PILOT-IN-THE-LOOP EVALUATION OF NEXT GENERATION WEATHER RADAR DISPLAYS

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Abstract

The focus of this paper is the comparative evaluation of pilot performance with conventional weather and Next Generation Weather Radar (NGR) display concepts. Forty-six pilots participated in an evaluation using a part-task simulator. Both subjective and objective data were collected during each scenario. Results indicate that there is a significant difference in hazardous weather detection rate between conventional and NGR displays. Mean detection times for the NGR displays were also superior. The NGR group weather avoidance decisions were significantly more prudent than those using conventional radar. Poor tilt management was the primary reason for the conventional weather display subjects missing significant weather targets. Overall, the Bedford workload ratings were lower for one of the NGR displays. The NGR displays received favourable perceived weather (situational) awareness ratings. Subjects also provided positive overall acceptability ratings and subjective comments reinforce these findings.

1. Introduction

Safety data indicate that weather continues to be a factor in aviation accidents [1]. There has been an extensive amount of research conducted into future airborne weather systems. Much of this work focuses on integrated weather data products using datalink as opposed to conventional airborne weather radar systems. In addition, there has been extensive research into flight crew decision-making related to hazardous weather avoidance (e.g., [2]-[5]). Flight crew judgement and a lack of timely and comprehensive weather information have been frequently associated with weather-related incidents and accidents [2]-[3].

The proper operation and interpretation of airborne weather radar is dependent upon pilots having an adequate understanding of its capabilities. It is speculated in some quarters that pilot weather radar training is limited. Ref. [6]-[7] argue that one of the least understood aspects of weather radar is antenna tilt management. Ref. [8] is an example of an incident where an aircraft was inadvertently flown into an area of severe convective weather activity. The official incident report indicates that factors included possible over-scanning of the convective cell and the flight crew did not appear to understand the limitations of the airborne weather radar (e.g., attenuation).

Improvement in flight crew training and flight deck weather information provides an opportunity to enhance operational safety.

1.1 Evaluation Objectives and Scope

This focus of this paper is the human factors evaluation of NGR display concepts. A comparative evaluation of pilot performance of two new display modes and conventional weather radar is presented. Pilot weather awareness, weather avoidance decision-making, workload and pilot acceptability of the new displays are fundamental to objectives of this investigation. Due to the space limitations of this paper only a sample of results are presented.

2. Candidate Weather Radar Displays

2.1 System Overview

The NGR is an airborne, solid state, X-Band weather radar system. The key functions provided are as follows:

- alternative views of reflectivity data;
- Predictive Windshear Detection (PWS);
- Turbulence (TURB) detection; and
- ground mapping (not for navigation).

The remainder of this paper focuses on the weather (reflectivity) modes. The radar system continuously scans the airspace ahead of the aircraft to a range of 320 nm and from sea-level to 60 000 ft. The reflectivity data is stored in a three-dimensional ("volumetric") memory buffer. Earth curvature corrections are applied and so the potential for misinterpretation of weather images (inherent to conventional radar) is reduced. The antenna movement is stabilized for aircraft pitch and roll.

The system contains an internal terrain database. Reflectivity data that correlates to terrain data is considered ground-clutter, and is extracted from the weather image without the significant losses associated with ground clutter suppression techniques. This ground-clutter reflectivity data is retained for the Map mode display. This obviates the need for manual tit control while in Map mode.

Buffer reflectivity data generate display views without having to make view-specific antenna scans – a limitation of conventional radar. See Figure 1. Once the aircraft has transitioned through airspace scanned for reflectivity data, the weather data behind the aircraft can be displayed e.g., Rose Mode on the Navigation Display. Both plan and vertical profile views can be generated. Only plan-view displays were subjected to evaluation in this study.

2.1.1 *AUTOMATIC Weather (AUTO)*

The flight deck control panel allows selection of MANUAL or AUTO display modes. The modes are independently controlled for both sides of the flight deck. Range and manual gain controls are available for both modes. See Figure 2.

