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ASSESSMENT OF HELMET-MOUNTED HUD SYMBOLOGY REFERENCING SYSTEMS

FINAL REPORT

30 March 2000

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Prepared by

Dr. Chris M. Herdman

Human Factors Consulting
Ottawa, Ontario, Canada

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ASSESSMENT OF HELMET-MOUNTED HUD SYMBOLOGY REFERENCING SYSTEMS

ABSTRACT

The TTCP Technical Panel 2 (TP2) developed a HUD symbology set using a "mixed" referencing system in which symbols portraying spatial analogue information are aircraft or world referenced, whereas non-spatial symbols are head referenced. One potential advantage to having non-spatial symbols referenced to head position is that critical flight and power information can be made available to the pilot even when the pilot's gaze is directed to the side of the aircraft, such as during sidestep maneuvers. It is not clear, however, whether pilots can effectively use a mixed referencing system. For example, one potential problem is that depending on moment-to-moment positioning of the head, one or more of the head referenced symbols may overlap with the aircraft referenced symbols. This may create intolerable perceptual/cognitive confusion and high mental workload.

There were two objectives of the present research. The first objective was to contrast the effectiveness of the TP2 mixed frames of reference against an aircraft and a fully head-referenced configuration. To do this, two ADS33-type tasks were used: formation flight and sidestep. The formation flight results showed that there was undifferentiated performance across the aircraft, mixed, and head FORs. The sidestep results showed an advantage for the mixed and head FORs over the aircraft FOR in two primary performance measures: maintaining heading and altitude. The superiority of the mixed and head FORs for the sidestep maneuver was also reflected in the pilots' ratings.

A second objective of the present research was to take a step toward establishing a paradigm to assess the effects of space-based and object-based attention in processing of HUD symbology. To do this, pilots' ability to discriminate targets that appeared on a HUD was assessed across the mixed, aircraft and head-referenced configurations. The results of this experiment were clear in showing that the processing of information on HUD displays is affected by space-based attention. Importantly, the spatial attention effects occurred in the head-referenced configuration, but not in the aircraft or the mixed FORs. The comparison of the head versus aircraft conditions supports the notion that referencing the HUD to head movements creates a near (HUD) domain perceptual layer that is distinct from the far domain of the external scene. On this view, the effect of

spatial attention occurred with the head FOR because attention is assigned to the HUD layer, in a manner similar to the placing of attention on perceptual objects. With the aircraft referenced configuration, the HUD (near-domain) and the external scene (far domain) are less likely to form distinct perceptual layers.

Keywords: Heads-Up Display (HUD), Helmet-Mounted Display (HMD), Symbology, Frame of Reference, ADS33, Attention, Aviation Displays.

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SECTION ONE: GENERAL OVERVIEW

1.1 INTRODUCTION

Helmet Mounted Displays (**HMDs**) offer several potential advantages for flying rotary and fixed wing aircraft, including protection from laser dazzling as well as the capability to fly in degraded visual conditions. In HMDs equipped with visually coupled systems (**VCS**), a direct view of the external world is projected onto the HMD along with symbology representing primary flight and power information.

In November 1998, technical experts from the allied nations in the Technical Co-operation Panel 2 (TTCP TP2) established a prospective symbology set for use in a helmet-mounted display. This symbology set was implemented on the Air Crew Demonstrator (ACD) at BAE Systems, Canada (formerly Canadian Maconi Company) and assessed in an initial study (SOW 3773-3HC16, DSTA 2, December 1998).

The TP2 symbology set (see Figure 1) was developed based on an assumed Search and Rescue (**SAR**) mission in which a helicopter equipped with a VCS HMD clears cloud at 500 feet and establishes contact with a crash site under degraded visual conditions. The helicopter is to descend to the rescue site along a prescribed glide path over rough terrain at which point a hover is achieved. The implementation of the TP2 symbology set in the present research conforms to the specifications listed in Statement of Work (SOW) #3773-3HC16 (DSTA 2): details concerning the description and function of the various symbols can be obtained from the SOW.

The original TP2 symbology set is a "mixed" referencing system in which symbols portraying spatial analogue information are aircraft or world referenced, whereas non-spatial symbols are head referenced. One potential advantage to having non-spatial symbols referenced to head position is that critical flight and power information can be made available to the pilot even when the pilot's gaze is directed to the side of the aircraft, such as during hover and sidestep maneuvers. It is not clear, however, whether pilots can effectively use a mixed referencing system. For example, one potential problem is that depending on moment-to-moment positioning of the head, one or more of the head referenced symbols may overlap with the aircraft referenced symbols. This may create intolerable perceptual/cognitive confusion and high mental workload.

The initial assessment of the TP2 set (SOW #3773-3HC16 DSTA 2) compared the TP2 mixed reference configuration to two other symbology referencing configurations: "aircraft" and "repeater". All of the symbology configurations used the same TP2 symbols shown in Figure #1. For the aircraft-referenced set, all of the symbology was referenced to the front and center of the aircraft, and was presented only in the forward field of view. For the repeater set, all of the symbology was aircraft referenced, plus some symbology that was not tied to aircraft orientation (Rad Alt, airspeed, and torque) was repeated 90° to the left and right periphery.

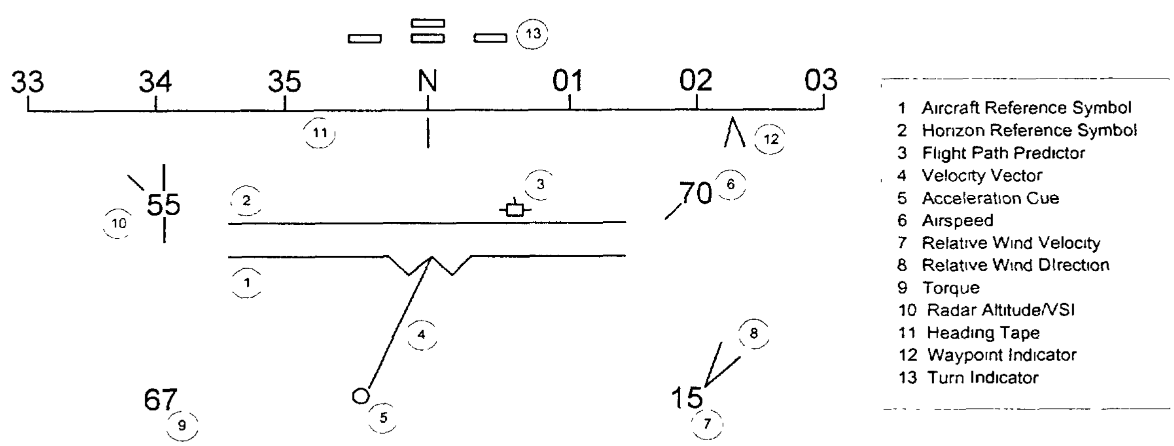


Figure 1: TP2 Symbology Set

The results of the initial assessment of the TP2 symbology showed that the mixed set resulted in performance that was as good as, and at times superior, to performance with a fully aircraft-referenced set. In addition, pilots indicated a preference for the mixed FOR as compared to an aircraft FOR.

The ability to effectively use the mixed FOR can be explained in terms of object-layering: through coherent motion, the symbologies that were head-referenced appear to exist and move in a unitary perceptual layer that is distinct from the aircraft- and world-referenced symbols.

Despite the relative utility of the TP2 set (as demonstrated in the initial study) there are numerous outstanding issues that must be addressed. One category of issues relates to the static and dynamic qualities of the various symbols in the TP2 set. Of particular concern is that, at times, pilots became disoriented when using the mixed set. Some of the disorientation was attributable to confusion that arose between the heading tape and the horizon line (as part of the AI). A modification to the TP2 heading tape was warranted.

A second important issue relates to FOR. In the initial study examining the TP2 set, a fully head-referenced system was not assessed. Given that there are currently several HMD systems that require complete head-referencing of symbology (e.g., ANVIS HUD and possibly early versions of ESVS), it is germane to evaluate this approach to referencing flight and power symbology.

1.2 PRESENT OBJECTIVES

There were two primary objectives of the present research. The first objective was to compare three frames of reference: the mixed and aircraft references used in the initial assessment and a fully head-referenced. The referencing for these three frames of reference are shown in Table 1. The second objective was to take a step toward establishing a paradigm to assess the effects of object layering in HUDs.

Table 1. Symbology referencing for the three experimental conditions

Symbol	Aircraft	Mixed	Head
Torque	aircraft	head	head
Hover	aircraft	aircraft	head
Attitude	aircraft	aircraft	head
Rad Alt	aircraft	head	head
IAS	aircraft	head	head
Rate of Turn	aircraft	aircraft	head
Wind direction and velocity	aircraft	aircraft	head
Velocity Vector	aircraft	aircraft	head
Heading Tape Lubber Line	world aircraft	world aircraft	world head
Heading Select Bug	world aircraft	world aircraft	world head

1.3 CHANGES TO THE ORIGINAL TP2 SYMBOLOGY SET

The primary cause of pilots' sense of disorientation when using the original TP2 set was attributed to the heading tape which remained in the pilots' field of view during all head movements. To correct this, the heading tape was changed from a 360° wrap around configuration to a 60° aircraft referenced symbology. No other changes were made to the TP2 symbology set.

1.4 EXPERIMENT OVERVIEW

Each pilot was tested across two days. On Day 1, pilots performed two ADS33-type tasks. On Day 2, pilots performed a task designed to assess attentional allocation to the symbology while flying a multifaceted mission.

1.4.1 Day One

On Day 1,.a formation flight task and a side-step task were used to assess the effectiveness of the aircraft vs. mixed vs. head symbology referencing systems. These tasks conform to the SAR mission adopted by the TP2 committee for the initial development of the TP2 symbology set. In addition, these tasks are well suited for indexing differences across the referencing sets because (a) head movements are intrinsic to good performance on these tasks and (b) flight and power information on the HUD is likely to be read and used to maximize performance on these tasks when the external scene is degraded.

1.4.2 Day Two

On Day 2, pilots flew missions that included takeoff, hover, enroute, low-level flight and recce components. While flying the missions, coloured targets were presented at the HUD symbology level and the pilots were required to perform a speeded discrimination task. The target discrimination task was performed while flying with the aircraft vs. mixed vs. head referencing systems.

1.4.3 Participants

Six male Canadian Forces helicopter pilots aged 36 to 43 years volunteered for this study (see Table 2). The pilots had an average of over 3,000 hours experience flying rotary aircraft. Most pilots had some simulator experience. Two of the pilots had little to no NVG experience. Seven pilots were originally scheduled to participate in the study. One pilot experienced simulator sickness brought on by use of the HMD, and did not complete the study.

1.4.4 Testing Facility

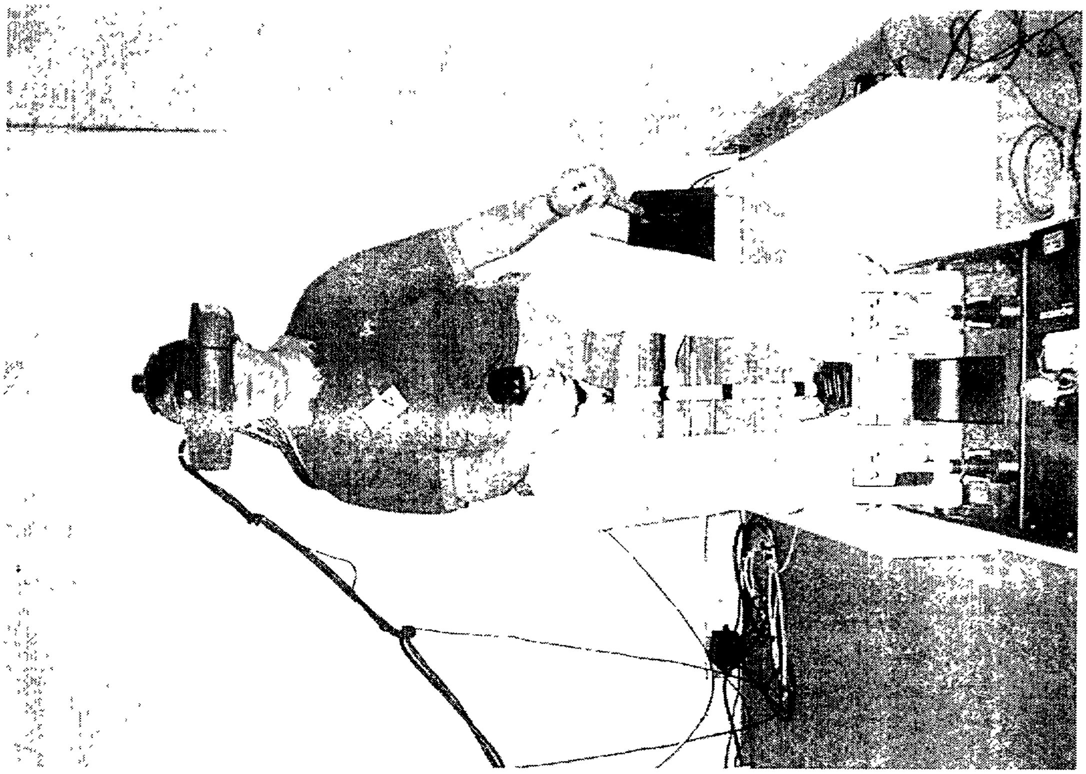
The study was conducted in the Human Factors Engineering (**HFE**) Laboratory, BAE Systems in Kanata, Ontario, Canada. The primary simulator hardware/software components utilized for this experiment included: (a) a Silicon Graphics-based workstation local area network, (b) a single-pilot physical flight structure with aircraft seating and low fidelity flight control systems (cyclic, collective, rudder pedals), (c) an N-Vision immersive HMD providing a 79 degree diagonal binocular field of view at VGA, (d) an external scene utility modified for the HMD, (e) a utility to generate the TP2 symbology set, (f) a facility to generate auditory input for the formation flight secondary task, and (g) a rotary wing flight model (see below).

