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ADDITIONAL APPLICATIONS OF BAT SOMBRERO SLIDER™ TECHNOLOGY

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ABSTRACT

This paper presents the results of several test programs in the further development of canopies and recovery systems using the BAT Sombrero Slider™. Particular attention is given to work in larger sizes, clusters and heavier weights. A brief summary of other recent uses of the technology is presented, including UAV, personnel, ejection seat and troop parachute applications. The paper is intended to be accompanied by a video which is available from the author.

PERSONNEL PARACHUTES

FAA Authorized Parachutes: Butler Parachute Systems has received FAA TSO C23d Authorization for seven basic canopy models in various configurations. See Table 1 for a listing of these canopies with the operating limitations.

Troop Parachutes: As part of a demonstration project to reduce the opening shock at higher opening altitudes (>7,000 MSL) BPS has successfully demonstrated the use of the Sombrero slider as a retrofit to the US Army MC1-1c steerable troop canopy. The installation did require the removal of the existing anti-inversion netting on the skirt. However, no other changes were required and the modified canopies fit comfortably in the standard deployment bag. In addition to the MC1-1c work, BPS has demonstrated several troop canopy sizes of its own development. Further information on these programs is available from the author.

Ejection Seat Parachutes: BPS was part of a government and industry team that successfully demonstrated three ground level sled ejection tests at the US Navy facilities at Lakehurst, New Jersey. The tests were conducted with T-38 ejection seats provided and supported by the USAF. The parachute systems for the dummy and the seats themselves were provided by Butler Parachute Systems, Inc. The tests were conducted with 50% dummies at speeds up to 250 knots at initiation.

UAV RECOVERY SYSTEMS

BPS has provided UAV recovery systems utilizing the BAT Sombrero Slider for several current programs.

AAI Shadow 200: The US Army Tactical UAV program is based on the AAI Corporation's Shadow 200 air vehicle. The Shadow program is currently in Low Rate Initial Production and late stage operational evaluation. BPS has recorded two saves in this program in the Spring of 2001.

Meggitt Sentry: BPS has also provided a UAV recovery system to Meggitt Defense Systems-Texas (S-TEC) for the Sentry UAV program. For simplicity, Meggitt has selected a system based on the BPS 550 LoPo personnel parachute with the flat version of the slider. BPS has also recorded a save in this UAV program in the Spring of 2001.

G-12 PARACHUTE PROGRAMS

G-12 Program Background: Butler Parachute Systems has recently finished the first phase of work under a US Army Natick R&D contract on the application of this technology to the existing inventory of large cargo parachutes such as the G12d. Tests to date on the G12d have shown significant improvements in initial inflation and time to stable descent.

The current cargo parachutes (G12 & G11) used by the US Army for routine delivery of equipment and supplies are essentially unchanged in nearly 50 years. They have generally proven adequate for use but do have significant operational limitations. For example, a significant constraint is that the cargo drop altitude is typically 1,000 to 1,200 feet above ground level (AGL), whereas the personnel drops are generally in the range of 400 to 500 feet above ground level. This dichotomy in capabilities, significantly increases the risk to the aircraft (by operating at a higher altitude) and to the personnel (by providing a convenient indication of their location). In addition, the current canopies are often used in clusters with the typical results of uneven inflation (causing extreme inter-cluster load differentials), blanketing of canopies, etc. Over the years, many projects have attempted to improve the overall performance of the cargo canopies but, to date, there have been no significant operational improvements (such as lowered drop altitudes, improved reliability, etc.), better inter-cluster consistency, etc.

BPS has successfully demonstrated that the BAT Sombrero Slider (which can be relatively easily added onto the existing canopies) significantly improves all aspects of the opening performance including opening time and altitude requirements, peak opening loads, inter-cluster consistency and overall reliability. The photographs on the next page show the basic layout of the sliders as used on the G12 drops.

BPS/Army Phase A1a Drop Tests: The first work completed under the Natick contract involved the basic proof of concept of adding the BAT Sombrero Slider to the G-12 series of canopies. A total of 10 drops at 1100 lb. gross weight were conducted under this phase. This work was funded by the contract.

