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THE DESIGN, DEVELOPMENT AND TESTING OF PARACHUTES USING THE BAT SOMBRERO SLIDER™

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ABSTRACT

This paper presents the design and development of parachute canopies utilizing the BAT (Butler Aerospace Technologies) Sombrero Slider, a new and unique parachute inflation control device. As background, a brief discussion of common parachute failure modes is presented to illustrate the impetus for the creation of this new device. The operation of the BAT Sombrero Slider is presented in detail along with results from numerous drop tests of parachutes that use the device.

Although this paper largely focuses on the development of personnel parachute canopies, the technology is broadly applicable to all typical uses of solid cloth canopies. To date (May 1999) over 300 tests have been conducted on slider equipped canopies with nominal diameters ranging from 16-feet to 53-feet; weights from 36-lb. to 1290-lb; and airspeeds from 30-fps to 300-fps. In addition to the single canopy systems mentioned above, a cluster of three 37-foot canopies has been dropped at a gross weight of 2090-lb. Quantitative test data summaries are presented for various canopies equipped with the slider and more detailed information is presented for one particular canopy size.

Photo 1. Live jump on HX-600.

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RELIABILITY OF PARACHUTE SYSTEMS

The reliability of a parachute system or subsystem is a complex and sometimes nebulous concept unless you specify the configuration in detail and the test conditions (weight, airspeed, altitude, etc.). For the purposes of this discussion, we will count as successful, any deployment that accomplishes the recovery of the payload with little or no damage to the parachute or payload. This will allow us to statistically ignore the minor damage that sometimes occurs for various reasons. Further, for simplicity, we will discuss only the raw reliability numbers (i.e. R=0.9, etc) rather than the more formal statistical methods (i.e. R=0.9 at 90% confidence). Also note that, by convention, a 1% failure rate (F) is equivalent to a reliability of 99% (or R=0.99) and conversely a 100% failure rate is equivalent to a reliability of 0% (R=0.0).

If we take the reliability as defined above as our measure of goodness or worth of a particular parachute, then a parachute with a reliability of R=0.99 (F=0.01) is ten times better than one with a reliability of R=0.9 (F-0.1) and R=0.999 (F=0.001) is 100 times better than R=0.9. Of course, the overall objective of designers is to have as many "9s" as practical (within the constraints of the program objectives) for the stated conditions.

Based on the author's extensive experience with a wide variety of canopies for personnel parachute systems, we feel that the suspended weight is almost irrelevant within a very wide range. Therefore, the airspeed at pack opening is usually the critical factor in determining the reliability of the system on any given deployment. This is true because the weight is a linear factor and velocity is an exponential factor in determining both the kinetic energy to be dissipated and the aerodynamic forces acting on the parachute. Therefore, we will largely ignore the suspended weight in the discussion that follows and discuss mainly the effects of velocity. Further, we will focus this discussion on catastrophic failures and largely ignore the minor problems.

CANOPY RELIABILITY

When looking at the canopy by itself, we find that there are basically two categories of catastrophic failures:

1) Structural failures of the canopy due to overload either in speed or weight or both (but not induced by any other factor such as an inversion or external damage)
2) Random failures (due primarily to inversions) that result in a catastrophic failure.

There are, of course, other parachute system failure modes but most of them are not directly tied to the canopy. Other failure modes might include pack closures due to bent pins; failure due to damage from external sources such as chemical contamination of the canopy cloth or physical damage to the parachute; and, unfortunately, failures caused by rigging errors. In the next sections we will examine the primary failure modes and then introduce a significant new solution to the random failures.

"NORMAL" STRUCTURAL FAILURE

To briefly discuss the easiest of the above items first, remember that any type of structure can be overloaded (a parachute, an airplane, the human body, etc.). However, failure points for most structures are fairly easy to predict for normal situations such as exceeding airspeed limits or overstressing the airframe by maneuvering. In an airframe, for example, the usual safety margin will generally allow for things like maneuvering loads, normal fatigue, minor assembly errors, minor corrosion during service, etc. However, the random (unknown and/or unpredictable) problems in airframes such as hidden damage, undetected material flaws, abnormal fatigue, incorrect repairs, unauthorized modifications and accumulated slop in the flight control system make it very difficult to quantify or predict in a manner that allows a reasonable structural margin to suffice.

In parachutes, as in airframes, if you can eliminate random failures then you can establish structural operating limits with a high degree of confidence. However, in both airplanes and parachutes, without some means to eliminate or control the random occurrences, then large structural margins or severely reduced operating limits must be applied to ensure safe operation. To further complicate the issue with parachutes, we have a non-rigid structure that has extensive interaction with the air itself during the opening process. That, coupled with the nature of textile construction, results in the need for parachutes to have a much higher margin of safety than aircraft (typically 100-200% margin rather than 50%).

Even though it is theoretically possible to build a personnel parachute strong enough to withstand many types of malfunctions without catastrophic failure, you could very well end up with a canopy that would kill the user with opening shock under certain conditions. Needless to say, such a parachute would be extremely heavy as well – so much so that many users would find it impossible to use it and would thus leave it behind. Therefore, a maximum allowable opening shock (at specified conditions) is often a key qualification parameter for parachute systems. Since any of these three cases (extreme opening shock, absence of a chute, or a catastrophic structural failure) has fatal consequences, it's obvious that the answer lies elsewhere.

In order to contrast normal openings, structural overload failures and random failures, we have included several video sequences taken from drop test video. Video sequence 1 shows a normal opening sequence on a lightweight, very low permeability, conical canopy at 130 KIAS with 220-lb. gross weight. This is actually a fairly good opening, even though it does show the usual asymmetry of the skirt during the inflation process and it exhibits minor overinflation and post inflation collapse shown by the dimpling in frames 1-D and 2-J. Video sequence 2 shows the same sequence from the side view wherein you can see the classic inflation sequence as the apex gradually collects air and inflates at an ever increasing rate, forming an onion profile, then eventually reaching a point where the skirt rapidly snaps full-open. This is, of course, the classic "top down" mode of opening and is the usual sequence for solid cloth parachute canopies without some sort of other device involved.

Video sequence 3 shows the exact same parachute with a catastrophic structural failure following a normal deployment and inflation. In this case, the failure is entirely due to overload because of the higher weight and airspeed (300-lb. @ 180 KIAS). As you can see in the sequence, this is a very nice opening, right up until the time the canopy literally explodes. In this sequence, there are no omitted frames in the vicinity of the failure, and you can see that about 40% of the canopy explodes from one frame to the next (roughly 0.03 seconds). Sequence 4 shows a side view of the same event. Again, this canopy shows the classic onion profile and a good opening, but the loads are such that the canopy fails. In the authors opinion, this canopy is a very well balanced design in that it fails over large areas at essentially the same time (rather than a single failure point that propagates through the canopy).

RANDOM CATASTROPHIC FAILURES

The parachute industry has spent years in the quest for parachutes that are structurally sound, damage tolerant, of reasonable weight, highly reliable and with opening characteristics that provide the greatest possible recovery envelope. Although progress has been made, the major stumbling block has always been the inversion problem and, until now, there has been no practical solution to the problem.

Random failures of any device are the hardest to manage and are, by definition, unpredictable (except statistically). The inversion malfunction (a.k.a., Mae West, line-over) is the ***genetic defect*** of all types of solid cloth (as opposed to ring slot or ribbon) round parachutes. ***Inversions will occur in all types of solid cloth round parachutes*** except those equipped with some means to prevent them; i.e. the anti-inversion netting found on many troop parachutes, the BAT Sombrero Slider™ (more details later), or perhaps some other device. The US Army adopted the anti-inversion net technique (originally developed in the UK) for their troop chutes in the 1970's and experienced a dramatic reduction in inversion malfunctions. Although the net has been very effective in troop chutes, it has not been widely adopted for other uses.

Video sequence 5 shows a close-up view (video from the tailgate) of a deployment sequence in which a partial inversion results in a catastrophic failure of the canopy. In frame 5-D you can see the beginning of the inversion that rather quickly results in failure. As clearly shown here, this small bubble inflates nearly instantaneously (because of its very small volume), grows rapidly then blows out as the lines fail and the canopy shreds itself. This failure occurred at the fairly modest conditions of 140 KIAS at 220 lbs.

Video sequence 6 shows the axis view of a most unusual opening sequence. Here we see an inversion from beginning to end; during which, a single gore of the canopy is split from bottom to top during the initial exposure of the skirt and then the canopy fully inverts itself by inflating and pulling through the split gore. This drop was at 150 KIAS with 300-lbs. gross weight with a light duty cargo canopy constructed of MIL-C-7020 nylon cloth with lightweight lines and reinforcements. Amazingly, the skirt band was not severed by the inversion process, which allowed the subsequent inflation rather than total collapse.

THE CAUSE OF INVERSIONS

During the 1970's, Robert Calkins[1], (now of Boeing Escape Systems but then at Wright-Patterson AFB in the USAF Parachute Systems Engineering Branch) conducted an extensive series of tests on 28' military canopies that revealed (for the first time) how inversions actually occurred. The hundreds of drop tests conducted by Calkins were filmed at a very high frame rate with sufficient resolution to show that the inversions actually occurred at, or just before, line stretch. In reality, the inversions were not "line-overs", they were actually "skirt-cross-unders" (for my lack of a better descriptive term).

Prior to the Calkins study, many people assumed that the inversion occurred as an artifact of over-inflation and rebound of the canopy. In fact, the so-called rebound inversion is extremely rare, if not non-existent. Further, since the Calkins study was confined to the 28' military canopy, (a flat circular design) there were presumably quite a few instances of post-inflation collapse with opportunities for the rebound inversion to occur. BPS has also seen the post-inflation collapse phenomena on several occasions while testing C-9's but has not yet captured a rebound inversion on the C-9 or any other canopy. Video sequence 7 shows an excellent example of the post inflation collapse phenomenon that did not result in an inversion. As valuable as the Calkins study was, there was little follow up in the industry because, although he had revealed the true nature of the problem, no one presented a readily available solution.

FIELD EXPERIENCE WITH INVERSIONS

Anecdotal evidence collected through the years by civilian and military parachute riggers suggests that temporary partial inversions actually occur much more frequently than is widely realized. Riggers who inspect and repack reserve canopies after use have informally reported these findings for years without realizing the cause. As many riggers have found (again, without realizing the cause) a temporary partial inversion leaves evidence in the form of a wide variety of friction burns and scuffing in the lower sections of the canopies; and occasionally, as friction burns on the lines. Further, when a temporary partial inversion occurs on canopies with deployment diapers, the damage tends to be concentrated in the immediate vicinity of the diaper, presumably because the diaper prevents the skirt or lines from easily sliding past that point on the canopy.

