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NSWC TR 90-284

NOTES ON THE APPLICATION OF APPARENT MASS EFFECTS ON PARACHUTE DEPLOYMENT

BY W. P. LUDTKE

UNDERWATER SYSTEMS DEPARTMENT

28 MAY 1990

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FOREWORD

The role of apparent mass effects in determining the magnitude of parachute opening shock force have been studied for many years. The ideas proposed in this report present arguments that the apparent mass effects may be neglected in calculating parachute opening shock force when using the dynamic drag area method of solution. It is also argued that the partial collapse of round personnel parachutes, at full inflation, may be due to the inertia of the entrapped air mass in concert with an air mass from aft of the canopy.

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ABSTRACT

This report sets forth, without experimental proof, the reasons as to why the author feels that apparent mass effects in parachute deployment are not as important to the analysis derived in Reference (1) as usually perceived. This commentary applies to the parachute opening shock phase of deployment. Canopy-wake recontact which occurs after the canopy has been fully inflated for a definite period of time is a different problem. In the final phase of finite mass deployments the unrestrained air mass that inflated the canopy has a higher trajectory velocity than the parachute system. This higher trajectory velocity together with changes in the canopy shape catapults the air mass from the parachute resulting in a temporary loss of system mass which tends to compensate for other air masses that may have been added. Infinite mass deployments also have added air masses in addition to the air mass contained within the canopy. Dynamic drag areas obtained from infinite mass deployments implicitly include these effects. In infinite mass deployments where the velocity differential between the internal air mass and the system are minimal the deflation effects will not occur. The validity of these ideas can be verified by the comparison between calculated and experimental results.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The dynamic drag area signatures of Figure 1 were obtained from infinite mass wind tunnel deployments of the several model parachutes. The application of the infinite mass dynamic drag area signatures to finite mass deployments has raised some questions, by other experimenters, in concern for apparent mass effects. The thoughts expressed in this report present why I feel that parachute apparent mass related to parachute opening shock force is not as strong an effect as usually believed. Opening shock effects are not the same problem as wake reattachment after full canopy inflation. Apparent mass may also be important in parachute stability. Recent conversations with other experimenters as to apparent mass effects indicates that they are asking similar questions. Therefore, these ideas are offered even though they have not been experimentally substantiated.

Observation of inflating personnel parachutes often shows that the canopy fully inflates and then attempts to turn inside out as the crown of the canopy moves forward and approaches the plane of the skirt hem. This deflation is attributed to the apparent mass pushing on the canopy from behind. If this is true then apparent mass effects should be significant. However, there are other events, indistinguishable by the naked eye, taking place at the same time which would produce the identical result and reduce the magnitude of the apparent mass effects. Two main events occur during the inflation cycle of the parachute that affect the added air mass performance.

APPROACH

The first event is the change in the canopy shape as the included air mass is collected, and the second is the velocity and kinetic energy of the included air mass and its relationship to the system velocity.

THE TRANSITION OF THE INFLATING CANOPY GEOMETRY

Figure 2 depicts the transition of the geometry of a solid cloth parachute from the stretched out geometry at line stretch to the inflated geometry at the time t_o. As air mass is collected the developing suspension line cone angle causes the canopy skirt hem to accelerate forward toward the payload. At the same time

