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Helicopter Visual Segment Evaluation: Phase 1 Performance Testing Report

September 2003

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16. Abstract

This report presents the results of a study, funded by the Federal Aviation Administration (FAA), of helicopter performance capabilities. Tests were conducted simulating instrument approaches with five different helicopter models. A total of five different helicopter models were included in the test matrix (S-76A, Bell 206L, Bell 430, AS-365 N2, and EC-135). The objective was to establish the maximum angle of descent from a missed approach point (MAP) for a given altitude and approach speed. All tests were flown by an FAA Aircraft Certification Test Pilot.

Descent maneuver profiles were collected using an Ashtech Z-12 Differential Global Positioning System provided by the FAA. The flight profile characteristics were observed and the descent maneuver success rate was tabulated for each helicopter. Data was analyzed by plotting each approach and departure individually. Summary statistics were calculated and composite plots were created for further analysis of aircraft behavior.

The implied objective was to gather data to determine the lowest altitude and steepest descent combination that could be flown by this sampling of twin-engine helicopters. Each helicopter was flown in descents that required descent profile designs with descent angle geometries of 6°-11° at MAP altitudes of 200′-700′ above ground level. In general, the results indicated that to achieve steeper descent angles at acceptable deceleration rates, lower approach speeds to the MAP were necessary. Approach speeds of 60-70 kts achieved the best altitude and descent angle combinations.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AFS	Flight Standards Service
AGL	Above ground level
CORS	Continuously Operating Reference Station
DGPS	Differential Global Positioning System
FAA	Federal Aviation Administration
FTE	Flight Test Engineer
GPS	Global Positioning System
HVSE	Helicopter Visual Segment Evaluation
IAS	Initial approach speed
MAP	Missed approach point
NGS	National Geodetic Survey
rpm	Revolutions per minute
VSI	Vertical speed indicator

EXECUTIVE SUMMARY

During the period of July 30 through October 2, 2002, five commercial helicopters (S-76A, Bell 206L, Bell 430, AS-365 N2, and EC-135) were flown in high descent angle maneuvers (6º-11º) to a standard 100′ by 100′ helipad target under the control of an Federal Aviation Administration (FAA) certification test pilot.

This report documents the results. Descent maneuver profiles were characterized using a proven Ashtech Z-12 Differential Global Positioning System; ground and airborne systems were provided by the FAA. The flight profile characteristics were observed and the descent maneuver success rate was tabulated for each helicopter and the group of helicopters. Data was analyzed by plotting each approach and departure individually. Summary statistics were calculated and composite plots were created for further analysis of aircraft behavior. Analyses of the pilot subjective opinions concerning the acceptability and perceived workload, safety, and control margins associated with the procedures flown are planned for the Pilot Variability Test phase (Phase 2).

The objective was to gather data to determine the lowest altitude and steepest descent combination that could be flown by this sample of twin-engine helicopters. Each helicopter was flown in descents that required descent profile designs with descent angle geometries of 6°-11° at missed approach point (MAP) altitudes of 200′-700′ above ground level. In general, the results indicated that to achieve steeper descent angles at acceptable deceleration rates, lower approach speeds to the MAP were necessary. Approach speeds of 60-70 kts achieved the best altitude and descent angle combinations.

The minimum recommended compliment of helicopters to be flown for Phase 2 sequences should include the S-76A, the Bell 430, the AS-365, and possibly the Bell 206L. This includes the worst through the best performers in the twin-turbine class and evaluates the limits of single-engine helicopter performance during the high descent maneuvers. A more detailed consideration of tail wind effects on this class of helicopter should be done in Phase 2.

INTRODUCTION

PURPOSE.

This document describes the results of the Federal Aviation Administration (FAA) Helicopter Visual Segment Evaluation (HVSE) Phase 1, which includes test parameters (data elements) and performance flight test results. Also described are flight test procedures, test site locations, analysis technique, conclusions, and recommendations. From this data, the FAA will be able to characterize commercial helicopter performance under a high angle of descent maneuver. With this information, the FAA can determine an acceptable range of visual segment approach profiles with associated helicopter deceleration performance. This will allow the FAA to develop approach criteria that considers the actual performance of the helicopter during a high angle of descent maneuver and will support a technical rationale and basis for the design and use of instrument approaches at a greater number of heliports.

The following flight test objectives were addressed.

- Collect helicopter performance data to determine the maximum sustainable visual segment descent angle during visual approaches to a heliport.

- Determine deceleration rate profiles for high-angle visual segment descents to a heliport.

BACKGROUND.

The FAA's Flight Standards Service (AFS), through its Flight Technologies and Procedures Division (AFS-400), is responsible for the development of standards and procedures for aircraft navigating within the National Airspace System. Within AFS-400, the Flight Procedures Standards Branch, AFS-420, has the responsibility to develop criteria for procedures for instrument approach and departure from civil and military airports and heliports. The Aircraft Certification Service (AIR), through its Rotorcraft Directorate (ASW-100), is responsible for certificating helicopters and tilt rotor aircraft for instrument operations. Testing has been conducted with helicopters flying instrument approaches to a helipad. However, there is no recent data on flying twin-engine turbine equipped helicopters at high descent angles under visual flight rule conditions.

The focus of the HVSE flight test program included the collection and evaluation of helicopter flight profile data and maximum speed and descent angles achieved, and pilot situational awareness and assessments of helicopter control behavior. All approaches were conducted under visual flight conditions during daytime operations. The following factors were either measured using the trajectory measurement Differential Global Positioning System (DGPS) unit or ground video photogrammetry.

- Helicopter three-dimensional orientation along a specified descent angle path to an arrested forward speed hover 10-15 feet above the ground (within ground effect region).

- Helicopter position relative to helipad boundary at point of hover.

- Visibility of landing area during high descent angle approaches.
- Tailskid clearance above ground at the point of arrested forward speed.
- Helicopter controllability at high descent angles.

Based on discussions from the July 2002 HVSE Team Planning Meeting, the flight test program was divided into two phases. Flight testing was designed to determine the aerodynamic limits of the various helicopter types by flying descents at angles of 6° to 11° and descent approach geometries allowing average deceleration rates of 0.07 g or less. An FAA Southwest Region certification test pilot flew the high angle of descent rate profiles and executed a hover over the landing pad to complete the descent. Based on his expert experience, the test pilot would execute the descent maneuver to a hover or perform a missed approach, depending on the helicopter's aerodynamic descent behavior (autorotation limits, settling under power, etc.). The helicopter position during the descent was measured to define a performance profile for each helicopter that would include maximum descent angles successfully executed and descent geometry characteristics (altitude at missed approach point (MAP), approach ground speed velocity, and descent trajectory profile) flown.

The Phase 2 flight tests will be flown as described in the Test Specification Document for helicopter types specified by the FAA. Evaluation pilots will be tasked randomly to execute descent angles less than and equal to the descent angle limits determined in Phase 1 for that particular helicopter type. Flight profiles would be measured as in Phase 1 and subjective pilot responses concerning confidence in flying the high angle of descent profiles would be collected and statistically analyzed.

METHODS

DATA COLLECTION ENVIRONMENT.

TEST LOCATIONS. Four of the five HVSE flight tests were conducted at the FAA William J. Hughes Technical Center's National Concepts Development and Demonstration Heliport adjacent to the Atlantic City International Airport (ACY), New Jersey. This facility provided parallel approach corridors to the helipad landing zone and access to a DGPS ground and rover station for the generation of helicopter trajectory data. This site is designated as M-77 and has the coordinates 39° 27′ 53.40127″ N by 074° 33′ 57.33250″ W. Estimated altitude is 56 feet (16.744 meters). The remaining flight test was conducted at the Airglades Airfield (Location Identifier: 2IS) located approximately 5 miles southwest of the town of Clewiston, Hendry County, Florida. The geographical coordinates of this facility are 26° 44′ 07.23″ N by 81° 02′ 41.46″ W. Estimated altitude is 20 feet (6.096 meters) mean sea level.

NAVIGATION FACILITIES. Helicopter time, space, and positioning information were collected using a Thales Navigation (formerly Ashtech Corporation) Z-12 DGPS receiver system. The FAA ACB-430 personnel provided Ashtech Z-12 DGPS receivers that functioned as the rover and ground reference stations during the flight tests. The Ashtech PNAV software was used to postprocess the receiver data and produce helicopter position trajectories. The site coordinates for the ground reference station at the Technical Center is 39° 26′ 58.72978″ N by 074° 34′ 00.04388″ W and is located on the hangar roof of building 301.

Alternate ground reference stations provided by the National Geodetic Survey's (NGS) (an office of National Oceanic and Atmospheric Administration) Continuously Operating Reference Station (CORS) Program were available at both test sites, if necessary, to ensure flight trajectory data was collected.

GROUND FLIGHT TEST PREPARATION. The test team performed two specific measurements during preparation of the helicopter for the flight test event. These were cockpit static cut angle measurement and the L1/L2 antenna position referenced to the outline of the helicopter. The cockpit cut angle was used to determine maximum pitch angles before over the nose visibility is lost and will be incorporated into Phase 2. The position of the L1/L2 antenna represents the actual position in space that represents the trajectory data. The predominant antenna position above the safety pilot's position (left seat) would cause a slightly higher altitude during a pitch up attitude reading, whereas a Global Positioning System (GPS) antenna position on the tail boom would result in a slightly lower altitude during a pitch down flight attitude.

Commercial helicopter truth reference and trajectory measuring instrumentation installations were engineered to minimize the level of modification to the helicopter. The team was successful in installing all instrumentation totally within the flight deck and passenger compartments.

FLIGHT TEST PROCEDURES. The HVSE test procedure used a selection of twin- and single-turbine engine helicopters typically used in medical evacuation, rescue, charter air service, and aerial photography and tourist sightseeing missions. The flight test environment was conducted under visual flight rule conditions at the William J. Hughes Technical Center, Atlantic City International Airport and at the Airglades Facility, in Florida. The second site was chosen to facilitate flight test aircraft located too far from the Technical Center to be economically ferried. In this case, the test team was deployed between September 29 to October 4, 2002, to the Airglades location and conducted flight tests on the EC-135 helicopter. Since determining the helicopter's performance was an objective in this test phase, the FAA certification test pilot selected the particular descent angle from a collection of approach altitudes, speeds, and deceleration rates to determine the descent limits of the helicopter.

An FAA helicopter certification test pilot flew all the flight approaches to the helipad (M-77) along either a 145° or 310° courseline relative to magnetic north in accordance with local flight rules (parallel to runway 13/31, ACY). Approach vectors at the Airglades facility were 225° and 45°. There was no requirement to simulate reduced visibility prior to the MAP. The FAA pilot used ground landmarks and onboard GPS to fly to the initial approach point and set up the approach heading to the MAP, as specified in the descent geometry design. This set up the approach to begin descent maneuvers for the desired descent angle, as determined by the FAA pilot. As the helicopter approached the MAP, as indicated on the Flight Test Engineer (FTEs) moving-map display, the pilot was given a descent countdown from the FTE to the MAP, where the particular descent angle geometry was achieved. The FAA pilot had to decide either to initiate the descent and fly the helicopter to a 10-foot altitude hover above the helipad center mark or abort the approach. The position of the helicopter within the helipad boundary was not being scored since the objective was to gather helicopter engineering data rather than pilot performance during the landing phase. All successful hovers were accomplished within the helipad boundary.

A safety pilot flew on each flight. The safety pilot functioned solely to maintain situational awareness of the surrounding local airspace environment and to recover the aircraft should aerodynamic situations require it.

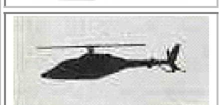
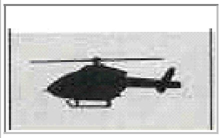
FACILITIES AND INSTRUMENTATION.

Test Aircraft. The helicopters used were either owned or leased by commercial and government entities or operated by the FAA.

All flight test aircraft required an FAA TSO C-129A-certified GPS navigation receiver with distance to waypoint flight management and planning capability. Typical specifications for the helicopters flown are shown in table 1.

Note: Due to the emergency medical service mission of agencies possessing the MD-900 and its general scarcity, an MD-900 was not tested during this phase.

TABLE 1. FLIGHT TEST HELICOPTER SPECIFICATIONS

SILHOUETTE	MODEL	ROTOR DIAMETER	FUSELAGE LENGTH	OVERALL LENGTH	POWERPLANT	EMPTY WEIGHT	MAX T/O WEIGHT	TYP LOAD
	Bell 206 BIII JetRanger	33 ft 5 in (10.16 m)	31 ft 2.4 in (9.5 m)	38 ft 11.4 in (11.82 m)	1x 420 shp (313 kW) Allison 250-C20J turboshaft	1,678 lb (761 kg)	3,200 lb (1,451 kg)	1,522 lb (690 kg)
	Bell 430	42 ft (12.8 m)	44.1 ft (13.4 m)	50.5 ft (15.39 m)	2 x 770 shp (573 kW) Allison 250-C40 turboshafts	5,285 lb (2,397 kg)	9,000 lb (4,082 kg)	3,715 lb (1,685 kg)
	Boeing MD Explorer	33 ft 10 in (10.32 m)	31 ft 8 in (9.7 m)	38 ft 3 in (11.7 m)	2 x 640 shp (469 kW) Pratt & Whitney Canada PW 206 turboshafts	3,275 lb (1,486 kg)	6,250 lb (2,835 kg)	2,975 lb (1,349 kg)
	Eurocopter EC 135 P1	33.46 ft (10.2 m)	33.33 ft (10.16 m)	39.7 ft (12.1 m)	2 x 621shp (463 kW) Pratt & Whitney Canada PW 206Bs	3,174 lb (1,440 kg)	6,000 lb (2,720 kg)	2,734 lb (1,240 kg)
	Eurocopter AS 365 N2 Dauphin	39.14 ft (11.93 m)	38.16 ft (11.63 m)	45.05 ft (13.73m)	2 x 736 shp (550 kW) Turbomeca Arriel 1C2 turboshafts	5,006 lb (2,271 kg)	9,369 lb (4,250 kg)	4,363 lb (1,979 kg)
	Sikorsky S-76A	44 ft (13.41 m)	43 ft 4 in (13.22 m)	52 ft 6 in (16 m)	2 x 651 shp (474 kW) PT6B-36B turboshafts	8,620 lb (3,909 kg)	11,700 lb (5,306 kg)	3,080 lb (1,395 kg)

AIRBORNE TEST INSTRUMENTATION. The Technical Center's Thales Navigation (Ashtech) Z-12 DGPS receiver was used as the primary onboard trajectory data collection system during the flight test. Based on a discussion with the Technical Center navigation branch, the system shown in figure 1 was chosen as the onboard instrumentation. This differed from the instrumentation proposed in the test specification in that no ground-based time space position information unit would be available, and the Z-12 DGPS receiver has demonstrated the ability to provide sufficient accuracy for the type of maneuvers flown. The primary flight profile truth reference system included a DGPS receiver configured as a differential GPS rover unit with data reduction using position correction postprocessing. The Ashtech Z-12 DGPS receiver was installed on all test helicopters to provide three-dimensional position, velocity, and time data during the approach setup track and descent to hover phase of the flight. An Ashtech AT2775 L1/L2 aircraft active antenna provided the Z-12's GPS signal, and power was provided by a 12 V lead acid gel cell battery with a measured endurance in excess of 4 hours.

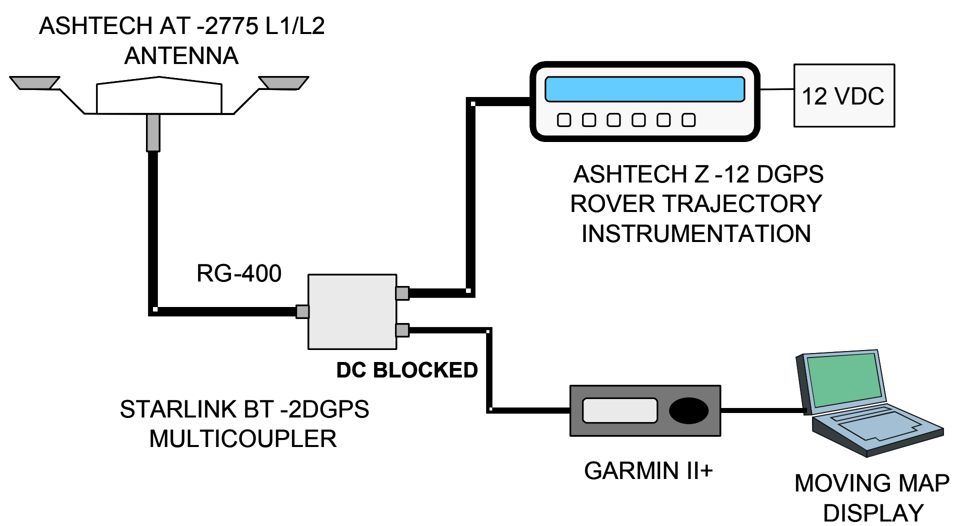


FIGURE 1. HELICOPTER VISUAL SEGMENT EVALUATION AIRBORNE INSTRUMENTATION

AIRBORNE VIDEO. Flight instrument readings, particularly rotor torque and rotor revolutions per minute (rpm), were captured using a mini DV camcorder. The unit, a Sony DCV10 and CVX-4 camera were provided by the Technical Center audio/visual group. The small size of this unit allowed for easier integration of the camera unit across the types of helicopters tested. A Pana-vise® and plastic base plate arrangement allowed mounting to a variety of shapes without marring the interior of the helicopter.

Ground Tracking Instrumentation. The ground truth reference instrumentation consisted of an Ashtech Z-12 configured as a reference base station. For testing conducted at the Technical Center, ACB-430 provided and operated the Z-12 during the flight test periods at the Technical Center. ACB-430 also provided the test team with the differential position correction files in order to produce the helicopter trajectory using the PNAV program. As stated earlier, the Technical Center base station antenna was located on the hangar roof of building 301.

A similar setup was used at the Airglades Facility test site. The Z-12 ground truth reference station was positioned at the airfield geodetic surveyed marker located approximately 90 yards from the end of the original runway. A backup ground reference source, the NGS's CORS, was used to ensure trajectory information could be postprocessed. A description of the CORS system can be found in appendix B.

Ground tracking systems were not used in this flight test program since all maneuvers by the Ashtech Z-12 produced excellent trajectory accuracies.

Ground Video Data Capture. Flight profile video from the descent to hover above the helipad was recorded on mini DV CAM or Beta Cam magnetic videotape media. The video was taken to allow a visual determination of descent angle and tail boom clearance above the helipad during the final stages of the hover maneuver. A surveyor's 5- or 2.5-meter sighting/leveling rod was used to establish a vertical distance reference at the helipad for later video analysis. A single frame showing the leveling rod was saved as a digital image and field reference for subsequent video. This digital image was superimposed over the analyzed video frames to show relative distance of the tail boom from the ground. All frames captured included a time/date stamp to identify the event being analyzed.

Site Weather Data. Surface weather data was provided by an automated terminal information system and augmented by a ground weather station that provided the necessary wind data to set up the helipad approach headings. This information was used to determine the predominant approach heading. The ground site provided a gross overall weather picture since winds at altitude were often different during the course of the descent maneuvers.

DATA PROCESSING AND ANALYSIS.

SOURCE OF DATA. The test data came from four sources: Z-12 trajectory files, FTE observer logs, postprocessed trajectory files, and airborne and ground video cameras.

Z-12 Trajectory Files. The Z-12 rover and ground reference stations were set up to produce B-files during the entire test flight period. These B-files represent the dual-frequency code (P-code) plus carrier phase float ambiguities that require processing after the test event to attain the stated accuracies.

Postprocessed Trajectory Files. These files are ASCII-formatted helicopter (rover) position in WGS-84 coordinates, resulting from the processing of rover data and ground station files in the Precise Differential GPS Navigation (PNAV) Trajectory software program.

Flight Test Engineer Observer Logs. The FTE maintains a record of each flight descent event and records key parameters and command pilot comments. Not only did the FTE keep notes of comments made by the test pilot, but the FTE kept observation notes as well. The notes are not precise and are only used to give a better understanding or augment the data already collected. After each flight, the test pilot would be debriefed of any observations or thoughts that he had. Again, this information is strictly to augment or clarify the data already collected.

Airborne and Ground Video. This data represents the cockpit instrument readings for the rotor rpm and torque and flight profiles from a ground position adjacent to the helipad.

ANALYSIS PROCEDURES. The analysis procedure for the flight tests involved the use of the PNAV software to generate flight profile trajectories for each of the following combinations of approach altitude: above ground level (AGL), approach velocity, and resulting descent angles. Each track was examined visually to determine the presence of any predominant flying strategies. Conditions where a maximum angle of approach occurred with a specified approach speed and minimum MAP altitude were determined. A complete set of trajectory charts for the five helicopters are shown in appendix A.

Visual observation of the profile helicopter position indicated that the pilot flew consistently above the planned direct path from the MAP to the helipad hover point in a majority of the maneuvers. Crabbing or yawing the helicopter was necessary, especially at the higher descent angles, to provide the test pilot sufficient visibility of the helipad to complete the hover maneuver.

At this point, the pilot's comments were reviewed to give a further understanding of the approach maneuver. This was very important to understand why some maneuvers had to be aborted or not attempted.

DESCRIPTIVE STATISTICS. Summary statistics listings were produced for the helicopter trajectory position in profile and rate of descent. A total of 76 descents were conducted over the range of angles from 6°-11°, MAP altitudes of 200-700 ft AGL, and approach velocities of 50, 60, 70, and 90 kts. Each integer value represents a successful descent ending in the required hover maneuver. A descent was considered successful if the helicopter was brought to an arrested forward speed hover 10-15 ft above the ground within the helipad boundary.

A composite of the results of the helicopter descents and their associated parameters was tabulated in order to determine the existence of the highest descent angle occurring for the lowest MAP altitude. These results were produced in two decision matrices and analyzed to establish the highest angle and lowest descent angle combination. These two matrices are shown in tables 2 and 3.

Examination of these tables show high incidences of successful hover events across all helicopters tested for altitudes of 250-300 ft AGL and 60-70 kts. In situations where a successful descent was achieved, but the command pilot indicated that autorotation or imminent rotor torque loss was apparent, the team scored that event as 0.5. Examination by descent angles for these conditions revealed that there was no helicopter that did not achieve a successful landing hover for the approach conditions of 50 kts, 250 ft AGL, and 9° descent angle. Although the descent was achieved with an initial approach speed (IAS) of 50 kts at a 9° approach angle, the 50 kts IAS could be too slow, given the variability in the various type helicopter pitot-static measurement systems. The maximum achievable descent angle was driven by the performance of the S-76A. If the S-76A is not considered, the other helicopters achieved a 60 kts, 350 ft AGL, 9°. The two American Eurocopter types demonstrated successful hovers at 60 kts, 350 ft AGL, 10°. The Bell 430 may have achieved this performance as well but was successful at a lower speed (50 kts and a slightly lower approach altitude of 300 ft AGL).

TABLE 2. DESCENT PERFORMANCE—DESCENT ANGLE VS ALTITUDE

Altitude AGL	Composite Helicopter Successful Landings						
		Descent Angle vs Altitude					
	6°	7°	8°	9°	10°	11°	Total
200	2		1				3
250	4	1	1	3	2	1	12
300	4	1	3	1	2	2	13
350	2	1	1	1	1	1	7
400			3	1		1	5
450	1		1	1			3
500	5		1		3	2	11
550							0
600		1				1	2
700				1			1

TABLE 3. DESCENT PERFORMANCE—DESCENT ANGLE VS VELOCITY

Helicopter Successful Hovers Descent Angle vs Map Approach Speed				
Angle	50 kts	60 kts	70 kts	90 kts
6°	1	5	7	5
7°		2	1	0.5
8°	1	2	4.5	1
9°	4	2.5	4	0.5
10°	3	1	2	
11°	2.5	2	2.5	
Total	11.5	14.5	21	7
Percent Success	60.53	80.56	77.78	63.64

SUMMARY OF RESULTS.

HELICOPTER PERFORMANCE LIMITS.

Angle of Descent Performance. For each individual helicopter, the achieved descent angles versus IAS are shown in table 4. Based on the discussion of potential minimum IAS effects, the maximum angle achieved for a 60 kts approach speed to the MAP is shown for each helicopter in the shaded region.

TABLE 4. MAXIMUM ACHIEVED DESCENT ANGLES BY HELICOPTER TYPE

Successful Descent Angles Achieved vs IAS		
Helicopter Type	Velocity	Max Descent Angle
S-76	60	7
	70	7
BELL 206L	Velocity	Max Descent Angle
	60	9
	70	8
BELL 430	Velocity	Max Descent Angle
	60	9
	70	8
AS-365	Velocity	Max Descent Angle
	60	11
	70	11
EC-135	Velocity	Max Descent Angle
	60	10
	70	10

Appendix C includes charts depicting the descent angle performance of each helicopter individually and as a group.

Appendix E provides the descriptive statistics of each helicopter as it performed at approach speeds of 70 kts and MAP altitudes of 400 ft AGL or greater. The mode for these events occurred at a descent angle of 9°.

Composite Deceleration Profiles (0.07 g). It was determined that the testing would use the 0.07-g acceleration rate as a basis for testing the different altitudes and speeds. The essential goal was to use this parameter as a standard from which to measure the performance of each helicopter.

Each of the velocities that were tested has not only unique flying characteristics but also affect each aircraft differently.

As shown in figure 2, the chart starts at 5° and each of the axes originates at 0 altitude and 0 degree. The speed component will determine the steepness of the axis. These axes represent each of the velocities that were tested. The specific velocities were 50, 60, 70, and 90 kts.

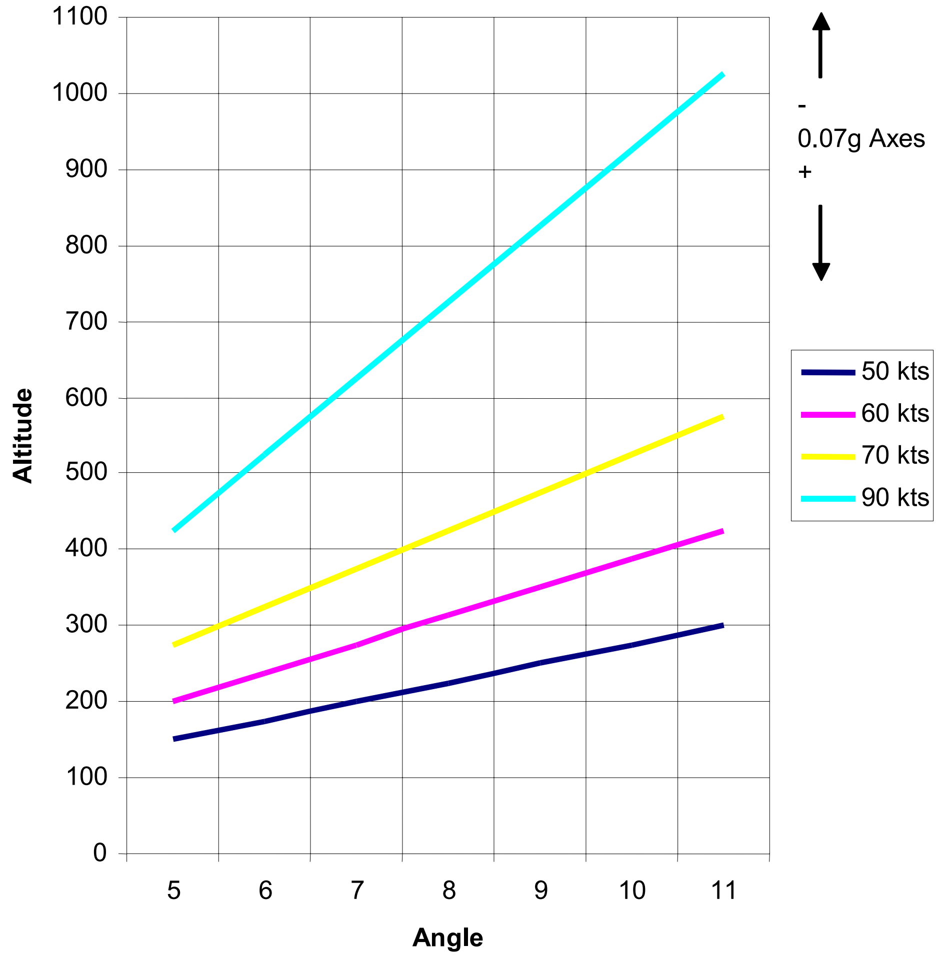


FIGURE 2. COMPARISON OF 0.07-g AXIS FOR EACH VELOCITY

There is some very basic information that can be gleaned from this chart. First, the 90 kts approaches require an initial altitude above 400 ft, while the 70, 60, and 50 kts approaches can be performed at this altitude and below. Second, the higher altitude approaches introduce a greater vertical velocity component along with the 90 kts velocity for the pilot to bleed off on the approaches. Third, even though it may not be apparent, the pilot will have visual acquisition issues of the heliport.

In the remainder of this section, the limits of each helicopter will be defined for each velocity tested. Figures 3-6 are the results of all approaches flown with an initial velocity of 50, 60, 70, and 90 kts respectively. A summary of final results and conclusions follows the figures. All approaches are broken down into velocity and helicopter types in appendix F.

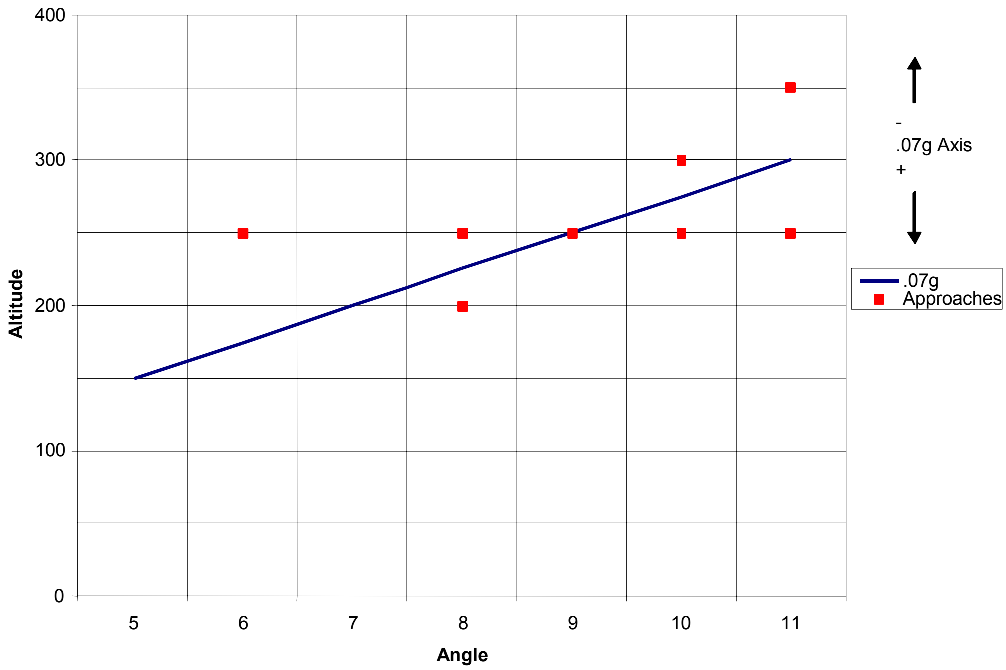


FIGURE 3. A COMPOSITE OF SUCCESSFUL 50-kts APPROACHES

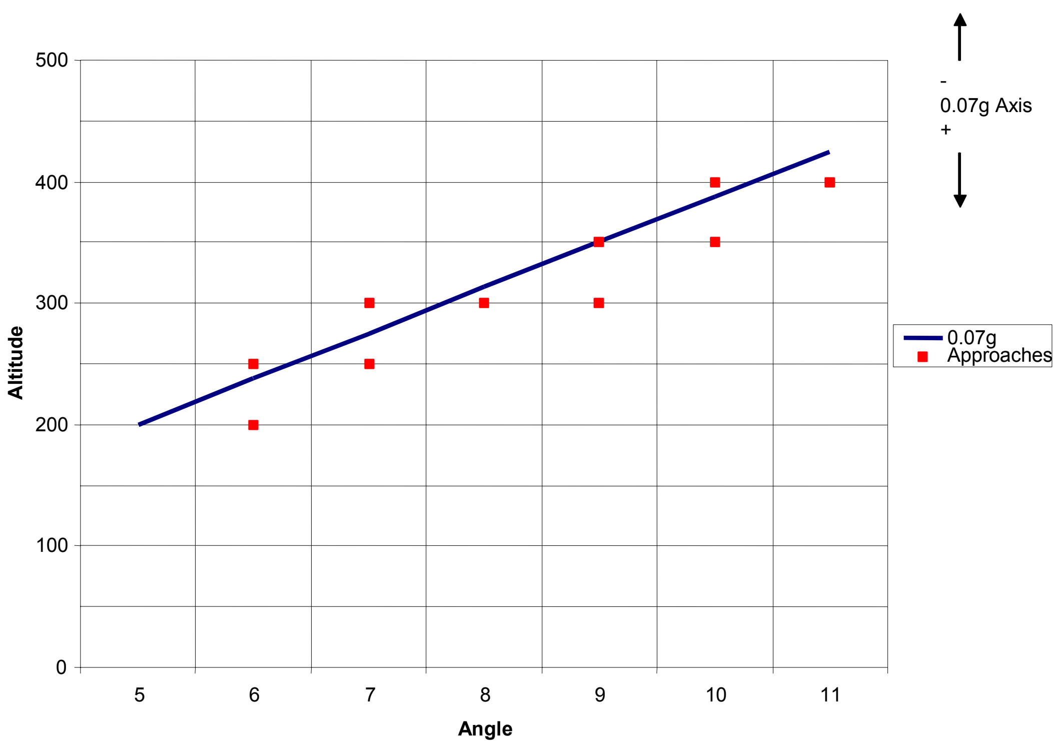


FIGURE 4. A COMPOSITE OF SUCCESSFUL 60-kts APPROACHES

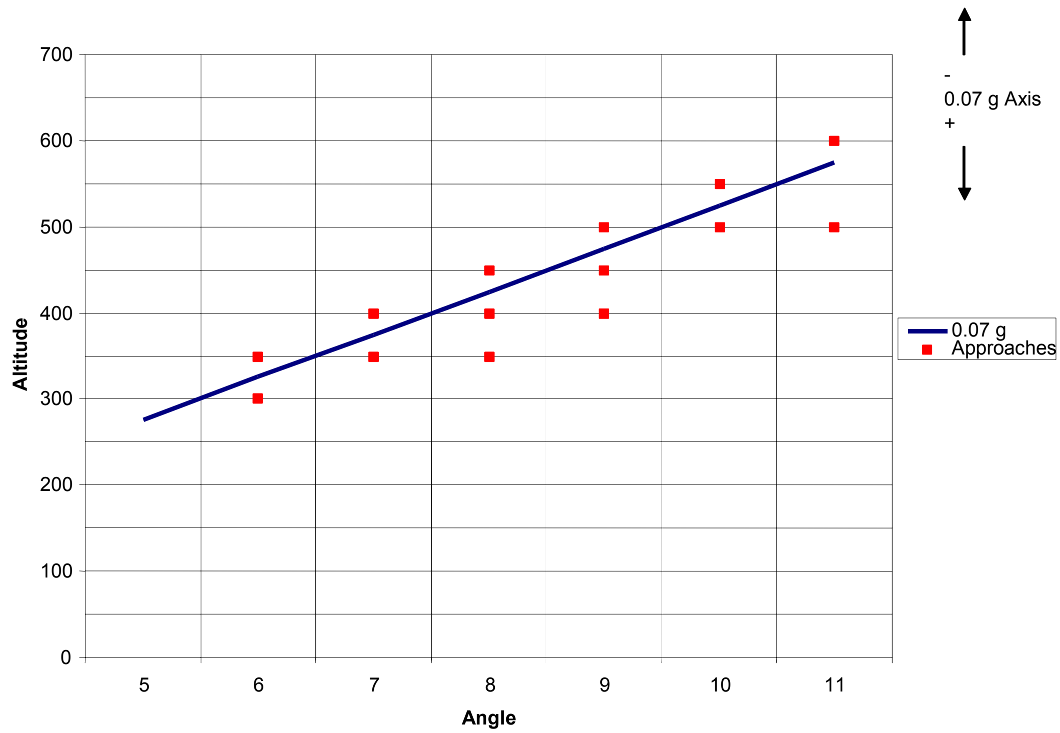


FIGURE 5. A COMPOSITE OF SUCCESSFUL 70-kts APPROACHES

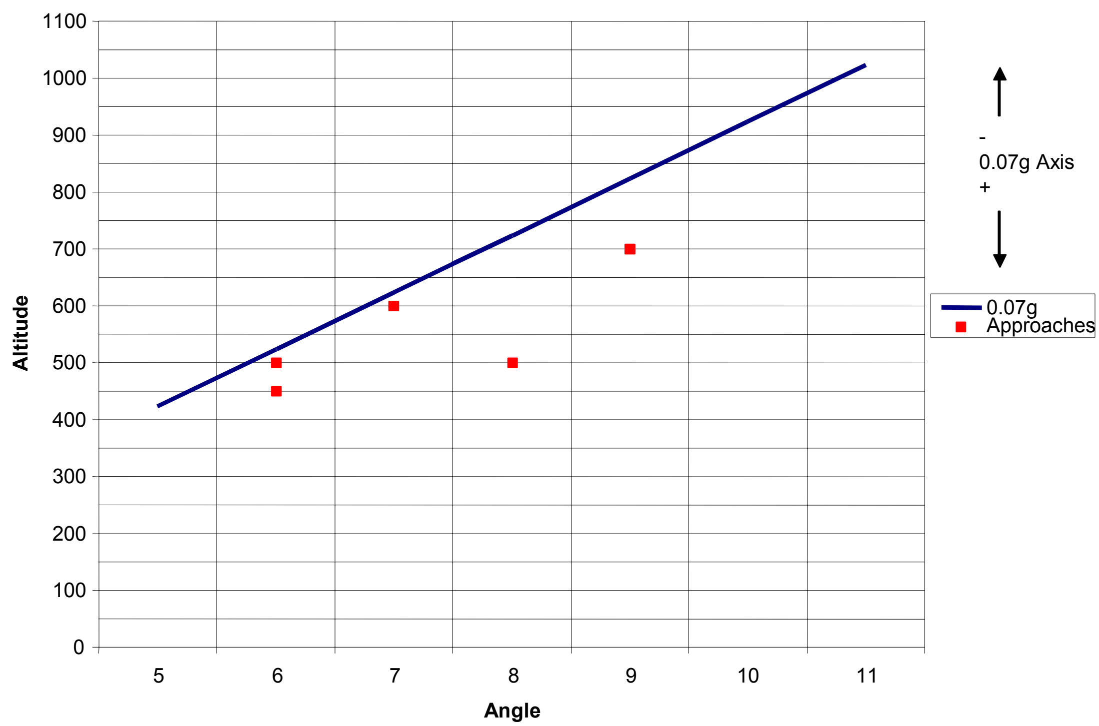


FIGURE 6. A COMPOSITE OF SUCCESSFUL 90-kts APPROACHES

- S-76. Knowing that the helicopter was marginally successful at a 9° angle, due to heliport visual blockage, greater angles were not attempted. Vision became the limiting factor at 9°. An 8° angle gives good visual and should be considered the upper limit of this helicopter.

- B-206. This helicopter was capable of a 10° approach but required a lot of crabbing at about 10 degrees. An 11° approach proved to be too great of a descent angle. A 9° angle should be the upper limit.

- AS-365. This helicopter was capable of achieving an 11° angle (the greatest angle that was tested). This helicopter proved to be very capable of performing high angle approaches with a good visual of the helipad.

- B-430. An 11° angle was accomplished but required a 15° crab to see the helipad, while a 10° angle had very good visibility of the helipad. This helicopter has a 10° approach limit.

- EC-135. Without losing sight of the helipad, a descent of 11° was accomplished.

- Overall Comment. At this low speed the helicopters tend to be more difficult to control or stabilize. The threshold speed tends to be about 40 kts. At 50 kts, a little tail wind will push the helicopter towards this threshold. The helicopter at this speed requires more pilot activity at the controls. This prevented many approaches from being attempted or accomplished.

- S-76. An 8° angle was the stopping point. No more 60 kts attempts were made. More than likely 8° could be done at a 400-ft level and possibly 9°. It has been evident that the 0.07 g is very sensitive on the S-76. Note. This helicopter is nearly maxed out in cargo weight with test equipment.

- B-206. A 9° angle was accomplished with good visual. At 10° the instrument panel started to block the pilot's visual acquisition of the helipad.

- AS-365. No approaches at 60 kts were attempted. It performed so well at other speeds that an effort was made to push the helicopter to its limit as long as the torques and visual lasted. This meant more effort was exerted on the acceleration. All approaches at 70 kts were successful.

- B-430. A 9° angle was successful. A 10° angle was not attempted since 9° was a marginal approach. Helipad visual, low torque (approaching autorotation), and bleeding of speed all became factors that prevented any further testing at greater angles.

- EC-135. All approaches up to 11° proved to be successful. The EC-135 and AS-365 constituted the best performers.

- S-76. It was successful up to an 8° angle. A 15° crabbing was required for visual, and it was getting close to 0 torque (approaching autorotation).

- B-206. This single-engine helicopter's only successful approach was at 6°. Both 7° and 8° were attempted without success. Beyond 6° the torque was going below 10%, indicating that autorotation can be a factor under certain conditions.

- AS-365. All approach angles were successful up to 11°. This proved to be the overall best performing helicopter.

- B-430. This helicopter accomplished a 10° angle. No other attempts were made since 5%-6% torque was left.

- EC-135. All approaches up to 11° were successful. This performed as well as the AS-365.

- S-76. A 7° angle at 600 ft proved to be the limit of this helicopter. The torque was very low. This became the stopping point.

- B-206. The limit was at 6° 500 ft due to a lack of enough collective reserve.

- AS-365. The helicopter maxed at 9° 700 ft; however, the vertical speed indicator (VSI) was very high at about 1800 ft/min.

- B-430. A 6° 450 ft approach was accomplished. The next attempt was at 8° 500 ft. No attempt at 7° was attempted, so there is no certainty that the helicopter could or could not perform this approach. High angle of descent rates precluded any other approaches.

- EC-135. An 8° angle was attempted only to verify the high VSI rate. The main limit to this test is high VSI and vortex ring state.

- Overall Comment. These very high speeds and angles required high-altitude approaches. This forces the pilot to not only bleed off high horizontal speed but also required a very high rate of vertical descent as well. During the tests, VSI rates of 1400 ft/min to 1800 ft/min were accomplished. This is beyond any sensible visual flight rules approach.

Deceleration Profiles. Average deceleration profiles were calculated from the descent trajectory data using the following formula:

$$\bar{A}_H = (\ddot{v}_{h2} - \ddot{v}_{h1})/(t_2 - t_1)$$

This formula represents the average acceleration along track toward the helipad between two ground speed readings as recorded by the Z-12 DGPS receiver. A similar formula is used for the vertical average deceleration component where the change in altitude versus time (rate of descent) is substituted for the horizontal distance closure. Examination of the average deceleration rates indicated that the helicopters were flown within the 0.07-g boundary, except when the speed and descent angle combination forced an aborted approach. A typical example for the acceleration components is shown in table 5. Appendix D provides the deceleration data profiles.

TABLE 5. AS-365 DECELERATION SUMMARY

Summary Deceleration Statistics		
AS36N2	Horizontal Deceleration	Vertical Deceleration
	-0.027	-0.004
	-0.07	-0.004
	-0.04	0.004
	-0.029	0.009
	-0.061	-0.003
	-0.054	-0.005
	0.009	0.005
	0.009	0.005
	-0.051	-0.011
	-0.043	-0.004
	-0.06	-0.002
	-0.057	-0.003
	-0.065	-0.001
	-0.04	-0.003
	-0.067	-0.001
	-0.04	-0.003
Average	-0.043	-0.001

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS.

Based on the flight performance of the five helicopters observed during the testing, the following statements can be made.

1. All helicopters achieved a 6° angle of descent at all approach speeds and altitudes up to 90 kts and 300 ft above ground level (AGL).

2. To achieve the higher angles of descent within the missed approach point (MAP) altitudes flown, lower speeds (50-60 kts) were required.

3. The combination of approach speed, altitude, and an angle of descent of 9°, 50 kts, and 250 ft AGL supports the creation of lower altitude minimum approach designs and steeper angles. The 9° angle of approach is prudent, but the 50 kts initial approach speed could be too slow, given the variability in the various helicopter pitot-static measurement systems. Fifty knots may be dangerously close to the lower limits of instrument

reliability for some helicopter types. During nighttime approaches, this could introduce a disorientation factor (unreliable airspeed indication) to the pilot during the critical and demanding phase of the final approach to a hover. These approach descent values should be reasonably adjusted to account for obstruction clearance zones and minimum velocity (ring tip vortex conditions). A combination of 9°, 60 kts at 300 ft AGL should give a sufficient margin for individual pilot ability levels.

4. The presence of significant tail and crosswind components at the MAP altitude affected the ability to control the helicopter during steep descents. The predominant effect was to force the helicopter beyond the helipad boundary and reduce the effectiveness of aerodynamic behavior, resulting in a greater ground speed to overcome.

5. The dashboard design and the need to maintain as much of the helipad target in full view during the descent maneuver required the pilot to yaw the helicopter from 5°-15°. This was reported by the command pilot and the flight test engineer. Unobstructed pilot visibility of the landing area during high angle of descent approaches to a helipad is essential to maintain situational awareness, prevent over controlling the aircraft, and maintain smoothness during a critical phase of helicopter flight. This is especially true if there are obstacles to be avoided in close proximity to the helipad. A potential exists that this visibility in itself is enough of a factor to limit the maximum approach angle recommended following the helicopter visual segment evaluation flight tests. The necessity for the pilot to have to maintain a certain degree of yaw during steep descent so that he can keep the landing area in view through foot-level chin Plexiglas can also introduce problems. There may not be sufficient antitorque engine power available during high-density altitude conditions with its associated requirement to add considerable power to attain a hover. This could lead to a dangerous loss of yaw control at a critical time when the helicopter might need all available power to arrest its descent and establish itself in a steady hover prior to landing. Indeed, many hard landing incidents have resulted from these circumstances.

6. Visual profile analysis indicated that the pilot flew consistently above the planned direct path from the MAP to the helipad hover point for all approaches. This was done to allow for visual acquisition of the landing zone and eventually led to greater instantaneous rates of descent and angle for these landing maneuvers. In some cases, a pitch up maneuver was initiated early on in the descent. The amount of this offset will be quantified during Phase 2.

7. Even though this test was not structured to define all aspects of the airspace requirements for steeper angle approaches, the aircraft flown demonstrated clear indications of unsuitable aerodynamic behavior (autorotation) at specific descent angles, approach speeds, and MAP altitudes. Arriving at the MAP at lower altitudes created a condition that required greater deceleration to stop the helicopter within the helipad boundary. Greater approach speeds placed greater demands on the aerodynamic braking capability of the helicopter up to the point where rotor torque was reduced to unacceptably low levels (onset of autorotation). Overall, the S-76A performed the worst, with the AS-365

and EC-135 being the best performers. The Bell helicopters performed with midrange success, although the Bell 430 was close in some respects. The MD-900 with its NOTAR system was not tested.

RECOMMENDATIONS.

The following recommendations are provided for consideration for future Helicopter Visual Segment Evaluation (HVSE) flight tests.

1. The minimum recommended compliment of helicopters to be flown for Phase 2 should include the S-76A, the Bell 430, and the AS-365. This provides a consideration of the worst through best performers in the twin-turbine class. Consideration should be given to including a single-engine helicopter in Phase 2 due to inherent single-engine power and aerodynamic limitations compared to dual-engine models. To ensure the broadest applicability of the ultimate test findings and recommendations, single-engine helicopters should definitely be factored into all aspects of this study due to their performance limitations during steep approach angles.

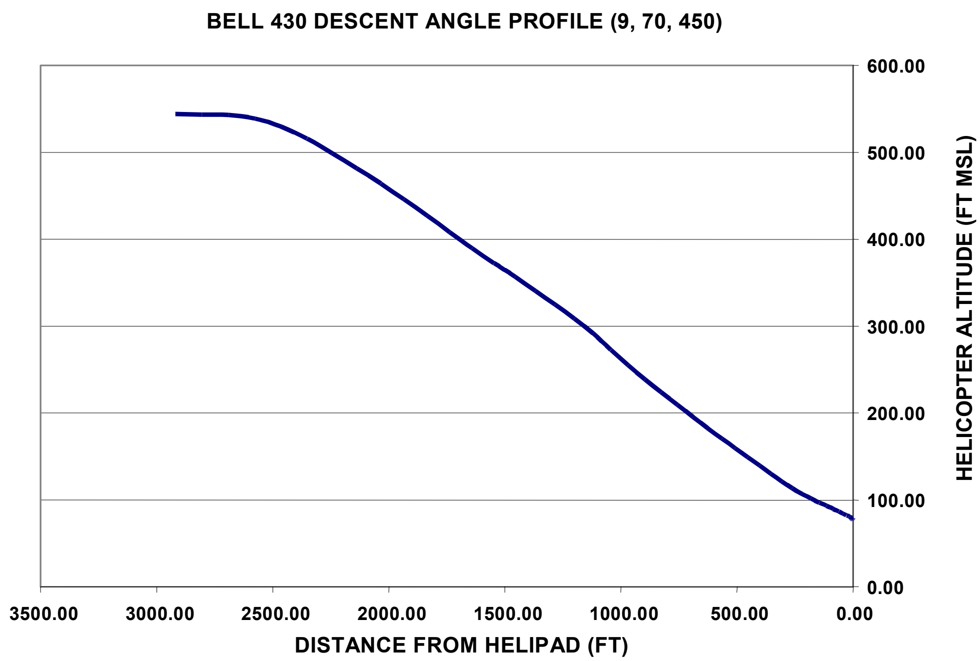
2. The angles of descent planned to be flown for Phase 2 should include angles below and progressing toward an upper limit of 9°. Starting angles for event data collection should begin at 7°. Safety familiarization flights may be done at 6°. Approach speed to the initial approach point will be 70 kts at an altitude of 400′ AGL.

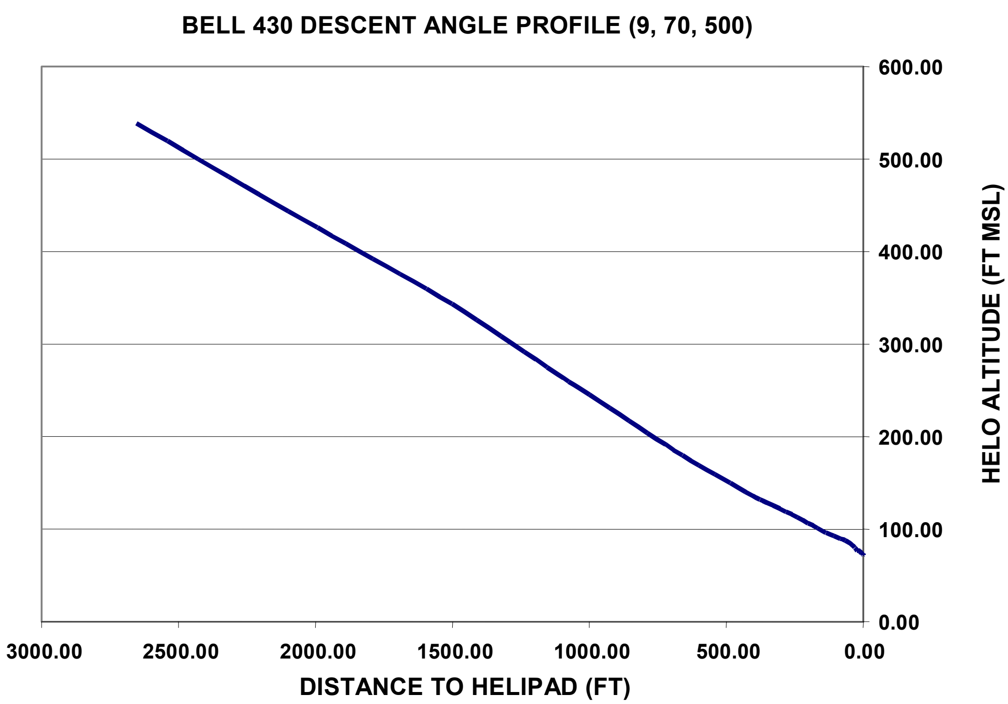
3. The impact of tail wind was estimated from pilot observation and comment. Quantifying the effects of tail wind on deceleration performance should be used in the certification process for a particular helicopter type executing steeper angle of descent maneuvers. Flying the same angle of descent geometry along approach headings 180° apart and averaging the results may be a technique used to quantify the variation in descent performance of a particular helicopter. Tail wind effects on those helicopters with tail rotors can be significant and have historically been associated with flight mishaps during the approach-to-hover phase of flight. The combination of a steep angle of descent, low forward airspeed, and a significant tail wind component can pose a flight danger and must be carefully considered in future HVSE flight tests. Significant tail wind components coupled with gusting wind conditions have the capacity to exceed a particular helicopter's aerodynamic limits and are a factor in the potential onset of vortex ring state (settling with power).

