Evaluation of a Helicopter Rescue Basket for Safe Human Carriage

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Abstract: Background: Expeditious aerial evacuation of civilians with helicopters is limited by the inability to extract more than one person with a helicopter rescue hoist. The small cabin size also limits the number of evacuees (5-6) to be carried to safety on each flight, and often results in long-term separation of families. A 15 person capacity helicopter rescue basket (Precision Lift Heli-Basket HB-2000) was recently provided to US Army Guard and Air Guard HH-60 helicopter units through a Congressional plus-up. Objective: Evaluate the Heli-Basket during flights while tethered to an HH-60 to determine the potential of injury to the occupants during all phases of flight (take-off, transport, and landing). Methods: A large and a small anthropomorphic manikin were placed in the Heli-Basket along with instrumentation to measure manikin and basket accelerations, rotations, velocity, and heading. Tests were supported by the 106th Rescue Wing (RQW), F.S. Gabreski Air National Guard, Long Island, New York. Data were analyzed against injury criteria to determine the probability of injury during several test flights. Results/Conclusions: The Heli-Basket was relatively stable, and analysis indicated that there was minimal probability of injury during all phases of flight.

Purpose: The purpose of this study and analysis is to determine if the Precision Airlift, Inc. Heli-Basket HB2000 can be certified for human carriage. This Congressionally mandated piece of equipment was bought for both the Army and Air National Guard. The US Army Soldier Systems Center (Natick Laboratories) did extensive flight testing and certified the Heli-Basket only for cargo carriage. The Air National Guard (ANG) Rescue Wings have articulated a Homeland Defense requirement to provide short range "water rescue" and "high rise building" emergency human carriage capability using the Heli-Basket.

Objectives: The following are the objectives of the study:

a. To determine if the Heli-Basket is safe for human carriage

b. To define the operational limits of the Heli-Basket for human transport

Test Overview: The Air National Guard Air Force Reserve Test Center (AATC) managed the test program which was conducted at, and supported by, the 106th Rescue Wing (RQW), F.S. Gabreski ANGS Suffolk CO., New York. These tests were part of the first of two test phases for this system, which consisted of flight profiles flying instrumented manikins in the Heli-Basket at various speeds, altitudes, and test configurations. Data collected during these tests included manikin chest acceleration and rotational rates, Heli-Basket Euler angles and velocities, and video documentation data. The data were analyzed to certify that a human passenger would not have been injured throughout the various flight profiles.

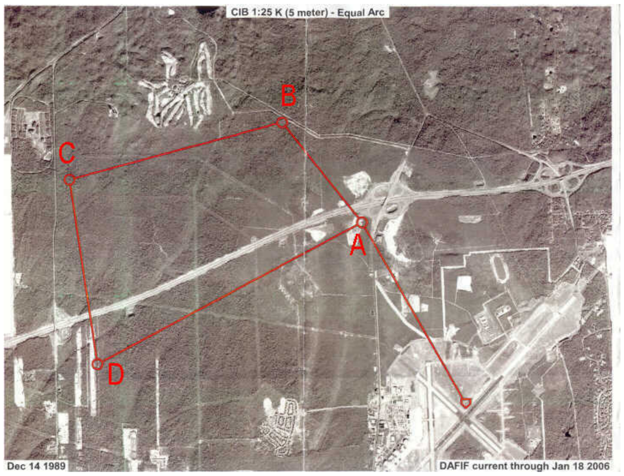

Figure 1. Flight Route

A total of five sorties were flown at various flight conditions to evaluate the stability and acceleration safety of the Heli-Basket. Three phases of flight were examined for stability and acceleration safety of the Heli-Basket: flights encompassing rectangular circuits, landings, and takeoffs. The flights through the circuits (Figure 1) were conducted at air speeds of approximately 20, 40, 60, 80, and 100 knots, with various payload configurations (Figure 2) including a 103-lb Lightest Occupant In Service (LOIS) manikin and a 218-lb Large Advanced Dynamic Anthropomorphic Manikin (ADAM) manikin. The manikins were secured in the basket with lap belts. The takeoffs and landings were either on a hard surface such as concrete or a soft surface such as grass. For a description of each test condition or "cell", see Table 1 below.