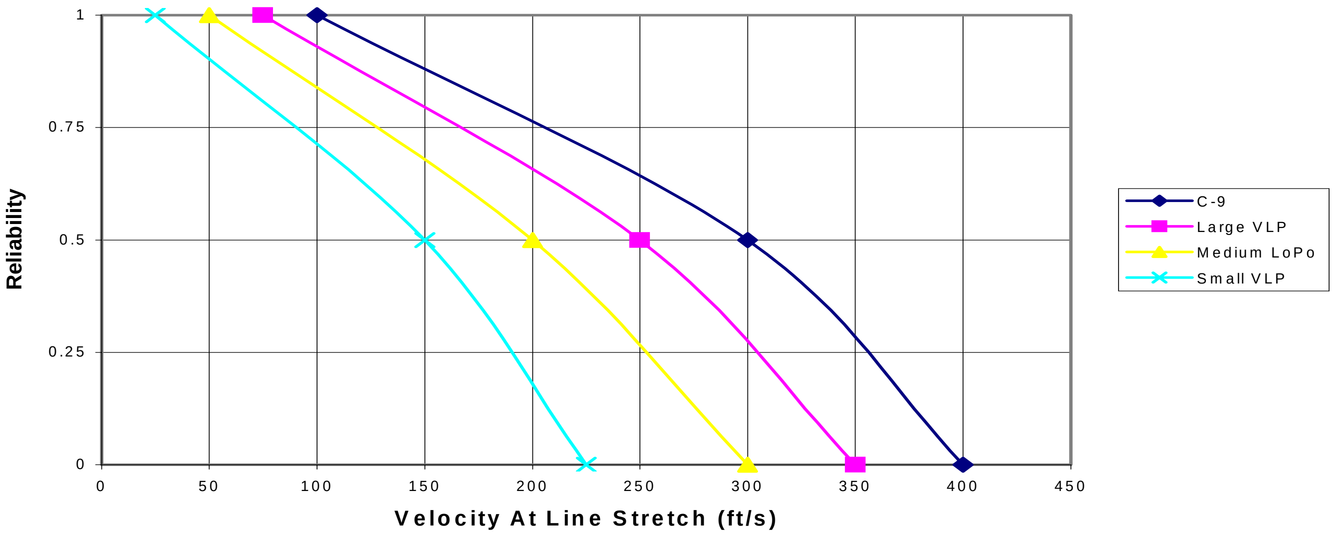
It is significant that many of these incidents reported by riggers servicing skydiving gear usually follow a main canopy malfunction and cutaway, which results in a low speed (perhaps in the range of 30 to 80 KTAS) deployment of the reserve canopy. Anecdotal evidence such as that related here suggests that temporary partial inversions, and sometimes even total inversions, can sometimes occur at low speeds (under 80 to 100 knots) without causing catastrophic damage to the canopy. However, catastrophic damage has been occasionally reported for even very low speed deployments. In addition, a line-over, or partial inversion that does not clear, will usually result in a survivable rate-of-descent and sometimes occurs with relatively minor damage to the canopy (at low speeds).

Even in light of the above discussion, the facts remain that an unfortunately common result of the inversion phenomena (partial, total and temporary) is the catastrophic failure of the canopy caused by localized overloading of the canopy and/or suspension lines. The prospects for survival are consequently poor in this case.

DEPLOYMENT EFFECTS ON RELIABILITY

Based on experience at BPS in testing of a very large number of personnel type parachutes (over 350 tests in 1998 alone) with very similar conditions, I now believe that every conventional parachute design will have several knees in the reliability vs. speed curve. That is, every parachute has some moderate speed below which, for most purposes, the reliability approaches 100%; the same parachute also has a corresponding speed at which the reliability is effectively 0% (zero). The graph at the bottom of this page shows the reliability vs. speed relationship in a qualitative manner for several different types of canopies.

Qualitative Representation of Reliability vs. Deployment Velocity



In between the extremes on the reliability curve, things get a lot harder to sort out. For example, I believe that there is a certain velocity (for every parachute design) where a significant increase in inversion type malfunctions occurs. The major factors appear to be the dynamic pressure at line stretch and the permeability of the cloth; i.e. the lower the permeability and/or the higher the dynamic pressure, the higher the instance of inversions. These two factors combine to generate a differential force across the skirt, between the outside and inside of the canopy. Unfortunately, the differential force is not symmetrically distributed around the skirt during the initial exposure to the air stream and large variations in the movement of the skirt are routinely seen. On the other hand, don't forget that the differential pressure across the canopy is what causes it to inflate in the first place.

The practical lower limit of the differential force across the skirt occurs with highly porous ribbon type chutes—like the landing deceleration drogue on the Space Shuttle for example—which have virtually a zero instance of inversion malfunctions. The upper limit on differential force (at a given speed) would occur with a true "zero permeability" cloth much like that used on the newest generations of ram-air sport parachutes. Therefore, somewhere along the speed range, a significant decrease in reliability will occur—the trick is to find that limit for each parachute application and stay well below it for operational use.

Based on a qualitative analysis of the personnel parachute canopy tests that BPS has conducted, some of the small, lightweight, low permeability canopies in use today will have in excess of 50% catastrophic failure rates at speeds of 130 to 150 knots. These same canopies would almost certainly exhibit a 100% failure rate at speeds over 180 knots. Some of the larger, low permeability personnel canopies have the same problems, but they occur at somewhat higher speeds. The medium size Low Porosity canopies will have the same problems, but I would expect the speed range to be somewhat higher than the very small canopies and probably about the same as the larger canopies. The C-9 (if equipped with deployment diapers, sleeves or bags) will exhibit the same tendencies but at much higher speeds due to the very high cloth permeability—perhaps in the range of 180 to 200 Knots for a spike in malfunctions and perhaps as high as 250 knots before approaching 100% structural failure. The C-9 not equipped with deployment devices will presumably experience the problems at a somewhat lower speed.

The graph to the left shows this relationship in a qualitative manner. The legends refer to Low Porosity Canopies (LoPo), the 28' military canopy (C-9) and large/small Very Low Permeability canopies (VLP).

INVERSIONS SOLVED

As part of an effort to control the opening shock of small, lightweight, very low permeability, personnel parachutes at speeds above 150 KEAS, Butler Parachute Systems, Inc. (BPS) and Butler Aerospace Technologies, Inc. (BAT) have jointly developed a simple, highly effective and elegant solution to both the opening shock and the inversion problems. The BAT Sombrero Slider™, provides a speed and weight sensitive, inherently self-modulating control of the inflation process. It is a significant technological breakthrough in parachute inflation control and we are confident that this device will prove to be one of the most important technologies ever developed in the field of parachute engineering. Incidentally, the nickname "sombrero" comes from the appearance of the device, which you will notice in photographs 1 and 2. In practice, the design and operation of the BAT slider has proven to make the occurrence of a line over or partial inversion type malfunction all but impossible.

Because it is the only device that, by itself, has enabled an increase in reliability by several orders of magnitude, we consider the BAT Sombrero Slider™ to be one of the most important new parachute technologies in decades. Among the many benefits, it:

- eliminates line-over malfunctions (the round parachute canopy's "genetic defect")
- enhances the canopy inflation and opening performance across the entire operating speed range with no detrimental side effects
- opens the canopy faster at low speeds while also slowing the canopy opening at high speeds
- provides self-modulating, continuous control of the inflation process
- forces the canopy to open from the bottom up in a controlled and consistent manner
- reduces the sensitivity to line twists.
- can be retrofitted to some existing canopies
- can be selectively "tuned" to nearly any opening time or force profile required
- provides nearly perfect symmetry of the canopy skirt for ideal structural loading
- has no pyrotechnics, no mechanical marvels, no electronic gizmos and no miracles occurring
- is a very sophisticated concept with a very simple execution
- is an aerodynamic solution to an aerodynamic problem

HOW THE BAT SOMBRERO SLIDER™ WORKS

As you can see from photographs 1 and 2, the slider itself is composed of two main elements. The first element is the inner section that is typically constructed as a hemisphere using the same cloth as the canopy. The second element is the mesh skirt that is typically constructed as a flat annular section and joined to the hemisphere during the manufacturing process. The outer perimeter of the mesh section is reinforced with tapes and webbing so that grommets can be set in the perimeter (ideally, one grommet per suspension line but many other arrangements could be used). During assembly, each line is routed thru the appropriate grommet on the slider and then to its particular connector link. Some type of slider stop is necessary to prevent the slider grommets from jamming onto the skirt or line attachment points. This can be easily accomplished with rings finger trapped into the lines (ala BPS HX canopies).

In practice, the BAT Sombrero Slider™ is stowed up against the skirt of the canopy when the parachute is packed and it is exposed to the airflow when the canopy reaches line stretch. During the opening process, the hemisphere acts like a very small canopy and inflates nearly instantaneously upon exposure to the airflow (typically less than 0.2 seconds). As the hemisphere inflates, it forces the skirt of the canopy radially outward away from the centerline of the parachute. After the hemisphere is fully inflated, the airflow inside the hemisphere causes a stagnation point to form below the hemisphere which then forces the air to go around the hemisphere and through the mesh panels, thus beginning to fill the main canopy. This causes the main canopy skirt to have nearly perfect symmetry as it begins the inflation process. However, at the point where the slider hemisphere reaches full inflation, the main canopy itself will still be in the wake of the slider's periphery (since the main has filled so little at this point) and thus will be contributing very little to the total drag of the system.

As the inflation process continues with air flowing into the canopy through the mesh, the canopy will soon have enough volume to begin to fill beyond the periphery of the slider. At this point, the constraining force of the slider on the lines resists further expansion of the skirt. But at the same time, the canopy will continue to fill and become more and more like a balloon. Eventually, the spreading force exerted by the inflating main canopy will overcome the restraining force from the slider and the slider will be forced down the lines, allowing the main canopy to completely inflate.

Photo 2. Live jump on HX-600.

