Comparison of Barrowman Stability Analysis with Wind Tunnel Data

Research and Development Project
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NAR 21412

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SUMMARY

Wind tunnel derived stability and C.P. (Center of Pressure) characteristics for two versions of the full-scale Arcas sounding rocket were compared with Barrowman C.P. estimates. Wind tunnel and configuration geometry data were obtained from NASA TN D-4013, "Static Stability Investigation of a Single-Stage Sounding Rocket at Mach Numbers from 0.60 to 1.20". The Barrowman C.P. estimates for both configurations proved to be very close to the wind tunnel derived C.P. values at Mach 0.6.

Thus, the Barrowman analysis provided a very good C.P. estimate. However, the wind tunnel data showed several additional stability characteristics the Barrowman analysis does not take into account. First, the wind tunnel C.P. showed a variation over the tested Mach number range of 0.6 to 1.2. Also, the wind tunnel pitching moment (or restoring moment) data shows that stability could be lost at angles of attack greater than 16°. This could occur when launching in a wind, or when a rocket reaches apogee and 'tailslides' backwards. While it shouldn't be assumed that the Arcas data generalizes to all rockets, the author has observed both of these kinds of instabilities in model rocket flights.

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Objectives: The objectives of this study were:
1) To compare the results of the Barrowman method of Center of Pressure analysis with wind tunnel-determined C.P.
2) To determine whether the wind tunnel data shows any additional stability characteristics not modeled in the Barrowman analysis.

Approach: Stability and C.P. data for two different Arcas sounding rocket configurations were taken from wind tunnel test results published in NASA TN D-4013, "Static Stability Investigation of a Single-Stage Sounding Rocket at Mach Numbers from 0.60 to 1.20". Barrowman C.P. computations were performed using the configuration geometry published in the same report, shown in Figure 1. Pitching moment data from the same source was evaluated to determine more detailed stability information.

Data: As noted above, all configuration data and wind tunnel results were taken from NASA TN D-4013. The NASA test covered a Mach number range from 0.6 to 1.2, and measured axial force, normal force, side force, pitching moment, rolling moment, and yawing moment.