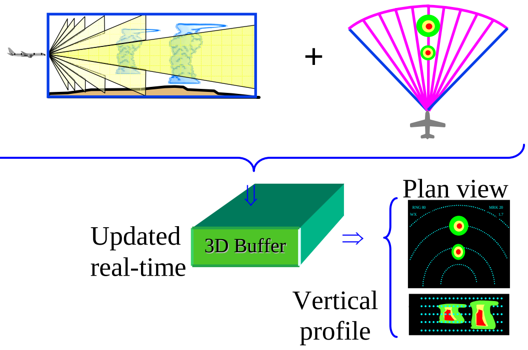

Figure 1 Three Dimensional Scanning

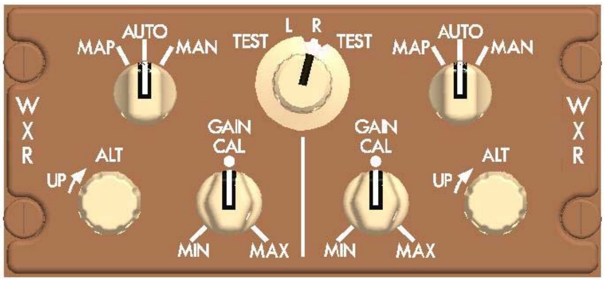

Figure 2 Prototype Control Panel

AUTO mode is intended for the strategic detection of weather. An automatic distinction is made between weather associated with the intended vertical flight path and weather that is not. Weather segregation is accomplished by establishing an envelope around the intended flight path: weather within the envelope is termed *Primary Weather*; and weather outside the envelope is *Secondary Weather*. Upper and lower boundaries for the envelope are established using Flight Management System (FMS) flight plan or current aircraft state data. Weather reflectivity is displayed using conventional colours for Primary Weather. Secondary Weather colours are identical, but black cross-hatch lines are also displayed. Figure 3 illustrates this concept.

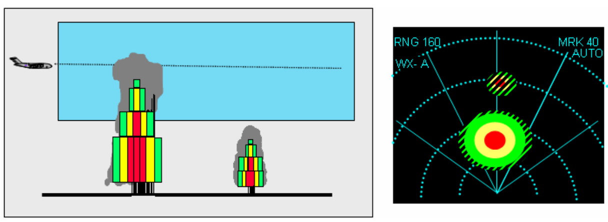

Figure 3 AUTO Mode Concept

2.1.2 MANUAL Weather - Constant Altitude

The task of exactly measuring cell height with conventional radar can be cumbersome due to Earth curvature effects. The MANUAL mode is a tactical weather analysis tool (e.g., determining vertical extent of weather returns). A plan view display of reflectivity at a specific (constant) altitude can be manually selected. Since the volumetric buffer corrects for Earth's curvature, the view is at constant Mean Sea Level (MSL) altitude.

Upon selection of MANUAL mode on the control panel (MAN), the altitude of interest is selected by a rotary controller (ALT). The selected altitude is either a relative altitude or actual MSL altitude (implementation depends on aircraft type). For the latter, the selected altitude is expressed in feet or Flight Level (FL) depending on the barometric selection (QNH vs. QFE). The selectable MSL altitude varies between ground level and 60000 ft in 1000 ft increments. For the relative altitude implementation, altitude is adjusted in increments of 1000 ft relative to current altitude. The selected altitude is presented on the display. See Figure 4.

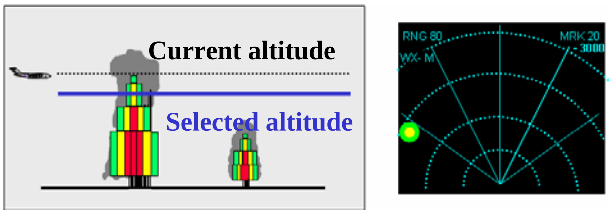

Figure 4 MANUAL Mode Concept

3. Experiment Design

A comparative evaluation of pilot performance with conventional radar and NGR weather display modes was the basis for experiment design. To counter the carry-over effect associated with over exposure of critical conditions and similar scenarios, a *between-subjects design* was adopted. The evaluation interfaces are shown in Table 1. Since it is not possible (nor desirable in this case) to test for interactions between the *display mode* and *control type*, Interfaces A, B and C were tested for main effects only. The MANUAL mode was implemented using relative altitude. The AUTO mode was implemented using current aircraft state data (as opposed to FMS data).

Table 1 Experimental Variables

	Tilt Control	Constant Altitude Control	No Control
Auto Display Mode	Not Applicable*	Not Applicable*	***Interface C*** AUTO Mode
Manual Display Mode	***Interface A*** Conventional TILT radar	***Interface B*** MANUAL Mode	Not Applicable*

* Does not physically exist

4. Evaluation Facility

This part-task evaluation was configured for a single pilot. The PC-based environment displayed the following (Figure 5).