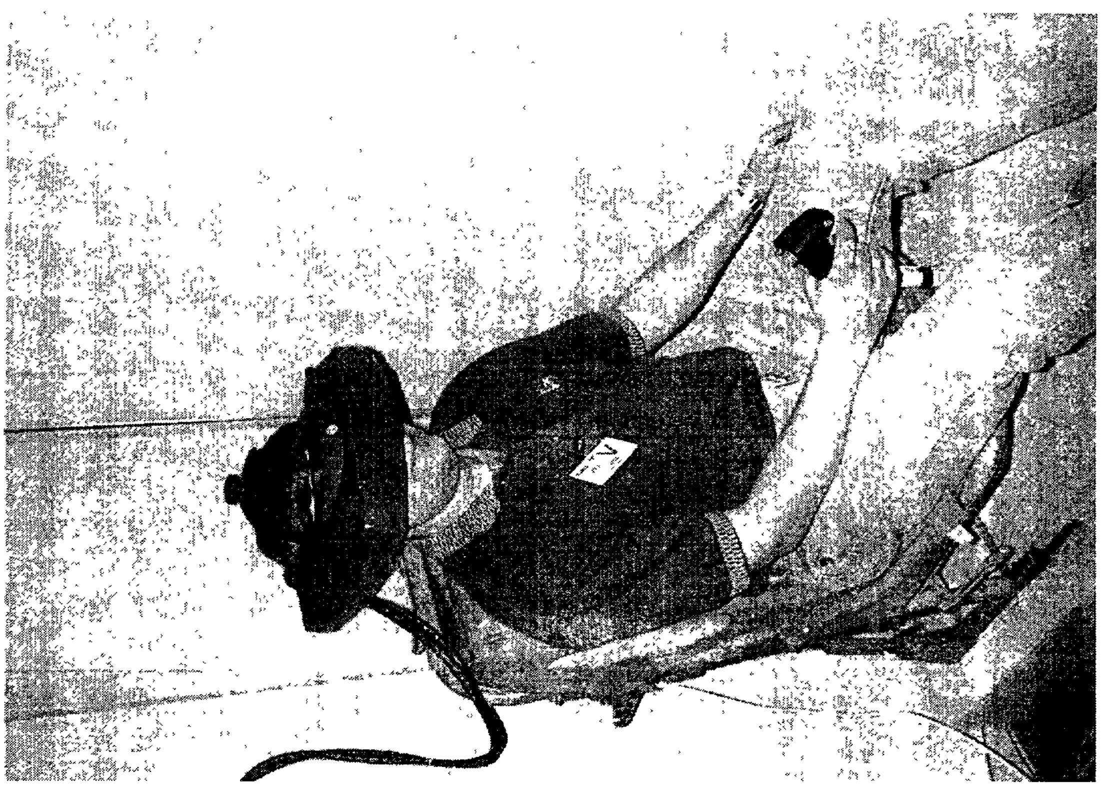
1.4.5 Flight Model

Flight dynamics were modeled using HELISIM, a high-fidelity, 6 degree of freedom simulation environment. The flight model utilized in the experiment was based on performance data for a Bell 412 helicopter. A Stability Augmentation System (SAS) algorithm was active in the flight dynamics model for the duration of the experiment. This algorithm was not implemented in the initial TP2 experiment.

Table 2: Summary of pilot experience

Ss	Training	Rotary Hrs.	Simulator Experience	Hrs G	Glasses
1	• HT406 Standards Flight Commander until. Dec 99 • Instructor Pilot Aug. 96 – Dec 99 • OFTT Instructor Sep 96 – Dec 99	• 1700 hrs overall • CH 139Jet Ranger • Sea King	• Sea King OFTT	0	Yes
2	• Military Pilot Wings Graduate 1981 • Instructor Bell 206 (1300 hrs) • Instructor Griffon (800 hrs)	• 3600 hrs overall • CH136 Kiowa • CH139 Jet Ranger • CH135 Twin Huey • CT134 Musketeer • CT114 Tutor • Ch146 Griffon	• Bell 212/412 Simulator • Griffon Simulator	60	Yes
3	• Tactical Helicopter (NOE) Fly • SAR; AB Initio Flight Instructor • Test Pilot	• 3600 hrs overall • Bell 206; 212 • MBB 105 • HV – 11 (Labrador)	• UH 1 • H 46 • H 53	40	Yes (Instrument Flight)
4	• Instructor 83-86 3CFFTS CT-134 Musketeer	• 2300 hrs overall • CH136 Kiowa • CH135 Twin Huey • CH139 Jet Ranger • CH146 Griffon • Bell 206; Bell 212 • Bell 412	• none	30	yes
5	• CH –135 OUT TAC Instructor Pilot 3yrs. • CH-135 NVG IP 5yrs. • CH-146 NVG SPEC 2yrs	• 3500 hrs overall • CH 136 Kiowa • CH 139 Jet Ranger • CH 135 Twin Huey • CH 146 Griffon	• ~10 hrs Griffon & FSI • CT 114 Tutor	600	No
6	• CT 134 Musketeer • CT 114 Tutor • CH 139 Jet Ranger • CH 135 Twin Huey • Kingair	• 3300 Overall • CH 139 Jet Ranger • CH 135 Twin Huey • Enstrom Single Engine Piston	• C 90 King Air • UTIAS/DCIEM Sea King Trials • C 17 Globemaster	2	No





SECTION TWO: ADS-33 TASKS

2.1 PROCEDURE

The pilots' personal history/experience was collected at the beginning of the study on Day 1. This was followed by a brief overview of the simulator and the set of TP2 symbols, a briefing regarding the purpose and layout of the study and instructions how to set the optics for the HMD. This was followed by a practice free-flight period (minimum of 15 minutes). For this period pilots were instructed to attempt a variety of flight tasks with the goal of familiarizing themselves with the TP2 symbology set, the flight simulator, and the flight model. No data was collected for this free-flight portion of the study.

Day 1 was divided in a morning practice session and an afternoon experimental session. In both the morning and the afternoon sessions, pilots performed the formation flight task followed by the sidestep task using each frame of reference (FOR) system (aircraft, mixed, head). The morning practice session consisted of 5 trials of formation flight and 5 trials of sidestep per each referencing system. The afternoon experimental session consisted of 10 trials per each task (formation flight, sidestep) per each FOR (aircraft, mixed, head) system.

At the conclusion of each of the tasks in the experimental session, pilots completed modified Cooper-Harper questionnaires (**MCH**) (Wierwille & Casali, 1983) regarding the workload associated with using the symbology for the formation flight and the sidestep tasks. Also ratings were obtained regarding the use of the symbology to perform the tasks, interference of the symbology with the perception of the external scene, and rankings of FOR preferences. Following completion of these questionnaires, responses to open-ended questions were solicited and additional comments were noted.

2.1.1 Formation Flight Task

The formation flight consisted of a series of discrete 2-minute trials. At the beginning of each trial, the following flight parameters were set: aircraft attitude (0 degrees pitch and roll), altitude (200 feet), airspeed (80 knots), and heading (00 North) as indicated with the "bug" on the heading tape. Pilots were instructed that their primary task was to maintain the altitude, airspeed and heading parameters.

A secondary task was introduced to induce the pilots to engage in head movements, thereby highlighting the differences across the aircraft vs. mixed vs. head referencing conditions. To this end, a voice prompt indicating "left" or "right" was presented via speakers. This prompt occurred approximately every 10 seconds (randomly determined). Pilots were to turn their head accordingly (left or right) to determine the colour of a light fixed to the nose of an aircraft flying in formation on either side of their aircraft. Upon acquiring the light, the pilots were instructed to make a speeded trigger response if the light was red and no response if the light was green (50/50 probability).

2.1.2 Side-step Task

The sidestep task consisted of a series of discrete 45-second trials. For each trial, pilots were positioned at the center of the left hover pad, performed a take-off activity, a brief hover and lateral transition to the right, and landed on a second target hover pad located to their immediate right, while following the center row of three rows of pylons. Pilots were instructed that accuracy and not speed should be the focus of the task and were instructed to maintain a heading of due north, an altitude of 15 feet, and attempt to follow the center row of the three rows of pylons. A tone cued the start of the trial, followed by a voice prompt indicating 15, 30, 40, and 45 seconds. The helicopter was returned to the initial starting location to start the next trial.

2.2 RESULTS

2.2.1 Formation flight

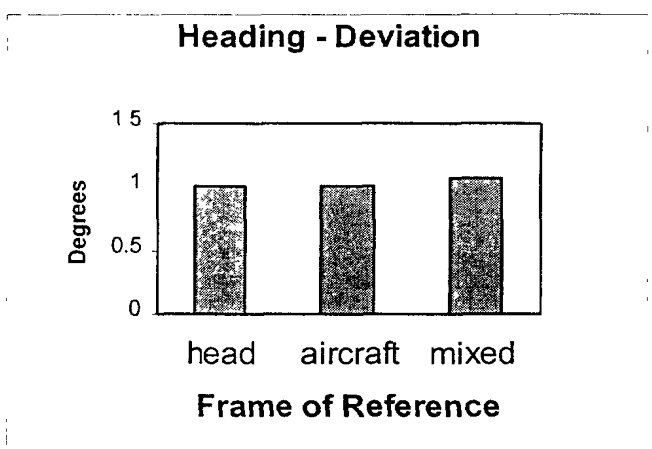
The pilots' primary requirements for this task were to maintain initial heading, altitude and airspeed parameters while responding to the auditory ("left vs. right") cues to look to the left or right side of the aircraft.

The original TP2 evaluation (SOW #3773-3HC16) showed that in the formation flight task, pilots were slightly better at minimizing deviations in heading, altitude and airspeed with the aircraft FOR than with the mixed FOR. As summarized below, these differences were not found in the present experiment.

2.2.1.1 Heading

The average deviation in heading is shown in Figure 2. A 3(FOR: aircraft, head, mixed) x 10(Trial: 1 to 10) repeated measures ANOVA showed no significant effects. The null effect of FOR on deviations in heading differs from the first TP2 experiment where the aircraft FOR showed a slight advantage relative to the mixed FOR.

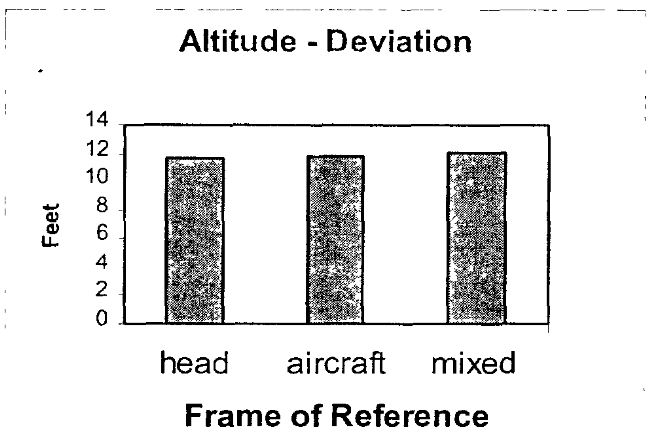
Figure 2



2.2.1.2 Altitude

The average deviation in altitude is shown in Figure 3. A 3(FOR: aircraft, head, mixed) x 10(Trial: 1 to 10) repeated measures ANOVA showed no significant effects. The null effect of FOR on deviations in altitude differs from the first TP2 experiment where the aircraft FOR showed an advantage relative to the mixed FOR.

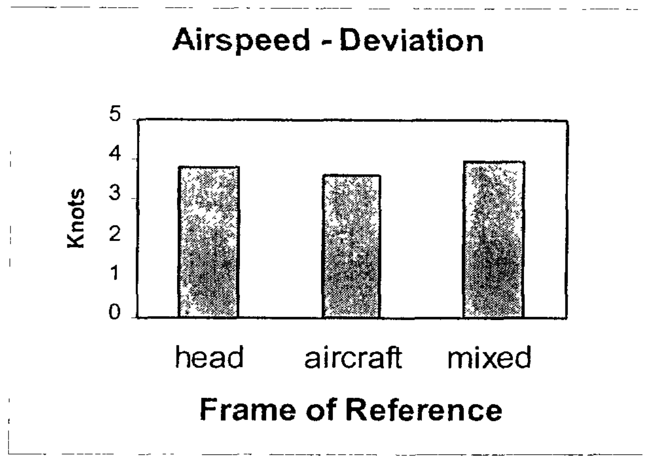
Figure 3



2.2.1.3 Airspeed

The average deviation in airspeed is shown in Figure 4. A 3(FOR: aircraft, head, mixed) x 10(Trial: 1 to 10) repeated measures ANOVA showed no significant effects. The null effect of FOR on deviations in airspeed differs from the first TP2 experiment where the aircraft FOR showed a slight advantage relative to the mixed FOR.

