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Inflating Parachute Canopy Differential Pressures

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A scheme is presented whereby local aerodynamic loading during the inflation of a symmetrical parachute in an incompressible airflow may be calculated. The technique is based upon an unsteady vortex sheet mathematical representation of the canopy and relies upon matching a calculated axial force with one anticipated for any particular canopy and set of flight conditions. Differential pressures computed in this fashion compare favorably with those measured on 3-ft diam wind-tunnel models inflating under infinite mass conditions.

Introduction

THE driving factor in parachute structural design is the maximum load generated during inflation. Although a great deal of experimental evidence and ample analytical modeling[1] exists to predict the net axial load produced by an inflating canopy, no suitable technique is available for calculating the transient pressure distribution generated during the inflation. Knowledge of this distribution cannot be directly inferred from the total axial load, the quantity which is generally used to size structural components. A priori information on local canopy loading would provide a much more efficient canopy design.

The present paper describes a calculation technique for differential pressures experienced by an inflating symmetrical parachute canopy. The mathematical model uses unsteady vortex sheets and requires the matching of a computed axial force with one either previously known or assumed for the case of interest.

Mathematical Model

The basic steady-flow vortex sheet model is described in some detail in Ref. 2. Briefly, the canopy surface is mathematically replaced by a series of conical frustum-shaped vortex sheet segments whose strengths (γ) are initially unknown. Assuming a linear variation of these strengths along the frustum segments permits the fluid velocities at any point on the sheet to be expressed as a linear function of the segment extremity γ values. Application of two kinds of boundary conditions are required to solve for the unknown extremity γ values. Once this set is solved, the resulting extremity γ values permit a full flowfield description.

Not previously described were the adjustments required for the model to represent pressures in an unsteady flow. Here the appropriate Bernoulli equation is:

$$\frac{p}{\rho}+\frac{V^2}{2}+\frac{\partial\phi}{\partial t}=F(t)$$

where ϕ is the velocity potential. The differential pressure across the canopy at any point is then

$$\Delta p=p_{\rm in}-p_{\rm out}=\rho\left(\frac{V_{\rm out}{}^2-V_{\rm in}{}^2}{2}+\frac{\partial\phi_{\rm out}}{\partial t}-\frac{\partial\phi_{\rm in}}{\partial t}\right)$$

The speed terms present no difficulty; once the γ distribution is known, all velocities are readily calculated. Treatment of the velocity potential time derivatives is not as straightforward. Consider a coordinate system whose directions are along (s) and normal (n) to the vortex sheet. Then $\gamma=\gamma(s,t)$ and $\phi=\phi(s,n,t)$. Using the facts that the local sheet strength is equal to the local tangential velocity discontinuity across the sheet

$$u_{\rm out}-u_{\rm in}=\gamma$$

and that the sheetwise velocities may be expressed in terms of the velocity potential as

$$u=\frac{\partial\phi}{\partial s}$$

then at any point on the sheet

$$\gamma=\frac{\partial\phi_{\rm out}}{\partial s}-\frac{\partial\phi_{\rm in}}{\partial s}$$

Differentiate both sides with respect to time

$$\frac{\partial\gamma}{\partial t}=\frac{\partial^2\phi_{\rm out}}{\partial t\partial s}-\frac{\partial^2\phi_{\rm in}}{\partial t\partial s}$$

then interchange the order of differentiation to give

$$\frac{\partial\gamma}{\partial t}=\frac{\partial}{\partial s}\left(\frac{\partial\phi_{\rm out}}{\partial t}-\frac{\partial\phi_{\rm in}}{\partial t}\right)$$

or

$$\left(\frac{\partial\phi_{\rm out}}{\partial t}-\frac{\partial\phi_{\rm in}}{\partial t}\right)=\int_{s_0}^{s}\left(\frac{\partial\gamma}{\partial t}\right)ds$$

This form of the velocity potential contribution to Δp may be handled in a relatively simple way. Choosing s_0 to be a sheet terminal extremity where a Kutta or Theodorsen condition has been applied causes the lower limit value of the integral to be zero. This is because at such an extremity $\gamma=0$ for all time. The $\partial\gamma(s,t)/\partial t$ term may be evaluated by using finite differences, thereby reducing t to a role as a parameter. The s-type integration may be done analytically. This feature follows from the facts that the γ values are expressed as linear functions of s and these functions would appear in a finite-difference form of $\partial\gamma/\partial t$.

