NASA/CP—2003-210964

Proceedings of the Second NASA Aviation Safety Program Weather Accident Prevention Review

January 2003

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Proceedings of a conference held at the Hilton South
sponsored by NASA Glenn Research Center
Independence, Ohio
June 5–7, 2001

National Aeronautics and
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January 2003

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Aviation Safety Program

Weather Accident Prevention Annual Project Review

Cleveland, Ohio
June 5-7, 2001

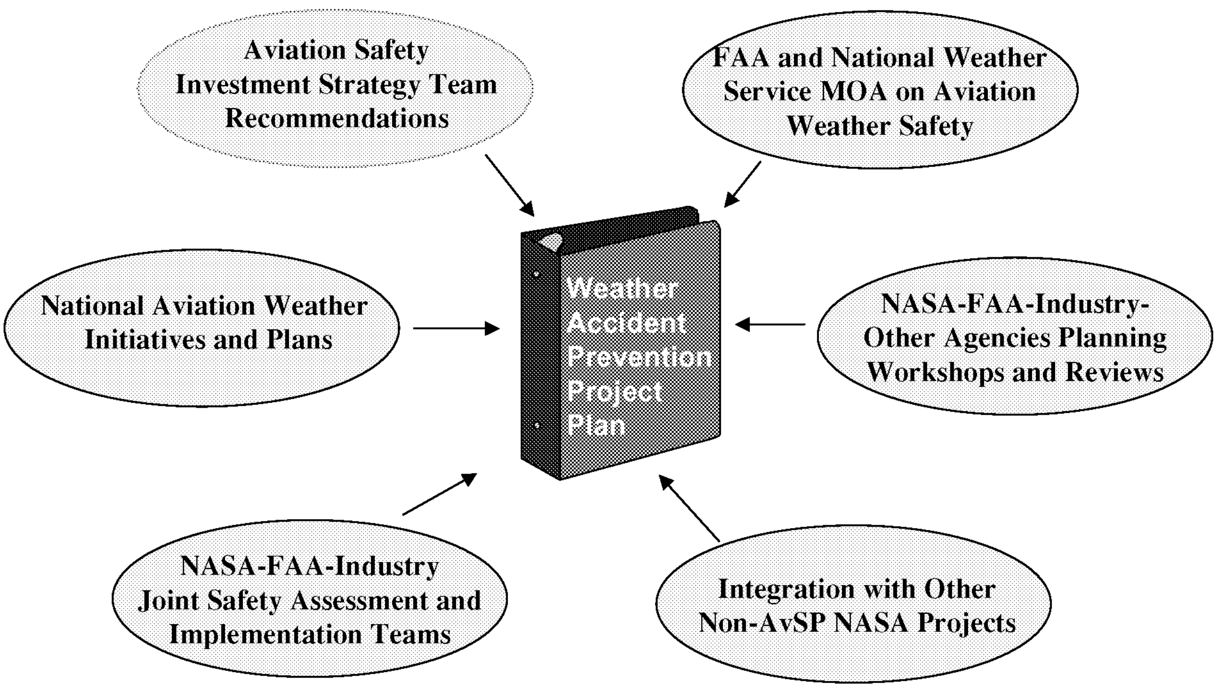
Review Objectives

Aviation Safety Program | Weather Accident Prevention

- Communicate progress to NASA Stakeholders, Partners, and Customers
- Solicit feedback on NASA's Weather Safety Plans and activities from the aviation community.
  - Q&A session after presentations
  - Discussion sessions following each topical session
  - Panel Discussion during last morning session (June 7)
  - Survey of NASA WxAP plans/products
- Catalyst for future partnerships and collaboration with aviation community
- Enhanced integration of NASA Weather Accident Prevention Project Elements
- Preparation for NASA FY02 detailed planning activities

Review Objectives

Aviation Safety Program — Weather Accident Prevention



Attendees of Review

NASA AvSP Management/Researchers
NASA Base Management/Researchers
FAA
NWS
NTSB
Avionics Industry
Airlines
Aircraft Manufacturers
Pilot Associations
Aircraft Associations
Academia
DoD

Survey

Aviation Safety Program Weather Accident Prevention

- Evaluate NASA's weaknesses/strengths
- Evaluate NASA products being developed
  - Technical Issues
  - Coordination Issues
  - Implementation Issues
  - Others
- Identity disclosure is voluntary
- Use postage-paid envelope
- Summary of surveys will be forwarded to all attendees

Meeting Logistics

Aviation Safety Program | Weather Accident Prevention

- Message Board available at registration table
    - Telephone Messages: 216-447-1300
    - FAX: 216-642-9334
- Coffee and snacks available during breaks
- Lunch available in the pool area Tuesday and Wednesday ($10 each) – Sign-up sheet at registration table
- List of local restaurants is available at registration table
- Presentations are on CD-ROM
- Break-out room available for side meetings – Sign-up sheet at registration table

NASA/CP—2002-210964

Day 1 Morning Agenda

Aviation Safety Program — Weather Accident Prevention

8:00 a.m.	Welcome	Sehra, GRC Rohn, GRC
8:15 a.m.	Meeting Objectives and Logistics	Nadell, GRC
8:30 a.m.	Weather Accident Prevention (WxAP) Project Overview and Status	Nadell, GRC
9:00 a.m.	Development of WxAP System Architecture and Concept of Operation	Grantier, GRC
9:30 a.m.	Aviation Weather Information Overview and Status	Stough, LaRC
10:15 a.m.	Break	
10:30 a.m.	Weather Information Communications Overview and Status	Martzaklis, GRC
11:15 a.m.	Turbulence Detection and Mitigation Overview and Status	Bogue, DFRC Watson, LaRC
12-1 p.m.	Lunch	

Day 1 Afternoon Agenda

Cockpit Weather Information Systems

1:00 p.m.	Weather Information Network	Leger, Honeywell
1:15 p.m.	NASA Langley WINN System Operational Assessment	Jonsson, LaRC
1:30 p.m.	United's SKY-PAD™ Project	Burns, UAL
1:45 p.m.	Enhanced Weather Radar and Aviation Weather Awareness & Reporting Programs	Kronfeld, Rockwell
2:15 p.m.	Satellite Weather Information Service	Kerczewski, GRC
2:35 p.m.	Pilot Weather Advisor™	Hoffler, Vigyan, Inc.
2:55 p.m.	The Results of the Evaluation of Using Lightning Data to Improve Oceanic Convective Forecasting for Aviation	Nierow, FAA
3:00 p.m.	Oceanic Weather Information: Oceanic Convective Convective Nowcasting Demonstration (OCND)	Lindholm, NCAR

Day 1 Afternoon Agenda (cont.)

Aviation Safety Program | Weather Accident Prevention

Cockpit Weather Information Systems (cont.)

3:15 p.m.	Break	
3:30 p.m.	VHF Datalink (Mode 2) for Cockpit Weather for Air Transports	Tanger, LMGT
3:40 p.m.	Preliminary VLD Mode 2 Bench and Flight Test Results	Skidmore, OU
4:00 p.m.	Decision-making In Flight With Different Convective Weather Information Sources: Preliminary Results	Latorella, LaRC Chamberlain, LaRC
4:30 p.m.	GA Cockpit Weather Information System Simulation Studies	McAdaragh, FAA Novacek, RTI
5:00 p.m.	Discussion: Cockpit Weather Systems	
5:30 p.m.	Conclude for the Day	

Day 2 Morning Agenda

Cockpit Weather Information Systems (cont.)

8:00 a.m.	General Aviation FIS Broadcast System	Joyce, Honeywell
8:20 a.m.	FIS Architecture Study Plan	Tanger, LMGT Nichols, Johns Hopkins APL

Airborne Weather Reporting System

8:45 a.m.	TAMDAR Development Strategy	Schmidt, FAA
8:55 a.m.	TAMDAR Capabilities Development	Daniels, LaRC
9:25 a.m.	TAMDAR Datalink Development	Andro, GRC
9:45 a.m.	Overview of the Business Feasibility of the TAMDAR System	Kauffmann, ODU
10:15 a.m.	Break	
10:30 a.m.	Impact of MDCRS/TAMDAR data on National Weather Service (NWS) Operations	Weiss, NWS

Day 2 Morning Agenda (cont.)

10:50 a.m.	Discussion: Airborne Weather Reporting System	

Airborne Turbulence Warning System

11:25 a.m.	Airborne Turbulence Warning System Development	Bogue, DFRC
11:40 a.m.	Meteorological Case Studies of Turbulence Encounters	Ferris, MIT Lincoln Labs.
12-1 p.m.	Lunch	
1:00 p.m.	Weather Associated With the Fall 2000 Turbulence Flight Tests	Hamilton, LaRC
1:20 p.m.	Numerical Simulation of Event 191-6 of NASA's Flight Tests	Proctor, LaRC
1:40 p.m.	Unbalanced Supergradient Flow – It's Role In Organizing Severe Turbulence In Both Convective and Clear Air Case Studies	Kaplan, NCSU
2:00 p.m.	Simulations of Continuous and Discrete Turbulence Events	Sharman, NCAR

Day 2 Afternoon Agenda (cont.)

Aviation Safety Program | Weather Accident Prevention

Airborne Turbulence Warning System (cont.)

2:20 p.m.	Development and Flight Test of In Situ Turbulence Algorithms	Robinson, AeroTech
2:45 p.m.	Turbulence LIDAR Development Status	Clark, LaRC
3:00 p.m.	Break	
3:15 p.m.	Flight Test Results for a Turbulence Detection Radar	Schaffner, LaRC
4:00 p.m.	Market Assessment of Forward-Looking Turbulence Sensing Systems	Kauffmann, ODU
4:30 p.m.	Turbulence Secure Cabin Exercise	Bogue, DFRC
5:00 p.m.	Discussion: Airborne Turbulence Warning System	
5:30 p.m.	Conclude for the Day	

Day 3 Morning Agenda

Aviation Safety Program — Weather Accident Prevention

Airborne Turbulence Warning System (cont.)

8:00 a.m.	Feasibility Study of Transport-Aircraft Control Systems for Turbulence Effects Mitigation	Borland, Boeing CAG
8:20 a.m.	Turbulence JSAT/JSIT Status	Bogue, DFRC

Implementation, Operation, and Technology Development

8:40 a.m.	NASA-FAA-NOAA Partnering Strategy	Colantonio, GRC
9:00 a.m.	Flight Information Services Data Link (FISDL)	Moosakhanian, FAA
9:20 a.m.	Airline Implementation of Cockpit Weather Systems	Sambrano, UAL
9:40 a.m.	Break	
10:00 a.m.	Panel Session: Cockpit Weather Information Systems: Current and Future Challenges for Implementation, Operation, and Technology Development	
11:45 a.m.	Annual Review Wrap-up	
12:00 noon	Annual Review Concluded	

Aviation Safety Program

Weather Accident Prevention (WxAP) Project Overview and Status

Shari-Beth Nadell, Acting Project Manager
NASA Glenn Research Center (GRC)
Cleveland, OH

Outline

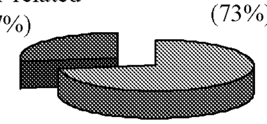
- Weather Accident Prevention Project Background/History
- Project Modifications
- Project Accomplishments
- Project's Next Steps

Weather Safety Benefits Needed

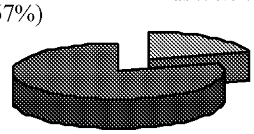
Aviation Safety Program — **Weather Accident Prevention**

41% during cruise

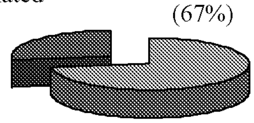
27% due to visual flight operation in instrument flight conditions



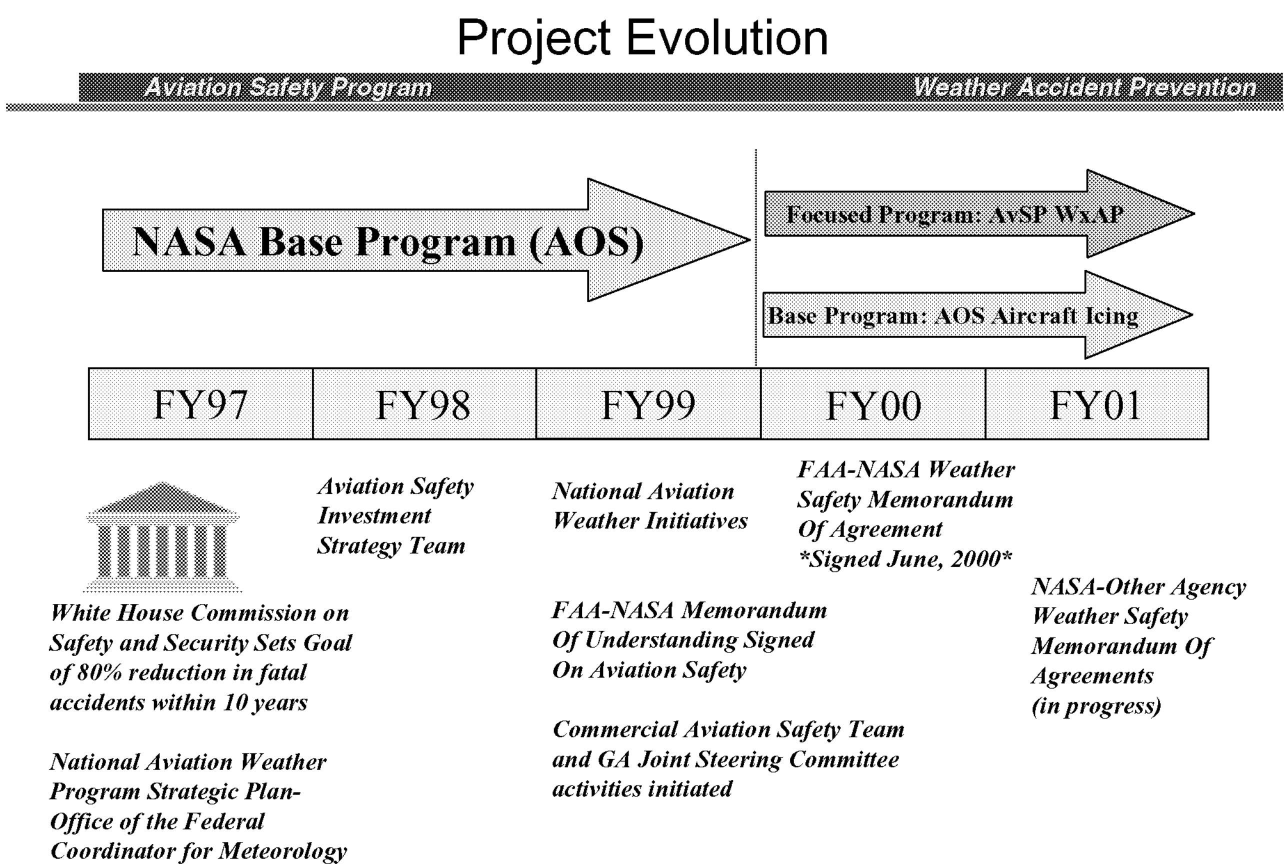
GA Aviation Accidents 1982-1993
(22,053 total accidents)
Source: AOPA Air Safety Foundation



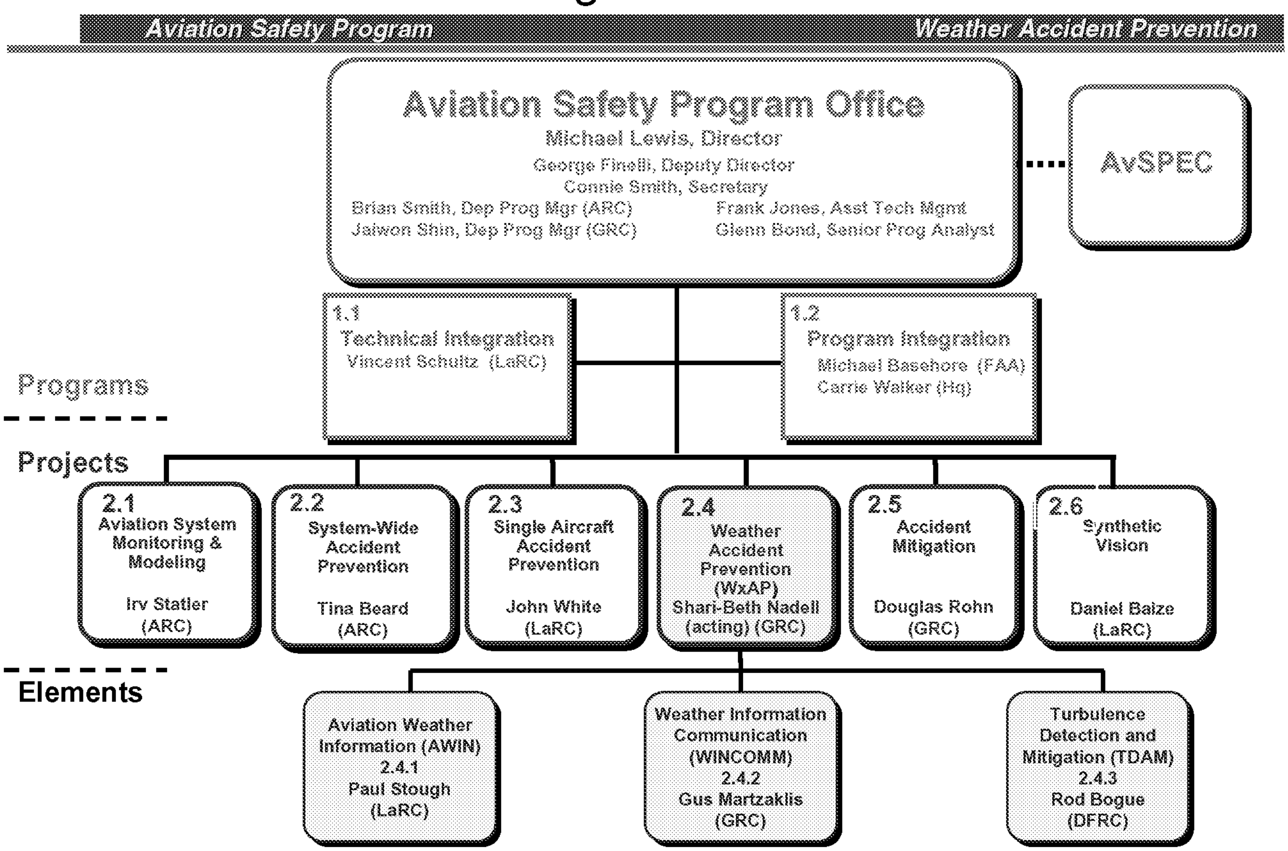
Commercial Transport Serious Injuries 1990-1996
Fatal/Non-fatal Accidents
Source: NTSB Data



Commercial Carrier Accidents 1983-1995
Source:NTSB


Project Evolution
Aviation Safety Program
Weather Accident Prevention
NASA Base Program (AOS)
Focused Program: AvSP WxAP
Base Program: AOS Aircraft Icing
FY97
FY98
FY99
FY00
FY01
White House Commission on Safety and Security Sets Goal of 80% reduction in fatal accidents within 10 years
National Aviation Weather Program Strategic Plan- Office of the Federal Coordinator for Meteorology
Aviation Safety Investment Strategy Team
National Aviation Weather Initiatives
FAA-NASA Memorandum Of Understanding Signed On Aviation Safety
Commercial Aviation Safety Team and GA Joint Steering Committee activities initiated
FAA-NASA Weather Safety Memorandum Of Agreement *Signed June, 2000*
NASA-Other Agency Weather Safety Memorandum Of Agreements (in progress)

NASA AvSP Organizational Structure



WxAP Project Goals/Objectives/Products

Aviation Safety Program | Weather Accident Prevention

Goal

Develop enabling technologies to reduce weather-related accident causal factors by 50% and turbulence-related injuries by 50% by year 2007.

Objectives

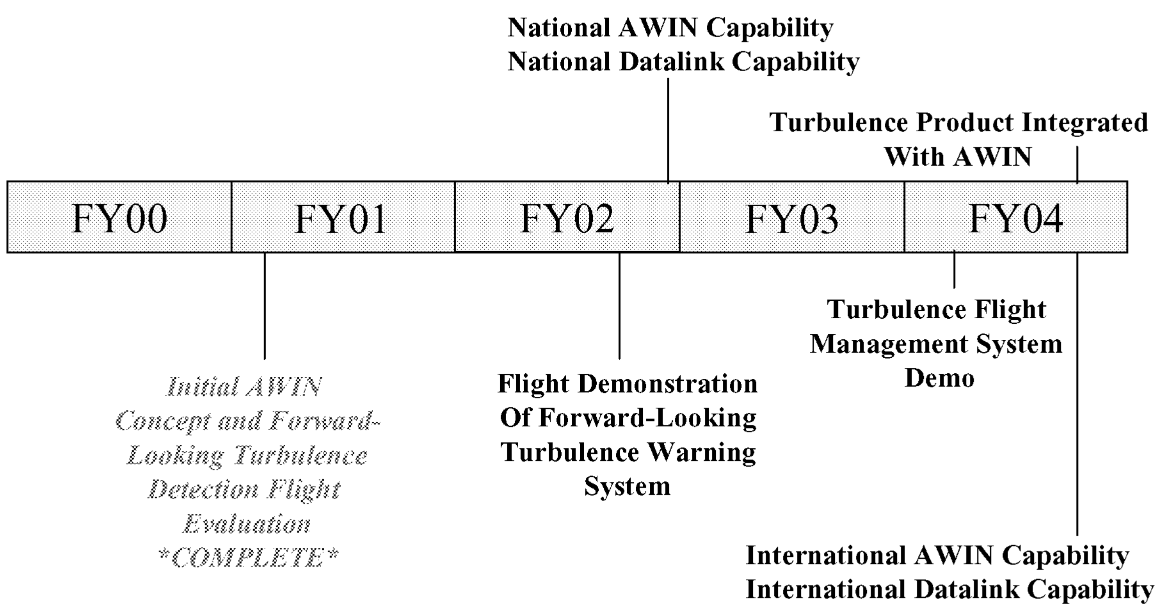
- **Provide the Flight Deck with Higher Fidelity, More Timely Intuitive Graphical Information**
- **Detect & Mitigate Weather Hazards**

Products

1. Cockpit weather display technologies and design guidelines and pilot decision support tools
2. Weather Information data link technologies, architecture, and design guidelines
3. Improved low-altitude Automet technologies and design guidelines
4. Turbulence hazard characterization
5. Forward-looking turbulence sensor technologies and system design guidelines
6. Turbulence mitigation procedure guidelines

Project Schedule and Milestones

Aviation Safety Program — Weather Accident Prevention



Product Development Strategy

Aviation Safety Program | Weather Accident Prevention

- Strong Industry cost sharing through Cooperative Research Agreements (CRA)
- Airline/operator participation in CRAs
- Cost/Market assessment studies funded
- FAA/NASA/NWS Working Groups being established
- Participation in Industry/Government working groups dealing with technology and standards development: RTCA, ICAO Joint Safety Assessment/Implementation Teams, etc.
- Strong National Turbulence Research Coalition assisting in defining NASA direction

Project Modifications

- Reasons for modifications
  - » *Resource limitations (funding, staff)*
  - » *Customer feedback and recommendations*

- Content of changes
  - » *Research area focus modifications*
  - » *WBS modifications*

- Research area focus modifications
  - » *Nowcasting/Forecasting technology development eliminated*
    - Feedback from joint Turbulence PDT and FAA meeting
    - FAA responsible for developing nowcasting/forecasting products
    - NASA responsible for investigating turbulence characteristics and defining hazard metrics
  - » *Turbulence Mitigation technology development refocused*
    - Flight System Controls development descoped to investigation of autopilot usage in turbulence encounters
    - Integration of turbulence warning information on the flight deck added

Project Modifications (concl.)

- Research area focus modifications (concl.)

  » *Specific technology development focus on commuter aircraft and rotorcraft eliminated*
  - Addresses the spectrum of users and key accident areas

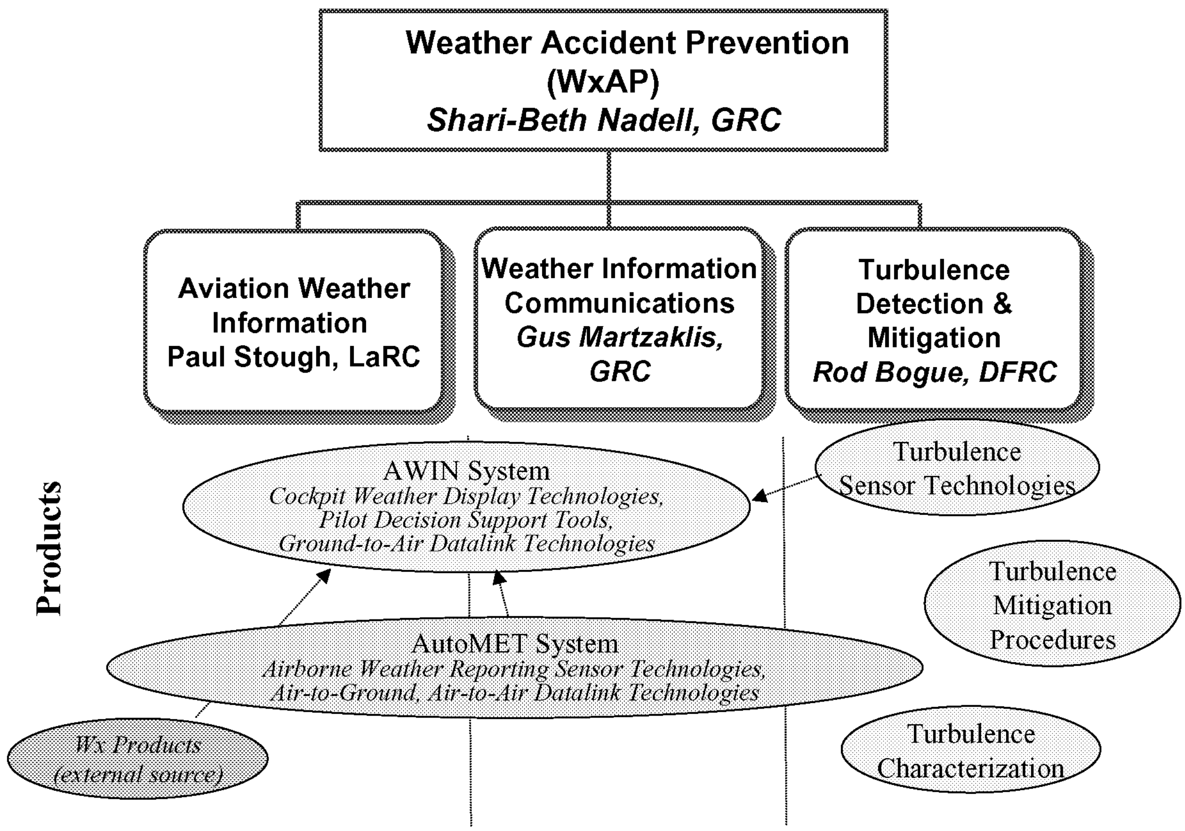
  » *Graphical weather presentation and usage research and technology development limited to cockpit systems*
  - FAA responsible for developing ATC and AOS products and technologies

  » *Research focus on AutoMET sensor and datalink technology development increased*
  - GA Wx JSIT Recommendation
  - National Aviation Wx Program Council feedback
  - FAA Wx requirements office input
  - WxAP Project Review feedback

  » *Research focus on Satellite Datalink Communications technology development increased*

Modified WxAP Products

Aviation Safety Program | Weather Accident Prevention

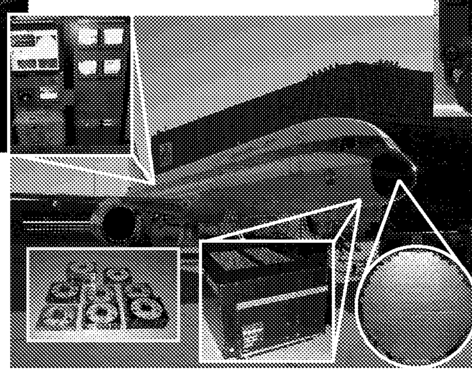


Project Accomplishments

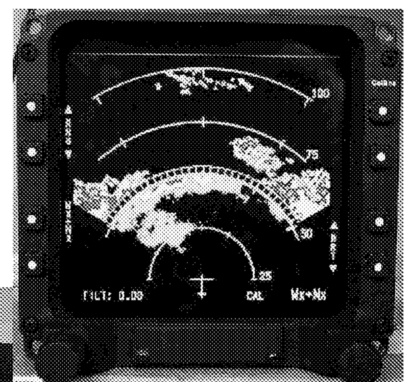
Aviation Safety Program — Weather Accident Prevention

- Completed Project Milestone #1: Initial AWIN and Forward-Looking Turbulence Detection Flight Evaluation
- Total of six flights between September and December 2000 (including two ferry flights to DFW)
- Four WxAP experiments were conducted:
  - In-Situ Turbulence Algorithm
  - Turbulence Radar
  - AWIN-Weather Information Network (WINN) System
  - Enhanced Weather Radar

WINN Display Mounted in the B757 Cockpit



Turbulence Radar Installation on B757

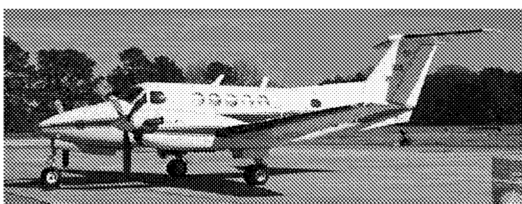


EWxR multifunction display with ship's weather radar data to 50 nmi and NEXRAD data beyond.

Project Accomplishments (cont.)

Aviation Safety Program — Weather Accident Prevention

- Successful completion of the first test subject data collection flight of the AWIN Convective Weather Sources (COWS) experiment on August 9, 2000
  - Experiment investigates how situation awareness and flight deck decision making is affected by access to different sources of weather information
  - Conditions investigated included: conventional audio information only, out-the-window visual cues plus conventional audio information, and a composite radar image (a tethered AWIN display) plus the conventional audio information



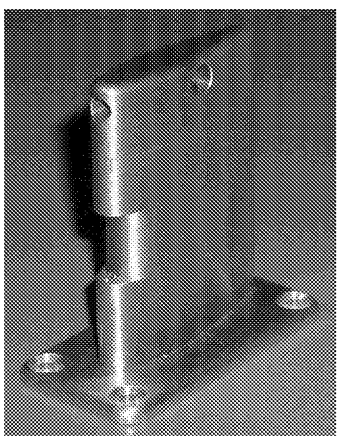
NASA BE-200 King Air

Honeywell AWIN Display in King Air Cockpit

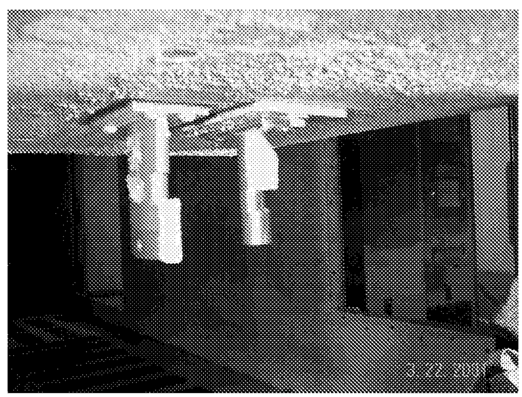
Project Accomplishments (cont.)

Aviation Safety Program — Weather Accident Prevention

- TAMDAR Sensor tested in NASA GRC Icing Research Tunnel, March 21-23
  - Preliminary results indicate the overall infrared sensing principle is sound and detected both glaze and rime ice
  - Probe de-icing method needs to be reworked with respect to heater size and placement and the software algorithm that tried to melt the ice or declare the sensor "contaminated"
  - Next-generation unit will have the temperature sensor better isolated thermally from the heater
  - TAMDAR sensor development task initiated with GTRI and ODS; kickoff meeting April 25



ODS TAMDAR sensor



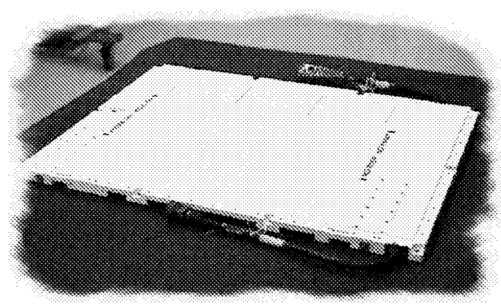
TAMDAR sensor (left), ODS Model 1000 Icing Sensor (right) in IRT

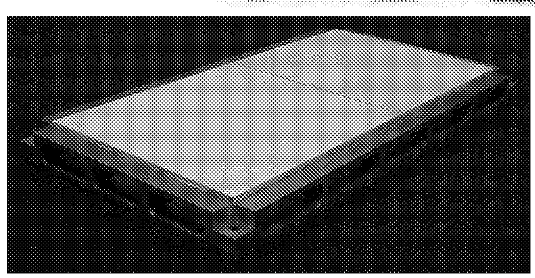
Project Accomplishments (cont.)

Aviation Safety Program | Weather Accident Prevention

- Continued to develop Broadband SATCOM Datalink
  - › Enabling technologies: phased array antennas, broadband mobile terminal
  - › Joint NASA/Boeing development
  - › Up to 1000x capacity increase
  - › Ground-mobile experiments
  - › Proof flight test Dec, 2000 (DC-8)
  - › Upcoming B-757 experiments
  - › Enabling to new *Connexion by Boeing* datalink service

NASA DC-8 Flight Test



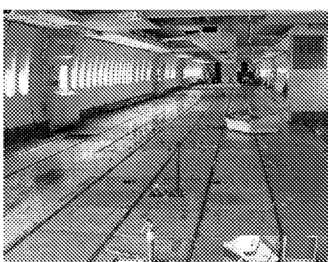


Ku-band Receive and Transmit
Phased Array Antennas

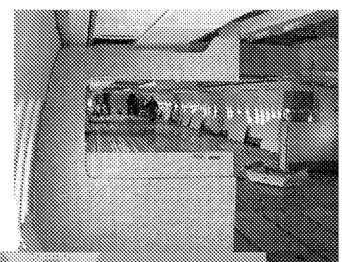
Project Accomplishments (concl.)

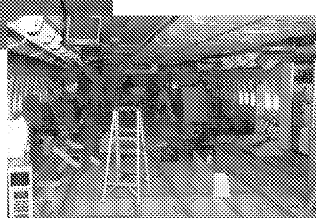
Aviation Safety Program — Weather Accident Prevention

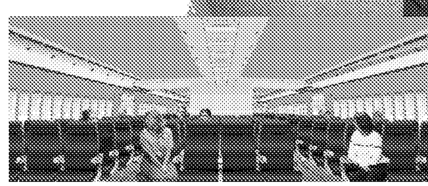
- Test development planning for Turbulence Secure Cabin Exercise
  - First implementation will use FAA CAMI B747 Cabin Evacuation simulator training facility
  - Secure Cabin Exercise team includes NASA, FAA, airlines, cabin attendants associations, etc.
  - Three cabin scenarios will be used to develop requirements for “securing” a cabin prior to a turbulence encounter
  - Will provide important input to the development of Airborne Turbulence Warning System requirements and procedural guidelines



FAA CAMI B747 Cabin Evacuation Simulator







Project's Next Steps

- Develop systems architecture and concept of operations for WxAP technology products.
- Revisit and redefine project milestones based on accomplishments over first two years of the program.
- Update NASA plans per stakeholder comments (i.e. THIS REVIEW), requirement studies, joint team recommendation etc.
- Continue to integrate and leverage activities with FAA, NWS and DoD.
- Continue to seek greater participation with aviation user community.

