The Design and Development of New Emergency Parachute Canopies Utilizing the BAT Sombrero Slider™

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Abstract

This paper presents the background and a brief history on aircrew emergency parachute systems in common civilian use. A discussion of common failure modes is presented to illustrate the impetus for the creation, and the benefits of, a new device to control the inflation characteristics of parachute canopies. The BAT Sombrero Slider™ is one of the most significant developments in parachute technology in decades and provides tremendous improvements in reliability and control of the inflation process and opening loads.

Background – A Short History of the Development of Parachute Equipment

Military Surplus Parachutes

Prior to about 1968, most pilots in civilian aircraft in the United States (and much of the rest of the world) used surplus military parachutes in their aircraft. The common harness/container models in use were the USAF B-4/B-12 and the USN NB-6/NB-8 backpacks as well as several variants of military seatpack parachutes. The most common canopies were the 28' personnel canopy (the C-9) used in all Air Force and most Navy parachutes, the 26' Navy conical used in the NB-6, and the 24' (T10A) canopy used as reserve for the Army troop parachutes. The common factors in all of these various models are that they are heavy, bulky and uncomfortable. Although there are still a great number of surplus military parachute systems in use, only a small number of these items are still available as new surplus and they have largely been supplanted by newer technology products (which will be discussed below) in sales of new equipment.

The 28' Military Canopy

Aside from being the only readily available canopy in the 1960's, the C-9 really didn't have all that much going for it when compared to the operational requirements in civil use. It is rugged and cheap but suffers from a variety of problems, mostly related to the fact that the basic design dates from the late 1920s. These problems include its relatively high weight and bulk; lack of steering capability; severe oscillations in the unmodified condition; a relatively high rate of descent that increases the injury rate; and tendencies for post-inflation collapse due to its flat circular design. It also has slow openings at low speeds such as a zero/zero ejection condition and hard openings at high speeds such as a low altitude, high-speed ejection.

Over the more than 60 years since its introduction, the only significant improvements to the C-9 have been: 1) the change to nylon cloth and lines in the late 1940's which effectively doubled the strength of the canopy; ; 2) the development of reefing systems for some versions which allowed the canopy to operate at somewhat higher speeds without the loads exceeding human tolerance and; 3) the addition of the 4-line release modification in the 1970's that significantly reduces the oscillations and rate-of-descent (*but only if activated by the user*).

Skydiving Equipment

Not surprisingly, given the paucity of available equipment, skydivers in the 60's were also using the same basic equipment albeit with an amazing variety of steering modifications to the main canopies (usually the 28'). But, during the 60's, Pioneer Parachute Company introduced the Para-Commander, which took the sport by storm and virtually owned the main canopy market until the early 70's when the first practical ram-air canopy appeared and sealed its fate. Skydivers in the 60's and 70's also used military surplus canopies for their chest reserve parachutes with the Navy 26' Conical being the most desirable. They also used modified military harness/container systems with chest reserve parachutes. During the late 60's and early 70's a number of companies (primarily Pioneer Parachute Company, Security Parachute Company and Strong Enterprises) began the introduction of a series of new products (main and reserve canopies and harness/container systems) that gradually replaced the military surplus equipment in use by skydivers. In the mid-70's Para-Flite ram-air canopies and the Relative Workshop Wonderhog harness/container system were introduced and largely completed the transition to purpose built skydiving equipment for the great majority of jumpers. During the 80's and 90's many more companies entered the skydiving equipment market (and some others dropped out) with the resulting competition fueling the development of an amazing variety and range of products.

New Materials

Significantly, the development of new products in the parachute industry has benefited enormously from the development of new materials (as has nearly every other industry). The most important new materials proved to be lower porosity (actually air permeability is the correct term) canopy cloth. Air permeability is an air flow measurement and is stated in cubic feet per minute (CFM) per square foot of cloth at 0.5 inch water pressure differential. The new cloth designs were based first on the ubiquitous MIL-C-7020, Type 1 1.1 oz/sq.yd. Nylon, ripstop cloth used in the military personnel canopies. The military cloth (80-120 CFM) is still in use in military parachutes and a low permeability (30-50 CFM) version was made by calendering (hot pressing between rollers). Later cloth developments were purpose built (from several companies) and ranged from 1.25 oz/sq.yd. to 1.1 oz/sq.yd. In the late 1990's the most popular cloth is a new fabric created specifically for the sport parachute industry during the late 80's and continually refined. The newest variants of this cloth (now covered by MIL-C-44378 and Performance Textiles Exacta-Chute) are available in 30-50 CFM, 0-3 CFM, 0-5 CFM and a true 0-CFM (with a silicone coating). Manufacturers of both the skydiving and emergency parachute canopies began taking advantage of the newer materials as soon as they were available (at each stage) and the result is that all types of personnel parachute canopies have become lighter and smaller.

The History of Civil Emergency Parachutes

The development of civil emergency parachutes has roughly paralleled the development in skydiving equipment, with the exception of the wholesale transition to ram-air parachute canopies. As companies began to build new skydiving equipment, they also began to design and build new emergency parachutes. Certainly the most successful of these parachutes was the Security Safety-Chute 150/250/350 which was one of the first to market; it was such a tremendous improvement on the military items that thousands were sold in only a few short years.

Over the past thirty years since the first Security 150 was introduced, many other companies and models have appeared on the market. Although Security Parachute Company itself was closed in 1984 and Pioneer withdrew from the civilian market about the same time, several other companies have come and gone. Currently, in the US, the primary producers of emergency parachute equipment for the civil market are Butler Parachute Systems, Inc. (BPS), Strong Enterprises (SE), National Parachute Industries, Inc. (NPI) and ParaPhernalia, Inc. (PPI). All of these companies produce their own canopies except for PPI, which uses canopies produced by Free Flight Enterprises, Inc. (FFE). Throughout the rest of this paper we will use FFE when discussing the canopies and PPI when discussing the harness/container systems.

In general, the modern round canopies discussed below have much faster openings at low speeds than the older military canopies and are much more resistant to post-inflation collapse due to the canopy profiles used. They are lighter and generally provide a better rate of descent than the C-9. They also have good maneuverability and are inherently more stable with strong damping characteristics. Of course, there is no free lunch and these canopies are generally not as rugged as the C-9 and tend to have very hard openings at higher speeds. They also exhibit a somewhat higher occurrence of inversions due to the lower permeability cloth that is used in their construction.

Even though the products manufactured by these companies are substantially better than the old military surplus equipment and, in all cases, many detail changes and improvements have occurred over the years, this equipment is not significantly different than that which has been on the market for over twenty years.

With the notable exception of the improved cloth mentioned above, there has, in fact, been ***no significant improvement in conventional parachute technology for over fifty years***. That has now changed with the introduction of the BAT Sombrero Slider™, which will be covered in detail below.

Common Features of Currently Produced Emergency Parachutes

To complete the background discussion, we will present a bit more detail on the products of the current producers. The products of these four companies have several common features (none of which are found on the common military surplus parachutes) that are generally agreed to improve the reliability and/or the performance of the parachute systems. For example:

- All use some sort of container flap arrangement to control (or stage) the deployment of the canopy by ensuring that the pilot chute is fully deployed and inflated prior to extracting the canopy.
- All utilize some sort of deployment control device such as a deployment diaper to ensure that the canopy reaches full line stretch before the skirt is allowed to open.
- All have canopies constructed of low porosity (SE) or very low porosity (all others) cloth to improve the drag coefficient of the canopy and thus allow a smaller, lighter canopy in comparison to the older military canopies. The flip

side to this is that all of these canopies are less robust than the military 28’ – however, they have been tailored to segments of the market that, in general, do not require that level of strength.

