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Evaluation of Wide Area Augmentation System Helicopter Operations Including Localizer Performance With Vertical Guidance (LPV) to a Point in Space (PinS) Approach

Flight Systems Laboratory
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Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

EVALUATION OF WIDE AREA AUGMENTATION SYSTEM HELICOPTER OPERATIONS INCLUDING LOCALIZER PERFORMANCE WITH VERTICAL GUIDANCE (LPV) TO A POINT IN SPACE (PinS) APPROACH

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12. Abstract

Use of the Global Positioning System (GPS) Wide Area Augmentation System (WAAS) for air navigation has increased dramatically, especially by General Aviation and Helicopter Operators. Localizer Performance With Vertical Guidance (LPV) is a feature provided by the WAAS avionics, providing lateral and vertical guidance similar to an Instrument Landing System (ILS).

The FAA previously approved a Third Party Developer's criteria for developing HLPV approaches for use only by specific operators. The FAA has no HLPV criteria in its US Standard for Terminal Instrument Procedures (TERPS) for developing public HLPV procedures. This Data Collection Effort (DCE) was flown to acquire the data necessary for the FAA to develop that criteria.

The FAA partnered with Bell Helicopter Textron, Air Methods, Mercy Medical Center, the University of Oklahoma (OU), and Hickok and Associates to acquire the data. Bell integrated a Garmin 530W WAAS navigator into its new B429 Helicopter and obtained FAA certification for steep angle approaches. Mercy One trained and provided its pilots as subjects, OU built the airborne data collection system to FAA specifications, and Hickok and Associates developed the HLPV Point in Space (PinS) approach, the helipad departure, and the enroute segments per FAA test requirements.

The flight tests were designed and flown to support the Mercy Medical Center, Des Moines, IA. The results of the data analysis will be used by the FAA to develop HLPV criteria for inclusion in TERPS for public helicopter departures, enroute segments, HLPV approaches and WAAS guided missed approaches.

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Executive Summary

Use of the Global Positioning System (GPS) Wide Area Augmentation System (WAAS) for air navigation has increased dramatically, especially by General Aviation and Helicopter Operators. Localizer Performance With Vertical Guidance (LPV) is a feature provided by the WAAS avionics, providing lateral and vertical guidance similar to an Instrument Landing System (ILS). As of February 10, 2011, there were 2367 public LPV approaches to runways. There were only 27 Special Helicopter LPV (HLPV) approaches for helicopters developed not by the FAA, but by a Third Party Developer, whose criteria for developing the approaches was approved by the FAA. Special indicates they were built for, paid for and flown by a specific operator. Most are to hospitals for Emergency Medical Service (EMS) Operators.

The FAA has no HLPV criteria in its US Standard for Terminal Instrument Procedures (TERPS) for developing public HLPV procedures. This Data Collection Effort (DCE) was flown to acquire the data necessary for the FAA to develop that criteria.

The FAA partnered with Bell Helicopter Textron, Air Methods, Mercy Medical Center, the University of Oklahoma (OU), and Hickok and Associates to acquire the data. Bell integrated a Garmin 530W WAAS navigator into its new B429 Helicopter and obtained FAA certification for steep angle approaches. Mercy One trained and provided its pilots as subjects, OU built the airborne data collection system to FAA specifications, and Hickok and Associates developed the HLPV Point in Space (PinS) approach, the helipad departure, and the enroute segments per FAA test requirements.

The flight tests were designed and flown to support the Mercy Medical Center, Des Moines, IA. The test were successfully completed in October, 2010, and the data collected by the FAA for analysis. The analysis has been completed, is presented in this report, and will be used by the FAA to develop HLPV criteria for inclusion in TERPS for helicopter departures, enroute segments, HLPV approaches and WAAS guided missed approaches.

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1.0 Introduction

The need for development of Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Terminal Instrument Procedures (TERPS) criteria for Point in Space (PinS) helicopter approaches was identified because of the growing use of WAAS guidance in recent years. Approaches developed with these criteria are called Localizer Performance with Vertical Guidance (LPV). WAAS provides navigation accuracy equivalent to Instrument Landing System (ILS) localizer and glideslope performance standards.

It was determined that criteria should be developed in three phases to support such procedures. Phase I was completed in November 2008. It was flown with the Sikorsky S-76A helicopter at the FAA William J. Hughes Tech Center Airport in Atlantic City, New Jersey, using a 7.5° final approach Glide Path Angle (GPA). The primary objective of Phase I was to validate display scaling requirements, determine the flyability of the Point in Space (PinS) HLPV steep angle procedure, and to determine if pilot workload was acceptable when flying these procedures. No departure or enroute procedures were flown. Phase II was completed in October 2010, at the Mercy Hospital in Des Moines, Iowa, utilizing the Mercy Flight EMS Bell 429 helicopter with the coordination of Bell Helicopter, AFS-420, AFS-440, and AFS-450.

This report contains the Human Factors and flight track analysis for the Phase II testing in terms of evaluation of WAAS helicopter operations, WAAS criteria including HLPV approach and guided missed approach criteria, the helicopter, and pilot performance.

Flight tracks are shown for Departure, Approach, Missed Approach, Enroute, and Landing. Iso-probability contours were constructed with probability of being outside the contour (ellipse) of either 1.0×10^{-5} (Missed Approach) or 1.0×10^{-7} (Approach, Enroute, Departure). Throughout all phases of flight the iso-probability contours fit within TERPS containment laterally. There was a minimum penetration vertically in the Missed Approach Segment. This was due primarily to a wide dispersion in the pilot technique utilized to reach the enroute altitude. It is suggested that training for HLPV Missed Approaches emphasize the urgency in climbing to the altitude required by the missed approach procedure in an expeditious fashion.

2.0 Test Procedures

The test helicopter was the Bell 429 helicopter shown in Figure 1.

Figure 1: The Bell 429

The Bell 429 is a twin engine helicopter capable of speeds up to 155 knots, with a maximum takeoff gross weight of 7,000 lbs, and is certificated for steep angle approaches using a GPA of less than or equal to 9.0^{o}.

During the tests, the on board AFS-400 data collection system (A4FDCS), recorded Garmin GNS530W data at 5 Hz from the Bell 429 ARINC 429 data buss and analog aircraft data. The A4FDCS includes a differentially corrected Global Positioning System (GPS) system known as Time-Space-Position Information (TSPI) which was used to provide aircraft truth. It is comprised of an Ashtech Z-Extreme airborne receiver which works in conjunction with an Ashtech Z-Extreme master receiver on the ground, located at a highly accurate surveyed position. Data provided from the data collection equipment is post mission processed to combine aircraft truth data with aircraft parameters.

A PinS Approach is an instrument approach procedure developed for heliports that do not meet the heliport design standards, but meet the standards for a non-instrument heliport, or to a landing area. The approach delivers the helicopter to a missed approach point (MAP). These procedures have either a visual flight rules (VFR) or visual segment between the MAP and the heliport or landing area. The procedure will specify a course and distance from the MAP to the heliport or landing area, and include a note to “Proceed VFR” or “Proceed Visually” from the MAP or to conduct the specified missed approach. When at, or prior to the MAP, the pilot must decide to remain in the instrument flight rule (IFR) structure and execute a missed approach or to transition to visual flight rules (VFR) and proceed visually.

Twenty sorties were flown including departure, enroute, approach, missed approach and visual segments to landing from October 18 through October 25, 2010, using a 5.8° final approach GPA. During these flights, 60 departures, 118 HLPV PinS approaches, 58 LNAV guided missed approaches, 58 enroute segments and 59 Landings were performed.

All of these helicopter operations were hand flown using raw data, with the auto-pilot disengaged and without flight director guidance. Figures 2 and 3 show the charts for the

approach and departure.

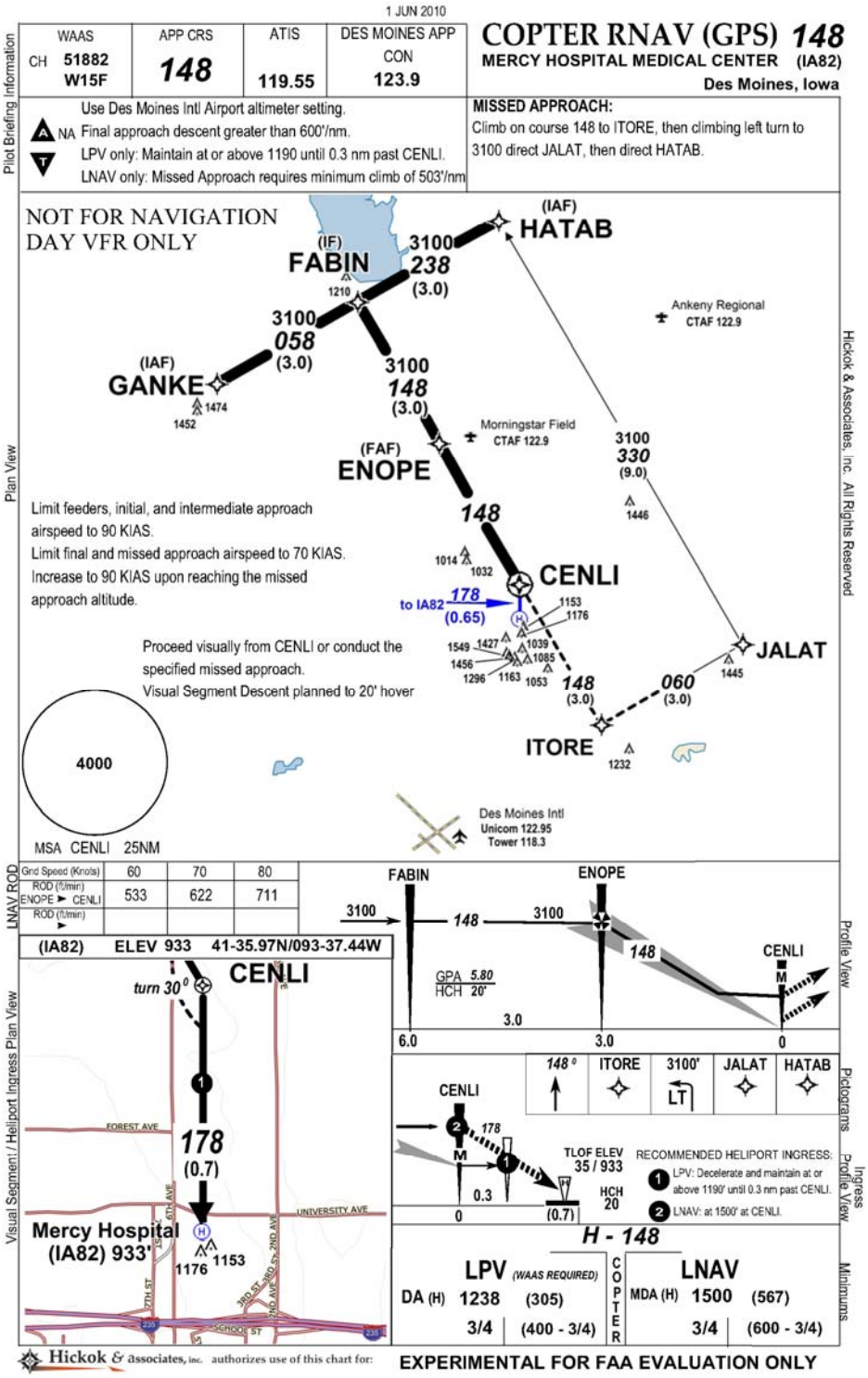

Figure 2: Copter LPV 5.8° GPA PinS Approach Procedure with "Proceed Visually" Visual Segment

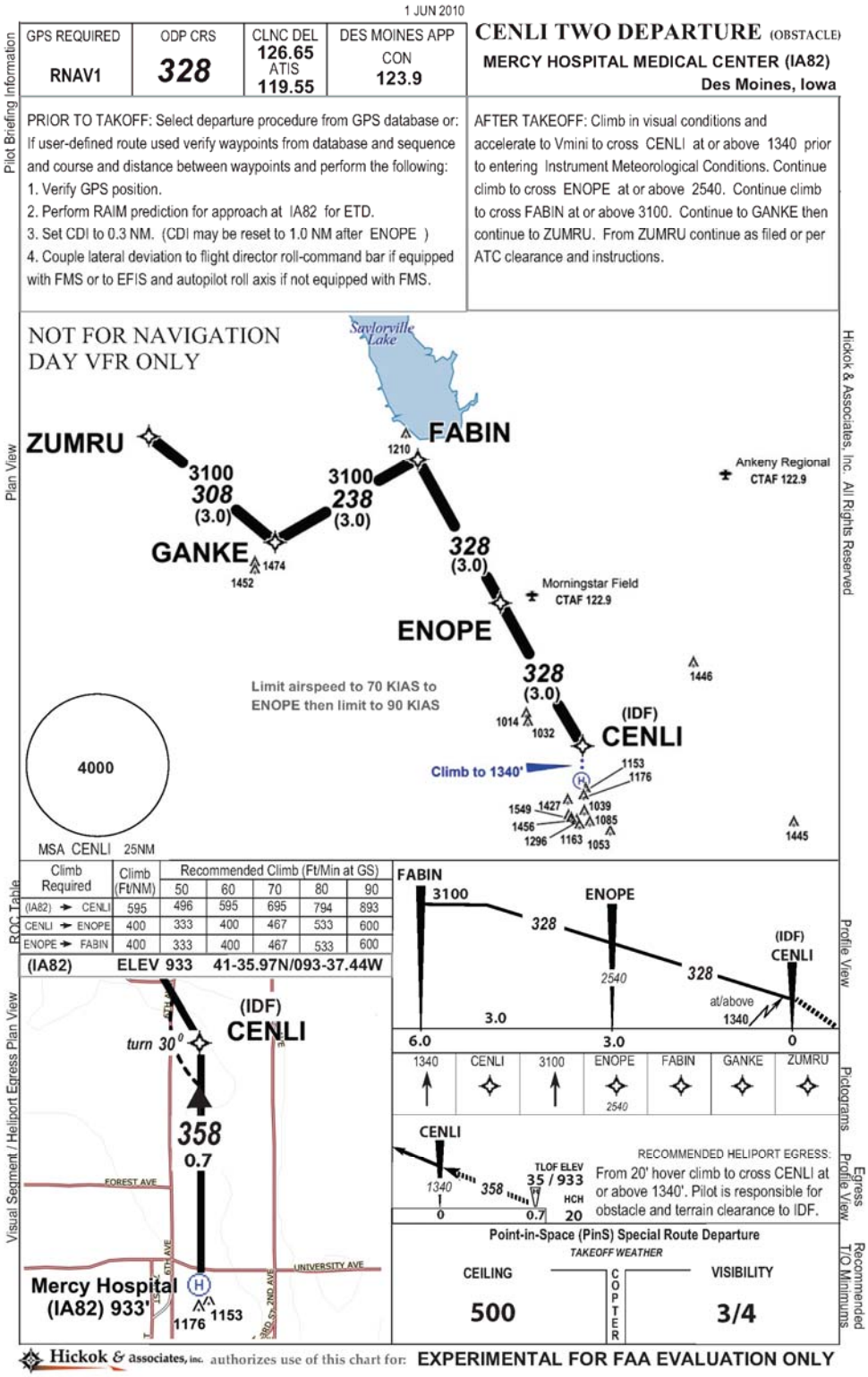

Figure 3: Copter Departure Procedure

3.0 Compilation/Reduction of Data

After completion of the data collection effort lead by AFS-440, data was delivered to AFS-450 via FTP site and solid-state media storage device. The 8 days of data collection yielded a total of 9 GB of data in the form of 65 comma separated value (csv) files, 20 binary files, and 8 event marker files. The binary files were converted to usable text format by AFS-450. Figure 4 shows a portion of the flight observer log provided by AFS-450 to AFS-440. The observer logs and event marker data were pivotal to completion of analysis.

HLPV2 FLIGHT TEST FLIGHT OPERATIONS OBSERVER LOG SORTIE GOLF

Date/Time: _____ WX_____Baro:_____Wind (D/S/G): _____ Subject Pilot #:_____

Run	Scenario	Event Marker @	☑	Comments: If run is not representative of test or normal operations, why. Also any external items influencing run, e.g., ATC instructions, Traffic, Change in Wind, Baro, etc.
1	DEPARTURE	Subject Control Safety Control	☐ ☐	
2	APPROACH from GANKE	Subject Control Cue: Heliport **Not** In Sight	☐ ☐	
3	MISS	Announce Miss Safety Control	☐ ☐	
4	ENROUTE	Subject Control	☐	
5	APPROACH from HATAB	Cue: Heliport In Sight	☐	
6	LAND	Announce Land Safety Control	☐ ☐	

Figure 4: Flight Observer Log

The data was collected and compiled to perform graphical and statistical analysis. Statistics of flight performance are collected via slices (windows or bins) orthogonal (perpendicular to the tangent) to the theoretical track. In lateral (planform) dimension, the data for the slices are a specific distance (lateral and/or longitudinal) from the Missed Approach Waypoint (MAP) for any straight portion of a flight track, For the turn portion of analysis, the orthogonal data is combined in increments of along track distance. As there is no precise theoretical track for a flyby waypoint, the turn analysis slices, were calculated by dividing the 90° arc into slices, at angular increments. That is, a theoretical RF leg (center and radius) was approximated to best-fit the data. The mean and standard deviation statistics are not affected by this center and radius chosen for slice analysis. The slices in the vertical (profile) dimension were set orthogonal to a level flight path. This approach yields a conservative result.

Iso-probability contours are based on the data roughly fitting a normal distribution. This is also a conservative assumption. The iso-probability contours describing the 95%, 99.999% and/or 99.99999% containment are calculated using the data in both the lateral and vertical dimensions. The iso-probability contours will be referred to herein as “contours.” Figure 5 shows an example of the slices orthogonal to the course in planform view. Figure 6 shows an example of the slices

orthogonal to a level flight in profile view.

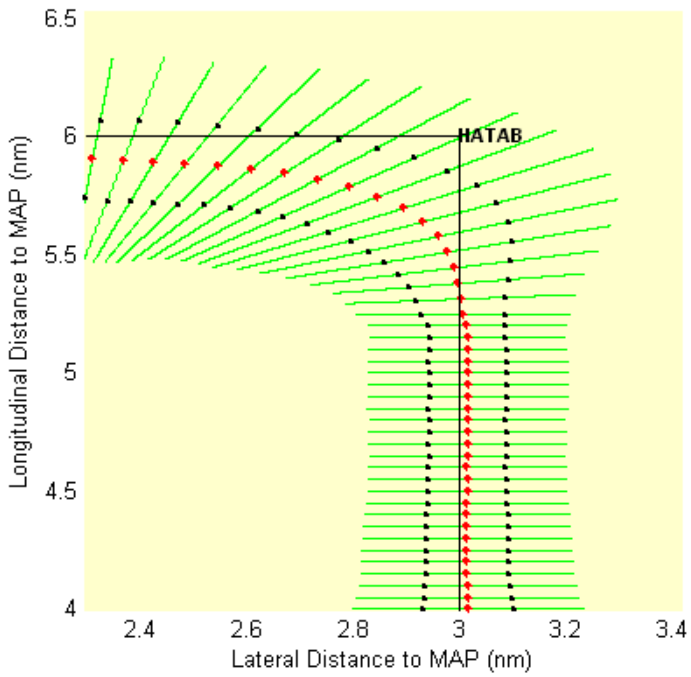

Figure 5: Example of Slices Planform View

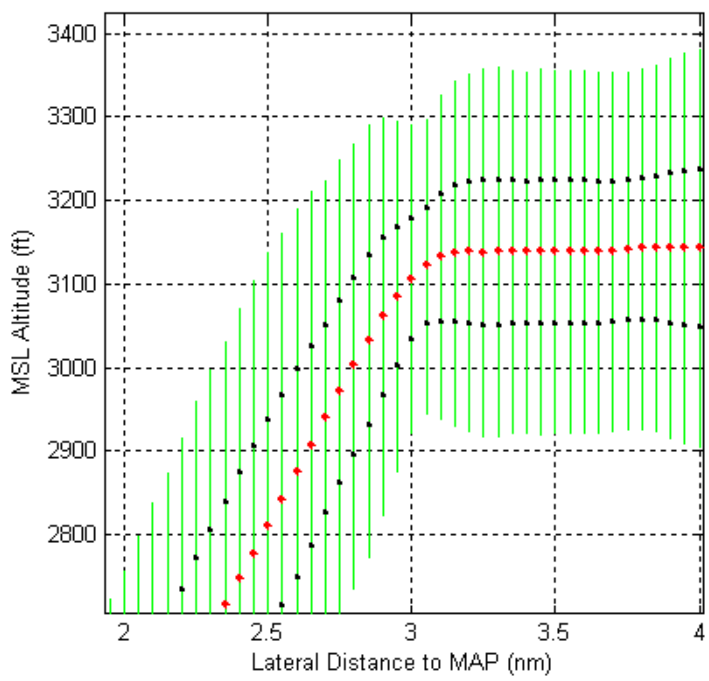

Figure 6: Example of Slices Profile View

4.0 Evaluation of Departure

The departure segment contained two straight segments, a 90° turn, and a 70° turn. There were no issues in the departure. Contours were within the protected areas and surfaces in the lateral and vertical dimensions. Figure 7 shows the planform view of the entire departure to scale. Figure 8 shows the planform view of the departure tracks from CENLI to the 90° turn at GANKE by subject pilot. All figures which show the tracks flown are color coded by subject pilot (1 blue, 2 green, 3 red, 4 cyan, 5 magenta). Figure 9 shows the profile view from FABIN to GANKE including the 70° turn at GANKE by subject pilot.

