Snatch Force during Lines-First Parachute Deployments

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Nomenclature

c = wave velocity
F_{re} = unfurling resistance due to friction and pressure forces
K' = specific modulus of elasticity
m' = linear mass density
n = number of suspension lines
P_T = theoretical snatch force
T = suspension-line tension
t = time
u = unfurling velocity of the parachute
V_R = velocity of the deployment bag relative to the vehicle
y = spatial coordinate of the extended parachute
δ = displacement of a suspension-line cross section relative to its equilibrium position

Subscripts

B = mouth of the deployment bag
c = canopy skirt
le = suspension-line extension
sl = suspension line

Introduction

SNATCH force is generally considered to be the maximum suspension-line tension at the vehicle during the deployment process prior to canopy inflation. For a canopy-first type of deployment, the maximum tension is generated immediately after the decelerator is completely extended. However, for a lines-first deployment, the maximum tension generally occurs as the canopy skirt emerges from the deployment bag.

The standard technique for calculating snatch force[1–3] is based on an energy balance between the strain energy of the suspension lines at line stretch, and the kinetic energy of the canopy mass, relative to the vehicle, at line extension. In the past, this technique has been quite useful in the analysis of deployments of the canopy-first type.

Unfortunately, the standard technique is also being currently used to predict the "snatch force" generated during deployments of the lines-first type. This procedure has resulted in large overpredictions (200–700%) (see Ref. 4) of the maximum tension prior to canopy inflation. These overpredictions can be explained by noting that snatch force, for a lines-first deployment, is caused by incremental acceleration of the canopy skirt as it emerges from the deployment bag, rather than by total absorption of the relative kinetic energy of the entire canopy. In the analysis to follow, a simple approximation for the snatch force generated during a deployment of the lines-first type is developed.

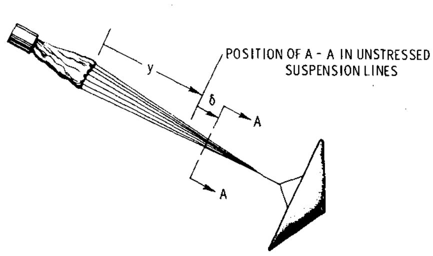

Fig. 1 Coordinates used to describe the behavior of elastic suspension lines.

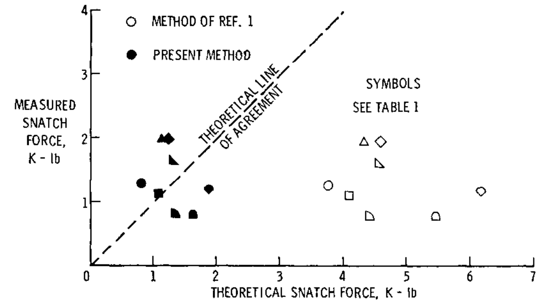

Fig. 2 Comparison between theoretical and measured snatch forces for deployments of the lines-first type.

Analysis

The suspension-line tension at the mouth of the deployment bag can be related to the unfurling rate by an impulse-momentum method. As a differential element of the decelerator mass emerges from the deployment bag, it undergoes a discrete increase in momentum equal to the difference in the impulses applied by the suspension-line tension at the bag mouth and the resistance to unfurling, due to bag friction and the internal pressure differential. This relationship can be solved for the suspension-line tension at the deployment bag mouth and written as

$$T_B = m'u^2 + F_{re} \tag{1}$$

The elastic behavior of the suspension lines is governed in general by a second-order nonlinear partial differential equation. Assuming linear elasticity and constant linear mass density, and neglecting damping and the stress gradient due to vehicle deceleration, reduces the governing equation to the one-dimensional wave equation (see Fig. 1)

$$\partial^2\delta/\partial t^2 = c^2(\partial^2\delta/\partial y^2) \tag{2}$$

where the wave velocity c is given by $c^2 = K'/m_{sl}'$. For cases in which the suspension lines are initially in static equilibrium, the general solution to Eq. (2) is given by

$$\delta = \delta(y - ct) \tag{3}$$

A boundary condition of compatibility at the leading edge of the canopy skirt is

$$(\partial\delta/\partial t)_{y=0} = u - V_R \tag{4}$$

where the relative velocity V_R is assumed constant over the time period of interest.

A second boundary condition resulting from the definition of suspension-line tension is

$$(\partial\delta/\partial y)_{y=0} = T_B/(K'n) \tag{5}$$

Table 1 Snatch-force parameters for sample configurations.

$K' = 2322$ lb			$m_{sl}' = 1.671 \times 10^{-4}$ slug/ft		
Flight test	Parachute	Symbol	m_c', slug/ft	n	$V_{R_{le}}$ ft/sec
PEPP R/L-3	30 ft DGB[a]	○	0.265	24	113
PEPP R/L-6	30 ft Cross	□	.264	36	113
SPED 1 R/L-1	40 ft DGB	◇	.355	32	122
SPED 1 R/L-3	40 ft DGB	△	.355	32	115
PEPP R/L-5	40 ft Ringsail	◺	.416	36	117
PEPP B/L-4	54.4 ft Cross	D	.412	64	93
PEPP B/L-3	54.4 ft Ringsail	⌓	.658	54	99
PEPP B/L-2	64.7 ft DGB	⬠	.531	72	104

[a]DGB = Disk-gap-band.