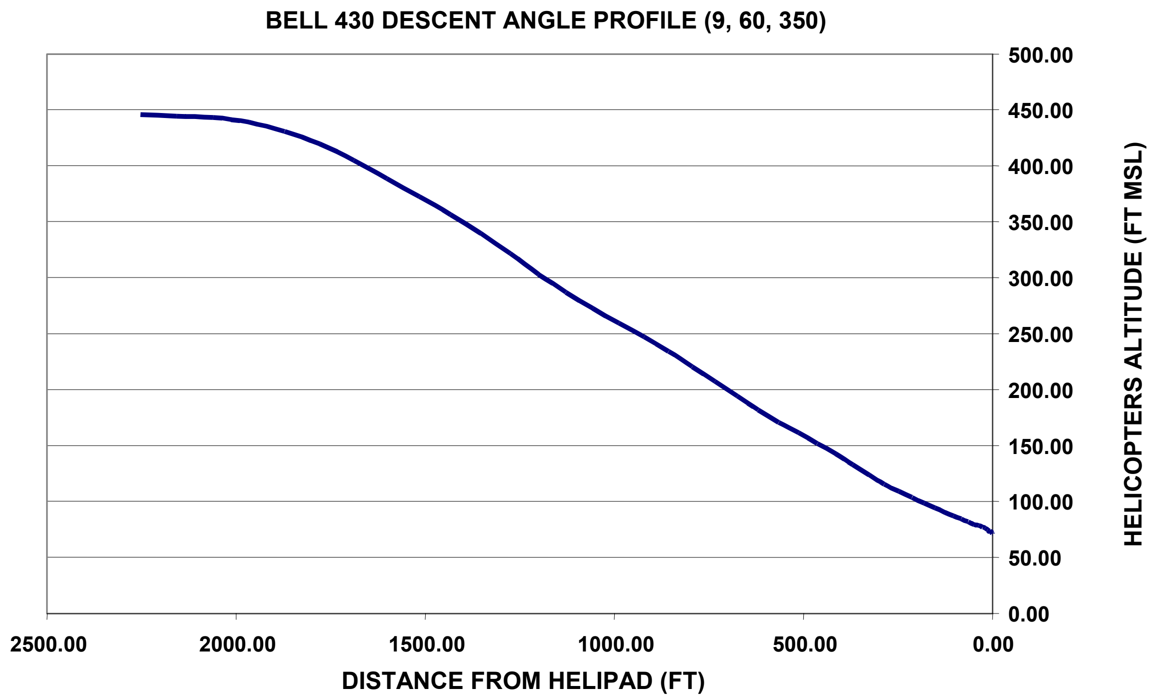
APPENDIX A—ANGLE OF DESCENT PROFILES

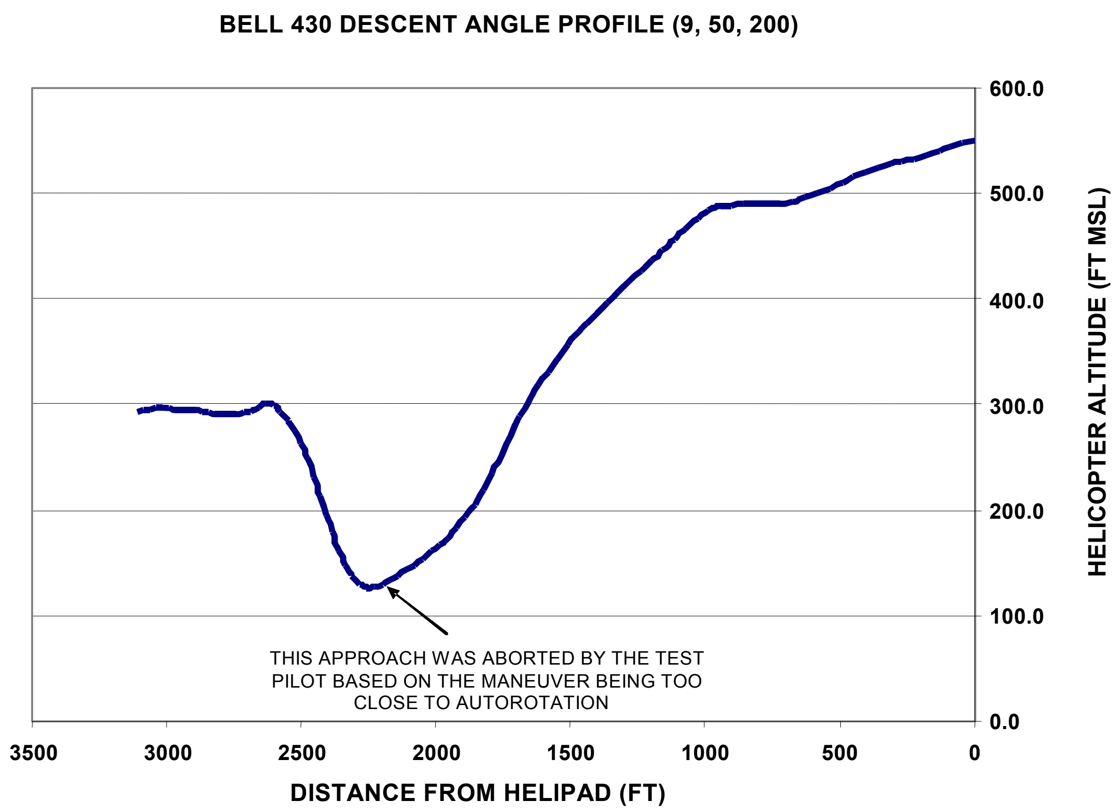
The angle of descent profiles for the five helicopters participating in the Helicopter Visual Segment Evaluation performance tests are included in this appendix.

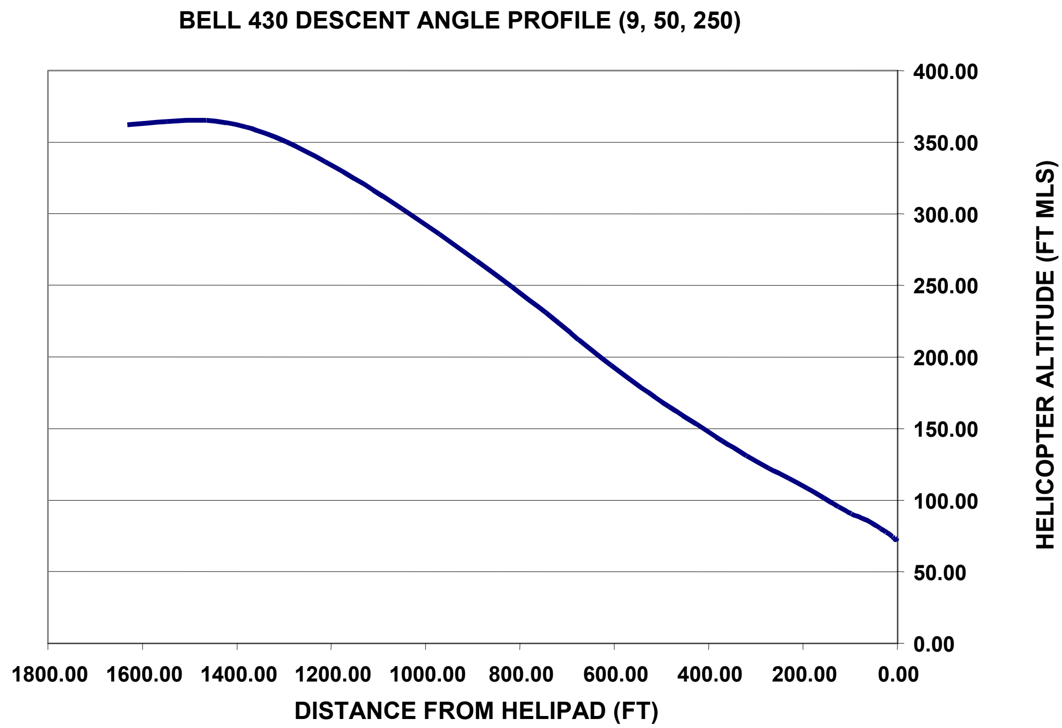
BELL 430 TRAJECTORY CHARTS.

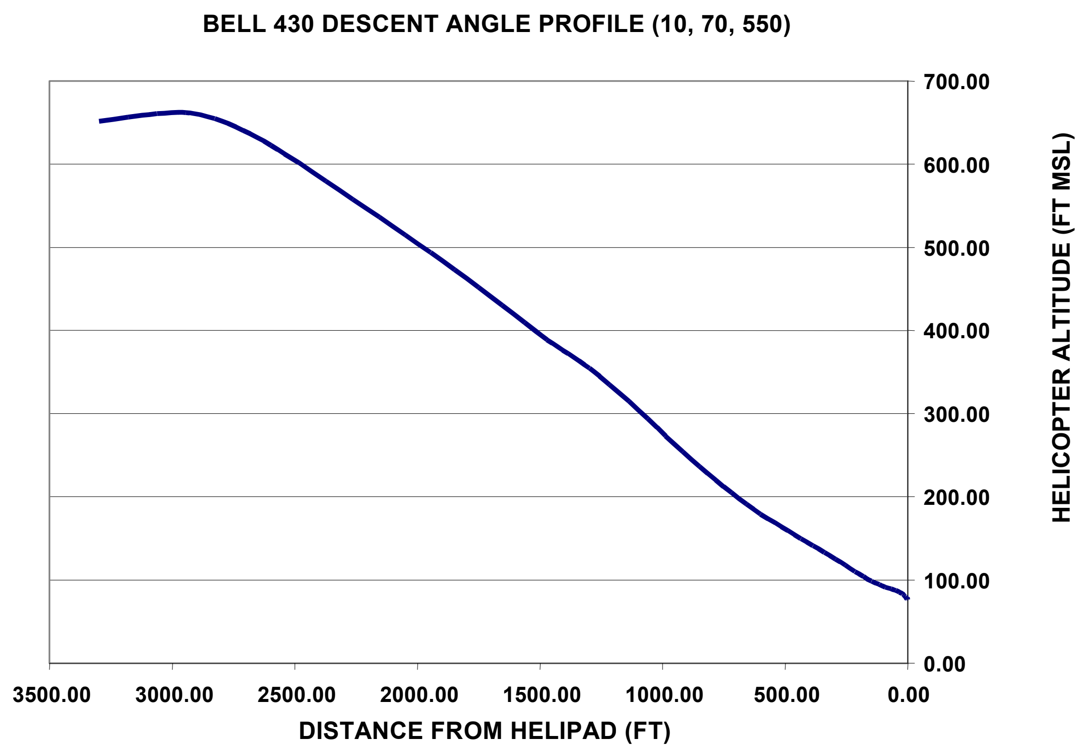




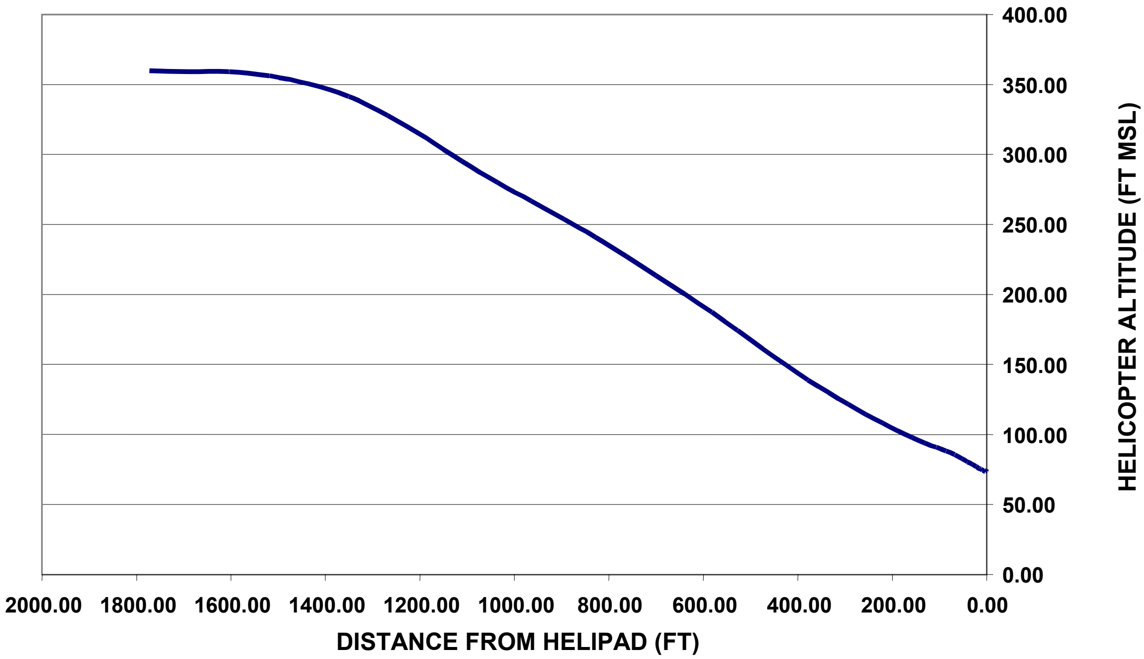

BELL 430 DESCENT ANGLE PROFILE (9, 60, 350)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)
HELICOPTERS ALTITUDE (FT MSL)


BELL 430 DESCENT ANGLE PROFILE (9, 50, 200)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
3500
3000
2500
2000
1500
1000
500
0
DISTANCE FROM HELIPAD (FT)
HELICOPTER ALTITUDE (FT MSL)
THIS APPROACH WAS ABORTED BY THE TEST PILOT BASED ON THE MANEUVER BEING TOO CLOSE TO AUTOROTATION

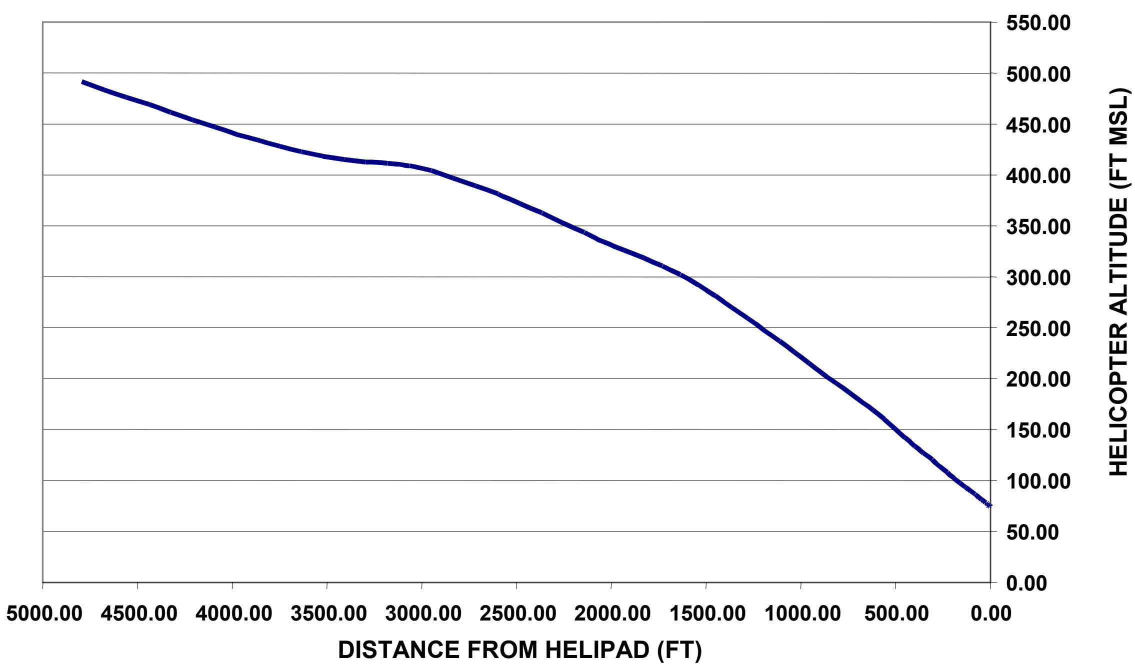

BELL 430 DESCENT ANGLE PROFILE (9, 50, 250)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MLS)
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE FROM HELIPAD (FT)


BELL 430 DESCENT ANGLE PROFILE (10, 70, 550)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

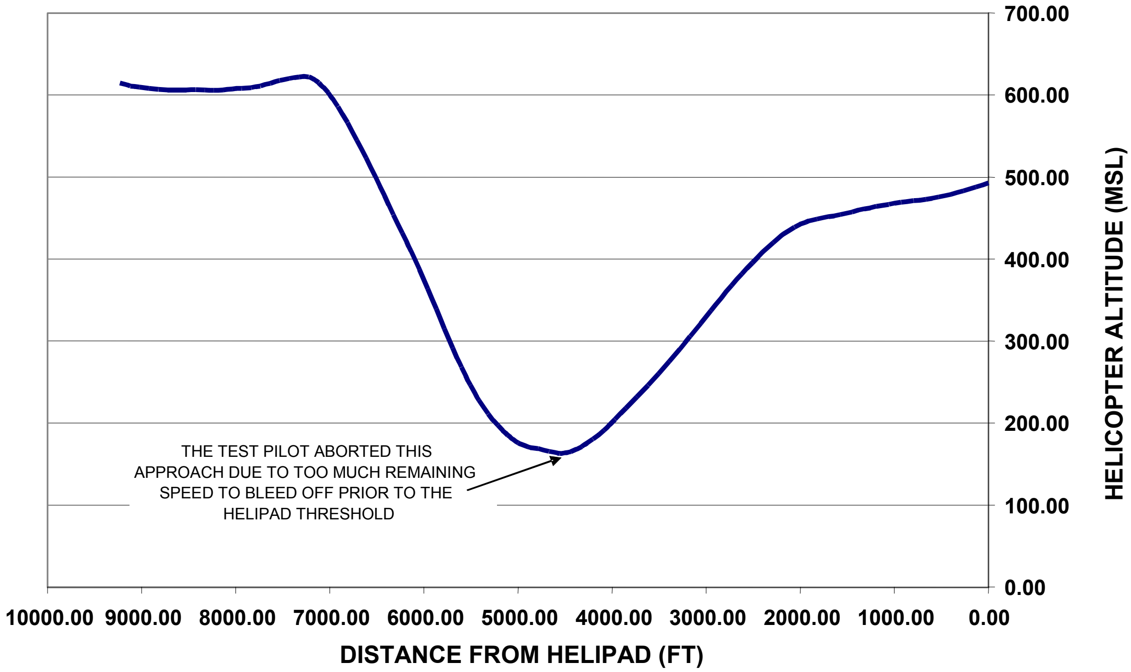
BELL 430 DESCENT ANGLE PROFILE (10, 50, 300)



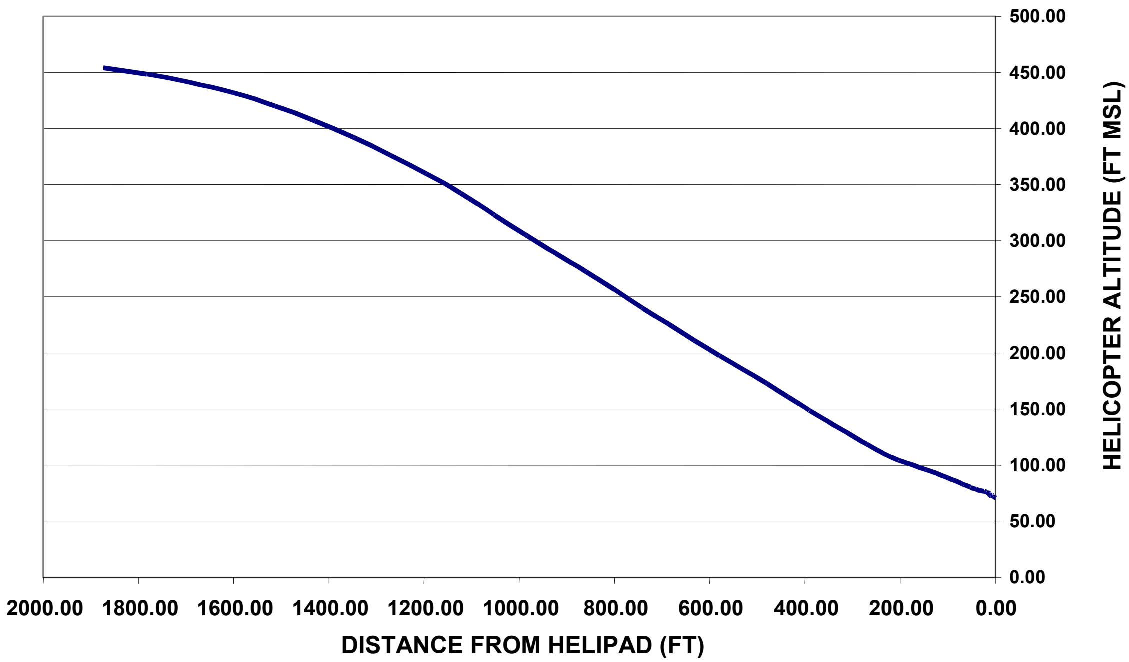
BELL 430 DESCENT ANGLE PROFILE (6, 70, 500)

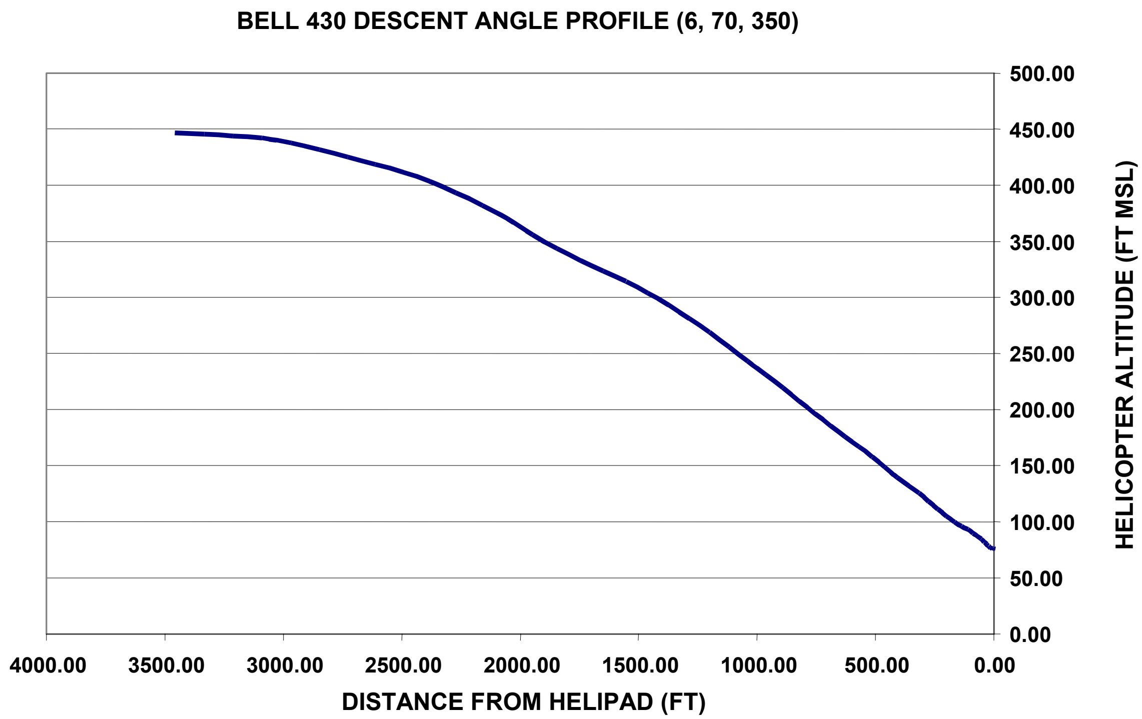


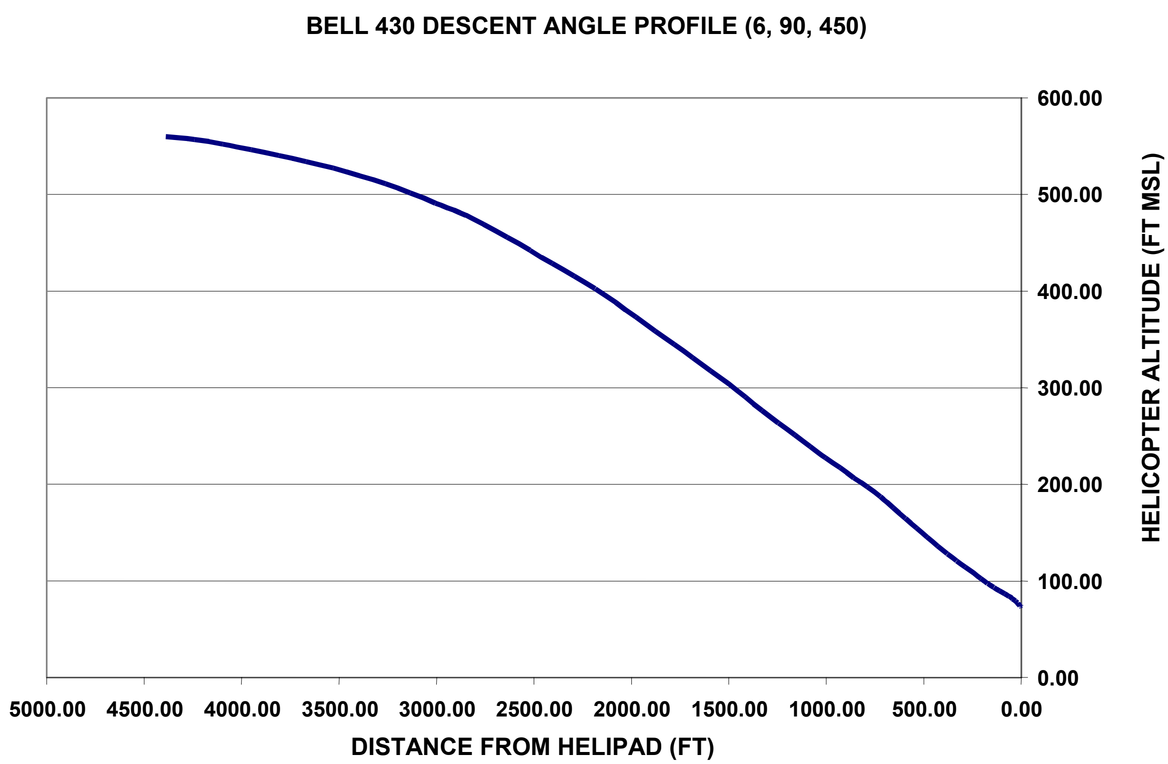
BELL 430 DESCENT ANGLE PROFILE (11, 60, 500)



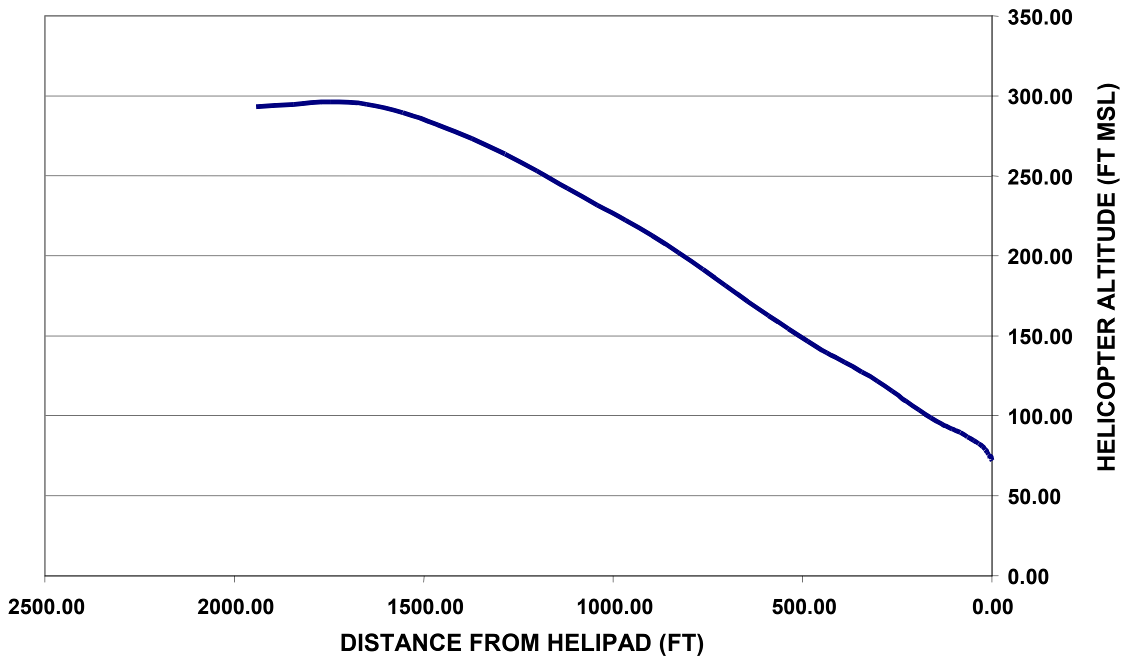
BELL 430 DESCENT ANGLE PROFILE (11, 50, 350)



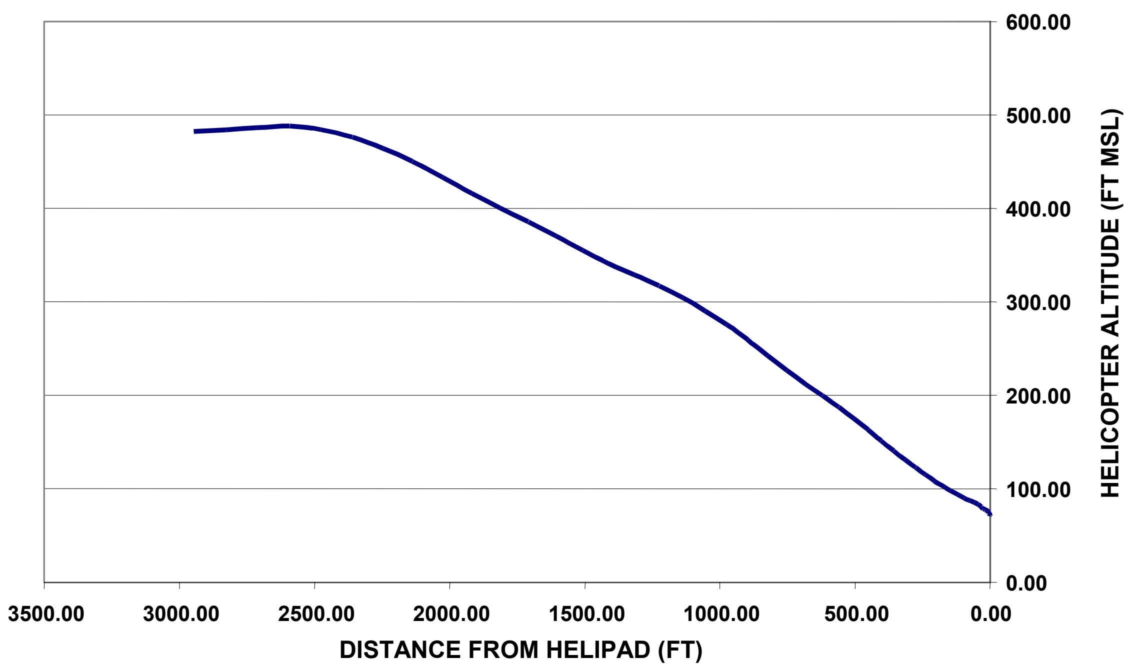

BELL 430 DESCENT ANGLE PROFILE (6, 70, 350)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

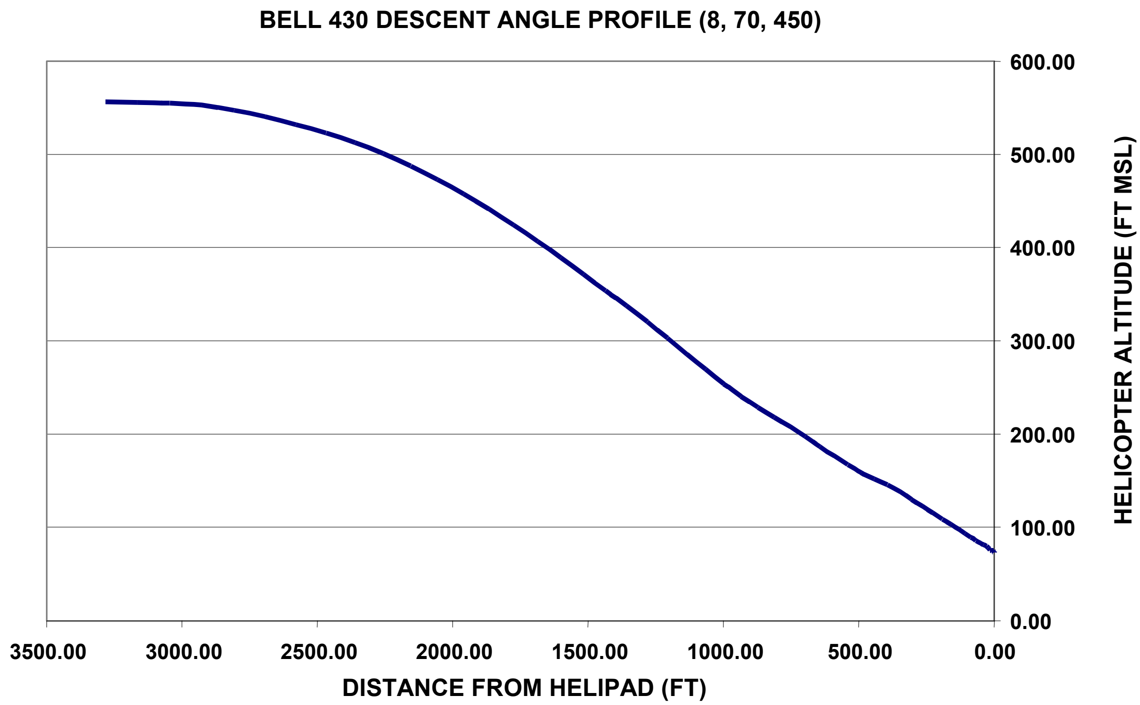

BELL 430 DESCENT ANGLE PROFILE (6, 90, 450)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
5000.00
4500.00
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

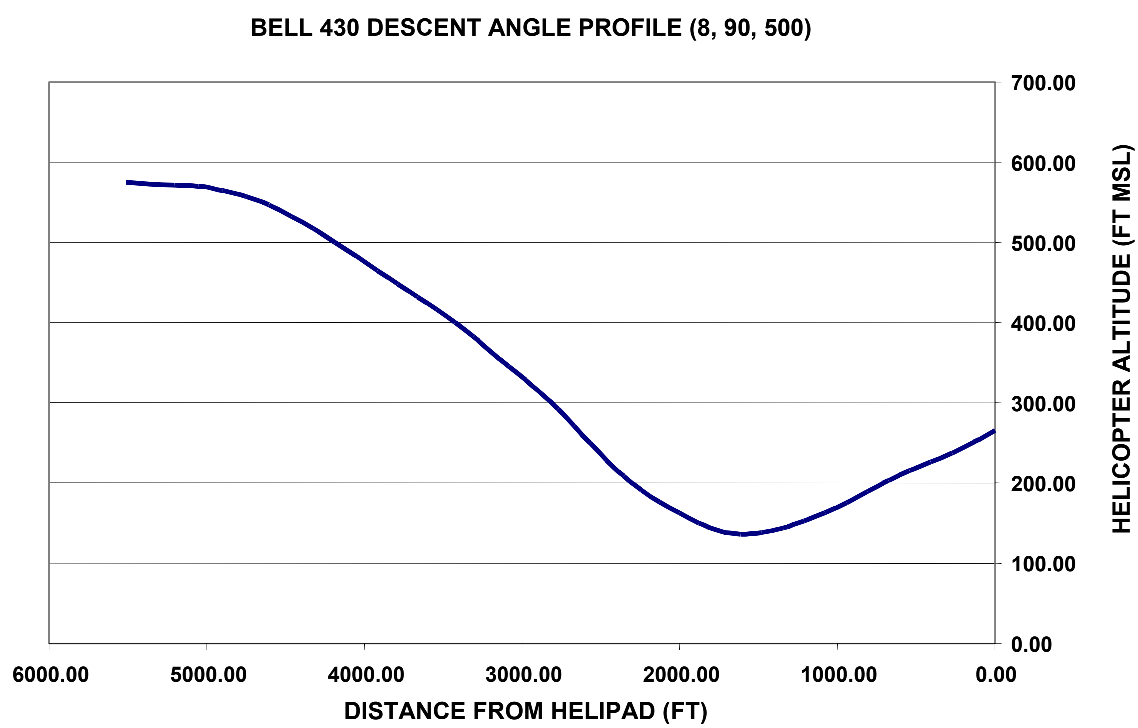
BELL 430 DESCENT ANGLE PROFILE (6, 60, 200)

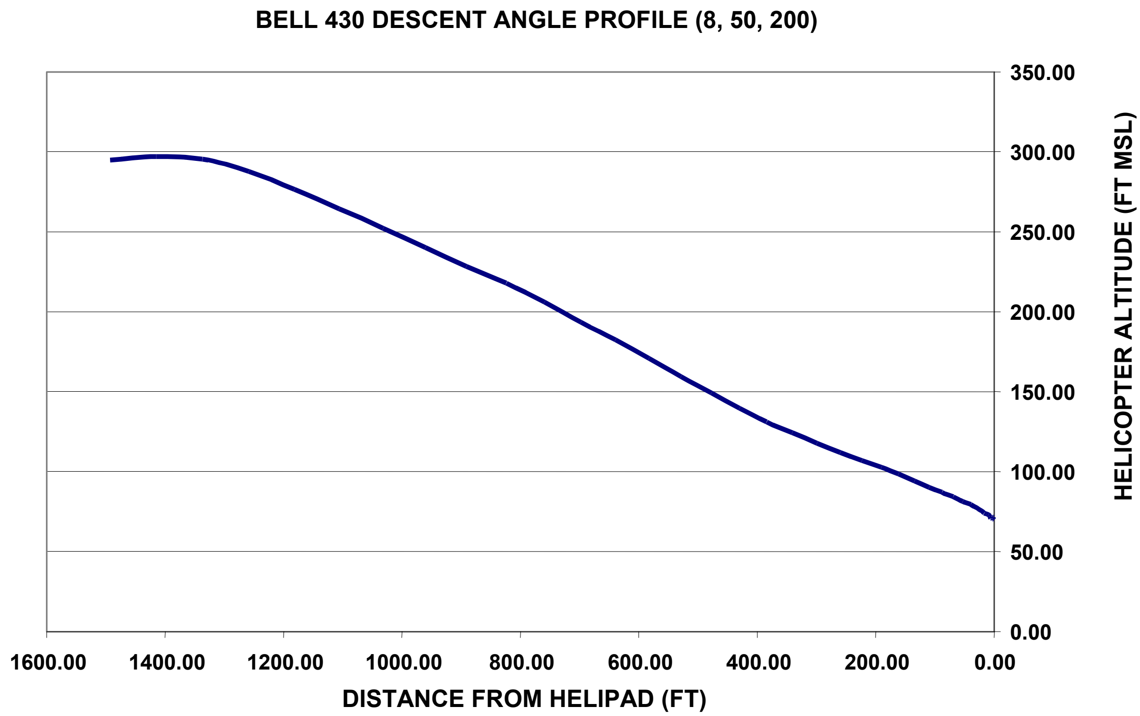


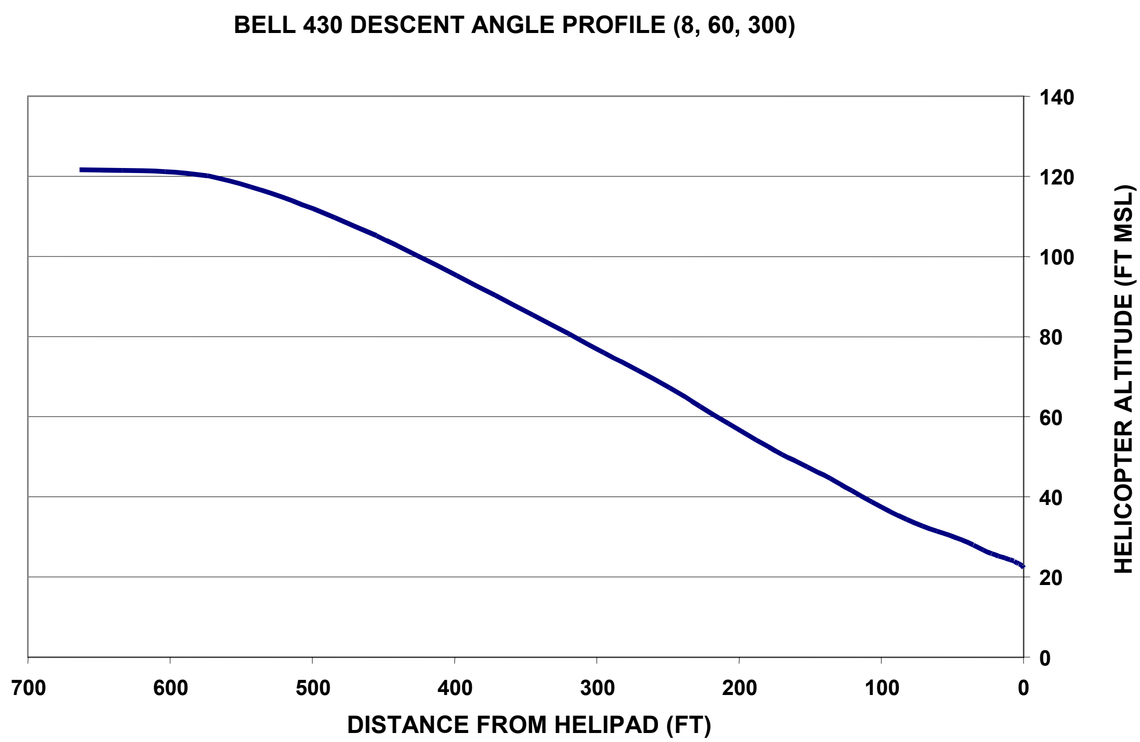
BELL 430 DESCENT ANGLE PROFILE (8, 70, 400)



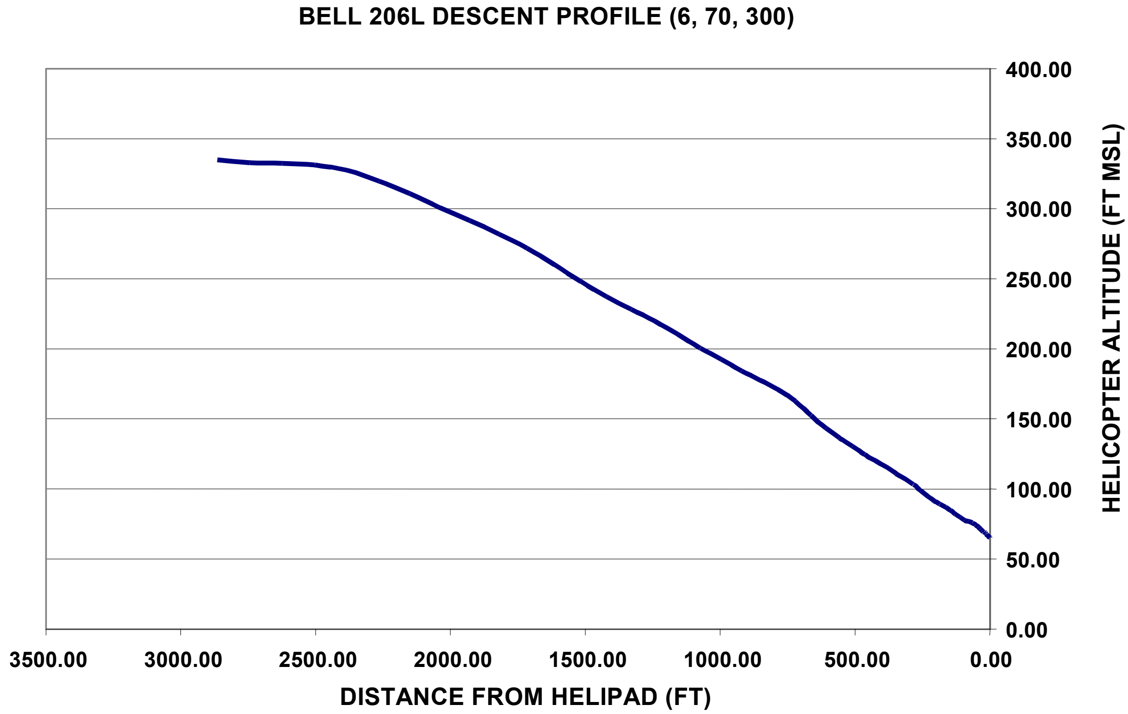

BELL 430 DESCENT ANGLE PROFILE (8, 70, 450)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

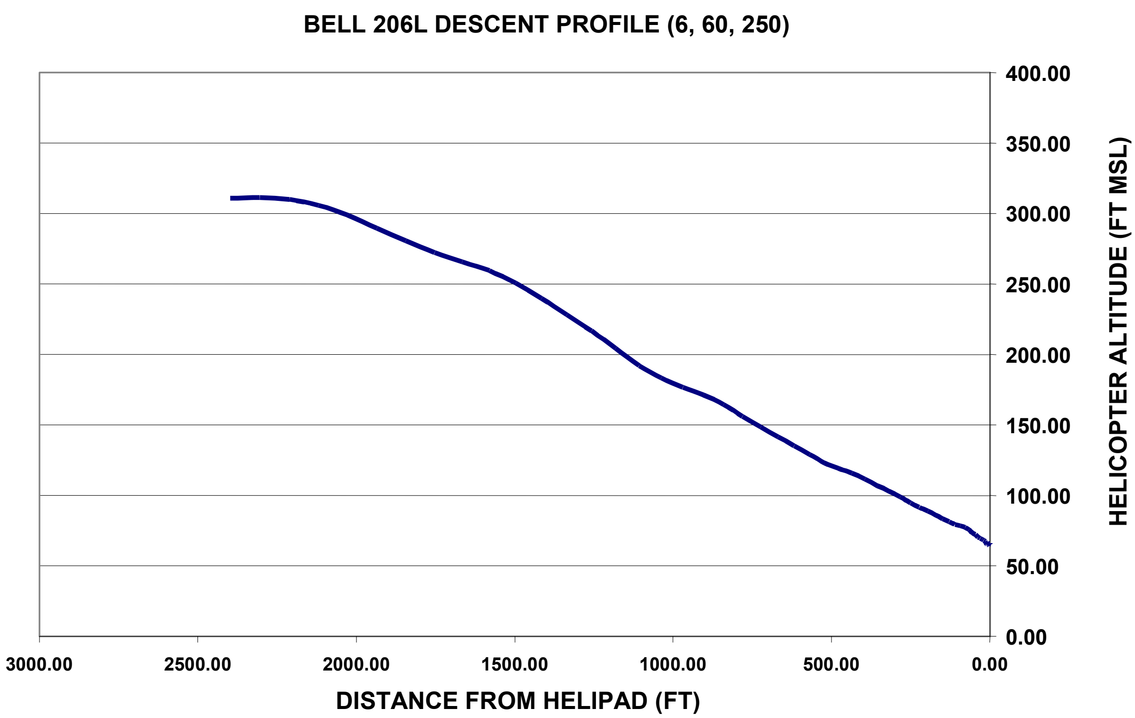

BELL 430 DESCENT ANGLE PROFILE (8, 90, 500)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
DISTANCE FROM HELIPAD (FT)

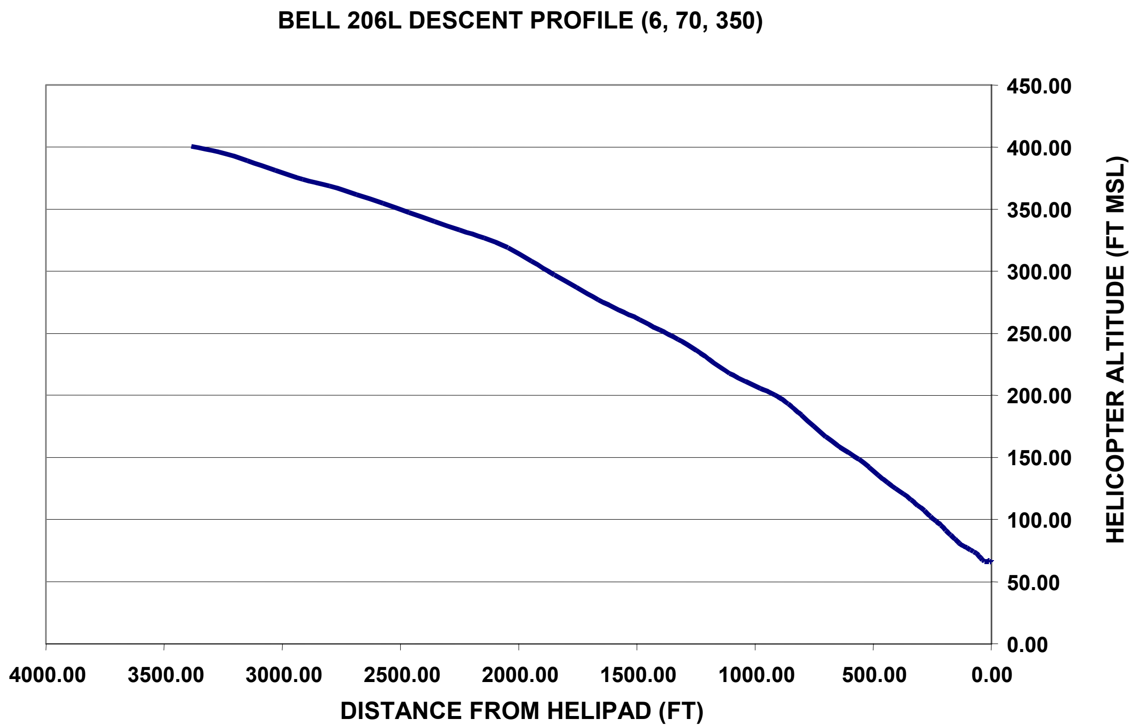

BELL 430 DESCENT ANGLE PROFILE (8, 50, 200)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE FROM HELIPAD (FT)

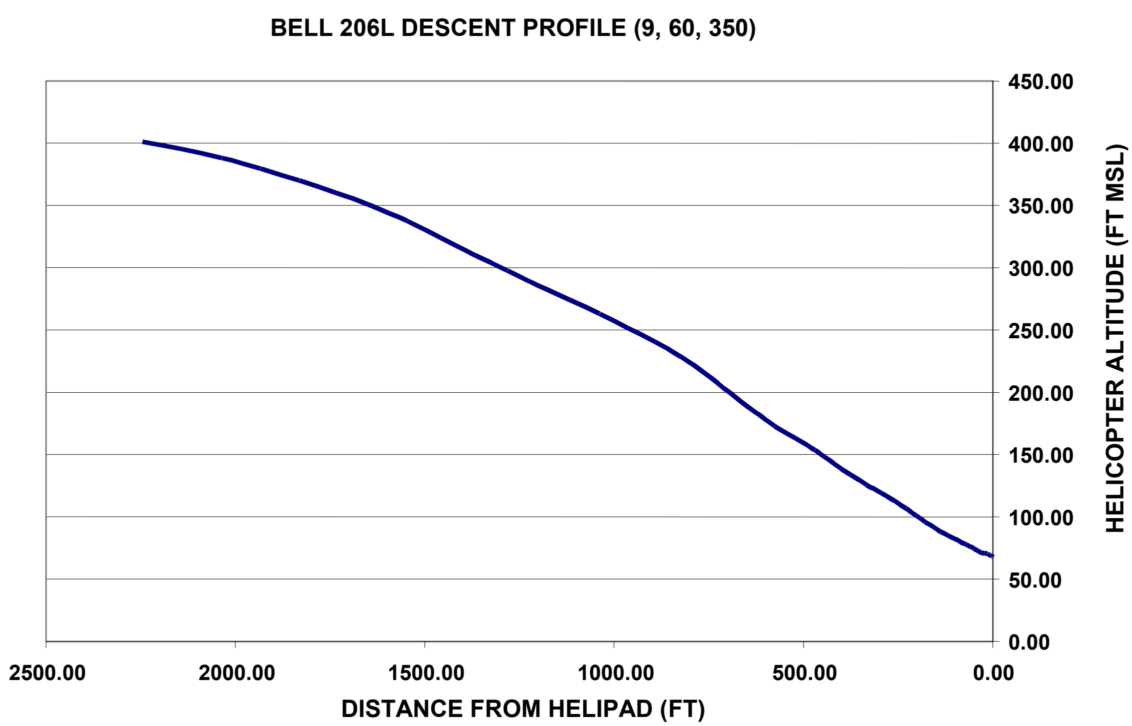

BELL 430 DESCENT ANGLE PROFILE (8, 60, 300)
140
120
100
80
60
40
20
0
HELICOPTER ALTITUDE (FT MSL)
700
600
500
400
300
200
100
0
DISTANCE FROM HELIPAD (FT)

<u>BELL 206L TRAJECTORY CHARTS</u>.