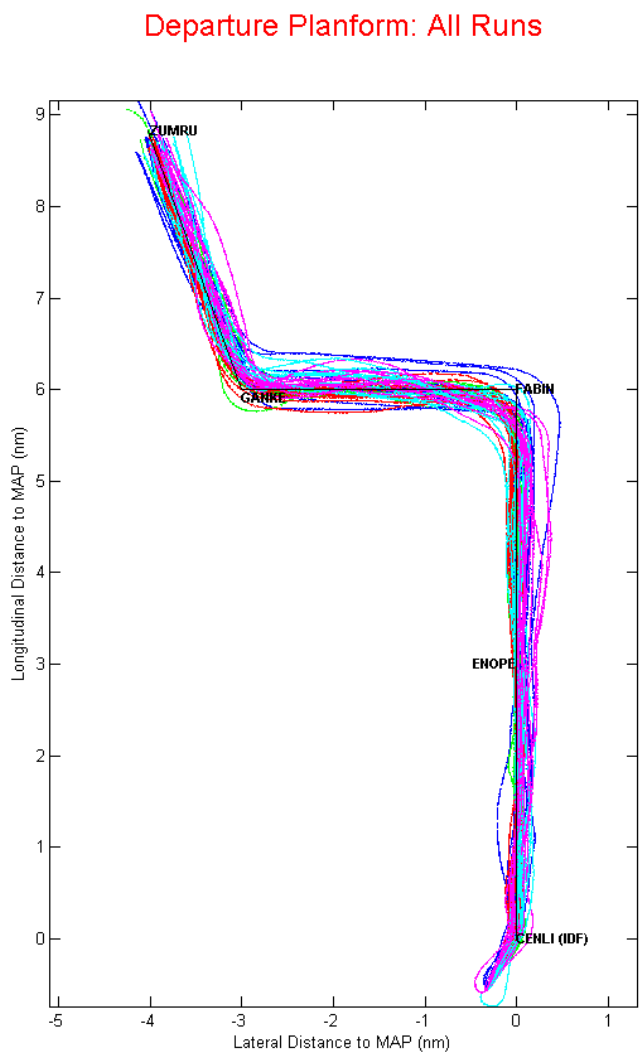

Figure 7: Departure, Planform View

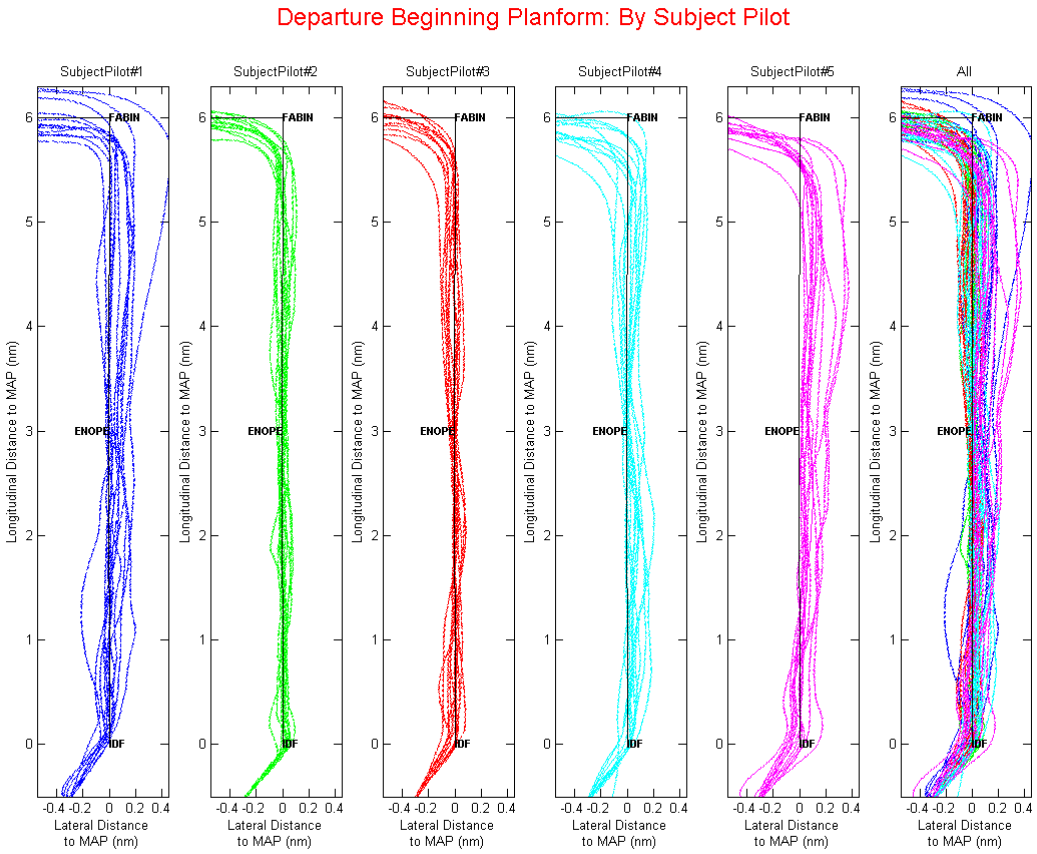

Figure 8: Beginning Departure by Subject Pilot, Planform View

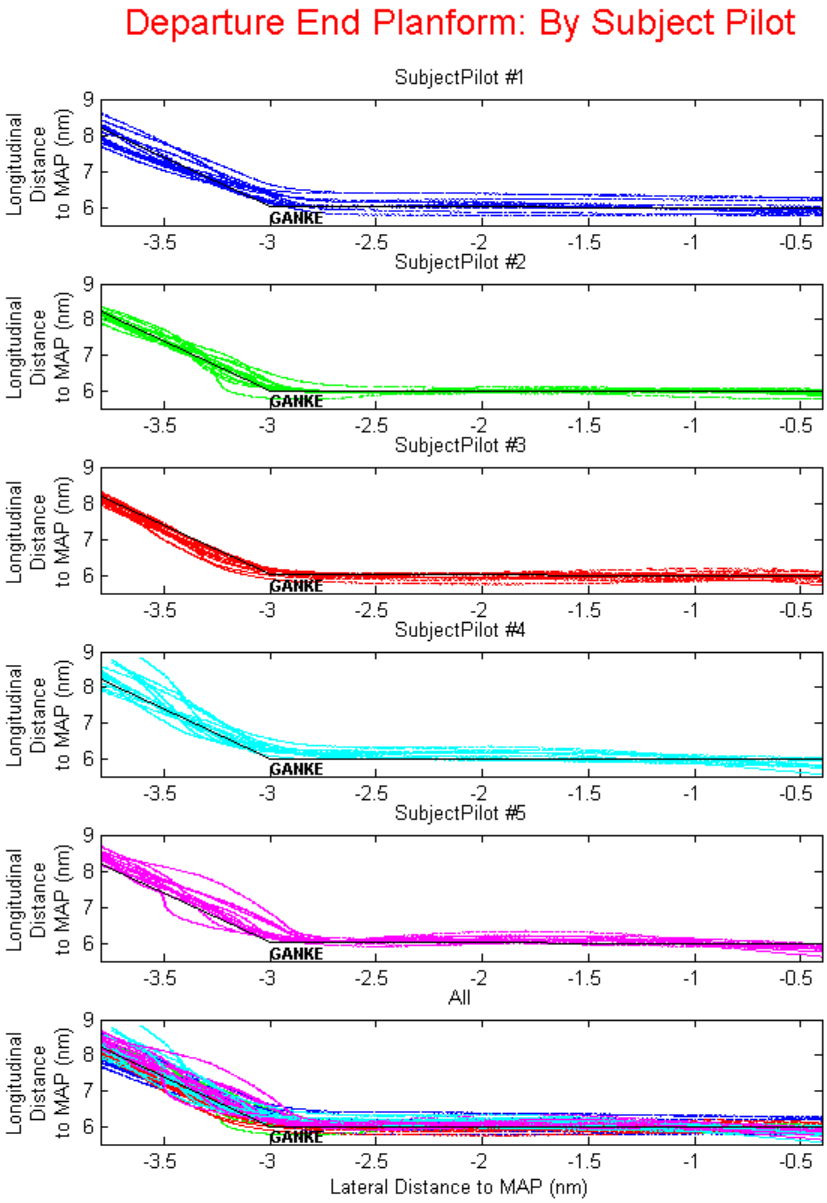

Figure 9: Departure End by Subject Pilot, Planform View

Figure 10 shows the contours are well within the lateral TERPS primary and secondary surfaces throughout the departure.

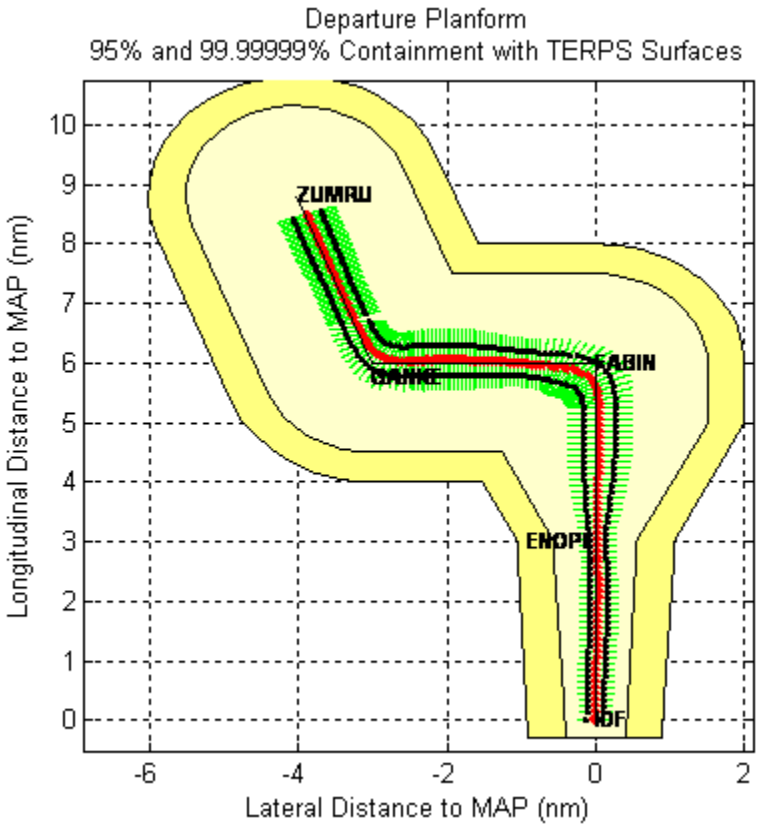

Figure 10: Contours of Departure within the Lateral TERPS Primary and Secondary Surfaces, Planform View

There was no vertical guidance in the departure. Departure instructions were as follows: "AFTER TAKEOFF: Climb in visual conditions and accelerate to Vmini to cross CENLI at or above 1340 prior to entering Instrument Meteorological Conditions. Continue climb to cross ENOPE at or above 2540. Continue climb to cross FABIN at or above 3100. Continue to GANKE then continue to ZUMRU. From ZUMRU continue as filed or per ATC (Air Traffic Control) clearance and instructions."

Figure 11 shows the variability in the vertical profile by run and subject pilot in addition to the completion of altitudes described above.

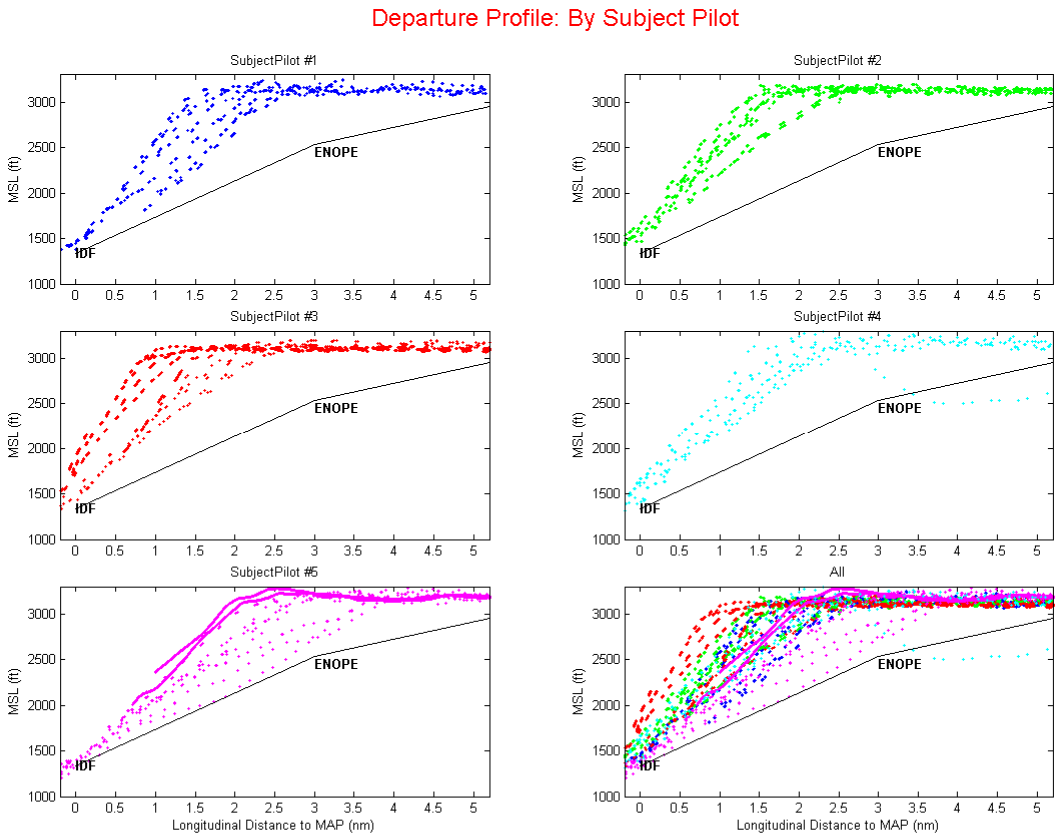

Figure 11: Departure by Subject Pilot, Profile View

Figure 12 shows the profile view of the vertical contours in the departure segment. The Obstacle Clearance Surface (OCS) is shown in gray. If a track contains a turn, a traditional profile view (lateral independent axis and height dependent axis) is misleading and does not communicate information well, i.e. during the turn; height continues to change independently of longitudinal distance from the MAP and would be depicted as a vertical line over a very short along track distance during the turn. Figure 12 shows the vertical contours with Route Distance to MAP as the independent axis. This distance is calculated based on the straight segments and turn track distance described in Section 3. Note to reader: the absolute distance from the MAP to FABIN is 6 nm. However, the Route Distance passing FABIN orthogonally is less than 6 miles due to the turn in the route.

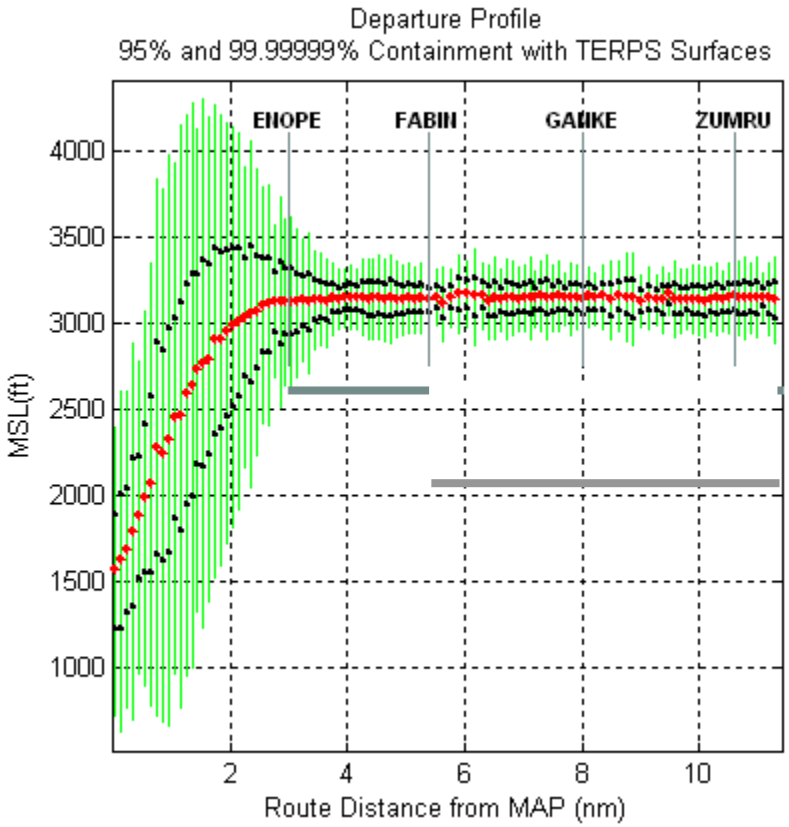

Figure 12: Contours of Departure within Obstacle Clearance Surface, Planform View

5.0 Evaluation of Approach

Figure 13 shows the planform view of all other tracks to scale: Approach from HATAB, the combination of the approach from GANKE, laid on top of the approach from HATAB for calculation and ease of viewing, Missed Approach, Enroute, and Turns at ITORE, JALAT, HATAB/GANKE, and FABIN.

