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# COCKPIT DISPLAY OF HAZARDOUS WIND SHEAR INFORMATION

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Based on the current status of windshear sensors and candidate data dissemination systems, the near-term capabilities for windshear avoidance will most likely include:

- Ground-based detection:
     TDWR (Terminal Doppler Weather Radar)
     LLWAS (Low-Level Windshear Alert System)
     Automated PIREPS

- Ground-Air datalinks:
     ATC voice channels
     Mode-S digital datalink
     ACARS alphanumeric datalink

The possible datapaths for integration of these systems are illustrated in the diagram.

In the future, airborne windshear detection systems such as lidars, passive IR detectors, or airborne Doppler radars may also become available. Possible future datalinks include satellite downlink and specialized en route weather channels.

WINDSHEAR AVOIDANCE IN THE ADVANCED ATC ENVIRONMENT

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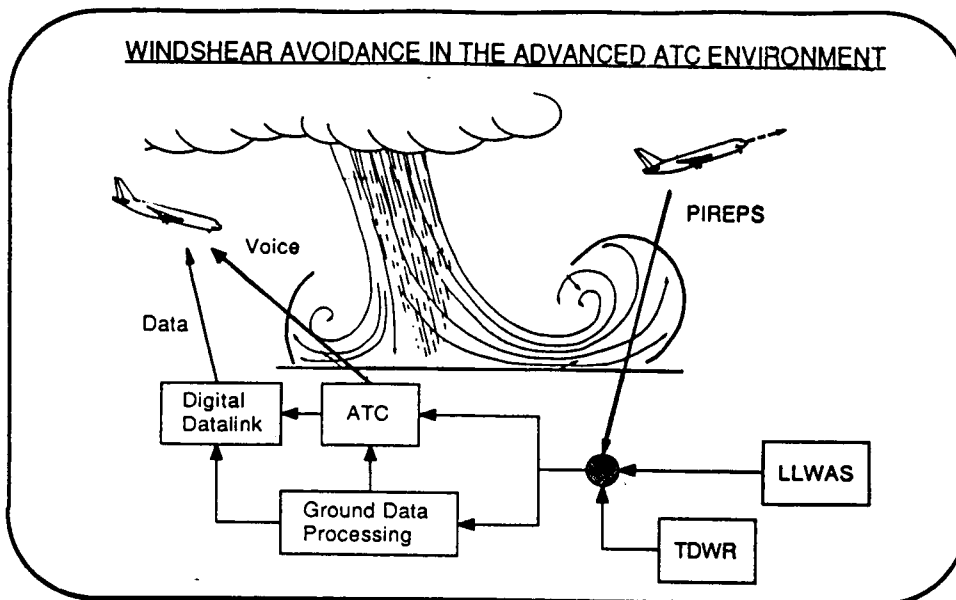
Uplink of ground-measured windshear information to the flight crew
presents a number of problems. Among these are:

*   Hazard Assessment:
    Based on ground-measured information and the current tactical
    situation, what constitutes a hazardous windshear?

*   Information Issues:
    What to send: what is 'critical'
    When to send it
    How to send it
    How to present critical info to the flight crew

The MIT effort is using the three methods outlined to address
these issues.

INVESTIGATIONS

*   PILOT OPINION SURVEYS
    Current Terminal Area Windshear Procedures
    Possible Future Windshear Warning Systems

*   HAZARD THRESHOLD STUDY
    Definition of Windshear Hazard Thresholds Through Simulation
    Studies and Flight Test Data

*   PART-TASK B-767 SIMULATION
    Simulation of Historical and Hypothetical Windshear Encounters
    Comparison of Verbal, Alphanumeric, and Graphical Presentation
    Options
    Effects of Message Delivery Time on Pilot Decisions
    Parallel Experiments with Graphical ATC Clearance Delivery

The survey has two sections: Current Procedures and Future Windshear Warning Systems. The first part included questions about:

