SURVIVABILITY SUSTAINABILITY SUPPORTABILITY

TECHNICAL REPORT
NATICK/TR-88/059

AD A198 240

PERFORMANCE OF A SINGLE BALLOON-SKIRT AIRBAG IN VERTICAL DROPS

BY

CALVIN K. LEE

JULY 1988
FINAL REPORT
OCTOBER 1986 - SEPTEMBER 1987

UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5000

AERO-MECHANICAL ENGINEERING DIRECTORATE

DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp Date Jun 30, 1986

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NATICK/TR-88/059	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION U.S. Army Natick Research Development & Engineering Center 6b OFFICE SYMBOL *(If applicable)* STRNC-UE	7a NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State, and ZIP Code)* Kansas Street Natick, MA 01760-5017	7b ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL *(If applicable)*	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)*	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 1L162786 PROJECT NO: D283 TASK NO: AH WORK UNIT ACCESSION NO: 002

11 TITLE *(Include Security Classification)*

Performance of A Single Balloon-Skirt Airbag in Vertical Drops

12 PERSONAL AUTHOR(S)

Calvin K. Lee

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT *(Year, Month, Day)*	15 PAGE COUNT
Final	FROM Oct 86 TO Sept 87	July 1988	44

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB-GROUP	Airbags, Airdrop Systems, Balloon-Skirt Airbags, Ground Impact Attenuation, Soft Landing

19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Airbags are currently being investigated by the Army as an alternative to paper honeycomb and retrorockets for soft landing of airdropped payloads. A double-chamber balloon-skirt airbag developed by a French company was claimed to provide low impact G forces and ground gliding capability. The performance of an eight balloon-skirt airbag-platform system was investigated in a previous study at NRDEC. The performance of the system was not satisfactory. In an attempt to improve the performance, a single balloon-skirt was modified in the current study and its performance was investigated at various test conditions. Test results showed that the double-chamber design of the balloon-skirt airbag is moderately better than the single-chamber design but its performance is still not as good as the manufacturer claimed.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Calvin K. Lee	22b TELEPHONE *(Include Area Code)* 617-651-5262 22c OFFICE SYMBOL STRNC-UE

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

Preface

The present investigation of the balloon-skirt airbag was conducted in-house from October 1986 to September 1987 under Project No. 1L162786D283AH002, Analysis of Performance of Multiple Airbag Platform System. Experimental assistance from James Tierney of the Engineering Services Division is appreciated.

Currently, airbags are being considered by the Army to be used as an alternative to retrorockets and paper honeycomb for soft landing of airdropped payloads. This report summarizes some of the work being carried out to achieve this goal.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLE

PERFORMANCE OF A SINGLE BALLOON-SKIRT AIRBAG IN VERTICAL DROPS

INTRODUCTION

Paper honeycomb is currently being used by the U.S. Army as an impact energy absorber to provide cushioning and protection for airdropped items, such as vehicles, cargos and field equipment. Strategic positioning of the paper honeycomb between the airdropped item and the platform, along with the extensive rigging of the item to the platform, is a time consuming and labor intensive operation. To increase airdrop efficiency and troop mobility, the U.S. Army has been investigating two other soft landing techniques for airdrop; they are retrorockets and airbags. Both techniques are anticipated to give low landing impact velocities less than 10 ft/sec and provide vehicle roll-on/roll-off capabilities. Using retrorockets along with parachutes to airdrop and soft land payloads has been intensively investigated[1,2,3] and is currently being tested in the field. However, the technique of using airbags for soft landing, especially for less than 10G deceleration has not been well developed and needs to be investigated.

The history and literature of airbags were well summarized by Nykvist[4] in his report on balloon-skirt airbags and will not be repeated here. Basically, airbags are a viable device for soft landing of payloads. Their major drawback is that they lack the ability to provide horizontal restraining forces; under conditions of high ground winds and excessive horizontal motion of the payload, the payload may overturn upon landing if only vertical airbags are used. The balloon-skirt double chamber airbag developed by Societe Bertin & Cie, France[4] was designed to overcome this difficulty. Figure 1A shows a schematic of the balloon-skirt airbag. The

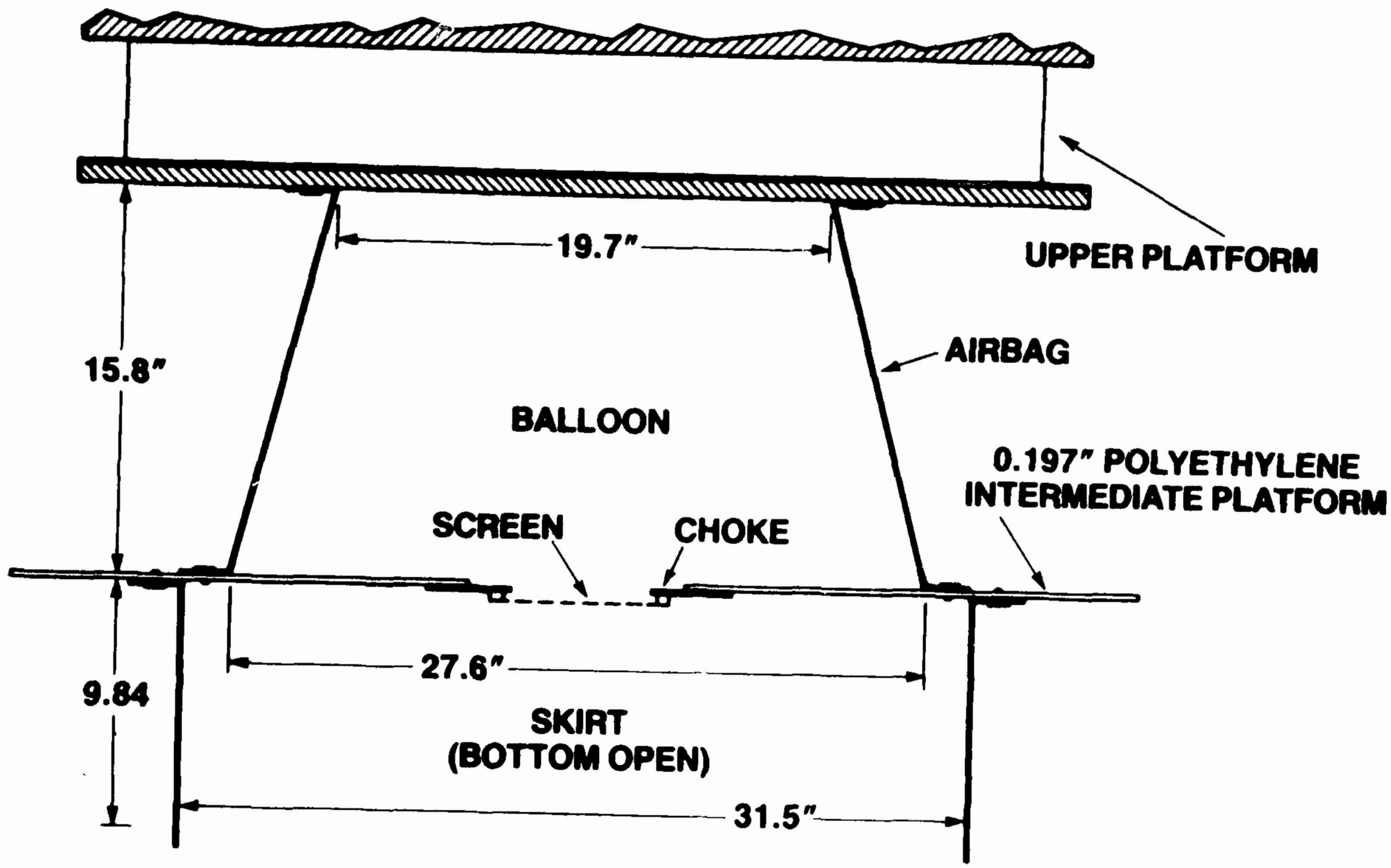

Figure 1. Design of Balloon-Skirt Airbag:

A. Cross-Section

upper chamber is the balloon and the lower chamber is the skirt, which is open at the bottom; the two chambers are separated by an intermediate platform with a choke opening as shown in Figure 1B. The special feature of the balloon-skirt airbag is that upon airbag compression during impact with the ground, for an appropriate choke size the balloon is supposed to be compressed first while the skirt remains inflated for about one second. Thus a ground hovering or gliding effect is generated by the high-pressure air layer between the skirt and the ground, thereby reducing the possibility of payload overturn during landing. Subsequent to the collapse of the balloon, the skirt is then compressed to complete the stroke. Thus a two-stage compression is produced by the design to avoid payload overturn and to provide soft landing.

Nykvist investigated an eight balloon-skirt airbag system that was designed to have the following capabilities:

a. maximum payload mass of 4,410 lb (2,000 kg)

b. vertical descent velocity up to 26 ft/sec (8 m/sec)

c. vertical payload impact deceleration less than 7 Gs.

d. horizontal velocity up to 49 ft/sec (15 m/sec)

Nykvist did extensive vertical drop tests of the eight airbag system. He did not observe the distinctive two-stage compression described above and claimed by the manufacturer. The measured G force was also in excess of the claimed 7 Gs.

In the current work, a single balloon-skirt airbag was modified to vary its air flow rate. The objectives were to investigate the performance of the airbag at various air flow rates, to determine its optimum performance (lowest G force), and to attempt to obtain a two-stage compression.

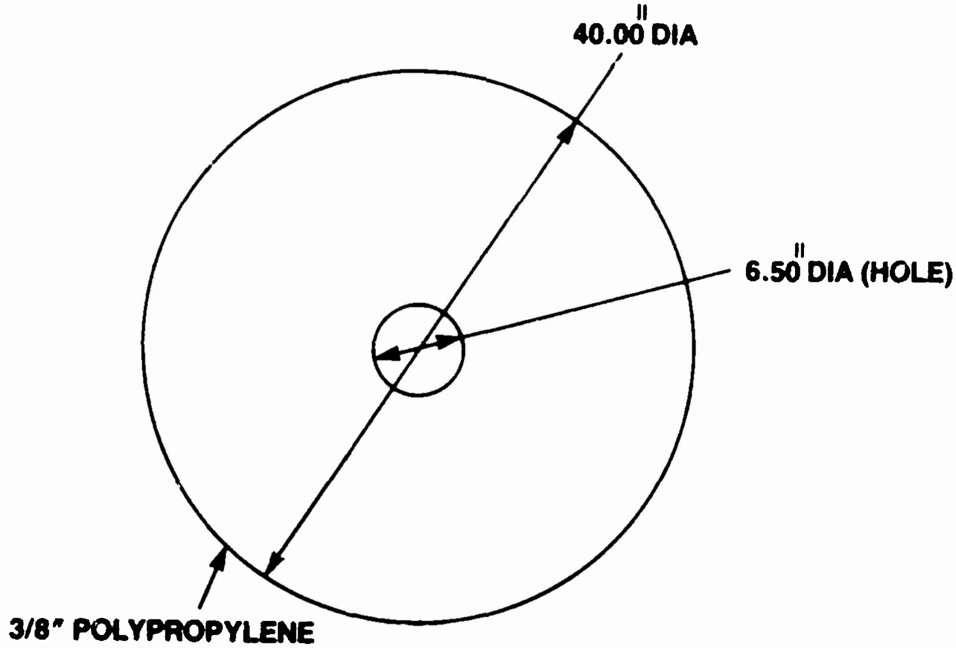

Figure 1. B. Schematic of Intermediate Platform

Current Balloon-Skirt Airbag Design

During the compression of the balloon-skirt airbag, air flows from the balloon through the choke opening into the skirt, and concurrently air is also vented to outside atmosphere through the circular air gap between the perimeter of the skirt and the ground. The air gap is not controlled; its size is dependent on the flexibility of the skirt fabric and the ground terrain. Therefore, the only adjustable parameter that affects the air flow is the size of the choke opening between the balloon and the skirt. Nykvist tried the choke diameters of 120 mm and 140 mm; both choke sizes failed to yield a two-stage compression.

In the current work, to alleviate the difficulty of controlling the airbag air release rate, a platform was added to the bottom of the skirt as shown in Figure 2A. The bottom platform has various vent sizes as shown in Figure 2B so that the air release rate can be varied by choosing a particular vent size. By varying independently the vent size at the bottom of the skirt and the choke size between the balloon and the skirt, the perf·rmance of the airbag can be investigated at various air flow rates. Admittedly, the added bottom platform defeats the purpose of the ground gliding effect claimed by the manufacturer. However, for the purpose of the current study, it is an experimental technique to investigate the optimum performance of the balloon-skirt airbag.

