RING FIN ROCKET CENTER OF PRESSURE, DRAG AND LIFT SLOPE COEFFICIENTS MEASURED USING THE AEROROCKET WIND TUNNEL
Technical Note 2022-2, V1 By John Cipolla

Several ring fin rocket designs were tested in the AeroRocket wind tunnel to determine drag coefficient, Cd center of pressure location, Xcp and lift slope coefficient, CNa verses rocket angle-of-attack. Results of these measurements are displayed in Figure-1 which provides ring fin rocket wind tunnel aerodynamic coefficients Cd, Xcp and CNa verses length ratio, Lring/Lbody for three cases of diameter ratio, Dring/Dbody. Curve-fit data are displayed in Figure 2, Figure-4, and Figure-5 which display Cd, Xcp and CNa for four ring-fin wind tunnel models. Each of the four models are 12.625 inches long and have a body tube that is 0.544 inches in diameter. The first model has a 1.594-inch diameter x 2.438-inch-long ring-fin positioned with the trailing edge of the ring-fin flush with the rear of the rocket. Similarly, model 2 was tested with its 1.594-inch diameter ring-fin, first with the ring-fin 4.875 inches long then 2.438 inches long, 1.25 inches long and finally 0.469 inches long. Model 3 was tested with its 2.219-inch diameter ring-fin, first with the ring-fin 6.688 inches long, then 3.375 inches long, 1.625 inches long and finally 0.625 inches long. Finally, model 4 was tested with its 2.594-inch diameter ring-fin, first with the ring-fin 7.875 inches long, then 4.0 inches long, 2.0 inches long and finally 0.75 inches long.

For CNa measurements, each wind tunnel model with its ring-fin diameter and ring-fin length was tested at 0-degrees, 5-degrees, 10-degrees and 15-degrees angle-of-attack. Temperature and wind tunnel velocity was recorded before each measurement to determine air density and air viscosity for Reynolds number computation. Reynolds number is based on model length while the aerodynamic coefficients are referenced to the body tube cross-sectional area behind the nose cone. Center of pressure location, Xcp is normalized by the total body tube and nose cone length of 12.625 inches for all the wind tunnel models. The measured raw data by itself is useless unless put into a form useful for aerodynamic prediction. Therefore, all aerodynamic coefficients were curve-fit using algebraic equations as a function of ring-fin length ratio, Lring/Lbody and ring-fin diameter ratio, Dring/Dbody. Using methods of interpolation, the drag coefficient, Cd, center of pressure location, Xcp and lift slope coefficient, CNa were curve-fit using the mathematical capability of Mathcad. There are three equations one for each aerodynamic coefficient described above, one equation for each model tested having a specific ring-fin diameter ratio, Dring/Dbody. Curve-fit equations that describe, Cd, Xcp and CNa are Equation-1, Equation-2, and Equation-3 respectively. In these curve-fit equations S1 and S2 were defined using AeroRocket wind tunnel measured data. Each aerodynamic coefficient is described by curve-fit equations corresponding to one of the following ring-fin diameter ratios. Dring/Dbody = 2.93, Dring/Dbody = 4.08 and Dring/Dbody = 4.77. Each aerodynamic coefficient, Cd, CN, and CNa is a function of Lring/Lrocket and Dring/Drocket derived by one of the three curve-fit equations. If the specified diameter ratios are not sufficient simply use the interpolation procedure described in Figure-7 to interpolate between diameter ratio curves. The aerodynamic coefficients are determined by interpolating between ring-fin diameter ratio curves to determine the aerodynamic coefficients. Figure-7 displays graphically how interpolation between coefficient curves is used to determine Cd, Xcp and CNa for new designs.