BPS G12 Cluster Drop: BPS has internally funded the initial drop test with a cluster of G12 canopies. The parachute assets were provided by Natick. Please see the video capture sequence (non-continuous) from the on-board video in the Appendix.

Yuma Proving Ground G12 Drops: Using some of the sliders manufactured during Phase A1a and existing G-12 canopies on site, YPG conducted three drops in December 2000. YPG riggers installed the sliders and packed the canopies in accordance with directions furnished by BPS. Partial results from YPG test 00-462 are shown below. All three YPG drops were at a gross weight of 1500 lb. at an altitude of approximately 9,000' MSL.

Note that the all of the YPG drops with the sliders exhibited strong oscillations throughout the descent, indicating that the slider may be aggravating the poor stability characteristics of the G12. Drop 462 appears to be the most severe. See the later discussion on stability.

TECHNICAL OUTLINE OF PHASE A1a

The BAT Sombrero Slider™ (US Patent 5,890,678) has proven to be very effective at making conventional round canopies (of all types tried to date) open more consistently and predictably, while limiting the maximum force to the payload. Although most of the work with the BAT Sombrero Slider has been on canopies with low permeability cloth (0 to 5 CFM), it has shown promise when used with canopies of higher permeability (including the C-9 and now the G-12). Further, it shows great promise in expanding the envelope of the G-12 canopy by reducing the minimum altitude required and in reducing the variance in the opening times and altitudes. Butler Parachute Systems has also demonstrated the use of the slider on a cluster of three low-permeability canopies with excellent results (less than 4% load variation).

Because of the potential to retrofit large numbers of canopies in the field, this test program included canopies representative of all three phases of service life (new, mid-time, old) to ensure that the desired opening characteristics are achieved for all applications. This drop test program successfully demonstrated and validated the use of the slider on a single G-12 canopy.

Photo 1. Fully extended slider for a G12 canopy. There is a grommet for each line.

Photo 2. Close-up of the hemisphere illustrating that this particular slider has four radials for each gore in the hemisphere and mesh skirt. BPS typically uses two radials up to about 40' diameter canopies.

G-12 SLIDER DESIGN APPROACH

NOTE: For a detailed explanation of how the BAT Sombrero Slider works, please see AIAA 99-1707, "The Design, Development and Testing of Parachutes Using the BAT Sombrero Slider". This document is available on the BPS web site www.butlerparachutes.com.

The design of the BAT Sombrero Slider provides very good control of the mass flow into the parachute canopy. However, this control is not very useful unless one knows the mass outflow of the canopy. Therefore, BPS requested a detailed survey of the actual cloth permeability of the particular canopies to be tested with the slider. Natick Labs selected three canopies (one new, one mid-time and one old) for examination and conducted detailed permeability measurements of all three canopies. The mapping revealed that there is a very wide range of permeability found in each of the canopies, particularly when one considers that the cloth is supposed to be uniform throughout the canopy. In addition, the high-time canopy shows significantly higher overall permeability than the new and mid-time canopies. The overall average permeability for the new and mid-time canopies was approximately 117 CFM; for the old, it was approximately 148 CFM.

The two main components of the slider as shown in the above photographs are the hemisphere in the center and the mesh skirt. The basic parameters that are manipulated are the equatorial section area of the hemisphere (as a percentage of canopy area) and the area of the mesh (as a percentage of the canopy area). You will note in the above pictures that there are numerous reinforcing tapes on the mesh and the hemisphere. Obviously, the tapes on the mesh influence the effective permeability of the mesh and this is accounted for in the Sombrero design spreadsheet. For most purposes, the open geometry of the mesh used in the slider allows us to ignore its influence and treat the mesh area as an equivalent open area.

MASS FLOW FILL RATE ESTIMATES

Previous BPS tests with the standard USAF/USN 28' C-9 canopy have been conducted in the range of 6-12% mesh with a 1% hemisphere. Based on this, we estimated that the approximate mesh percentage for the G-12 sliders would fall in the range of 8-10%, again with a 1% hemisphere. However, given the wide range of permeability in the three sample canopies, we clearly needed the permeability mapping to refine our first estimates.

Note: For comparison purposes, the BPS HX series personnel parachute canopies (0-5 CFM cloth) generally utilize sliders with 2% hemispheres and 2.5-3.5% mesh.