- All of the canopies open significantly faster than the military 28’ canopy – with some canopies of this general type capable of producing 20 g’s or more at only 180 knots. While this quicker opening is a great benefit at low speeds and/or low altitudes (such as skydiving cutaways) it is definitely a mixed blessing in the bailout environment. It must be further noted that smaller canopies inherently open faster than larger ones (due to the smaller internal filling volume).
- All canopies utilize a tri-vent steering configuration which gives the canopies a small glide ratio and allows limited maneuverability and significantly reduces oscillations.
- All systems utilize harness and container systems with a minimal amount of hardware and pack stiffeners in order to reduce weight and increase comfort.
- All offer products that are FAA Authorized under TSO C23 in various versions.

Differentiating Features of Currently Produced Emergency Parachutes

There are, however, some significant differences between the products of these companies. For example:

- Only BPS produces canopies that were originally designed and built for emergency parachute systems. The remaining canopies were originally designed and produced as skydiving reserve parachute canopies (see above discussion) and later marketed as emergency parachutes to increase sales of the same basic product. The NPI and FFE canopies (in particular) have been optimized for light weight and low bulk at the expense of structural margins and an increase in rate-of-descent (with smaller canopies). We at BPS sometimes refer to these as “wimpy, warmed-over skydiving stuff”.
- Only BPS has produced and qualified a round parachute canopy under TSO C23d. The minimum qualification condition for C23d is slightly more stringent than C23c and significantly more stringent than C23b. However, C23d does allow qualification of a parachute assembly at any weight and airspeed above the minimums (220 lb. @ 150 knots). BPS has taken advantage of this flexibility to produce the H-X Series™ canopies with weight capacities of up to 550 lb.
- Only BPS and SE have produced canopies under TSO C23c, Category B. Note that the structural testing required under C23c is significantly more stringent than C23b. Although the NPI and FFE canopies are qualified under TSO C23b and are legal for use, the test methods required under the relevant performance standard (NAS-804) were not really germane to any canopy designs except military. These test methods have allowed canopies to be qualified under conditions that do not adequately represent what might occur during a pilot bailout emergency. Both companies are reported to have attempted qualification under C23c when it was first issued in 1984 but apparently were unable to pass the structural test. Since the minimum structural test under C23d is essentially the same as under C23c, neither is apparently planning to qualify their existing products under the latest revision.
- Only BPS has qualified any parachute under TSO C23d at speeds higher than the minimum requirement of 150 KEAS. The H-X Series canopies from BPS are qualified for use at 170 KEAS and have been tested to 205 KEAS.
- Only BPS uses bias canopy construction because it is significantly stronger and provides a more favorable load path from the line attachments into the canopy; however, bias construction is significantly harder to produce and takes considerably more labor. All others utilize block construction for their canopies because it is cheaper and easier to build.
- Only BPS uses an extended skirt, tri-conical design because the extended skirt provides significantly better opening and stability characteristics and the tri-conical shape provides much higher drag coefficient than a straight conical canopy. It also provides significantly better resistance to post-inflation collapse. All others utilize single angle conical canopies because it is cheap, quick and easy to design and build and can significantly reduce the amount of scrap cloth in cutting.
- Only BPS offers truly custom products that are built to order to fit the individual in a particular airplane. BPS also offers several standard configurations that can fit a very wide range of aircraft and individuals (though not as well as the custom items). For example, BPS currently offers five different canopy sizes, five different harness configurations (each with sub-variants) and over 250 container configurations (each with sub-variants). In contrast, PPI offers two canopies, five container and two harness configurations; NPI offers three canopies, three containers, two harnesses; SE offers one canopy, four containers, and two harnesses.

Definitions

As discussed above, most modern emergency parachutes are definitely better than the antique military equipment, and, in general are pretty reliable at low and moderate speeds. However, reliability is a nebulous concept unless you specify the conditions (weight, airspeed, etc.). For the purposes of this discussion, we will count as successful, any deployment that saves the life of the user with little or no damage to the parachute. This will allow us to statistically ignore the minor damage that occurs as discussed below. 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 a 1% failure occurrence 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 is ten times better than one with a reliability of R=0.9. Taken from the other view, R=0.9 is equivalent to one failure in 10 uses; R=0.99 is equivalent to one failure in 100 uses. And, of course, R=0.999 is 100 times better than R=0.9. The overall objective of designers in the aircrew emergency equipment business is to have as many "9s" as possible on the reliability number for the stated conditions.

Deployment Conditions and Other Effects

I must also point out that, for personnel parachute systems, suspended weight is almost irrelevant (within a very wide range) and that the airspeed at pack opening is the critical factor in determining actual performance of the system on any given deployment. This is true because the weight is a linear factor and velocity is a square factor in determining kinetic energy. Therefore, we will largely ignore the suspended weight in the discussion that follows and discuss mainly the effects of velocity.

Since few (if any) of the harness and container systems currently produced have any glaring defects, it is most educational to examine the heart of the parachute system, (the canopy) and ignore the harness/container effects. Further, we will limit this discussion to 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 due to overload either in speed or weight or both (but not induced by any other factor such as an inversion for example)
2) random failures (due primarily to inversions) that result in a catastrophic failure.

There are, of course, other 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 two sections we will examine the primary failure modes and then introduce a significant new solution to the random failures.

Normal Deployment Conditions and Structural Failure

To briefly discuss the easiest of the above items first (#1), remember that any type of structure can be overloaded (a parachute, an airplane, your 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, fatigue, minor assembly errors, minor corrosion during service, etc. However, the random (unknown and/or unpredictable) problems in airframes such as hidden damage, material flaws, incorrect repairs, unauthorized modifications and accumulated slop in the control surfaces cannot be sufficiently quantified or predicted in a manner that allows any reasonable structural margin (that which would allow a practical airplane) 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 huge 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%).

However, even though it is theoretically possible to build a parachute strong enough to withstand all types of malfunctions without catastrophic failure, you could very well end up with a canopy that would kill the user with opening shock. Needless to say, such a parachute would be extremely heavy as well – so much so that many users would find it impossible to get in their airplane with it. 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.

Photo sequence 1 shows a normal opening sequence on a lightweight conical canopy at 130 KIAS with 220-lb. gross weight. This is actually a fairly good opening, even though it does show the asymmetry of the skirt during the inflation process and it also exhibits minor over-inflation and post inflation collapse as seen by the dimpling in frames 1-D and 2-J.

Photo sequence 2 shows the same sequence from the side view. In the side view you can see the classic inflation sequence where 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 referred to as the "top down" mode of opening and is the usual sequence for solid cloth parachute canopies.

Photo 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 the 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.

Random Failure Modes – The Inversion Problem

The parachute industry as a whole has spent years trying to develop parachutes that are structurally sound, damage tolerant, of reasonable weight, highly reliable and with opening characteristics that provide the greatest possible recovery envelope. The main stumbling block has always been the inversion problem and, until now, there has been no practical solution to the problem.

As mentioned above, the random failures are the hardest to manage and are, by nature, unpredictable (except statistically). The inversion type 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 or the BAT Sombrero Slider™ (more details later).