Figure 4

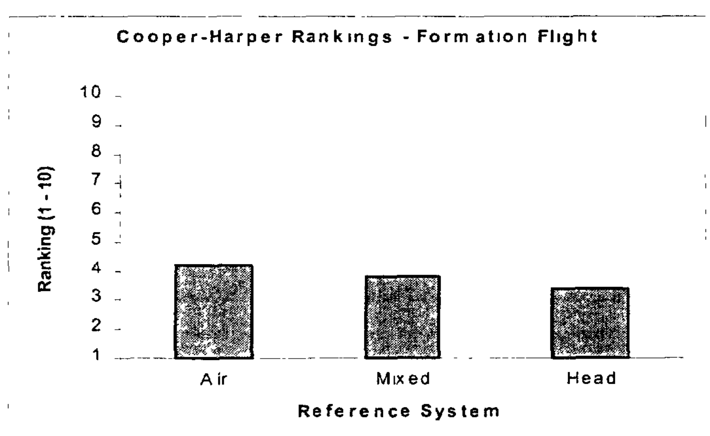


2.2.1.4 Subjective Measures

2.2.1.4.1 Modified Cooper-Harper

After performing the formation flight trials, pilots provided MCH ratings for the three referencing systems. As shown in Figure 5, the average MCH rating across the three FOR was 3.8, which corresponds to the categories indicating "fair, some mild deficiencies" - to - "minor, but annoying deficiencies". The MCH ratings did not differ significantly across the three FORs.

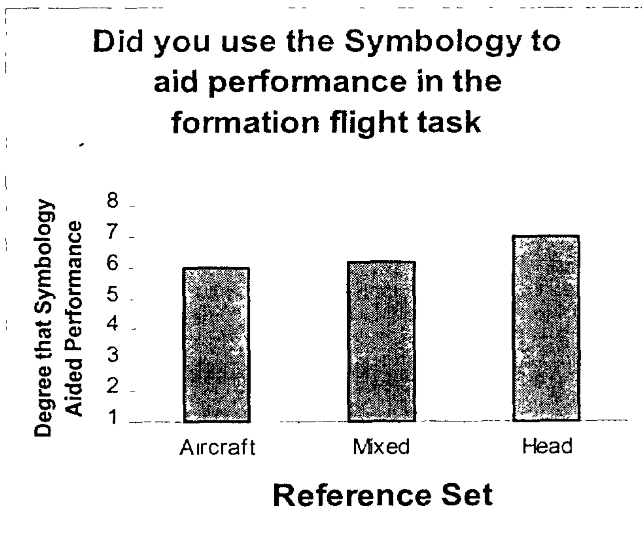
Figure 5



2.2.1.4.2 Use of Symbology for Formation Flight

Pilots rated the degree to which the symbology aided performance when performing the formation flight task. These ratings are shown in Figure 6. Paired t-tests showed that the ratings of the FORs did not differ significantly from one another.

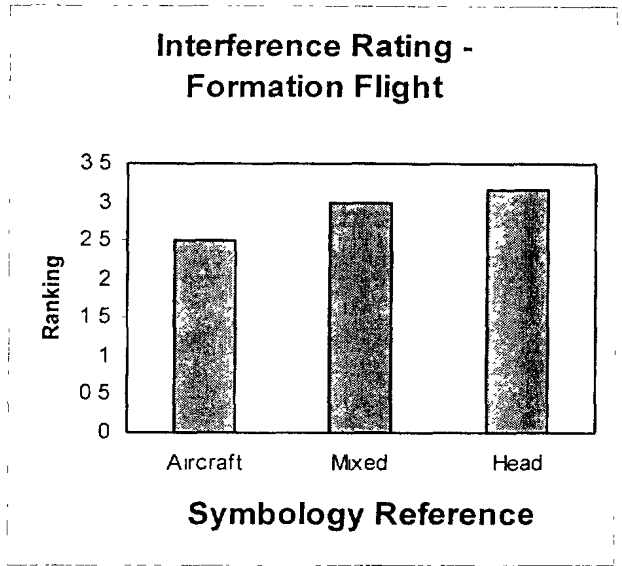
Figure 6



2.2.1.4.3 Interference With External Scene

Figure 7 shows pilots' ratings of the extent to which the symbology interfered with the perception of the external scene during the formation flight task. Paired t-tests showed that the ratings did not differ across the three FORs.

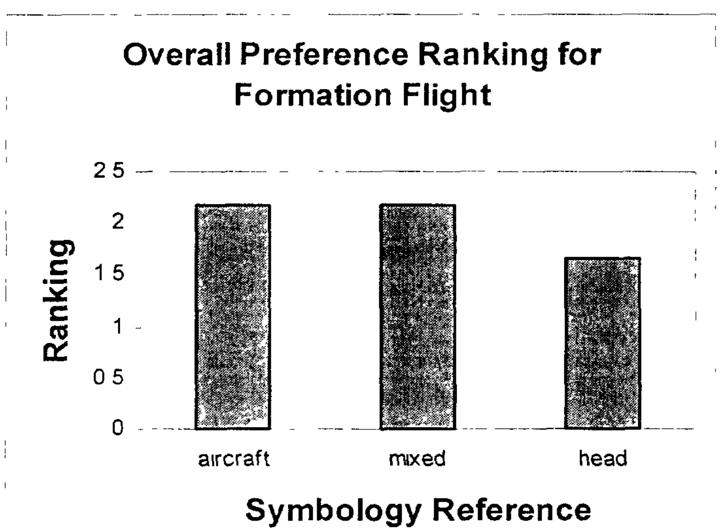
Figure 7



2.2.1.4.4 Preference Rankings for Formation Flight

Figure 8 shows the preference rankings associated with using the three FORs in the formation flight task. Paired t-tests did not show any significant differences in preference across the three FORs for this task.

Figure 8



2.2.1.5 Summary of Formation Flight Results

In sum, the heading, altitude, and airspeed measures suggest that pilots were able to use the three frames of references with equal effectiveness to control heading, altitude, and airspeed in the formation flight task.

2.2.2 Sidestep Task

For the sidestep task the helicopter was initially positioned at the center of the left hover pad. Pilots were to perform a take-off, a lateral transition (sidestep) to the right at an altitude of 15', and then land on a second target hover pad located to the right. Pilots were to follow the center row of three rows of pylons: deviations in fore/aft from the center row were measured. A heading of 00 North was to be maintained throughout the sidestep.

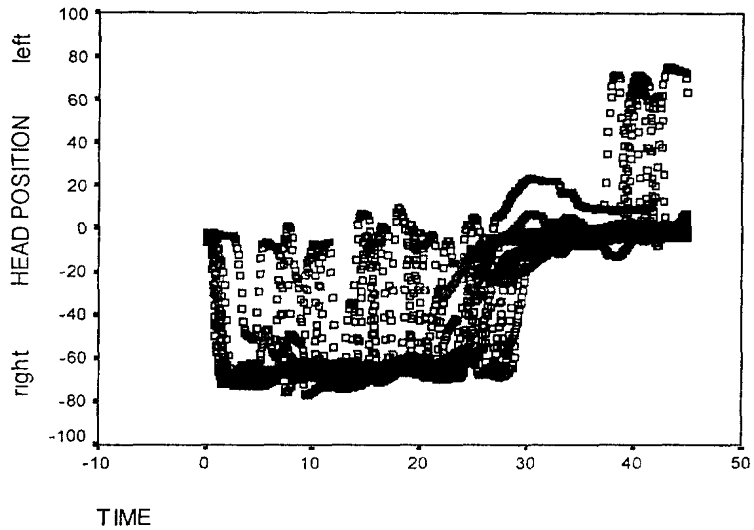
2.2.2.1 Head Position

When performing a sidestep maneuver, pilots typically look in the direction that they are heading. In the present situation pilots should look right. Figure 9 shows head positioning across the 10 trials for each of the three symbology conditions. For data management reasons, only the head position data from only one pilot (#6) is shown in Figure 9: the data for this pilot is representative of the complete sample.

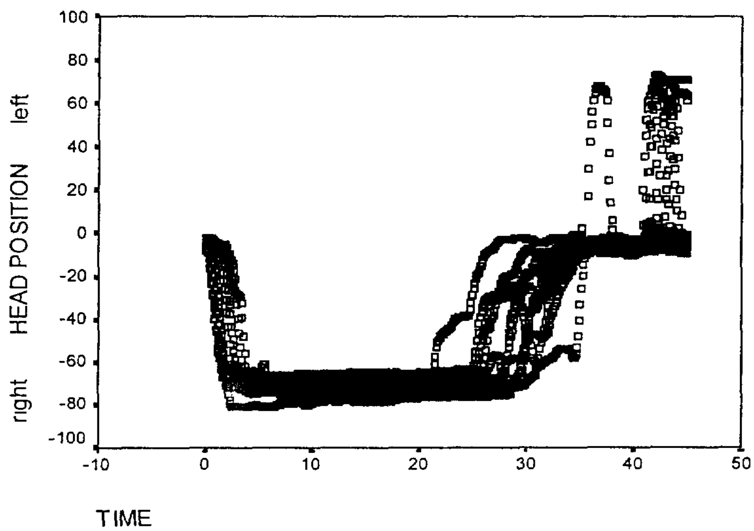
As shown in each panel of Figure 9, the pilot started trials by looking toward the front of the aircraft (y value of 0) and then turned his head to the right (negative y values). As the right hover pad was approached, pilots looked back toward the front of the aircraft as they began to execute a hover and landing maneuver and at times, executed a head movement to the left (positive y values) to check their position against the sidestep cones after landing.

Of particular interest is that in the mixed and the head referenced conditions, (middle and bottom panels of Figure 9) pilots maintained a rightward gaze throughout the sidestep. With these FORs, pilots only returned their gaze toward the front of the aircraft as they were at the right hover pad. For the aircraft FOR (top panel), gaze was returned to the front (y=0) numerous times throughout the sidestep: this was done to acquire the altitude and torque information. To the extent that minimizing head movements during

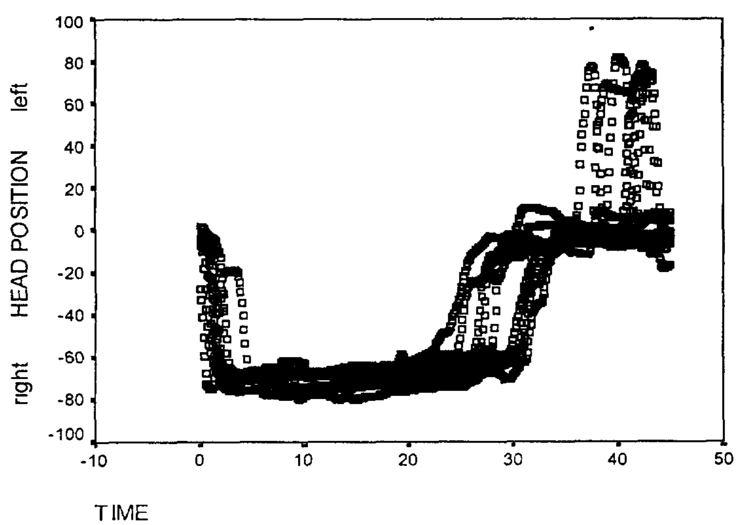
Aircraft Referenced



Mixed Referenced



Head Referenced



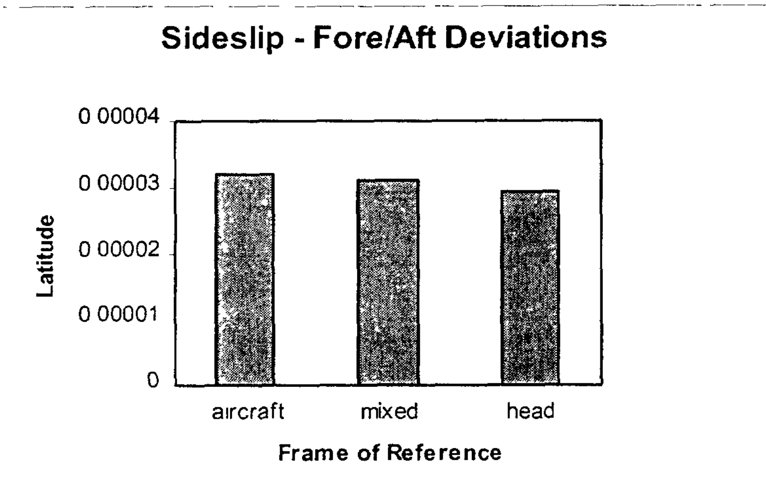
sidestep maneuvers is important, the mixed and the head FORs clearly offer an advantage over the aircraft referenced set.