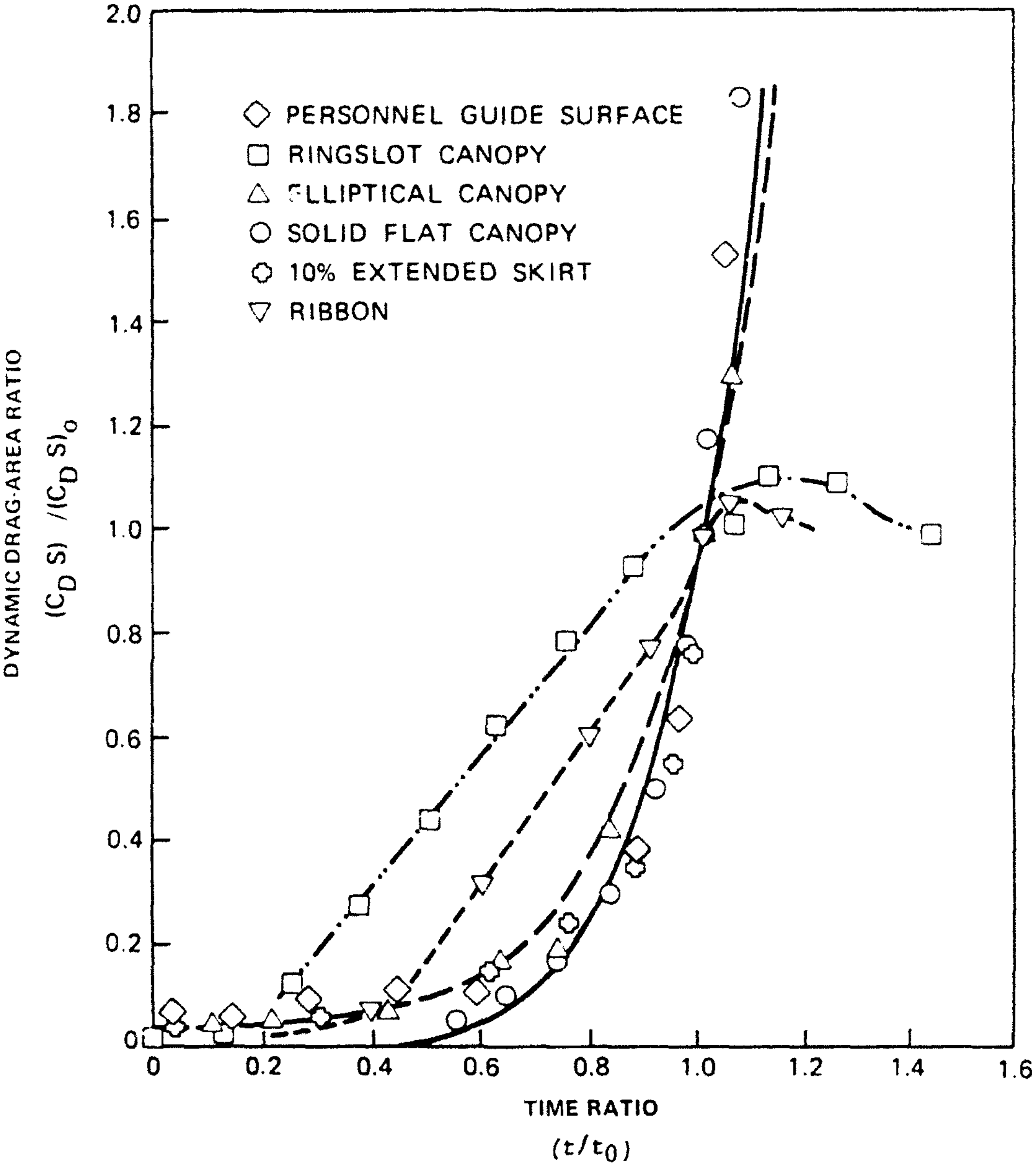


FIGURE 1. DYNAMIC DRAG-AREA RATIO VERSUS DIMENSIONLESS FILLING TIME

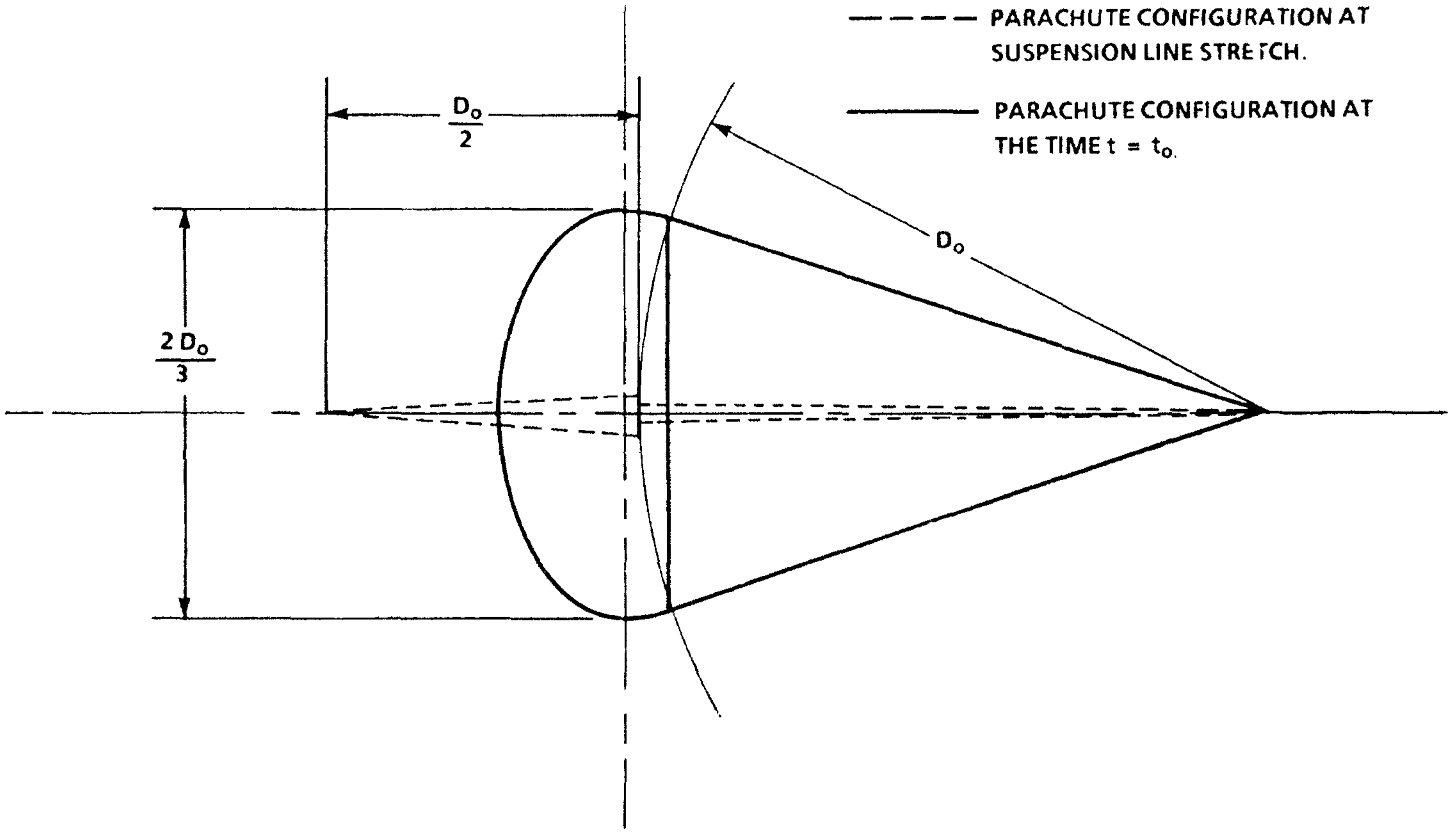


FIGURE 2. SOLID CLOTH PARACHUTE GEOMETRY AT SUSPENSION LINE STRETCH AND AT THE TIME t_o

the canopy vent and the entrapped air mass has an additional forward acceleration applied. With reference to Figure 1, the solid cloth parachutes develop drag area slowly at first and then more rapidly as the canopy inflates. The drag area growth represents a growth of the canopy radially; that is perpendicular to the trajectory. This radial growth accelerates as the canopy inflates. The acceleration is represented by the instantaneous slope of the dynamic drag area signatures in Figure 1. As the radial growth accelerates the parachute vent and crown area should be under severe accelerations along the trajectory in order to keep pace with the radial inflation. Acceleration of the canopy cloth also accelerates the air mass contained within the canopy and raises the velocity and kinetic energy level of the entrapped air.

SYSTEM VELOCITY PROFILE DURING INFLATION

The next consideration is the system velocity profile during inflation. Finite mass deployments exhibit substantial trajectory velocity reduction during canopy inflation. As weight is added to the system the velocity profile has less variation, the canopy inflates faster, the opening shock force increases and occurs later in the inflation process. Example 1 illustrates how the velocity profile varies during inflation of a solid cloth parachute for finite mass thru infinite mass weight-to-drag-area ratios.