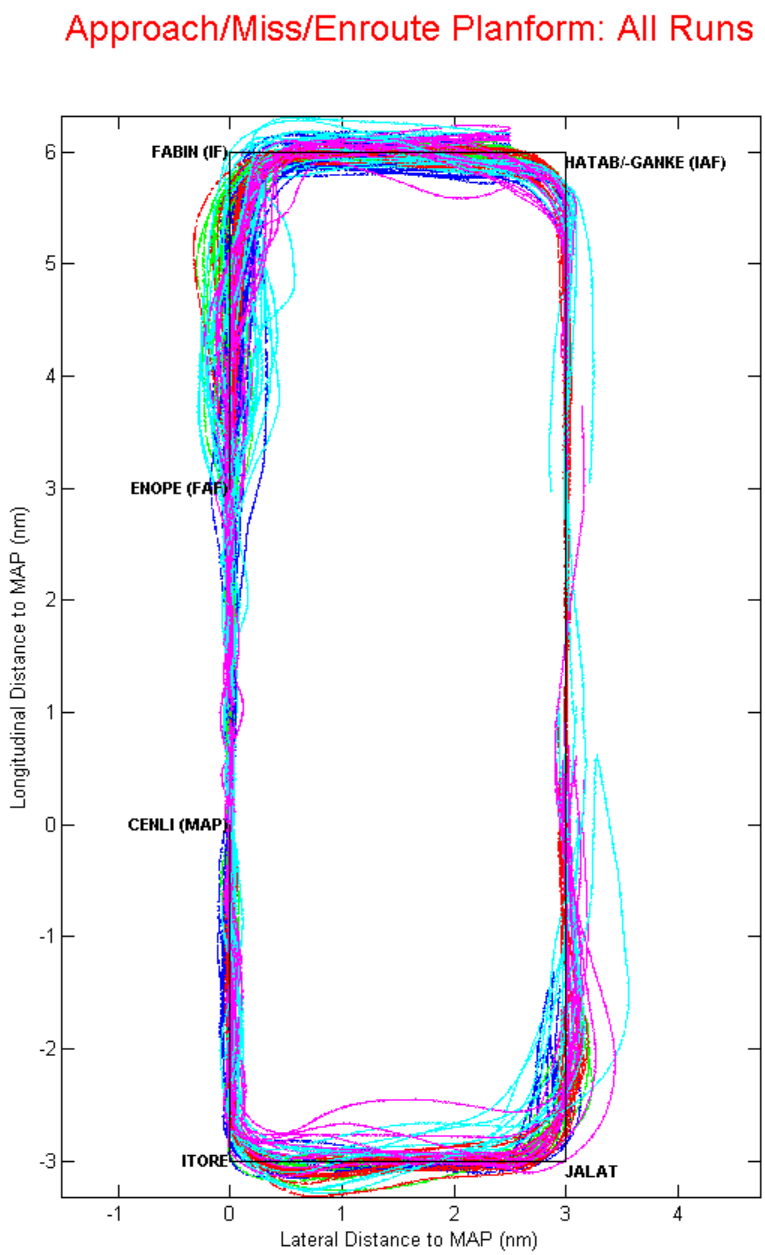

Figure 13: Approach, Missed Approach, Turns and Enroute, Planform View

Figure 14 shows the planform view of approach from the intermediate fix (IF), FABIN to the MAP, CENLI, by subject pilot. The contours describing containment within the approach were well within the TERPS primary and secondary surfaces. This, Figure shows the variability in lateral performance by subject pilot Figure 15 shows the profile view by subject pilot of the

approach from the IF to the MAP.

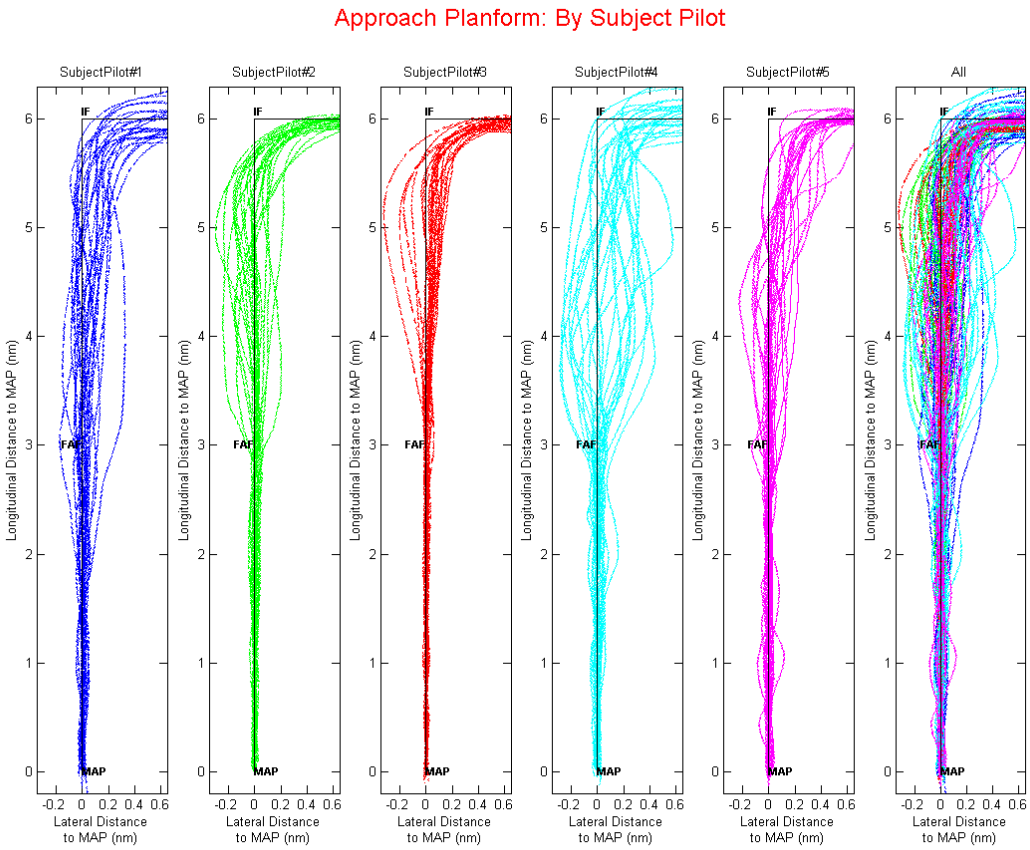

Figure 14: Approach by Subject Pilot, Planform View

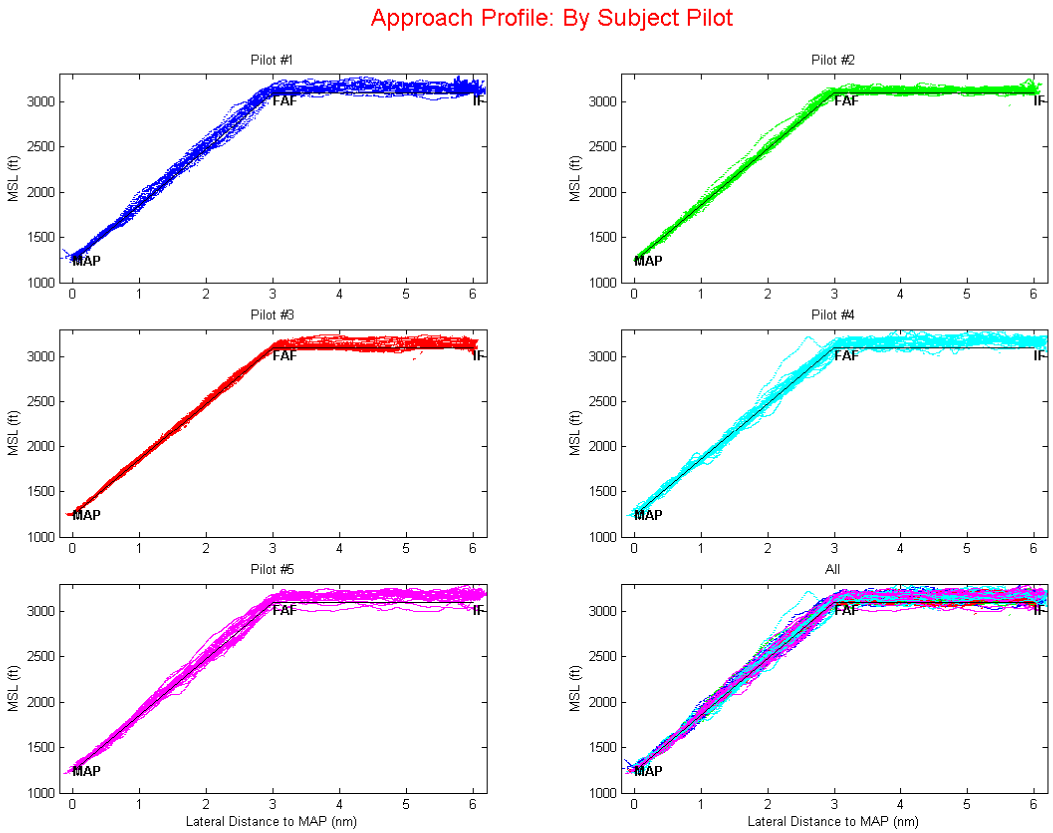

Figure 15: Approach by Subject Pilot, Profile View

Figure 16 shows the planform view of contours are within TERPS primary and secondary surfaces. Figure 17 shows a 3D view of the contours and TERPS surface near the MAP. Figure 18 shows the profile view of the contours and the Obstacle Clearance Surface by Route Distance from MAP.

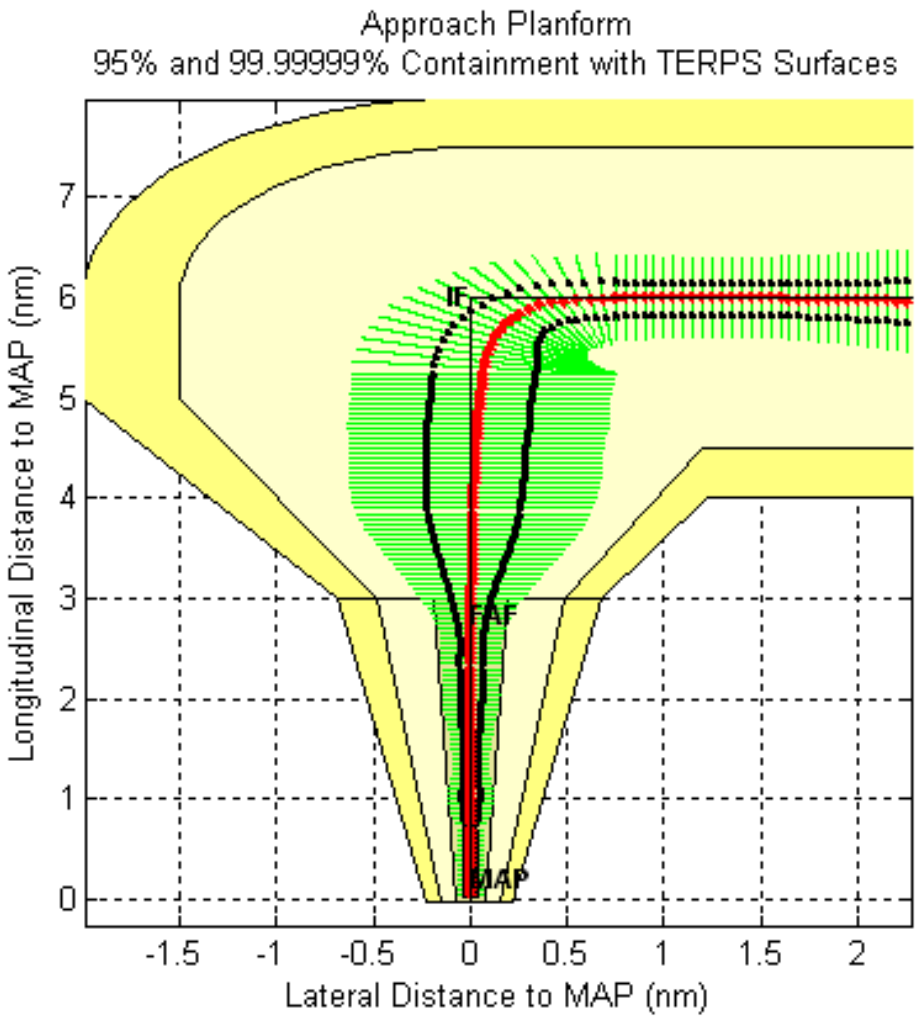

Figure 16: Contours of Approach within TERPS Primary and Secondary Surfaces, Planform View

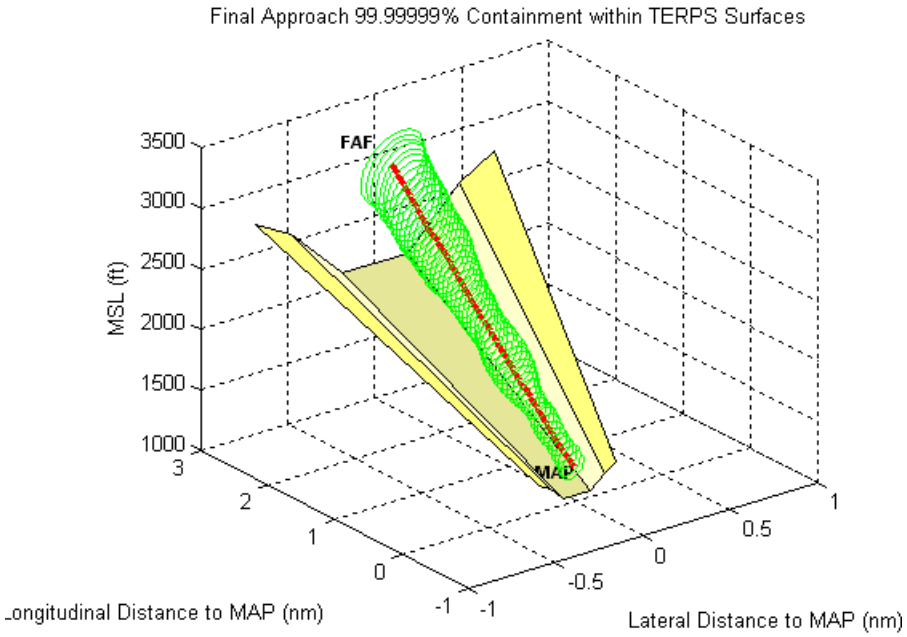

Figure 17: Contours of Approach within TERPS Protected Surfaces, 3D View

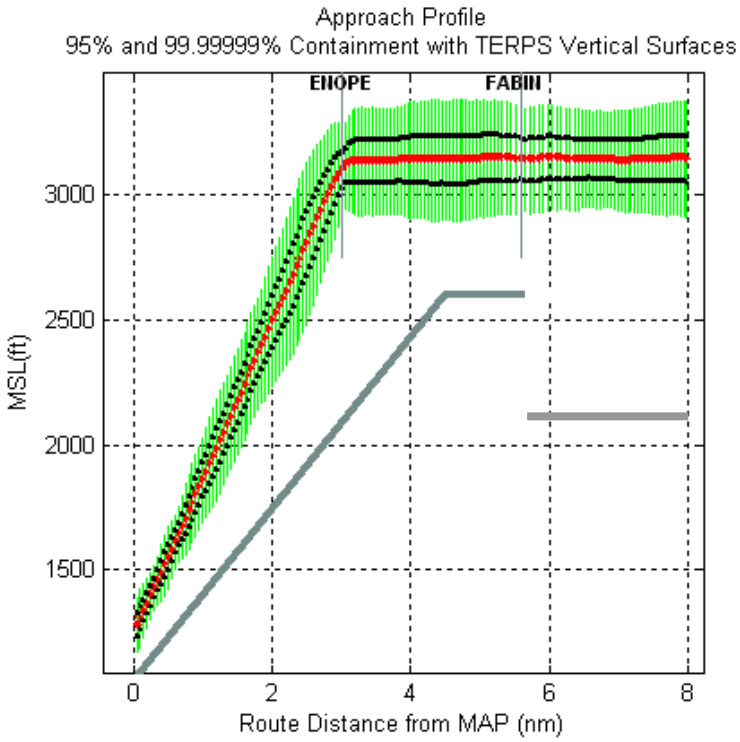

Figure 18: Contours of Approach within Obstacle Clearance Surface, Planform View

6.0 Evaluation of Turns

Figures 19 and 20 show the profile and planform view of the turns at ITORE and JALAT by subject pilot respectively.

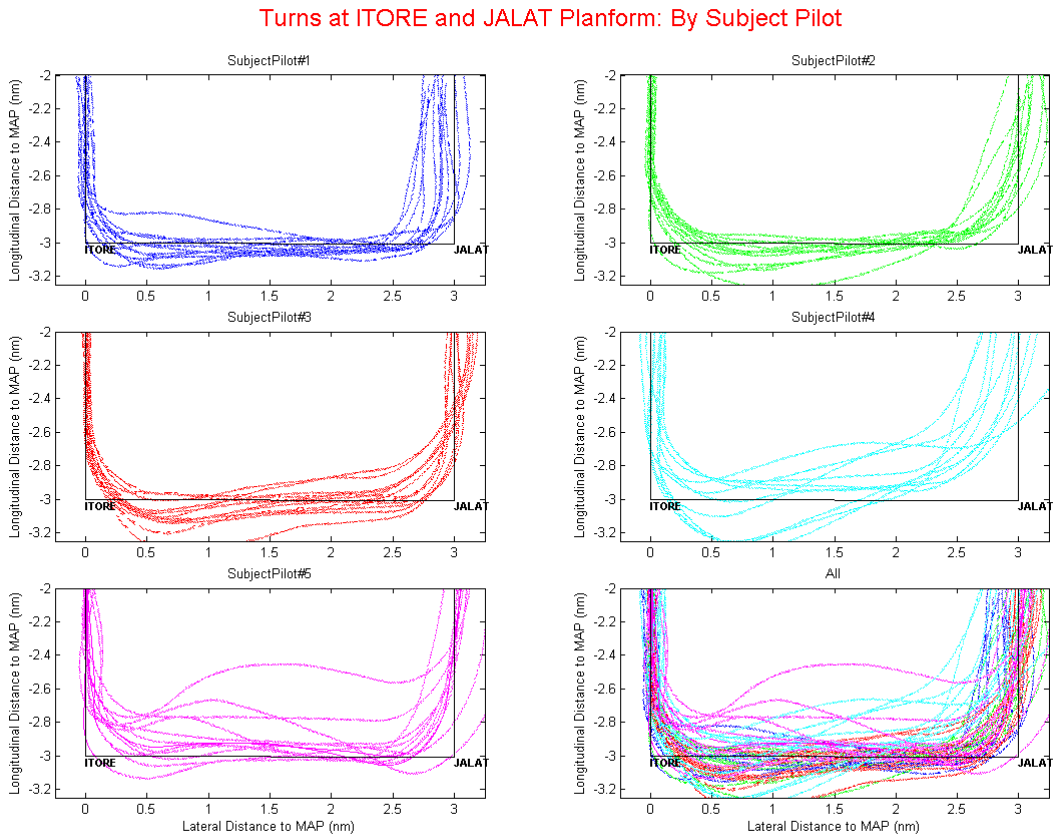

Figure 19: Turns at ITORE and JALAT by Subject Pilot, Planform View

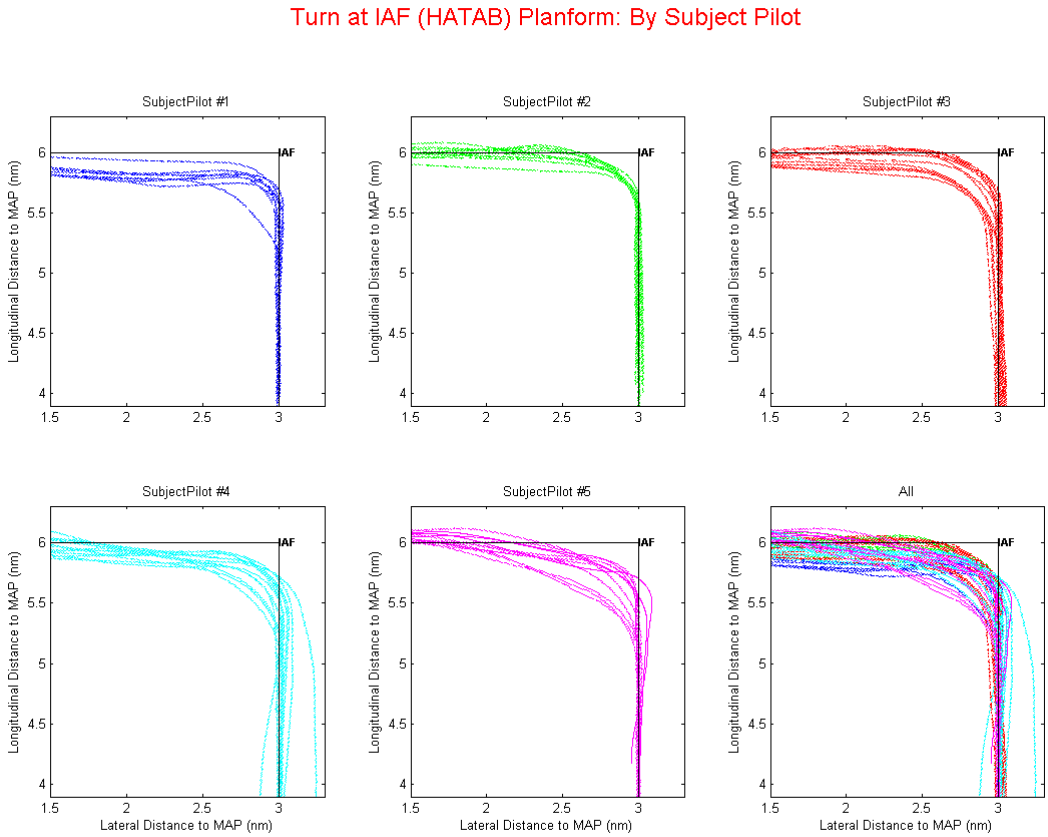

Figure 20: Turns at ITORE and JALAT by Subject Pilot, Profile View

7.0 Evaluation of Enroute

Figures 21 and 22 show the profile and planform view of the Enroute segment between JALAT and HATAB by subject pilot respectively. The data for calculation of containment areas and graphical representation of tracks includes only track data where subject pilot was flying the aircraft. So that the subject pilot could complete a Human Factors questionnaire, the Safety pilot took controls of the aircraft between JALAT and HATAB. Observer logs documented transfer of control, enabling statistics to be completed on only subject pilot performance, hand flown with raw data. The amount of time that the Safety pilot had the controls was different for each Enroute run. This is why the reader will see what appears to be "missing data." Additionally, this is why the contours along the Enroute segment change markedly from one window to another. Additionally, Figure 22 shows that during the enroute segment the tracks are frequently above 3100'. This is most likely due to the pitot static system on board the single airframe during testing. Once the aircraft acquired the glideslope, there were no issues flying the glide path to DA.

