RASAero II Comparisons with ARCAS Center of Pressure (CP) and Drag Coefficient (CD) Wind Tunnel Data

Wind Tunnel Data Sources NASA TN D-4013 and TN D-4014

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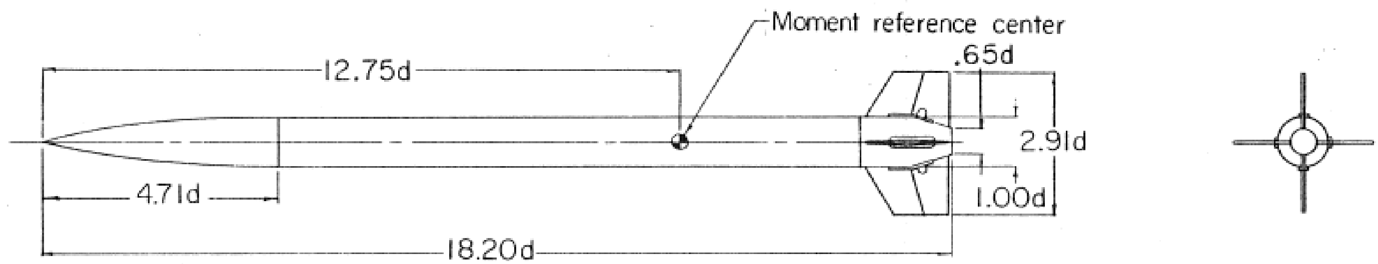
Included in these slides are RASAero II predictions for Subsonic, Transonic, and Supersonic Center of Pressure (CP) and Drag Coefficient (CD) compared to wind tunnel data for two configurations of the ARCAS sounding rocket (ARCAS Short and ARCAS Long). The Supersonic wind tunnel data is up to Mach 4.63, approaching Hypersonic (Mach 5). The wind tunnel data is from NASA TN D-4013 and TN D-4014.

Slides 3-5 present the wind tunnel model configurations, and Slide 6-7 show the two ARCAS configurations entered into RASAero II.

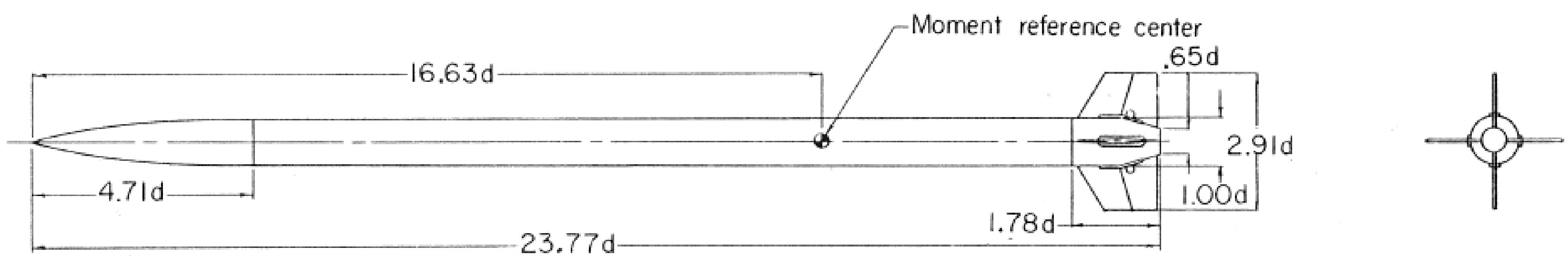
The protuberance drag of the fin anchors at the fin roots (see the fin anchor details on Slide 4, and in (b) on Slide 5) is included by taking the frontal area of all four of the fin anchors. Typically a rail guide will have 5 times the drag of a typical rocket body, so dividing the frontal area by five, and since the rail guide entry in RASAero II assumes that there are two rail guides, the frontal area is divided again by two. The resulting final frontal was turned into a square (same diameter and height) rail guide, and entered into RASAero II. The small lip around the base of the boattail (in the full-size ARCAS sounding rocket apparently a flange associated with the solid rocket motor nozzle) was not included, as it was assumed that this small lip was buried in the boattail boundary layer.

From NASA TN D-4013
ARCAS Sounding Rocket



ARCAS Short Model

Short model



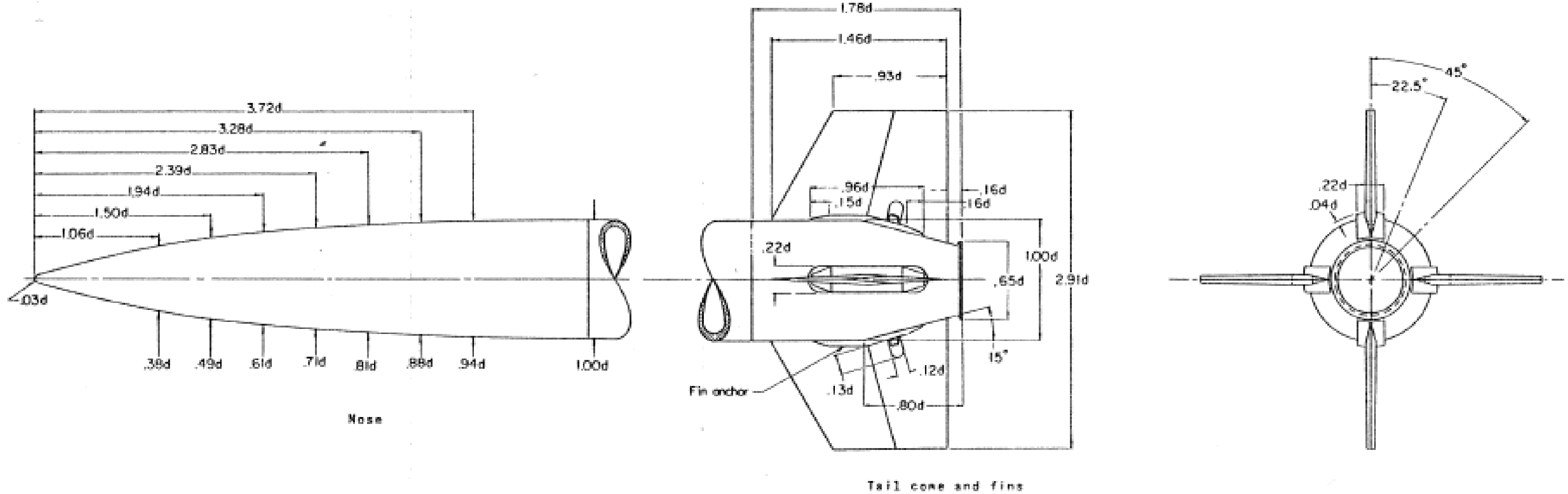
ARCAS Long Model

Long model

(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.).