Experience has shown that we generally need a positive mass inflow rate equivalent to that provided by 0.5-4% of the surface area of the canopy (this number tends to be higher for higher permeability cloth and higher for larger canopies) depending on the opening characteristics desired. For a very rough cut at the mass outflow on the G-12 canopy, we can ignore the vent area (less than 0.25%) as a minor factor compared to the cloth permeability. We can roughly calculate the equivalent geometric porosity from the cloth permeability according to Knacke (§5.5.2) as 1% = 27.4 ft^3/ft^2 at ½" water pressure. Therefore, our coarse estimate (based on the overall average from the perm mapping) would give approximately 4.3% geometric porosity for the new and mid-time canopies (~117CFM/27.4) and 5.4% for the old canopy (~148CFM/27.4). Since we need a solution that is independent of the canopy condition (as long as a particular canopy remains in service), we elected to use the higher number (5.4%) as our baseline. To this we added the 4% fill rate mentioned above and arrived at a target mesh area of 9.4%.

Based on the permeability mapping, our experience with other canopies, and the target value derived above, we selected a fairly wide range of slider mesh percentage (7-11% nominal) in order to "bracket" the reasonable range of values. This allowed us to evaluate the sensitivity of the three samples of the G-12 to the parameters and to ensure that we achieve desirable opening characteristics with one or more of the slider configurations. Accordingly, we selected nominal (& effective) mesh areas of 11%(9.68%), 9%(7.84%), and 7%(6.02%) based on the canopy area (A_o = 3217 ft^2). Note that the hemisphere was set at 1% for all tests in order to evaluate the changes in the fill rate independently from changes in the hemisphere.

The finished sliders weighed in at 10.9-lb. (11%), 9.5-lb. (9%) and 8.1-lb. (7%) respectively. Since the hemisphere is identical for all sizes, one can assume that the mesh and reinforcing tapes make up the differences. Also note that there is one grommet per suspension line (in this case, a #2 rolled rim, spur grommet, brass with nickel plating). Given that the G-12 canopy will typically weight 130-140 lb. without the deployment bag, the weight of the slider itself is not considered significant.

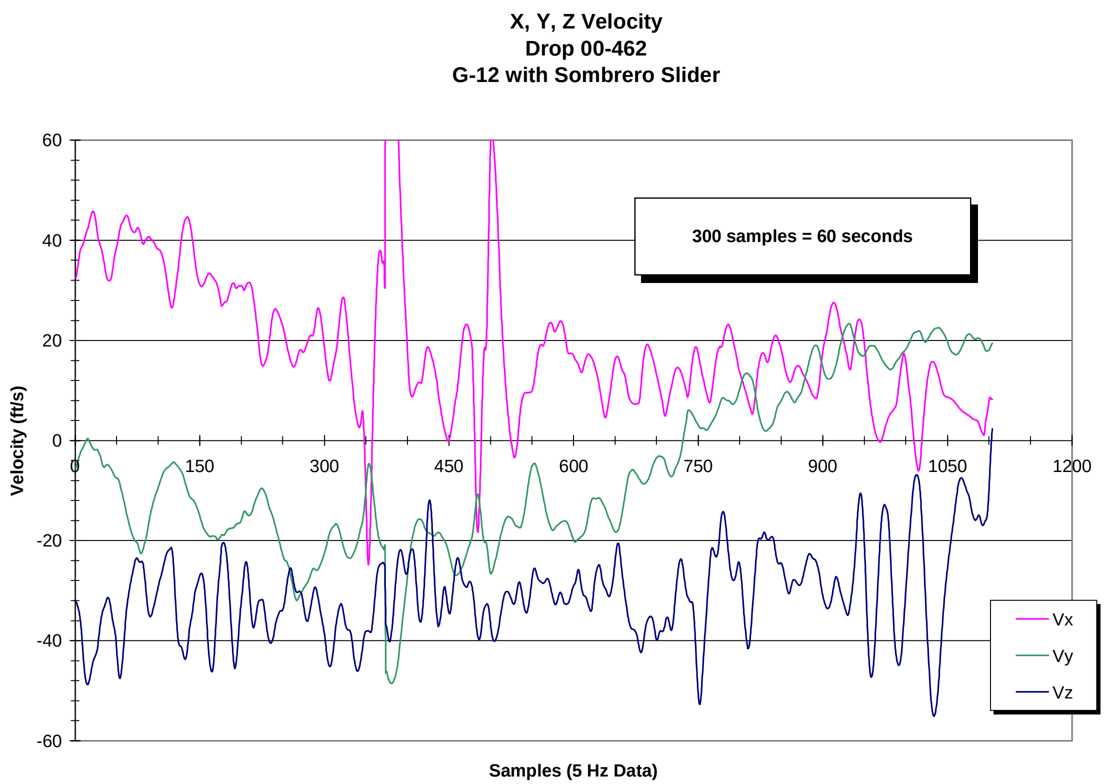
Note that in the early stages of development program like this there was some risk of reaching an "arrested opening condition" somewhere in the test matrix because of the wide range of canopy conditions. Arguably, we did reach this condition on the last test with the old canopy when using the smallest mesh percentage. When reviewing the test video, you can see on test configuration 3 with the old canopy, the slider did not show any tendency to move downward prior to ground impact. However, keep in mind that this test was conducted at only 500 feet above ground level. Furthermore, there is significant drag area even when the slider is still fully up against the skirt (perhaps as much as 50-60% with the G12).