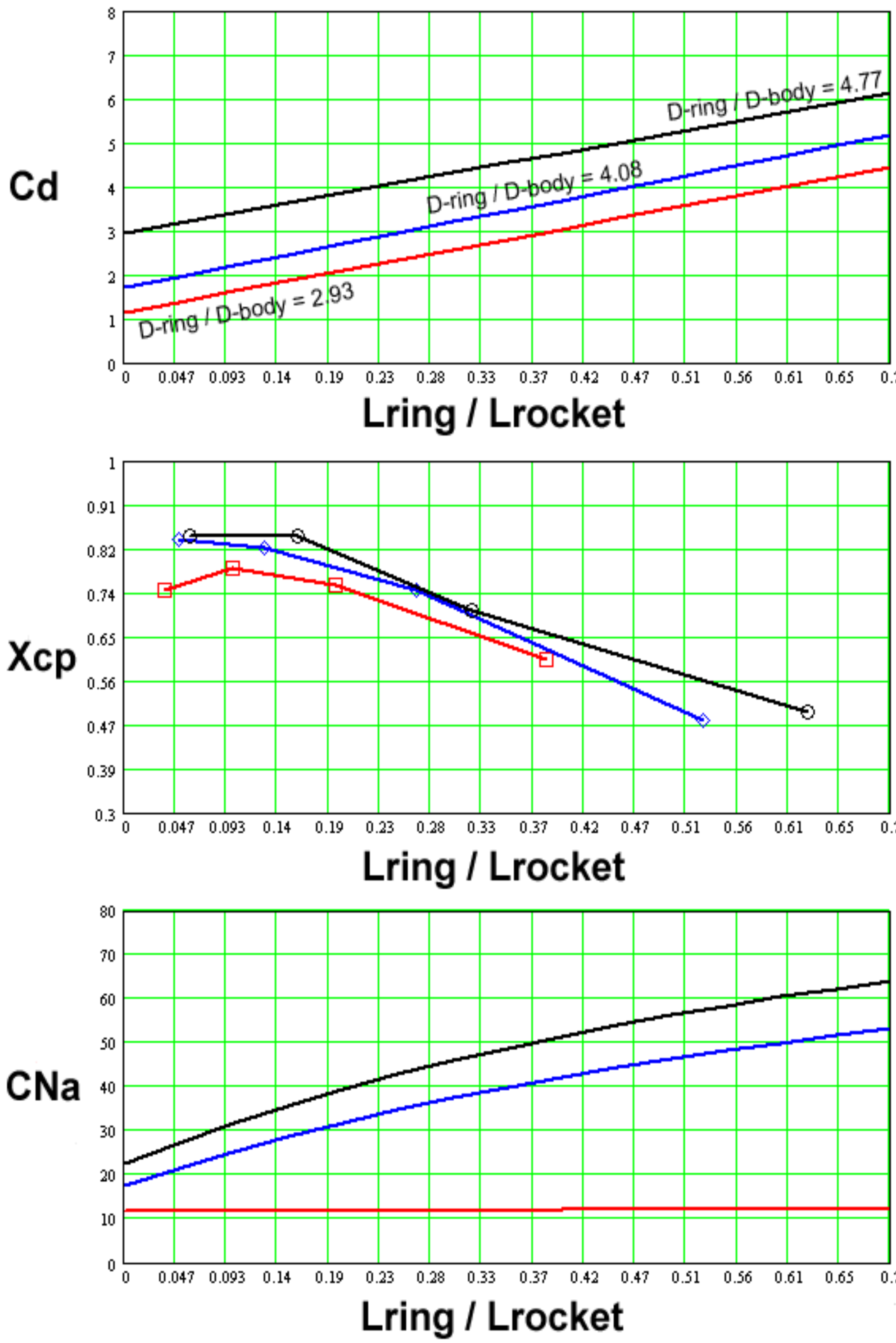

Figure-1 Cd, Xcp and CNa curve-fit results from wind tunnel tests

RING FIN DRAG COEFFICIENT, Cd

Cd vs. Lring / Lrocket. Ring-Fin Cd (**0.0-degree** AOA w/o body)

Dring / Dbody	**2.93**	**4.08**	**4.77**
S1	4.717786	4.954520	4.586682
S2	1.146967	1.709692	2.933179