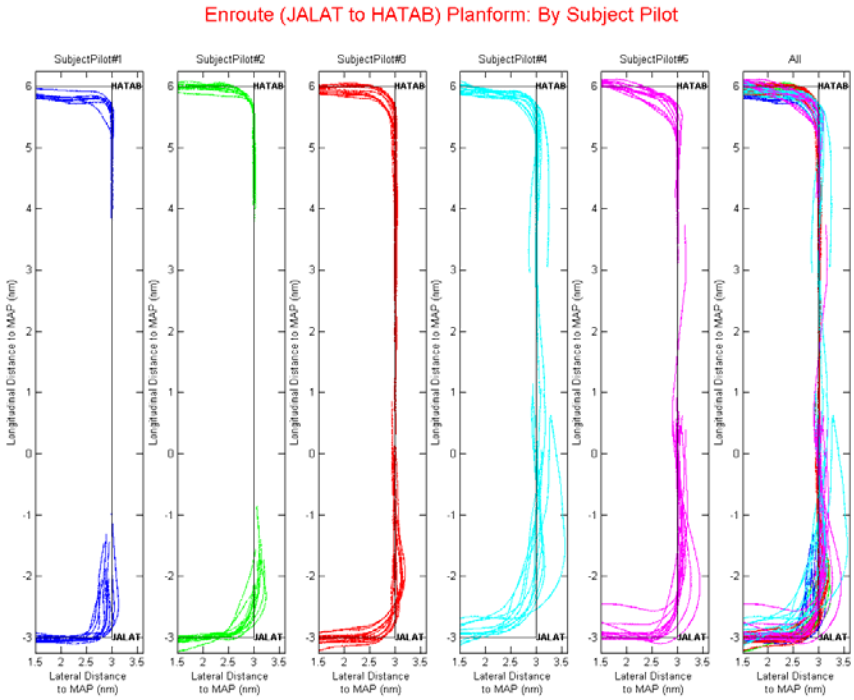

Figure 21: Enroute Segment by Subject Pilot, Planform View

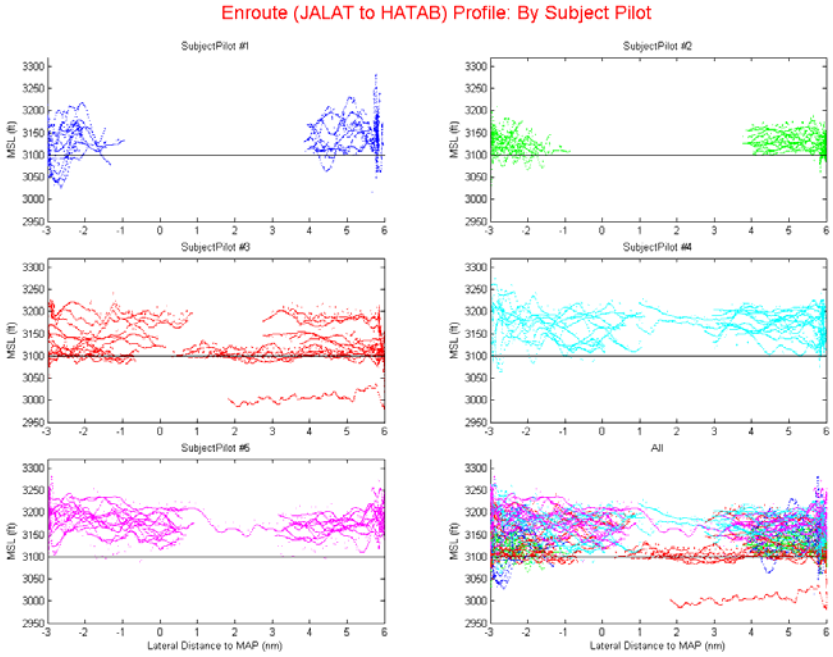

Figure 22: Enroute Segment by Subject Pilot, Profile View

8.0 Evaluation of Missed Approach

Figure 23 shows the planform view of the Missed Approach tracks by subject pilot. Figure 24 shows the profile view of the Missed Approach tracks by subject pilot. Figure 25 shows the profile view of all runs.

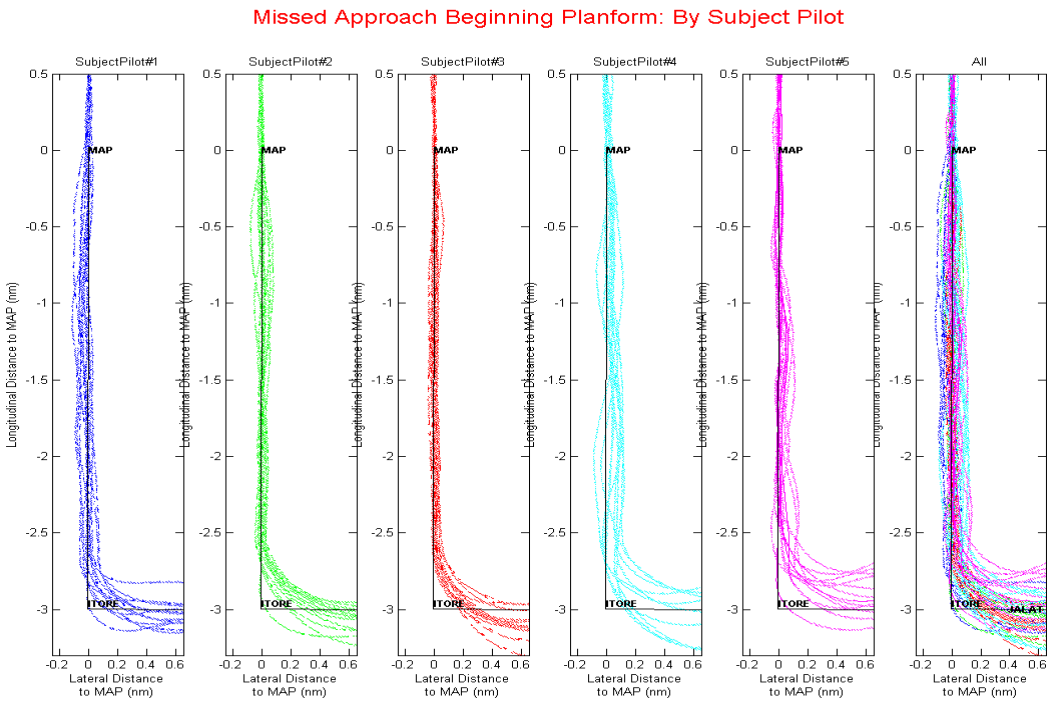

Figure 23: Missed Approach Beginning by Subject Pilot, Planform View

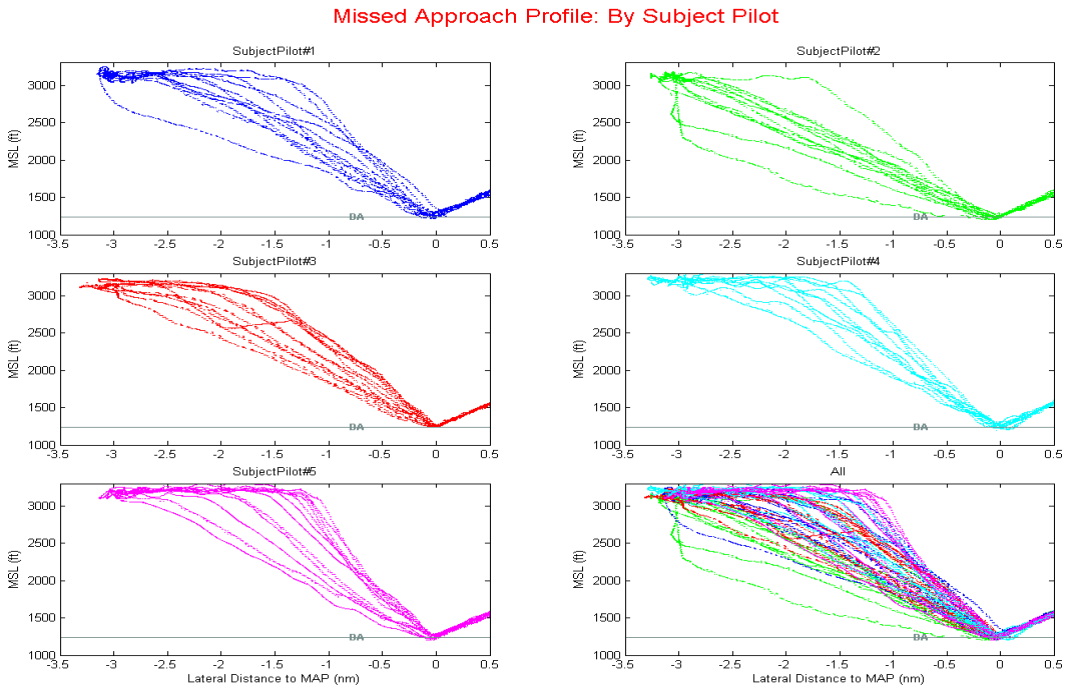

Figure 24: Missed Approach by Subject Pilot, Profile View

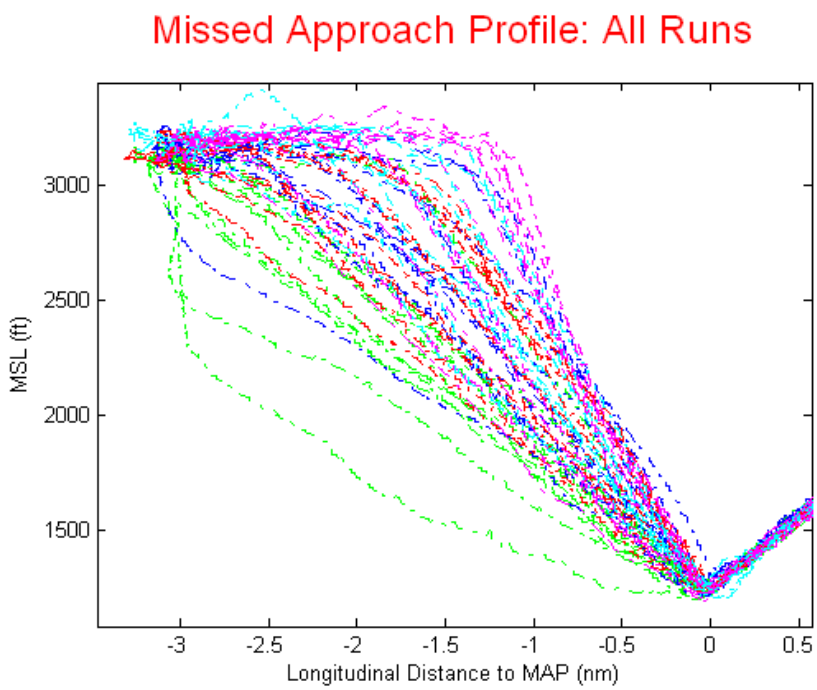

Figure 25: Missed Approach, Planform View

In review of the track data, there were a few tracks in which the rate of climb executed was notably different than most of the other runs. Examination of the flight observer logs, revealed three runs in which the wind conditions exceeded the required test conditions. Therefore, these runs were eliminated from the calculation of the contours. The three colored tracks in Figure 26 were eliminated due to wind conditions.

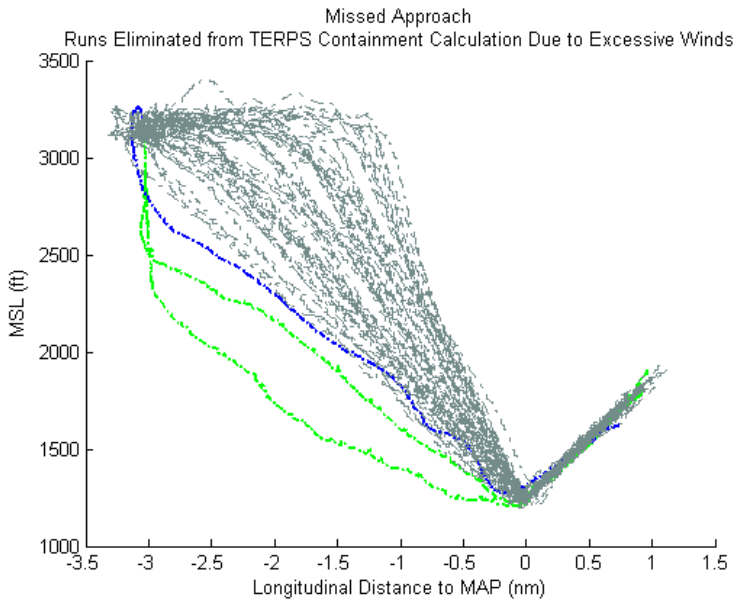

Figure 26: Missed Approach Runs Eliminated in Contour Calculation Due to Excessive Winds during Data Collection

The reader is reminded that the slices for contours were computed orthogonal to level flight rather than theoretical track. Figure 27 shows the profile view of tracks containing a yellow line of one of the orthogonal slices.

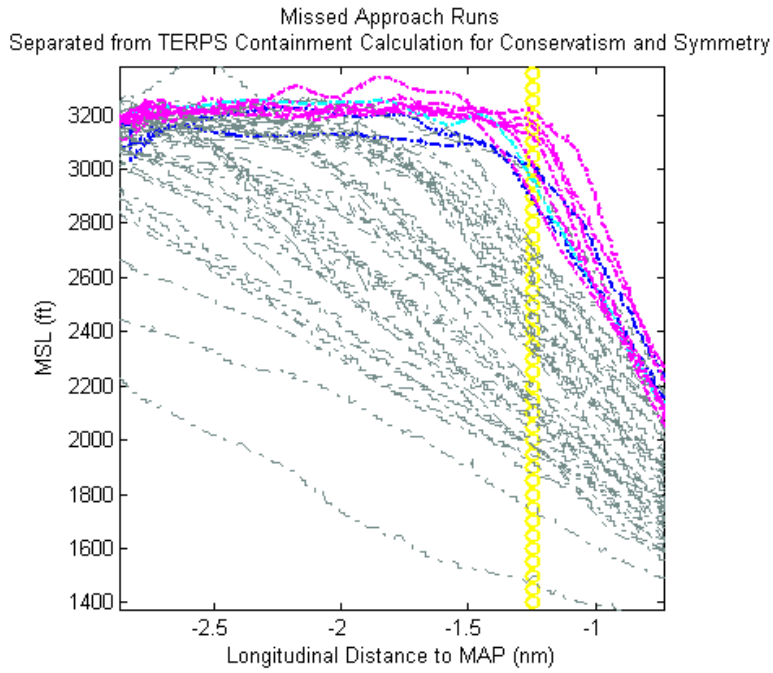

Figure 27: Missed Approach Runs Eliminated from Contour Calculation for Symmetry (Creating Conservative Contours)

Another conservative assumption with regard to statistical analysis of contours was that the tracks are symmetric about the mean. However, analysis showed that the vertical tracks during the climb phase of the missed approach segment were very skewed (non-symmetric). Thus the contours with this skewed data were considerably unrealistic.

Figure 27 contains a set of colored tracks in which the missed approach altitude was reached within one and a half nautical miles of the MAP. These tracks have the least likelihood of penetrating the missed approach obstacle clearance surface. To create a more symmetric set of data, the portion of these particular tracks from 0.75 nm to 2 nm were eliminated from calculation of the contours. This is a conservative approach to calculating appropriate contours because it will result in a missed approach obstacle clearance surface that provides a higher degree of protection from obstacles.. An indicator of symmetric distribution is the relative closeness of the mean of the data and the median (middle value). In this interval, the difference between the mean and the median in the entire data set was 56 feet. With the reduced data set, the difference between the mean and the median was 12 feet.

Figure 28 shows the lateral contours are within proposed TERPS protected surfaces at the 99.999% level. Figures 29 and 30 show the slight penetration of the contours within the vertical surface and the 3D surface, respectively.