Photo sequence 5 shows a close-up view (video from the tailgate) of a deployment sequence that 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 occurs at the fairly modest speed of 140 KIAS at 220 lbs. – note that this is the manufacturer's recommended maximum limit for the canopy.

Photo 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 enough, the skirt band was not severed by the inversion process, which presumably allowed the subsequent inflation rather than total collapse.

The Origin of Inversions

During the 1970's Bob Calkins, 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 Bob 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 lack of a better descriptive term). Prior to Bob's work, most 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. However, since Bob's study was confined to the 28' military canopy, (a flat circular design) there were presumably quite a few instances of post-inflation collapse. BPS has also seen this phenomena on several occasions while testing C-9's. See photo sequence 7 for an excellent example of the post inflation collapse phenomenon. As valuable as Bob's study was, there was very little follow up in the industry because, although he had revealed the true nature of the problem, no one had suggested 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 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 kts) 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, so there are no guarantees. 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 inversions (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 naturally pretty poor in this case.

Inversions & Reliability

As stated above, modern parachutes are fairly reliable at low and moderate speeds. However, based on experience at BPS in testing a very large number of parachutes (over 350 tests in 1998 alone), 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.

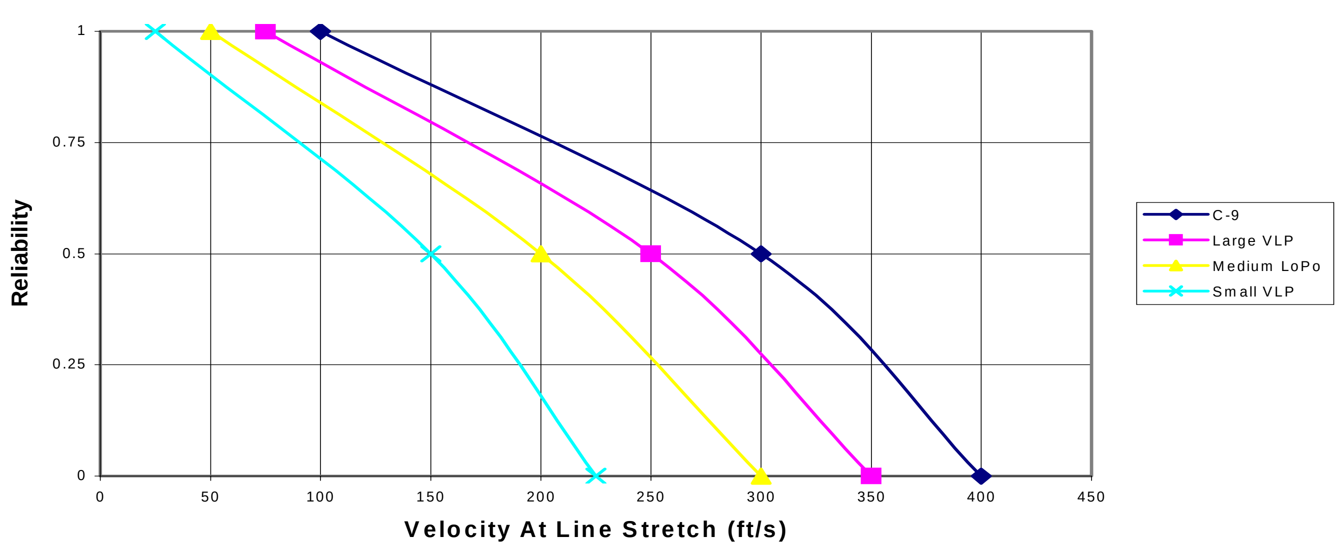
In between the extremes on the reliability curve, things get a lot harder to sort out. For example, I believe that there is a certain velocity (for every parachute design) where a significant increase in inversion type malfunctions occurs. The major factors appear to be the dynamic pressure at line stretch 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 lower limit of the differential force across the skirt occurs with highly porous ribbon type chutes—like the landing drogue on the 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. So, somewhere along the speed range, a significant decrease in reliability will occur—the trick is to find that limit and stay well below it for operational use.

Based on my qualitative feel for the overall experience of the tests that I've conducted, some of the small, very lightweight canopies (NPI/FFE) in use today 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 canopies (such as the BPS XTC-500) have the same problems, but they occur at significantly higher speeds. The medium size Low Porosity Chutes (Strong LoPo for example) 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 like the XTC-500. Military canopies (if equipped with deployment diapers) 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 graph below 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).

Qualitative Representation of Reliability vs. Deployment Velocity



Of course, you have probably deduced that I would not want to discuss all of these problems unless I had a solution to offer. And, as mentioned above, BPS and others have been searching for a practical solution to the inversion problem for years. In addition to solving the inversion problem, we have also been trying to control the opening shock of the canopies so we can go to higher opening speeds without damaging the parachute or the user.

Until now, the only practical solution to inversions has been the "anti-inversion" skirt netting developed by the British in the 1960's. The US Army adopted this technique shortly thereafter for their troop chutes 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.

Now, however, I am very pleased to say that Butler Parachute Systems, Inc. (BPS) and Butler Aerospace Technologies, Inc. (BAT) have jointly developed a simple, elegant solution to the inversion problem. Our invention, the BAT Sombrero Slider™, provides speed and weight sensitive, inherently self-modulating control of the inflation process. It is truly a significant technological breakthrough in parachute inflation control. In fact, we are confident that this device will prove to be one of the most important technologies ever developed in the field of parachute engineering and science. The nickname "sombrero" comes from the appearance of the device, which you will notice in the pictures below.

The BAT Sombrero Slider™ was invented by the author, Manley Butler. A US Patent is about to be issued and additional patent protection is currently pending worldwide. A separate company, Butler Aerospace Technologies, Inc. (BAT), was formed to hold the rights to this invention and to market and license the technology worldwide. The technology will be available to license under the usual sort of commercial arrangements.

In our (admittedly biased) opinion, the ***BAT Sombrero Slider™*** is the ***<u>single most important new parachute technology in decades.</u>*** It is the only device that, by itself, has ever enabled an increase in reliability by several orders of magnitude.

It is the first and only device that:

- 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
- 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

H-X 300 live jump

H-X 500 live jump

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). During assembly, each line is routed to the appropriate grommet on the slider and then to its particular connector link. Some type of slider stop is required on each line; this can be accomplished with rings finger trapped into the lines (ala BPS HX canopies) or some other method that will positively prevent the slider grommets from jamming onto the skirt or hanging up something.

During the opening process, the hemisphere acts like a very small parachute and inflates nearly instantaneously upon exposure to the airflow. 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, just after the point where the slider reaches full inflation, the main canopy itself will still be in the shadow of the slider's periphery (since the main has filled so little at this point).

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 ball. 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.

The BAT Sombrero Slider™ provides speed sensitive, self modulated control of the inflation 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. 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". The equal 'g' condition means that a small person would receive the same deceleration loads as a large person, but not the same absolute load. This has obvious benefits for ejection seats as well as bailout parachutes.

One of effects of the design of the BAT Sombrero Slider is its self-modulation capability. This is evident when looking at drop tests of the same canopy at constant weight but increasing airspeed. If you watch one of the sequences you will discover that the slider stays up against the skirt longer and longer as the speed is increased. This is highly desirable and is easily explained by the aerodynamics of the system and 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 mesh so nicely) the fill rate of the main canopy is 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 $ft.^2 = ft^3/sec$). However, the force holding the slider up against the canopy is a squared function of velocity, as are all other force calculations using airspeed.

