TRIAL IGUANA – A FLIGHT EVALUATION OF CONFORMAL SYMBOLOGY USING DISPLAY NIGHT VISION GOGGLES

David C Thorndycraft
QinetiQ
Ively Road
Farnborough, England

Dr Gregory Craig
Institute of Aerospace Research
National Research Council
Ottawa, Canada

Abstract

This paper describes a Flight Trial jointly conducted by QinetiQ and NRC, the purpose of which was to establish the usability of various types of symbology presented to the pilot using Display Night Vision Goggles. The Trial was performed using the Variable Stability Bell 205 operated by NRC at the Flight Research Laboratory, Ottawa in October and November 2003 and conducted under the auspices of The Technical Co-operation Programme (TTCP). World stabilised symbology including Pathway-in-the-Sky representations and more conventional Hover and Hover taxi symbology was evaluated. A key objective of the Trial was the development of an experimental flightworthy system that enabled complex symbology to be rapidly prototyped and displayed at low latency and registered with a high degree of accuracy to the outside world image. This was achieved by reducing delays throughout the whole system, from the aircraft Inertial Navigation System through to the final display source. The Trial successfully demonstrated the usage of world stabilised symbology and showed that under certain circumstances it was a great benefit to the pilot in performing manoeuvres under very degraded visual conditions. The paper describes the overall hardware system, the evaluation methodology employed and presents a summary of the results.

Abbreviations

ADS-33D	Aeronautical Design Standard-
AFS	Advanced Flight Simulator
ALM	Air Littorial Manoeuvre
AMEL	Active Matrix Electroluminescent
ANVIS	Aviator Night Vision Imaging System
BDR	Basic Development Rig
BU	Bob-Up
CA	Curved Approach
DEC	Directorate of Equipment Capability
DGPS	Differential Global Positioning System
DNAW	Day Night All Weather
DVE	Degraded Visual Environment
DVR	Digital Video Recorder
FCC	Flight Control Computer
FoV	Field of View
GDP	Graphics Display Processor
GVE	Good Visual Environment
HTS	Head Tracked Symbology
IIT	Image Intensifier Tube
INS	Inertial Navigation System
MoD	Ministry of Defence
NRC	National Research Council
NVD	Night Vision Device
NVG	Night Vision Goggles
OLED	Organic Light Emitting Diode
PAL	Phase Alternate Line
PCI	Peripheral Component Interconnect
PNVG	Panoramic Night Vision Goggles
SVGA	Super Video Graphics Adaptor
TTCP	The Technical Co-operation Program
VCCS	Visual Cue Control Strategy
VCE	Visual Cueing Environment
VCRs	Visual Cue Ratings

Introduction

This paper describes a recent flight Trial, codenamed Iguana, aimed at improving the adverse weather and low light operating capability of UK battlefield helicopters and was sponsored by the MoD DEC (ALM) Day Night All Weather Helicopter Operations Applied Research Programme (ARP). A tenet of this programme is that accurately positioned and stable geo-referenced symbology acts as a significant aid to pilotage in the Low Level Transit (100 ft agl) and Nap of the Earth (<50ft) regimes.

Trial Iguana continued the work commenced in Trial Groundhog [1], conducted at NRC in 2002. Although Groundhog was primarily an investigation of the performance of the Panoramic Night Vision Goggles compared to conventional NVGs, useful work was performed in the presentation of symbology aimed at improving Situational Awareness in low level Nap of the

Earth (NOE) Pilotage. Display Night Vision Goggles (DNVGs) were used in this Phase of the work but limitations in the equipment prevented the Trial from being more than a preliminary investigation of symbology. The equipment used was identified as needing improvements in the following areas:

- Improvements to the DNVGs to include a modern, fast update rate display source;
- Improvements to the daylight filtering system to enable a more repeatable simulation of degraded visual conditions;
- Inclusion of a scene camera facility for monitoring, fault diagnosis, evaluation of pilot usage of the symbology and presentation of results achieved;
- Provision of a powerful graphics processing computer and versatile input/output facilities.

Objectives

In the past, issues of latency and low precision have dominated the assessment of conformal symbology and the aim of this Trial was to redress this situation. This leads to two sets of objectives, the first to design and evaluate a suitable system and the second to evaluate the use of such a system in performing operational relevant tasks.

Technical Objectives:

- Reduction of system latency together with determination of the delays in the various system components;
- Alignment with the various aircraft and geographic reference frames with a high degree of precision and known uncertainty;
- Derivation of display laws that accurately compensate for both aircraft and head rotations in terms of final image registration with the real world.

Experimental Objectives:

- Assess the value of symbology under highly degraded Visual Cueing Environments;
- Assess the specific utility of conformal symbology for various tasks and manoeuvres;
- Determination of system uncertainties.

System Design

The overall system comprises a head-borne component and an aircraft-borne component.

HEAD WORN COMPONENT

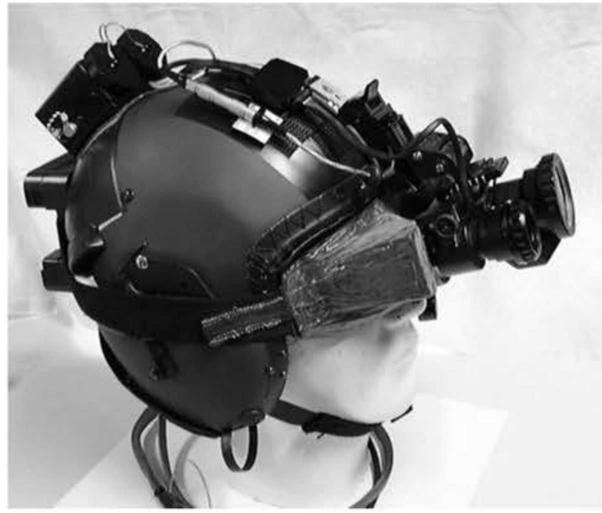

Figure 1 QinetiQ Experimental DNVG

The QinetiQ Experimental DNVG is illustrated in Figures 1 and 2. Symbology from a Flat Panel Micro Display was injected into the eyepiece of a lightweight NVG representative of the latest UK in-service type. A specially designed combination of daylight filters, light exclusion mask and anti-fogging mask enabled simulation of Degraded Visual Environments (DVE) to be achieved in normal daylight conditions. A Scene Camera was included to capture the image viewed by the wearer. This system represented a considerable improvement in capability over the system reported in [1].