For the following analyses, the beginning of the sidestep maneuver was defined as the point when the helicopter reached the right edge of the initial (left) hover pad. The conclusion of the sidestep maneuver was defined as the point when the helicopter reached a distance of 2 times the center-side distance from the left edge of the right hover pad. The data analyzed below was combined across all 6 pilots and across the 10 trials per each symbology condition.

2.2.2.2 Fore/Aft Movement

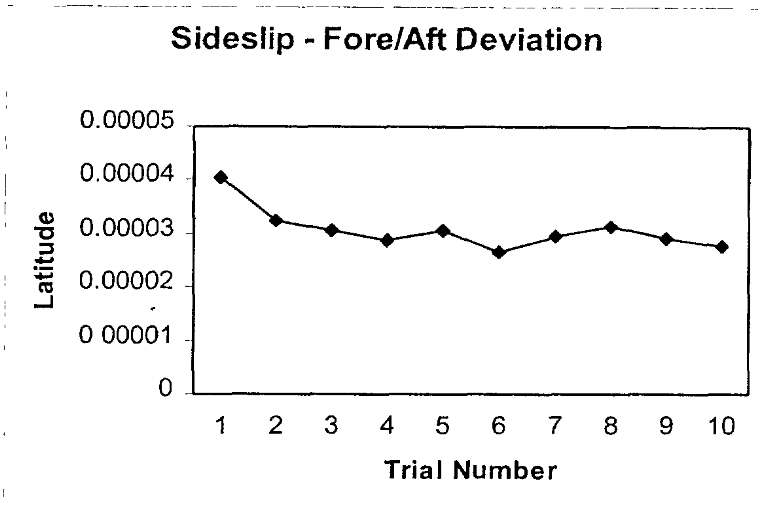
Average deviations in fore/aft movement are summarized in Figure 10. A 3(FOR) x 10(Trial) repeated measures ANOVA did not show any significant effects. The main effect of FOR was not significant: the absence of a FOR effect is expected given that, regardless of FOR, the information provided by the symbology set does not bear upon fore/aft control of the aircraft in a sidestep task.

Figure 10



The effect of Trial approached significance, $F(9,45) = 1.85$, $Mse = 0.144$, $p = .085$. As shown in Figure 11, performance in minimizing deviations in the fore/aft movement of the aircraft generally improved across trials.

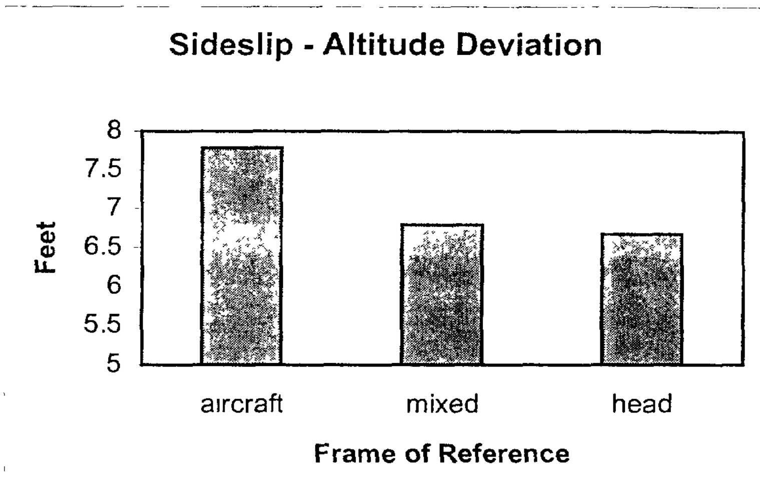
Figure 11



2.2.2.3 Altitude

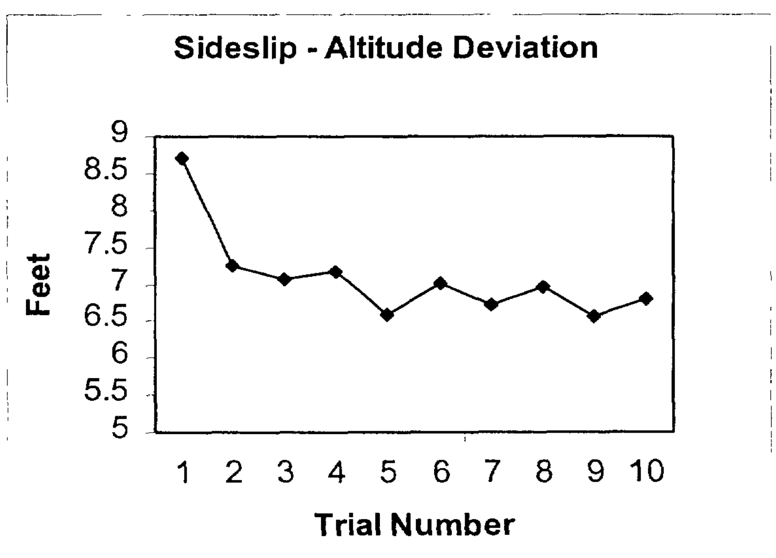
Average deviations from a target altitude of 15 ft. are summarized in Figure 12. A 3(FOR) x 10(Trial) repeated measures ANOVA showed significant main effects of FOR, $F(2, 10) = 5.48$, $Mse = 4.052$, $p < .026$ and of Trial, $F(9, 45) = 4.92$, $Mse = 1.41$, $p < 001$. As shown in Figure 10, pilots had more difficulty maintaining a 15' altitude in the aircraft than the mixed and head referenced sets. The mixed and head references resulted in similar performance.

Figure 12



The main effect of Trial on altitude deviation is illustrated in Figure 13. As can be seen in Figure 13, pilots' performance in minimizing deviations from the target altitude of 15' improved across trials.

Figure 13



2.2.2.4 Heading

Average deviations around a target heading of 00 degrees are shown in Figure 14. A 3(FOR) x 10(Trial) repeated measures ANOVA showed a significant linear trend for FOR, $F(1,5) = 24.54$, $Mse = 1.66$, $p < .005$. This supports the notion that pilots are better able to maintain the aircraft's heading in the head-referenced set because the heading tape is in the field of view while looking to the side in the sidestep task. There was also a significant linear trend for Trial: as shown in Figure 15, pilots' ability to minimize deviations in heading improved across trials.

Figure 14

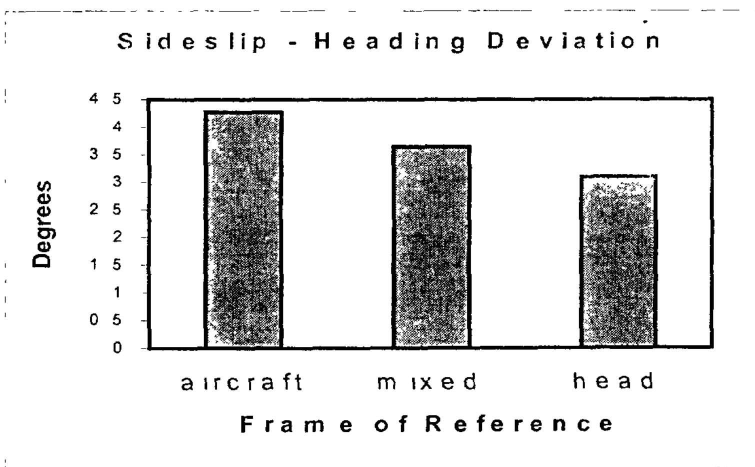
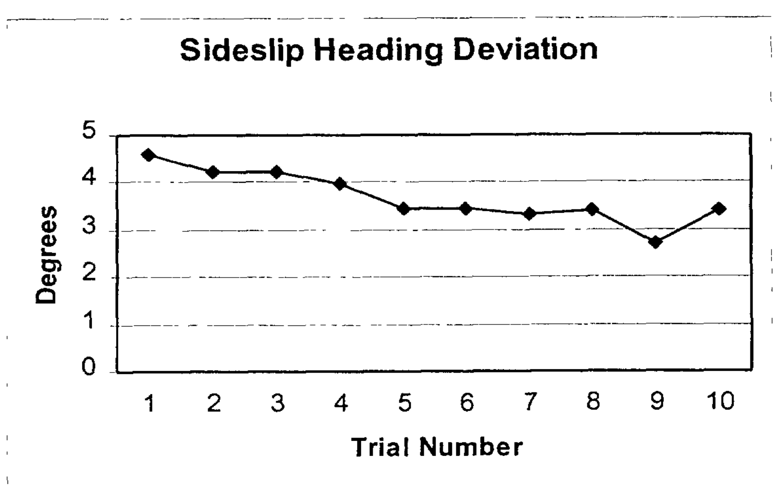


Figure 15



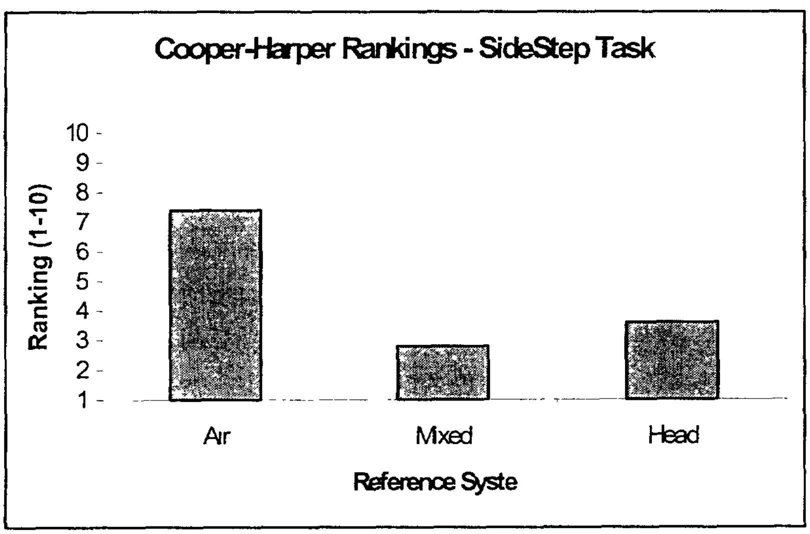
2.2.2.5 Subjective Measures

2.2.2.5.1 Modified Cooper-Harper

After performing the sidestep trials, pilots provided MCH ratings for the three referencing systems. The MCH ratings for the sidestep task are shown in Figure 16. The average MCH rating across the three FOR was 2.0, which corresponds to the categories indicating "fair, some mild deficiencies" - to - "minor, but annoying deficiencies". Paired t-tests showed that for the sidestep task, the aircraft reference was rated also significantly hard to use than both the mixed reference, $t(5) = 5.66$, $p < .006$, and the head reference, $t(5) = 3.92$, $p < .018$. MCH ratings of the mixed and head referenced sets did not differ.

Figure 16

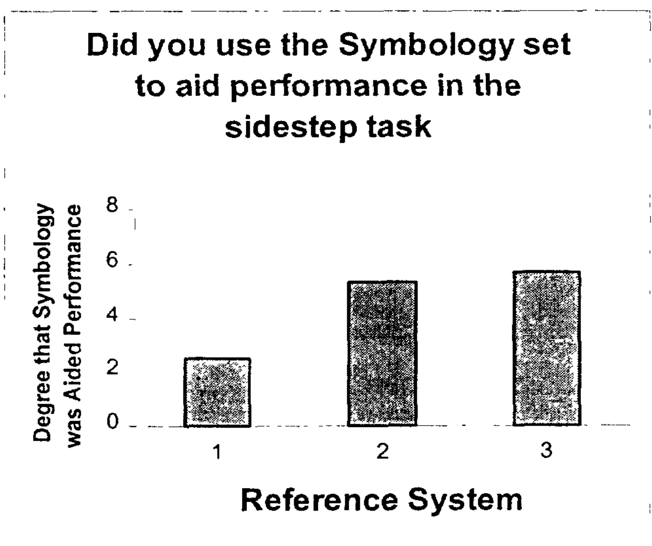
(Larger numbers refer to higher workload)



2.2.2.5.2 Use of symbology

Pilots rated the degree to which the symbology aided performance when performing the sidestep task. These ratings are shown in Figure 17. Paired t-tests showed that the symbology aided performance less in the aircraft configuration than in the mixed configuration, $t(5) = 3.11$, $p < .027$, or the head-referenced configuration, $t(5) = 2.94$, $p < .033$. The ratings did not differ across the mixed versus head-referenced configurations. This finding shows that, even though the symbologies were identical across FORs, the way in which the symbologies are referenced is important.

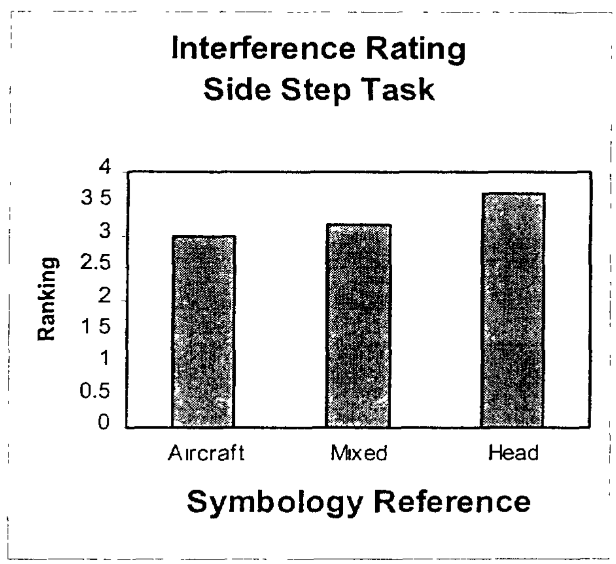
Figure 17



2.2.2.5.3 Interference with perception of external scene

Pilots rated the degree to which the symbology interfered with the perception of the external scene. As shown in Figure 18, these ratings did not differ across the three FORs.