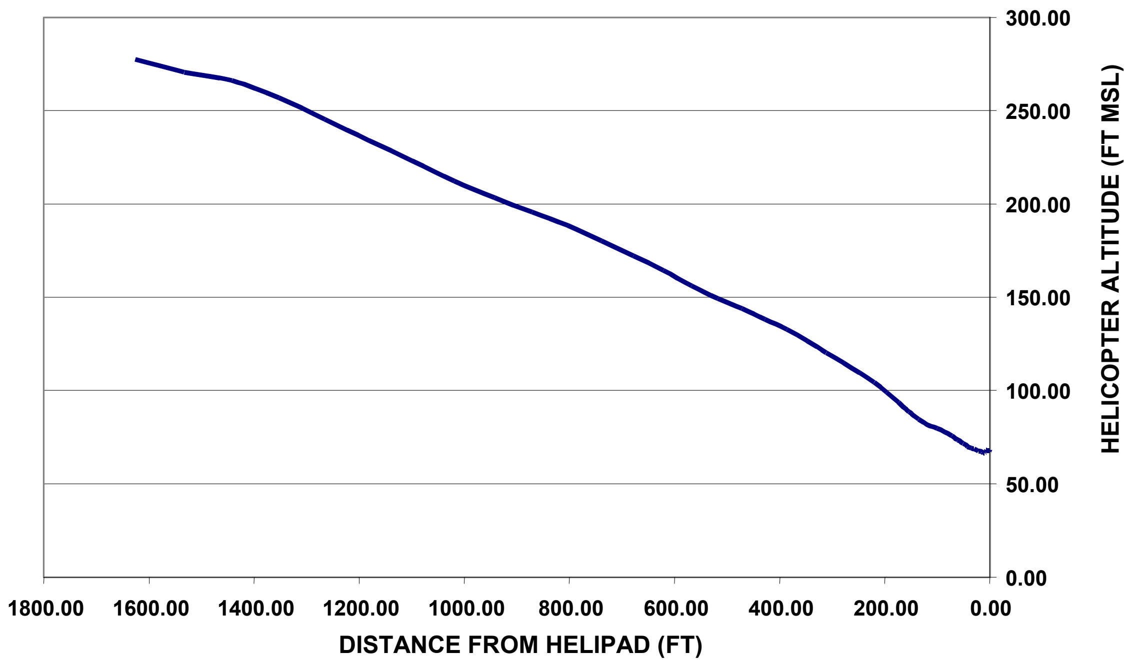




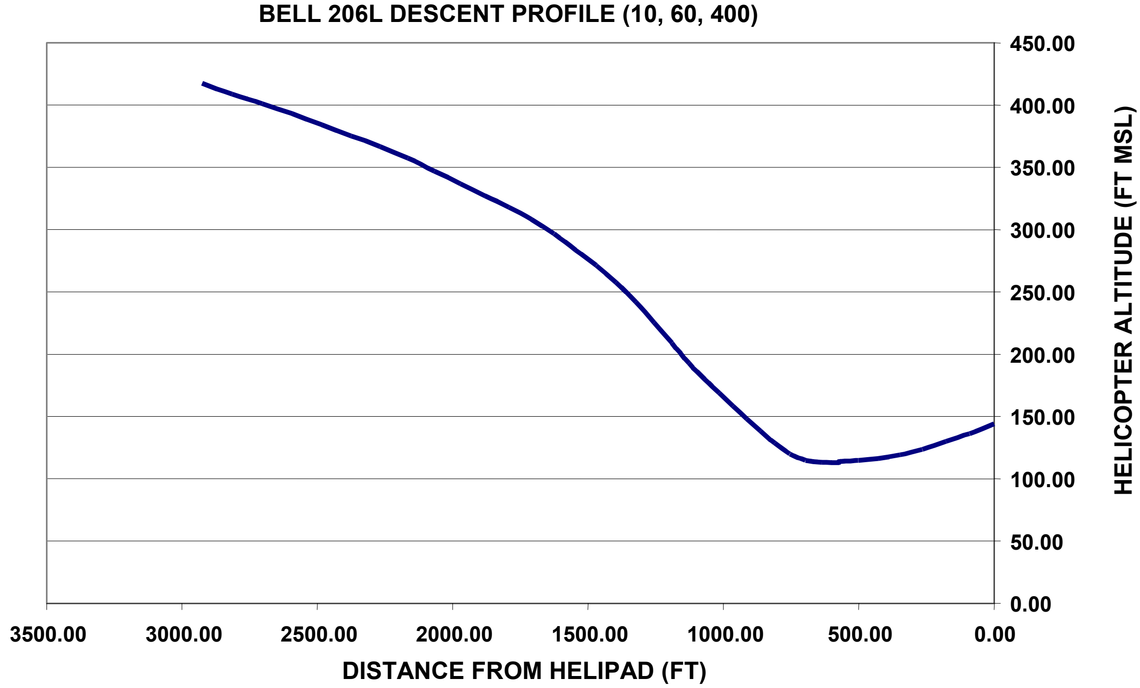

BELL 206L DESCENT PROFILE (6, 70, 350)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

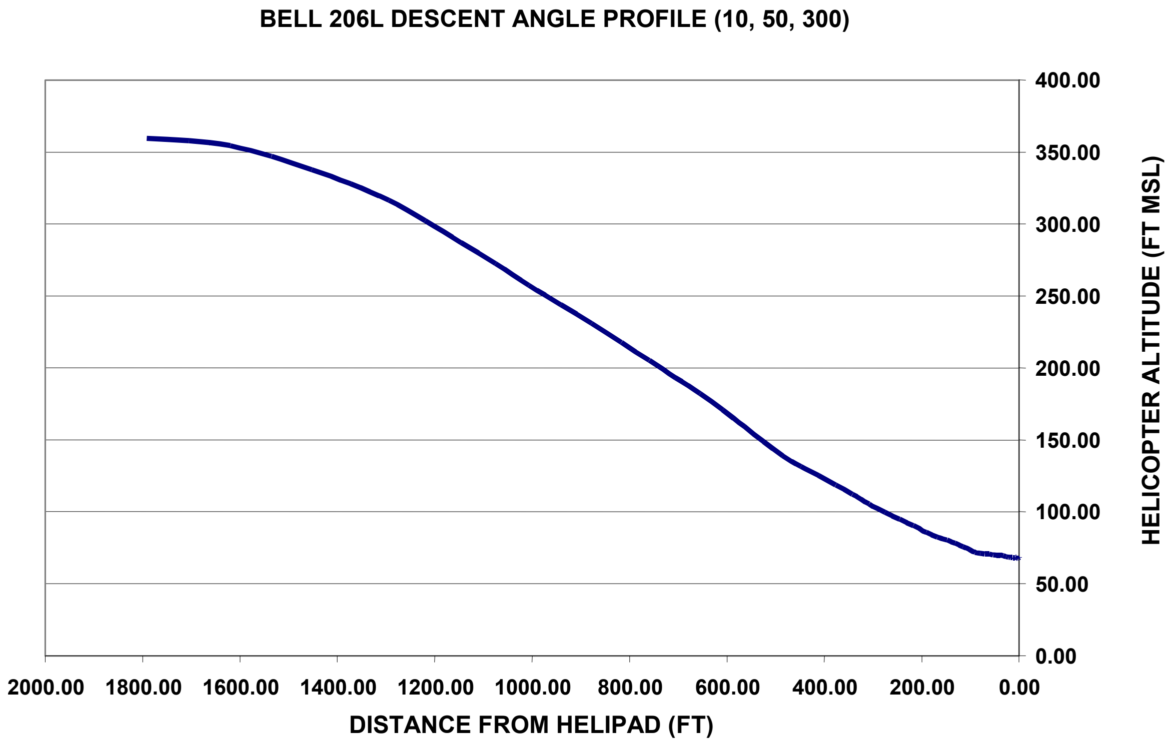

BELL 206L DESCENT PROFILE (9, 60, 350)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

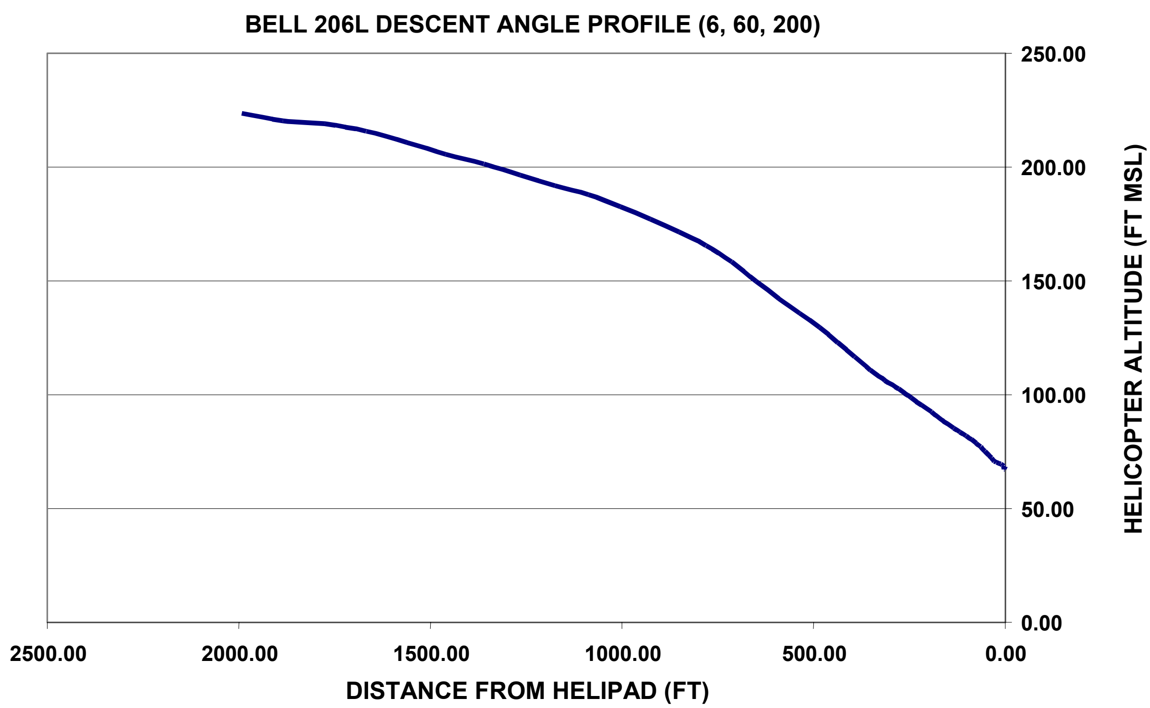
BELL 206L DESCENT PROFILE (9, 50, 250)



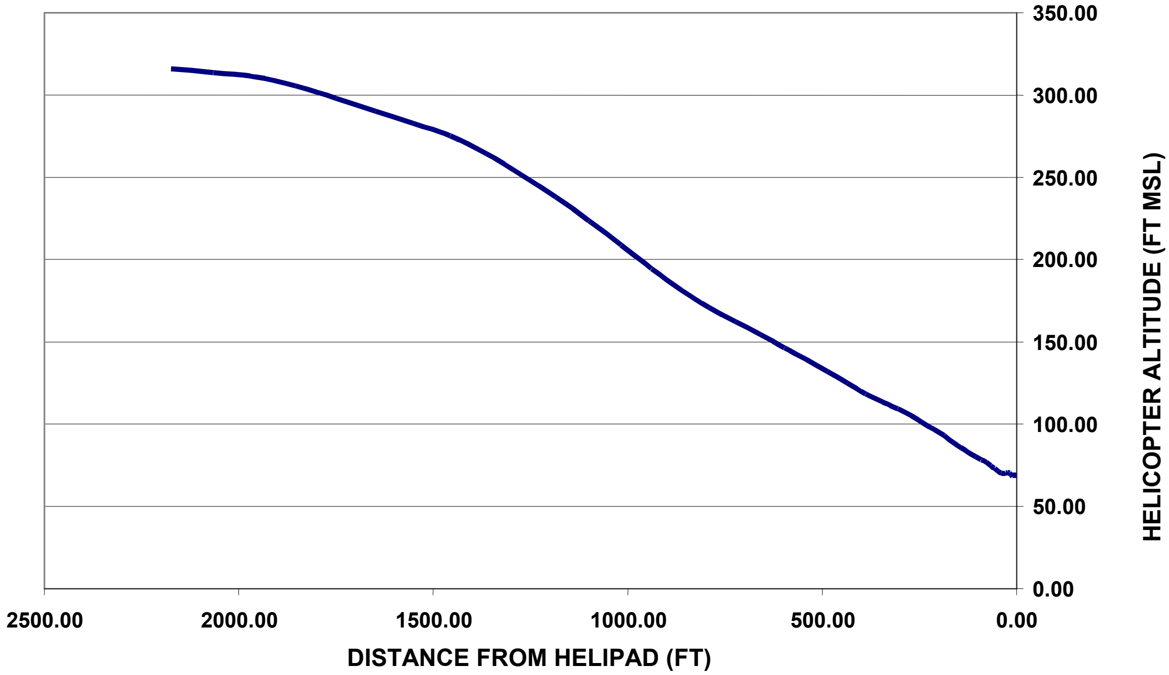
BELL 206L DESCENT PROFILE (10, 60, 400)



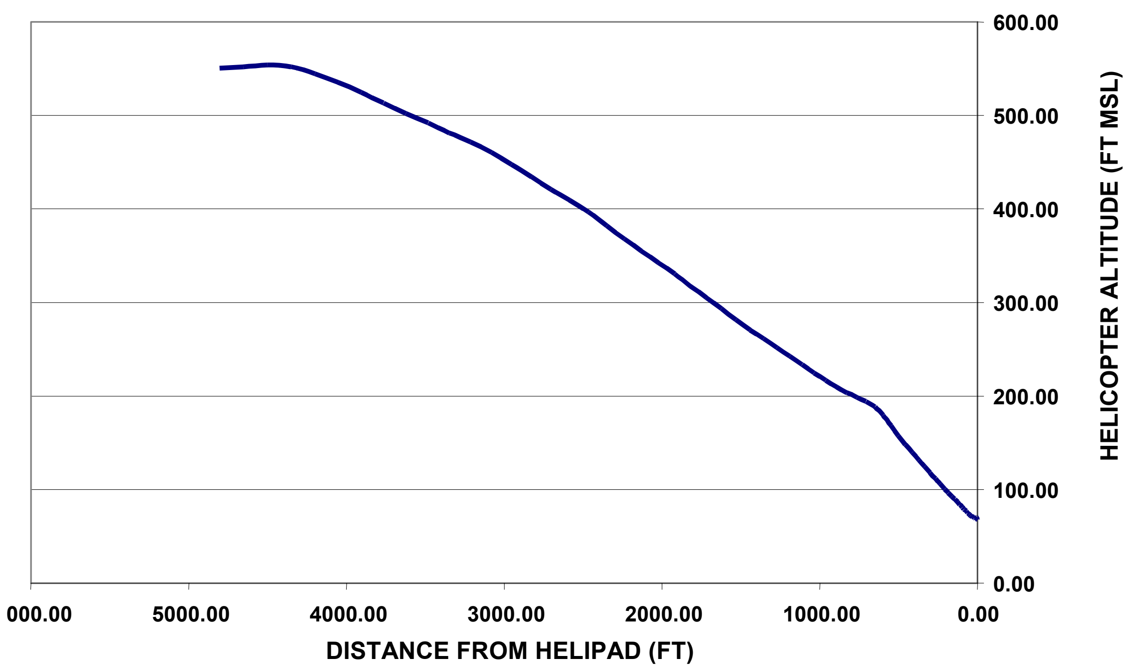

BELL 206L DESCENT ANGLE PROFILE (10, 50, 300)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE FROM HELIPAD (FT)


BELL 206L DESCENT ANGLE PROFILE (6, 60, 200)
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

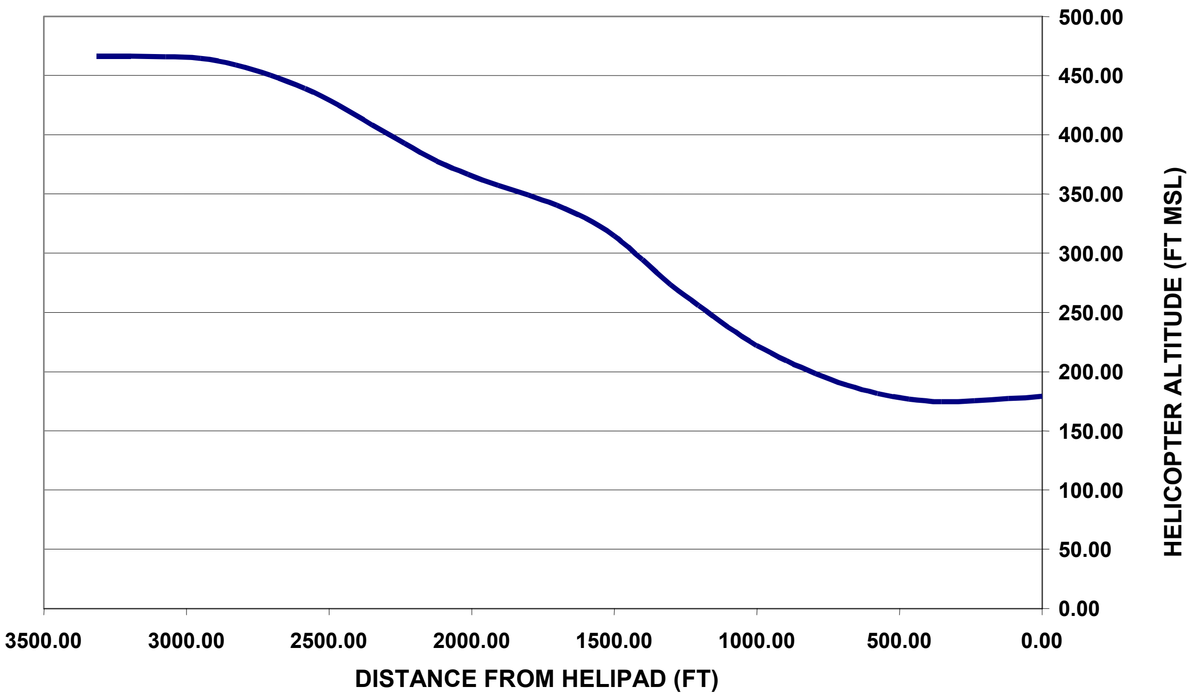
BELL 206L DESCENT ANGLE PROFILE (8, 60, 300)



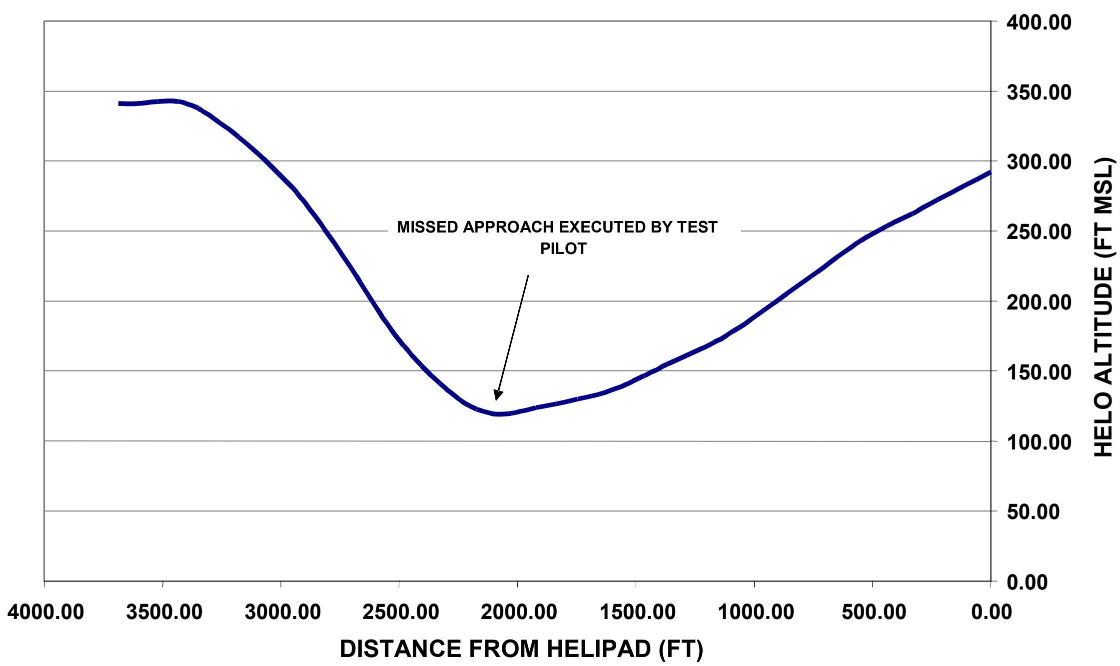
BELL 206L DESCENT ANGLE PROFILE (6, 90, 500)

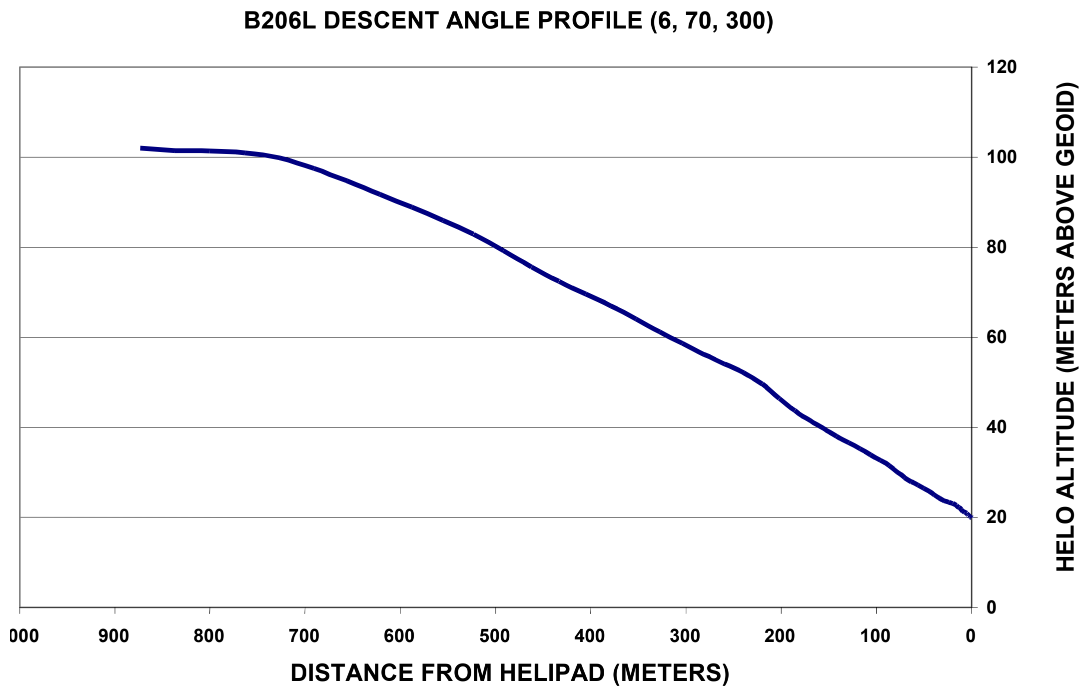


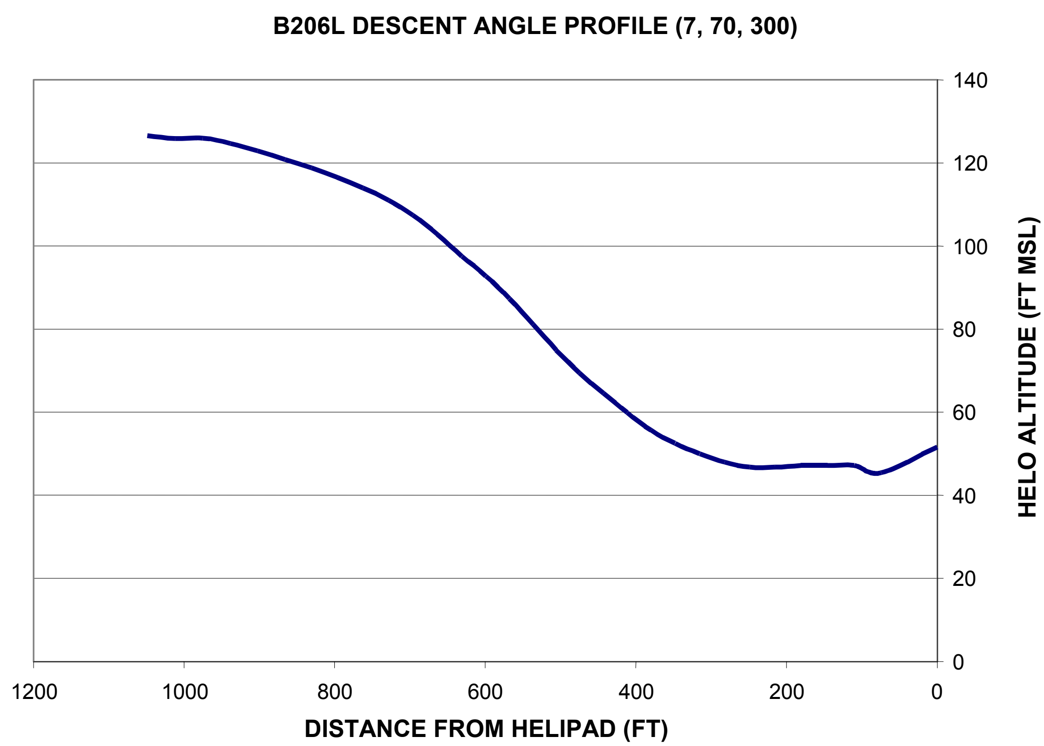
BELL 206L DESCENT ANGLE PROFILE (8, 70, 400)



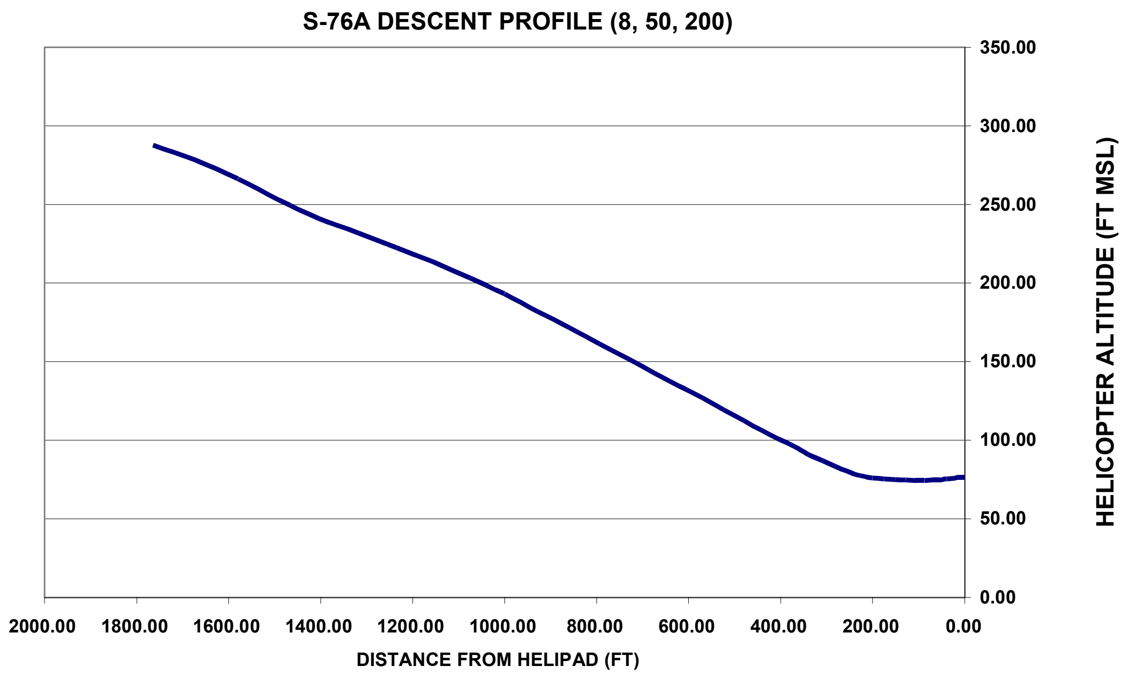
B206L DESCENT ANGLE PROFILE (11, 50, 300)

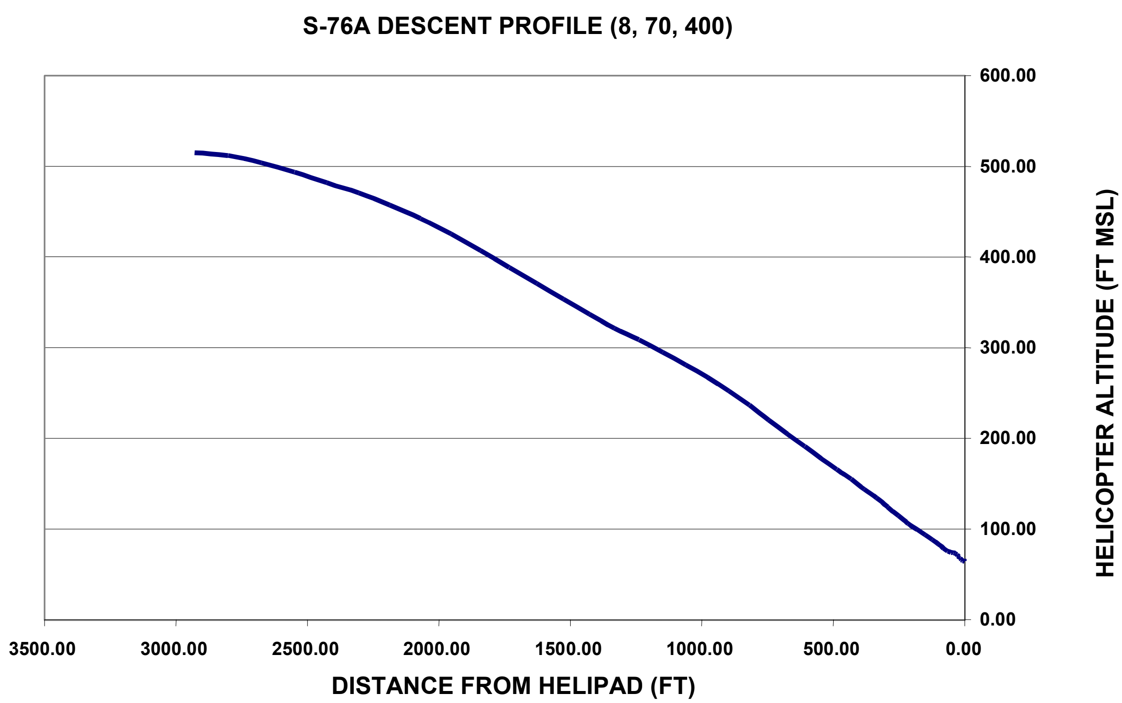


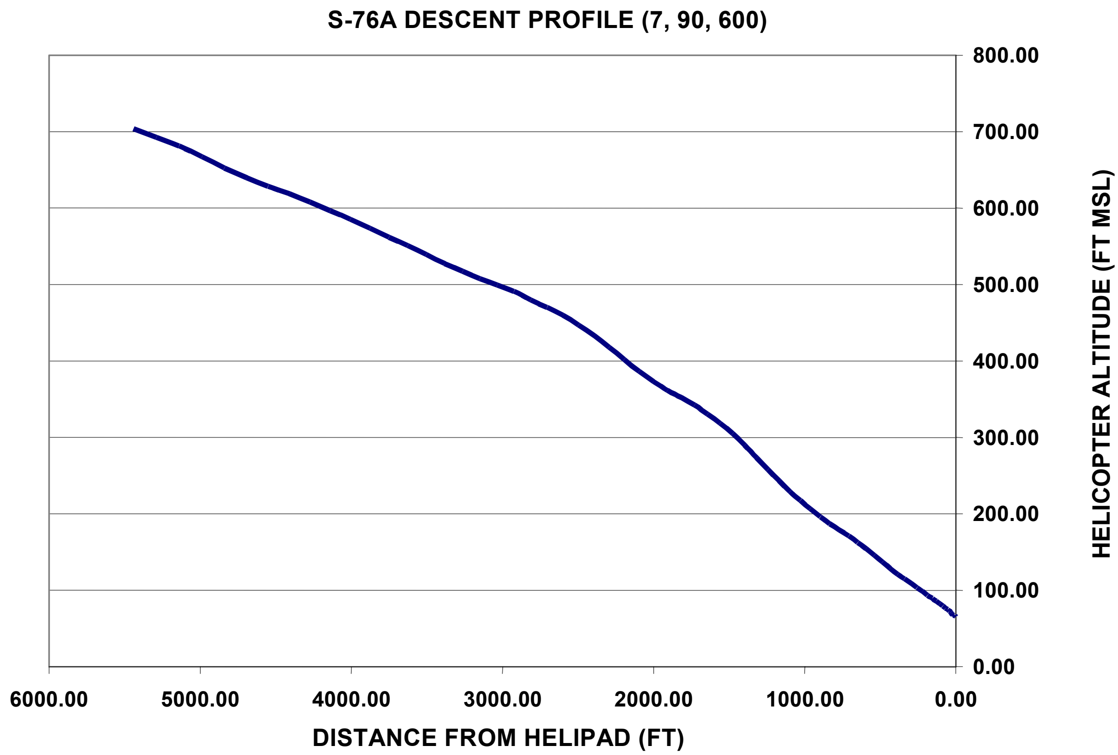

B206L DESCENT ANGLE PROFILE (6, 70, 300)
120
100
80
60
40
20
0
HELO ALTITUDE (METERS ABOVE GEOID)
000
900
800
700
600
500
400
300
200
100
0
DISTANCE FROM HELIPAD (METERS)

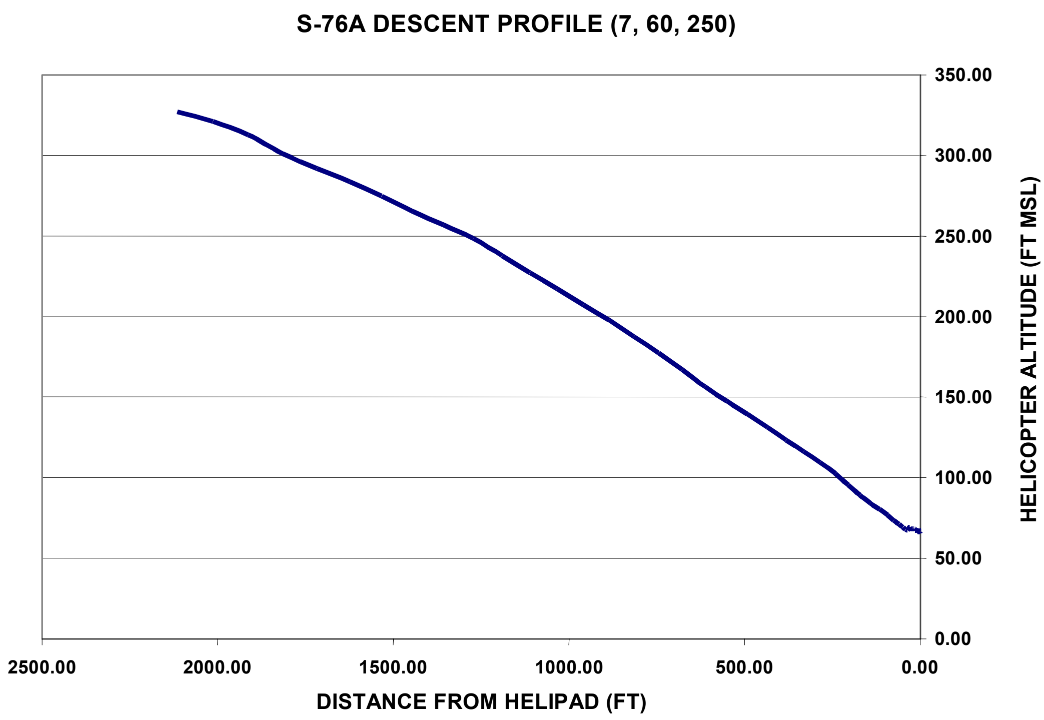

B206L DESCENT ANGLE PROFILE (7, 70, 300)
140
120
100
80
60
40
20
0
HELO ALTITUDE (FT MSL)
1200
1000
800
600
400
200
0
DISTANCE FROM HELIPAD (FT)

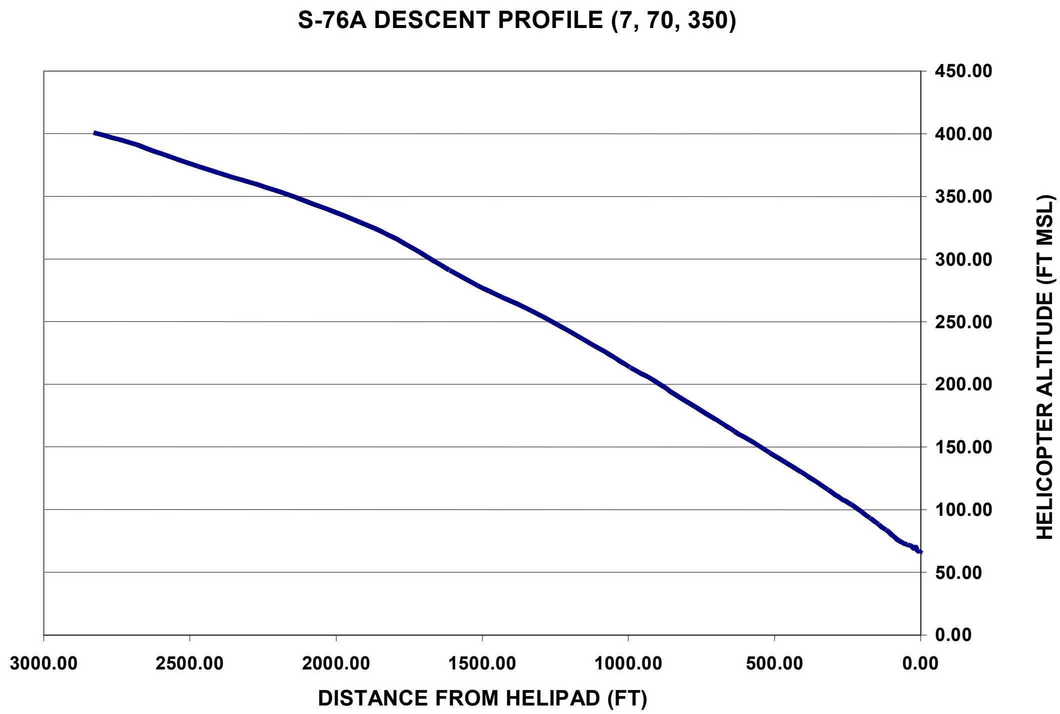
<u>S-76 TRAJECTORY CHARTS</u>.



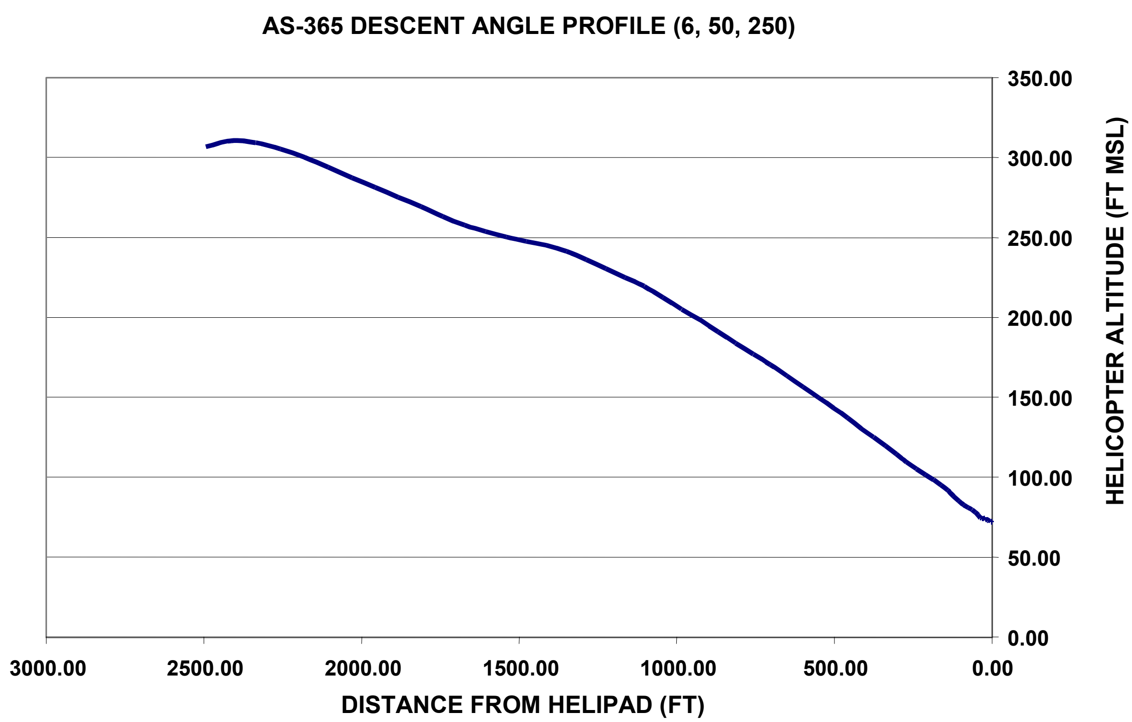



S-76A DESCENT PROFILE (7, 90, 600)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
DISTANCE FROM HELIPAD (FT)

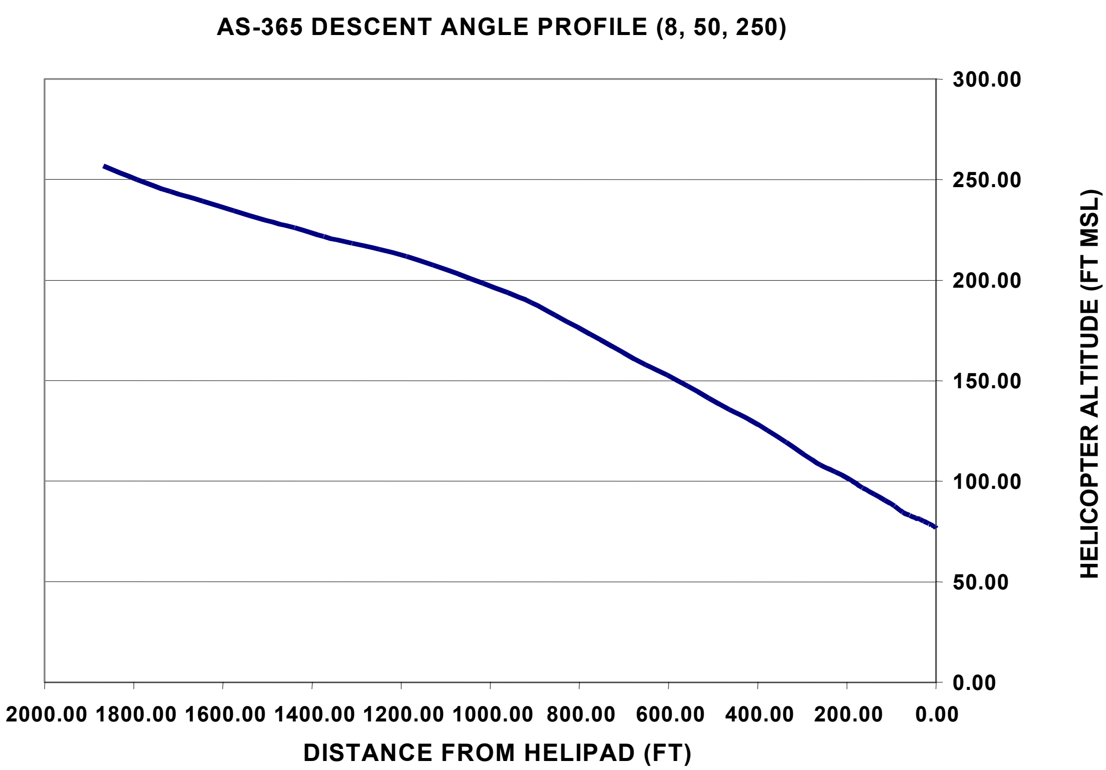

S-76A DESCENT PROFILE (7, 60, 250)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)



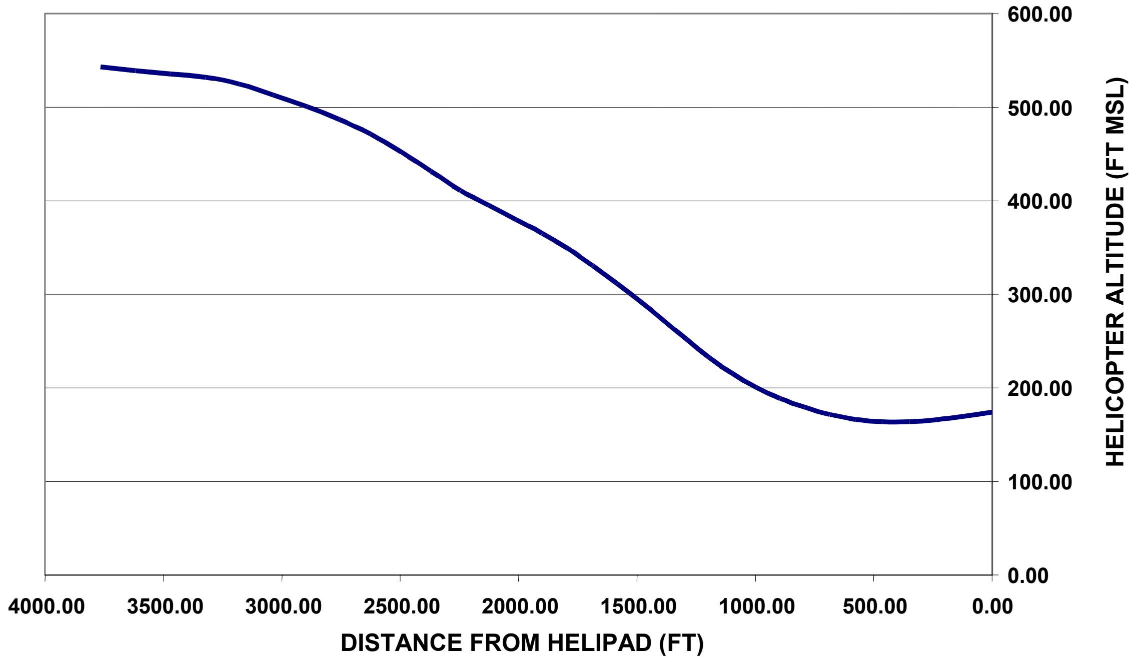
AS-365 N2 TRAJECTORY CHARTS.



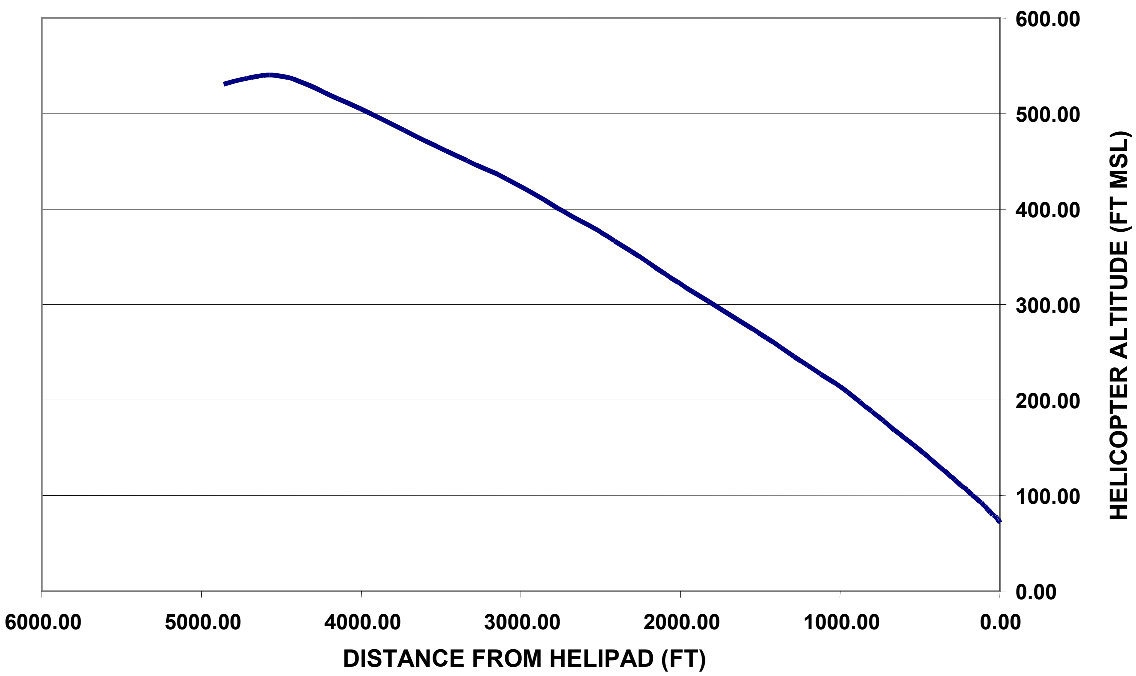

AS-365 DESCENT ANGLE PROFILE (8, 90, 500)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

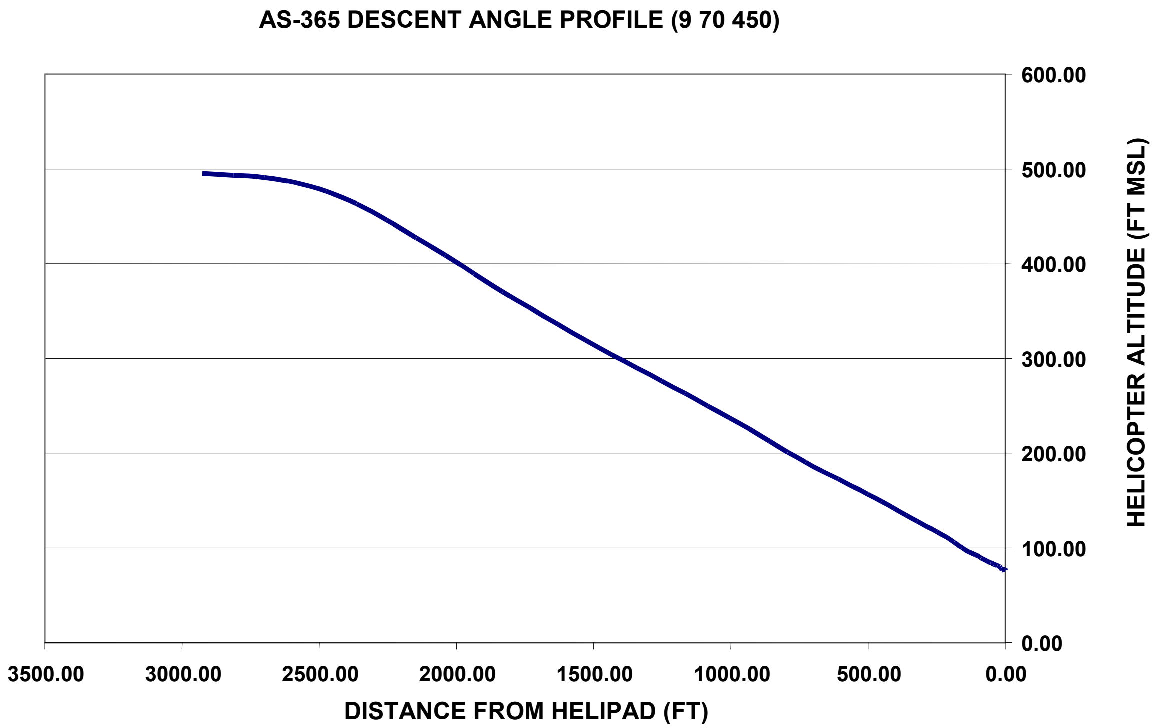

AS-365 DESCENT ANGLE PROFILE (8, 50, 250)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE FROM HELIPAD (FT)

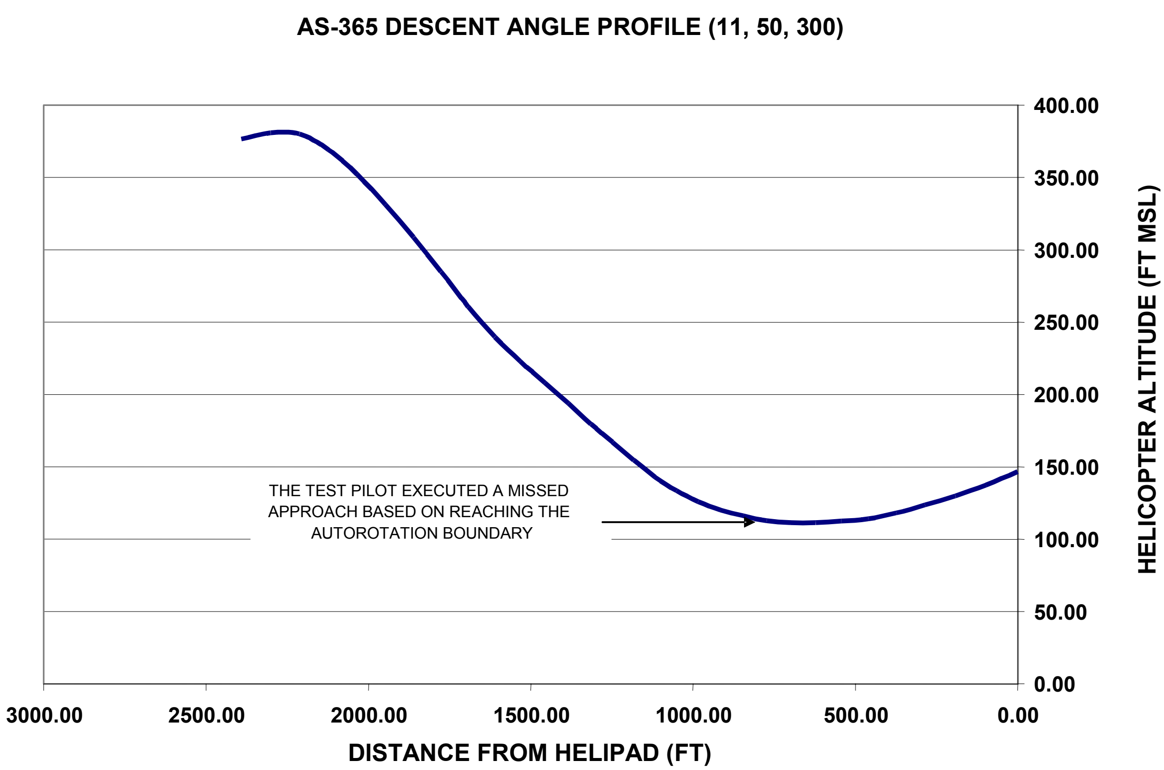
AS-365 DESCENT ANGLE PROFILE (9 90, 500)



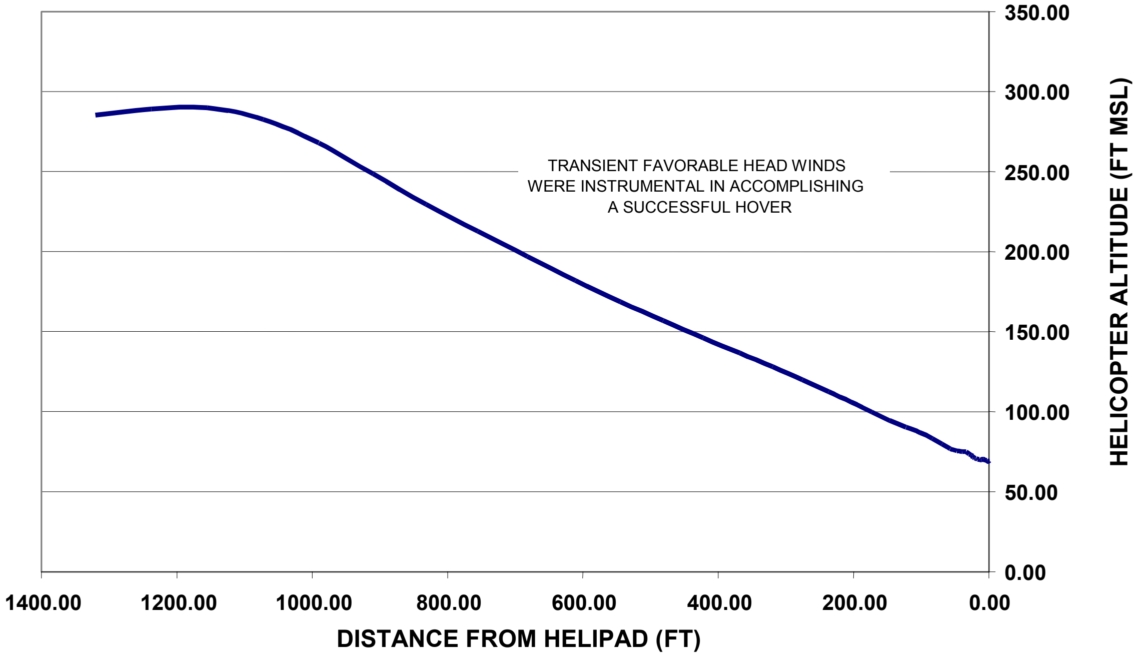
AS-365 DESCENT ANGLE PROFILE (6, 90, 500)



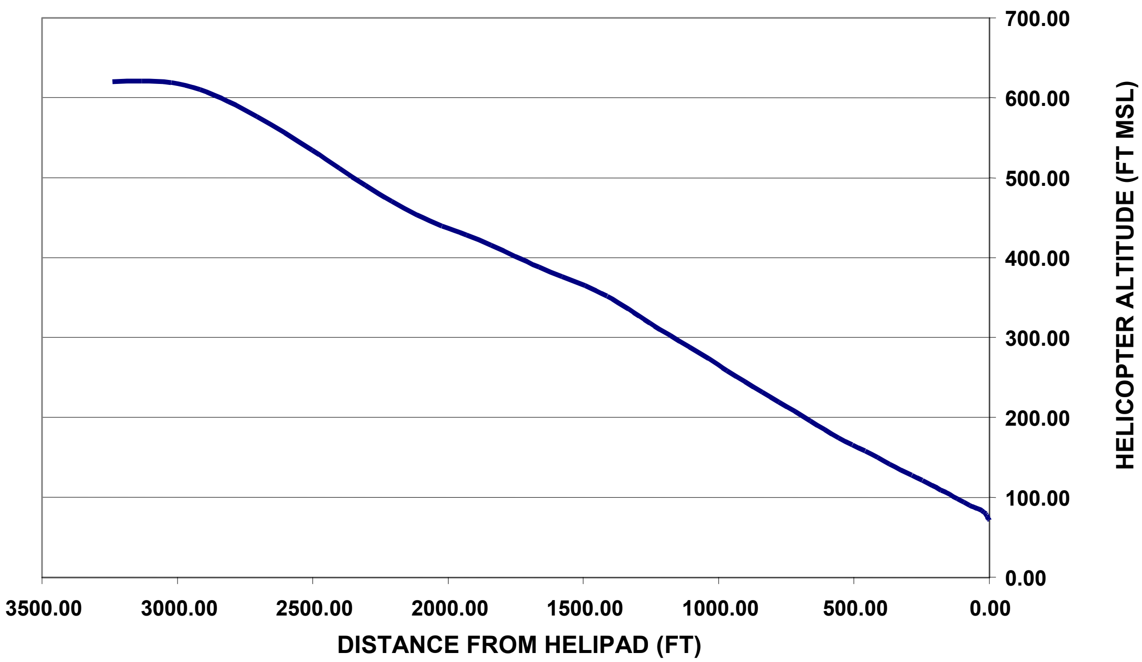

AS-365 DESCENT ANGLE PROFILE (9 70 450)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)