Aviation Safety Program

Weather Accident Prevention (WxAP) Development of WxAP System Architecture And Concepts of Operation

David Grantier, WxAP LII Systems Engineer
7800 Systems Engineering Division
NASA Glenn Research Center
Cleveland, OH

Outline

Aviation Safety Program - Weather Accident Prevention

- Background Information on System Architecture/CONOPS Activity
- Activity Work In Progress
- Anticipated By-Products

WxAP Project Evolution FY'01

- Prior Systems Engineering Activities
  - AvSP LI Product Notebooks
  - Bob Sutton, Pat Corcoran ARI, AvSP LI Systems Engineers
- Project philosophy/structure towards Product Based Development
  - Acceptance to modify Level II, III Milestones
  - Define, identify NASA WxAP Products
- Focus on WxAP technologies, not an optimized NASA WxAP System
  - AWIN, WINCOMM, TDAM
  - 2/7-8/01 GRC LII/LIII TIM

Task Origin

- 3/27/01 WxAP LIII Integration Meeting at LaRC

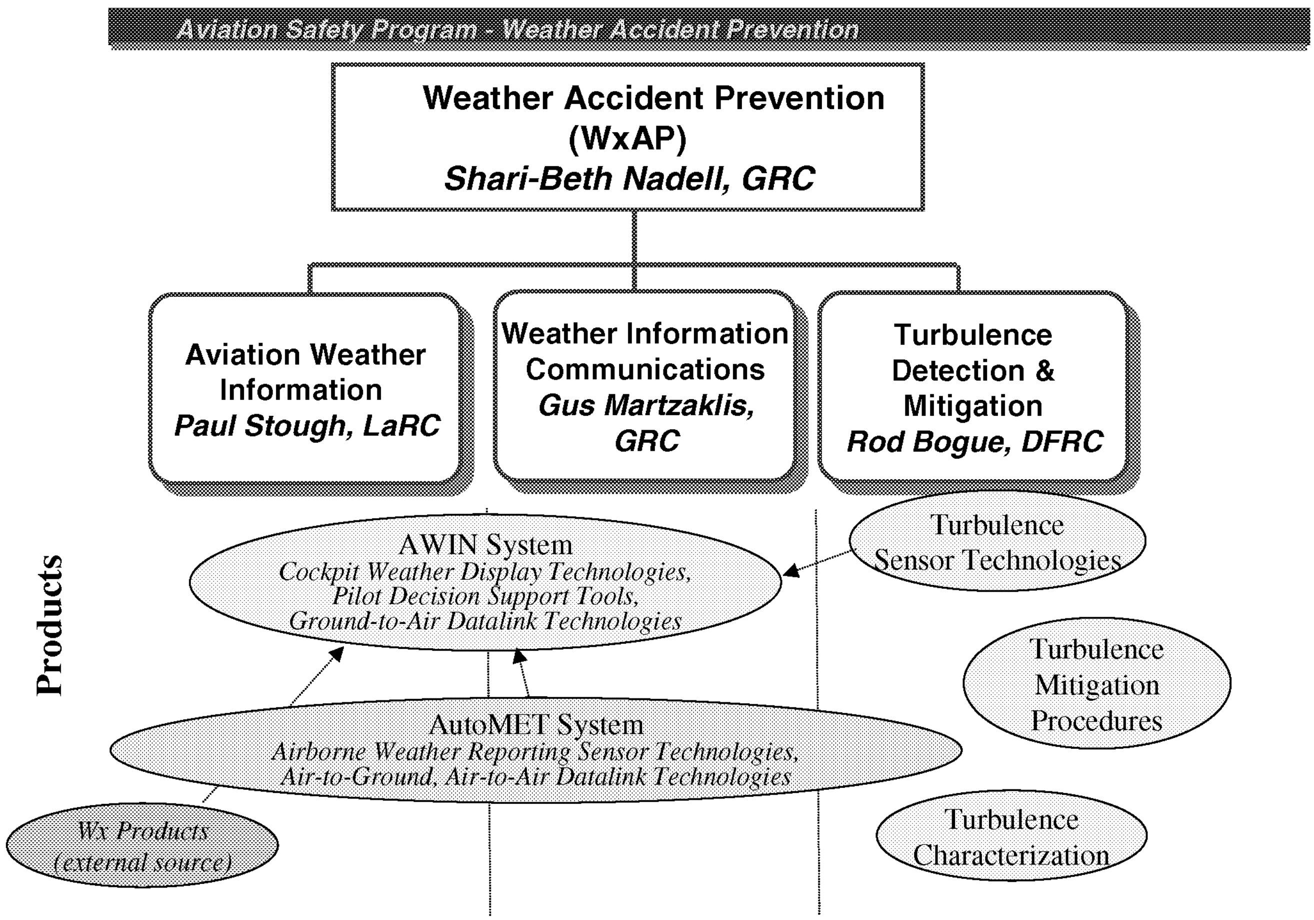
- Scope:
  - To create a NASA WxAP System Architecture and associated Concept of Operations Document.
  - Demonstrate a system implementation that includes AWIN, WINCOMM, and TDAM technologies for Commercial Transport and GA (where applicable).
  - Systems may not fully utilize the full scope of capabilities that are available from any one of the WxAP LIII elements.
  - System will be the WxAP Level II and Level III's vision of potential applications of these technologies.

Task Origin (cont.)

Aviation Safety Program - Weather Accident Prevention

- Justification:
  - To date, WxAP Level III development has been largely a bottoms-up effort with limited systems guidance from WxAP Level II due in large part to the maturity level of the LIII technologies.
  - The Level III Elements are moving into a more critical period of technology development and demonstration and the need for a WxAP System Architecture is evident.
  - The products of this activity will allow the WxAP Level III elements to refine their development activities and to accommodate WxAP system level requirements in their technologies.
  - Anticipated by-products of this activity include WxAP ’02 (and ’04) Flight Requirements.

Modified WxAP Products



Architecture Task Goal:
Map WxAP Products on System Architecture

WxAP Proposed Products:

- Cockpit Weather Display Technologies and Pilot Decision Support Tools
- Airborne Weather Reporting Sensor Technologies
- Weather Information Datalink Systems Technologies for Ground-to-Air Dissemination
- Weather Information Datalink Technologies for Air-to-Ground and Air-to-Air Dissemination
- Turbulence Characterization Technologies
- Forward-looking Turbulence Sensor Technologies
- Turbulence Mitigation Procedures

Aviation Safety Program - Weather Accident Prevention

5/10-11/01 WxAP LII/LIII SE Meeting at LaRC

Attendees:

Dave Grantier/GRC	WxAP LII SE
Dwayne Kiefer/GRC/QSS	WxAP LII SE
John Bowen/GRC/ZIN	WxAP LII SE
Ed Johnson/LaRC	AWIN LIII SE
Tom Tanger/GRC/CMST	WINCOMM SE
Dale Force/GRC	WINCOMM SE
Jim Watson/LaRC	TDAM SE (acting)
Pat Corcoran/ARI	AvSP LI SE

Meeting Summary:

The objective of this meeting was to familiarize each of the WxAP, AWIN, WINCOMM and TDAM personnel with each other, and to uncover the basic composition of each element. The meeting consisted of the WxAP LII System Engineers presenting their understanding gleaned from the available Level III documentation. The presentations were then supplemented and where necessary, corrected by the Level III System Engineers. The overall result of the meeting laid the informational and personal groundwork for future collaborations within the groups, and a starting point for the genesis of a NASA WxAP System Architecture.

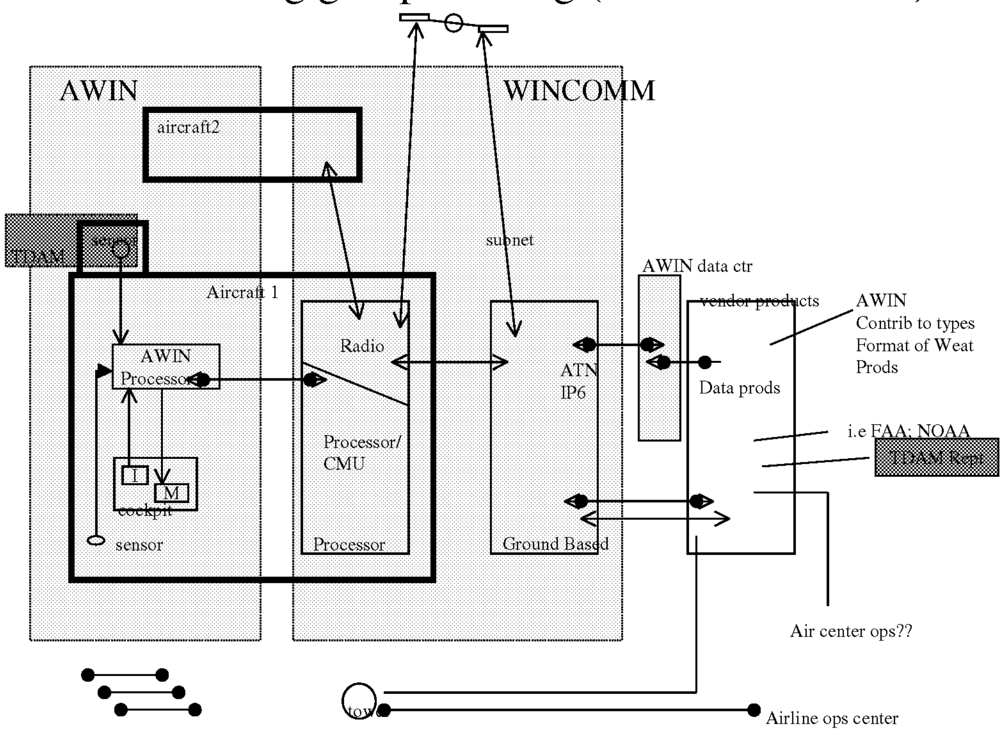
NASA WxAP CONOPS Issues Currently Identified

(5/11-12/01 WxAP SE TIM at LaRC)

- NASA WxAP Implementation Time Phasing
  - ✓ Past, Present, 2007, beyond 2007
- NASA WxAP Flight Phase
  - ✓ Preflight, Take-off, Enroute, Landing, Postflight
- Aircraft Classifications
  - ✓ GA, Transport, Other?
- Communications Protocols
  - ✓ VDL-2,3, UAT, Mode S, SatCom
- Aircraft Hardware
  - ✓ Radio, Processors, Sensors, Cockpit Displays
- Aircraft Services
  - ✓ Other AvSP technologies, other Wx information on plane
- Ground Communications Network
  - ✓ IP-6, ATN

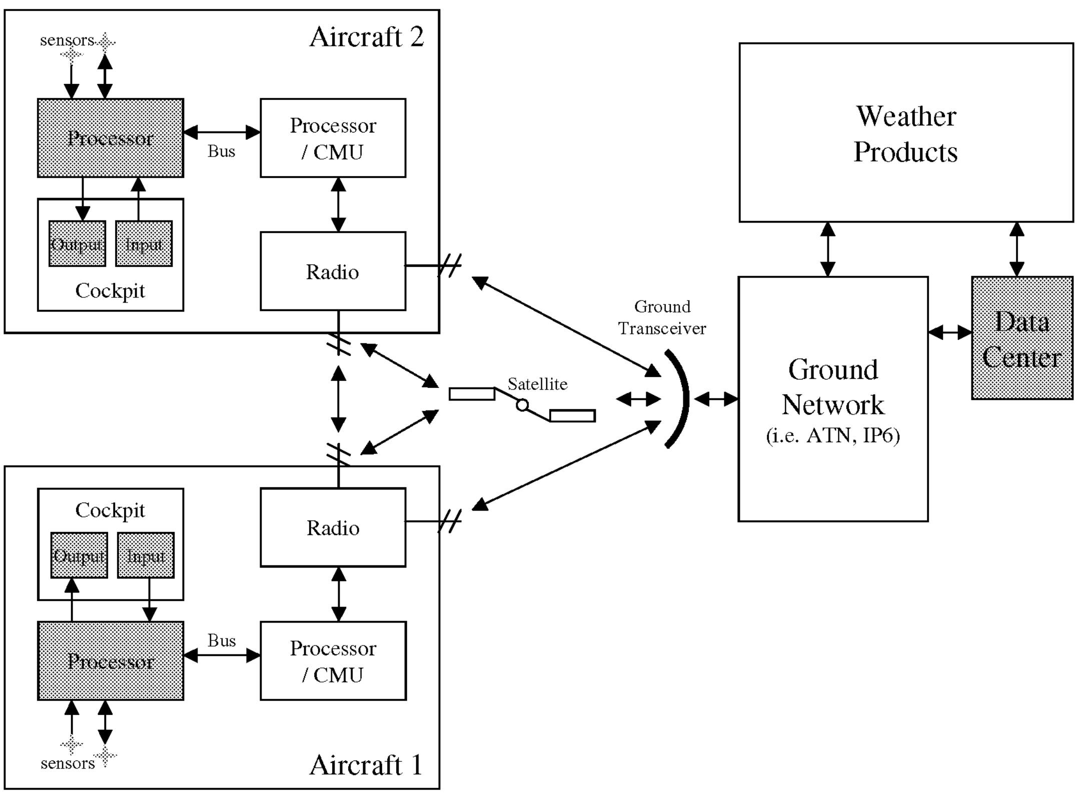
Aviation Safety Program - Weather Accident Prevention

Examples of WxAP System Architecture sketches from WxAP SE working group meeting (5/11-12/01 LaRC)



Example WxAP Architecture Sketch

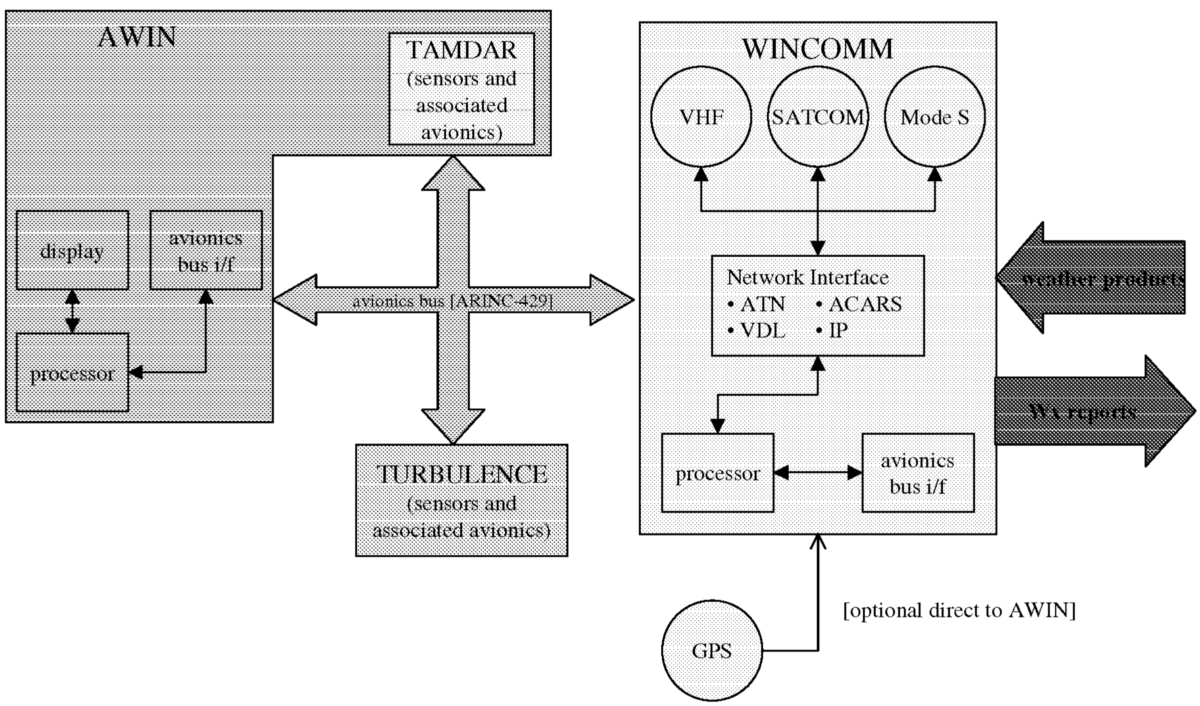
Aviation Safety Program - Weather Accident Prevention



Example WxAP Architecture Sketch

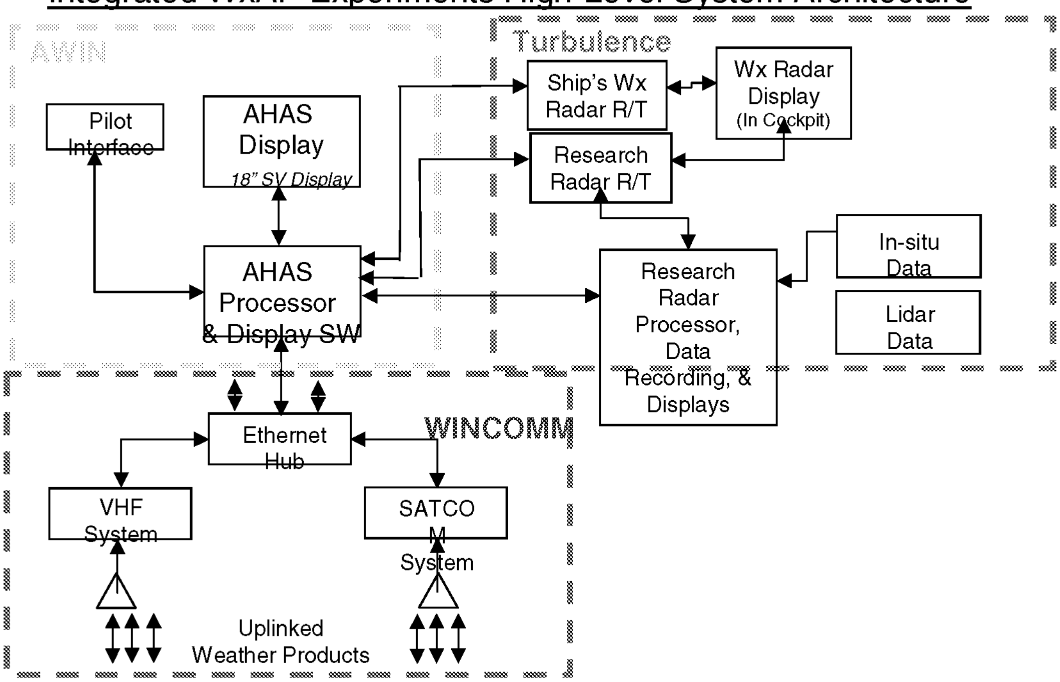
Aviation Safety Program - Weather Accident Prevention

Revised Architecture



Example of WxAP initial System Architecture from FY'01 B-757 ARIES Flight Test Requirements Document (S. Rickard/LaRC)

Integrated WxAP Experiments High-Level System Architecture



Aviation Safety Program - Weather Accident Prevention

NASA WxAP Elementary CONOPS

<u>The "Building Blocks" of a WxAP CONOPS</u>:

✓ Data is Transferred to Aircraft

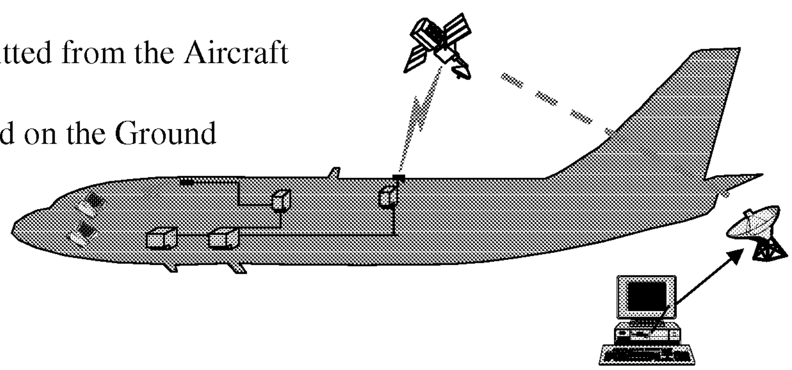
✓ Data is Received by the Aircraft

✓ Data is Displayed to the Pilot

✓ Data is Collected on the Aircraft

✓ Data is Transmitted from the Aircraft

✓ Data is Received on the Ground



Aviation Safety Program - Weather Accident Prevention

Anticipated By-Products of Architecture/CONOPS Activity

- WxAP LII Requirements Document
- Formulation of WxAP FY'02 and '04 Flight Requirements
- More efficient evaluation of potential WxAP integration with other AvSP LII projects
- More efficient participation in AvSP LI Systems Engineering activities
- WxAP LII and LIII Project Management tool

NASA/CP—2002-210964

Aviation Weather Information Overview and Status

Weather Accident Prevention Project Review

Cleveland, Ohio

June 5 to 7, 2001

Paul Stough
Crew/Vehicle Integration Branch
NASA Langley Research Center
Hampton, VA 23681-2199
(757) 864-3860
E-mail: h.p.stough@larc.nasa.gov

Outline

Aviation Weather Information

- Background
- Research Areas
- Progress since last year

Background

Aviation Weather Information

- Weather is a major contributing factor in accidents:
  - 33% Commercial carrier
  - 27% General aviation

- Many accidents are due to lack of weather situation awareness and poor decisions.

- Provision of strategic weather information during the en route phase enables avoidance of adverse conditions.

Guidance

Aviation Weather Information

- **NASA Aviation Safety Program**
  - Aviation Safety Investment Strategy Team
  - Executive Council
- **National Aviation Weather Program Council**
  - National Aviation Weather Program Strategic Plan
  - National Aviation Weather Initiatives
- **FAA Safer Skies: Focused Safety Agenda**
  - Weather Joint Safety Analysis Teams
  - Weather Joint Safety Implementation Teams
- **FAA Aviation Weather Research Program**
- **Friends of Aviation Weather**
- **WxAP Project Review**

Plan

Aviation Weather Information

Goal

Develop technologies and methods for providing pilots with accurate, timely and intuitive information during the en route phases of flight which, if implemented, will enable a 25 to 50% reduction in aircraft accidents attributable to weather situation awareness

Objectives

- Develop Needed Weather Products and Sensing Capabilities
- Develop Enhanced Weather Presentations and Decision Aids

Challenges

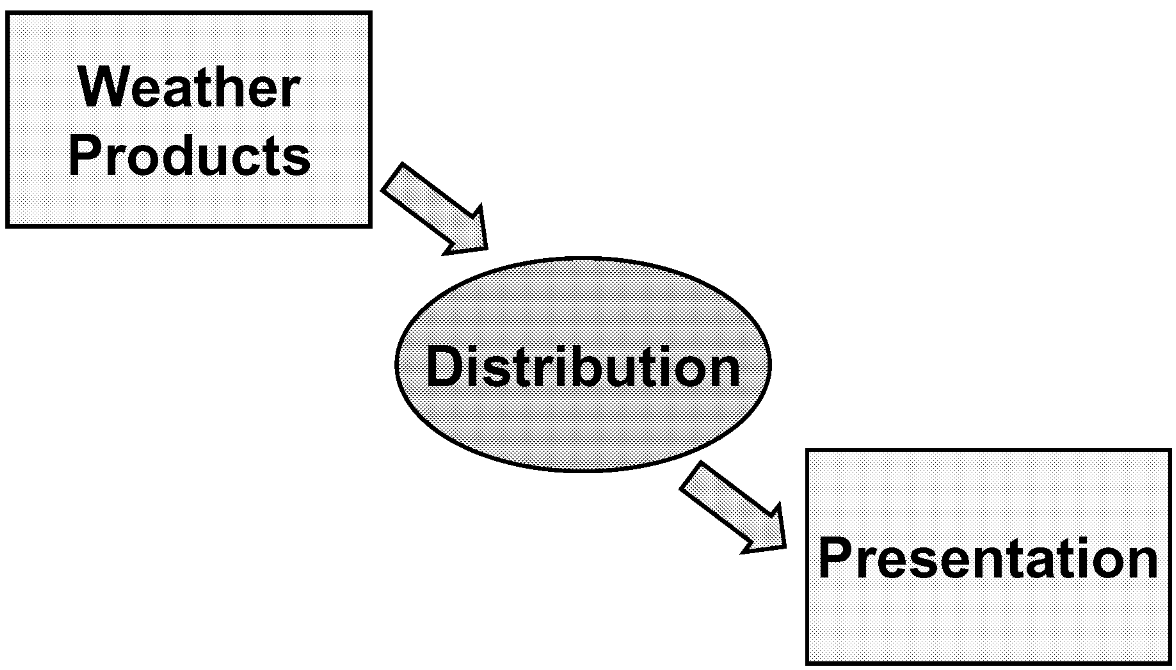
- Improved Forecasts Need Better Input Data
- Existing Aircraft Need Retrofit Capability
- Pilot Workload Should Not Be Increased
- Diverse Aviation User Groups

Approach

- Use Aircraft as Airborne Weather Data Collectors
- Develop Multi-Purpose Sensor Systems
- Develop Installed and Portable Systems
- Provide Decision Aids

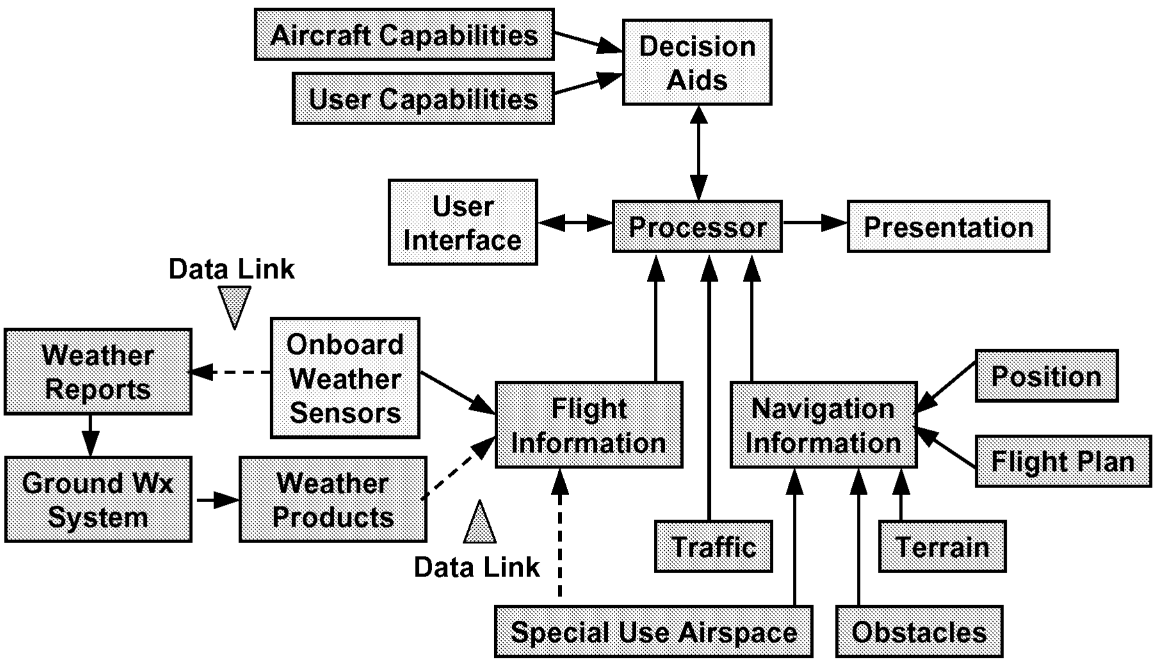
System Elements

Aviation Weather Information



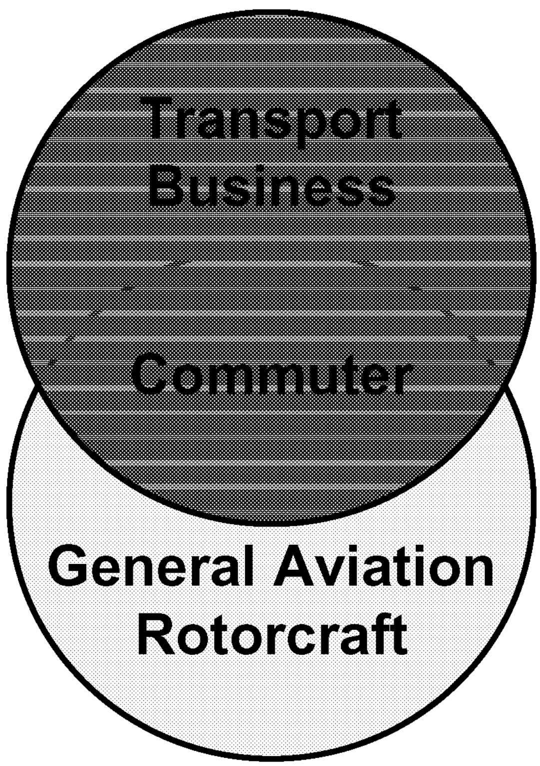
AWIN System

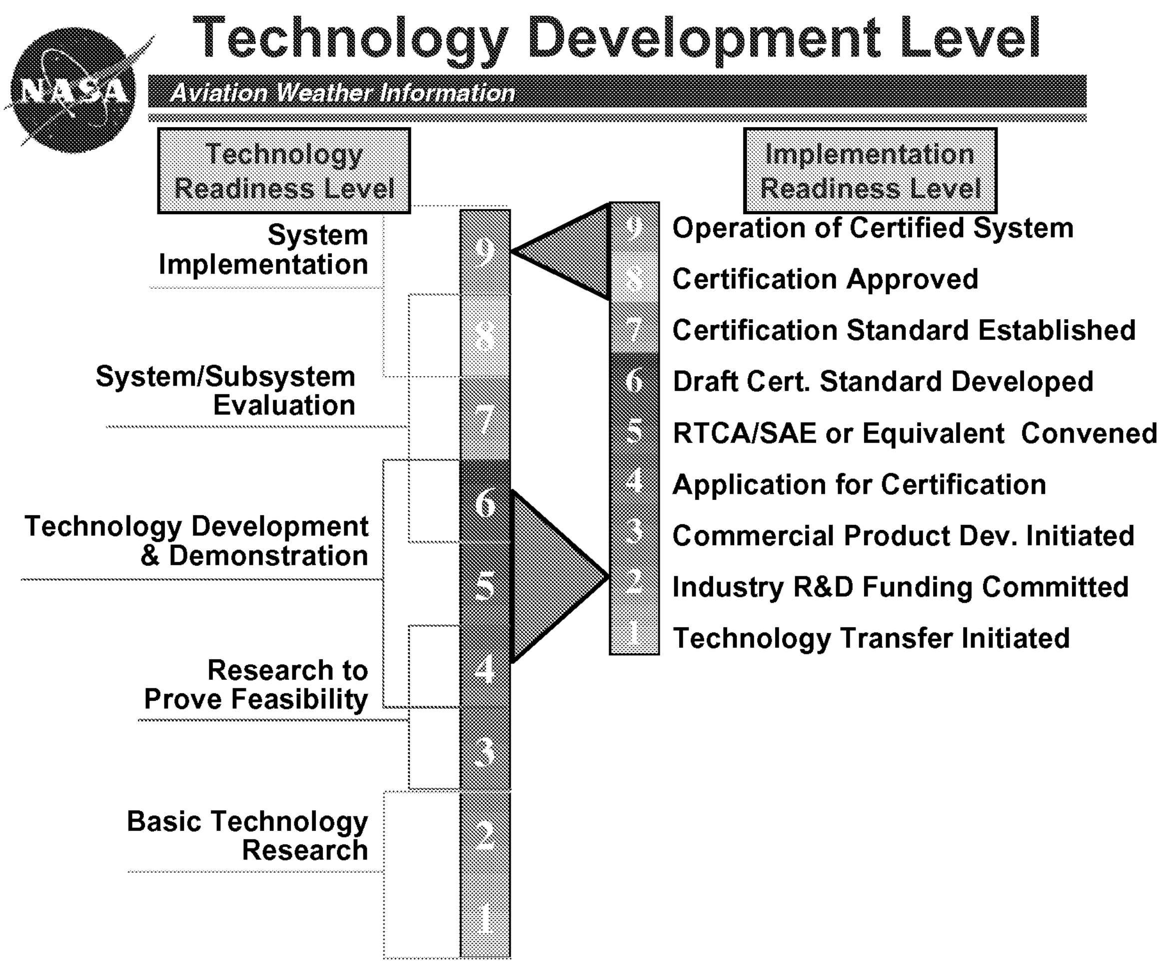
Aviation Weather Information



Market Segments

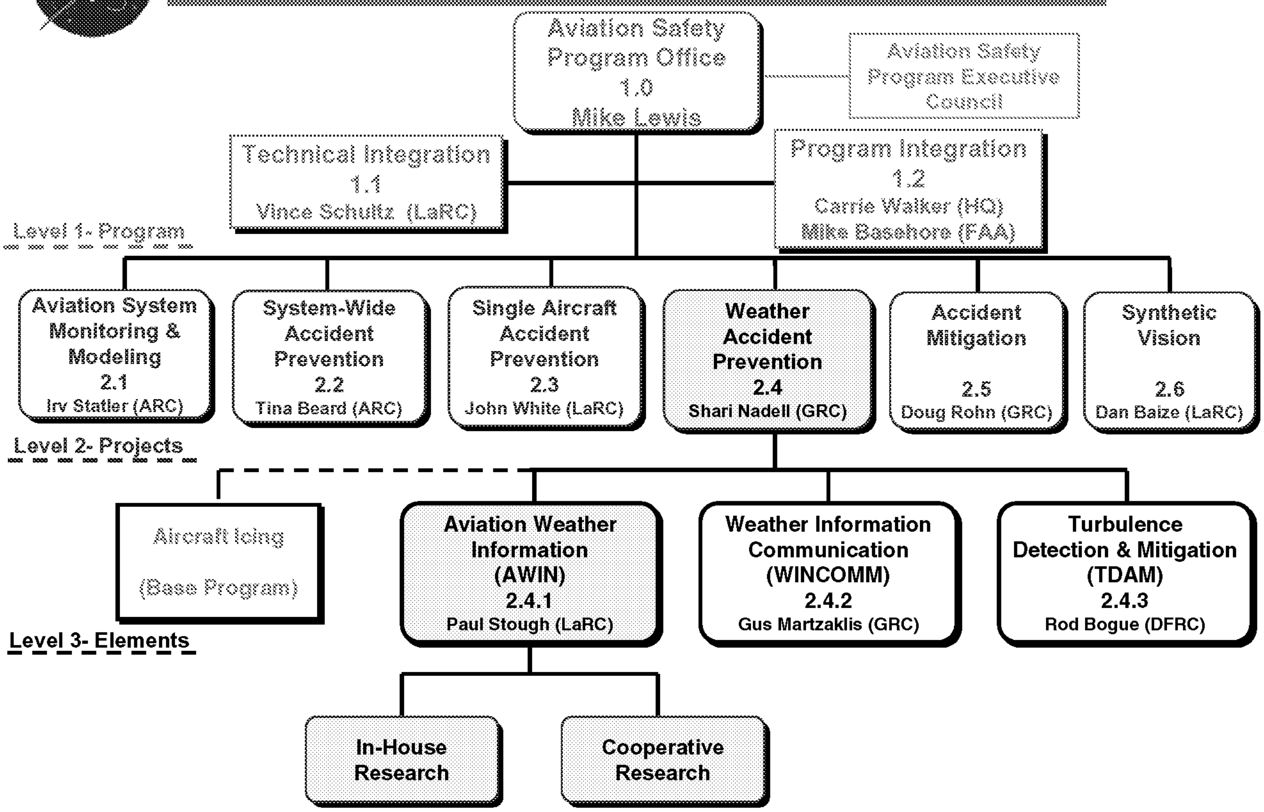
Aviation Weather Information




Technology Development Level
NASA
Aviation Weather Information
Technology Readiness Level
Implementation Readiness Level
System Implementation
System/Subsystem Evaluation
Technology Development & Demonstration
Research to Prove Feasibility
Basic Technology Research
9
8
7
6
5
4
3
2
1
9 Operation of Certified System
8 Certification Approved
7 Certification Standard Established
6 Draft Cert. Standard Developed
5 RTCA/SAE or Equivalent Convened
4 Application for Certification
3 Commercial Product Dev. Initiated
2 Industry R&D Funding Committed
1 Technology Transfer Initiated

Aviation Safety Program Organization

Aviation Weather Information



NASA Research Team

Aviation Weather Information

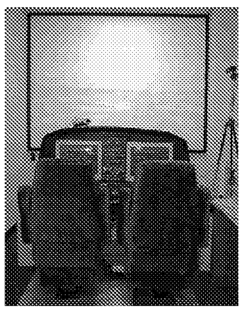
- **Dr. Jennifer Burt** (757) 864-8304
  Human Factors/Presentation
- **Mr. Jim Chamberlain** (757) 864-2147
  Flight Experiments
- **Mr. Taumi Daniels** (757) 864-4659
  Airborne Weather Sensing
- **Mr. Walt Green** (757) 864-3355
  Systems Engineering
- **Dr. Ed Johnson** (757) 864-7602
  Systems Engineering
- **Mr. Ken Jones** (757) 864-5013
  Flight Experiments
- **Dr. Jon Jonsson** (757) 864-2001
  Human Factors/Presentation
- **Dr. Kara Latorella** (757) 864-2030
  Human Factors/Decision Aiding
- **Dr. Ray McAdaragh** (757) 864-1941
  Human Factors/Presentation
- **Mr. John Murray** (757) 864-5883
  Meteorology
- **Dr. Robert Neece** (757) 864-1827
  Enhanced Weather Radar
- **Mr. Phil Schaffner** (757) 864-1809
  Airborne Hazard Processor