Display Optics and Electronics: The Active Matrix Electroluminescent (AMEL) device used in [1] is no longer manufactured and it was decided to replace it using the eMagin SVGA+ Organic Light Emitting Diode (OLED) Micro Display source. The OLED had a smaller active area than the AMEL and, when used with the original optical module, this resulted in a reduction in the Field of View (FoV) of the DNVG. This reduction was considered to be unacceptable and thus a redesign of the optics was undertaken. A key feature of the design of the new DNVG was the use of off-the-shelf optical components coupled with in-house design of the housing. The eventual design solution was similar in design and weight to the original DNVG optical module and the housing was fabricated using Stereo Lithography (SLA). The resultant image had low distortion and good linearity over a 25 deg H x 21 deg V Field of View.

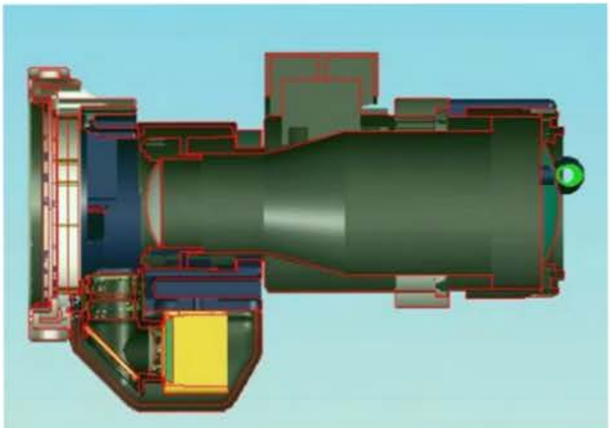

Figure 2 Experimental DNVG layout

The original eMagin SVGA+ demonstrator kit was re-packaged in order to reduce the amount of head worn mass and the OLED microdisplay chip enabled PC video to be received using a few external components. The display and display driver was repackaged in a small SLA module that was mounted directly below the optics module as shown in Figure 2.

Scene Camera: The Scene Camera used a COTS low light CCD camera module and a small folded optical train to transfer the image seen by the DNVG eyepiece onto the Charge Coupled Device (CCD). The optical module and housing was designed and built in-house using COTS components and SLA. The optical module component nearest to the wearers eye was only approximately 6mm in diameter and was positioned at the edge of the eyepiece, as shown in Figure 2, so as to cause minimal obstruction to the wearer. The reduction in eye relief was also approximately 6mm. The sensitivity of the camera was high enough to capture a useable image under all the ambient illumination conditions envisaged for Iguana.

Daylight Filter System: The ability to set a simulated Degraded Visual Environment (DVE) that remained relatively constant during the duration of a Trial sortie was considered vital to the overall success of Iguana. A daylight filter system was developed, known as SHADES. SHADES used a polariser/analyser combination that provided photopic attenuation over a two decade range (Optical Density of 2) and rotation was effected by turning an outer annular ring (left-most component shown in Figure 2). The polariser combination was ineffective at attenuating light at longer wavelengths than visible (380-700 nm) and thus an IR cut filter was used to restrict the range of wavelengths. A proprietary filter combination provided a carefully tailored response with a cut off wavelength at 650 nm, and effectively zero transmittance to beyond the IIT passband. The cut-on filter used in the NVG objective starts to allow light to reach the IIT's at about 620 nm. There was therefore only a narrow range of wavelengths, in the visible red region, that were allowed through to the IITs and this enabled lightweight film polarisers and neutral density filters to be used, thus saving weight.

A rubber light exclusion mask was designed that works in conjunction with a low profile anti-fogging ski-mask to provide extremely good light exclusion.

The remaining head worn components comprised a mount for the Head Tracker Sensor and a battery box to power the NVGs.

PARAMETER	PERFORMANCE
Basic Goggle FoV	46° +/- 2°
Basic Goggle Resolution	1 cyc/mrad
Symbology FoV	25 °H x 21° V
Display Source	AMOLED 800 x 600 pixels
AUW (inc scene camera)	807 grams
Power Consumption	5V at 300mA max 12V at 50mA max
Scene Camera output	CCIR PAL 625 line
DNVG input	SVGA at 85Hz Vertical Refresh

Table 1 Experimental DNVG Specification

AIRCRAFT COMPONENT

The schematic of the Trial Project Equipment is shown in Figure 3.

INS: A significant change to the aircraft system used in Trial Groundhog was the fitting by NRC of a strap down inertial navigation package based upon the Litton LN200 fibre optic gyroscope and a Novatel Differential GPS (DGPS). A single board computer calculates the navigation equations and uses a Kalman filter approach to refine/reduce the error reducing the sensitivity of the system to GPS drop-outs.

Head Tracking System (HTS): The Ascension Technologies LaserBIRD, introduced in 2002, was evaluated by QinetiQ and NRC as a possible replacement to the mechanical and electromagnetic HTS' used in previous Trials. The system proved to be reliable and accurate under the vibration conditions encountered and thus was used in the Trial. Installed Yaw axis coverage was limited to about +/- 70-75° owing to the cockpit layout, although this was not considered to be a major problem. Data was output to the Graphics Display Processor (GDP) via RS-232 in continuous 'streaming' mode. In practice it was found that some filtering had to be added. The effect on latency of this filtering is, at present, unknown and will be determined by empirical means.

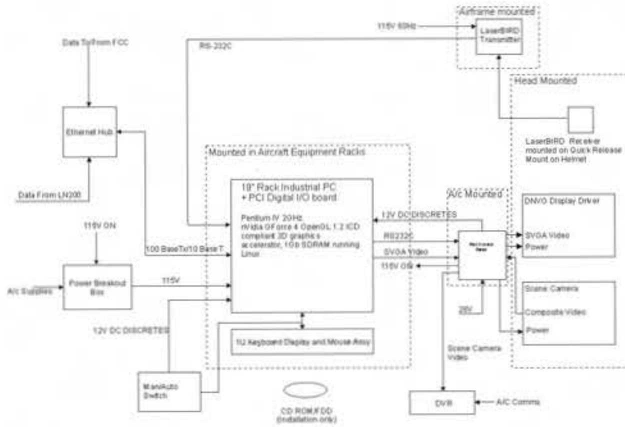

Figure 3 System Schematic

Graphics Display Processor (GDP): A 19" rack industrial PC was used in this Trial to replace the lap-top PC used in Trial Groundhog. This allowed standard industrial I/O boards to be used. A standard PC OpenGL Graphics board based on a GeForce 4™ graphics chip was used to ensure that graphics rendering was performed as fast as possible. The GDP software was designed to receive and process data and render the display as fast as possible. The update rate used was the maximum rate of 85Hz.

User Interface: The main Pilot interface to the system was via switches on the Collective, which allowed the Display Mode to be changed. A Pilot Control Panel (PCP) was also provided to allow the system to be turned on or off and for the system alignment function to be performed. The PCP also contained a diagnostic display together with the ability to set the various system operating modes.