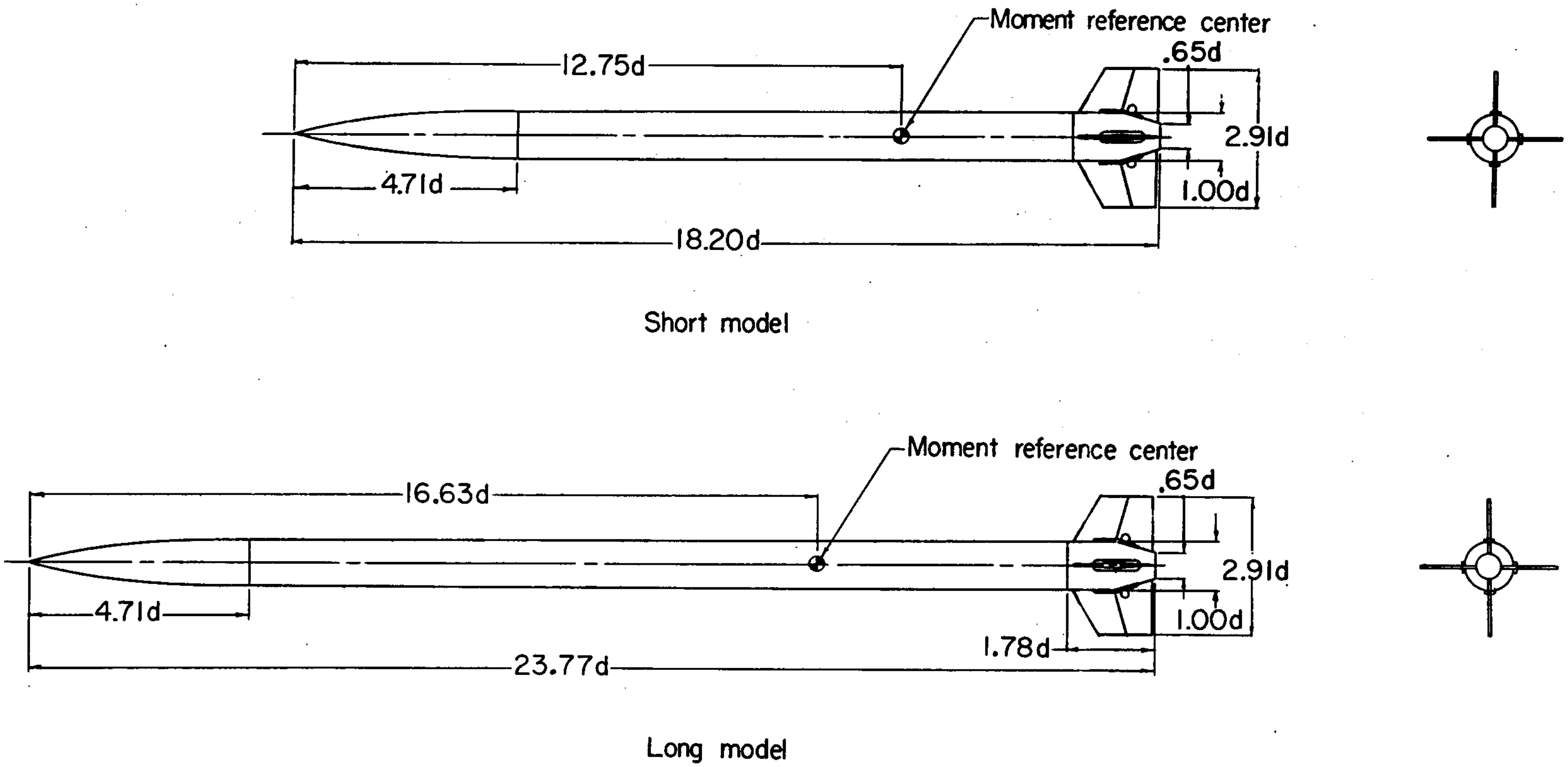
Results: Figure 2, from the NASA report, shows the wind tunnel derived C.P. position for the short Arcas configuration at varying Mach numbers. Using the Barrowman analysis, C.P. position was estimated to be 13.65 in. from the nose, or 75% of body length, which agrees closely with the wind tunnel result for Mach 0.6. The fact that the Mach 0.6 data best matches the Barrowman results may be because this Mach number is closest to typical model rocket flight conditions, or may be coincidence. The Barrowman analysis does not model the variation of C.P. with Mach number. Figure 3, also from Ref. 1, shows the C.P. of the long Arcas configuration from wind tunnel data. The Barrowman analysis estimated C.P. position at 18.3 from the nose, or 77% of body length, which again agrees well with the Mach 0.6 wind tunnel C.P.

More insight into the stability characteristics of the long Arcas configuration can be found in the wind tunnel pitching moment data (Figure 4). This pitching moment was measured about a reference point (or nominal C.G.) ahead of the C.P., and can be thought of as the restoring moment (or 'rotational force') which stabilizes the rocket. For angles of attack (or angle to the airflow) up to about 14°, the pitching moment becomes more negative, or stabilizing. However, pitching moment decreases at higher angles of attack, crossing zero above 16° AOA. In other words, above 16° AOA, there would be no restoring moment, and the rocket would not be pushed back to 0 AOA.

In most circumstances this high-AOA instability does not cause problems. Rockets are normally launched at low AOA, and aerodynamic stability tends to prevent any buildup in AOA. However, there are certain instances where AOA could be pushed beyond the stable region. First, in windy conditions, a rocket can leave the launch rod at a significant angle to the local airflow. For example, at a liftoff speed of 40 ft/sec, any wind beyond a modest 11 ft/sec pushes AOA above 16°. A rocket can also experience a high angle of attack (up to +/-180°) during a 'tailslide', if it reaches apogee with little or no horizontal airspeed, and then falls backward.

While it shouldn't be assumed that these aerodynamic characteristics generalize to every model rocket configuration, the author has observed both of these kinds of high-AOA instabilities in some model rocket flights. Rockets launched in high wind have gone unstable, and rockets falling in tailslides can stabilize at a high AOA. (At times, this can even be advantageous, causing a rocket to descend more slowly in the event of a too-long delay or non-ejection.)