Therefore, at very low speeds (say 50 ft/sec ≅ 30 KIAS) there is almost no 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.

In practice, as the main canopy fills at any particular speed, it will reach a momentary equilibrium condition wherein the force holding the slider up is sufficient to prevent further expansion of the main canopy. At the same time airflow into the main canopy will stagnate as the canopy reaches its maximum beach ball condition (for the slider still up). You must remember however, that the entire system (parachute and payload) are 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 and the related canopy factors can be tuned for nearly any result desired. Further design guidance for potential users of the technology may be obtained from BAT.

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. It does add somewhat to the bulk distribution problem encountered with canopies equipped with deployment diapers; however, when a new canopy is designed with the slider in mind, quite often the slider equipped canopy will be equal to or lighter than the same size canopy without the slider.

Now that we've told you how it works, please examine the photo sequences and the captions so you can relate the text to actual deployment events. Photo sequence 8 shows an axis view (from the ground) of a canopy equipped with the slider during inflation. Photo 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.

The H-X Series™ Canopies

The H-X Series™ Canopies from BPS are the first commercially available products utilizing the BAT Sombrero Slider™. The H-X canopies are the most thoroughly tested canopies ever introduced into service and have proven to be the most reliable emergency parachutes ever built. They also have the highest airspeed and weight ratings of any FAA TSO Authorized emergency parachute canopies. During the spring of 1998, Butler Parachute Systems conducted ***over 300 test drops*** for our H-X development program in which, there were ***zero malfunctions and zero structural failures*** while within the design parameters set for the production parachutes. This astounding performance record was made possible by the use of the BAT Sombrero Slider™ (patent pending) on the H-X Series™ Canopies.

The H-X series 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. In fact, the design and operation of the BAT slider makes the occurrence of a line over or partial inversion type malfunction all but impossible.

Table 1 lists the H-X Series™ Canopy sizes and the maximum demonstrated test conditions for each.

Conclusion

We have demonstrated beyond any 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 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.

We are confident that, over the coming years, the BAT Slider will prove to be one of the most significant technology developments in the history of parachutes. Please feel free to contact us to discuss your particular application.

About the Author

Manley Butler 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.

Manley 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 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) in-flight ejection test using a ram-air canopy.

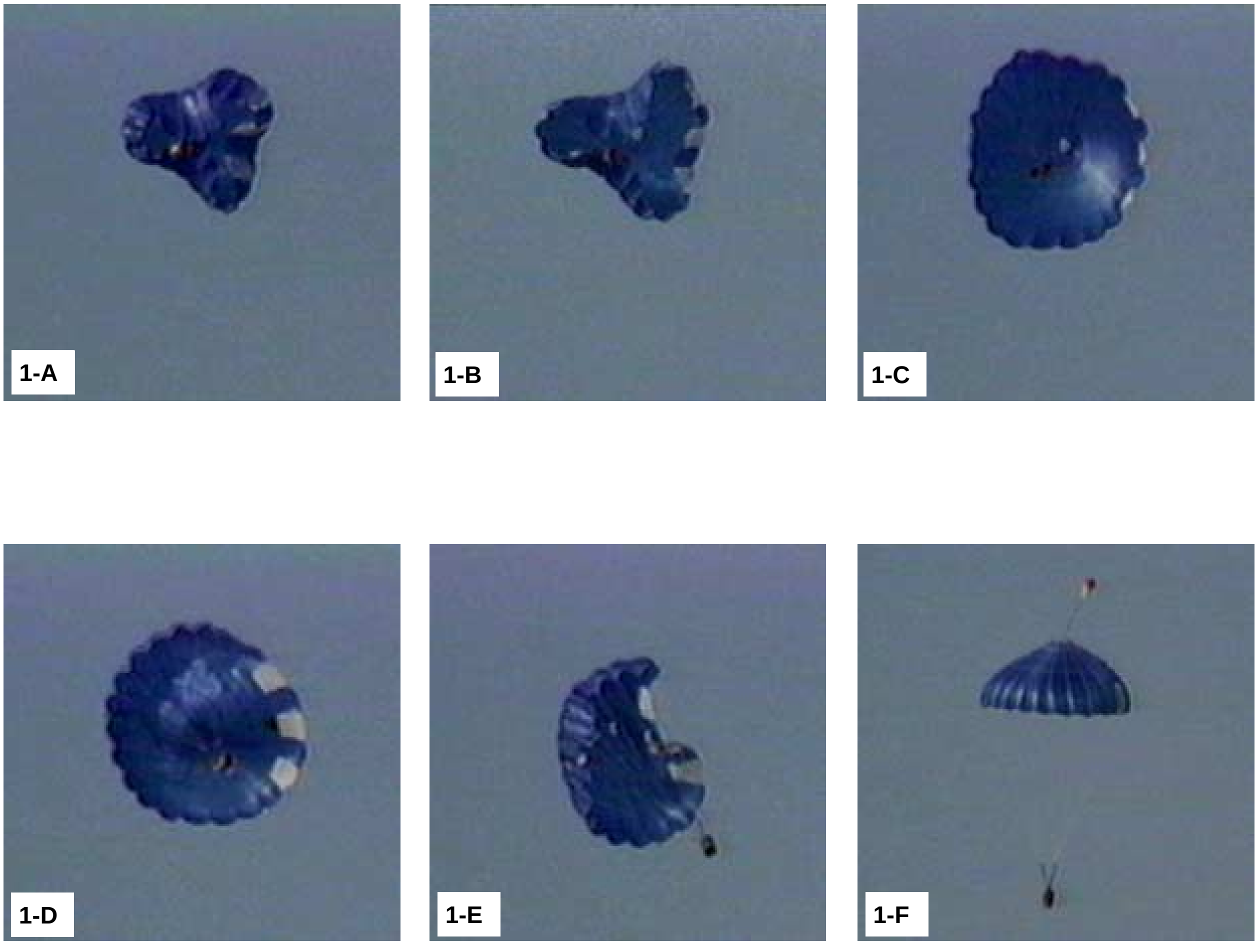
From 1973 through 1988 he made over 1200 jumps, including over 200 jumps on modified 28' military canopies and over 100 test jumps on various BPS products. He has a current FAA Master Parachute Rigger License with all ratings. He is a licensed pilot with experience in a wide variety of aircraft including aerobatics and soaring.

Incidentally, along with his other experience listed above, he is apparently the only parachute systems designer in the parachute industry with any tactical aircrew experience, which gives him a unique and valuable insight into the environment and the problems to be solved.