Data and Video recording: Data was recorded onto a standard 2.5 inch Hard Disc Drive (HDD), contained in the GDP, and retrieved onto a lap-top via Ethernet after each flight. Video from the Scene Camera and cockpit audio was recorded onto a Sony Digital Video Recorder (DVR).

System Architecture: The INS outputs navigation solutions at 133.33Hz and it was decided to stream this data directly into the Graphics Processor rather than via the FCC, thus removing a performance bottleneck. This required no changes to be performed to the INS electronics and minimal changes to the aircraft architecture.

Trial Methodology

Trial Iguana consisted of 3 Phases:

- Phase I was an assessment of various symbology types used in Low Hover (10-20 ft agl) and High Hover (200 ft agl) tasks;
- Phase II was an investigation of performance of conventional versus conformal symbology using a reduced version of the QinetiQ Racetrack described in [1]. Only the Spot Turn, Low Speed Hover taxi, Hover and Bob-up portions of the Racetrack were used in this evaluation;
- Phase III was an assessment of advanced display concepts including pathway in the sky symbology.

Phase I - Low and High Hover Tasks: The low Hover task was performed facing the Maritime Hover Board as shown in Figure 5. The high Hover task, for safety, was performed facing into wind and at an adequate clearance from any obstructions. This meant that the cueing environment varied from pilot to pilot depending on the wind direction although all the cues were essentially distant. A method was provided whereby the heading at the start of the high Hover became the 'reference' axis for some of the symbology sets used.

Phase II - The Racetrack: Previous evaluations of PNVG versus NVG [2] have used ADS-33D [3] as a methodology. This Standard, originally developed to estimate military helicopter Handling Qualities, was based around a common set of strictly defined manoeuvres and comprised the basis of military helicopter evaluation and certification in the US and, as such, is still widely accepted. Efforts have been made in the past few years to adapt this method to include visual displays as part of the control system. Due to practical constraints it is not ideal as a method for rapidly assessing novel display concepts and therefore an alternative method has been used for this purpose in simulator Trials at QinetiQ for a number of years. This 'Racetrack' method tries to simulate the trade-off between precision and tempo experienced in helicopter operations. The method is conducted in a natural cueing environment and requires the pilot to achieve accurate positioning tasks as quickly as possible without going outside generous boundaries between the positions. Typically the Racetrack course comprises a descent from cruise speed, some low speed manoeuvres followed by a rapid egress. The course uses natural terrain with minimal features such as cones. A simplified version was used in Trial Iguana as shown in Figure 4.

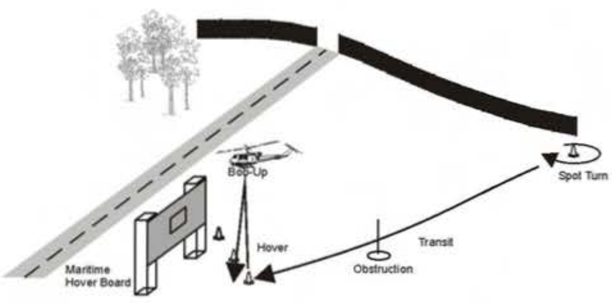

Figure 4 Racetrack used in Trial Iguana

An accurate survey of the ADS-33 field had been performed prior to the Trial. This enabled the position of the various features to be known to an uncertainty of approx. 20 cm with respect to the geographic reference frame. This not only enabled conformal symbology to be accurately positioned but also increased the precision at which a/c position may be analysed.

Spot turn and Hover taxi: A spot turn over a position marked by a large bin was made, followed by a low speed Hover taxi across the field to hover in front of a large structure known as the Maritime Hover Board (Figure 5).

Between the start and finish of the task was an 8ft high pole marking the Precision Hover portion of the ADS-33 field. A conformal 'hazard' marker was positioned at this point. The presence of the obstruction increased the task difficulty.

Low Hover: In the hover position the MHB was directly in front of the pilot, thus giving strong streaming and vertical and horizontal backdrop cues. The hover task lasts for approximately one minute.

Bob-Up: The pilot was required to acquire a height of 60 ft in the minimum time, maintain that height for 5-seconds and then descended to 20 ft. The Pilot lined up the markers on the near pole with the target box on the rear structure. As the height increased the visual cues changed considerably and thus the task was considered to be a good discriminator by condition.

Phase III - Advanced Display Concepts: An objective of this phase was to implement a simple Pathway-in-the-Sky to aid the pilot in performing a complex multi-axis control task. A Curved Approach (CA) task was chosen. This was a multi-axis control task comprised of a turning, descending, decelerating approach to a hover capture. One of the Assessing Pilots flew the Curved Approach in GVE, as if he were flying the route using NVGs in degraded conditions. The aircraft GPS position data was then processed such that a series of gates was generated, positioned 3 seconds apart. The disadvantage of this method was that it did not allow for changes in wind direction rendering the pathway more difficult to fly than when first generated. The pathway markers were trough-shaped and 30ft wide by 10ft high. The base of the trough was 20 ft wide. The pathway terminated at the start position for the racetrack and this position could be marked with a conformal symbol and surrounded by a series of conformal markers thus forming an artificial confined area from which the pilot should not stray.

Figure 5 Maritime Hover Board (MHB) and acuity chart.

Visual Acuity: The symbology evaluations were performed at two values of simulated light level approximating 1mLx and 0.1 mLx. In order to provide consistency an acuity chart was placed by the MHB as shown in Figure 5. The SHADES day light filter system was adjusted until the appropriate line on the chart could be read correctly. In practice the light level varied considerably but with practice pilots were able to use SHADES to keep the perceived resolution approximately constant.

Symbology Evaluated

APACHE-type Symbology: This is illustrated in Figure 6. It was functionally similar to the WAH-64D symbology although where necessary modifications were made to cater for the tasks envisaged, for example there was no weapons related symbology, neither was there any Sensor/HMD Field of Regard box or cues. The low speed Hover and Transition set only were implemented, hence there was no Pitch Ladder symbol.

Heading: This is a simple heading tape scale with a digital display in the centre. It was driven directly from INS aircraft true heading.