G-12 TEST PROGRAMS

For Phase A1a Butler Parachute Systems conducted a small-scale test program at our usual facilities in Louisburg, North Carolina. For safety and convenience, we performed the initial testing at 1,100 lb. (half the maximum weight rating of the canopy) gross weight. The drop tests were made at various altitudes (see summary table and videotape) at 130-KIAS with two 1,100-lb. test vehicles on each flight. A total of five test flights were made for this program.

In order to conduct this testing as efficiently as possible, BPS originally requested that the Army provide three appropriately qualified riggers to help with the test program. However, due to personnel shortages, only a single rigger was available and only for part of the test program. Therefore, BPS was unable to complete all of the original tests (we had planned to repeat the tests at 150 KIAS) in the allotted time at the drop zone. BPS and Fayard Enterprises provided all other required personnel, facilities and equipment for the drop test program.

BPS used the same facilities and basic procedures to conduct the G-12 cluster drop test program. For the higher weights (2000 lb.) we utilized a standard 15' drogue to extract the payload with a 2-second time delay to release and deployment of the canopy cluster. This system worked quite well for all three heavy drops conducted in May 20001.



SUMMARY OF G-12 TEST RESULTS AND CONCLUSION

A total of ten tests were conducted in the Army funded part of the program. All tests resulted in successful deployment, inflation and opening of the parachute canopy. The first round of tests was conducted at 1000' AGL and the canopies opened so quickly that we repacked the new canopy and dropped it again at 400' AGL (again successfully). The remaining tests were conducted at 500' AGL.

This small scale development and evaluation program has conclusively shown that the BAT Sombrero Slider can be successfully used with the US Army G-12 cargo canopy. Furthermore, G-12 canopies equipped with the slider have shown significant improvement in inflation and opening characteristics and a significant reduction in the total time to full open. Further development of this concept is easily warranted given its ability to improve all areas of the envelope.

Following the successful single canopy drops, a cluster of three G-12s was dropped to conclusively demonstrate the validity of the use of the slider in small clusters.

OTHER BPS CARGO PARACHUTE DROP TEST PROGRAMS

BPS 37' Cluster Drop: In 1999, in cooperation with the Canadian Forces, BPS funded the development and early testing of a cluster of three 37' canopies for a payload of approximately 2,000 lb. suspended weight. For the 1999 tests, we designed a single large deployment bag that contained three individual T-10 deployment bags and the riser extensions for the cluster. This configuration was deployed once with a direct bag static technique; once with a pilot chute (60") technique; and once (May '01) with a 15' extraction drogue method. Although the 1999 tests were successfully completed, we did not obtain very good video coverage. Therefore, we repeated essentially the same test in May, 2001 in order to obtain better video and force data. The force data from the 1999 tests showed less than 5% inter-cluster variation; however, the latest test shows approximately 20% variation from highest to lowest. This can be clearly seen in the on-board video where one canopy is significantly ahead of the other two during initial inflation. See the video capture sequence (non-continuous) from the on-board video in the Appendix.