From NASA TN D-4013
ARCAS Sounding Rocket

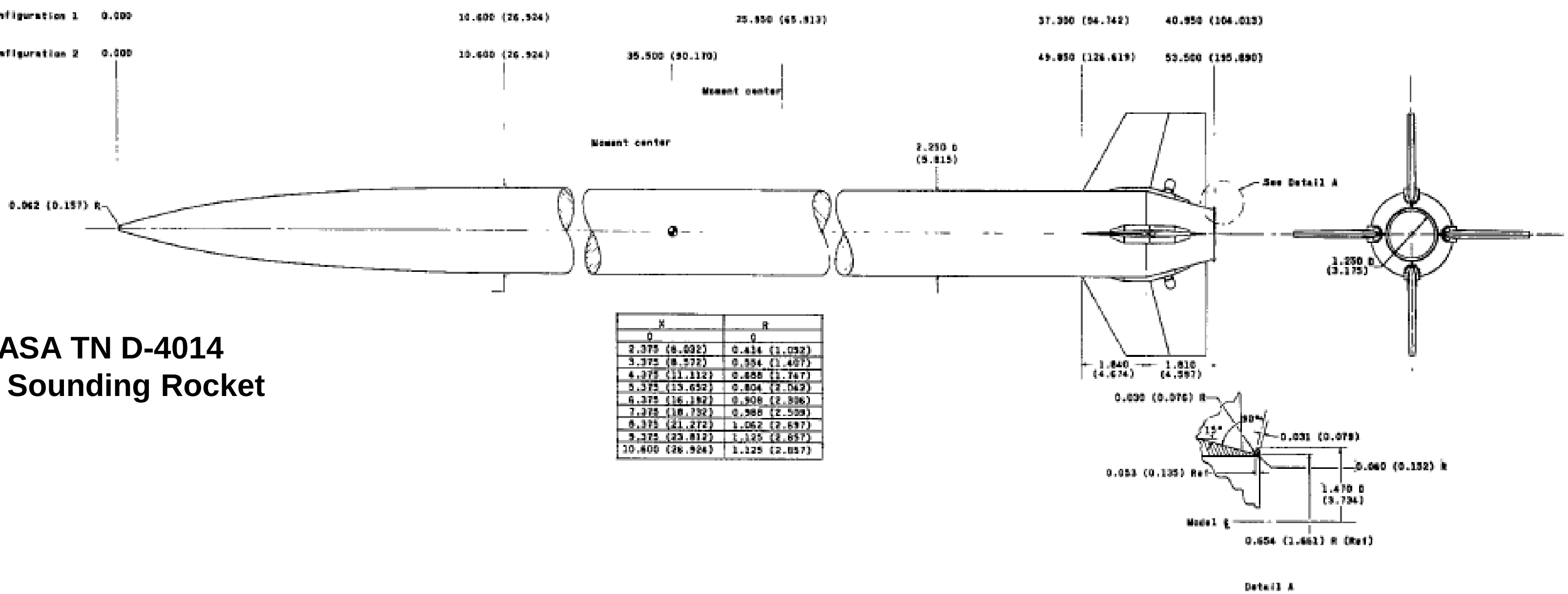


(b) Details of forebody, tail cone, and fins.

Figure 1.- Concluded.

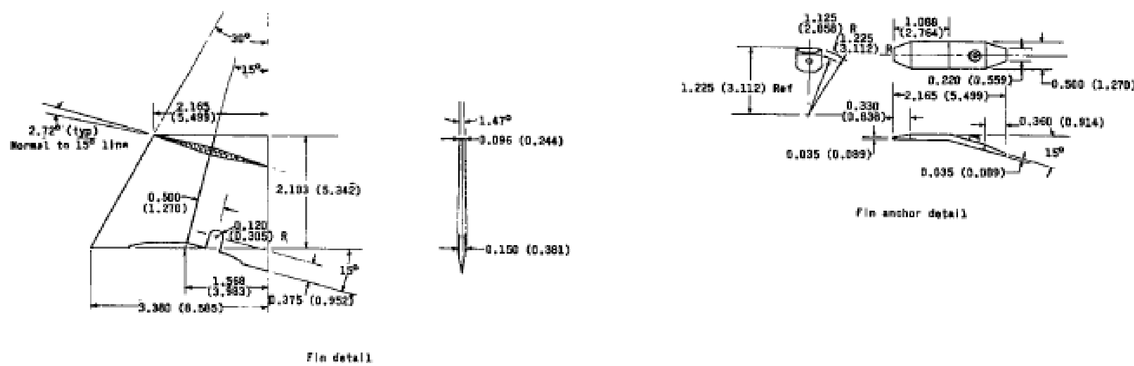
Configuration 1 is ARCAS Short Model
Configuration 2 is ARCAS Long Model

From NASA TN D-4014
ARCAS Sounding Rocket



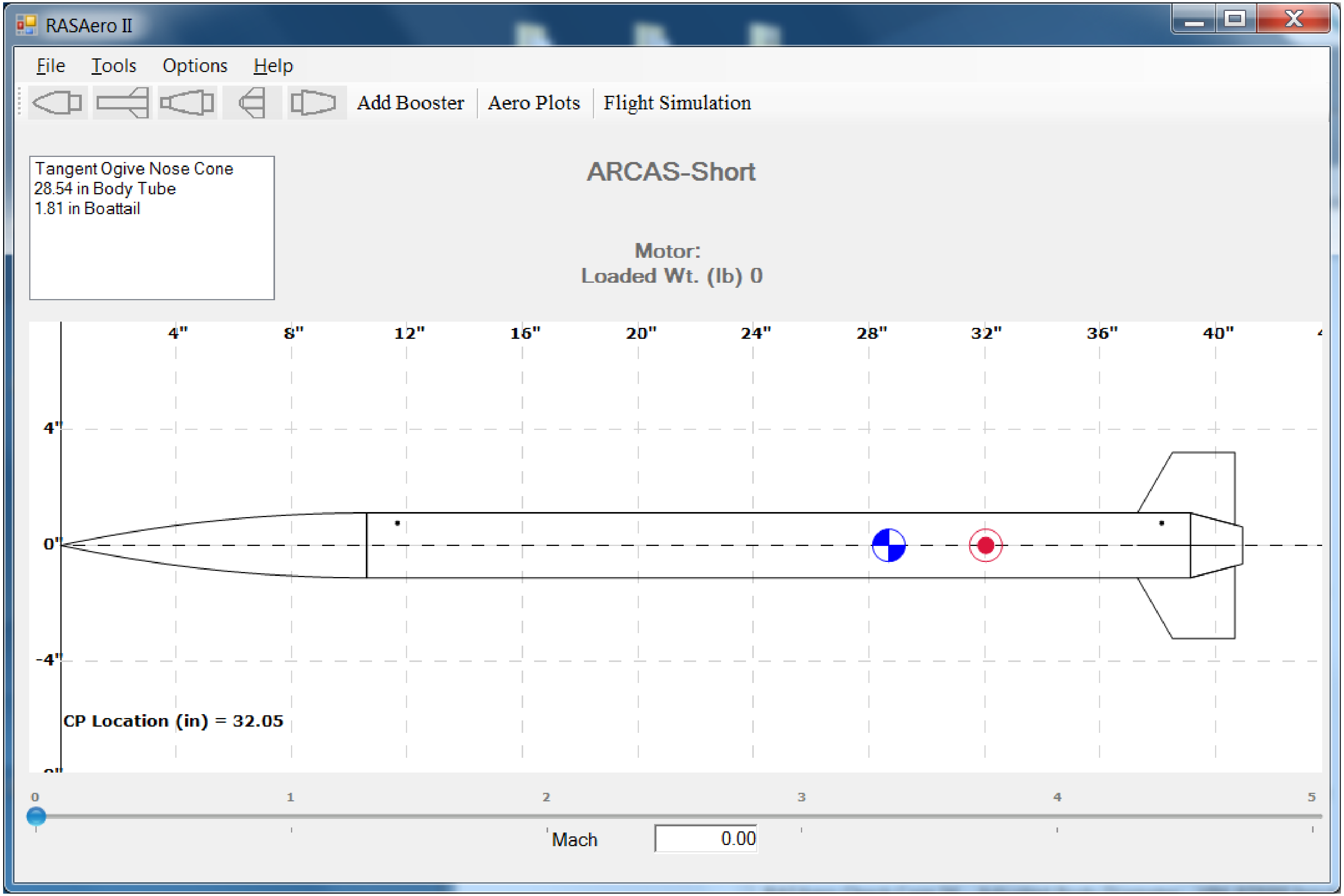
X	R
0	0
2.375 (6.032)	0.414 (1.052)
3.375 (8.572)	0.554 (1.407)
4.375 (11.112)	0.688 (1.747)
5.375 (13.652)	0.804 (2.042)
6.375 (16.192)	0.908 (2.306)
7.375 (18.732)	0.988 (2.509)
8.375 (21.272)	1.062 (2.697)
9.375 (23.812)	1.125 (2.857)
10.600 (26.924)	1.125 (2.857)