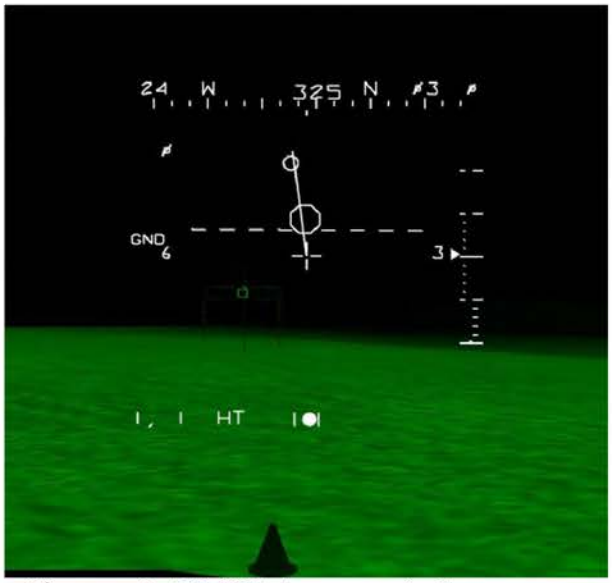

Figure 6 APACHE-type symbology

Height: This was an analogue tape scale and a digital height display. It was driven from a filtered version of the Radar Altimeter signal.

Speed: This showed either Indicated Airspeed (IAS) or GPS derived Groundspeed, selectable via software. It was shown as a digital display only.

Note: The above variables may be displayed as digits only and this is referred to in future as the 3-Digit Set.

Vertical Speed Indicator (VSI): This analogue instrument was contained alongside the height tape scale. It was driven from the INS Vertical Velocity signal.

Velocity Vector (VV): This provided the primary guidance symbology in the Apache-type symbology. The symbol was referenced to the centre reticle and showed the a/c velocity with regard to the longitudinal axis of the aircraft. It was driven from INS derived Northing and Easting Velocity

Acceleration Ball: This was referenced to the tip of the Velocity Vector and showed the acceleration of the a/c with regard to the body axes. It was driven from the INS accelerometers with some smoothing applied.

Torque Digits: This digital display was driven directly from the Flight Control Computer Torque signal.

Horizon: This was either a fully conformal horizon or an APACHE-type (aircraft roll and pitch stabilised only) selectable via software.

Hover Box. This was an Octagonal symbol which gave a Plan Position indication of a/c position relative to a desired landing position. The Hover box could either be in a pre-set position or 'dropped' by using a button on the collective.

Hover Arrow Symbology: This symbology, shown in Figure 7, was developed by QinetiQ and aimed to solve some known problems associated with the APACHE symbology, examples of which are disorientation when moving the head off-axis and a somewhat cluttered central area.

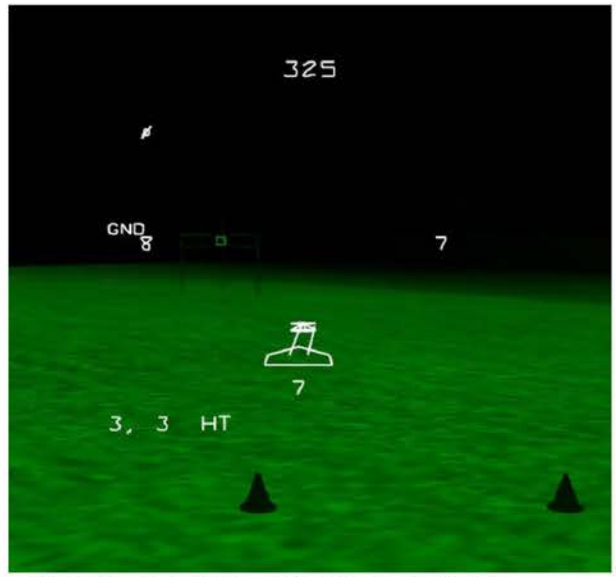

Figure 7 Hover Arrow symbology

The Hover arrow symbology comprises a 3-Digit Set + the following symbology:

Home Plate: This was a large arrow symbol that showed the longitudinal axis of the a/c irrespective of head position. It was depressed from the normal line of sight so as not to obstruct the central view.

Velocity Vector (VV): This was similar to the Apache symbol and was driven from the same variables. The length of the vector was marked with lines that indicated speed increments.

Acceleration/VSI: This was a combined symbol referenced to the tip of the VV. The VSI was shown as an upwards or downwards pointing cone, the position of which was related to acceleration and the length of the arrows was related to vertical speed.

Hover Arrow Maritime: This symbology, shown in Figure 8, was originally developed by QinetiQ to aid pilots in landing large helicopters on small ships, comprises the 3-Digit Set + the following symbology:

Hover Position Indicator (HPI): This showed the position of the aircraft with regard to a desired hover or landing position in a defined axis system. The axis system was typically one that provides strong orientation cues, i.e. landing on the back of a ship the longitudinal axis of the ship and the hangar etc provided the visual reference frame. Similarly landing in a confined area the shape and dominant features could provide a strong 'preferred direction'. The square box symbol shows when the a/c was within the desired limits.

Line-Up: Arrows at the top of the display showed the difference in angle between the preferred direction and the a/c yaw.

ASAR: Arc Segmented Attitude symbol. This is a symbol that combines Roll and Pitch into one display.

HEIGHT scale and DATUM: This analogue display was designed so that the top of the height tape was at the datum position, shown by a pointer at a desired hover height. The height bar was set to this position by pressing a button on the collective.

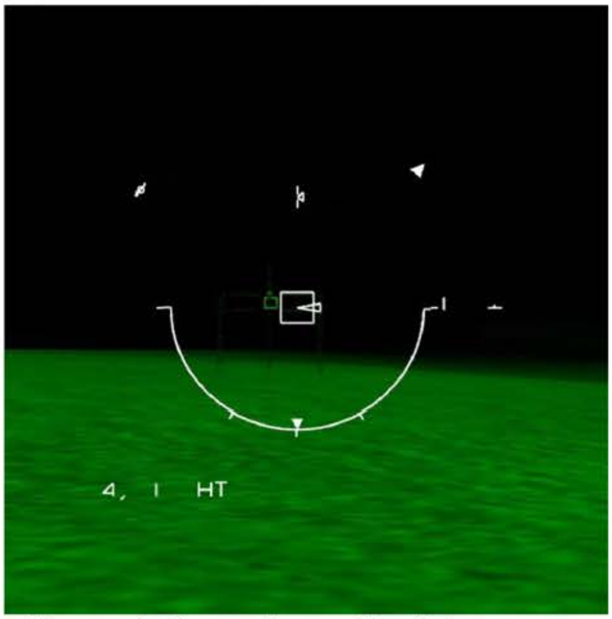

Figure 8 Hover Arrow Maritime.

Perspective display: This is illustrated in Figure 9 and combines a 3-Digit display Set with a pair of conformal symbols designed to give longitudinal, lateral and height cues. There was an identical symbol pair at 45 degrees to the right that was used to aid in longitudinal positioning. The relative spacing or 'gearing' of the symbol was software definable.

Conformal symbology types: The conformal symbology comprised a number of display elements:

Hazard marker: This was shown as a pole and a zigzag symbol at the top. The circle at the base of the pole was used to give perspective cues.

Landing or Hover marker: This was shown as a pole with a 'Vee' symbol attached to the top and illustrated in Figure 10.