This highly desirable self-modulation capability is one of the most significant benefits of the design of the BAT Sombrero Slider but it is easily explained by examining the aerodynamics of the interaction between the slider and the main canopy. Because the area of the mesh section fixes the inlet area that fills the main canopy (and the canopy stays tucked behind the edge of the slider periphery for the first portion of the inflation sequence) the fill rate of the main canopy is very nearly a linear function of airspeed. That is, instantaneous velocity (ft/sec.) times the mesh area (sq. ft.) results in "X" cubic feet of air per second flowing into the canopy (ft/sec x $\text{ft.}^2 = \text{ft}^3/\text{sec}$). However, the force holding the slider up against the canopy is an exponential (square) function of velocity. Thus, for speeds above a certain point, a condition is reached where the slider is held up against the skirt with sufficient force to prevent its downward movement until the system decelerates below the transition velocity (see below).

In practice, as the main canopy fills at any particular speed, it will reach a temporary equilibrium condition wherein the force holding the slider up is sufficient to prevent further expansion of the main canopy until the slider is forced downward when the system decelerates through the transition velocity. While the slider is help up against the canopy, the airflow into the main canopy will stagnate as the canopy reaches its maximum beach ball condition (for the slider still up). However, the entire system (parachute and payload) is constantly decelerating throughout this process; therefore, the force holding the slider up is constantly decreasing along with the airspeed. For a particular application, the various parameters in the slider sizing details and the related canopy factors can be tuned for nearly any result desired.

As an example, at low speeds (say 50 ft/sec ≅ 30 KIAS) there is very little force holding the slider up against the canopy and it can be forced down very quickly. Conversely, at much higher speeds (say 300 ft/sec ≅ 175 KIAS) the force holding the slider up would be 36 times greater ($(300/50)^2$) than the corresponding force at the lower velocity. However, the fill rate is only six times greater (300/50) than at the lower velocity.

Incidentally, the initial drag rise on the system is significantly faster than a similar parachute without the slider. In fact, given the very rigid shape and sharp leading edge of the hemispherical portion of the slider, we can safely assume a very high C_d (at least 1.0). Thus, we can easily (at least conceptually) separate out the slider drag from the total drag of the system up until the point where the slider begins its downward movement after which its effect is largely finished as far as total system drag is concerned. Although we have not conducted tests specifically to examine this, we plan to do so in the very near future.

The BAT Sombrero Slider™ provides speed sensitive, self modulated control of the inflation process; however, it also fundamentally changes the physics of the opening process. In effect, when compared to the same canopy without the slider, the addition of the slider causes the canopy to open faster at slow speeds (by forcing the skirt to open instantaneously) and also causes the same canopy to open slower at high speeds. This modulation effect works throughout the speed range and is completely dependent on the conditions (i.e. slider geometry selected, suspended weight and airspeed). The effect is highly sensitive to airspeed variations (as described previously) and somewhat sensitive to weight variations. Varying the weight for the same speed will result in a slower opening for a lighter weight—which is desirable because that tends to move toward the ideal situation of “equal ‘g’ for equal velocity” which has obvious benefits for ejection seats as well as bailout parachutes.

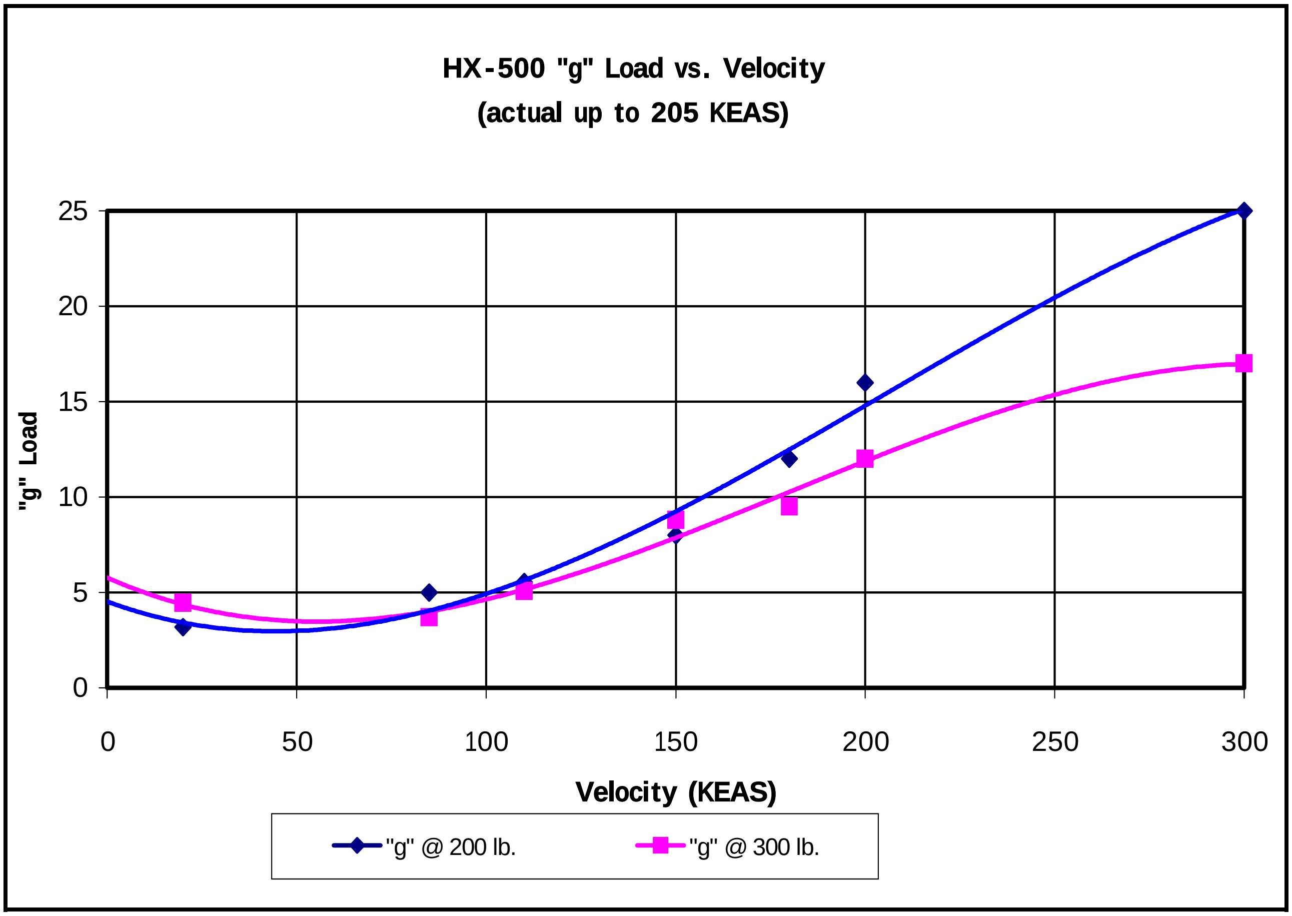
For examples of specific deployments, please examine the video sequences and the captions so you can relate the text to actual deployment events. Video sequence 8 shows an axis view (from the ground) of a canopy equipped with the slider during inflation. Video sequence 9 shows a close up on the opening process shot from an on board video camera. Notice that each of the steps described above is evident as you step through the frames.

TEST RESULTS, DATA AND TRENDS

Butler Parachute Systems has conducted over 300 test drops for a commercial product development program. These were performed primarily during the spring of 1998, but many since as well. During the program (see HX Series below) there were zero malfunctions and zero structural failures while within the design parameters set for the production parachutes. These new canopies can operate at significantly higher weights with more consistent and predictable openings and with dramatically improved reliability when compared to any canopy without the BAT slider.

We did, however, experience a few pure structural failures at very high weights and speeds. Further, we had one test in which the slider itself failed by tearing away the center sections from the perimeter (grommet location). In response to this failure of a lightly reinforced slider, we immediately halted the test program for a few days and strengthened the slider radial tapes and junctions with the periphery. Since then, we have had no further structural failures of the sliders but we have occasionally blown small sections of the hemisphere for the larger sizes. In response to the blown sections, we have added a "belly band" and are using a heavier cloth for the larger sizes. These minor problems are usual to any development effort and must be expected – after all, the hemispherical part of the slider, is essentially a very small parachute canopy and must be designed as such.

Because of the cost of the instrumentation systems only a few of the tests have been conducted with full instrumentation. However, about 25% have been conducted with Brinnell type load cells which are much cheaper and almost indestructible. The Brinnell cells provide a peak load reading that is fairly accurate (+/-2 to 3%) up to about 10,000-lb. on the systems we have devised and they are now routinely used on all drops. Further, we have devised a more accurate method of reading the "dent". You may find more details on the operation of the Brinnell load cells on the BPS web site at www.butlerparachutes.com.