BPS 77.7' Single Canopy Drop: BPS also funded a demonstration drop test (2000 lb. @ 110 knots) using a single existing canopy left over from the Predator UAV Recovery System Program (see AIAA 95-1673). This is an extended skirt, tri-conical canopy with nylon lines. A slider was designed and constructed for the canopy and installed with no modifications to the canopy itself. It was packed into a standard G12 deployment bag with the usual techniques. The payload was extracted with a standard issue 15' ringslot drogue which was released from the payload by 2.0-second time-delay cutters and then deployed the canopy. This test was nominal except for a pronounced oscillation that did not have time to damp out prior to ground impact. Given that the same canopy was absolutely dead stable on the Predator drop test at the same weight, one must conclude again that the slider may have adversely affected the stability of the system. Note that this canopy was designed for the Predator program for minimum impact energy and has somewhat smaller vents than would otherwise be used. Also note that this canopy will be tested at up to 3500 lb. in the near future without any changes to the configuration. There is a video capture sequence (non-continuous) of this drop in the Appendix

The author is the inventor of the BAT Sombrero Slider (US Patent 5,890,678 & worldwide); he has previously presented data on its use in parachutes of sizes typically used for personnel applications.

ABOUT THE AUTHOR

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,

Table 1. Personnel Canopies

Basis for Limitation ->			(US/FAA)*	(BPS)**	(BPS)**	(US/FAA)*	(BPS)**	(BPS)**	(DOD)***	(BPS)**
BPS Part Number	**BPS Canopy Model**	**Authorized Under FAA TSO C23 Revision**	Maximum Permitted Gross Weight @ 150 KEAS	Maximum Recommended Gross Weight @ 150 KEAS	Maximum Recommended Gross Weight @ 165 KEAS	Maximum Permitted Gross Weight @ 170 KEAS	Maximum Recommended Gross Weight @ 170 KEAS	Maximum Recommended Gross Weight @ 190 KEAS	Maximum Recommended Gross Weight @ 225 KEAS	Maximum Demonstrated Structural Overload
2101-1	350 LoPo	C23d	220 lb.	175 lb.	175 lb.	n/r	n/r	n/r	n/a	264 lb. @ 180 KIAS
2101-2	450 LoPo	C23d	285 lb.	235 lb.	235 lb.	n/r	n/r	n/r	n/a	345 lb. @ 180 KIAS
2101-3	550 LoPo	C23d	350 lb.	300 lb.	300 lb.	n/r	n/r	n/r	n/a	420 lb. @ 180 KIAS
120	XTC-500	C23c, Cat.B	254 lb.	254 lb.	n/r	n/r	n/r	n/r	n/a	300 lb. @ 175 KIAS
3101	HX-300	C23d	250 lb.	175 lb.	175 lb.	250 lb.	n/r	n/r	n/a	300 lb. @ 180 KIAS
3102	HX-400	C23d	340 lb.	235 lb.	235 lb.	340 lb.	235 lb.	235 lb.	n/a	400 lb. @ 205 KIAS
3103	HX-500	C23d	440 lb.	310 lb.	310 lb.	416 lb.	310 lb.	310 lb.	n/a	500 lb. @ 205 KIAS
3106	HX-500/24	C23d	440 lb.	310 lb.	310 lb.	416 lb.	310 lb.	310 lb.	n/a	500 lb. @ 205 KIAS
3104	HX-600	C23d	550 lb.	382 lb.	382 lb.	500 lb.	382 lb.	382 lb.	n/a	600 lb. @ 205 KIAS
n/a	USAF 28'	C23b ***	275 lb.	275 lb.	275 lb.	275 lb.	275 lb.	275 lb.	275 lb.	unknown

NOTES:

* US FAA regulations under TSO C23d allow the parachute to be certificated for any weight up to that which results in a rate-of-descent of 24 ft/sec at sea level. BPS uses this weight to set our requirements for structural overload testing (+20% speed & +2

** BPS recommended weight limits for all canopies (except 28' military) are based on 20 ft/sec. at sea level to reduce the potential for landing injuries. Outside of the US, the manufacturers recommendations become the governing factor. Based on the consis

*** The recommendation for 28' military canopy is based on structural limitations and 24 ft/sec. at sea level (with 4-line release device activated!). US Military parachutes are considered by the FAA to be equivalent to C23b, Standard Category.