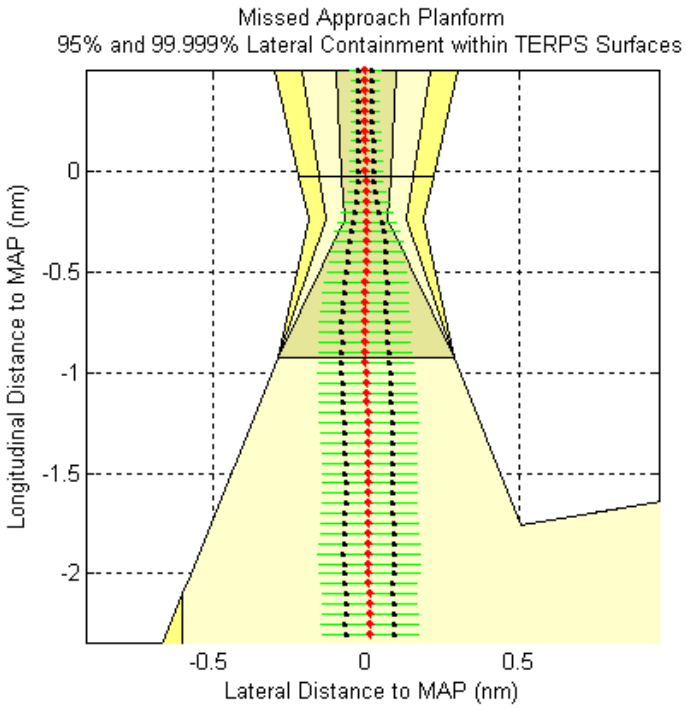

Figure 28: Contours of Missed Approach within Proposed TERPS Primary and Secondary Areas

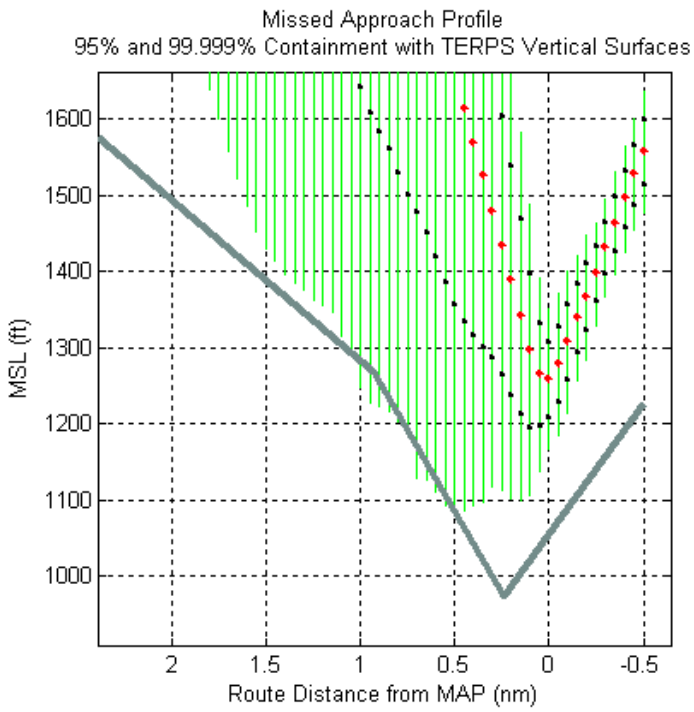

Figure 29: Contours of Missed Approach with slight penetration of OCS, ProfileView

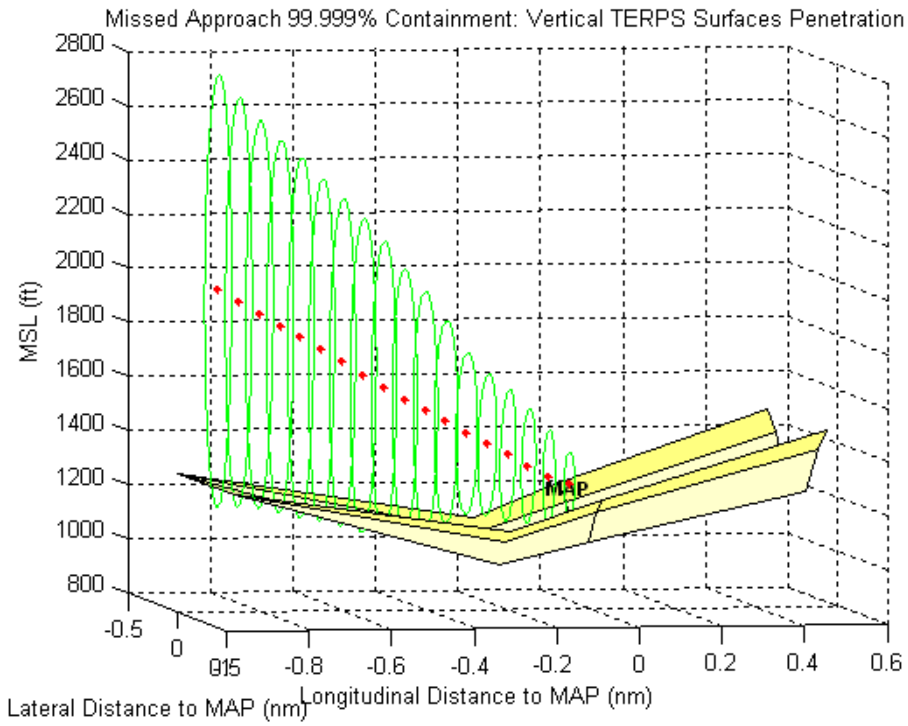

Figure 30: Contours of Missed Approach with slight penetration, 3D View

Figure 31 shows the contours are well within proposed and current TERPS primary and secondary surfaces throughout the Missed Approach, turns at ITORE, JALAT, and HATAB, and the Enroute segment. The reader is reminded that the "jumpy" appearance of the Enroute contours is due to the time in which control was changed from the Subject Pilot to Safety Pilot. Figure 32 shows the profile view of the vertical contours in the same segments

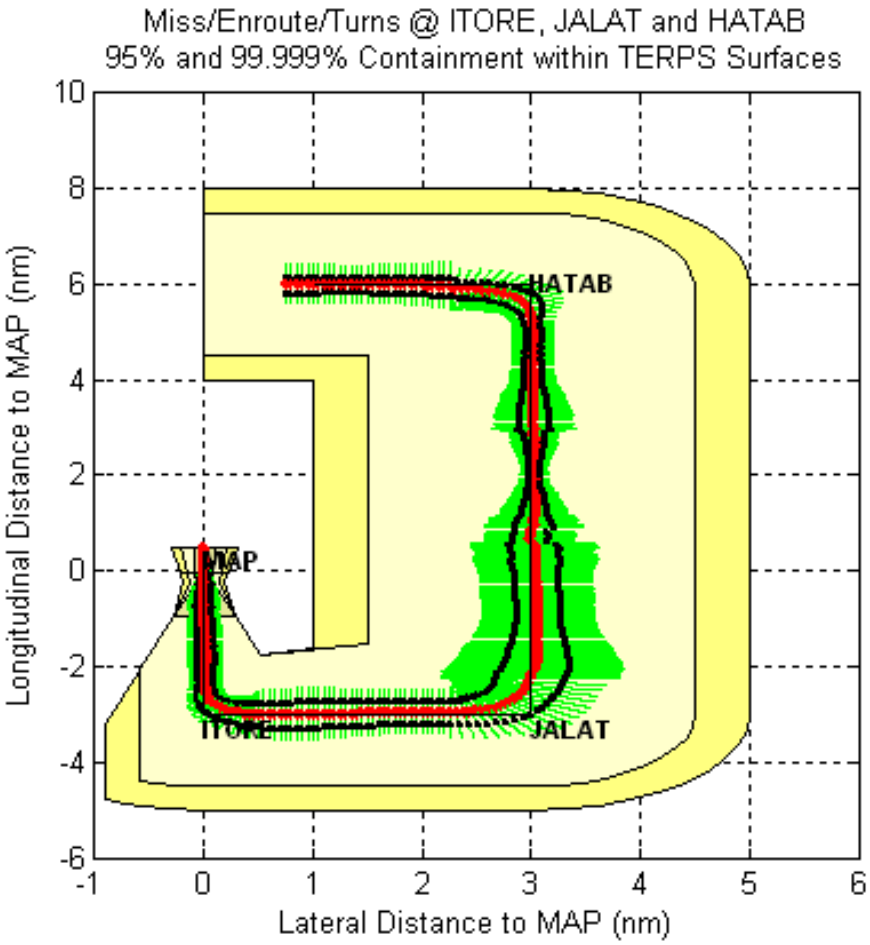

Figure 31: Contours of Missed Approach, Turns and Enroute, within Proposed and Current TERPS Primary and Secondary Areas

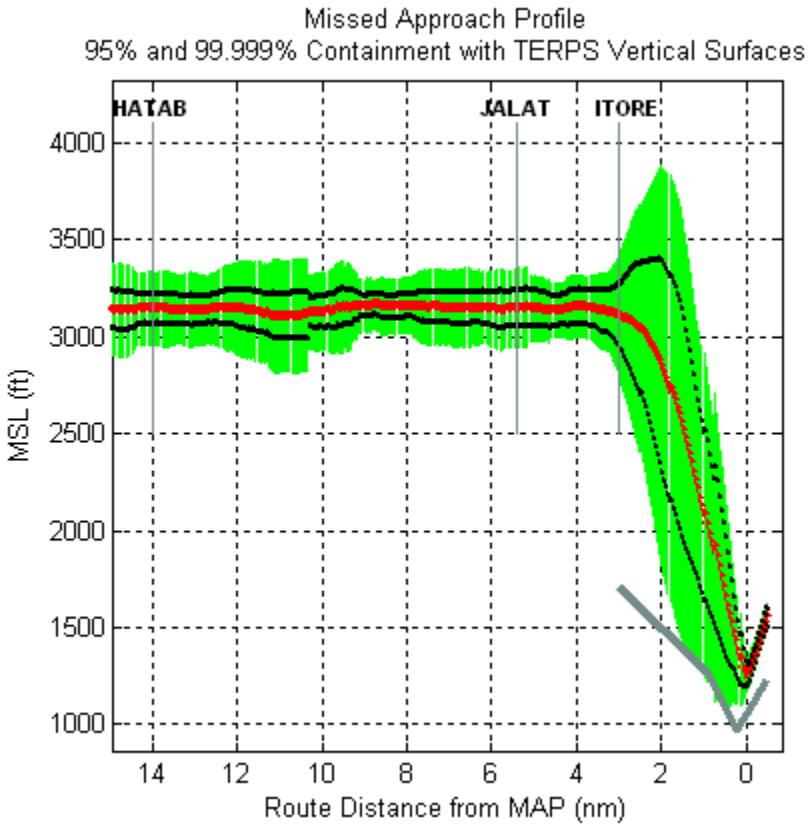

Figure 32: Contours of Missed Approach with slight penetration of Obstacle Clearance Surfaces, ProfileView

9.0 Evaluation of Landing

There were no significant issues in the landing segment. There were a few landings made from alternate directions due to wind conditions. Figures 33 and 34 show the planform and profile view of landings made by proceeding directly to the Heliport. Figure 35 shows the planform view of the landings made from alternate directions due to winds. Figure 36 and 37 show the 3D view of the direct landing and the alternative direction landing.

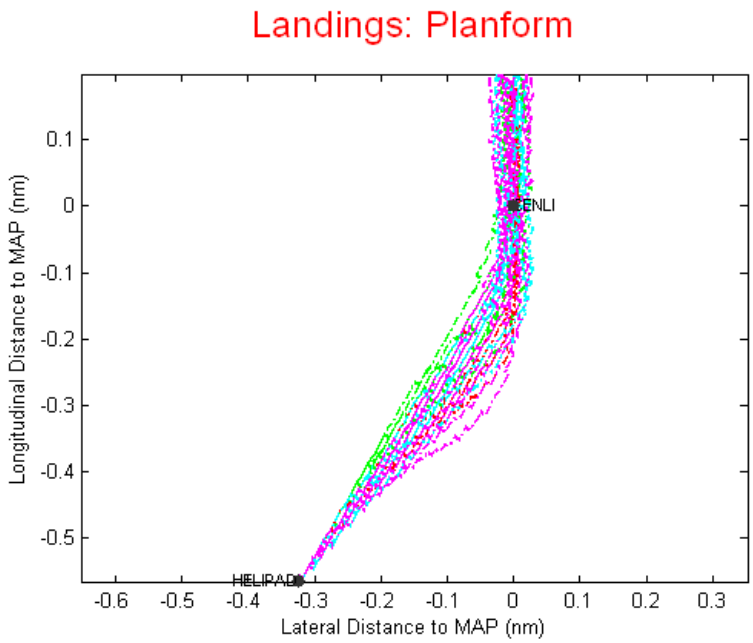

Figure 33: Landings Planform View

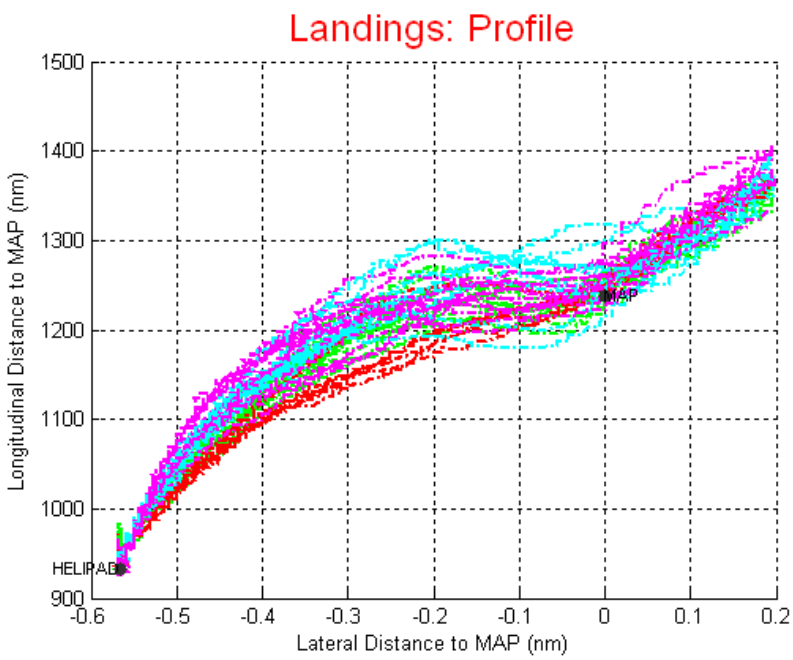

Figure 34: Landings Profile View

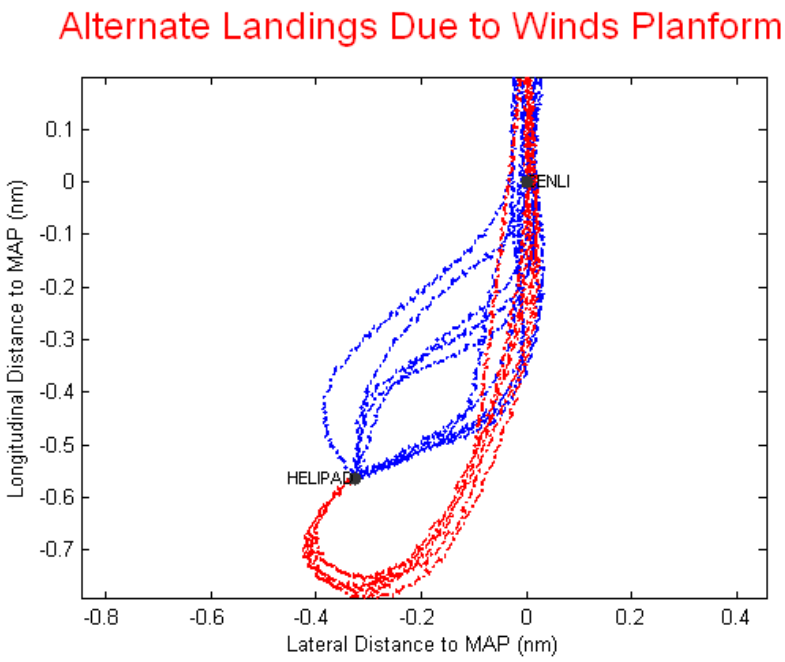

Figure 35: Alternate Landings Planform View

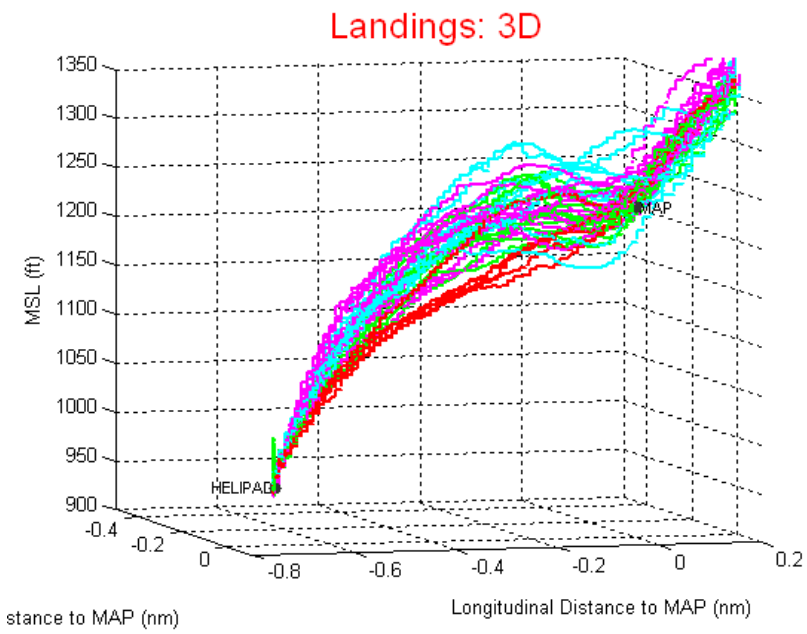

Figure 36: Landings 3D

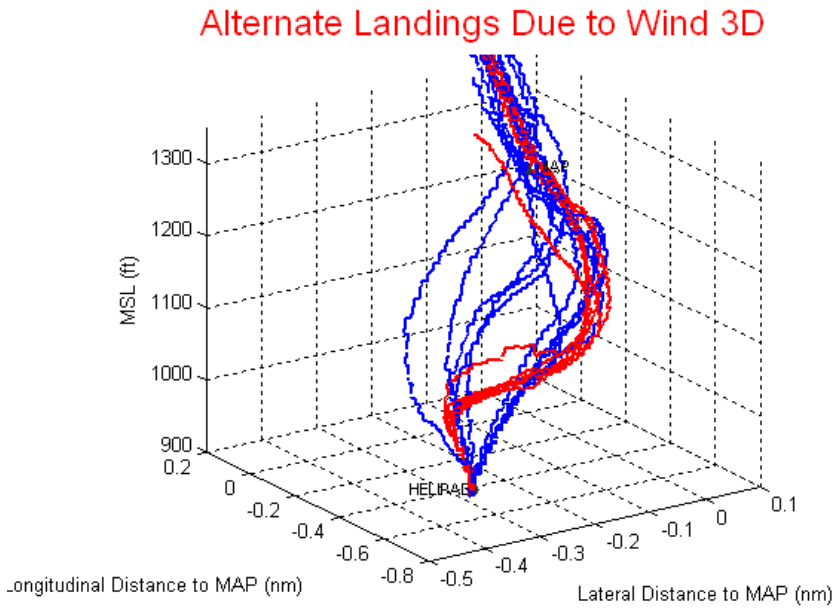

Figure 37: Alternate Landings 3D

10.0 Human-in-the-Loop Evaluation/Observations

10.1 HITL Test Methodology

The human factors analysis included data provided by the subject pilots on post approach and post flight subjective questionnaires provided by AFS-440. These questionnaires employ a multi-dimensional rating scale (Appendix A – Questionnaires). Each observer used a flight data log (Appendix X) to collect required and pertinent data.

Objective human performance measures were limited in scope. This was accomplished through simple observation of pilot/crew performance. Observation data was taken by in-the-cockpit observers (both pilot and human factors specific). All flight scenarios were carefully scripted. During those periods in a given flight sequence when a pilot/crew performed a maneuver out of the norm from what was either expected or planned, both Primary and Secondary task completion were monitored. The basic logic behind the Primary/Secondary task measure methodology is that spare mental/physical capacity, not being used by the primary task, will be devoted to accomplishing the secondary task. The greater the demand for resources made by the primary task (in this case, performance of approaches under the specified conditions of this demonstration), the less resources available for performance of secondary tasks (e.g. aircraft control within stabilized flight criteria, communication procedures, timely checklist completion, etc.) Specifically, during periods of heightened activity or workload, reaction times, latency of task completion or task shedding may take place. These events were observed, recorded, and analyzed, commensurate with aircraft performance metrics.

During the entirety of the data collection and evaluation, the Flight Observer/data system operator sat directly behind the subject pilot. He monitored the operation of one of two stand-alone data collection systems, located on a Toughbook Laptop Computer and responsible for gathering data directly off the Garmin 530, 429 Arinc Bus. He had a prescribed sequence of event marks that he was responsible for recording. All event marks are stamped in the data and annotated in the respective observer logs. Additionally, as a helicopter pilot and Aviation Safety Inspector (ASI), his duties included monitoring aircraft instruments and maintaining a log of all flight-related events/anomalies.

The on-board Flight Test Director also functioned as the Human-in-the-Loop observer, responsible for the operation of the Ashtech Z-Extreme Data Collection System. When anomalies or unplanned points of note occurred in any given sortie sequence, the HF Observer depressed the plunger on a data event marker. Each depression stamped the data. Also, a written annotation was made in the observer log. The HITL Observer was primarily concerned with maintaining a running log of Human Factors events/anomalies in the area of pilot workload and comfort. Note: The HITL Observer/Test Director was also a rated helicopter pilot and instructor.