$$C_d = S_1 \frac{L_{ring}}{L_{body}} + S_2 \quad (1)$$

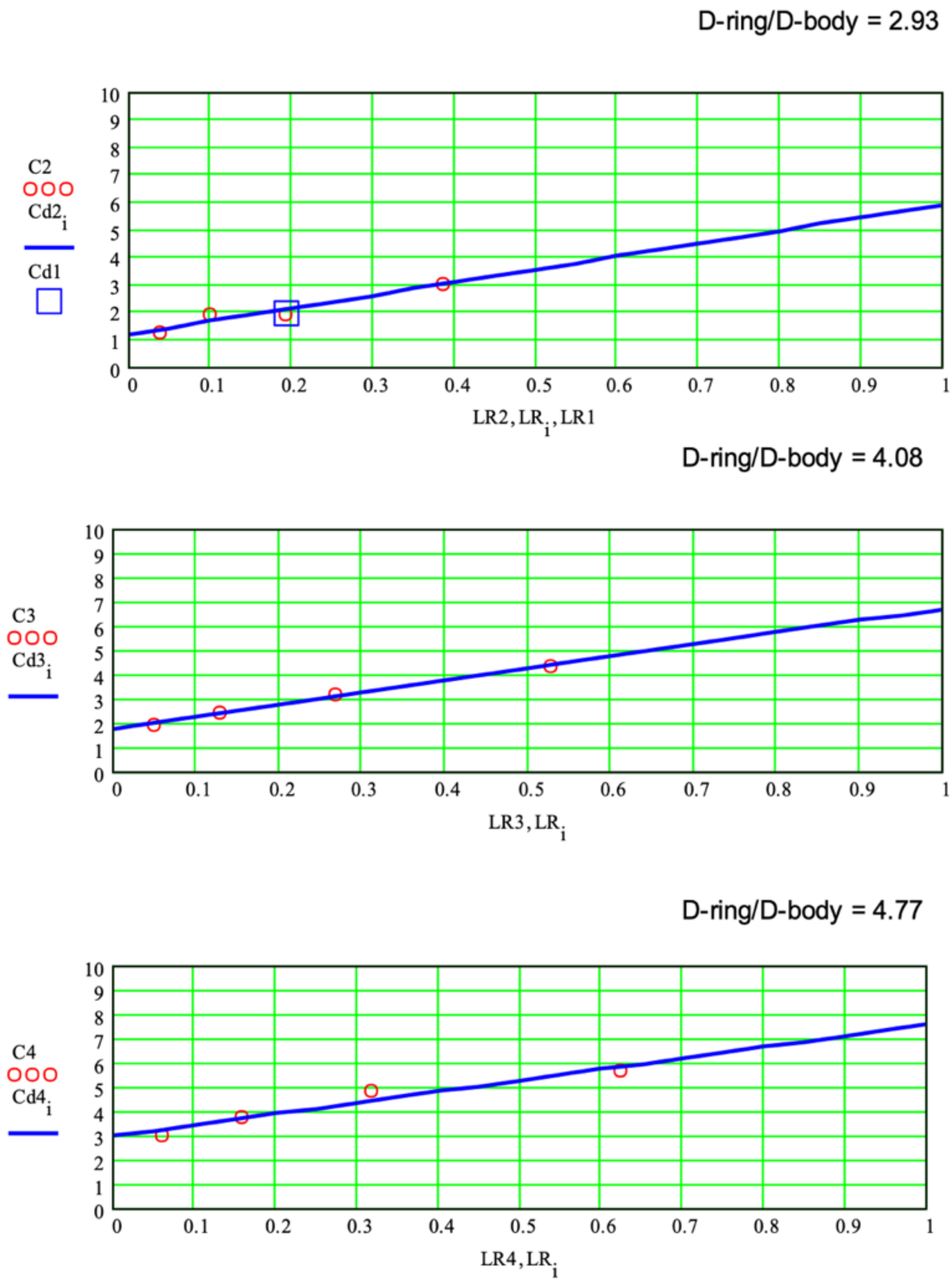

Figure-2, Rocket Cd vs Lring / Lrocket at 0-degree AOA for data and curve-fit

CENTER OF PRESSURE LOCATION, Xcp

Center of pressure location measurements are performed using a special Xcp-Caliper that secures the model in the wind tunnel test section using two opposing low friction points. Figure-3a illustrates a ring-fin model rocket being tested in the AeroRocket wind tunnel for measuring center of pressure location. The ring-fin model in this configuration is stable because the support point is ahead of the actual center of pressure. The actual center of pressure location, Xcp is determined by moving the sting support location rearward until the model becomes unstable and "noses over" to one side or the other when the wind tunnel is operating. Figure-3b further illustrates how the ring-fin rocket model is secured in place during center of pressure location testing. Please notice the pitot tube used to measure the difference between static pressure and dynamic pressure for determining flow velocity in the wind tunnel. An analog velocity meter is used to convert the resulting pressure differential to test section flow velocity measured as 3,500 in feet per minute.