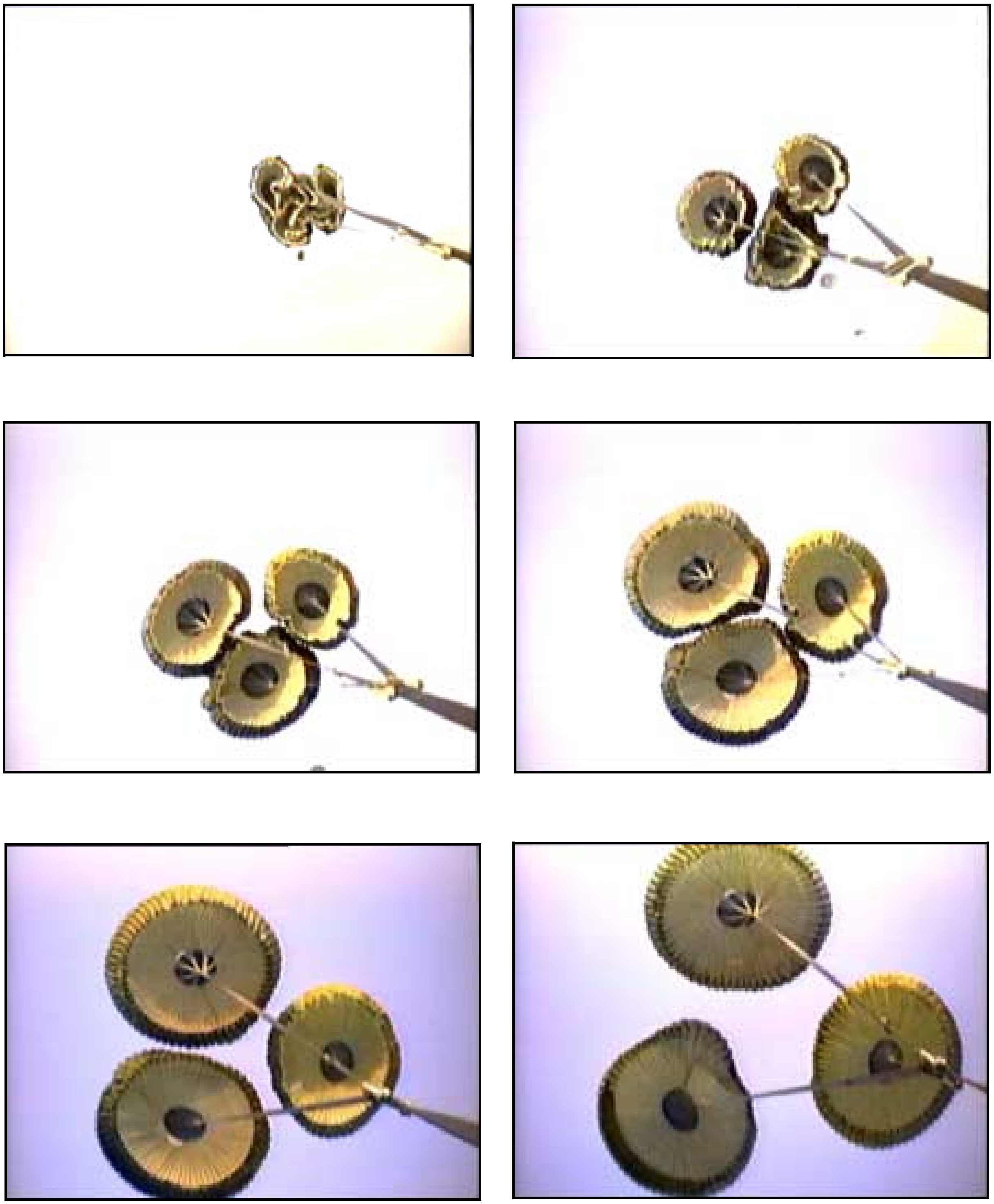
California as a recovery systems engineer and program manager from early 1983 until the end of 1986. One of his projects at China Lake was the first (and so far the only) successful in-flight ejection test using a ram-air canopy.

