Prediction of the Drag Coefficient of a 20° Conical Ribbon Parachute

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Theme

A 20° conical ribbon parachute has been selected as the drogue parachute for the Space Shuttle Solid Rocket Booster Recovery System. In this paper, a mathematical expression for the steady-state drag coefficient of a 20° conical ribbon parachute in subsonic flow is formulated. The expression takes into account the effect of suspension line length, geometric porosity, and reefing line length. The factors representing the effect of design parameters on the drag coefficient have been determined from the various wind tunnel test results. The developed mathematical model can predict the drag coefficient of a 20° conical ribbon parachute for a wide range of the parachute size (nominal diameter, 2.89 ft-78.3 ft).

Contents

Aerodynamic characteristics of a 20° conical ribbon parachute depend upon its design parameters, such as geometric porosity and suspension line length. An explicit dependence of the parachute drag coefficient on its design parameters is difficult to obtain analytically because of the complicated way they affect the shape of the inflated canopy and influence its performance. The following approach is taken to define the steady-state drag coefficient. The drag coefficient of a solid (zero geometric porosity) 20° conical ribbon parachute having a suspension line length equal to its nominal diameter is regarded as a basic drag coefficient. The effect of geometric porosity, and suspension line lengths greater than one nominal diameter, is introduced by adding correction factors to the basic drag coefficient. Neglecting flexibility and aeroelastic effects the parachute steady-state drag coefficient at subsonic speeds is described as a function of the design parameters in the following expression

$$C_D = C_{D_I} + \Delta C_{D_{\lambda_g}} + \Delta C_{D_{\ell_S}} \cdot f_0(\ell_R) \qquad (1)$$

where, C_{D_1} = steady-state drag coefficient of a 20° conical ribbon parachute with geometric porosity $\lambda_g = 0\%$ and suspension line length to nominal diameter ratio $L_S/D_0 = 1.0$, $\Delta C_{D_{\lambda_g}}$ = correction factor for the drag coefficient of parachutes with geometric porosity, $\Delta C_{D_{\ell_S}}$ = correction factor for the drag coefficient of parachutes with suspension line length ratio of more than one, and $\ell_S = (L_S/D_0 - 1)$. Also, $f_0(\ell_R)$ is a function of the reefing line length defined as follows

$$f_0(\ell_R) = \begin{cases} 1 & \text{for full open canopies} \\ 0 & \text{for reefed canopies} \end{cases}$$

To predict the drag coefficient of a 20° conical ribbon parachute with known design parameters, the basic drag coefficient C_{D_1}, and the correction factors $\Delta C_{D_{\lambda_g}}$ and $\Delta C_{D_{\ell_S}}$ need to be determined. A good fit for the correction factors was obtained using wind tunnel test results[1] and their estimates are given as

$$C_{D_1} = 0.874$$

$$\Delta C_{D_{\lambda_g}} = -2.29\lambda_g + 1.953(\lambda_g)^2$$

$$\Delta C_{D_{\ell_S}} = (0.055 + 1.145\lambda_g)\ell_S + (0.012 - 0.775\lambda_g)(\ell_S)^2$$

The drag coefficient of a reefed canopy is obtained by subtracting a correction factor corresponding to a particular reefing line length from the full open drag coefficient given by Eq. (1)

$$C_D/_R = C_D - \Delta C_{D_{\ell_R}} \qquad (2)$$

where $\Delta C_{D\ell R}$ = correction factor for the reefed canopy, and ℓ_R = nondimensional reefing line length L_R/D_0. An estimate of the correction factor for the reefed parachute was obtained using the two wind tunnel test results.[2,3]

$$C_{D_{\ell_R}} = [1.7(\lambda_g)^2 - 1.03\lambda_g + 0.47](\ell_R{}^* - \ell_R)$$

$$\ell_R^* = (2.37 - 2.5\lambda_g)$$

The drag coefficient of 20° conical ribbon parachute given by Eqs. (1) and (2) is based on parachute nominal area. The applicable range of the variables is limited to the following: 1) $0 \leq \lambda_g \leq 24\%$; 2) $1 \leq L_S/D_0 \leq 2$; and 3) $0.5 \leq L_R/D_0 \leq$ full open skirt circumference.

