Zarling Aero and Engineering

June 12, 2000

Jim Raudenbush
Alaska Smoke Jumpers
Bureau of Land Management
Ft. Wainwright, Alaska

Dear Jim

Enclosed with this letter are my findings concerning forces on the three-ring mechanism and freeze times. I hope this information is useful to your investigation.

Jim, I have run the following scenario through my mind as a possible explanation but it has a lot of IFS.

1. If the three-ring release mechanisms used by the two jumpers became wet during their earlier jump on the accident day, and
2. If both mechanisms froze (became stiff) prior to the jumpers pulling their release cords, and
3. If the forces on their harness rings were low (because of pulling the release cord within seconds of exiting the aircraft), then
4. If all these elements are taken together, the result is a possible explanation for the hesitation experienced in the release of three-ring mechanisms.

Sincerely yours,

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Report
Findings on Three-Ring Release Mechanism

1.0 Introduction

On Wednesday May 17, 2000 Jim Raudenbush and Jim Veitch briefed me on the harness and parachute system used by the Alaska Smoke Jumpers. Some details of the fatal accident, which occurred earlier this spring were also discussed. I was informed that the three-ring release mechanism was one of the foci of the investigation. I was given a three-ring release mechanism to examine and experiment with as well as a paper written by Kyle Collins of the Relative Workshop entitled "Advanced Three-Ring Technology". This paper, presented at the 1999 PIA Symposium, discusses the mechanics of the three-ring release system.

The jumpers on the day of the accident were exposed to below freezing temperatures reported to be about 28°F at the 3,000-foot agl (3,500-foot msl) jump altitude. Two of the jumpers, on the accident jump flight, had jumped previously that day and landed in a wet area. On the accident flight one of these jumpers experienced a hesitation on his main chute release mechanism and it is theorized the other jumper, who lost his life, experienced a similar hesitation of his mechanism as well.

As a jumper exits the jump aircraft, his drogue chute is automatically deployed. After the jumper has become stabilized, he pulls his main chute release cord, which releases the three-ring release mechanism. This allows the drogue chute to deploy the main chute. If a hesitation occurs during the action of releasing the main chute, the jumper has been trained to immediately go to his emergency chute. The jumper, when leaving the jump aircraft, decelerates in the horizontal direction because of wind drag and accelerates in the vertical direction because of gravity. Free falling feet first in the vertical direction, would allow the jumper to reach terminal speeds estimated at 130 mph to140 mph (B. Mendenhall, over 3,000 jumps as a skydiver) to 180 mph (B. Fuller, ex U.S. Army Paratrooper). However, with the drogue chute deployed, this terminal speed is reduced to 80 mph to 90 mph (Jim Raudenbush, BLM).

If the air drag were zero on the jumper, then the drogue chute would carry the entire 300 pound load at terminal speed. However, because there is air drag on the jumper, the drogue chute does not carry the total load. The maximum force on the drogue chute and harness ring at

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terminal speed, as shown below, is also function of the jumpers drag coefficient (Higher jumper drag coefficient yields a lower maximum force on the harness ring). Prior to reaching terminal speed with the drogue chute deployed, the force on the harness ring would be less, starting near zero, and increasing with the square of the falling speed of the jumper.

If the jumper with full gear are assumed to weigh 300 pounds, then his drag coefficient-area product are estimated at 6.1 at 140 mph and 3.7 at 180 mph free fall terminal speeds. The drogue chute drag coefficient-area products are estimated at 12.6 and 15 at a drogue chute deployed terminal speed of 80 mph using the 140 mph and 180 mph free fall speeds, respectively. These numbers yield forces on the drogue chute of 202 pounds (140 mph free fall terminal speed) and 240 pounds (180 mph free fall terminal speed) at 80 mph drogue chute terminal speed. These forces are also equal to the forces on the harness ring. I was informed that the force on the harness ring has been measured at 90% to 95% of the jumper's weight. For a jumper and gear weighing 300 pounds, this would be a force of 270 pounds to 285 pounds. My calculations indicate the force on the drogue chute and harness ring are less than that which was measured.

Neglecting the air drag on the jumper, it would take about and 3.6 seconds to reach 80 mph and 6.4 seconds to reach 140 mph (assumed terminal speed) in a free fall. Air drag on the jumper and the drogue chute would increase these times. Numerically solving the governing differential equations of motion including the effects of air drag for the free fall case yields about 4.1 seconds to 80 mph and about 11.6 seconds to 133 mph, which is 95% of the terminal speed. If the drogue chute were deployed immediately at the beginning of the jump, it would take about 6.5 seconds to reach 95% and 9.3 seconds to reach 99% of the 80 mph terminal speed.

2.0 Freezing Experiments

The three-ring release mechanism was wetted with water from the faucet at my home and placed in the freezer and allowed to cold soak for several hours. It was then removed from the freezer and immediately pulled-on with my hands and would not release. It was next allowed to dry for about an hour and placed back in the freezer. After several hours it was again removed and pulled-on. This time the mechanism did release but not as freely as when entirely dry. No attempts to measure moisture contents were made. It is noted that not only does the loop stiffen but the nylon webbing also stiffens when frozen, which all contribute to a higher release force.

3.0 Review of Paper – "Advanced Three-Ring Technology"

The paper by Kyle Collins of the Relative Workshop was reviewed. Measurements of the three-ring release system given to me were made and calculations were performed to determine the relationship between the harness ring and loop forces. It was assumed that in doing these calculations, the geometry was identical to that in the paper with one exception. The paper presents calculated results based on the loop making a 180° pass over the smallest ring. I based my calculations on the loop making a 90° pass over the third ring based on the construction of the three-ring release I was working with.