Conclusions: The Barrowman C.P. estimate agreed well with the wind tunnel value at low Mach numbers. However, this C.P. only reflects behavior at low angles of attack, and does not model the C.P. variation with Mach number seen in the wind tunnel results. At high AOA conditions, such as launching in wind, or falling in a tailslide, stability is no longer assured with the Barrowman C.P. behind the C.G. This potential instability is one reason not to fly in high winds.



(a) General arrangement of short and long models.

FIGURE 1 - Model geometric characteristics. All dimensions are in terms of centerbody diameter d, 5.72 cm (2.25 in.).

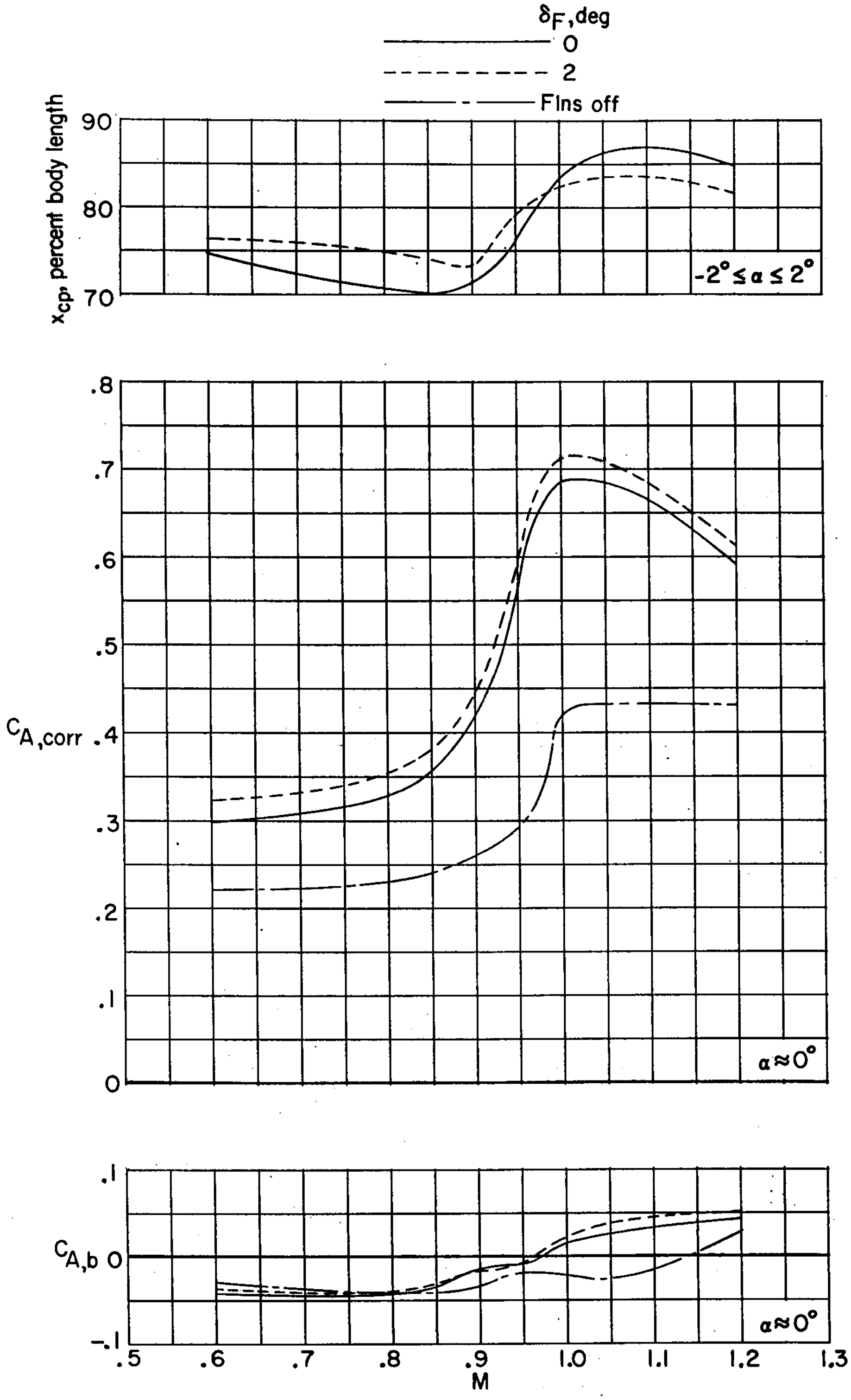


FIGURE 2

Variation of center-of-pressure location, $C_{A,corr}$, and $C_{A,b}$ with Mach number. Short model; $\Phi = 0^{\circ}$.