The empirical relationship derived is for a particular porosity distribution used in the SRB drogue parachute models. This porosity distribution is characteristized by equally spaced horizontal ribbons. Variation in geometric porosity is achieved by varying the gap size, keeping the apex vent size constant. The reader is also cautioned to note that the suspension line length is measured from the drag producing surface to the single confluence point. In case of two or more risers, or the designs where the suspension lines are attached to the forebody at more than one point, it is desirable to find an effective single confluence point before

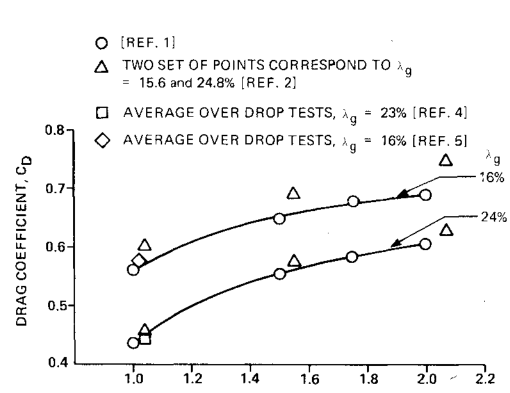

Fig. 1 Effect of suspension line length and geometric porosity on freestream drag coefficient.

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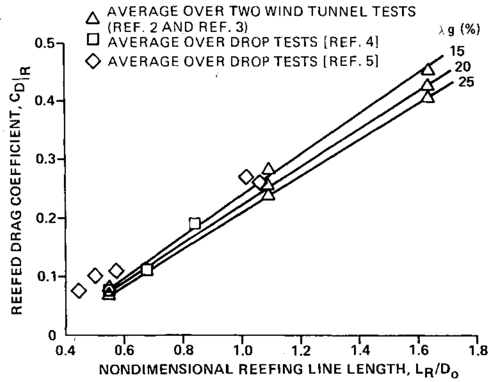

Fig.2 Effect of reefing line length on drag coefficient.

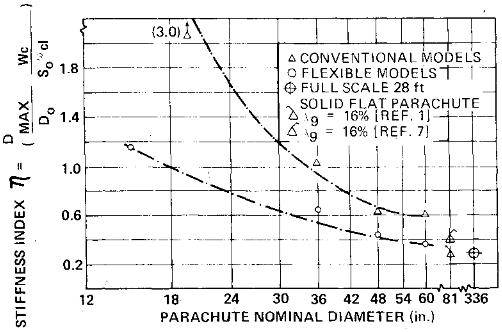

Fig. 3 Stiffness index comparison of suspended model solid flat and conical ribbon parachutes.

using the same equations. Reefing line length used in the definition is the circumference of the canopy at the skirt. The total length of the reefing line would be L_R plus an additional length needed for splicing.

Figures 1 and 2 depict a comparison of the experimental and calculated full open and reefed drag coefficients of the available 20° conical ribbon parachute respectively. The data for the various size parachutes has been converted to a case of $L_S/D_0 = 1.0$ using the mathematical model. It is appropriate to mention here that the flexibility has significant effect on the performance characterisitcs of a parachute. In an effort to determine the flexibility effects Heinrich and Hektner[6] proposed a stiffness index and showed that models with different stiffness indexes exhibited significantly different drag coefficients. Stiffness indexes of two 16% geometric porosity 20° conical ribbon parachutes have been plotted in Fig. 3 reproduced from Ref. 6. It was found out from the wind tunnel tests[1,7] that the canopy with higher stiffness index[7] exhibited 6% lower drag coefficient compared to the canopy with lower stiffness index.[1] This result agrees with Heinrich's[6] findings.

Reference 8 presents a complete and original version of a parametric investigation of the dependence of the drag coefficient on geometric porosity, suspension line length, reefing line length, and the wake effects behind a forebody. Curve fitting determination of the drag coefficient has agreed reasonably well with the experimental and the drop test results.

Acknowledgment

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