The fourth crew member was the Safety Pilot who sat in the left seat during each sortie. He was

a Bell Test Pilot from Bell-Textron's Mirabel, Canada, test and production facility. He is the most experienced pilot in the Bell 429 Helicopter. His technical expertise was invaluable, especially during initial set up of the aircraft and avionics systems. At no time did he intervene in the conduct of any scenario nor did he assist any subject pilots, compromising the integrity of the data-collection. For the purposes of the date collection, he only existed to provide safety of flight, since the data collection effort was conducted as a single-pilot operation. He did assume control of the helicopter during the runs where it was required of the subject pilot to complete a questionnaire. Transfer of control back to the subject pilot was made immediately upon completion of the questionnaire.

10.2 Subject Pilots

Demographically, subjects represented a mix of pilots with varied aviation backgrounds and experience. Four of the pilots were trained and flew in the military while one pilot was trained and flew in exclusively in the civilian sector. Pilot Rotary-Wing time ranged from a low of 5000 to a high of 14,000 total hours. The total time that pilots flew in either actual IMC conditions or with a hood (IFR) ranged from a low of 250 hours to a high of 1000 hours. During the de-briefing, one pilot commented that the bulk of his most recent flight time, prior to flying in his current position, was flying in a corporate jet under predominantly IFR conditions. There may be a correlation between the amount of instrument time flow and the recency of having flown that time and also between IFR versus VFR experience but we did not experimentally control for those variables.

It's important to note that pilots were required to fly every phase of every sortie with the auto-pilot completely disengaged and without Flight Director Guidance. Also, each subject pilot was required to wear a vision-limiting device, restricting their point-of-regard/primary field of view of the cockpit instrument display.

10.3 Subjective Pilot Response Data

Subjective pilot feedback was taken during the entirety of the evaluation. Subjective questionnaires were passed to the pilot after the completion of each prescribed scenario (i.e. Departure/Landing/Missed Approach). The questionnaires were designed to gather pilot feedback and perspective in the following areas:

a. Comparison to a CAT I ILS (Departure/Missed/Landing)
b. Level of Safety (Departure/Missed/Landing)
c. Perception of Workload (Departure/Missed/Landing)
d. Difficulty (Departure/Missed/Landing)

Questionnaires are included in Appendix XX. Pilot subjective responses from the post-run questionnaires have been tabulated and are graphically portrayed in Figures 38 through 52. They are broken down into Departure, Landing and Missed Approach phases of each sortie.

Figure 38, 39 and 40 show that subject pilots indicated in each scenario that this approach was as easy or easier for them to accomplish, differing little from current CAT I ILS approach procedures that they fly. Pilot two consistently felt that all phases of this procedure were easier compared to those of a CAT I ILS.

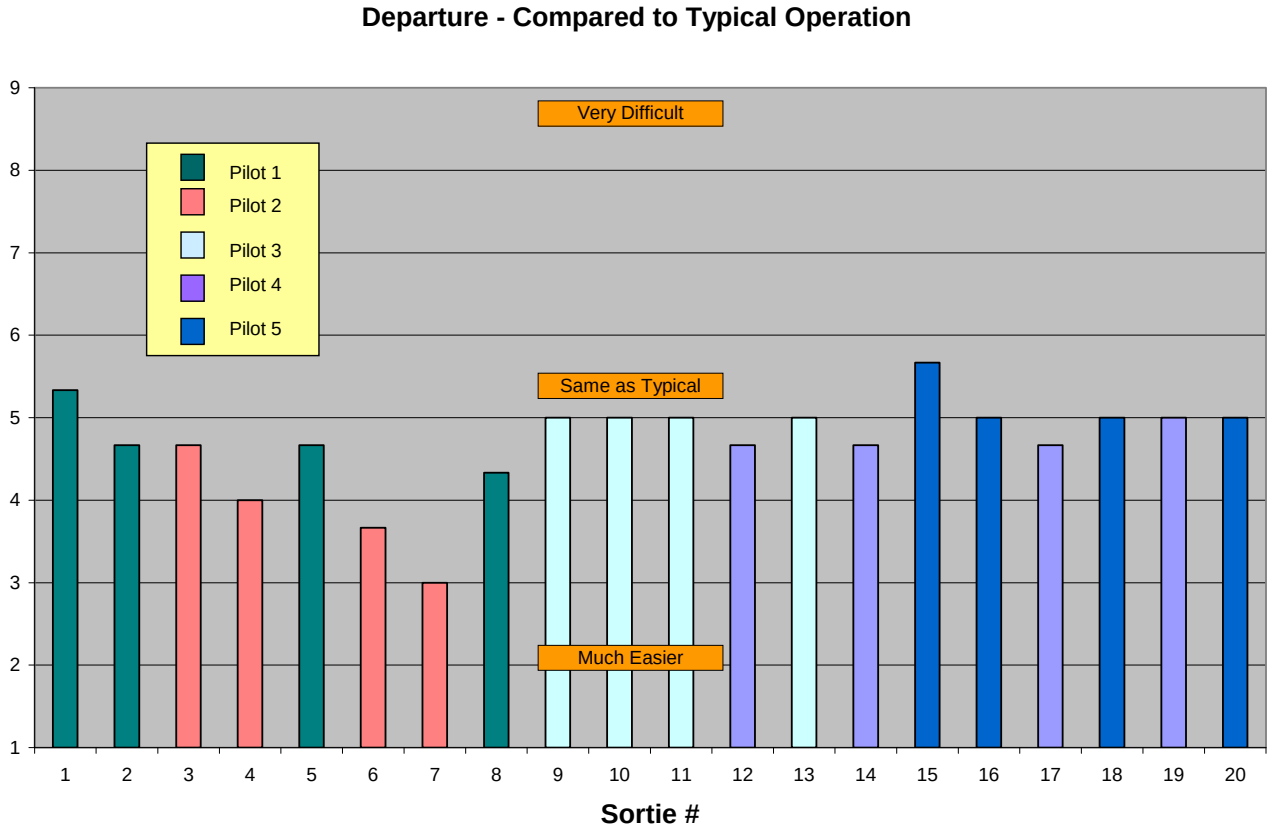
Departure - Compared to Typical Operation
Very Difficult
Same as Typical
Much Easier
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 38

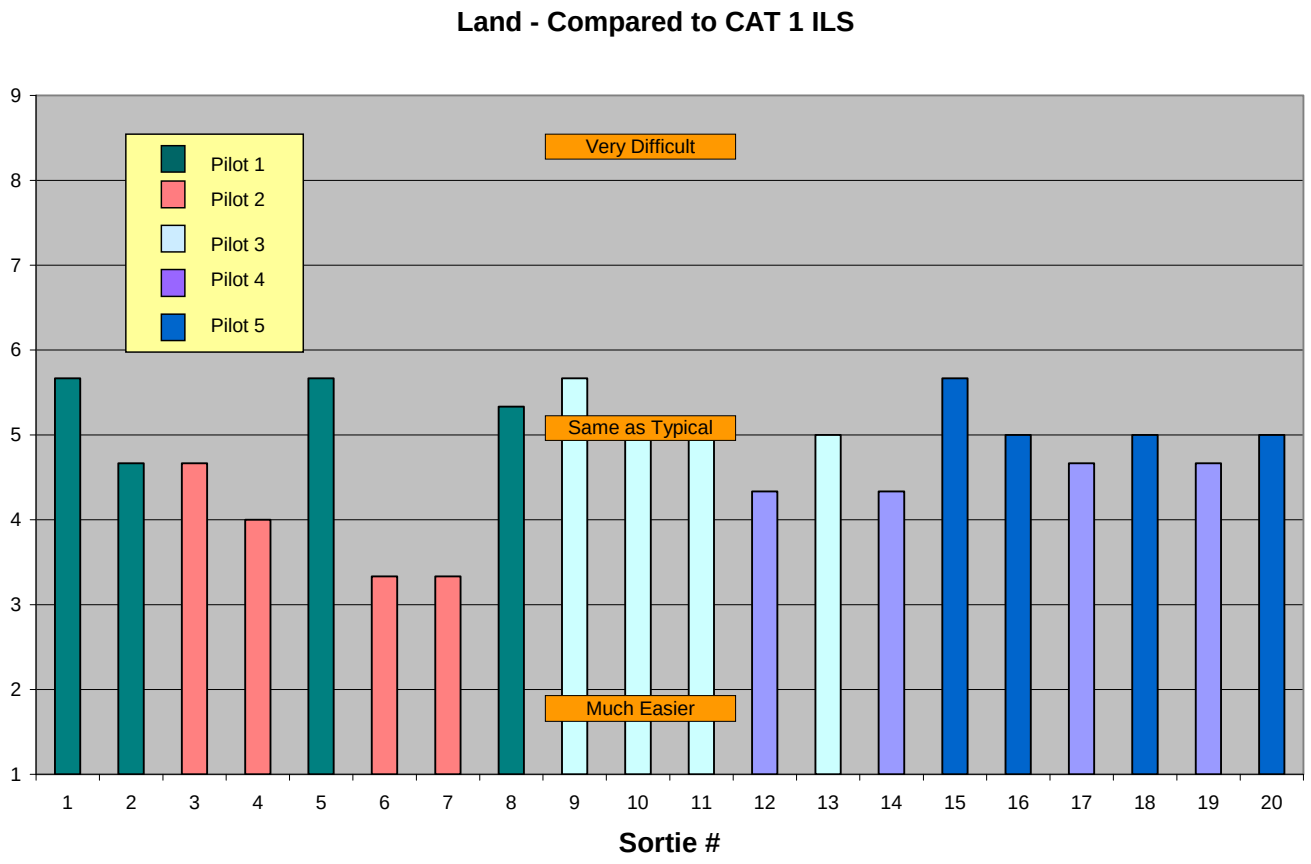
Land - Compared to CAT 1 ILS
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very Difficult
Same as Typical
Much Easier
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 39

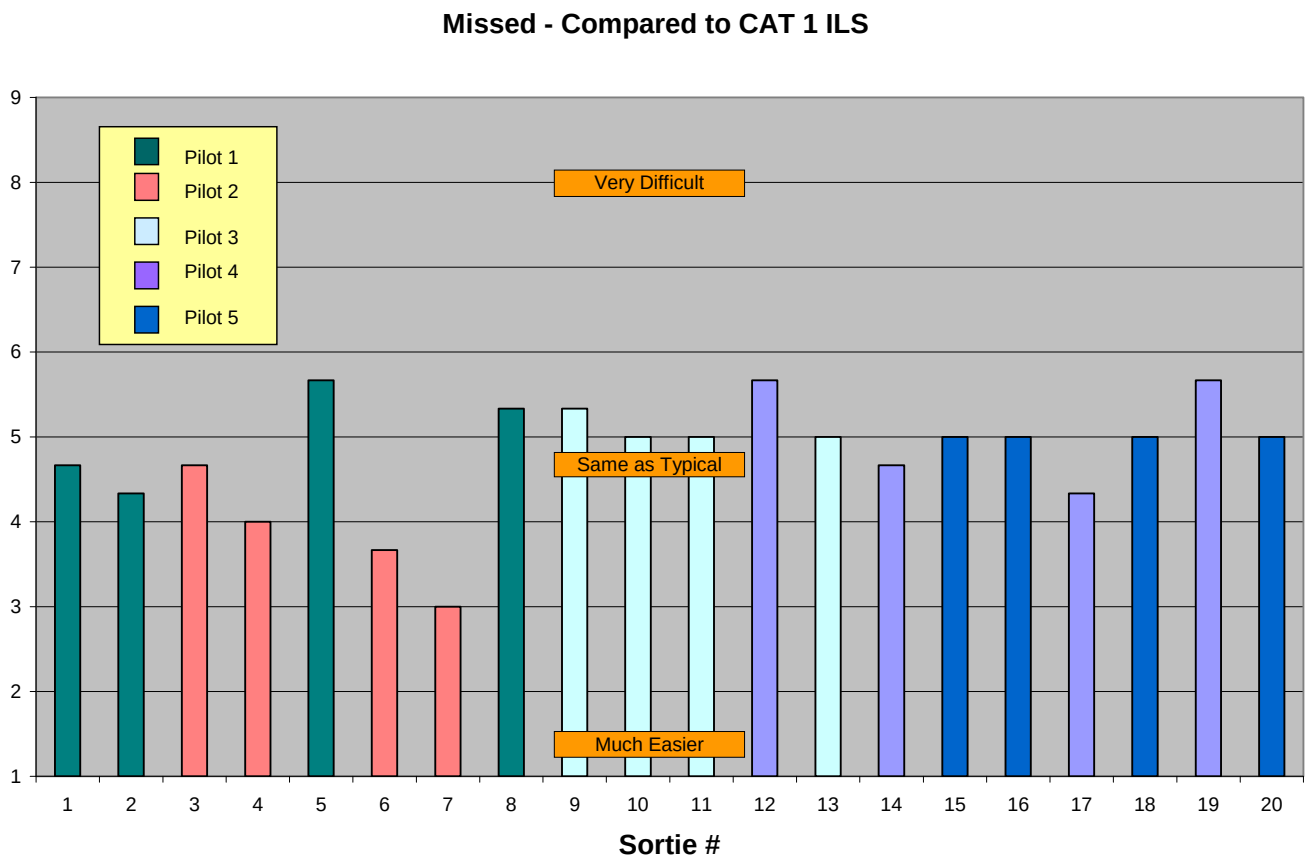

FIGURE 40

As previously stated, pilots were required to fly every phase of every sortie with the auto-pilot completely disengaged and without Flight Director Guidance. That resulted in the subject pilot feedback presented in Figures 41, 42 and 43. While pilot feedback indicates the perception that these procedures were as easy or easier than a standard CAT I ILS, scores most probably would be lower (i.e. "Easier") if pilots were allowed to use either Flight Director Guidance or the Autopilot or both. Pilot de-briefing comments validate this assertion.

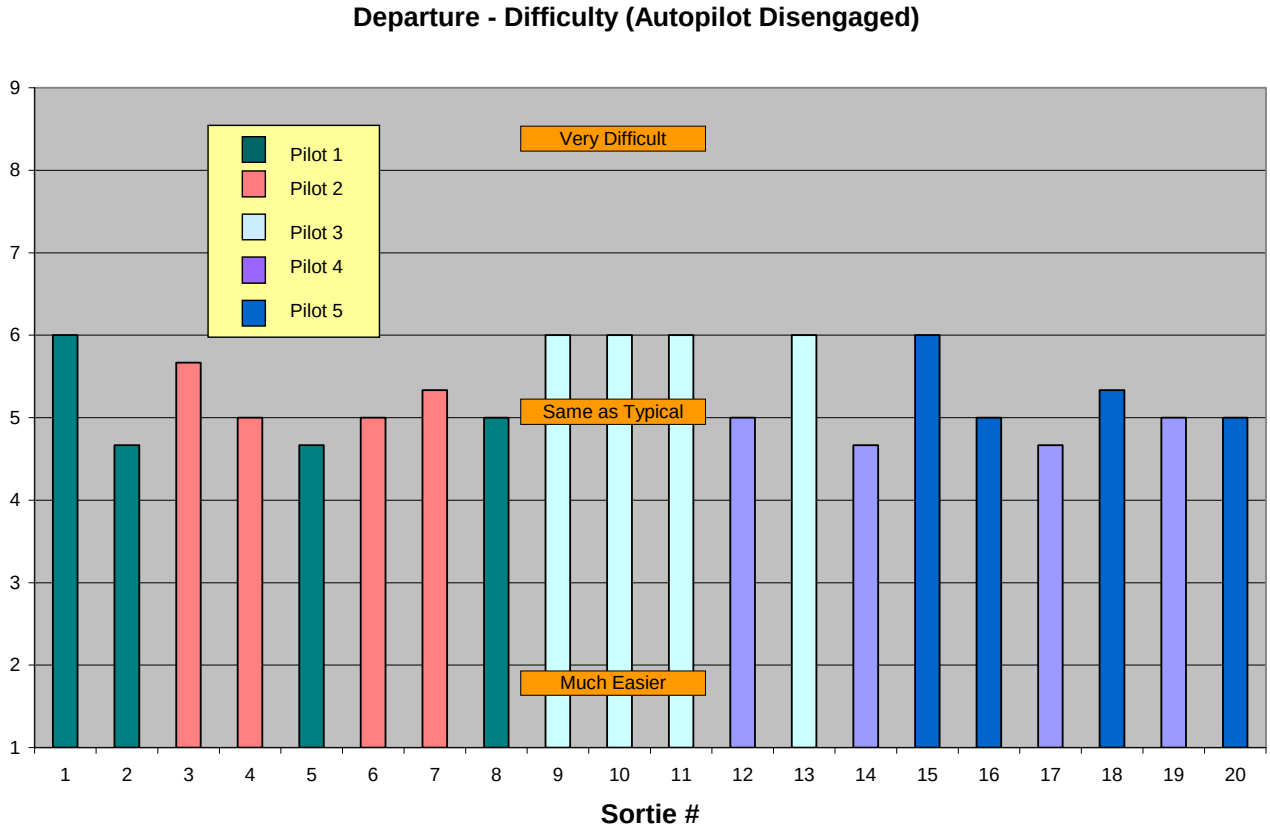
Departure - Difficulty (Autopilot Disengaged)
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very Difficult
Same as Typical
Much Easier
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 41

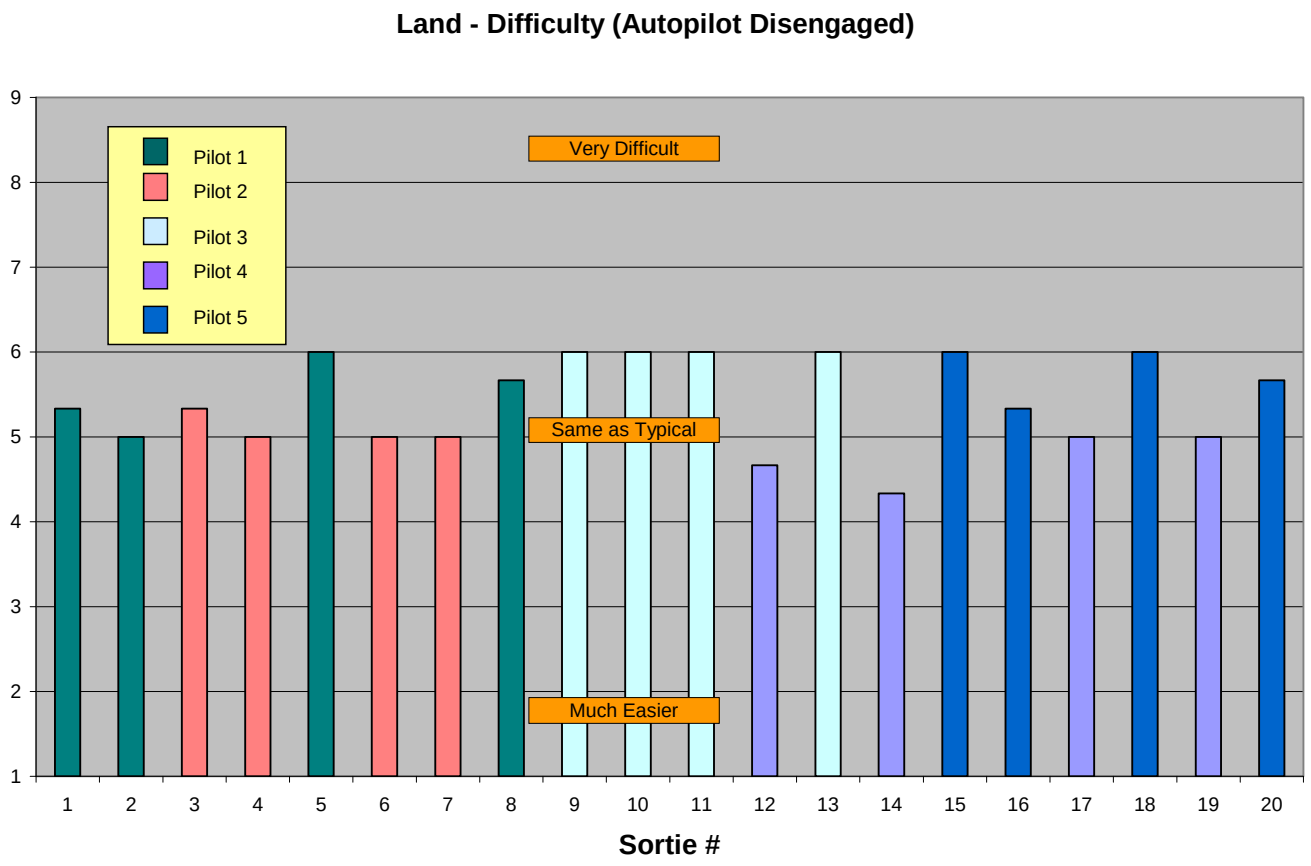
Land - Difficulty (Autopilot Disengaged)
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very Difficult
Same as Typical
Much Easier
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 42