- Pilot impressions of the hazard posed by microbursts

- Pilot confidence in windshear information obtained from ATIS, LLWAS, and PIREPS

- Pilot evaluation of the adequacy of currently available windshear alert data and the need for better and more timely alerts

The section on future procedures included questions about

- Modes of information relay and presentation

- When the crew should be alerted

- How much head-to-tail windshear is a threat

- What items of windshear information are important

- Who makes the avoidance decision - pilot or controller

<u>PILOT OPINION SURVEYS</u>

- Obtain flight crew evaluations of current windshear warning and avoidance systems and procedures

- Obtain flight crew feedback on future windshear warning systems and possible display formats

- Distribution: 250 United A/L flight crews

- Current Data Set: 47
  51% of respondents have had a hazardous windshear encounter

- Data are being used to design part-task simulator experiments with advanced graphic and alphanumeric display formats

General results indicate that microbursts are perceived as a major safety threat and that currently available windshear alert data are not sufficient for safe terminal area operations. Also, there is strong pilot support for an improved windshear alerting system. The fairly low windshear threshold specified by the respondents is another indication of the belief that windshear is a major threat.

Sample comments from the last question listed:

"Only the pilot can judge the capabilities of his a/c type and his ability to cope with reported data."

"(Controller) Must make judgment calls to report only those shears meeting some minimum standards to avoid reporting 'everything'."

51% of the respondents have had (by their own definition) a hazardous windshear encounter.

PILOT SURVEYS: GENERAL RESULTS

	Agree	Disagree
Microbursts pose a major safety hazard to transport category aircraft.	90.2%	4.9%
Currently available windshear alert data are sufficient for safe operation.	14.6%	43.9%
A system to provide crews better and more timely windshear information is necessary.	97.6%	0.0%

- Perceived windshear warning threshold: Advisory: 10.6 kts
     Warning: 15.1 kts

- Who should have the responsibility for judging the threat due to a particular windshear event from the (assumed reliable) available data?   PILOT: 83.0%
   CONTROLLER: 9.5%

The data are from the question:

Listed below are four currently available sources of information about windshear in the terminal area. Please rank them in order of usefulness, from 1 (most useful) to 4 (least useful).

_____ Low Level Windshear Alert System (LLWAS)
_____ Pilot Reports (PIREPS)
_____ Airborne Weather Radar
_____ Visual Clues (Thunderstorms, Virga etc.)

Pilot Rankings: Usefulness for Windshear Avoidance of

Pilot Reports
Visual Clues
LLWAS (Low Level Windshear Alert System)
Airborne Weather Radar
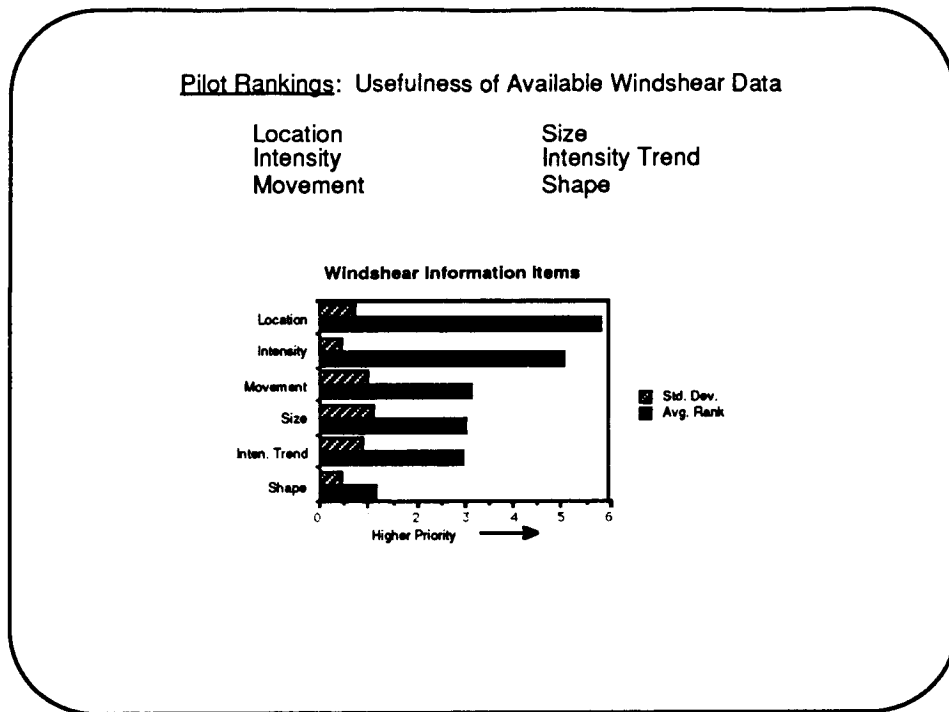
Windshear Information Sources
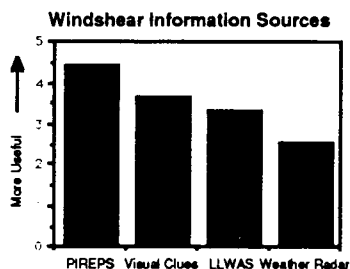
The data are from the question:

A windshear alert could contain the following items of information.
Please rank them in order of importance. (1 = most important, 6 = least important)

_____ Location   _____ Shape
_____ Intensity   _____ Intensity Trend
_____ Size   _____ Movement

Pilot Rankings: Usefulness of Available Windshear Data

Location   Size
Intensity   Intensity Trend
Movement   Shape

Windshear Information Items

The data are from the question:

Assuming windshear is detected by reliable ground-based sensors, how should this information be relayed to the flight deck? Please rank in order of preference. (1 = most preferable, 5 = least preferable)

_____ Voice (ATIS)
_____ Voice (ATC)
_____ Alphanumeric/Text uplink (similar to ACARS)
_____ Graphical display of windshear location on EFIS display
_____ Graphical display of windshear location on separate
graphic device

Pilot Rankings: Mode of data relay/presentation:

Verbal (ATC)
EFIS EHSI (Moving Map) Display
Alternate Graphical Display
Alphanumeric Display
On ATIS

Windshear Information Relay/Presentation
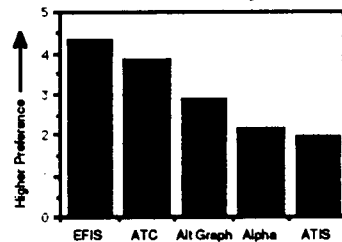
The hazard assessment part of this project is motivated by the TDWR (Terminal Doppler Weather Radar) operational evaluations performed by MIT Lincoln Laboratory and NCAR over the past three years. In these experiments, TDWR proved able to detect hazardous microbursts nearly 100% of the time with a false alarm rate of 5%.

Despite the accuracy of the radar, some dangerous incidents still occurred. One potential problem is assessment of the hazard due to a particular microburst in a particular situation. The hazard reported by the detection system must relate directly to what the threatened aircraft would experience if it does penetrate the microburst. If a large threat is predicted, and little dynamic effect is encountered, an accurate warning can be perceived as a 'false alarm' and damage pilot confidence in the system.

As listed, this study will compare the factors contributing to the windshear hazard and attempt to determine a useful and relevant hazard criterion.

<u>WINDSHEAR HAZARD THRESHOLD EVALUATION</u>

1987-88 TDWR OPERATIONAL EVALUATIONS
- Proved ability of TDWR to detect hazardous windshear
- Problems in dissemination of warnings:
  - Delays in voice transmission
  - Message format problems
  - Pilot-perceived "false alarms"

PROBLEM:
Given perfect knowledge of the windfield, what is the most accurate and relevant assessment of a windshear hazard in terms that the flight crew can relate to the actual dynamic effects on their particular aircraft?