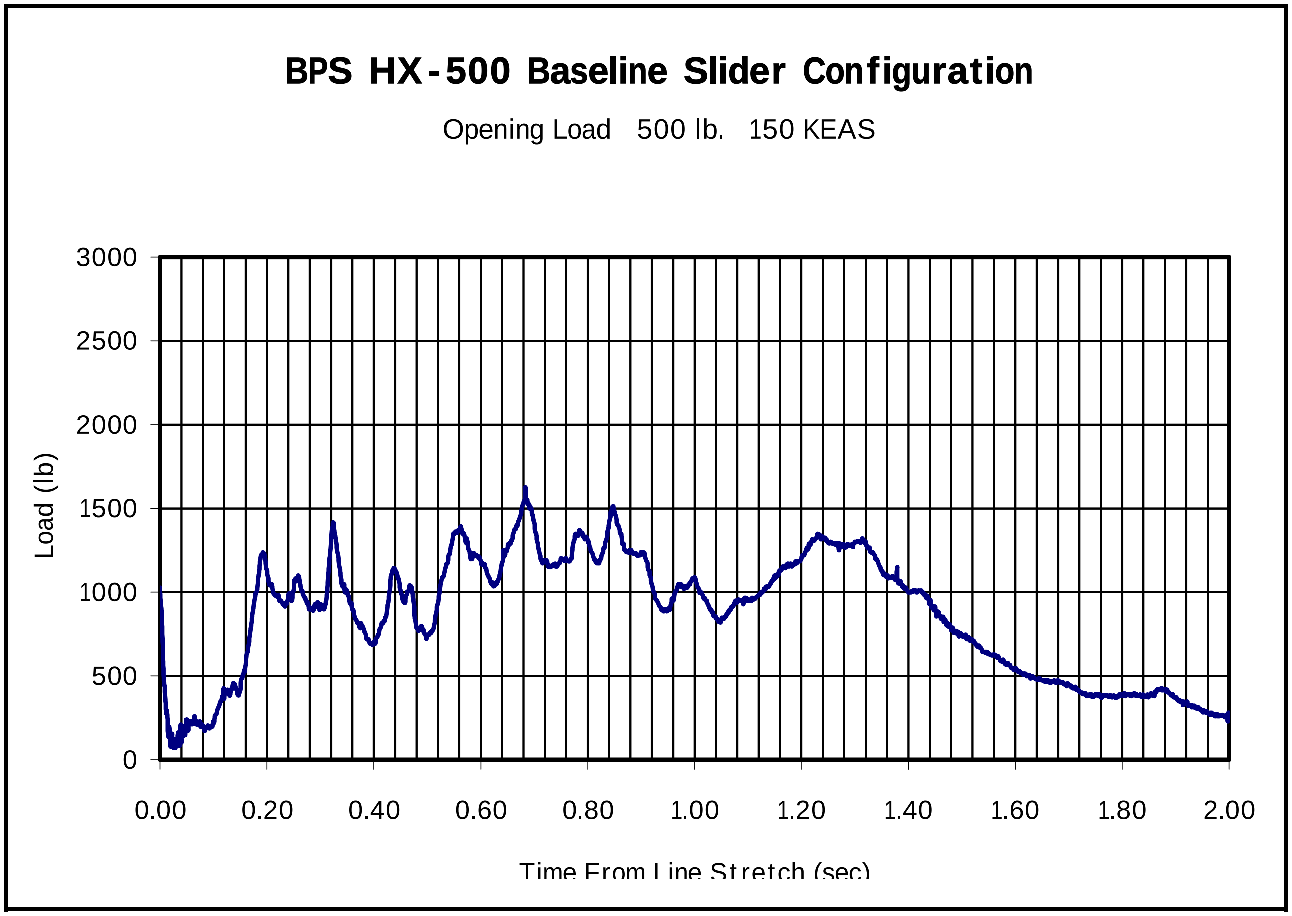


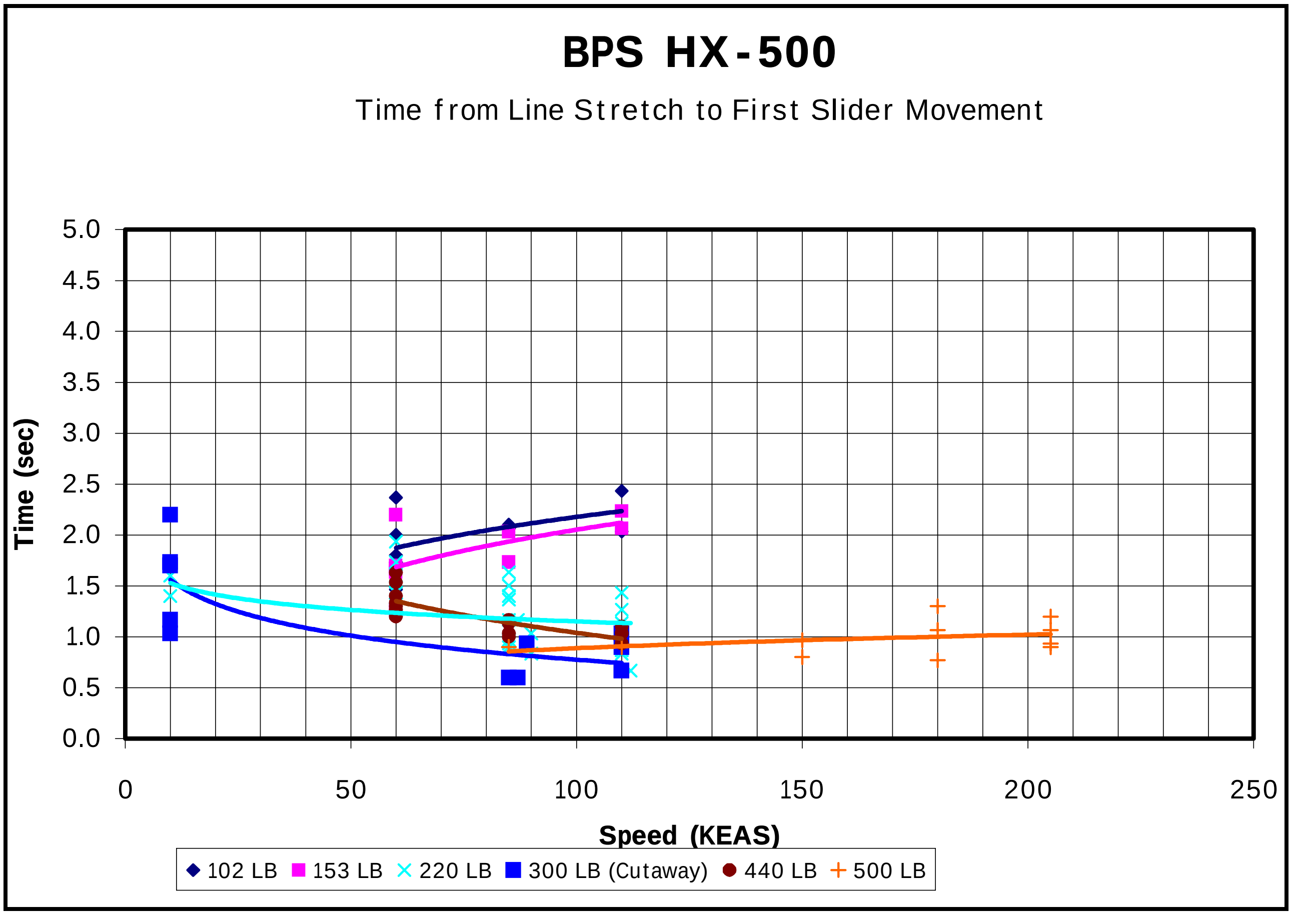
In addition to the load data, we have a minimum of two (and usually three or four) video views of every drop made during this program. By using multiple cameras and training our camera operators carefully, we have managed nearly 500 drop tests over the past four years without a totally missed event (knock on wood!!). As a result, there are literally thousands of video clips that have been examined, timed and cataloged. By using the best available view of each drop we have extracted the event timing on Sony Hi-8 EVS-7000 professional video decks with RC time code (hours, minutes, seconds, and frames). The frame counts were then entered into a spreadsheet and converted to real relative time. For most purposes, we use line-stretch as time zero although some data was presented to the FAA with pack opening as time zero (per their performance testing requirements under AS-8015b).

Because of the tremendous amount of data generated during our testing programs, I have elected to present data here from only one of the twelve canopy sizes tested to date. The canopies tested to date are geometrically similar and we have begun normalizing the data on the basis of canopy loading (W/C_dS). The trends appear to track closely among the sizes but there is simply too much data to present here in a useful format.

The charts presented here illustrate some of the test results of the HX500 (25.25 D_o) canopy tests at various conditions. You will notice that at higher canopy loading the curves are a bit better behaved, and in several cases are essentially flat from 85- to 205-KEAS. This extraordinary result is further evidence that the BAT Sombrero Slider dramatically and fundamentally alters the opening process for the better.

Further, it is evident that about 80-90% of the work of decelerating the payload is already complete by the time the slider begins its downward movement (particularly at lower canopy loading). The time of slider movement and first full open are marked on one of the charts below for reference; however, we are using the time to slider movement for most of our modeling efforts.





EFFECTIVENESS IN PARACHUTE CLUSTERS

As one would probably deduce after viewing the video tapes and carefully considering the mode of operation, the BAT Sombrero Slider has proven quite effective in testing in clusters. During March 1999, BPS participated in a demonstration program sponsored by the Canadian Forces Parachute Center in Trenton, Ontario. Two drops were made at approximately 130 KEAS, 1000' AGL and 1690-lb. and 2090-lb. gross weight (respectively).

The first drop was a direct bag static line deployment of three 37' D_o canopies (in individual T-10 d-bags inside an outer bag) and resulted in less than 2% variation in peak opening load among the three canopies. The second drop was a pilot chute deployment of the same canopies at 2090-lb. and again resulted in a very small variation in canopy loads (although at a higher peak load per canopy). This variation of less than 3% in both cases is very significant given that a 3-canopy cluster will typically see as much as 100% variation from lowest to highest and occasionally will have one or more canopies fail to inflate at all.

Video sequence 10 shows clips taken from the first cluster drop. Although not at the ideal viewing angle, the video clearly shows how evenly the canopies are inflating. We are very encouraged by these preliminary cluster drops and plan to pursue additional cluster drops in the near future.

DEMONSTRATED APPLICATIONS

Although the BAT Sombrero Slider is a very new development, there have already been quite a few applications of the technology. For example, the HX Series™ Emergency Parachute canopies from BPS are the first commercially available products utilizing the BAT Sombrero Slider™. They have the highest airspeed and weight ratings of any FAA Authorized emergency parachute canopies certificated under C23b/c/d.

Applications demonstrated to date have included:

- The four HX-Series Canopies (19.5’ to 27.9’ D_o) in production under FAA TSO-C23d.
- The BPS troop parachute programs, including the adaptation of the BAT Sombrero Slider to the US Army MC1-1c (net removed) and development of a family of troop parachutes by Butler Parachutes.
- A UAV program for a 900-lb. VTOL UAV.
- A target demo program at 200 KEAS at 1290-lb.
- The 3-canopy cluster mentioned above.

CONCLUSIONS

Butler Parachute Systems has demonstrated beyond any reasonable doubt that the BAT Sombrero Slider™ is the most effective device ever invented for controlling the inflation process of conventional parachutes. It completely eliminates inversion type malfunctions and provides the parachute designer with one of his most effective and versatile tools in controlling opening shock and force profiles. Further, it is the only device ever invented that benefits the entire speed range of the parachute system with no detrimental side effects.

ABOUT THE AUTHORS

Manley C. Butler, Jr. is the founder and President of Butler Parachute Systems, Inc. now located in Roanoke, Virginia. He also serves as the President of Butler Aerospace Technologies, Inc. (or BAT) which owns the rights to the invention that is the subject of this paper.

He has been involved in aviation activities all of his adult life, beginning with his time in the US Navy as an Acoustic Sensor analyst on the S3A Viking. He spent three years in the fleet with VS-22, during which he accumulated some 350-flight hours in Navy tactical aircraft and 35 traps onboard the USS Saratoga. In 1976 Manley was selected for a Navy commissioning program and left the fleet to attend the University of Texas at Austin, where he received a BS in Aerospace Engineering in 1980. After graduation he spent one year as Director of Engineering at ParaFlite Inc. then moved on to the Naval Weapons Center at China Lake, California as a recovery systems engineer and program manager from early 1983 until the end of 1986. One of his projects at China Lake was the first (and so far the only) successful in-flight ejection test using a ram-air canopy.

