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NAVIGATING THE AIRPORT SURFACE: ELECTRONIC VS. PAPER MAPS

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ABSTRACT

Recent advances in the Differential Global Positioning System (DGPS) and ground/aircraft data-links provide a basis for the generation of an accurate cockpit navigational map display including data-linked ATC-cleared ground routes. Such an electronic map may have the potential to improve pilots' situation awareness and taxi performance and thereby lessen runway incursions. The objective of this simulator study was to assess the potential improvements in these areas when using an advanced electronic map (compared to using today's paper map) under two outside scene visibility levels. Results showed average taxi speed increased under both good and poor visibilities, by as much as 24 percent, due in part to eliminating the time used for orientation with the paper map. Pilots made only one-third as many errors as well and commented that they believed that the electronic map gave them better awareness.

INTRODUCTION

As air traffic has increased in recent years, the airport surface has also become more congested. Numerous accidents and runway incursions (e.g., Tenerife, Detroit, Los Angeles, to name a few) underscore the need for better situation information, not only within the transport cockpit but also within the air-traffic control tower. Advances in terrain/feature/airport databases, [1,2] the Differential Global Positioning System (DGPS) [3,4,5,6,7,8] and ground/aircraft data-links [9,10] provide a basis for the generation of a cockpit map display having accurate airport features, A/C navigational position, and data-linked ATC-cleared taxi routes. Such an electronic map is believed to have the potential to improve pilots' situation awareness, taxi performance and safety during airport surface operations. The objective of this study was to assess the potential improvements in these areas, through comparing differences in pilot taxiing performance (speed and accuracy) when using conventional paper maps (today's technology) and an electronic surface map (tomorrow's technology).

REAL-TIME SIMULATION FACILITIES

NASA-Langley's Transport Systems Research Vehicle (TSRV) Simulator (Figure 1) was configured to present outside scenes in four windows. Independent scenes for these windows were created by a graphics generator from a 3-D database of Denver Stapleton (Figure 2) and were driven by a transport aircraft model hosted on a mainframe computer. Aircraft were placed in the outside scene along the taxi routes in both static and dynamic situations. Two visibility conditions were used -150 feet RVR and 16,000 feet visibility (VMC) under daylight conditions.

The 2-D map display was developed to run on a second raster-based graphics generator. Since the TSRV Navigation Display (ND) was unused during taxi and was incompatible with the graphics generator, a removable 8.3 x 6.2 inch, 640 by 496 pixel, back-lit color LCD panel [11] was placed in front of the pilot's ND and used to display the map. An experiment station at the rear of the cockpit was used to control the individual display runs and to monitor taxi errors during the paper chart runs.

EXPERIMENT DESIGN

Approach:

In an effort to incorporate a maximum of pilot-desired features into the electronic map for this study, pilot input was solicited earlier through the use of a demonstration program and pilot interviews. For the simulation, it was assumed that aircraft position was determined from DGPS and that ATC-cleared routes were data-linked. Both arrival and departure scenarios were used. Two of the pilot performance measures were taxi times for each of the scenarios and ground navigation

Figure 1. TSRV Simulator with Map Display

technical error (measured as RMS error). Ten airline and four NASA pilots participated as single-pilot crews.

Display and Features

Pilot-desired features included were:

- Ability to change map scales
- Runways colored differently from taxiways
- North pointing arrow
- Active runway indicators of traffic direction
- Aircraft symbol with main and nose gear
- Ground speed readout adjacent to ownship
- Heading tape
- Velocity trend vector
- Stop bars short of active runways
- Declutter switches
- Cleared route
- Identifying airfield features
- Whole-airfield insert

