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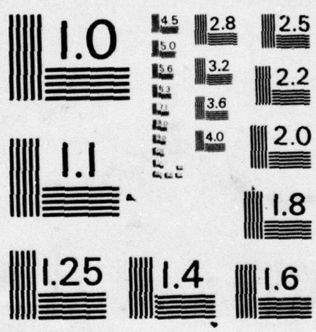

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A FEASIBILITY STUDY ON DRAG REDUCTION OF A CONE AT LOW SPEEDS

by

Joseph Huerta

September 1971

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Research Laboratories
Office of the Director
Edgewood Arsenal, Maryland 21010

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Task 1W062116A08102

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
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Office of the Director
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FOREWORD

The work described in this report was conducted under Task 1W062116A08102. This work was started in December 1970 and completed in March 1971.

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DIGEST

A 10-inch cone with a 4-inch-diameter base was utilized in this feasibility study to determine the possibility of overall drag reduction by introducing a jet of gas near the nose of the cone to change the boundary layer characteristics favorably thereby minimizing friction drag. Initial tests were made at selected velocities with a smooth-finished wooden model to determine baseline drag values, followed by an instrumented aluminum model with an annular slot located 25 percent of the body length from the nose. Gas was injected into the boundary layer through the annular slot and the results indicated that a thrust was developed by the emitted gas accounting for the drag reduction.

CONTENTS

A FEASIBILITY STUDY ON DRAG REDUCTION OF A CONE AT LOW SPEEDS

I. INTRODUCTION.

The Aerodynamics Research Group (ARG) received a request from the Propellant Actuated Devices Laboratories (PAD), Frankford Arsenal, Philadelphia, Pennsylvania, to conduct an investigation on possible drag reduction due to skin friction by injecting a gas from an annulus located near the nose of a cone into the boundary layer along the cone surface. The study was performed in the ARG 24 by 34-inch subsonic wind tunnel utilizing smooth surface cone models with and without gas ejection provision.

II. BACKGROUND.

Initial efforts have been conducted on a project entitled "Emergency Control of Boundary Layer on Aircraft Wings by Propellent Energy - PAD Antistall" at Frankford Arsenal.* This study was to determine the effects of coexisting propellent gas and boundary layer and their resultant drag reduction characteristics on typical airfoils. As a result of this investigation, it was mathematically demonstrated that drag reductions of 33 percent or more were possible on flat-plate models. Based on promising results indicated in the mathematical analysis on skin friction drag reduction, a PAD cone was designed with a gas discharge slot located 25 percent aft of the tip. This cone was to be bench and wind-tunnel tested to verify experimentally the drag reduction indicated by the mathematical analysis. Ultimately, free-flight firing tests were to be conducted.

III. SYMBOLS.

The symbols used to define the aerodynamic parameters in this report are listed below.

C_D - drag coefficient

C_{D_1} - drag coefficient before gas injection into boundary layer

C_{D_2} - drag coefficient with gas injection into boundary layer

C_{D_3} - drag coefficient after gas injection into boundary layer

ΔC_D - $\frac{T}{qS}$

q - dynamic pressure

S - model reference area

* Litz, Charles J., Jr. Emergency Control of Boundary Layer on Aircraft Wings by Propellant Energy - PAD Antistall. PAD Two-Phase Boundary Layer and Its Drag Reduction Characteristics (Part II). Frankford Arsenal Memorandum Report M66-13-4. March 1967.

T - jet thrust at slot at static conditions (V = O)

V - wind-tunnel velocity

ψ - angle of yaw

IV. MODEL DESCRIPTION.

The models tested in the ARG subsonic wind tunnel were 10-inch-long cones with a 4-inch-diameter base (figure 1).

Initial tests were conducted with a smooth wooden cone to obtain basic drag data. An instrumented aluminum model was designed and fabricated by Frankford Arsenal for the gas injection phase of the test. The gas discharge nozzle was located 25 percent of the body length aft of the tip of the cone (see figure 1).