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Figure 2. Test Setup

Table 1. Test Cells

Cell	Velocity (KEAS)	Floats	Altitude (feet agl)
A	20	NO	500
B	40	NO	500
C	60	NO	500
D	80	NO	500
E	100	NO	500
AF	20	YES	500
BF	40	YES	500
CF	60	YES	500
BF1	40	YES	9000
CF1	60	YES	9000
LG	0		Landing Grass
TG	0		Take Off Grass
LC	0		Landing Concrete
TC	0		Take Off Concrete

Data Processing: Data collected during the flights included manikin accelerations and angular rates using the LOIS-manikin-mounted digital Data Acquisition System (DAS), Heli-Basket position and velocities using an Embedded GPS/INS (EGI) system, and standard digital video from a camera mounted in the Heli-Basket, pointing at the manikins. Each of these three systems had its own timing system which had to be correlated against each other. The DAS had a time reference with respect to the triggering of data collection as well as an IRIG time (days, hours, minutes, and seconds) with respect to GMT. The EGI system logged the data against day-seconds, which is the number of seconds that have passed since the beginning of the current day at the Prime Meridian (GMT). The video digital time display was synchronized to an atomic clock, but to local time (GMT – 5). The data on the DAS were collected at 1000 Hz, and on the EGI at 16 Hz for periods up to 52 minutes. This resulted in large amounts of data from each sortie for a variety of test conditions. In order to make the data manageable and to easily identify discrete test conditions, data were parsed out of the total data set from each of the five sorties and organized into discrete test numbers and test conditions (Table 2).

Table 2. Text Matrix

Test	Cell	Vel. KEAS	Payload	Float	Alt. feet	Sortie
1	TG	0	LOIS	NO	0	1
2	A	20	LOIS	NO	500	1
3	B	40	LOIS	NO	500	1
4	LG	0	LOIS	NO	0	1
5	TG	0	LOIS	NO	0	1
6	LG	0	LOIS	NO	0	1
7	TG	0	LOIS	NO	0	1
8	LG	0	LOIS	NO	0	1
9	TG	0	LOIS	NO	0	1
10	LG	0	LOIS	NO	0	1
11	TG	0	LOIS	NO	0	1
12	TG	0	LOIS	NO	0	2
13	C	60	LOIS	NO	500	2
14	C	60	LOIS	NO	500	2
15	D	80	LOIS	NO	500	2
16	D	80	LOIS	NO	500	2
17	E	100	LOIS	NO	500	2
18	E	100	LOIS	NO	500	2
19	LC	0	LOIS	NO	0	2
20	TC	0	LOIS	NO	0	2
21	LC	0	LOIS	NO	0	2
22	TC	0	LOIS	NO	0	2
23	LG	0	LOIS	NO	0	2
24	TG	0	LOIS	NO	0	2
25	LG	0	LOIS	NO	0	2
26	TG	0	LOIS	NO	0	2
27	LG	0	LOIS	NO	0	2
28	TG	0	LOIS	NO	0	2
29	LC	0	LOIS	NO	0	2
30	TC	0	LOIS	YES	0	3
31	AF	20	LOIS	YES	500	3
32	BF	40	LOIS	YES	500	3
33	CF	60	LOIS	YES	500	3
34	CF	60	LOIS	YES	500	3
35	CF1	60	LOIS	YES	9000	3
36	BF1	40	LOIS	YES	9000	3
37	TC	0	L+A+B	YES	0	4
38	CF	60	L+A+B	YES	500	4
39	CF	60	L+A+B	YES	500	4
40	BF	40	L+A+B	YES	500	4
41	AF	20	L+A+B	YES	500	4
42	LC	0	L+A+B	YES	0	4
43	TC	0	L+A+B	NO	0	5
44	LC	0	L+A+B	NO	0	5
45	TC	0	L+A+B	NO	0	5
46	LC	0	L+A+B	NO	0	5
47	TC	0	L+A+B	NO	0	5
48	LC	0	L+A+B	NO	0	5
49	TC	0	L+A+B	NO	0	5
50	LC	0	L+A+B	NO	0	5
51	TC	0	L+A+B	NO	0	5
52	C	60	L+A+B	NO	500	5
53	B	40	L+A+B	NO	500	5
54	LC	0	L+A+B	NO	0	5

*L+A+B = LOIS + ADAM + Ballast

Takeoffs and Landings: The takeoffs and landings were treated as discrete events, so the DAS and EGI data were time shifted so that the event (takeoff or landing) occurred at time = 0. The data from the takeoffs were processed from 2 seconds prior to the liftoff to 8 seconds after liftoff, and the data from landings were processed from 6 seconds prior to landing to 4 seconds after landing. The DAS data were filtered at 200 Hz and reduced to an output rate of 500 Hz, and the EGI data were processed using no filtering and the native 16 Hz sample rate.