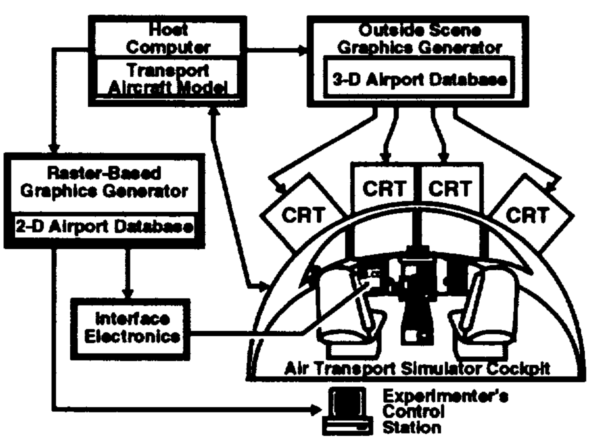

Figure 2. Experiment Simulation Setup

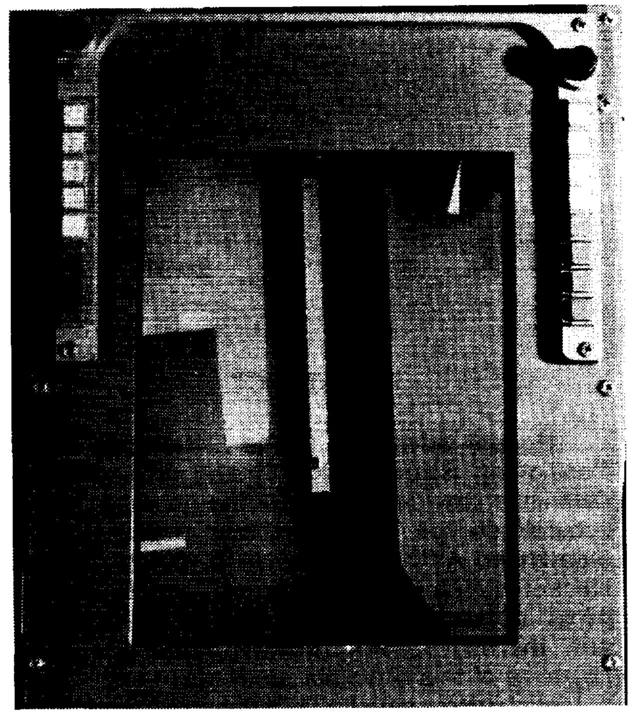

Figure 3. Color LCD Display and Bezel Switches

The color LCD display panel is shown in Figure 3. Bezel switches were used to select desired map features (Table 1).

Figure 4 shows the closest zoom scale. The landing gear, trend vector, and stop bars (solid parallel lines near top) are easily seen. The whole-airfield insert can be presented in the lower right corner and used for orientation when closer zoom scales are selected on the main chart.

Table 1. Bezel Switch Functions

LABEL	FUNCTION	LABEL	FUNCTION
T/N UP	Track Up or North Up	ZOOM IN	Move Closer to Ground
LBL 0/1	Show or Hide Labels	ZOOM OUT	Move Farther from Ground
AINS 0/1	Show Airfield on Insert	VECT 0/1	Show or Hide Ownship Velocity Vector
RTE 0/1	Show or Hide Cleared Ground Route	EXEC RTE	Execute Proposed ATC Taxi Route
OWN POS	Select Ownship Position at Center or 1/3 Up		