The weight of the payload for the current study was chosen to be 460 lb, which was 1/8 of the 3,690 lb payload supported by 8 airbags that Nykvist used. The purpose of choosing this value was to scale the current

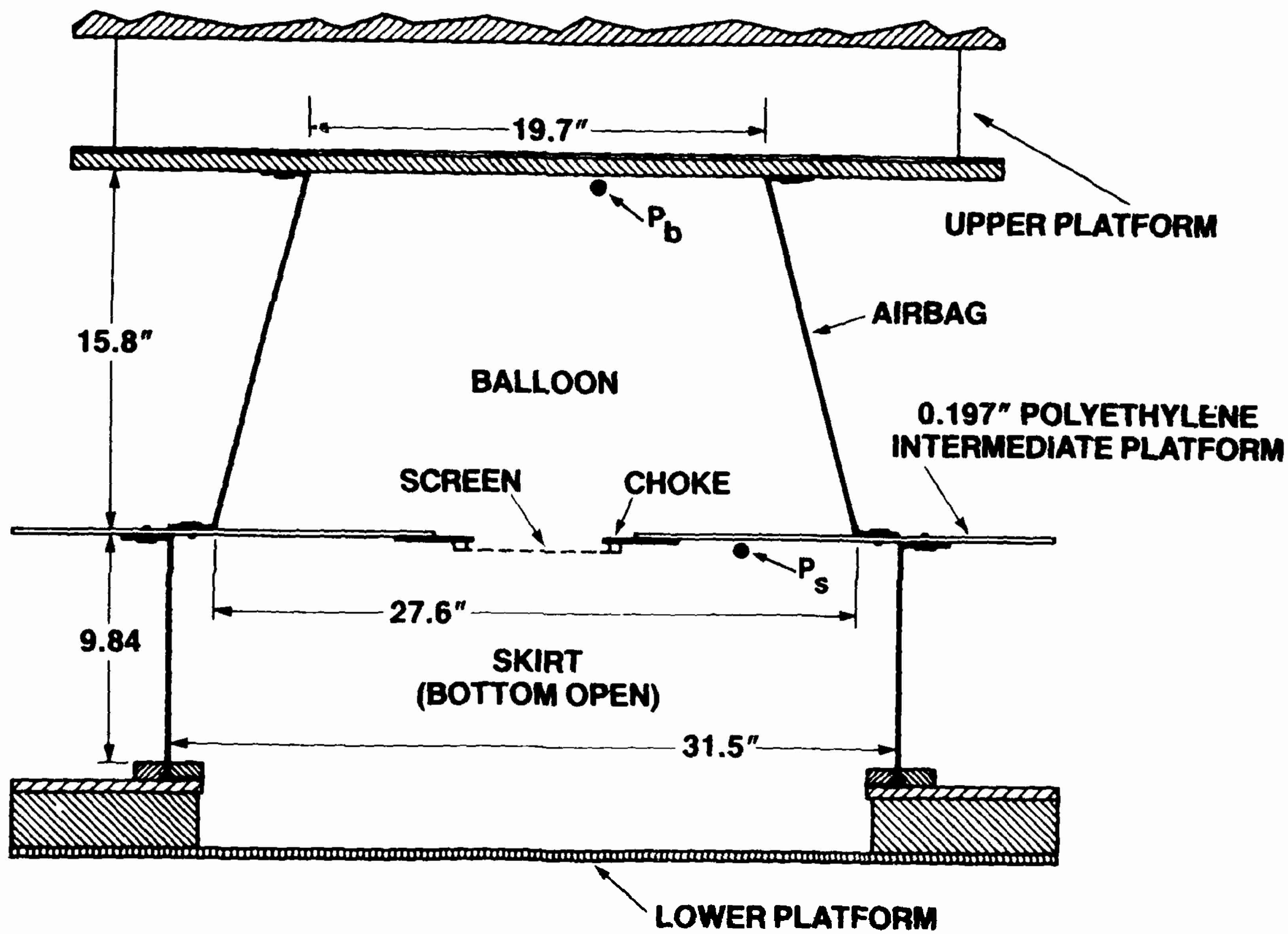

Figure 2. Design of Balloon-Skirt Airbag with Bottom Platform:
A. Cross-Section

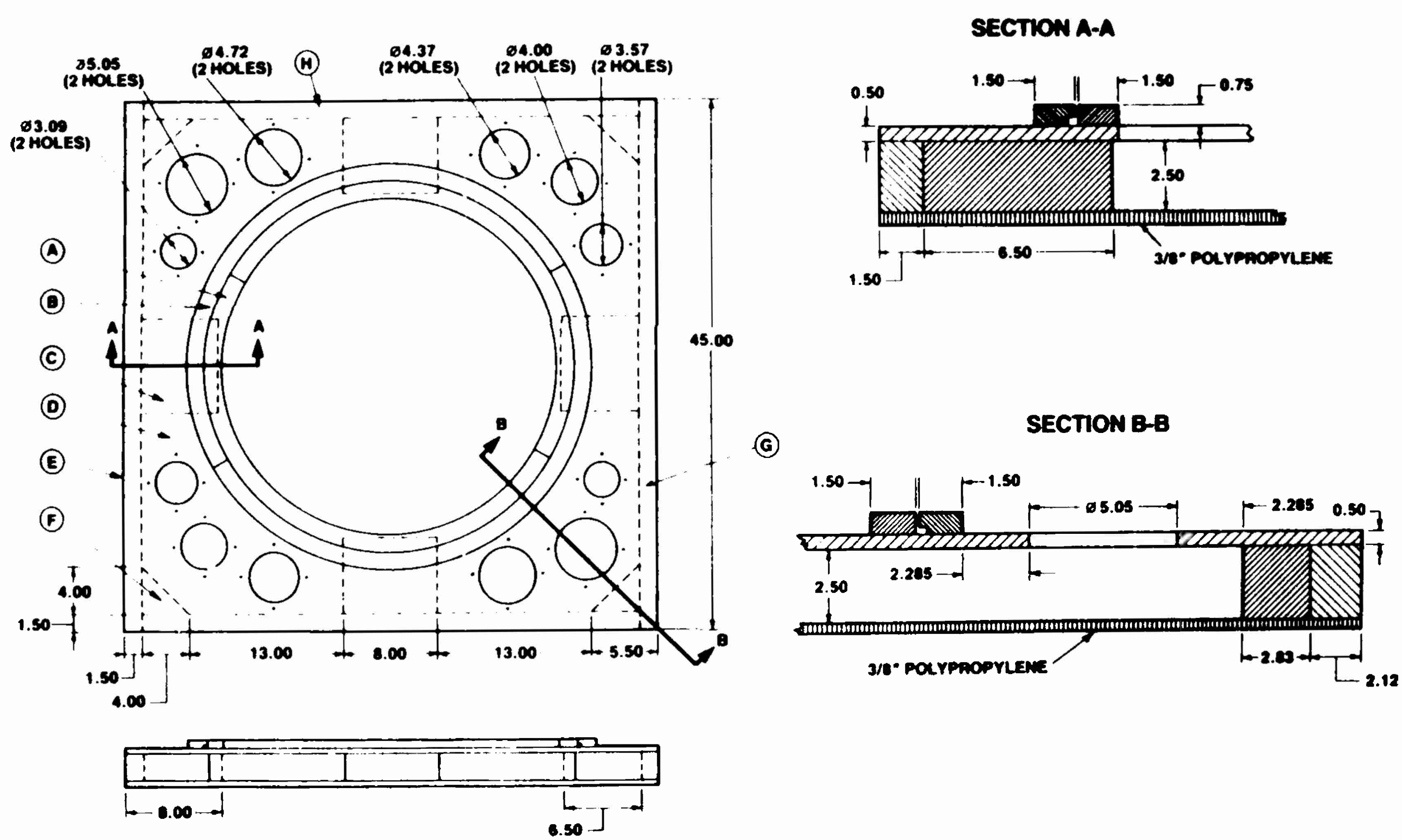

Figure 2. B. Details of Bottom Platform

single airbag system to be 1/8 of Nykvist's 8-airbag system so that the performance between the two systems could be easily compared.

As shown in Figure 2, with the exception of the bottom platform, the design and the dimensions of the balloon-skirt airbag used for the current study are identical to those of the airbags provided by the manufacturer and used by Nykvist. The sizes of the choke diameter, D_c, and the vent area, A_v, are shown below:

D_c(in) - 3, 4, 5 (127 mm), and 6.3 (160 mm).
- 27.6.

A_v(in^2) - 5, 10, 15, 20, 25, and 30.

The range of the choke sizes covers and exceeds the sizes used by Nykvist. At the extreme when the diameter of the choke is 27.6", which is the diameter of the skirt, the double chamber balloon-skirt design is reduced to a single chamber airbag. The sizes of the vent are estimates of a fixed vent area for a 460 lb payload using the airbag design guidelines from Browning.[5]

The fabric used for the airbag is a neoprene coated nylon with the following properties:

Areal density	=		33 oz/yd^2
Thickness	=		0.039"
Tensile strength	=	Warp -	580 lb/in at 28% elongation
		Fill -	590 lb/in at 35% elongation
Tearing strength	=	Warp -	120 lb
		Fill -	129 lb

Test Plan and Procedure

Vertical drop tests of the airbag/payload system were conducted by using a crane for drop heights of 4' to 9' to simulate landing velocities that ranged from 11.3 to 24.1 ft/sec. In each test, the vertical acceleration of the payload or the G force, G, was measured at the center of the upper platform by using a piezo-resistive type accelerometer. The balloon pressure, P_b, and the skirt pressure, P_s, were also measured in the two chambers as shown in Figure 2A with piezo-resistive pressure transducers. The three measurements were gathered using a personal computer based data acquisition system. For some tests, high speed motion pictures were also taken to reveal the airbag compression process during ground impact.

Forty-five tests were conducted. Their test conditions are shown in Table 1.

Table 1

Test Conditions

D_c in.	h_o ft	A_v, in^2 5	10	15	20	25	30
3	6		1	2	3	4	
(76.2mm)	7		5	6	7		
4	4	8	9	10	11	12	13
(102mm)	5	14		15	16	17	18
	6	19	20	21	22	23	24
5	6		25	26	27		
(127mm)	7			28	29		
6.3	6		30	31	32	33	
(160mm)	7			34	35		
	8				36		
	9				37		
27.6	5		38		39	40	
(No	6		41	42		43	
Choke)	7			44	45		
		d, in					
		0.0505	0.101	0.152	0.202	0.253	0.303

As shown in Table 1 and mentioned earlier, the choke diameter, D_c, and the vent area, A_v, were varied in order to determine the optimum performance of the balloon-skirt airbag. To examine the difference between the double chamber balloon-skirt airbag and the single chamber balloon-skirt airbag, one set of tests was conducted without the intermediate platform, i.e., D_c = 27.6", so that the double chamber became a single chamber.

In Table 1, the width d is the equivalent uniform air gap width between the skirt and the ground calculated from dividing the vent area, A_v, by the skirt circumference, πx31.5". The calculated values vary from 0.0505" to 0.303", which seem to be reasonable air gap values for the air release. In an actual airdrop situation, the width of the air gap is probably not uniform along the skirt, but rather uneven, depending on the flexibility of the airbag fabric and the terrain of the ground.

Results and Discussion

To facilitate result presentation and discussion, important tests in Table 1 are selected and grouped together as follows:

Group 1 - Effect of A_v for constant D_c

A. D_c = 6.3", h_o = 6'

$A_v(in^2)$ = 10, 15, 20, and 25

B. D_c = 4", h_o = 6'

$A_v(in^2)$ = 5, 10, 15, 20, 25, and 30

C. D_c = 3", h_o = 6'

$A_v(in^2)$ = 10, 15, 20, and 25

Group 2 - Effect of D_c for constant A_v

$A_v = 15\ in^2$, $h_o = 6'$

$D_c(in)$=3, 4, 5, 6.3 and 27.6 (D_b)

Group 3 - Effect of h_o

$D_c = 6.3"$, $A_v = 15\ in^2$

$h_o(ft)$=6, 7, 8, and 9

Test results from each group will be discussed first; a performance comparison will then be made between the current single airbag and Nykvist's 8-airbag system.

Group 1:

The measured G force, balloon pressure, P_b, and skirt pressure, P_s, of the tests in Group 1 are shown in Figures 3 to 9. In these figures, time t=o is the instant when the bottom platform connected to the skirt touches the ground (i.e., the time instant when the airbag begins to be compressed). Typically, both the G force and the pressures increase and then decrease in a total stroke time of about 0.18 sec. Figures 3 to 5 show the measured G force time profiles for each D_c as a function of A_v. All the G forces increase approximately linearly upon airbag impact with the ground. After reaching peak values, they start to decrease also fairly linearly until the airbag is collapsed and the payload lands on the ground. Such a triangular or half sinusoidal shape of G profiles resembles those obtained for a typical single-chamber airbag. Viewing the high speed film coverage of the drop tests shows that the current double-chamber balloon-skirt airbag did not undergo any distinctive two-stage compression depicted by a one second skirt inflation time as described by the manufacturer's claim.