Alignment symbol: This shows the position of the Maritime Hover Board and was used during the boresighting procedure. This is shown as the X symbol in Figure 10.

Conformal Waypoint marker: This was a single or double pole symbol with a hexagonal shape attached to the top and a hexagonal base. It was used as a general purpose marker.

Pathway gate symbol: This was a trough shaped symbol with the bottom of the trough being parallel to the horizon.

Wireframe overlay: This was a ground mesh overlay

Flight Path Marker (FPM): An optional conformal FPM indicated the intersection of the ground plane with the aircraft instantaneous flight path.

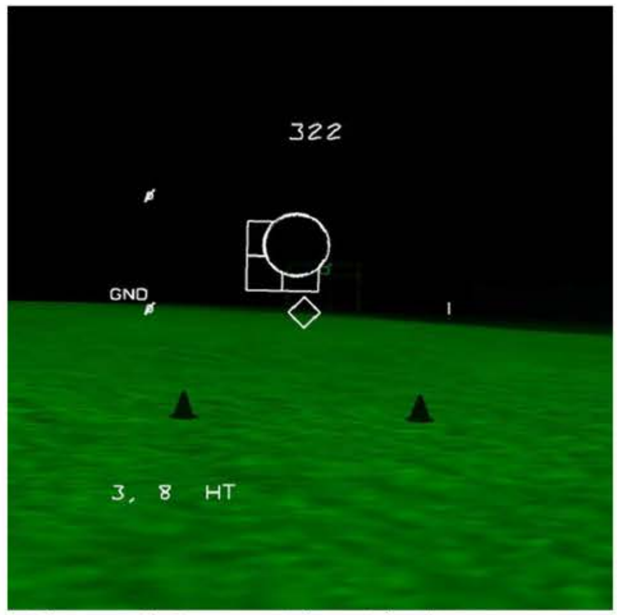

Figure 9 Perspective Display

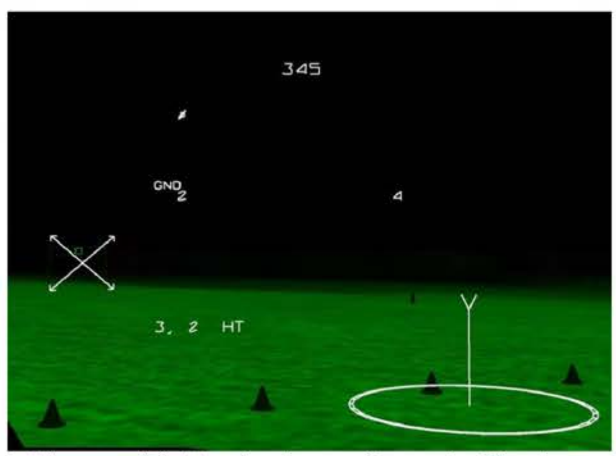

Figure 10 Typical conformal displays.

Advanced Concepts Display symbology: The symbology was designed such that the various display primitives were able to be combined with minimal problems regarding overlap or occlusion of important information. The Advanced Concepts symbology thus used a combination of Pathway symbology, ASAR display, Wireframe overlay, and FPM for the Curved Approach changing to Hover Arrow and Conformal Marker symbology at the hover capture position. A typical display is shown in Figure 11. This picture was captured in flight using the scene camera

Figure 11 Pathway Symbology (from Scene Camera)

Analysis Methods

A number of metrics both subjective and objective were used to analyse the performance achieved in the various Trial Phases.

Subjective Metrics (In Flight):

The following conventional metrics were used:

- China Lake Situational Awareness
- Bedford Workload Scale
- Visual Cue Ratings
- Handling Quality Ratings

Subjective Metrics (Post Flight):

Manoeuvre/ Symbology Questionnaire: The pilot was required to rate the manoeuvres used in order of difficulty. This was useful at the objective analysis phase in prioritising the order in which detailed analysis was performed. The pilot was also required to score the symbology in terms of whether a) it helped in performing the task b) hindered c) noticed but not used or d) not noticed. This was very useful in the objective analysis phase. For example if the pilot notes that the height display was not noticed although a very precise control of height is obtained, a false conclusion may be avoided.

Subjective Workload Dominance (SWORD): This is an easily used subjective paired question technique used to compare the various symbology sets for the various manoeuvres.

Objective Metrics (Post Flight)

Drift plots: The drift of the a/c in the hover and bob-up was plotted and a drift box area, the product of Standard Deviation in both the longitudinal and lateral directions, calculated as a metric.

Phase Plane Plots: These plot aircraft rate versus drift in both longitudinal and lateral axes. They are useful in determining how controlled the a/c hover was and the shape of the plot can be used to deduce the control strategy adopted. For example small tight circles around the zero position indicate a well controlled a/c whereas a divergent spiral shows progressive loss of control.

Time Histories: Time histories of height variation and head tracker angles were plotted

Velocity Plots: These plots show along track and cross track velocities. They can be used to assess how confident the pilot is getting from A to B. The maximum along track velocity is used as a metric.

DIMSS Workload metric: The DIMSS (Dynamic Interface Modelling and Simulation) metric is the product of the number of control reversals and the standard deviation of control deflections in a moving 3-second window. A control reversal is defined as a min or a max in the control deflection time history with reversals at frequencies higher than 3.3Hz filtered out. The premise of the metric is that high frequency, large amplitude control movements, resulting in high values of the metric, represent high pilot control workload, and therefore one of the contributing factors to overall workload. Similarly, low frequency, low amplitude control movements, resulting in low values of the metric, represent low pilot control workload. The mean of the resultant time-history is the objective workload metric used in this paper.

Power Spectral Density (PSD): The premise with PSD analysis is that the pilot will reflect his workload in terms of the power generated for the task and that the pilot's cut-off frequency will change with workload. That is, the harder the pilot works to establish and maintain a position, the higher the input power and generally the higher the cut-off frequency. Moreover, [4] states that human control of helicopter flight comprises low frequency guidance and higher frequency stabilisation motor stimuli and the relative proportions of each yields information about the pilots 'stability margin'. [4] argues that a separation of the two components can indicate the onset of PIO. The author of this paper contends that PSD and DIMSS analysis should be used together. A high DIMSS metric does not necessarily indicate that pilot input has reached a limiting value if the PSD shows the majority of the energy is contained in the low frequency bands (<0.5 HZ).

Time to complete: This was either the time taken to traverse the field, time to complete the Curved Approach part of the racetrack circuit or the time to perform the Bob-up task.

Pathway metrics: For the Pathway-in-the-Sky analysis three metrics, were calculated: cross track error, height above gate error and gate passing time error.

Results

System Performance.