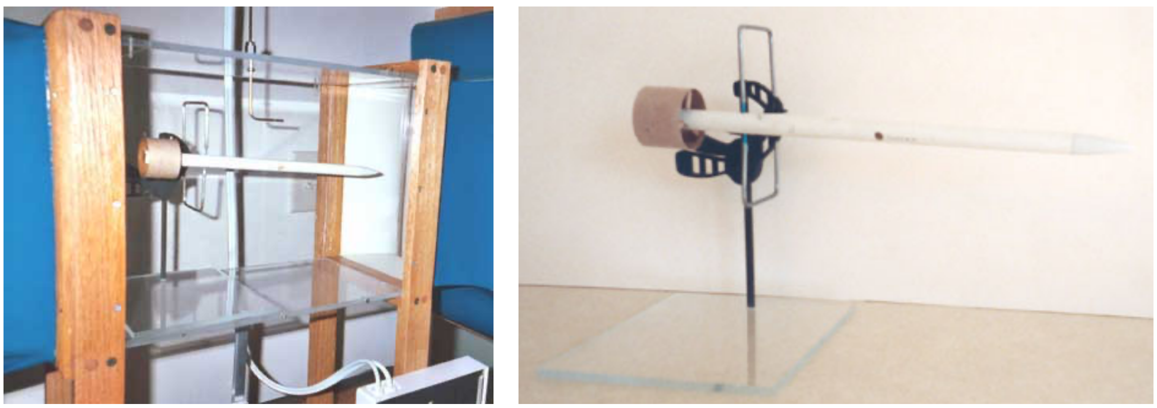

Figure-3a, Figure-3b, Xcp caliper uses two opposing low friction points to determine center of pressure

MATHCAD CURVE-FIT ANALYSIS COEFFICIENTS

D_{ring}/D_{rocket}	**2.93**	**4.08**	**4.77**
D_i/D_o	0.34	0.25	0.21
S1	0.639859	1.219973	1.137153
S2	0.172234	-0.276811	-0.178476

Ring Fin S1 and S2 coefficients for various D_{ring}/D_{rocket}

CENTER OF PRESSURE ESTIMATION EQUATION

$$\frac{X_{cp}}{L_{rocket}} = S_1 \frac{L_{rocket}}{L_{ring}+L_{rocket}} + S_2 \qquad (2)$$