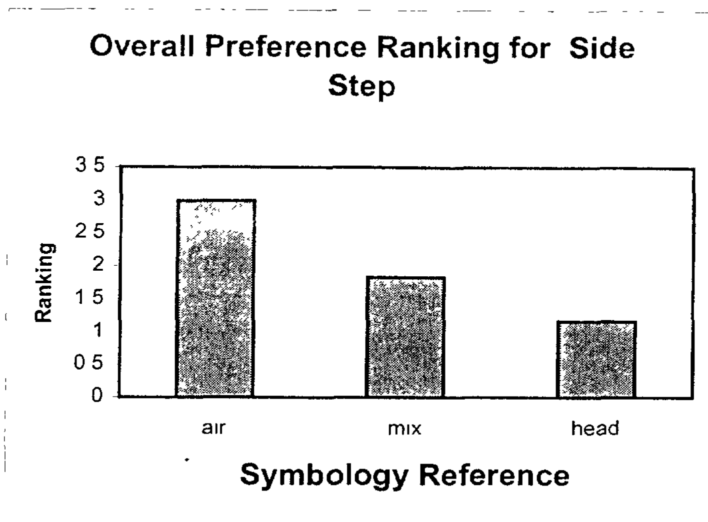
Figure 18



2.2.2.5.4 Preference Rankings

Figure 19 shows the preference rankings associated with using the three FORs in the sidestep task. Paired t-tests showed that for sidestep, the mixed FOR was preferred over the aircraft reference, $t(5) = 7.32$, $p < .002$ and the head FOR was also preferred over the aircraft reference, $t(5) = 10.25$, $p < .001$. The pilots' preferences for the mixed FOR and the head FORs did not differ.

Figure 19
(Low number refers to highest preference)



2.2.2.6 Summary of the Results

The pilots' subjective ratings are clear in showing that for the sidestep task, the mixed FOR and head FOR are preferred over the aircraft FOR, and as requiring less mental effort to use than the aircraft FOR. The superior preference and MCH rankings for the mixed and head FORs may, in part, reflect the fact that fewer head movements are required to perform a sidestep maneuver when altitude and torque information is available in the direction that the helicopter is moving. On this view, pilots indicated that they used the task-relevant symbology (altitude, torque) more with the mixed FOR and head FOR than the aircraft FOR.

The sidestep performance measures show that pilots were better able to control the aircraft's altitude and heading with the mixed and head FORs as compared to the aircraft FOR. Heading was especially well controlled with the head FOR, for which the heading tape was in the pilot's field of view throughout the sidestep maneuver.

2.3 DISCUSSION

The ADS33 tests showed that there was undifferentiated performances in all aspects of the formation flight task across the aircraft, mixed, and head FORs. There are several possible reasons why differences across the FORs were not found in the formation flight task.

First, the pilots exhibited high and stable levels of performance in this task. Indeed, the plots in this experiment performed at a much higher and stable level than those in the initial TP2 ADS-33 experiment. This high level of performance may be attributed to the extensive practice session given prior to the experimental trials in the present experiment.

Second, as noted by the pilots, tended not to rely heavily on the symbology to perform the formation flight task. To this end, a more difficult formation flight task in which the visual referents are degraded would be more likely to challenge the pilots and exercise the symbology.

Third, the flight model in the initial TP2 ADS-33 experiment was somewhat unstable, thereby making the task of flying the aircraft generally quite difficult. Upgrades to the flight model, and in particular, the addition of a partial SAS algorithm have made the aircraft much more stable. This addition has diminished the workload of the pilots, possibly to the extent that the HUD symbology is less necessary to perform the formation flight task.

The sidestep results showed an advantage for the mixed and head FORs over the aircraft FOR in maintaining heading and altitude. The superiority of these two FORs for the sidestep maneuver was also reflected in the pilots' ratings.

In sum, both the mixed and head referenced FORs offer clear advantages over an aircraft referenced configuration. The advantage of these FORs will depend on the task that the pilot is required to perform. It is of particular importance to note that the mixed FOR did not result in any disadvantages relative to the other two FORs. This suggests that having some symbology yoked to head movements while others are referenced to the aircraft is a plausible configuration for HUD and HMD design.

SECTION THREE: ATTENTON AND HUD REFERENCING

3.1 INTRODUCTION

A growing body of experimental and neuropsychological research supports the conclusion that attention is referenced to perceptual groups or objects within the visual field. This is known as the object-based attention hypothesis. The object-based attention hypothesis provides an account of attentional effects in both static displays and in situations where objects must be tracked. An in-depth summary of the object-based attention hypothesis, and the application of this hypothesis to HUDs, can be obtained in Report PWGSC File No: W7711-9-7577/A).

The object-based attention hypothesis has implications for research and development of HUDs and for the integration of HUDs into HMDs. For example, based on Gestalt principles, perceptual groupings of HUD symbology will be formed based on common motion, colour, proximity, closure and/or figure-ground separation. Object-based attention may underlie difficulties associated with pilots' need to process near (HUD) and far (external scene) domain information: near and far domains differ along one or more of the Gestalt grouping principles. An object-based attention framework, and a corresponding paradigm for assessing object-based attention effects, would be useful for gaining a metric on near versus far domain attentional capture and cognitive tunnelling.

The objective of this experiment was to take a step toward establishing a paradigm to assess the effects of object layering in HUDs. To do this, the discrimination of targets that appeared on a HUD was assessed across three HUD referencing configurations described in section on DAY 1 testing: aircraft, mixed, and head. It was assumed that the head and the mixed referencing configurations facilitate the perceptual grouping of the HUD symbology into a near domain that is distinct from the far domain of the external scene. These two domains are termed layers. It should be more efficient to allocate attention to targets that are presented on the HUD layer in the mixed and head referenced configurations as compared to when the symbology is referenced solely to the aircraft. This should be reflected in faster (and more accurate) target discrimination.

3.2 METHOD

3.2.1 Participants, Facility and Flight Environment

Participants were the same six male Canadian Forces helicopter pilots who participated in the Day 1 ADS33 testing. The same testing facility and flight model were used as in the Day 1 testing.

The virtual environment used for this study was generated with a Silicon Graphics Octane workstation, rendered in VGA with 1024 X 768 lines of resolution and displayed with a refresh rate of 30 Hz. The environment consisted of a centrally located airport, with four major 'sites of interest' in each corner of the square shaped environment. The terrain consisted of flat plains populated with virtual trees approximately 25 – 75 feet in height, with continual clear visibility. Each 'site of interest' consisted of virtual buildings designed with the intent to provide areas for participants to explore and conduct tactical maneuvers with the various symbology references in a realistic environment. The various sites ranged from a 400' castle, an enclosed monastery with a courtyard large enough to permit hover-landings, a small village consisting of three small houses, and a farmhouse.

3.2.2 Procedure

The object-layering hypothesis was tested by presenting two circles simultaneously at random within three possible configurations. When the targets were presented, they would encircle the radalt, torque, or airspeed indicators. For any possible target configuration, only two of three indicators were encircled. Both circles could either appear as mauve, or sky blue. Participant responses were recorded by pressing one of two possible triggers on the cyclic control stick.

The facilitator monitored the position of the participants aircraft within the environment by way of a moving map display that presented the aircraft current heading, relative flight parameters, and the aircraft's current position in relation to the target UFO and major buildings within the environment.

3.2.3 The Flight Task

Pilots flew through a morning practice session and an afternoon experimental session. During each session, pilots flew three ten-minute missions for each of the symbology reference sets. The order that participants flew each symbology set was counterbalanced across subjects.

The morning sessions were used to allow the participants to practice flying the various missions, and practice the target discrimination task. Subjects were instructed to fly through the environment by following heading and flight-parameter directions provided aurally by the facilitator. Each route provided the opportunity for the participants to experience using each symbology set while performing circuits, recces, hovers, hover landings, hover transits and NAV tasks. In order to ensure that participants continually performed off-axis head movements, participants were instructed to scan and report the location of a light-blue "UFO" during transits between 'sites of interest.' The transit phase of each mission provides the opportunity for pilots to perform off-axis head movements under relatively low workloads by searching for the UFO. The facilitator controlled the appearance of the UFO, randomly placing the object at various locations around the aircraft. When subjects were within 2km of a task area, they were instructed to refrain from performing the UFO search and proceed onto their assigned task.

3.2.4 The Object Layer Task

In order to test the object-layering hypothesis, participants performed an target discrimination task while flying the various missions. Participants were instructed to monitor their 3 primary flight symbologies (airspeed, torque, and radalt indicators) for the simultaneous appearance of two circular targets. The two targets simultaneously appeared encircling two of the three flight displays. For each appearance, the targets would either appear as the same colour (both mauve, both light blue) or as different colours (one mauve, the other blue). Participants were asked to press the main trigger on the cyclic if the targets were the same colour and a thumb trigger if they were different colours. In order to ensure that participants did not solely focus on the symbology, they were instructed to perform the target task without sacrificing flight performance.

3.2.5 Design – Target Task

The purpose of the target detection task was to test both the object layering hypothesis and spaced-based attentional hypothesis, to test the effects of clutter within a symbology set, and to provide further evidence supporting the efficacy of head-tracked reference systems. The design of the object layer test was a 3(Frame of Reference - FOR: aircraft, mixed, head) x 3(Location of targets: radalt/torque, radalt/airspeed, airspeed/torque) x 2(Type of target: same, different) repeated-measures design, where each subject experienced each reference set and all possible target combinations.

For each ten-minute mission, a total of 30 targets were randomly presented throughout the duration at approximately 10s intervals. Out of 30 targets, 15 targets appeared as the same colour and 15 as different colours. For each colour block, five of each possible symbology combination was presented (i.e. targets appearing around radalt/torque, radalt/airspeed, and airspeed/torque). Therefore, for each symbology reference, subjects experienced a total of 90 trials, consisting of 45 same-trials, 45 different-trials, and 15 trials of each target/symbology combination.

3.3 RESULTS

3.3.1 Response latencies

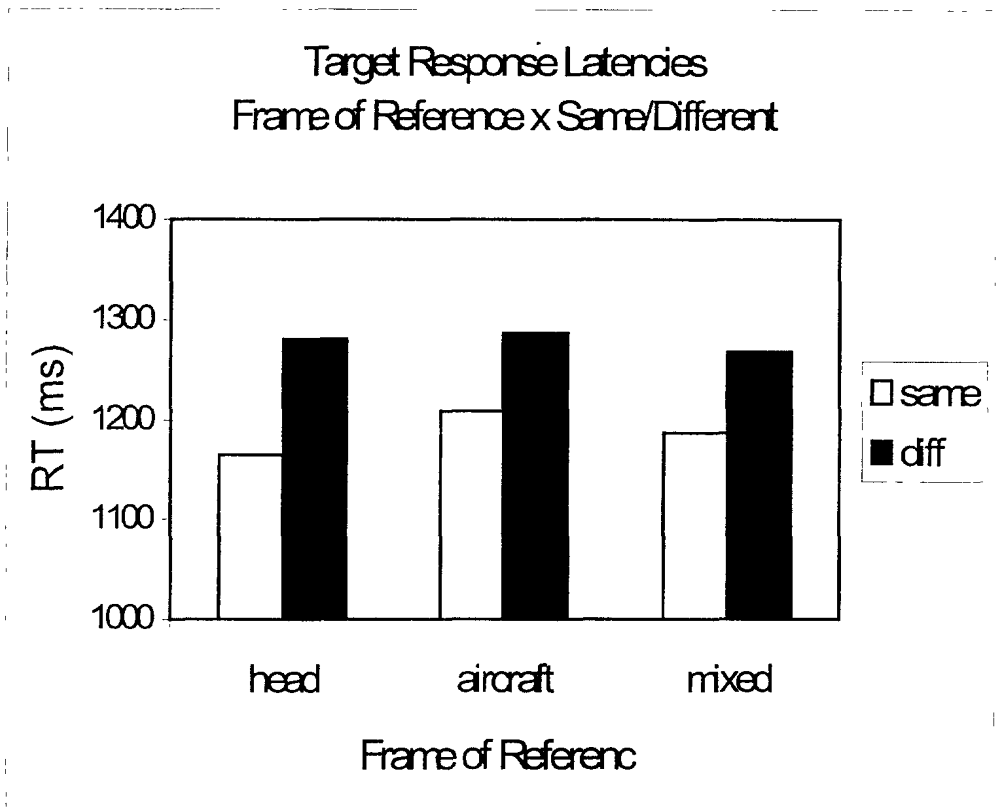
Latencies to correct responses were analyzed in a 3(FOR: head, aircraft, mixed) x 2(Type: same, different) x 3(Location: 1, 2, 3) ANOVA with repeated measures on all factors. The source table for this analysis is shown in Table 3.