DNVG: The redesigned DNVG provided a crisp, clear image. The use of an OLED resulted in some background off-pixel glow and this required a filter to be used to attenuate the overall output of the display

SHADES: The SHADES daylight filter system was effective under most of the lighting conditions experienced. However the range of illuminances encountered exceeded the dynamic range on a number of occasions and thus a better system is required. In addition the limited range of wavelengths passed by the system resulted in a slightly unnatural NVG view in that the visible red components were accentuated. A new system is currently under development. The anti-fogging goggles and the light exclusion hood were very effective.

Scene Camera: The Scene Camera was very effective in use. The pilot feedback was that the visual impact of the eyepiece mounted component was negligible. The system enabled post-flight diagnosis of problems that would otherwise have required QinetiQ /NRC staff to flight test the equipment.

LaserBIRD HTS: The LaserBIRD system worked extremely well for the duration of the Trial. Overall accuracy was 0.33 degree and the high update rate enabled a system of low latency to be achieved. There was no evidence that operation was degraded by the high vibration environment.

NRC-LN200 system: This was reliable in operation with no reported errors in the navigation solution. The overall uncertainty of the navigation solution at 0.2m with regard to the reference frame was confirmed.

Overall system performance: The overall system accuracy at positioning conformal symbols was tested and at no time, with a correctly boresighted system, was the error worse than 0.5m. Latency was not measured but was felt to be adequately low for most tasks. The display update rate at 11msec was subjectively the limiting parameter in the end-to-end latency budget. On a fast head scan the conformal symbology visually 'steps' rather than exhibits a pronounced 'lag'.

Human Factors: The all up weight of the system was felt to be satisfactory and the balance was good. The pilots felt that control of symbology brightness was important so sufficient contrast over the imagery may be achieved.

Discussion of Subjective Evaluation results

Results of the subjective evaluation were generally disappointing. There was a general agreement that the task difficulty increased as the effective light level, as set by SHADES, decreased. However there was very little evidence of discrimination between the symbology sets, even when the objective data revealed performance differences (see next section) between the symbology sets.

The most severe shortcoming was the ability of the pilot or non-handling (safety) pilot to determine whether the desired and adequate limits had been achieved. Whilst ADS-33 allows task performance to be subjectively assessed QinetiQ consider it important that task cueing bounds are checked using objective data to ensure that desired performance can be achieved with the cues provided. There was evidence from the objective data that the level of precision required to give correct VCR's and HQRs was insufficient. This alone rendered the majority of the performance based subjective evaluation invalid. It is therefore recommended that in future a reduced set of subjective questionnaires are used and that where possible objective data analysis replaces subjective analysis. The SWORD technique was useful, as were HQRs and VCRs providing that accurate assessments are made of performance achieved. The simple symbology questionnaire was a useful aid in establishing whether the pilot was using all the display or whether further training time was required.

Discussion of Objective Evaluation results

This discussion covers Phase I and Phase III evaluations. The Racetrack evaluation is not covered in detail for the sake of brevity and also because the velocity vector guidance was found, post Trial, to be incorrect thus invalidating the analysis. A brief discussion on the Bob-up task is included.

High Hover Drift: The Apache-type symbology gave the greatest improvement in drift. Figures 12-1 to 12-2 shows the drift achieved for the various symbology conditions for both simulated DVE conditions, referred to as SHADES light and SHADES dark. In all but one case the Apache-type symbology achieved the lowest absolute drift and two pilots achieved better performance than in the GVE condition. Usage of the other symbol sets gave varying degrees of performance. The 3-Digit set provided no guidance information, however the drift performance was clearly worse than the no-symbology case i.e. the symbology only served as a distraction. The conformal markers + wireframe symbology clearly provided no benefit in controlling drift.

High Hover DIMSS: Typical plots of DIMSS metric are shown in Figures 13-1 to 13-2. The analysis shows that 3 out of the 4 pilots experienced the highest control workload using the HAM and relatively low control workload using the Apache-type symbology compared to the no symbology condition. This confirms that pilots using the Apache-type symbology achieved low values of drift at the expense of a minimal increase in control workload. The plots also show clear between-subjects variation of the metric. The author contends that this is due to pilot 'gain', i.e. describing the pilot as part of the aircraft control loop. Whilst a pilot will effectively alter his gain depending on the workload and feedback provided for any task, each individual pilot will have a natural bias. Effectively a 'high gain pilot' is one who reacts more rapidly and aggressively to errors than average, this requires a high gain aircraft to be effective and is often associated by one whose early experiences are of a high gain aircraft. Conversely a 'low gain' pilot often employs a slower but higher control displacement strategy suited to a low gain aircraft, again generally associated with ones early experiences. *N.B In 13-1 and 13-2 the plots are arranged such that the low-gain pilots are at the front.* The use of the DIMSS metric can be used to assess whether an increase in control activity brings about a concomitant increase in performance. Inspection of 12-1 and 13-1 identifies the HAM as a condition where increase in control activity reduces the drift error, for pilots 2 and 3.

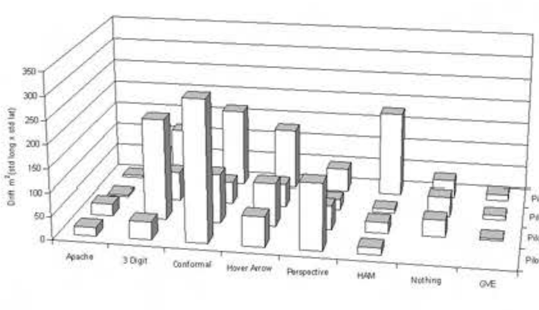

Figure 12-1 High Hover Drift (SHADES light)

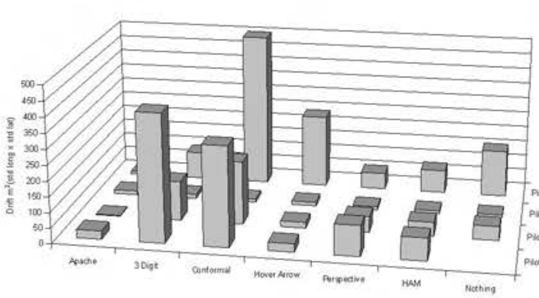

Figure 12-2 High Hover Drift (SHADES dark)

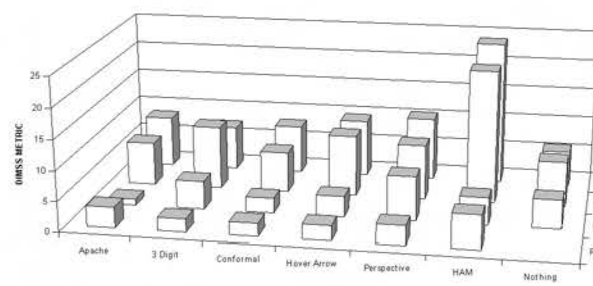

Figure 13-1 High Hover DIMSS (SHADES light)