Close examination of the G profiles shows that for each fixed D_c, the peak G force, G_p, varies as a function of A_v; the optimum A_v that yields the lowest G_p varies as a function of D_c. This is further shown in Figure 6 where the G_p values obtained from Figures 3 to 5 are plotted versus the area ratio A_v/A_c for each of the choke diameters. It is seen that for each D_c, there is an optimum A_v that gives a minimum G_p. For the larger D_c values of 4" and 6.3", the optimum A_v is about 20 in^2; for the smaller D_c of 3", the optimum A_v is smaller at about 15 in^2. Referring to Table 1, for A_v = 20 in^2, the air gap width between the airbag and the ground, d, is 0.202"; it decreases to 0.152" for A_v=15 in^2. This finding has a practical significance in the original open bottom balloon-skirt airbag. For an open bottom skirt, the vent area between the skirt and the ground depends significantly on the ground terrain, the stiffness of the bag fabric, and the manner in which the skirt impacts the ground. Therefore, this vent area is not controllable. The above experimental results show that any vent area that deviates from the optimum vent area will result in higher G values. Since the landing of a payload/airbag system is a random process, it is highly unlikely that optimum performance of a balloon-skirt airbag can be obtained in an actual airdrop operation. The same result and deduction should apply to other open bottom airbag designs. It appears that closed bottom airbags with separate air vents are preferred because of their highly controllable nature.

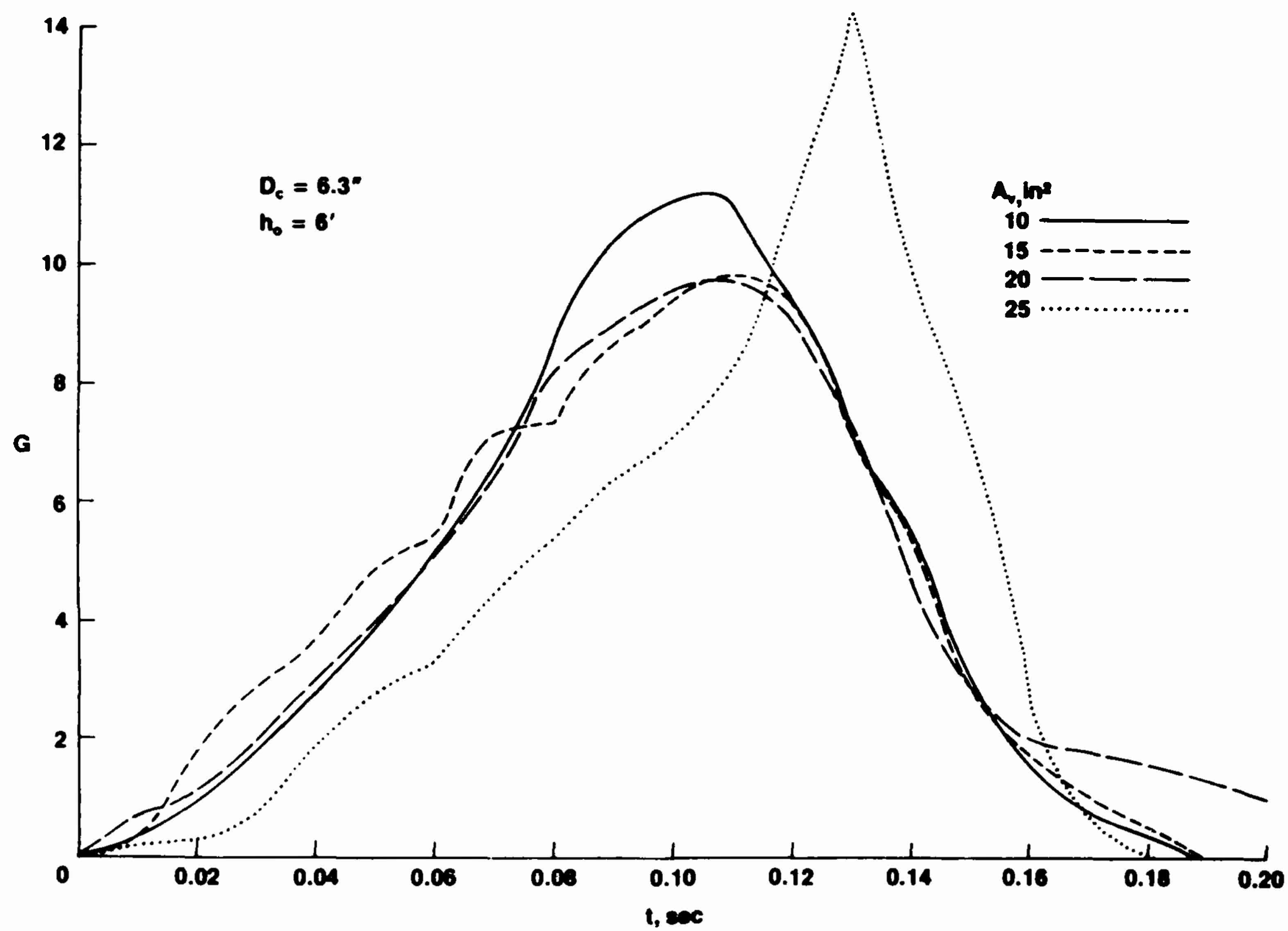

Figure 3. Effect of Vent Size on Platform Acceleration for Constant Choke Size D_c = 6.3"

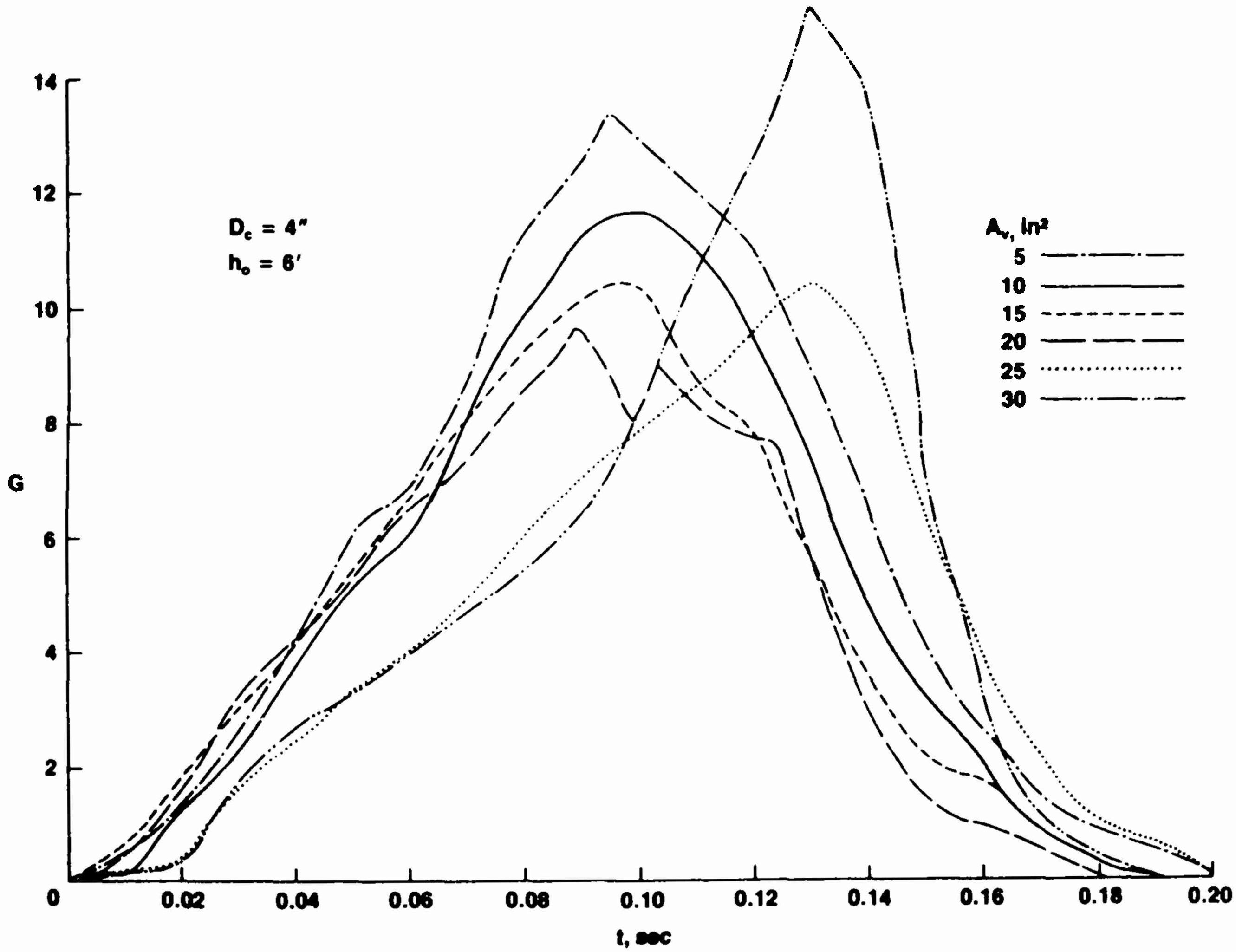

Figure 4. Effect of Vent Size on Platform Acceleration for Constant Choke Size D_C = 4"

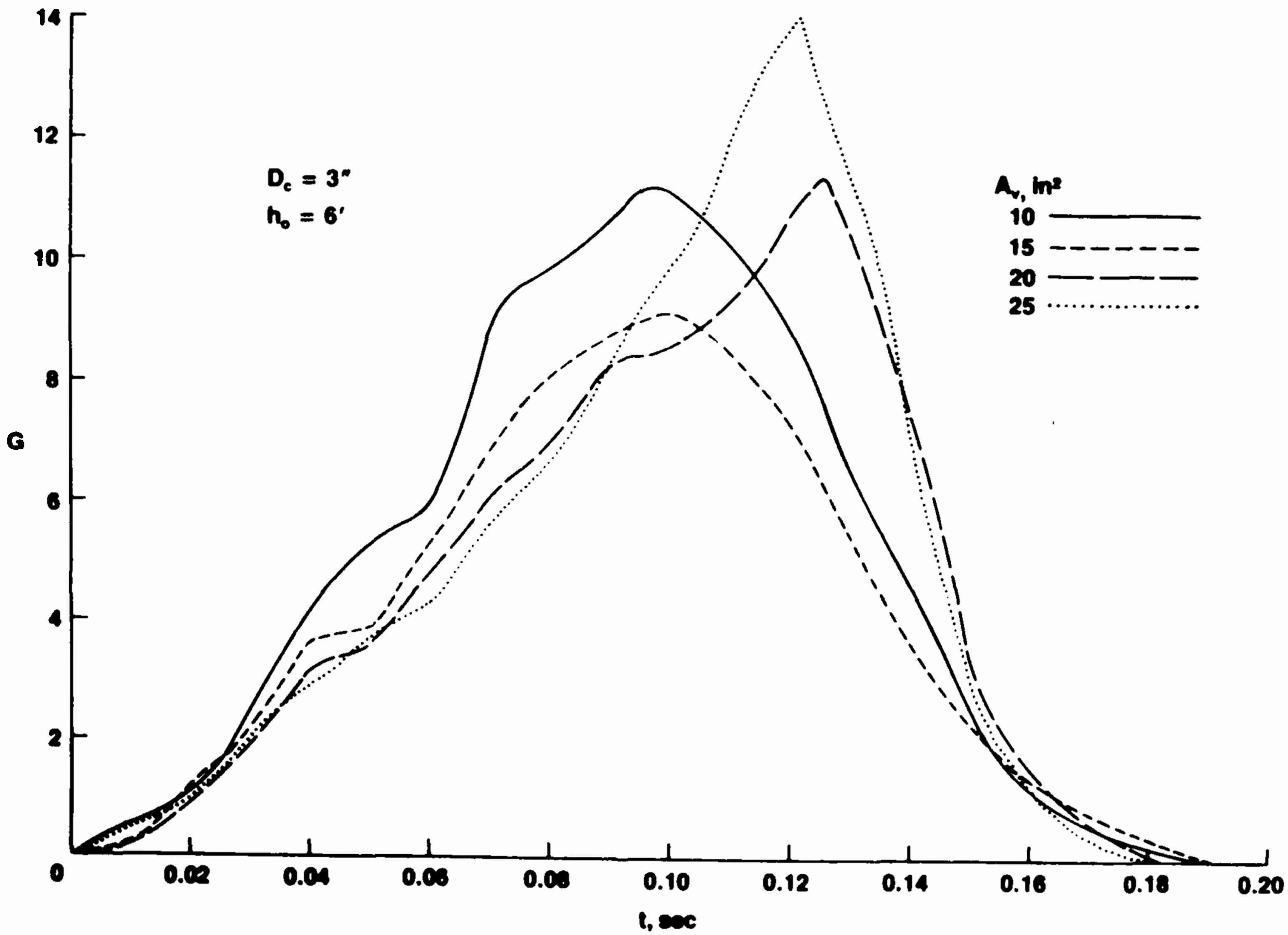

Figure 5. Effect of Vent Size on Platform Acceleration for Constant Choke Size D_c = 3"

Similar to the G force profiles, the air pressure profiles also exhibit the same typical triangular or half sinusoidal shape of a single chamber airbag as shown in Figures 7 to 9. During the initial compression of the stroke, the balloon pressure, P_b, is higher than the skirt pressure, P_s. For the largest choke size D_c=6.3 in, after P_b and P_s reach the peak, they become equal to each other and decrease until the end of the stroke. However, when D_c decreases to 4" and 3", resulting in lower air flow rates from the balloon to the skirt, P_b remains higher than P_s in the second half of the stroke. This signifies that for these smaller D_c values, the balloon chamber remains inflated throughout the entire stroke; this defeats the design goal of the balloon-skirt airbag. Therefore, for D_c = 4" the choke size is too small; D_c=6.3" is a better choke size. However, even if D_c=6.3", for A_v = 20 in^2, the vent area is too large and the pressure increase is too slow for an effective deceleration of the payload.

