatory sketch of the vapor-screen photographs is given in Fig. 5; the leeward wake and vortices appear black in the plane of light. The photographs were taken at an angle from outside the tunnel windows. The model and the light cut off by the model create the dark region at the bottom of the photographs. At 10-deg angle of attack, the photographs show a symmetric pair of vortices which tend to elongate and become slightly asymmetric at $\alpha = 15$ deg. When the angle of attack is increased to 17 deg, the photographs show that the vortices have begun to break off into the familiar von Kármán vortex street. No notable effects of spin were detected in the vapor-screen photographs.

The effects of the nose being pitched to 1 deg with respect to the body (nose at ϕ_n = 200 deg, see Fig. 1) are presented in Fig. 6. Pitching the nose produced considerable variation of C_y and C_n with angle of attack.

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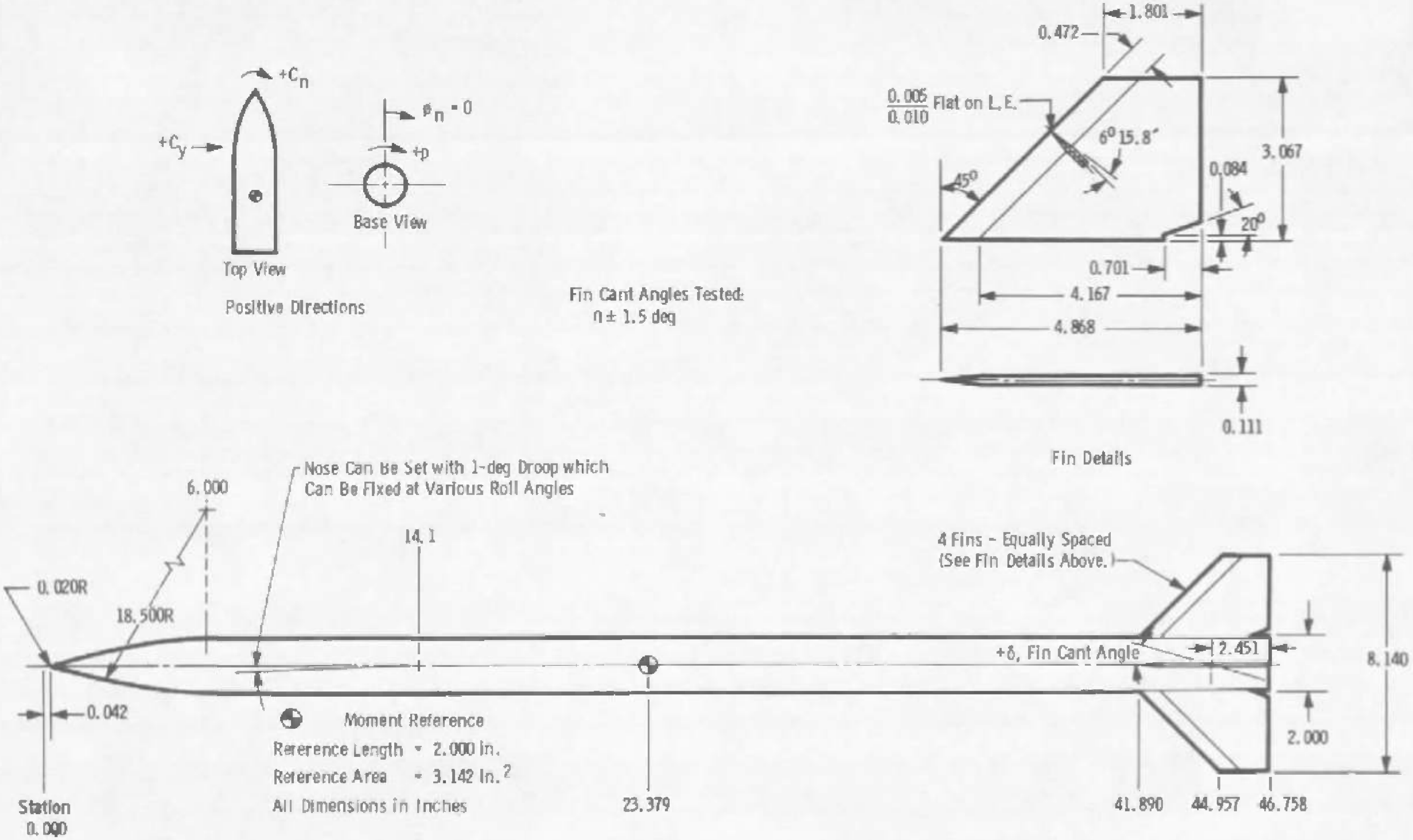
2. Reis, George E. and Sundberg, Wayne D. "Calculations of the Aeroelastic Bending of a Sounding Rocket Based on Flight Data." Paper presented at the AIAA Sounding Rocket Vehicle Technology Specialist Conference, February 27, 1967.