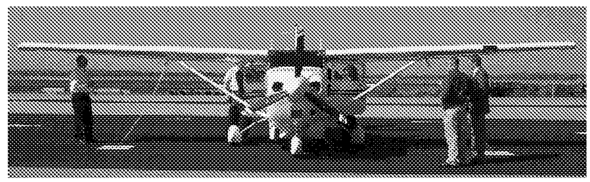
Mr. Paul Stough (757) 864-3860
Project Management

NASA Facilities

Aviation Weather Information

General Aviation Work Station

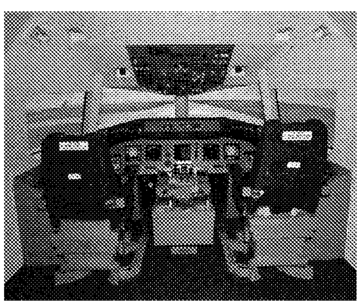




NASA C-206

NASA BE-200

Transport Research Flight Deck



NASA B-757

Partnerships

Aviation Weather Information

Flight Standards
Certification
Weather Policy
Weather Products
Flight Information Services

Aviation Weather Center
Forecast Systems Lab

[redacted] Honeywell Rockwell Collins

[redacted]

Cooperative Research Agreements

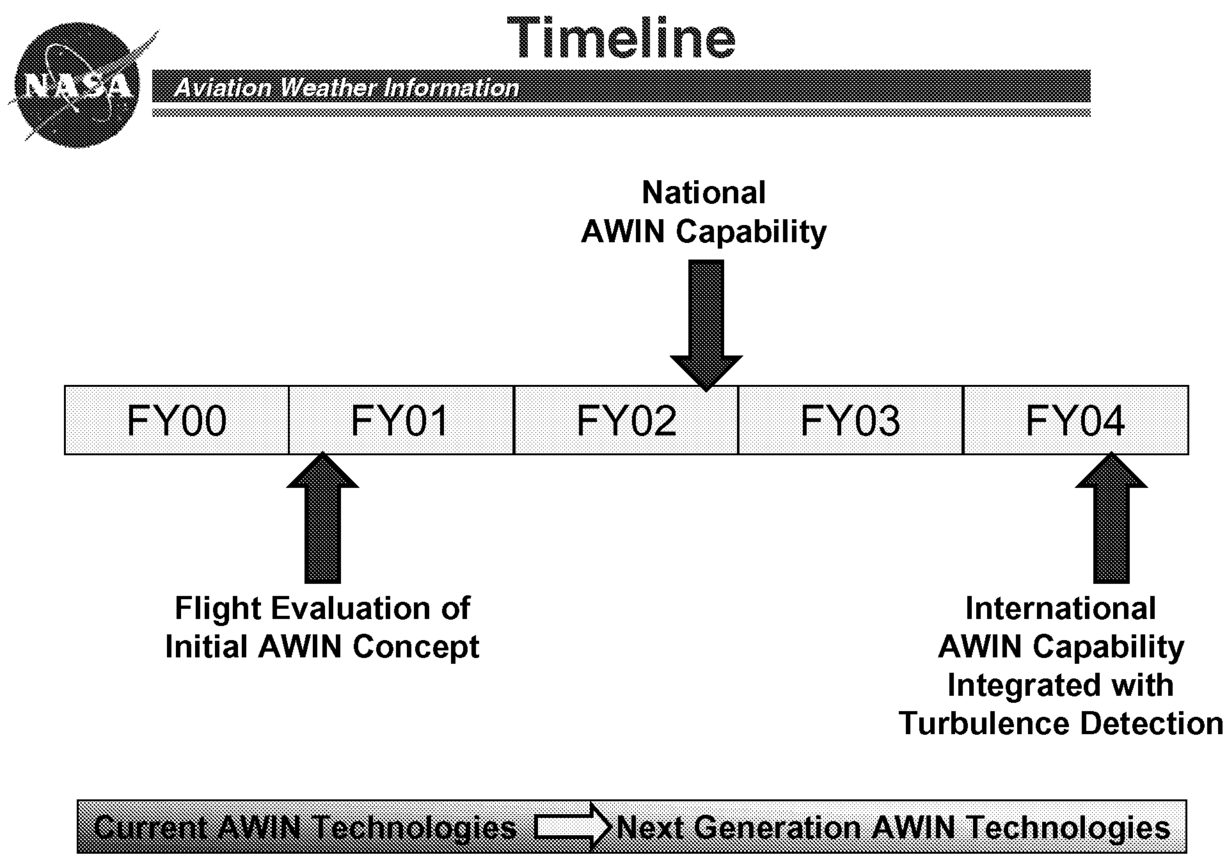
Georgia Tech Research Institute

Research Triangle Institute RTI

Old Dominion University

VirginiaTech

Academia


Timeline
NASA
Aviation Weather Information
National
AWIN Capability
FY00
FY01
FY02
FY03
FY04
Flight Evaluation of
Initial AWIN Concept
International
AWIN Capability
Integrated with
Turbulence Detection
Current AWIN Technologies
Next Generation AWIN Technologies

AWIN Research Areas

Aviation Weather Information

- Enhanced Weather Radar
- Airborne Weather Reporting
- Airborne Hazard Awareness System
- Display Guidelines
- Decision Aids
- Automatic Speech Recognition
- Cooperative Research Agreements

Cooperative Research with FAA

Aviation Weather Information

- **Human factors researcher assigned to the AWIN Team**
- **Joint funding of research**
- **Data-link Weather Information Systems Enhancements**
  - Investigate effects of data-linked in-flight weather displays on pilot decision making and flight operations
  - Investigate the benefits and limitations of using cockpit presentations of time-delayed data-linked weather information with real-time airborne weather radar for Part 121 operations
  - Investigate feasibility of using cockpit access to data-linked weather information in place of in-situ destination weather reporting for Part 135 operations
  - Define the cost considerations and incentives for aircraft owners to equip their aircraft and provide airborne weather reporting as part of a national implementation

Cooperative Research

Aviation Weather Information

- **Worldwide Transport Weather Information Systems**
  - Honeywell Weather Information Network (WINN)

- **Nationwide General Aviation Weather Information Systems**
  - ARNAV
  - Honeywell

- **Elements of Weather Information Systems**
  - Honeywell — Weather Avoidance Using Route Optimization as a Decision Aid
  - Rockwell — Aviation Weather Awareness and Reporting Enhancements (AWARE)
  - Rockwell — Enhanced On-Board Weather Radar (EWxR)
  - Rockwell — Airborne Hazard Awareness System (AHAS)
  - NCAR — Oceanic Convective Nowcasting Demonstration (OCND)
  - NRL — Ceiling and Visibility Forecasting Improvements

Honeywell Weather Information Network

Aviation Weather Information

Technology Development

Honeywell Citation Jet
Honeywell simulator
UAL B-777 simulator
NASA B-757

Avionitek display in NASA B-757

Electronic Flight Bag in UAL Airbus

In-Service Evaluation

United Airlines Spring 2001

Weather Information Communications (WINCOMM) Overview and Status

Weather Accident Prevention

2nd Annual Project Review

June 5-7, 2001

Cleveland, OH

K. (Gus) Martzaklis
NASA Glenn Research Center
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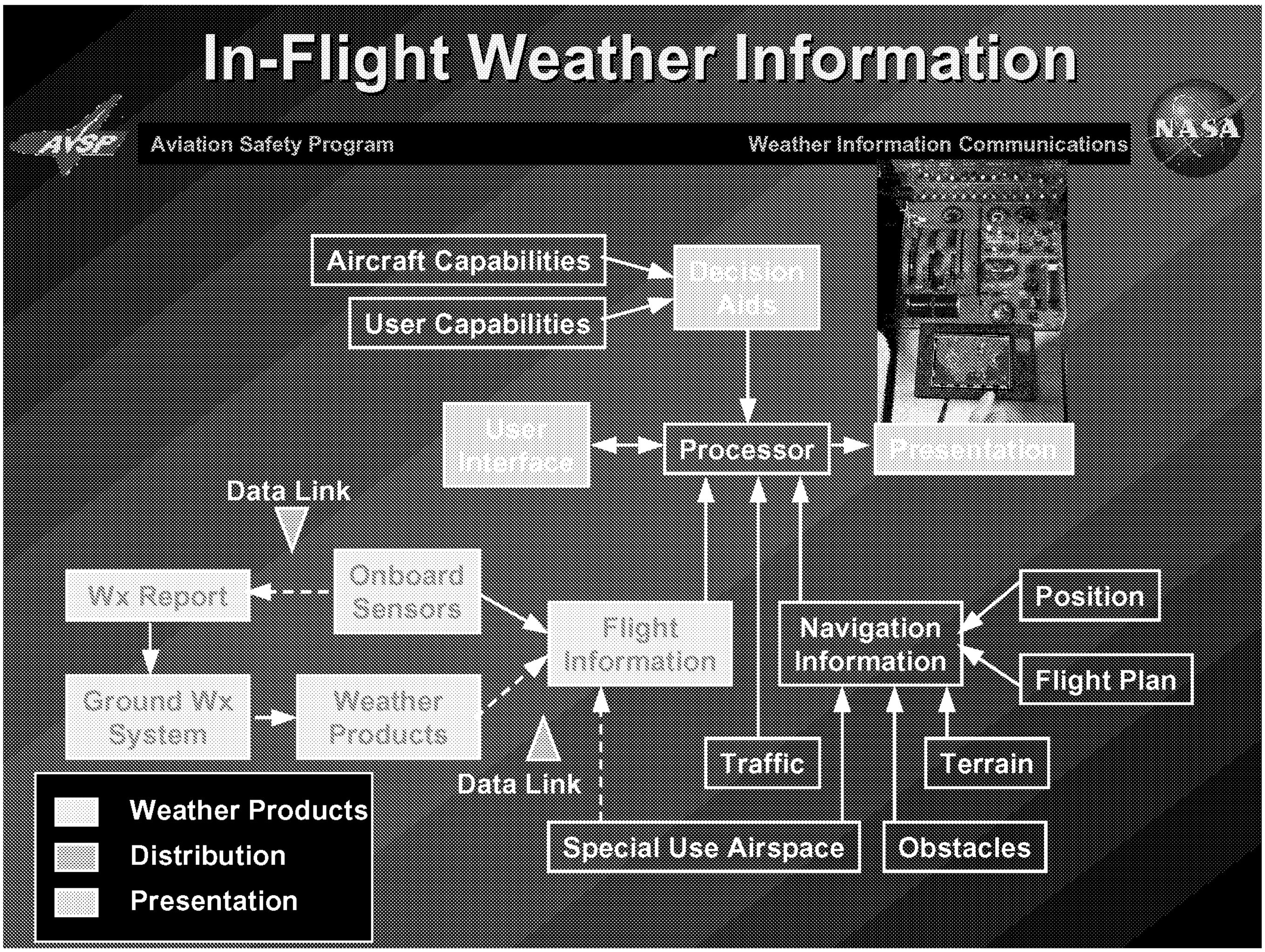
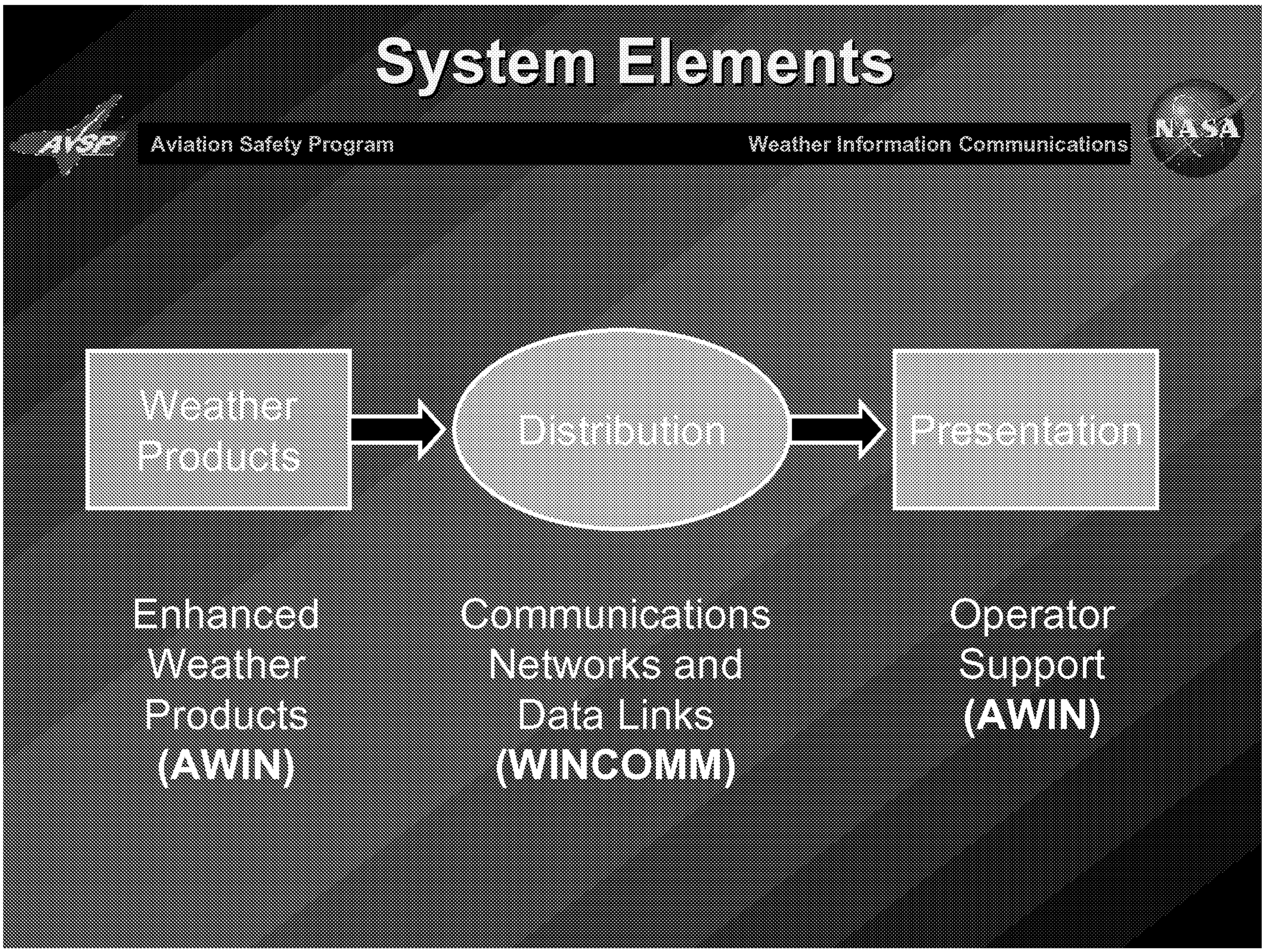

In-Flight Weather Information
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Aircraft Capabilities
User Capabilities
Decision Aids
User Interface
Processor
Presentation
Data Link
Wx Report
Onboard Sensors
Flight Information
Navigation Information
Position
Flight Plan
Ground Wx System
Weather Products
Data Link
Traffic
Terrain
Special Use Airspace
Obstacles
Weather Products
Distribution
Presentation

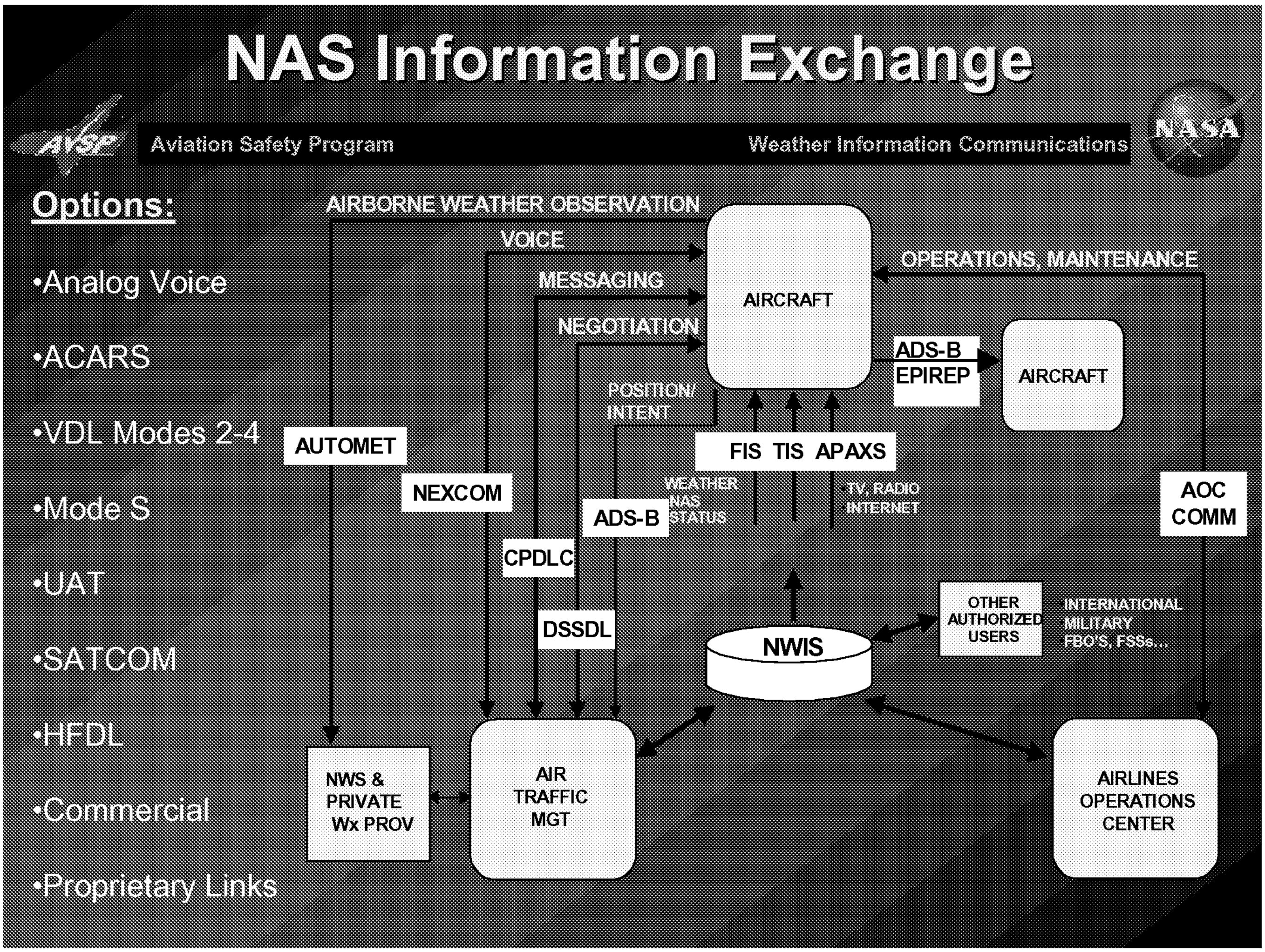

System Elements
AvSP
Aviation Safety Program
Weather Information Communications
NASA
Weather Products
Distribution
Presentation
Enhanced Weather Products (AWIN)
Communications Networks and Data Links (WINCOMM)
Operator Support (AWIN)

Technology Investment Areas

Aviation Safety Program — Weather Information Communications

- Datalink Requirements & Architecture Analyses:
  - Mid-Term (2010)
  - Far-Term (>2020)
- Air/Ground Datalinks
  - Ground-based (terrestrial)
  - Satellite-based
  - Airborne-based
- Network Technologies
  - Aeronautical Telecommunications Network (ATN)
  - Internet Protocol (IP)

(Focus: Commercial Air Transport and General Aviation)

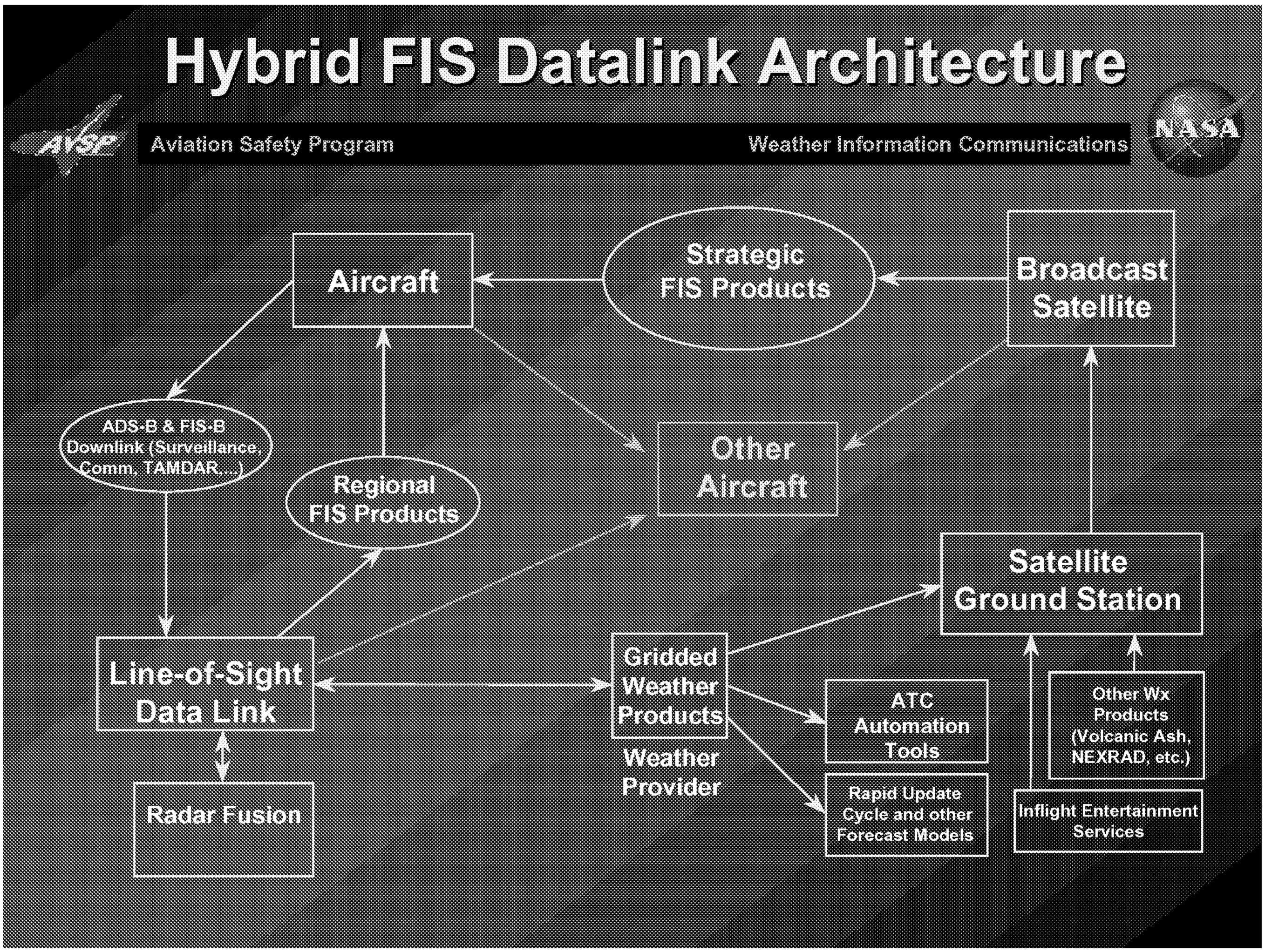

NAS Information Exchange
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Options:
•Analog Voice
•ACARS
•VDL Modes 2-4
•Mode S
•UAT
•SATCOM
•HFDL
•Commercial
•Proprietary Links
AIRBORNE WEATHER OBSERVATION
VOICE
MESSAGING
NEGOTIATION
POSITION/ INTENT
AIRCRAFT
OPERATIONS, MAINTENANCE
ADS-B EPIREP
AIRCRAFT
FIS TIS APAXS
WEATHER NAS STATUS
TV, RADIO INTERNET
AUTOMET
NEXCOM
ADS-B
CPDLC
DSSDL
AOC COMM
NWIS
OTHER AUTHORIZED USERS
INTERNATIONAL MILITARY FBO'S, FSSs…
NWS & PRIVATE Wx PROV
AIR TRAFFIC MGT
AIRLINES OPERATIONS CENTER

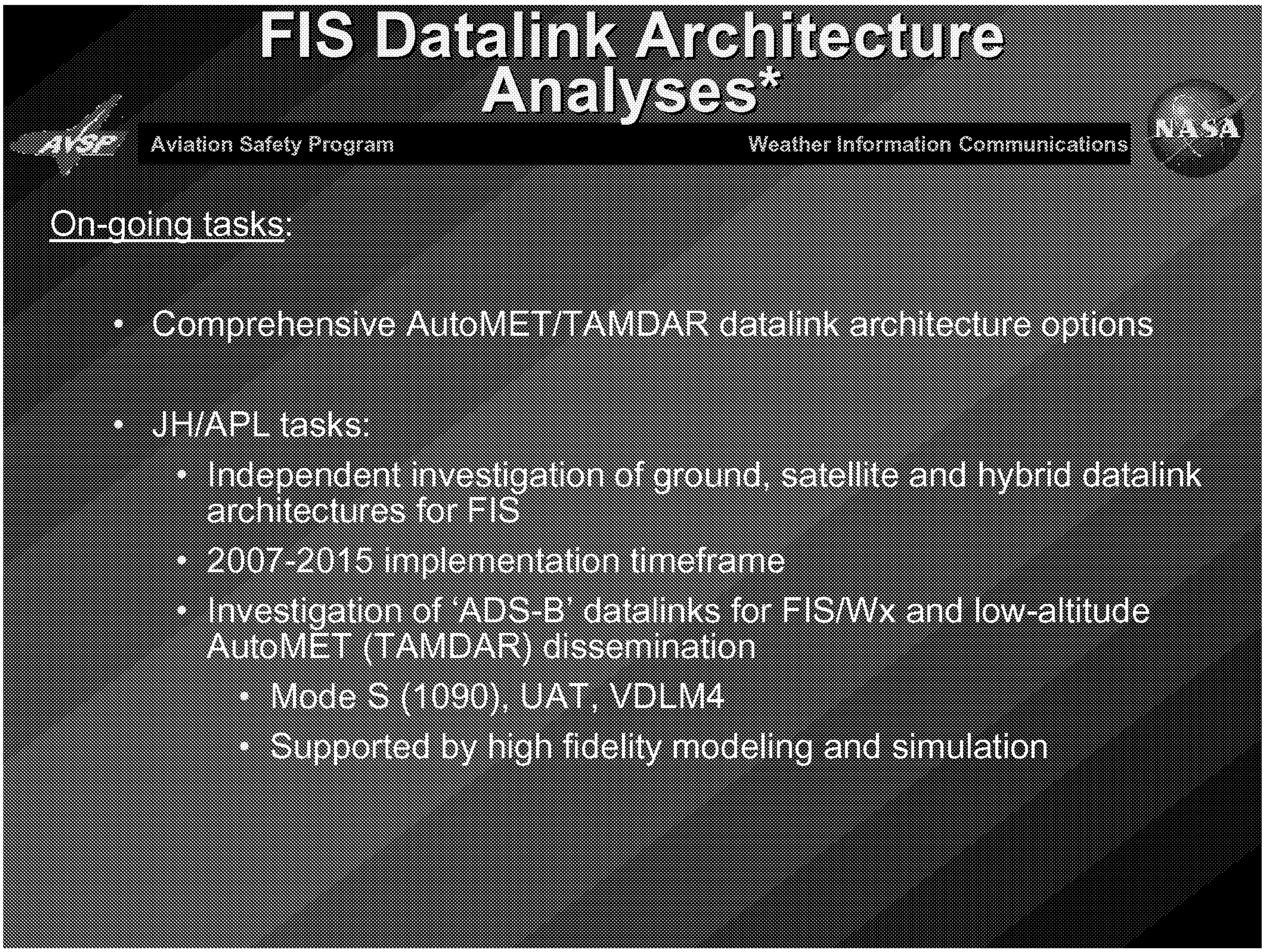
FIS Datalink Architecture Analyses*

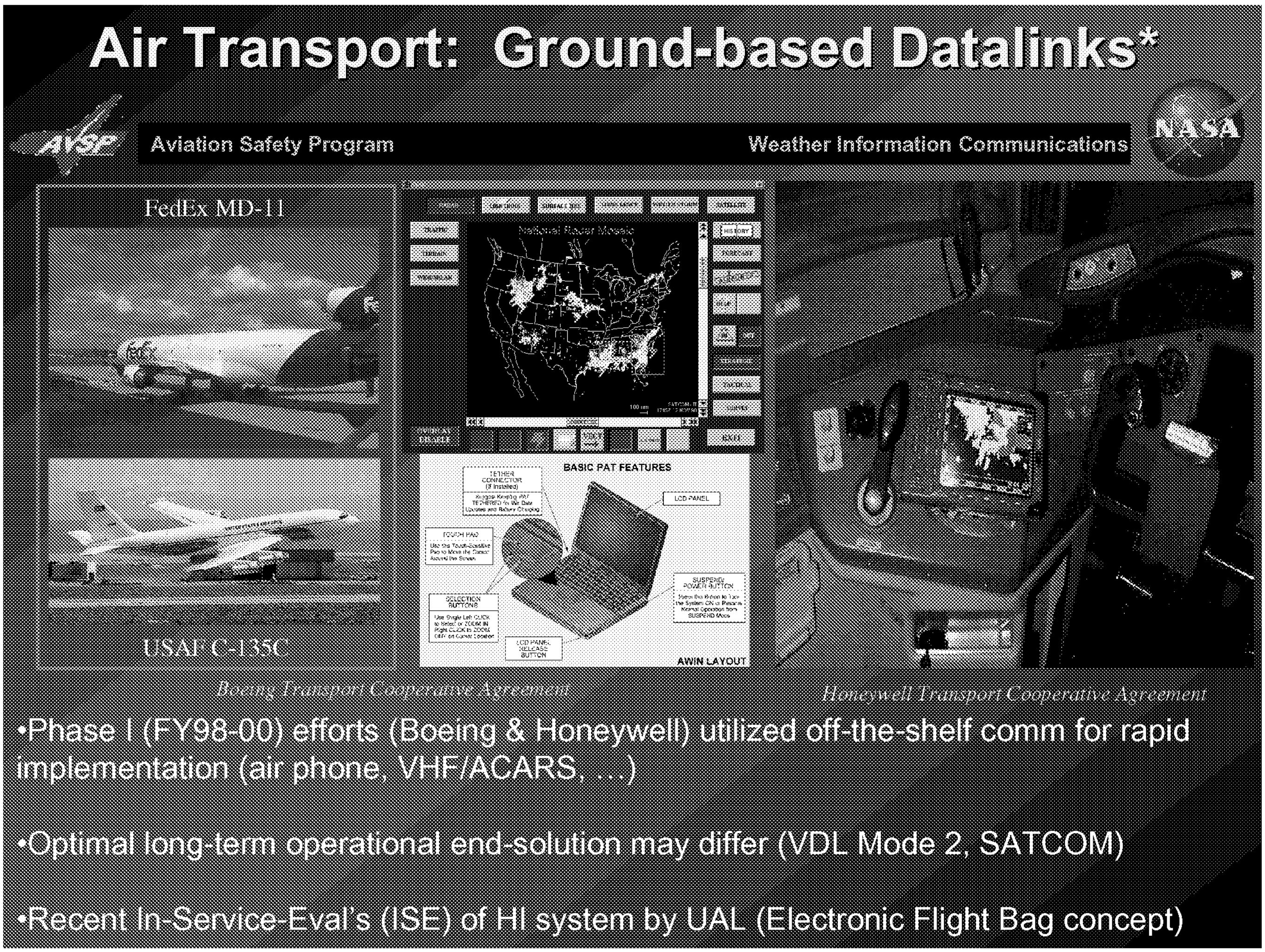
Aviation Safety Program — Weather Information Communications

Key results to date:

- SAIC, ARINC, TRW, Crown Communications Weather Datalink Architecture Study (May, 2000) and in-house analyses:
  - Broadcast is preferable to addressed 2-way for FIS (Weather)
  - VHF-Broadcast can support regional FIS data, however challenge to meet national implementation goals (coverage/interference)
  - Need broadband solution which could support regional/national goals (SATCOM and/or line-of-sight)
  - Hybrid broadcast solution, optimal:
    - Ground-based narrowband for local/regional FIS
    - SATCOM for national/strategic


Hybrid FIS Datalink Architecture
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Aircraft
Strategic FIS Products
Broadcast Satellite
ADS-B & FIS-B Downlink (Surveillance, Comm, TAMDAR,...)
Regional FIS Products
Other Aircraft
Satellite Ground Station
Line-of-Sight Data Link
Gridded Weather Products
Weather Provider
ATC Automation Tools
Other Wx Products (Volcanic Ash, NEXRAD, etc.)
Radar Fusion
Rapid Update Cycle and other Forecast Models
Inflight Entertainment Services


FIS Datalink Architecture Analyses*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
On-going tasks:
• Comprehensive AutoMET/TAMDAR datalink architecture options
• JH/APL tasks:
• Independent investigation of ground, satellite and hybrid datalink architectures for FIS
• 2007-2015 implementation timeframe
• Investigation of 'ADS-B' datalinks for FIS/Wx and low-altitude AutoMET (TAMDAR) dissemination
• Mode S (1090), UAT, VDLM4
• Supported by high fidelity modeling and simulation



Air Transport: Ground-based Datalinks*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
FedEx MD-11
USAF C-135C
National Radar Mosaic
BASIC PAT FEATURES
LCD PANEL
AWIN LAYOUT
Boeing Transport Cooperative Agreement
Honeywell Transport Cooperative Agreement
•Phase I (FY98-00) efforts (Boeing & Honeywell) utilized off-the-shelf comm for rapid implementation (air phone, VHF/ACARS, …)
•Optimal long-term operational end-solution may differ (VDL Mode 2, SATCOM)
•Recent In-Service-Eval's (ISE) of HI system by UAL (Electronic Flight Bag concept)

Air Transport: Ground-based Datalinks*

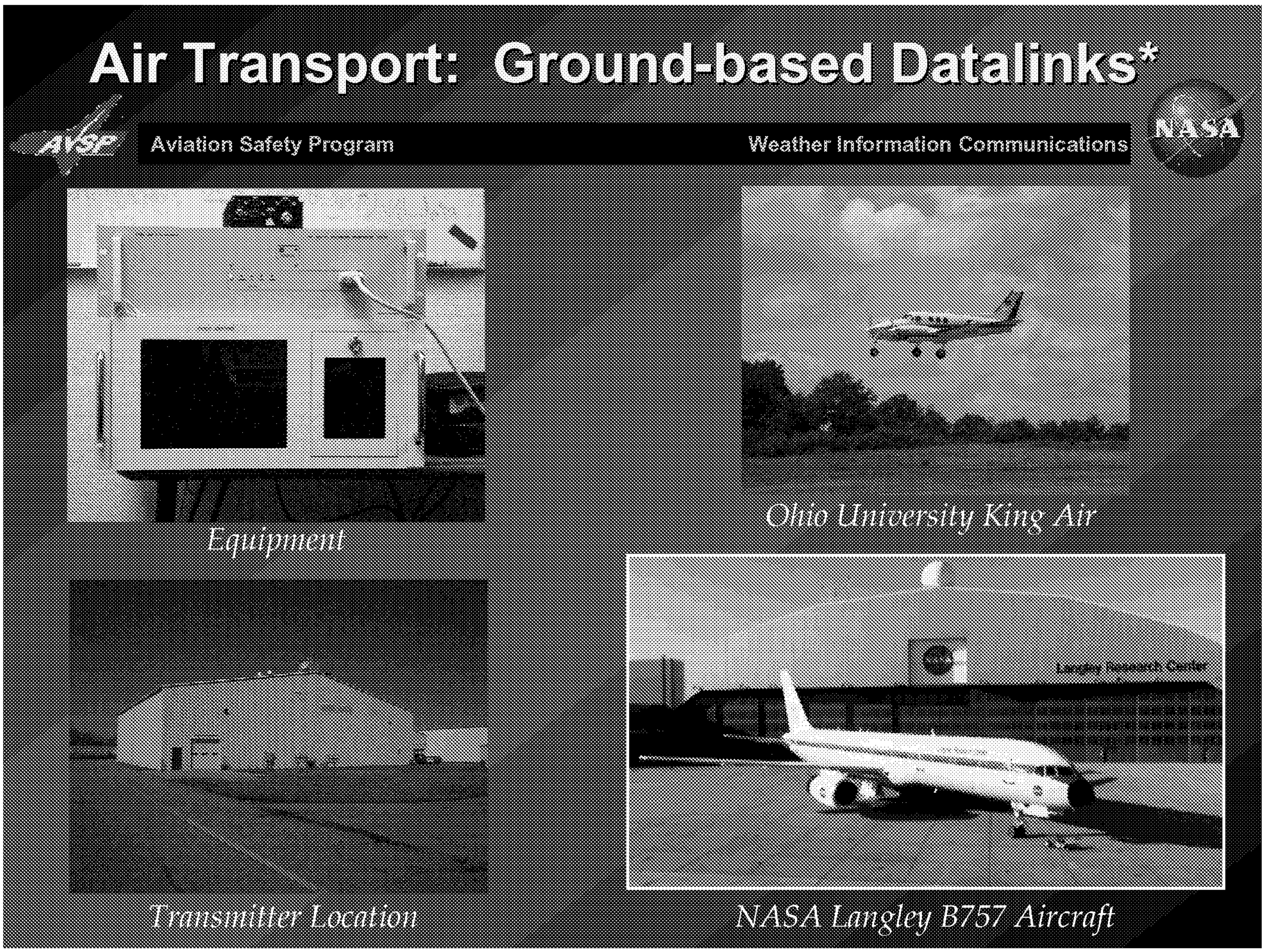
AvSP Aviation Safety Program — Weather Information Communications