Example 1: Determine the velocity profile during canopy inflation of a 200 lb. payload being recovered by a 30 gore solid cloth parachute with a D_o = 35 ft. when deployed at 1000 ft altitude with the following system parameters. Vary W/C_DS_o to illustrate finite thru infinite mass performance.

Let ρ = 0.002309 slugs/FT^3, k=1.46, C_p=1.7, A_{SO}=962.1 FT^2, A_{MO}=399.53 FT^2, $\underline{V}_o$ = 4690.83 FT^3, V_S=250 FPS.

I. Inflation distance, V_St_O, from Reference 1.

$$V_St_O = \frac{14W}{\rho g C_D S_O}\left[e^{\frac{g\rho \underline{V}_O}{2W}\left[\frac{C_DS_O}{A_{MO}-A_{SO}\,k\left(\frac{C_p\,\rho}{2}\right)^{1/2}}\right]}-1\right] \quad ;\ \tau = 0 \qquad (1)$$

for the given problem data

$$V_St_O = 284.56\ \text{FT}$$

2. Inflation reference time, t_o.

$$t_o = \frac{V_s t_o}{V_s} \qquad (2)$$

$$t_o = \frac{284.56}{250}$$

$$t_o = 1.138 \text{ SEC}$$

3. Empirical inflation time, t_f.

$$t_o = t_f = \frac{nD_o}{V_s} \qquad (3)$$

$$t_o = t_f = \frac{8 \times 35}{250}$$

$$t_o = t_f = 1.120 \text{ SEC}$$

The two independent methods of calculating the parachute inflation time show a reasonable agreement. The advantage of Equation (1) is the ability to adjust the inflation time for variation of the several parameters. In this example, weight. See Figure 3 for the effects of W/C_DS_O on the inflation time.