V. DISCUSSION OF RESULTS.

The drag characteristics of a smooth surface wooden cone model were determined at velocities of 73, 110, 147, 183, and 220 feet per second and at yaw angles of 0° through 10°. These data served as a basis to compare drag results with the more complex instrumented cone incorporating an annular slot near the nose for gas ejection into the boundary layer. A cubic regression curve was determined for the set of drag data at each velocity by using the yaw angle as the independent variable. The following equations were defined for prediction of drag coefficient at each velocity.

V = 73 fps (50 mph)

$$C_D = 0.351 - 0.000858\psi + 0.000521\psi^2 + 0.0000126\psi^3$$

V = 110 fps (75 mph)

$$C_D = 0.339 - 0.00214\psi + 0.00166\psi^2 - 0.0000719\psi^3$$

V = 147 fps (100 mph)

$$C_D = 0.342 + 0.00278\psi + 0.000182\psi^2 + 0.0000352\psi^3$$

V = 183 fps (125 mph)

$$C_D = 0.346 - 0.0000990\psi + 0.00137\psi^2 - 0.0000562\psi^3$$

V = 220 fps (150 mph)

$$C_D = 0.353 + 0.00125\psi + 0.000779\psi^2 - 0.00000958\psi^3$$

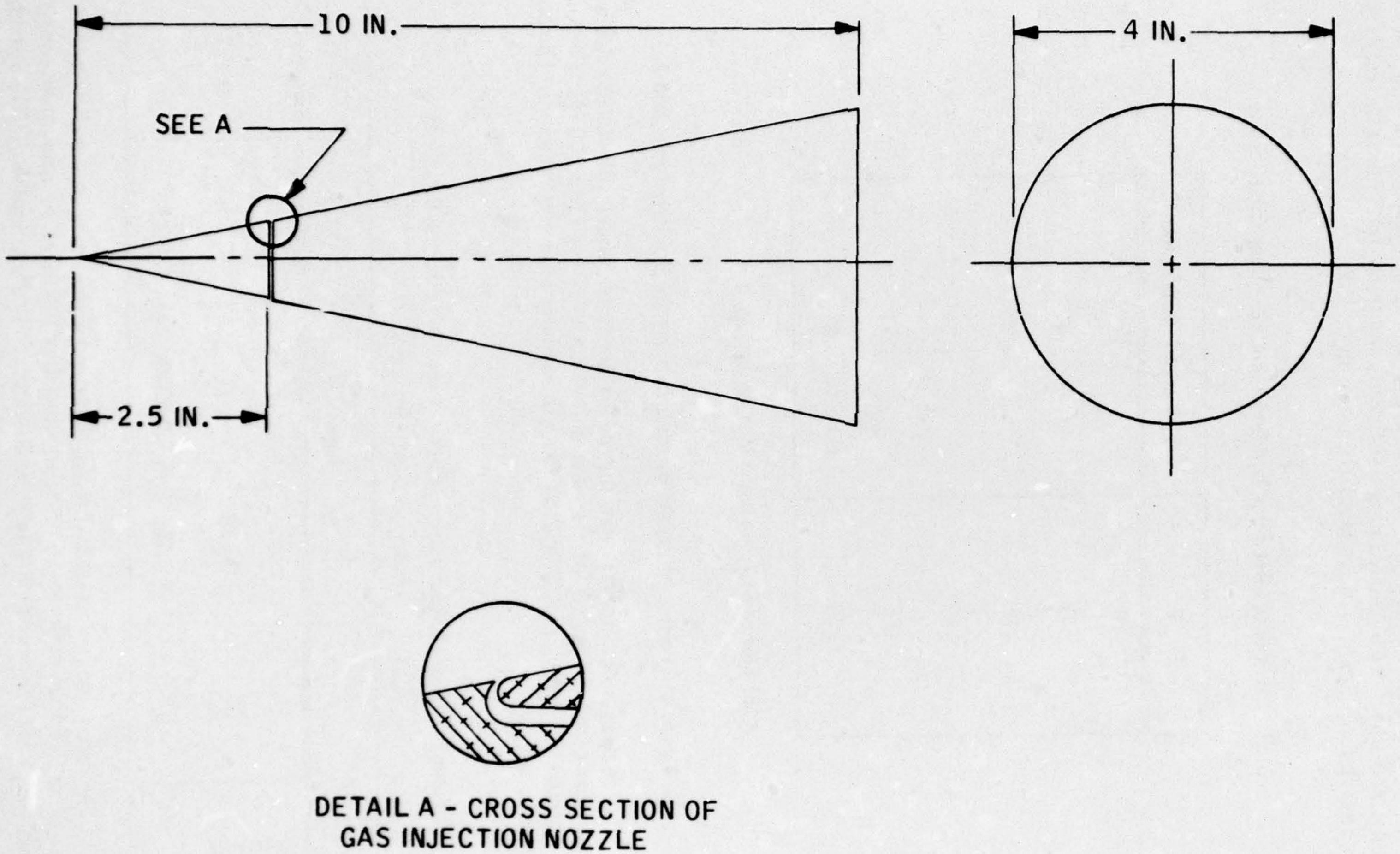

Figure 1. Schematic Diagram of Test Model

Using the above equations to predict drag for angles of yaw up through 10°, maximum differences between estimated drag coefficients and those determined by test data were established for each test velocity and are tabulated below in table I.

Table I. Differences Between Test and Estimated Drag Coefficients

V	Maximum differences
fps	%
73	3.4*
110	1.7
147	1.2
183	1.5
220	0.4*

* The predicted C_D was higher than the test C_D.

The drag coefficient data and regression curve for each velocity are presented in figure 2.

Drag data at zero angle of yaw for the instrumented model with annular slot without gas injection are presented in figure 2 for tunnel velocities ranging from 73 to 220 fps. Carbon dioxide was injected into the boundary layer through the annulus at several velocities. The results are tabulated in table II.

Table II. Drag Characteristics with CO_2 Injected into the Boundary Layer Through an Annular Slot

V	ψ	C_{D_1}	C_{D_2}	C_{D_3}	ΔC_D
fps					
147	0°	0.330	0	0.330	0.372
220	0°	0.334	0.186	0.330	0.165

The data presented in table II reveal that the apparent drag reduction indicated, when CO_2 is injected into the airstream, is in reality caused by the thrust resulting from the gas flowing through the slot of the cone. It should be noted that a limited number of CO_2 cartridges