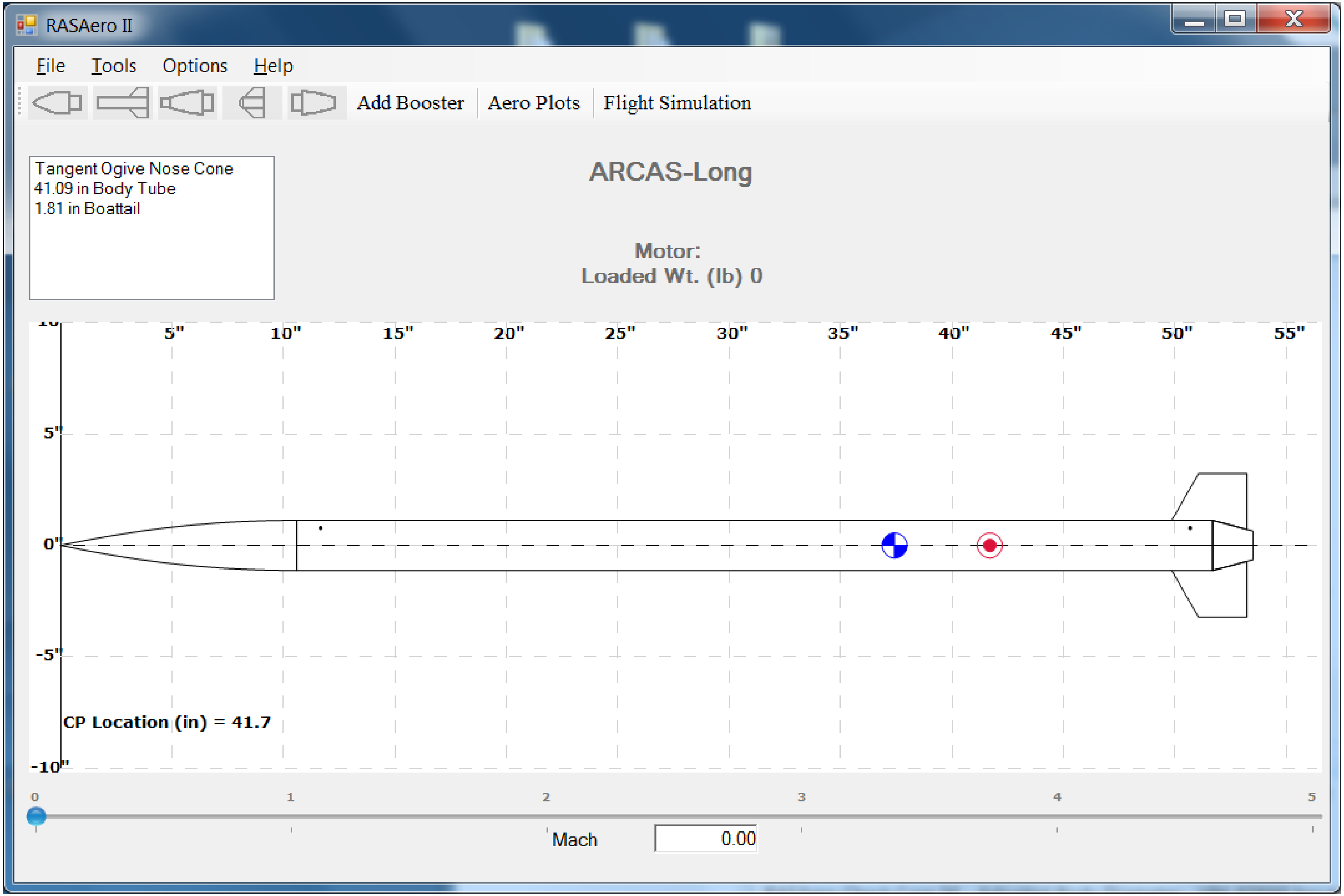
(a) Complete model.



(b) Fin details.

Figure 1.- Model details. All dimensions are in in. (cm).


RASAero II
File Tools Options Help
Add Booster Aero Plots Flight Simulation
Tangent Ogive Nose Cone
28.54 in Body Tube
1.81 in Boattail
ARCAS-Short
Motor:
Loaded Wt. (lb) 0
4" 8" 12" 16" 20" 24" 28" 32" 36" 40"
4"
0"
-4"
CP Location (in) = 32.05
0 1 2 3 4 5
Mach
0.00

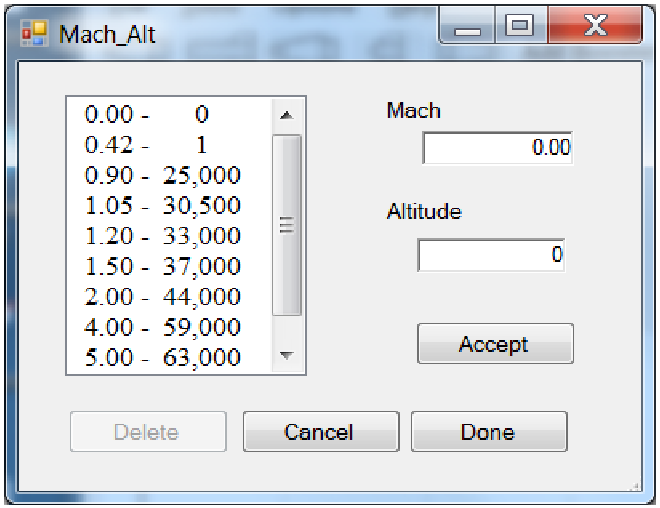

RASAero II
File
Tools
Options
Help
Add Booster
Aero Plots
Flight Simulation
Tangent Ogive Nose Cone
41.09 in Body Tube
1.81 in Boattail
ARCAS-Long
Motor:
Loaded Wt. (lb) 0
5"
10"
15"
20"
25"
30"
35"
40"
45"
50"
55"
5"
0"
-5"
-10"
CP Location (in) = 41.7
0
1
2
3
4
5
Mach
0.00