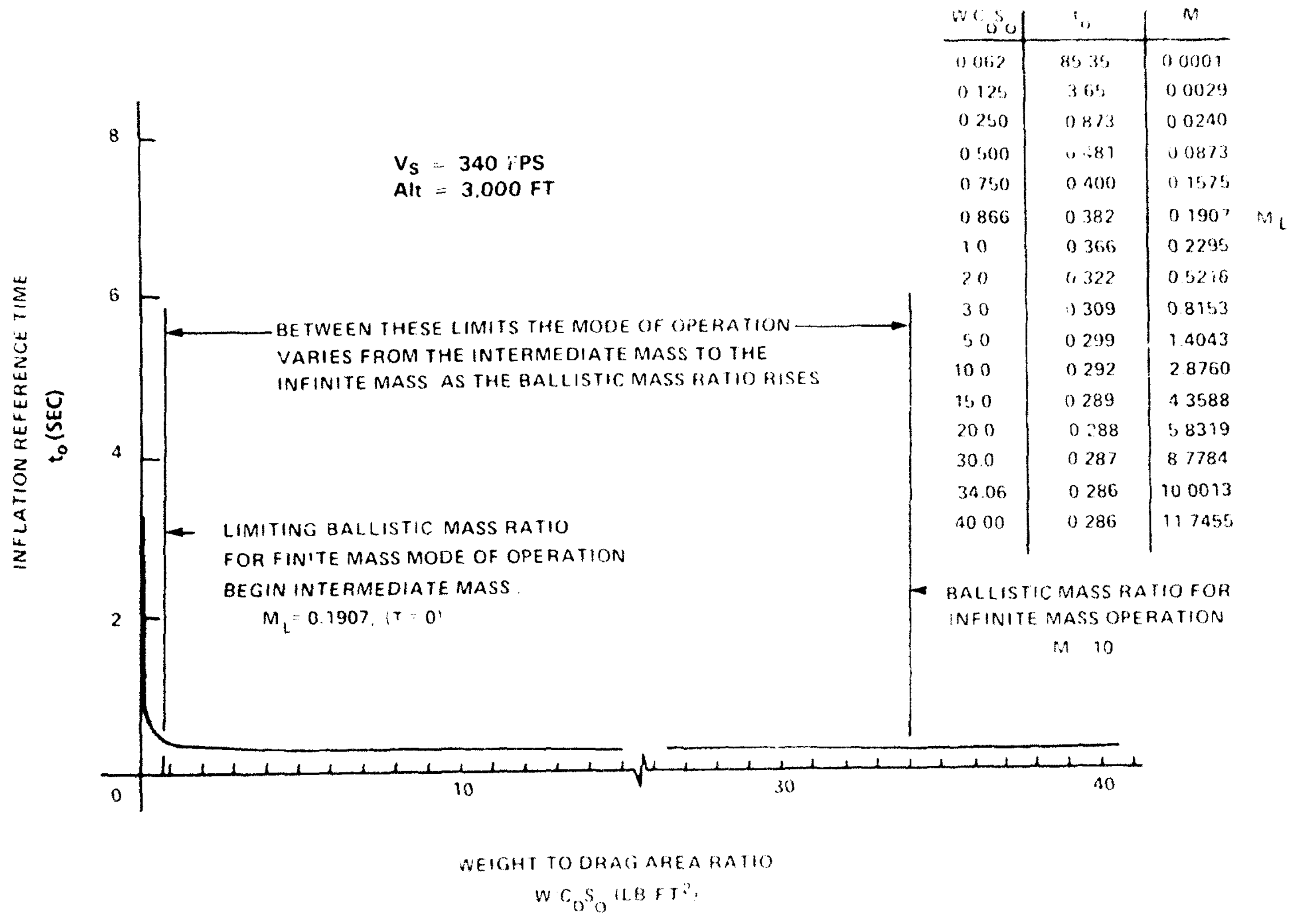
4. Ballistic Mass Ratio

$$M = \frac{2W}{\rho g V_s t_o C_D S_o} \qquad (4)$$

$$M = \frac{2 \times 200}{0.002309 \times 32.2 \times 250 \times 1.138 \times 721}$$

$$M = 0.0262$$

M = 0.0262 which is below the limiting value of M_L = 0.1907 for finite mass operation



W/C_oS_o	t_o	M	
0.062	85.35	0.0001	
0.125	3.65	0.0029	
0.250	0.873	0.0240	
0.500	0.481	0.0873	
0.750	0.400	0.1575	
0.866	0.382	0.1907	M_L
1.0	0.366	0.2295	
2.0	0.322	0.5216	
3.0	0.309	0.8153	
5.0	0.299	1.4043	
10.0	0.292	2.8760	
15.0	0.289	4.3588	
20.0	0.288	5.8319	
30.0	0.287	8.7784	
34.06	0.286	10.0013	
40.00	0.286	11.7455	

FIGURE 3. VARIATION OF THE INFLATION REFERENCE TIME AS A FUNCTION OF SYSTEM WEIGHT FOR THE FLAT CIRCULAR SOLID CLOTH PARACHUTE OF EXAMPLE 1

5. Velocity equation

$$\frac{V}{V_s} = \frac{1}{1 + \frac{1}{7M}\left(\frac{t}{t_o}\right)^7} \quad ; \tau = 0 \qquad \text{from Table 1, Reference 1} \tag{5}$$

$$V = \frac{250}{1 + 5.453\left(\frac{t}{t_o}\right)^7}$$

The velocity-time ratio results are plotted in Figure 4 for several weight-to-drag-area ratios which result in performance modes of finite mass through infinite mass. In the finite mass deployment mode half of the inflation time is required to lower the trajectory velocity by 10 fps as compared to the last half of the inflation cycle where the trajectory velocity is reduced an additional 200 fps. During this final deceleration the higher velocity and kinetic energy of the entrapped air mass, including the vent and skirt hem acceleration effects, propel the entrapped air from the canopy mouth as though it were in a catapult. As the air leaves the canopy the crown cloth follows as if it were only being pushed from behind by the external apparent mass. As the mode of operation approaches infinite mass the velocity reduction during inflation approaches zero and the differential velocity between the system and the entrapped air mass is minimized. Deployments where there is minimal velocity differential between the entrapped air mass and the system do not exhibit catastrophic deflation as do finite mass deployments where the entrapped mass-system velocity differential at $t/t_o=1$ is substantial.