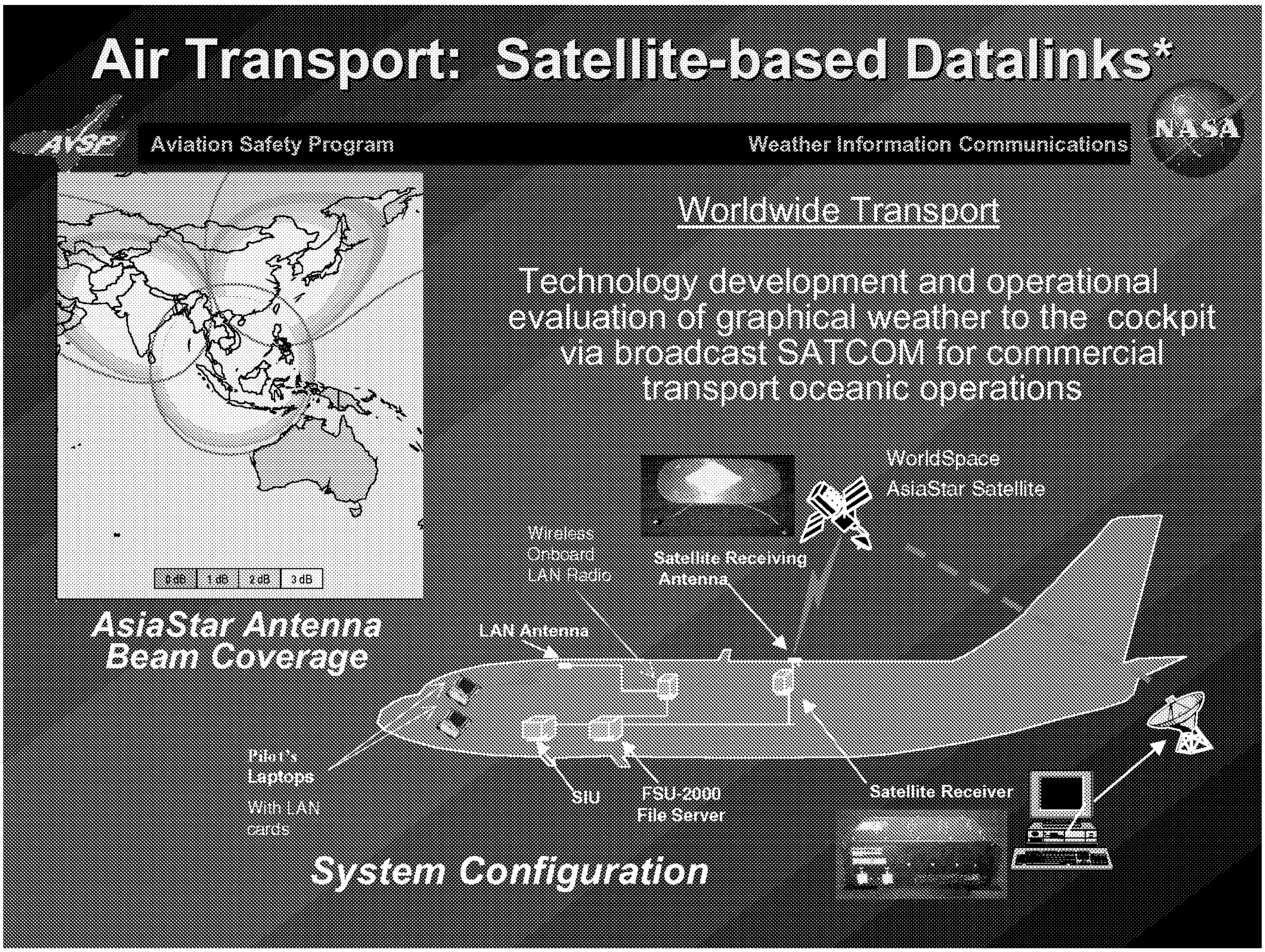
Results to date:

- Grants with Ohio University to assess addressed VDL-Mode 2 datalink for weather dissemination.
- Laboratory bench testing completed
- Initial flight experiments completed (Ohio U King Air)

Future activity:

- Partnering with ARINC to jointly evaluate VDL-2 datalink performance for FIS (Weather) applications. (VDL-2 is future upgrade to ACARS)
- Experiments will include both signals-in-space as well as network characterization (ATN).
- Hardware will be integrated on NASA B-757 research aircraft for upcoming flight experiments with ARINC ground-system.


Air Transport: Ground-based Datalinks*
AvSP
Aviation Safety Program
Weather Information Communications
NASA
Equipment
Ohio University King Air
Transmitter Location
Langley Research Center
NASA Langley B757 Aircraft


Air Transport: Satellite-based Datalinks*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Worldwide Transport
Technology development and operational evaluation of graphical weather to the cockpit via broadcast SATCOM for commercial transport oceanic operations
0 dB
1 dB
2 dB
3 dB
AsiaStar Antenna Beam Coverage
WorldSpace AsiaStar Satellite
Wireless Onboard LAN Radio
Satellite Receiving Antenna
LAN Antenna
Pilot's Laptops
With LAN cards
SIU
FSU-2000 File Server
Satellite Receiver
System Configuration

Air Transport: Satellite-based Datalinks*

Aviation Safety Program — Weather Information Communications

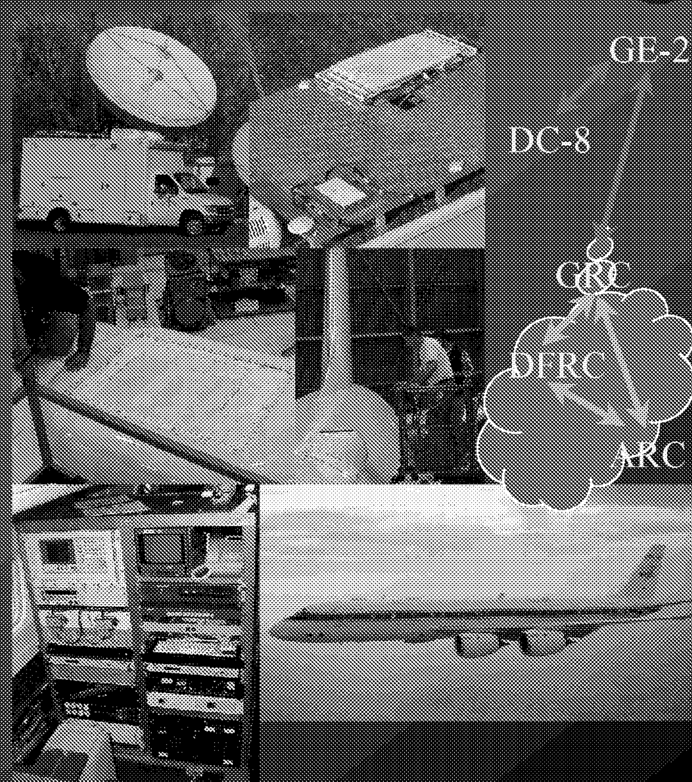
Worldwide SATCOM Transport Datalink:

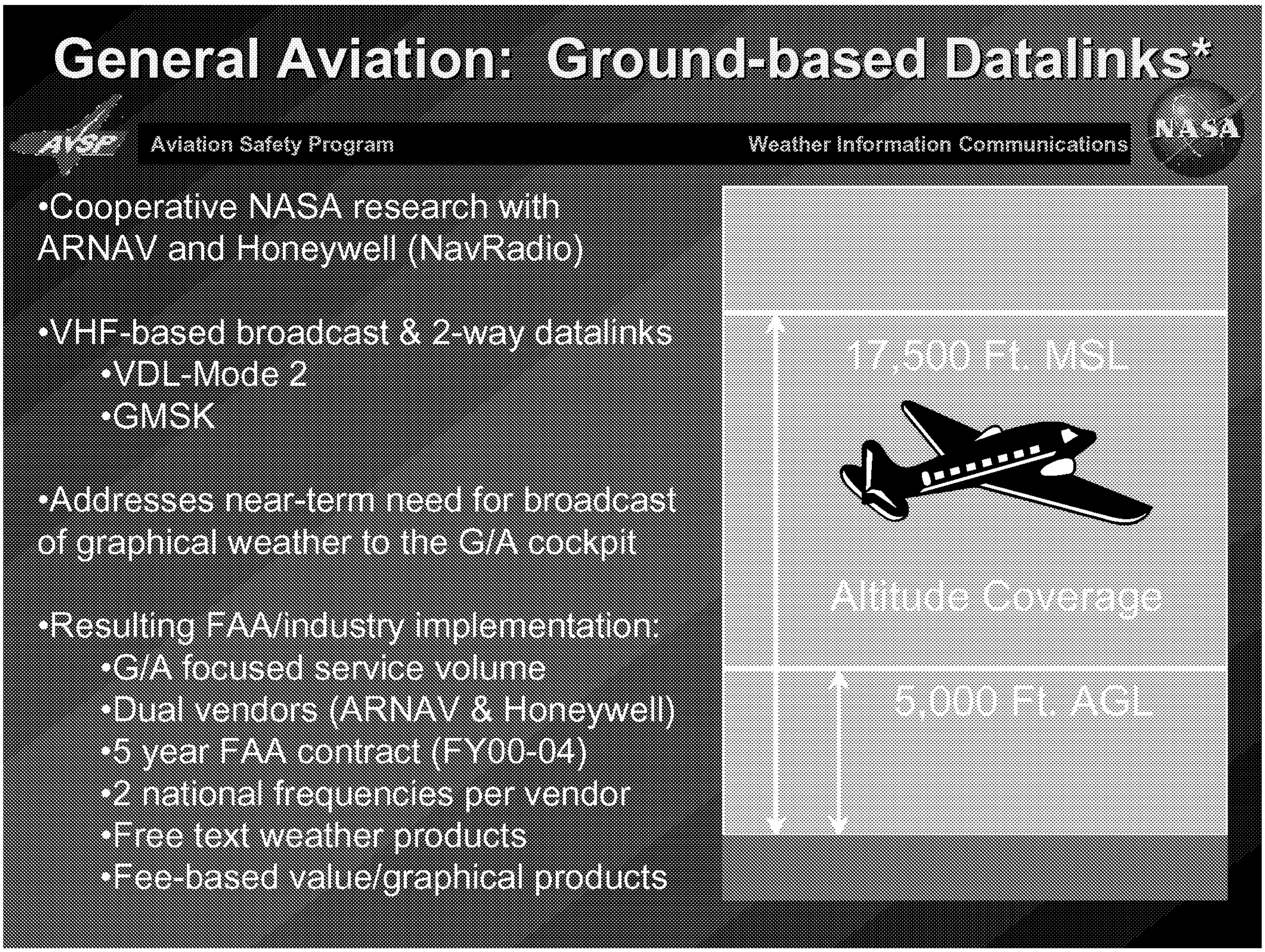
- NASA / Rockwell Collins / Jeppesen / American Airlines / Worldspace team
- Government/industry cost-sharing
- In-Service Evaluation via two American Airlines B-777s flying trans-pacific routes
- 1st 777 install completed, including all certs
- 2nd 777 install completion May, 2001
- Trial ‘runs’ completed to Japan
- First ‘official’ flight May 21, 2001; commence data collection thereafter

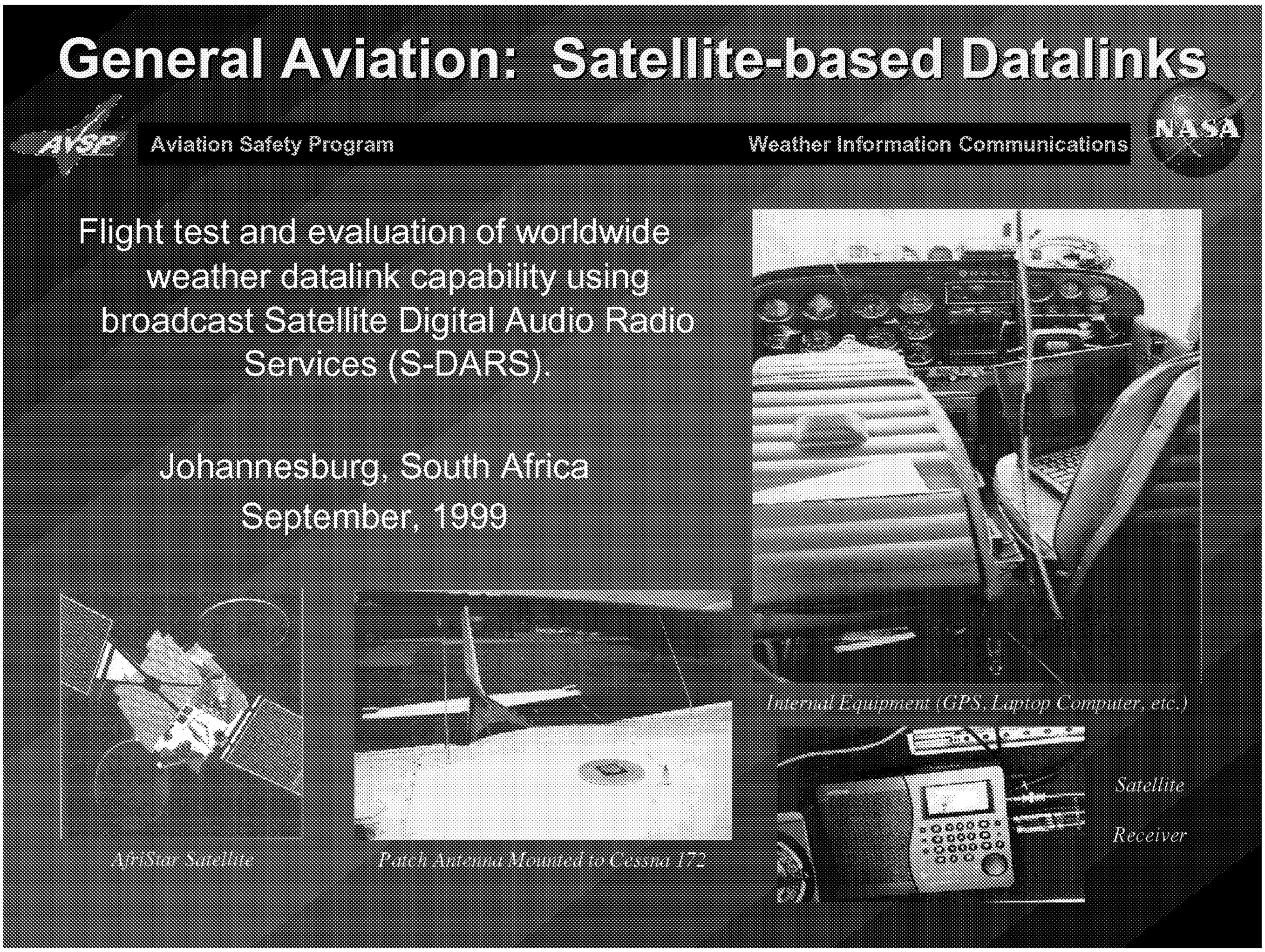
Air Transport: Satellite-based Datalinks

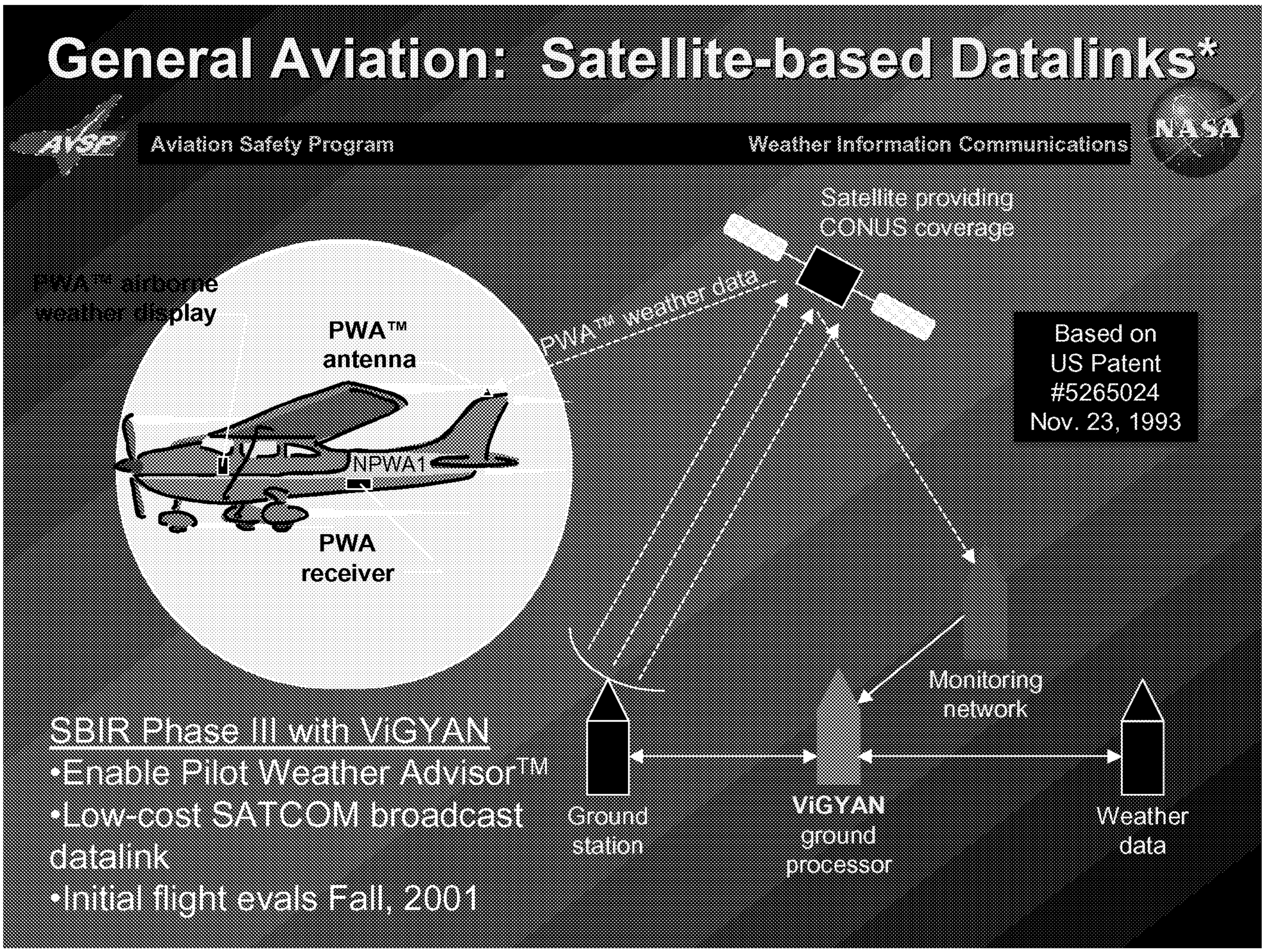
Aviation Safety Program — Weather Information Communications

- Enabling technologies:
  - Phased array antennas
  - Broadband mobile terminal
- Joint NASA/Boeing development
- Up to 1000x capacity increase
  - 256 Kbps off aircraft
  - 2.18 Mbps to aircraft
- Ground-mobile experiments
- Proof flight test Dec, 2000 (DC-8)
- Upcoming B-757 experiments
- Enabling to *Connexion by Boeing*




General Aviation: Ground-based Datalinks*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
•Cooperative NASA research with ARNAV and Honeywell (NavRadio)
•VHF-based broadcast & 2-way datalinks
•VDL-Mode 2
•GMSK
•Addresses near-term need for broadcast of graphical weather to the G/A cockpit
•Resulting FAA/industry implementation:
•G/A focused service volume
•Dual vendors (ARNAV & Honeywell)
•5 year FAA contract (FY00-04)
•2 national frequencies per vendor
•Free text weather products
•Fee-based value/graphical products
17,500 Ft. MSL
Altitude Coverage
5,000 Ft. AGL

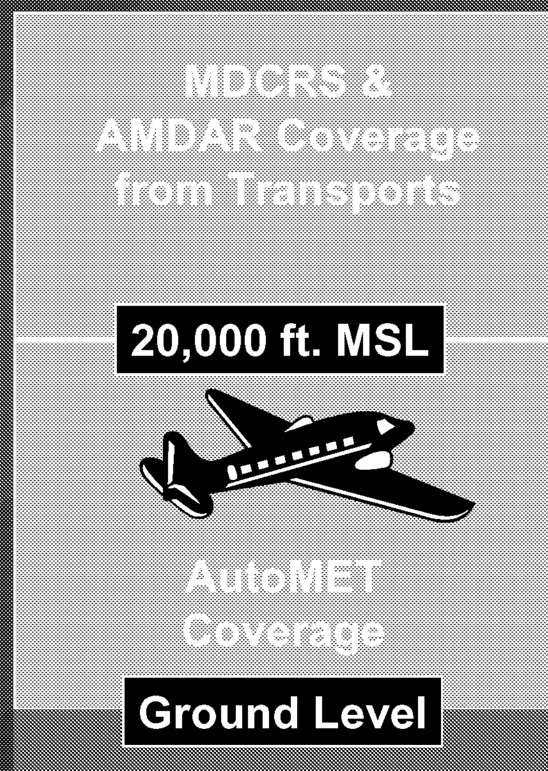

General Aviation: Satellite-based Datalinks
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Flight test and evaluation of worldwide weather datalink capability using broadcast Satellite Digital Audio Radio Services (S-DARS).
Johannesburg, South Africa
September, 1999
Internal Equipment (GPS, Laptop Computer, etc.)
AfriStar Satellite
Patch Antenna Mounted to Cessna 172
Satellite Receiver

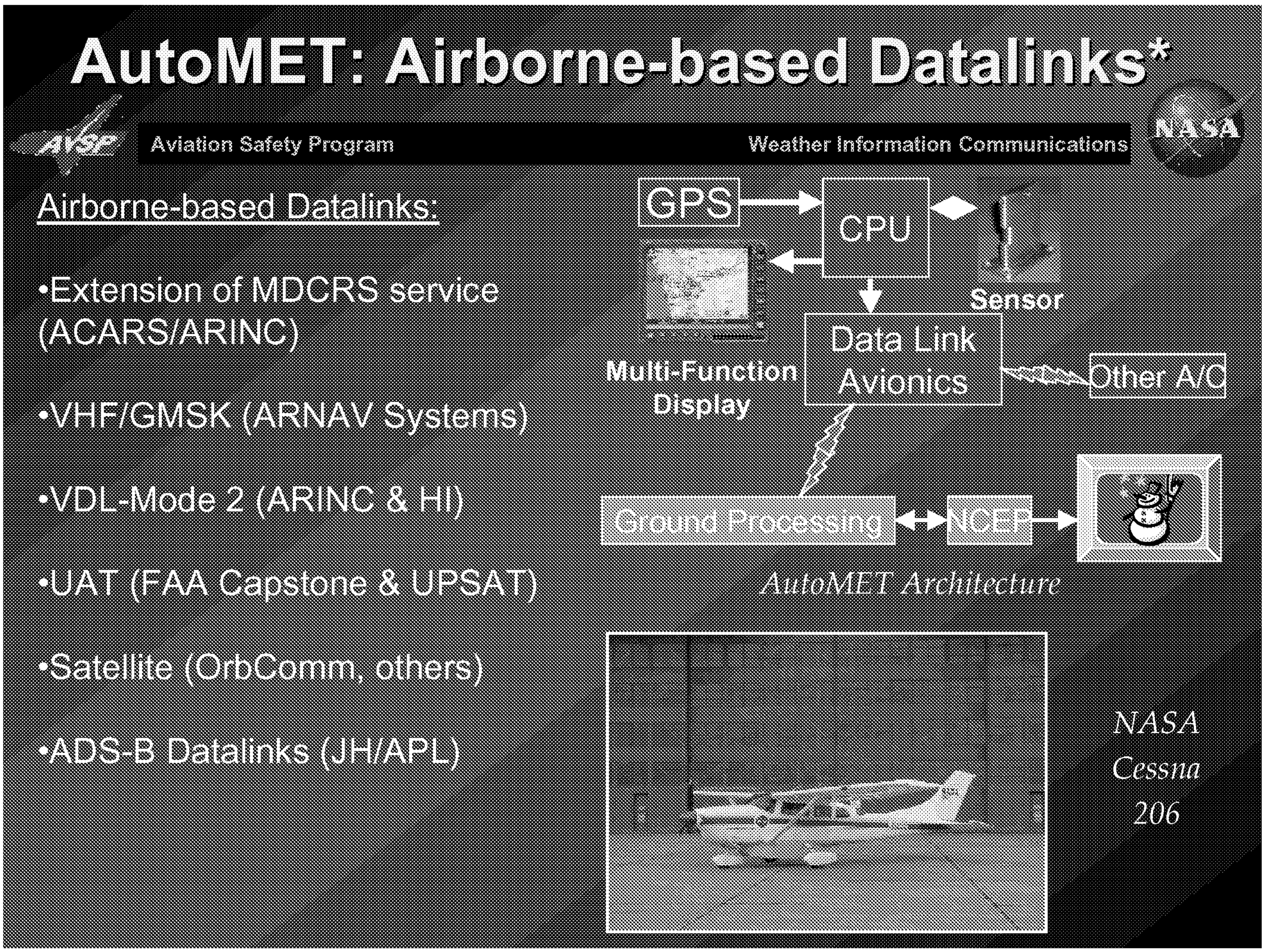

General Aviation: Satellite-based Datalinks*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Satellite providing CONUS coverage
PWA™ weather data
PWA™ airborne weather display
PWA™ antenna
NPWA1
PWA receiver
Based on US Patent #5265024 Nov. 23, 1993
Monitoring network
Ground station
ViGYAN ground processor
Weather data
SBIR Phase III with ViGYAN
•Enable Pilot Weather Advisor™
•Low-cost SATCOM broadcast datalink
•Initial flight evals Fall, 2001

Low-Altitude AutoMET Reporting

Aviation Safety Program — Weather Information Communications

- Use aircraft operating below 20,000 ft altitude to sense and report
    - Moisture
    - Temperature
    - Winds
- To be used by:
    - Forecast models
    - Weather briefers
    - Controllers
    - Other aircraft
- Investigating numerous airborne-based datalinks and architectures for technical feasibility

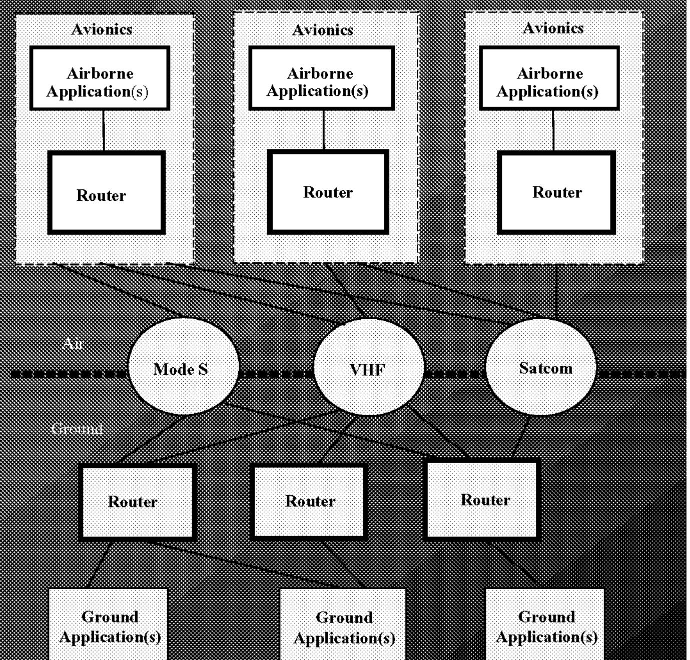



AutoMET: Airborne-based Datalinks*
AVSP
Aviation Safety Program
Weather Information Communications
NASA
Airborne-based Datalinks:
•Extension of MDCRS service (ACARS/ARINC)
•VHF/GMSK (ARNAV Systems)
•VDL-Mode 2 (ARINC & HI)
•UAT (FAA Capstone & UPSAT)
•Satellite (OrbComm, others)
•ADS-B Datalinks (JH/APL)
GPS
CPU
Sensor
Multi-Function Display
Data Link Avionics
Other A/C
Ground Processing
NCEP
AutoMET Architecture
NASA Cessna 206

Network Protocols Development

Aviation Safety Program | Weather Information Communications

- Past tasks with MIT/LL for FIS:
  - ATN and Internet Protocol (Mobile IP) network feasibility
  - IP-over-VDL Mode 2 datalink interface definition
- Joint NASA/ARINC research:
  - FIS over IP/VDL-Mode 2
  - FIS over ATN/VDL Mode 2
- ATN over broadband SATCOM feasibility
- Next-generation Mobile IP research for aeronautical app's



Network Routing Connectivity

FAA/NASA Collaboration

Aviation Safety Program | Weather Information Communications

- FIS Datalink & Weather Requirements Offices (AUA & ARW)
  - Co-funded tasks under NASA/FAA Memo of Agreement:
  - Low-altitude AutoMET datalink technical architecture alternatives
  - FIS/Weather datalink technical architecture analyses:
    - Mid-Term (2004-2007)
    - Far-Term (2010 and beyond)
  - Terminal area weather datalink communications alternatives

- Office of Architecture and System Engineering (ASD)
  - Joint Research Project Definitions (JRPDs):
  - FIS datalink architecture analyses & NAS Architecture integration
  - Terminal area broadband communications

- CAPSTONE Program (Alaska)
  - UAT datalink investigation for AutoMET; SATCOM augmentation

Summary

Aviation Safety Program | Weather Information Communications

- NASA datalink technology investments in
  - FIS datalink architecture development guidelines
  - Ground, satellite and airborne weather datalink systems and supporting network standards

- Strong partnerships with industry, FAA and academia evidenced by
  - Cost-shared NASA/industry technology development
  - Jointly co-funded NASA/FAA tasks

- As a result, beginning to see introduction of 1st generation systems into the marketplace

- Continued future NASA research and technology development into breakthrough, next-generation systems and component technologies.

NASA/CP—2002-210964

Turbulence Detection & Mitigation Element

Weather Accident Prevention
Second Annual Review
June 5-7, 2001

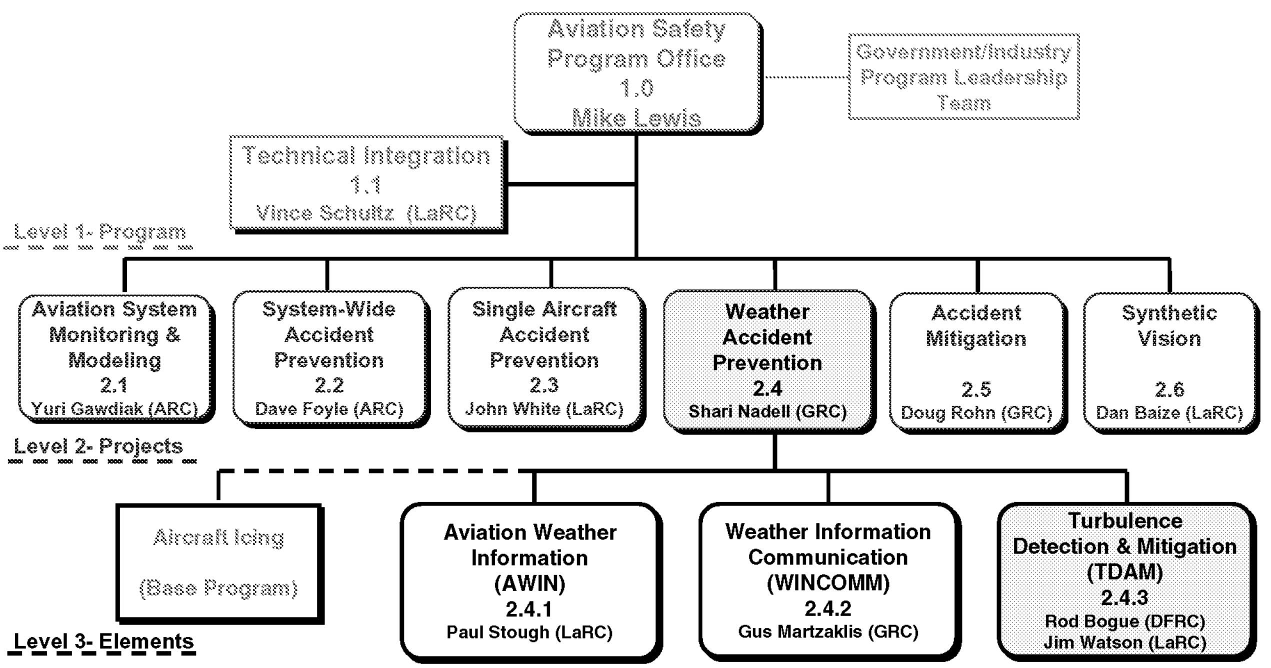
Rod Bogue
NASA Dryden Flight Research Center

Briefing Outline

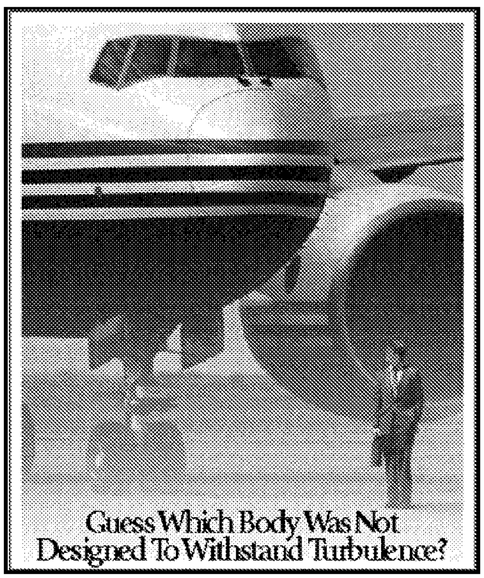
Organization
Scope of Turbulence Effort
Background
Turbulence Detection & Mitigation Program Metrics
Approach
Turbulence Team Relationships
WBS Structure
Deliverables
TDAM Changes
FY-01 Results/Accomplishments
Out-year Plans
Element Status

Aviation Safety Program Weather Accident Prevention

Aviation Safety Program Organization



Scope of Turbulence Effort



- Turbulence from Natural Atmospheric Processes
- Parts 121, and 91 (Scheduled Carriers, Commuters & GA)
- Tactical (Enroute)
- Both Avoidance & Encounter Mitigation*⇓
- Flight Deck Integration*⇑

Note:*⇓ = Reduced effort, *⇑ = Starting effort.