Group 2:

Figure 10 shows the effect of the choke size, D_c, on the G force for a fixed vent area, A_v, of 15 in^2; the corresponding pressure profiles are shown in Figure 11. In these figures, measurements for the single chamber balloon-skirt airbag with the intermediate platform removed are also included for comparison. In Figure 10, the measurements show that the G profile is not significantly affected when varying D_c from 3" to 6.3". However, P_b remains higher than P_s as D_c decreases to 4" and 3" as mentioned in the last section. Removal of the choke increased the peak G force by about 30%. This shows that the choked double-chamber balloon-skirt airbag does decrease the G force and provides a softer landing than that of a single-chamber airbag. This improvement is also obtained for other A_v values as shown in Figure 12.

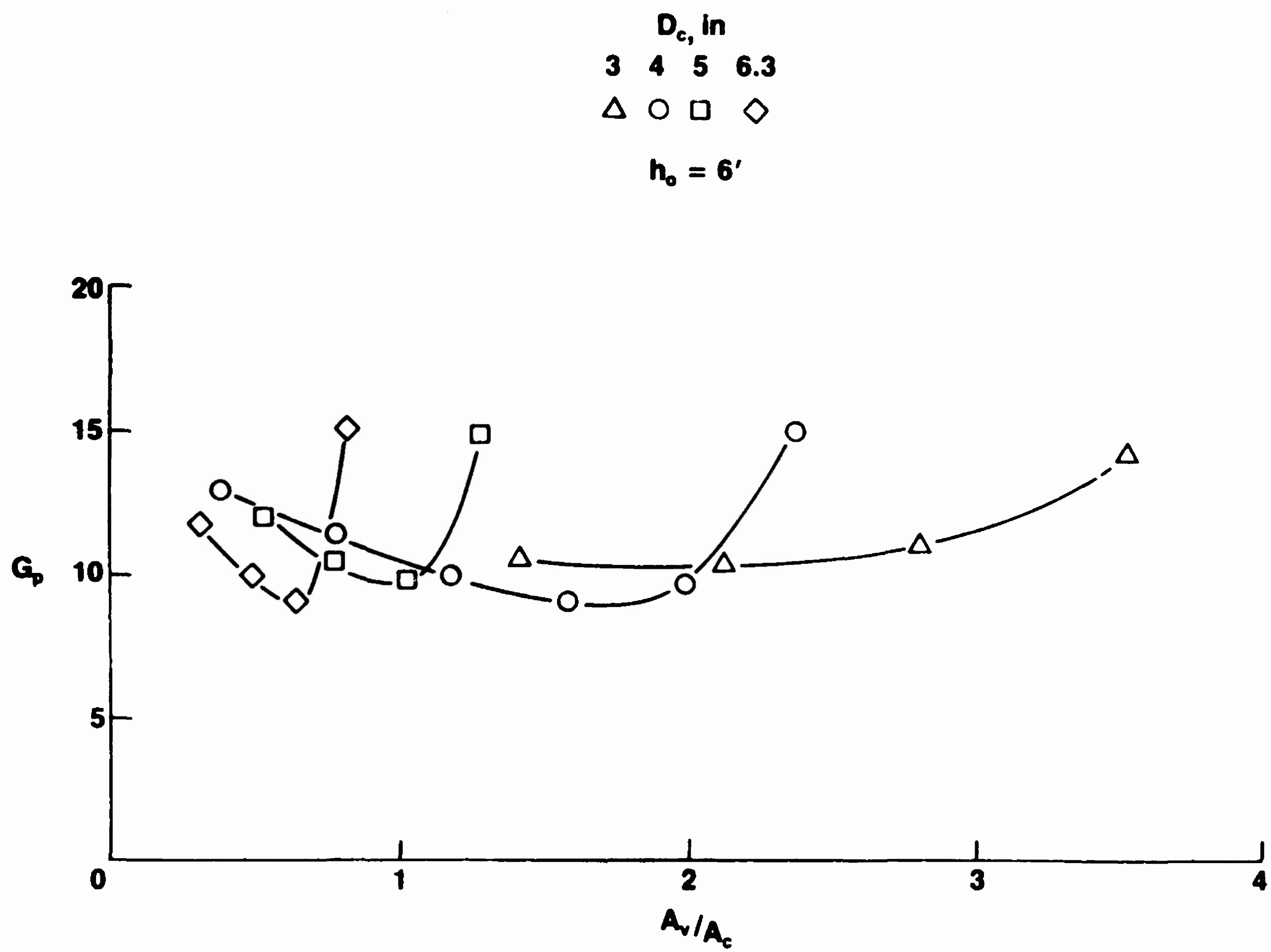

Figure 6. Peak G force As a Function of Vent Size and Choke Size

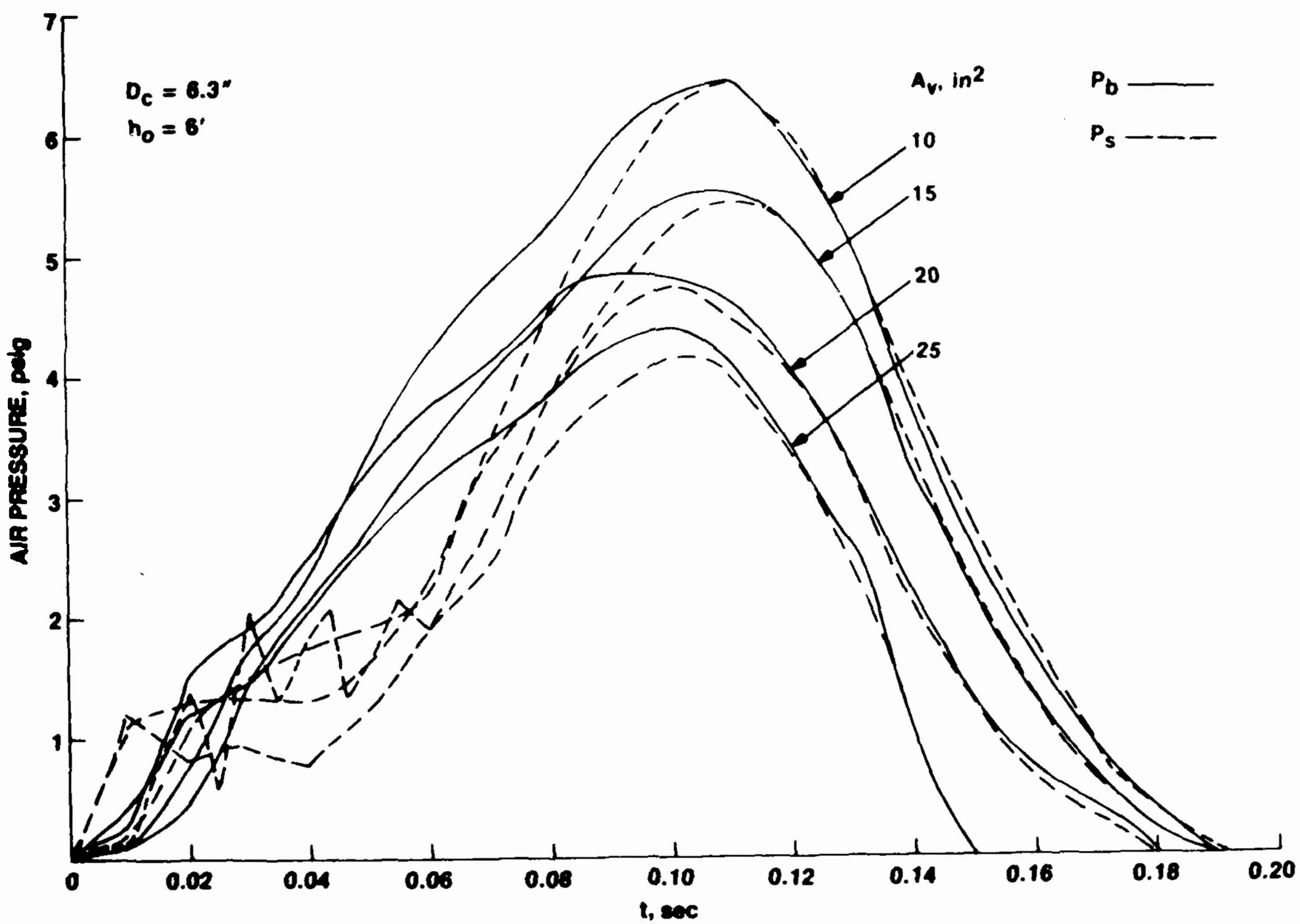

Figure 7. Effect of Vent Size on Air Pressure for Constant Choke Size D_c = 6.3"

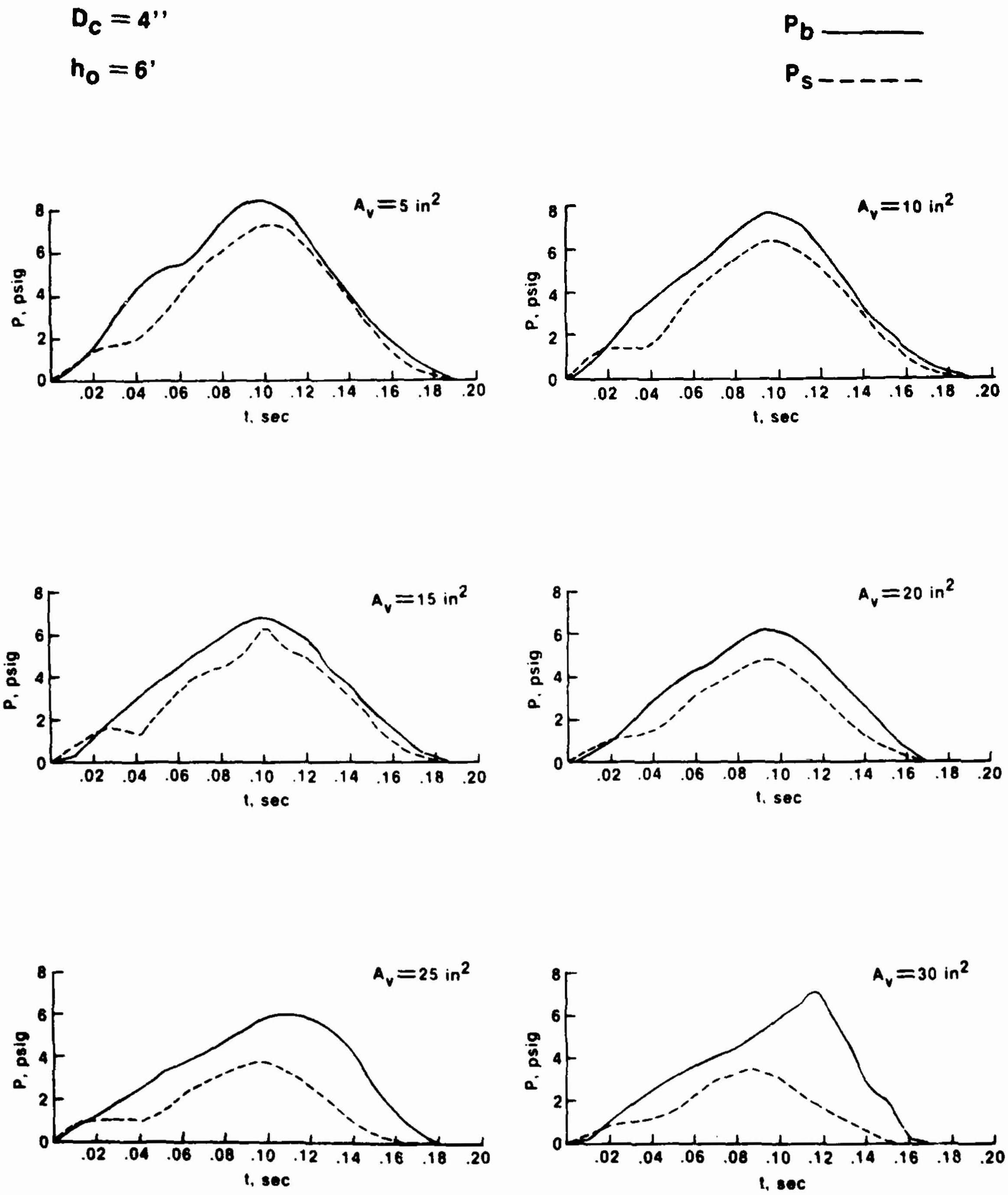

Figure 8. Effect of Vent Size on Air Pressure for Constant Choke Size D_c = 4"

