5-9

Session III. Flight Management

N91-24172

Microburst Avoidance Simulation Tests
Dr. John Hansman, MIT

IMPLEMENTATION ISSUES FOR UPLINKED MICROBURST ALERTS

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Third Combined Manufacturers' and Technologists'
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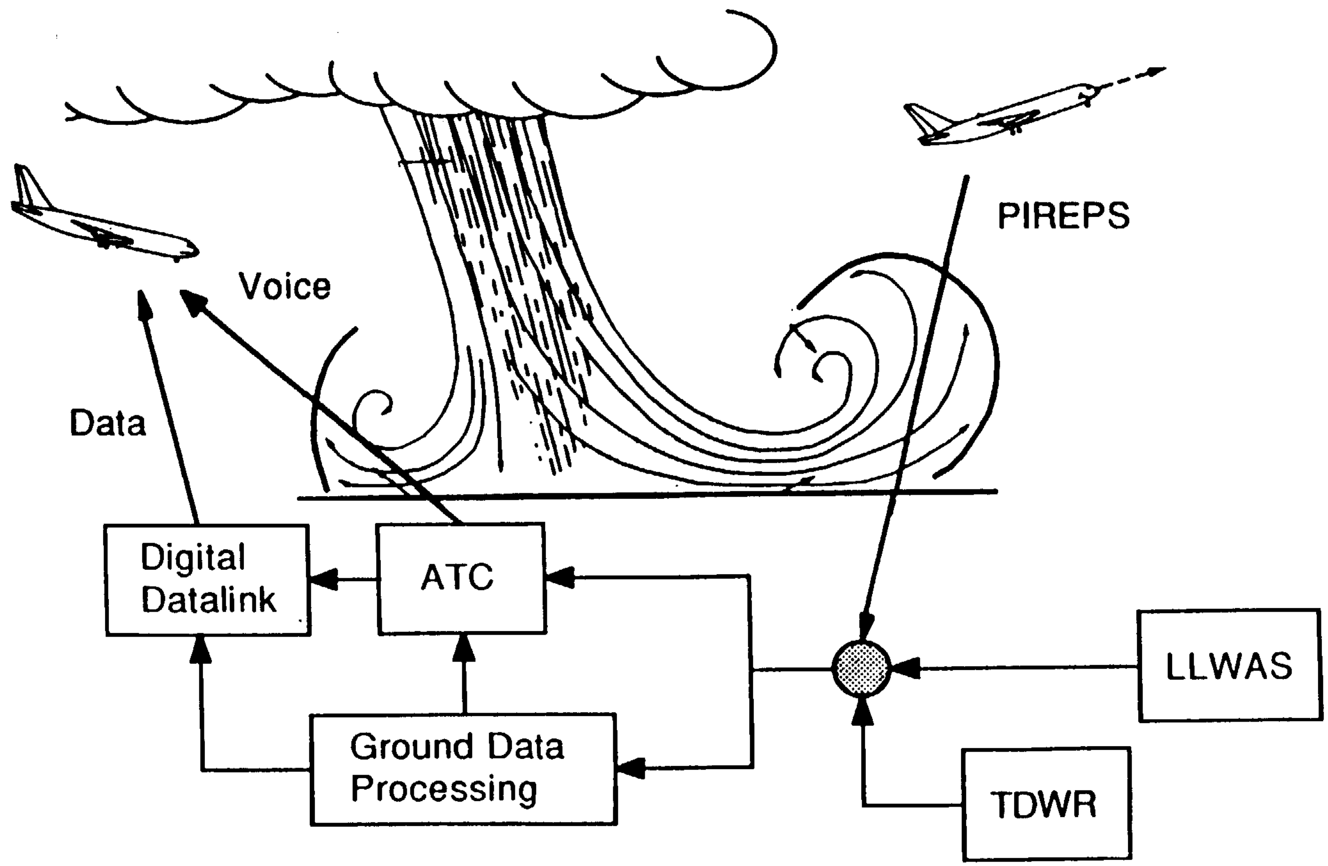
WINDSHEAR AVOIDANCE IN THE ADVANCED ATC ENVIRONMENT



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RESEARCH FOCUS

- OVERALL: EVALUATION, TRANSMISSION, AND PRESENTATION OF GROUND-BASED DOPPLER WEATHER RADAR DERIVED INFORMATION THROUGH A LIMITED BANDWIDTH DIGITAL DATALINK.

- ELECTRONIC COCKPIT PRESENTATION OF UPLINKED WINDSHEAR ALERTS

    PILOT OPINION SURVEYS

    PART-TASK SIMULATION EXPERIMENT

  PRESENTATION MODES:

    VERBAL: Standard radio communications

    TEXTUAL: Electronic presentation of the literal text of the message

    GRAPHICAL: Combined pictorial/text presentation of alert information on an electronic map-like display

- HAZARD EVALUATION OF GROUND-MEASURED WINDSHEAR DATA

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PILOT OPINION SURVEYS

- 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: 51
  51% of respondents have had a hazardous windshear encounter
- Data applications include design of part-task simulator experiments with advanced graphic and alphanumeric display formats and identification of data priority for datalink constraint analysis

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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 is sufficient for safe operation.	14.6%	43.9%
A system to provide crews better and more timely windshear information is <u>necessary</u>.	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%

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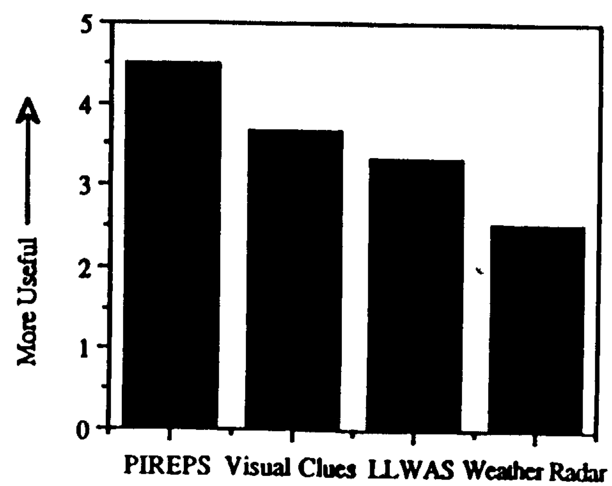
PILOT RANKINGS

Usefulness for windshear avoidance of:

Pilot Reports
Visual Clues
LLWAS (Low Level Windshear Alert System)
Airborne Weather Radar



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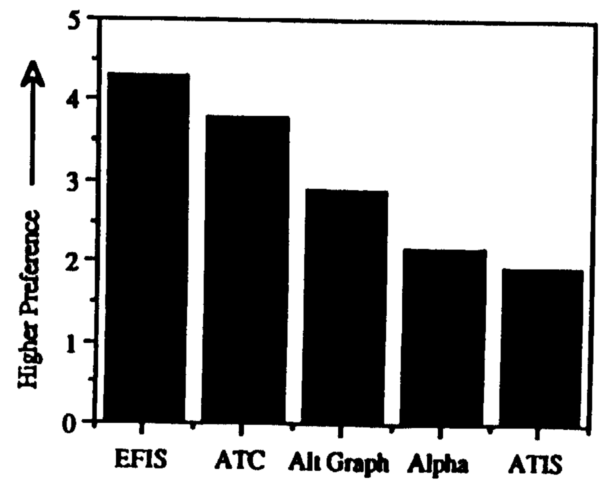
PILOT RANKINGS