- Primary instruments (*basic-T*).
- Weather radar display. To focus the study on main effects listed in Section 3, other data such as TURB, PWS, FMS flight plan and terrain were excluded.
- A control panel with range, gain, constant altitude and tilt controls. Tilt was enabled for the reference treatment condition (Interface A) and constant altitude control was enabled for MANUAL mode on a shared control (disabled for AUTO mode evaluation).

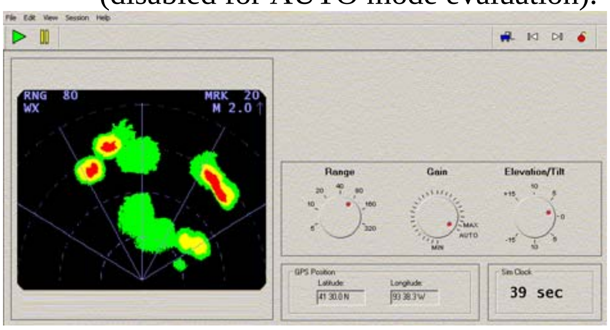

Figure 5 Evaluation Display and Control Panel

A dynamic display presentation was provided for each test scenario. The aircraft performance characteristics were similar to that of a medium-sized transport aircraft. Scenarios that followed specific aircraft trajectories were adopted. Therefore, flight controls were not provided to subjects and the study is limited to an investigation of the pilot monitoring instruments and decision making (i.e., information processing). However, pilots were required to negotiate clearances for hazard avoidance with the experiment leader, who functioned as the Air Traffic Controller (ATC).

5. Evaluation Scenarios

The scenarios adopted included a range of conditions, see Table 2. Scenario order was randomized to reduce potential for order-effect.

Table 2 Evaluation Scenario Matrix

Scenario Overview
1. Los Angeles Five Departure (Vector) Runway 24L This was a training scenario. Two areas of heavy thunderstorm with rain (+TSRA) were located at 30 mi/heading 230° and 65 mi/heading 260° from initial position. This weather was not a factor as the route included Northbound vectors during the initial climb.
2. Seattle (KSEA) Three Departure (Vector) Runway 34R Initially holding-short of runway 34R. Large area of heavy thunderstorm with rain (+TSRA) 10 mi North of runway 34R to avoid: red and amber echoes on weather radar. Clearance required climb to 10 000 ft, maintain runway heading, and expect Eastbound radar vectors.
3. Portland (KHIO) SCAPO Three Departure Runway 20 A Northbound Standard Instrument Departure (SID) with significant initial turning manoeuvres. +TSRA located: 80 mi East of Northbound portion of SID to waypoint SCAPO; and 30 mi North of SCAPO. Prior to SCAPO, ATC issued Eastbound vectors to avoid the weather North of SCAPO. The cells located 80 mi East of SCAPO were encountered if pilot accepted Eastbound vectors.
4. Cruise Flight at FL 280 – Overhead Wichita (KICT) Westbound level flight. Varying cloud tops from 19000–23000 ft between 40-100 mi range on track. Intensities amber and red displayed on a diagonal South-North line. Weather cell at approximately 240˚ heading and 30 mi range had lowest cloud top: TSRA 3000/19000 tops. Key feature of scenario was detection of latter weather cell.
5A. Northbound Low Altitude Cruise Flight at 13000 ft – Overhead Des Moines (KDSM) This was a storm cell analysis task. +TSRA areas on either side of aircraft track located within 6000 ft of cruise altitude: 25-40 mi to West <u>below</u> aircraft; 20 mi Northeast <u>above</u> aircraft. Red and amber intensities displayed. Key issue was whether subject could identify vertical position of these cells relative to current altitude.
5B. Diversion to Waterloo (KALO) 40 mi North of initial position, destination airport declared closed. ATC required turn to East, followed by Northbound vectors with climb to 17000 ft to the alternate KALO. Significant +TSRA to avoid were located 30 mi East of turn point. Transition of Secondary Weather to Primary Weather also observed in the climb (AUTO display).
6. ILS Approach Runway 34 Richmond (KRIC) This was a demanding Instrument Landing System (ILS) approach with a reported 200ft ceiling, ¾ mi visibility and rain. Initial position was 16 mi Southeast of Initial Approach Fix (IAF). Significant convective activity located 5 mi SW of runway 34 (amber/red returns), wind was 270° /3 kt. +TSRA also located in vicinity of holding pattern for missed approach procedure. Although it was possible to land in this scenario, the focus was on whether subjects detected the two areas of significant weather and how it impacted decision-making.
7. KHIO CANBY Six Departure Runway 30 Scenario was focused on scrutinizing unnecessary False Alarms, especially for AUTO display based on flight path vector (as opposed to FMS intent data). The SID required a right turn to heading 110°, then Southerly track to waypoint CANBY. Significant +TSRA areas 30 mi North and Northeast of airport. No significant weather South of airport. None of the displayed weather was within 25 mi of SID route.
8. Cruise and Descent at FL 370 – Overhead KICT Westbound level flight. Two areas of significant weather within 40 mi of initial position: +TSRA at 11 o' clock; and 2 o' clock. Both areas initially appeared as Primary Weather (AUTO). These cells not an immediate threat but close enough to warrant attention. Also, +TSRA on track at 55 mi range. Initially displayed as Secondary Weather (AUTO) with red/amber echoes. An unusual descent to FL 180 was required 20 mi from initial position. Latter weather cell transitioned to Primary Weather (AUTO) during descent. Scenario focus was detection of cell on track and subject behaviour when Secondary red & amber echoes are displayed on aircraft track.