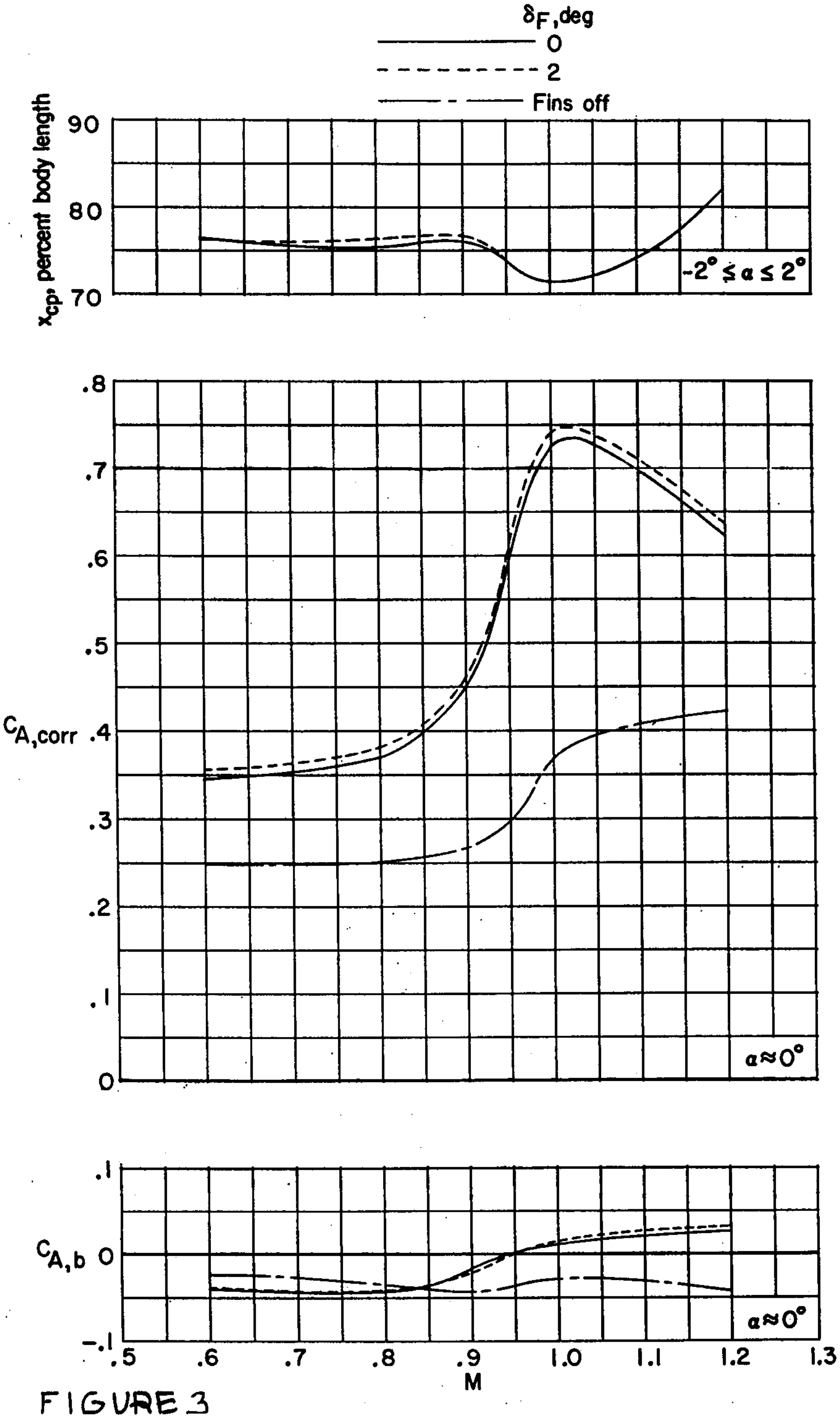


FIGURE 3

Variation of center-of-pressure location, $C_{A,corr}$, and $C_{A,b}$ with Mach number. Long model; $\Phi = 0^0$.