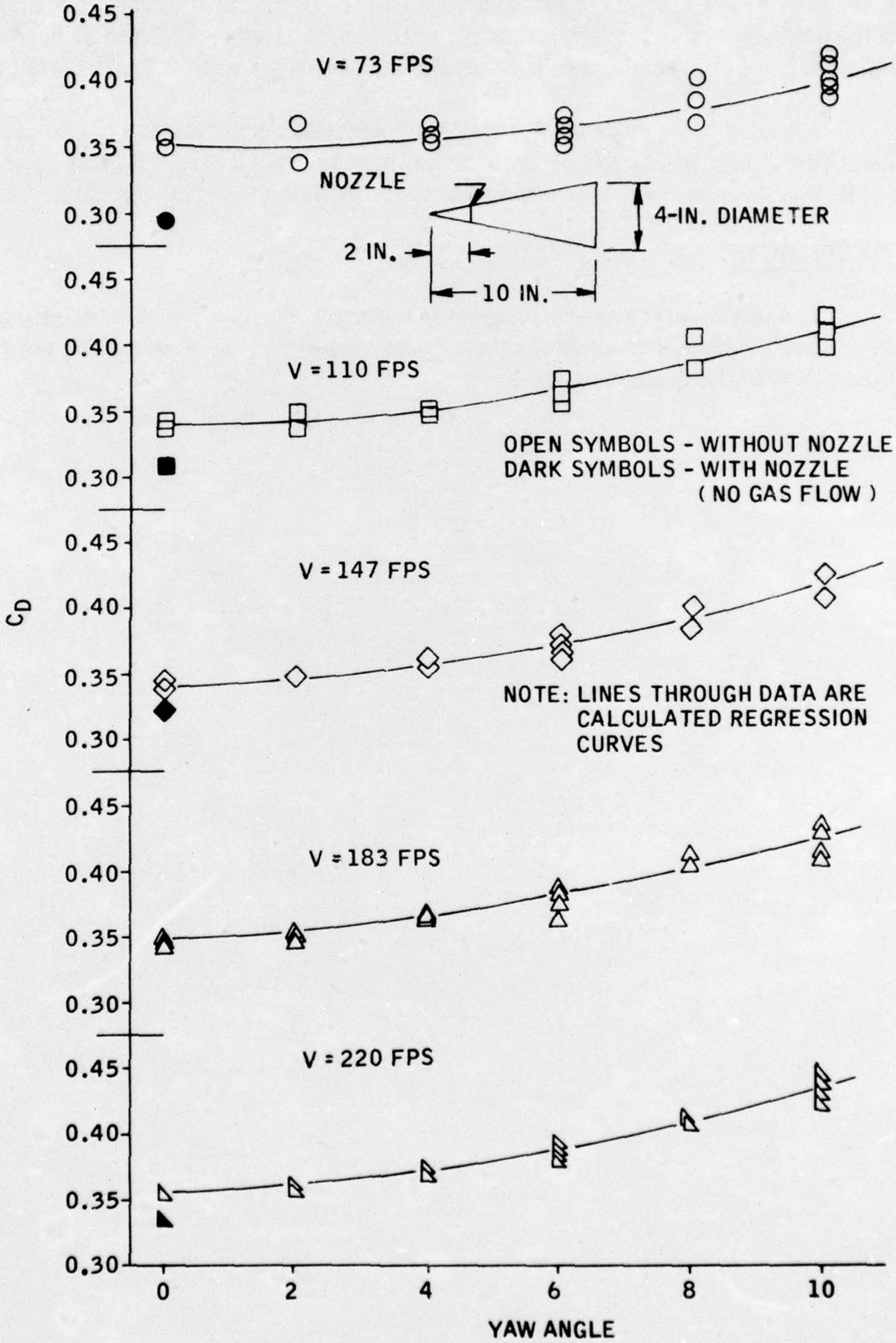

Figure 2. C_D Versus Yaw Angle

were available for this test and difficulty was experienced in proper discharging of gas from the cartridges. The results presented here are from singular tests of unknown accuracy because of lack of data on the discharge characteristics of the gas cartridges. Therefore, differences between total drag reduction (C_{D_1} - C_{D_2}) and CO_2 thrust measurements (ΔC_D) reflect this uncertainty.

Attempts were made to obtain data by injecting a hot gas into the boundary layer. A modified M91 cartridge with a T31E1 initiator was used to generate the hot gases. The duration of the gas flow was so short that it was impossible to secure data for the hot gas flow tests.

VI. CONCLUSIONS.

The test results from this program indicate gas injection into the boundary layer reduces the drag of a cone as a result of the thrust generated by the gas emission and not from change in the boundary layer characteristics.

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13. ABSTRACT

A 10-inch cone with a 4-inch-diameter base was utilized in this feasibility study to determine the possibility of overall drag reduction by introducing a jet of gas near the nose of the cone to change the boundary layer characteristics favorably thereby minimizing friction drag. Initial tests were made at selected velocities with a smooth-finished wooden model to determine baseline drag values, followed by an instrumented aluminum model with an annular slot located 25 percent of the body length from the nose. Gas was injected into the boundary layer through the annular slot and the results indicated that a thrust was developed by the emitted gas accounting for the drag reduction.

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