6. Evaluation Procedure

The evaluation procedure included briefing, training, evaluation and debrief. Each pilot was required to use all available resources to conduct tasks listed below.

- Assess Automatic Terminal Information Service (ATIS), Meteorological Aerodrome Report (METAR), Pilot Report (PIREP), winds aloft.

- Monitor the basic instruments.
- Manage the radar control panel.
- Monitor weather radar display to detect potential weather hazards.
- Decide any pilot action necessary for weather avoidance. As pilot control of the aircraft was not under scrutiny, the subject was required to verbally state the action and request appropriate clearance from ATC. Following the decision, pilots were required to state the range and clock-position of hazardous weather.

Jeppesen charts were used for the evaluation.

7. Test Subjects

All participants were holders of an Air Transport Pilot Certificate and experienced with conventional weather radar. Each group comprised a culturally diverse mixture of corporate, major carrier and aircraft manufacturer pilots. A summary of pilot experience is presented in Table 3

Table 3 Subject Age and Experience Summary

Display	N	Mean Age Years	σ Age Years	Mean Total Time Hours	σ Total Time Hours
TILT	13	54	6	12423	8502
MAN	16	52	7	13981	6353
AUTO	17	51	8	11253	4543
All	46	52	7	12533	6437

The differences between group means and variances for age and total hours are highly insignificant ($p > 0.24$). This provides an excellent basis for across-group comparisons. Note, “TILT” and “conventional” are used interchangeably herein.

8. Data Collection

The following data were collected during the evaluation, namely

- detection and time-to-detect hazardous weather during the scenario;
- pilot operational decision for weather avoidance and time-to-decision;
- response to probe questions regarding range, position and intensity of specific weather cells;
- workload rating for each scenario;
- control panel activity (range, elevation and tilt changes);
- subject comments during the scenario and during the debriefing; and
- post-experiment questionnaire to qualitatively assess factors such as pilot acceptability of new concepts, perceived weather awareness, symbology, etc.

9. Results

9.1 Weather Awareness and Decision-Making

In each scenario subjects were required to detect any potential weather hazards and decide the action necessary for weather avoidance. The four possibilities for weather detection are:

- *Hit* – detection of hazardous weather;
- *Correct rejection* – absence of hazardous weather acknowledged by subject;
- *Miss* - failure to detect hazardous weather;
- *False alarm* – subject indicating hazardous weather is present when conditions do not include such weather.

A significant False Alarm rate was not encountered with any display. The weather detection data combined for all scenarios are presented in Figure 6 (Scenario 7 excluded since it focused on False Alarms). The difference in weather detection capability between displays is highly significant ($p < 0.001$). The AUTO detection rate is better than either MANUAL ($p = 0.048$) or conventional (TILT) display ($p = 0.000$). The MANUAL mode detection rate is higher than the conventional display ($p < 0.003$).

Figure 7 presents the aggregate weather avoidance decision-making data. An “incorrect decision” implies encounter with significant weather. The between-group differences in decision-making are highly significant ($p < 0.001$). The AUTO ($p = 0.000$) and MANUAL

(p = 0.000) displays resulted in significantly more correct decisions than the conventional display. The difference between AUTO and MANUAL groups is not significant (p = 0.22).