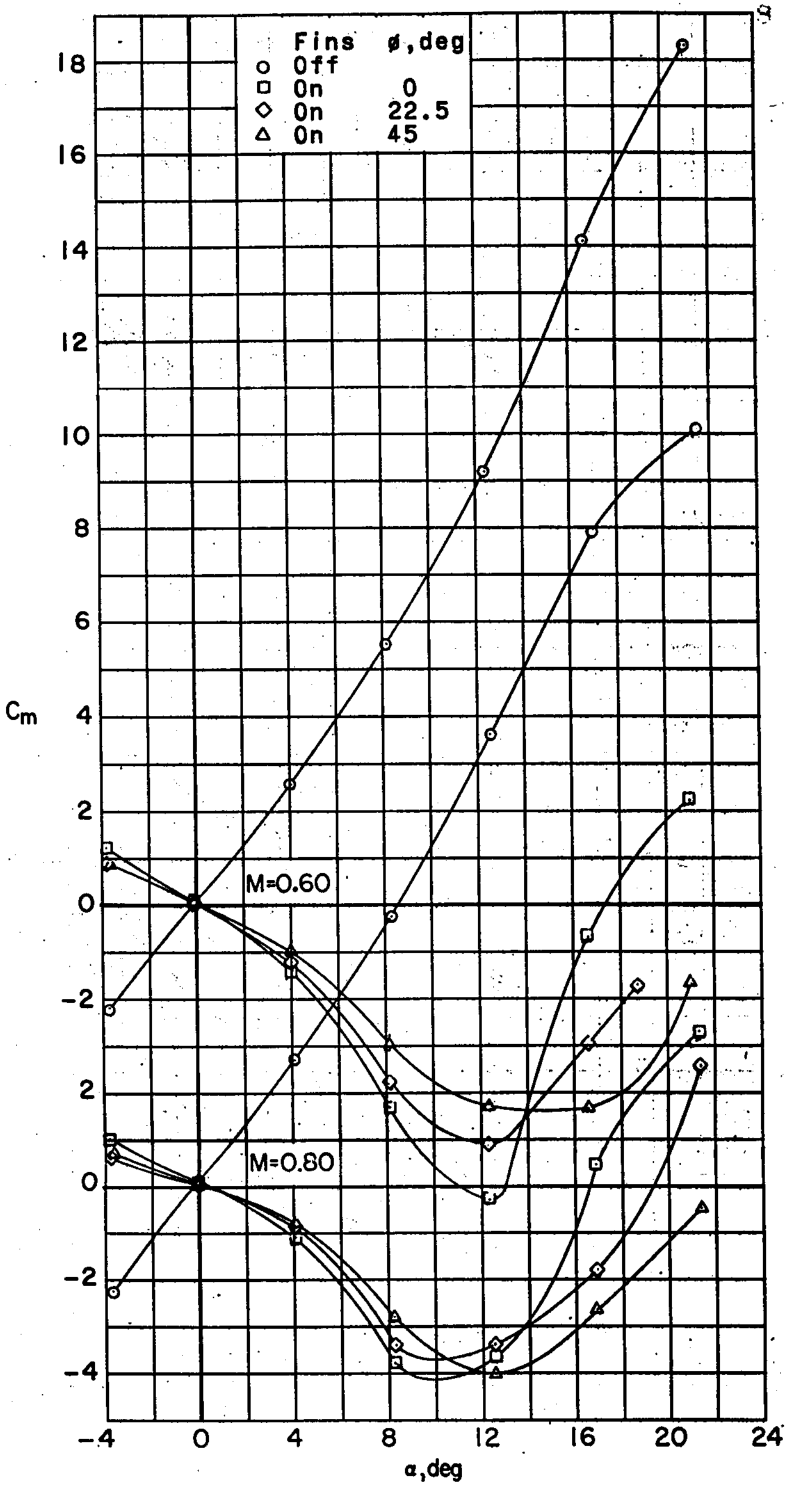


FIGURE 4

Pitching-moment coefficient.

(LONG MODEL)