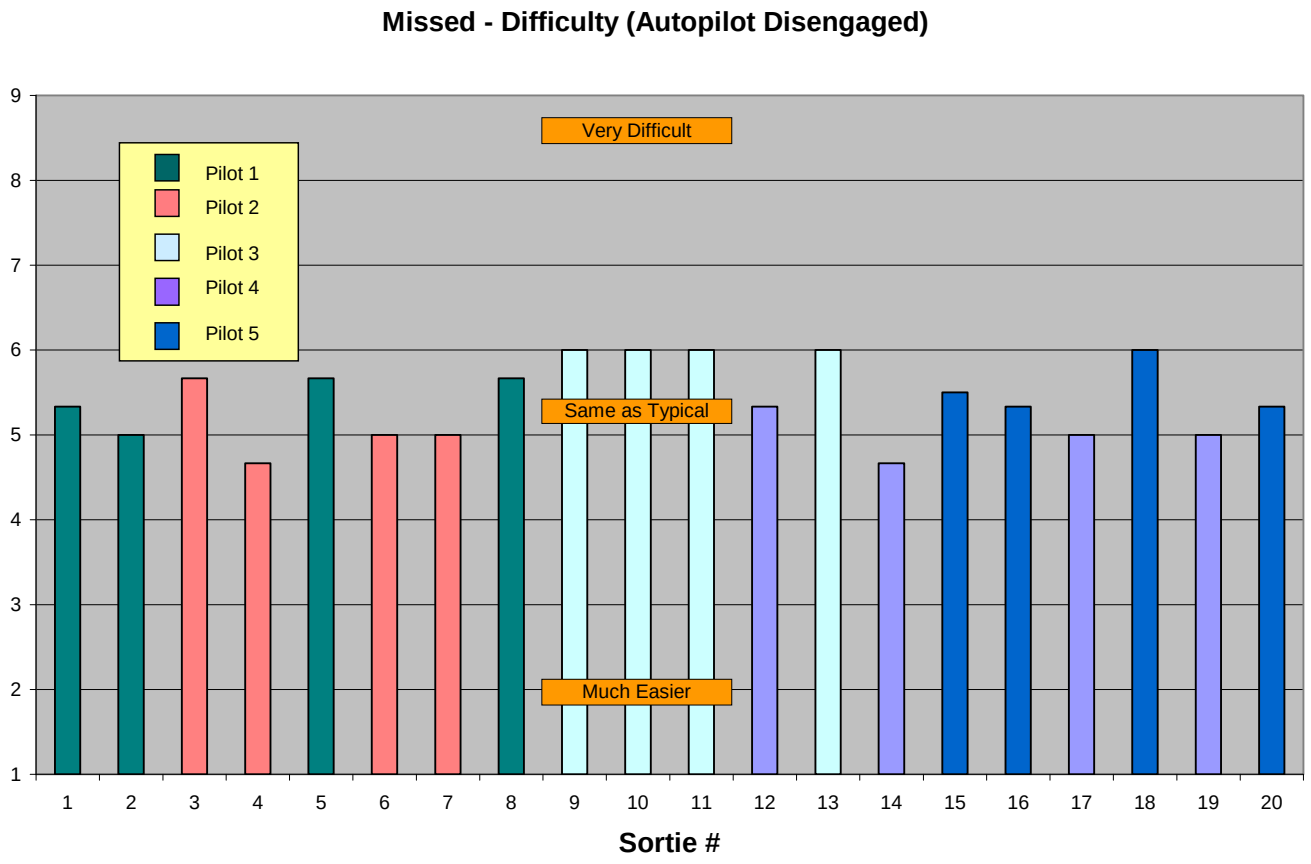
Missed - Difficulty (Autopilot Disengaged)
Very Difficult
Same as Typical
Much Easier
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 43

In all phases of the flight profile (Departure, Landing and Missed Approach), Pilot 2 felt that workload was actually lower for these approaches as compared to a CAT I ILS (see figures 44, 45, 46 and 47). The other four pilots indicated that workload was typical or slightly higher than compared to a CAT I ILS.

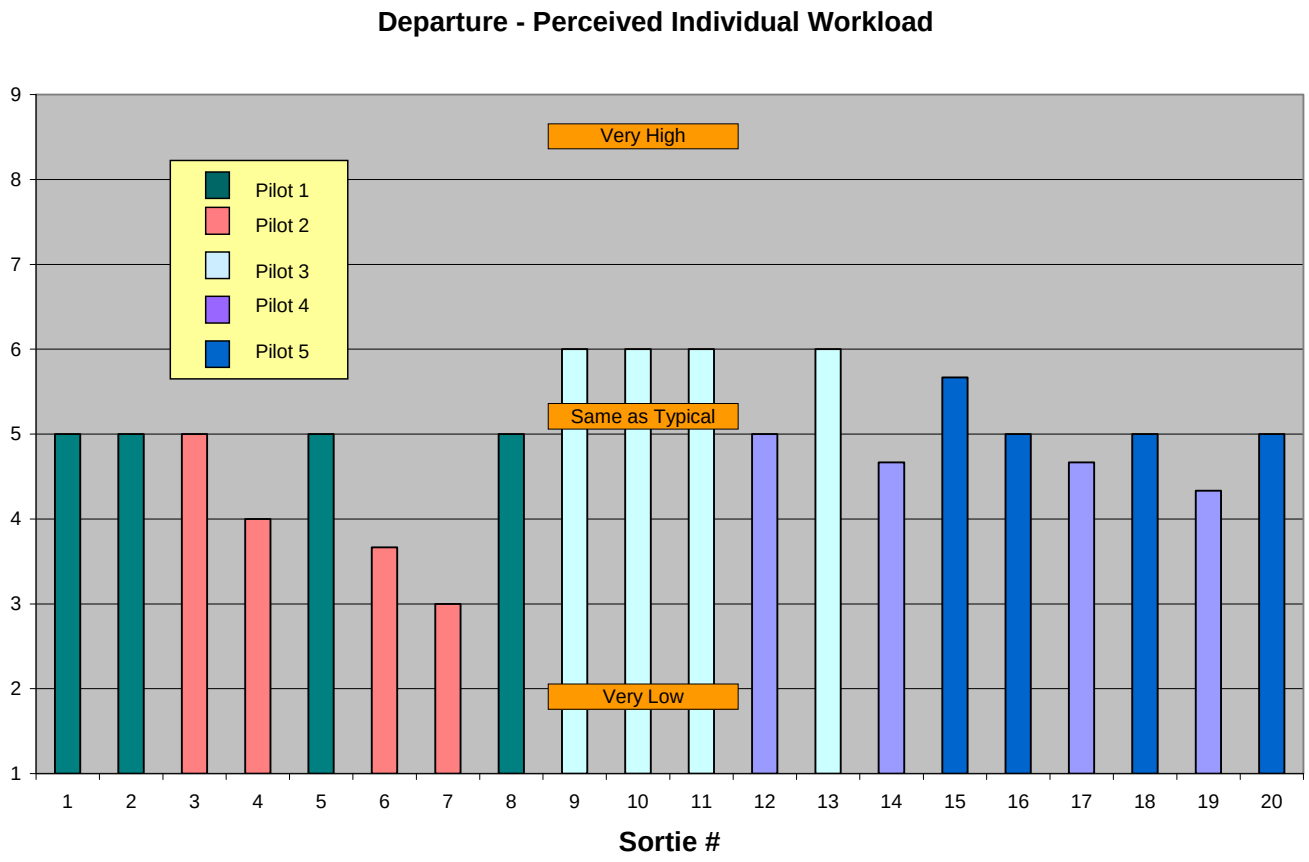
Departure - Perceived Individual Workload
Very High
Same as Typical
Very Low
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 44

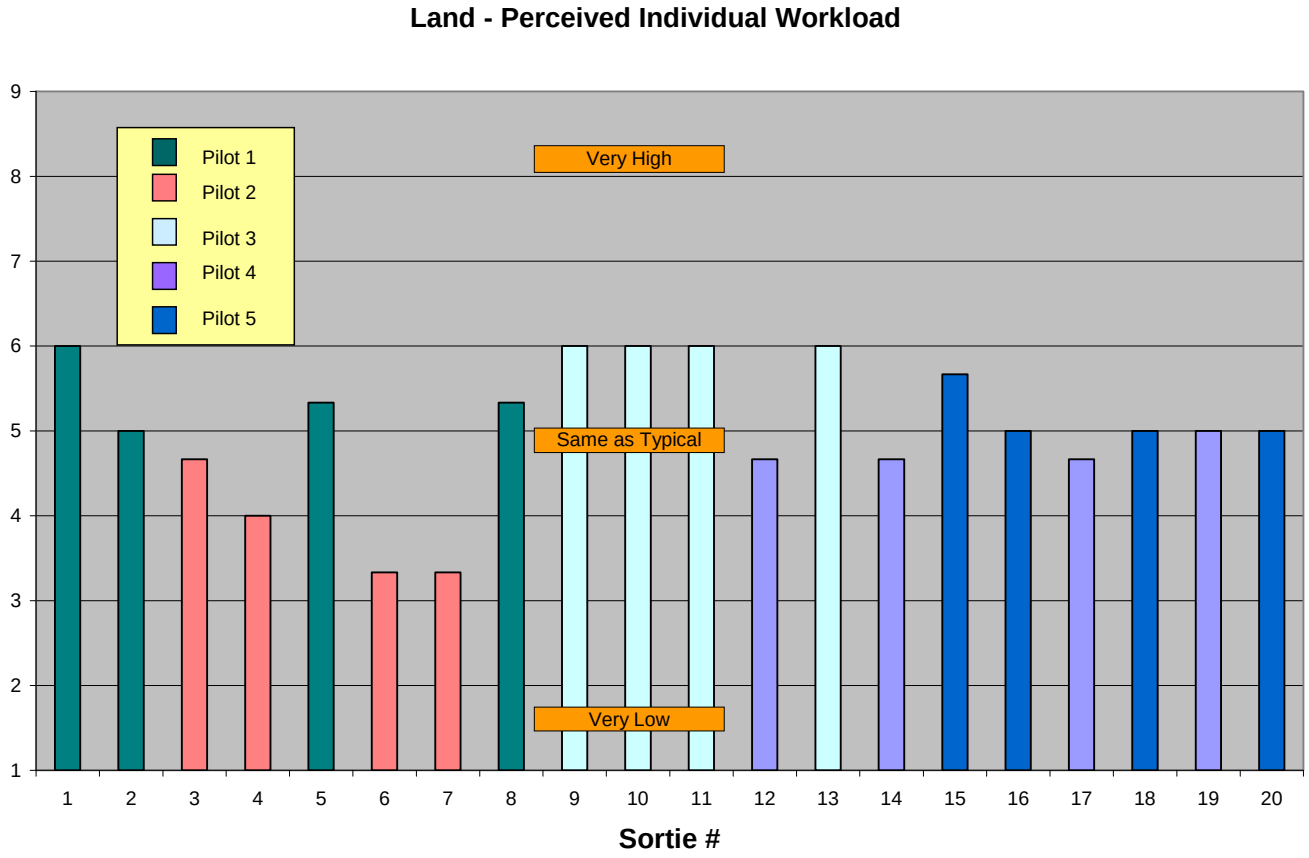
Land - Perceived Individual Workload
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very High
Same as Typical
Very Low
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 45

Missed - Perceived Level of Workload (Approach)
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very High
Same as Typical
Very Low
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 46

Missed - Perceived Workload (Missed Approach)
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very High
Same as Typical
Very Low
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 47

In Figure 48 and 49, three and four of the subject pilots, respectively, felt the steep angle approach and the offset caused the workload of the approaches to landing or executing a missed approach to be just slightly higher than what they normally experienced in day-to-day flights. They felt that at no time was safety compromised (see figures 50, 51 and 52).

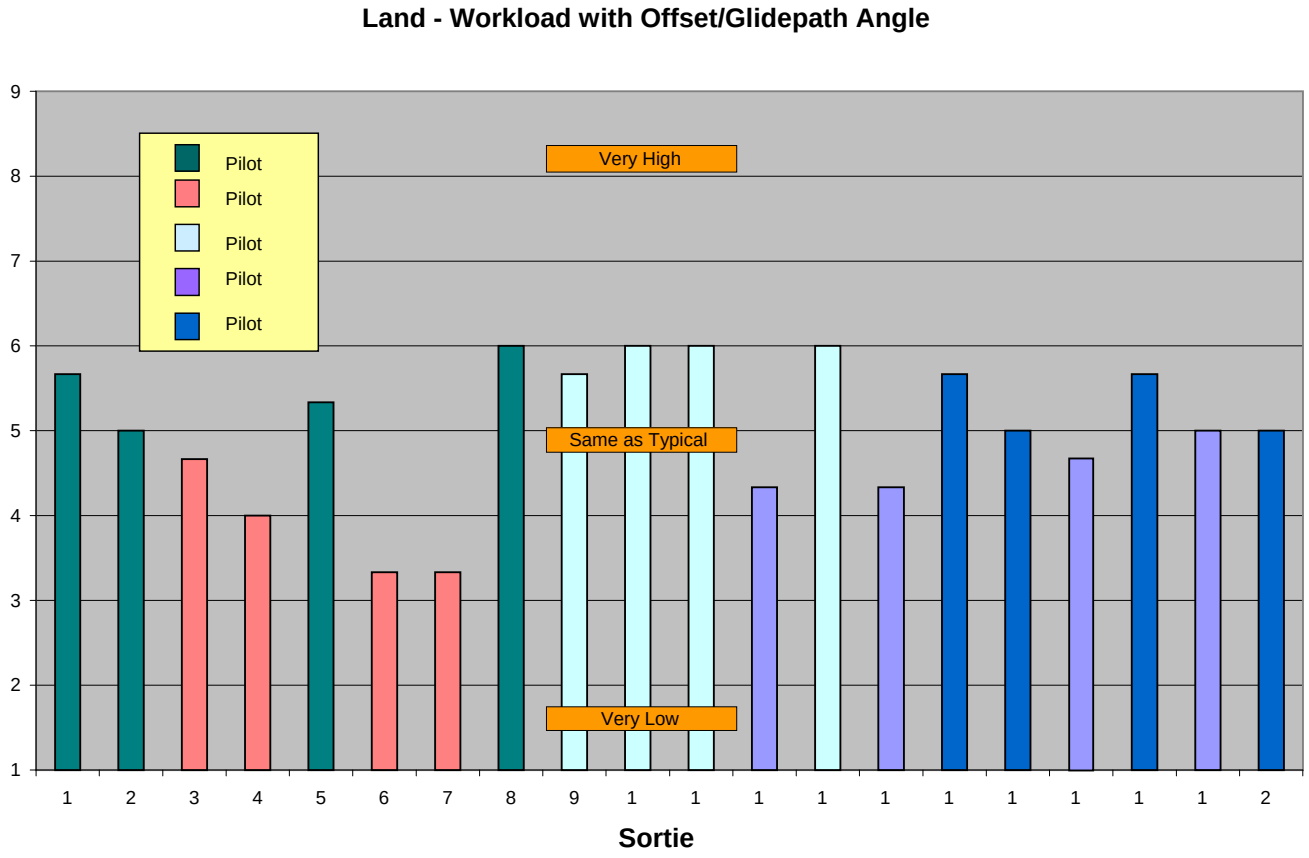
Land - Workload with Offset/Glidepath Angle
Pilot
Pilot
Pilot
Pilot
Pilot
Very High
Same as Typical
Very Low
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 1 1 1 1 1 1 1 1 1 2
Sortie

FIGURE 48

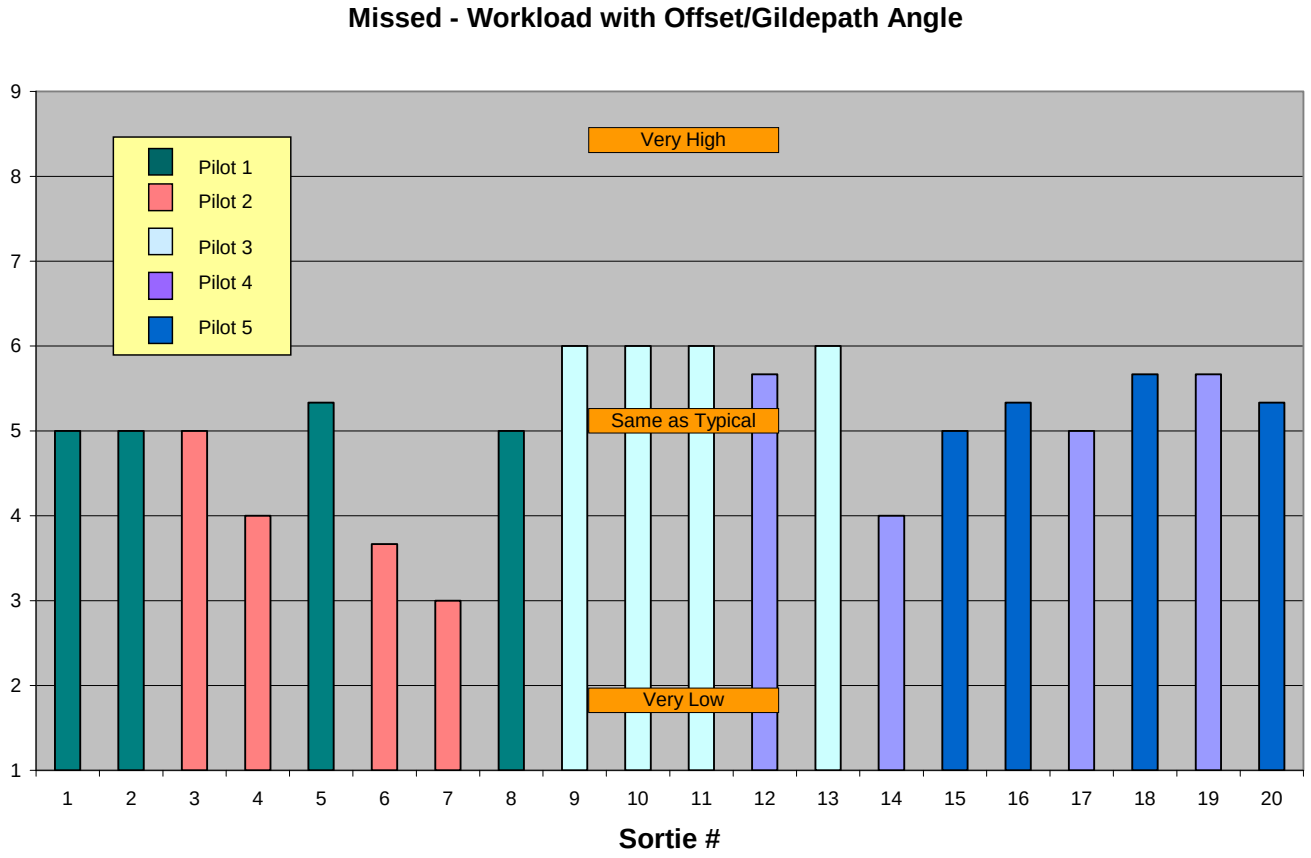
Missed - Workload with Offset/Gildepath Angle
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
Very High
Same as Typical
Very Low
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 49