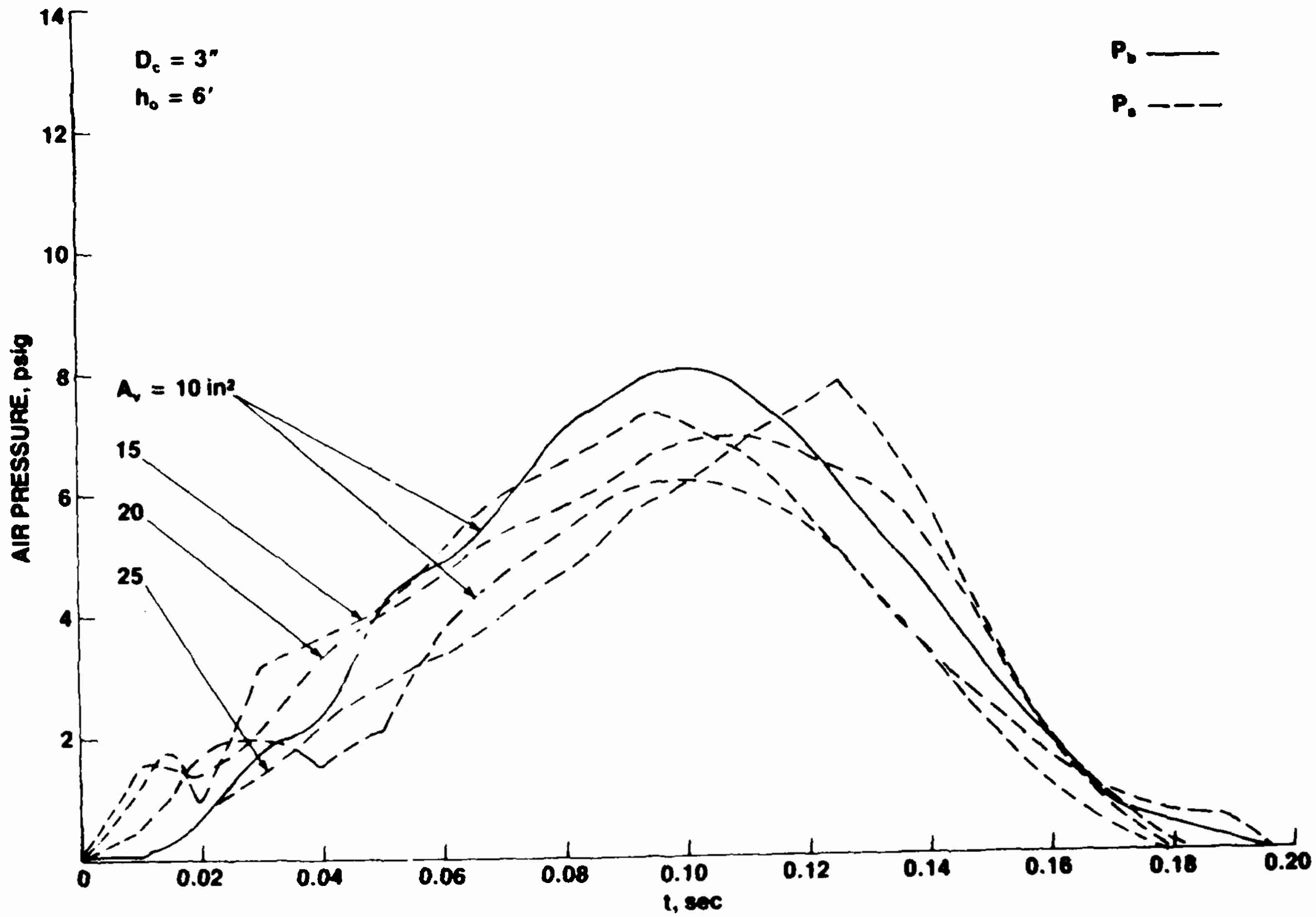

Figure 9. Effect of Vent Size on Air Pressure for Constant Choke Size D_c = 3"

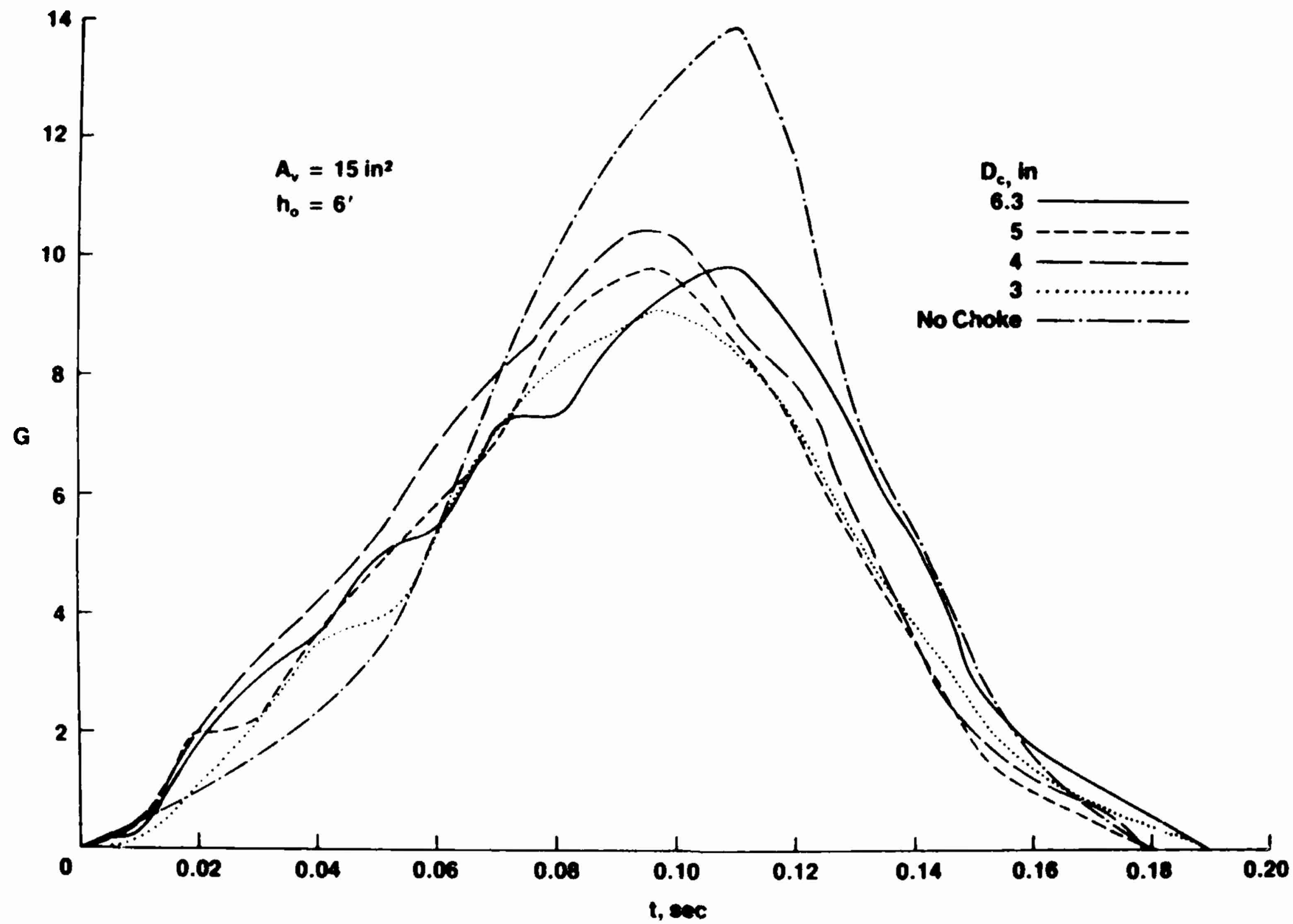

Figure 10. Effect of Choke Size on Platform Acceleration for Constant Vent Size $A_V = 15\ in^2$

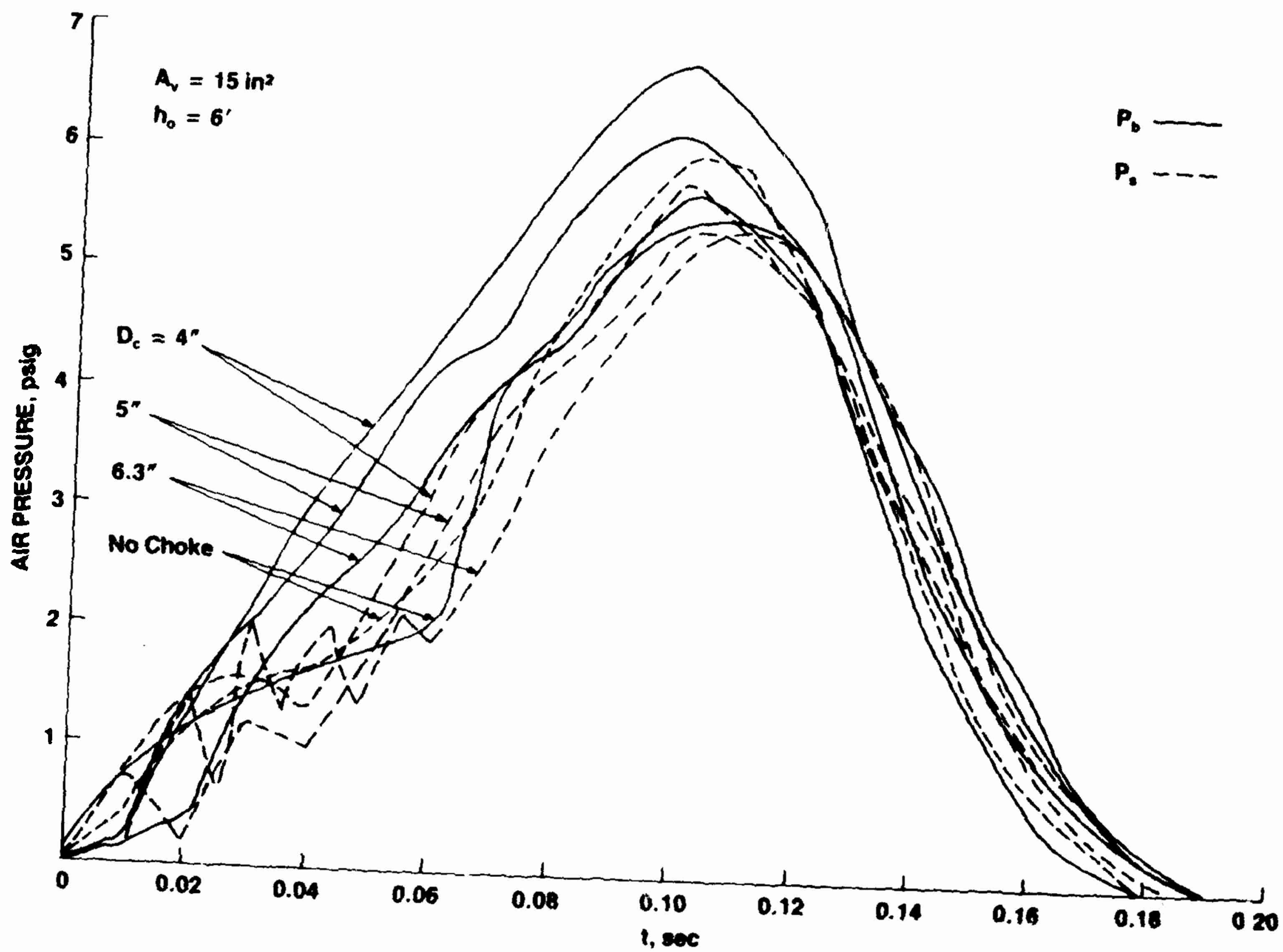

Figure 11. Effect of Choke Size on Air Pressure for Constant Vent Size $A_v = 15\ in^2$