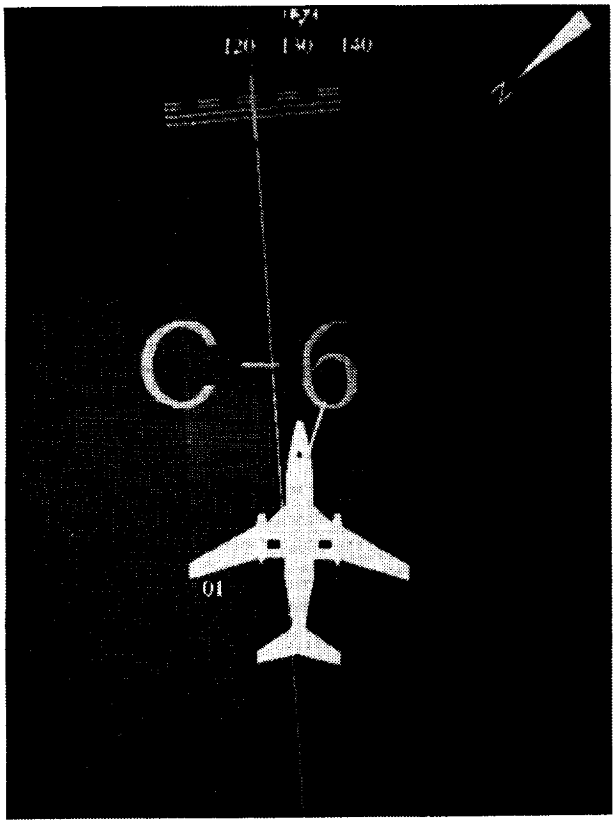

Figure 4. Map Showing Closest Zoom Level

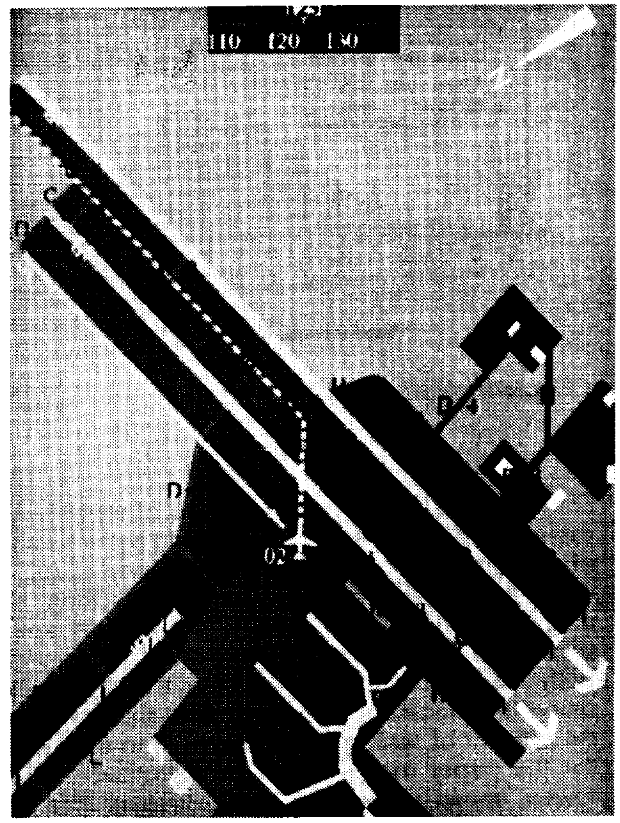

Figure 5. Map Showing Cleared Route

Routes

Two departure and two arrival taxi routes were used. One departure route is shown as a dashed white line in Figure 5. (Arrows indicate active runway traffic direction). After the pilot has examined the route and has accepted it by pressing the "EXEC RTE" switch, the route changes to a solid magenta line. In this particular scenario, the departure runway was changed from runway 26L to runway 35L after the pilot crossed runway 26R, and the procedure just described was repeated.

Two pilot groupings were used to reduce by half the number of experiment runs per pilot. Consequently, pilot-visibility comparisons were performed between-pilots while pilot-display media (paper or electronic) comparisons were within-pilots. Two replicates of each condition were conducted for a total of sixteen runs per pilot.

Experiment Protocol

At the beginning of each piloted session, the subject was allowed time to practice until he was ready to start. The experimenter sat in the right seat and issued clearances from a script. The assistant was stationed at the Control Station, initiated each run, and operated the stop bars according to issued clearances. During paper map runs, the assistant also monitored pilot's taxi errors.

At the start of each run, for both the paper and electronic maps, the experimenter read the aircraft's current location and taxi clearance. A typical scenario went as follows:

Experimenter: "Initial position of NASA 515: Southeast corner of terminal ramp."

[Pause]

"NASA 515, taxi to runway 26L via Charlie 6 and Charlie."

[After aircraft crossed Runway 26R, a change of departure runway was issued.]

"NASA 515, your departure runway is now 35L, taxi to runway 35L via Charlie 7, Delta 3, Zulu and Zulu 1. Expect intersection departure from Zulu 1."

At the conclusion of each experiment, the pilots were requested to fill out a questionnaire.

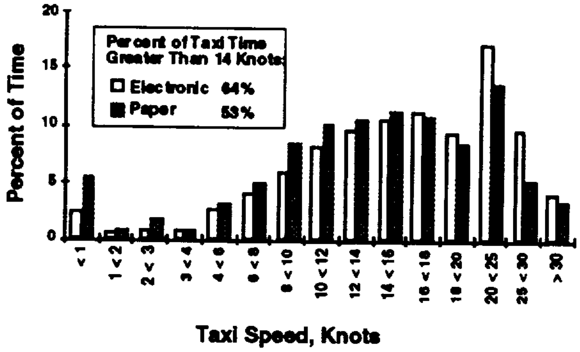

Figure 6. Route 2 Speed Histogram

RESULTS

Under almost all combinations of visibility and route conditions, the pilots performed better with the electronic map than with the paper map, as measured by taxi speed, centerline tracking, and errors committed. Figure 6 shows the speed histogram for the above-mentioned route under both visibility conditions. Note that the speed when using the electronic map is greater than 14 Knots 64 percent of taxiing time compared to 53 percent for the paper map. It can be assumed that the lowest speed range time bars represent stop time and hence time spent studying the map after route-change instructions.

