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A REFINEMENT TECHNIQUE FOR UNGUIDED ROCKET DRAG COEFFICIENTS

By

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ABSTRACT

A technique for approximating the drag coefficients from radar beacon tracks of previously fired unguided rockets is presented. Corrections for the effect of wind conditions at launch and for the Coriolis and centripetal accelerations due to the rotation of the radar with the earth are included, but the yaw angle is assumed to be zero.

CONTENTS

INTRODUCTION

There are two methods of prelaunch determination of the drag characteristics of a missile. One method is to obtain purely theoretical values by combining a knowledge of missile geometry with existing aerodynamic theory, and the other is to conduct wind tunnel tests on a scale model of the missile. Full-scale wind tunnel tests are seldom used, however, because they are economically and physically impractical.

Regardless of the method used, the original drag data obtained usually require some refinement after initial firings of a missile. When only minor refinement is needed, a trial and error adjustment of the drag coefficients sometimes suffices, however, when the performance records show more than a 10% error in the drag data, the trial and error method of adjustment is both time-consuming and of dubious accuracy.

Missile-borne accelerometers could provide reasonably accurate results, but, because of the expense and sacrifice of payload capacity, this approach is not completely satisfactory.

The solution which will be discussed here involves the determination of the missile acceleration from a radar track. The radar should provide acceptable accuracy if a radar beacon is utilized in the missile and if care is exercised in data reduction and smoothing.

DISCUSSION

The ballistic theory used here is that of Walter (1). The basic coordinate system has its origin at mean sea level directly beneath the launcher, Z axis along the local vertical positive upward, X axis positive to the east, and Y axis positive to the north. In the body coordinate system the origin is at the center of gravity, and only one axis is necessary to arrive at drag information, i.e. an axis positive in the direction of the aerodynamic velocity vector, V_a. Assuming zero yaw angle, both the thrust and drag forces will lie on this axis, The force of gravity is assumed to act parallel to the Z axis (Figure 1).