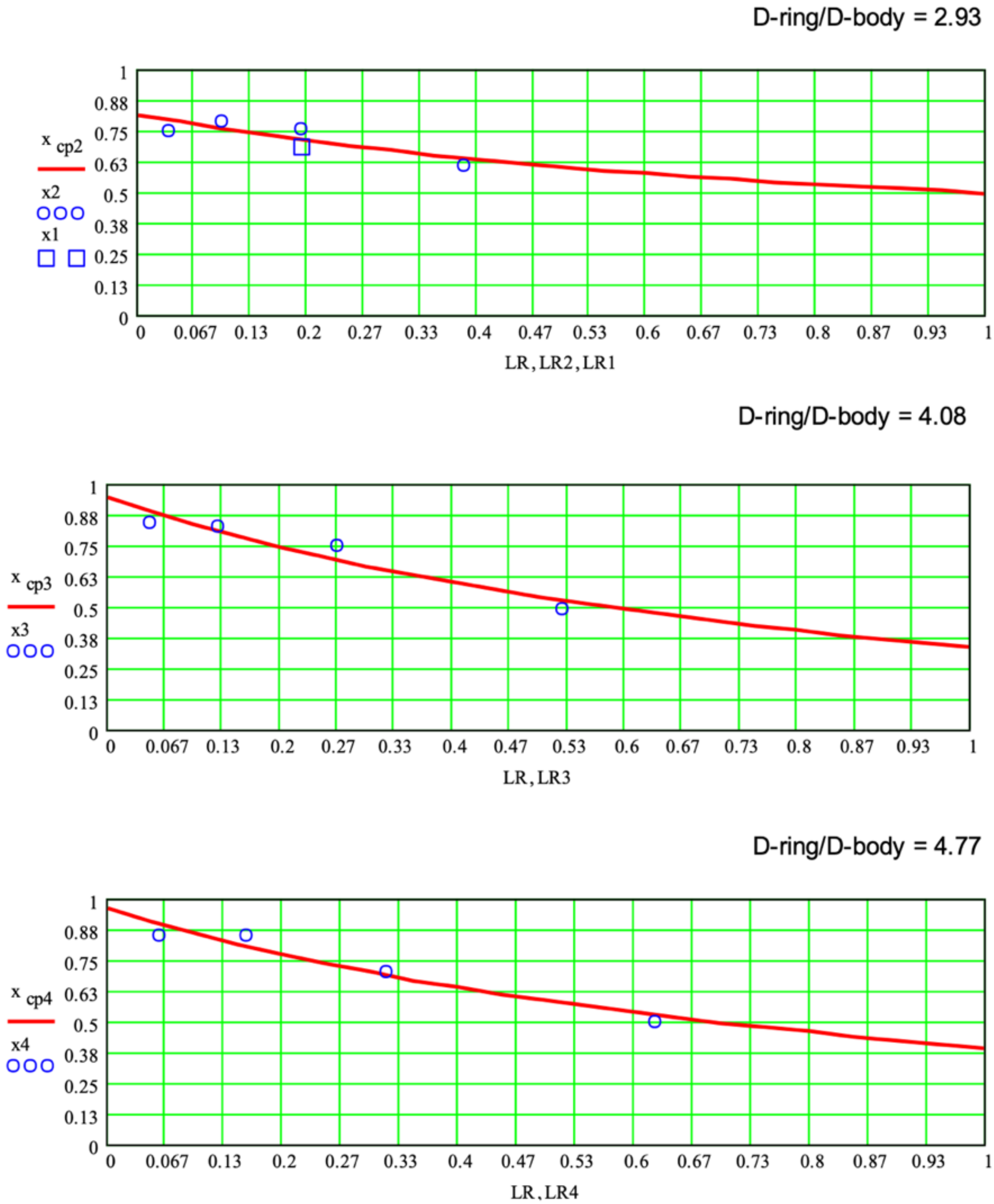

Figure-4, Rocket Xcp vs Lring / Lrocket for data and curve-fit

RING FIN LIFT SLOPE COEFFICIENT, CNa

Ring Fin CNa (w/o nose). CNa vs. Lring / Lrocket

Dring / Dbody	**2.93**	**4.08**	**4.77**
S1	-1.021229	-86.783769	-101.05531
S2	12.671390	104.146040	123.546993