Background

- Turbulence Costs
  - Primary Cause of In-Flight Injuries (9 encounters/24 injuries per month)
  - Cost estimated at >$100M/yr. for airlines
- Turbulence Initiators
  - Convective Storms (within and as far as 40 miles away from visible clouds in clear air)
  - Jet Stream (at confluence of multiple streams and near boundaries)
  - Mountain Wave (upward propagating from disturbances near the surface)

Turbulence Detection & Mitigation Program Metrics

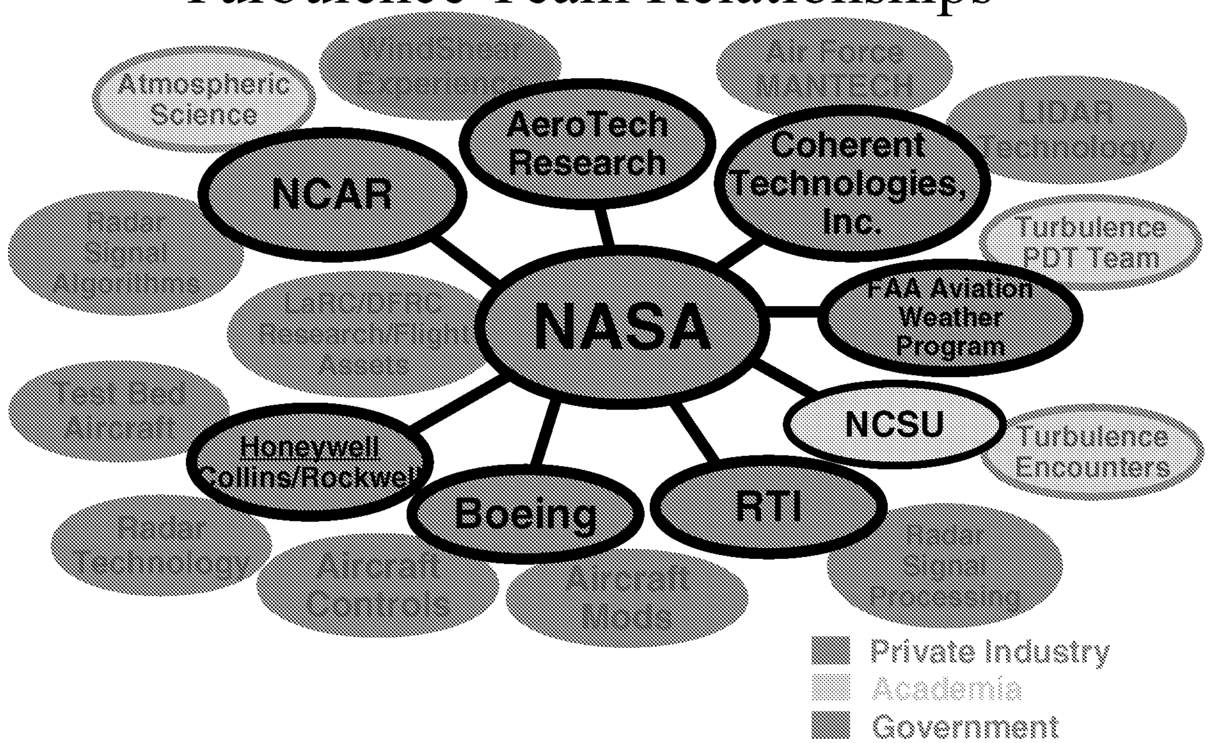
- **WxAP Objective # 3:** Provide commercial aircraft sensor with 90% probability of detection of severe Convective and Clear Air Turbulence thirty seconds to two minutes before encounter.

- **WxAP Milestone #2:** Flight demonstrate certifiable forward-looking on-board turbulence warning system with Type-I and Type-II error probability commensurate with airborne wind shear technology (TRL/IRL of 7/4)

Approach

- Build a Turbulence Team from Industry, Academia, and Government to address requirements, approaches, and solutions
- Utilize the Commercial Aircraft Safety Team (CAST) to determine requirements for Air Carriers (http://www.cygnacom.com/turbulence/)
- Address Air Carrier Issues with Technology Approaches with assistance from FAA Rule-Making, and Improved Procedures
- Address GA Issues with improved Weather Products Disseminated through Aviation Weather INformation

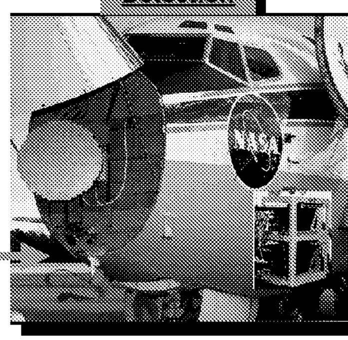
Turbulence Team Relationships



WBS Structure

Turbulence Characterization

Detection



Mitigation/Flight Deck Integration

- Requirements Definition (CAST)
- Severe Events Database
- Hazard Metric Development

- Sensor Performance Assessment
- Sensor Development
- Algorithm Development
- Demonstration & Verification

- Turbulent Flt. Control Algorithm
- Flight Deck Display Integration
- Assess Mitigation Options

Major Deliverables/Products

- Turbulence Characterization
  - Validation of In-situ Algorithm
  - Turbulence Hazard Metric
- Detector Technology
  - Radar (software)
  - Lidar (hardware/software)
- Encounter Mitigation Technology
  - Assessment of Conventional Aircraft Control Authority
- Flight Deck Integration
  - Display Integration

Element Changes

- Program Changes
  - Elimination of Forecasting/Nowcasting WBS
  - De-scope of Mitigation
  - Initiation of Flight Deck Integration
- Staffing Changes
  - Level III Deputy
    - Bruce Kendall - interim
    - Jim Watson
  - Level IV
    - Neil O'connor - Turbulence Characterization Lead
    - Robert Neece - Detection & Mitigation Lead
    - Phil Schaffner - Radar Principal Investigator
    - Ivan Clark & Phil Gatt - Lidar Co-principal Investigators

Aviation Safety Program   Weather Accident Prevention

Element Accomplishments

- Turbulence Characterization & Sensor Development
  - Research Radar Flight Experiments
    - 3 Flights (15 hours)
    - Predicted atmosphere along flight path
    - Verified turbulence in-situ algorithms
    - Established relationship between rms aircraft g-load and radar observables
  - CDR for B-757Lidar Installation
- Radar Flight Sensor Certification/Flight Deck Integration
  - Participated in NASA-FAA-Industry Workshops (3) for Forward Looking Turbulence Sensor Certification*
  - Selected and modeled 4 turbulence encounters for candidate sensor verification & certification

Note: * indicates item will not be covered later in detail

Element Accomplishments (cont.)

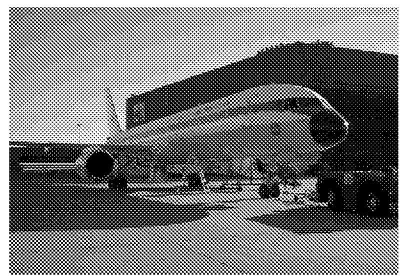
- Turbulence Mitigation
  - Flight Control Report (Boeing)
  - Phase 2 SBIR for Feedforward Active Encounter Mitigation (CTI)*
- Guidance Activities
  - Commercial Aviation Safety Team
    - Completed Turbulence Joint Safety Assessment Process
      - (30 Interventions- Technology Development, Procedures, Training)
    - Chartered Turbulence Joint Safety Implementation Process
      - Prioritized Interventions - Selected for Implementation
      - Developed Projects - Identified Outputs
  - Secure Cabin Exercise
    - Established Team - FAA (CAMI), Airlines (5), Flight Attendant Organizations(2), ARI Consultant
    - Exercise Planning in Progress

Element Plans

- Turbulence Characterization & Sensor Development
  - Research Radar Flight Experiments with real-time Radar Algorithm in operation (Early FY-02 and Late FY-02)
  - Research Lidar Flight Experiments (Summer FY-01 on DC-8, Later FY- 02 on B757)

- Radar Flight Sensor Certification
  - Support NASA-FAA Certification Team effort with flight tests and algorithm validation activities
  - Continue analysis of turbulence encounters for sensor verification & certification

Element Plans (cont.)

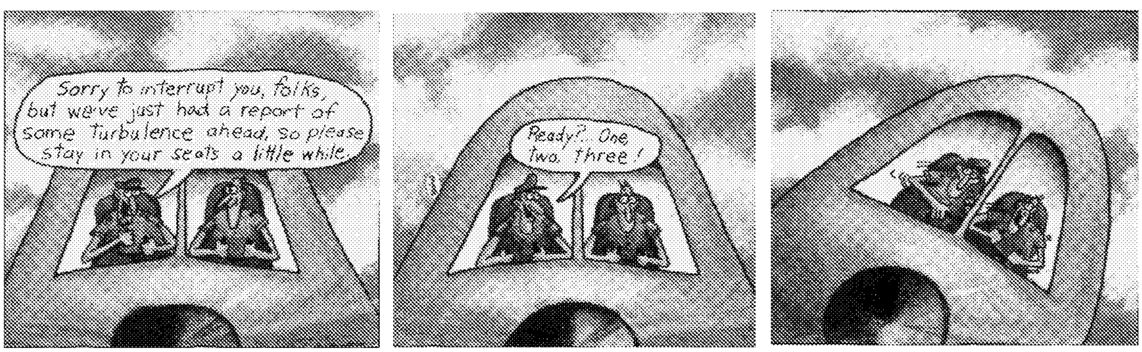


- Turbulence Mitigation
  - Flight Control Assessment (Boeing)
  - Support Phase 2 SBIR for Feed-forward Active Encounter Mitigation
- Commercial Aviation Safety Team
  - Complete Turbulence Joint Safety Implementation Process
    - Refine Projects and Outputs
    - Transition Projects to CAST Management
- Secure Cabin Exercise
  - Conduct wide-body exercise at CAMI in September 01
  - Develop Plans and conduct narrow-body exercise in FY-02

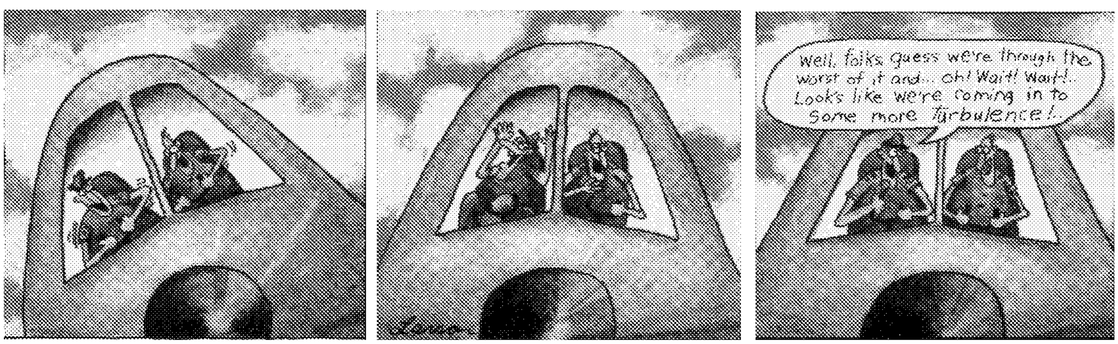
Summary - Status of Elements

- Turbulence Characterization
  - Accident analysis developing robust cases for certification
  - Developing turbulence weather analysis models
- Detection
  - Radar flight tests in December provided promising results for detecting turbulence in the vicinity of convective activity
  - Lidar flight tests in FY-01expected to confirm/validate performance at cruise altitude
- Encounter Mitigation
  - Promising assessment of mitigation control options
- Flight Deck Integration
  - Planning for display integration with NASA-FAA Certification Team

Out-of-Scope "Turbulence"



Out-of-Scope "Turbulence" (cont.)



Weather Information Network

Weather InformatioN Network
WINN
Honeywell

NASA
Aviation Safety Program
June 5, 2001

Honeywell

Data

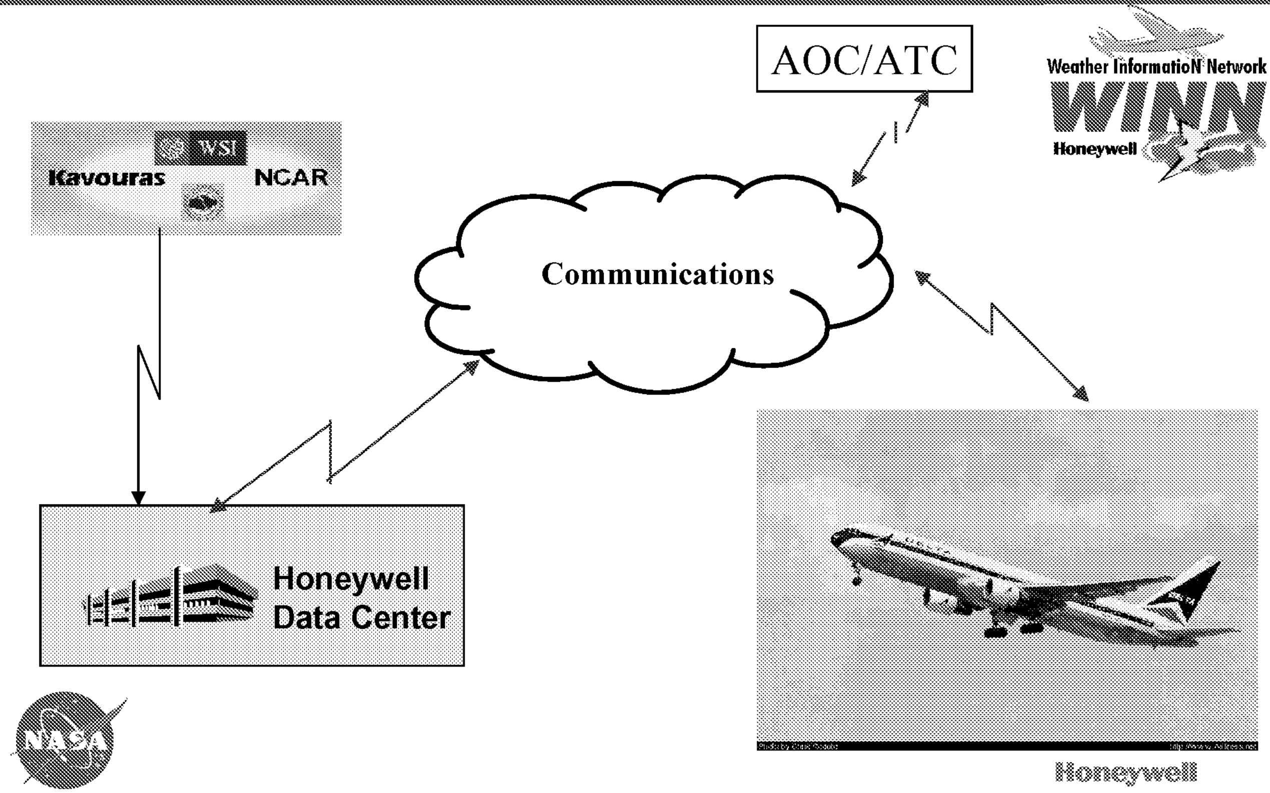
- Turbulence Detection and Forecast
- Weather Radar (US only)
- Satellite
- Convective Detection and Forecast
- Icing Detection and Forecast
- METARs (icon and text)
- TAFs (text)
- SIGMETs
- High level Sig Wx Prog
- Surface Analysis
- Winds Aloft

Weather InformatioN Network WINN Honeywell

Honeywell

WINN Overview
June 2001

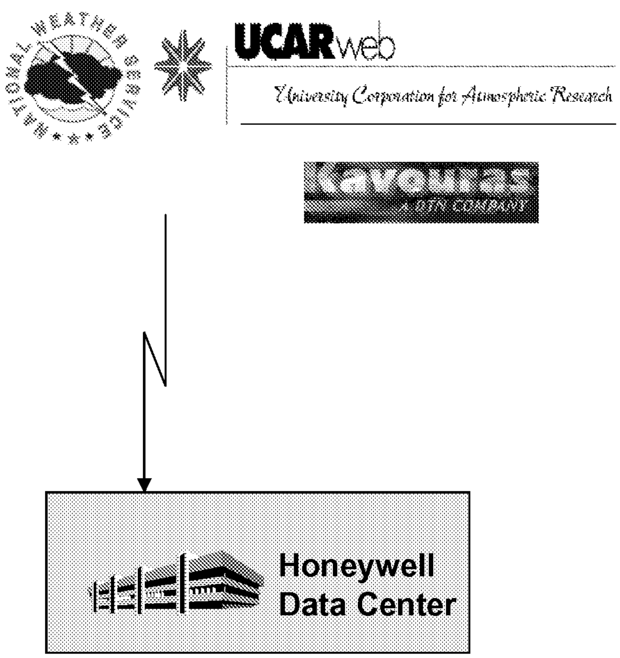
System Overview



Honeywell

WINN Overview
June 2001

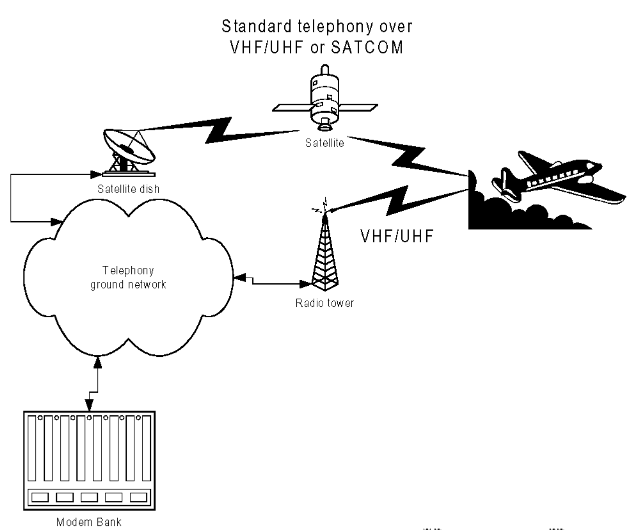
Ground processing



- Multiple weather providers push information to the Honeywell Data Center (HDC)
- The HDC receives, decompresses, reformats and recompresses the information
- Once reprocessed the HDC stores the information in a ready directory until called on for delivery

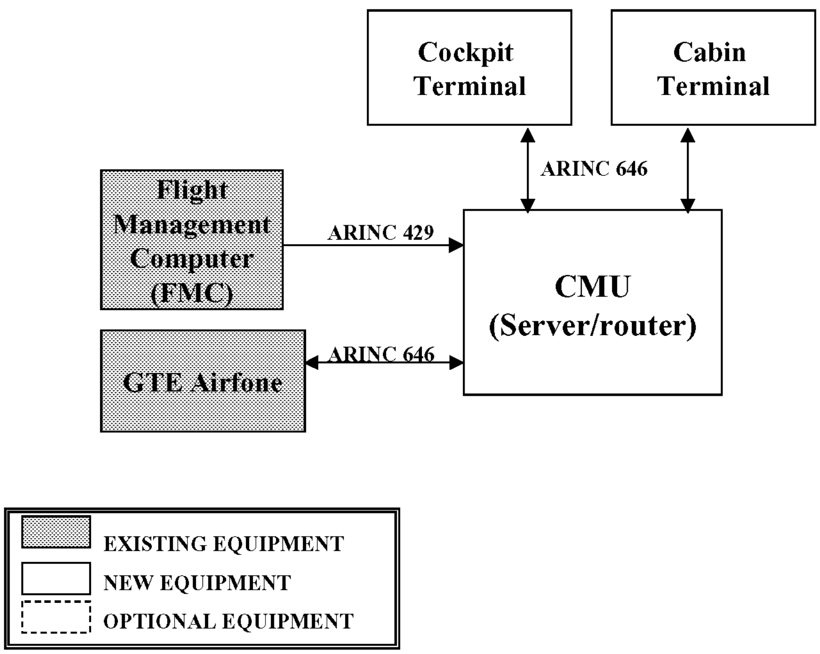
Communications

- **Using standard airborne telephony (UHF or Satcom) the user establishes a link with the HDC**
- **Once established, the user requests an update of information, based on position**
- **The HDC replies by sending all information requested, through matching the user's request with the current master directory of all information**
- **This process is repeated on a periodic basis**

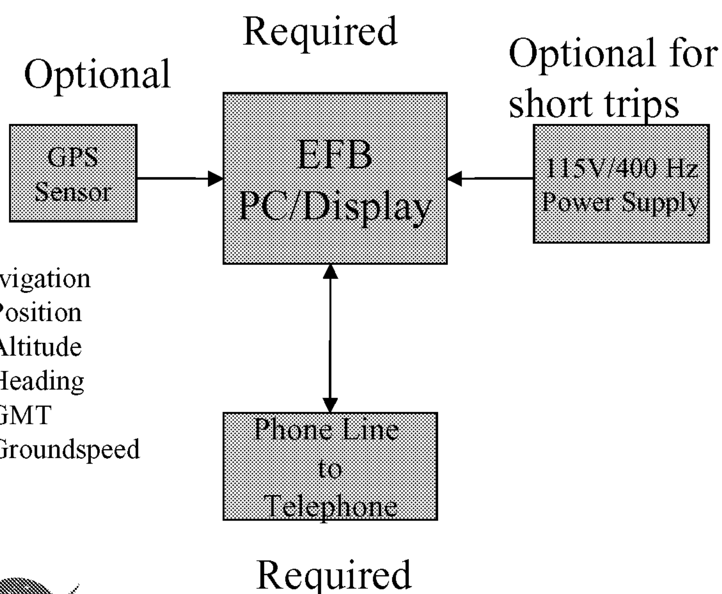


Airborne

Weather InformatioN Network WINN Honeywell



Airborne 2



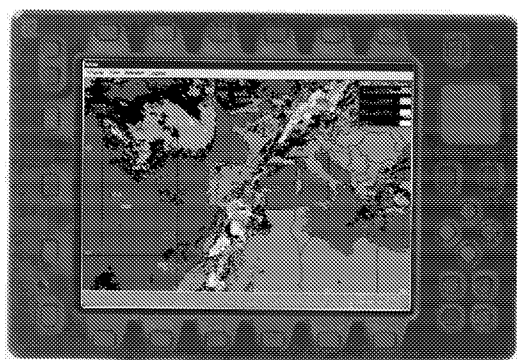
Navigation
- Position
- Altitude
- Heading
- GMT
- Groundspeed

- **Once information is received it resides on the PC until requested**
- **The unit will require power for durations greater than the battery life**
- **The unit may use navigational (GPS) information to facilitate moving map display**

Honeywell

Airborne Displays

- LRU
  - Avionitek ICIS
  - Northstar CT-1000
  - Honeywell flat panel
- Portable Electronic Device
  - Fujitsu 3400
  - HP OMNI 4150
  - Toshiba Tecra
  - Qube
  - Fujitsu 2300
  - Northcoast



Honeywell

WINN Overview
June 2001

Current status

- Completed evaluation flights on UAL A-320 and Delta B-777
  - "CHANGED ALT. TO TEST THE CAT FUNCTION. APPEARED TO WORK WELL."
  - "IMPLIMENT A S A P !!!!!!!!!"
  - "NEED TO BE ABLE TO INSERT WPT'S INTO MIDDLE OF FLT PLAN ROUTINE."
- Additional, multiple evaluations now under contract and planned for the summer of 2001
- Officially a commercial offering
- Technical thrust
  - Further cost and function improvements
  - Overall robustness improvements

Our Airspace System

- **Current and projected growth in the air carrier and air cargo industry is 5.6% for the next 20 years**
  - **Currently 11,000 jet aircraft worldwide**
  - **Projected 33,000 jet aircraft by 2019 (IATA, 1999/ Boeing 2000)**
- **ATA projects a 250% increase in delays by 2007, caused by a 43% passenger increase and 2500 addl. A/C. (ATA, 1999)**
- **FAA projects that, in 2007, more than 800 million passengers will fly in the United States –three times the number who flew in 1980. (Gore, 1997)**
- **The ATS data link focus group suggests that "airline operations will be critically constrained by the year 2005 if nothing is done to curb delay growth." (ATS Data Link Focus group, 1999)**

NASA/CP—2002-210964

NASA Langley WINN System Operational Assessment

Jon Jonsson, Ph.D.
NASA Langley Research Center

Aviation Safety Program
AWIN B-757 Flight Test

OBJECTIVES

- ❑ Determine if near real-time weather information presented on the flight deck improves pilot situational awareness of weather.

- ❑ Identify pilot interface issues related to the use of WINN system during test flights.

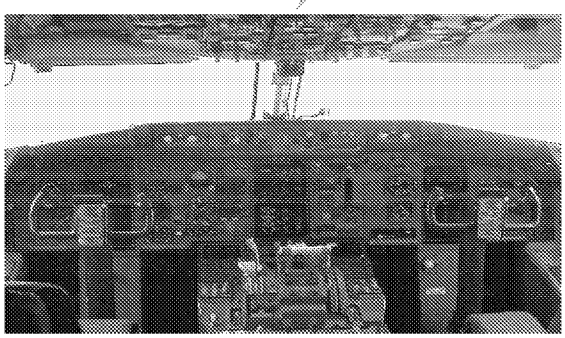
Aviation Safety Program
AWIN B-757 Flight Test

APPROACH

- NASA pilots used for test subjects (4).
- Flights conducted on typical airline routes.
- Test flights scheduled on days of expected convection along the flight path.
- Video and audio recording of pilot use of WINN.
- Situational awareness data (verbal & scaled).
- Post test questionnaire.

Aviation Safety Program

AWIN B-757 Flight Test



Flight Deck Research Station (FDRS)

Conventional B-757

NASA/CP—2002-210964

Aviation Safety Program

AWIN B-757 Flight Test

Near-Time Cockpit Weather Display on NASA B-757

Selected Post-Test Questionnaire Results

- ✓ Overall WINN interface intuitive to pilots.
- ✓ Bezel buttons preferable to touch screen to access weather products.
- ✓ Weather forecast products useful in decision making.
- ✓ WINN anticipated to save time and fuel.
- ✓ History feature useful for *strategic* planning.
- ✓ History feature not useful for *tactical* planning.

Selected Post-Test Questionnaire Results

- ✓ ΔColors on the display appeared clearly and accurately.
- ✓ ΔEntering different altitudes to examine CAT wx product.
- ✓ ΔMETAR and TAF entry for reporting.

Δ **Squawks corrected on WINN-Lite Display.**

NASA/CP—2002-210964

"Six to One; Half Dozen to the Other"

Areas Requiring Further Research

- ✓ Position of display.
- ✓ Ease of determining displayed weather product age.
- ✓ Identification of a precision controller.
- ✓ Ideal time for automated weather updates.

Tactical versus Strategic Wx Replanning

Generally I think, this [system] can obviously provide some very good strategic weather planning information. I still think that for tactical [flying]--deviating around individual cells--or looking out to about 100 miles, I would probably still prefer [using] my aircraft weather radar. But looking down the road, an hour or two down the road, this system could be very helpful.

How best to implement new products (NEXRAD, CAT) with existing systems?

NASA/CP—2002-210964

Research Issues Emerging from 757 Flight Test

Color schemes with multiple weather products being shown on the display.

Cloud top information **crucial** for decision making.

NEXRAD: Is the db Reflectivity occurring at **my** cruise level or 10,000 feet below me?

Age of data.

- Update Rate?
- How to Display?

Questions and Comments


United's SKY-PADtm Project
20
20
FLIGHT
OPERATIONS
TECHNOLOGY
Innovations in flight
Capt. Joe Burns
Flight Operations Technology

Overview

- Previous AWIN project
- Current AWIN/EFB Activity – Phase I
- UAL Future "Sky-Pad" activity – Phase 2-4

UAL Sky-Pad


AWIN Team Members
Honeywell Inc. (Team Lead)
National Center for Atmospheric Research
National Weather Service
The SITA Group
ARINC
WSI
Kavouras
Allied Signal
United Airlines
NASA
UAL Sky-Pad
innovations in flight

Products WINN Tested:

- CONUS Radar*
- Worldwide Satellite*
- Convection*
- Nowcasting
- Airports (METARS/TAFS)
- Turbulence Forecast

UAL Sky-Pad

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

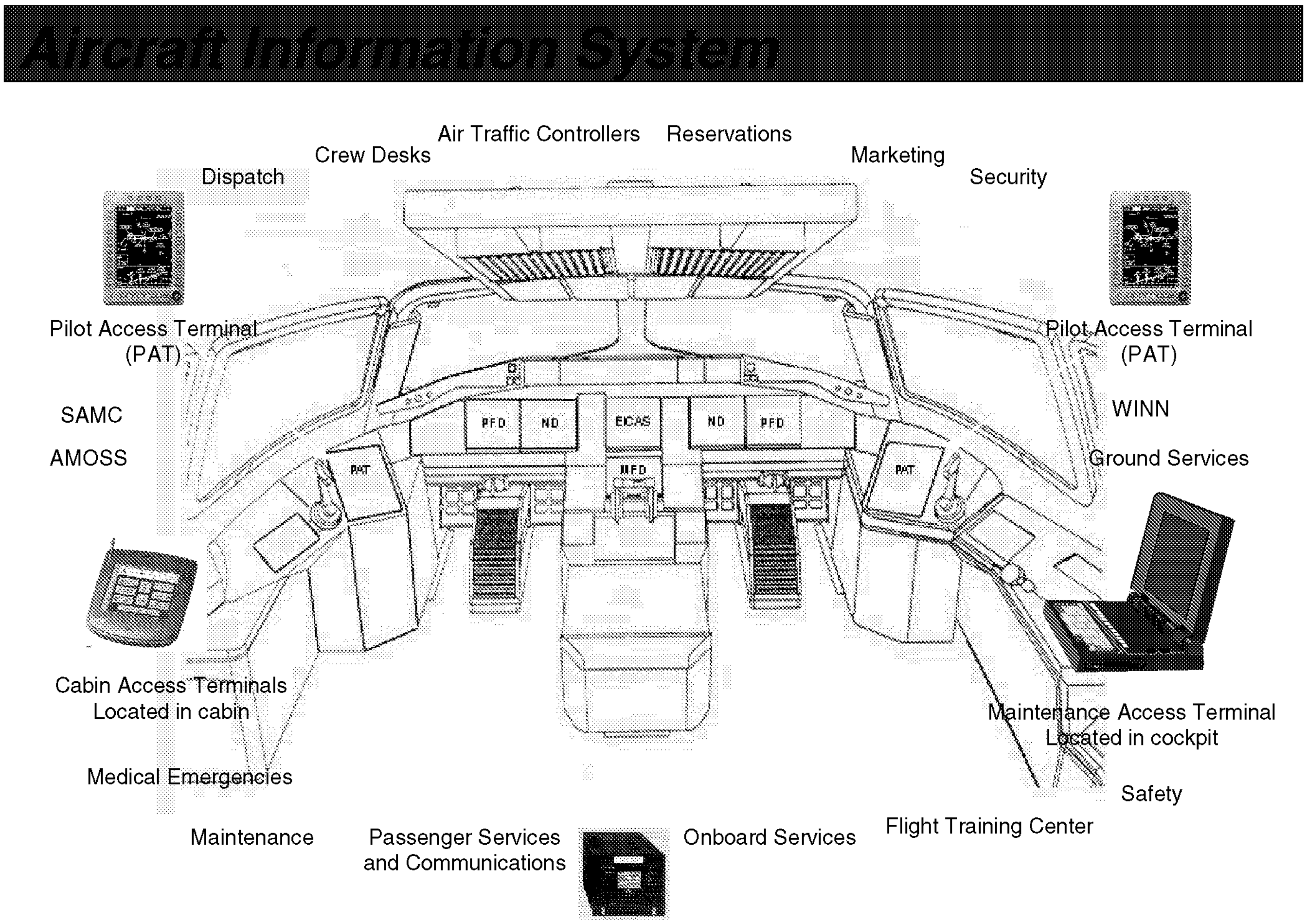
United WINN Enablers:

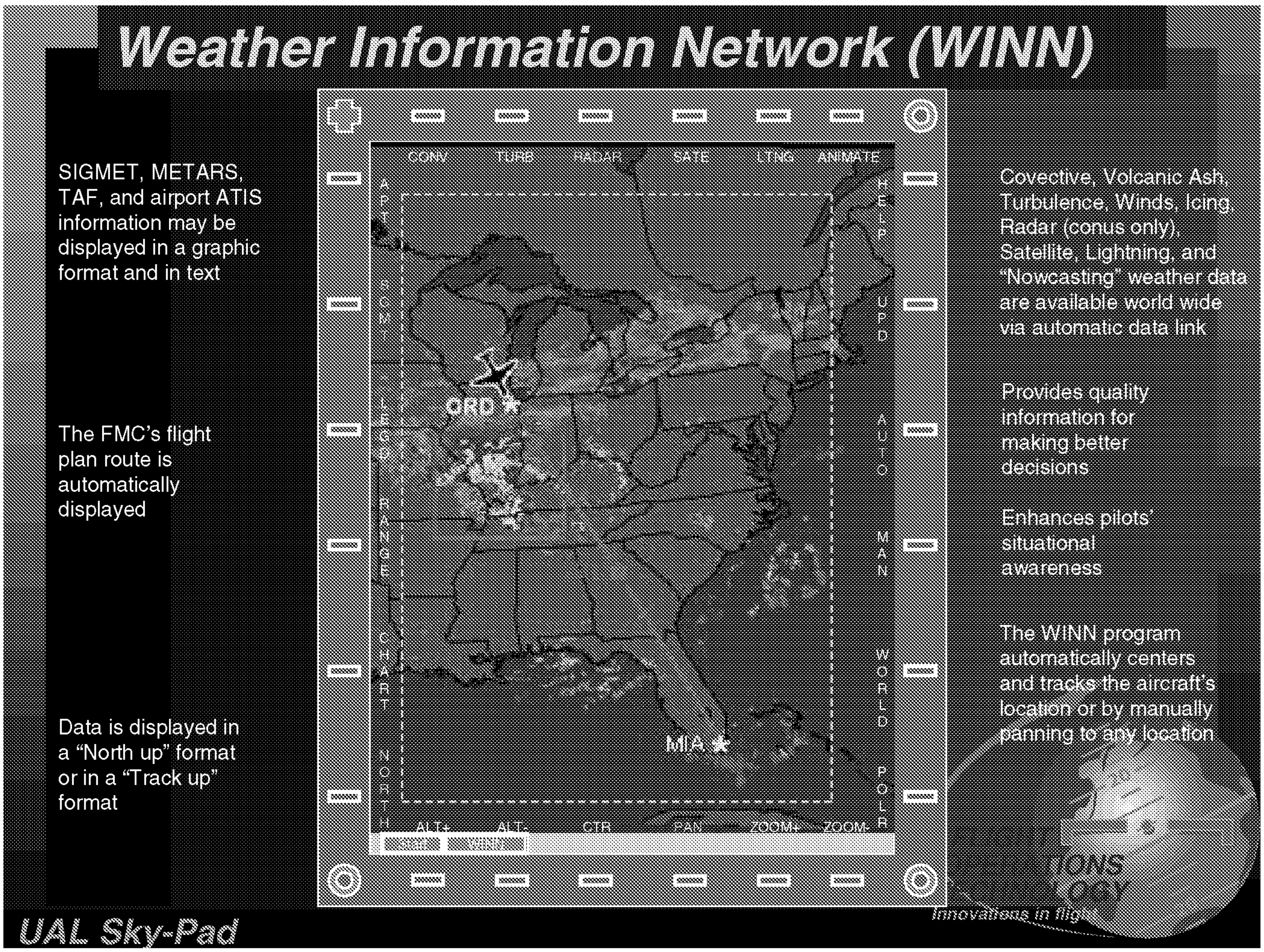
- ClassTrax/CrewTrax
- TrainTrax
- PubTrax
- Netlink
- PalmLink

UAL Sky-Pad

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight


B-777 PAT Locations
• The First Officer's PAT location is on the right sidewall. The Captain's PAT is located on the opposite sidewall.
UAL Sky-Pad
Innovations in flight


Aircraft Information System
Air Traffic Controllers
Reservations
Crew Desks
Marketing
Dispatch
Security
Pilot Access Terminal
(PAT)
Pilot Access Terminal
(PAT)
SAMC
WINN
AMOSS
Ground Services
PFD
ND
EICAS
ND
PFD
MFD
PAT
PAT
Cabin Access Terminals
Located in cabin
Maintenance Access Terminal
Located in cockpit
Medical Emergencies
Safety
Maintenance
Passenger Services
and Communications
Onboard Services
Flight Training Center