Mode of data relay/presentation:

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



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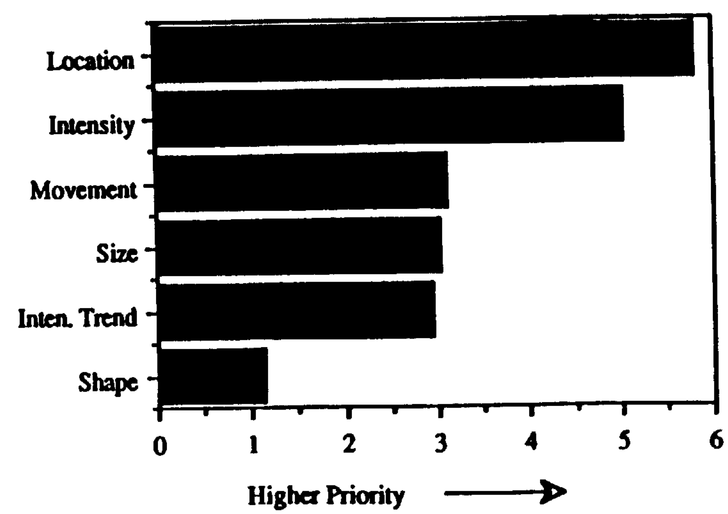
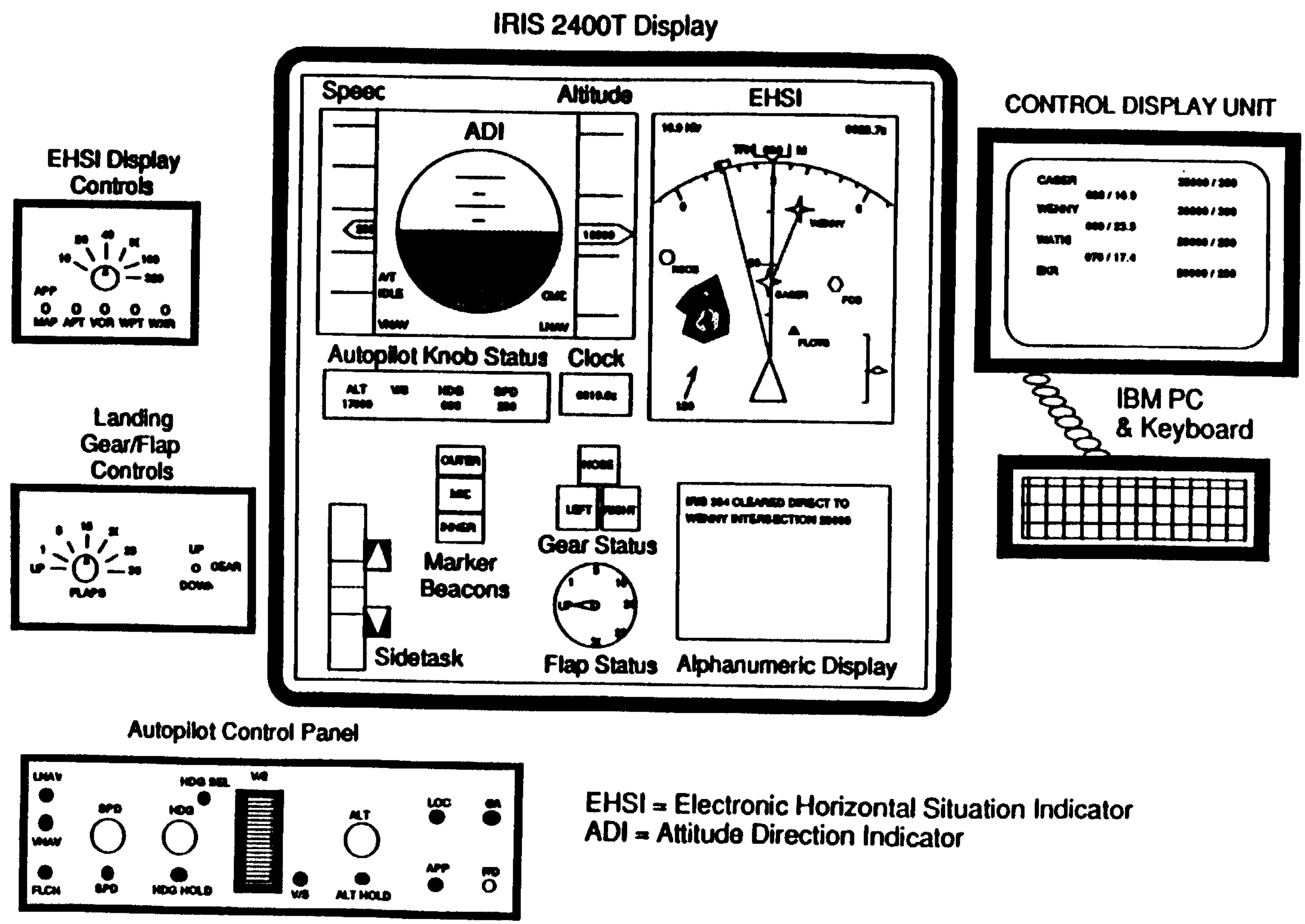
PILOT RANKINGS

Usefulness of available windshear data:

Location	Size
Intensity	Intensity Trend
Movement	Shape



BOEING 767 PART-TASK SIMULATION



EHSI = Electronic Horizontal Situation Indicator
ADI = Attitude Direction Indicator

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INITIAL EXPERIMENT

- Designed to compare verbal, textual, and graphical modes of windshear alert presentation
- Performed in concert with ATC clearance amendment delivery expt
- Subjects: 8 total, active 757/767 qualified line pilots
- 9 scenarios flown by each subject:
  - Descent and Approach to Denver-Stapelton Airport
  - 3 scenarios for each mode tested, groups rotated
  - Same information given in each mode, same mode used throughout each scenario
  - Descent: 3 ATC clearance amendments
  - Approach: microburst alerts - varying threat, alert time
- Sidetask, NASA subjective workload evaluation for workload monitoring
- Post-session debriefing