Model Usage

Application of the model requires a priori knowledge or the assumption of canopy shape, radial and axial velocity

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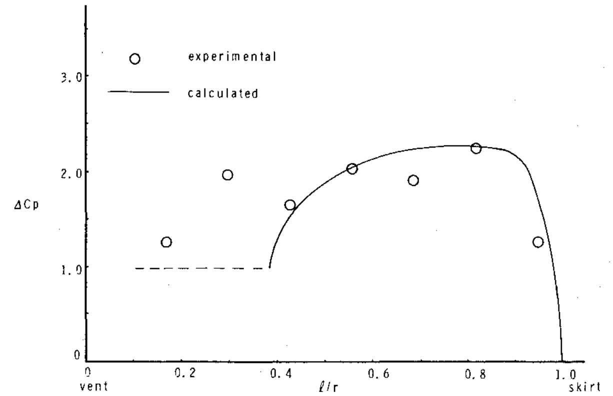

Fig. 1 Differential pressure coefficient vs radial location, 25% λg ribbon parachute, 3-ft diam, inflating under infinite mass conditions.

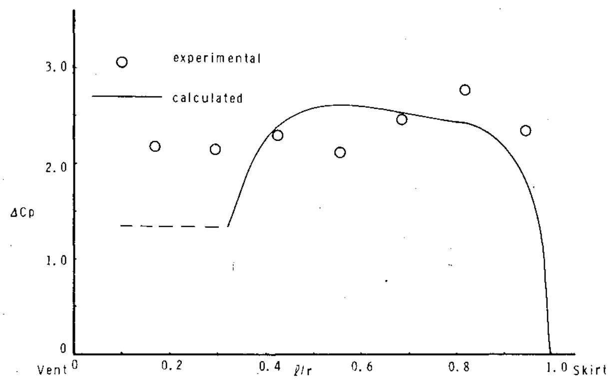

Fig. 2 Differential pressure coefficient vs radial location, solid flat circular parachute, 3-ft diam, inflating under infinite mass conditions.

distributions, and axial deceleration and load. Experience has shown that a semielliptical cup/conical frustum combination reasonably and simply represents canopy shape from a reefed condition through the inflation process to full open. The apportionment of canopy between frustum and cup depends upon the extent of inflation. The frustum angle depends upon both the extent of inflation and suspension line length. An eccentricity of 0.8 seems appropriate for the semiellipsoid, although this may vary with porosity. Relative radial and axial velocity distributions are given by a single parameter when the cup/frustum shape is assumed. These relative velocities are zero in many cases of interest; maximum loads are often generated at the same time that radial dimensions of the canopy are at a relative maximum. The total canopy's translational (axial) velocity and deceleration and axial load would normally be calculated via a deployment, inflation, and trajectory dynamics scheme such as the one described in Ref. 1. After setting the preceding parameters, the model is run for various assumed values of a relative radial and axial deceleration parameter. The resulting pressure distributions are then integrated to give an axial load. Computations cease when this axial load equals the one obtained or assumed a priori.

The pressure distribution producing the axial load match may then be used as input to a structural design code such as CANO.[3] Here the various elements of the parachute are individually sized to most efficiently handle the applied loads. Iteration on canopy shape may be required before the local loads generated by the flexible structure are consistent with the canopy shape producing these loads and vice versa. A detailed specific design example is given in Ref. 4.

Comparison with Experiment

Plotted in Figs. 1 and 2 are transient pressures measured during infinite mass inflations of a 25% geometric porosity (λ_g) 20 deg conical ribbon and a flat circular solid wind-tunnel model parachute, respectively. Both models had 3 ft diameters, 3 ft suspension line lengths, and 24 gores. Each was fitted with seven Kulite Semiconductor Products, Inc., Model No. LQH-68-125-250 differential pressure transducers. The transducers were distributed almost evenly in the circumferential direction and at equal radial intervals for $0.17 \leq l/r \leq 0.95$ (r is the 18 in. radial length and l is the local radial location measured from the 10% vent's center). The canopy was allowed to stream (reefed with a 9 in. long line) behind a 3 ft-long, 4 in./diam streamlined body cable-mounted along the centerline of the Vought Corporation 7 × 10 ft low-speed wind tunnel. Disreefing was done at a freestream dynamic pressure of 110 psf. The time at which these pressures were recorded corresponded to the time at which maximum axial load was measured. Each plotted experimental pressure value is the mean from two inflations.

Also plotted in Figs. 1 and 2 are the ΔC_p values predicted by the present scheme. When integrated, these pressure distributions provide axial forces that equal those maxima measured during inflation. In general, both the quantitative and qualitative natures of the predictions are in agreement with those measured. An exception is the region near the vent (indicated by dashed lines) where the technique calculates unreasonably low Δp values. The dashed-line values are the last acceptable pressures calculated and are assumed to be applicable from their point of computation to the vent. This is not felt to be a serious shortcoming because of the relatively small area involved.

Summary

A scheme is described wherein the maximum differential pressures generated by an inflating axisymmetric parachute canopy in an incompressible airstream may be calculated. The scheme is based upon an unsteady vortex sheet mathematical model and requires matching of an integrated axial load with one that is known or assumed a priori. When compared to distributions measured on inflating wind-tunnel models, the method appears to predict actual loadings reasonably well.

References

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