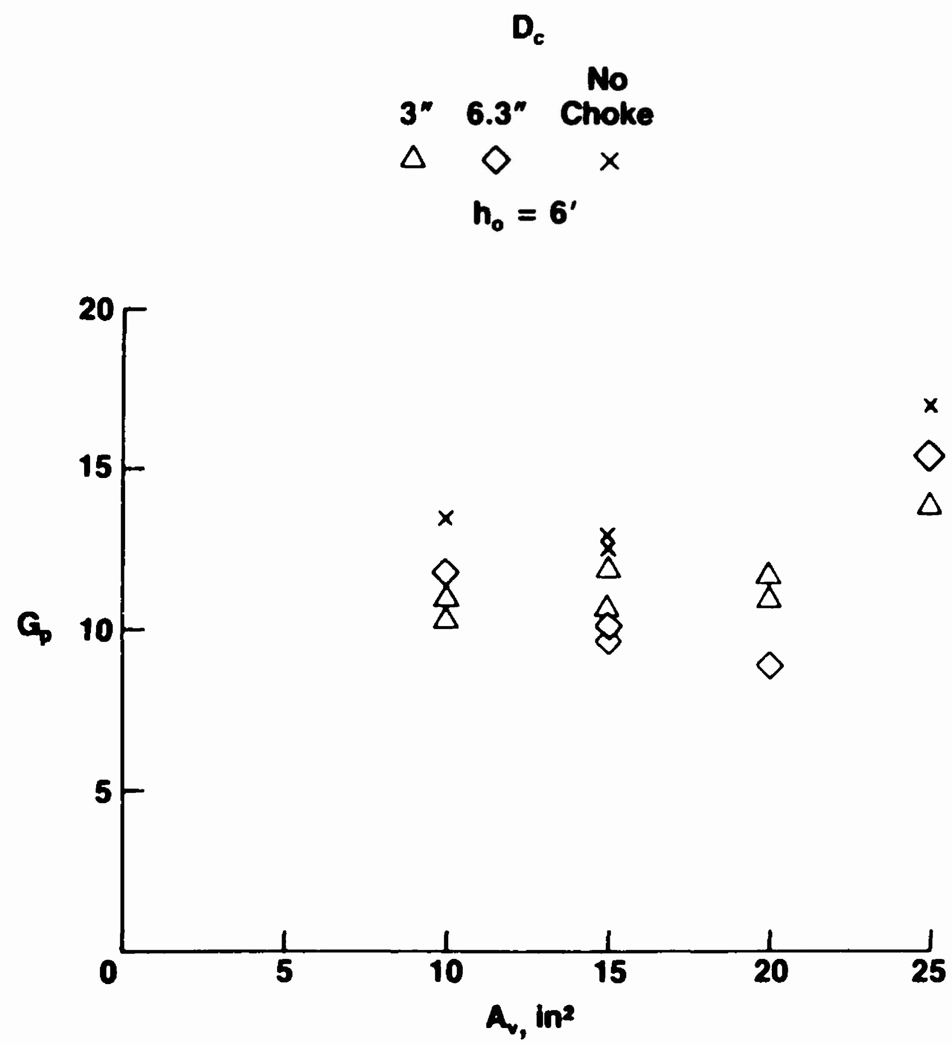

Figure 12. Comparison of Peak G Force Between Double-Chamber and Single-Chamber Balloon-Skirt Airbags: A. $h_o = 6'$

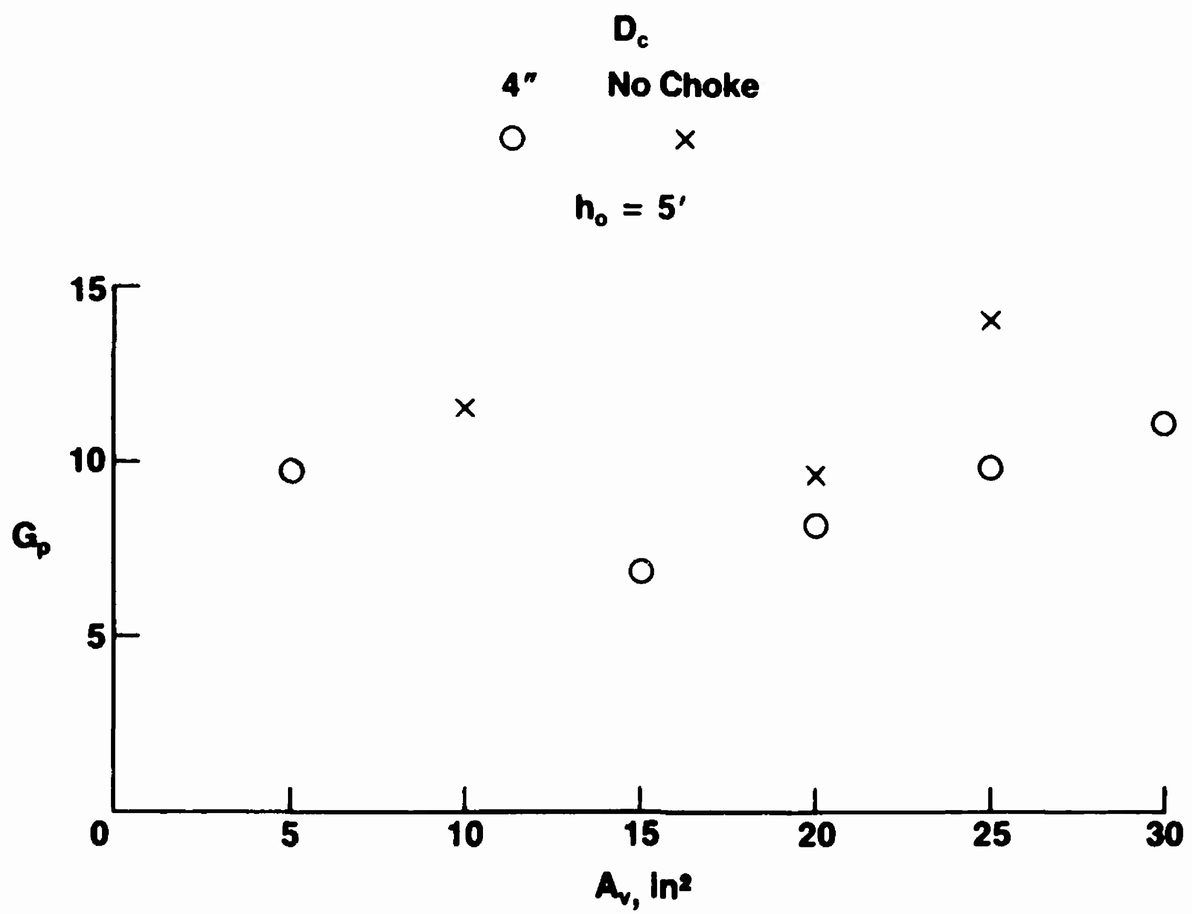

Figure 12.B. $h_o = 5'$

Group 3:

Figures 13 and 14 show the effect of the drop height or the impact velocity on the G and p profiles for D_c=6.3" and A_v=15 and 16 in^2, which are effective combinations for the current airbag based on the results in Groups 1 and 2. It is seen that both G and p increase rapidly to 16.5 g and 7.1 psig when the impact velocity reaches 24.1 ft/sec. The peak values from Figures 13 and 14 are shown in Figure 15. It is seen that the peak pressure increases linearly with impact velocity whereas the increase in peak G is nonlinear. Extrapolation of the current data shows that the peak G could be as high as 25 G's at 26 fps, which is much higher than the 7 G's claimed by the manufacturer. Therefore, the performance claimed by the manufacturer seems to be unreasonable.

Comparison Between Single and Multiple Airbags

As mentioned earlier, the weight of the payload for the current single airbag was selected to be 460 lb, 1/8 of the 3,690 lb payload that Nykvist used for his 8-airbag system, so that the performance of the single airbag could be compared to that of the 8-airbag system. The choke size used by Nykvist was 4.73" (120 mm), slightly smaller than the current 5" choke. Since the peak G forces for D_c=4", 5", and 6.3" are not significantly different for A_v = 20 in^2 in the current study, these tests have been chosen for comparison with those from Nykvist. In Nykvist's tests, the G_p measurements at the center of the platform are selected for a consistent comparison with those from the current study. The G_p measurements from the single-and the 8-airbag systems for various drop heights are shown in Figure 16. It is noted that the 8-airbag data scatter considerably for the three drop tests from h_o = 10.5'. This is