Weather Information Network (WINN)
SIGMET, METARS, TAF, and airport ATIS information may be displayed in a graphic format and in text
The FMC's flight plan route is automatically displayed
Data is displayed in a "North up" format or in a "Track up" format
CONV
TURB
RADAR
SATE
LTNG
ANIMATE
APT
SGMT
LEGD
RANGE
CHART
NORTH
HELP
UPD
AUTO
MAN
WORLD
POLR
ORD
MIA
ALT+
ALT-
CTR
PAN
ZOOM+
ZOOM-
Start
WINN
Covective, Volcanic Ash, Turbulence, Winds, Icing, Radar (conus only), Satellite, Lightning, and "Nowcasting" weather data are available world wide via automatic data link
Provides quality information for making better decisions
Enhances pilots' situational awareness
The WINN program automatically centers and tracks the aircraft's location or by manually panning to any location
UAL Sky-Pad

Electronic Documents

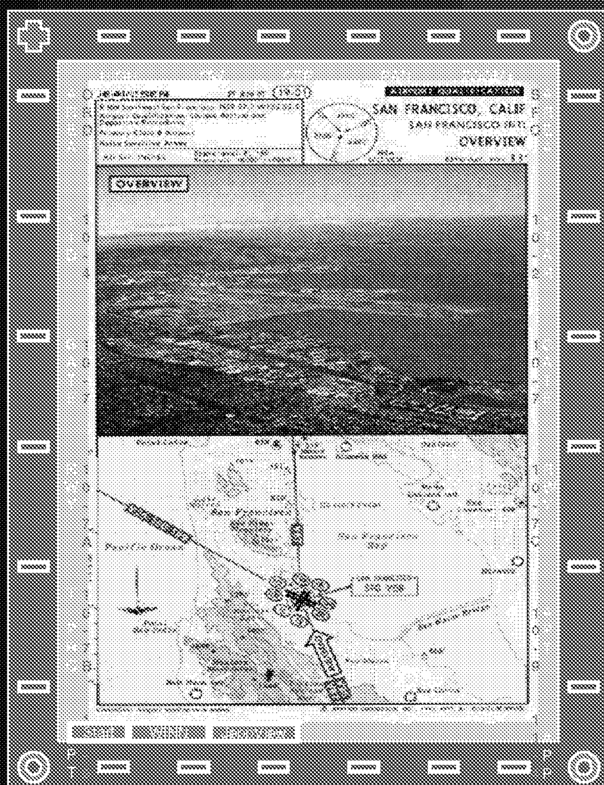
Jepp View

Origin airport tabs are displayed on the left side of document

The FMC's current flight plan route is displayed on to High, Low, Area, Departure, and Arrival charts

Waypoint functionality on charts is the same as on the Navigation Display

Emergency escape route documents for high terrain areas are available (E RTE)



JeppView interfaces with the FMC to select origin and destination airports' SID, STAR, runway data, emergency engine out procedures ("T Pro"), airport, and approach charts

Aircraft's printer provides copies of selected chart

Find and Help functions provide access to legend and glossary information

Innovations in flight

UAL Sky-Pad

Current EFB/AWIN Project

- Just finished 40+ segments on A320 in-service evaluation
- 90% mission success rate
- Average of 1-2% per leg gain due to increased wx enhancement!
- Trial Turbulence plot very successful (+5 min. notification in radar style graphics
- Potential reduction in 40-50% of ACARS traffic

UAL Sky-Pad

Current EFB/AWIN Project

- Cooperative agreement helped pay for product development of our system
- Fujitsu Pen Tablet, GPS, GTE Airphone
- Tested products included:
  - WINN-Lite graphical Weather software with NEXRAD, Turbulence, SAT, SIGMETS, TAFs. METARs, etc in GPS Geo-referenced moving map.
  - Full World Jepp plates with moving map ship's position overlay (including airport diagrams)
  - Digital FOM and AFM (from PUBTRAX)

UAL Sky-Pad

Innovations in flight

Current EFB/AWIN Project

- 3.3 lbs vs 48
- At home/hotel Unimatic/Apollo access
- 50/50 Line/TK crews in Test
- First ever Approved use of Internet Protocol to 121 Line service flight deck

UAL Sky-Pad

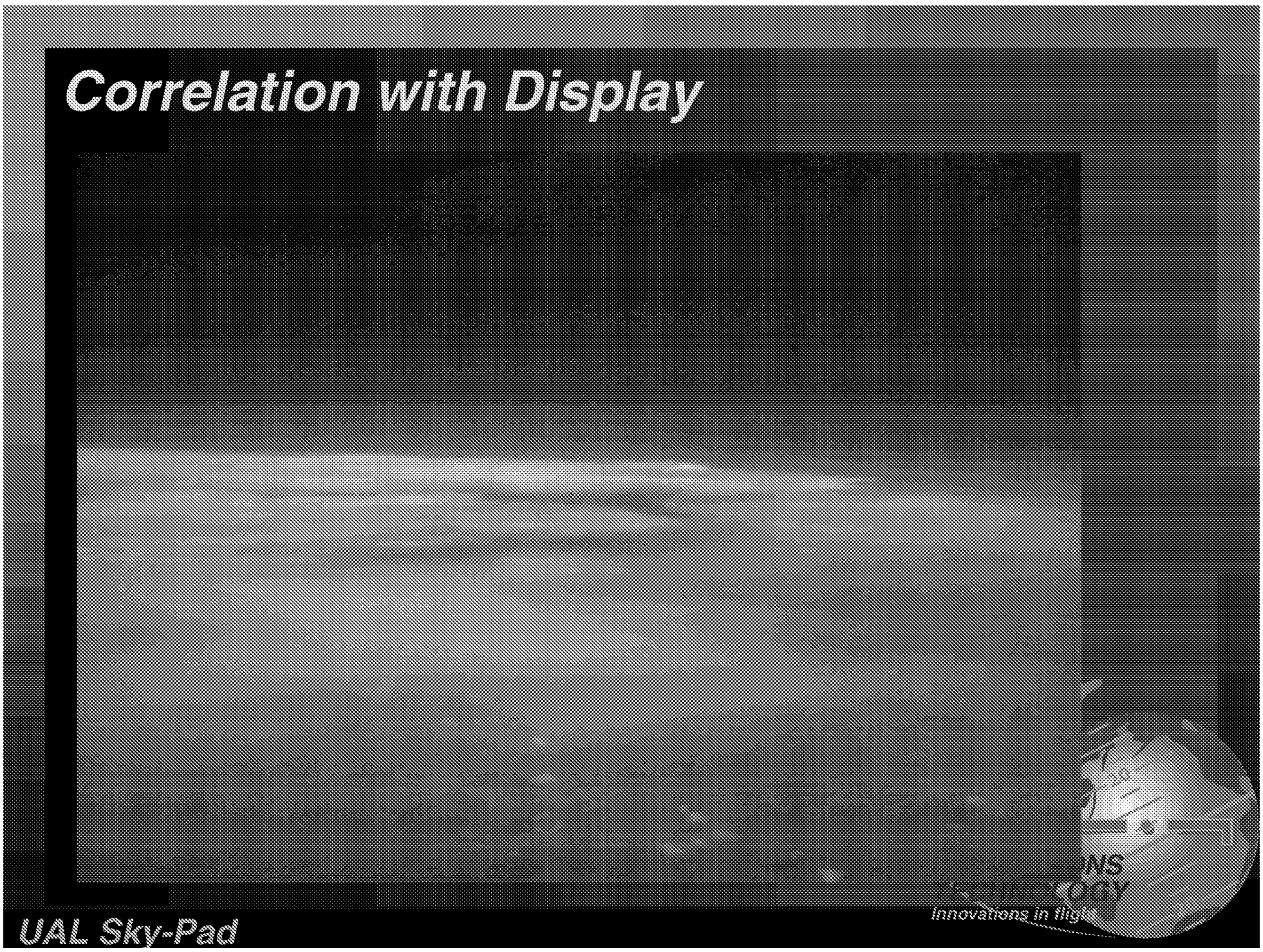
FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

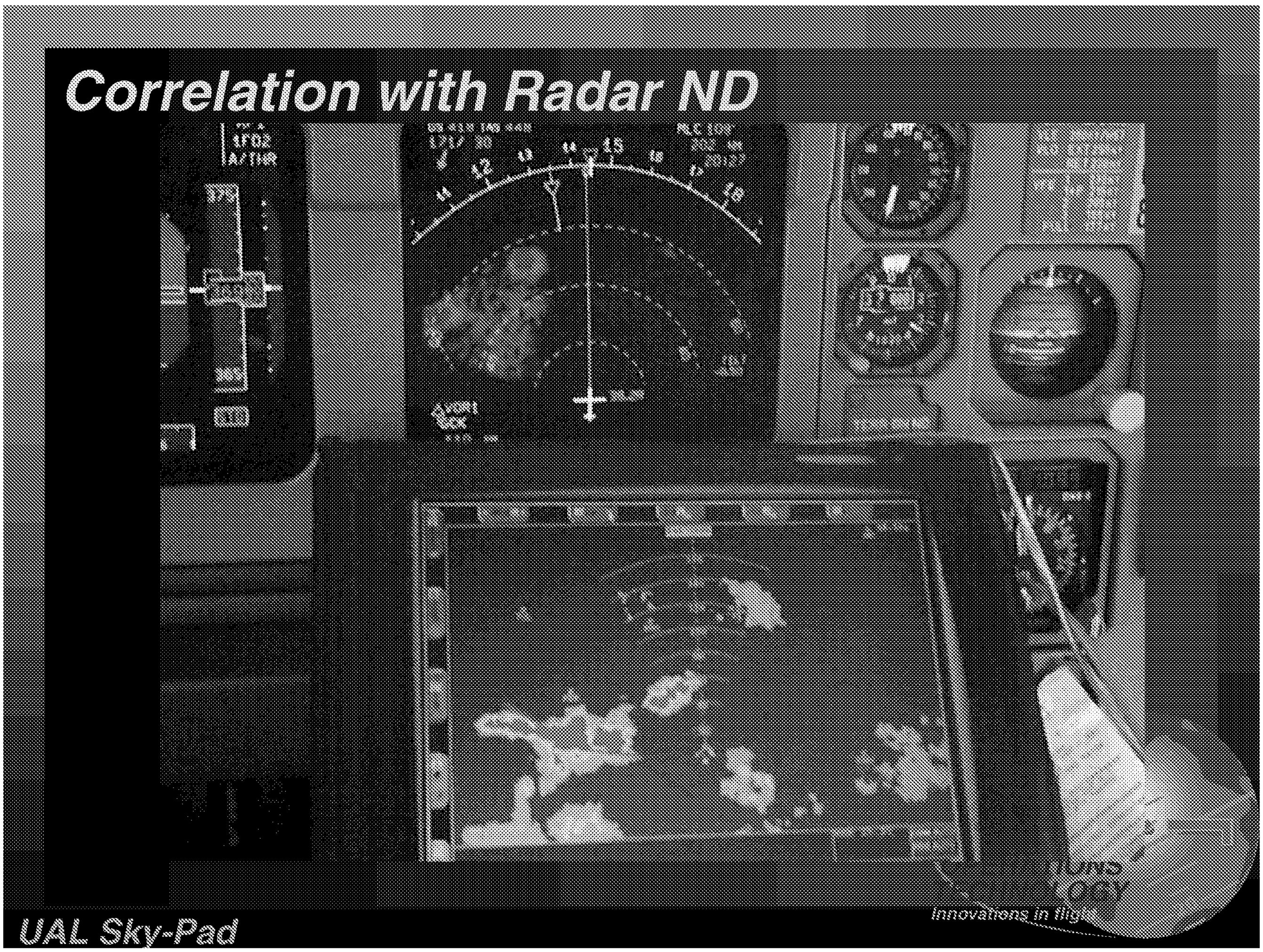
Joe and Dave with AWIN/EFB Unit

UAL Sky-Pad

Innovations in flight


Graphical Sigmets on WINN Display
UAL Sky-Pad
Innovations in flight


Correlation with Display
UAL Sky-Pad
Innovations in flight


Correlation with Radar ND
UAL Sky-Pad
Innovations in flight

Future "Sky-Pad" activity – Phase II

- Potential funding from FAA
- Human Factors design in Simulators
- Permanently mounted monitor (same size as Jepp Chart) or Tablet on moveable arm with FMS style keyboard attached to removeable docking station
- L-Band, VDL/2, or Airphone weather receiver, power interface
- All EFB functions, weather, and Moving Map situation display (runway inc
- STCs to be included

UAL Sky-Pad

Innovations in flight

Future "Sky-Pad" activity – Phase II

- 2 Airbus aircraft to be part of FAAs OpEval/3 next May
- Teaming partners include:
  - L-band sat –or- VDL/2 Network –or- GTE
  - Commodity weather, messaging, receiver
  - NASA – funding?, WINN weather software
  - FAA – funding and certification
  - FMS style display vendor
  - UAL – Project management, General Contractor, digitized manuals, charts, hf

UAL Sky-Pad

UAL "Sky-Pad" Fleet Deployment – Ph III

- A320/777 in 2002/2003
- All others in 2004-2005
- Includes – all paper docs, aircraft CBT, Weather Graphics, Wireless messaging, Animated Jepps, FMS position overlay, Moving Map, home access to all UAL network systems, home study and training, Bluetooth or RF airport link

UAL Sky-Pad

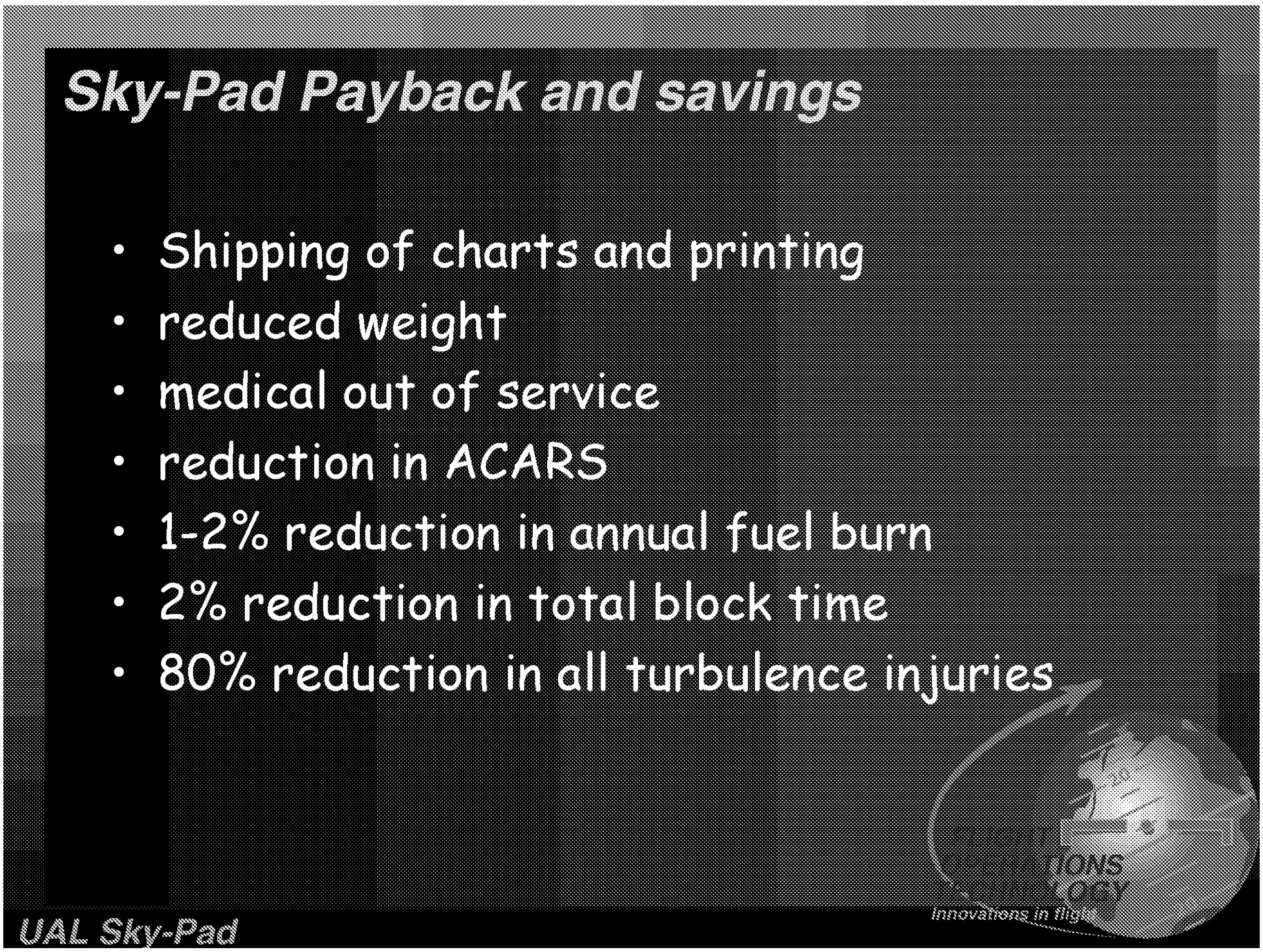
Innovations in flight

Phase IV – Broadband integration

- 2003-05
- Integrates with broadband server
- Total high speed internet appliance
- 80% of AOC communications
- Customer Resource Management
- Crew Resource Management

UAL Sky-Pad

Innovations in flight


Sky-Pad Payback and savings
• Shipping of charts and printing
• reduced weight
• medical out of service
• reduction in ACARS
• 1-2% reduction in annual fuel burn
• 2% reduction in total block time
• 80% reduction in all turbulence injuries
UAL Sky-Pad


Questions?

Enhanced Weather Radar and Aviation Weather Awareness & Reporting Programs

Kevin Kronfeld
EWxR Program Manager
Rockwell Collins
Advanced Technology Center

Rockwell Collins NASA Rockwell Science Center

NASA/CP—2002-210964

NASA/CP—2002-210964

Motivation

- Weather is the cause or contributing factor to nearly 25% of aviation accidents and 35% of fatalities.
  - *Improved weather information for pilots may break the chain of events that lead to an accident.*
- Weather is the number one source of flight delays in the United States.
  - *Improved weather information may provide pilots with a more efficient means of navigating around hazardous weather.*

Rockwell Collins NASA Rockwell Science Center

Background

- In 1998, NASA initiated the Aviation Weather Information (AWIN) program.
  - Enhance the safety and efficiency of aircraft operations by improving the availability and quality of weather information to the flight crews.
- September 1998, NASA, Rockwell Collins, and Rockwell Science Center started two cooperative research agreements, termed Enhanced Weather Radar (EWxR), Aviation Weather Awareness and Reporting (AWARE).
- January 2001, NASA, Rockwell Collins, and Rockwell Science Center began development of the Airborne Hazard Avoidance System (AHAS).

Rockwell Collins NASA Rockwell Science Center

EWxR

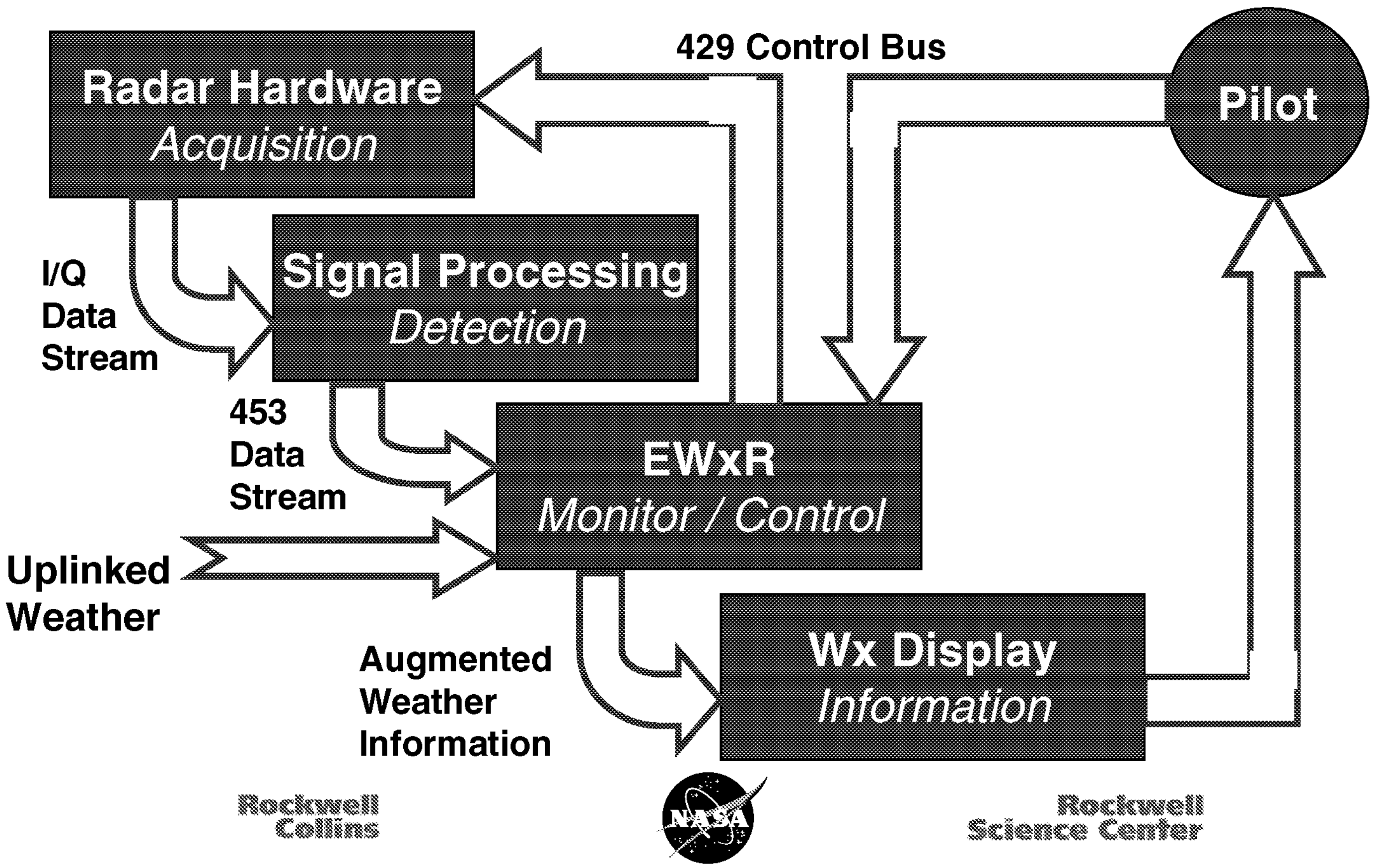
- 1999 Accomplishments:
  - Track storms.
  - Determination of storm dynamics, such as speed and heading.
- 2000 Accomplishments:
  - Integrate NEXRAD image data into ARINC 453 video data format and display it on a standard radar indicator, multi-function display (MFD), or xVGA monitor.
  - 9/24/00 - Successful flight test on NASA's 757.
- 2001 Accomplishment
  - Flight plan analysis

Rockwell Collins

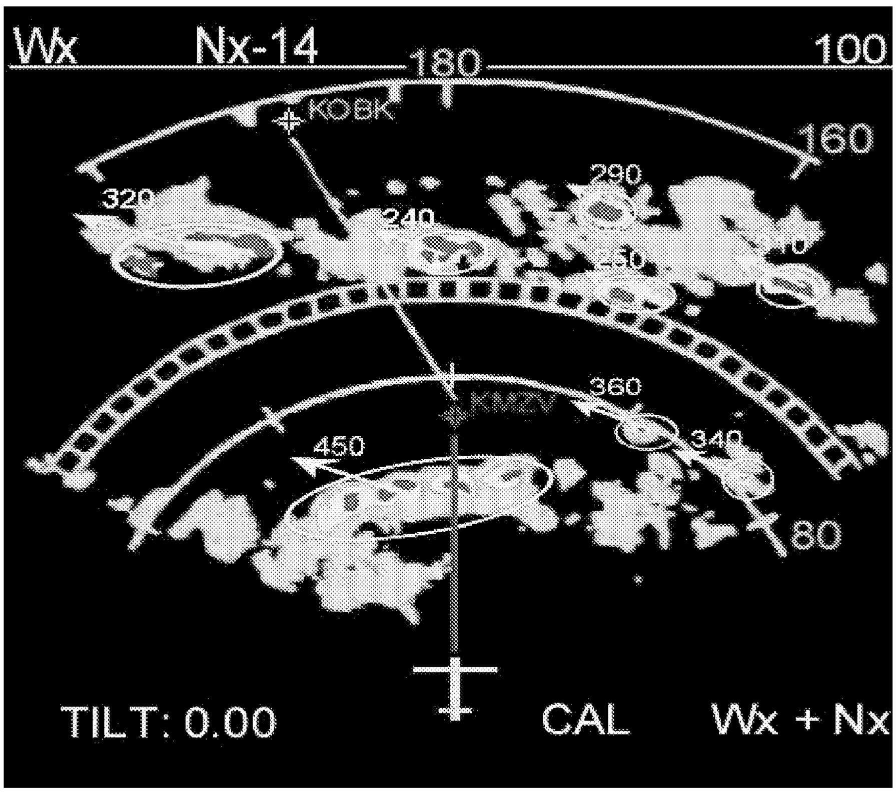
NASA

Rockwell Science Center

EWxR Processing



EWxR Display



Rockwell Collins

Rockwell Science Center

AWARE

- 1999 Text -> Graphics interpretation and decision analysis.
  - METARs and SIGMETs.
- 2000 Experimental NCAR products integration.
  - Icing, turbulence, convective weather products.
- 2001 IFR Summary Display Implementation.
  - Implement IFR Summary Display.
  - Incorporate Area Forecast data into Hazard Analysis model.
- 2001 PIREP Integration.
  - PIREP integration.
  - Hazard Analysis for IFR pilots.
- 2001 Demonstration on NASA 757.

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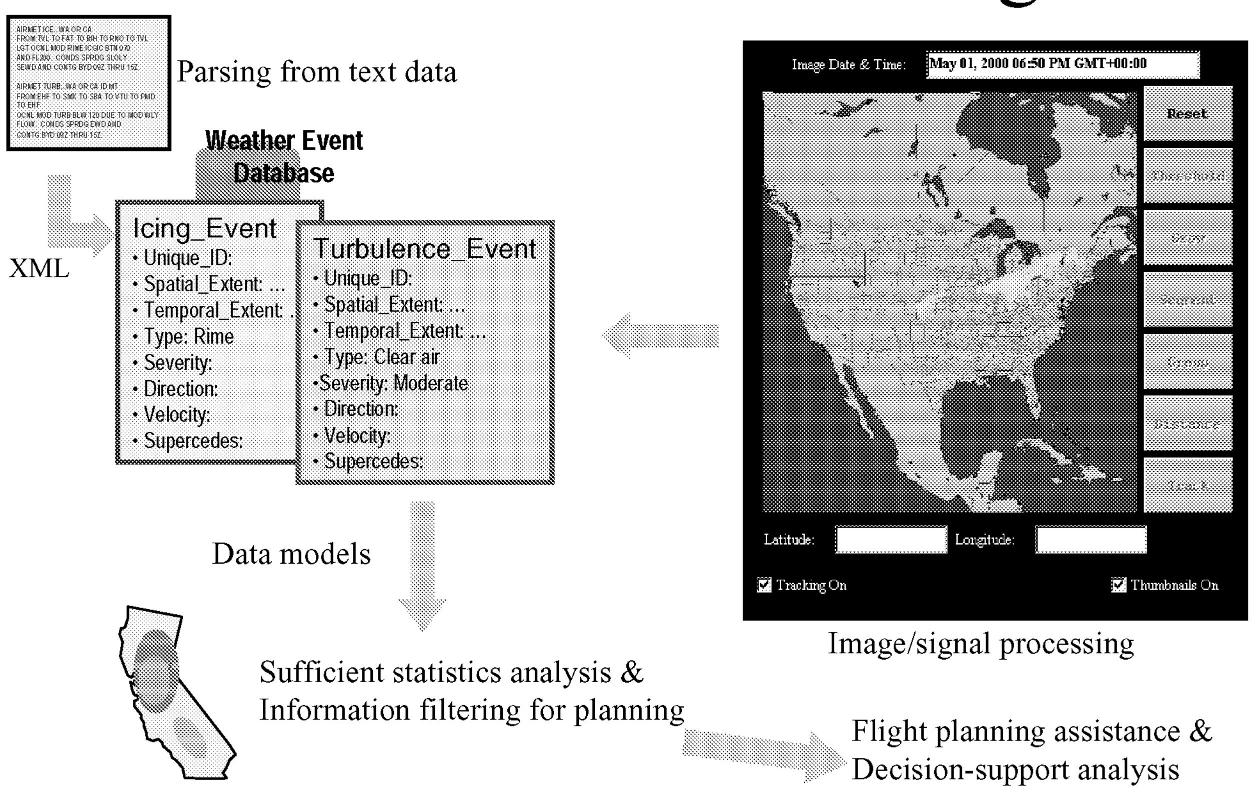
AWARE Processing



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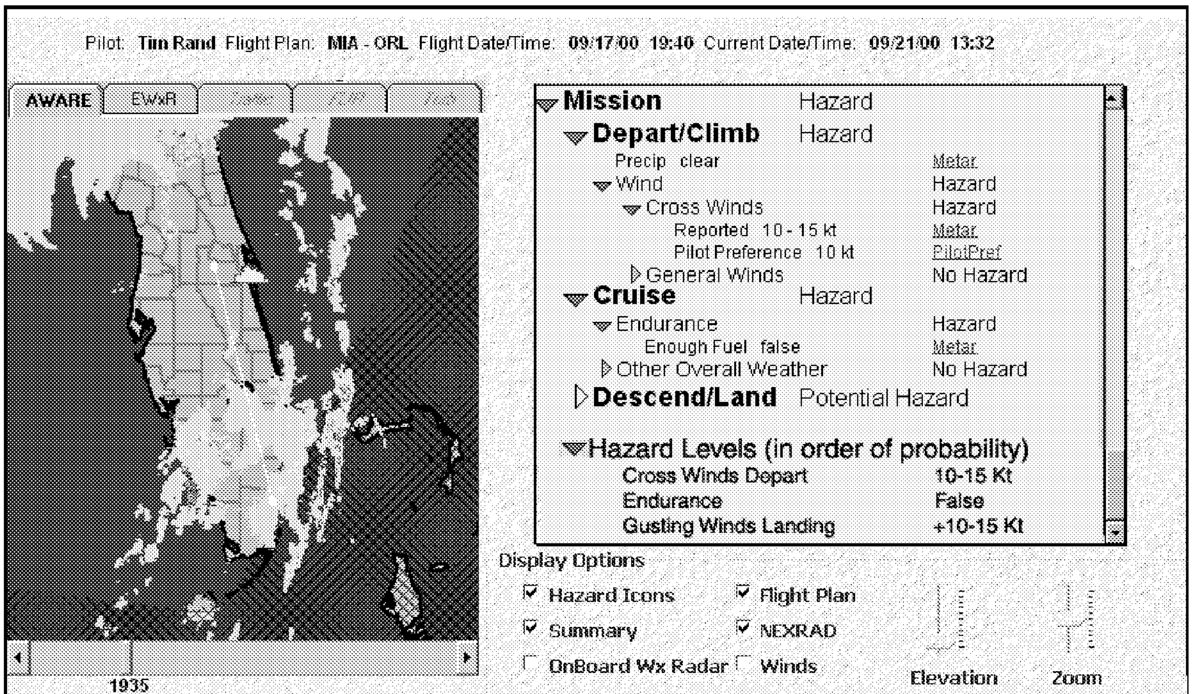
AWARE Display



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KMIA 180202Z 00000KT 10SM FEW026 SCT070 BKN150 23/22 A2998 RMK AO2= (SPECI)

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AHAS

- Develop flexible COTS-based platform with aircraft interfaces necessary for operational evaluation of:
  - AWIN systems
    - EWxR display formats, storm analysis, flight plan analysis logic
    - AWARE weather analysis and decision aids
  - Integrate new datalinked weather products from the AWC.
  - Integrate new atmospheric hazard sensors, such as the TDAM experiment.

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Further Studies

- What ranges are useful for display of NEXRAD on a weather radar indicator?
- What will be the effect of simultaneously displaying radar data taken from different angles and altitudes?
- How well does the data from from various weather data sources correlate?
- What NEXRAD update rate is necessary and how much latency is acceptable?
- Which weather product(s) will be most useful?

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Further Evaluations

- Continue experiments of EWxR, AWARE, and AHAS systems on NASA's 757 through Fall 2001.
- Fall 2001 - Participate in FAA's study of utility of ground-based weather information in the cockpit.

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Satellite Weather Information Service

June 5, 2001 Update

R. S. Haendel

Rockwell Collins

NASA/CP—2002-210964

Agenda

- Overview
- Program Phases
- Phase 1 Description
- Phase 2 Aircraft Configuration
- Satellite World Wide Coverage
- Team Members
- Phase 2 Status
- Weather Graphics
- Air Coverage
- Data Routing and timing
- Weather Benefits

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Overview

- In-service evaluation of real time graphical weather information on flight deck
- Provide updated graphical weather to pilots while enroute for strategic flight decisions
- Trials to verify commercial benefits and technology feasibility
- End solution is to provide wide area coverage for all classes of aircraft

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Program Phases

- Phase 1, Installed on single engine aircraft
- Phase 2, Installed on two revenue service Air Transport Aircraft
  - - Transoceanic routes
- Phase 3 Plan, Install on 6-15 aircraft, all types
  - Transcontinental routes
  - CONUS operations

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Program Phases

Phase 1. Verified that geostationary satellite can provide a sufficient signal level to aircraft using a fixed pattern antenna.