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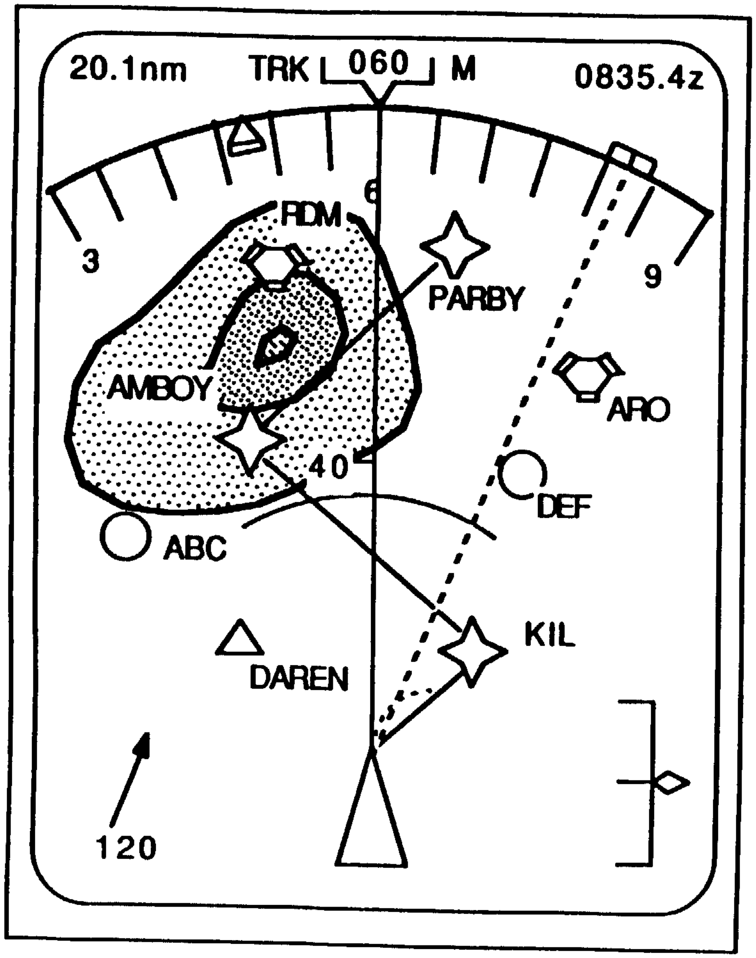
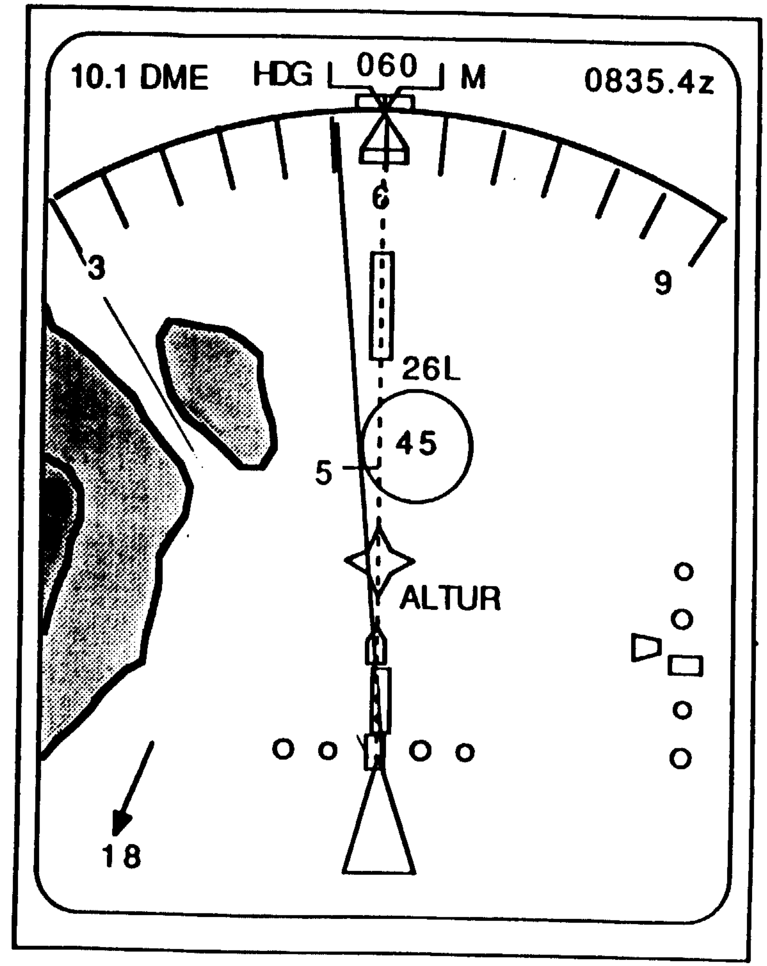
767 EHSI: MAP AND ILS MODES





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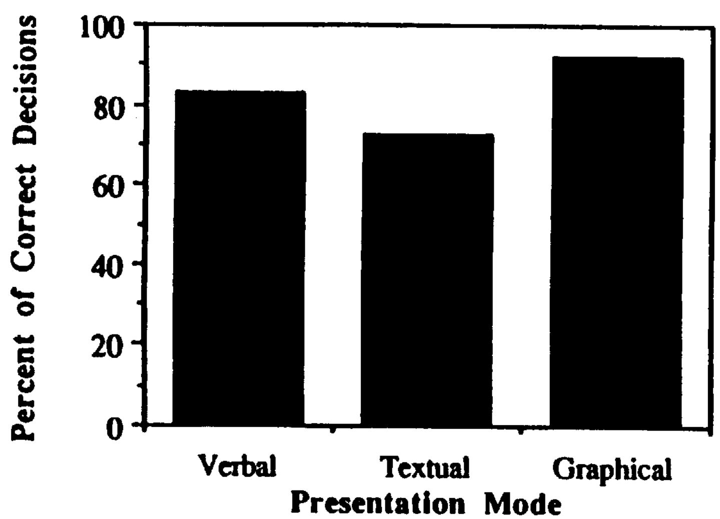
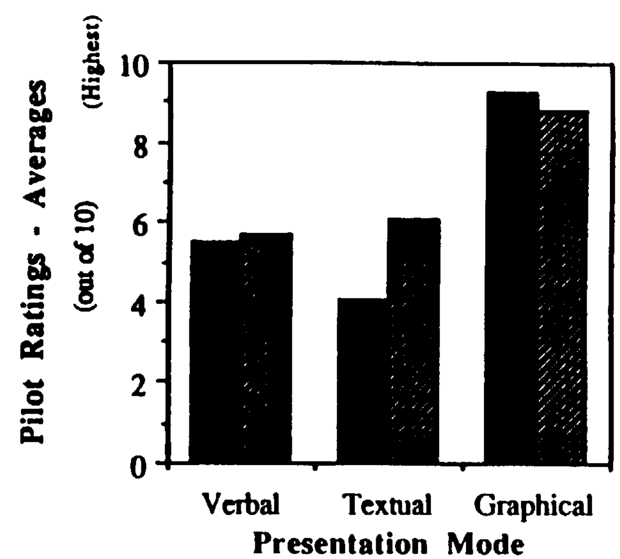
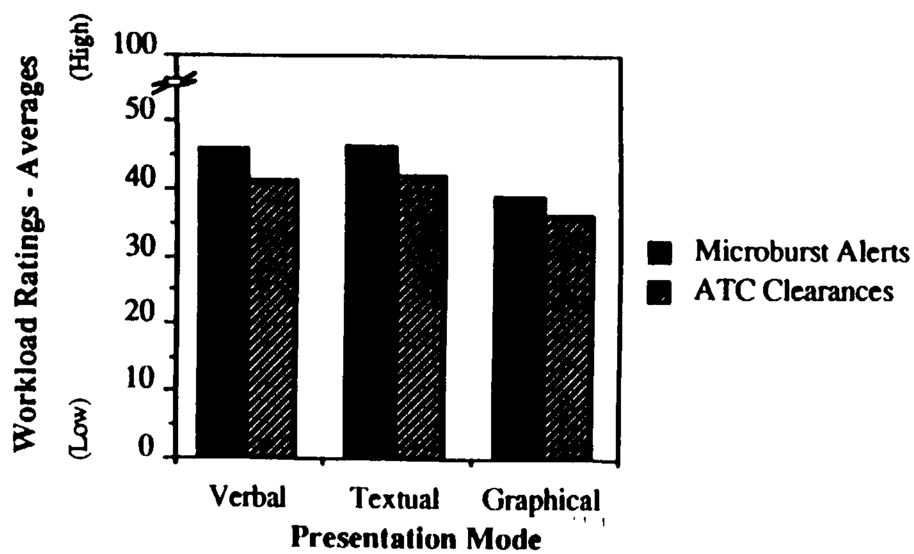
SIMULATOR EXPERIMENT: MODE RESULTS