AS-365 DESCENT ANGLE PROFILE (11, 50, 300)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
THE TEST PILOT EXECUTED A MISSED APPROACH BASED ON REACHING THE AUTOROTATION BOUNDARY
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

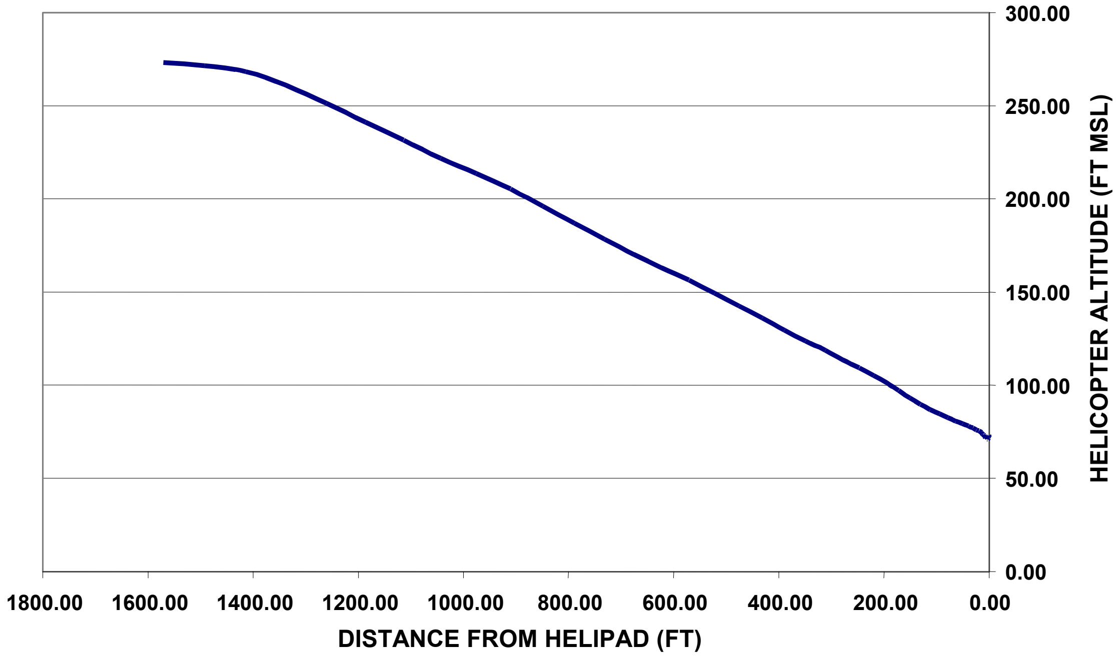
AS-365 DESCENT ANGLE PROFILE (11, 50, 250)



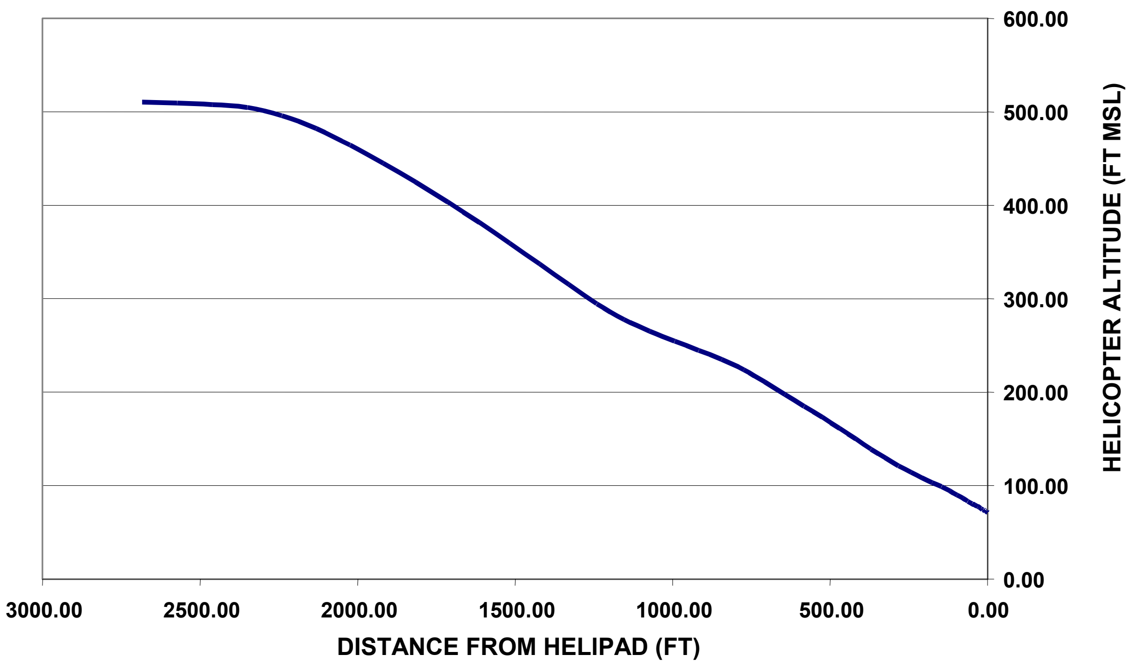
AS-365 DESCENT ANGLE PROFILE (11, 70, 600)

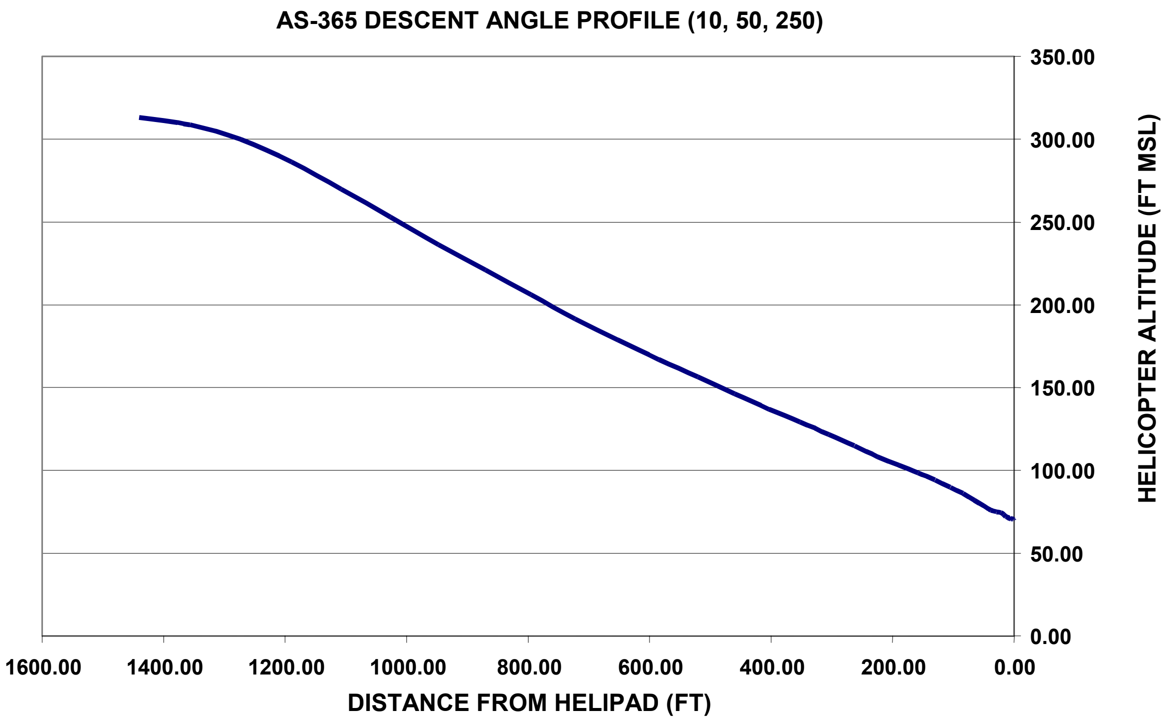


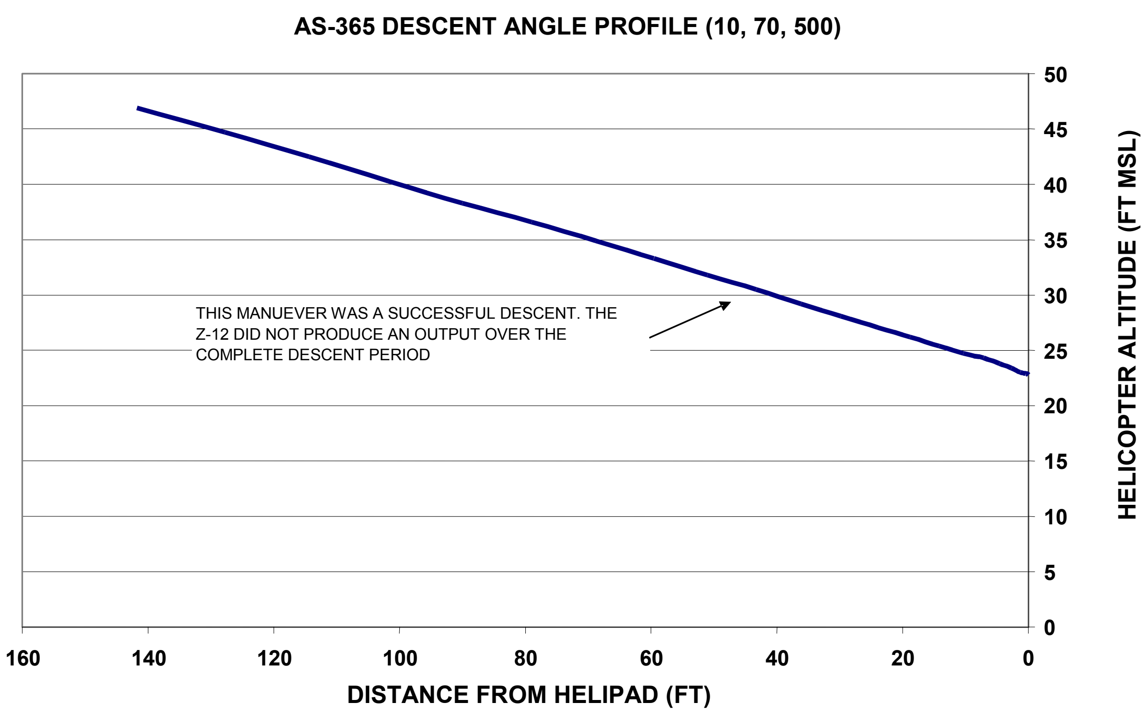
AS-365 DESCENT ANGLE PROFILE (9, 50, 250)

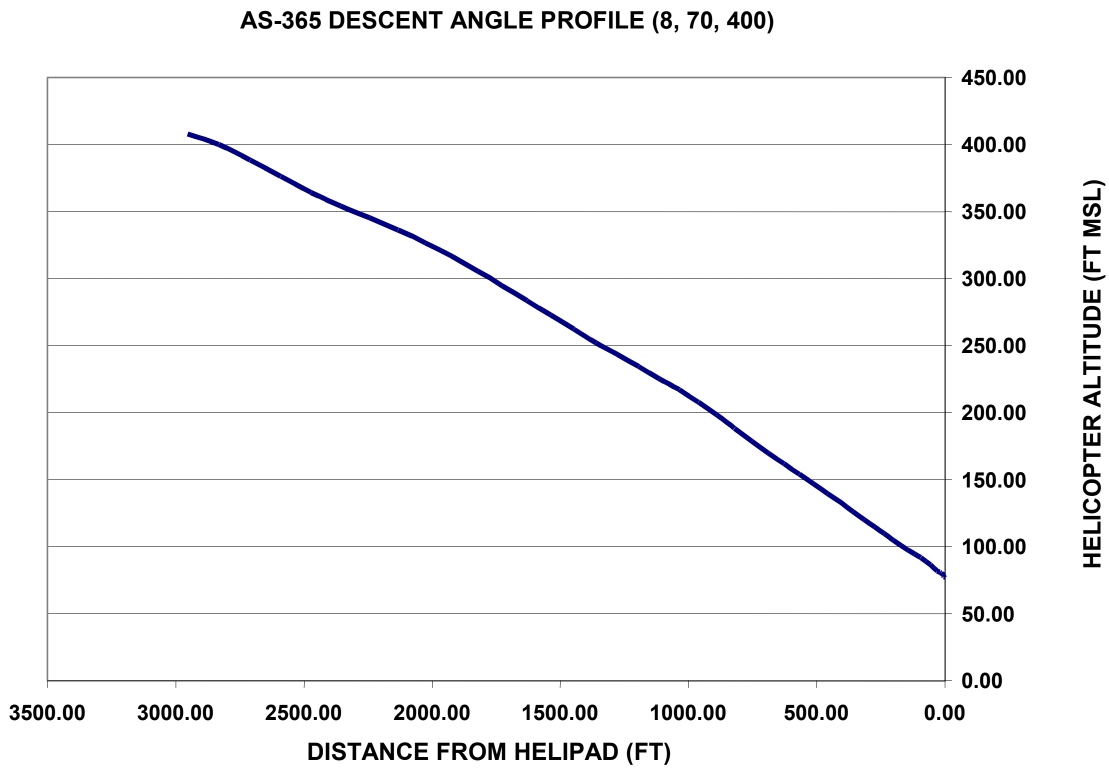


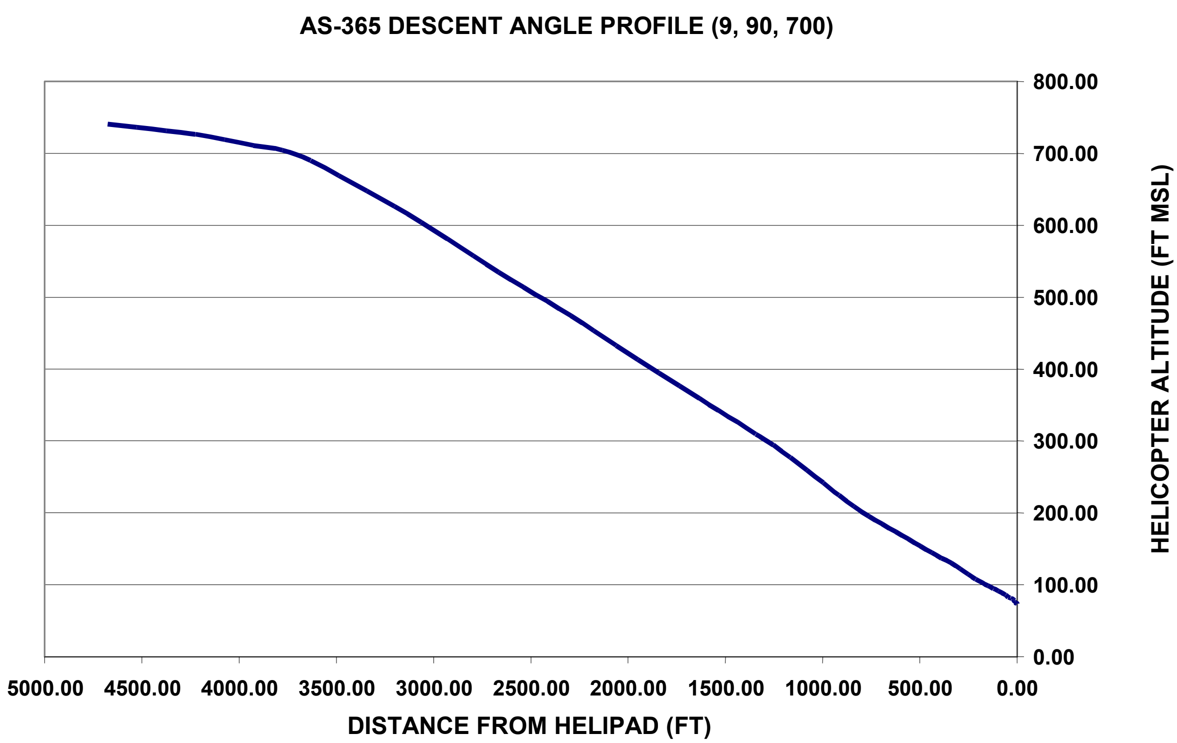
AS-365 DESCENT ANGLE PROFILE (11, 70, 500)

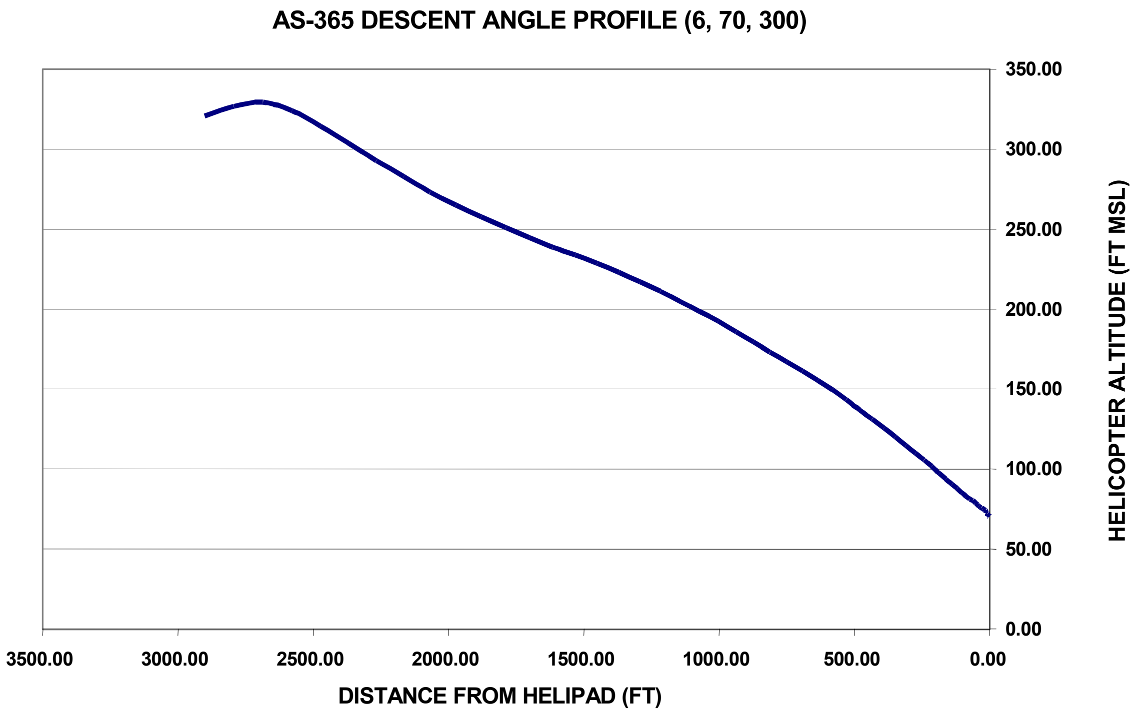



AS-365 DESCENT ANGLE PROFILE (10, 50, 250)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE FROM HELIPAD (FT)

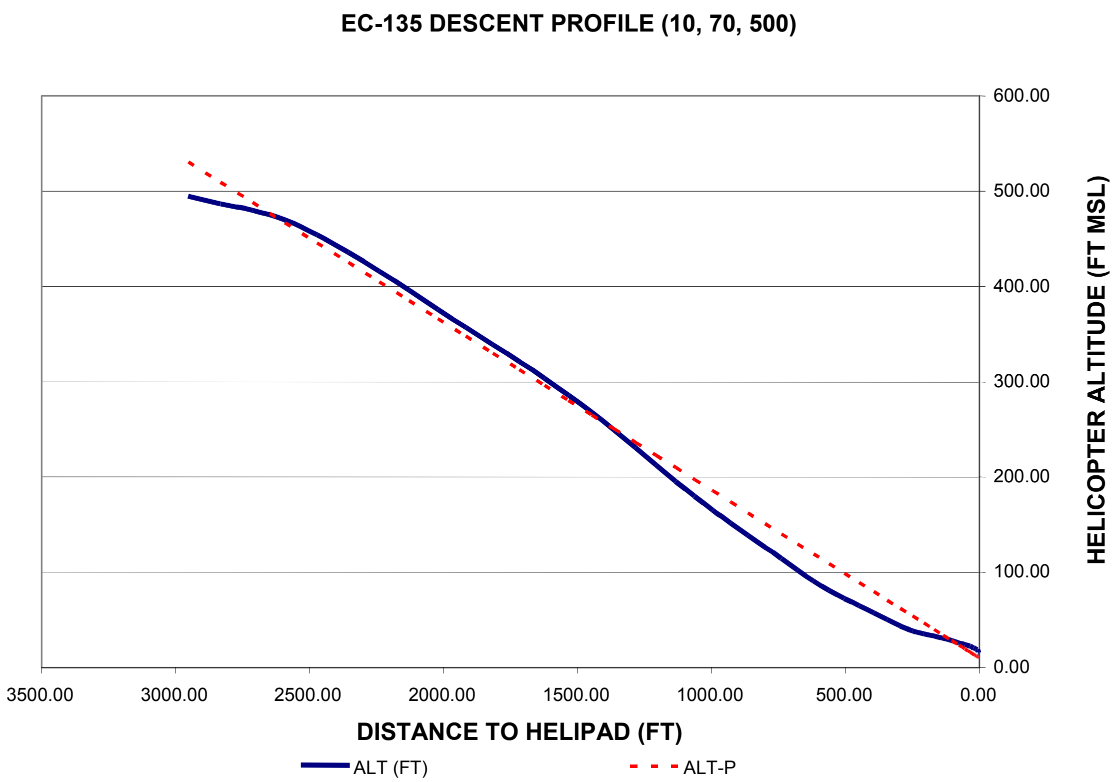

AS-365 DESCENT ANGLE PROFILE (10, 70, 500)
50
45
40
35
30
25
20
15
10
5
0
HELICOPTER ALTITUDE (FT MSL)
THIS MANUEVER WAS A SUCCESSFUL DESCENT. THE Z-12 DID NOT PRODUCE AN OUTPUT OVER THE COMPLETE DESCENT PERIOD
160
140
120
100
80
60
40
20
0
DISTANCE FROM HELIPAD (FT)


AS-365 DESCENT ANGLE PROFILE (8, 70, 400)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)

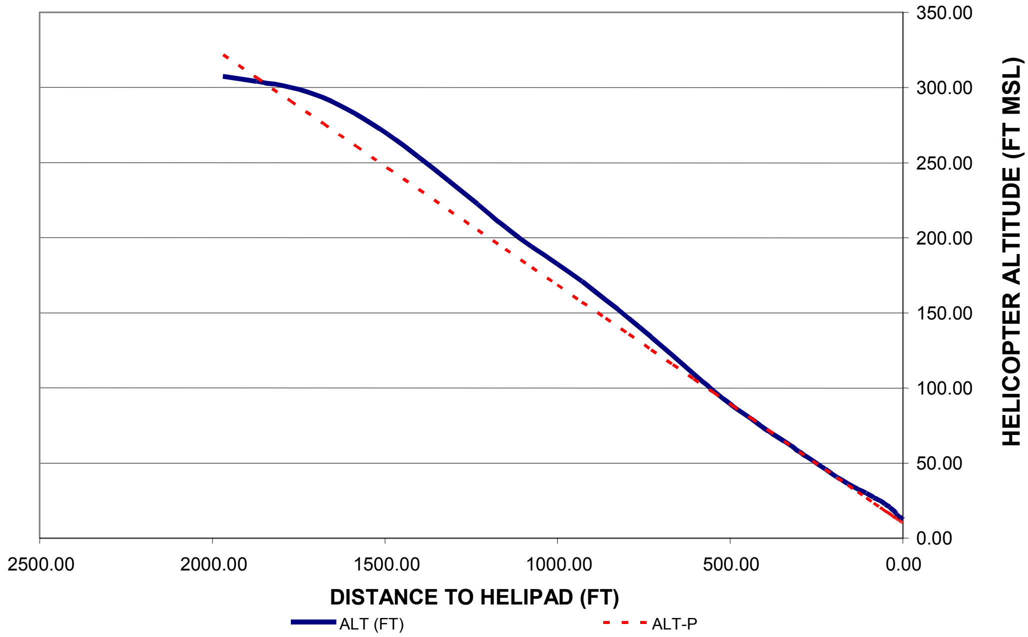

AS-365 DESCENT ANGLE PROFILE (9, 90, 700)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
5000.00
4500.00
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE FROM HELIPAD (FT)



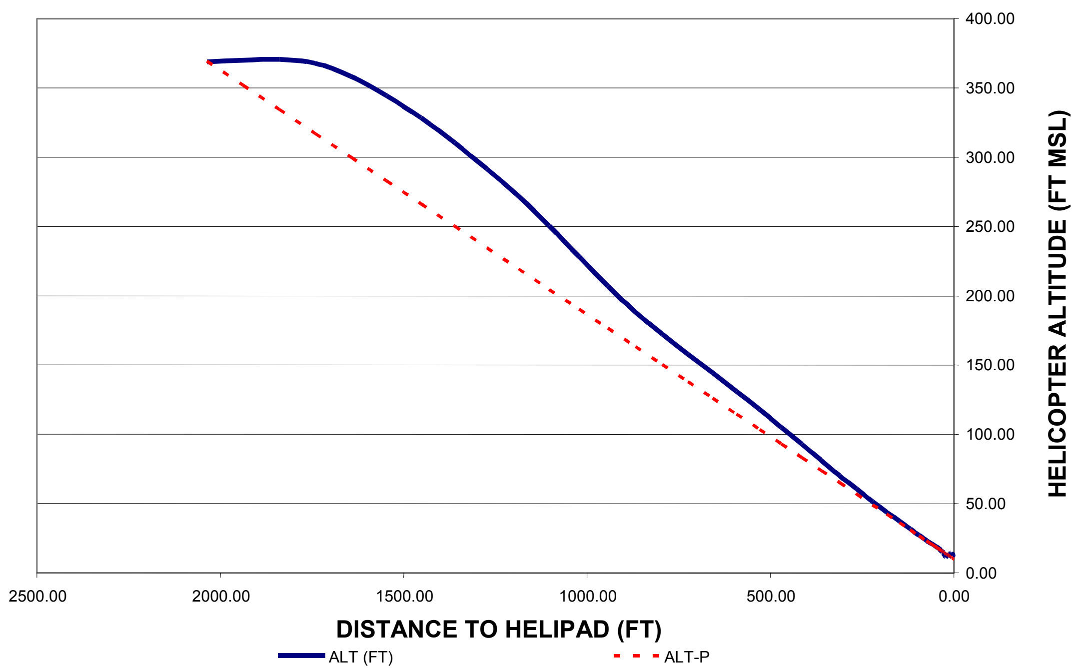
EC-135 TRAJECTORY CHARTS.

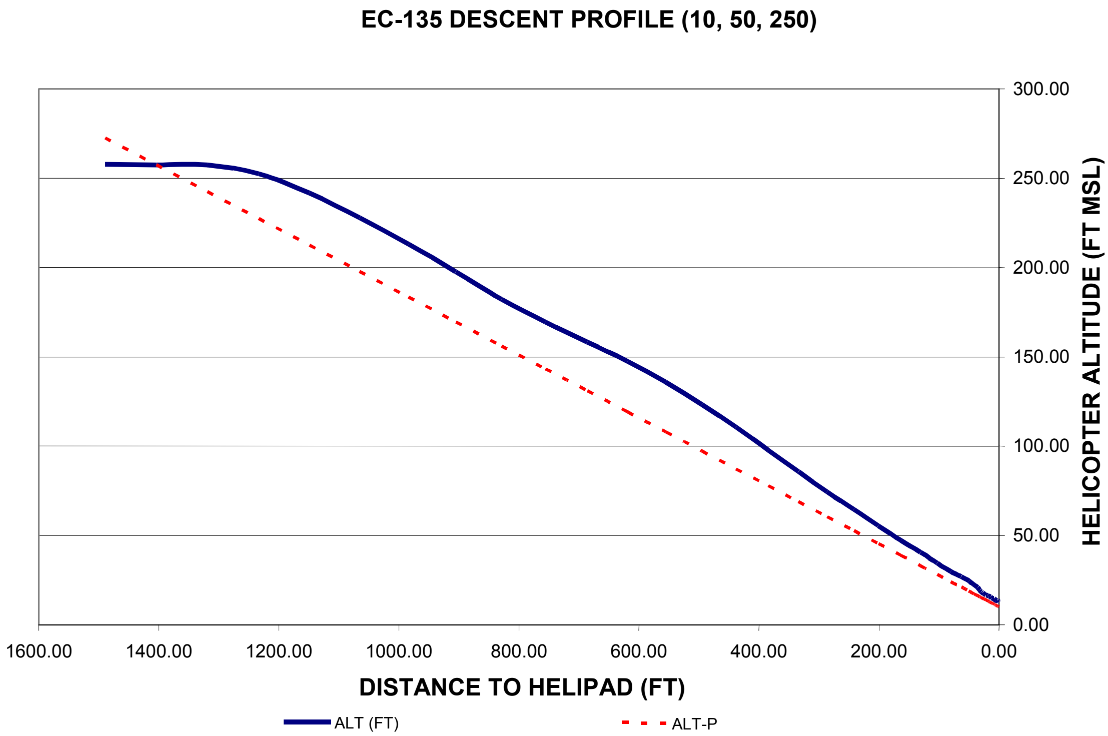


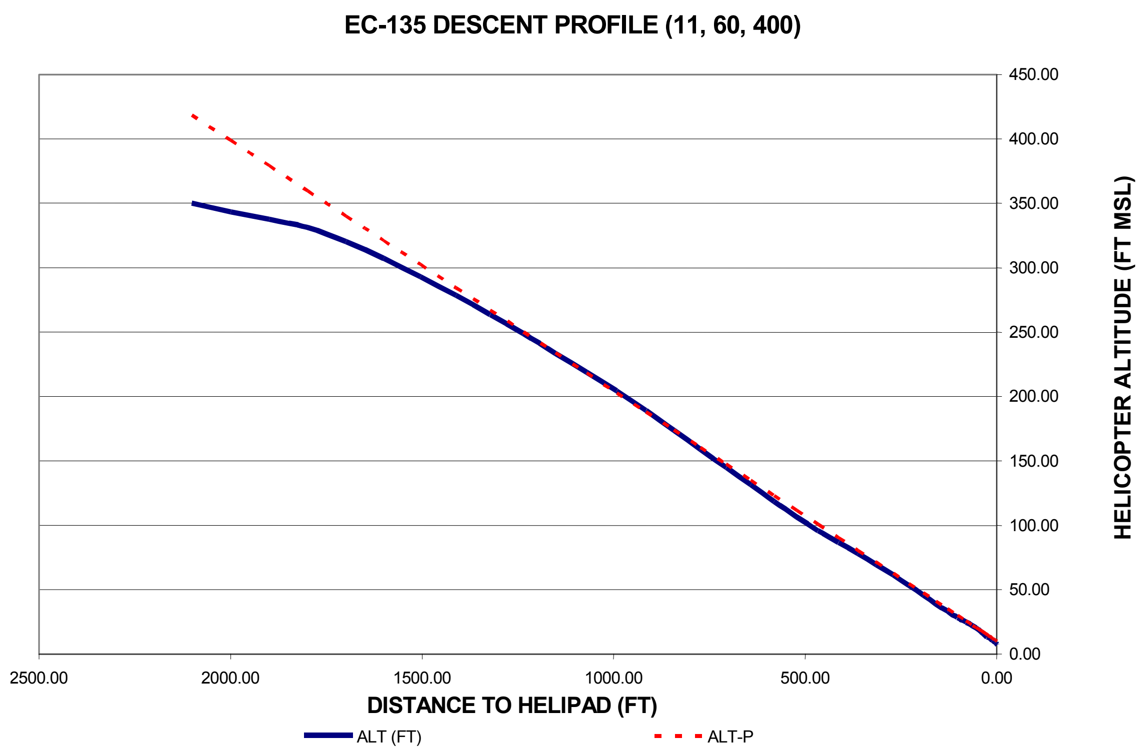
EC-135 DESCENT PROFILE (9, 60, 300)

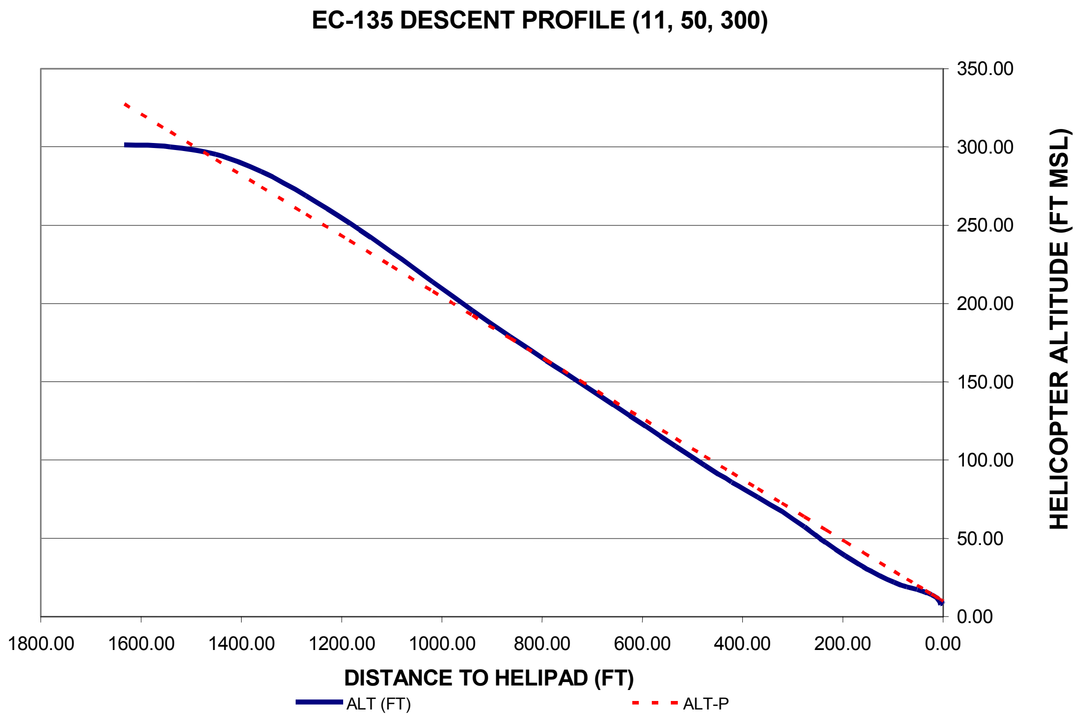


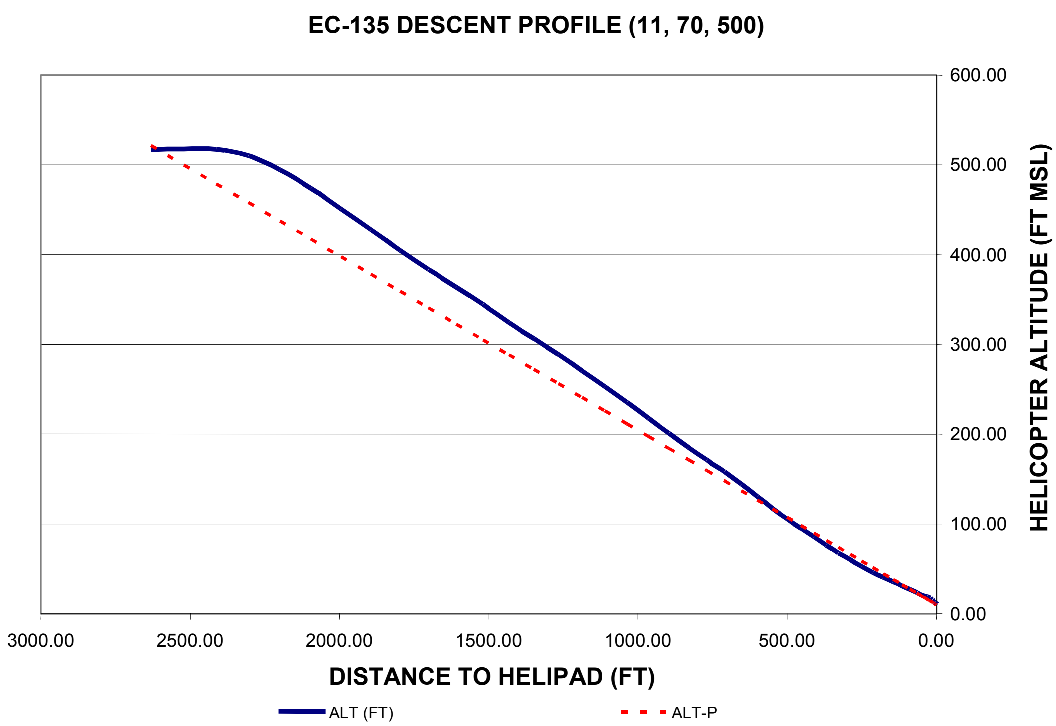
EC-135 DESCENT PROFILE (10, 60, 350)




EC-135 DESCENT PROFILE (10, 50, 250)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE TO HELIPAD (FT)
ALT (FT)
ALT-P


EC-135 DESCENT PROFILE (11, 60, 400)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE TO HELIPAD (FT)
ALT (FT)
ALT-P


EC-135 DESCENT PROFILE (11, 50, 300)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
HELICOPTER ALTITUDE (FT MSL)
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
DISTANCE TO HELIPAD (FT)
ALT (FT)
ALT-P


EC-135 DESCENT PROFILE (11, 70, 500)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HELICOPTER ALTITUDE (FT MSL)
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
DISTANCE TO HELIPAD (FT)
ALT (FT)
ALT-P

APPENDIX B—CONTINUOUSLY OPERATING REFERENCE STATIONS

The National Geodetic Survey, an office of National Oceanic and Atmospheric Administration's National Ocean Service, coordinates a network of continuously operating reference stations (CORS) that provide Global Positioning System (GPS) carrier phase and code range measurements in support of three-dimensional positioning activities throughout the United States and its territories. The Southeast region CORS sites are shown in figure B-1.

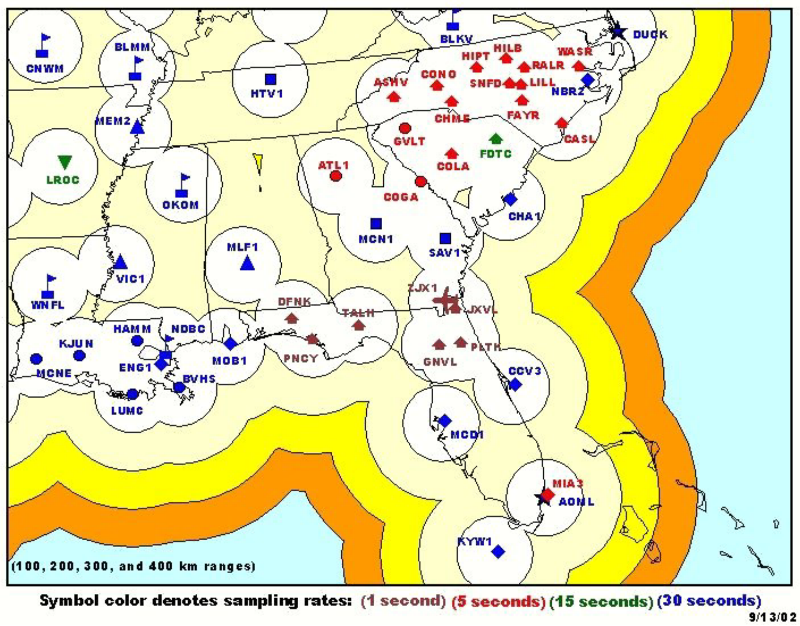


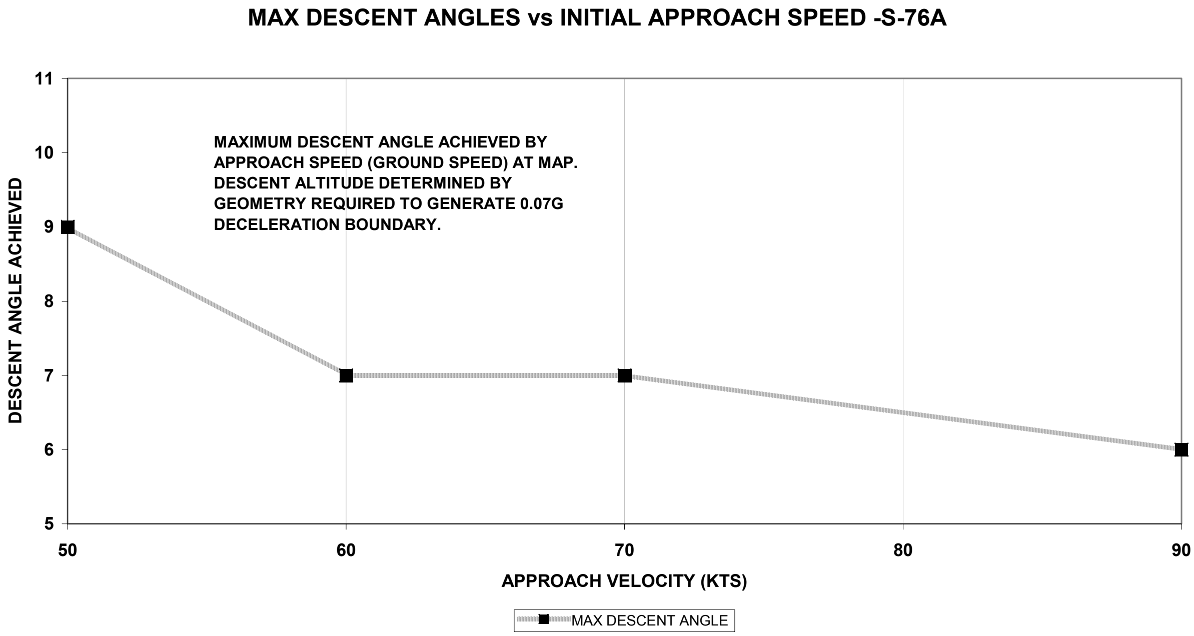
FIGURE B-1. SOUTHEAST CORS SITES

Surveyors, (GIS/LIS) professionals, engineers, scientists, and others can apply CORS data to position points at which GPS data have been collected. The CORS system enables positioning accuracies that approach a few centimeters relative to the National Spatial Reference System, both horizontally and vertically.

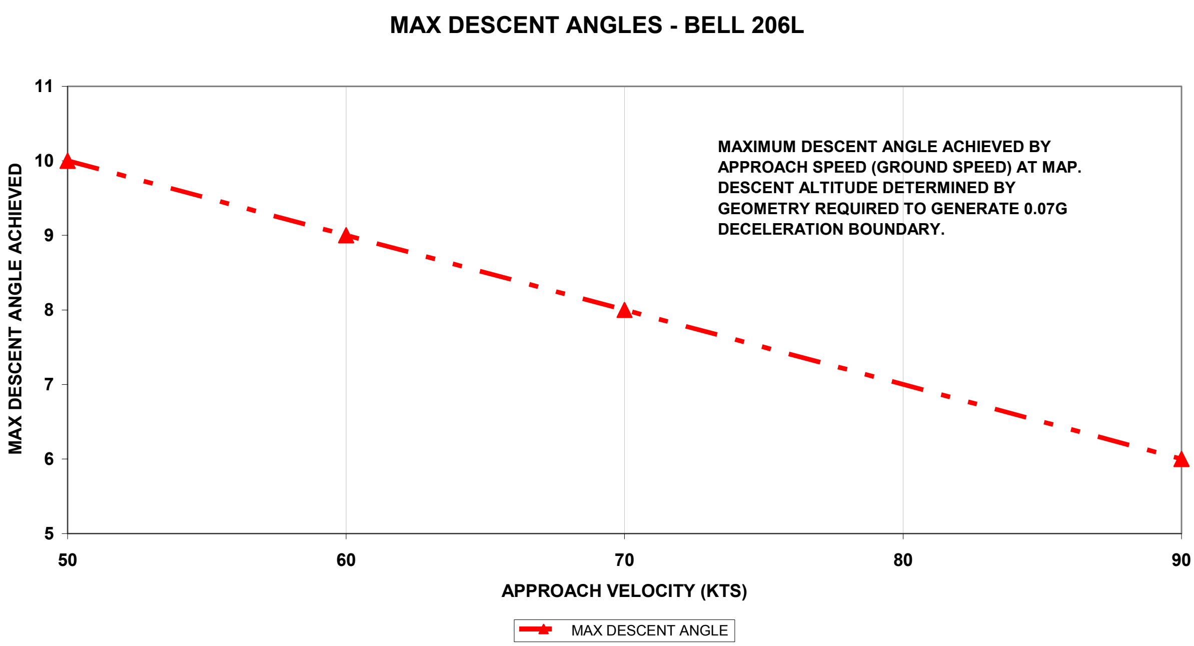
APPENDIX C—HELICOPTER ANGLE OF DESCENT PERFORMANCE CHARTS

The following charts provide the maximum achieved angles of descent versus approach speed. Various missed approach point altitudes were used to establish a 0.07-g average deceleration rate limit for the descents. Each individual helicopter's performance as well as a comparative chart for all helicopters is included.

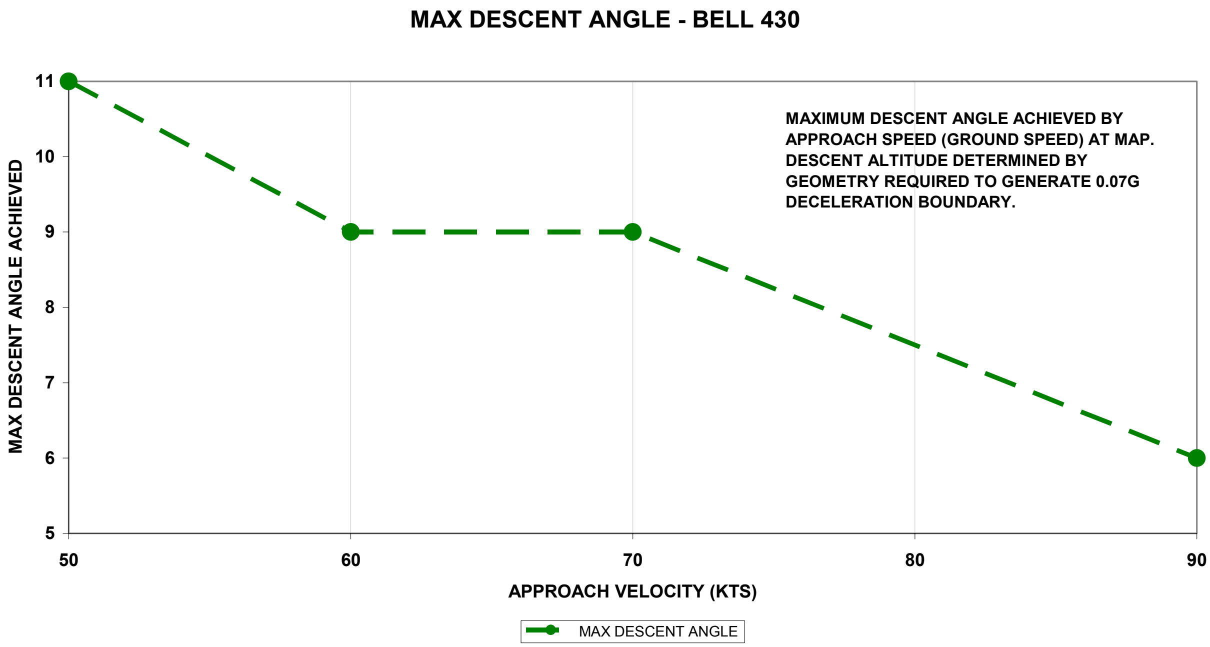
<u>S-76</u>.



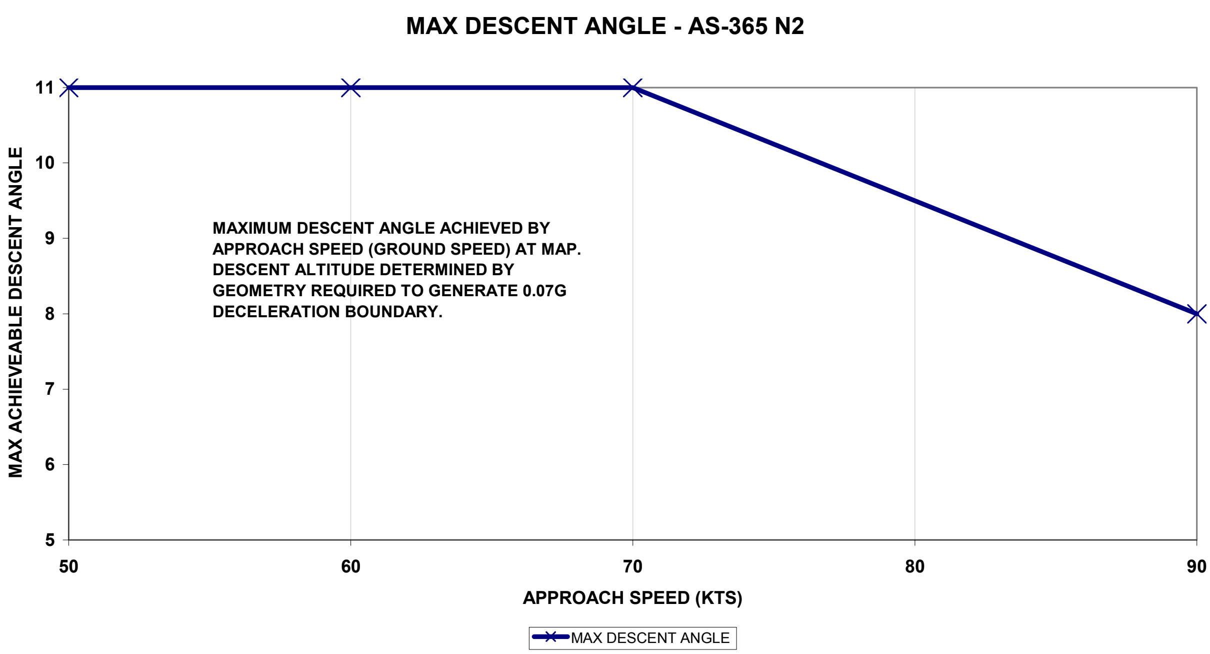
<u>BELL 206L</u>.



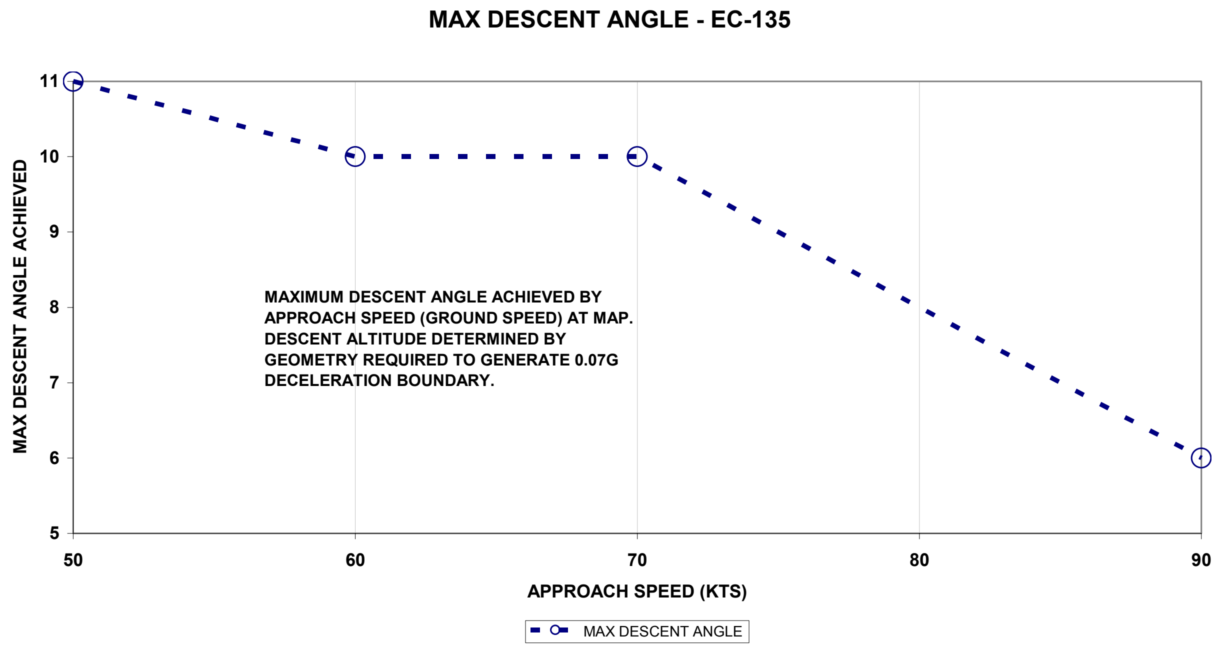
BELL 430.



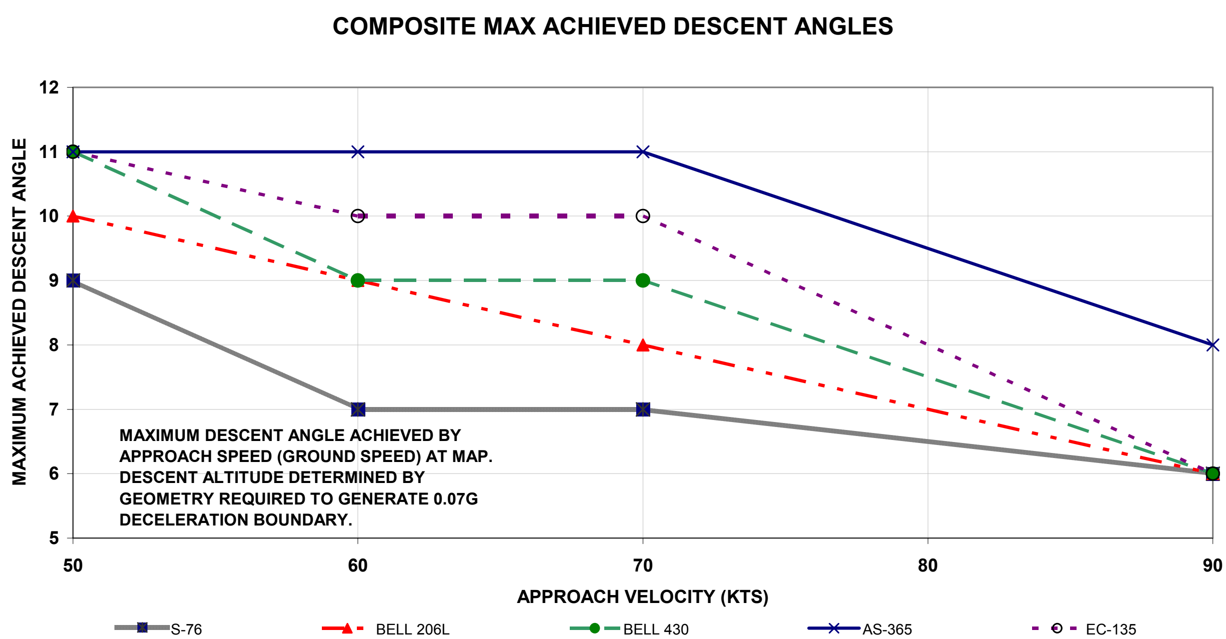
AS-365 N2.