$$CN_a = S_1 \frac{L_{body}}{L_{ring}+L_{body}} + S_2 \qquad (3)$$

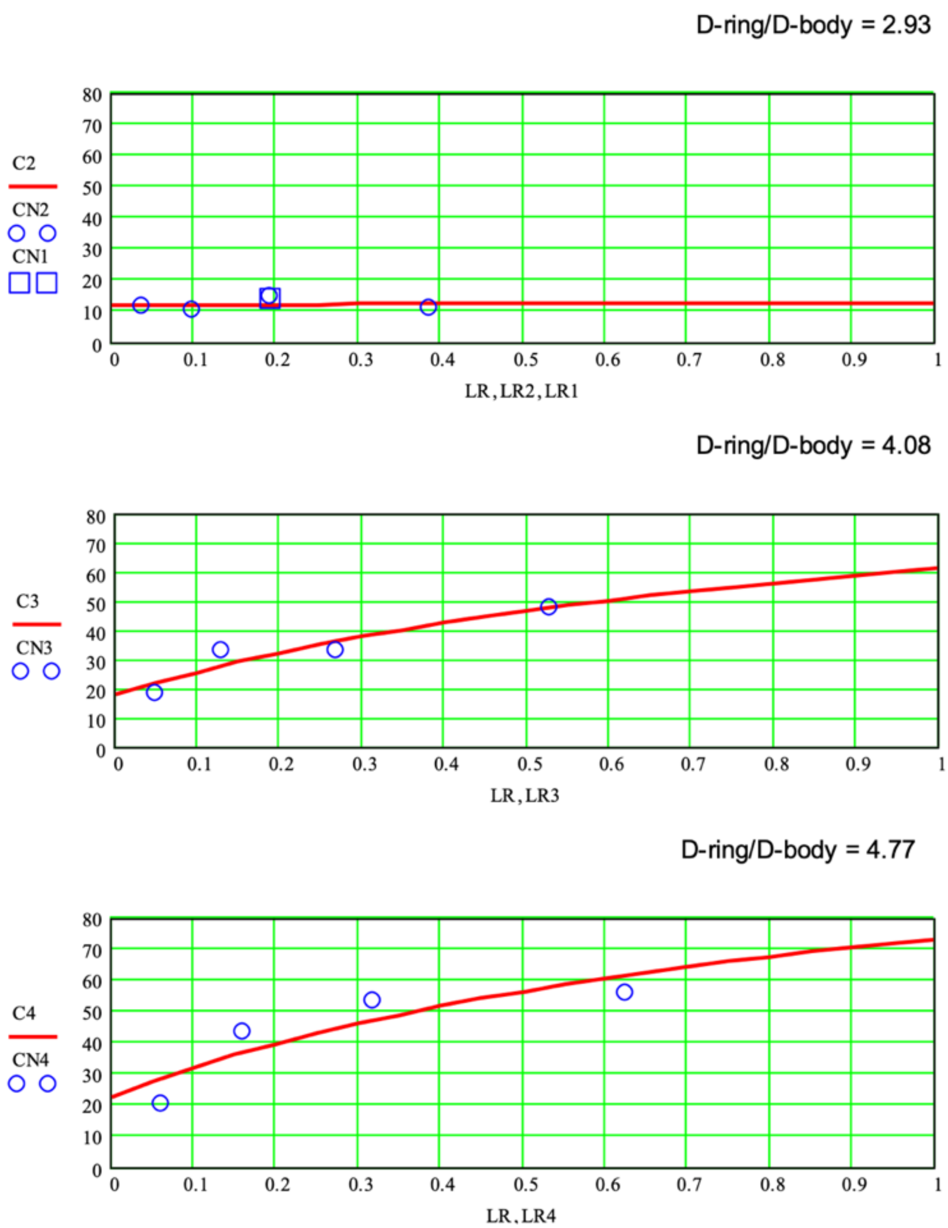

Figure-5, Ring Fin CNa (w/o nose) vs. Lring / Lrocket for data and curve-fit

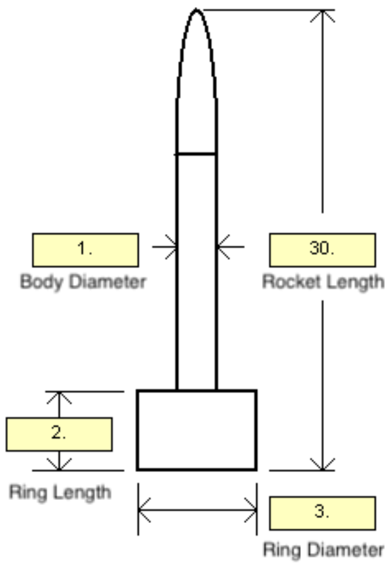

Figure-6, Ring fin geometry

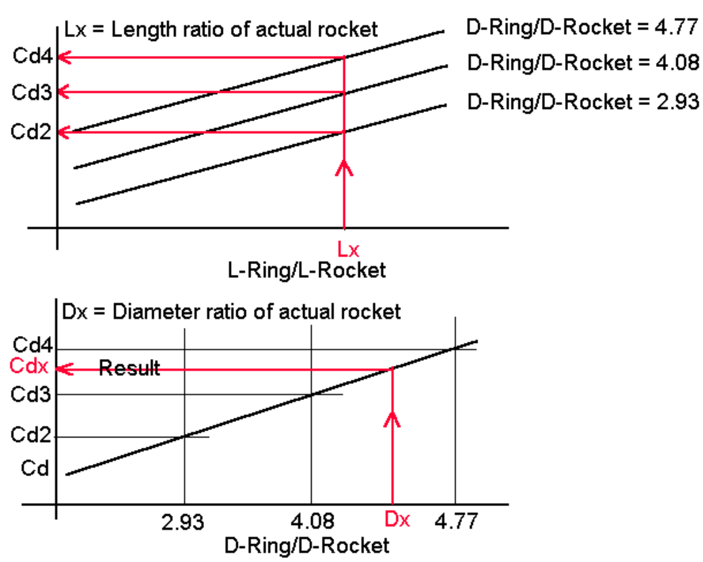

Figure-7, Ring Fin Interpolation methodology

Classical Barrowman Ring Fin Xcp Analysis

$$CN_{a\,nose} = 2.0 \tag{4}$$

$$X_{cp\,nose} = 0.667\,L_{nose} \tag{5}$$

$$X_{cp\,fin} = \frac{1}{4}c,\ \ Location\ of\ ring\ fin\ aerodynamic\ center \tag{6}$$

$$X_{cp} = \frac{CN_{a\,nose}\,X_{cp\,nose} + CN_{a\,fin}\,X_{cp\,fin}}{CN_{a\,nose} + CNa_{fin}} \tag{7}$$

$$C_{d\,nose-body} = 0.305, measured\ rocket\ drag\ without\ ring\ fin \tag{8}$$

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