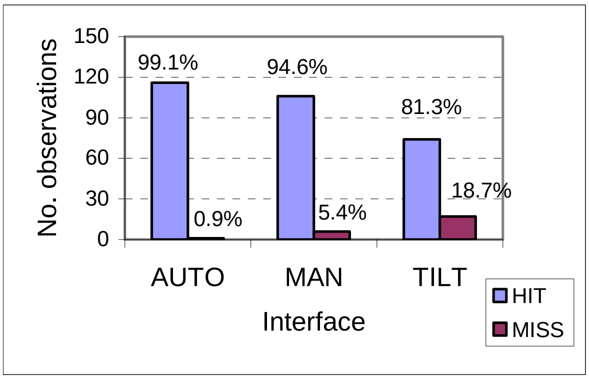

Figure 6 Weather Detection Rate

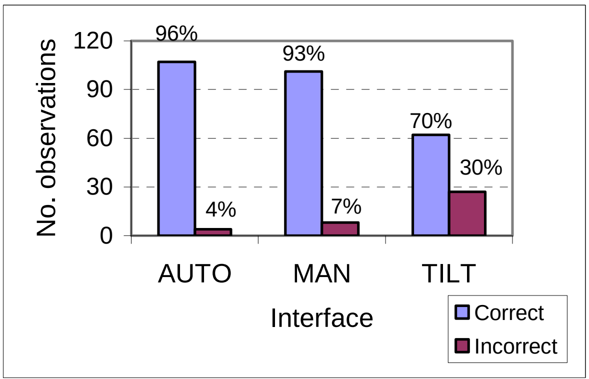

Figure 7 Weather Avoidance Decision Making

9.1.1 Scenario Two

All subjects, except one conventional radar pilot, detected the weather threat on runway heading (see Figure 8). The between-group differences are insignificant.

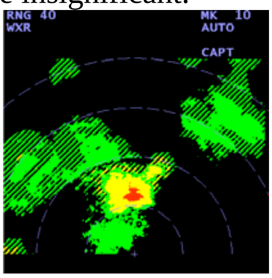

Figure 8 Scenario Two – AUTO Display

A Kruskal-Wallis ANOVA demonstrates that the between-group difference between mean detection times is significant (p = 0.015). There is no significant difference in mean detection times between AUTO (19.8s) and MANUAL (22.4s) modes. The mean detection time (34.8 s) for the conventional group is significantly longer than either AUTO or MANUAL modes (p = 0.001 and 0.007 respectively). All subjects, except two, made appropriate decisions to avoid weather. The between-groups differences are insignificant (p < 0.1). Subjects generally requested either a delay in take-off or an immediate right turn after take-off. A Kruskal-Wallis ANOVA reveals that the mean decision-making times for weather avoidance are significantly different between groups (p = 0.01). There is no significant difference between the AUTO (36 s) and MANUAL (39 s) groups, but the mean decision-time for the conventional group (57s) is significantly longer than either AUTO or MANUAL groups (p = 0.013 and 0.043 respectively).

9.1.2 Scenario Three

Only one subject (conventional tilt group) failed to detect the weather North of SCAPO. Hence the between-groups difference is non-significant (p > 0.05). However, a significant difference in mean detection times exists. The AUTO group had the fastest detection time of 138 s (p = 0.014). There is no significant difference in mean detection time between the MANUAL (180 s) and conventional groups (174 s) (p = 1).

All AUTO and MANUAL subjects detected the significant weather East of SCAPO. Fifteen percent of the conventional group did not detect these cells. The relative vertical position of the cells North and East of SCAPO required subjects to appropriately manage the tilt control to detect each of the threat areas. A Kruskal-Wallis ANOVA reveals that the mean detection time differences are significant (p = 0.004). The difference between AUTO (323 s) and MANUAL (335 s) mean detection time was not significant (p = 1.00). However, mean detection time for the conventional group (404 s) was significantly higher than both the AUTO and MANUAL groups (p = 0.02 and 0.005 respectively). Note that the right turn to the East occurred at 340 s. Therefore, conventional group pilots detected the weather after the right turn and at a distance closer to the weather. All AUTO and MANUAL group pilots requested timely weather avoidance vectors. However, 15% of conventional group pilots continued flight towards the weather cells. The mean group decision times to avoid the Eastbound weather are significantly different ($p = 0.001$). There is no difference between AUTO and MANUAL groups. Both AUTO and MANUAL groups were quicker than the conventional group ($p = 0.006$ and 0.017 respectively).

9.1.3 Scenario Four

Of primary interest was the ability of subjects to detect a weather target at 240˚ heading/30 mi range from initial position [A]. See Figure 9.