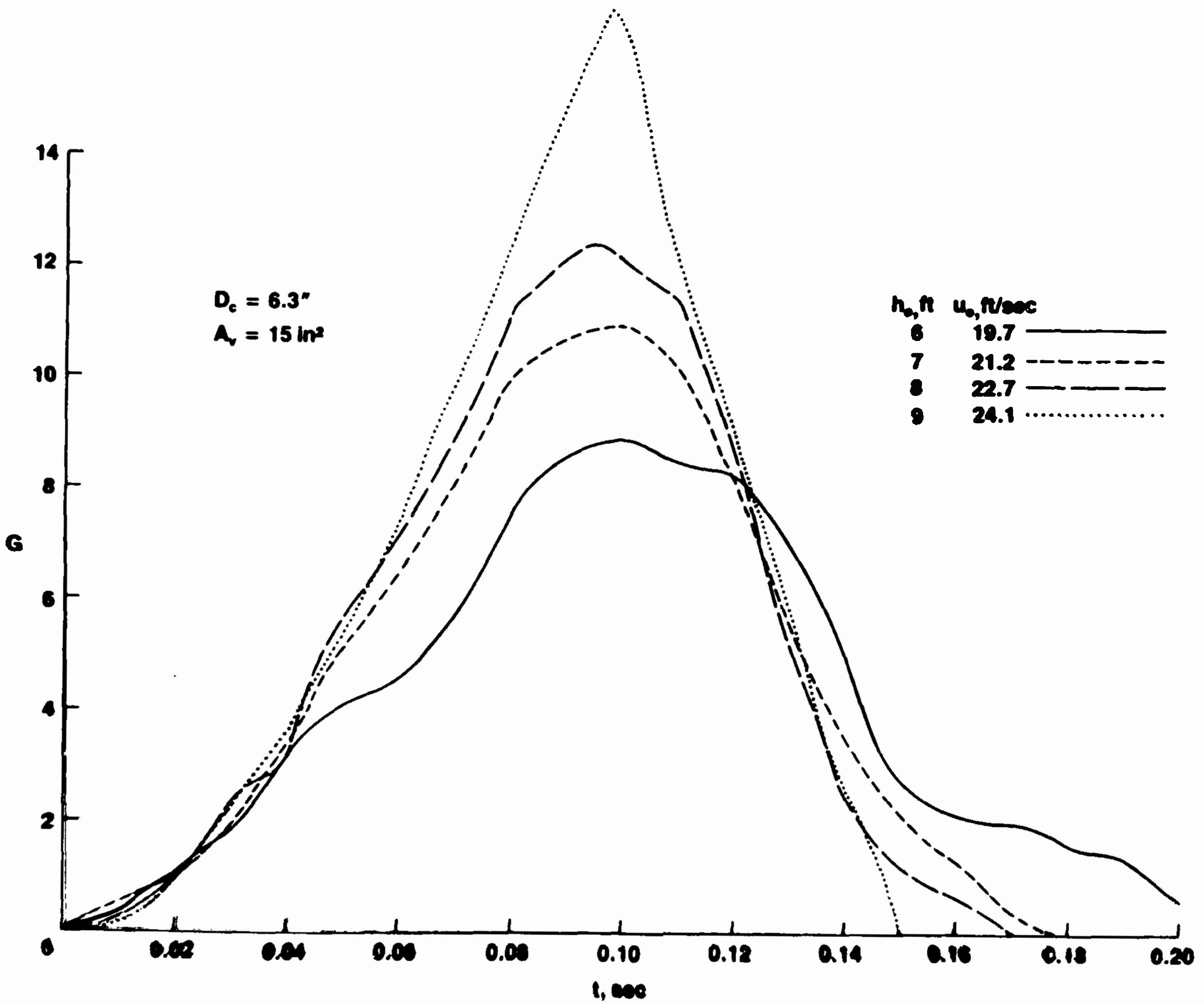

Figure 13. Effect of Impact Velocity on Platform Acceleration

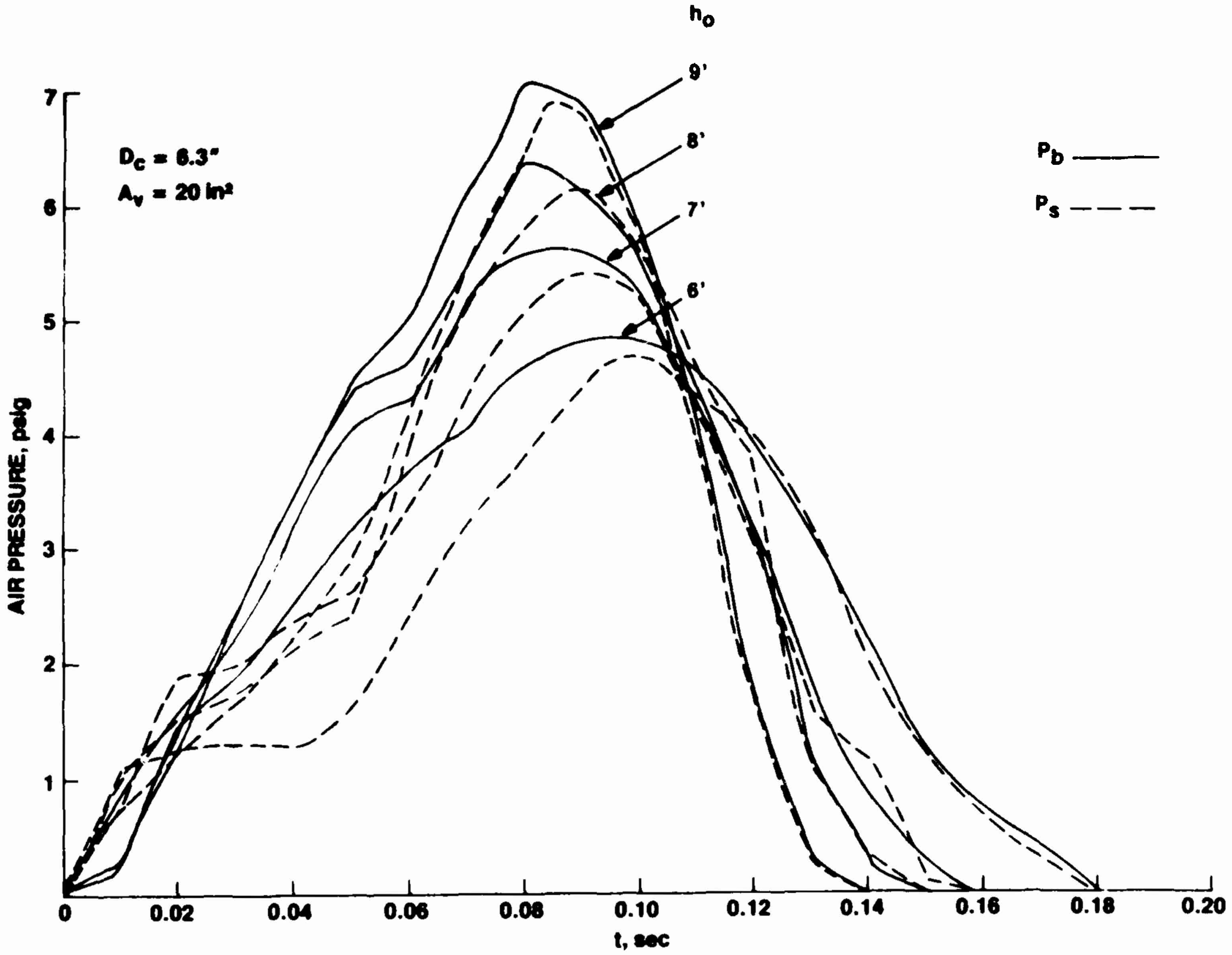

Figure 14. Effect of Impact Velocity on Air Pressure

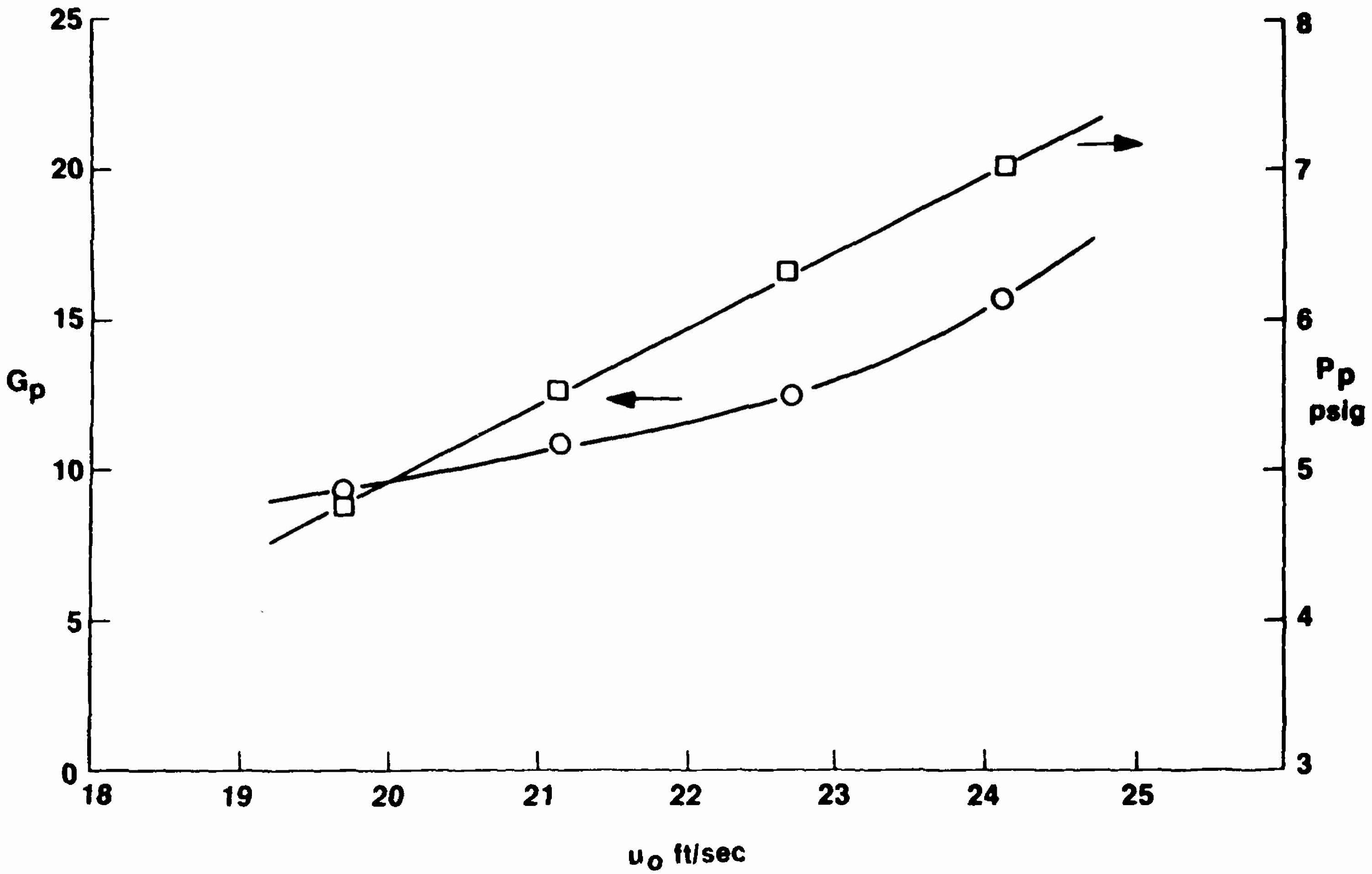

Figure 15. Effect of Impact Velocity on Platform Peak G Force and Peak Air Pressure

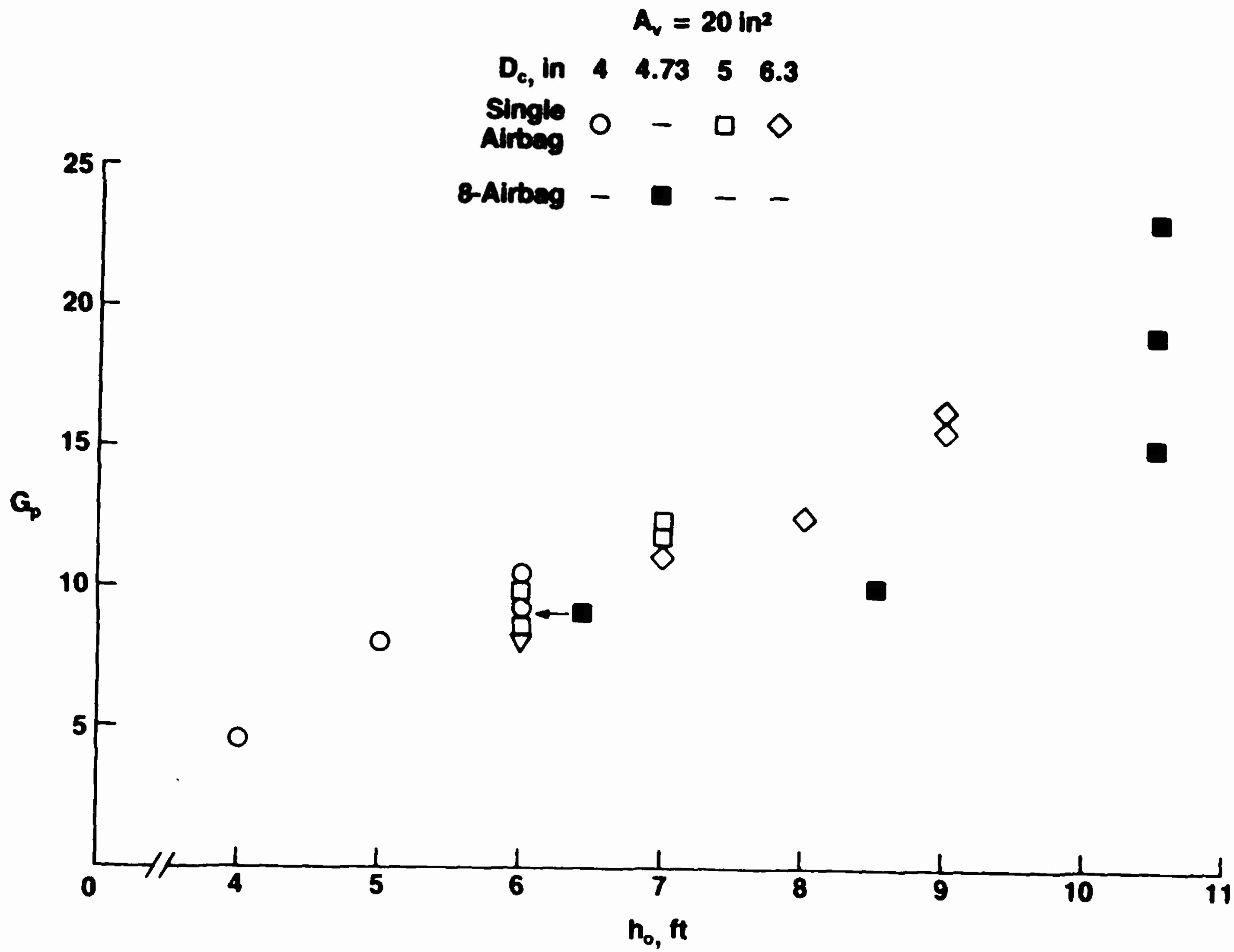

Figure 16. Comparison of Peak G Force Between Single-Airbag and Eight-Airbag Systems

most likely due to the non-one-dimensional motion of the 8-airbag/platform system as described later in this section. The comparison between the two systems is fair; it appears that a qualitative prediction of G_p of a multiple airbag system can be made from a single airbag. However, detailed comparison of the G and p profiles shows that the behavior of the 8-airbag system is more complicated than that of the single airbag.

Figures 17 and 18 show the comparison of the G and p profiles between the current single airbag and the 8-airbag system. Air pressures and G forces of airbag No. 1 (near the center of the platform) and airbag No. 7 (near the side of the platform) of the 8-airbag system[4] are also included in the figures for comparison. As seen in these figures, the profiles are quite different between the current single airbag and the 8-airbag system. As observed and described by Nykvist, during airbag compression in his system, the intermediate platform was first bent upward on the outside by the airbags and then returned back to the horizontal position. This three-dimensional flipping motion caused the two peaks of the p and G profiles shown in the figures. (To avoid the flipping motion, a stiffer intermediate platform will have to be used.) On the other hand, a one-dimensional single peak is observed for the single airbag. The non-one-dimensional behavior of full-scale multiple-airbag systems is probably typical in a real airdrop operation in the field. Such a disparity in performance between single- and multiple-airbag systems emphasizes the importance of full-scale field testing and the caution of using single-airbag test results.