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GENERAL OBSERVATIONS AND PILOT COMMENTS

- Positional info was more readily absorbed from graphical alerts
  - Missed approach planning
- Textual alerts in time-critical situations require too much head-down time, refocussing can be difficult for older pilots
- Loss of 'party line' and voice inflection information with digital datalink
- Lax attitude due to over-automation
- Graphical alert of microburst needs to be bright and easily interpreted, in contrast with original LLWAS implementation, for example
- Audible alert saturation problems
- Education about microburst encounter is necessary
- Positional information is great, but can the microburst threat be evaluated that exactly?

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CONCLUSIONS: CREW INTERFACE RESEARCH

GRAPHICAL PRESENTATION OF INFORMATION IS DESIRABLE

- Pilot performance improved in both accuracy and speed
- Crew workload decreased
- Extremely positive pilot response to presentation
- Consistent with human cognitive mapping: speeds comprehension and improves situational awareness

TEXTUAL PRESENTATION IS NOT GENERALLY DESIRABLE

- No improvement over verbal communications in performance or workload reduction shown: subject to misinterpretation in time-critical situations
- Generally disliked by pilots
- Difficult to present clearly for quick scanning: added head-down time
- Elimination of copying errors
- Familiarity of aircrews with verbal communications

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CONCLUSIONS: CREW INTERFACE RESEARCH

WINDSHEAR ALERT IMPLEMENTATION WITH DIGITAL DATALINK

- Minimum presentation: symbol with location, approximate size, intensity
- Mode-S datalink: 48 bits of info every 4 to 12 sec in surveillance mode
- TDWR update rate: 1 minute
- MODE-S LINK CAN BE USED TO DISPLAY AND TRACK SEVERAL MICROBURST EVENTS WITHIN TDWR UPDATE RATE

IMPORTANT ISSUES FOR USE OF DIGITAL DATALINK

- Loss of 'party-line' communications
- Loss of prosodic (voice-inflection) information
- Additional head-down time required
- Information density considerations
- Over-automation problems: humans are poor monitors

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HAZARD ASSESSMENT WORK: MOTIVATION

- TDWR OPERATIONAL EVALUATIONS
  - Overwarning is a problem - "Nuisance Alarms"
- PIREPS collected from 111 pilots who landed or took off during alert periods (Summer 1988 @ DEN):
  - 34% "Nothing was encountered"
  - 31% "Nothing much was encountered"
- Effect of overwarning:
  - Interference with normal airport operations
  - Reduced pilot confidence in alerting system
- Why does overwarning occur?

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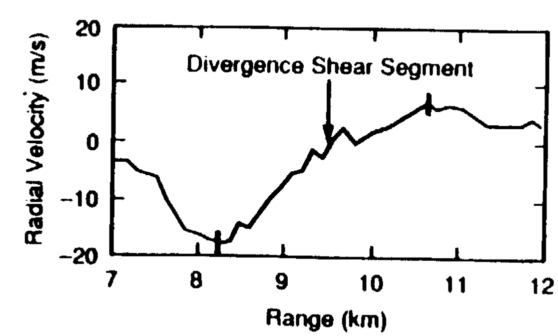
GROUND-BASED SINGLE DOPPLER MEASUREMENTS

- Reference frames: earth-fixed vs. aircraft fixed
  - Ground-based radar has area coverage
  - Airborne sensors know aircraft state, look along own flight path
- Terminal Doppler Weather Radar:
  - based off airport (~ 15 km) - does not look along runways
  - pencil-beam of 1° half-power beamwidth
  - scan strategy designed to provide microburst update every minute, gustfront update every 5 minutes
- Microburst detected by identifying segments of radial velocity divergence
- Groups of segments are "boxed", subjected to tests for strength and size, and identified as microburst regions



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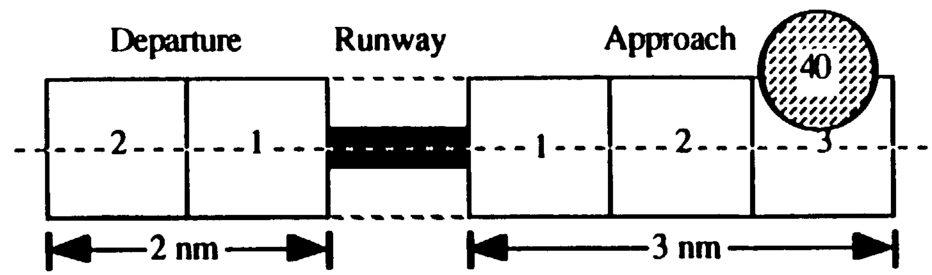
TDWR MICROBURST ALERTS



The alert corresponding to the 40 knot microburst pictured might be:"United 226, Denver tower, threshold wind one six zero at six, expect a forty knot loss on three mile final."

Possible contributing factors to overwarning problem:

- Microburst asymmetry
- Divergence as the intensity measurement
- Lateral displacement of microburst w.r.t. flight track
- Altitude variations in windfield
- Dynamics of pilot/autopilot/aircraft system

MICROBURST ASYMMETRY

- Microburst asymmetry ratio: the ratio of total headwind change through the cross-section of greatest change to the total change in the direction of least change.

- In the Joint Airport Weather Studies (JAWS) Project, multiple doppler radar measurements of Colorado microbursts were taken:
  - Average asymmetry ratio of greater than 2
  - Extreme cases of greater than 5

- A study of Oklahoma downbursts indicated asymmetries up to 5.5

- A single doppler measurement of one radial microburst slice can be significantly different from the shear intensity along another slice.