EC-135.

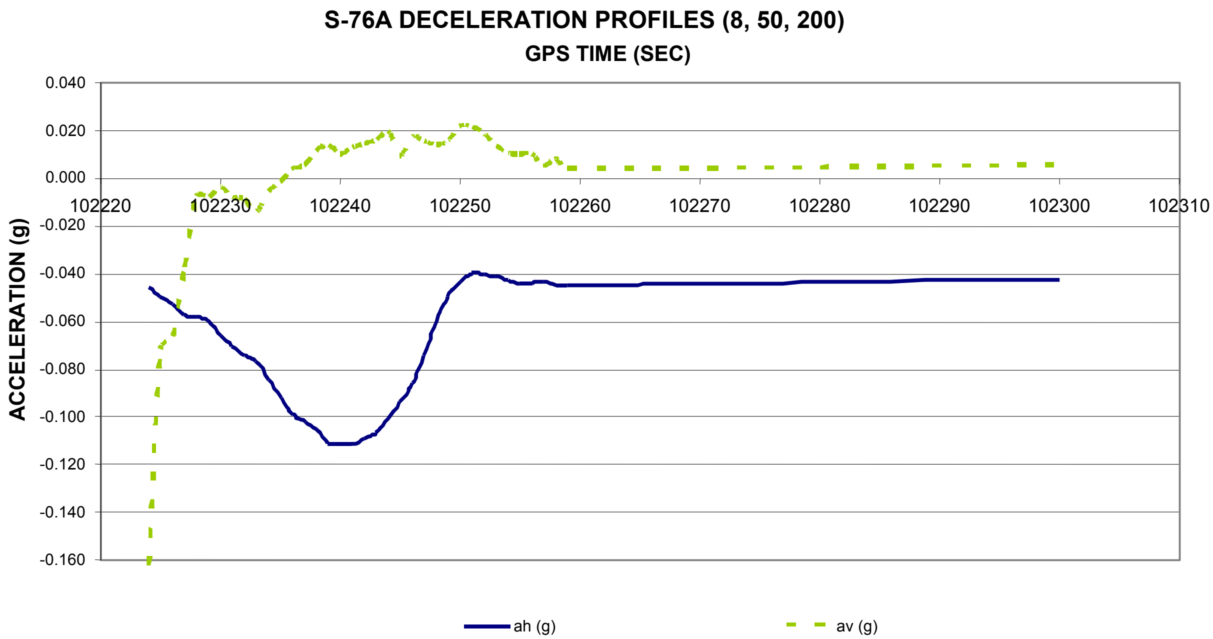


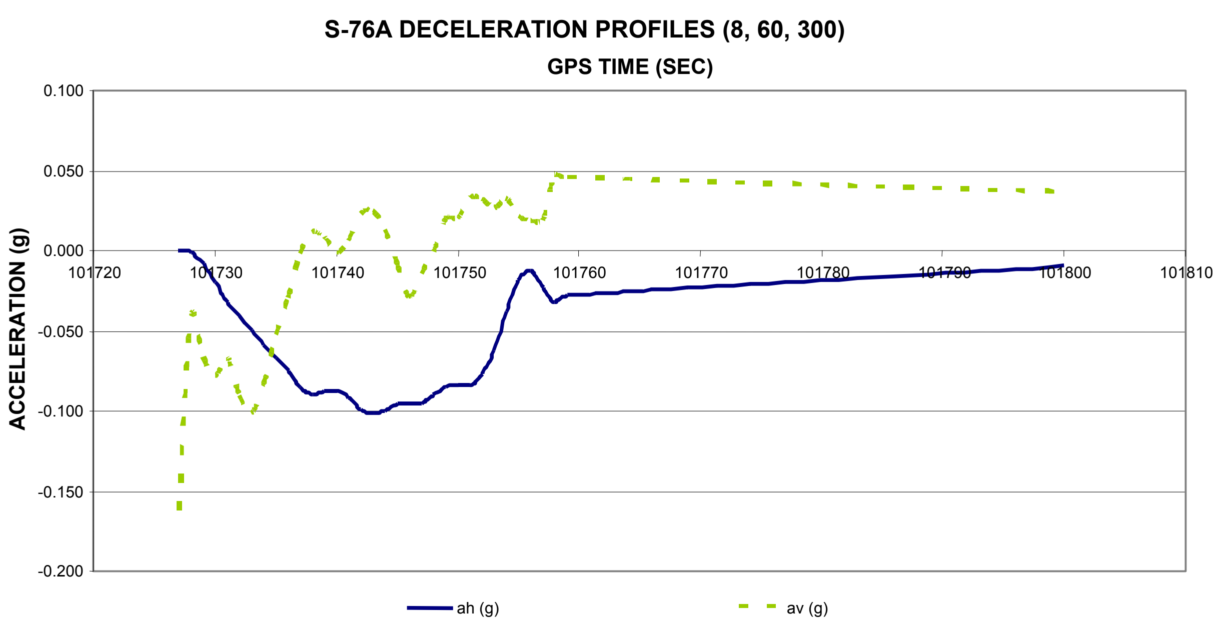
COMPOSITE CHART PROVIDING A COMPARATIVE VIEW OF ALL HELICOPTER'S DESCENT PERFORMANCE.

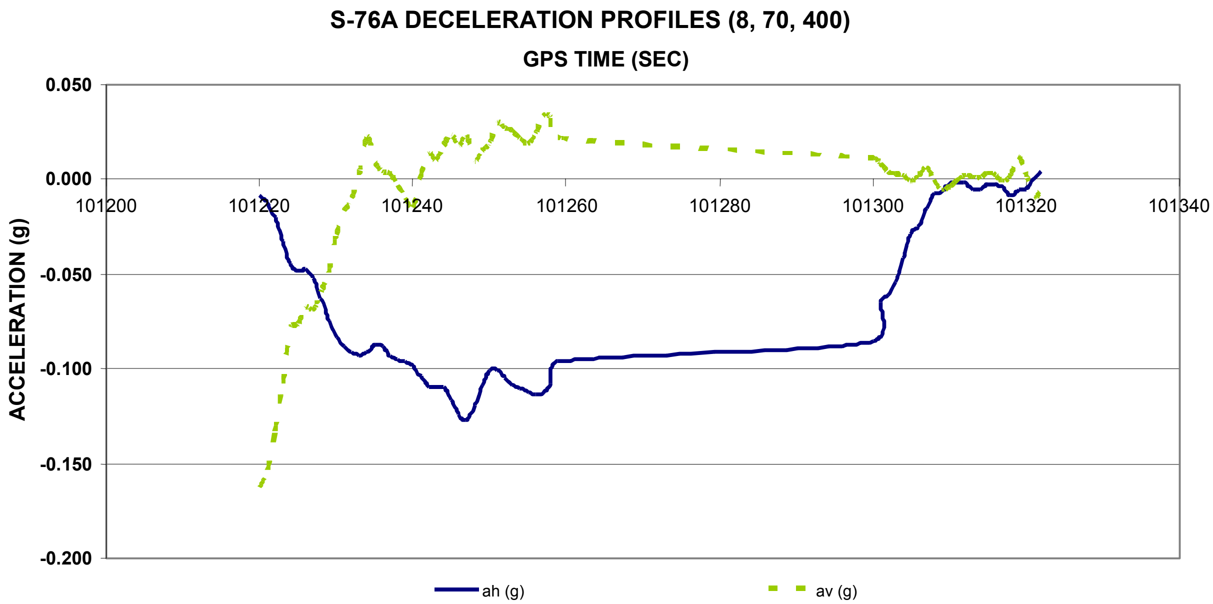


APPENDIX D—DECELERATION PROFILES

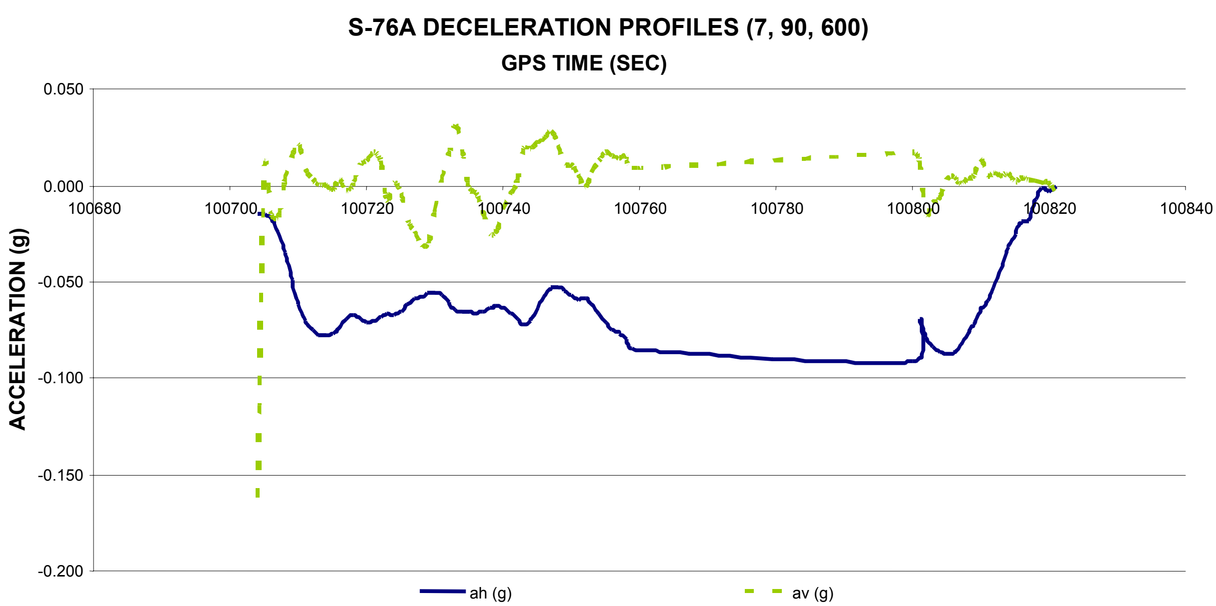
S-76 DECELERATION PROFILES AT MAXIMUM ANGLE OF DESCENT.



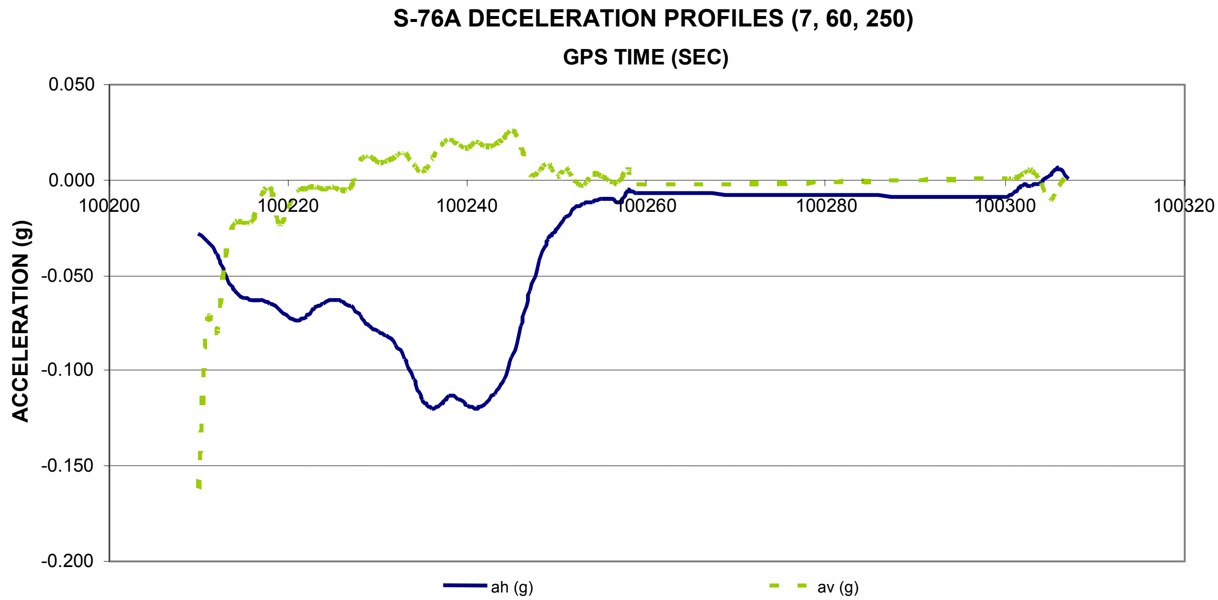




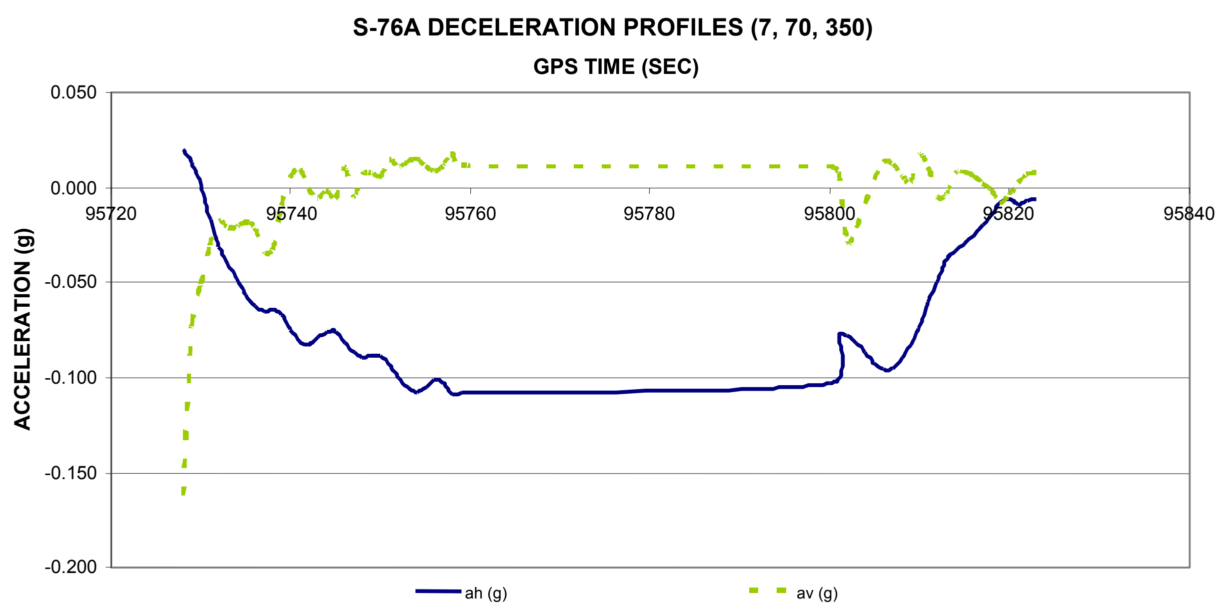
S-76A DECELERATION PROFILES (8, 70, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.050
0.000
-0.050
-0.100
-0.150
-0.200
101200
101220
101240
101260
101280
101300
101320
101340
ah (g)
av (g)



S-76A DECELERATION PROFILES (7, 90, 600)
GPS TIME (SEC)
ACCELERATION (g)
0.050
0.000
-0.050
-0.100
-0.150
-0.200
100680
100700
100720
100740
100760
100780
100800
100820
100840
ah (g)
av (g)

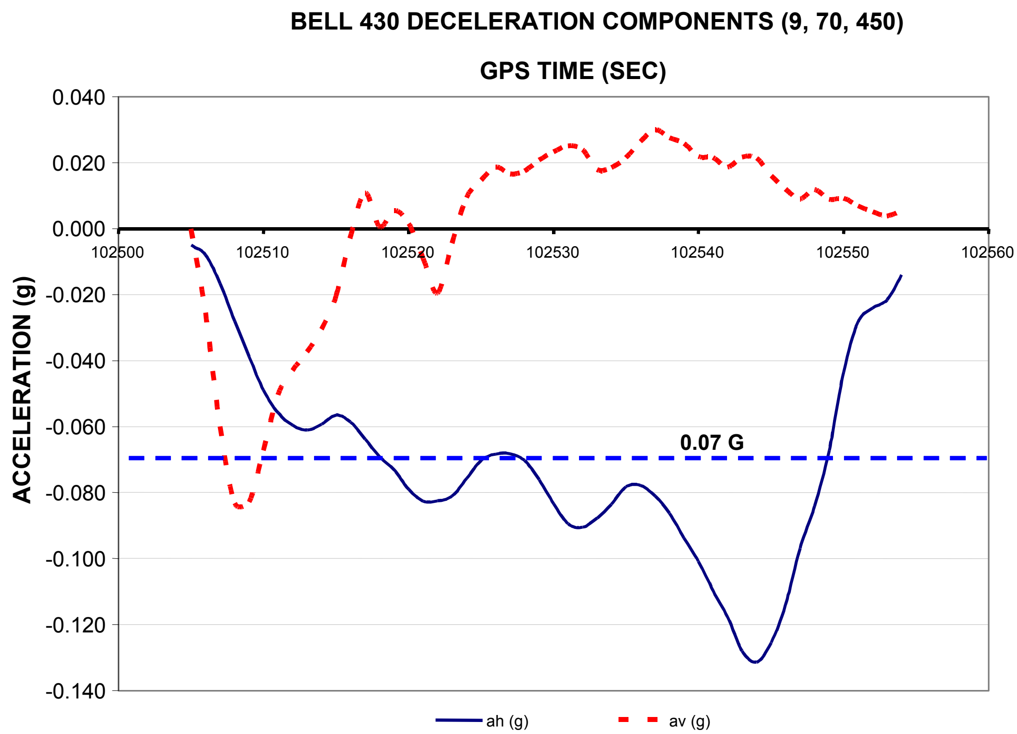


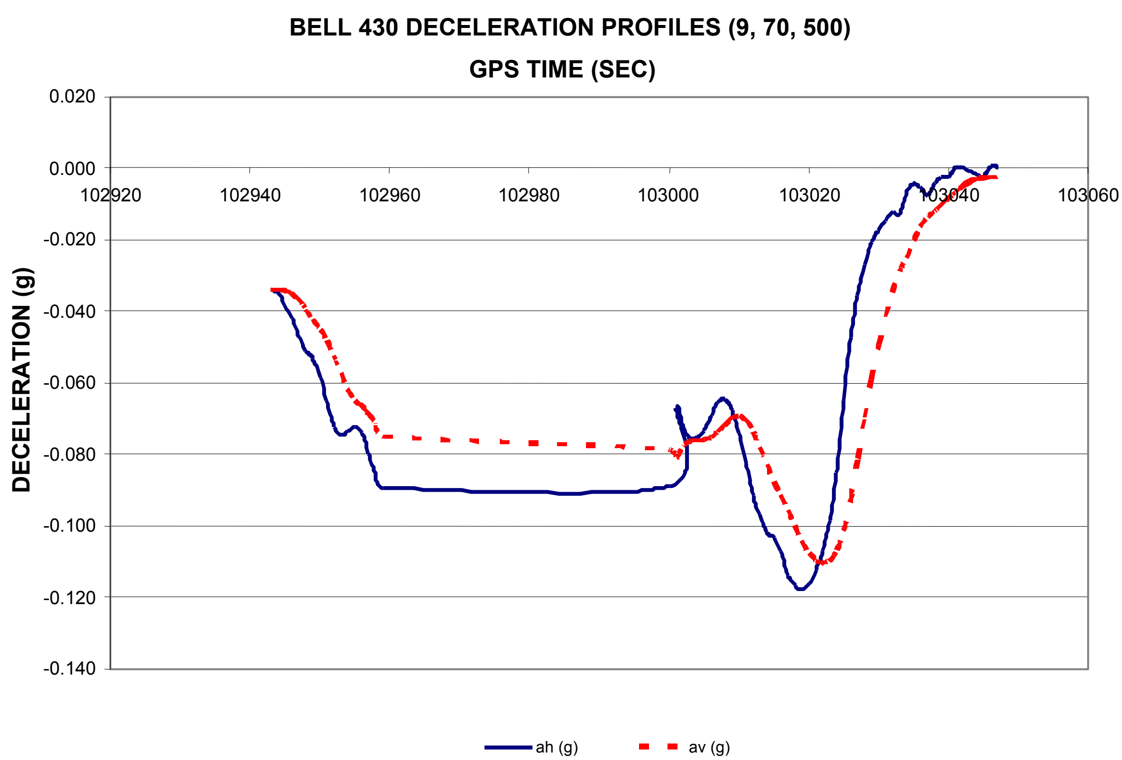
S-76A DECELERATION PROFILES (7, 60, 250)
GPS TIME (SEC)
0.050
0.000
-0.050
-0.100
-0.150
-0.200
100200
100220
100240
100260
100280
100300
100320
ACCELERATION (g)
ah (g)
av (g)

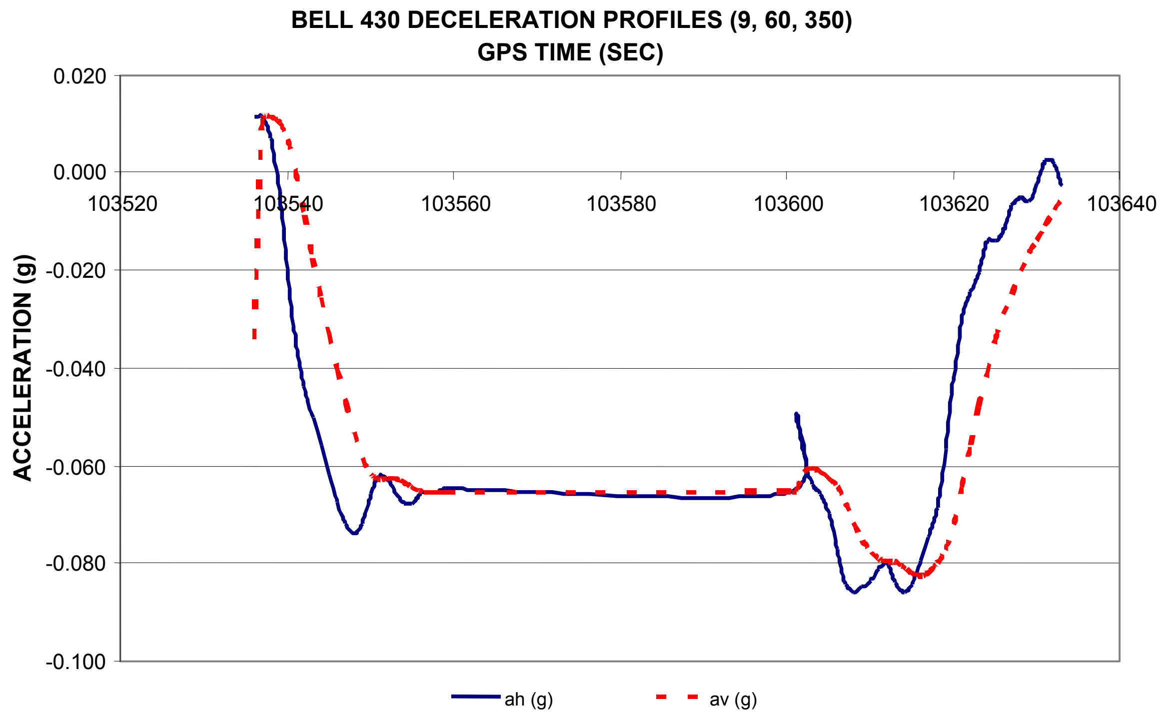


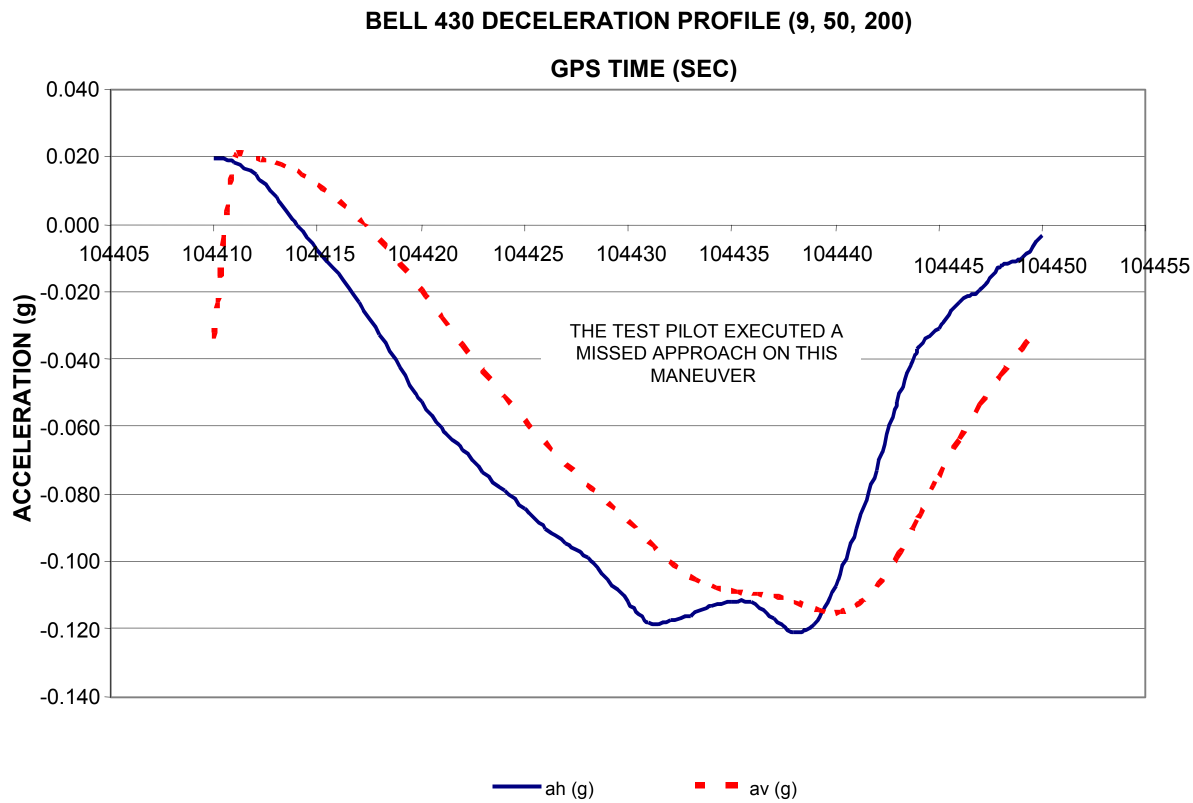
S-76A DECELERATION PROFILES (7, 70, 350)
GPS TIME (SEC)
0.050
0.000
-0.050
-0.100
-0.150
-0.200
95720
95740
95760
95780
95800
95820
95840
ACCELERATION (g)
ah (g)
av (g)

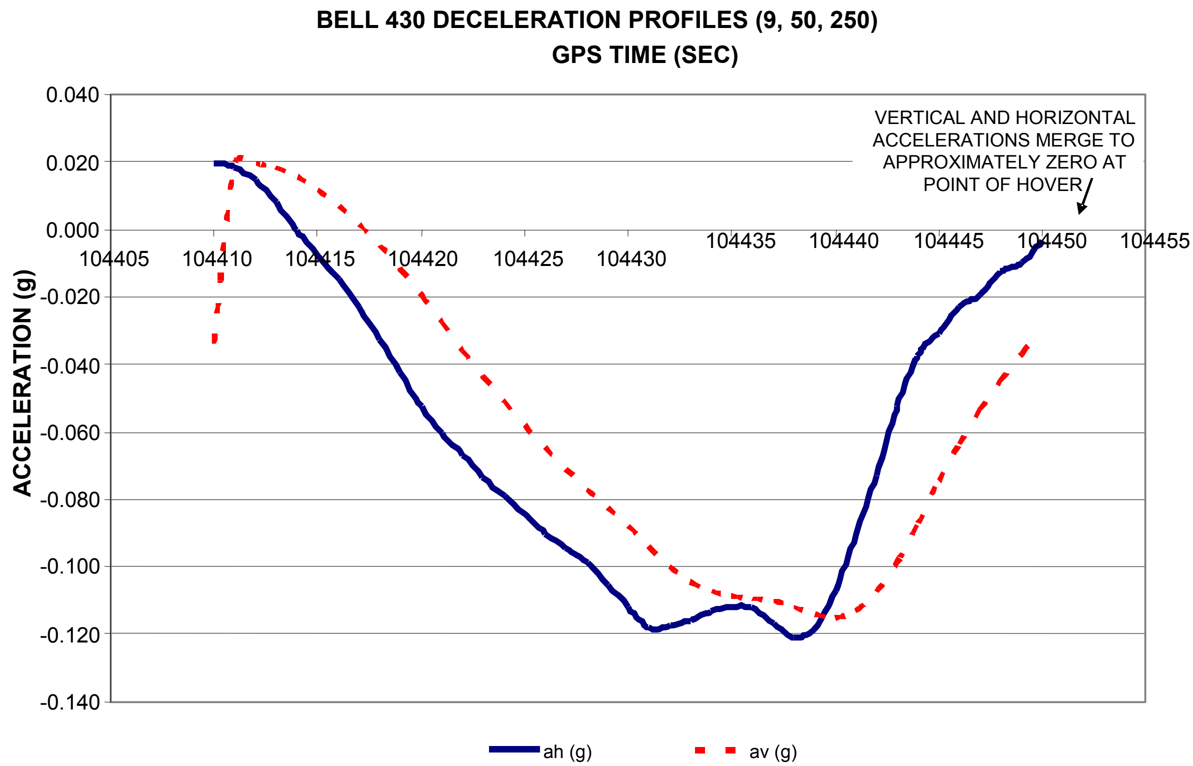
BELL 430 DECELERATION PROFILES AT MAXIMUM ANGLE OF DESCENT.

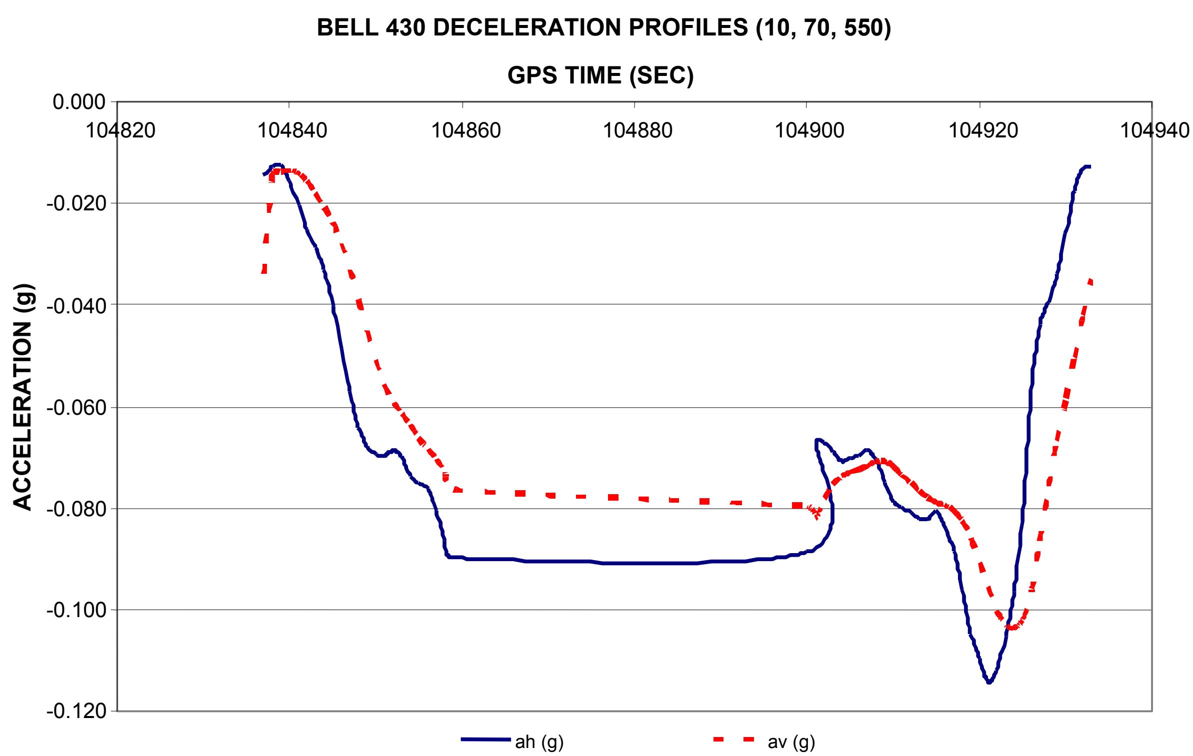


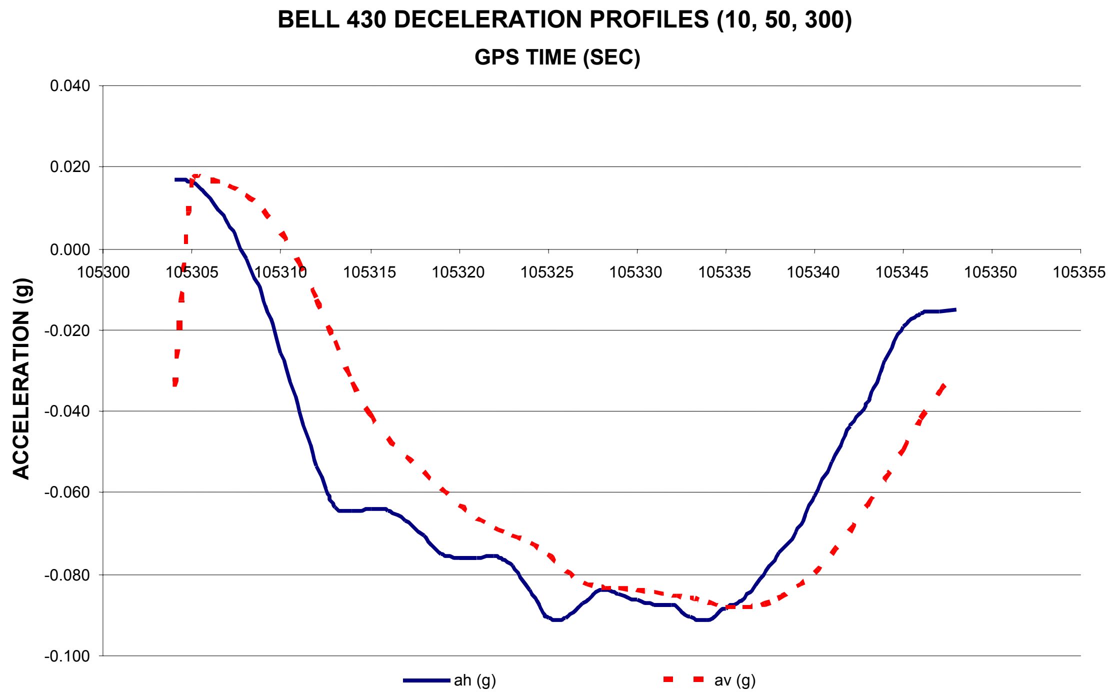


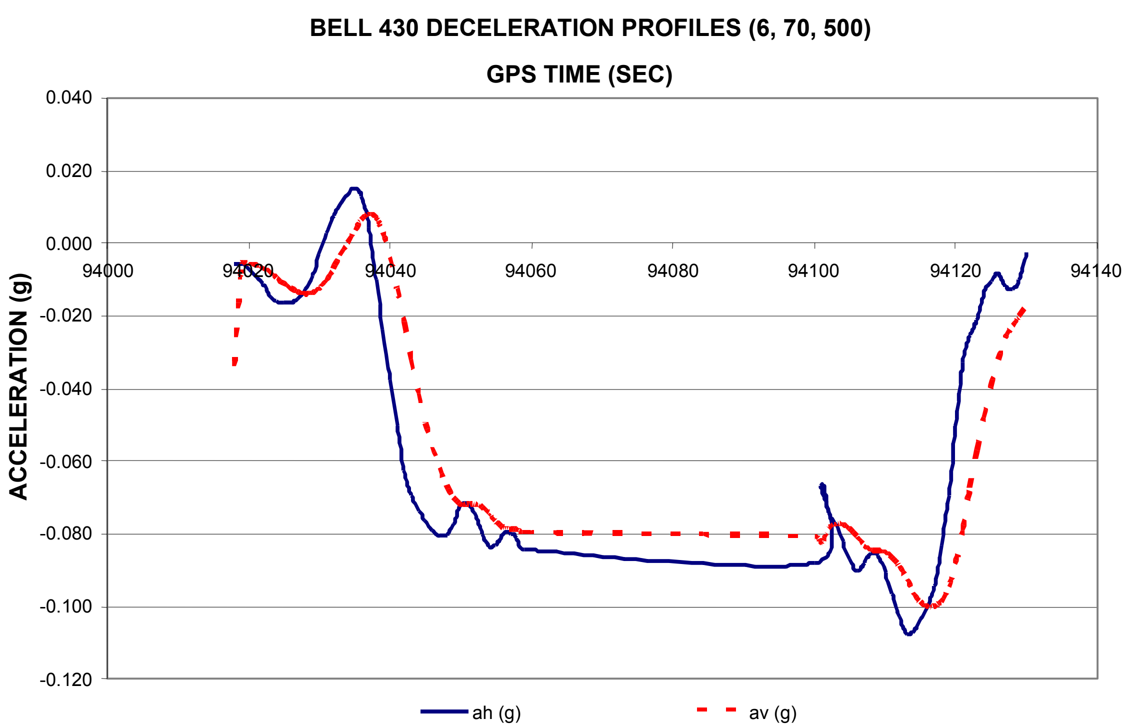

BELL 430 DECELERATION PROFILES (9, 60, 350)
GPS TIME (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
103520
103540
103560
103580
103600
103620
103640
ah (g)
av (g)

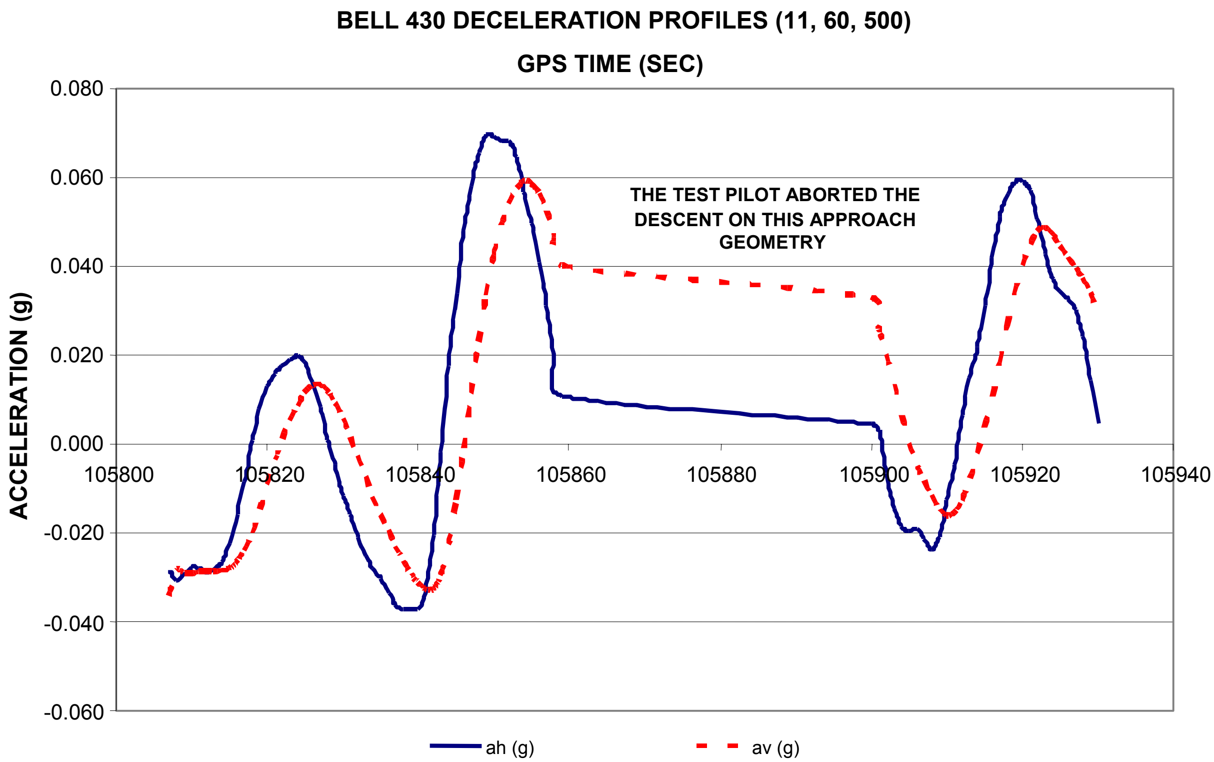

BELL 430 DECELERATION PROFILE (9, 50, 200)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
104405
104410
104415
104420
104425
104430
104435
104440
104445
104450
104455
THE TEST PILOT EXECUTED A
MISSED APPROACH ON THIS
MANEUVER
ah (g)
av (g)

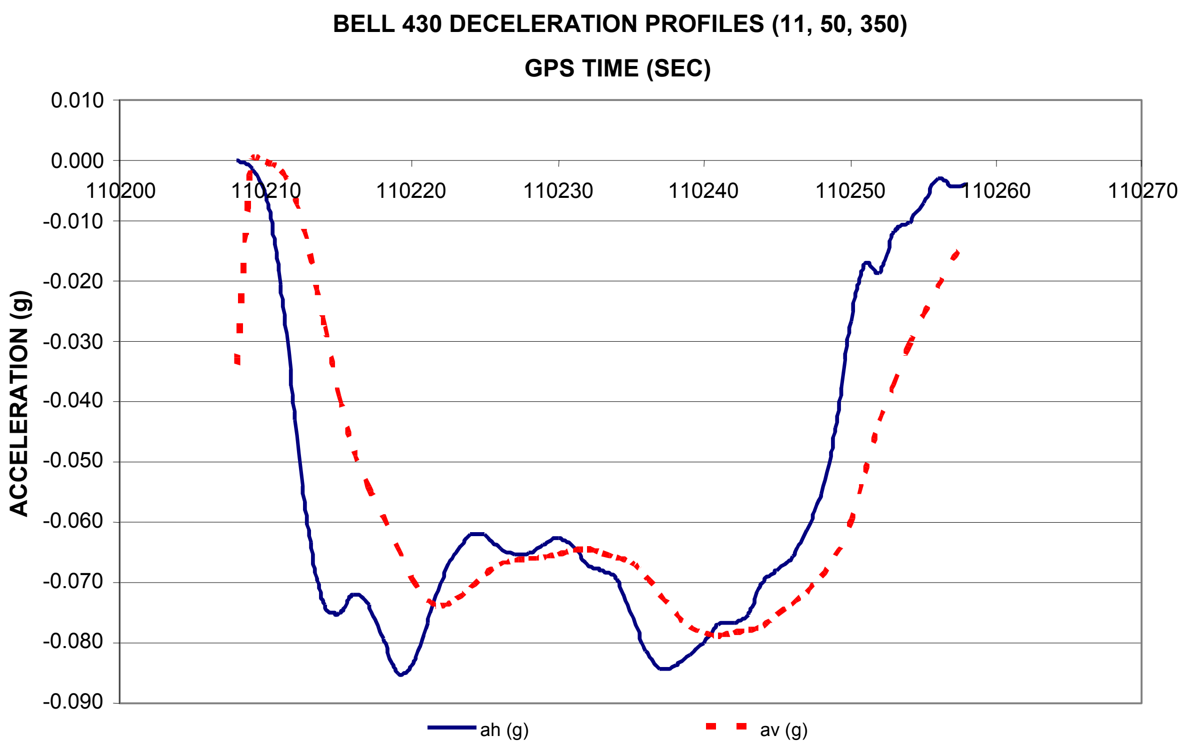

BELL 430 DECELERATION PROFILES (9, 50, 250)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
104405
104410
104415
104420
104425
104430
104435
104440
104445
104450
104455
VERTICAL AND HORIZONTAL ACCELERATIONS MERGE TO APPROXIMATELY ZERO AT POINT OF HOVER
ah (g)
av (g)

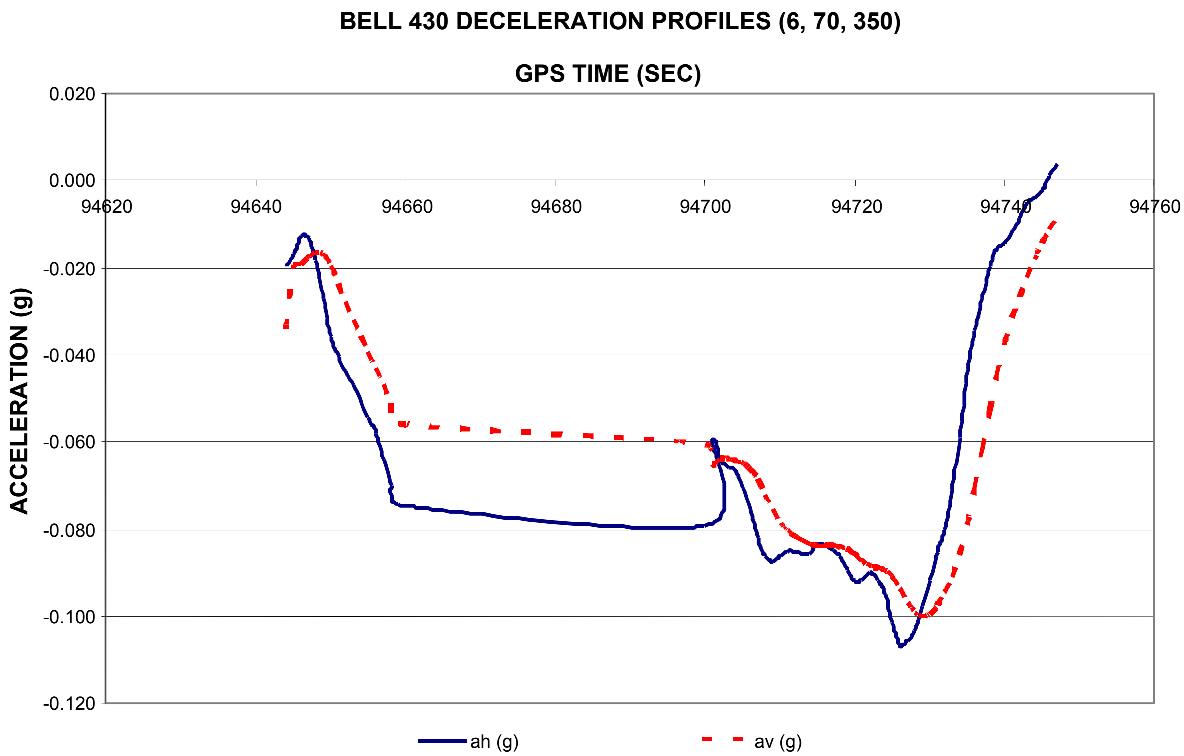

BELL 430 DECELERATION PROFILES (10, 70, 550)
GPS TIME (SEC)
ACCELERATION (g)
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
104820
104840
104860
104880
104900
104920
104940
ah (g)
av (g)

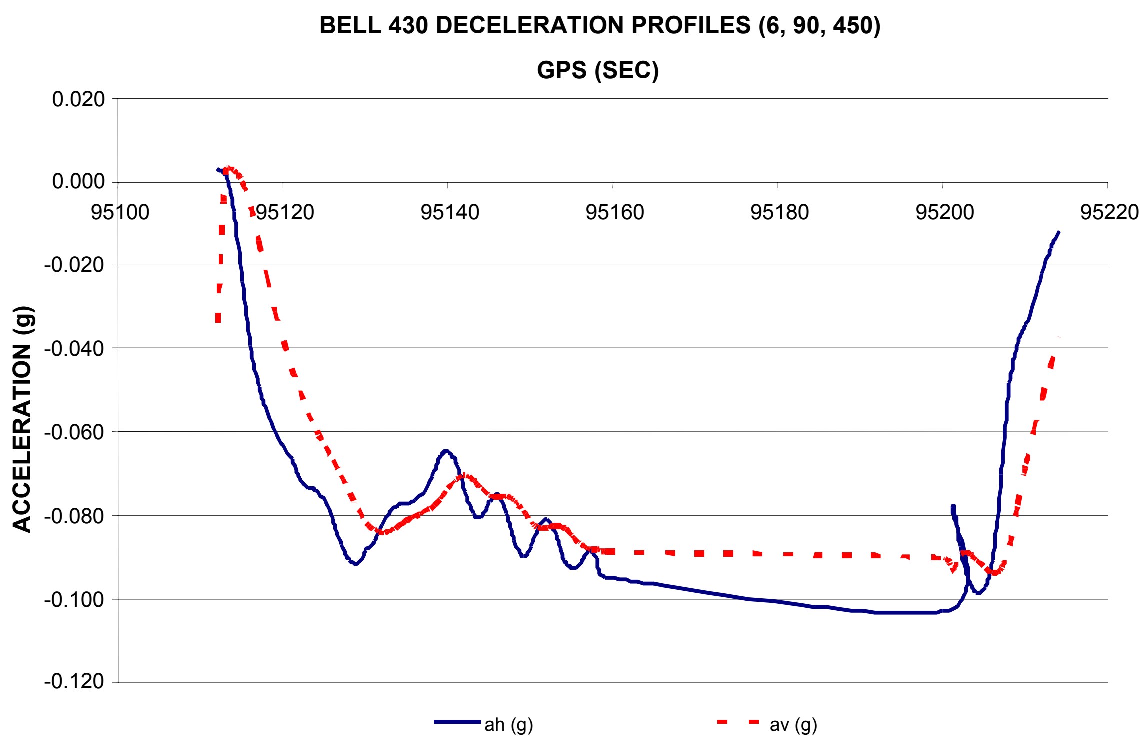

BELL 430 DECELERATION PROFILES (10, 50, 300)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
105300
105305
105310
105315
105320
105325
105330
105335
105340
105345
105350
105355
ah (g)
av (g)

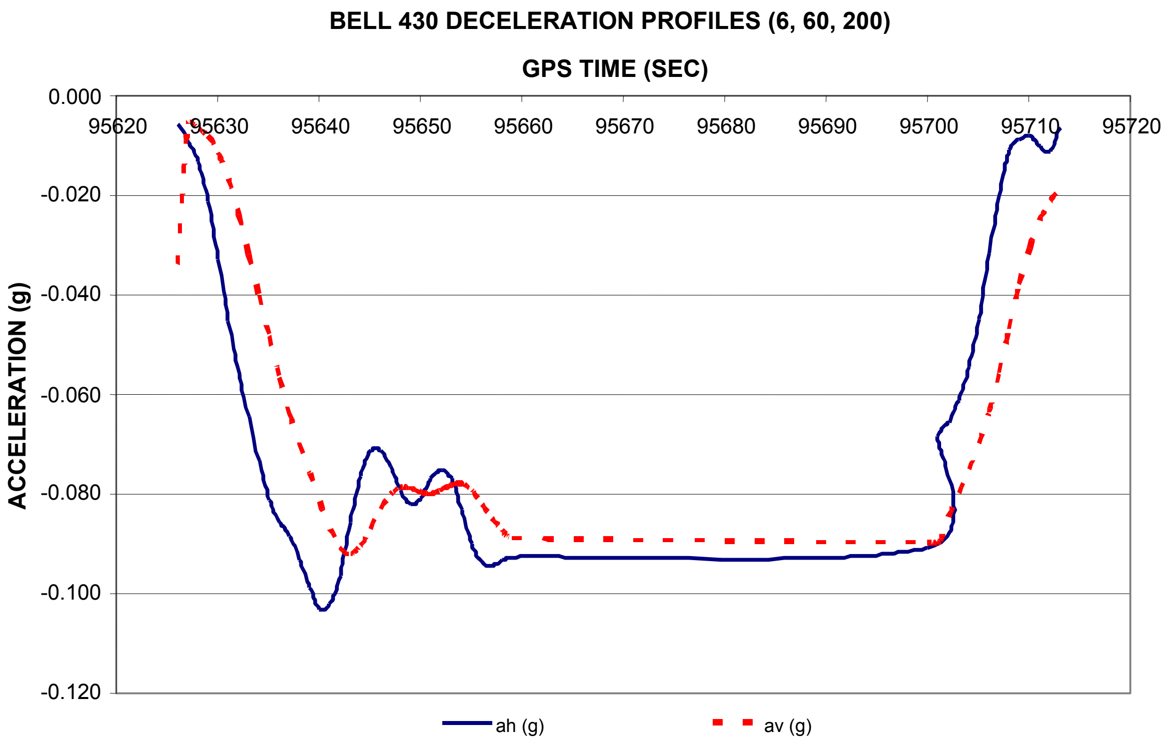

BELL 430 DECELERATION PROFILES (6, 70, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
94000
94020
94040
94060
94080
94100
94120
94140
ah (g)
av (g)

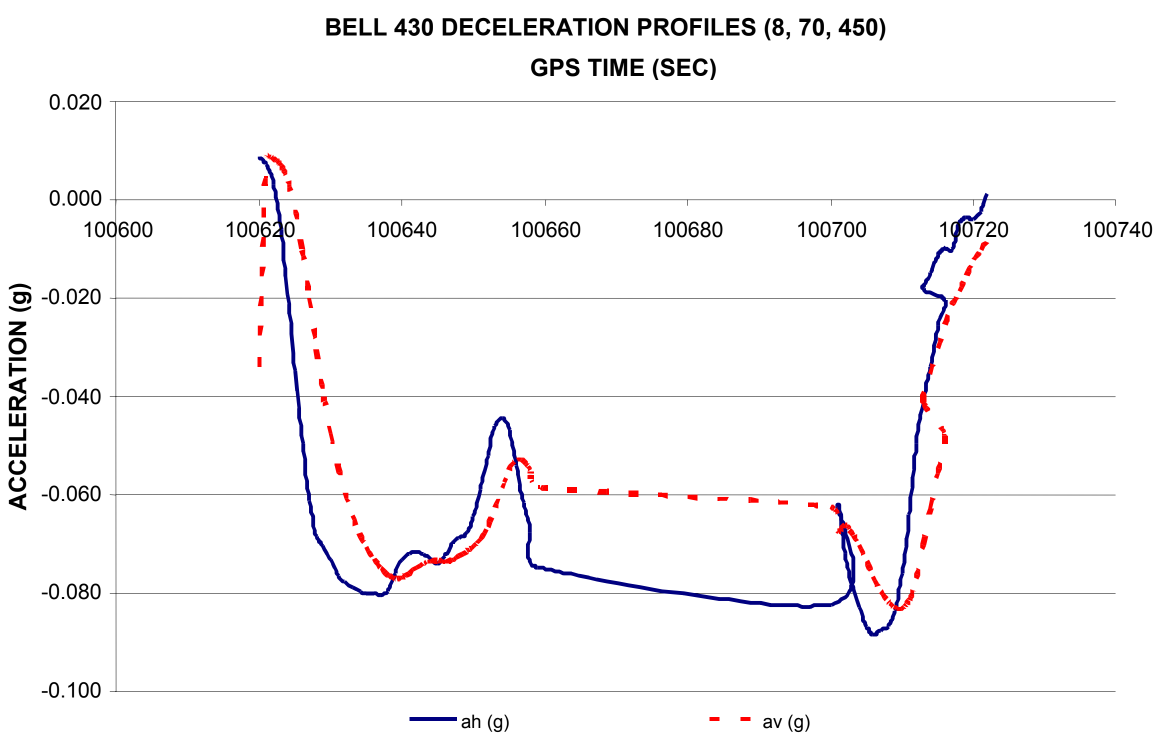

BELL 430 DECELERATION PROFILES (11, 60, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
105800
105820
105840
105860
105880
105900
105920
105940
THE TEST PILOT ABORTED THE DESCENT ON THIS APPROACH GEOMETRY
ah (g)
av (g)