$$V = \frac{V_s}{1 + \frac{1}{7M}\left(\frac{t}{t_o}\right)^7} \; ; \tau = 0$$

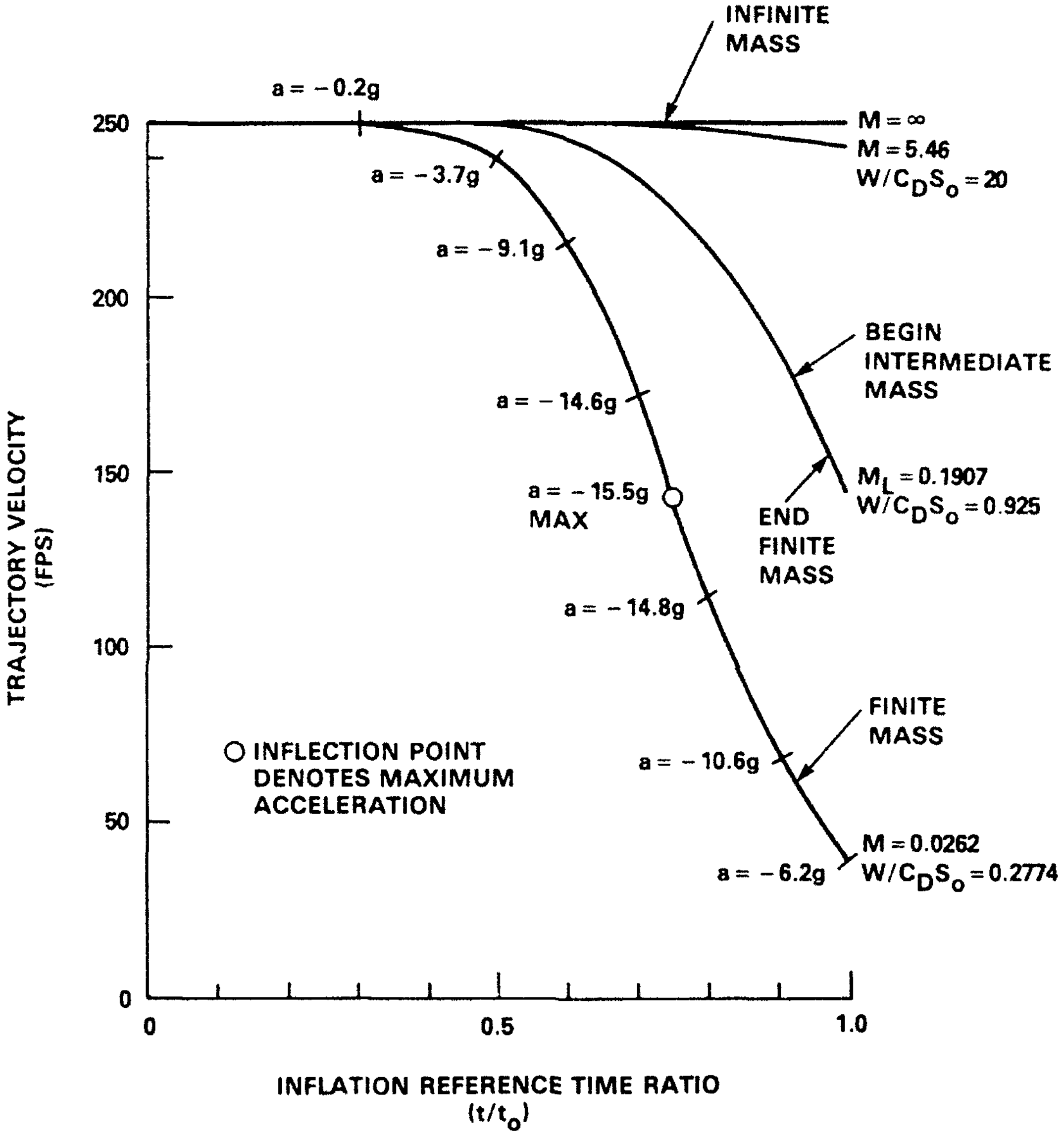


FIGURE 4. TRAJECTORY VELOCITY PROFILE OF THE INFLATING SOLID CLOTH PARACHUTE OF EXAMPLE 1.

Parachutes are designed to be flexible structures. This flexibility and the subsequent partial collapse at full inflation give the appearance of a substantial air mass overtaking the parachute from behind. If, however, the canopy motion is due to the catapulting of the entrapped air mass the actual "other" associated air mass may be small enough to be neglected in the analysis. A rigid, no airflow, parachute shape may perform quite differently and have a much larger apparent mass. What is needed is a "seat belt" to restrain the included air within canopy.