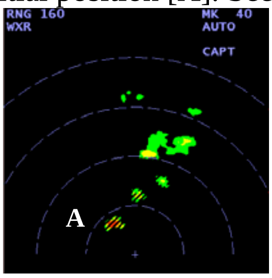

Figure 9 Scenario Four – AUTO Display

The between-group differences in detection rates are highly significant ($p < 0.001$). The AUTO group detection rate (100%) is greater than both MANUAL (69%) and conventional group rates (8%) ($p = 0.012$ and 0.00 respectively). Only one conventional group pilot detected weather cell A. The difference between MANUAL and conventional group is significant ($p = 0.001$).

Almost one-third of the MANUAL group did not detect weather cell A. Figure 10 presents the lowest selected elevation for these subjects. They did not select an elevation low enough to detect the weather cell, but most subjects looked for weather at elevations of 3000 ft or more below the current Flight Level. These results support the hypothesis that the AUTO mode is more suitable for strategic use than the MANUAL mode.

When the tilt control data for the conventional group are analysed, it becomes apparent that most subjects did not follow standard tilt control procedures for cruise flight (i.e., poor tilt management.)

Prudent weather avoidance decisions were made by most AUTO subjects (93%) and 69% of the MANUAL group. All conventional group subjects accepted vectors over cell A or continued towards other significant weather. These between-group differences in decision-making are significant ($p < 0.001$). The AUTO and MANUAL group difference is not significant ($p = 0.1$). The paired differences between AUTO-conventional ($p = 0.000$) and MANUAL-conventional ($p = 0.000$) decision-making are highly significant.

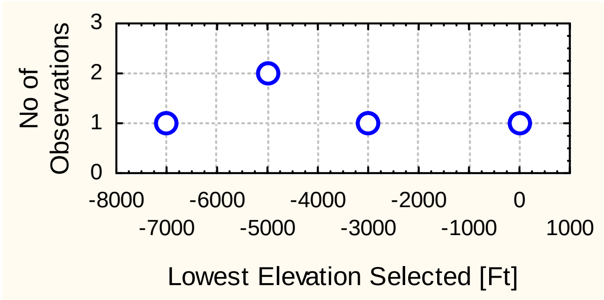

Figure 10 MANUAL Elevation Selection

9.1.4 Scenario Six

All subjects detected the significant weather Southwest of the airport. A Kruskal-Wallis ANOVA reveals that between-group mean detection times are significantly different ($p = 0.009$). The conventional group mean detection time (77 s) is slower than the MANUAL group time 26 s ($p = 0.007$). There is no significant difference between mean detection times of the AUTO (48 s) and conventional groups (77 s). Below 10 000 ft and in the terminal area, significant weather should be avoided by about 5 mi. With a 200 ft ceiling and location of the weather activity, it was possible to commit to the landing. Almost 80% of subjects decided to land, with the remainder electing to go-around or divert. Differences between the groups were non-significant. All subjects initiating a go-around were cognizant of significant weather over the missed approach area and requested an alternative missed approach path.

9.1.5 Scenario Eight

All but two conventional group subjects detected the weather threat on track. Hence the between-group differences are non-significant ($p > 0.05$). The differences in mean detection times between groups are significant ($p = 0.015$). The only paired difference is between

AUTO (58 s) and conventional groups (141 s), the AUTO group being significantly faster (p = 0.013). During the initial level flight segment, MANUAL group subjects (mean detect time 117s) could detect the target cell if the selected elevation exceeded 11000 ft below current altitude. The difference in decision-making between groups is significant (p = 0.001). Almost half (46%) of the conventional group made imprudent weather avoidance decisions – the aircraft entered the threat area. All AUTO group, and all but one MANUAL group subjects, requested appropriate weather avoidance vectors. In most cases these subjects refused to accept the clearance for a descent to FL 180 on the current heading. The mean decision times are not significantly different between groups (p = 0.39).

9.2 Storm Cell Analysis - Scenario Five

The first segment of this scenario was designed to scrutinize the storm cell analysis capability of the displays. The analysis focused on whether subjects were able to correctly identify the vertical position of two weather cells (to the West [B] and Northeast [C]) relative to current aircraft altitude: above or below. See Figure 11. A probe question technique was adopted to solicit the required feedback.