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HAZARD CRITERION: F-FACTOR

Aircraft Energy Height:

$$h_p = \frac{E}{W} = \frac{V^2}{2g} + h$$

Using aircraft equations of motion with "small" flight path angles:

$$\dot{h}_p = V\left(\frac{\dot{V}}{g}\right) + \dot{h} = V\left(\frac{T - D}{W}\right) - V\left[\frac{\dot{W}_x}{g} - \frac{W_z}{V}\right] + V\left(\frac{\dot{V}}{g}\right)$$

For a constant airspeed trajectory:

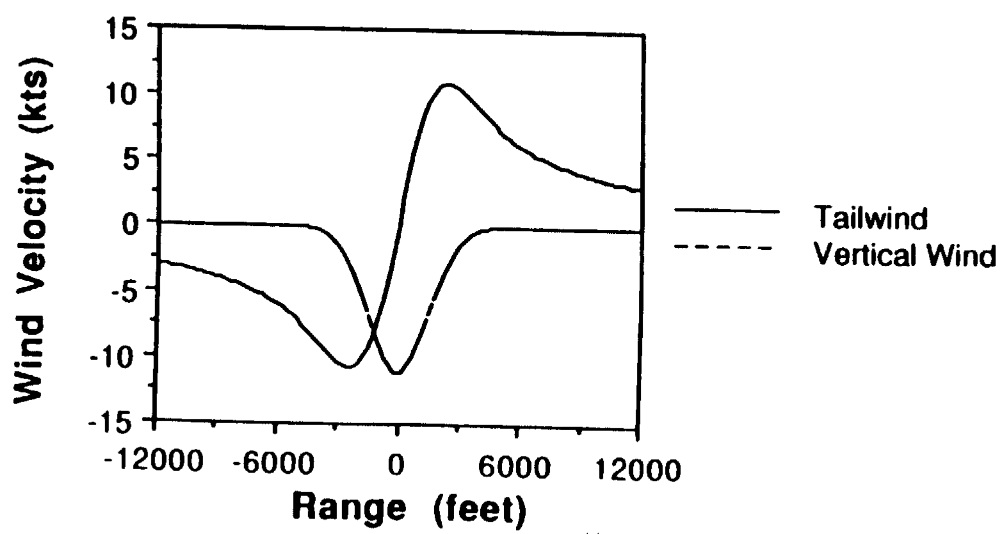
$$\dot{h}_p = V\left(\frac{T - D}{W} - F\right)$$

where F-factor is defined as:

$$F \equiv \frac{\dot{W}_x}{g} - \frac{W_z}{V}$$

DIVERGENCE AS INTENSITY MEASUREMENT

- The maximum divergence measured is reported as "loss"
- Pilot interpretation: loss = maximum headwind change = maximum loss of airspeed when crossing center of microburst
- Actual airspeed change is function of control (energy management) strategy employed and F-factor, not explicitly divergence
- Airspeed loss vs. reference (commanded) airspeed as opposed to loss vs. maximum airspeed



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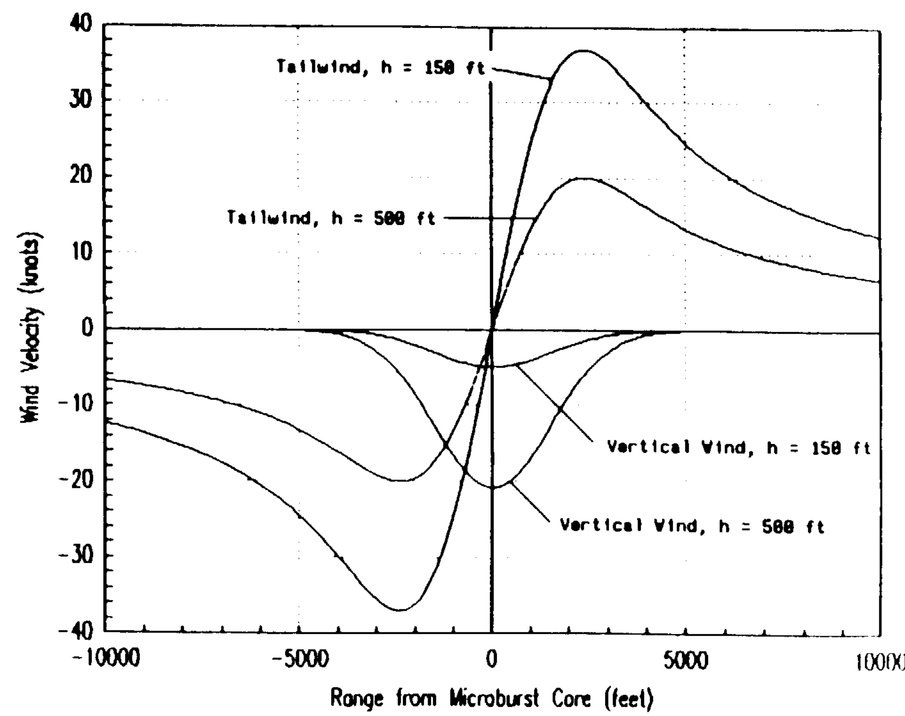
OSEGUERA AND BOWLES MICROBURST MODEL

- Based on boundary layer stagnation flow (wall jet) fluid dynamics, with relationships from TASS model
- Axisymmetric, smooth 3-D windfield
- Defined by 3 parameters:
  - Radius of downburst shaft
  - Maximum outflow velocity
  - Altitude of maximum outflow
- Sample windfield at right:
  - Radius = 2133 feet
  - Max outflow = 37 knots
  - Altitude of max outflow = 120 ft

  "Footprint" is about 2400 feet



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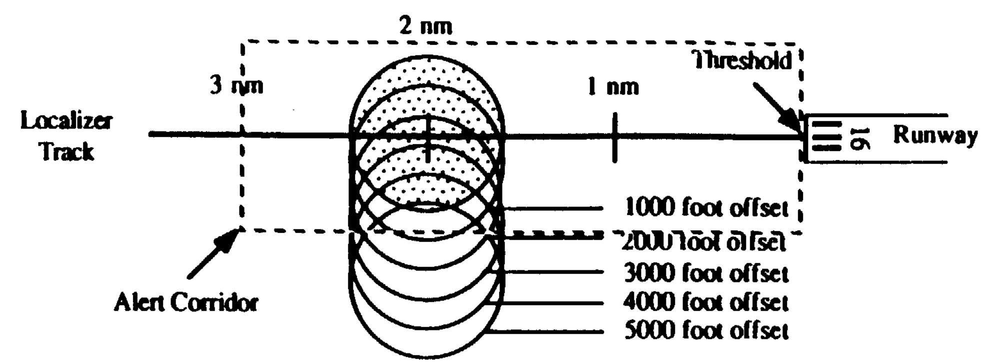
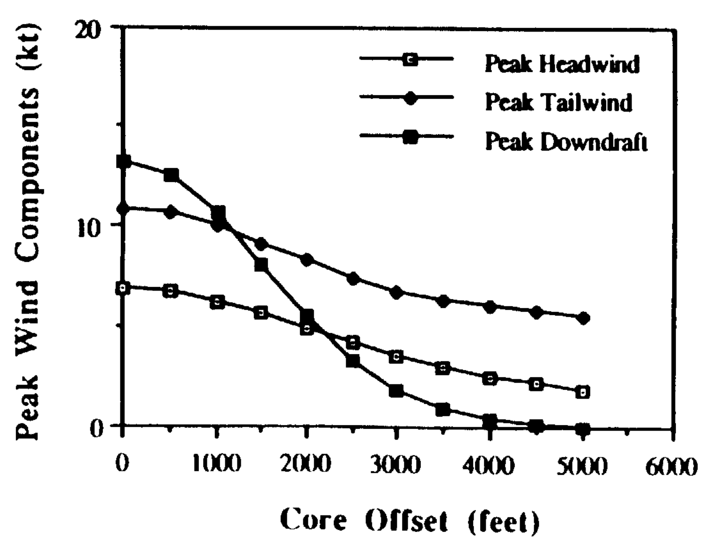
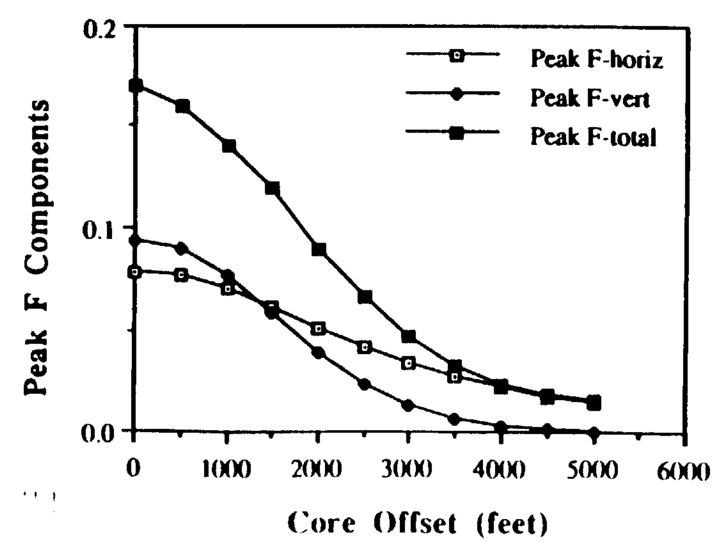
LATERAL DISPLACEMENT EFFECTS: O&B MODEL