FACTORS:
- Windshear intensity measurement
- Spatial factors: off-axis penetration, microburst asymmetry
- Aircraft characteristics, weight, configuration

The most critical factor in the threat evaluation is how to quantify the microburst intensity. Three possible ways are listed. The delta-V measurement is currently used by TDWR. F-factor, a measure of instantaneous threat, is more applicable to *in situ* and airborne sensor systems. An integrated energy loss calculation is another possibility, better suited to long range sensors such as TDWR.

<u>WINDSHEAR INTENSITY MEASUREMENT</u>

- DELTA-V

   Maximum headwind-to-tailwind component an aircraft can be expected to encounter over a specified distance

- F-FACTOR

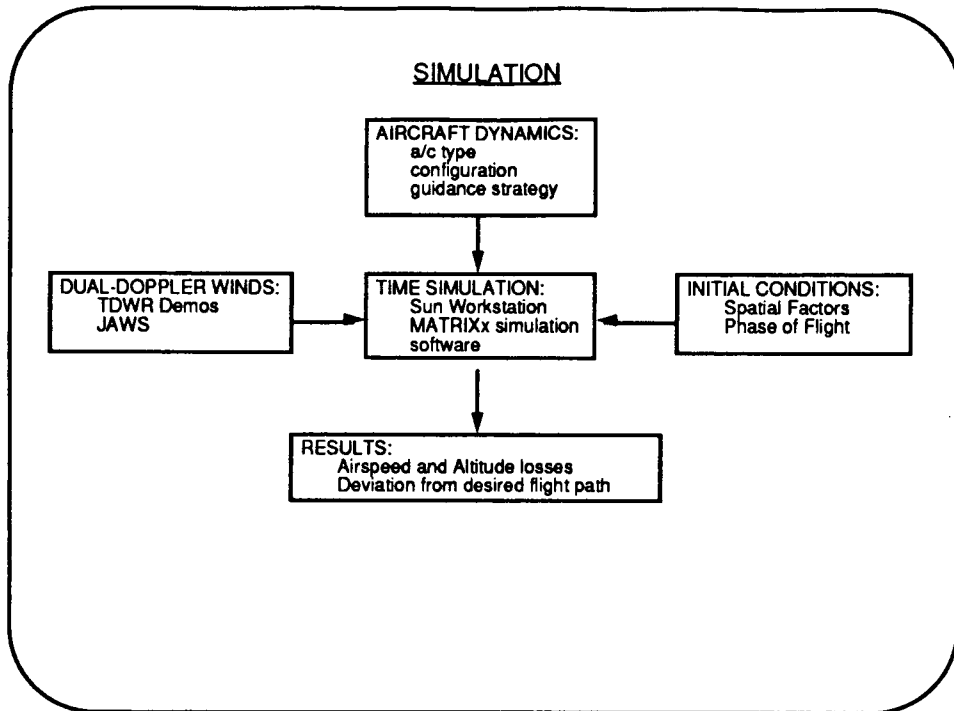$$= \frac{\dot{W}_x}{g} - \frac{W_h}{V}$$

   Developed for *in situ* sensors, measures loss of "potential altitude" due to immediate windfield

- INTEGRATED ENERGY LOSS

   Measures expected loss of energy over a projected flight path: including kinetic (airspeed) and potential (altitude) energy components

These issues will be evaluated through parametric flight simulations and possibly actual flight data. As listed, measured dual-Doppler windfields will be used with available aircraft models to examine the effects of various factors on the microburst hazard. Once a candidate hazard threshold has been determined, the dual-Doppler data will be degraded to simulate a single TDWR measurement and the hazard criterion will be re-evaluated. Supporting data may be gained from flight tests flown this summer by the University of North Dakota in conjunction with the TDWR evaluation.

PLANNED APPROACH

- Literature Search: Microburst-Aircraft interaction studies

- Develop Simulation
   Aircraft Dynamics: 737-100, Cessna Citation
   Windshear model - assume ideal sensor using
      NCAR/MITLL dual doppler radar windfields

- Perform Parametric Studies

- Evaluate and modify hazard criteria based on studies

- Evaluate flight test data from UND Citation

- Simulate effect of sensor limitations on hazard threshold validity

The simulation is currently under development. It will be run on a Sun 3/80 workstation with MATRIXx simulation software to minimize development time and allow easy automation of parametric studies.