A comparison of overall average taxi speeds shown in Figure 7 indicates that speeds with the electronic map were 24 percent faster under 150' RVR and 21 percent faster under VMC conditions. (Seven out of eight ANOVA tests were significant at the .03 level or better). One might ask if centerline tracking suffers as a result of increased taxi speeds, but Figure 8 shows that averaged centerline tracking RMS error for the electronic map is less under both conditions of visibility by approximately 10 percent. (However, this difference is not

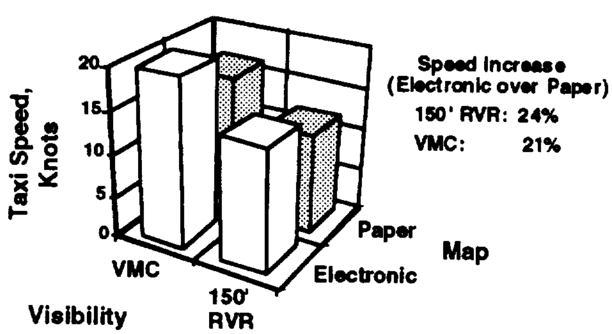

Figure 7. Average Taxi Speed, 14 Pilots, All Routes

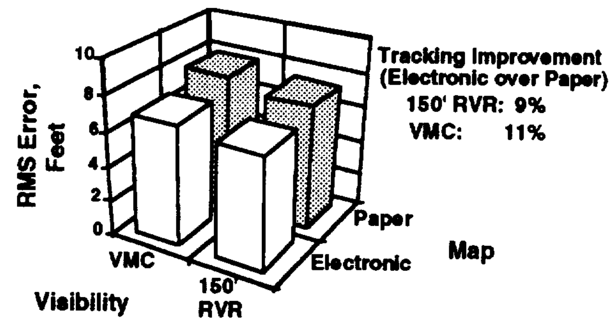

Figure 8. Centerline Tracking Error, 14 Pilots, all Routes

statistically significant). Errors (wrong turns and wheels off pavement) are shown in Figure 9. Again, the electronic map was useful in that pilots made only one-third as many errors as they did with the paper map. Some of the errors with the electronic map occurred when the pilot was looking out the window instead of monitoring the map.

A typical set of pilots' centerline tracking performance in curves is shown in Figure 10. The tendency was to track inside the curves on turns. (Note one missed turn.)

Figures 10 and 11 show the map option switch usage. The smaller map scales were selected during 150' RVR conditions while the mid-range levels were chosen during VMC. Scale changes were frequent primarily because the pilots tended to select a scale which allowed them to see the next turn on their path. As the turn approached, they would zoom closer to better see their position relative to the turn.

Figure 12 shows the use of the other switches. Track-up mode was used almost 100 percent of the

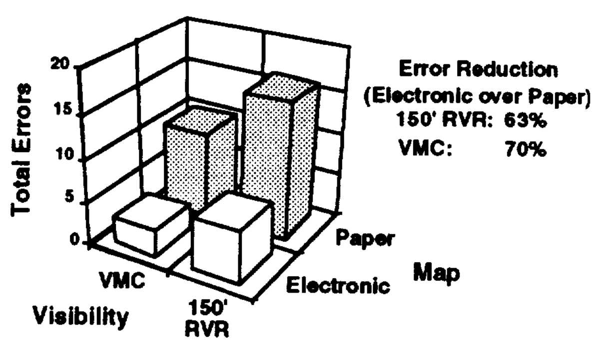

Figure 9. Pilot Taxiing Errors

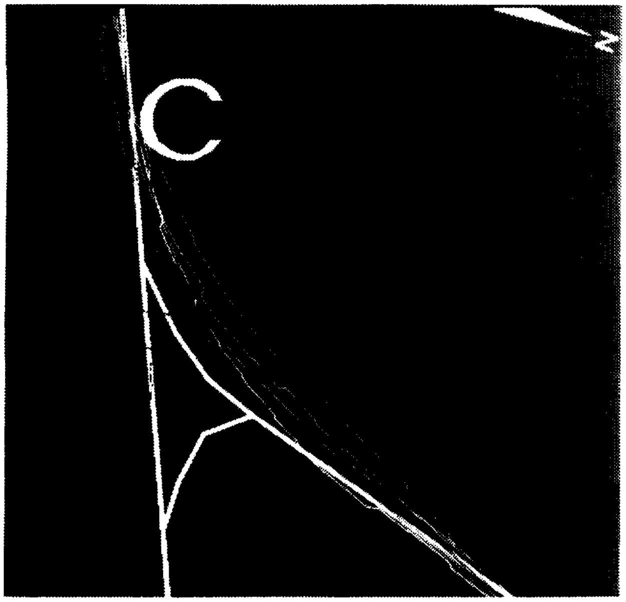

Figure 10. Typical Curve Centerline Tracking Performance

time. However, North-up mode was used occasionally for orientation. The two declutter options, path and labels on/off, were left on for most of the time. The ownship symbol was left at 1/3 up over 95 percent of the time, which corresponds to its position on current NAV displays. The trend vector, likewise, was left on 95 percent of the time. The map insert option, however, was exercised only 16 percent of the time under VMC and 25 percent under 150' RVR conditions.