Table 3: ANOVA Source Table
Latency Data: FOR x Type x Location

Source	SUM OF SQUARES	df	MEAN SQUARE	F	Sig.
FOR	12816.380	2	6408.190	.504	.619
Error(FOR)	127246.837	10	12724.684		
TYPE	226207.683	1	226207.683	8.377	.034
Error(SMDIF)	135015.343	5	27003.069		
LOCAT	72964 319	2	36482.160	4.403	.043
Error(LOCAT)	82854.168	10	8285.417		
FOR * TYPE	8004.672	2	4002.336	.543	.597
Error(FOR*TYPE)	73665.642	10	7366.564		
FOR * LOCAT	21469.834	4	5367.459	.381	.820
Error(FOR*LOCAT)	281832.061	20	14091.603		
SMDIF * LOCAT	72048.289	2	36024.144	7.011	.012
Error(TYPE*LOCAT)	51379.402	10	5137.940		
FOR * TYPE * LOCAT	66973 576	4	16743.394	1.330	.293
Error(FOR*TYPE*LOCAT)	251734.495	20	12586.725		
Error(FOR*TYPE*LOCAT)	251734.495	20	12586.725		

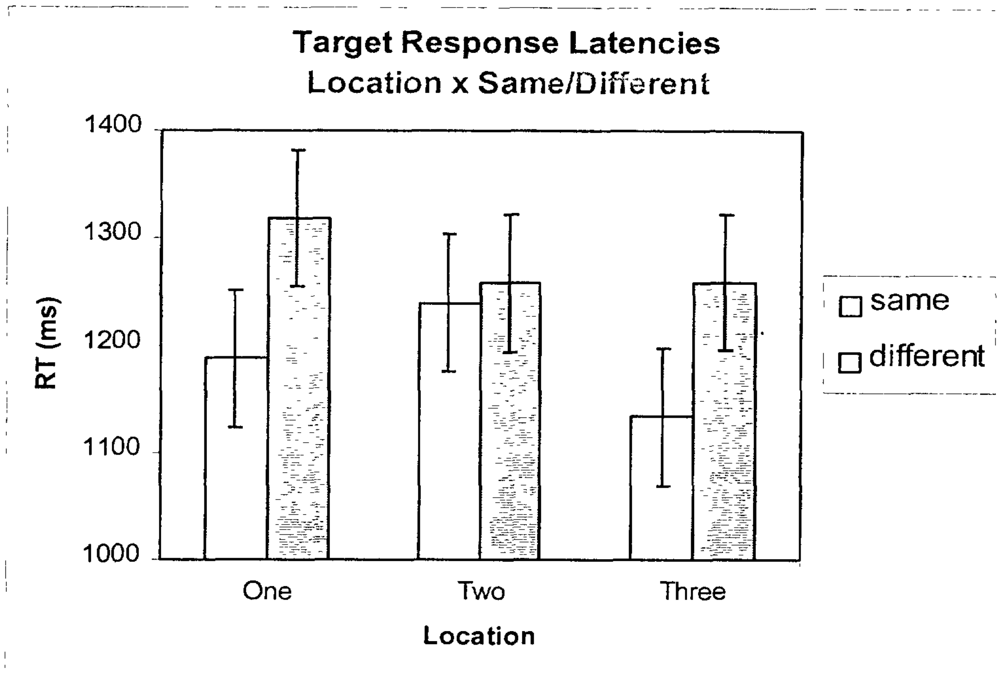
As shown in Figure 20, there was a significant main effect of Type where responses were faster on same than on different trials: faster responses on same trials than on different trials is typical in the literature. This result shows that the target detection paradigm in the present experiment was sufficiently sensitive to index characteristics of the stimuli/task. There was, however, no main effect of FOR and FOR did not interact significantly with any of the other variables. Although caution must be exercised when interpreting null effects, the null effect of FOR suggests that the attentional demands associated with discriminating the targets was not differentially influenced by the type of HUD symbology referencing system.

Figure 20



There was also a significant main effect of Location (see Table 3). As shown in Figure 21, and accord with the spatial hypothesis, responses were generally faster when the targets appeared in the radalt/torque combination, as compared to the radalt/airspeed or the torque/airspeed combinations. This fits with the **spatial hypothesis** because the radalt/torque symbols are spatially closer together than are the radalt/airspeed and the torque/airspeed combinations. The impact of Location was isolated to the same trials, as indicated by a significant interaction between Location and Type.

Figure 21
(bars are 95% confidence intervals)



3.3.2 Error Analyses

There were two types of errors. Errors in classification where same targets were classified as different and vice versa. Also, there were misses, where no response to targets was elicited.

3.3.2.1 Classification Errors

The percent classification errors were analyzed in a 3(FOR: head, aircraft, mixed) x 2(Type: same, different) x 3(Location: 1, 2, 3) ANOVA with repeated measures on all factors. The ANOVA source table for this analysis is shown in Table 4.

There was a main effect of Type, where fewer errors were made on same than on different trials (20.44% vs. 28.44%). This coincides with the latency data and is consistent with same/different effects found in the literature. The main effect of FOR showed a trend toward where fewer errors were made in the head than the other two referencing systems. This trend is shown in Figure 22. This was qualified with a near significant FOR x Location interaction. The primary source of this interaction is that pilots made substantially fewer target classification errors in the combination of the head FOR with the targets being located at the radalt /torque locations. Indeed, as shown in Figure 23, the error rate was approximately half that found in the other FOR x location combinations.

The superior performance in discriminating targets presented in the altitude/torque combination while using the head FOR, does not appear to be due to chance: this superior performance was consistent across all 6 pilots. Also, this finding generally concurs with the latency data where an advantage in probe responses was found for the altitude/torque combination, thereby ruling out a speed/accuracy trade-off.

Table 4: ANOVA Source Table
Classification Errors: FOR x Type x Location

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
FOR	542 256	2	271.128	.929	.427
Error(FOR)	2919.518	10	291.952		
LOCAT	1036.585	2	518.293	2.411	.140
Error(LOCAT)	2149.315	10	214.932		
SAMDIF	1728.545	1	1728.545	8.021	.037
Error(SAMDIF)	1077.452	5	215.490		
FOR * LOCAT	979.185	4	244.796	2.421	.082
Error(FOR*LOCAT)	2022.649	20	101.132		
FOR * SAMDIF	40 608	2	20.304	.451	.649
Error(FOR*SAMDIF)	450.417	10	45.042		
LOCAT * SAMDIF	157.567	2	78.783	.592	.572
LOCAT * SAMDIF	157.567	2	78.783	.592	.572
Error(LOCAT*SAMDIF)	1331 162	10	133.116		
Error(LOCAT*SAMDIF)	1331.162	10	133.116		
FOR * LOCAT * SAMDIF	211.905	4	52.976	1.475	.247
FOR * LOCAT * SAMDIF	211.905	4	52.976	1.475	.247
Error(FOR*LOCAT*SAMDIF)	718.333	20	35.917		
Error(FOR*LOCAT*SAMDIF)	718 333	20	35.917		

Figure 22

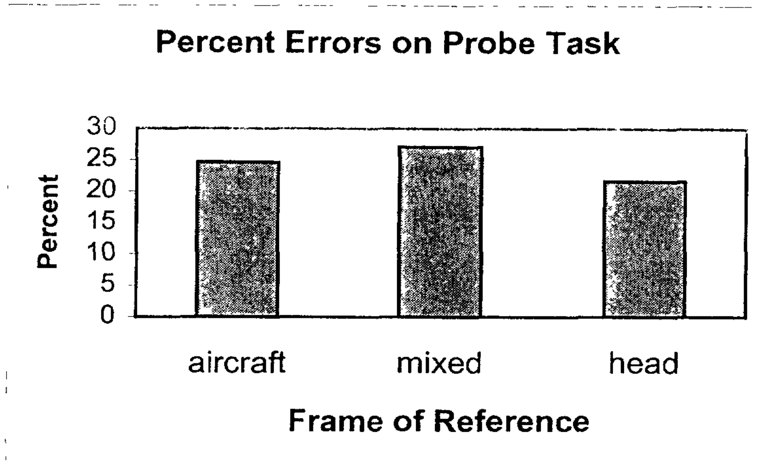
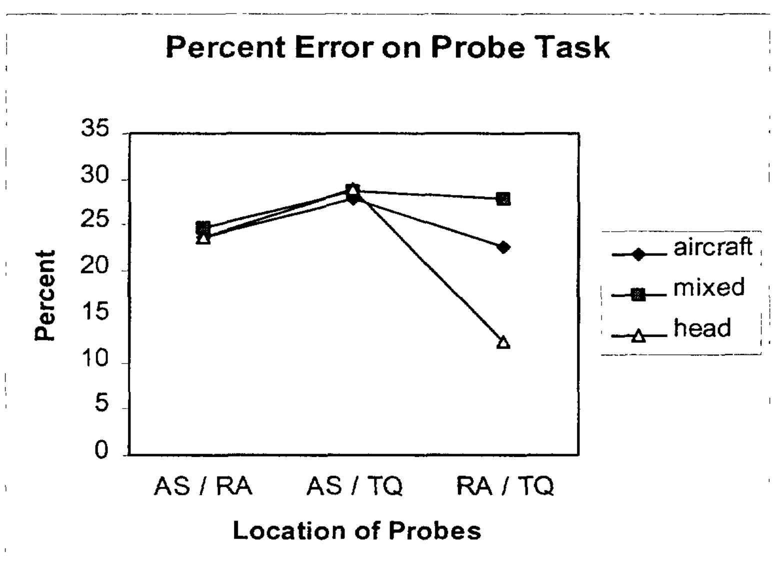


Figure 23
(AS = airspeed; RA = radalt; TQ = torque)



3.3.2.2 Target Misses

The percent misses (no response to targets) were analyzed in a 3(FOR: head, aircraft, mixed) x 3(Location: 1, 2, 3) repeated measures ANOVA. On average 5.52% of the targets were missed by the pilots. There were no significant effects of FOR or Location on percent Misses.

3.4 DISCUSSION

The purpose of this experiment was to take a step toward developing a paradigm to assess the functioning of object-based and space-based attention in HMDs equipped with HUDs. This research links directly to laboratory research conducted under PWGSC File No: W7711-9-7577/A, that showed a role for both object- and space-based attention in the processing of dynamic displays.

The results of this experiment are clear in showing that the processing of information on HUD displays is affected by space-based attention. In particular, it takes longer to interrogate targets that are presented on the HUD in spatially distant locations.

An important finding in this experiment is that these spatial attention effects occurred in the head-referenced configuration, but not in the aircraft or the mixed FORs. The comparison of the head versus aircraft conditions is interesting because it supports the notion that referencing the HUD to head movements creates a near-domain perceptual layer that is distinct from the far-domain of the external scene. On this view, the effect of spatial attention occurred with the head FOR because attention is assigned to the layer, in a manner similar to the placing of attention on perceptual objects. With the aircraft referenced configuration, the HUD (near-domain) and the external scene (far domain) are less likely to form distinct perceptual layers.

It was predicted that the mixed FOR would also create distinct perceptual layers, and that this would facilitate target discrimination. This hypothesis was not supported.

a possible confound inherent to the mixed FOR may have precluded the possibility of finding the expected advantage with this FOR. In particular, there would be trials (possibly many trials) where the targets were presented while the head-referenced symbologies in the mixed set were physically overlapping the other symbols on the HUD thereby making target discrimination difficult: there was no way to control for this confound in the present experiment.

Further mining of the present data set needs to be done. The missions flown by the pilots in this experiment were purposefully multi-faceted and included relatively low workload components such as enroute flight, and high workload components such as hover and recce. It would be useful to examine the attentional effects as a function of the type of task the pilot was performing when targets were presented.

In sum, the present research represents an important step toward establishing a framework for examining and modelling the role of object- and space-based attention in the processing of information in dynamic displays. The combination of simulator and laboratory research on these issues will have a direct impact on the development of HUD and HMD systems, such as those proposed by the TP2 panel.

APPENDIX

EXPERIMENTAL FORMS

Forms Package

for Subject n

Conduct of Experiment – Day 1

Initial:

- Gather Personal History
- Provide ACD Overview
- Review Experimental Protocol
- Review Questionnaire
- Sign Consent Form

Sessions:

- Describe Session Segments - Familiarization Flight, Formation Flight, and Side Step Manoeuvres
- Describe Symbology Set and Reference Systems
- Fly all three references systems (Reference Systems 2 and 3 are conducted as per Reference System 1)
- Fly null symbology segments for Side Step manoeuvres

Post Flights:

- Fill out questionnaire (Modified Cooper-Harper, then Subjective)
- Ranking sheet
- Debriefing/Observations
- Provide Contact Sheet

Personal History

Name: ______________________________

Age. ______ Sex·

Training Background: ______________________________

____

____

Approximate Hours on Rotary Wing Aircraft: ______

Types of Helicopters Flown: ______________________________

____

____

Simulated Flight Experience: ______________________________

____

____

Approximate Hours NVG: ______ Are Glasses Required: ______

Other Pertinent Information: ______________________________

____

____

Contact Information: ______________________________

____

____

ACD Overview

- developed by CMC under contract to DND
- Objective provide an environment for the evaluation of proposed Operator Machine Interfaces
- low fidelity demonstration tool, comprised of generic flight controls, low fidelity flight models for a small library of fixed and rotary wing aircraft, high resolution instrument panel and an integrated external scene
- latter development included the integration of a Helmet Mounted Display (HMD) and head tracking unit to provide a 360 degree scene
- Note: It is not intended that the ACD fulfil the role of a simulator. The level of fidelity is sufficient as a Human Factors Engineering testbed. These analyses spawn further testing in high fidelity systems and operational aircraft in the equipment definition and implementation phases.