SIMULATION

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                    ┌──────────────────────────┐
                    │ AIRCRAFT DYNAMICS:       │
                    │   a/c type               │
                    │   configuration          │
                    │   guidance strategy      │
                    └──────────────────────────┘
                                 │
                                 ▼
┌──────────────────────┐  ┌──────────────────────┐  ┌──────────────────────┐
│ DUAL-DOPPLER WINDS:  │  │ TIME SIMULATION:     │  │ INITIAL CONDITIONS:  │
│   TDWR Demos         │─▶│   Sun Workstation    │◀─│   Spatial Factors    │
│   JAWS               │  │   MATRIXx simulation │  │   Phase of Flight    │
│                      │  │   software           │  │                      │
└──────────────────────┘  └──────────────────────┘  └──────────────────────┘
                                 │
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              ┌──────────────────────────────────────────┐
              │ RESULTS:                                 │
              │   Airspeed and Altitude losses           │
              │   Deviation from desired flight path     │
              └──────────────────────────────────────────┘
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An ongoing focus of the MIT windshear effort is the dissemination of ground-measured and evaluated windshear information. As displayed, several information-related issues arise and are being addressed with several resources, including the previously discussed pilot opinion surveys. Current research is focused around the 767 part-task simulation.

UPLINK OF CRITICAL WINDSHEAR INFORMATION

OBJECTIVE:
   Examine transfer and presentation of vital windshear information to flight crews, based on modern ground-based sensors and datalink capabilities.

ISSUES: What information to transmit
             When to send information
             Information mode: Verbal, Alphanumeric, Graphical

RESOURCES: Pilot surveys
                Analysis of past windshear encounters (7/11/88)
                GA part-task simulator study
                Boeing 767 part-task simulator

On July 11, 1988 a group of very severe microbursts occurred on the final approach path to Denver/Stapleton runway 26L. Five aircraft were affected by the event. The TDWR evaluation was in progress, and successfully detected the microbursts. However, four of the five aircraft involved still attempted to land and penetrated the microbursts, in one case passing below 100 feet AGL one mile short of the runway threshold. The problem in this case was with dissemination of the warnings, not with detection of the microbursts. In this case, the effectiveness of the alert was degraded sharply by a number of factors:

• Variability of aircrew interpretation of warnings: In one case, two aircraft were given virtually identical warnings within 30 sec of each other and made entirely opposite decisions.

• Delay inherent in voice transmissions: The minimum delay between detection and message transmission was about 60 sec.

• The messages were often imbedded in a routine landing clearance message, resulting in a lack of urgency; this, combined with the high crew workload at the outer marker, may have caused the warnings to be missed or go unheeded.

• PIREPS are critical - once the lead aircraft reported windshear, later aircraft initiated earlier missed approaches.

MICROBURST EVENT: 11 JULY 1988

• Occurred during 1988 TDWR Operational Demonstration at Denver-Stapleton Airport: Doppler Radar was operational.

• 20 minute period of intense microburst activity on final approach to active runway 26: shear intensity up to 80 kts

• 5 aircraft involved

• Microburst warnings promptly and accurately produced by TDWR system: given to final approach controller

• Despite timely warnings, 4 of 5 aircraft penetrated microbursts and encountered significant performance losses before aborting the approach