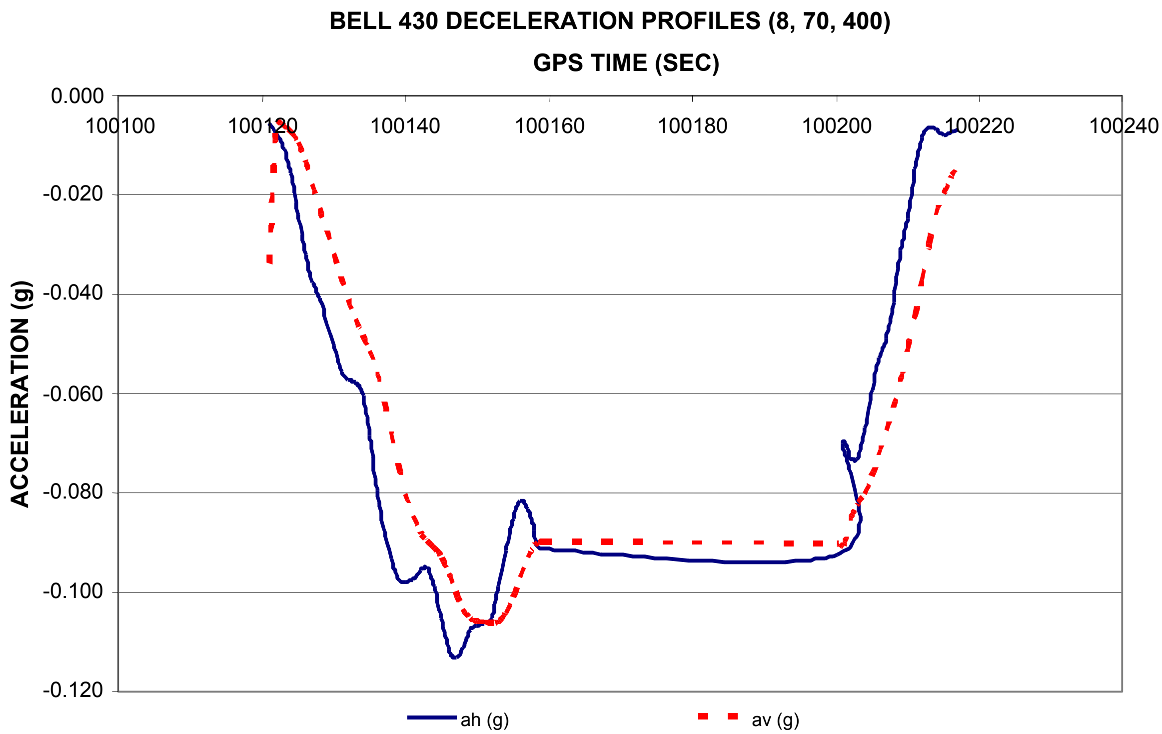

BELL 430 DECELERATION PROFILES (11, 50, 350)
GPS TIME (SEC)
ACCELERATION (g)
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
-0.090
110200
110210
110220
110230
110240
110250
110260
110270
ah (g)
av (g)

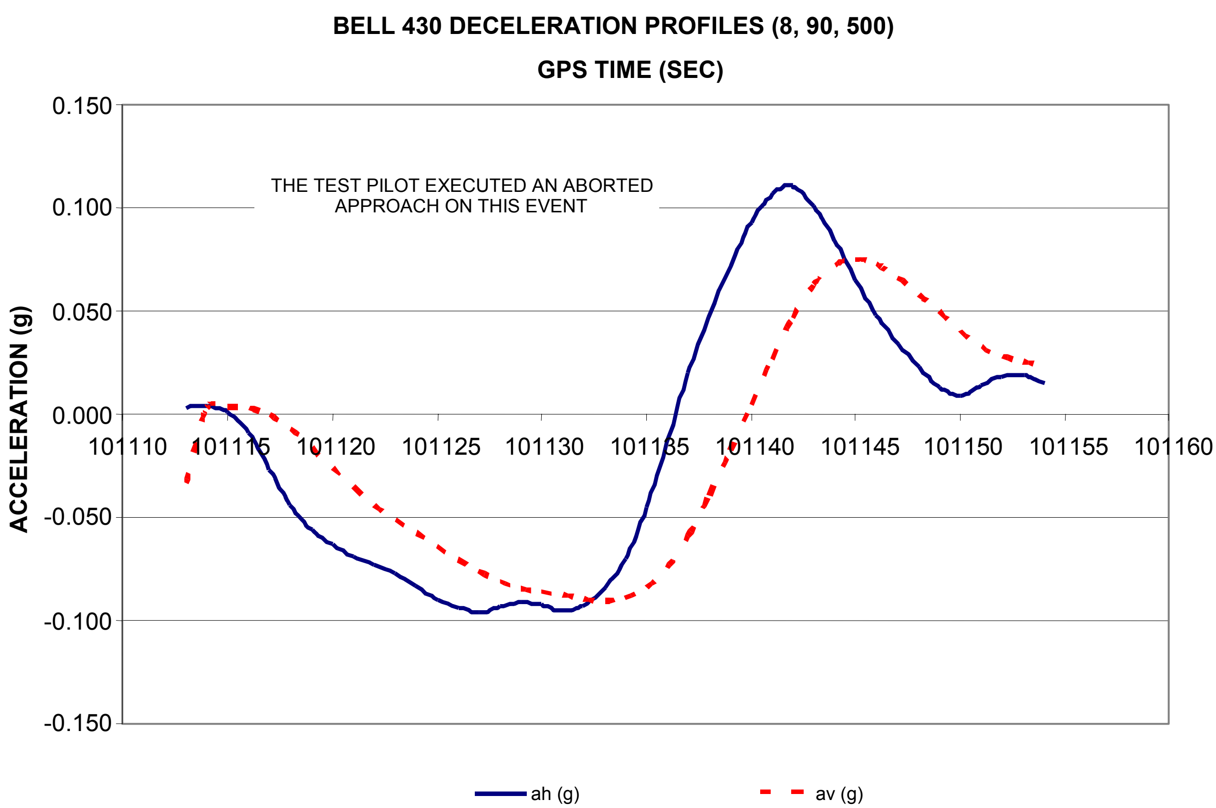

BELL 430 DECELERATION PROFILES (6, 70, 350)
GPS TIME (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
94620
94640
94660
94680
94700
94720
94740
94760
ah (g)
av (g)

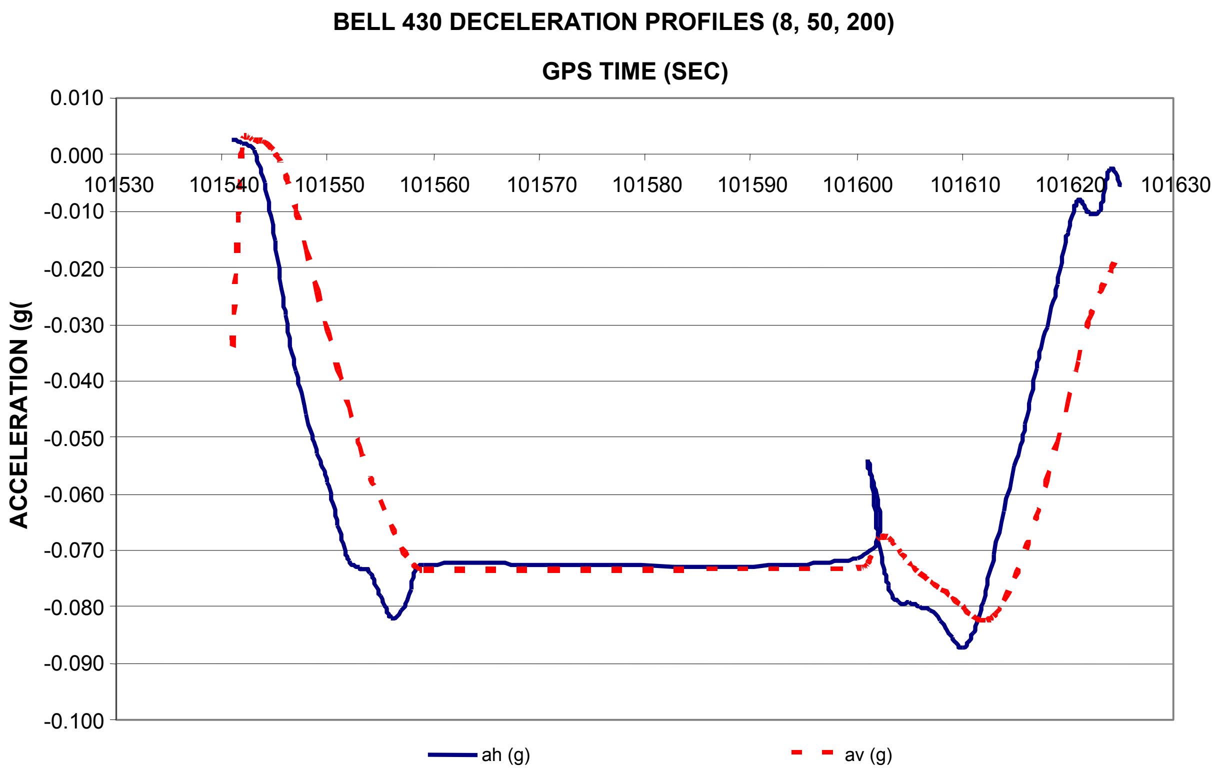

BELL 430 DECELERATION PROFILES (6, 90, 450)
GPS (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
95100
95120
95140
95160
95180
95200
95220
ah (g)
av (g)


BELL 430 DECELERATION PROFILES (6, 60, 200)
GPS TIME (SEC)
ACCELERATION (g)
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
95620
95630
95640
95650
95660
95670
95680
95690
95700
95710
95720
ah (g)
av (g)

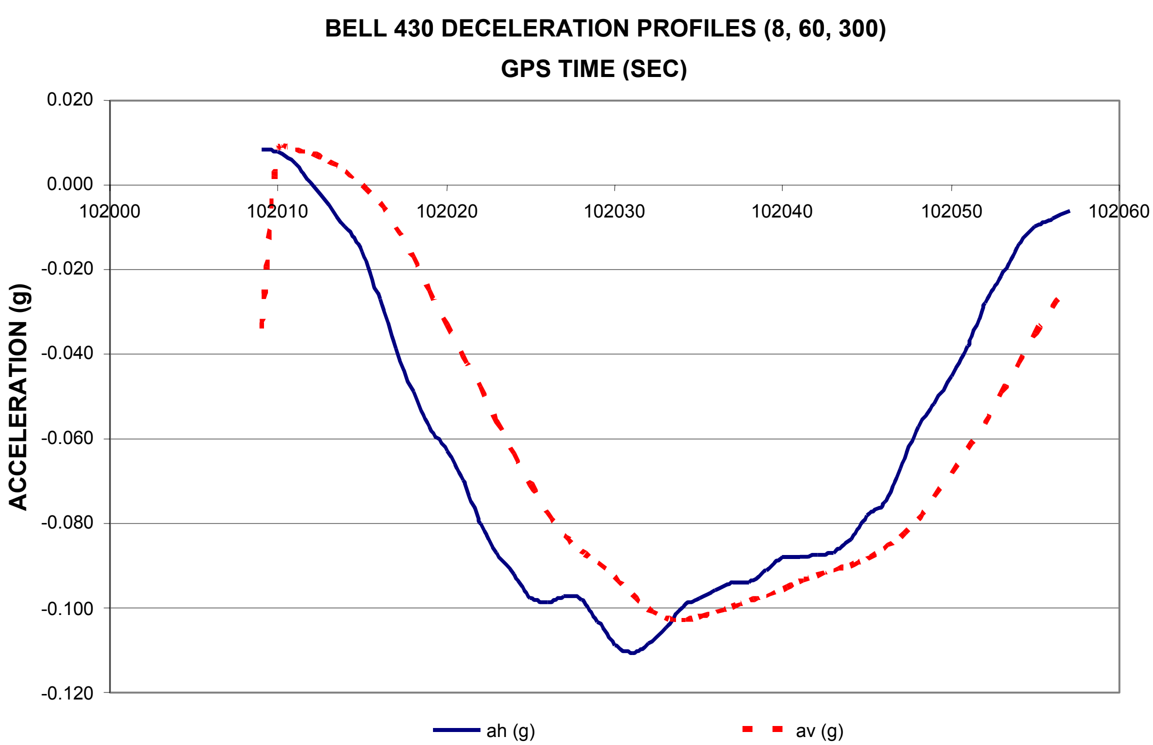

BELL 430 DECELERATION PROFILES (8, 70, 450)
GPS TIME (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
100600
100620
100640
100660
100680
100700
100720
100740
ah (g)
av (g)


BELL 430 DECELERATION PROFILES (8, 70, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
100100
100120
100140
100160
100180
100200
100220
100240
ah (g)
av (g)


BELL 430 DECELERATION PROFILES (8, 90, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
101110
101115
101120
101125
101130
101135
101140
101145
101150
101155
101160
THE TEST PILOT EXECUTED AN ABORTED
APPROACH ON THIS EVENT
ah (g)
av (g)

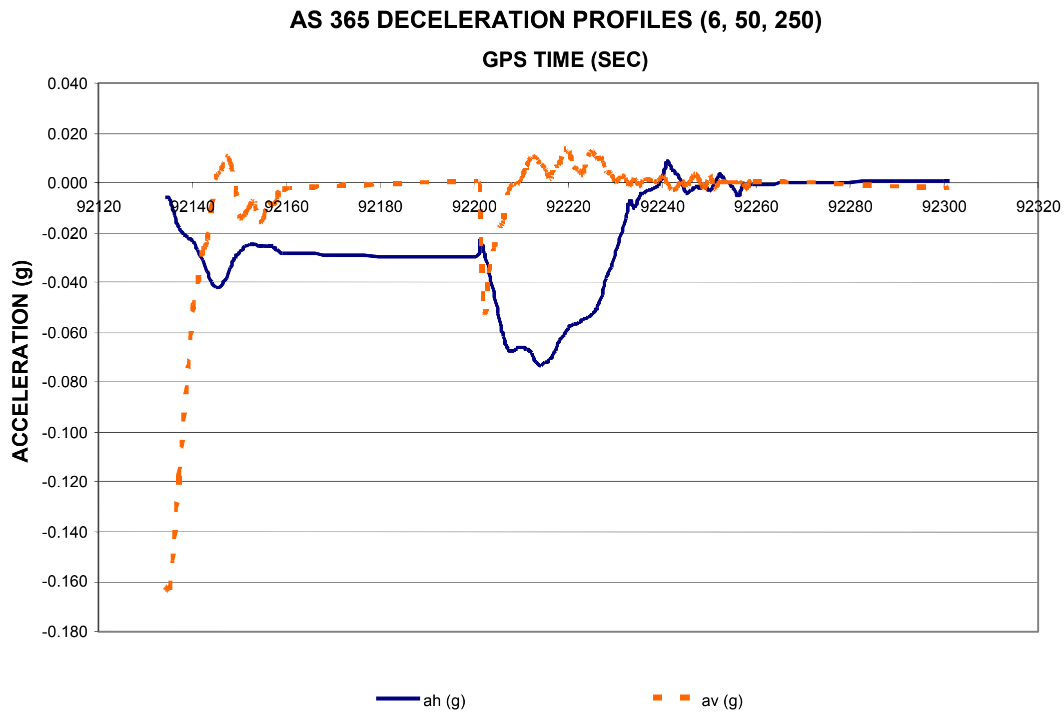


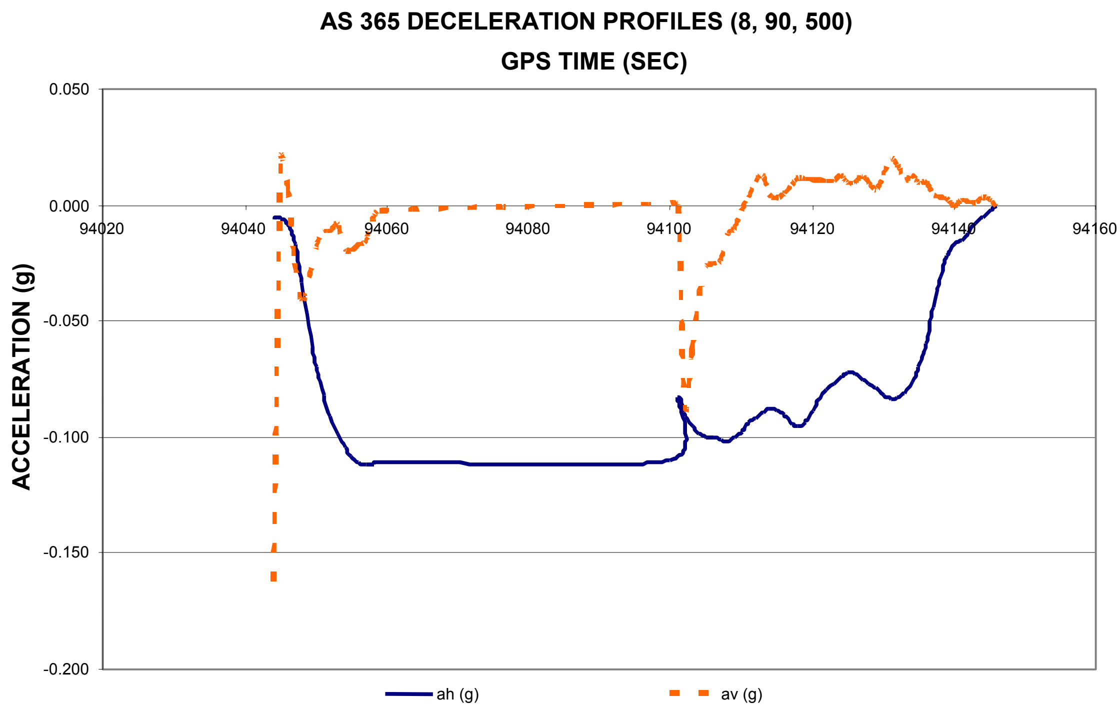
BELL 430 DECELERATION PROFILES (8, 50, 200)
GPS TIME (SEC)
ACCELERATION (g(
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
-0.090
-0.100
101530
101540
101550
101560
101570
101580
101590
101600
101610
101620
101630
ah (g)
av (g)



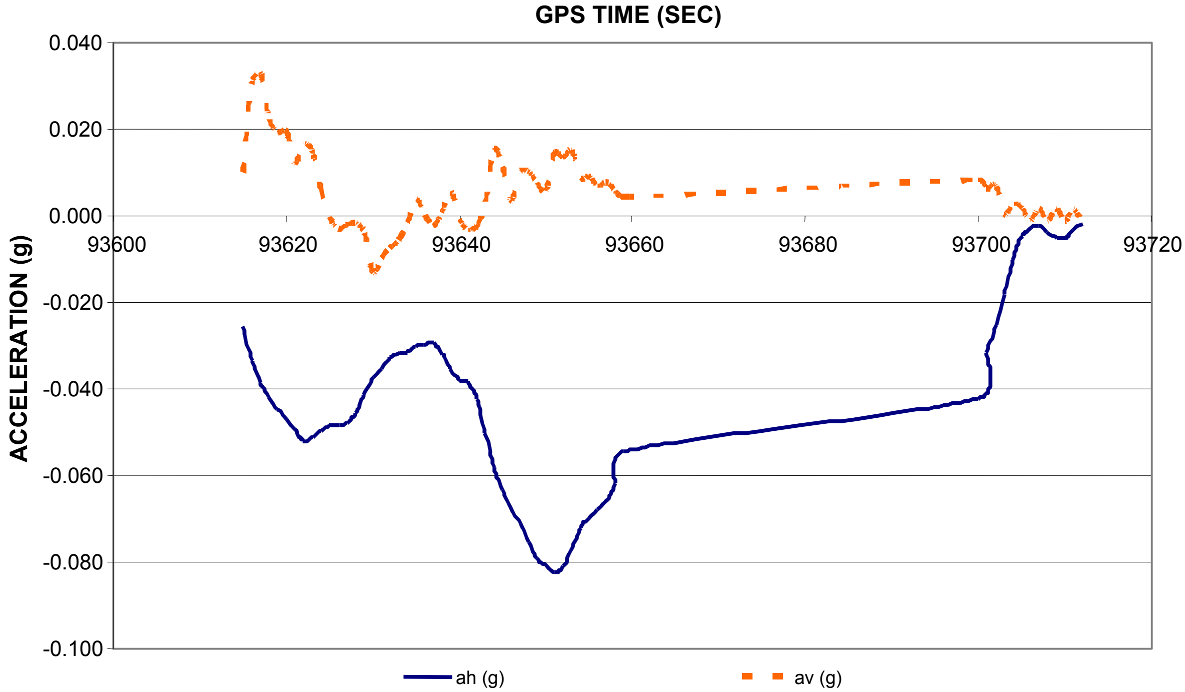
BELL 430 DECELERATION PROFILES (8, 60, 300)
GPS TIME (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
102000
102010
102020
102030
102040
102050
102060
ah (g)
av (g)

<u>AS-365 N2 DECELERATION PROFILES</u>.

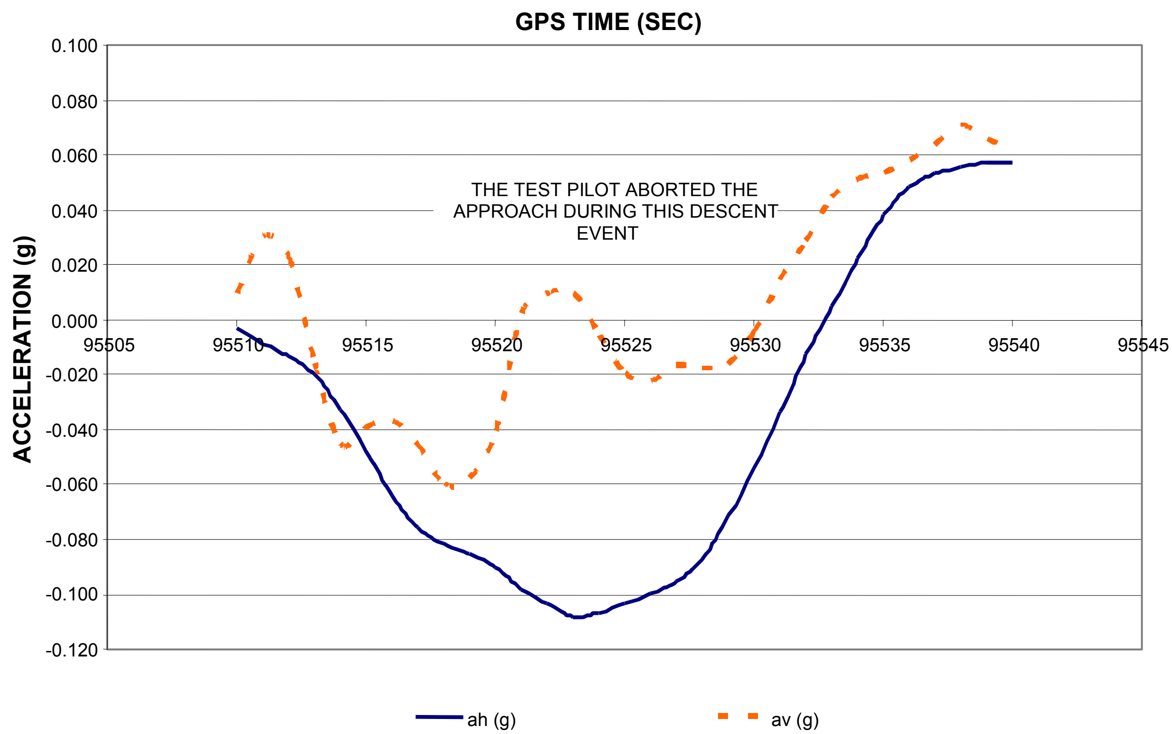


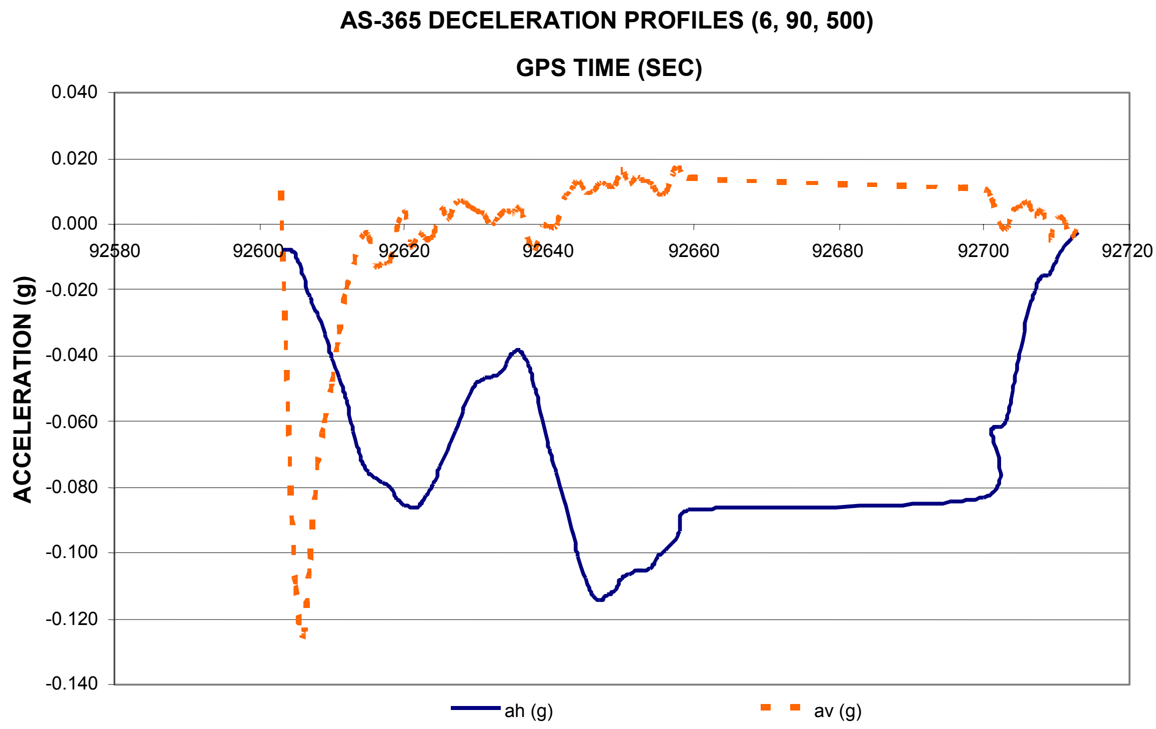


AS 365 DECELERATION PROFILES (8, 50, 250)

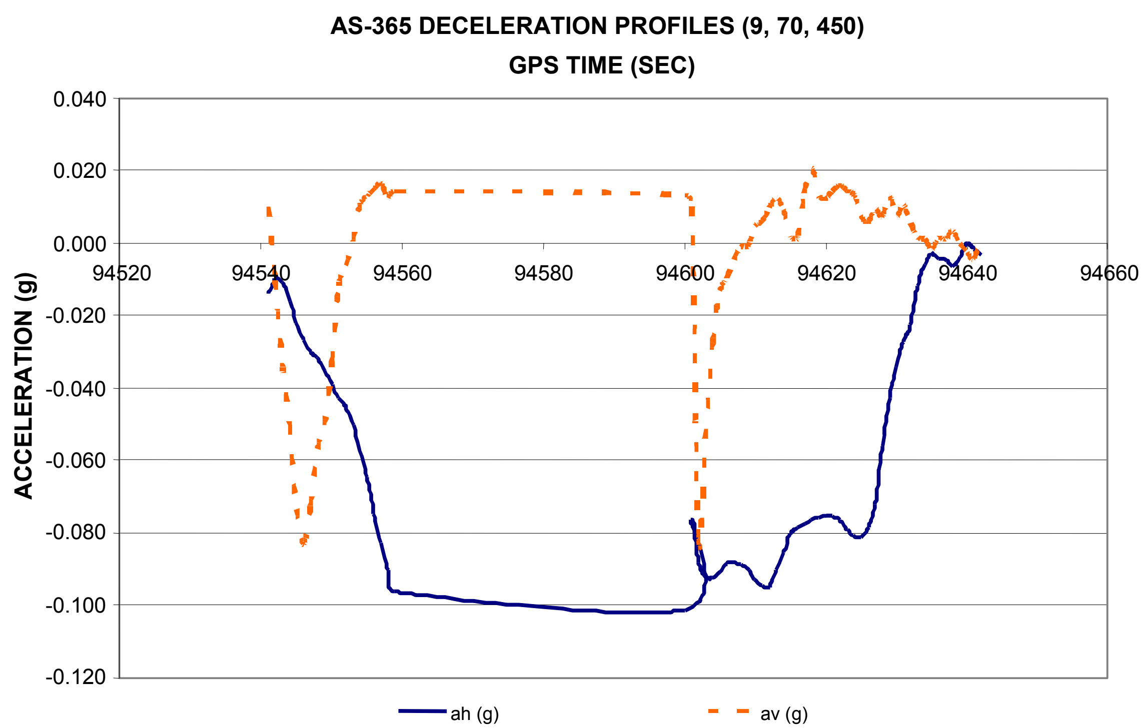


AS 365 DECELERATION PROFILES (9, 90, 500)

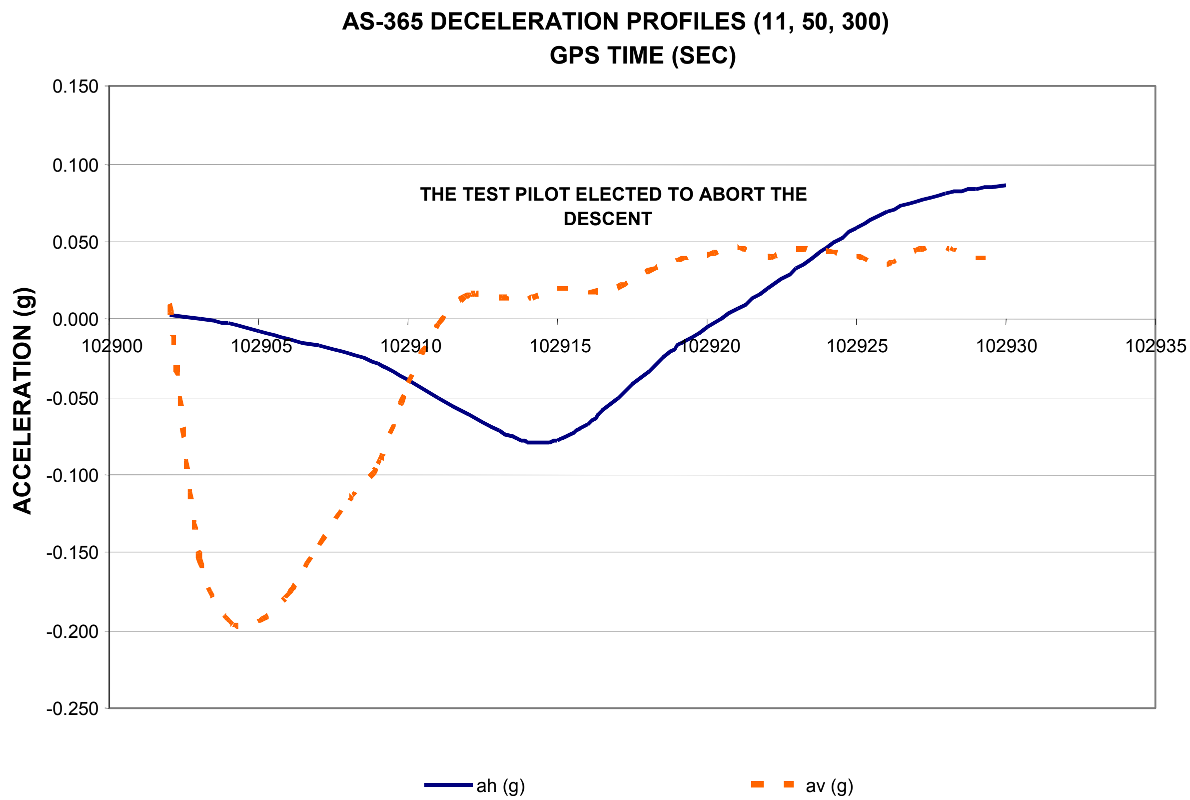


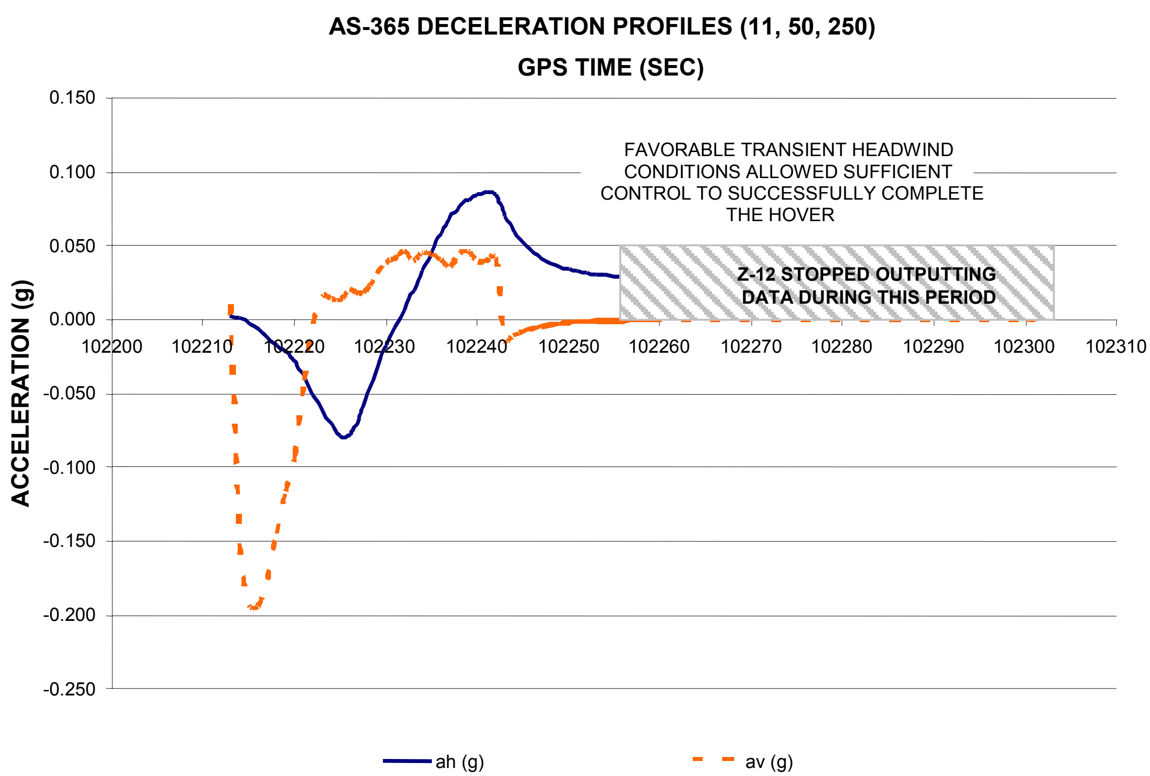


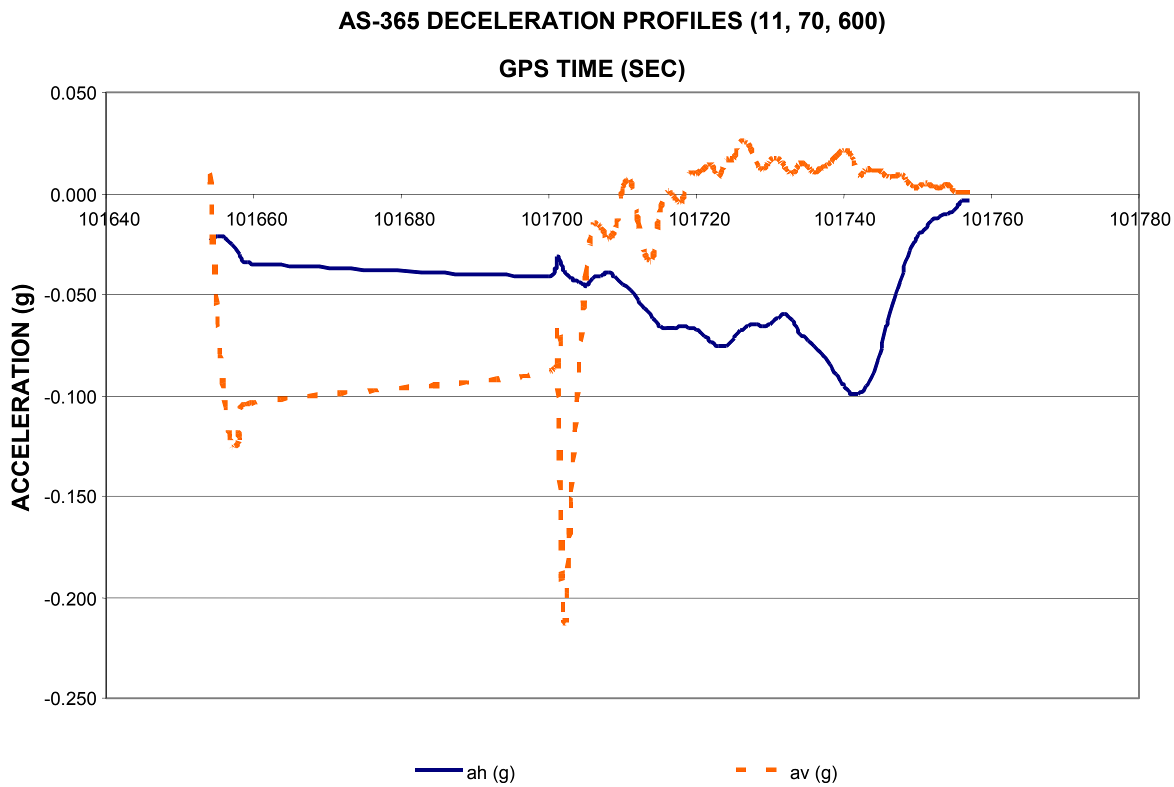
AS-365 DECELERATION PROFILES (6, 90, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
92580
92600
92620
92640
92660
92680
92700
92720
ah (g)
av (g)



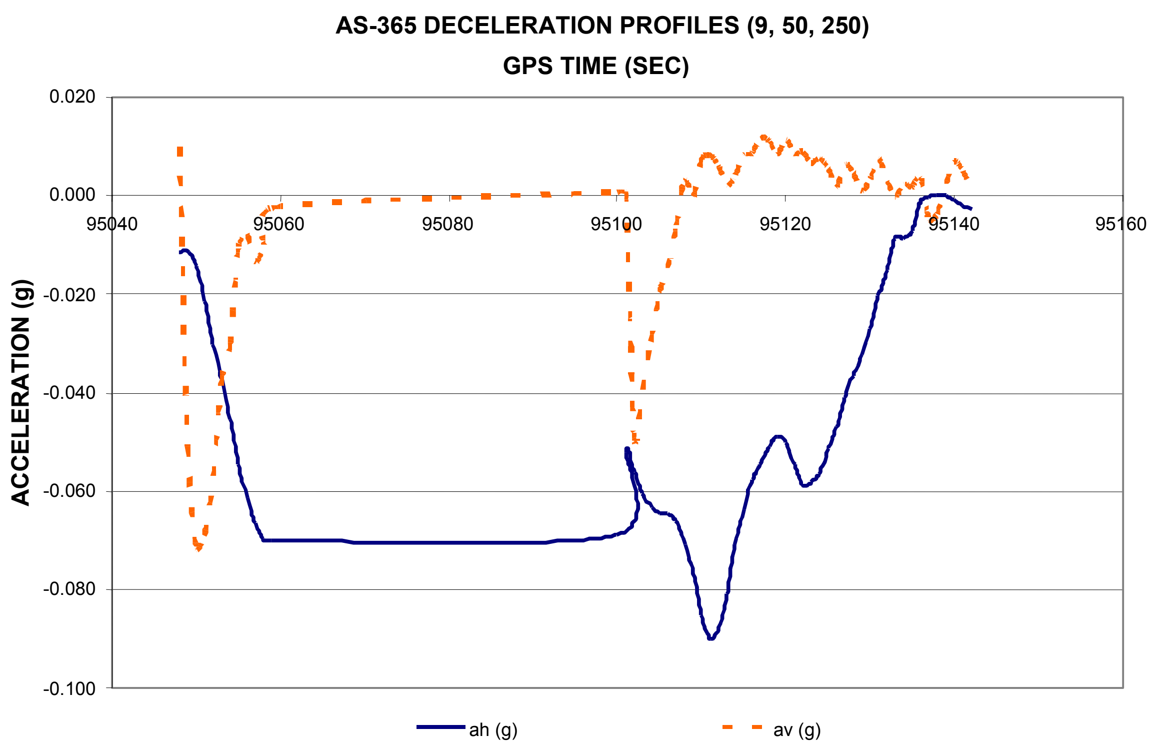
AS-365 DECELERATION PROFILES (9, 70, 450)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
94520
94540
94560
94580
94600
94620
94640
94660
ah (g)
av (g)


AS-365 DECELERATION PROFILES (11, 50, 300)
GPS TIME (SEC)
ACCELERATION (g)
THE TEST PILOT ELECTED TO ABORT THE DESCENT
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
102900
102905
102910
102915
102920
102925
102930
102935
ah (g)
av (g)

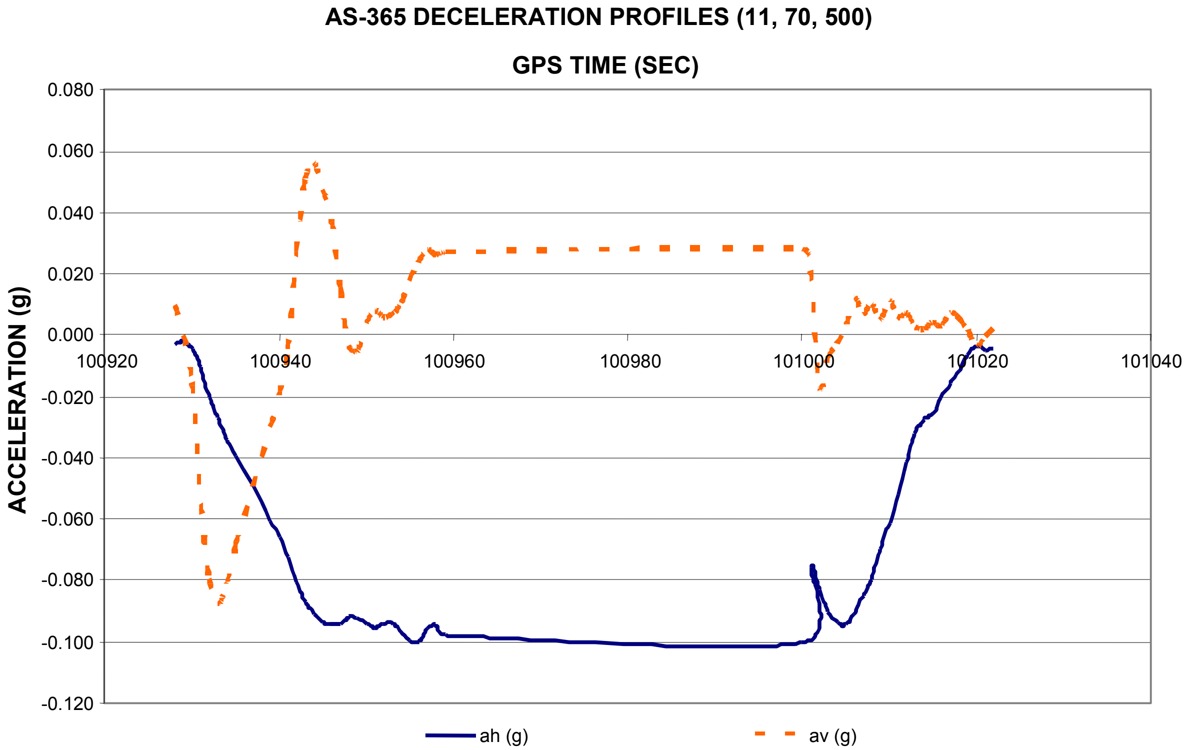

AS-365 DECELERATION PROFILES (11, 50, 250)
GPS TIME (SEC)
ACCELERATION (g)
FAVORABLE TRANSIENT HEADWIND CONDITIONS ALLOWED SUFFICIENT CONTROL TO SUCCESSFULLY COMPLETE THE HOVER
Z-12 STOPPED OUTPUTTING DATA DURING THIS PERIOD
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
102200
102210
102220
102230
102240
102250
102260
102270
102280
102290
102300
102310
ah (g)
av (g)

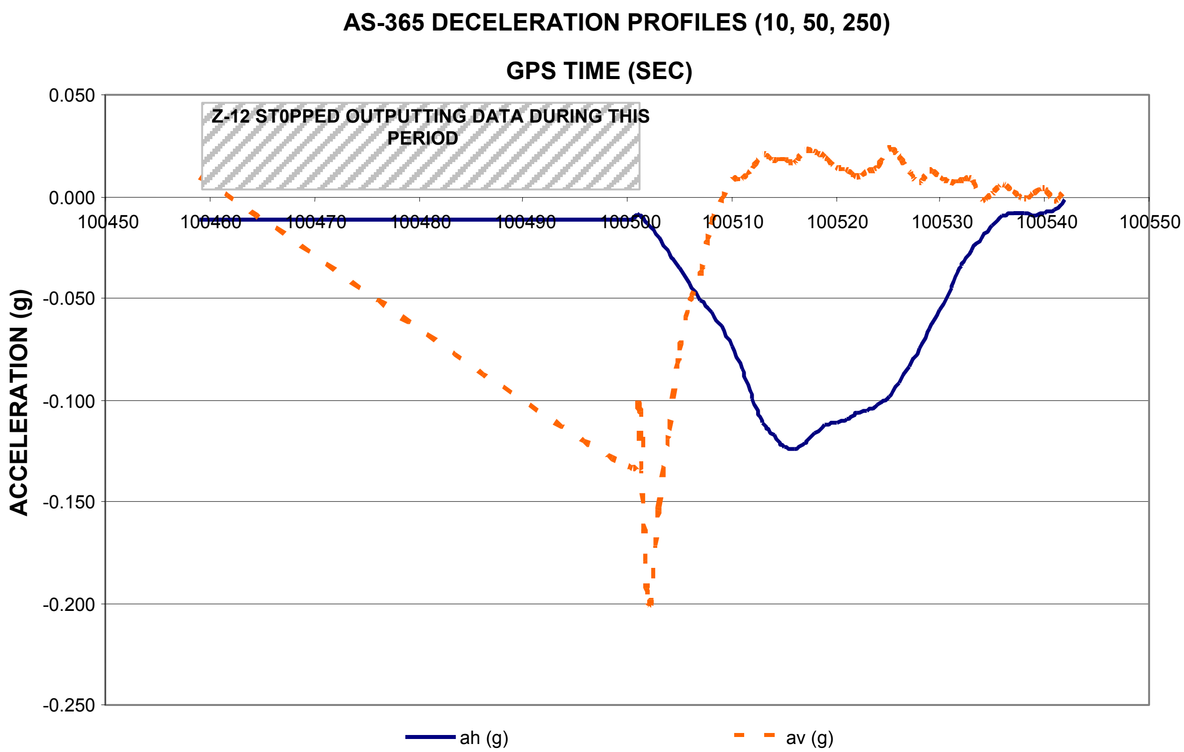


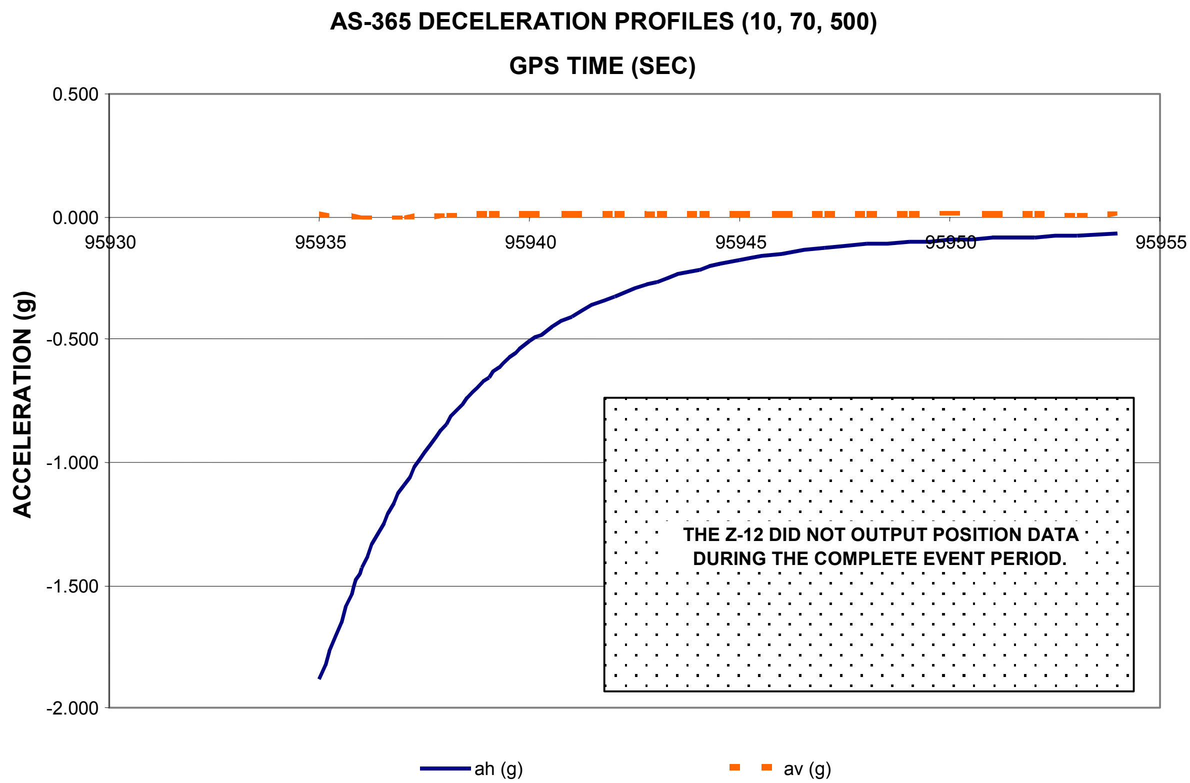
AS-365 DECELERATION PROFILES (11, 70, 600)
GPS TIME (SEC)
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
101640
101660
101680
101700
101720
101740
101760
101780
ACCELERATION (g)
ah (g)
av (g)

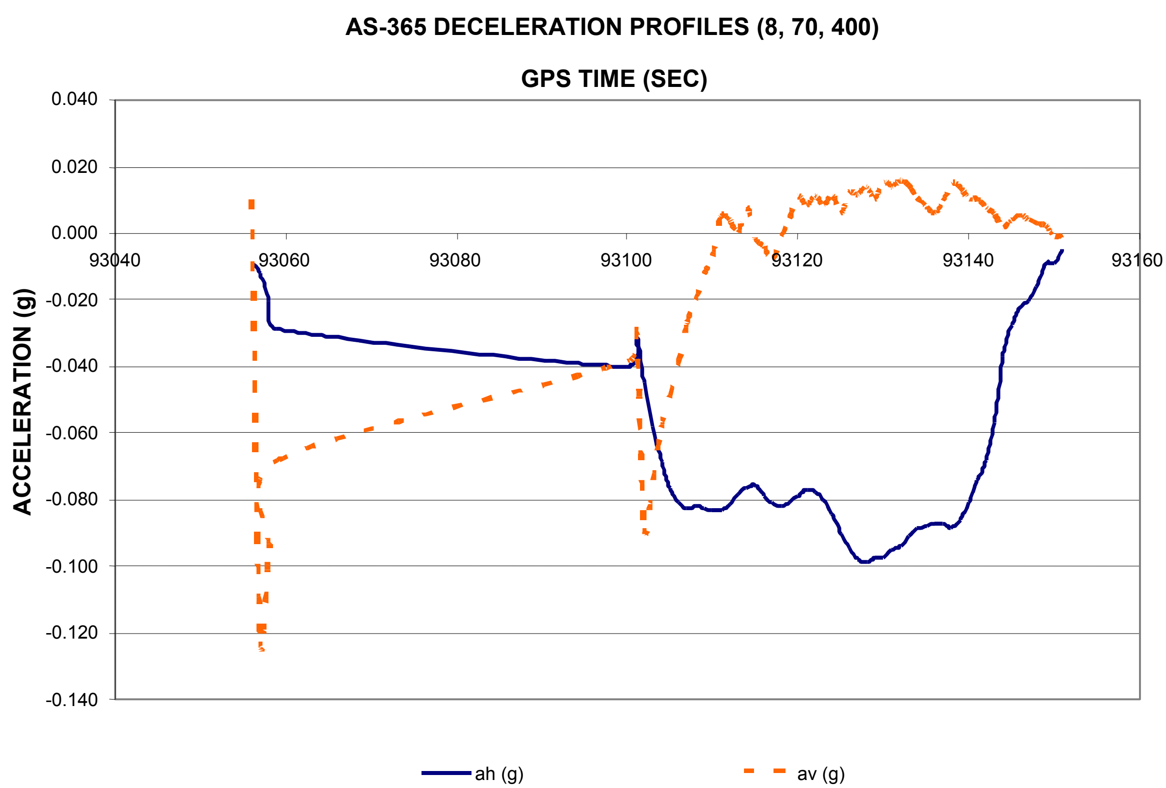


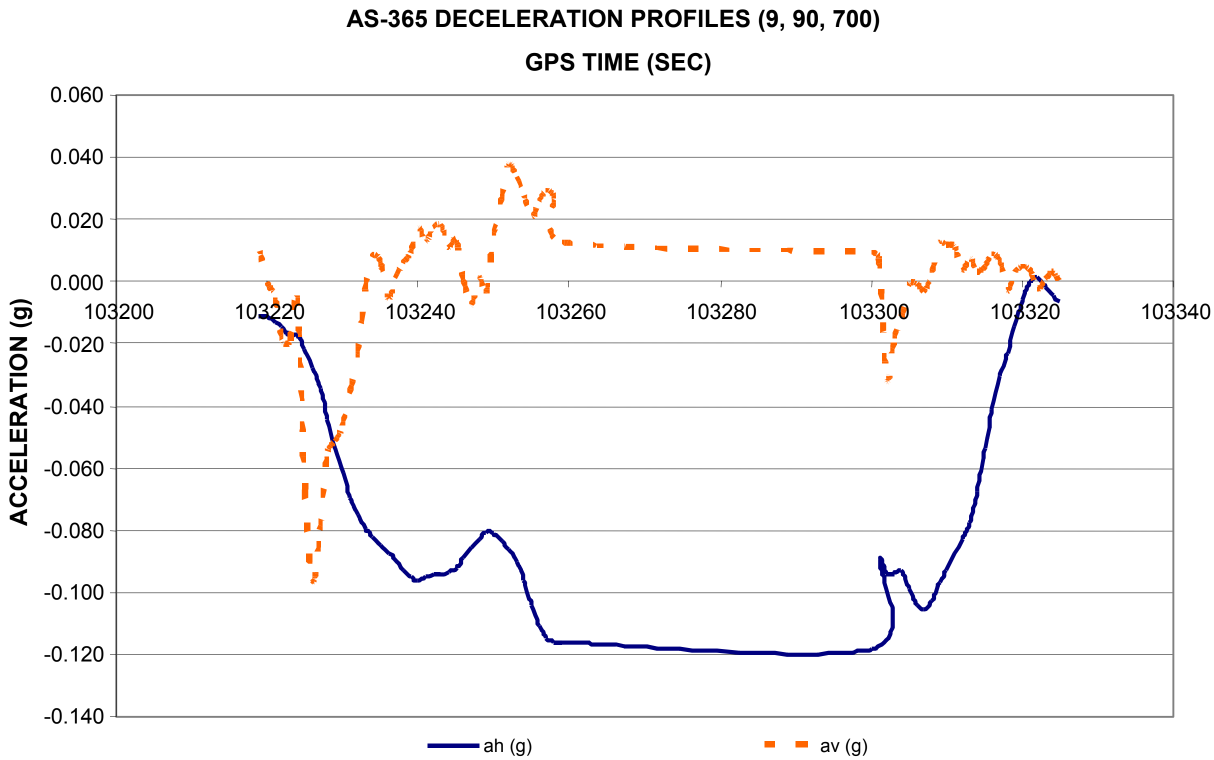
AS-365 DECELERATION PROFILES (9, 50, 250)
GPS TIME (SEC)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
95040
95060
95080
95100
95120
95140
95160
ACCELERATION (g)
ah (g)
av (g)