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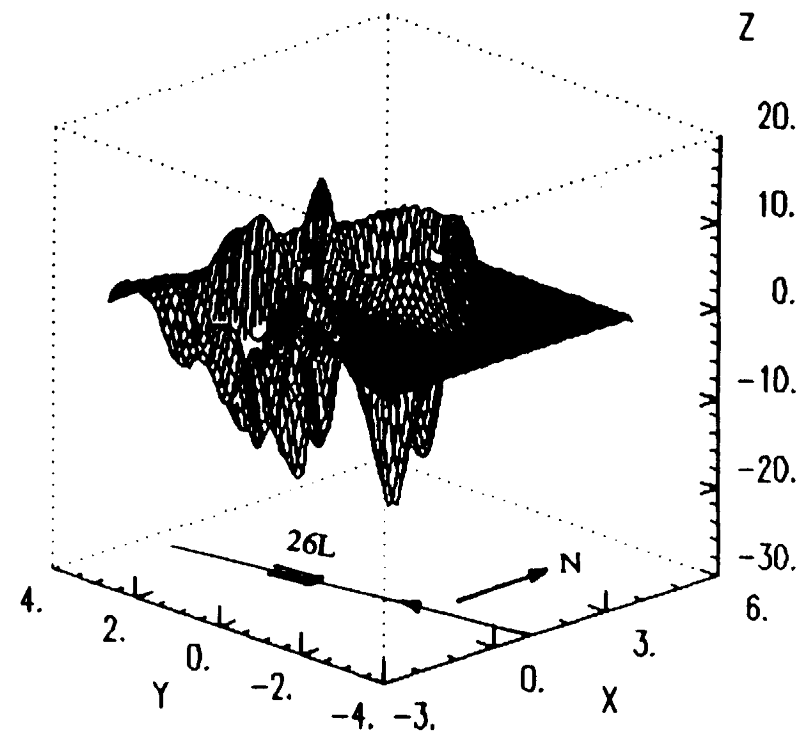
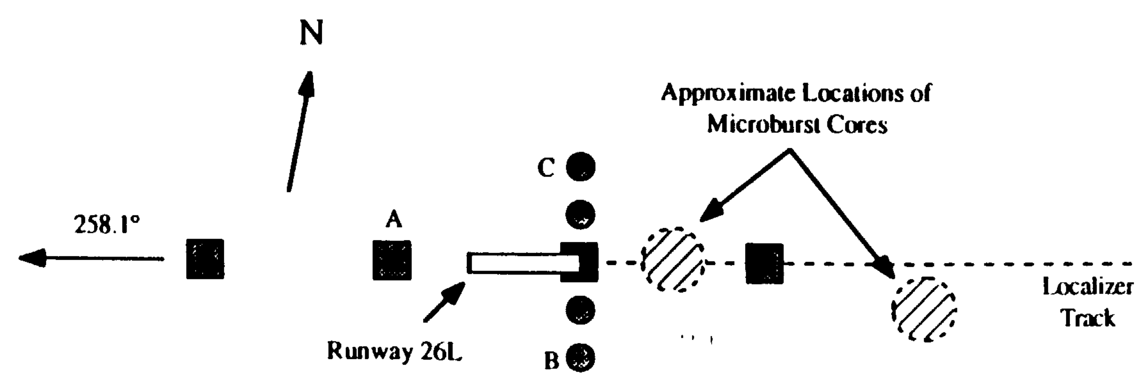
TASS (Terminal Area Simulation System) MODEL

- Detailed numerical simulation of microburst dynamics
- Windfield computed for 7/11/88 event at Denver-Stapelton airport
- Full 3-D windfields for 5 times during event available for analysis