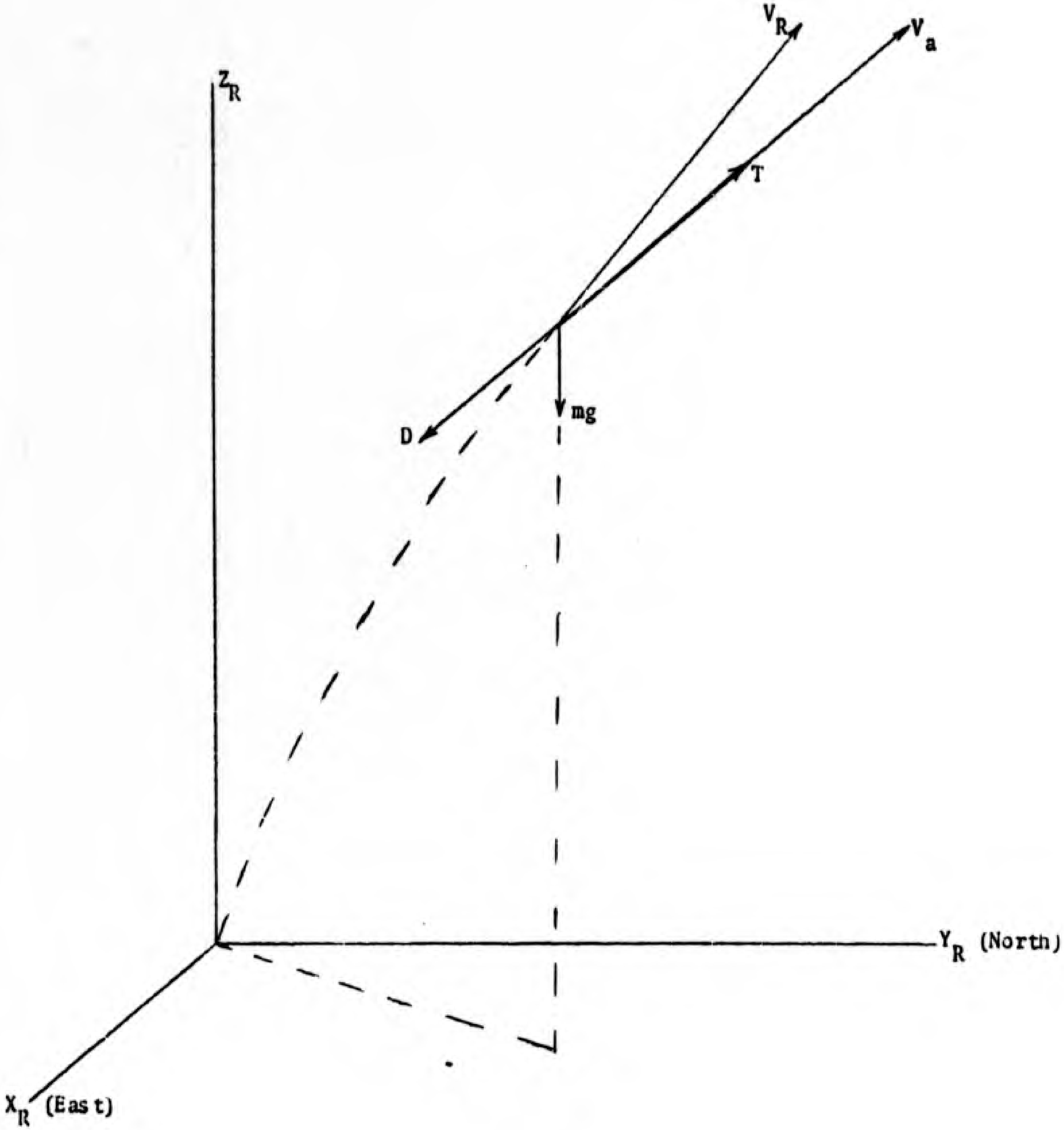

Figure 1. Force Diagram

Radar position data are usually reduced into components in a Cartesian coordinate system with origin at the radar or at the launcher, thus the altitudes must be adjusted to mean sea level. The accelerations relative to the launcher system must first be resolved onto the aerodynamic velocity axis with appropriate corrections made for the rotation of the radar with the earth. The relationship between accelerations in an earth-centered inertial frame and a surface-fixed frame is

$$\vec{a}_I = \vec{a}_R + 2\,\vec{w} \times \vec{V}_R + \vec{w} \times (\vec{w} \times \vec{R}_e) + \vec{w} \times (\vec{w} \times \vec{R}_R),$$

where subscript R indicates quantities as measured by the radar in the rotating frame, $\vec{w}$ is the angular velocity of the earth, and $\vec{R}_e$ is the radius of the earth (2).

Separating the rotational terms into components in the launcher system one has

$$C_X = 2\dot{Z}_R w \cos\lambda - 2\dot{Y}_R w \sin\lambda - X_R w^2$$

$$C_Y = 2\dot{X}_R w \sin\lambda + R_e w^2 \sin\lambda \cos\lambda + w^2 (Z_R \cos\lambda - Y_R \sin\lambda)\sin\lambda$$

$$C_Z = -2\dot{X}_R w \cos\lambda - R_e w^2 \cos^2\lambda - w^2 (Z_R \cos\lambda - Y_R \sin\lambda)\cos\lambda$$

where $\dot{X}_R$, $\dot{Y}_R$, $\dot{Z}_R$ are the velocities measured by the radar, and λ is the latitude of the radar. Then the accelerations corrected for the rotation of the earth are:

$$\ddot{X}_R + C_X$$

$$\ddot{Y}_R + C_Y$$

$$\ddot{Z}_R + C_Z.$$

The magnitude of the aerodynamic velocity is

$$V_a = [(\dot{X}_R + U_X)^2 + (\dot{Y}_R + U_Y)^2 + \dot{Z}_R^2]^{1/2},$$

where U_X and U_Y are horizontal wind components at altitude Z_R (north and east winds positive), and vertical winds are disregarded due to: 1) the absence of a suitable measuring capability and 2) the fact that vertical winds have little effect on a rocket fired near the vertical. The direction cosines of the aerodynamic velocity are

$$\xi_a = \frac{\dot{X}_R + U_X}{V_a}$$

$$\eta_a = \frac{\dot{Y}_R + U_Y}{V_a}$$

$$\zeta_a = \frac{\dot{Z}_R}{V_a}.$$

Thus, the acceleration along the aerodynamic velocity axis is

$$A = (\ddot{X}_R + C_X)\xi_a + (\ddot{Y}_R + C_Y)\eta_a + (\ddot{Z}_R + C_Z)\zeta_a.$$

This acceleration results from the external force components along the aerodynamic velocity axis which are thrust, drag, and a component of gravity (the lift force is assumed to be perpendicular to the aerodynamic velocity).

Therefore, $$mA = T\text{-}D - mg\frac{\dot{Z}_R}{V_a} = T\text{-}D - mg\zeta_a.$$

Defining dynamic pressure to be (1)

$$q = .7\ P_a\ (\frac{V_a}{V_s})^2,$$

where P_a and V_s are the atmospheric pressure and velocity of sound respectively at Z_R, the drag force is

$$D = C_d q S,$$

C_d being the drag coefficient and S the reference area. Gravity may be given as a function of height to a sufficient degree of accuracy by

$$g = g_s \left(\frac{R_e}{R_e + Z_R}\right)^2,$$

where g_s is the mean sea level gravity. Solving for D,

$$D = C_d q S = T - m(A + g\zeta_a)$$

or

$$C_d = \frac{T - m\{(\ddot{X}_R + C_X)\xi_a + (\ddot{Y}_R + C_Y)\eta_a + (\ddot{Z}_R + C_Z)\zeta_a \left(\frac{R_e}{R_e + Z_R}\right)^2 \zeta_a\}}{qS}.$$

At any particular time the thrust and mass may be obtained from interpolation of tables giving thrust or mass as a function of time, and the atmospheric pressure and local velocity of sound may be obtained from standard atmosphere tables if Z_R is known.

CONCLUSION

The technique presented here gives a straightforward determination of drag coefficients from flight data whose accuracy is limited by the accuracy of the thrust, mass, and radar information, and the validity of the zero yaw assumption. Errors due to inaccuracies of the first three parameters should be minimal if the results obtained from several flights are averaged. For typical unguided sounding rockets, the zero yaw assumption is valid except during the first few seconds of flight and will contribute a bias of one or two percent at most in the drag coefficient.

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A technique for approximating the drag coefficients from radar beacon tracks of previously fired unguided rockets is presented. Corrections for the effect of wind conditions at launch and for the Coriolis and centripetal accelerations due to the rotation of the radar with the earth are included, but the yaw angle is assumed to be zero.

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