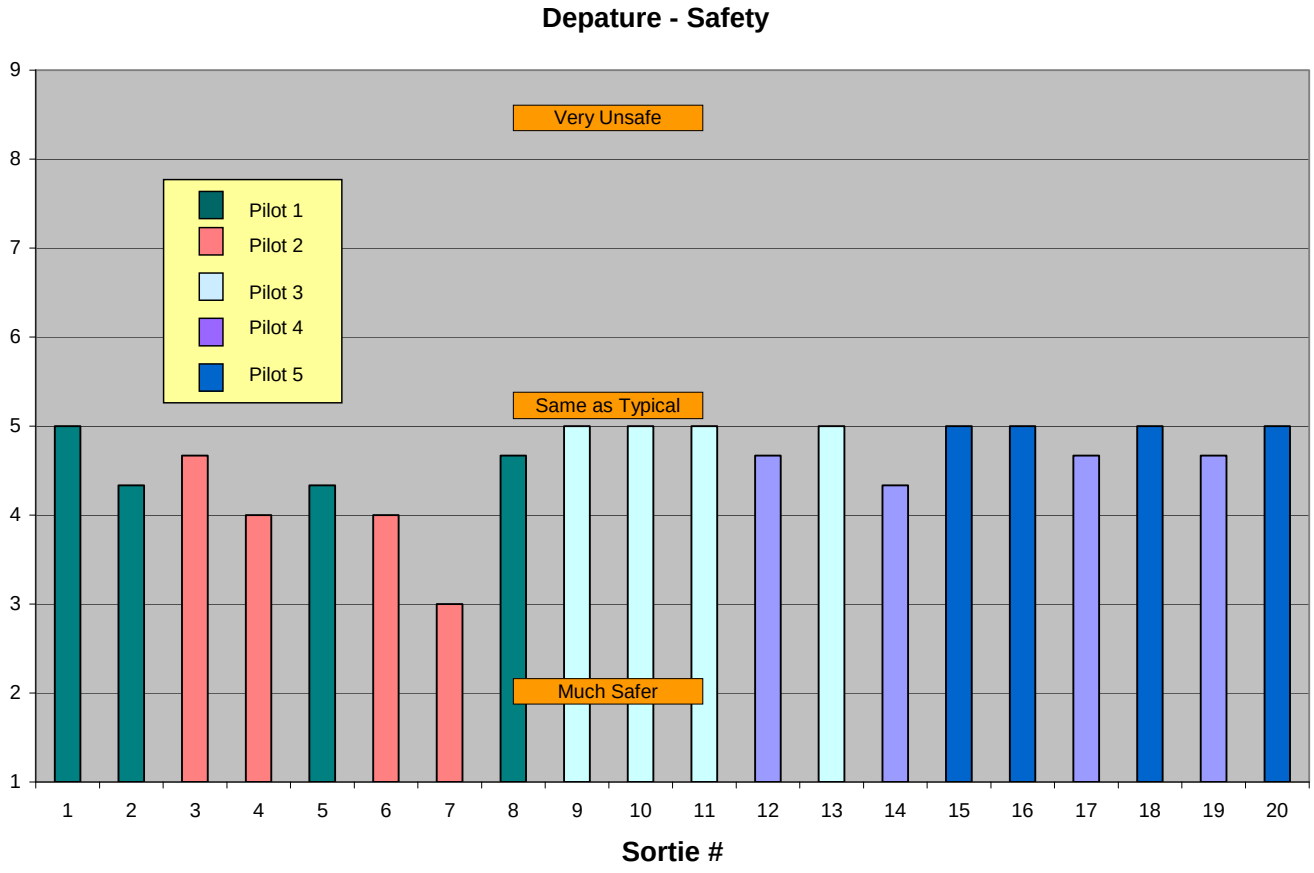
Depature - Safety
Very Unsafe
Same as Typical
Much Safer
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 50

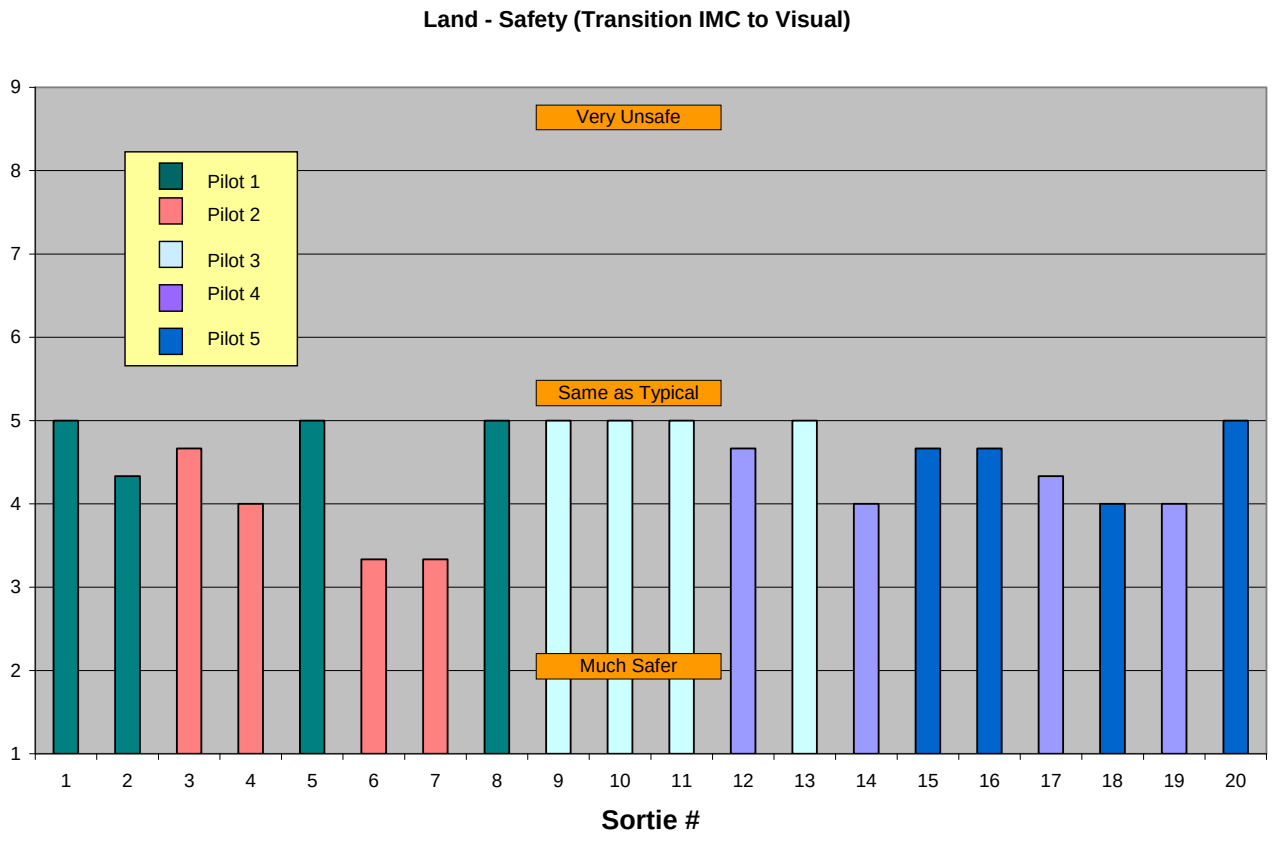
Land - Safety (Transition IMC to Visual)
Very Unsafe
Same as Typical
Much Safer
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 51

Missed - Safety
Very Unsafe
Same as Typical
Much Safer
Pilot 1
Pilot 2
Pilot 3
Pilot 4
Pilot 5
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sortie #

FIGURE 52

10.4 Objective Performance Data (Observations)

Initially (during each pilot's first sortie), each pilot appeared to be slightly busy but we observed no significant degradation of performance or task-shedding. Performance was fairly consistent across all pilots with the exception of one pilot whose instrument flying technique and performance was exceptional, even with severe cross-wind conditions of up to 40+ knots. The last pilot in the testing queue was not completely familiar with the use of the Garmin 530 system and, initially had to receive minimal coaching from the safety pilot. After that, it did not affect that subject pilot's performance.

Enroute segments were generally uneventful. A portion of those segments were flown by the Safety Pilot, allowing the Subject Pilots to complete subjective evaluations of this phase of the procedure. The same transfer of controls took place upon completion of the departure segment. The Safety pilot repositioned the helicopter to enter the approach while the subject pilot completed the questionnaire. Upon accepting and confirming transfer of the controls from the Safety Pilot, the Subject Pilots maintained course heading or track, altitude, monitored and answered radio calls timely and accurately.

At no time did it appear the subject pilots were anticipating reaching the missed approach point. The subject pilots were briefed beforehand that the safety pilot would call "pad in site, land" or "no pad, miss" at DA. They were to respond, "in sight, landing", or "missed approach". That testing procedure was very effective and insured that test integrity was preserved. HITL observer notes indicate several times the mandatory "missed approach" response was made slightly later than the norm, pointing to a potential primary/secondary task shedding condition. While this might be attributable to an increase in individual workload during the missed approach, safety was never compromised and the timing of the radio calls was well within acceptable parameters.
As previously stated, we did not control test variables for total pilot flight time, currency, type ratings or IMC/Hood experience but it may be worth investigating the effect of those variables on performance. Pertinent pilot demographic information can be found in the beginning of this section.

Pilot control techniques varied widely across the subject pilots, especially in the area of Force Trim use. The Force Trim system incorporates several mechanical functions. One is the use of the Force Trim Adjustment Knob that adjusts force trim without disengaging it. The other is a Force Trim Release Button that temporarily suspends Force Trim until the pilot releases the button, at which time the Force Trim Gradients are reactivated at the particular point where the control(s) (cyclic and collective) are physically positioned. The third method of Force Trim use does not require the use of a button or switch. The pilot has the option of pushing against the force trim gradient until the desired aircraft movement is effected. As pressure is released, the controls return immediately to their previous positions.

Since the autopilot was disengaged for the entirety of each sortie, the Force Trim system helped

reduce physical workload significantly, relieving the pilots from having to put excessive and constant pressure on the controls to maintain aircraft stability. Pilot use of the force trim system's various components varied across all pilots. Some pilots utilized each force trim function separately or in combination. Note that no one method appeared to yield better or worse performance. The various pilot techniques are visible in the captured video footage. This has implications for future training as validated by one pilot who pointed out that he continually "experimented" with the force trim.

The safety pilot remained completely objective throughout all 20 sorties and provided no guidance or assistance to the subject pilots beyond what was previously noted or what was required to keep the aircraft and crew safe.

10.5 Post-Evaluation De-Briefing Comments

Pilot de-briefing comments were consistent with observed pilot performance. The general perceptions of the subject pilots were supportive of the procedure design, safety, workload level and flyability. One pilot noted that increased difficulty/workload with flying these procedures without both the autopilot and flight director guidance is offset by the simplicity of these procedures, compared to a standard ILS approach.

Most of the comments were based upon high winds and meteorological conditions. As a rule, all those pilots who experienced moderate to heavy wind conditions commented that it increased workload. Debriefing comments revealed that at no time did any pilot feel that these procedures, or any segment of them, were unsafe. In fact, two pilots pointed out that second, third and fourth sortie difficulty (due to winds and reduced weather conditions) was offset by increased familiarity with the procedures. This points to an increase in comfort and perceived performance with repetition and training.

NOTE: The test parameter of a 10 knot maximum tailwind component was established to prevent pilots from having excessive ground speeds on final approach and possibly flying through the Decision Altitude and exceeding airspeed limits. All pilots had enough situational awareness to adjust their indicated airspeed (or groundspeed) accordingly to perform a safe approach and landing/missed approach without exceeding performance or human limitations. Each pilot noted that in tailwind conditions, pilots may need to reduce indicated airspeed to keep ground speed within controllable limits.

Pilots did not feel that visual acquisition of the landing pad was a problem.

All sorties were flown during Day VMC conditions but, during each post-flight debriefing, we asked the subject pilots for their opinions of the difficulty of flying these approaches at night and whether or not lighting needed to be augmented or modified. With the exception of one pilot, they all felt that the approaches would be no more difficult or easy at night versus day. In addition, they all felt that the existing helipad lighting configuration was adequate. Note there

was general agreement that the pad had to meet at least the basic requirement for lighting. Without that, pilots would be uncomfortable flying to the pad, at night, without prior experience. When asked, pilots indicated that they do not typically navigate to the pad (in the visual segment) using lights or combinations of lights in the surrounding area (i.e. proximate light poles, buildings, towers, etc.). The single differing pilot felt that night approaches might be slightly easier given the more pronounced discriminability of surrounding versus pad lighting at night versus day. Several caveats to these comments were made. One, familiarity with the landing area prior to executing the approach is important and two, pilots should be trained (or refreshed) in the transition from IFR to the Visual Segment.

11.0 Summary

The need for development of Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Terminal Instrument Procedures (TERPS) criteria for helicopter approaches to a heliport was identified [1] because of the growing use of WAAS guidance in recent years. Approaches developed with these criteria are called Helicopter Localizer Performance with Vertical Guidance (HLPV). WAAS provides navigation accuracy equivalent to an Instrument Landing System (ILS) localizer and glideslope performance standards.

Twenty sorties were flown including departure, enroute, approach, missed approach and visual segments to landing from October 18 through October 25, 2010, using a 5.8° final approach GPA. During these flights, 118 helicopter LPV Point in Space (PinS) approaches were flown combined with 60 departures, 58 enroute segments, 58 missed approaches and 59 visual segments to landing. All of the segments were hand flown using raw data with the auto-pilot completely disengaged and without flight director guidance.

Subjective pilot feedback within the indices of Comparison to the Difficulty of a CAT I ILS, Perception of Workload and Level of Safety, fell on or close to the mid-range. All subject pilots felt that these procedures were comparable to procedures that they have been accustomed to flying (e.g. CAT I ILS). Pilots did generally feel, however, that the use of autopilot would potentially reduce workload.

Observed pilot performance was fairly consistent across all pilots with the exception of one pilot whose instrument flying technique and performance was exceptional, even with severe cross-wind conditions of up to 40+ knots.

Pilot de-briefing comments were consistent with observed pilot performance. The general perceptions of the subject pilots were supportive of the procedure design, safety, workload level and flyability.

Iso-probability contours were constructed with the probability of being outside the contour (ellipse) of either 1.0×10^{-5} (Missed Approach) or 1.0×10^{-7} (Approach, Enroute, Departure). Due to urgency of completion of initial analysis, these iso-probability contours were calculated from tangent to level flight and the data fitting a normal distribution. These are both conservative assumptions.

Throughout all phases of flight, the iso-probability contours fit within proposed and current TERPS containment laterally. There was a slight penetration vertically in the missed approach segment. This was due primarily to a wide dispersion in the pilot technique utilized to reach the missed approach altitude. It is suggested that training for HLPV missed approaches emphasize the urgency in climbing to the altitude required by the missed approach procedure in an expeditious fashion.

References

[1] Helicopter WAAS Localizer Performance With Vertical Guidance (LPV) IFR To a Heliport (IVH) Approach and Missed Approach Engineering Evaluation, FAA William J. Hughes Technical Center Navigation System Performance Team, Atlantic City, NJ., 8/08.

Post-Run (Departure) Questionnaire (please make comments, as needed, in margins)

Sortie Letter _____ Date _____
Run Number _____ Subject _____
Autopilot Engaged/Disengaged

1. Characterize the departure procedure flown in this phase, compared to a CAT I ILS

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

2. Rate the safety of the departure procedure from lift-off to level flight (obstacle avoidance, radio calls, aircraft maneuvering/handling).

Much Safer		Somewhat Safer		**Same as Typical Operation**	Somewhat Unsafe		Very Unsafe	
1	2	3	4	5	6	7	8	9

3. Rate the level of difficulty of this departure procedure with the autopilot disengaged compared to your current techniques, procedures and policies.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

4. Rate your perceived level of Individual Workload (mental/physical) from the standpoint of deciding, calculating, remembering, looking, searching, maneuvering.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

Post-Run Approach (Land) Questionnaire (please make comments, as needed, in margins)

Sortie Letter _____ Date _____
Run Number _____ Subject _____
Approach Angle _____ Autopilot Engaged/Disengaged

1. Characterize the overall approach flown in the test, compared to a CAT I ILS

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

2. Rate the safety of this approach during the transition from the IFR segment to the visual segment (location, finding the heliport, maneuvering).

Much Safer		Somewhat Safer		**Same as Typical Operation**	Somewhat Unsafe		Very Unsafe	
1	2	3	4	5	6	7	8	9

3. Rate your level of workload (mental/physical) with the particular offset and glidepath angles of this approach.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

4. Rate the level of difficulty of this procedure with the autopilot disengaged compared to your current techniques, procedures and policies.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

5. Rate your perceived level of Individual Workload (mental/physical) from the standpoint of deciding, calculating, remembering, looking, searching, maneuvering.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

Post-Run

Missed Approach Questionnaire (please make comments, as needed, in margins)

Sortie Letter _____ Date _____
Run Number _____ Subject _____
Approach Angle _____ Autopilot Engaged/Disengaged

1. Characterize the overall approach flown in the test, compared to a CAT I ILS

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

2. Rate the safety of this approach during the transition from the IFR segment to the visual segment (location, finding the heliport, maneuvering).

Much Safer		Somewhat Safer		**Same as Typical Operation**	Somewhat Unsafe		Very Unsafe	
1	2	3	4	5	6	7	8	9

3. Rate your level of workload (mental/physical) with the particular offset and glidepath angles of this approach.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

4. Rate the level of difficulty of this procedure with the autopilot disengaged compared to your current techniques, procedures and policies.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

5. Rate your perceived level of Individual Workload (mental/physical) from the standpoint of deciding, calculating, remembering, looking, searching, maneuvering.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

6. Rate your level of workload (mental/physical) with the missed approach segment of this procedure.

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

Post-Test Questionnaire

Sortie_____ Date _____

Subject _____

1. In general, compared to instrument procedures that you normally perform, characterize the departures and approaches flown in the test.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

2. Rate the overall safety of WAAS HLPV Procedures.

Much Safer		Somewhat Safer		**Same as Typical Operation**	Somewhat Unsafe		Very Unsafe	
1	2	3	4	5	6	7	8	9

3. Rate your level of comfort with the varying offset and glidepath angles of these approaches

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortab	
1	2	3	4	5	6	7	8	9

4. Rate your level of comfort with these procedures with the autopilot disengaged

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortab	
1	2	3	4	5	6	7	8	9

5. Rate your perceived level of individual workload of these procedures from the standpoint of mental demand (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.).

Very Low		Somewhat Low		**Same as Typical Operation**	Somewhat High		Very High	
1	2	3	4	5	6	7	8	9

POST-TEST DEBRIEFING COMMENTS

Sortie_____ Date _____

Subject _____

1. Do you think that these procedures, or any segment of them, are unsafe?_____
Why?/ Why Not?

_____
_____
_____
_____

2. Were you uncomfortable during any segment of any of these procedures?
Why/Which segments?

_____
_____
_____
_____

3. What additional mental/physical requirements, if any, were imposed on you during these procedures?

_____
_____
_____
_____

4. Do you feel theses approaches require lighting to maximize flyability/safety? If so, to what level/type?

_____
_____
_____
_____

5. Do you feel there would be a significant difference flying these procedures during the day versus night?_____ If so, why?

_____
_____
_____
_____

6. Do you have any suggestions/comments for these procedures in the future?

_____
_____
_____