From 1973 through 1988 he made over 1200 jumps, including over 200 jumps on modified 28' military canopies; over 50 jumps on modified T-10 troop canopies, and over 100 test jumps on various BPS products. He has a current FAA Master Parachute Rigger License with all ratings. He is a licensed pilot with experience in a wide variety of aircraft including aerobatics and soaring.

Michael D. Crowe was employed at Butler Parachute Systems as aerospace engineer and management assistant; most recently serving as the Operations Manager until early May 1999. He has a BS in Aerospace Engineering and an MBA from Virginia Polytechnic Institute and State University. In his two years at Butler Parachutes, he was involved in parachute system design, product testing, and inventory control. During the development of the canopies utilizing the BAT Sombrero Slider™, his primary responsibility was to manage and direct the test program, data reduction and analysis. His assistance is greatly appreciated.

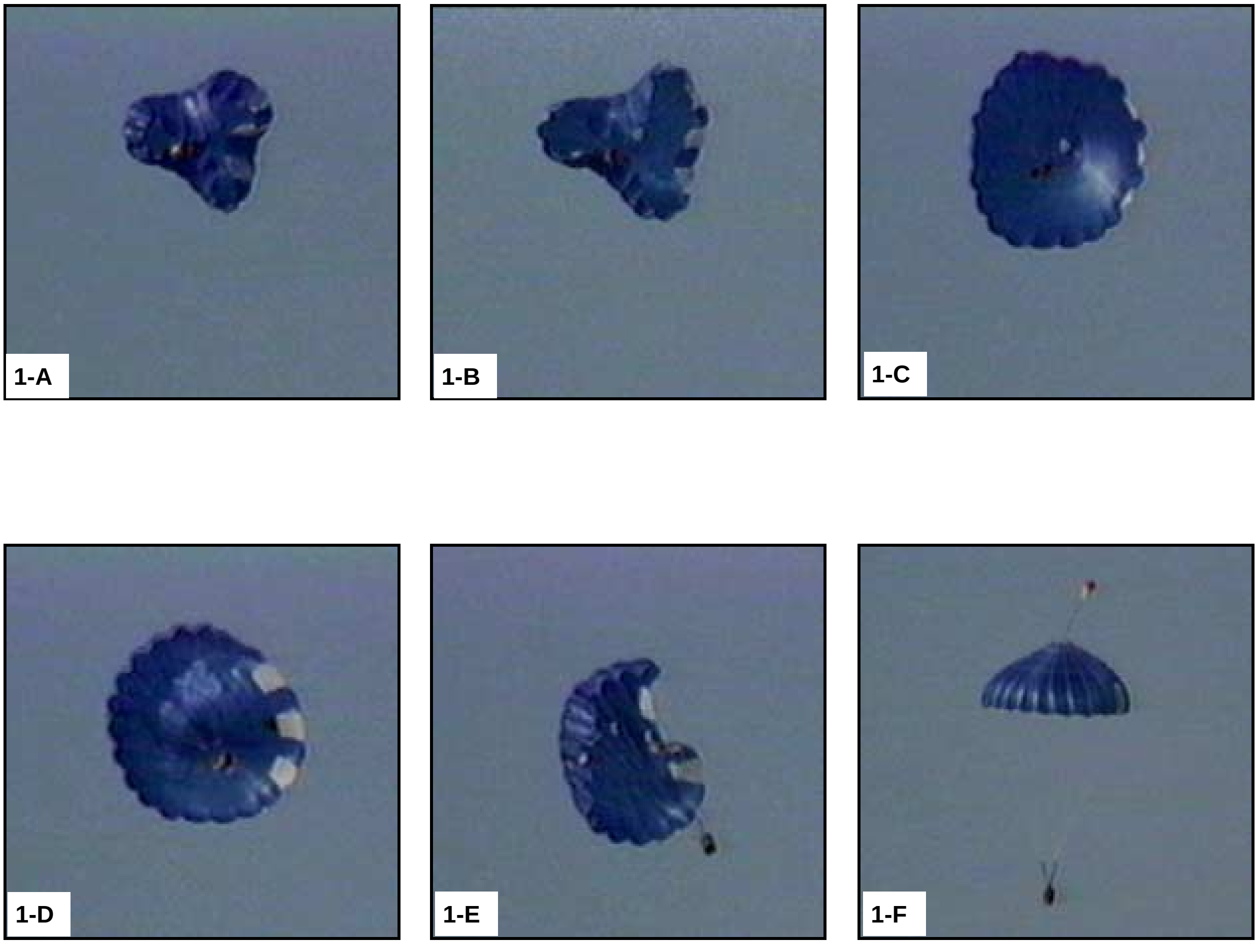
Administrative Notes:

- This paper includes dozens of video clips and photographs that are reproduced here in black and white. After June 30th, 1999, this paper will also be posted on the Butler Parachute Systems web site, where they may be viewed in color if desired.
- This paper also has an accompanying video presentation which, while not strictly necessary, greatly aids in illustrating the technology. A copy of the video may be requested from the authors.
- The BAT Sombrero Slider™ was invented by the primary author of this paper, Manley C. Butler, Jr. (US Patent 5,890,678, patents pending worldwide). A separate company, Butler Aerospace Technologies, Inc. (BAT), holds the rights to this invention and will license the technology under the usual sort of commercial arrangements.
- Please feel free to contact the author to discuss your particular application.