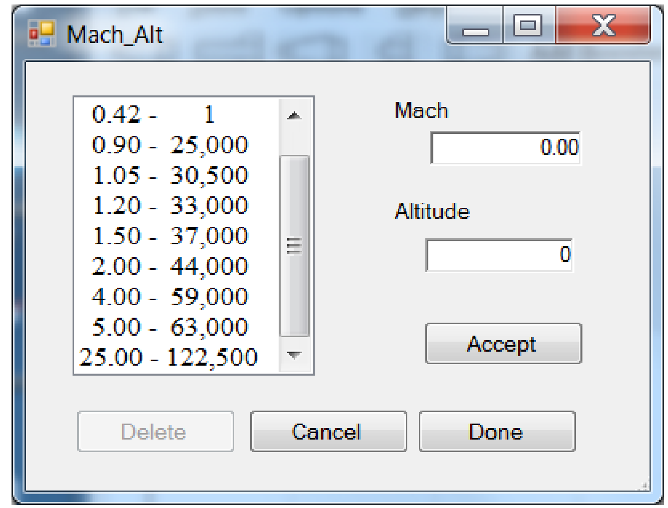
In the RASAero II Flight Simulation the rocket aero data is calculated for each time step with the Reynolds number varied during the flight based on the altitude and velocity of the rocket, and the speed of sound varied with the altitude of the rocket (for Mach number). The RASAero II Aero Plots aero data is plotted for sea level.

The RASAero II Mach-Alt feature (see the Other Inputs - Mach-Alt Input section in the RASAero II Users Manual) can be used to vary the Reynolds number to match wind tunnel data for the Aero Plots aero data plots, and the Run Test aero data tabular output. Note that the Mach-Alt feature doesn't need to be used to run Flight Simulations on RASAero II, in fact it isn't even used by the Flight Simulation code. The User can run Flight Simulations and user Aero Plots to plot out sea level aero data without ever having to enter anything in the Mach-Alt table. Mach-Alt is only needed when trying to match wind tunnel data, like on the attached slides. The wind tunnel data from NASA TN D-4013 and TN D-4014 was run at a Reynolds number of 3.0 x 10^6 per foot. The length of the two ARCAS configurations (ARCAS Short and ARCAS Long) in feet is then used to come up with the Reynolds number for that configuration used for the wind tunnel tests. The Mach-Alt inputs used to match the Reynolds number is shown on Slide 9.

RASAero II Mach-Alt Inputs for Matching NASA TN D-4013 and TN D-4014 Wind Tunnel Reynolds Number.

For Both NASA TN D-4013 and TN D-4014 Wind Tunnel Reynolds Number was 3.0 x 10^6 per foot for Both ARCAS Short and ARCAS Long Configurations.





The RASAero II CP and CD predictions are compared to the Subsonic, Transonic, and low Supersonic wind tunnel data for the ARCAS Short and ARCAS Long configurations on Slides 11 and 12. With the boattail only on part of the fin root, the exact way to implement the Barrowman Method is somewhat up to debate. The method used in RASAero II is to calculate the volume of the cylinder and the part of the boattail that are under the fin root, and then calculate the diameter of a cylinder of the same length that has the same volume. The diameter of this cylinder is now the diameter of the rocket body under the fins, and the fins are projected toward the centerline of the rocket until they intersect that cylinder. Thus the RASAero II Barrowman Method results are labeled on the graphs on Slide 11 and 12 as RASAero II Implementation of the Barrowman Method.

Note on Slides 11 and 12 that the Rogers Modified Barrowman Method and the Barrowman Method (as implemented in RASAero II) give similar results, very similar results in the case of the ARCAS Long configuration. Generally the Rogers Modified Barrowman Method is more accurate than the Barrowman Method, but in many cases the Rogers Modified Barrowman and Barrowman Methods will produce similar results, as shown here. This is because Barrowman left off additional normal force at the nose and the tail, but since he missed additional normal force at both the nose and tail, more accurate methods will in many cases produce surprisingly small changes in the CP. For these particular two cases (ARCAS Short and ARCAS Long), the Barrowman Method was more accurate, although the two predictions were close, very close for the ARCAS Long configuration. Both methods got very close to the Subsonic CP for the ARCAS Long configuration.

Note for the ARCAS Long configuration wind tunnel data on Slide 12 the unusual forward movement of the CP at Transonic, and then the CP moves aft again going into low Supersonic. The ARCAS Short configuration wind tunnel data on Slide 11 shows a more typical looking CP curve with Mach number, where the CP moves aft Transonic, and then for Supersonic the CP starts moving forward with increasing Mach number. This illustrates why you want to have an additional 1.0 calibers stability margin on top of the Subsonic minimum 1.0 calibers stability margin, for a total stability margin of 2.0 calibers at Supersonic Mach numbers to cover for possible CP mispredictions like shown on Slide 12.