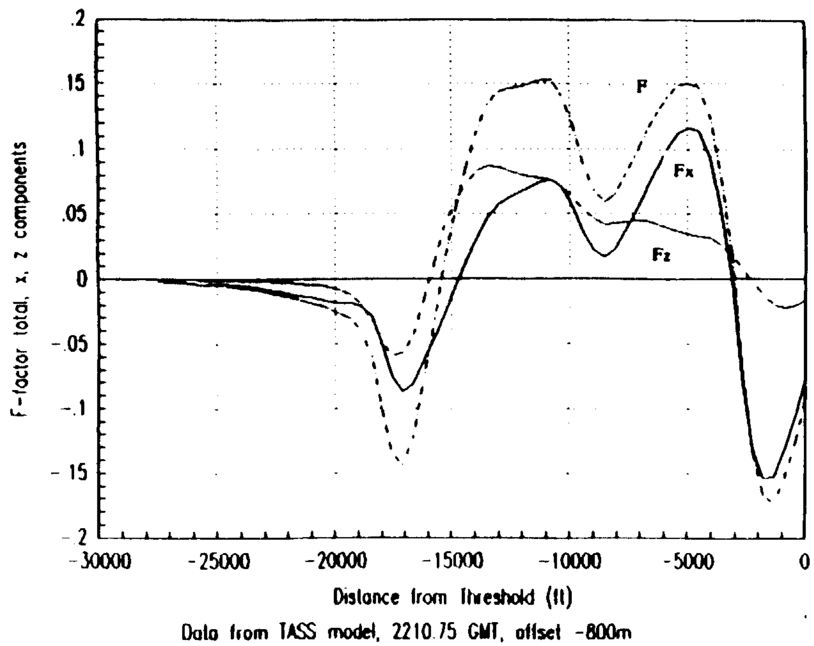




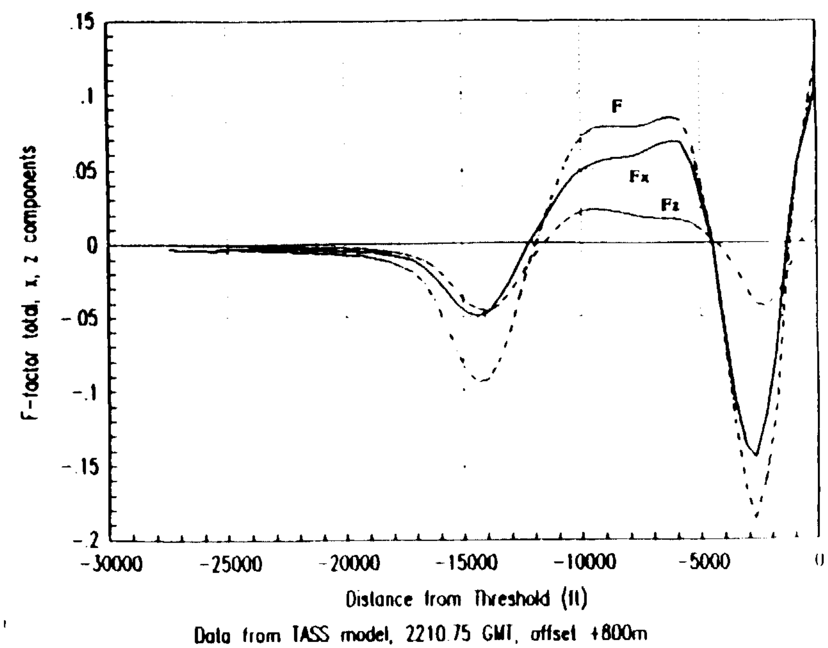
LATERAL DISPLACEMENT EFFECTS: TASS MODEL

- TASS windfields: Offset approaches to DEN 26L at 2210.75 UTC on 7/11/88. F-factor and its components are plotted.

Approach offset 0.5nm to South



Approach offset 0.5nm to North



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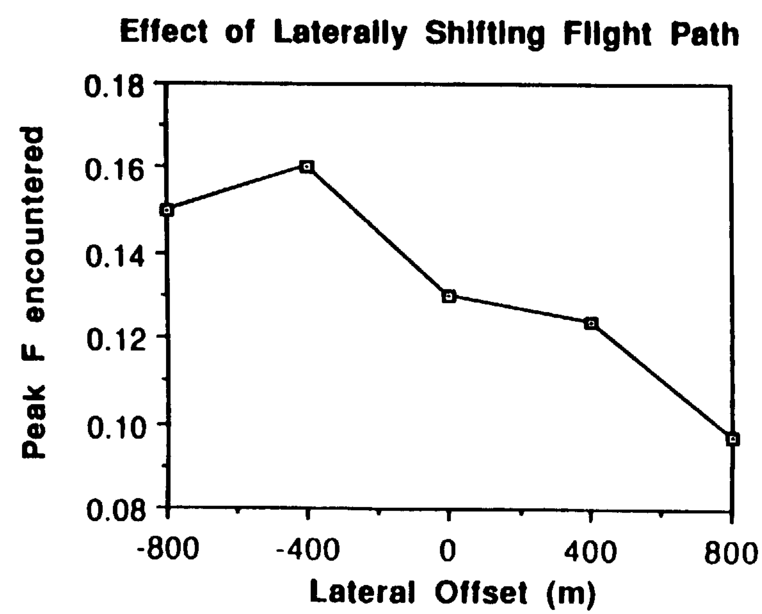
LATERAL DISPLACEMENT EFFECTS: TASS MODEL

- Windfields encountered during simulated approach to DEN 26L during 7/11/88 microburst event
- Runway displaced to North and South to demonstrate sensitivity of windfield to small lateral displacements



- Location of peak F along flight path also changes significantly

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MICROBURST VARIATION WITH ALTITUDE

- Microburst windfields can vary strongly over the lowest 1000 feet AGL
- Hazard is due primarily to horizontal shear near the ground, primarily to downdraft at higher altitudes
- Finite radar beamwidth (~ 1°) causes weighted averaging of measured wind velocity over the lowest 500 to 1000 feet AGL
- Is the peak F-factor for paths through a microburst invariant with altitude?

  R. Oseguera model: YES

  TASS windfields: YES for fully developed single microbursts
NO for developing microbursts, compound events
- Altitude invariance is useful if F is to be estimated from horizontal winds and microburst diameter only (as with TDWR measurement)

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MICROBURST VARIATION WITH ALTITUDE

- O&B model microburst: 40 knot max divergence
  Core encounter on approach at varying distance from threshold

Microburst Dist. From Threshold	Approx. Altitude of Encounter	Peak Winds (knots) Headwind	Tailwind	Downdraft	Peak F-factors F_x	F_z	Ftotal
1 nm	**314 feet**	12.1	18.7	8.21	0.13	0.058	**0.19**
2 nm	**628 feet**	6.82	10.8	13.2	0.078	0.094	**0.17**
3 nm	**942 feet**	3.85	6.10	16.1	0.044	0.12	**0.16**

- TASS model windfield: July 11, 1988 simulation @ 2210.75 UTC
  Core encounter on approach at varying distance from threshold

Runway Displacement	Approx. Altitude of Encounter	Peak Winds (knots) Headwind	Tailwind	Downdraft	Peak F-factors F_x	F_z	Ftotal
-1 nm	70 feet	26.1	14.7	3.50	0.083	0.025	**0.11**
0 nm	380 feet	21.6	24.2	7.32	0.090	0.052	**0.13**
+1 nm	690 feet	15.7	22.6	11.0	0.084	0.079	**0.14**
+2 nm	1000 feet	9.51	16.6	11.9	0.051	0.085	**0.13**

- How does the altitude-averaged divergence value measured by TDWR correlate to peak F?

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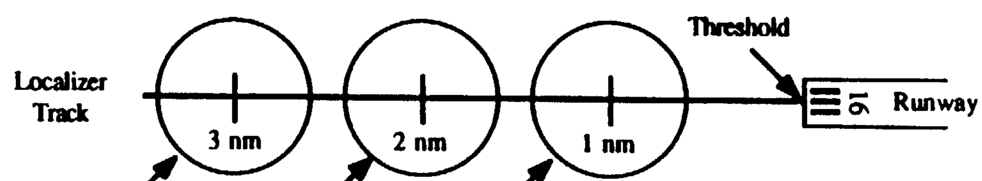
FLIGHT PATH DEVIATIONS and F

- Deviations (airspeed and altitude) from the desired flight path are a function of the total F-factor profile and the energy management strategy used.

- Deviations are not dependent on whether or not the hazard is due to horizontal shear or downdraft.