- Trials in South Africa in September, 1999
- Cessna 182 aircraft, Afristar satellite

Phase 2. Validate the usefulness and pilots preferences of real time weather data

- Routes to the Pacific rim with American Airlines B777-200.
- Trials beginning June 2001, using Asiastar satellite

Phase 3. Planned extended trials to include Air Transport, Business, and General Aviation in USA and South America

- XM radio or other satellite (USA) , Early 2002.
- Ameristar satellite (S. America) , July 2002

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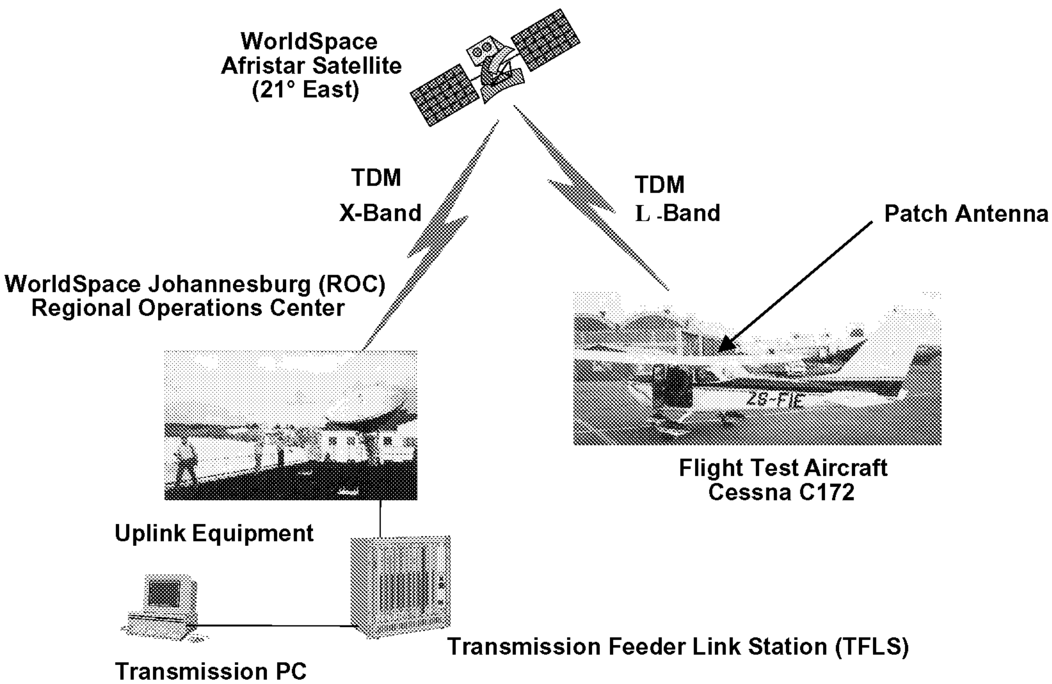
Phase 1 System



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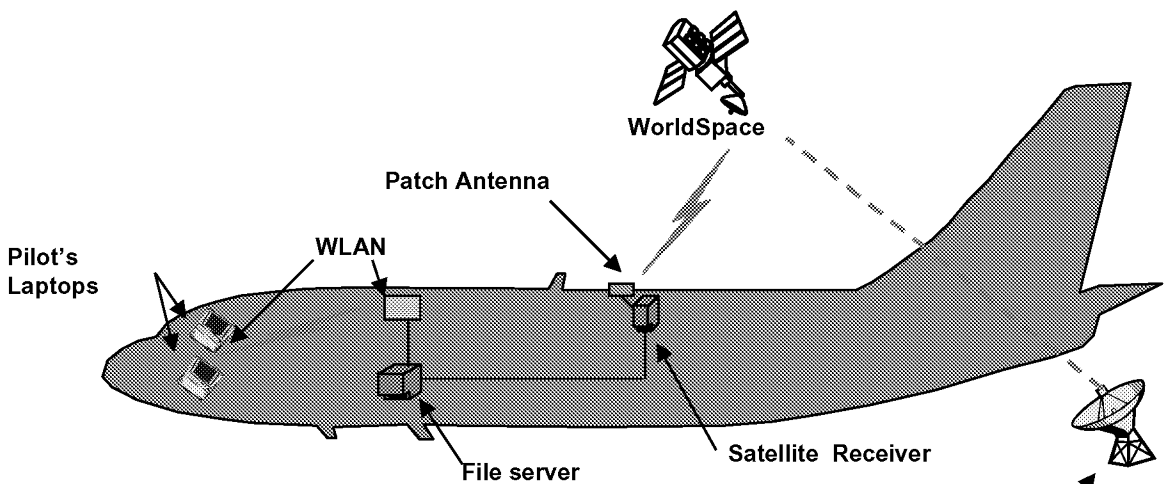
Phase 2 System Configuration



- Laptops
- File Server
- Satellite Receiver
- Low Cost Antenna
- Wireless LAN

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Geographical Coverage

WorldSpace satellites located at:

- Africa serves entire Africa and some Europe
- Asia, serves all of Pacific rim from Korea through Malaysia China and Eastern Russia, India, etc.
- Central America (2002), serves S. American and Caribbean

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WorldSpace Coverage Areas

(NOTE: AmeriStar footprint shown pending frequency coordination outcome)

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Phase 2 Team Members

- Rockwell Collins
  - Data Storage, Displays, Receivers, Antennas, Integration, STC, Data Reduction and Analysis
- WorldSpace Corporation
  - Satellite channel, Receiver card, Ground Station Feed
- Jeppesen
  - Weather Products & Laptop Software
- American Airlines
  - STC Installation Support, Flight Test and Evaluation

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Phase 2 Status

- Systems installed on two American Airlines B777-200. STC approved by FAA. Aircraft now in revenue service.
  - System includes:
    - **Patch antenna,**
    - **Satellite receiver,**
    - **File Server Unit (FSU),**
    - **Avionics Secure Interface Unit,**
    - **Wireless LAN network and**
    - **Pilot laptop computer(s)**
    - **Approved Software**
  - Test Coverage uses Asiastar NE Beam.

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Weather Graphics

- Winds and Temperatures aloft
  - Flight Levels 050 through 450
- Surface Weather (Ceiling, Winds and Visibility)
- Hi-level Significant Weather
- Visible and Infra Red satellite imagery
- Surface analysis
- Update rate varies from once per hour to once per 6 hours
  - Specific to type of graphic
- All weather graphics have track file and aircraft position overlays, zoom capability.
- Detailed geographic features and airport diagrams can be inserted by pilots as needed.
- File server provides "time lapse" weather movement graphics as called for by pilots

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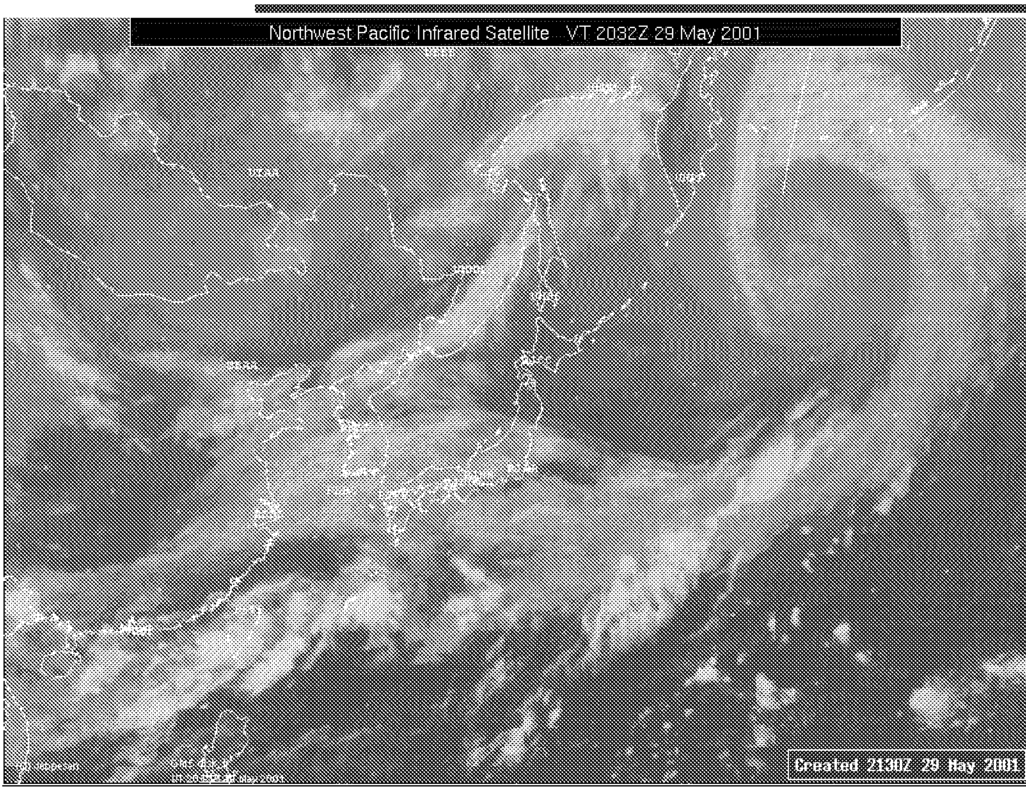
Satellite Infrared Imagery



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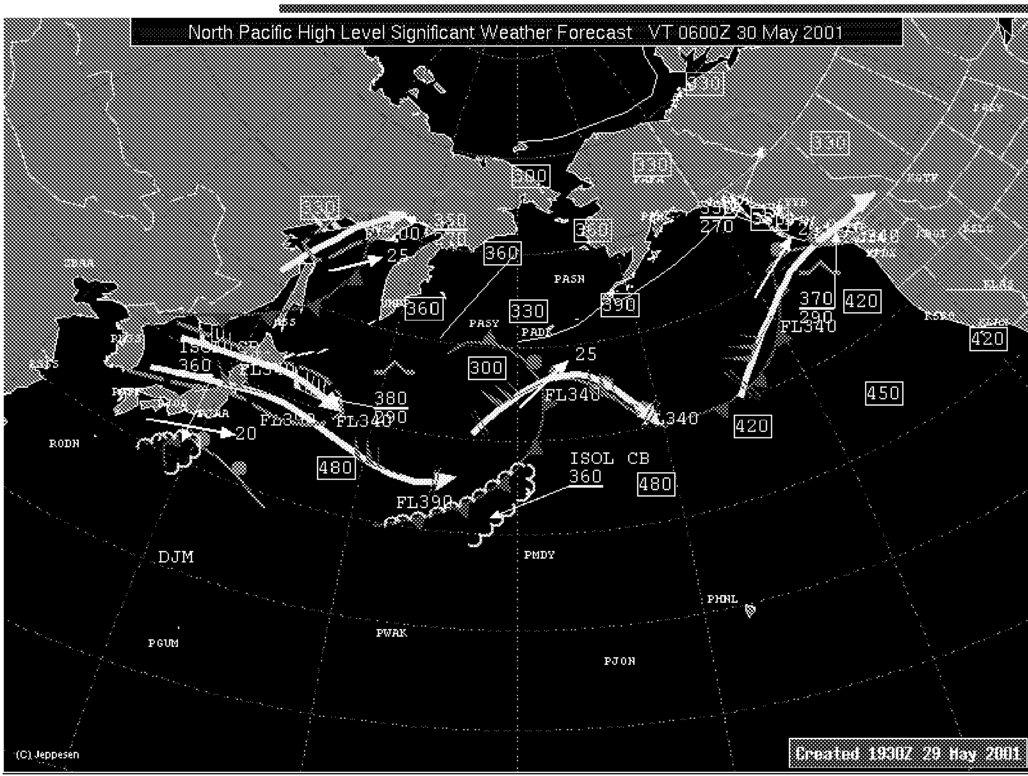
N. Pacific High level Significant WX



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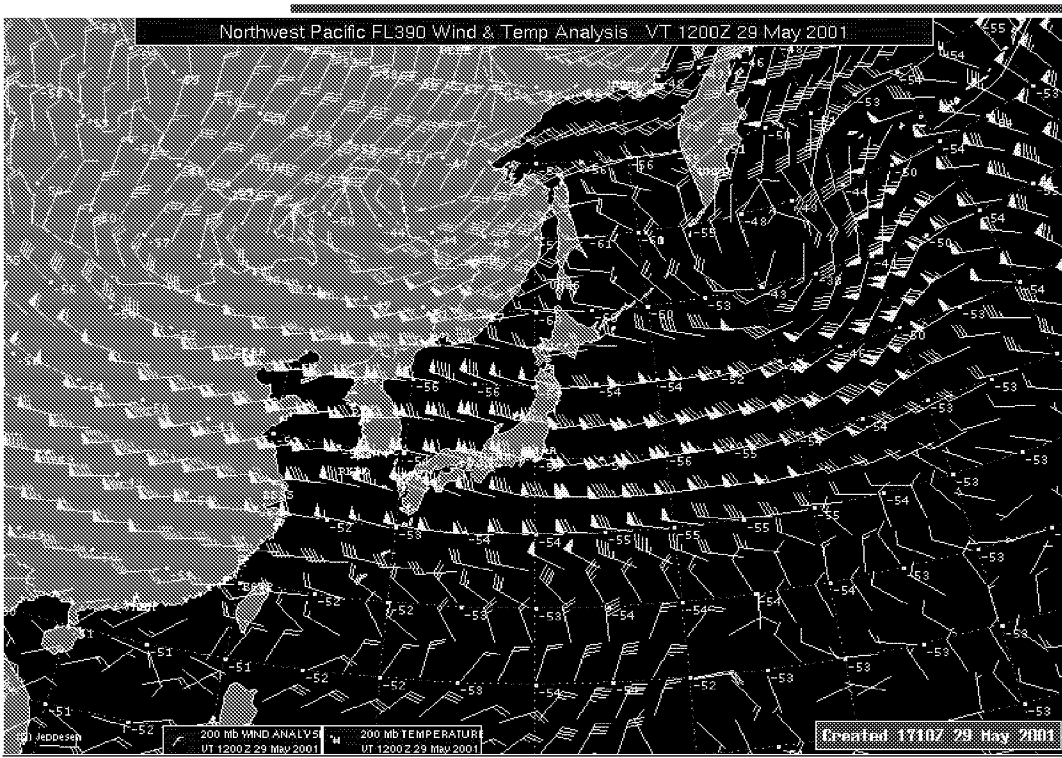
Winds & Temps Aloft at 39,000 ft



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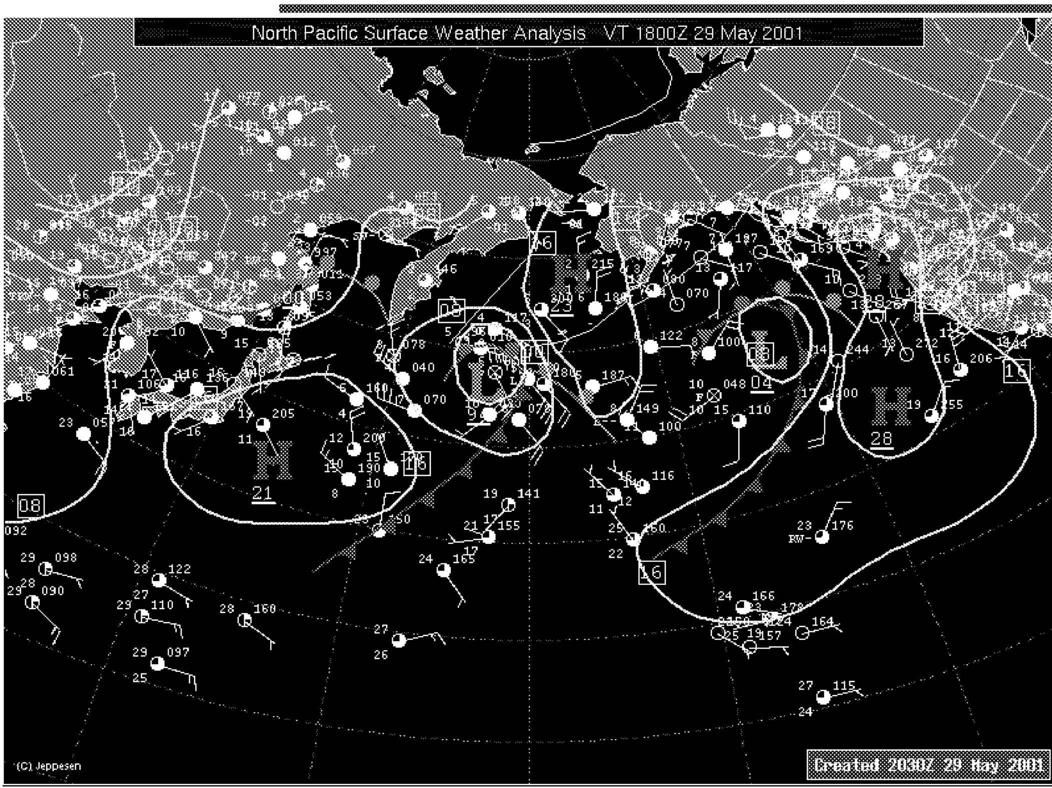
Surface Analysis



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Air Coverage and Pilot Updates

- Two B777-200 aircraft operate as needed for all long haul routes for American Airlines.
  - These aircraft are not restricted only to Trans-Pacific routes.
- City pairs presently covered include:
  - Chicago, Dallas, San Jose CA to/from:
  - Narita, Osaka and Taipei.
- System provides coverage using NE Asiastar Beam (see map)
  - Coverage enroute up to 5 hours.
- Pilots get same material on the ground via AA's company Intranet at both ends of the routes.
- Analysis data obtained from Questionnaires and FDRs.

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Data Routing

- Jeppesen generates weather graphics at scheduled intervals at Los Gatos, CA.
- Graphics are encoded and sent to WorldSpace GES in Melbourne, Australia and American Airlines in Dallas via Internet FTP.
- Melbourne GES uplinks each file to satellite 3 times at short intervals.
- Satellite transmits data at 64 Kbits/second.
- Satellite receiver recovers files, checks data validity and transfers valid data to File Server Unit (FSU) for storage.
- FSU manages data files and makes files available to pilot via WLAN on aircraft. FSU maintains aircraft position and time. Provides information to laptop to allow aircraft to be plotted on graphics.

- Time delay from Jeppesen to Aircraft is less than 60 seconds.
    - Satellite typical transmission time - 2.5 to 8 seconds

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Weather Benefits

- American Airlines has keen interest in adverse weather.
  - Early flight change decisions based on weather data leading to:
    - Higher on-time arrival rates
    - Improved fuel savings
    - More comfortable ride to passengers (avoid turbulence)
  - Better weather data for remote routes such as South America and Pacific rim.
- Enhanced flight safety
  - Reduce number of injuries due to unexpected turbulence.

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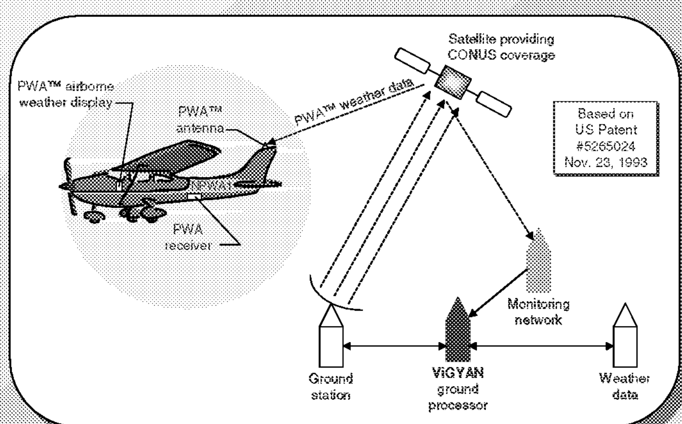
PILOT WEATHER ADVISOR™



Rockwell Collins

Keith D. Hoffler
757-865-1400x221
keithh@vigyan.com
Hampton, Virginia

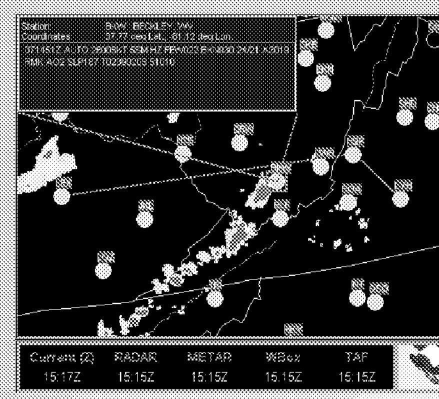
NASA Weather Accident Prevention Workshop June 4-7, 2001

PWA Briefing_03_01

Keith Hoffler
757-865-1400 x221

Outline

- Brief history of Pilot Weather Advisor™
- Pilot Weather Advisor™ - SBIR Phase III
  - System overview
  - Work planned
- Commercialization of Pilot Weather Advisor™
- Concluding remarks



NASA Storms Hazard Program

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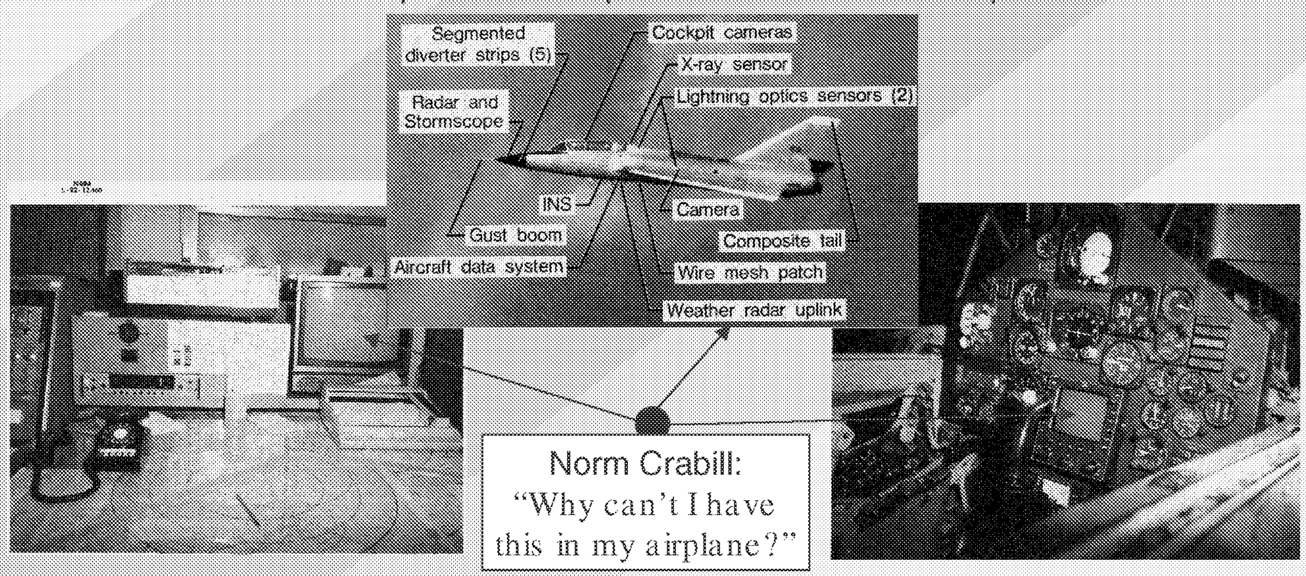
- 1978: Program initiated
- 1982: Uplink RADAR data to NASA F-106
- 1988: White paper for FAA "Cockpit Weather Research, Development and Applications-Survey and Recommendations," Dec. 1988, Branstetter and Crabill
- 1989: System studies of uplinking Wx data to cockpit
- 1991: Weather Data Requirements Report: DOT/FAA/RD-91/9 April 1991



SBIR Phase I and II

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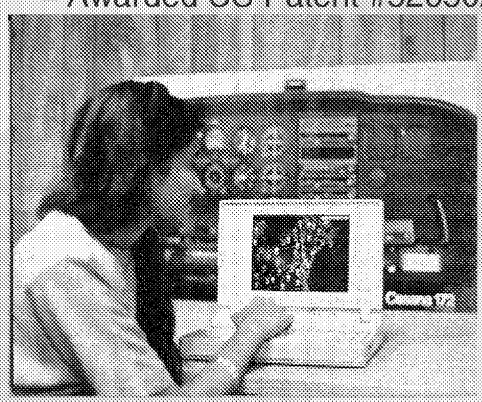
- Phase 1 awarded Dec. 1990 by NASA Langley Research Center
  - Developed display icons and system architecture
  - Demonstrated system using Qualcomm's Omnitrac Satellite system aboard a Piper Malibu (fixed map)
  - Briefed NASA LaRC in '91 (NASA CWIN followed)
- Phase 2 awarded Dec. 1991 by NASA Langley Research Center
  - Developed and demonstrated GPS based moving map in C-182
  - Demonstrated cell phone based datalink before takeoff in a C-182
  - Developed business plan and sought satellite provider
  - Awarded US Patent #5265024 on Nov. 23, 1993



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Since SBIR Phase II

- Matured system and business components for commercialization
  - Weather data
  - Airborne antenna and receiver
  - Datalink
  - Multi-function display and electronic flight bag
- Serve on RTCA SC-195 committee developing FIS-B MASPS
- Revised client software and ported to CT-1000 and Flight Guide 3000
- Demonstrated in Cessna 182 using satellite phone
- Updated broadcast schedule – from every 15 minutes to 5 minutes
- Developing concepts for additional weather products
  - Lightning
  - Turbulence and icing
  - Winds aloft
  - Others
- Developed revised business plan
- Seek investment
- SBIR Phase III awarded by NASA Glenn – March 2001

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Multi-Function Displays

- GA instrument panels are currently experiencing dramatic changes
  - Satellite navigation, GPS
  - Affordable daylight readable displays
  - FAA's interest in benefits of new technology (FIS-B)
- Multi-Function Displays are becoming widely accepted
  - Panel mounted, portable
  - Wide cost range, applicable to all market segments
  - Ingest, process, and display various types of information
    - Present uses
      - Moving map
      - Engine monitoring
      - Attitude instruments
      - Onboard weather
    - Future capabilities
      - Datalinked weather
      - Traffic
      - Terrain
      - ATC directives

Avidyne display installed in Cessna 182

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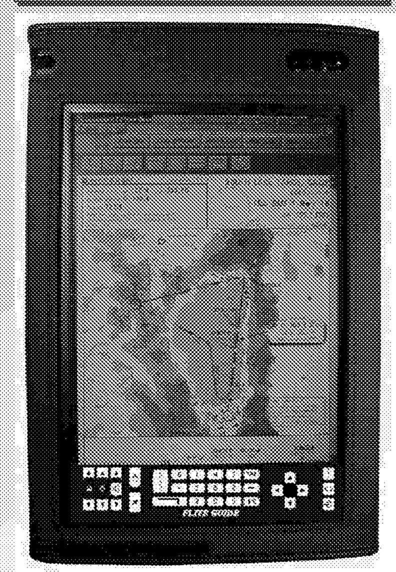
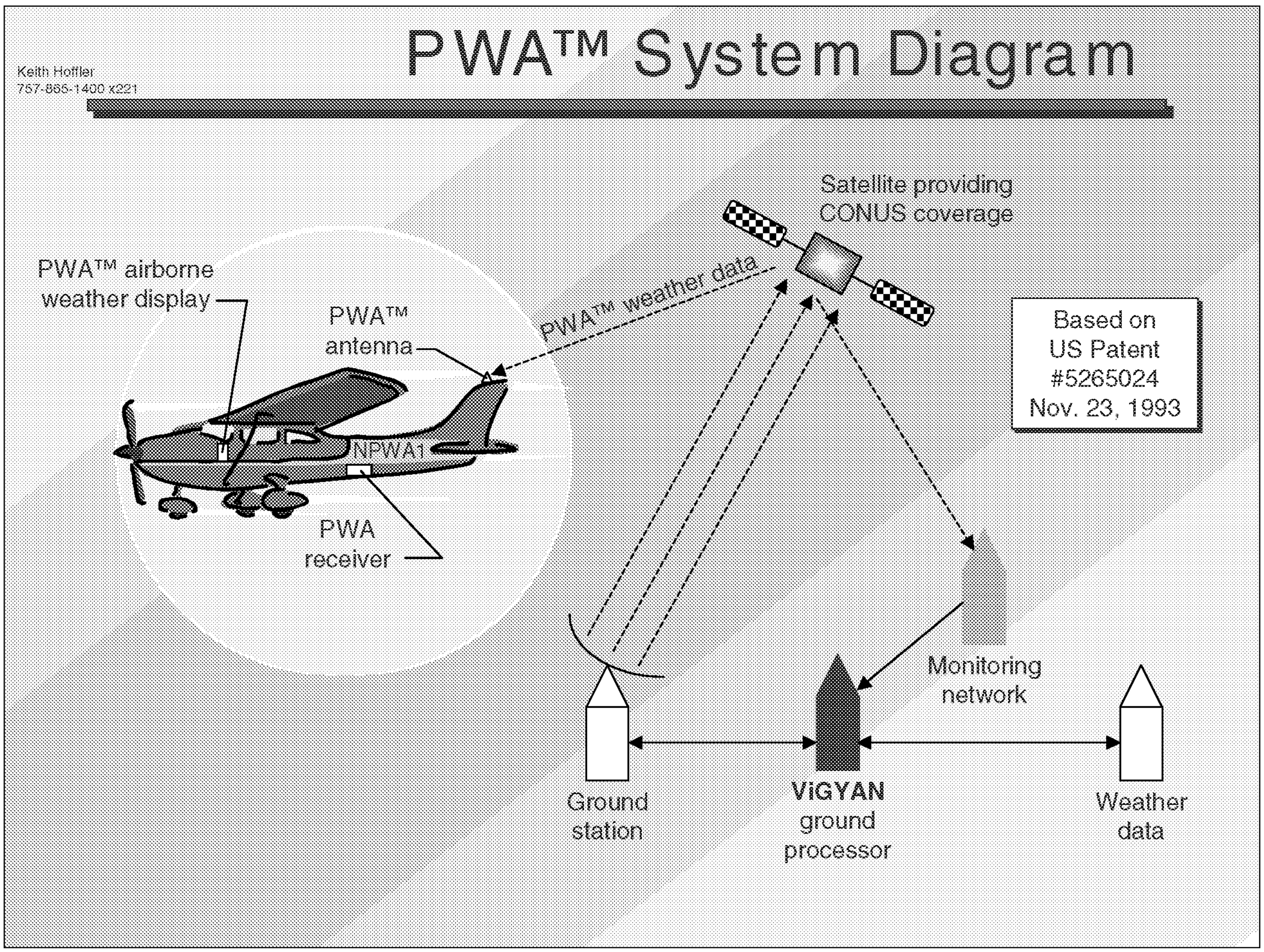
Electronic Flight Bags

Northstar CT-1000

ADR Flight Guide 3000




PWA™ System Diagram
Keith Hoffler
757-865-1400 x221
Satellite providing
CONUS coverage
PWA™ weather data
PWA™ airborne
weather display
PWA™
antenna
NPWA1
PWA
receiver
Based on
US Patent
#5265024
Nov. 23, 1993
Monitoring
network
Ground
station
ViGYAN
ground
processor
Weather
data

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Work Planned

- Conform to FIS-B MASPS and MFD platform requirements

- Develop Hardware
  - Satellite link design: hub and receiver
  - Antenna design and qualify
  - Electronic flight bag
    - CT-1000
    - FlightGuide 3000
  - MFDs

- System Integration and Testing
  - Ground Integration Testing
  - Aircraft In-Flight Evaluations (begin October 2001)

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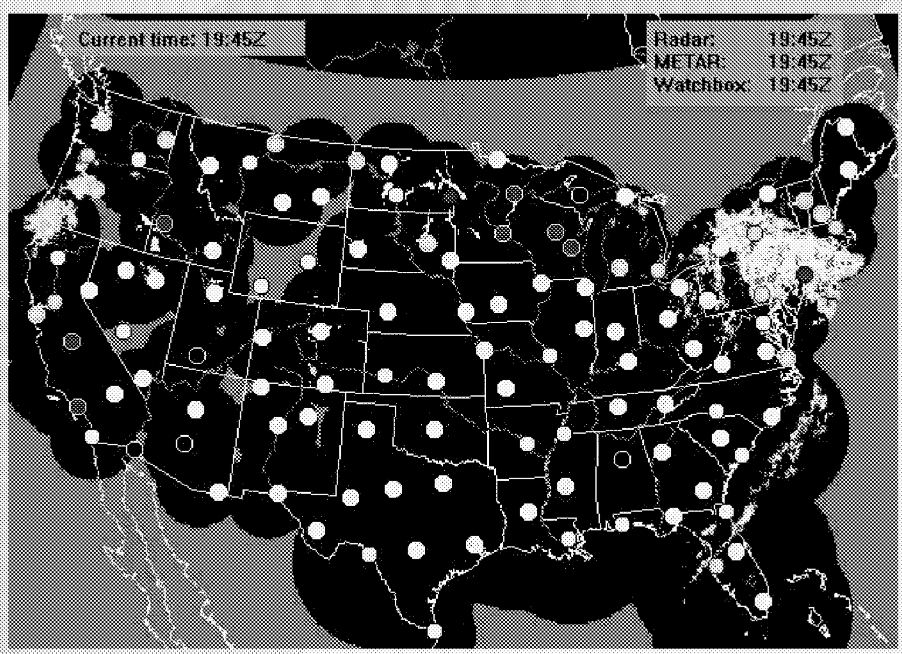
PWA™ Coverage

- Full Continental US coverage at all altitudes
- All US data
  - Composite radar
  - METARs
  - TAFs
  - Other



PWA™ Images From CT-1000

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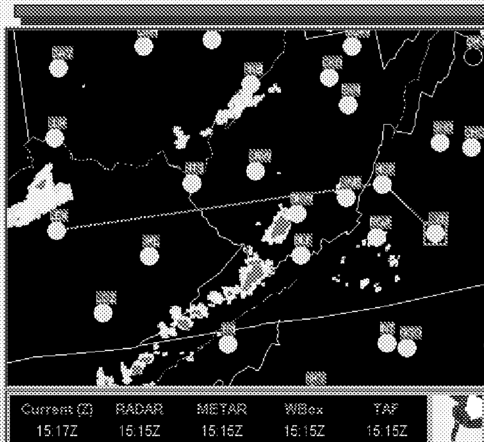
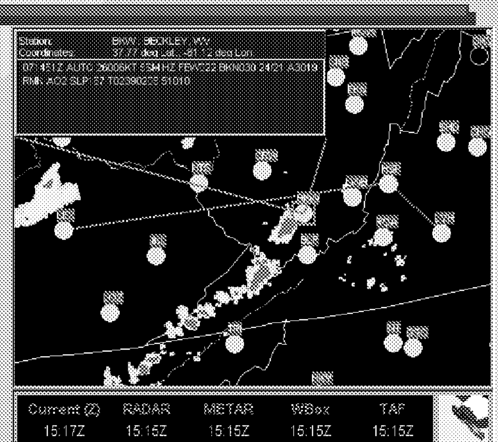
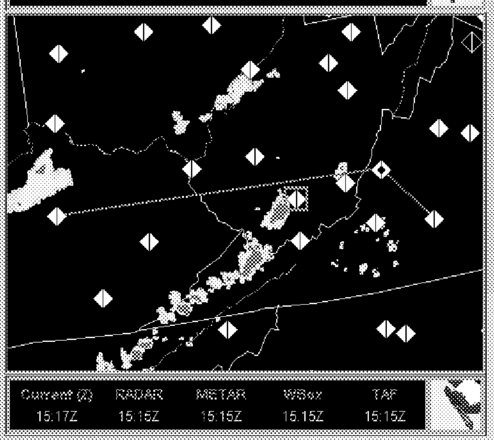
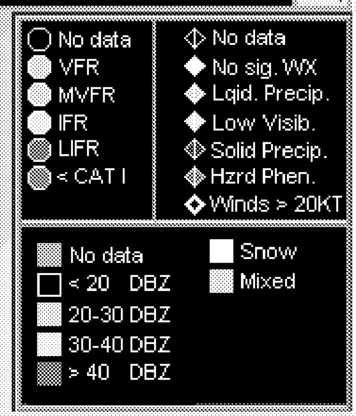






- Colors now compliant with RTCA SC-195 FIS-B MASPS
- Higher resolution radar image (2km grid)
- CT-1000 initial user interface developed
- 5 minute update rate



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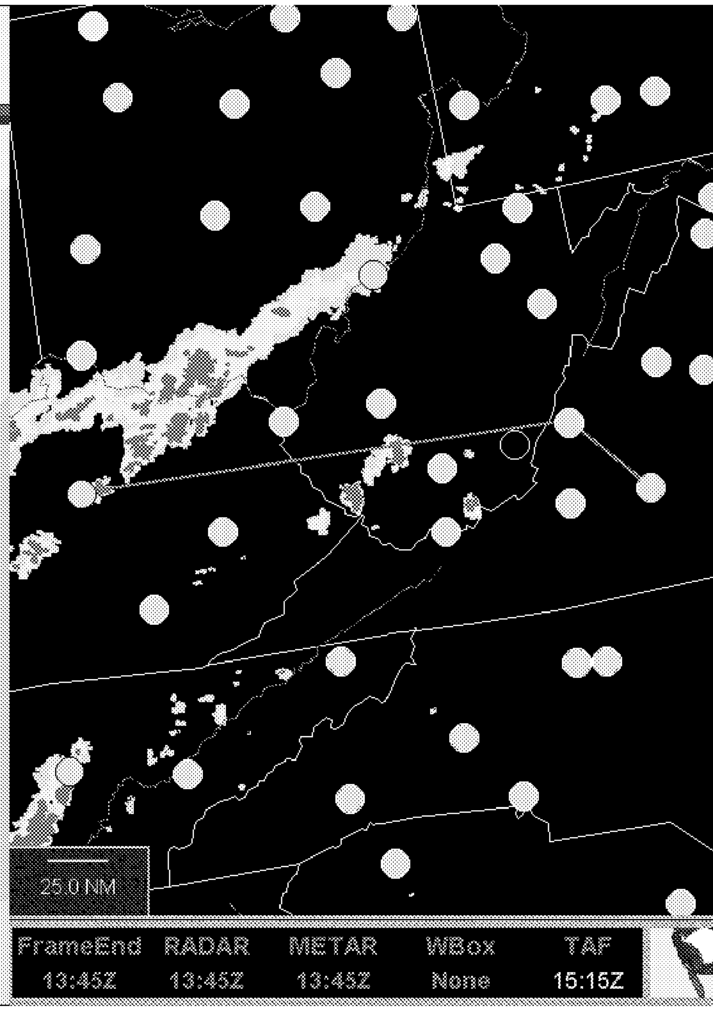
PWA™ Animation Loop



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PWA™ Commercialization

- ViGYAN has formed **Indra Systems** to commercialize PWA™
- Expect to make first announcement at Oshkosh, 2001
- Flight evaluations begin October 2001
- Limited sales late in 2001
- Expect certification in first quarter of 2002
- Expand to marine and other markets
- Additional weather products in the future

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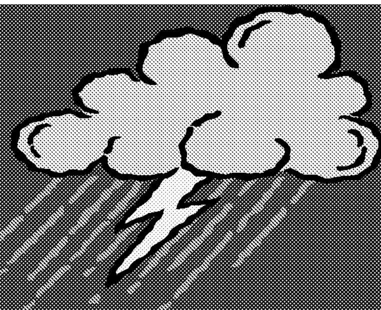
Concluding Remarks