NASA TN D-4013

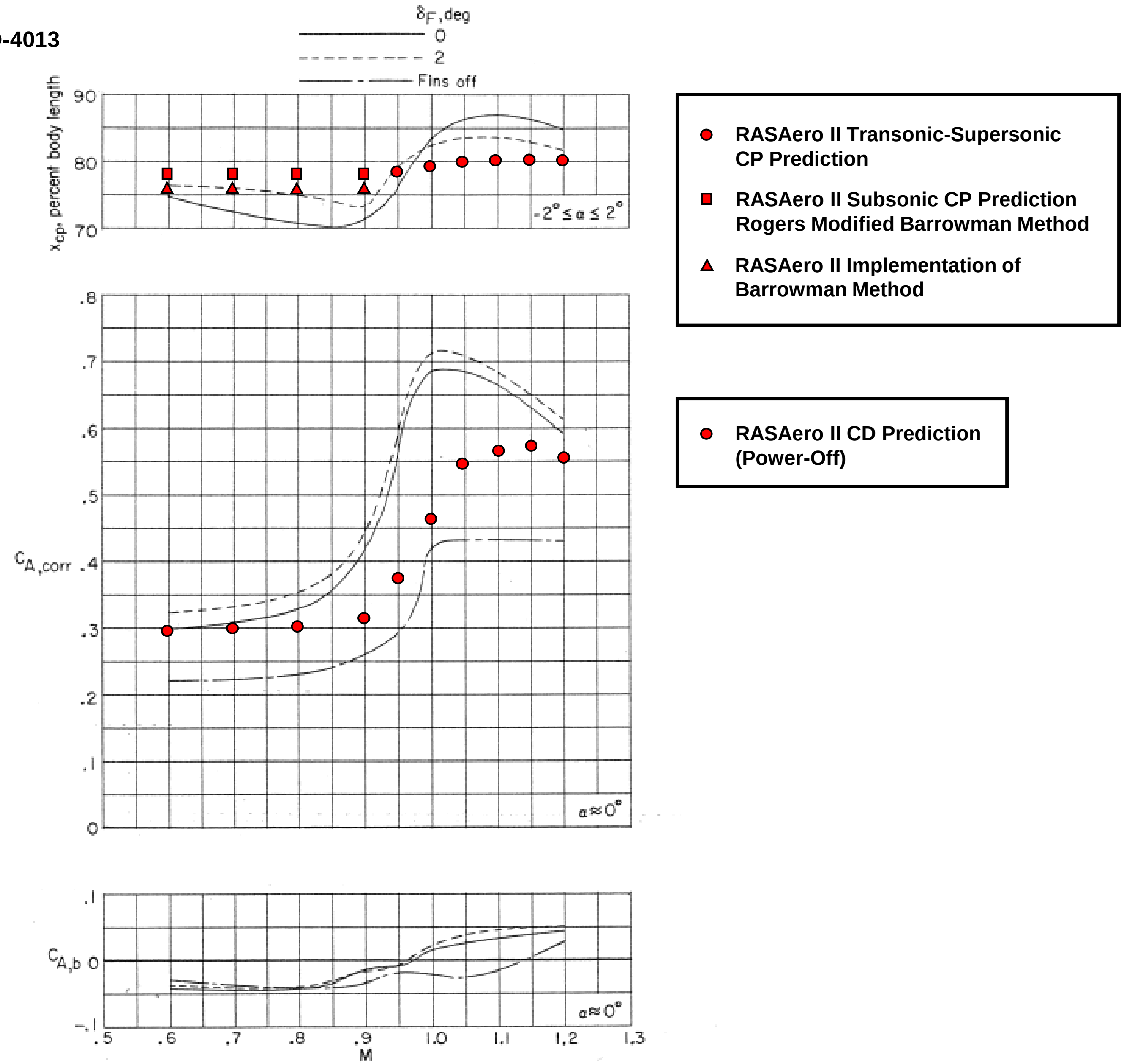


Figure 11.- Variation of center-of-pressure location, $C_{A,corr}$, and $C_{A,b}$ with Mach number. Short model; $\Phi = 0^0$. **(Roll Angle 0 deg)**

NASA TN D-4013

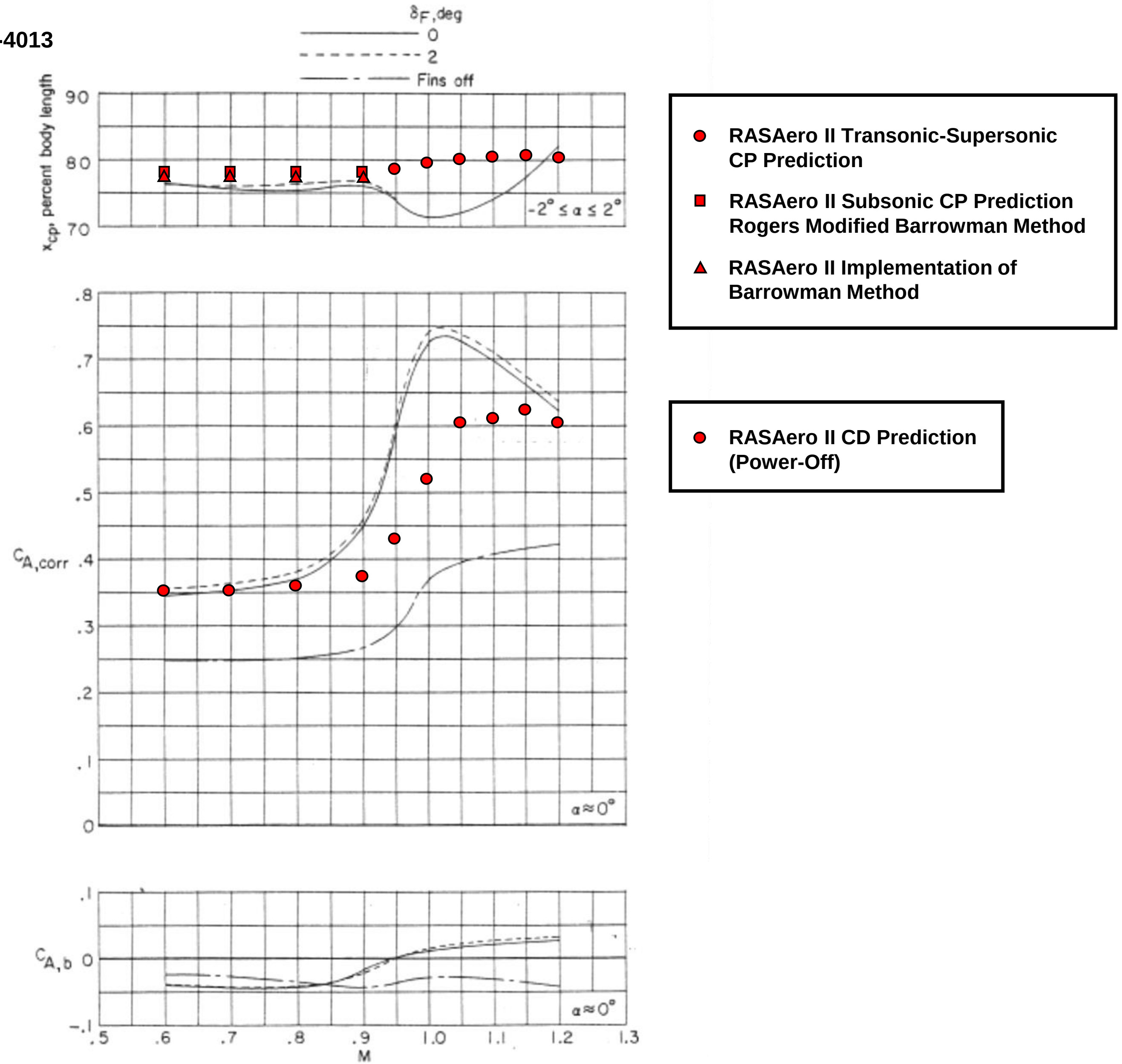


Figure 12.- Variation of center-of-pressure location, $C_{A,corr}$, and $C_{A,b}$ with Mach number. Long model; $\Phi = 0^0$. **(Roll Angle 0 deg)**

Slides 14 and 15 show the RASAero II predictions for the Supersonic CP compared to the wind tunnel data for the ARCAS Short and ARCAS Long configurations. RASAero II produced very accurate predictions for the Supersonic CP from Mach 1.5 to Mach 3, the area of interest for the forward movement of the CP for high power rockets.

Note that by extrapolating the wind tunnel CP data shown on Slides 14 and 15 out to higher Mach numbers, by Mach 5 the ARCAS CP is approaching one-half the way up the length of the rocket (CP at 50% of the body length).

Slides 16 and 18 are the wind tunnel data, and Slides 17 and 19 are the wind tunnel data plotted on the RASAero II predictions, for the Supersonic CD for the ARCAS Short and ARCAS Long configurations. The RASAero II CD prediction compares pretty well with the ARCAS Short wind tunnel data, and the RASAero II CD prediction compares very well with the ARCAS Long wind tunnel data.