References

1. Calkins, Robert B. *Parachute Partial Inversion,* AIAA 79-0451

VIDEO SEQUENCE # 1

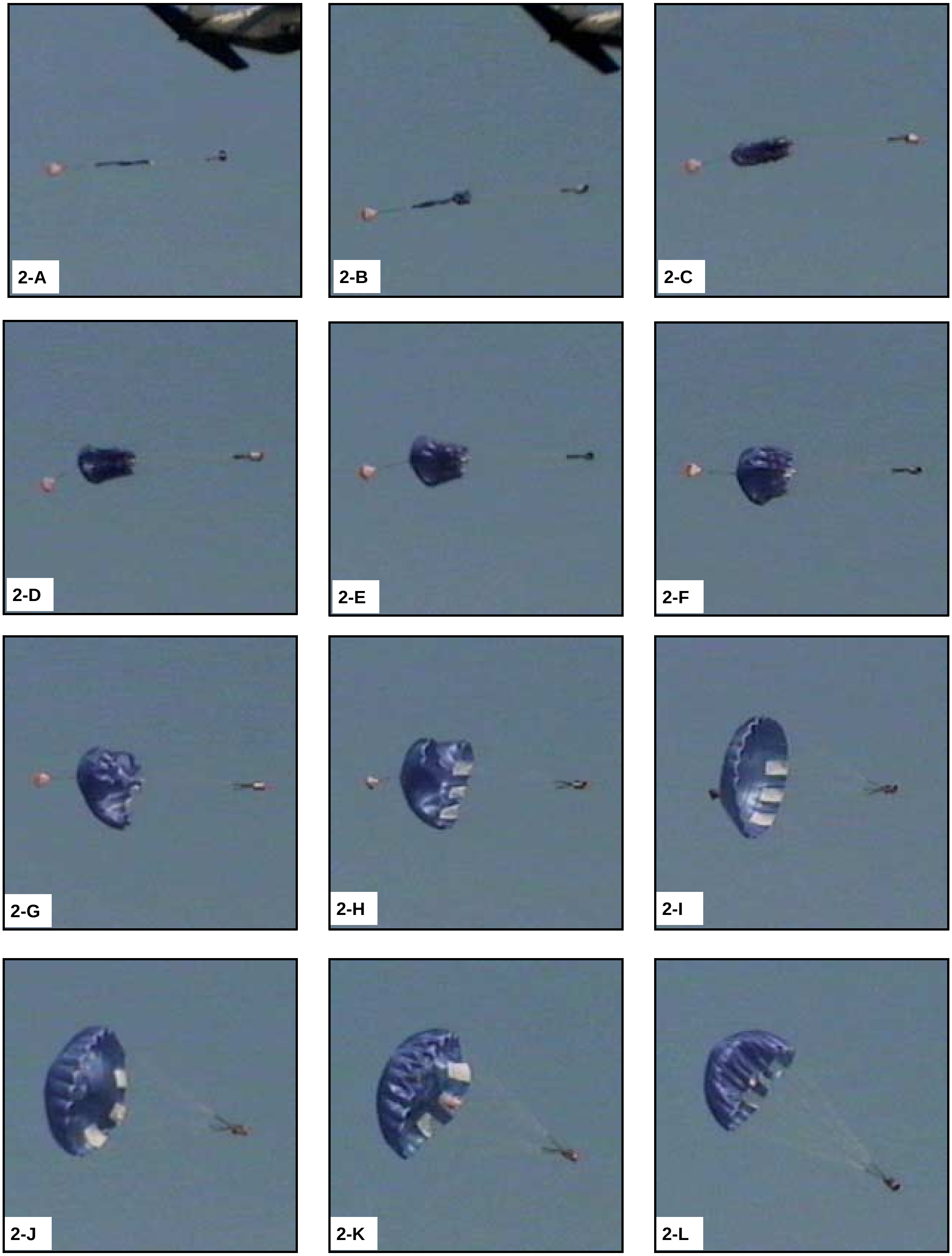


1-A 1-B 1-C

1-D 1-E 1-F

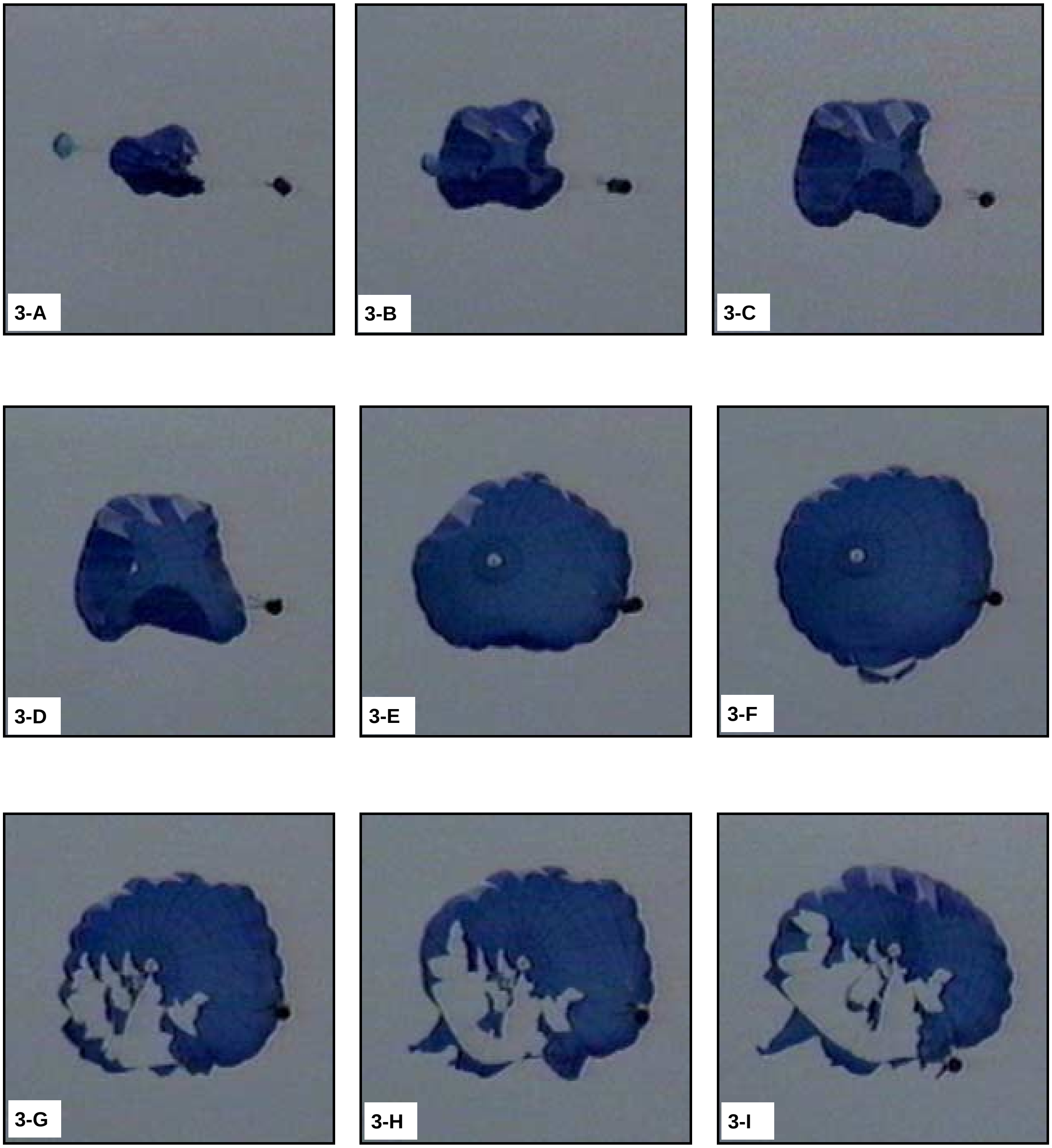
ParaPhernalia/FFE 24' Conical. 130 KIAS @ 220 lb.
Normal opening sequence (axis view)
Same test as sequence #2.

VIDEO SEQUENCE # 2



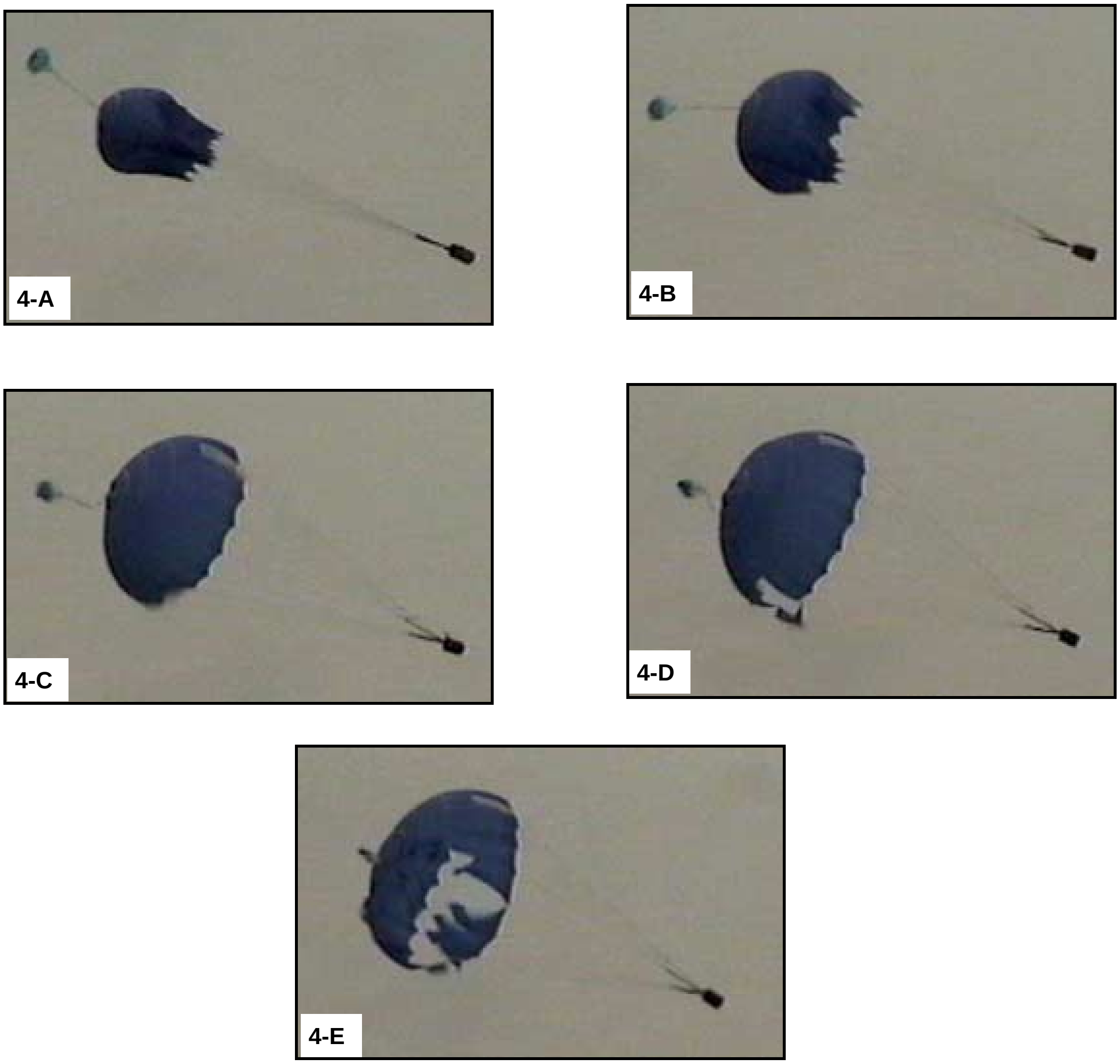
ParaPhernalia/FFE 24' Conical. 130 KIAS @ 220 lb. Normal opening sequence (side view)
Same test as sequence #1.

VIDEO SEQUENCE # 3



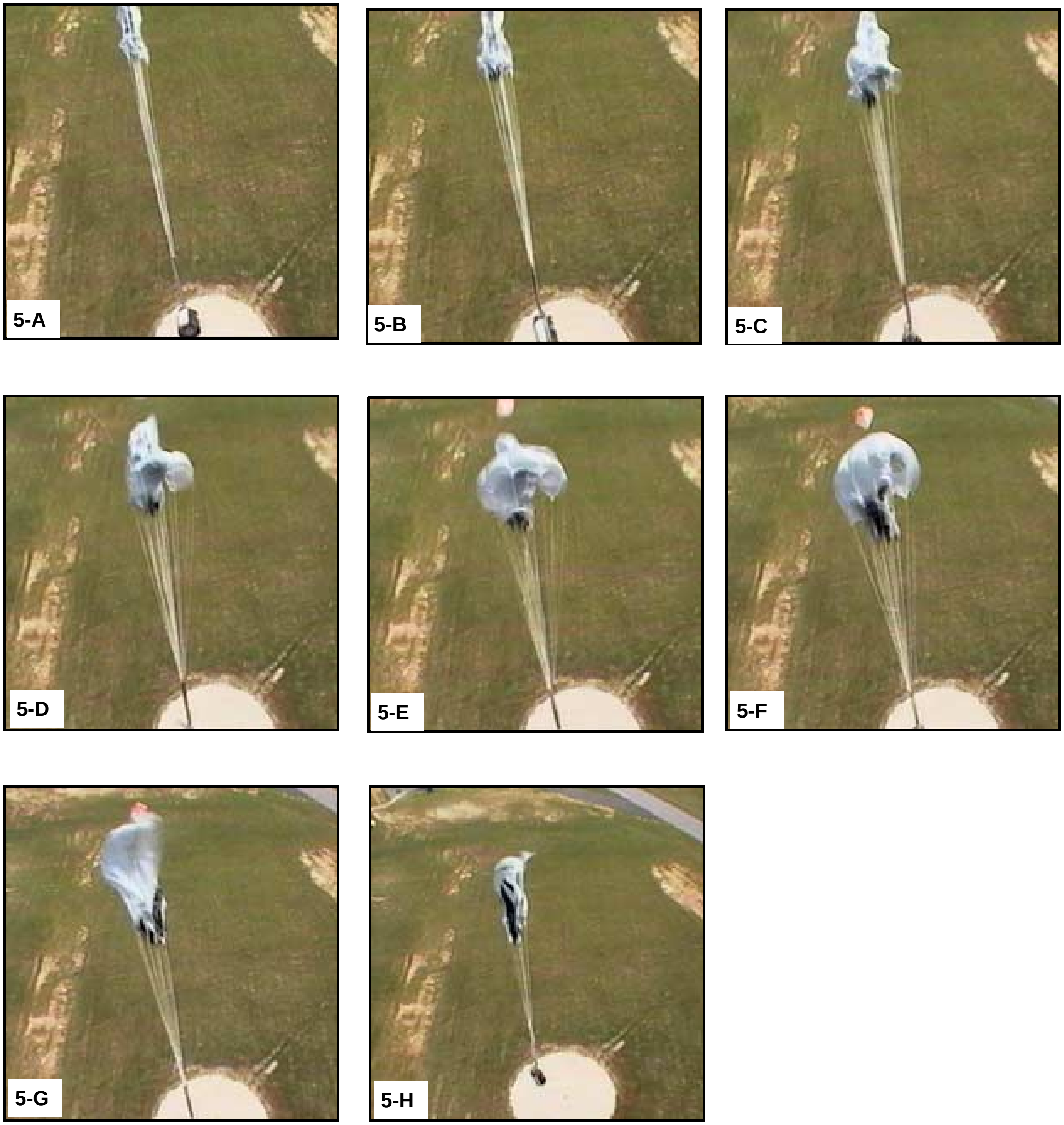
ParaPhernalia/FFE 24' Conical. 180 KIAS @ 300 lb.
Catastrophic failure (axis view)
Same test as sequence #4.