Experimental Protocol

- General

1. Follow subject order listed

Subject No.	First Reference	Second Reference	Third Reference
1	Aircraft	Mixed	Head
2	Aircraft	Head	Mixed
3	Mixed	Aircraft	Head
4	Mixed	Head	Aircraft
5	Head	Aircraft	Mixed
6	Head	Mixed	Aircraft

2. State general purpose of experiment to subjects

- *Our long-term goal is to develop symbology sets that can be effectively integrated into HMDs. In the present study, we are examining 3 different reference systems for a symbology set that has been proposed in support of a joint Canadian, American, British and Australian programme. The Reference Systems being evaluated within this context include:*

- ❑ *Aircraft referenced: The HUD symbology is presented in the centre of the forward field of view (dash mounted) and is fixed to the aircraft system*

- ❑ *Mixed referenced: A combined reference system was established in support of this experiment, that blends Aircraft reference systems with a Head reference systems As such, the HUD components will move independent of one another in accordance with the subject reference specification.*

- ❑ *Head referenced: In accordance with the Aircraft Reference system, the primary HUD symbology set will be fixed to the centre of the forward field of view. The entire HUD symbology set will move in conjunction with the pilots head motion, remaining centrally fixated at all times.*

- ❑

- *This study is of limited scope - that is, we are not trying to answer all possible questions at once. Instead, we are focusing on the impact made on basic flight tasks by the reference system used to display HUD symbology information.*

- *To do this, we will have you fly a generic rotary wing model through partially degraded conditions (similar to dusk/fog) using each of the three reference systems. For each reference system you will be flying for approximately 1 hour, for a total of 3 hours.*

- *Your primary task throughout the experiment is to maximize your performance within the specific flight tasks by achieving/maintaining specific altitude, heading, and airspeed parameters. The data collected and the performance scores generated reflect timing, heading, altitude and airspeed information as appropriate.*

- *There are two flight modes within each session, including Formation Flight, and Side Step manoeuvres To make the Formation Flight task challenging, we will be introducing a secondary observation task requirement*

- *Each Formation Flight period will consist of ten 2 minute periods. At the beginning of each period, aircraft attitude, altitude and airspeed will be reset to their initial settings. This reset will be preceded by a brief interruption of the external scene, approximately 3 seconds The initial settings for aircraft attitude are 0 degrees in pitch and roll, altitude is 200', an airspeed of 80 knots, following a heading dictated by a bug on the*

Heading Tape Also, during the Formation Flight, as a secondary task, you will be asked to determine the colour of a lamp affixed to the nose of the aircraft flying in formation with your aircraft Data collection includes heading and altitude deviations

- *The Side Step period entails the performance of a take-off activity, followed by a brief hover at an altitude of 20-30', and a Side Step manoeuvre to depart from the hover zone with the nose of your aircraft at due north The aircraft will proceed at an altitude of 25', to the next hover location, and attain a 25' hover over the target zone. Maintain a constant heading, altitude and path to target Once a stable hover is attained, perform a landing as quickly as possible Data collection includes heading, flight path, altitude and timing information*
- *Finally, after all sessions have been completed, we will ask you to fill out a few questionnaires.*
- *Do you have any questions?*

- Session #1

- . Train on how to set HMD
- Free flight period (approx. 15-30 min.)

- ❑ *It is important that you become familiar with both the simulator and with the symbology set that you will be using in this session. Therefore, we would like you to engage in free flight for a minimum of 5 minutes (we will stop you after 5 minutes and more time will be given if you wish) We would like to recommend attempting each of the specific manoeuvres during this free flight period.*
- ❑ *Although the experiment is run in a visually obscured environment of combined fog and dusk lighting conditions, this familiarization period will be conducted in a visually unrestricted scene An opportunity to fly in the obscured environment will also be provided.*
- ❑ *We are not recording ANY data during this time period So, please use this time to perform any type of flight task that you want with an eye toward learning how to obtain and use attitude information from the symbology set as it is presented. At any time during this initial free flight period please ask questions and try to get comfortable with the setup and the symbology.*

Block #1: Formation Flight

Block #2: Side Step

Block #3 (follow-on testing): We will ask you to fly the Side Step manoeuvres without any symbology information whatsoever.

Once the trial starts, pretend that we are not here: DO NOT STOP TO MAKE COMMENTS UNTIL THE END OF THE TRIAL.

- Questionnaires

- Remove subject from the ACD, take to a quiet room to complete questionnaires

Consent Form

I, ______________________________, having reached the age of majority, agree to participate in the research project entitled HUD Symbology Research under the direction of Dr. Chris Herdman conducted at BAE Systems Canada. I acknowledge that my participation in this research project is completely voluntary.

I have been advised and understand the description of the project, including its purpose, methods of research and the risks associated with my participation.

I understand that the findings of the study may be published, but my anonymity in material arising from this study will be maintained. In no way will my name be identified or attached to the study.

I understand that my participation in this study is entirely voluntary and that I may decide to stop participating at any time without any consequences to my career.

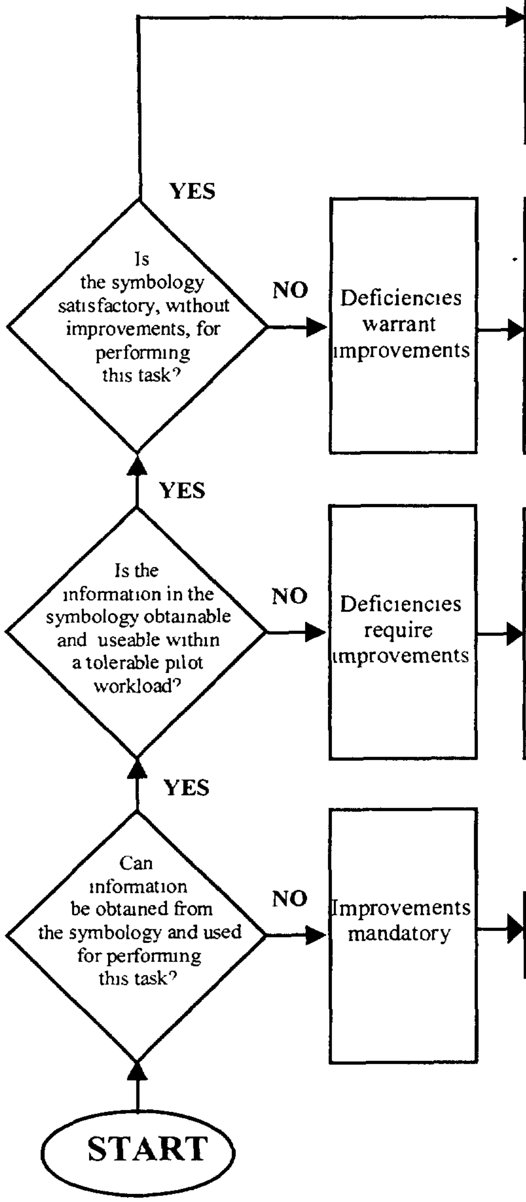
Details of the study have been explained to me and my questions about the study have been answered.

I may obtain additional information about the project and have any additional questions answered by contacting Dr. Chris Herdman.

______________________________	______________________________
Name of Participant	**Name of Witness**
______________________________	______________________________
Signature of Participant	**Signature of Witness**
______________________________	______________________________
Date	**Date**

Rating: Ability to obtain and use information from the symbology to support **Formation Flight**

Reference System: **Aircraft**



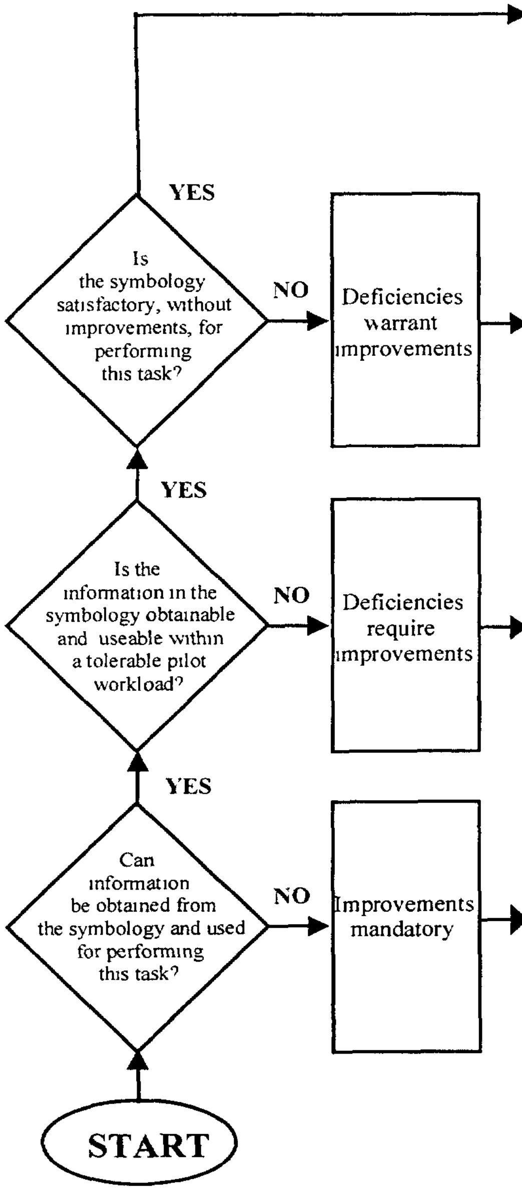
Symbology Characteristics	Demands on Pilot Associated with Formation Flight Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	1
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	2
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	3
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required	4
Moderate, objectionable deficiencies	For adequate performance, moderate levels of mental effort are required.	5
Very objectionable but tolerable deficiencies	For adequate performance, extensive but manageable levels of mental effort are required.	6
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required	7
Major deficiencies	For adequate performance, close-to-maximum and unmanageable mental effort is required	8
Major deficiencies	For adequate performance, maximum and intolerable mental effort is required.	9
Major deficiencies	Symbology cannot be used for the performance of this task	10

PILOT DECISIONS

Rating: Ability to obtain and use information from the symbology to support **Side Step**

Reference System: **Aircraft**

Symbology Characteristics	Demands on Pilot Associated with Side Step Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	**1**
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	**2**
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	**3**
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required.	**4**
Moderate, objectionable deficiencies	For adequate performance, moderate levels of mental effort are required.	**5**
Very objectionable but tolerable deficiencies	For adequate performance, extensive but manageable levels of mental effort are required	**6**
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required	**7**
Major deficiencies	For adequate performance, close-to-maximum and unmanageable mental effort is required	**8**
Major deficiencies	For adequate performance, maximum and intolerable mental effort is required	**9**
Major deficiencies	Symbology cannot be used for the performance of this task	**10**

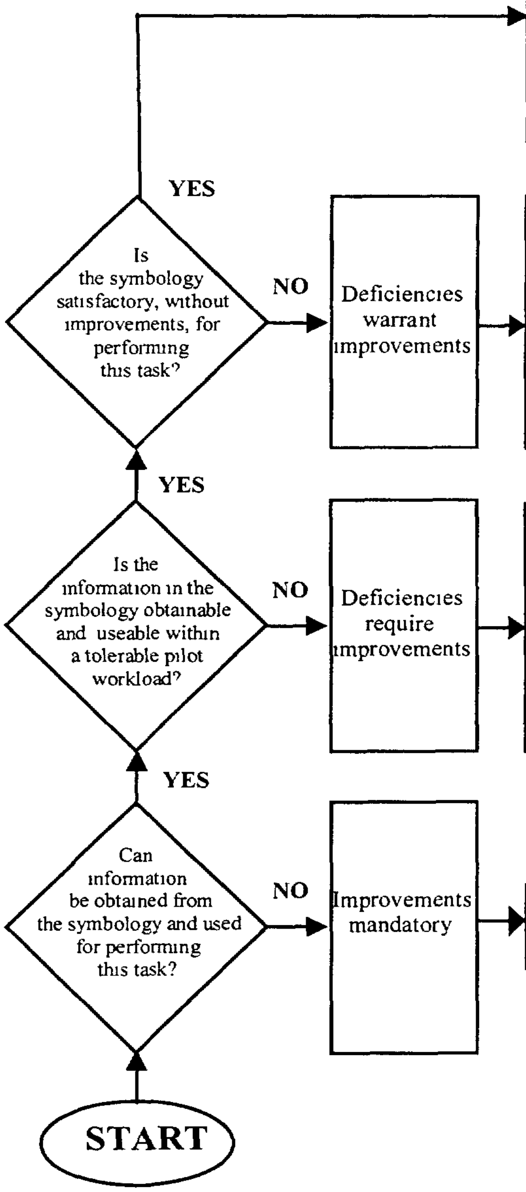


PILOT DECISIONS

Rating: Ability to obtain and use information from the symbology to support **Formation Flight**