NASA TN D-4014

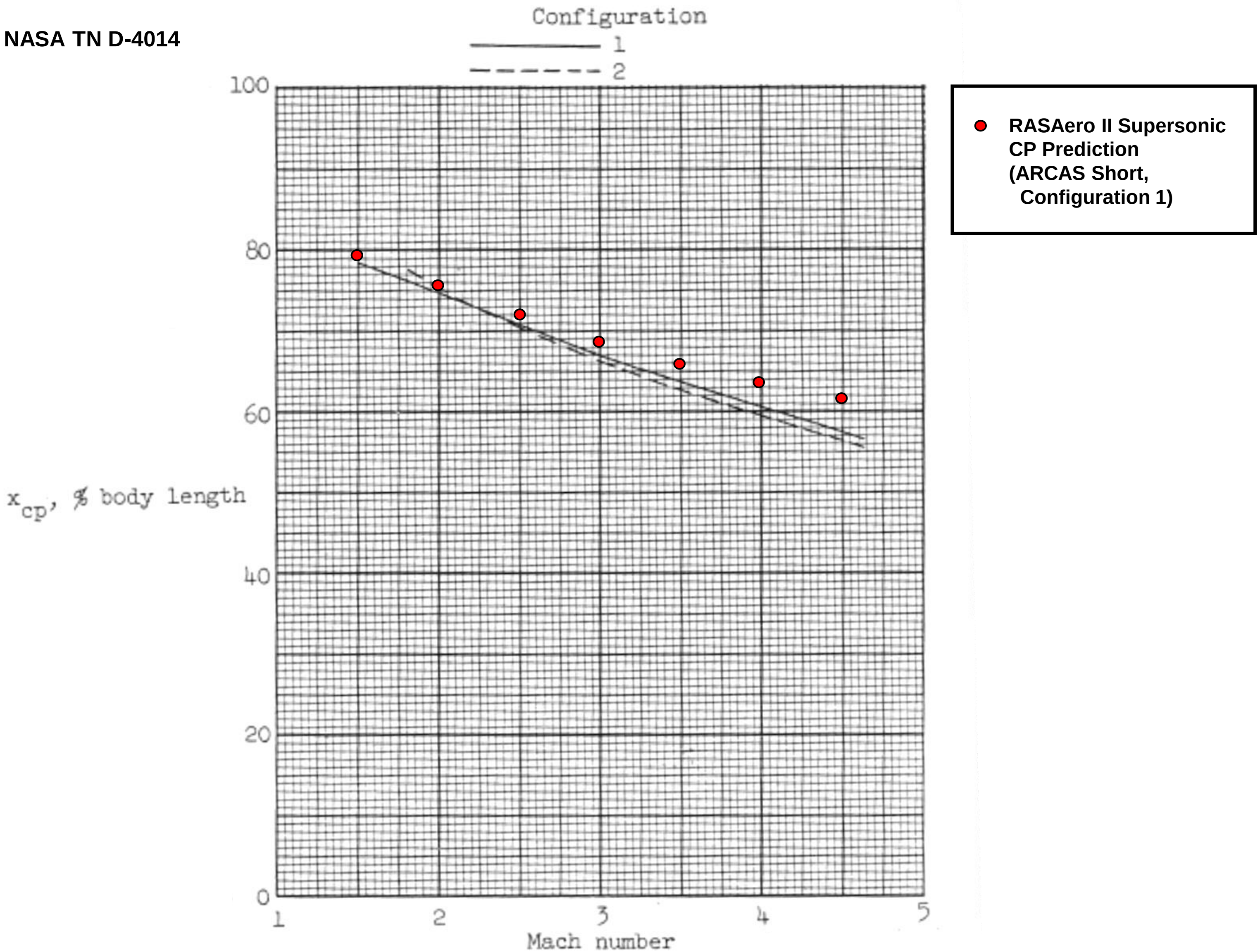


Figure 7.- Variation of center of pressure with Mach number at low angles of attack.

NASA TN D-4014

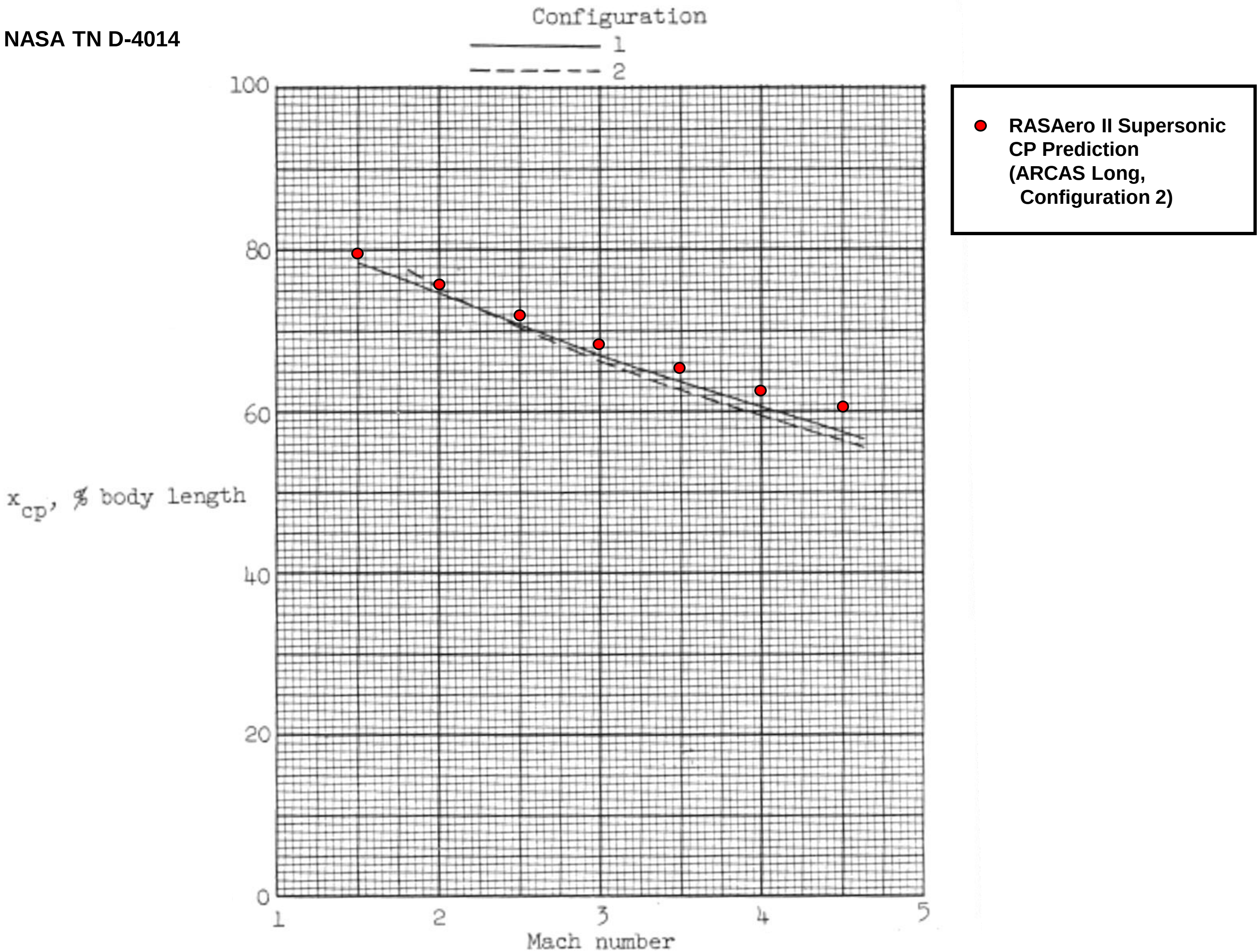
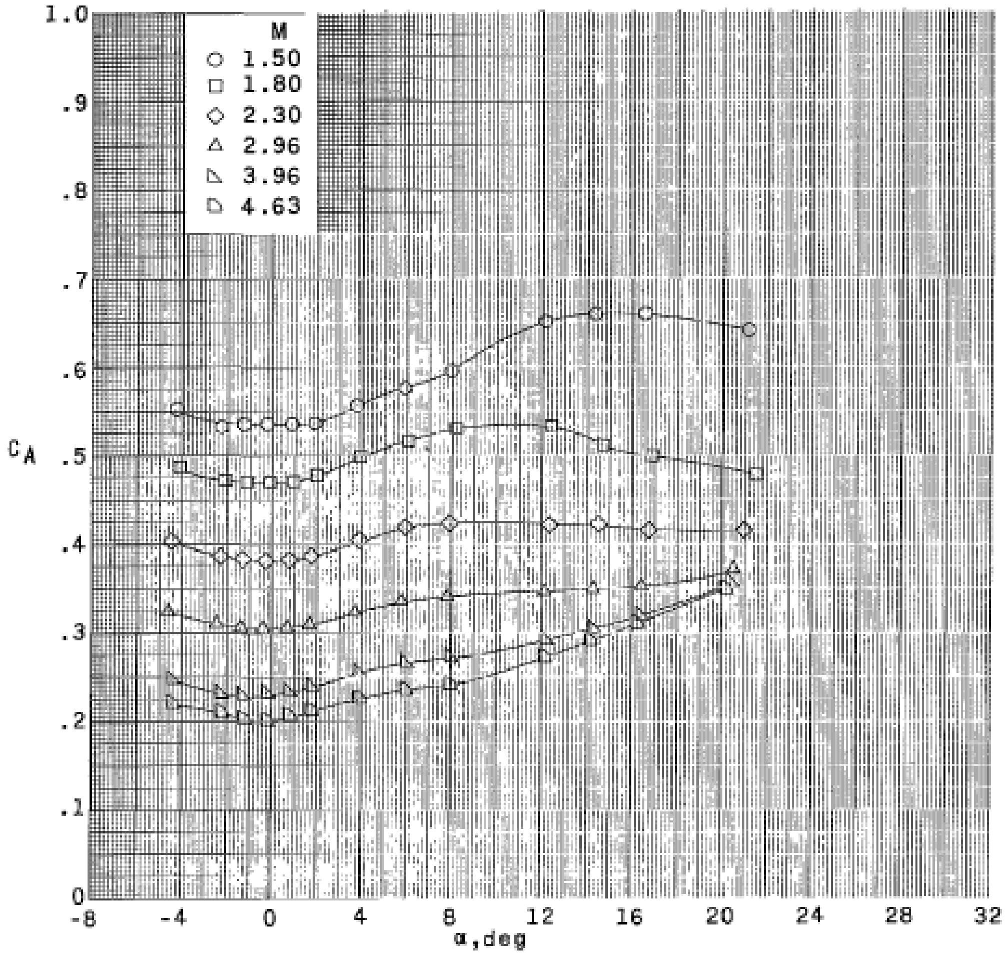