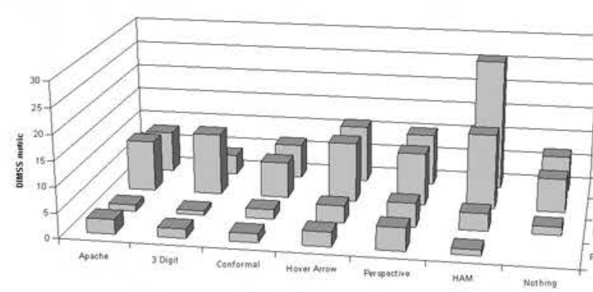

Figure 13-2 High Hover DIMSS (SHADES dark)

High Hover Height performance: Figures 14-1 shows the height variation achieved by the symbol sets. The perspective display seems to work well in this situation, in the SHADES dark condition achieving the best height control for all the pilots, despite comments from the pilots that the longitudinal and lateral line-up cues were non-intuitive. The relative movement of the two symbols seems to impart an easy to interpret height cue and this feature should be investigated further.

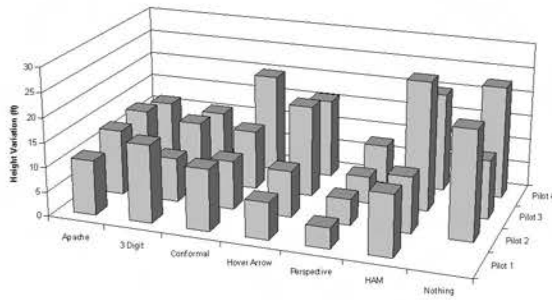

Figure 14-1 High Hover Height Variation

High Hover Headscan: Analysis of the pilot headscan showed that each symbology set produced a different, characteristic pattern that was unique to a pilot and consistent between identical runs. It proved to be a valuable method of determining whether or not a pilot was using the symbology. This is summarised below:

No-symbology	Rapid head NVG scan pattern;
Conformal	Rapid head NVG scan pattern;
3 Digit	Rapid head NVG scan pattern;
Apache-type	Little or no head scan;
Hover Arrow	Moderate head scan;
Perspective	Rapid head-scan between 0 and 45 degrees to longitudinal axis of a/c;
HAM	Low head scan.

A commonly held tenet is that high amounts of headscan are a contributory factor to high workload. The authors contend that although high head-scan rates are generally undesirable, the ability to move the head at moderate rates is natural and that displays that tend to 'lock' the pilots head in one direction, i.e. Apache-type, are hence unnatural and can result in poor Situational Awareness (SA). The use of symbology that generates the moderate head scan rates of normal unaided daylight conditions is hence desirable.

Low Hover Drift: Figures 15-1 and 15-2 show the Drift performance achieved in the low hover and show that the best performance was achieved with no guidance symbology being displayed. Note, however, that pilot P4 achieved the best performance with the Apache-type symbology in both light and dark conditions. An interesting difference between the low and high hover tasks was that the 3-Digit set did not cause the decrease in performance noted in the high hover, being broadly similar to the no-symbology condition and the GVE condition. A reason for this could be that because the quantity and quality of the visual cues in the low hover was higher and thus the 3-Digit symbology was less of a distraction. There was a general increase in the drift in the SHADES dark condition compared to SHADES light.

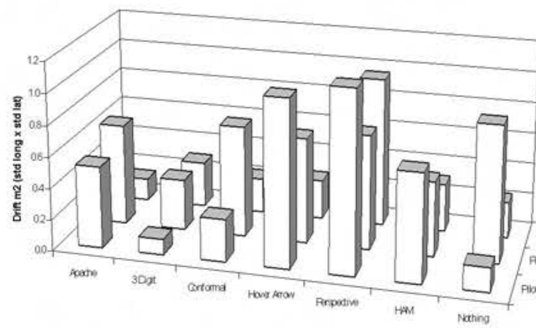

Figure 15-1 Low Hover Drift (SHADES light)

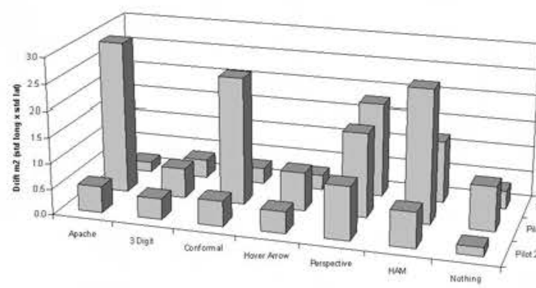

Figure 15-2 Low Hover Drift (SHADES dark)

Low Hover DIMSS: Analysis of the DIMSS workload metric showed that there was an overall increase in the metric over the high hover condition and a general increase in level for the SHADES DARK conditions compared to SHADES LIGHT. Figure 16-1 shows that the Hover Arrow Maritime had the highest associated workload, again probably related to incorrect scaling. The between-subjects variation is again apparent with the low gain pilots shown at the front t of the plots.

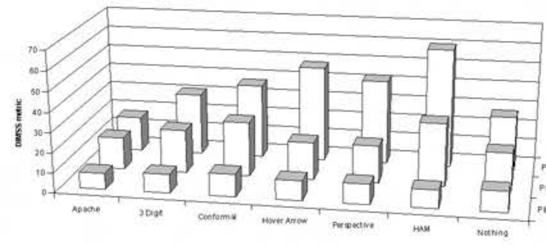

Figure 16-1 Low Hover DIMSS (SHADES light)

Low Hover height variation: The variation in height was generally less than 1 ft (1 σ) which is below the resolution of the height display. It is assumed the pilot was relying on purely visual cues for height control.

Pathway track: Use of the pathway symbology enabled the a/c track to be controlled accurately. The curved approach followed the line of a main road for much of the first portion and this provided a much stronger visual cue of desired track than if the approach had been conducted over featureless terrain.

Inspection of Figure 17-1 (top left plot), a run made without symbology shows that rather than flying a smooth, curving approach the pilot made distinct corrections to his track, corresponding to the remaining visual cues. The cross track error plot (bottom left plot) similarly shows quite large deviations. There was a large amount of drift at the end of the pathway and the Hover taxi passes the hazard marker on the wrong side.

Using symbology, in this case the pathway symbology shown in Figure 11 during the Curved Approach and the hover arrow during the Hover taxi, resulted in much improved track following performance, as shown in Figure 17-2. The drift was only just outside the hover-capture area and the track across the field was much improved.