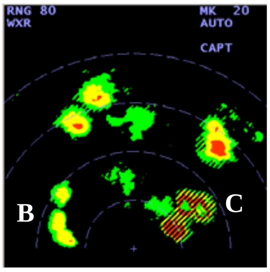

Figure 11 Scenario Five – AUTO Display

Figure 12 shows the results. “Yes” implies that both target cells were correctly analysed. The between-group differences are highly significant (p < 0.001), the MANUAL group exhibiting the best performance (75%). The difference between AUTO and conventional groups is insignificant (p > 0.05). MANUAL and AUTO subjects not correctly identifying the relative vertical position of the cells did however detect significant weather in the corresponding locations. The AUTO mode display does not provide information that allows users to determine whether target cells are above or below current altitude.

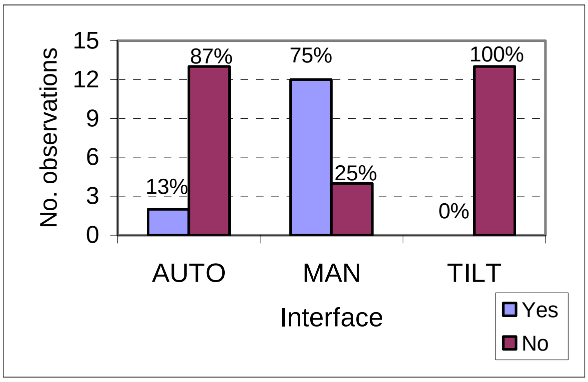

Figure 12 Storm Cell Analysis

9.3 False Alarm Scenario- Scenario Seven

This scenario focused on the possibility of unnecessary False Alarms. This is especially important for an AUTO display based on the current flight path (as opposed to FMS intent data). Although significant weather was displayed in the proximity of the SID, it did not pose a threat for the published routing (more than 25 mi from SID). During the right turn to 110^o heading, significant weather was evident on the current heading, but always at a range of more than 25 mi. Upon completion of the right turn, significant weather was observed 30 mi to the Northeast. See Figure 13. The criteria for a False Alarm required a subject to deviate from the published SID. Only two subjects, both in the conventional group (15%), generated False Alarms. The differences between groups are non-significant (p = 1).

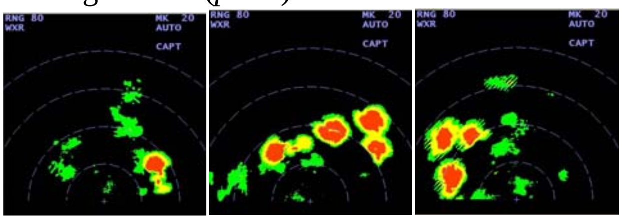

Figure 13 Scenario Seven – AUTO Display Progression

9.4 Workload Ratings

Subjects were asked to provide a Bedford Workload Rating at the termination of each scenario. It is recognized that this part-task evaluation did not involve all the normal flight deck tasks. However, the utility of the Bedford Rating is well-known and in this study it is the relative workload ratings between different interfaces that are relevant. Figure 14 shows that a median rating of two was achieved for the AUTO group, and higher median ratings were attained for the conventional and MANUAL groups. A Kruskal-Wallis ANOVA confirms that the workload ratings between groups are significantly different (p = 0.002). Both MANUAL and conventional workload ratings are significantly higher than the AUTO group ratings (p = 0.023 and 0.011 respectively). There are no significant differences in the workload ratings between the MANUAL and conventional group (p =1).

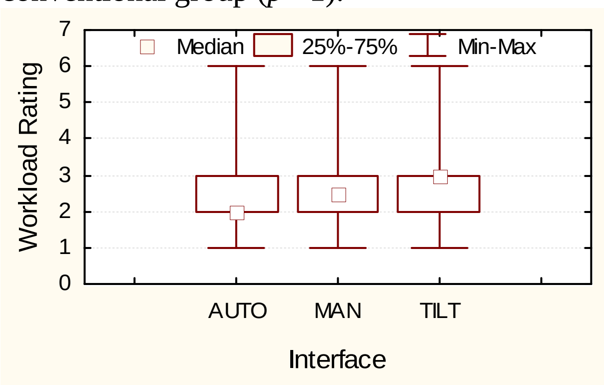

Figure 14 Bedford Workload Rating Box Plot

9.5 Perceived Weather Awareness

The distributions of perceived weather (situational) awareness ratings are presented in Figure 15. Most AUTO (87%) (p < 0.004) and MANUAL (94%) (p < 0.000) subjects provided "high" and "very high" ratings. However, the proportion of conventional group subjects providing "high" and "very high" ratings (69%) is not significant (p < 0.17). These ratings relate well to pilot performance (weather detection) data in Section 9.1.