Table 1 – FAA Approved H-X Canopies

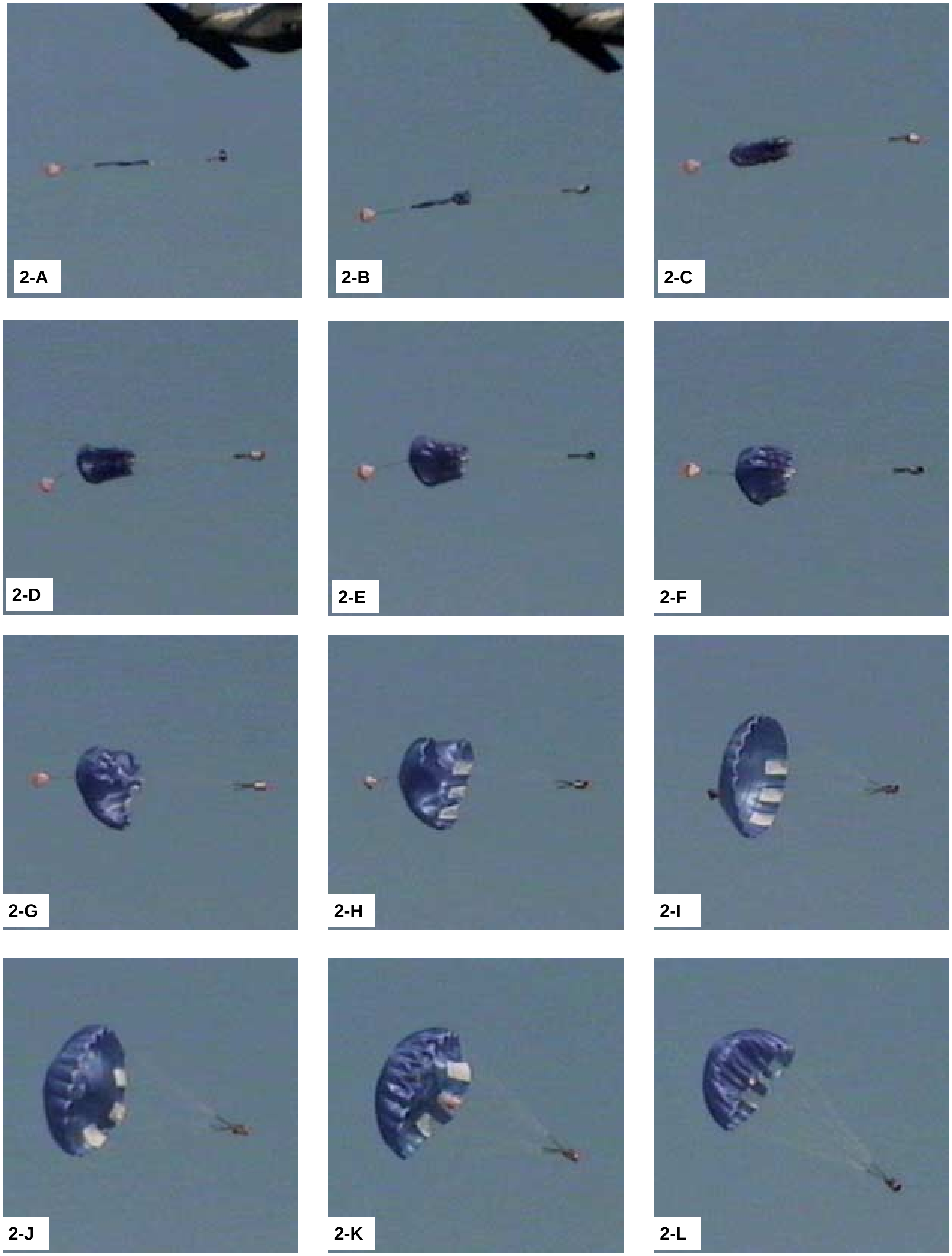
Canopy Designation	Nominal Diameter (feet)	Number of Gores	Surface Area (sq.ft.)	Canopy Weight (lbs.)	Manufacturer's Recommended Maximum Gross Weight	FAA TSO C23d Certificated Maximum Gross Weight	FAA TSO C23d Certificated Maximum Pack Opening Speed	Demonstrated Structural Test Weight @ 180 KEAS	Demonstrated Structural Test Weight @ 205 KEAS
H-X 300	19.56	16	300	5.8	175 lb.	250 lb.	150 KEAS	300 lb.	300 lb.
H-X 400	22.58	18	400	6.4	236 lb.	340 lb.	170 KEAS	408 lb.	400 lb.
H-X 500	25.23	20	500	7.9	306 lb.	440 lb.	170 KEAS	528 lb.	500 lb.
H-X 600	27.64	22	600	9.1	382 lb.	550 lb.	170 KEAS	660 lb.	600 lb.

Photo Sequence # 1



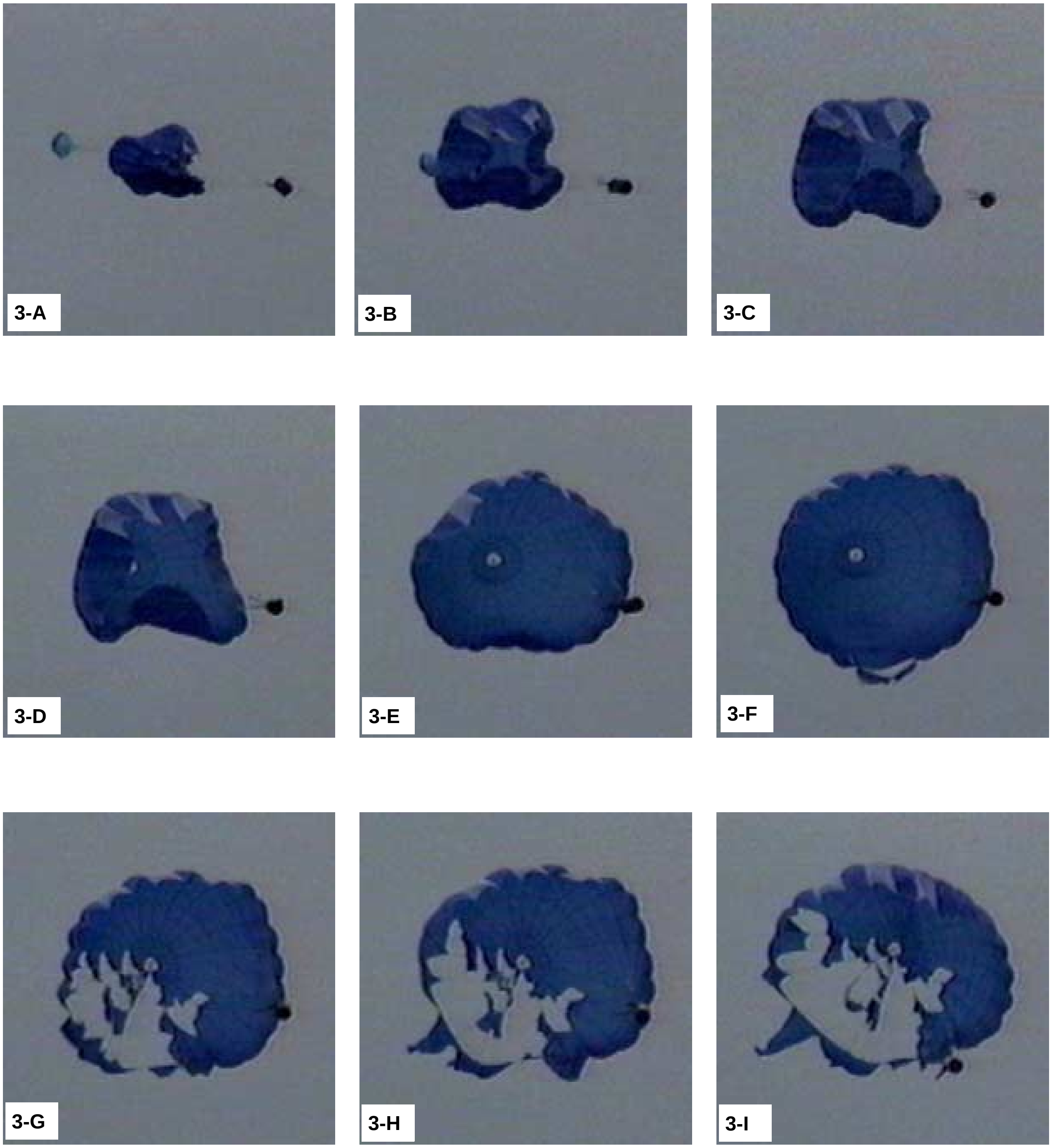
ParaPhernalia/FFE 24' Conical. 130 KIAS @ 220 lb.
Normal opening sequence (axis view)
Same test as sequence #2.