These data were analyzed against impact injury criteria that were developed primarily for ejection seat evaluation and crash load analysis using AnalyzeTest Version 0.0.18 software that was developed in-house (AFRL/HEPA). The injury criteria included the Dynamic Response (DR) model for 5 axes (+/-X, Y, +/-Z), Multi-axial Dynamic Response Criteria (MDRC), and analysis of a moving average on the chest accelerations. The limits for the DR and MDRC correspond to approximately 0.5% probability of injury, and each of these criteria are shown in Table 3 below along with the extrema values from all of the tests conducted.

The analysis from the tests indicates that the accelerations encountered during takeoffs and landings result in a minimal probability of injury due to the acceleration. Further analysis of the injury results using a One-way ANOVA were conducted to determine if there were statistically significant differences between test variables such as the manikin size, landings on concrete versus grass, effect of total weight, etc (Table 4).

Table 3. Injury Limit Criteria and Test Results

Injury Criteria	Limit		Test Data	
	Min	Max	Min	Max
DRX	-28	35	-3.06	3.28
DRY	-15	15	-3.67	4.04
DRZ	-13.4	15.2	-2.70	5.77
MDRC	N/A	0.8		0.35
Chest X (g)	-35	35	-2.21	3.13
Chest Y (g)	-15	15	-2.62	1.54
Chest Z (g)	-20	25	-0.92	7.98
Chest Resultant (g)	N/A	25		8.24

The results of the statistical analysis of the MDRC and Resultant Chest Acceleration (Table 4) indicate that there is a greater probability of injury when landing on concrete versus grass (p = 0.0214), and that there is a greater probability of injury when landing with a heavy load versus a light load (p = 0.0072). The effect of the

Table 4. Injury Limit Statistical Results

Effect	Conditions	p	Cell	MDRC Mean	MDRC Std.Err.	Resultant Mean	Resultant Std.Err.
Grass/Concrete	LOIS Only, Landing Only	0.0214	Grass	0.12	0.026	2.23	0.66
			Concrete	0.24	0.023	5.11	0.58
Weight Effects, Landing	LOIS Only, Landing Only	0.0072	Light	0.14	0.021	2.86	0.59
			Heavy	0.27	0.028	5.50	0.76
Weight Effects, Takeoffs	LOIS Only, Takeoffs Only	0.0624	Light	0.10	0.007	1.64	0.16
			Heavy	0.10	0.010	2.02	0.23
Manikin Effects	Concrete Only	0.0498	LOIS	0.17	0.021	3.51	0.46
			L-ADAM	0.16	0.026	2.54	0.56
Takeoff versus Landing	LOIS Only	0.0013	Takeoff	0.10	0.015	1.77	0.37
			Landing	0.19	0.016	3.85	0.40

Table 5. Heli-Basket Stability Indices

	Velocity (knots)	20	40	60	80	100
Average Pitch Angle (deg)	LOIS	-8	-24	-39	-48	-52
	LOIS Float	-2	-31	-49		
	LOIS/ ADAM		-23	-33		
	LOIS/ ADAM/ Float	-11	-18	-25		
Average Roll Angle (deg)	LOIS	4	18	36	44	51
	LOIS Float	1	14	29		
	LOIS/ ADAM		-11	-15		
	LOIS/ ADAM/ Float	-4	-6	-13		
Max Heading Oscillation +/- (deg)	LOIS	30	10	18	15	17
	LOIS Float	140	70	13		
	LOIS/ ADAM		8	10		
	LOIS/ ADAM/ Float	50	40	4		

payload weight on the probability of injury during takeoffs was not statistically significant (p = 0.0624). Analysis of the accelerations seen on the heavier manikin (Large ADAM) and the small manikin (LOIS) indicates that a smaller occupant has a slightly greater probability of injury than a large occupant (p = 0.0498). The statistical analysis also indicates that there is a greater probability of injury during the landing than during takeoff (p = 0.0013). However, it should be noted that the injury analysis for even the worst-case tests were well below the established injury limits.