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.

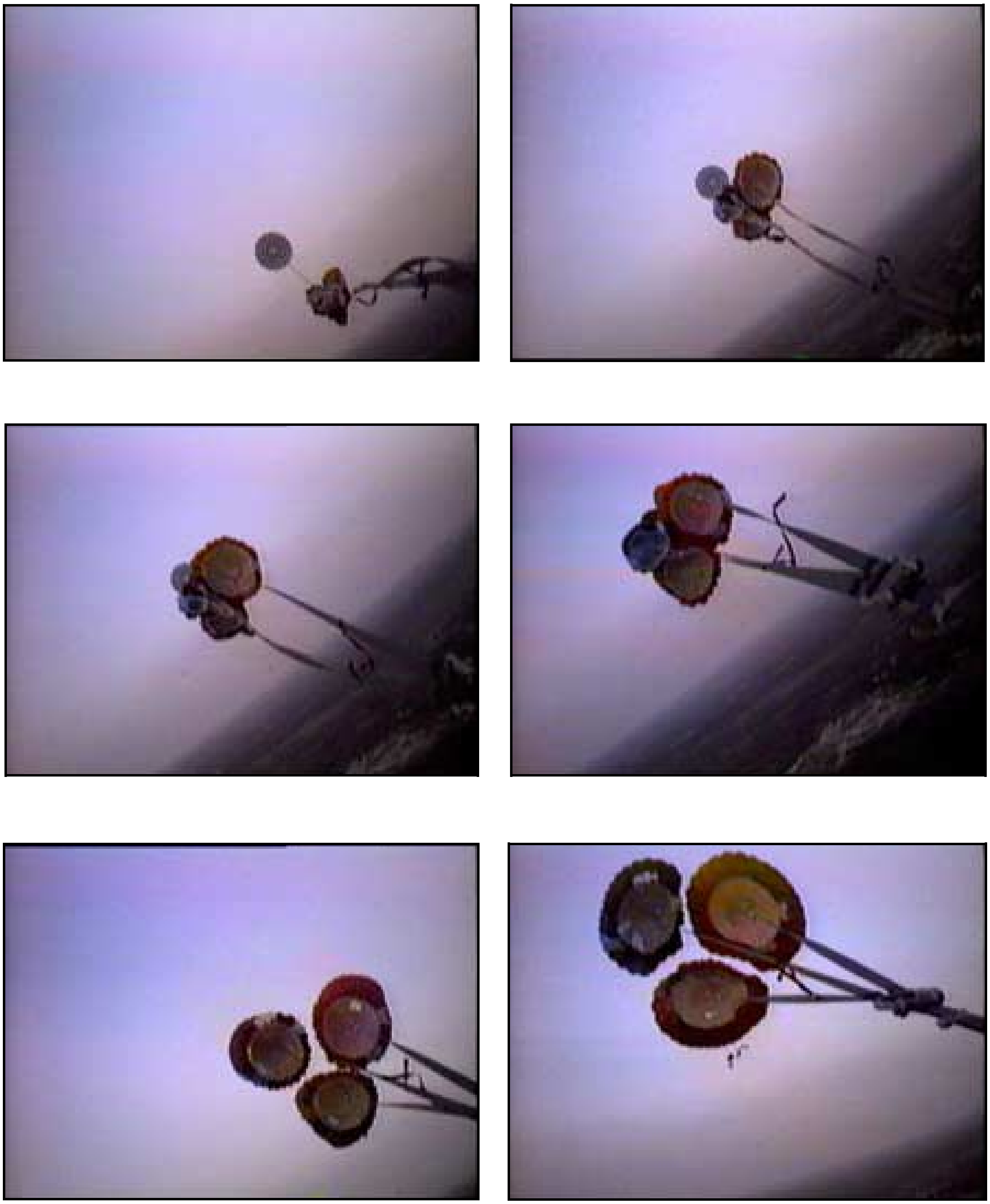
ADMINISTRATIVE NOTES:

- 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.

Video Sequence – G12 Cluster Drop.



Video Capture Sequence for Cluster of Three 37' BPS Canopies
(2000 lb. Suspended Wt. @ 110 KIAS)



Video Sequence for BPS 77.7' Canopy