Figure 7.- Variation of center of pressure with Mach number at low angles of attack.

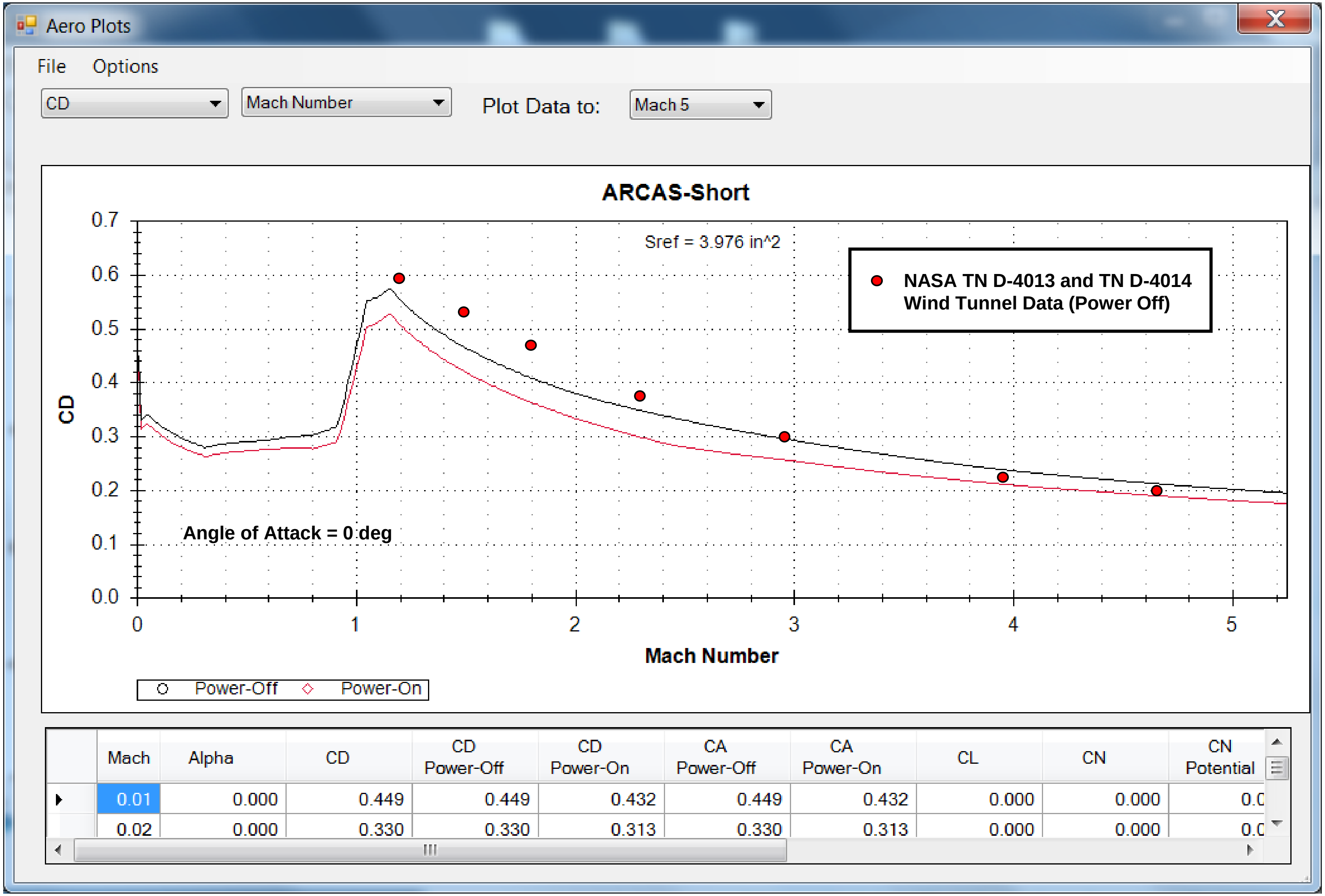


(b) $\delta_F = 0^0$.