Reference System: **Mixed References**

Symbology Characteristics	Demands on Pilot Associated with Formation Flight Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	**1**
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	**2**
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	**3**
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required	**4**
Moderate, objectionable deficiencies	For adequate performance, moderate levels of mental effort are required.	**5**
Very objectionable but tolerable deficiencies	For adequate performance, extensive but manageable levels of mental effort are required.	**6**
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required.	**7**
Major deficiencies	For adequate performance, close-to-maximum and unmanageable mental effort is required	**8**
Major deficiencies	For adequate performance, maximum and intolerable mental effort is required.	**9**
Major deficiencies	Symbology cannot be used for the performance of this task	**10**



PILOT DECISIONS

Rating: Ability to obtain and use information from the symbology to support **Side Step**

Reference System: **Mixed References**

Symbology Characteristics	Demands on Pilot Associated with Side Step Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	**1**
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	**2**
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	**3**
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required	**4**
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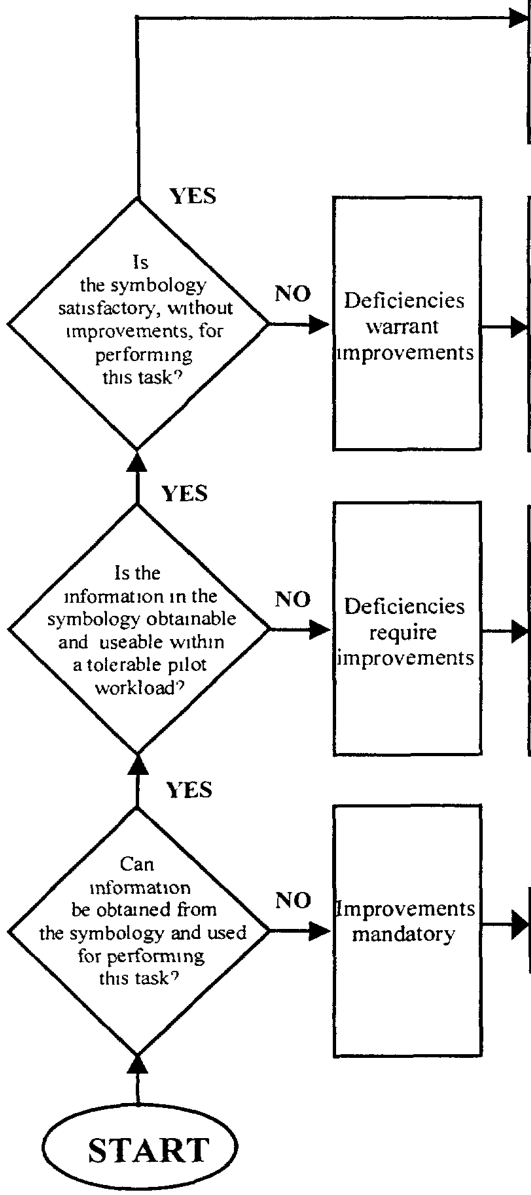
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required.	**7**
Major deficiencies	For adequate performance, close-to-maximum and unmanageable mental effort is required	**8**
Major deficiencies	For adequate performance, maximum and intolerable mental effort is required	**9**
Major deficiencies	Symbology cannot be used for the performance of this task	**10**

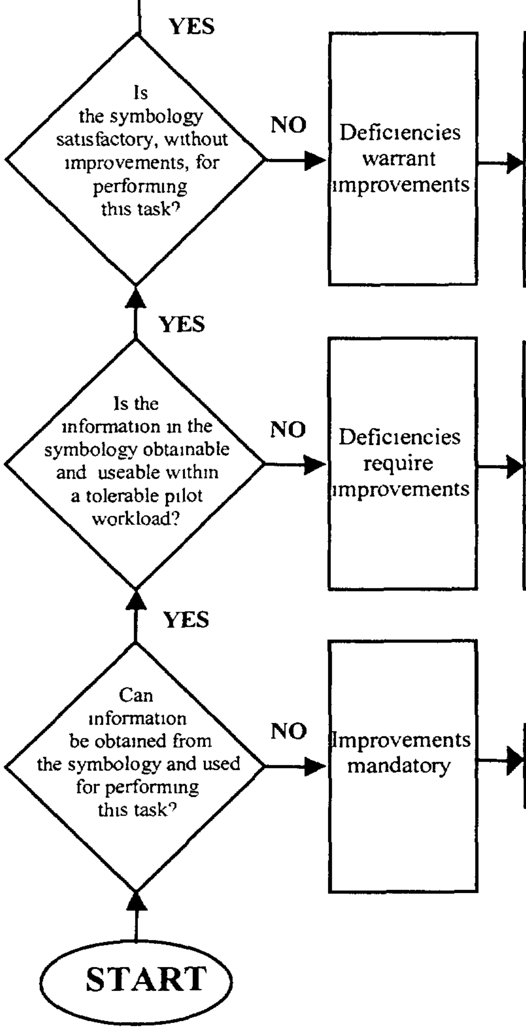


PILOT DECISIONS

Rating: Ability to obtain and use information from the symbology to support **Formation Flight**

Reference System: **Head Reference**

Symbology Characteristics	Demands on Pilot Associated with Formation Flight Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	**1**
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	**2**
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	**3**
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required.	**4**
Moderate, objectionable deficiencies	For adequate performance, moderate levels of mental effort are required	**5**
Very objectionable but tolerable deficiencies	For adequate performance, extensive but manageable levels of mental effort are required	**6**
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required.	**7**
Major deficiencies	For adequate performance, close-to-maximum and unmanageable mental effort is required	**8**
Major deficiencies	For adequate performance, maximum and intolerable mental effort is required.	**9**
Major deficiencies	Symbology cannot be used for the performance of this task	**10**



PILOT DECISIONS

Rating: Ability to obtain and use information from the symbology to support **Side Step**

Reference System: **Head Reference**

Symbology Characteristics	Demands on Pilot Associated with Side Step Task	Rating
Excellent, highly desirable	Information can be easily obtained from the symbology and used without mental effort	1
Good, negligible deficiencies	Information can be obtained from the symbology and used with very little mental effort	2
Fair, some mild deficiencies	Information can be obtained from the symbology and used with a low and acceptable level of mental effort	3
Minor, but annoying deficiencies	For desired performance, moderate levels of mental effort are required	4
Moderate, objectionable deficiencies	For adequate performance, moderate levels of mental effort are required	5
Very objectionable but tolerable deficiencies	For adequate performance, extensive but manageable levels of mental effort are required	6
Major deficiencies	For adequate performance, extensive and nearly unmanageable mental effort is required.	7
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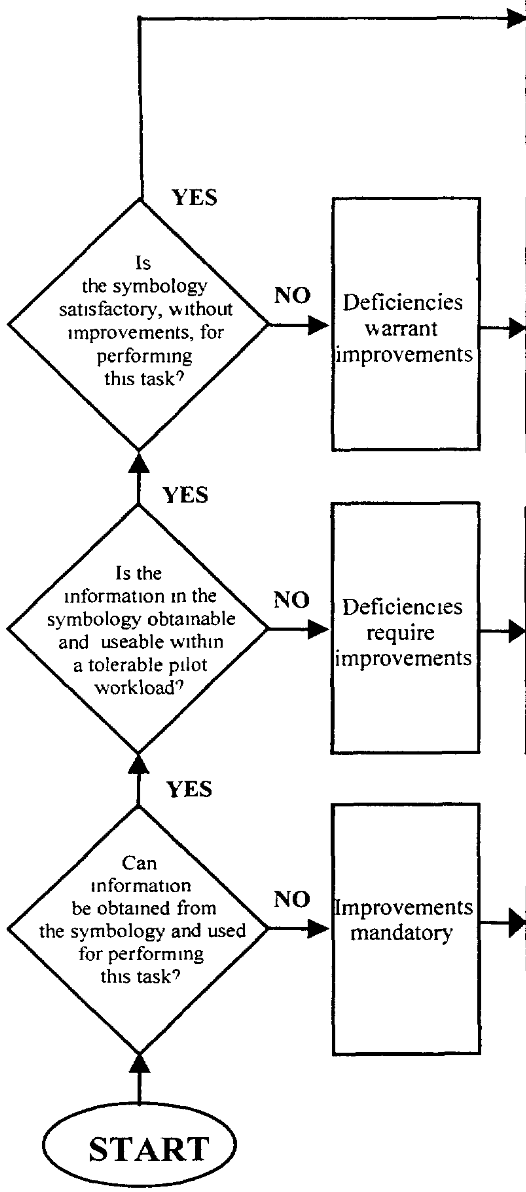

PILOT DECISIONS

Pilot comments and insights

Did you use the Symbology Set to aid performance during the flight task?

Aircraft

Mixed not at all continually

Head

Did the presentation of the symbology set interfere with your perception of the external scene?

Aircraft

Mixed not at all excessively

Head

Flight tasks/situations where the various reference systems would be particularly well suited (if any).

Aircraft ______________________________

Mixed ______________________________

Head ______________________________

Aspects of Reference System that are particularly good.

Aircraft ______________________________

Mixed ______________________________

Head ______________________________

Aspects of Reference Systems that are particularly bad.

Aircraft ______________________________

Mixed ______________________________

Head ______________________________

Please provide any additional insights/comments that you have concerning the symbology set. Are there further developments to the symbology set that you would like to see take place?

Reference System Rankings

In this series of tests, you were exposed to the following reference systems:

Aircraft Mixed Head

Please rank order (write in) the reference systems in terms of your preference for use. From Most Preferred down to Least Preferred.

Formation	**Side Step**
______	______
______	______
______	______

Debrief

- reiterate the intent of the experiment

- ask pilots not to talk to colleagues about the specifics of the experiments (e.g., symbologies, methods) until the April timeframe.

- Secondary interest: the ACD is a research and development tool established by the Directorate Technical Airworthiness to assist in the successful integration of operator and machines in the CF airborne context. It is important to all agencies that this capability be presented to the user community through studies like this one.

Observations

Are there any general observations regarding the facility or the experiment that the subjects would like to make.

Contact Information

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Dr Chris Herdman
Professor, Centre for Applied Cognitive Psychology
Carleton University
Ottawa, Ont. K1S 5B6
phone: (613) 520-2600 ext 8122
email: cherdman@ccs.carleton.ca

Joseph Armstrong
Graduate Students
Carleton University
237-2595

BAE Systems Canada Inc
415 Legget Drive
Kanata, Ontario
K2K 2B2

Gordon Youngson
Project Engineer
phone: (613) 592-7400 ext 2454

Murray Gamble
Design Specialist
phone: (613) 592-7400 ext 2208

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14. ABSTRACT

(U) The TTCP Technical Panel 2 (TP2) developed a HUD symbology set using a "mixed" referencing system in which symbols portraying spatial analogue information are aircraft or world referenced, whereas non-spatial symbols are head referenced. One potential advantage to having non-spatial symbols referenced to head position is that critical flight and power information can be made available to the pilot even when the pilot's gaze is directed to the side of the aircraft, such as during sidestep maneuvers. It is not clear, however, whether pilots can effectively use a mixed referencing system. For example, one potential problem is that depending on moment-to-moment positioning of the head, one or more of the head referenced symbols may overlap with the aircraft referenced symbols. This may create intolerable perceptual/cognitive confusion and high mental workload.

There were two objectives of the present research. The first objects was to contrast the effectiveness of the TP2 mixed frames of reference (FOR) against an aircraft and a fully head-referenced configuration. To do this, two ADS33-type tasks were used: formation flight and sidestep. The formation flight results showed that there was undifferentiated performance across the aircraft, mixed, and head FORs. The sidestep results showed an advantage for the mixed and head FORs over the aircraft FOR in two primary performance measures: maintaining heading and altitude. The superiority of the mixed and head FORs for the sidestep manuever was also reflected in the pilot's ratings.

A second objective of the present research was to take a step toward establishing a paradigm to assess the effects of space-based and object-based attention in processing of HUD symbology. To do this, pilots' ability to discriminate targets that appeared on a HUD was assessed across the mixed, aircraft, and head-referenced configurations. The results of this experiment were clear in showing that the processing of information on HUD displays is affected by space-based attention. Importantly, the spatial attention effects occurred in the head-referenced configuration, but not in the aircraft of the mixed FORs. The comparison of the head versus aircraft conditions supports the notion that referencing the HUD to head movements creates a near-(HUD) domain perceptual layer that is distinct from the far-domain of the external scene. On this view, the effect of spatial attention occurred with the head FOR because attention is assigned to the HUD layer, in a manner similar to the placing of attention on perceptual objects. With the aircraft referenced configuration, the HUD (near-domain) and the external scene (far-domain) are less likely to form distinct perceptual layers.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Heads-Up Display (HUD); Helmet-Mounted Display (HMD); symbology; Frame of Reference (FOR); ADS33; attention; aviation displays

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