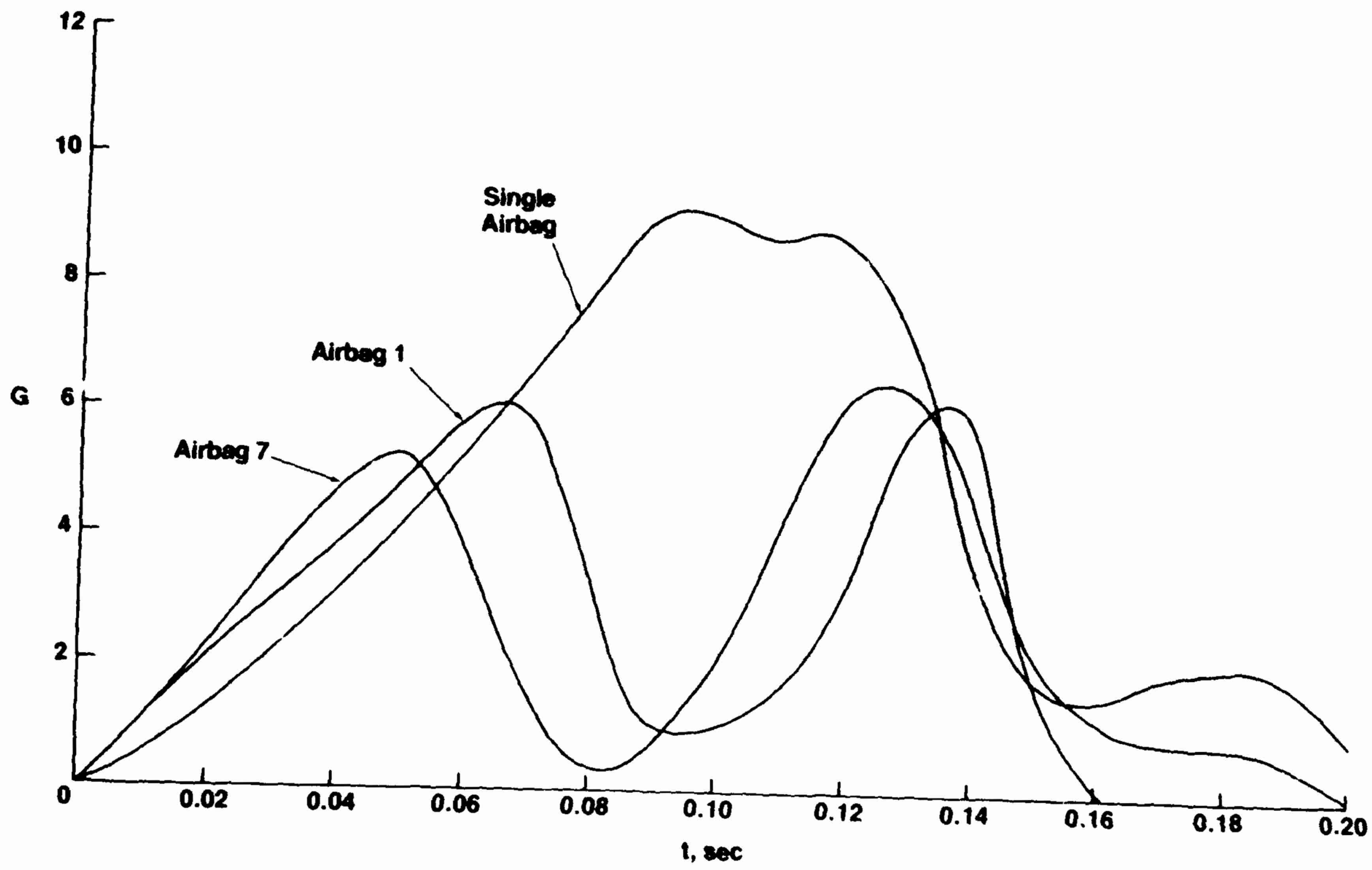

Figure 17. Comparison of Platform Acceleration Between Single-Airbag and Eight-Airbag Systems:
A. Comparison Between Airbags

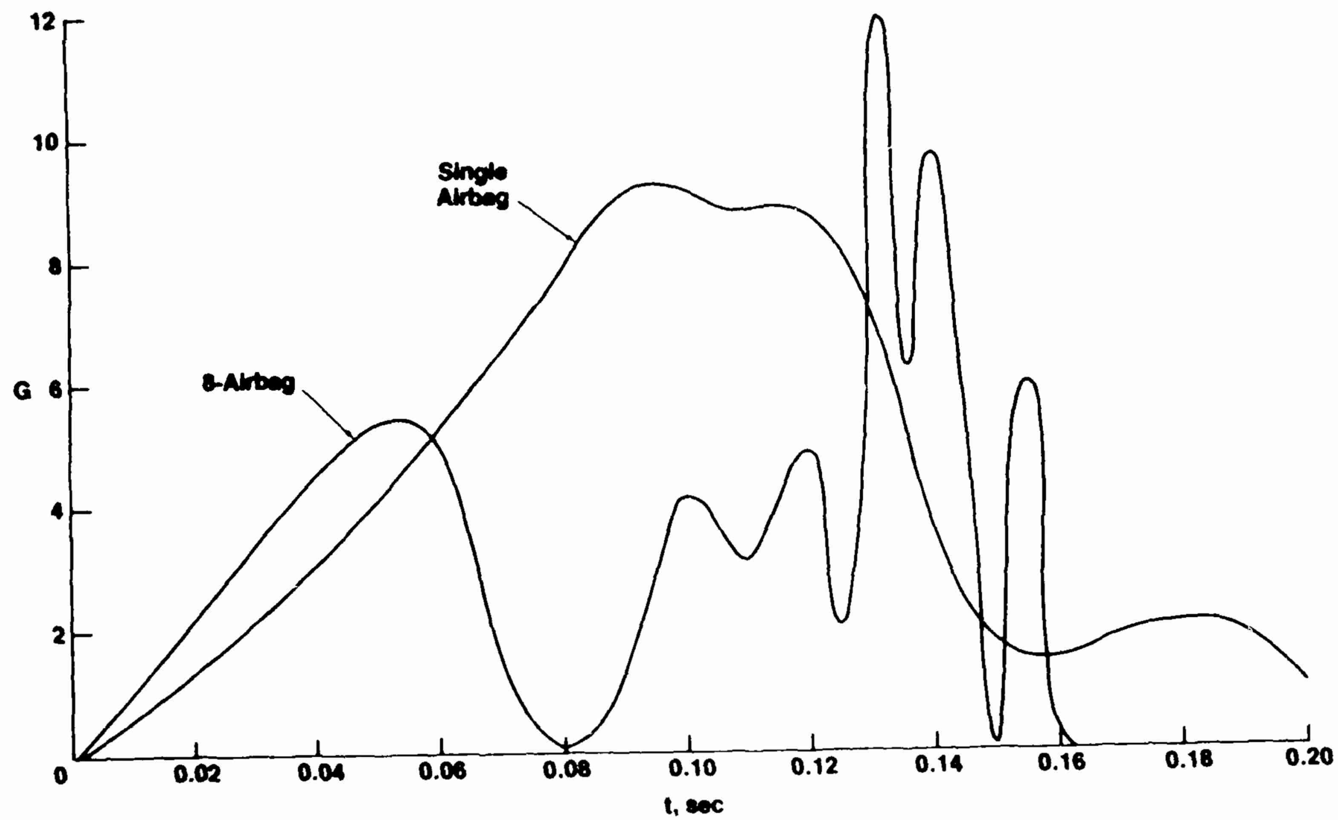

Figure 17.B. Comparison Between Centers of Gravity

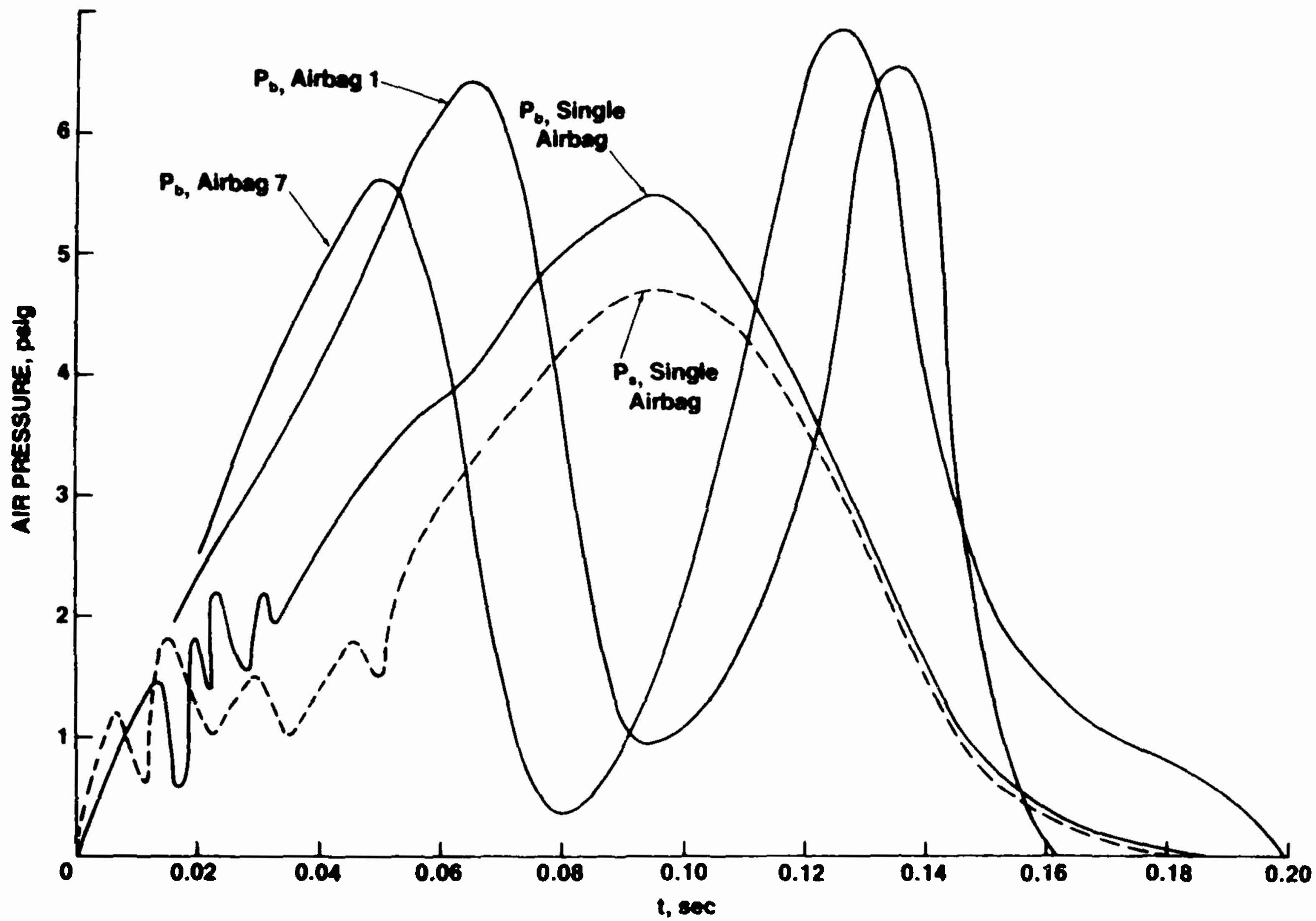

Figure 18. Comparison of Air Pressure Between Single-Airbag and Eight-Airbag Systems

Conclusions

The performance of a double chamber balloon-skirt airbag, made from the same design and dimensions as recommended by its manufacturer, has been investigated using various sizes of choke and air vent. It was found that for a 460 lb payload descending at a 20 ft/sec velocity, the performance varies as a function of the choke size and the air vent size. The optimum size combination for the lowest peak G force level of 9 and minimal rebound of the payload was found to be D_c=6.3 in and A_v=20 in^2. The corresponding equivalent width of the air gap, d, between the skirt and the ground for this vent area was 0.202". Even at this optimum operating condition, distinctive two-stage compression (balloon compression preceding skirt) with a one second sustained skirt inflation time was not observed.

For a higher descending velocity of 24 ft/sec, peak G level was higher at 16. Based on the current test results, G levels higher than 9 are anticipated for payloads heavier than 460 lb. These results show that the balloon-skirt airbag does not meet the soft landing capability as the manufacturer claims. In the 8 balloon-skirt airbag system studied by Nykvist, peak G levels higher than that claimed by the manufacturer were also observed. However, an optimum sized choke inside a single-chamber vented airbag does improve its performance by decreasing the peak G level by about 30%. It appears that to further decrease the peak G level for a softer landing, the airbag pressure or the air release rate has to be controlled so that p and G profiles will become a rectangular shape (lower G force for a longer time duration) instead of a triangular shape.

Currently, this improvement is being investigated by using controlled air release valves.

Comparison between the current single balloon-skirt airbag and the 8 balloon-skirt airbag system shows that the behavior of a full-scale multiple-airbag/payload system is more complicated than that of a single airbag system because of the non-one-dimensional effect. Thus one should be cautious in extending single airbag laboratory test results to multiple airbag full-scale systems. In a typical full-scale airdrop situation, the landing process is highly random and most likely three dimensional. A single airbag system that performs well in laboratory tests might behave unsatisfactorily in a real airdrop situation. It appears that the design features of an airbag soft landing system should be such that they are insensitive to the randomness of the landing; furthermore, the design should have some mechanisms to provide resistance to the possible horizontal swinging motion of the payload. Currently, these design features along with the controlled air release concept are being investigated to achieve soft landing by airbags.

REFERENCES

1. Chakoian, G., A Parachute Retrorocket Recovery System for Airdrop of Heavy Loads, Technical Report TR-34-AD, Airdrop Engineering Laboratory, U.S. Army Natick Laboratories, Natick, MA., Nov. 1969 (AD 699 342)

2. Cyrus, J.D. and Nykvist, W., Retrorocket-Assisted Parachute Inflight Delivery (RAPID) System Study, AIAA 8th Aerodynamic Decelerator and Balloon Technology Conference, Hyannis, MA., April 2-4, 1984

3. Cyrus, J.D., and Lee, C., Retrorocket-Assisted Parachute Inflight Delivery (RAPID) System Development Update, AIAA 9th Aerodynamic Decelerator and Balloon Technology Conference, Albuquerque, NM, Oct 7-9, 1986

4. Nykvist, W., Balloon-Skirt Airbags As Airdrop Shock Absorbers: Performance in Vertical Drops, Technical Report NATICK/TR-82/026, Aero-Mechanical Engineering Laboratory, U.S. Army Natick Research and Development Laboratories, Natick, MA 01760, Dec. 1981 (AD 118 228)

5. Browning, A.C., A Theoretical Approach to Air Bag Shock Absorber Design, Technical Note No. Mech. Eng. 369, Royal Aircraft Establishment (Farnsborough), Ministry of Aviation, London. W.C.2, Feb. 1963 (AD 421 946)