• Problems:
   Time delays
   Message format

This simple experiment was designed to demonstrate the gain in pilot situational awareness due to graphical displays. By linking a schematic graphical display of windshear location to a general aviation simulator, a significant improvement in pilot performance was measured. This experiment, although simple, indicates that graphical displays are desirable and that further investigation of graphical formats and measurement of achievable performance gain is required.
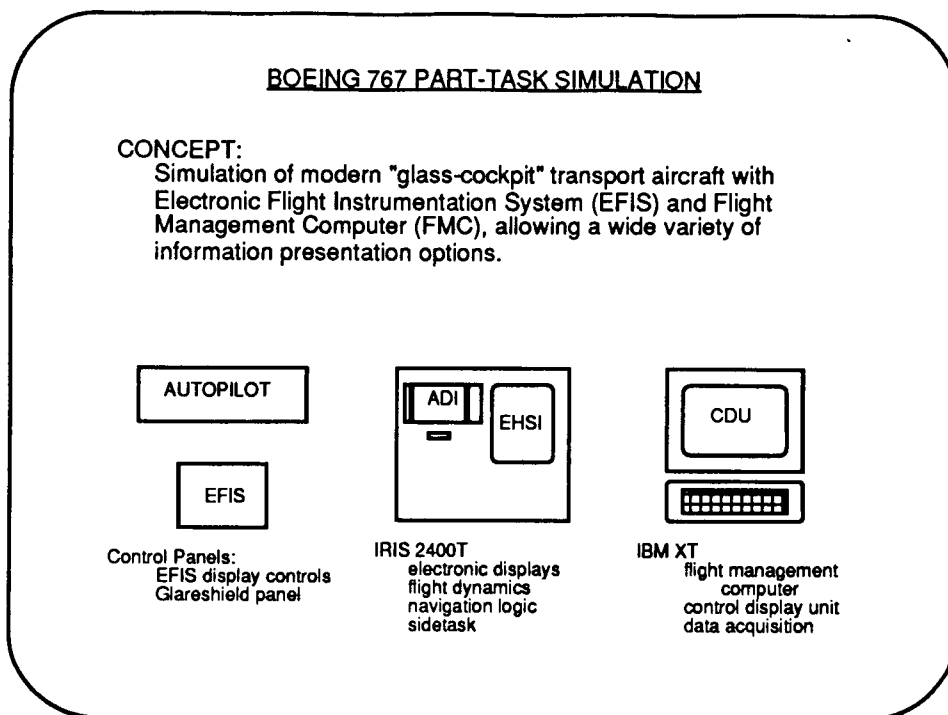
PART-TASK GA SIMULATION

- GA Simulator and IBM PC display

- Microburst occurring on final approach

- Non-standard missed approach procedure required for avoidance

Display Type Used	Avoidance Rate
Voice only	43%
Runway-fixed display without a/c position	62%
Runway-fixed display with a/c position	94%

- 8 Pilots: 210 to 1700 hours total time
  16 Approaches per display

Further information presentation options are being explored through a Boeing 767 part-task simulation, which has just been completed. The 767 was selected because its advanced 'glass-cockpit' instruments allow for many possible alphanumeric or graphical presentations. The major electronic and electromechanical instruments are simulated on an IRIS graphic workstation, and an IBM is used for simulation of the major features of the Boeing FMC (flight management computer). Mockups of the autopilot control panel and electronic display control panel are linked into the system through a data acquisition unit. In addition, the crew workload is adjusted and monitored through a simple compensatory sidetask controlled by the IRIS mouse. The final component is a pair of headsets for pilot and 'controller'.

BOEING 767 PART-TASK SIMULATION

CONCEPT:
  Simulation of modern "glass-cockpit" transport aircraft with Electronic Flight Instrumentation System (EFIS) and Flight Management Computer (FMC), allowing a wide variety of information presentation options.

AUTOPILOT

EFIS

ADI

EHSI

CDU

Control Panels:
  EFIS display controls
  Glareshield panel

IRIS 2400T
  electronic displays
  flight dynamics
  navigation logic
  sidetask

IBM XT
  flight management
  computer
  control display unit
  data acquisition

This figure illustrates a typical EHSI (Electronic Horizontal Situation Indicator) in map mode for an aircraft equipped with a flight management computer. Information displayed includes the currently programmed flight path, nearby navaids, intersections, and airports, wind information, and the aircraft's current heading and groundtrack. Weather radar returns are also overlaid on the EHSI, making it even more desirable to place windshear information on this display.