Photo Sequence # 2



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

Photo Sequence # 3



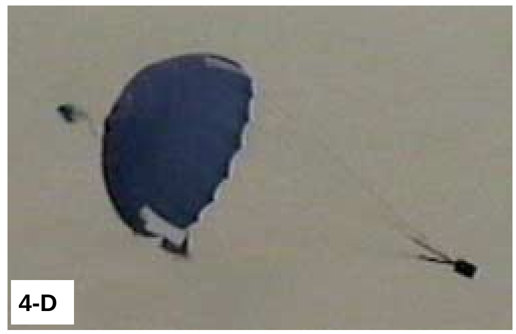
ParaPhernalia/FFE 24' Conical. 180 KIAS @ 300 lb.
Catastrophic failure (axis view)
Same test as sequence #4.

Photo Sequence # 4


4-A


4-B

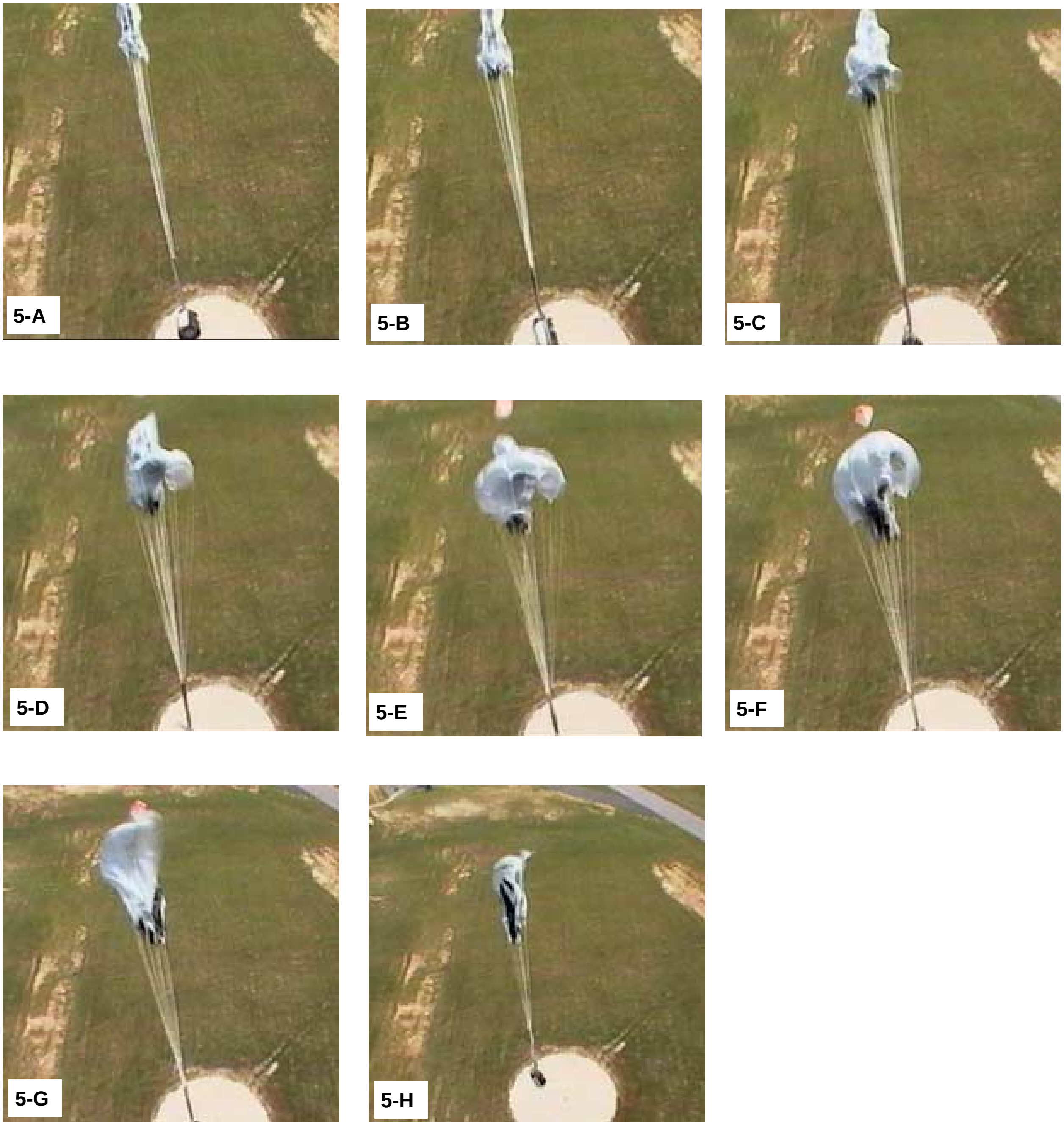

4-C


4-D


4-E

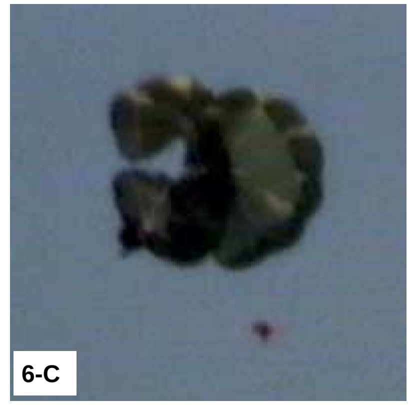
ParaPhernalia/FFE 24' Conical. 180 KIAS @ 300 lb.
Catastrophic failure (side view)
Same test as sequence #3.

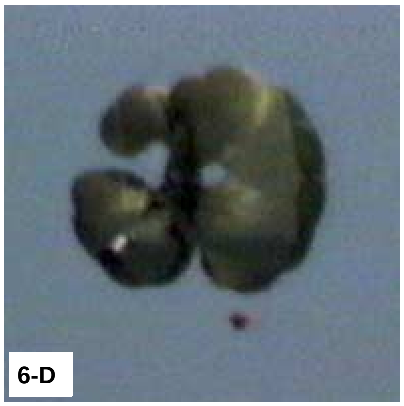
Photo Sequence # 5

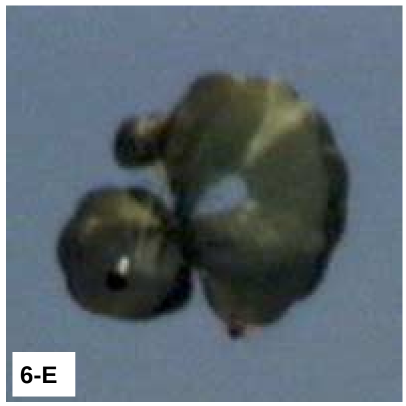


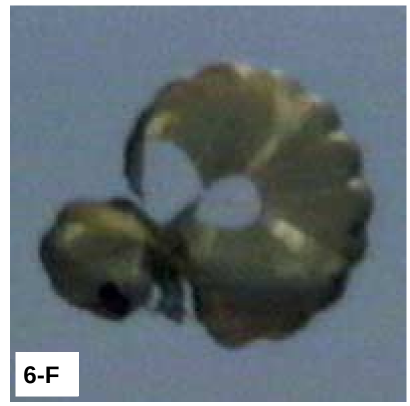
National Parachute Industries Phantom 26.
(National 425) 140 KIAS @ 220 lb.
Catastrophic failure caused by inversion.