9.6 Pilot Acceptability

The overall ratings for AUTO and MANUAL subjects are presented in Figure 16. Most AUTO (75%, p < 0.045) and MANUAL (94%, p < 0.000) subjects provided "good-excellent" ratings. These results indicate a high level of pilot acceptability. Subjects providing "fair"-"very bad" ratings detected all hazardous weather conditions: thus pilot performance and subjective data do not relate well for these subjects.

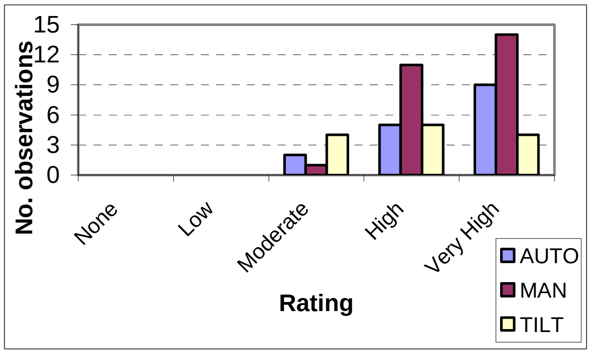

Figure 15 Weather Awareness Subjective Ratings

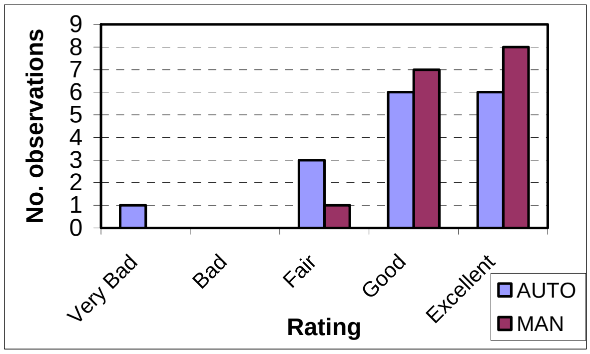

Figure 16 Overall Acceptability Ratings

The following are examples of feedback from the AUTO group:

- "Very good feature."
- "Reduces cockpit workload."
- "Very significant improvement in weather radar technology."

Comments for the MANUAL group were also generally positive:

- "It gives me a better view of the altitude with greatest radar reflectivity."
- "[It] takes out the mental calculations as to the altitude of the weather."
- "No longer a need to apply formulas of beam width vs. distance to interpret altitude of weather."
- "Better weather awareness."

Only two pilots suggested that the tilt control should be maintained. Subjective ratings for ease of interpretation, learnability and symbology were also favourable.

10. Conclusions

1. The difference in weather detection capability between displays was highly significant. The AUTO weather detection rate was better than that of either MANUAL or conventional weather displays. The MANUAL weather detection rate was higher than that of the conventional display.
2. Poor tilt management was the primary reason for the conventional weather subjects missing significant weather targets.
3. Most AUTO and MANUAL subjects provided “high” and “very high” ratings of perceived weather (situational) awareness. The proportion of conventional group subjects providing a “high” or “very high” rating was not significant.
4. In six out of eight instances, either the AUTO, MANUAL or both displays equally provided the quickest mean detection times. The conventional group did not exhibit the fastest mean detection time in any scenario.
5. The difference in the quality of weather avoidance decision-making between groups was highly significant. The AUTO and MANUAL groups had significantly more correct decisions than the conventional display. The difference between AUTO and MANUAL group decision-making was not significant.
6. In three out of five scenarios, the AUTO and MANUAL groups equally resulted in the fastest mean decision-making times. In two scenarios, there was no significant difference between groups. The conventional group did not exhibit the fastest mean decision time in any scenario.
7. Overall, the mental workload ratings between groups were significantly different. Both MANUAL and conventional group workload ratings were significantly higher than the AUTO group ratings. There were no significant differences in the workload ratings between the MANUAL and conventional group.
8. The MANUAL group performed significantly better than either AUTO or conventional group in a storm cell analysis task.
9. The scenario designed to analyze unnecessary False Alarms did not result in any cases of AUTO or MANUAL group pilots incorrectly identifying weather threats.
10. Most AUTO and MANUAL subjects provided “good-excellent” ratings for overall acceptability. Positive subjective comments reinforce these findings.

11. Recommendations

The AUTO and MANUAL display concepts discussed herein support ongoing development of actual weather radar products. The NGR concepts discussed herein will be further evaluated on a flight test aircraft. The impact of adding weather on a vertical profile display should be investigated. Aircraft operators should provide formal training for conventional weather radar – effective tilt management should be included.

12. References

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