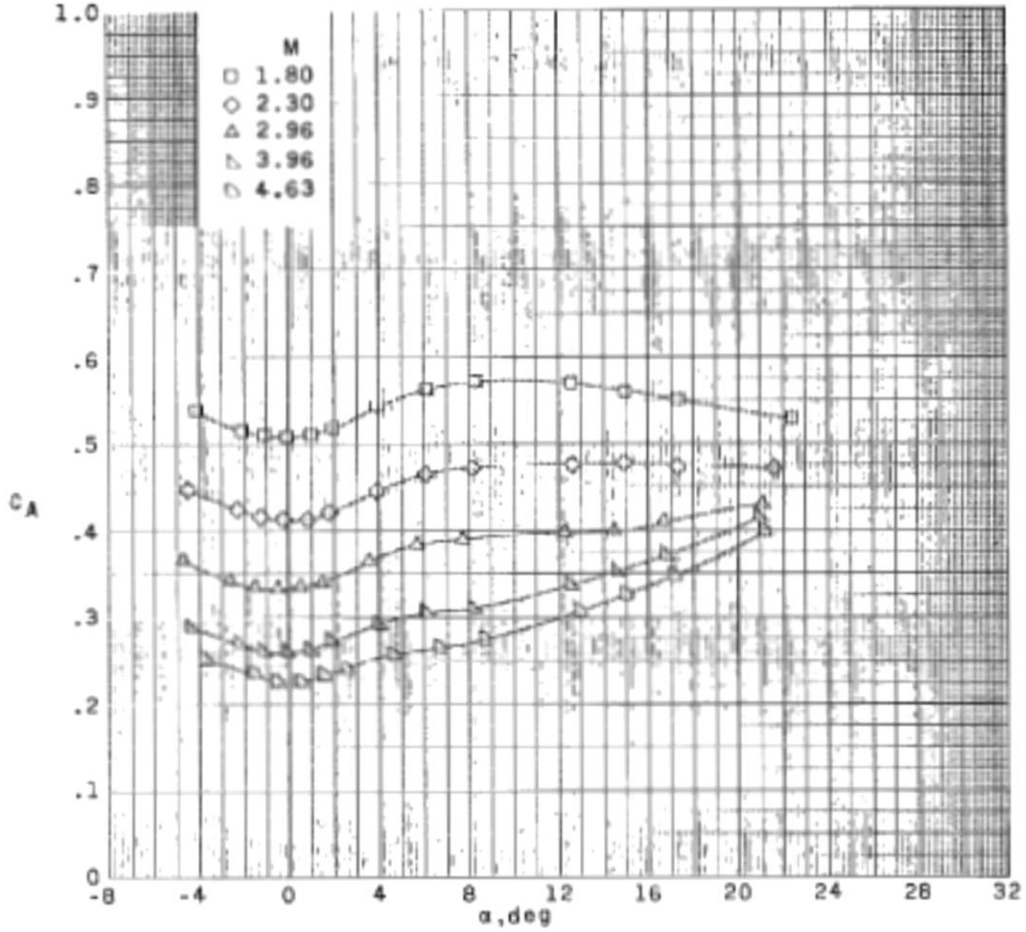
Figure 5.- Continued.

Figure 5.- Aerodynamic characteristics in pitch for configuration 1. **(ARCAS Short)**

www.rasaero.com



	Mach	Alpha	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
▸	0.01	0.000	0.449	0.449	0.432	0.449	0.432	0.000	0.000	0.0
	0.02	0.000	0.330	0.330	0.313	0.330	0.313	0.000	0.000	0.0



(b) $\delta_F = 0^{\circ}$.

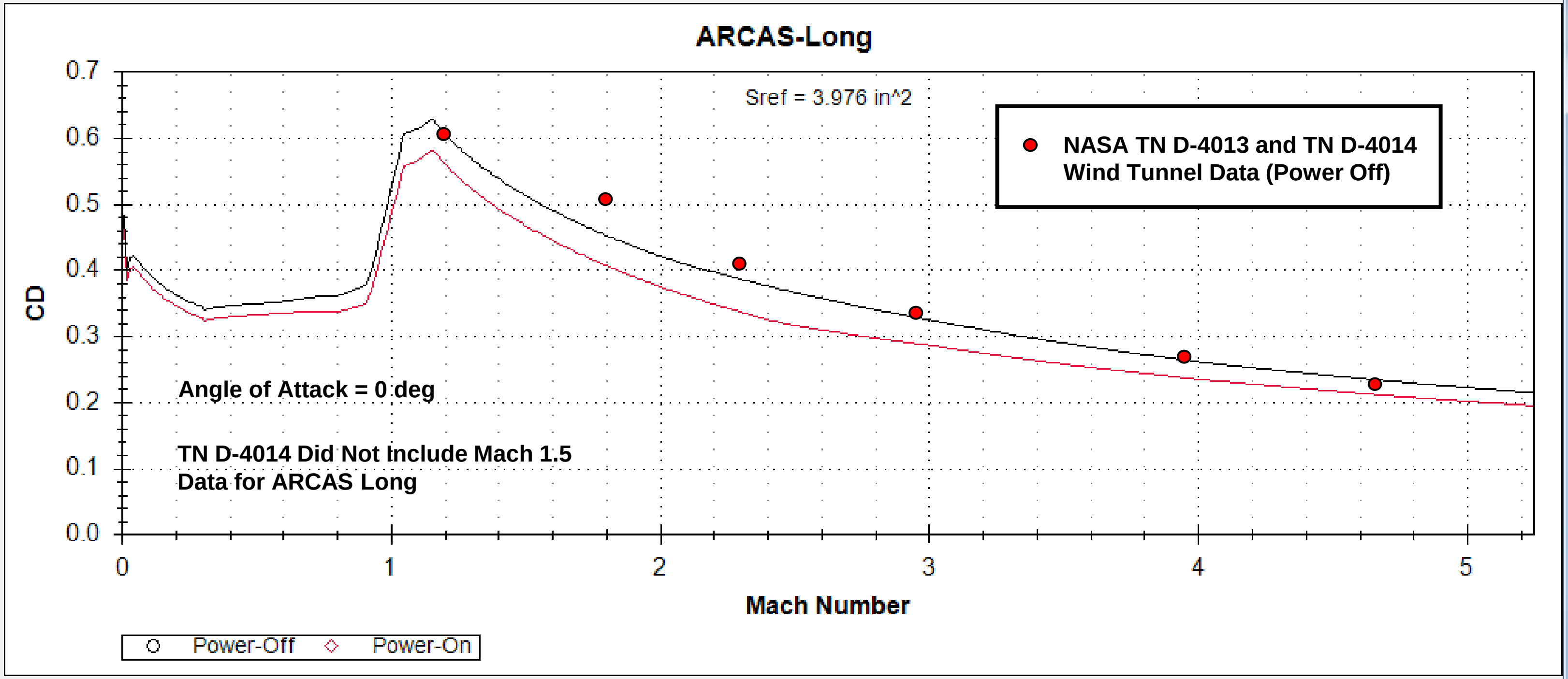
Figure 6.- Continued.

Figure 6.- Aerodynamic characteristics in pitch for configuration 2. **(ARCAS Long)**

Aero Plots

File Options

CD | Mach Number | Plot Data to: Mach 5



	Mach	Alpha	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
▸	0.01	0.000	0.482	0.482	0.465	0.482	0.465	0.000	0.000	0.0
	0.02	0.000	0.400	0.400	0.383	0.400	0.383	0.000	0.000	0.0