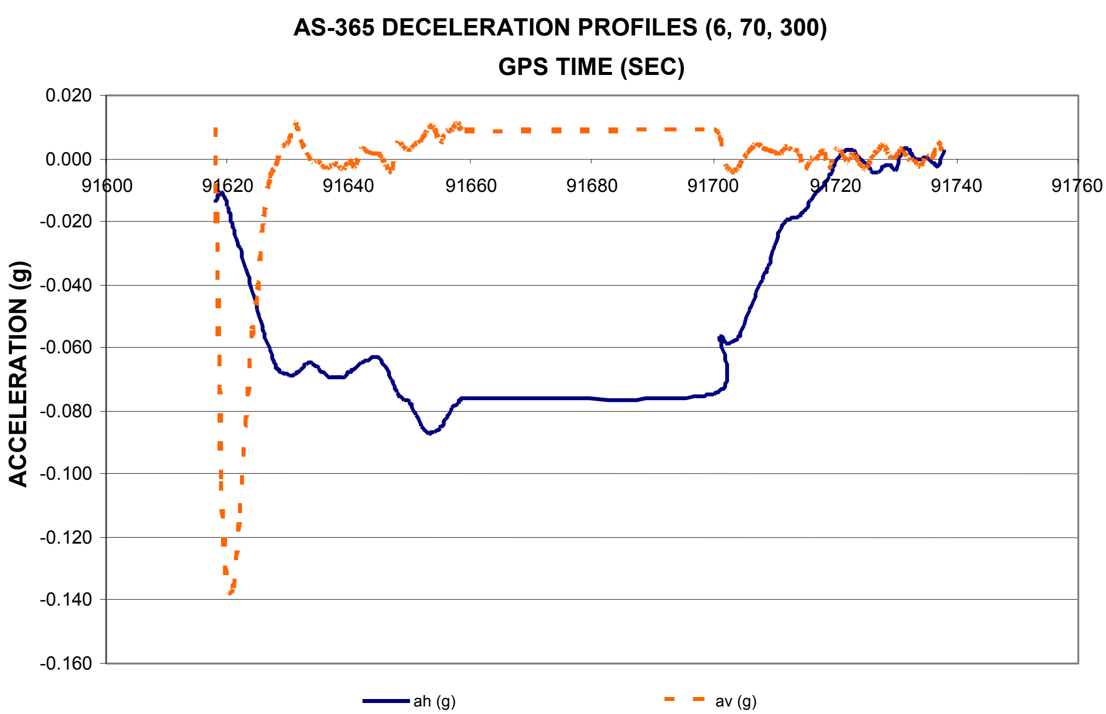

AS-365 DECELERATION PROFILES (11, 70, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
100920
100940
100960
100980
101000
101020
101040
ah (g)
av (g)


AS-365 DECELERATION PROFILES (10, 50, 250)
GPS TIME (SEC)
ACCELERATION (g)
Z-12 ST0PPED OUTPUTTING DATA DURING THIS PERIOD
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
100450
100460
100470
100480
100490
100500
100510
100520
100530
100540
100550
ah (g)
av (g)

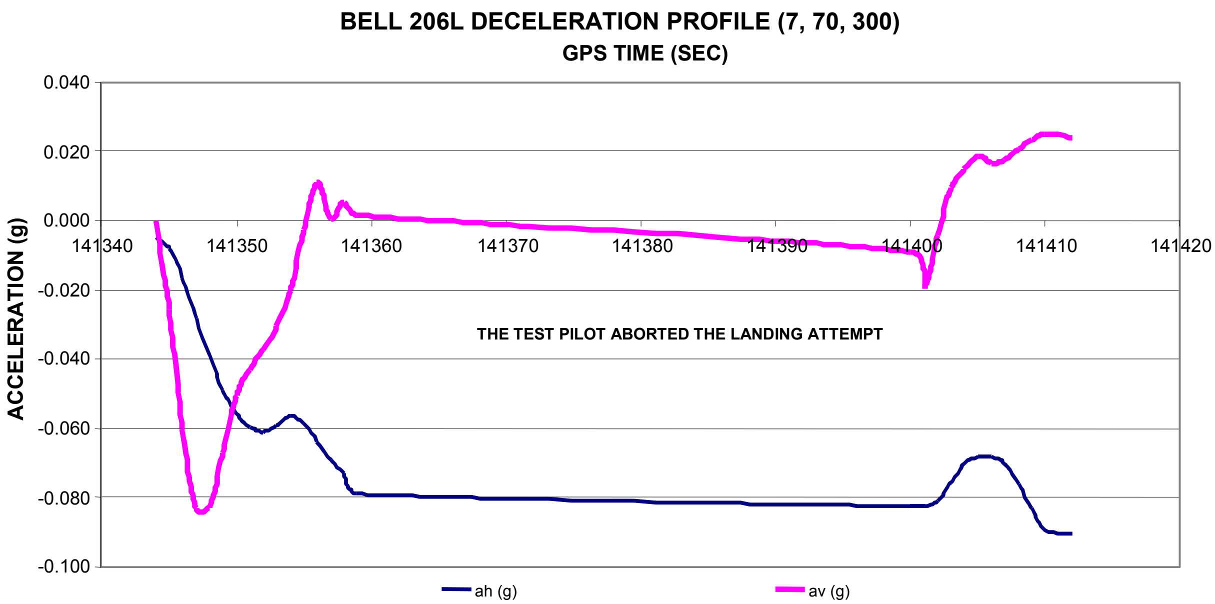

AS-365 DECELERATION PROFILES (10, 70, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.500
0.000
-0.500
-1.000
-1.500
-2.000
95930
95935
95940
95945
95950
95955
THE Z-12 DID NOT OUTPUT POSITION DATA DURING THE COMPLETE EVENT PERIOD.
ah (g)
av (g)

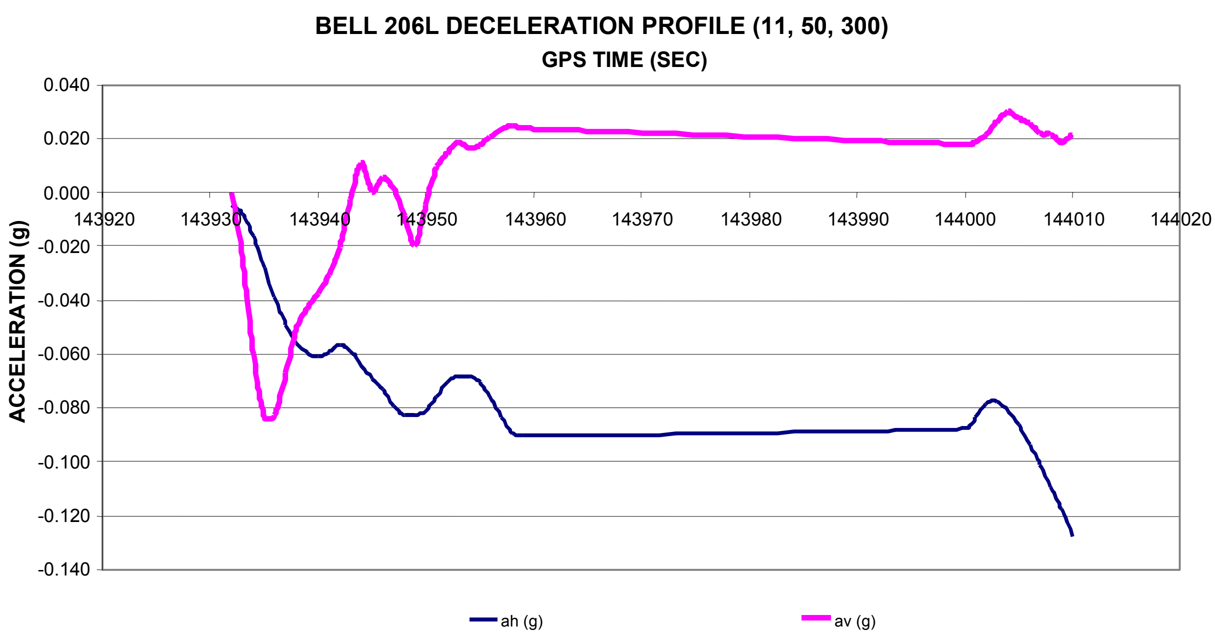

AS-365 DECELERATION PROFILES (8, 70, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
93040
93060
93080
93100
93120
93140
93160
ah (g)
av (g)

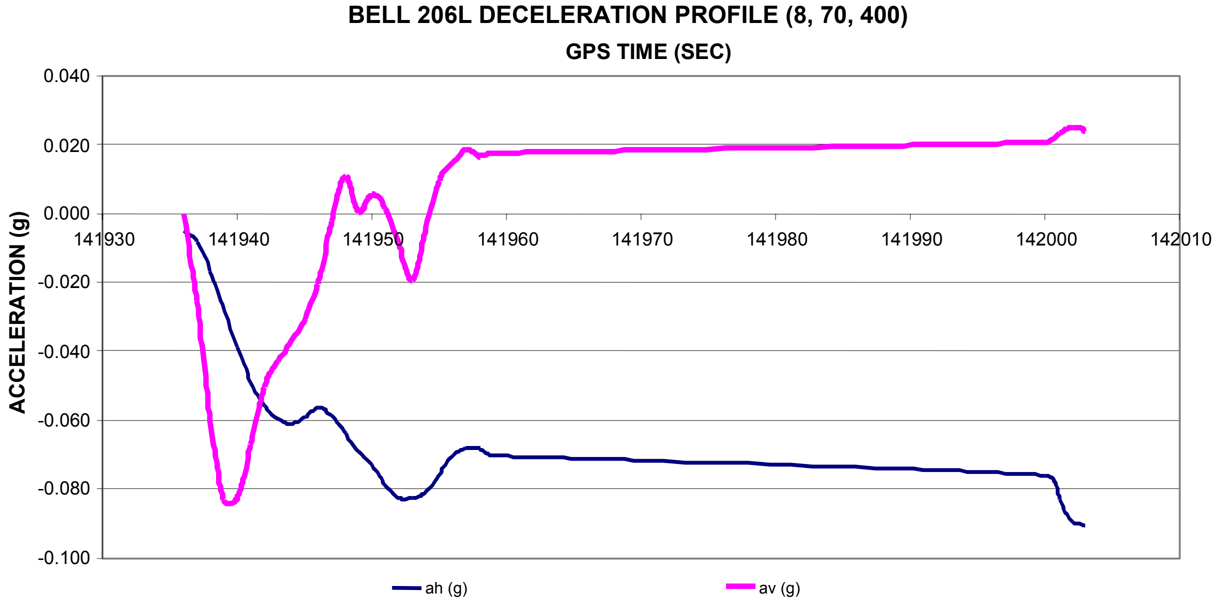

AS-365 DECELERATION PROFILES (9, 90, 700)
GPS TIME (SEC)
ACCELERATION (g)
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
103200
103220
103240
103260
103280
103300
103320
103340
ah (g)
av (g)


AS-365 DECELERATION PROFILES (6, 70, 300)
GPS TIME (SEC)
ACCELERATION (g)
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
-0.160
91600
91620
91640
91660
91680
91700
91720
91740
91760
ah (g)
av (g)

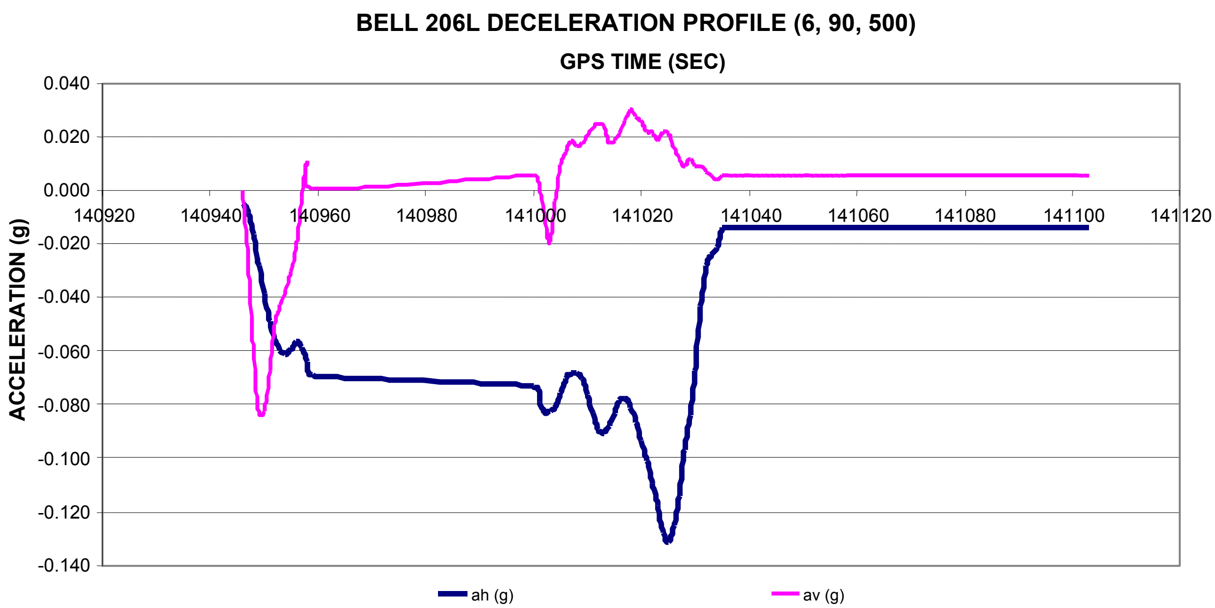
BELL 206L DECELERATION PROFILES.



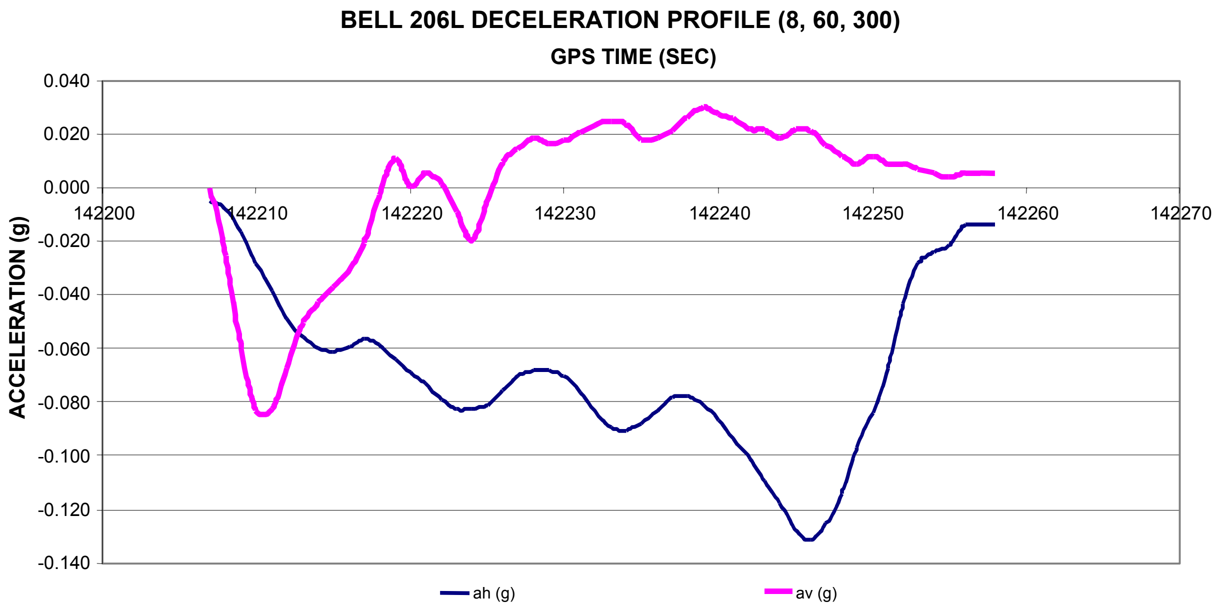


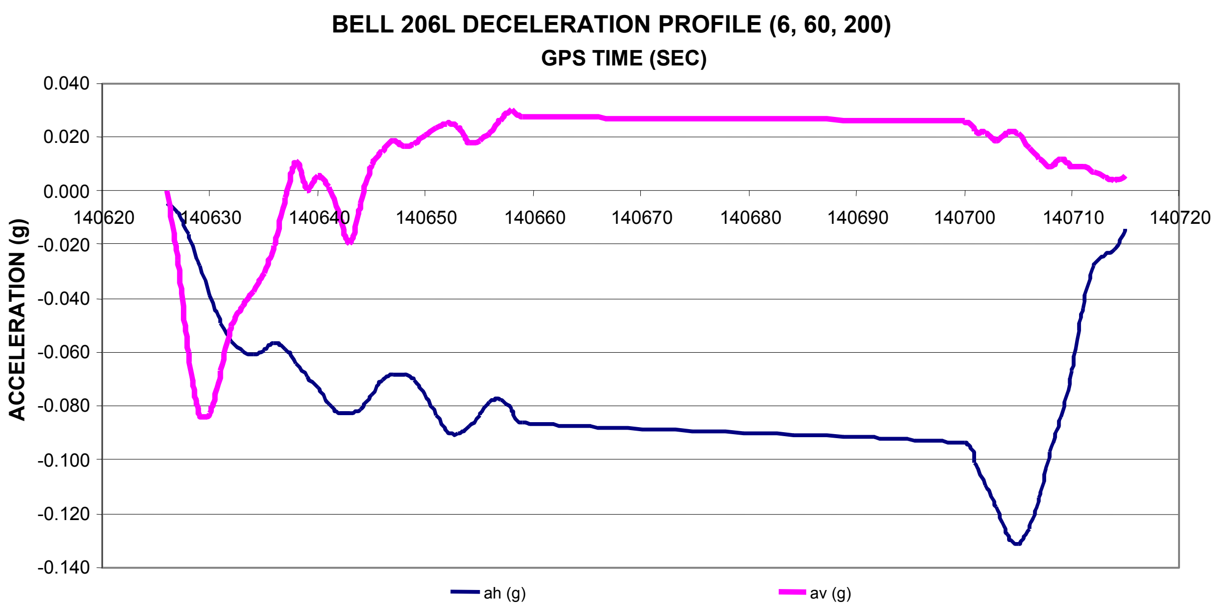


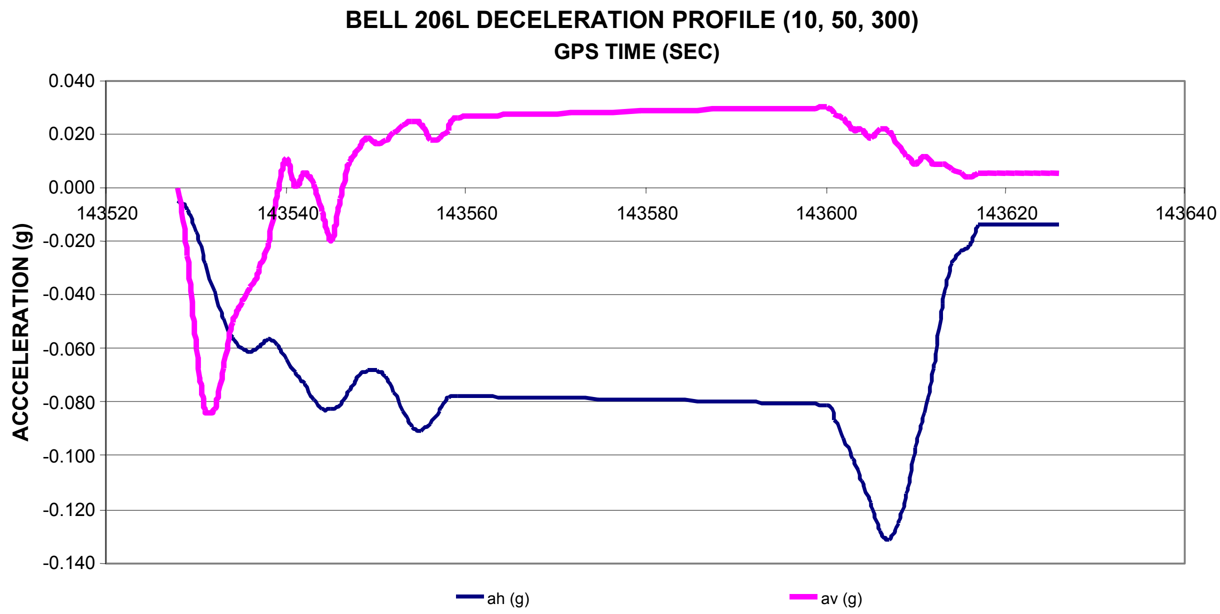
BELL 206L DECELERATION PROFILE (8, 70, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
141930
141940
141950
141960
141970
141980
141990
142000
142010
ah (g)
av (g)

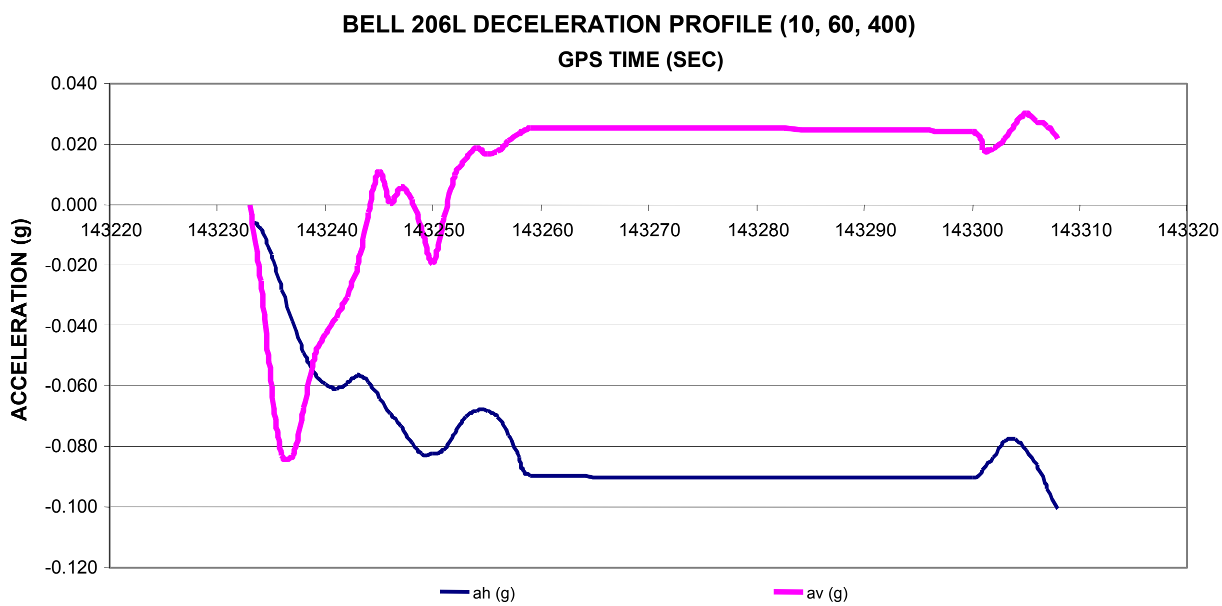


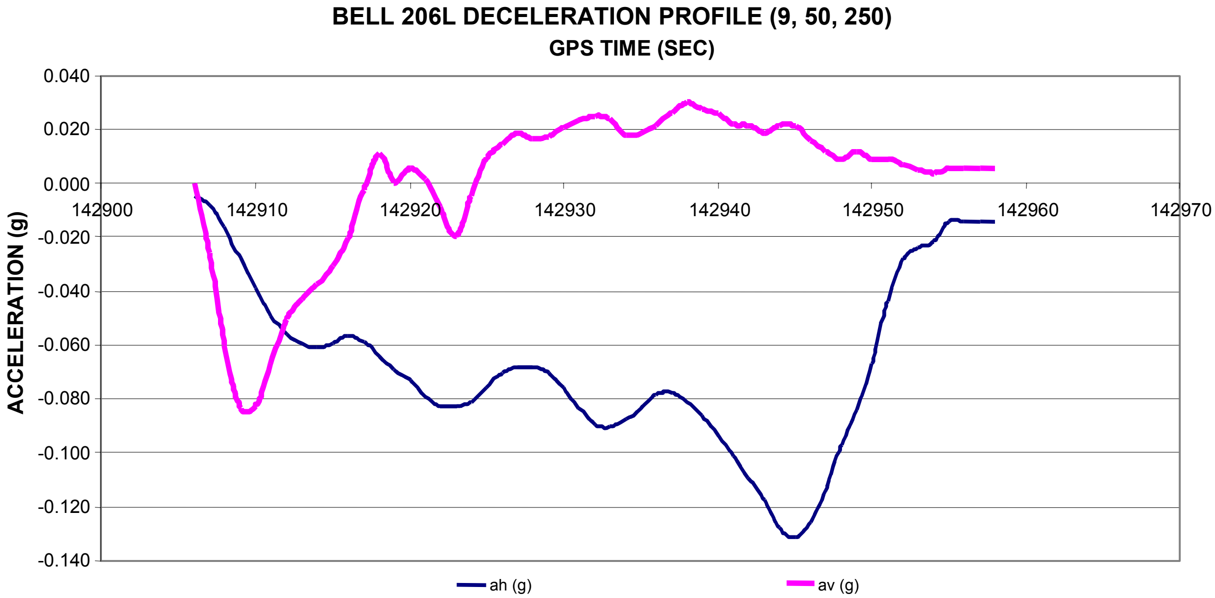
BELL 206L DECELERATION PROFILE (6, 90, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
140920
140940
140960
140980
141000
141020
141040
141060
141080
141100
141120
ah (g)
av (g)

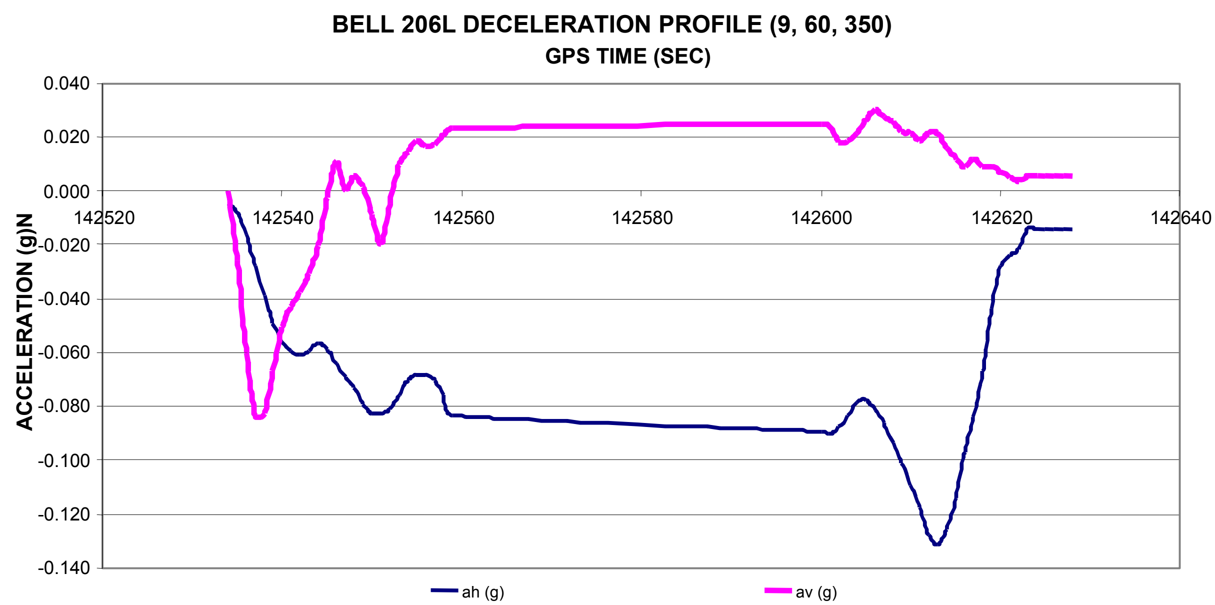

BELL 206L DECELERATION PROFILE (8, 60, 300)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
142200
142210
142220
142230
142240
142250
142260
142270
ah (g)
av (g)

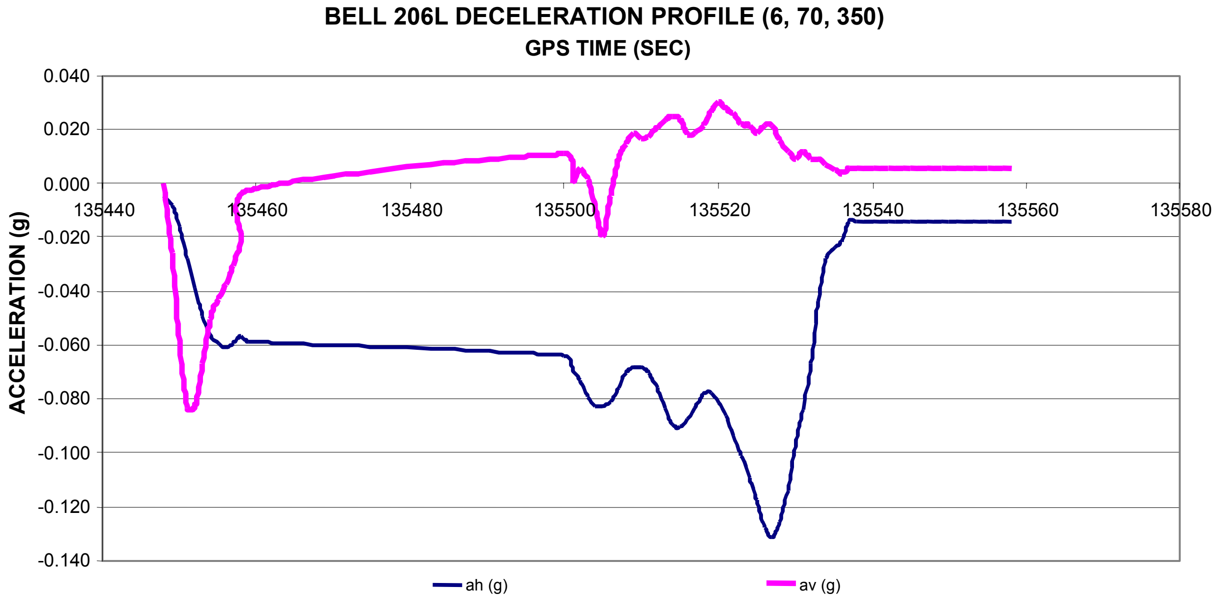

BELL 206L DECELERATION PROFILE (6, 60, 200)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
140620
140630
140640
140650
140660
140670
140680
140690
140700
140710
140720
ah (g)
av (g)

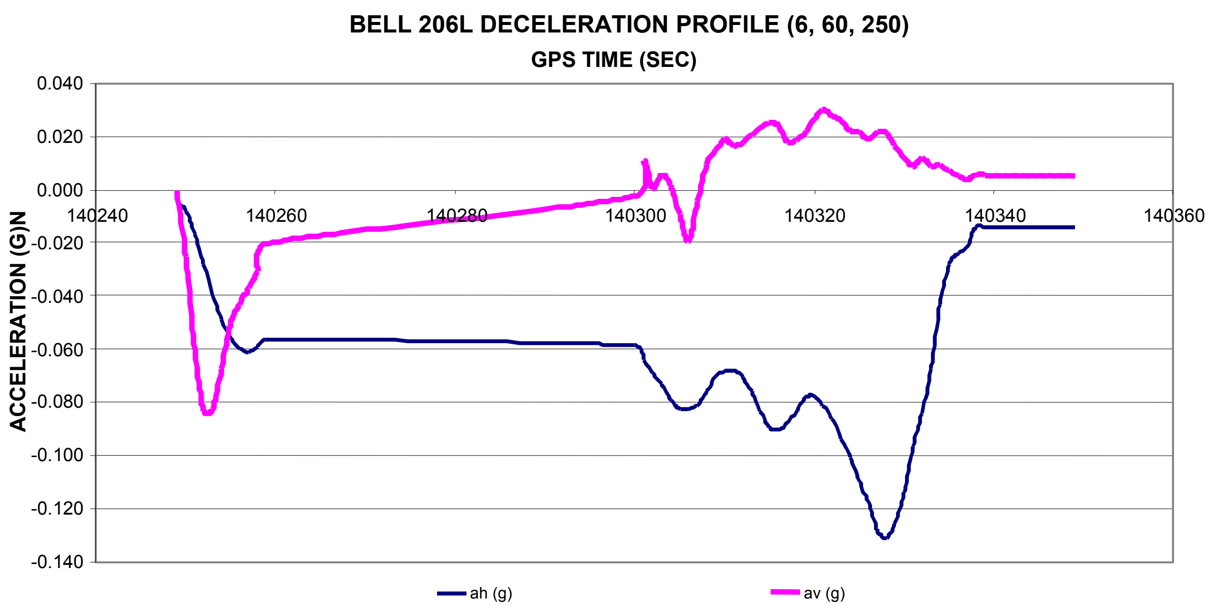

BELL 206L DECELERATION PROFILE (10, 50, 300)
GPS TIME (SEC)
ACCCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
143520
143540
143560
143580
143600
143620
143640
ah (g)
av (g)

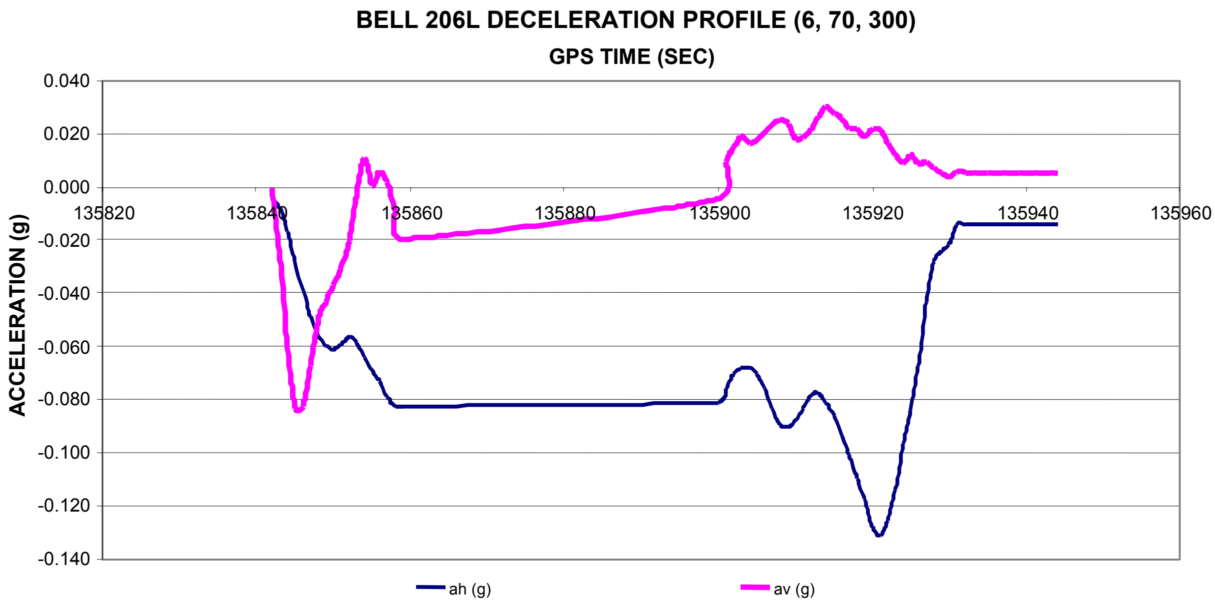

BELL 206L DECELERATION PROFILE (10, 60, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
143220
143230
143240
143250
143260
143270
143280
143290
143300
143310
143320
ah (g)
av (g)


BELL 206L DECELERATION PROFILE (9, 50, 250)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
142900
142910
142920
142930
142940
142950
142960
142970
ah (g)
av (g)

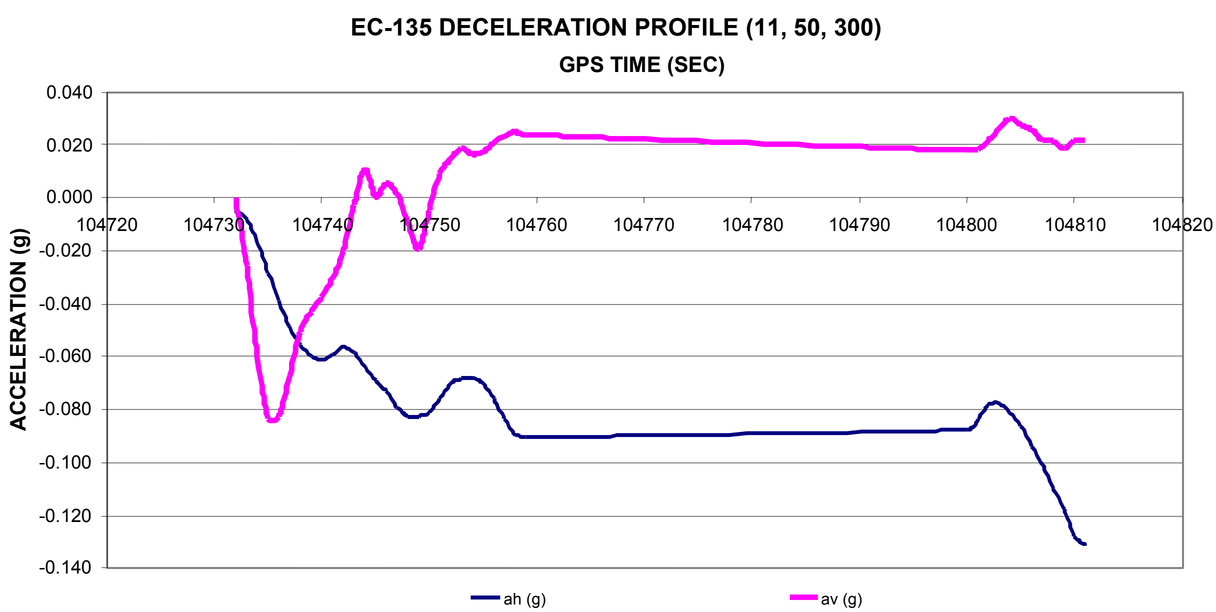

BELL 206L DECELERATION PROFILE (9, 60, 350)
GPS TIME (SEC)
ACCELERATION (g)N
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
142520
142540
142560
142580
142600
142620
142640
ah (g)
av (g)

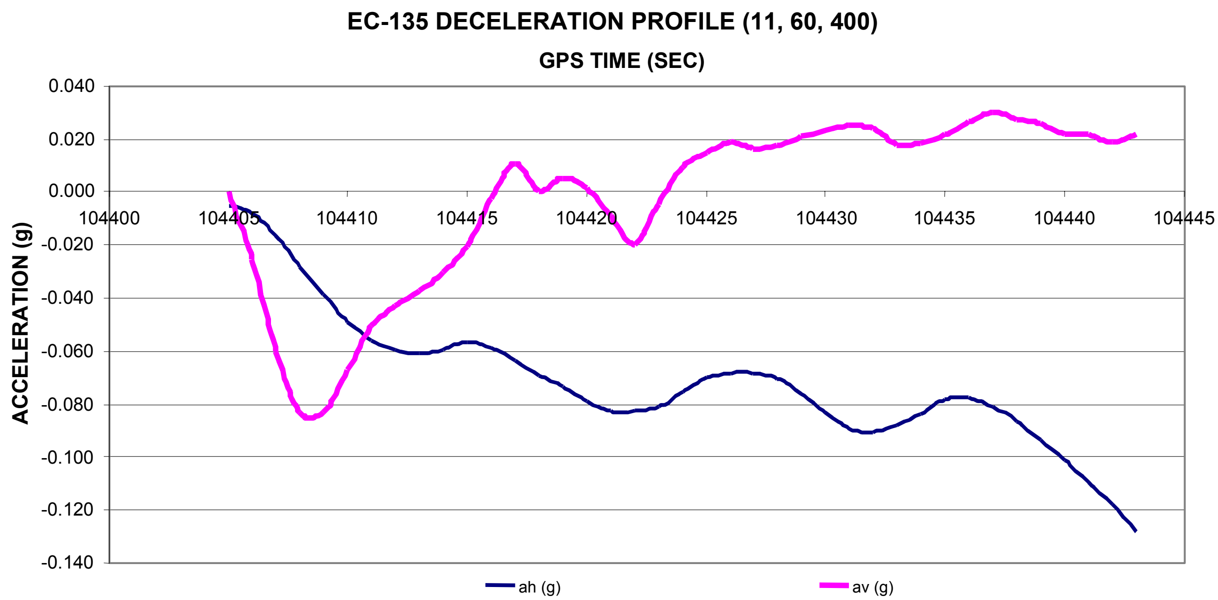

BELL 206L DECELERATION PROFILE (6, 70, 350)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
135440
135460
135480
135500
135520
135540
135560
135580
ah (g)
av (g)

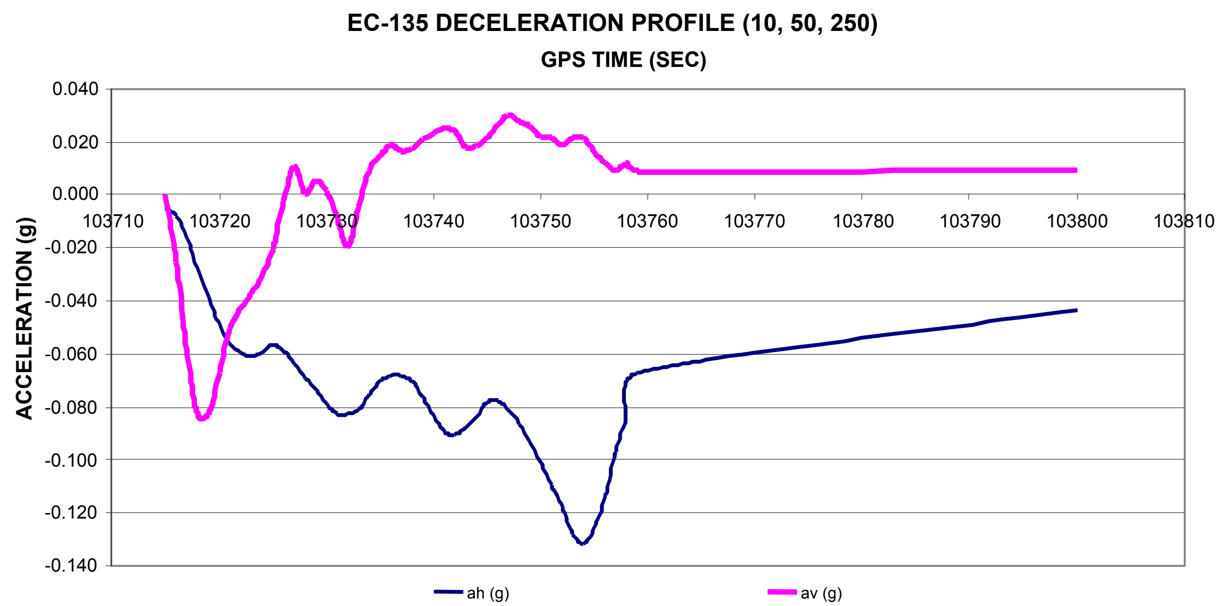

BELL 206L DECELERATION PROFILE (6, 60, 250)
GPS TIME (SEC)
ACCELERATION (G)N
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
140240
140260
140280
140300
140320
140340
140360
ah (g)
av (g)

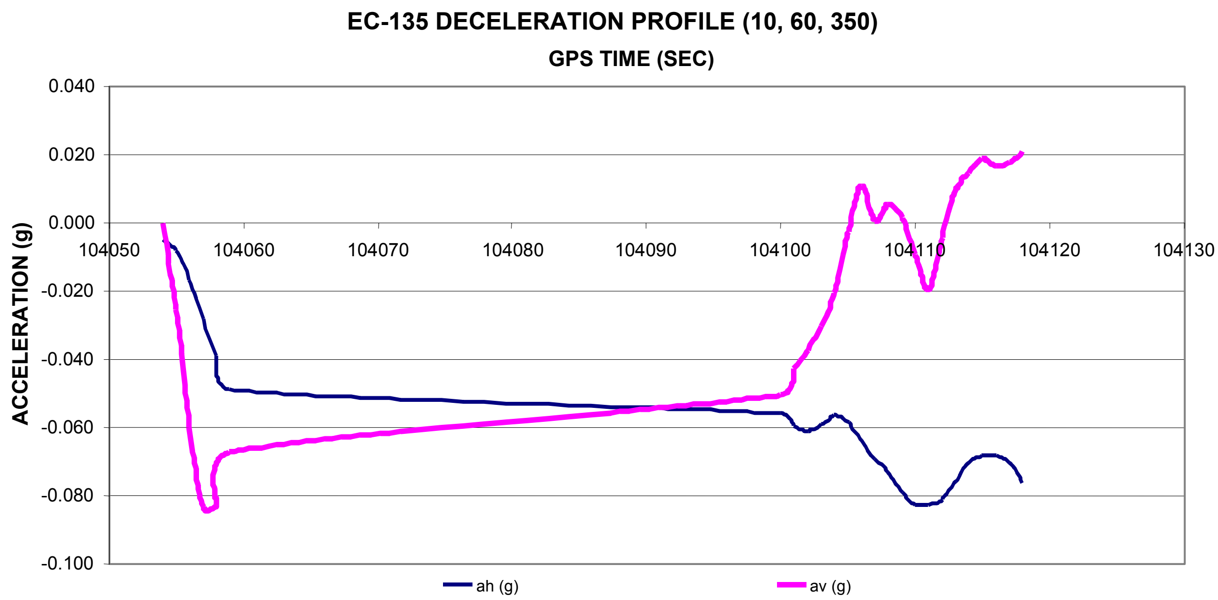


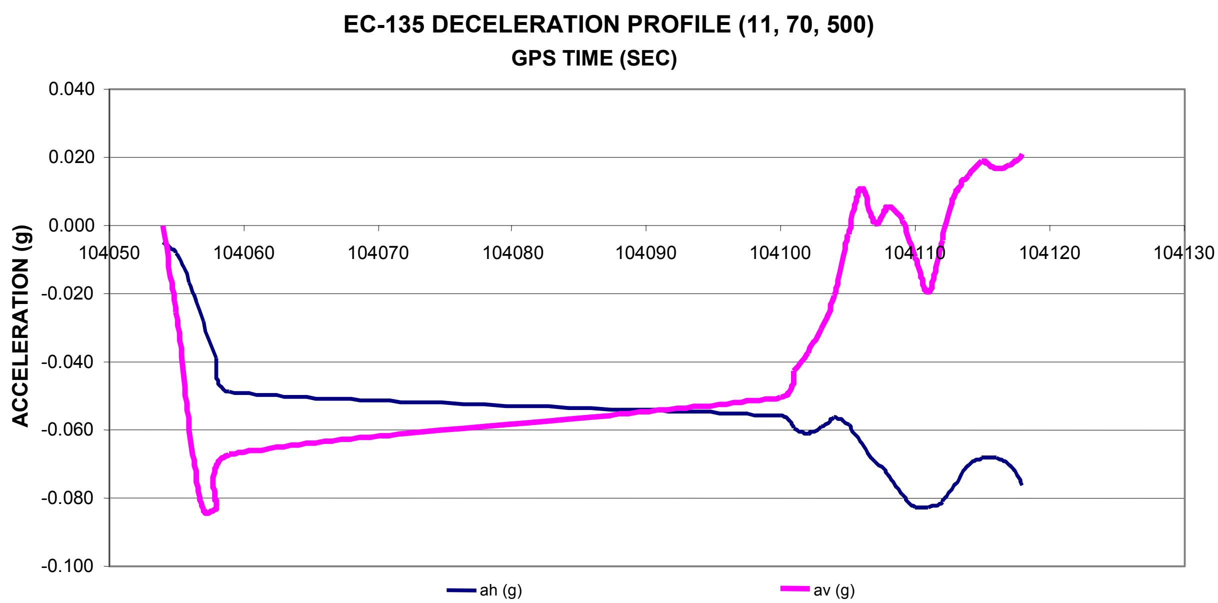
EC-135 DECELERATION PROFILES.