VIDEO SEQUENCE # 4



ParaPhernalia/FFE 24' Conical. 180 KIAS @ 300 lb.
Catastrophic failure (side view)
Same test as sequence #3.

VIDEO SEQUENCE # 5

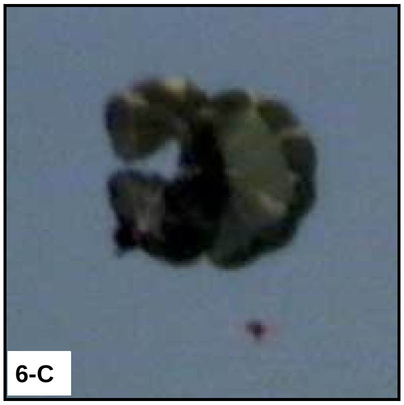


National Parachute Industries Phantom 26.
(National 425) 140 KIAS @ 220 lb.
Catastrophic failure caused by inversion.

VIDEO SEQUENCE # 6


6-A


6-B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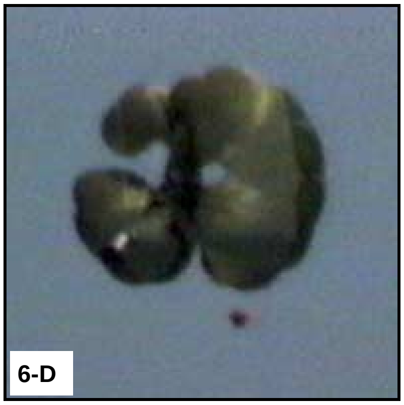
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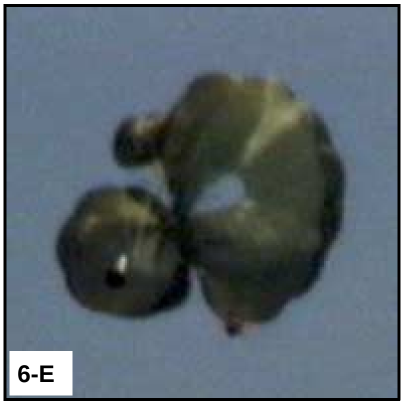
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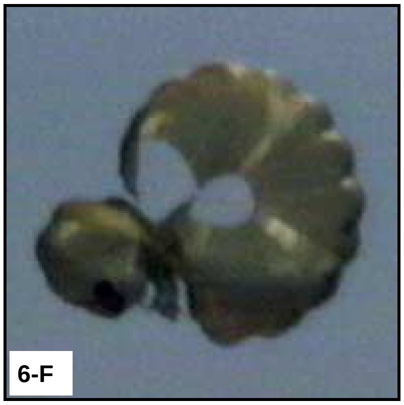
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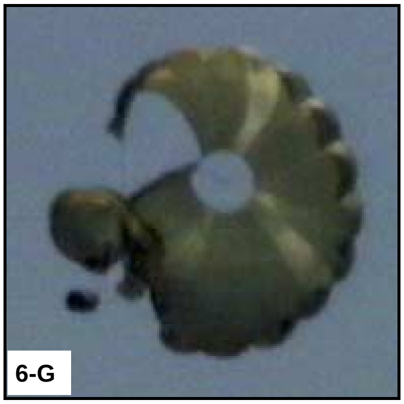
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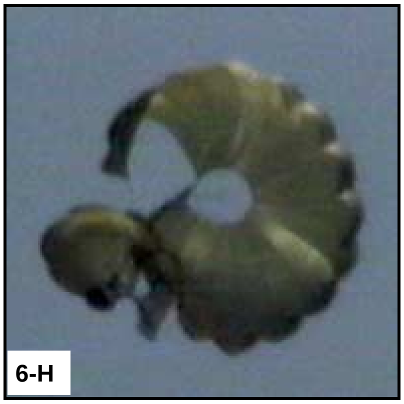
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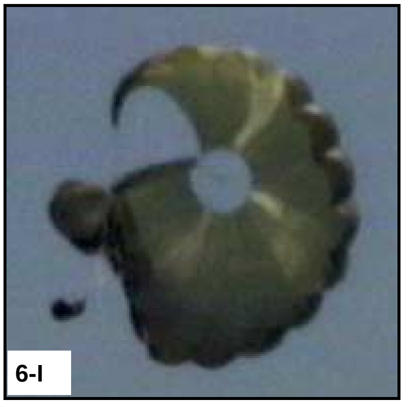
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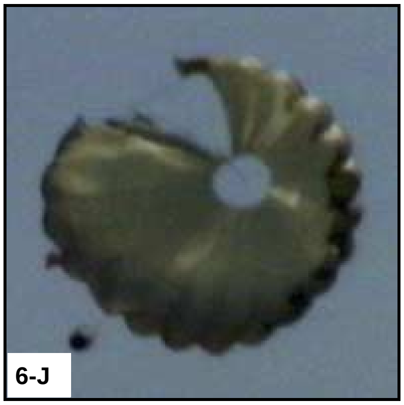
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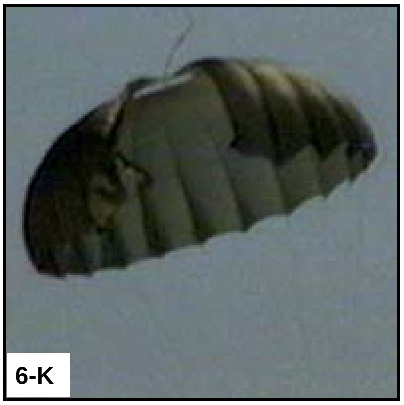
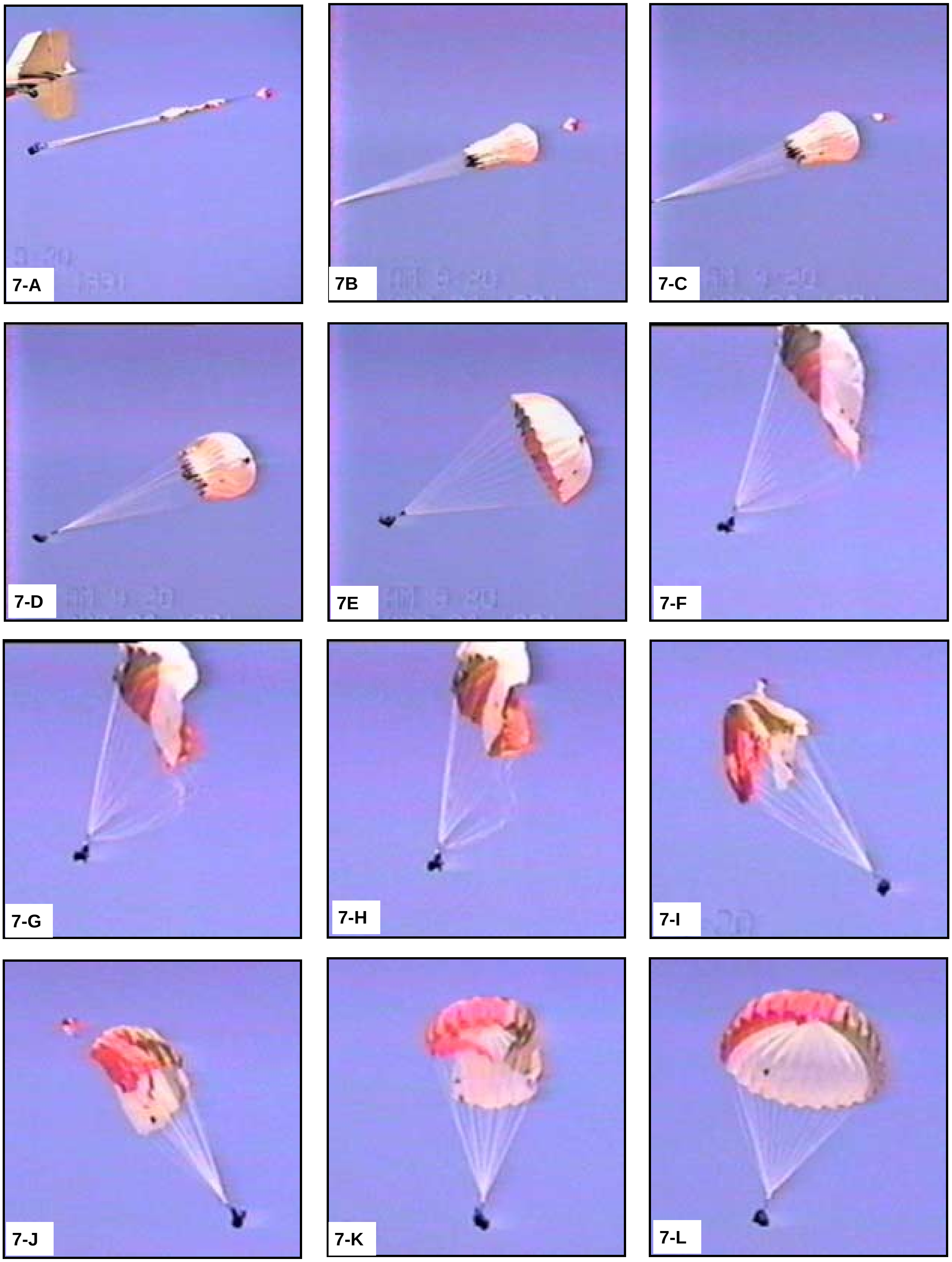