Pilot Questionnaire Response

Responses to the Pilot Questionnaire were interesting and helpful. Several questions and a few typical individual responses were:

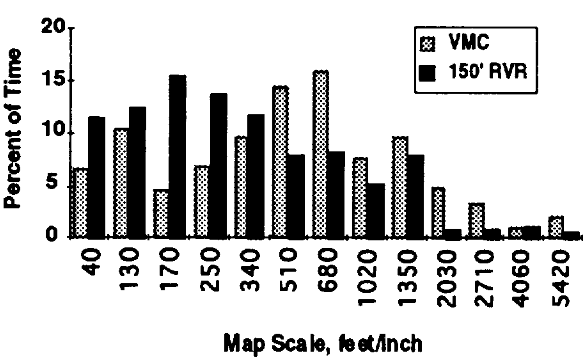

Figure 11. Zoom Levels Used

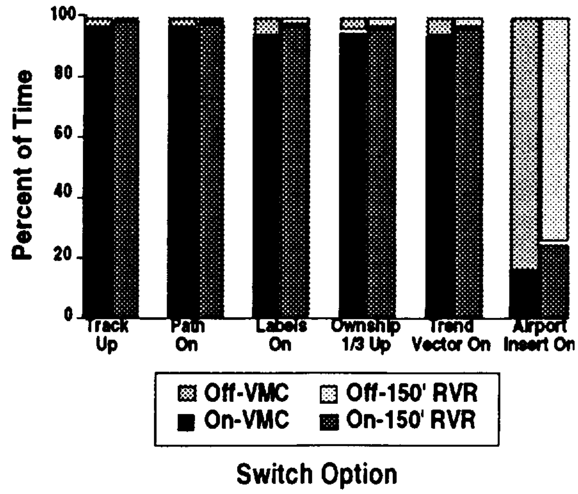

Figure 12. Switch Options Used

Based upon your experience in this experiment, how would you see this map used in normal operations?

D. Could really enhance situation awareness during the clearance, planning and execution of taxi.

K. I see this map as a great help when operating in and out of strange airports. I also see the map being very useful at night and/or with low visibilities at a familiar airport.

L. On a daily basis in good visibility and low visibility.

Do you think there were differences in your performance between the paper map and the electronic map?

N. Definitely. I was much more confident and had a higher level of situation awareness with the electronic map. In low visibility, I could anticipate turns and be more aware of position on the field. The electronic map was very useful at first when I was unfamiliar with the taxiway names and layout.

Assuming FAA approval for full GPS use, would you like to have the electronic map in your cockpit tomorrow?

L. Today would be better! Yes I would like to have this unit in the aircraft of tomorrow.

O. Yes. I can see great advances in safety with virtually no runway incursions or missed intersections or taxi instructions.

DISCUSSION

Pilots were enthusiastic in their acceptance of the electronic map. Most felt it gave them better awareness not only under low-visibility conditions but under good visibility conditions as well. Average taxi speeds increased as much as 24 percent with use of the electronic map over the paper map under each of the conditions studied, while maintaining tracking performance. Part of this increase was due to eliminating the time used for orientation with the paper map and part was due to increased confidence with the electronic map. Pilots made only one-third as many errors (wrong turns and wheels off the pavement) as they did with the paper map.

Significance:

The electronic map used in this study appears to have increased the pilot's awareness of his location on the airport surface. As a result of this one factor, runway incursions could potentially be avoided. Additionally, significant taxiing time could potentially be saved by following the cleared routes as shown on the map and by not having to refer to the paper map. Changes in clearance could potentially be swiftly implemented and understood by the pilots as well. If the time savings experienced in this study is representative of potential time savings in actual taxi situations, significant fuel savings could be expected. Cockpit efficiency during this busy portion of the flight could be significantly increased by the data-linked cleared path, eliminating the usual time spent writing down the clearance and then checking it.

CONCLUSIONS

Under all combinations of visibility conditions and routes, the pilots performed better with the electronic map than with the paper map, as measured by taxi speed and errors committed. Pilots were enthusiastic in their acceptance of the electronic map. Most believed it gave them better awareness not only under low-visibility conditions but under good visibility conditions as well. Cockpit efficiency may improve through use of the data link for the cleared ground route. In addition to the safety aspects, the potential fuel savings through reduced taxiing time would represent significant savings during surface operations.

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