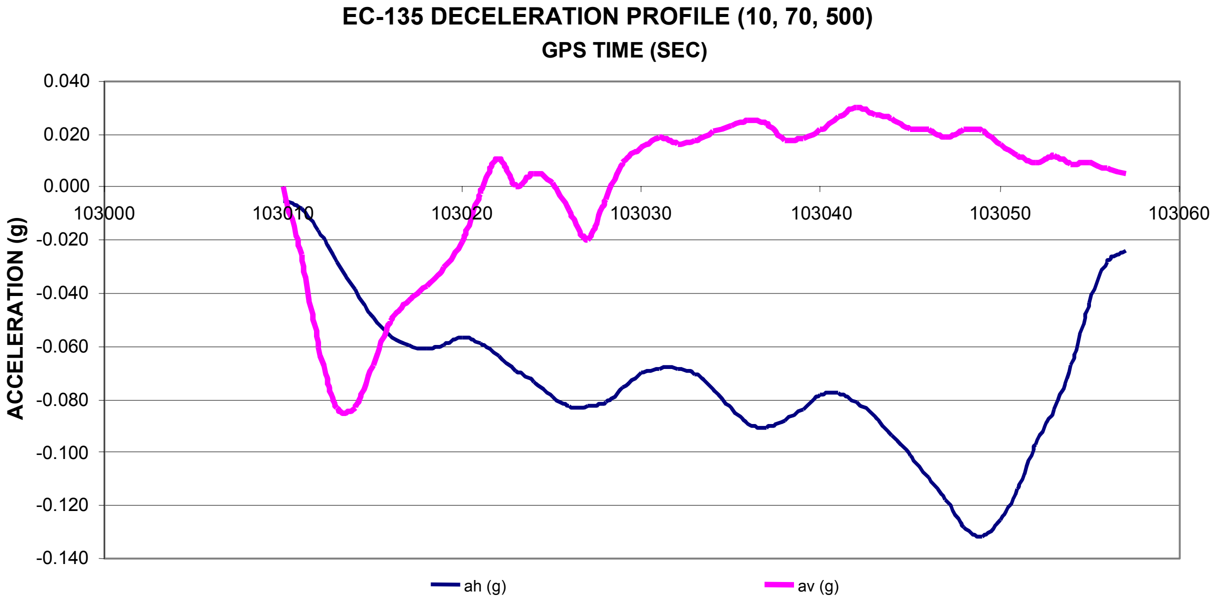


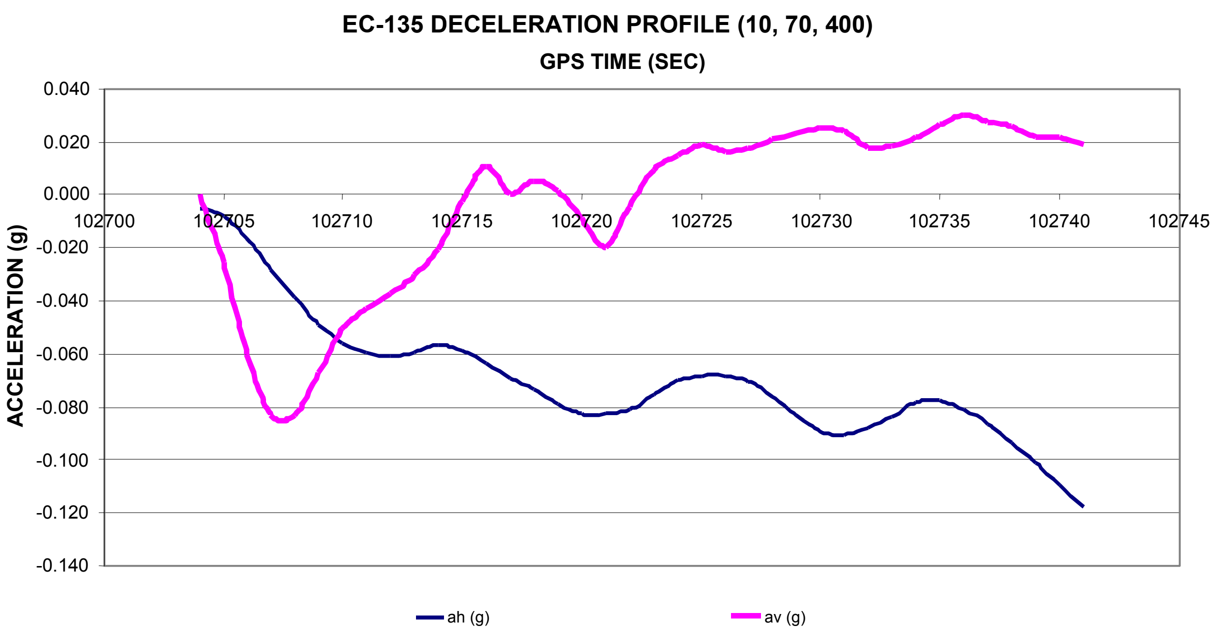

EC-135 DECELERATION PROFILE (11, 60, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
104400
104405
104410
104415
104420
104425
104430
104435
104440
104445
ah (g)
av (g)

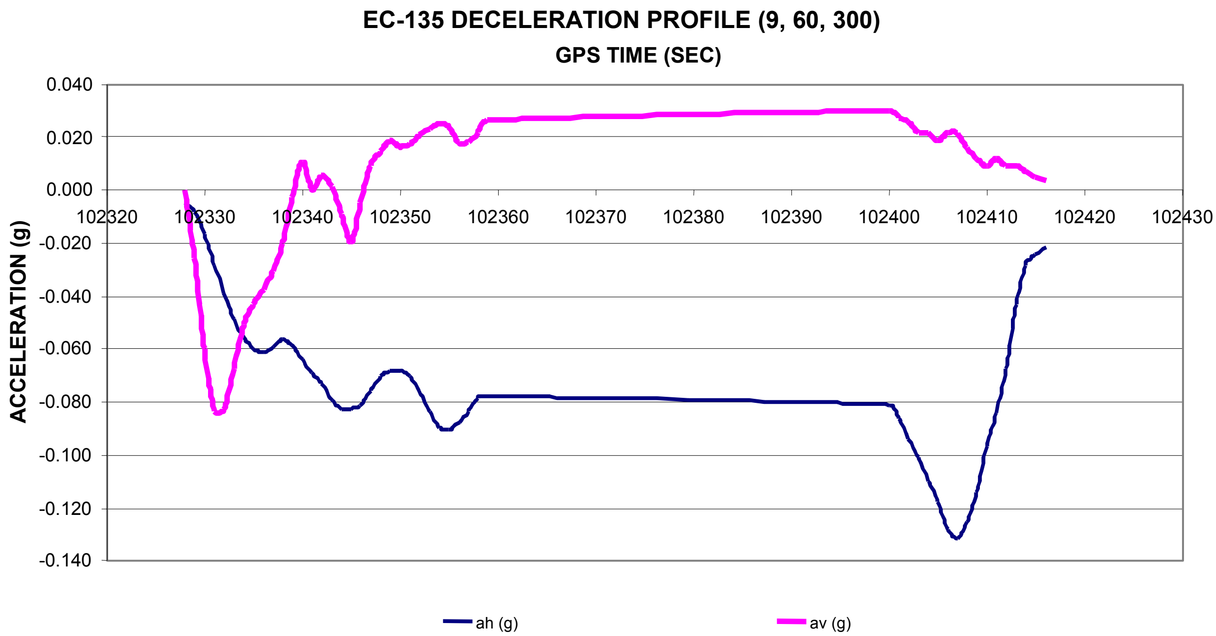

EC-135 DECELERATION PROFILE (10, 50, 250)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
103710
103720
103730
103740
103750
103760
103770
103780
103790
103800
103810
ah (g)
av (g)

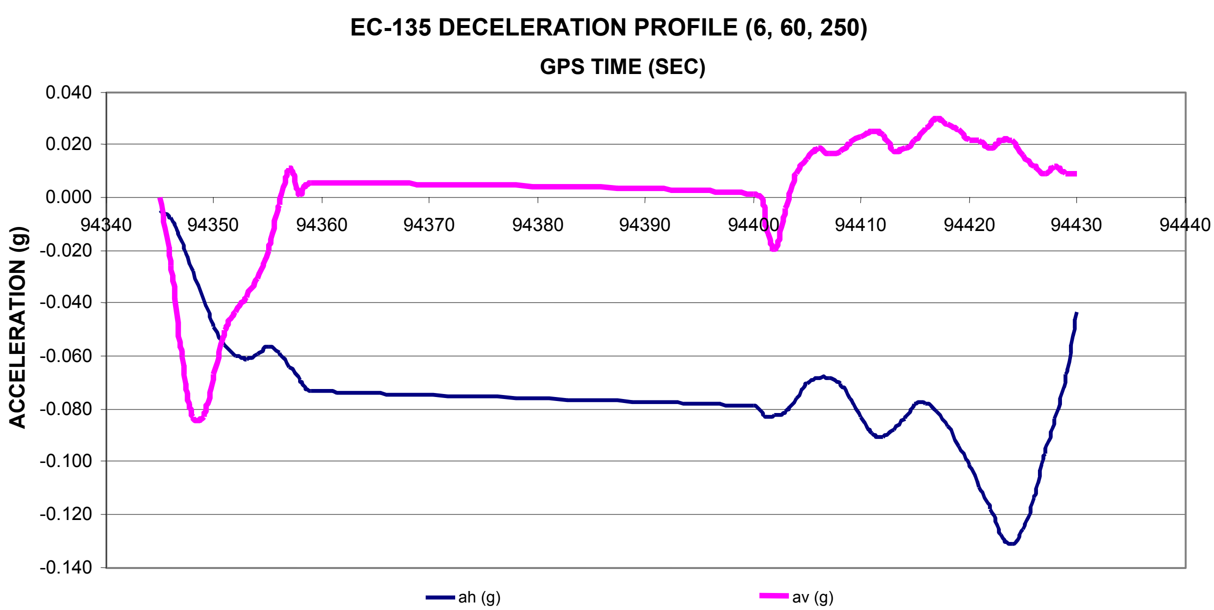

EC-135 DECELERATION PROFILE (10, 60, 350)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
104050
104060
104070
104080
104090
104100
104110
104120
104130
ah (g)
av (g)


EC-135 DECELERATION PROFILE (11, 70, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
104050
104060
104070
104080
104090
104100
104110
104120
104130
ah (g)
av (g)


EC-135 DECELERATION PROFILE (10, 70, 500)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
103000
103010
103020
103030
103040
103050
103060
ah (g)
av (g)

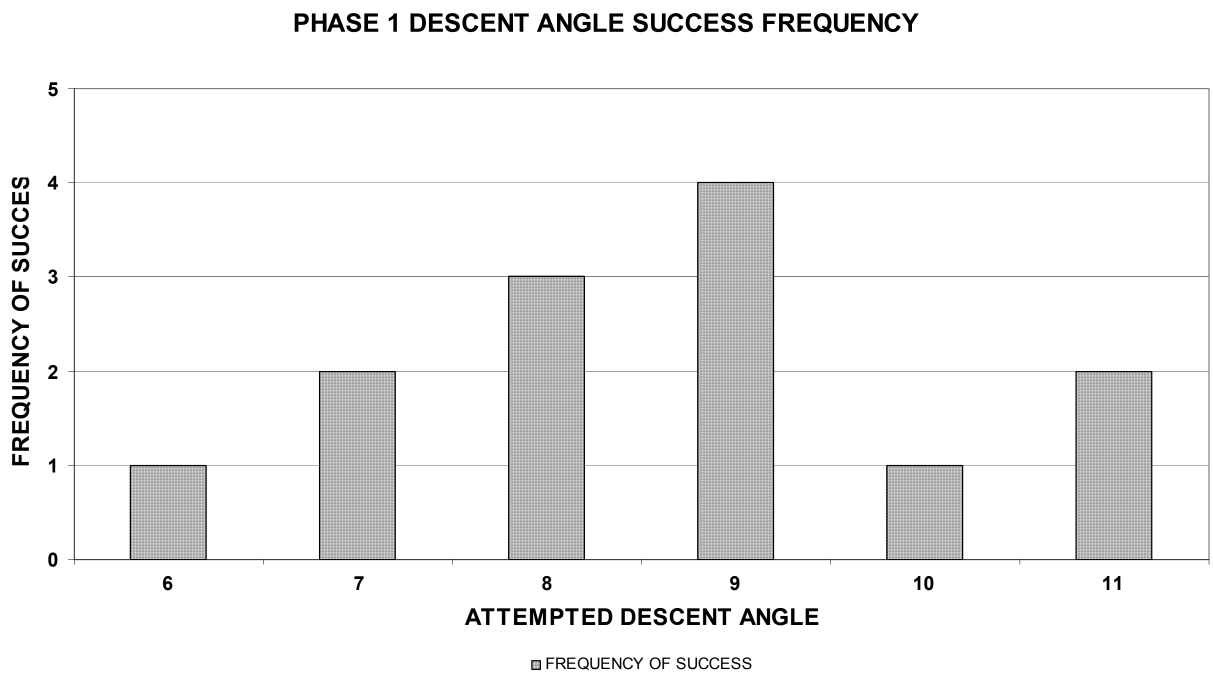

EC-135 DECELERATION PROFILE (10, 70, 400)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
102700
102705
102710
102715
102720
102725
102730
102735
102740
102745
ah (g)
av (g)


EC-135 DECELERATION PROFILE (9, 60, 300)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
102320
102330
102340
102350
102360
102370
102380
102390
102400
102410
102420
102430
ah (g)
av (g)


EC-135 DECELERATION PROFILE (6, 60, 250)
GPS TIME (SEC)
ACCELERATION (g)
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
94340
94350
94360
94370
94380
94390
94400
94410
94420
94430
94440
ah (g)
av (g)

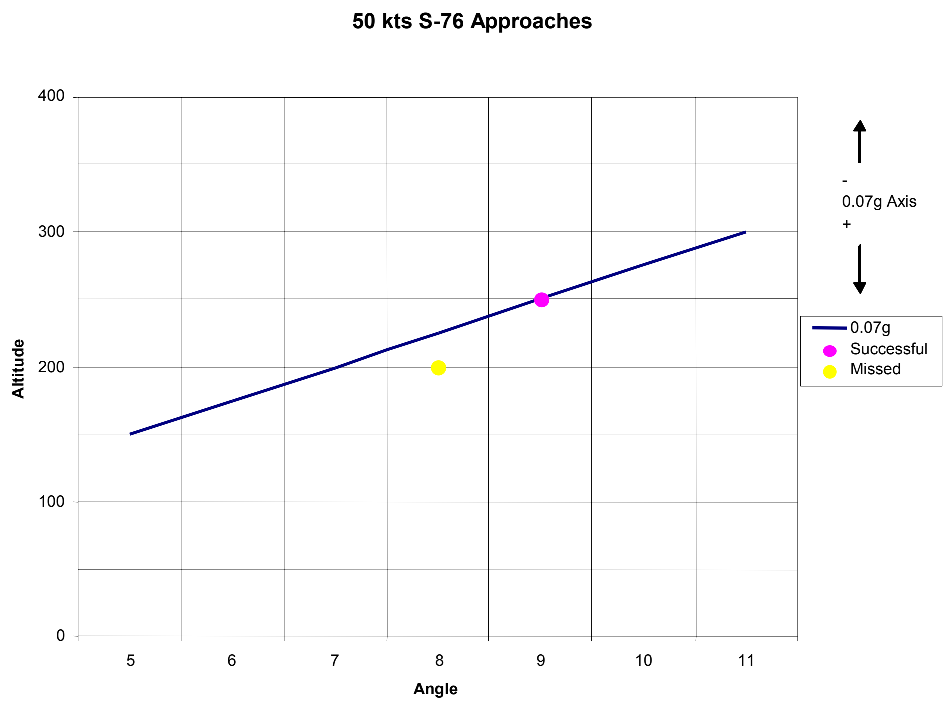
APPENDIX E—ANGLE OF DESCENT SUCCESS FREQUENCY

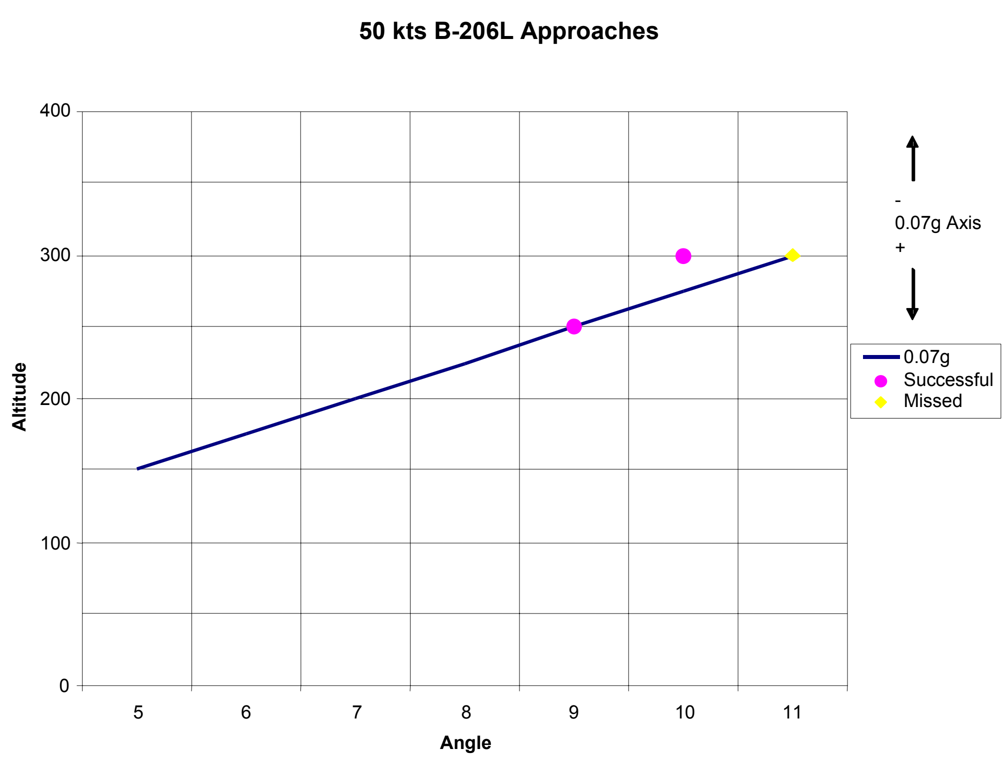
The following chart shows the frequency of successful hover maneuvers accomplished at an approach speed to the initial approach speed of 70 kts and minimum altitude of 400 ft above ground level. Descent angle geometries for the flight tests were designed to require an average deceleration of 0.07 g to achieve the hover at zero forward velocity.



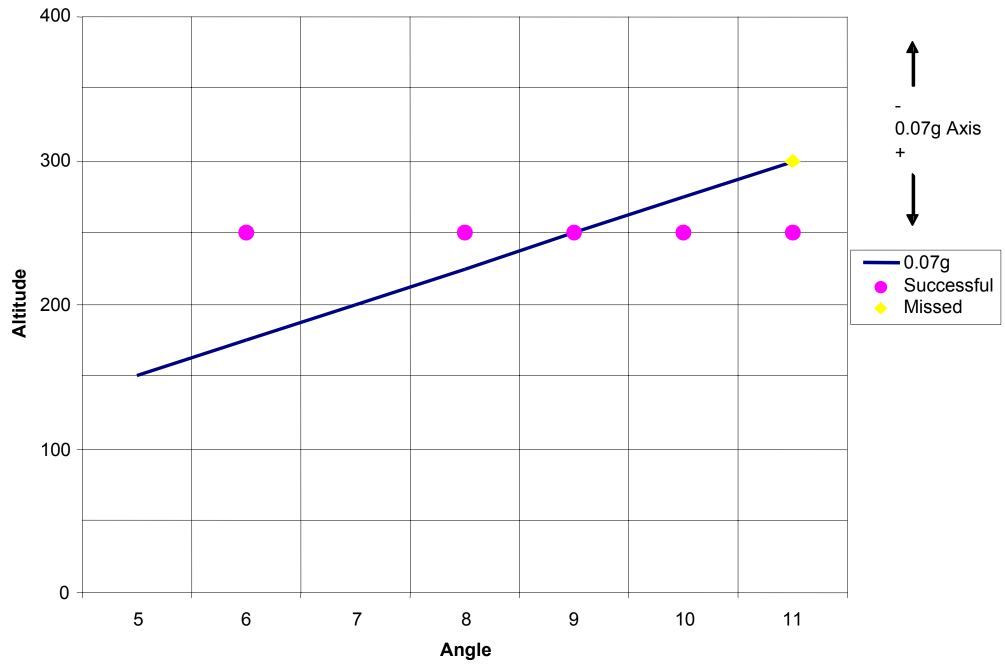
APPENDIX F—SUCCESSFUL AND MISSED APPROACHES BY HELICOPTER

The following charts are arranged by velocity then by helicopter types. These charts give an overall snapshot of approaches attempted and does not contain information on how each aircraft actually performed.

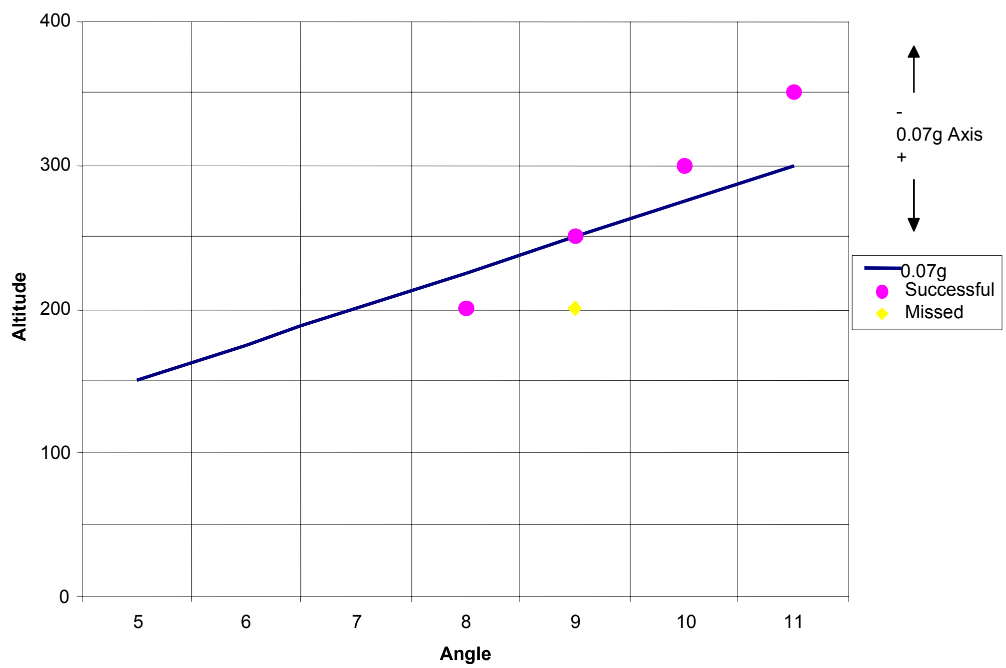


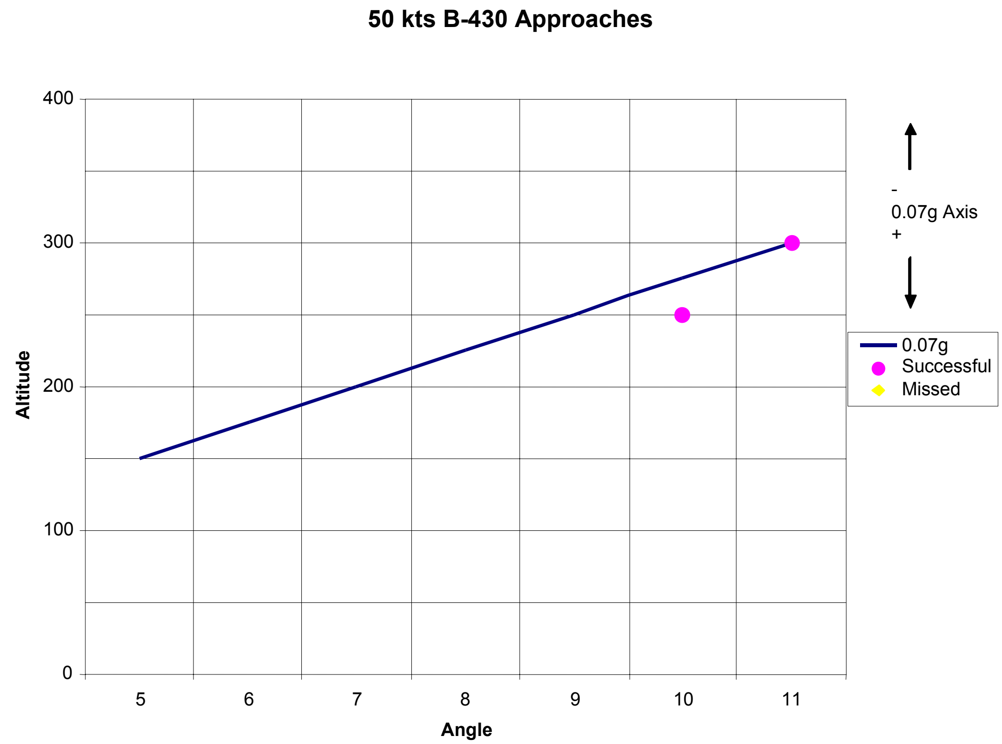


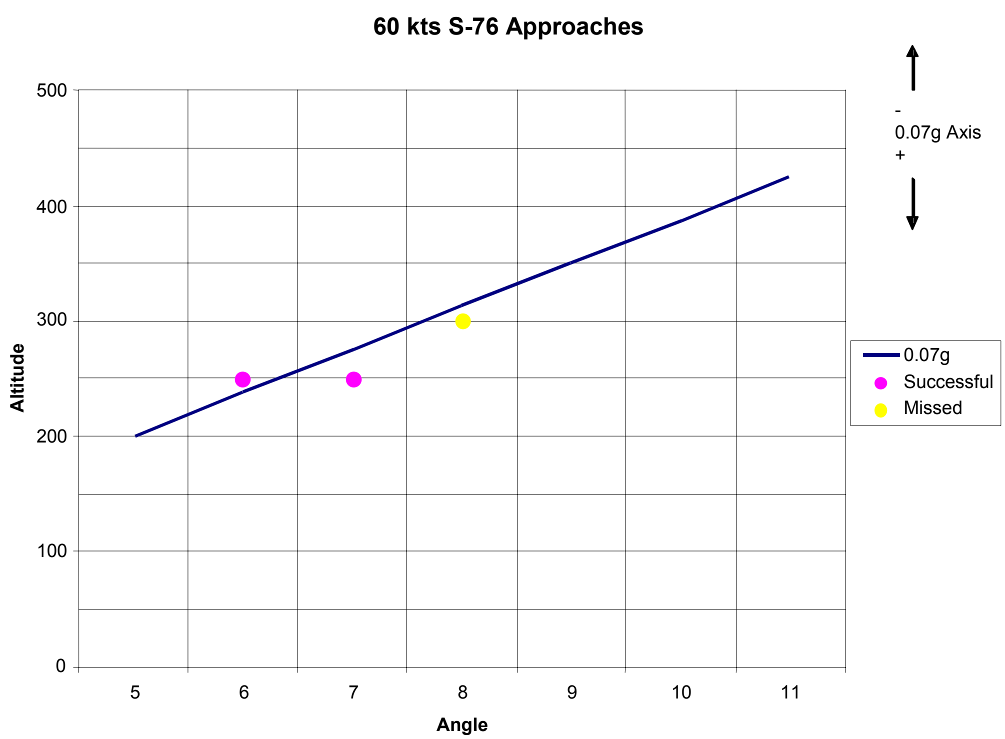
50 kts AS-365 Approaches



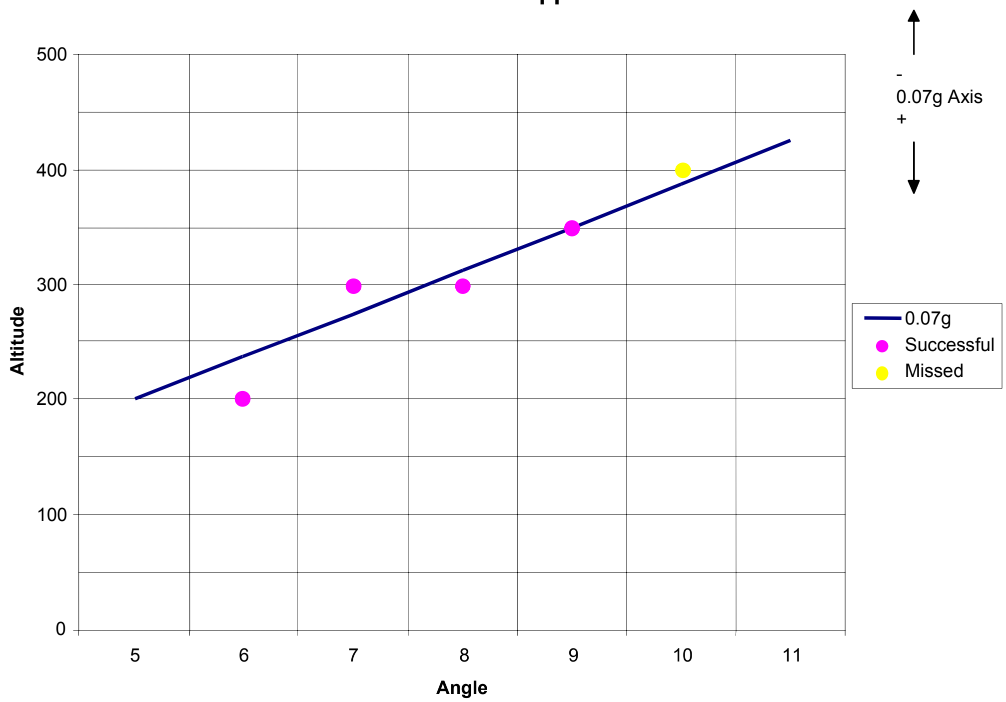
50 kts B-430 Approaches



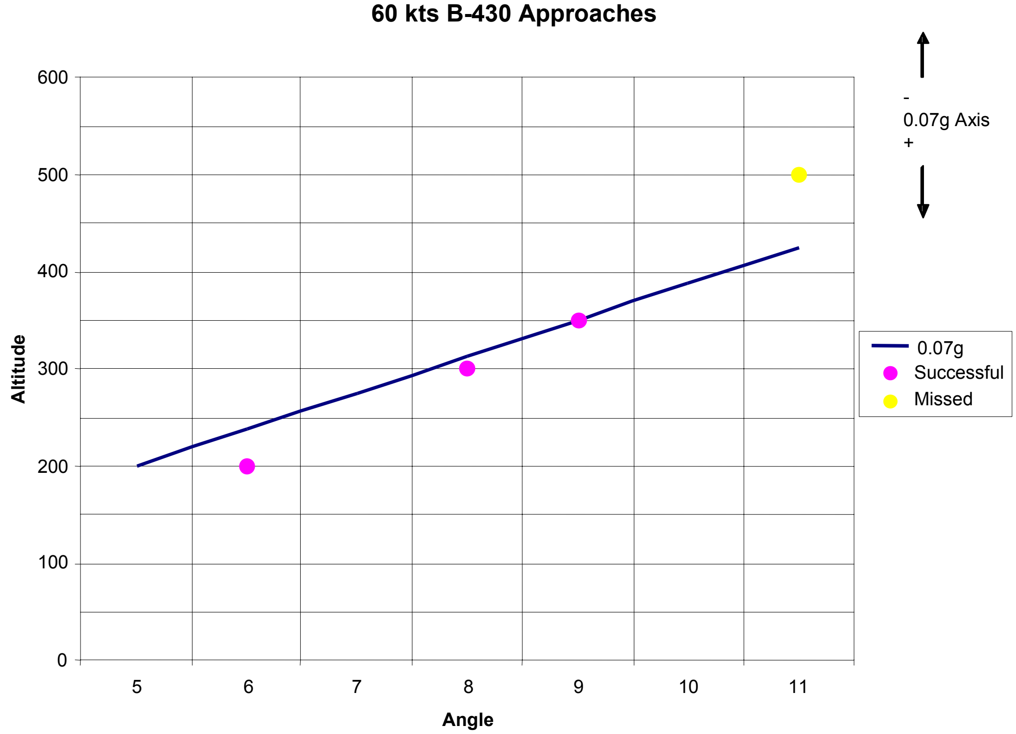

50 kts B-430 Approaches
400
300
200
100
0
Altitude
5
6
7
8
9
10
11
Angle
-
0.07g Axis
+
0.07g
Successful
Missed

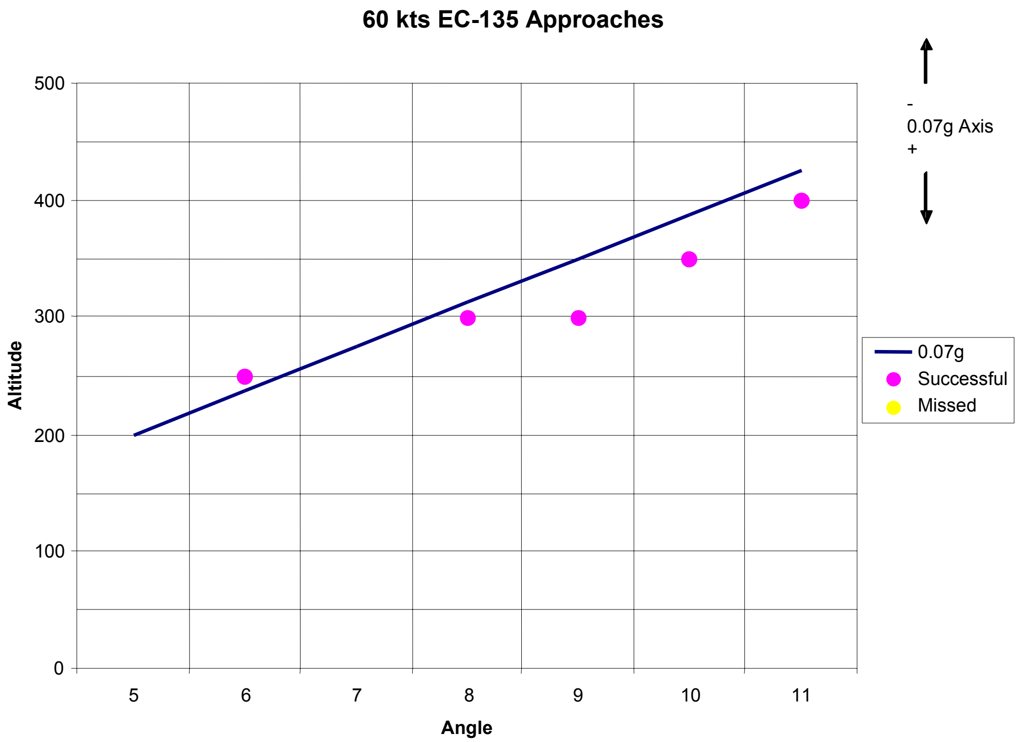

60 kts S-76 Approaches
500
400
300
200
100
0
Altitude
5
6
7
8
9
10
11
Angle
-
0.07g Axis
+
0.07g
Successful
Missed

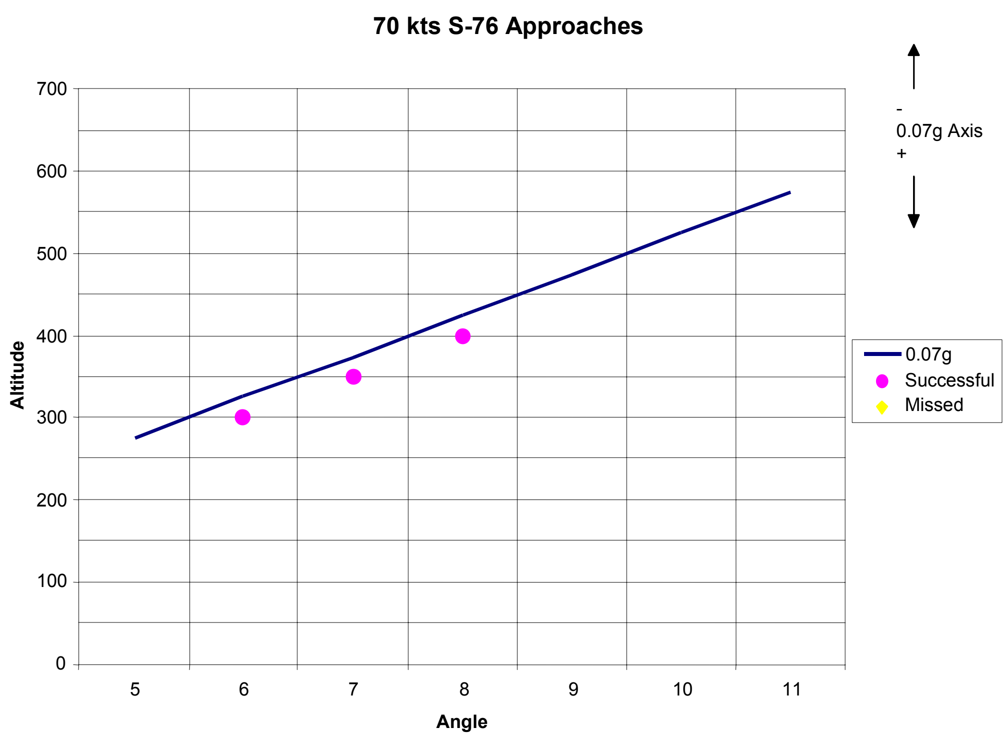
60 kts B-206L Approaches

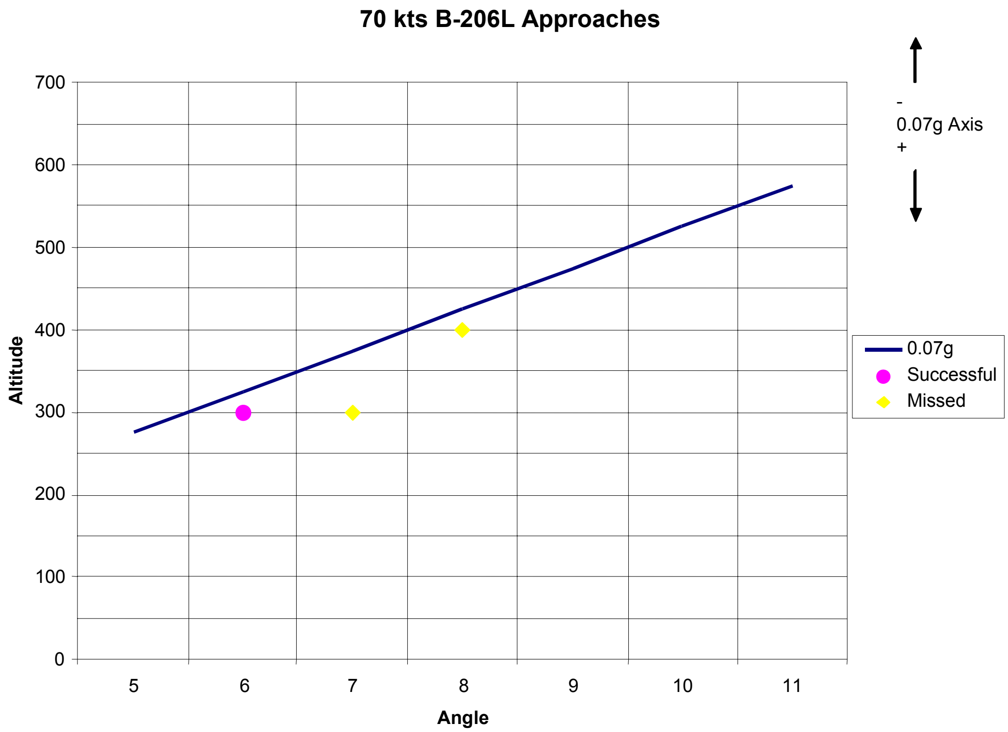


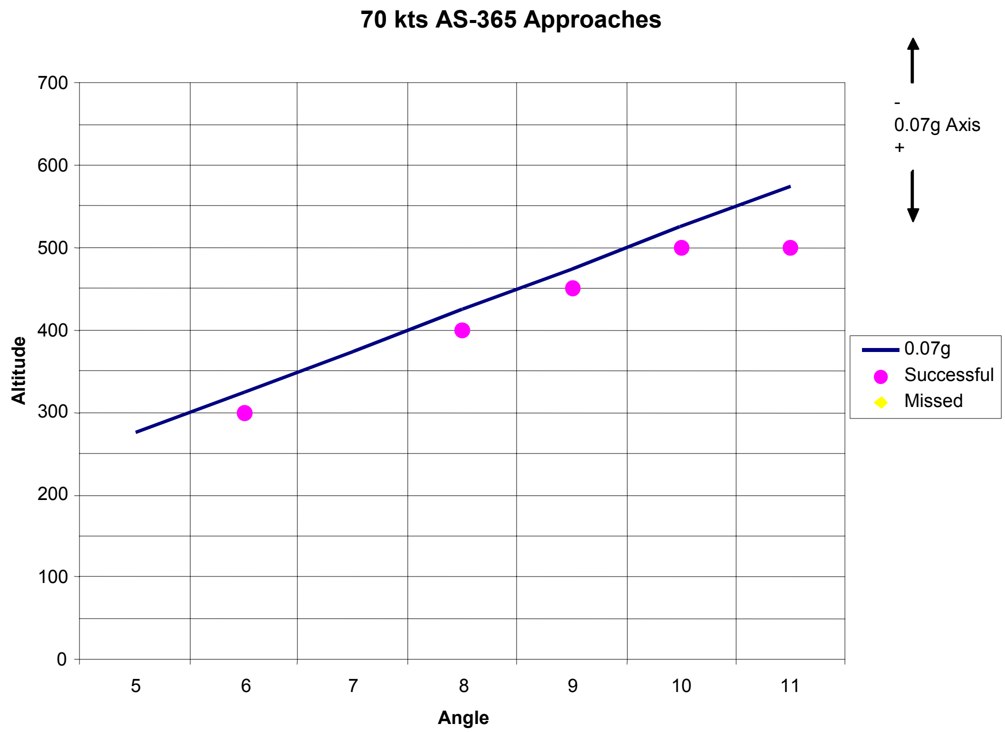
60 kts B-430 Approaches

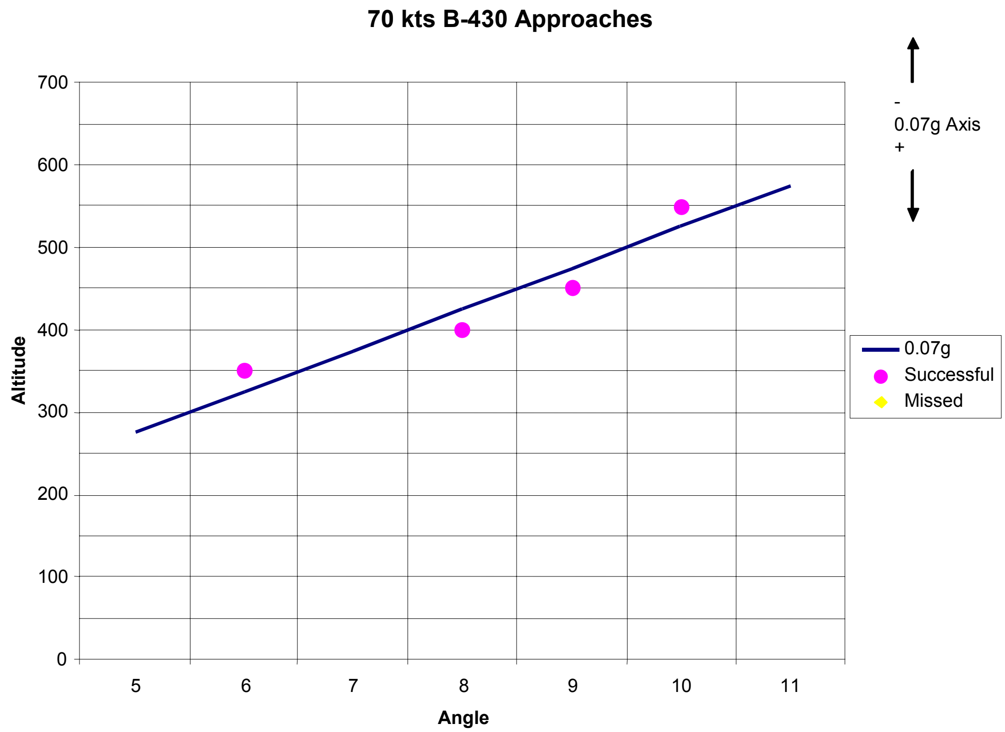


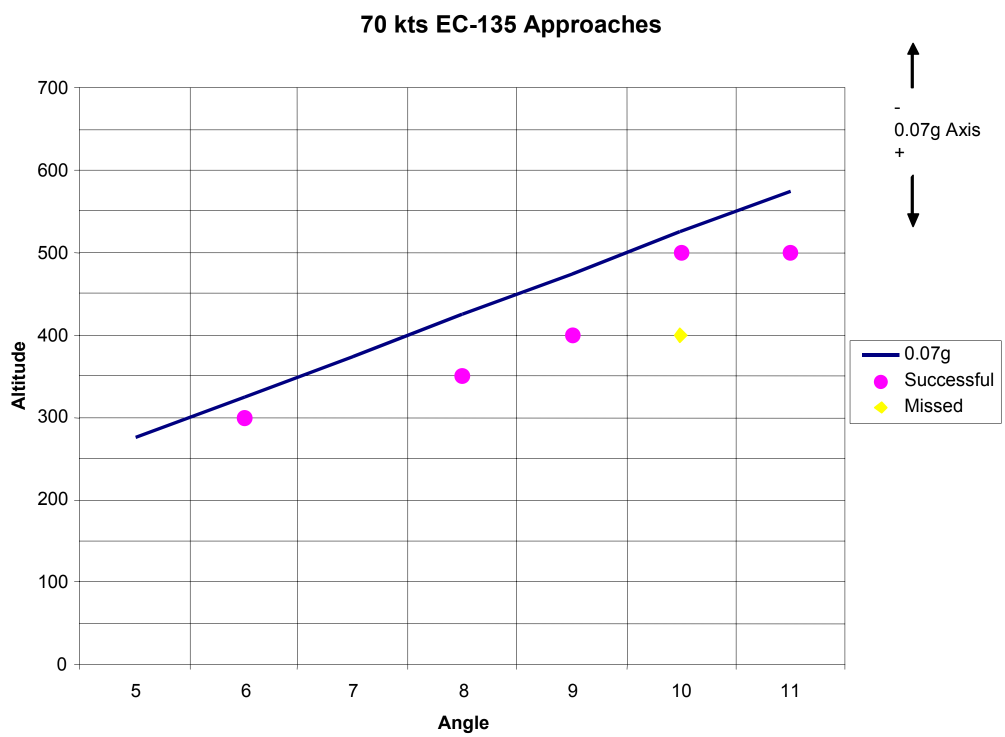

60 kts EC-135 Approaches
500
400
300
200
100
0
5
6
7
8
9
10
11
Angle
Altitude
-
0.07g Axis
+
0.07g
Successful
Missed


70 kts S-76 Approaches
700
600
500
400
300
200
100
0
5
6
7
8
9
10
11
Angle
Altitude
-
0.07g Axis
+
0.07g
Successful
Missed

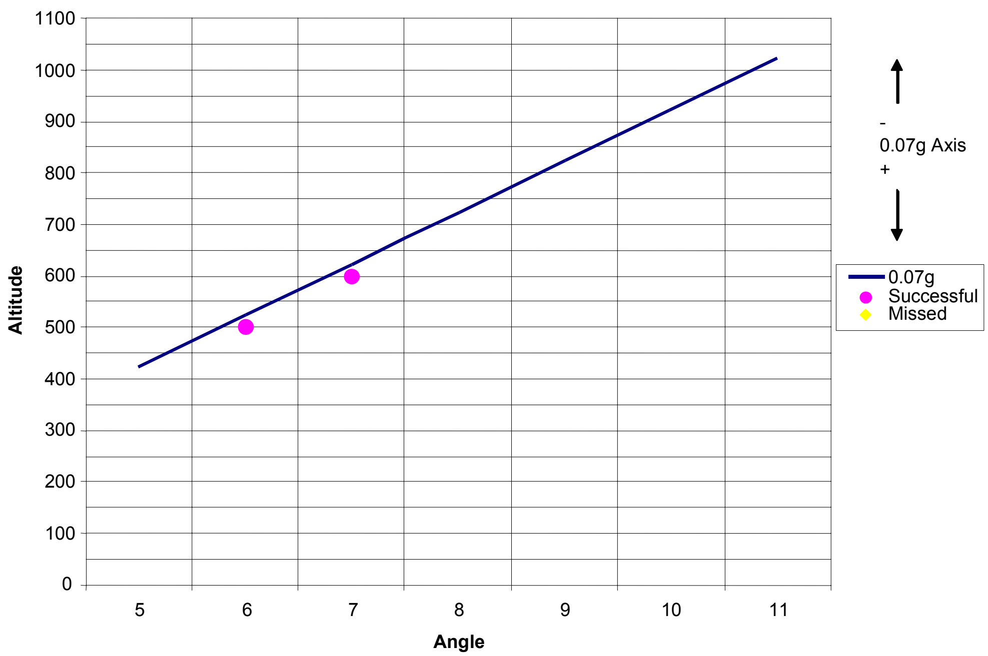

70 kts B-206L Approaches
Altitude
Angle
0.07g Axis
0.07g
Successful
Missed


70 kts AS-365 Approaches
Altitude
Angle
0.07g Axis
0.07g
Successful
Missed

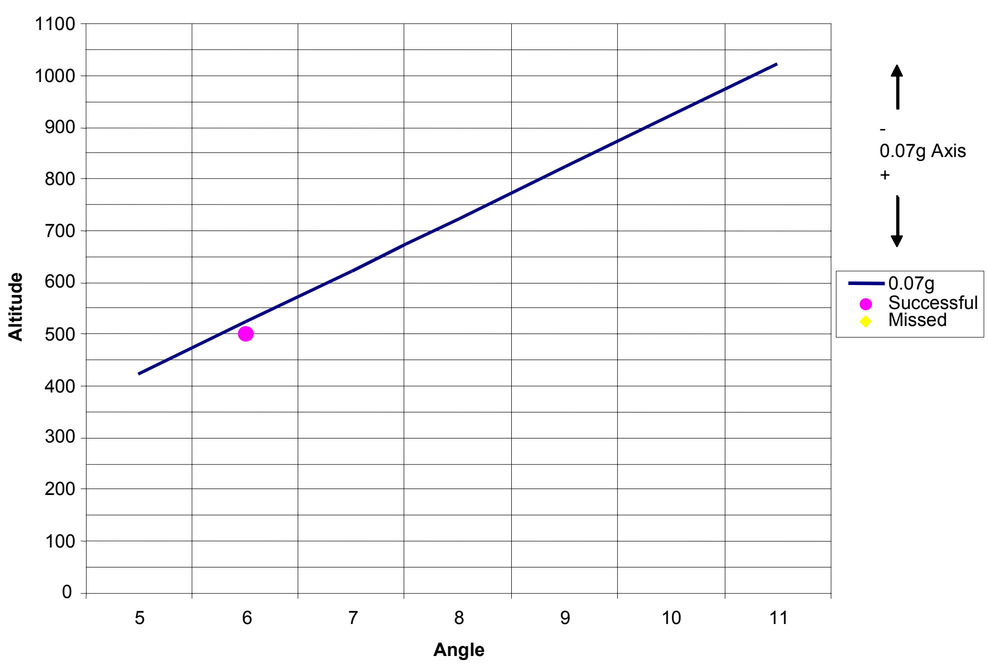

70 kts B-430 Approaches
700
600
500
400
300
200
100
0
Altitude
5
6
7
8
9
10
11
Angle
-
0.07g Axis
+
0.07g
Successful
Missed

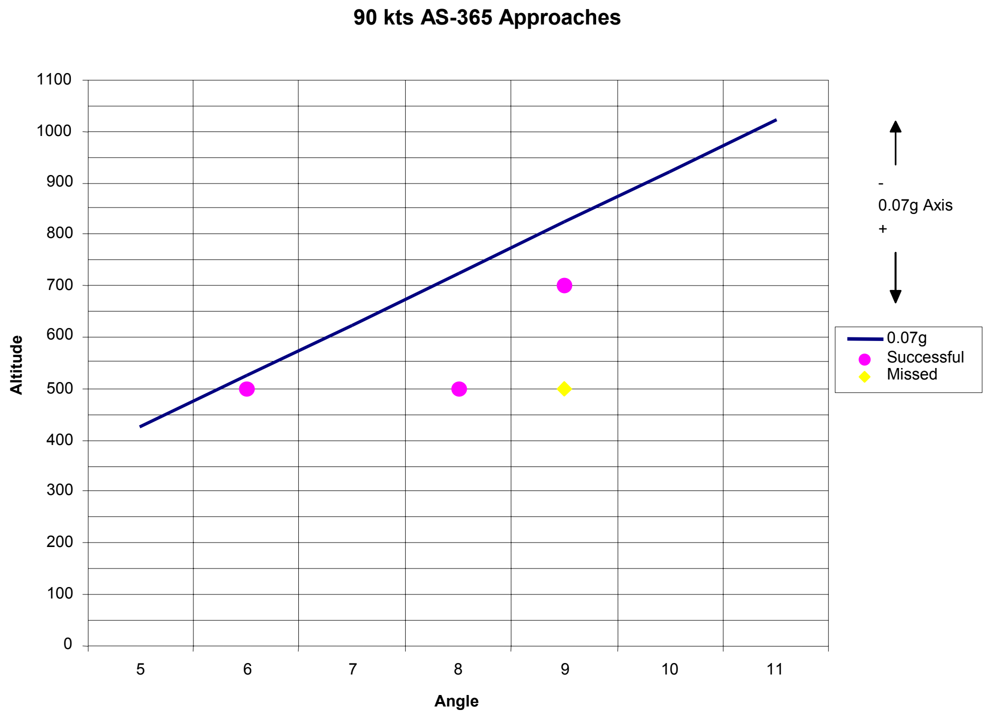

70 kts EC-135 Approaches
700
600
500
400
300
200
100
0
Altitude
5
6
7
8
9
10
11
Angle
-
0.07g Axis
+
0.07g
Successful
Missed

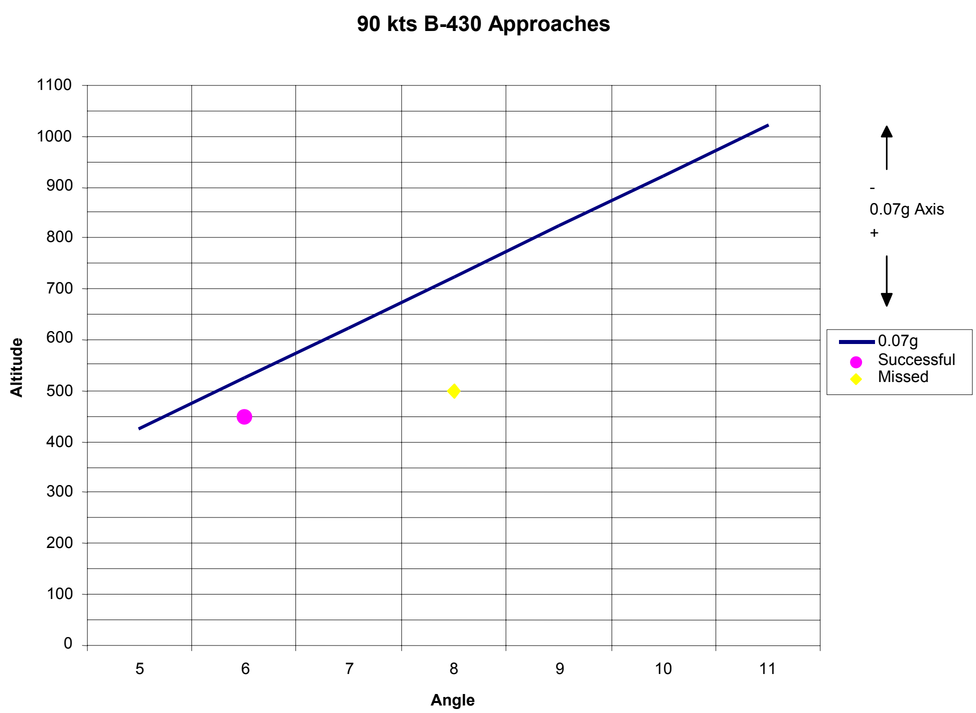
90 kts S-76 Approaches

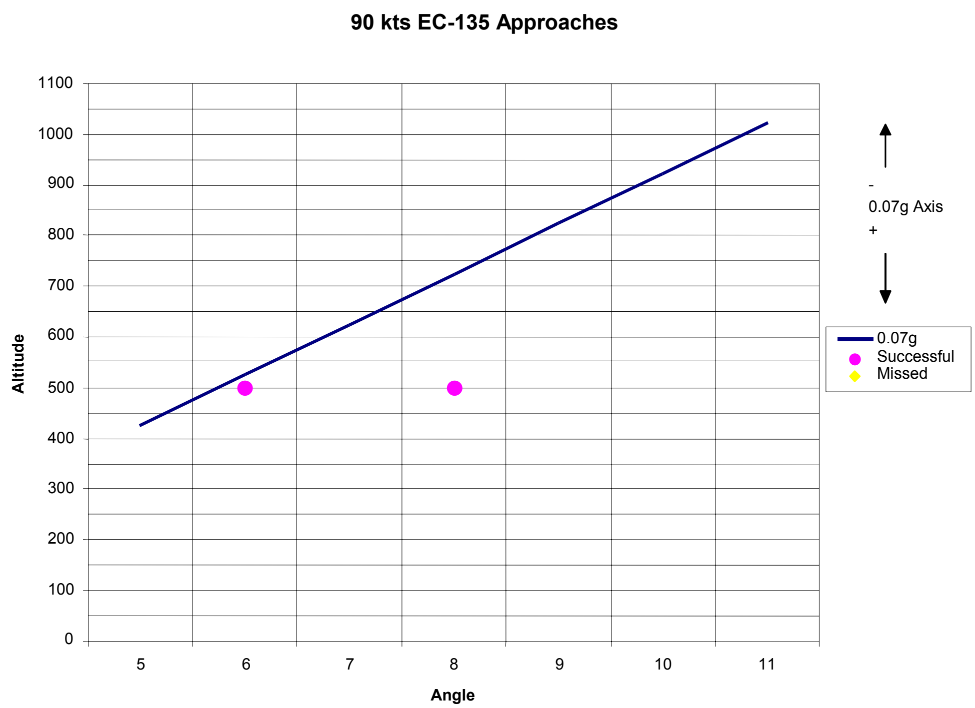


90 kts B-206L Approaches




90 kts AS-365 Approaches
Altitude
Angle
0.07g Axis
-
+
0.07g
Successful
Missed


90 kts B-430 Approaches
Altitude
Angle
0.07g Axis
-
+
0.07g
Successful
Missed


90 kts EC-135 Approaches
1100
1000
900
800
700
600
500
400
300
200
100
0
Altitude
5
6
7
8
9
10
11
Angle
-
0.07g Axis
+
0.07g
Successful
Missed