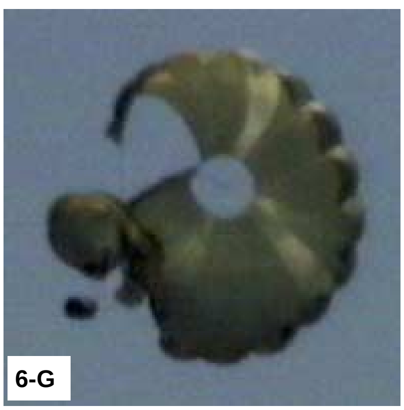
Photo Sequence # 6

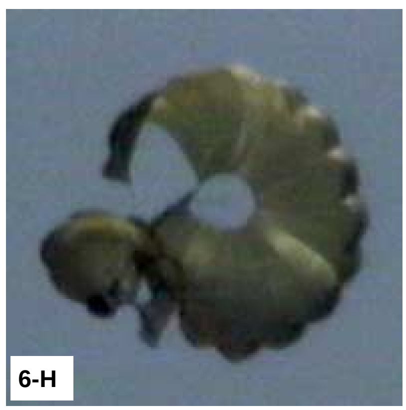


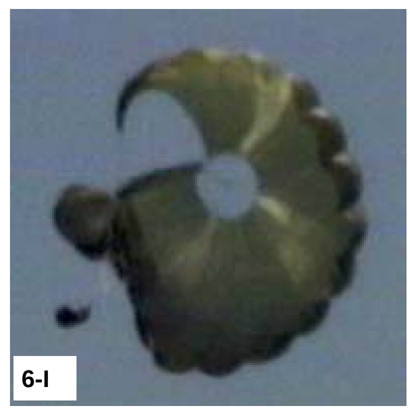


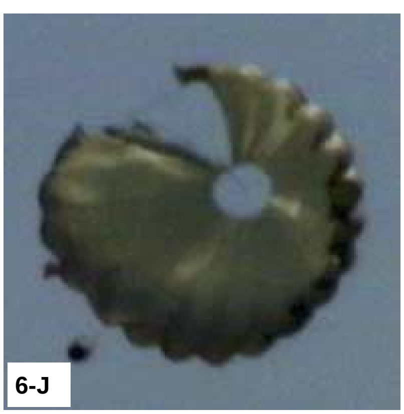






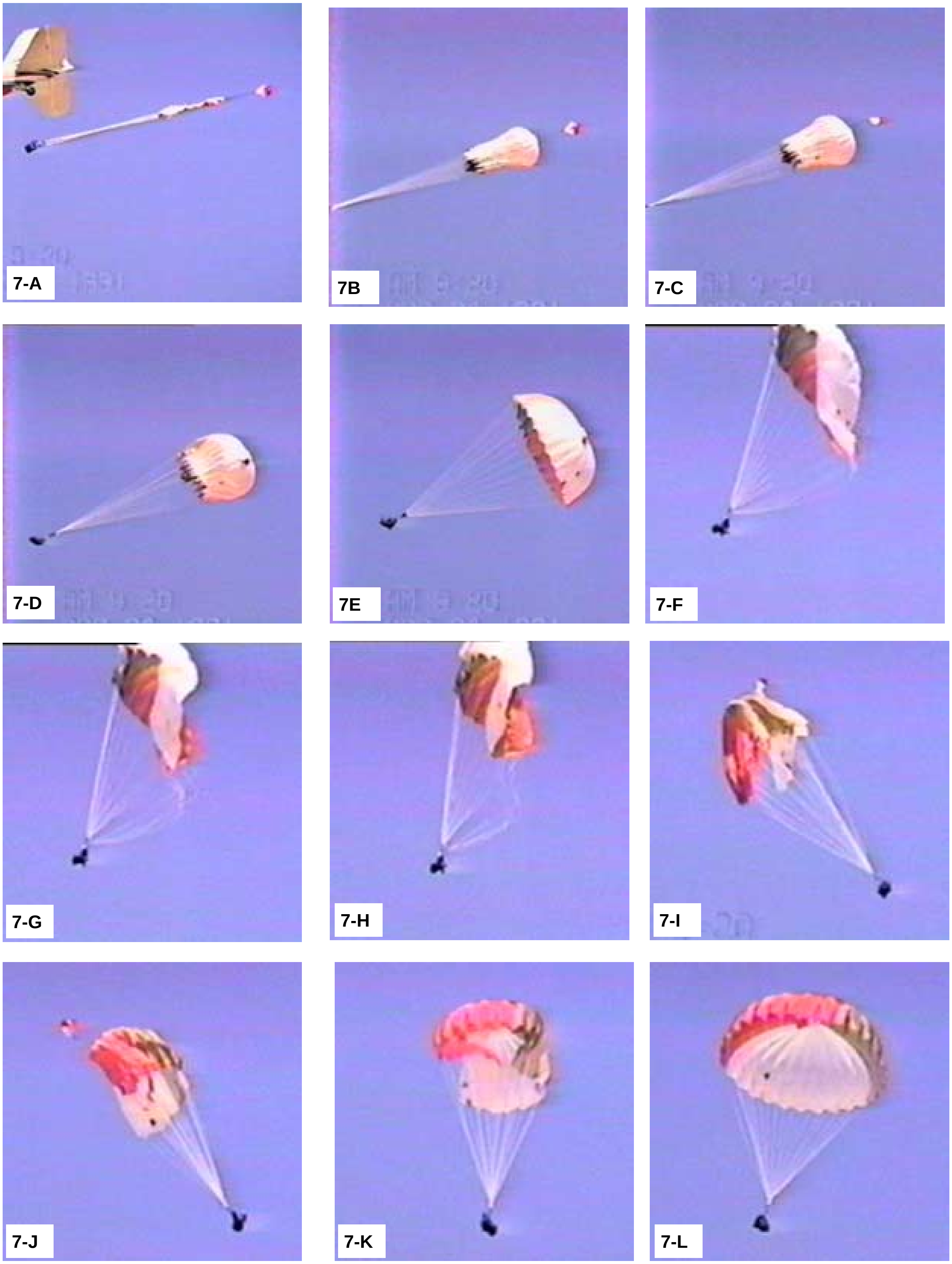






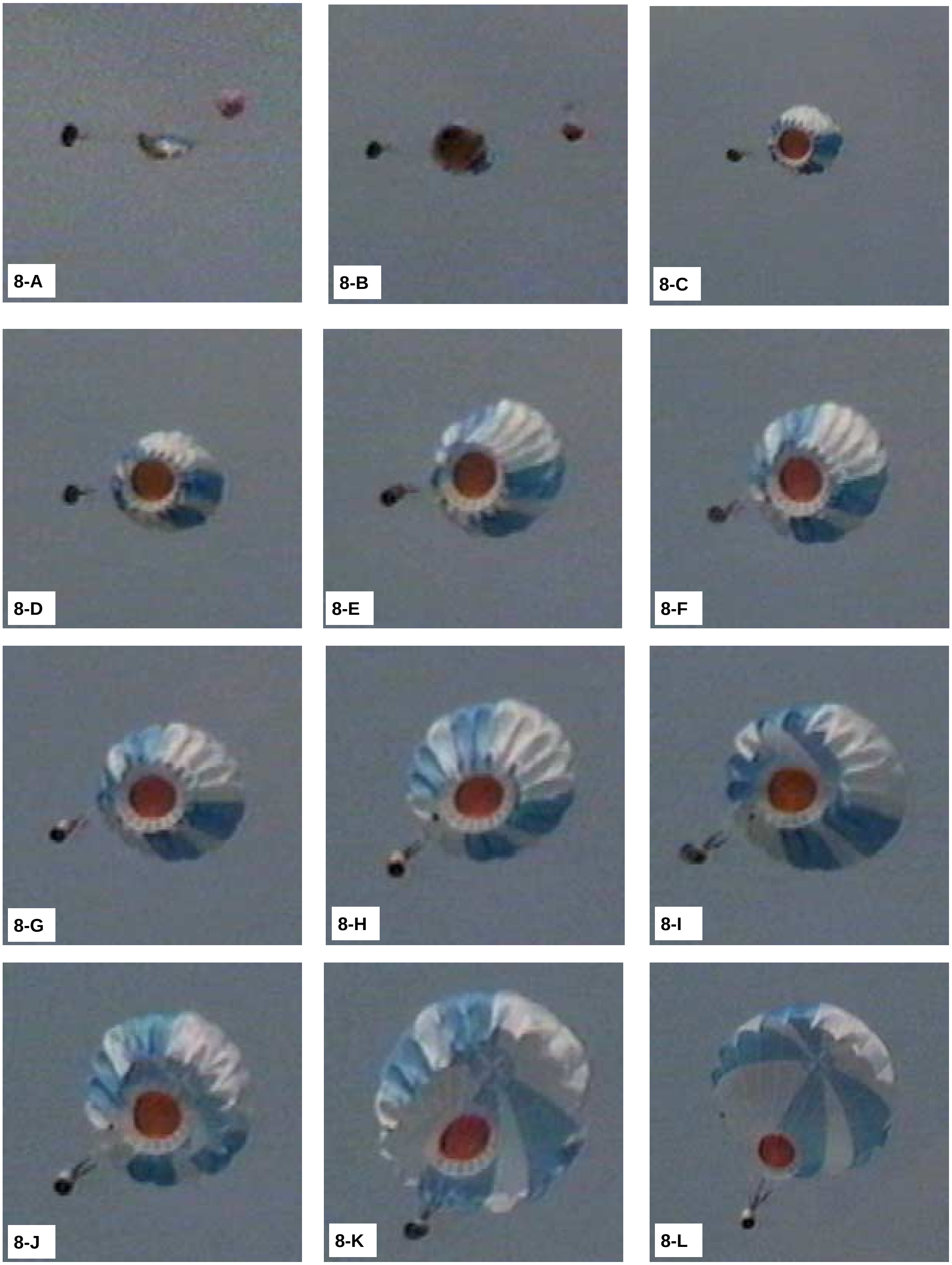
Butler Parachute Systems lightweight 28' Cargo Canopy. 150 KIAS @ 300 lb. Major damage caused by inversion.