CONCLUSIONS

1. As a result of the canopy accelerations and the catapult effect, the actual apparent mass effects due to air striking the canopy from behind may be much less than expected. If this is so the use of drag area signatures obtained from infinite mass deployments should be applicable to the finite mass case.

2. In infinite mass deployments the canopy geometry transitions as in finite mass deployments but the inflation time is reduced. Since the trajectory velocity of the parachute system and the entrapped air remain the same, the catapult effect is minimal. Any effects that may be in the system due to canopy accelerations are not visible to the observer.

3. The inertial effects of the air mass within the inflating canopy must be taken into account when addressing parachute apparent mass.

4. Parachute canopy flexibility is a factor in reducing apparent mass effects.

5. The difficulty in finding a solution to a given problem and the input required to accomplish the solution are directly related to the approach to the problem.

REFERENCES

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2. William P. Ludtke, OBSERVATIONS ON THE INFLATION TIME AND INFLATION DISTANCE OF PARACHUTES, NSWC TR 88-292, 28 May 1988

NOMENCLATURE

A_{MO} - Steady-state inflated mouth area, FT^2

$S_O = A_{SO}$ - Canopy surface area, FT^2

$C_D S$ - Canopy drag area at any instant during inflation, FT^2

$C_D S_i$ - Canopy drag area at the time $t=0$, FT^2

$C_D S_O$ - Canopy steady state drag area, FT^2

C_P - Average pressure coefficient is equal to the parachute drag coefficient based on projected area of the canopy.

D_O - Nominal diameter of the aerodynamic decelerator = $\sqrt{4S_O/\pi}$, FT

g - Gravitational acceleration, FT/SEC^2

k - Canopy cloth permeability constant

M - Ballistic Mass Ratio - ratio of the mass of the retarded hardware (including parachute) to a mass of atmosphere contained in a right circular cylinder of length ($V_s t_O$), face area ($C_D S_O$) and density (ρ)

M_L - Limiting Ballistic Mass Ratio is the system mass ratio which causes the maximum opening shock to occur at t_O. The limiting BMR varies with the type of parachute

t - Instantaneous time, SEC

t_f - Canopy inflation time when the inflated canopy has reached its maximum physical size, SEC

t_O - Reference time when the parachute has reached the design drag area for the first time, SEC

V - Instantaneous system velocity, FT/SEC

V_O - System velocity at the time $t=t_O$, FT/SEC

NOMENCLATURE (cont)

V_S - System velocity at the end of suspension line stretch, FT/SEC

$\underline{V}_O$ - Volume of air which must be collected during the inflation process, FT^3

W - Hardware weight, including the parachute LB

W/C_DS_O - Ballistic coefficient, ratio of system weight to parachute steady state drag area, LB/FT^2

ρ - Air density, $SLUGS/FT^3$

τ - Ratio of system drag to steady state drag area at t=0, C_DS_i/C_DS_O

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13. ABSTRACT (Maximum 200 words)

This report sets forth, without experimental proof, the reasons as to why the author feels that apparent mass effects in parachute deployment are not as important to the analysis derived in Reference (1) as usually perceived. This commentary applies to the parachute opening shock phase of deployment. Canopy-wake recontact which occurs after the canopy has been fully inflated for a definite period of time is a different problem. In the final phase of finite mass deployments of the unrestrained air mass that inflated the canopy has a higher trajectory velocity than the parachute system. This higher trajectory velocity together with changes in the canopy shape catapults the air mass from the parachute resulting in a temporary loss of system mass which tends to compensate for other air masses that may have been added. Infinite mass deployments also have added air masses in addition to the air mass contained within the canopy. Dynamic drag areas obtained from infinite mass deployments implicitly include these effects. In infinite mass deployments where the velocity differential between the internal air mass and the system are minimal the deflation effects will not occur. The validity of these ideas can be verified by the comparison between calculated and experimental results.

14. SUBJECT TERMS

PARACHUTE TECHNOLOGY	FINITE MASS OPERATION
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CATAPULT EFFECT	INFINITE MASS OPERATION

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