767 EHSI - MAP MODE
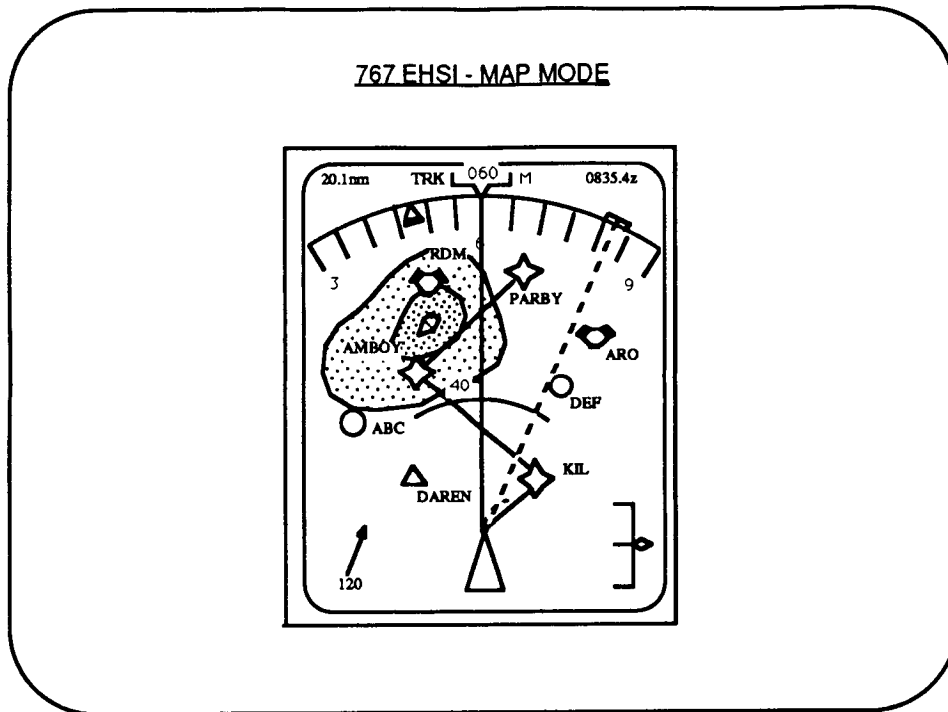
The initial experiments as described are designed to gather more data about modes of information presentation. The experiment is being performed in concert with a study on the benefits of delivering ATC routing amendments graphically. Each scenario has elements from both experiments, which should reduce the pilot learning curve and result in better quality data. All pilot actions, including ATC transmissions and sidetask performance, will be recorded and time-stamped by the simulation computers. Audio and video coverage will also be taken.

INITIAL SIMULATIONS

- Performed in concert with Graphical Amendment Delivery experiments

- 9 scenarios will be flown by each subject:
  - Denver-Stapleton Airport
  - 3 Initial Conditions, 3 ILS approaches
  - Modes:
    - Verbal, Alphanumeric, Graphical
  - Microburst Position:
    - Off to side of approach
    - On final approach
    - On final approach and cleared missed approach path
  - Alert times:
    - When cleared for approach
    - 2 nm outside outer marker
    - At or inside outer marker
  - Simple compensatory sidetask for workload monitoring

If 9 subjects are obtained, as described a total of 81 approaches will be flown. Allowing 3 modes of communication and 3 different microburst threat conditions, 9 points per set of parameters will be obtained. These experiments are planned for July and August of 1989.

Possible future experiments will deal with such issues as delay times and possible graphical format options.

INITIAL SIMULATIONS

SUBJECTS:

Active Transport Category a/c crews

Time requirement: 5 hours per subject

Minimum 9 subjects desired for initial simulations

Subjects are being contacted through ALPA, to be tested during BOS layovers

STATUS:

Simulator 99% operational

Subjects currently being sought

Results should be available for next Tri-U Conference...