Microburst locations: 3, 2, 1 nm from runway threshold

Results from longitudinal Boeing 727 simulation through above windfields:

Microburst Dist. from Threshold	Max Deviations from Nominal Approach: A/S Loss	Altitude Loss	Peak F-factors: F_x	F_z	Ftotal
1 nm (314 ft AGL)	13.7 kt	138 ft	0.13	0.075	0.19
2 nm (628 ft AGL)	12.6 kt	134 ft	0.094	0.092	0.18
3 nm (942 ft AGL)	11.6 kt	132 ft	0.071	0.10	0.17

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IMPORTANT POINTS

- Overwarning during the TDWR Operational Evaluation due to lateral displacement of microbursts from aircraft track and difficulties in conveying hazard from divergence measurements.

- F-factor should be the hazard criterion, both from aircraft performance considerations and to allow fusion of data with airborne measurements.

- F-factor, although a natural measurement with airborne sensors, is difficult to estimate from the ground.

  Contibuting factors: no look along flight path, difficult to measure vertical winds, incomplete knowledge of aircraft state vector

- Since F is roughly invariant with altitude for models studied, should be able to couple TDWR measurements (horiz. wind, diameter) with fluid dynamic model to estimate F.

RECOMMENDATIONS

- Near-term TDWR alert modifications to reduce overwarning
  - Add: "left of approach," "right of approach," "on approach" "divergence" vs. "loss"
- Improved pilot briefing about TDWR
- How to accurately estimate total F-factor from TDWR data?
  - Available data: measured velocities and reflectivity, features aloft, known/correlated microburst characteristics, continuity, analytical fluid-dynamic modeling
- Multi-level alert generation:
  - Alert levels correspond to recommended or required action by pilot and/or controller
  - Alert thresholds defined for aircraft classes based on multiple data sources: TDWR, LLWAS, PIREPS, Airborne sensors

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CURRENT RESEARCH

- Development and evaluation of candidate crew procedures for use with multiple windshear sensors
  - airborne look-ahead sensors
  - airborne reactive sensors
  - ground-based sensors

- Further piloted simulations:
  - Evaluate graphical display formats and candidate crew procedures

- Improved microburst hazard assessment from TDWR data

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Microburst Avoidance Simulation Tests - Questions and Answers

Q: SAM SHIRCK (Continental Airlines) - On graphic EHSI presentation can a pilot in a timely manner pull wind shear information from the EHSI when cluttered with weather radar returns, TCAS information, way points, etc., etc., etc. I like it, but can and will it work?

A: JOHN HANSMAN (MIT) - There is basically a problem of EHSI clutter, and as I said before, EHSI has become the most popular piece of real estate in the cockpit, everybody wants to put something there. I think it's a matter of good EHSI design. Currently you can deselect basically any piece of information off the EHSI, so you don't necessarily have to have the weather radar or the way points. You can deselect those. However, if you're going to put alert information up there you have to think about whether you're going to allow the crew to deselect alert information or not, probably not. And you would probably have to prioritize the alert information.

Q: PAUL KELLY (21st Century Technology) - Given the limitations on ATC voice communications, how sensible it is to depend on ATC voice for uplinking of hazard alert information like a TDWR microburst.

A: JOHN HANSMAN (MIT) - Clearly, if you have the equipment, the data link would be a more desirable system. It reduces the latency lag times inherent in ATC voice communication and gets rid of the frequency blocking effects. On the other hand, for the foreseeable future, and also in the third world, for example, you're probably not going to have data links and you're going to have to depend on voice for a long time.

Q: MARILYN WOLFSON (MIT Lincoln Laboratory) - You mentioned reduced wind shear hazard flying through the edge of the microburst versus going through the middle. Are there any significant known hazards from cross wind or leading vortex on the gust front?

A: JOHN HANSMAN (MIT) - We did do a study looking at cross wind effects and we actually found that if you penetrated the microburst just slightly off center, you got an increased performance loss due to cross wind and basically weather cocking effects and in fact that control gains required to keep the airplane on the straight trajectory on a slightly off center microburst were much higher In fact, inordinately high which basically leads to the question, which we tend to ignore here, of the controllability in turbulence problem. F-factor is a good measure of the total integrated energy loss but if you look at some of the accident cases, Delta 191 is a classic example, that airplane hit the ground with a lot of energy. Some of the issues may be controllability issues which we tend to ignore because we basically don't have the measurements of the fine structure of the turbulence that's encountered. That's something to think about when we think about hazard criteria because it's a problem we wrestle with but nobody has a real clear measure of.

DAN VICROY (NASA Langley) - In regard to your controllability statement, we have done some work (about two years ago) where we tried to estimate not the performance impact but what the handling qualities impact of wind shear is. We did a simple analytical study that showed that when you're in that vortex roll, that can be a considerable handling qualities problem.

JOHN HANSMAN (MIT) - It should be pointed out that it's likely that the regions of high turbulence and handling problems probably correlate reasonably well with the areas of high F-factors. So, using F-factor as the criteria at the current status is probably not a bad idea.

UNKNOWN - If I could tell a personal story about running a 727 off the edge of the runway at Denver during the JAWS project . There was a case where unreported, just after touchdown, the airplane experienced enough of a cross wind from an associated suspected downburst that the airplane was blown completely off the dry runway. I've always contended that on take off and landing roll that the industry needs to take a look at some of the hazards rather than just figuring that the landing is complete after touch down.

JOHN HANSMAN (MIT) - That's an important point. Most of the analysis has been done for basically a two dimensional case, looking at the longitudinal dynamics. It's hard to do the analysis for the three dimensional lateral dynamics but there are cases where that can be very important. We didn't expect that when you displace the trajectory slightly, only about 100 or 200 feet off the center axis of the microburst, you actually get a significant increase in the performance degradation.

ROLAND BOWLES (NASA Langley) - To follow up on his point and what Dan said; with the question of cross wind and scales of turbulent motion on the order of the mean wing core and span of the airplane, you get into another problem. You've got to now address the question of how do you model the distributed aerodynamics of that airplane. You can have outboard sections on one wing stalling before another and that can be bad news. The lateral directional problem is very complicated. We found that conventional yaw dampers on big airplanes may actually, because of some root bifurcations going on in the dynamics, may actually hurt you rather than help you. You want to stay out of cross winds and scales of motion, severe ones anyway.

UNKNOWN - Most of the experiences we have with microburst penetrations are not actually symmetric penetrations, there's some degree of cross wind component. In fact, July 7 was a unique case because it was lined up on the runway on the center line it targeted. There was a strong cross wind in that case. Remember real world microbursts are not nice, perfect, axisymmetric events. Even when you're going through the center line or the mean center line of the event you can get and do get cross winds.

UNKNOWN - This has some interesting applications with regard to predictive sensors. With a 40 second warning, if the pilot makes the missed approach at 1000 feet, those problems are somewhat reduced. We're getting a lot of discussions in committees like the S7 about what to do if you have an alert with a predictive system. For example, AM539 following 191 got what would be a 28 second warning and went through the same event at about 3000 feet and 220 knots and didn't have much of a problem. So a lot of those problems go away if you've got some altitude when you go through the event. It bears on what predictive systems have to deal with and what people need to do when they get a predictive alert.