3. Test Facilities Handbook (Sixth Edition), "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

APPENDIX
ILLUSTRATIONS


+Cn
+Cy
ϕn = 0
+p
Top View
Base View
Positive Directions
Fin Cant Angles Tested:
0 ± 1.5 deg
0.472
1.801
0.005 / 0.010 Flat on L.E.
6° 15.8'
3.067
45°
0.084
20°
0.701
4.167
4.868
0.111
Fin Details
Nose Can Be Set with 1-deg Droop which
Can Be Fixed at Various Roll Angles
6.000
14.1
4 Fins - Equally Spaced
(See Fin Details Above.)
0.020R
18.500R
+δ, Fin Cant Angle
2.451
8.140
0.042
Moment Reference
Reference Length = 2.000 in.
Reference Area = 3.142 in.²
All Dimensions in Inches
2.000
Station
0.000
23.379
41.890
44.957
46.758

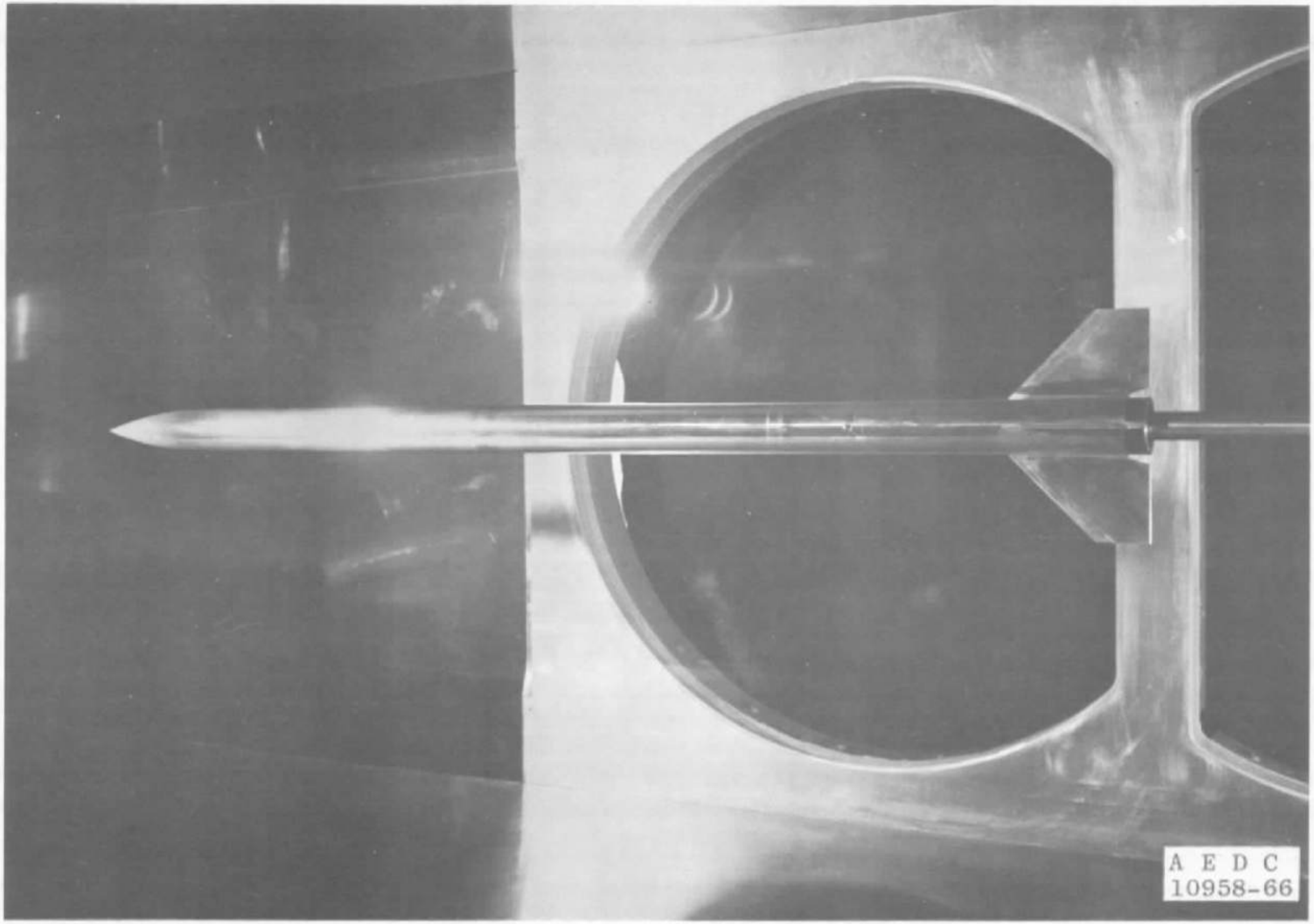


Fig. 2 Model Installation Photograph

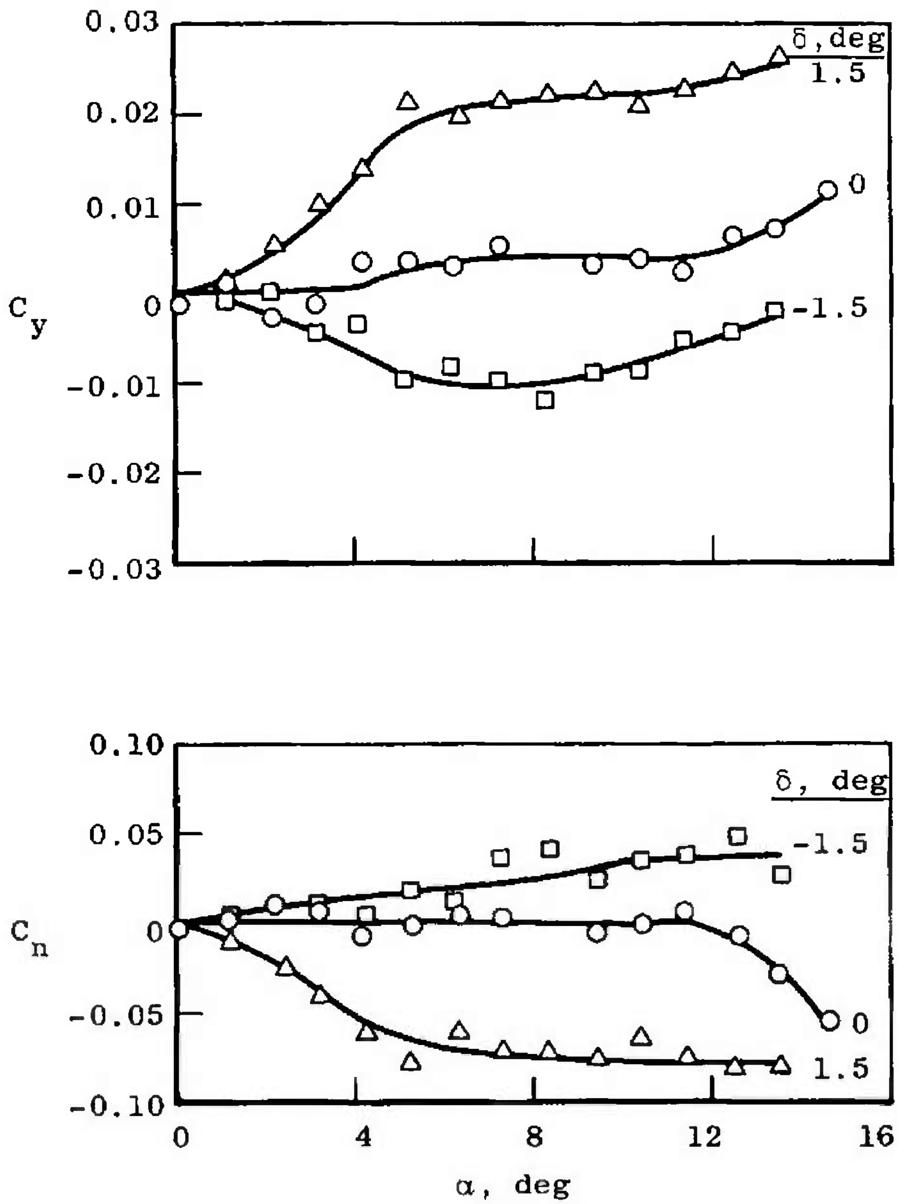


Fig. 3 Variations of C_y and C_n with Angle of Attack, δ = 0, ±1.5 deg

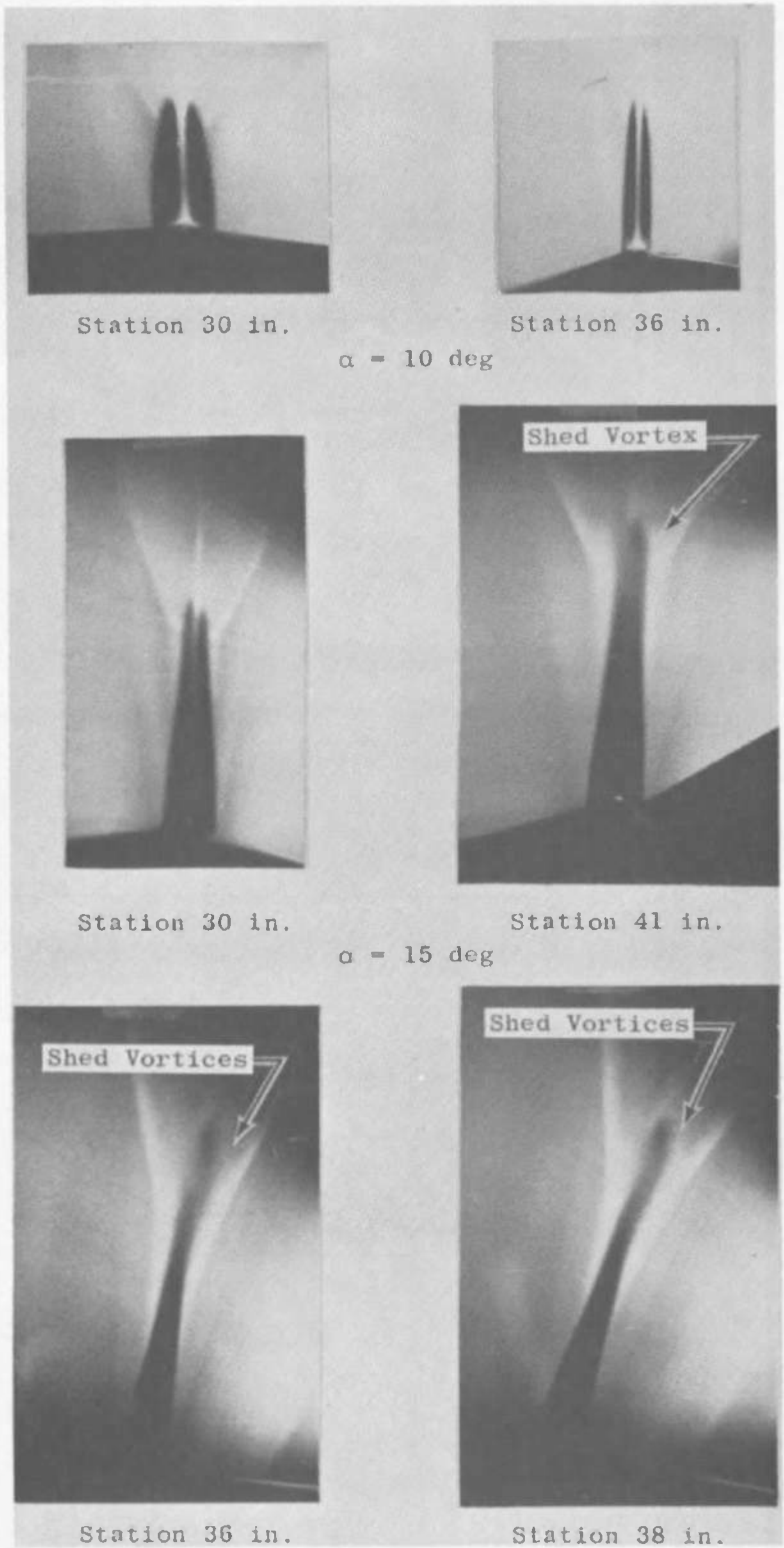


Fig. 4 Photographs of the Leeward-Flow Patterns with Model Locked (P = 0)