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The functional form of the general solution implies the following equality:

$$\partial\delta/\partial t = -c(\partial\delta/\partial y) \tag{6}$$

Substituting the boundary conditions, and solving for the suspension-line tension at the deployment bag mouth gives

$$T_B = K'n(V_R - u)/c \tag{7}$$

An approximate expression for the snatch force is obtained from Eqs. (1) and (7). The suspension-line tension is eliminated from Eq. (7) using Eq. (1) and the resulting quadratic solved for the steady-state unfurling rate. The corresponding tension (snatch force) is found by substituting the steady-state unfurling rate in Eq. (1). This result can be expressed as

$$P = nK'[\{1 - (1 + 4A)^{1/2}\}/(2r) + V_{Rl_e}/c] \tag{8}$$

where

$$A = r[V_{Rl_e}/c - F_{r_e}/(nK')],\ r = m_c'/(nm_{sl}')$$

Results and Discussion

The present snatch-force theory was compared with flight data obtained during the Planetary Entry Parachute Program (PEPP) and the Supersonic Planetary Entry Decelerator Program (SPED).[4] For these calculations, the deployment velocity at line extension was determined by numerical integration of the general equations describing the dynamics of lines-first deployments.[5] The unfurling resistance was neglected. The elastic modulus of the suspension lines was determined from static test data. The linear mass density of the canopy skirt was determined by dividing the mass of the skirt hem (including the tape reinforcement, the overlapping radial tapes, and an appropriate amount of canopy cloth) by the width of the hem. Calculated values for these parameters are summarized in Table 1. The resulting snatch-force predictions using Eq. (8) are compared with flight data in Fig. 2. Also shown in this figure is a comparison between the flight data and the "handbook method"[1] for calculating snatch force. As can be seen, the present method significantly improves the prediction accuracy. The remaining disagreement between theory and flight is thought to be the result of nonideal packing and construction, angle of incidence between the deployment bag and the suspension lines, undetermined unfurling resistance, and nonlinearities in the elastic properties of the suspension lines.

Concluding Remarks

Snatch force, for a lines-first deployment, has been related to the increase in linear mass density of the unfurling decelerator as the canopy skirt emerges from the deployment bag. An approximation to the snatch force was obtained from a steady-state solution to the wave equation which approximates the linear elastic behavior of the suspension lines. Prediction accuracy using the present theory was significantly better than results obtained by applying the canopy-first theory of the "handbook method."

References

[1] "Performance of and Design Criteria for Deployable Aerodynamic Decelerators," ASD-TR-61-579, Dec. 1963, U.S. Air Force.

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Effect of Asymmetrical Flow from Trailblazer Flight Measurements

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A MAJOR problem in predicting r.f. (radio frequency) conditions in a re-entry environment is the extreme complexity of the flow in all but the simplest of situations. The difficulties may arise from a number of causes: vehicle shape, nonequilibrium effects, and the addition of chemical additives to the flow, either deliberately or as a byproduct of ablation, are some of the principal ones. In a recent flight experiment a payload, consisting basically of a 9°-half-angle cone with a cylindrical VHF monopole antenna at the nose, was flown aboard a Trailblazer vehicle. Data received by various ground stations were in good agreement, but there was considerable fluctuation of the received signal strength. A detailed analysis of the flight showed that maximum signal attenuation occurred when the leeward flow was between the on-board VHF transmitter and the ground-based VHF receivers. The envelope of the received signal is shown in Fig. 1. From 407 sec $< t <$ 418 sec the vehicle was undergoing a coning motion with the angle of attack α decreasing from a maximum of 8° to a minimum of 2°. The re-entry velocity was essentially constant at 16,800 fps. The vehicle spin was stabilized at ~3 rps.

Based upon an axisymmetric inviscid flow calculation (stream tube method), it was found that except for a few db all attenuation was due to the thermal boundary layer on the antenna.[1] The gross validity of the inviscid flow calculations was substantiated by schlieren photographs of $\frac{1}{4}$-scale-model wind-tunnel tests, with $\alpha = 4°$. The purpose of this Note is to account for the windward-leeward variation in the transmitted VHF signal.

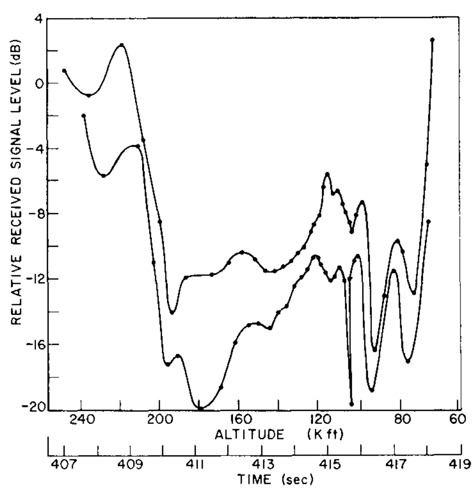

Fig. 1 Average VHF signal recorded by three ground based receivers (lower curve leeward aspect, upper curve windward aspect, abscissa linear with time).

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