Analysis of Circuit Flights: Data were also extracted from each circuit for each test condition. Flying a complete circuit could take up to 18 minutes to complete depending on the speed of the test. The data from both the DAS and EGI were converted to day-seconds and the DAS data were filtered at 20 Hz and reduced to 40 Hz, and the EGI data were again kept unfiltered and at the native sample rate of 16 Hz. The trim and stability were evaluated by examining the pitch and roll average angles and deviation or oscillation in the Heli-Basket heading (Table 3) and by examining the test videos.

As one would expect, the greater the velocity, the greater the magnitude of the trim angles. Note that although the roll angles change with velocity, this is due to the fact that the Heli-Basket yaws during flight, and as the velocity increases, the basket lags behind the helicopter resulting in an apparent roll angle. The effects of velocity, payload, and the flotation devices on the average pitch and roll angles are illustrated in Figures 3 and 4 below. These figures indicate that as the velocity increases to 100 knots, the pitch and roll angles increase to -52 and 51 degrees respectively. The figures also indicate that the addition of the flotation devices to the low weight conditions (LOIS alone) reduces the yaw during flight, thereby resulting in the system increasing in pitch but decreasing in roll. Increasing the weight by the addition of the Large ADAM and 600 lbs of ballast tends to reduce the magnitude of the pitch and roll trim angle.

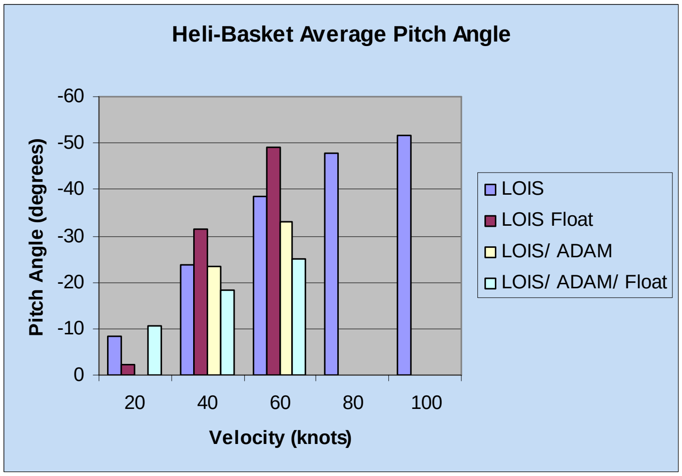

Figure 3. Heli-Basket Average Pitch Angle

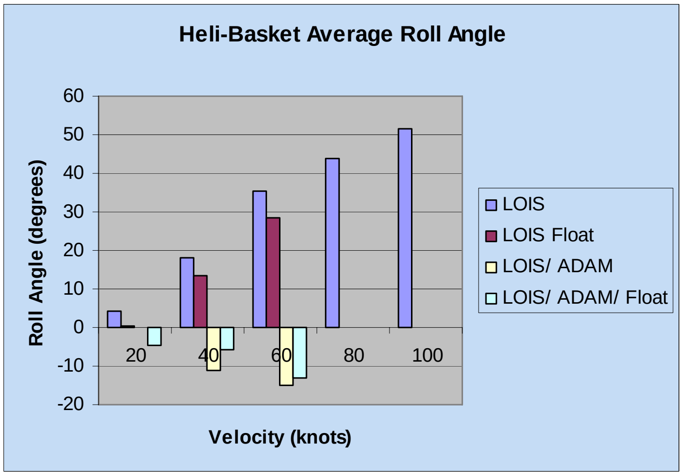

Figure 4. Heli-Basket Average Roll Rate

Examination of the data collected on the Heli-Basket during the flights through the rectangular circuits indicates that the Heli-Basket is extremely stable with a few exceptions (Figure 5). The Heading Oscillation in Table 5 shows the relationship between the test conditions and the peak-to-peak oscillation angles. In general, the Heli-Basket had minimal rotational oscillations during flight, with typical rotations limited to +/- 10 degrees in pitch and roll, and +/- 25 degrees in yaw (heading), with low rotational rates typically less than 15 degrees per second. However, the lightweight configuration (a single 103-lb manikin) with the flotation system produced greater rotations and higher rates, especially at 20 knots. In this configuration, the Heli-Basket headings varied by +/- 140 degrees (Figure 6) with rates up to 41 degrees per second (Figure 7). As the velocity increased to 40 knots, the yaw oscillations decreased to +/- 50 degrees. While there is no evidence that these rates can directly result in injury to humans, the frequency of these oscillations (approximately 0.17 Hz, or 1 cycle every 6 seconds as determined by FFTs), can result in motion sickness within a few minutes of flight. In general, increasing airspeed, payload weight, or removal of the flotation system results in a much more stable system.