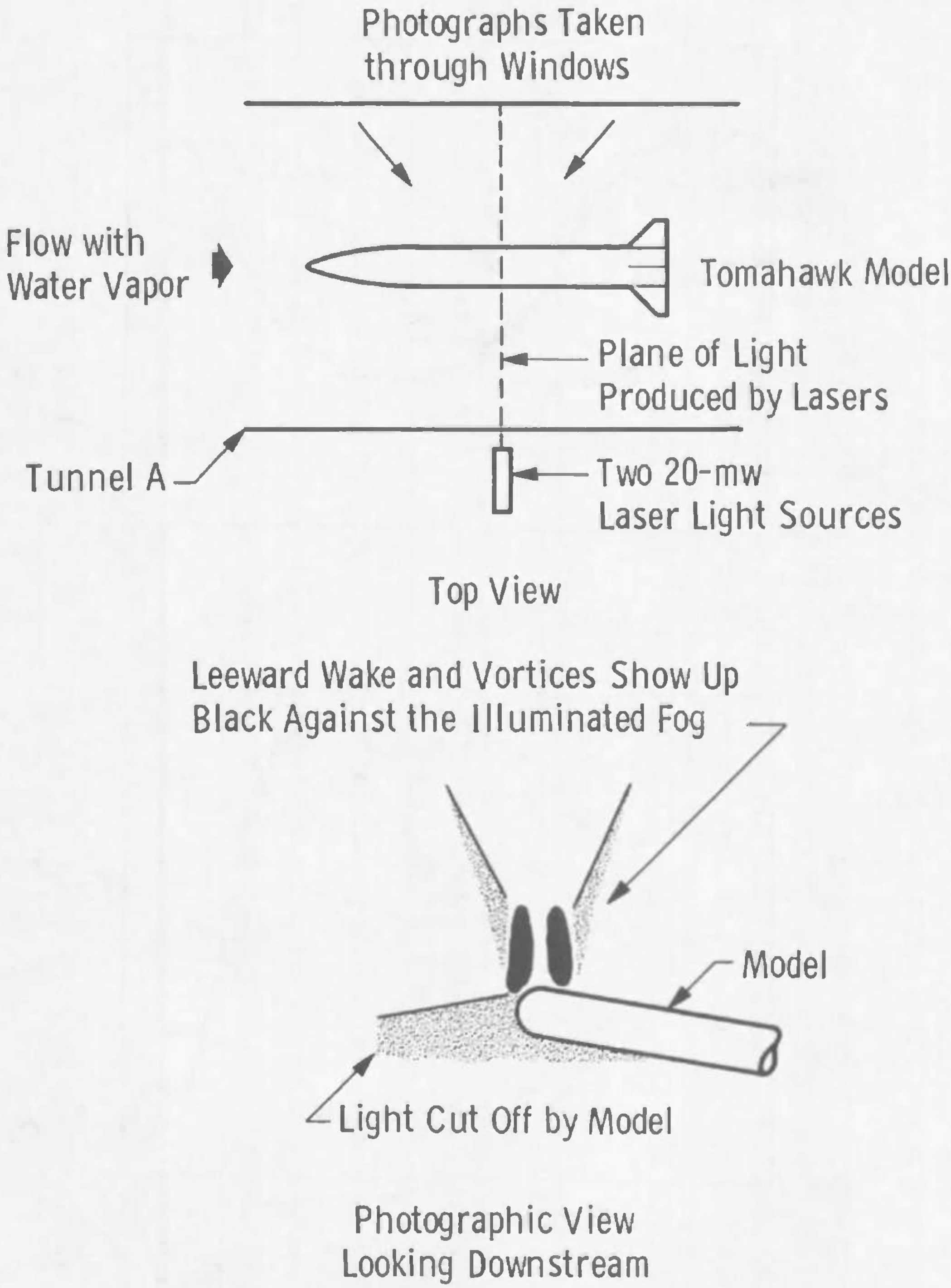


Fig. 5 Explanatory Sketch of Vapor-Screen Photographs

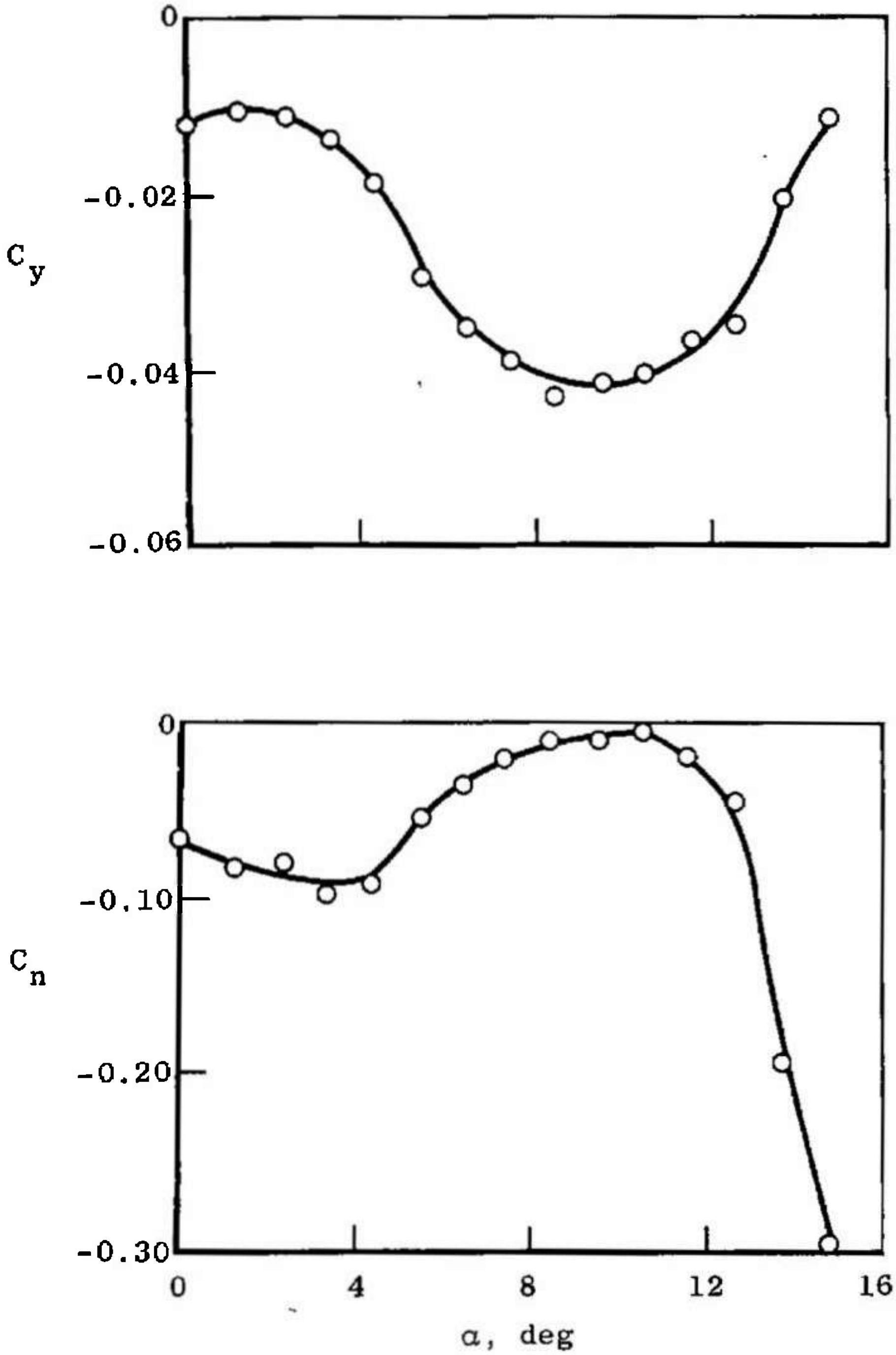


Fig. 6 Effects of the Nose Pitched 1 deg at ϕ_n = 200 deg on the C_y and C_n Variations (P = 0, δ = 0)

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