Measurements from the three-ring release system I was working with are:

Harness ring
OD = 2.25 inches ID = 1.76 inches t = 0.248 inches
Second ring
OD = 1.25 inches ID = 0.871 inches t = 0.188 inches
Third ring
OD = 0.808 inches ID = 0.556 inches t = 0.125 inches

D_2 = 0.360 inches D_3 = 0.980 inches D_4 = 0.160 inches D_5 = 0.682

Beta = 90°, Theta = 0 °, Coefficient of friction assumed at 0.2

Using the above values in Equation (11) of Collins' paper yields the following result

$F_{loop} = 0.1\ F_{harness}$

At a 55-pound harness force, the loop force would be predicted at 5.5 pounds.

It is noted that the three-ring release mechanism I was working with does not have the rings lying in parallel planes as shown in the Collins' paper. The second and third rings are at an angle of about 20° from the plane of the harness ring. Also, the paper neglects friction between the loop and the third ring. This friction force would reduce the release force on the free end of the loop.

4.0 Force Experiments

The three-ring release system was also tested with respect to the harness ring force versus loop force. A five-gallon pail of salt was suspended by the three-ring release attached to a 25-kg spring fish scale, which read

25 kg or 55 pounds. The loop force was measured using a second spring fish scale of 2 pound capacity. The force on the loop ranged from 1.2 to 1.5 pounds with the 55-pound load on the harness ring. This loop force is much less than predicted by the analysis conducted in Section 3.0. Geometric differences and flexibility variations in the nylon webbing (increasing the internal friction of the device) are the most likely explanations. These differences/variations have not yet been pursued.

A force on the harness ring is required to deploy the main chute when the loop is released. Based on the results of the calculations in the Section 1.0, the force applied by the drogue chute on the harness ring varies from near zero early in the jump and then increasing to a steady state maximum at terminal speed. It appears that the maximum force on the harness ring at terminal speed has a lower bound in the 200 pound range "calculated" to an upper bound of 285 pounds "measured". If the same ratio applies between the harness ring and loop forces measured in these experiments, then a force applied to the loop greater than 4.5 to 5.5 pounds at the lower bound and 6.2 to 7.8 pounds at the upper bound would prevent the release of the three-ring mechanism. Prior to reaching terminal speed with the drogue chute deployed, the harness force is less and therefore the loop force necessary to prevent release is less. (It is noted that if the loop force is to high, then "pull through" of the release cord through the grommet is possible.)
Using the drag coefficient-area product of 12.6 yields the following forces on the harness ring as a function of time after the jumper exits the airplane: 90 pounds at 3 seconds, 174 pounds at 6.0 seconds and 197 pounds at 9.0 seconds (Note: the maximum force is 202 pounds at the 80 mph terminal speed for this case.)

5.0 Freezing Time Calculations

The freezing times of the loop have been estimated based on 50% and 10% moisture content by volume. The thermal conductivity of the nylon was estimated based on the values given for nylon resin in the Handbook of Applied Engineering Science to be similar to ice (k = 1.3 BTU/hr-ft-F°). Experiments should be made to determine the amount of water that can be absorbed by the nylon loop as well as the webbing in the three-ring release mechanism. Along with these experiments, the "stiffening effect" caused by this water when frozen on/in the webbing and loop materials may help address a possible cause of hesitations that reportedly occur in three ring release mechanisms. The freezing times reported in the table are based on wind speeds of 15 mph, 60 mph, and 120 mph over the loop and an air temperature of 28°F. The freezing times were estimated for one-sided freezing (freezing from one side only) and two-sided freezing (freezing occurring from both sides) of the loop. The thickness of the loop was measured at 0.044 inches and the width of the loop measured 0.21 inches. The heat transfer coefficients are based on flow over a flat plate for the 60-mph and 120 mph conditions. The standard ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) heat transfer coefficient was used for the 15-mph wind.

Estimated Freezing Times of the Loop at 28°F

Wind Speed Mph	One Sided Freeze Time, sec. 10% Moist.	One Sided Freeze Time, sec. 50% Moist.	Two Sided Freeze Time, sec. 10% Moist.	Two Sided Freeze Time, sec. 50% Moist.
15	460	2300	230	1150
60	57	290	28	140
120	45	223	21	106
Infinite	4.8	24	0.96	4.8

If the outdoor temperature were 24°F at the jump altitude, then the estimated freeze times would be one half of the values in the Table above. The Table below presents the freezing times recalculated at 24°F.

Estimated Freezing Times of the Loop at 24°F

Wind Speed Mph	One Sided Freeze Time, sec. 10% Moist.	One Sided Freeze Time, sec. 50% Moist.	Two Sided Freeze Time, sec. 10% Moist.	Two Sided Freeze Time, sec. 50% Moist.
15	230	1150	115	575
60	28	145	14	70
120	23	112	11	53
Infinite	2.4	12	0.48	2.4

6.0 Statistical Analysis of Release Times

It is believed that the distribution of release times for the three ring release mechanism would follow a positive skewed distribution, i.e. a distribution that is asymmetric about the mean. A positive skewed distribution would have a tail extending further from the positive side of the mean. The skewness of a distribution can be determined. Most spreadsheet programs have built-in functions to perform this task. Actual data on release times would be required to calculate a mean, standard deviation, and skewness of the data. The mean and standard deviation values would have dimensions of time (seconds).