Pathway height: Height control with symbology was better than without symbology as shown in Figures 17-1 and 17-2 (top centre plot). The pilots generally flew higher than the gate height, converging on the desired height just before the end of the straight portion of the curved approach. The pilots consistently performed a levelling out at the 4th or 5th gate from the end of the pathway. Because of this the pilot would end the hover some 20ft AGL. One explanation was that the end speed was too high necessitating quite a pronounced flare out and consequent height 'ballooning'. An alternative, and more likely, explanation was that the waypoints marking the simulated 'confined area' provided strong height cueing.

Pathway Speed: The primary speed cues were the IAS digits and the rate at which the gates were passed. Speed control was noticeably different between the two Assessing Pilots that evaluated the pathway symbology. With symbology, P3 would fly the approach at a constant speed as indicated by the linearly decreasing time per gate shown in Figure 17-2 (bottom right plot). With no symbology P3 would maintain a far more constant, but slower, time per gate. P2, by comparison, would decelerate during the approach and thus keep the time/gate more constant. It was hence apparent that different speed control strategies were being adopted. Simulation studies led these gates to be set to a passing rate of one every three seconds, mainly to ensure that the amount of visual clutter was kept to reasonable limits. Simulator evaluation may be used to further explore the trade-offs between gate frequency and speed control, the objective to make this as intuitive as possible.

Subjective comments: Pilot comments on the pathway were very encouraging. The pilots had the confidence to fly in extremely degraded simulated DVE conditions with very marginal outside world cues.

Conclusions

The system used in Trial Iguana showed that by utilising a holistic design approach useable conformal symbology at high precision and low latency can be achieved using available COTS technology. The residual errors in the system were the limiting inaccuracies of the headtracker and the uncertainty of the position of real world objects with respect to the geographic reference frame. The use of an accurately surveyed field enabled these errors to be bounded and it is expected that further work will be performed in subsequent years to investigate similar tasks, at more realistic system uncertainties.

The following conclusions are made as a result of the work performed in Trial Iguana:

- The Apache-type symbology enabled the pilots to reduce the drift in the high hover down to the levels achieved in GVE conditions, at minimal increase in control activity workload however the noticeable lack of head movement could have an adverse impact on SA;
- The perspective display provided some indications of improved height performance in the high hover;
- The symbology provided no benefit in the low hover condition;
- The Pathway symbology enabled good control of Track and Height to be achieved and turned a very difficult task into one that could be flown with confidence;

- The use of Conformal Symbology provided the pilot with confidence as to where hazards are positioned and increases SA;
- The DIMSS metric appeared to be a promising technique for determining output-task (control) workload.

Acknowledgements

QinetiQ gratefully acknowledges the support of the staff at NRC during Trial Iguana.

References

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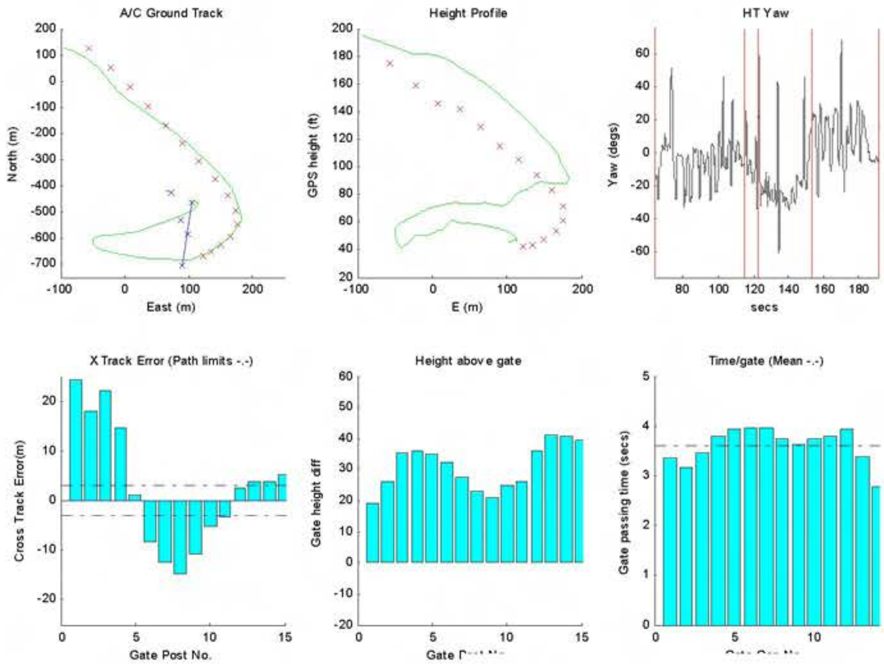

Figure 17-1 Pathway and hover taxi with no symbology

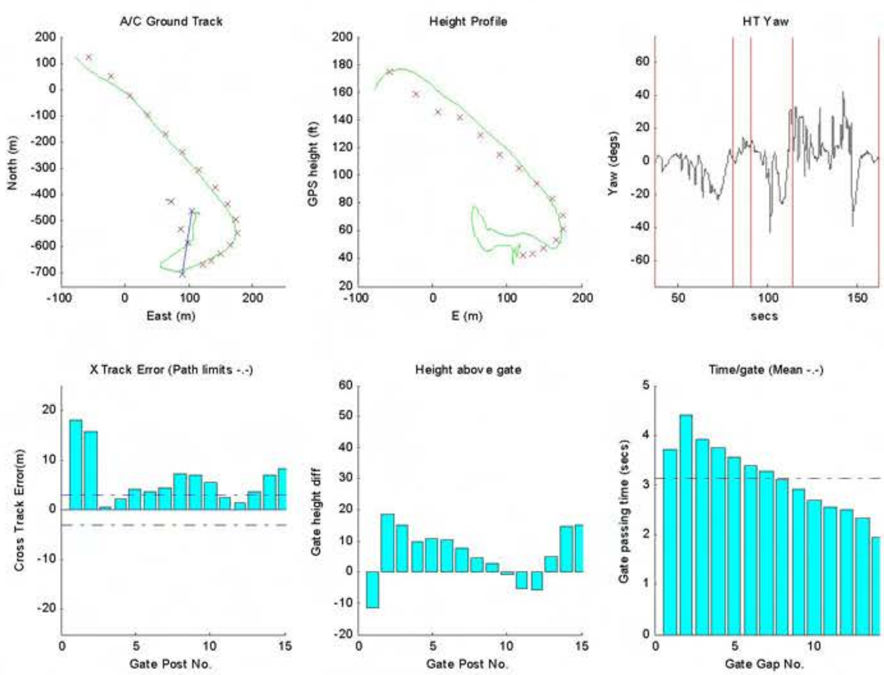

Figure 17-2 Pathway and hover taxi with symbology