6-K

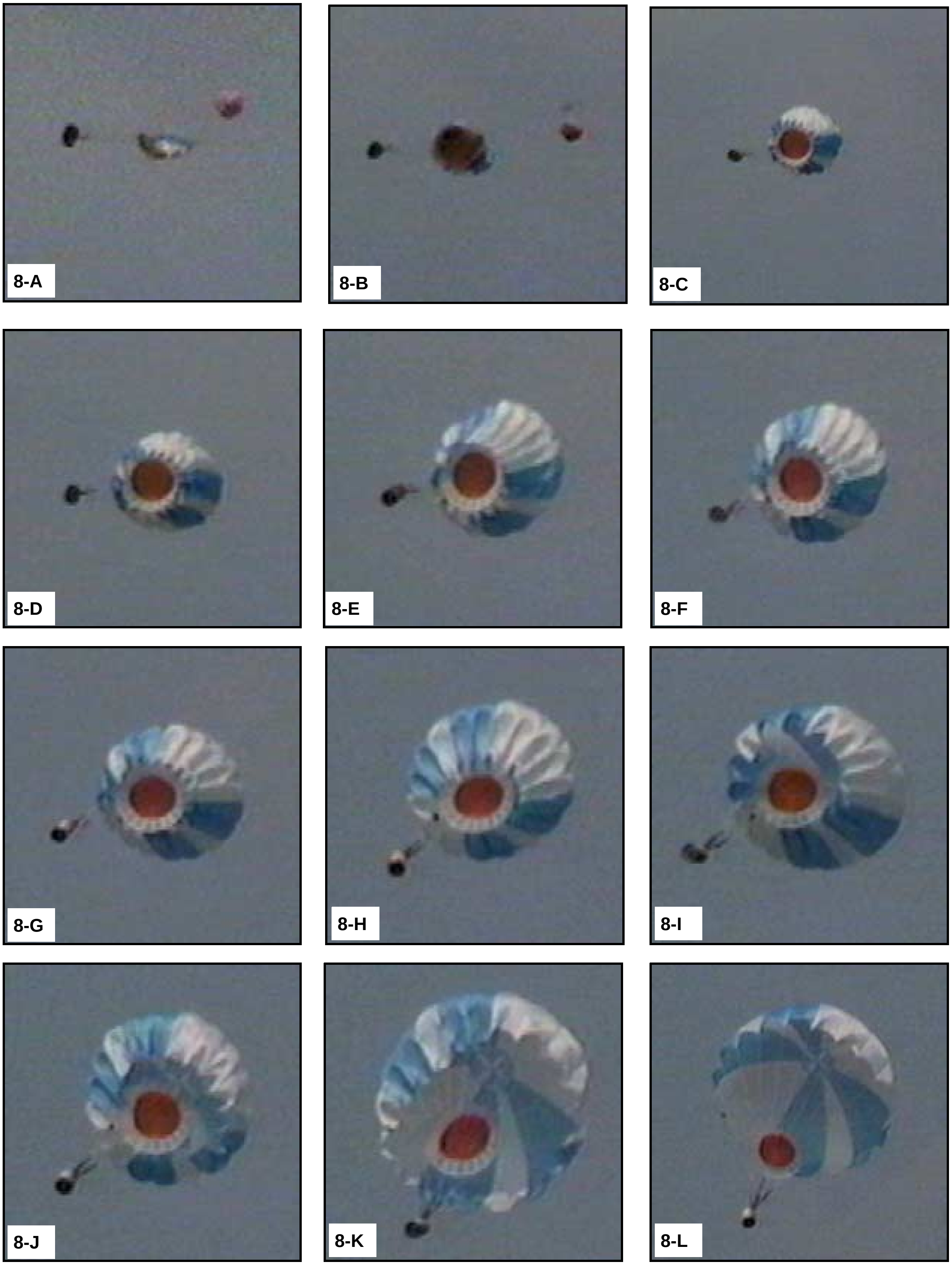
Butler Parachute Systems lightweight 28' Cargo Canopy. 150 KIAS @ 300 lb.

VIDEO SEQUENCE # 7



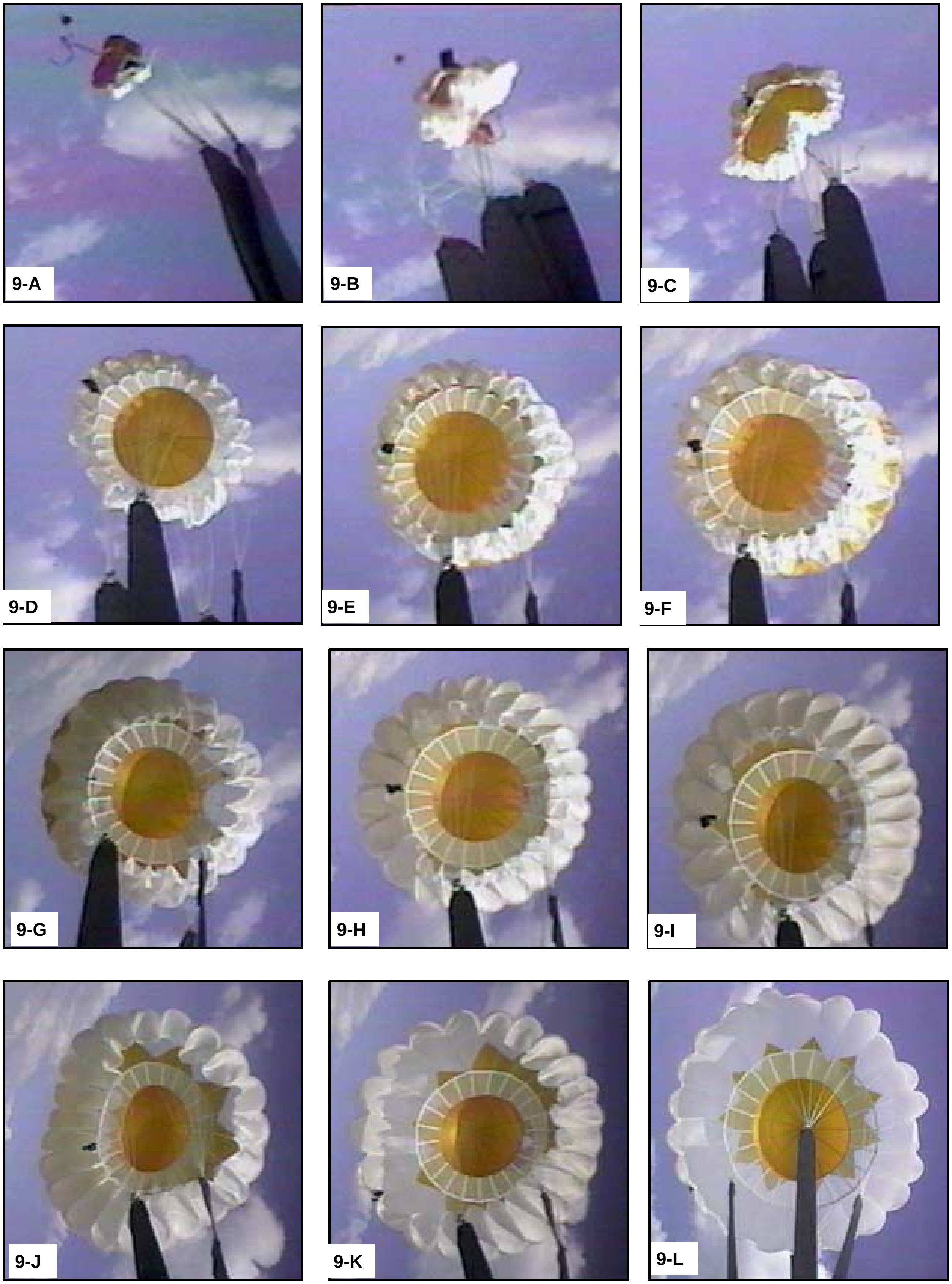
28' military surplus canopy. 175 KIAS @ 300 lb.
Extreme post-inflation collapse.

VIDEO SEQUENCE # 8



Butler Parachute HX-400 test drop. 205 KIAS @ 408 lb.
Successful drop showing effectiveness of the BAT Sombrero Slider™.

VIDEO SEQUENCE # 9



Butler Parachute HX-500 test drop. 180 KIAS @ 528 lb.
On-board camera showing close-up of inflation process.

VIDEO SEQUENCE # 10


10-A


10-B

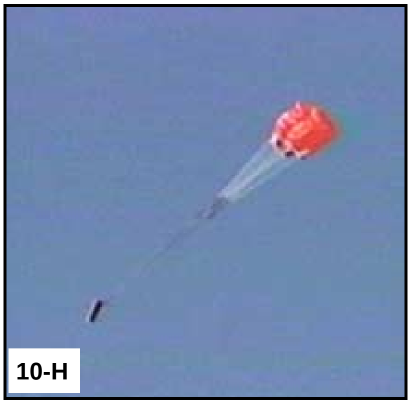

10-C


10-D


10-E


10-F


10-G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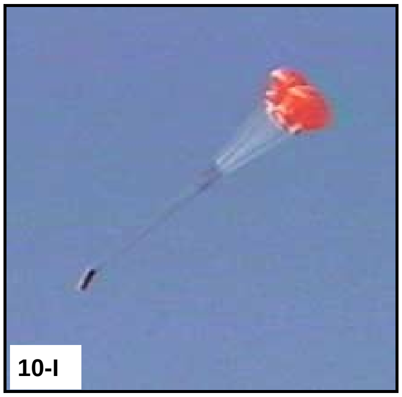
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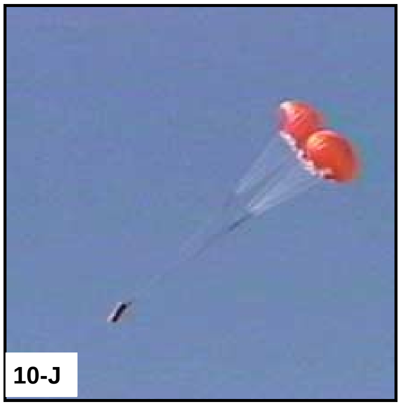
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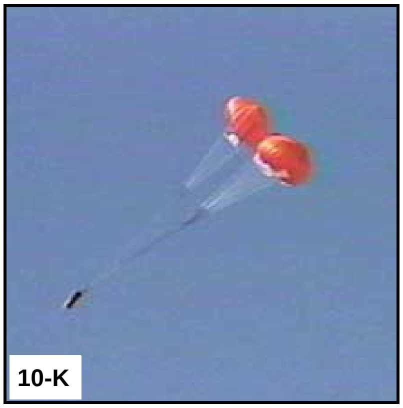
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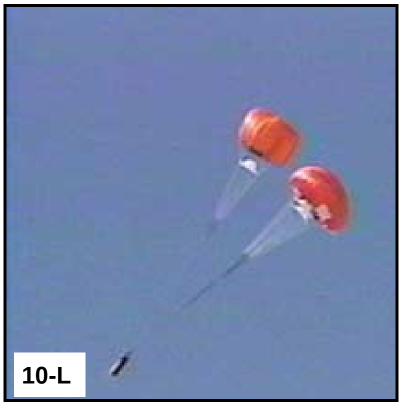
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