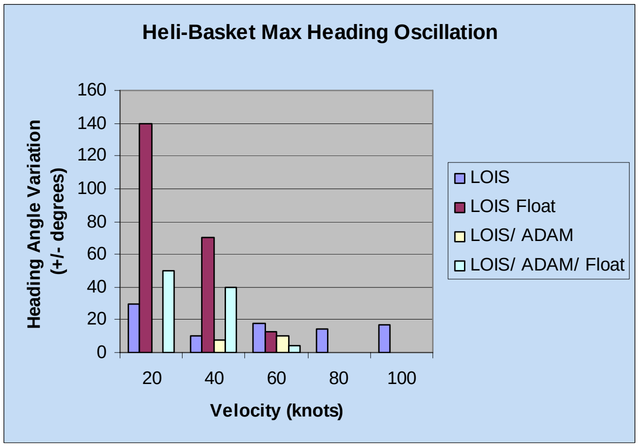

Figure 5. Heli-Basket Maximum Heading Oscillations

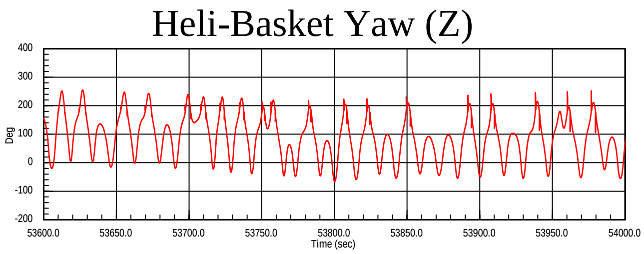

Figure 6. Test 31 Heli-Basket Yaw Data

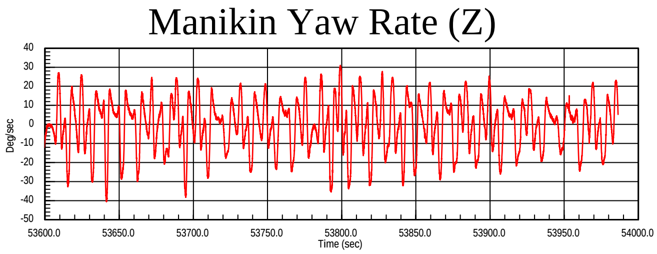

Figure 7. Test 31 Manikin Yaw Rate Data

Additional Considerations: Although a variety of configurations were tested, it is never possible to examine every variable. The flight testing focused on the typical flight regimes envisioned for use with the Heli-Basket with additional examination of high altitude flights that may be encountered during mountain rescues. The flights were flown by only three different pilots, in good weather conditions (sunny, low winds, 40-50 °F), which provided a limited variation in the effect of pilot performance. But even with uncertainties of pilot performance, the probability of injury due to accelerations was extremely low.

Summary: Examination of the data collected during the Heli-Basket testing conducted 10-12 January 2006 indicates that there is a very low probability of injury to human occupants due to the acceleration environment. Flights with low payloads using the flotation system are less stable at low speeds, but there is no evidence that this will pose additional risk to the occupants other than possible motion sickness. Increase in air velocities tended to make the system more stable and increase the Heli-Basket's pitch and yaw angles, especially at velocities greater than 60 knots. Although these higher angles should not change the probability of injury, they may result in distress to naive civilian rescuees. Higher altitudes had no discernable effect on the stability of the system. The overall results of the testing of the Heli-basket system indicate that there is minimal probability of injury to human occupants.

About the Author: John Plaga is a research aerospace engineer who has been with the Biomechanics Branch of the Human Effectiveness Directorate, Air Force Research Laboratory for 17 years. He has been involved in escape system research since his graduation from The Ohio State University in 1989. His research projects have included flow stagnation concepts, windblast deflection studies, biomechanics of helmet-mounted displays, development of ejection seat instrumentation systems, studies of ejection seat dynamics, investigation of the Russian K-36 ejection seat, investigation of the implications of women in combat aircraft, and effects of downwash on pararescuemen.

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