Photo Sequence # 7



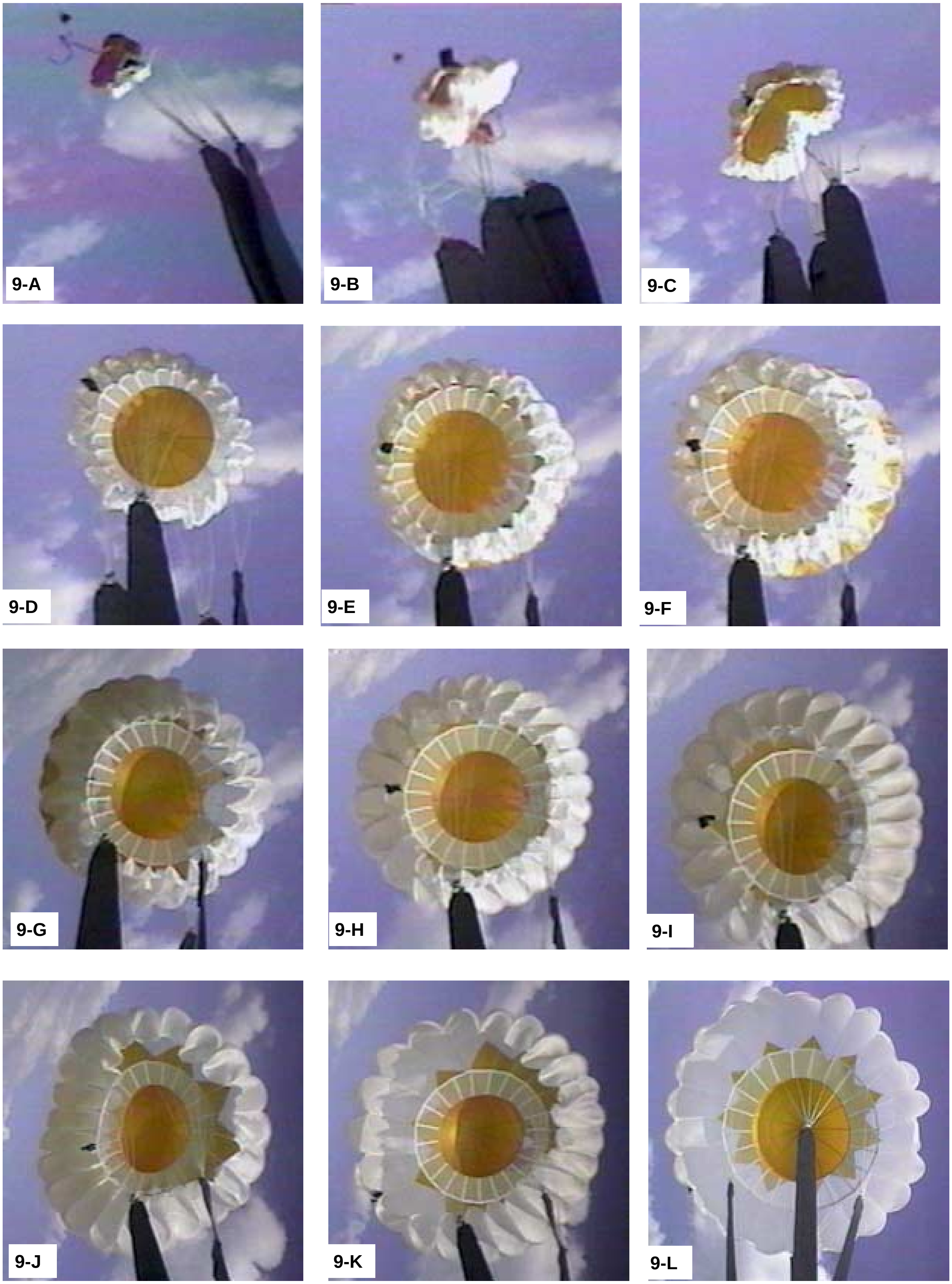
28' military surplus canopy. 175 KIAS @ 300 lb.
Extreme post-inflation collapse.

Photo Sequence # 8



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

Photo Sequence # 9



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