- Pilot Weather Advisor™ system will be a NASA R&D and SBIR success story
- System provides continental US coverage at all altitudes
  - All continental US data
  - Automatic continuous updates
- Initial flight evaluations expected in October 2001
- **Indra Systems** has been formed to commercialize the system



The Results of the Evaluation of Using Lightning Data to Improve Oceanic Convective Forecasting for Aviation

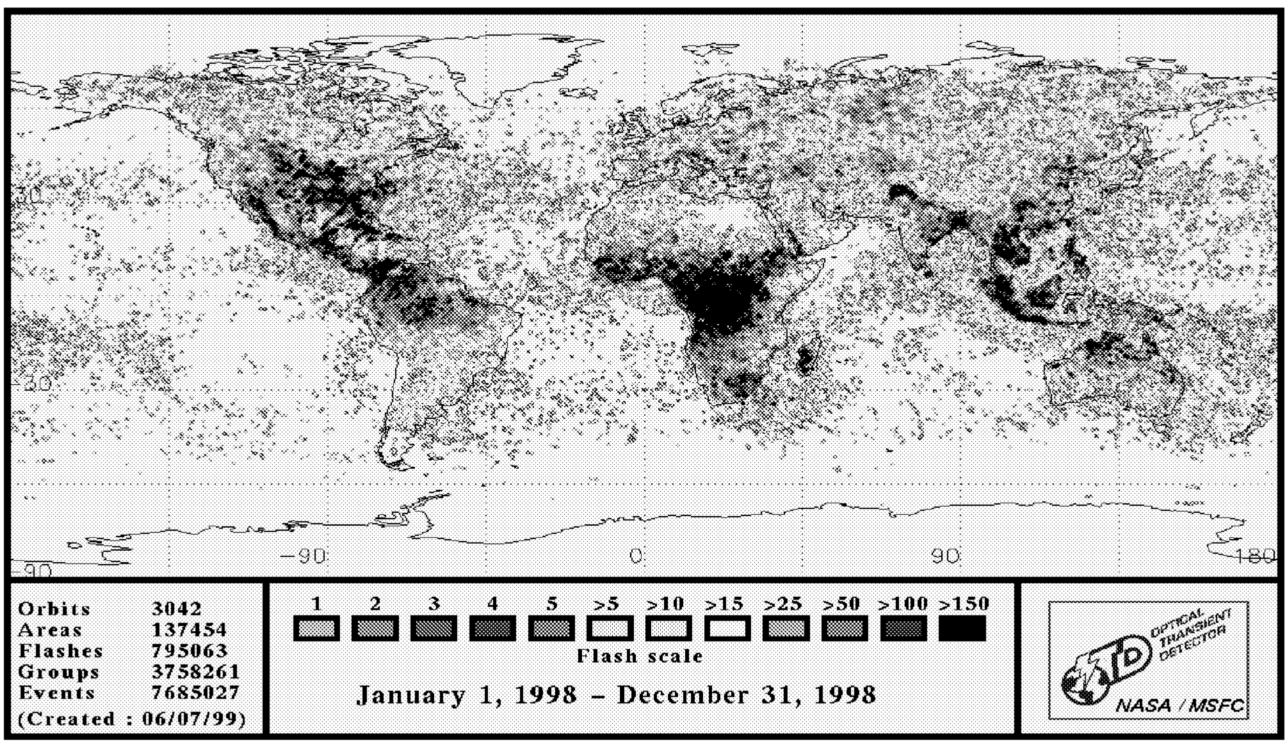
Wx Accident Prevention Review (NASA)

Cleveland, Ohio

June 5, 2001

Dr. Alan Nierow - FAA (alan.nierow@faa.gov)

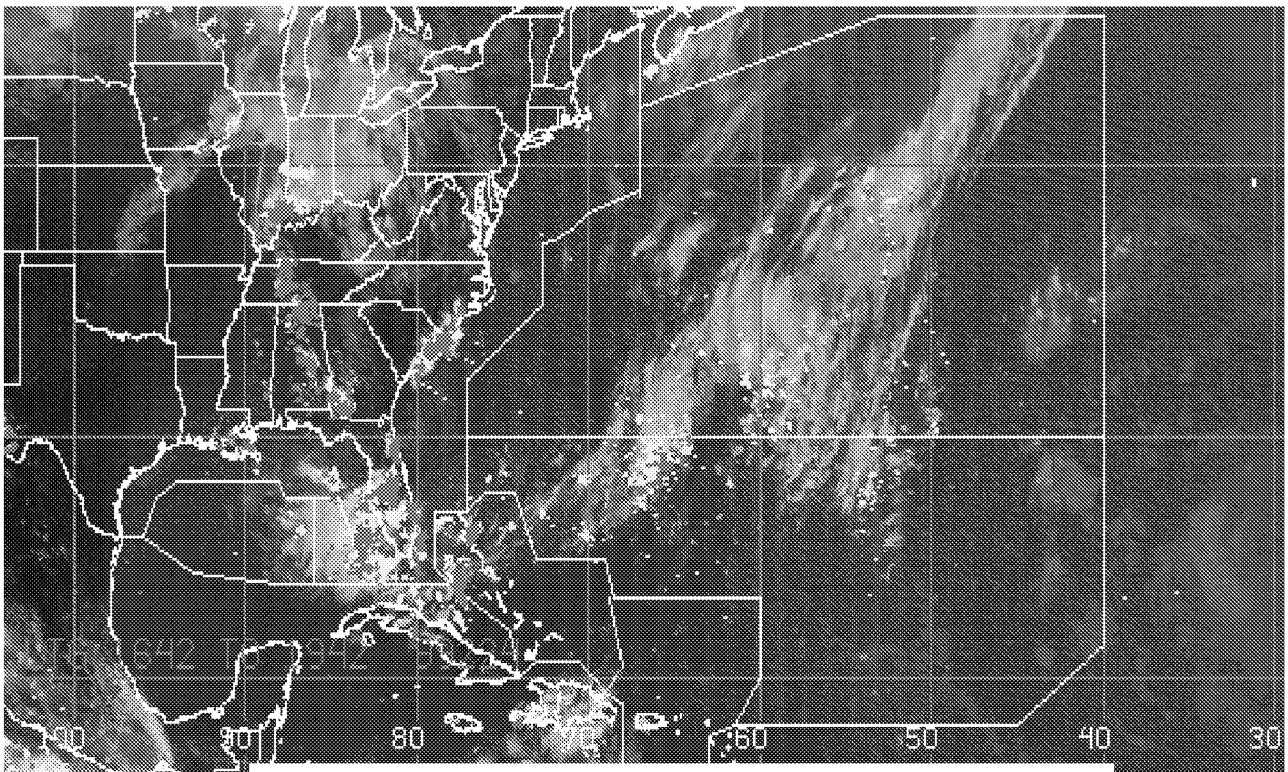
TOTAL LIGHTNING FROM NASA's OTD (1998)



Oceanic Lightning Experiment

- **WHY:**
  - International Convective SIGMET Coverage (by AWC)
  - Explore possible requirement from other agencies
- **WHO:**
  - Sponsors: AWC, Global Atmospherics Inc (GAI) & FAA.
  - Networks: U.S., Canada, France, Germany & Japan.
- **PARTICIPATION:**
  - FAA → Oceanic ARTCCs (OAK, NYC) + MIA/JAX
    - CWSUs & Traffic Managers
  - Other → NWS/DoD/Airlines for Evaluation
- **WHERE:** Gulf of Mexico, Atlantic & Pacific regions
- **DURATION:** April 1999 - January 2000

NOTE: NASA's AWIN Safety program investigating feasibility of displaying lightning data in cockpit



AWC product (Atlantic sector)

Need for Extended Coverage for

International Convective SIGMETs

Participants' Responses

ENHANCED SAFETY

- **AIRLINES - Yes, the only real-time tool available to meteorologists/dispatchers is satellite imagery which users often have trouble interpreting.**

- **NWS/FAA - This product can identify concentrated areas of convection outside of previous limitations, it most certainly has the potential of enhancing safety.**

- **DOD - Helps us avoid areas of turbulence caused by convection which cannot be predicted by current weather models.**

- **FAA - The ability to better predict and avoid areas of severe weather will increase the safety of flights.**

Participants' Responses (cont'd)

INCREASED EFFICIENCY

- **AIRLINES - Knowing where the convective areas are enhances pre-flight planning which will save fuel...the product should be available to ATC, pilots and dispatchers.**
- **NWS/FAA - An oceanic weather short-term planning product (similar to convective SIGMETS) could be developed as a result of this product.**
- **DOD - Fuel savings and better routing would also result from the product.**
- **FAA - This product can allow controllers to slightly alter the routings if needed and keep the traffic flowing smoothly. There will be much less "reaction" to weather events based on PIREPS and deviation requests.**

Results of the Experiment

- Lightning data found useful for producing International Convective SIGMETS
  - Provides AWC forecasters means of detecting oceanic convection in satellite imagery
- FAA personnel (TMU)/Airlines found it useful for flight planning over Gulf of Mexico, Western Atlantic, and Caribbean regions
- CWSUs issued Center Wx Advisory based upon this product
- DoD personnel used data to
  - Delineate potential areas of turbulence or windshear
  - Assist in pre-flight briefings over Caribbean & Central America
- Concerns
  - Tropical/Mid Pacific & Eastern Atlantic: Accuracy & detection efficiency needs improvement

SUMMARY

- **Collaborative Decision Making/Situational Awareness**
  - Capability to differentiate between clouds (cirrus) and convection
  - Improved common situational awareness of hazardous weather by ATC, dispatch & cockpit
  - Earlier track adjustment - minimal route deviation & enhanced thunderstorm detection in data-sparse regions

- **Future work**
  - Possible use of operational/experimental product via Internet, FAA WX system (WARP) for use by Traffic Managers and also into cockpit
  - Oceanic Convective products could utilize satellite/model data and *lightning* data for Strategic and Tactical planning purposes
    - OCND

* Note: MIT/LL study cited a $16M potential savings due more efficient flight routing & reduced incidence of turbulence-related injuries for Atlantic, Caribbean & South America

NASA/CP—2002-210964

Oceanic Weather Information: Oceanic Convective Nowcasting Demonstration (OCND)

Weather Accident Prevention Annual Review
Cleveland OH
5 June 2001

Tenny Lindholm
The National Center for Atmospheric Research
Boulder Colorado

National Center for Atmospheric Research

NASA/CP—2002-210964

Overview

- Oceanic/remote area aviation weather requirements
- On-going research addressing requirements
- Oceanic Convective Nowcasting Demonstration (OCND)

National Center for Atmospheric Research

What the industry needs

- Timely generation and distribution of weather information for en route oceanic operations
  - Weather *information* (vs. data) addressing hazards
    - » Convection
    - » Turbulence—convective induced and clear air (CIT/CAT)
    - » Icing
    - » Volcanic ash dispersion
    - » High-resolution (time and space) flight-level winds
  - Distribution infrastructure and displays—ground and airborne

What we are doing

- FAA sponsored Product Development Teams (PDTs) within AUA-430 and led by NCAR
  - Oceanic Weather PDT. Products for data sparse regions include
    - » Convective diagnoses, nowcasts, forecasts
    - » Turbulence, all types
    - » In-flight icing
    - » Volcanic ash
    - » High resolution winds
  - National C&V PDT
    - » High-resolution (time and space) national C&V diagnoses and forecasts
- Development and implementation of “intelligent weather systems”

Oceanic Weather

- "Intelligent weather systems"
  - Use of expert system framework to mimic what a meteorologist does to generate a forecast
  - Allows fast and precise assimilation of all data that can add skill to generate *informational* products
  - Result: rapidly and frequently updated, high resolution, 4-dimensional graphic of the weather hazard that is easily transmitted to ground and airborne users

Oceanic Convection

- For example, diagnosing and nowcasting convection
  - Visual satellite imagery to locate clouds
  - Infrared satellite imagery to determine cloud tops
  - Water vapor channel to determine spot winds
  - Global numerical model data for assimilating spot winds and creating a uniform wind field
  - Lightning data and cloud classification algorithms to distinguish convection
  - Plus use of any available ground station data and radar data

Integration yields a precise diagnosis and nowcast of convection in 3 dimensions

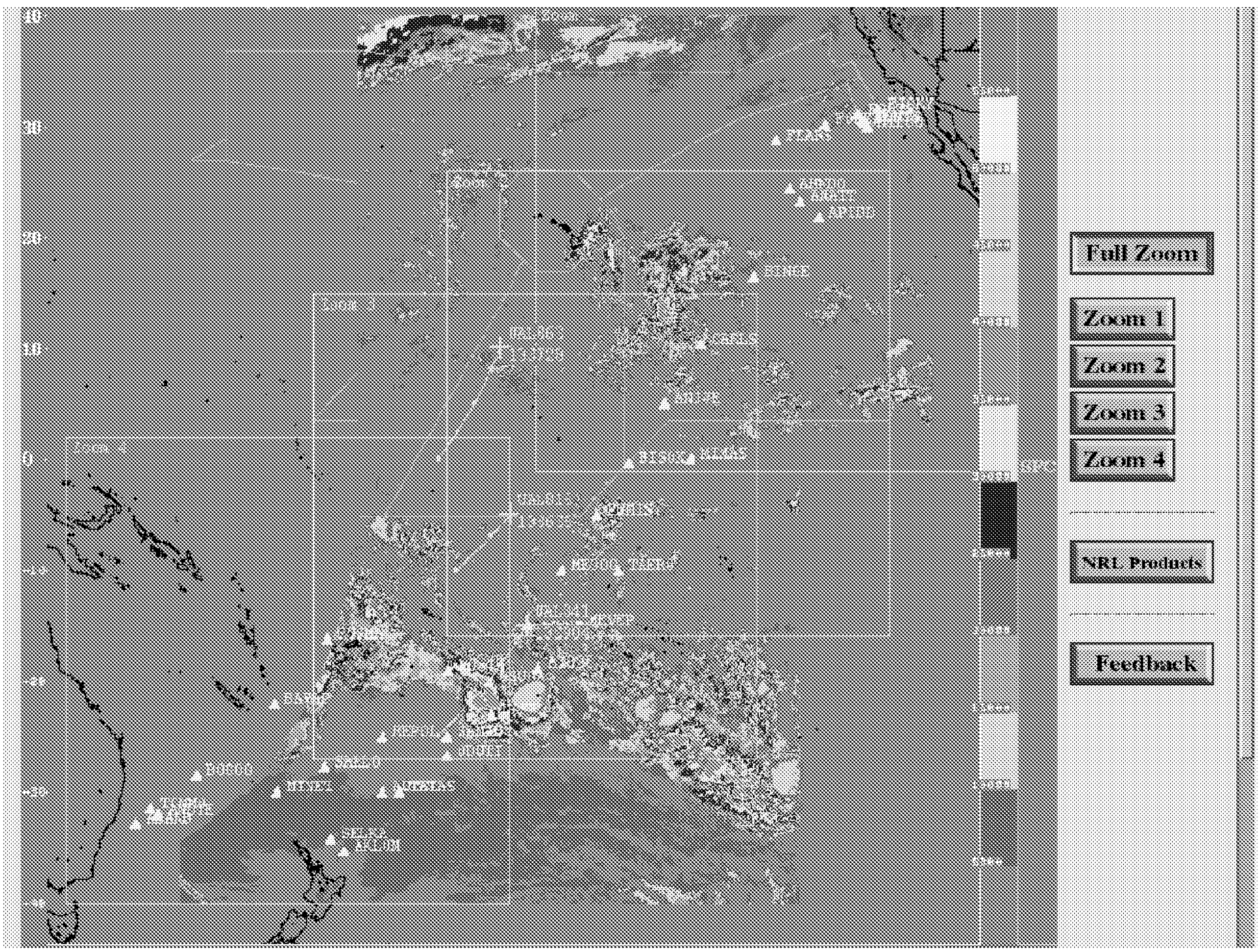
OCND—Prelude to OWPDT

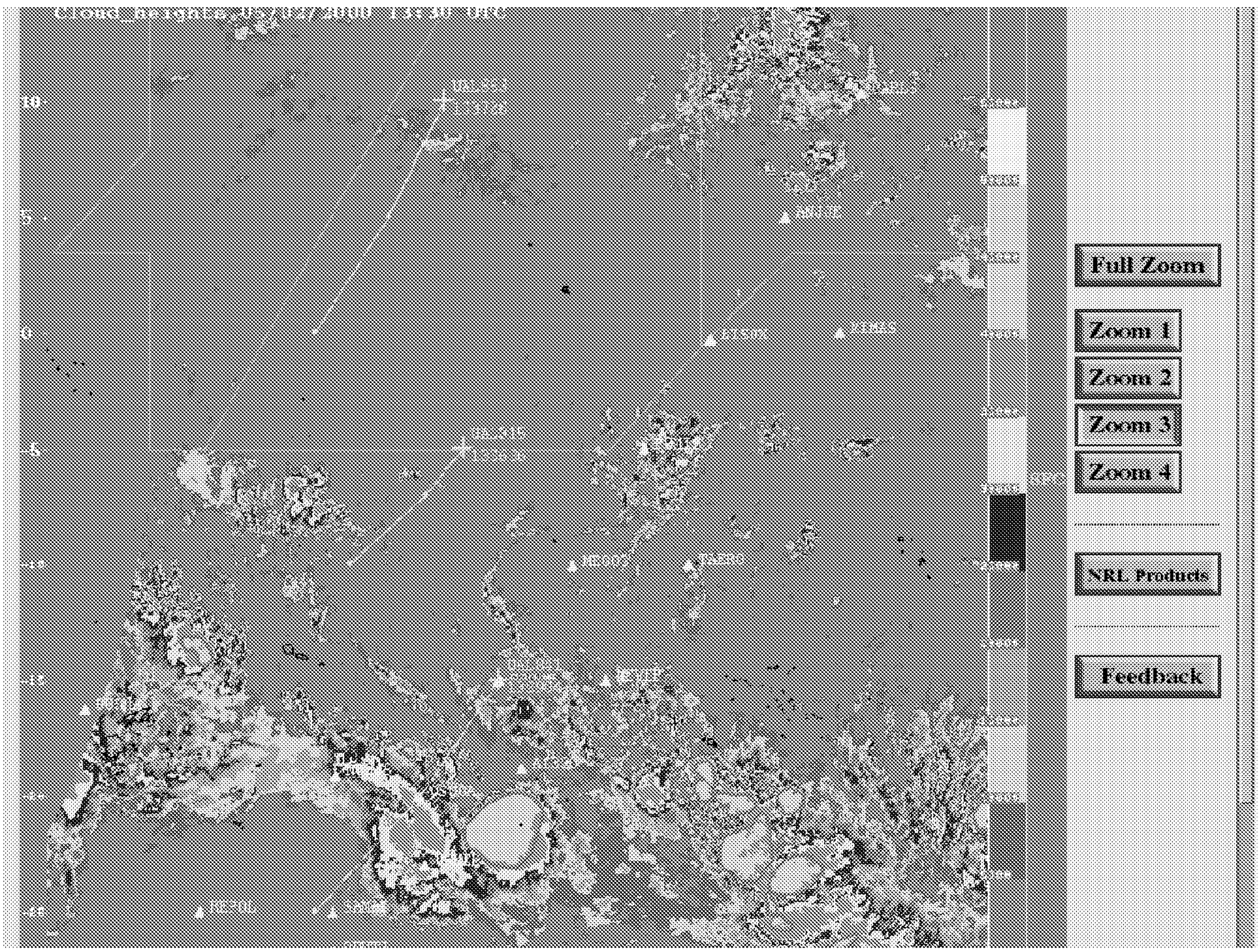
- Purpose
  - Primary focus: Demonstrate and implement an end-to-end weather hazard and product dissemination system for remote/oceanic areas. Users include airline dispatch, air traffic control, and the airborne flight crew (data link).
  - Develop operationally useful weather products, including the automated process to create them, for remote/oceanic areas. Products include convection, turbulence, in-flight icing, and satellite-based winds (diagnoses, forecasts).
- Participants—NCAR (lead), United Airlines, Aviation Weather Center (NWS), Naval Research Laboratory, Oakland Oceanic ARTCC, ARINC
- Sponsors—FAA Aviation Weather Research Program (AWRP) and NASA Aviation Weather Information (AWIN) Program

OCND Program

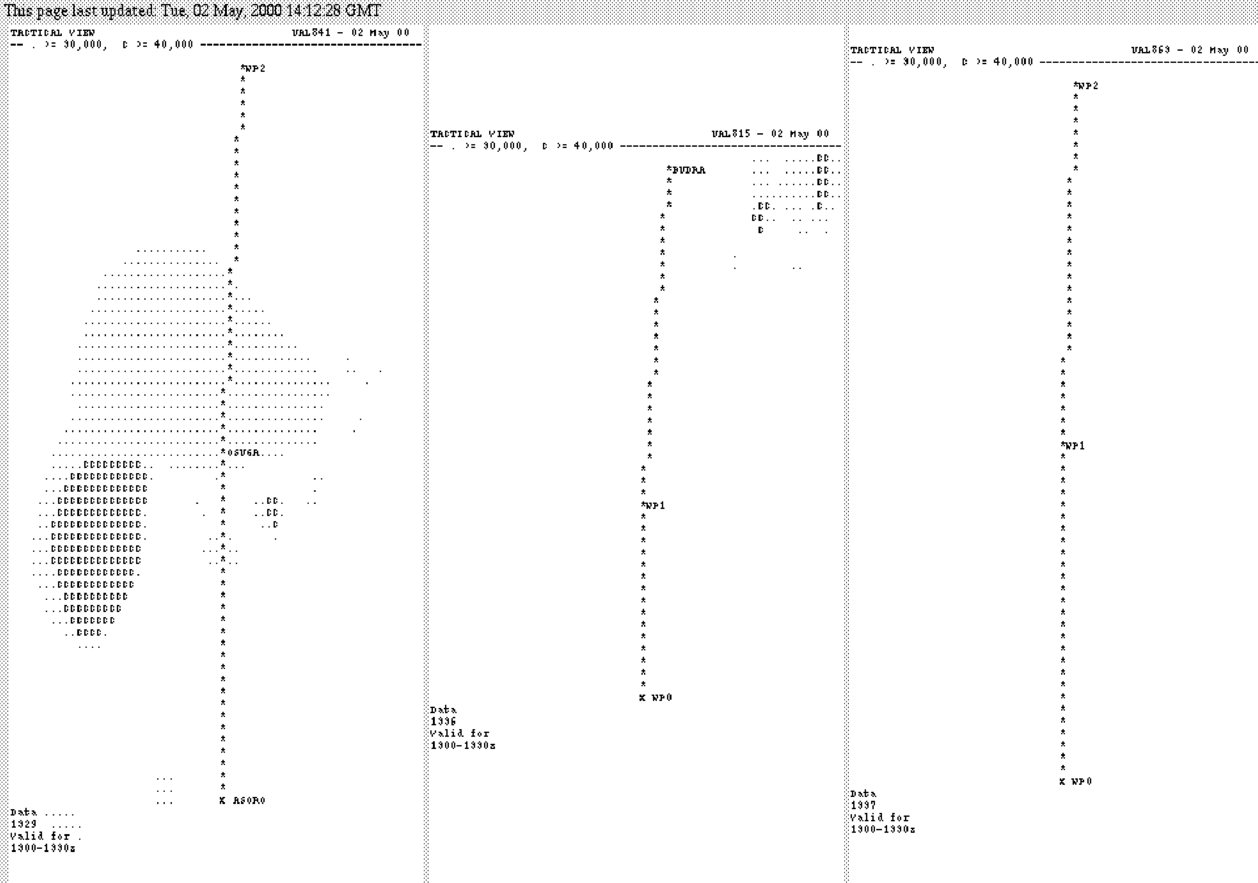
- OCND regional focus—flights to/from CONUS and New Zealand/Australia
  - Automated product creation (convective hazards initially) at NCAR
  - Transmission to and display at United dispatch and Oakland Center
  - Data link to the aircraft via ARINC
  - Evaluation, feedback, and further development

National Center for Atmospheric Research

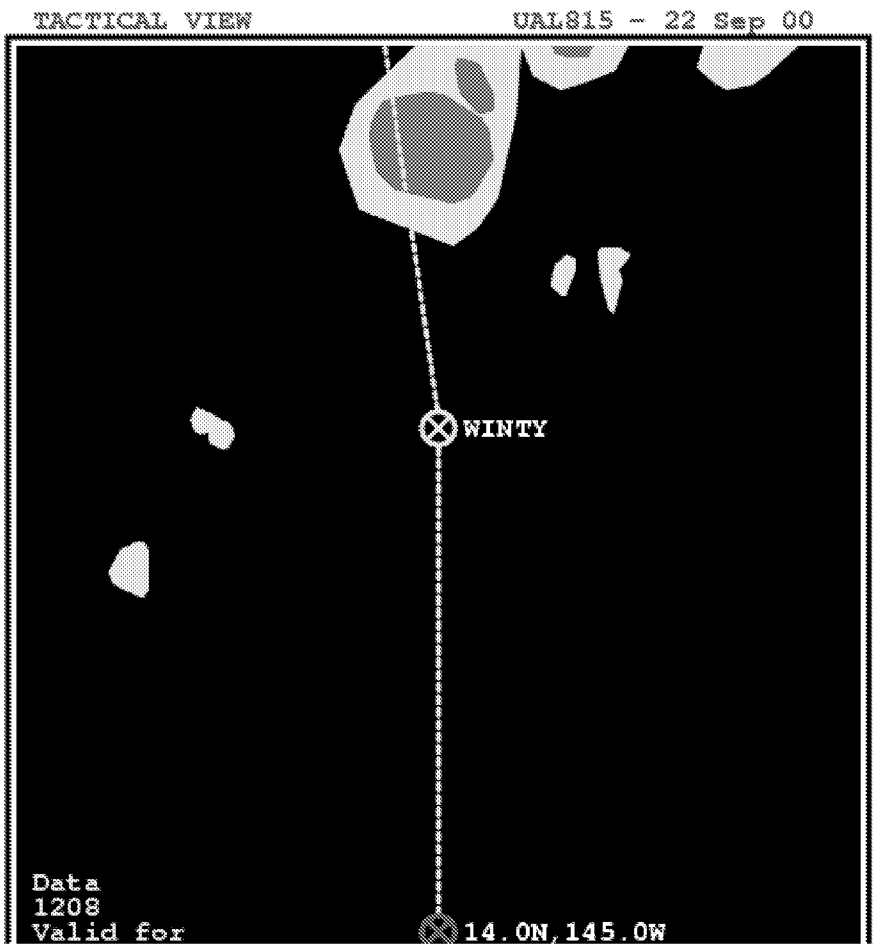

Full Zoom
Zoom 1
Zoom 2
Zoom 3
Zoom 4
NRL Products
Feedback


Full Zoom
Zoom 1
Zoom 2
Zoom 3
Zoom 4
NRL Products
Feedback

This page last updated: Tue, 02 May, 2000 14:12:28 GMT



The displays on this page are generated automatically when new position reports are received from ARINC. When a position report is received for an existing flight, the newly generated display


TACTICAL VIEW
UAL815 - 22 Sep 00
WINTY
Data
1208
Valid for
14.0N,145.0W

Summary

- Convective diagnosis—ready now. Check it out at http://www.rap.ucar.edu/projects/ocnd/realtime_sys/
- Convective nowcasts, CIT, CAT, in-flight icing—in the development pipeline and will be ready for evaluation in FY03
- Product development includes dissemination infrastructure
- Initial feedback from flight crews and dispatch indicates the information is of high value
- Status of data link to the flight deck…

National Center for Atmospheric Research

NASA/CP—2002-210964

VHF Datalink (Mode 2) for Cockpit Weather for Air Transports

Weather Accident Prevention

2nd Annual Project Review

June 5-7, 2001

Cleveland, OH

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VHF Datalink (Mode 2) for Cockpit Weather for Air Transports

WxAP - Weather Information Communications Experiments

- **Overall Goal/Objective:**
  - Assessment of the datalink capabilities of VDLM2 for potential use in dissemination of Weather to the cockpit in 2007 based on the WINCOMM requirements. This assessment will provide characterization including identification of any gaps for potential improvements/enhancements.
- **Implementation Mechanism:**
  - Ongoing in-house/external effort
  - Ohio University Grant
- **Technical Results to Date:**
  - Ohio University Grant:
    - The emphasis of this grant was to provide characterization of the Physical and Link Layer of VDLM2. A combination of both Lab and Flight Tests were conducted. The radios generally performed as expected with minor discrepancies being noted.

VHF Datalink (Mode 2) for Cockpit Weather for Air Transports

WxAP - Weather Information Communications

- In-House
  - An analysis of existing studies and simulations were performed looking at the full 7 Layer Stack, Application Layer to Physical Layer. Results were inconclusive due to unresolved conflicts existing between the studies and simulations.

- Future Plans:
  - Additional testing and analysis to resolve discrepancies noted in the Ohio University testing.
  - Modeling and simulation of VDLM2 to resolve conflicts identified in the existing studies and simulations analysis.
  - Performance characterization of VDLM2 in a relative environment with a representative traffic load depicting a fully loaded VDLM2 operational network.

NASA/CP—2002-210964

Preliminary VDL Mode 2 Bench and Flight Test Results

Trent A. Skidmore and Aaron A. Wilson
Ohio University Avionics Engineering Center

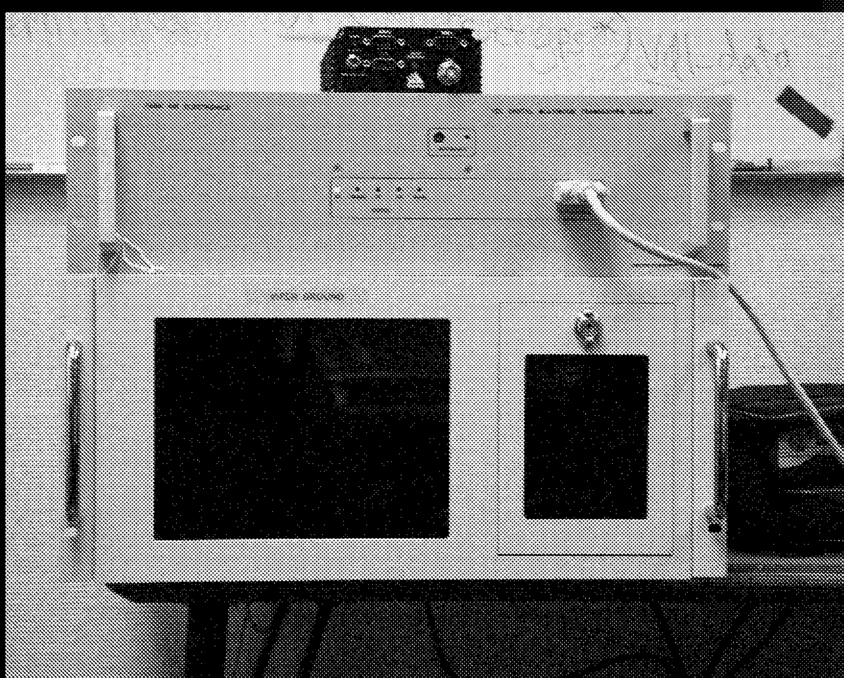
Presentation Overview

- VDL Integrated Performance Evaluation Rack
  - VIPER Ground & Airborne Equipment Description
- Pre-flight Bench Testing
  - Spectral characteristics and Receiver (Rx) sensitivity
  - Block Diagram & Sample Test Message
- Flight Testing
  - Goals
  - King Air Antenna Performance
  - Flight Test Results

VIPER Equipment Description

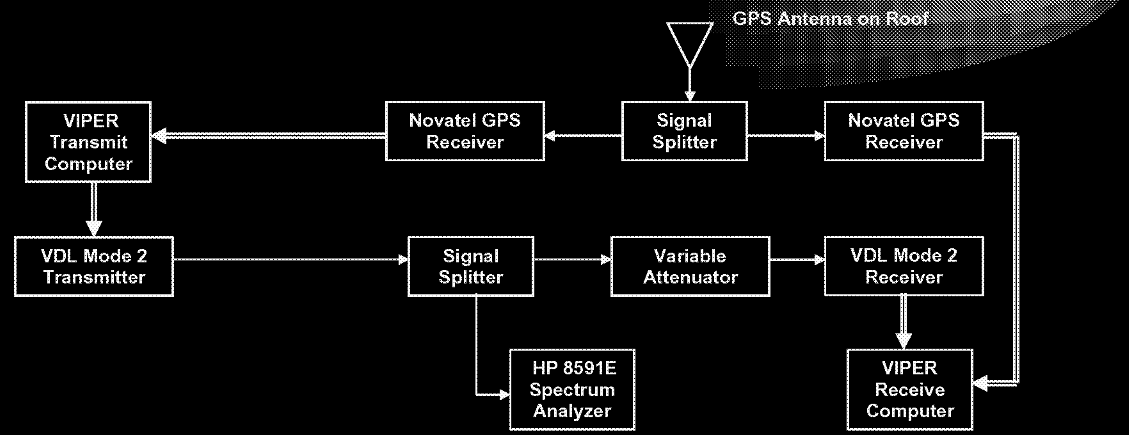
- VDL Mode 2 (VDLM2) Equipment
  - Park Air Radio (PAR) 5525D8 Multimode Transceivers
    - Currently operate in transmit (Tx) or receive (Rx) mode only
    - Advanced Relay Corporation HDLC Cards
- Host Computers
  - CyberResearch MPC-6020 with 10.4” LCD Display
    - Software configures Tx or Rx option
    - Spectrum analyzer & Ohio U. program measures power
- GPS Receivers
  - Novatel 3151 (12 Channels)

VIPER Ground and Airborne Components



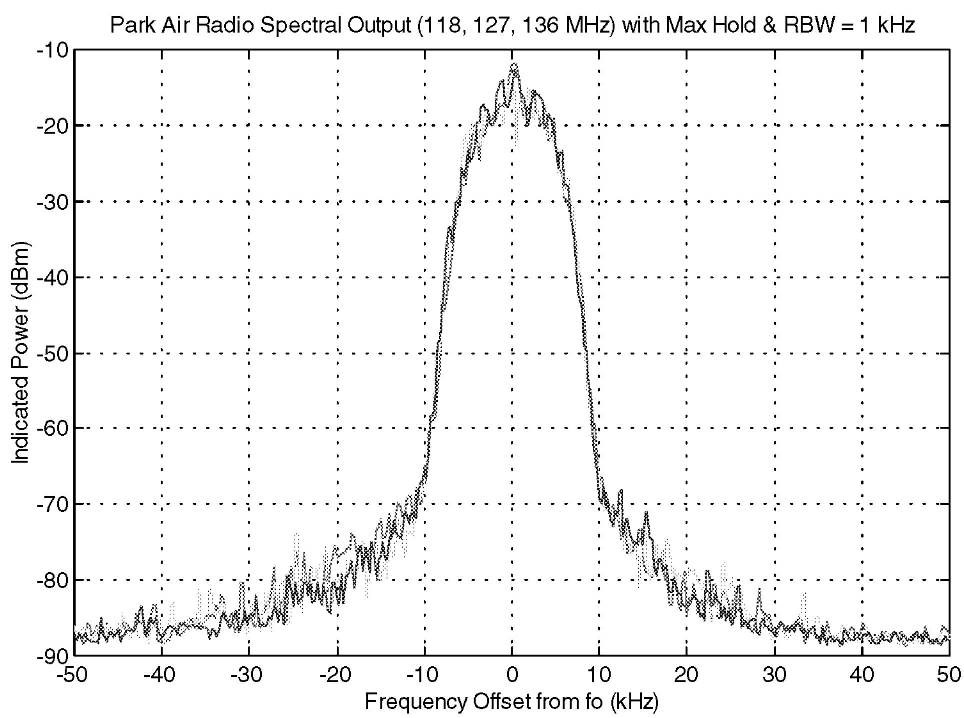
- Top
  - Novatel GPS Receiver
- Middle
  - Park Air VDL Mode 2 Transceiver
- Bottom
  - CyberResearch Computer

VDL Mode 2
Bench Test Configuration



- Bench test simulates flight test environment
- VIPER Tx Computer Generates Test Messages
  - Simulated "weather-related" data (Actual weather info to be used later)
  - Message length and duty cycle limits require further investigation

Measured Spectral Characteristics



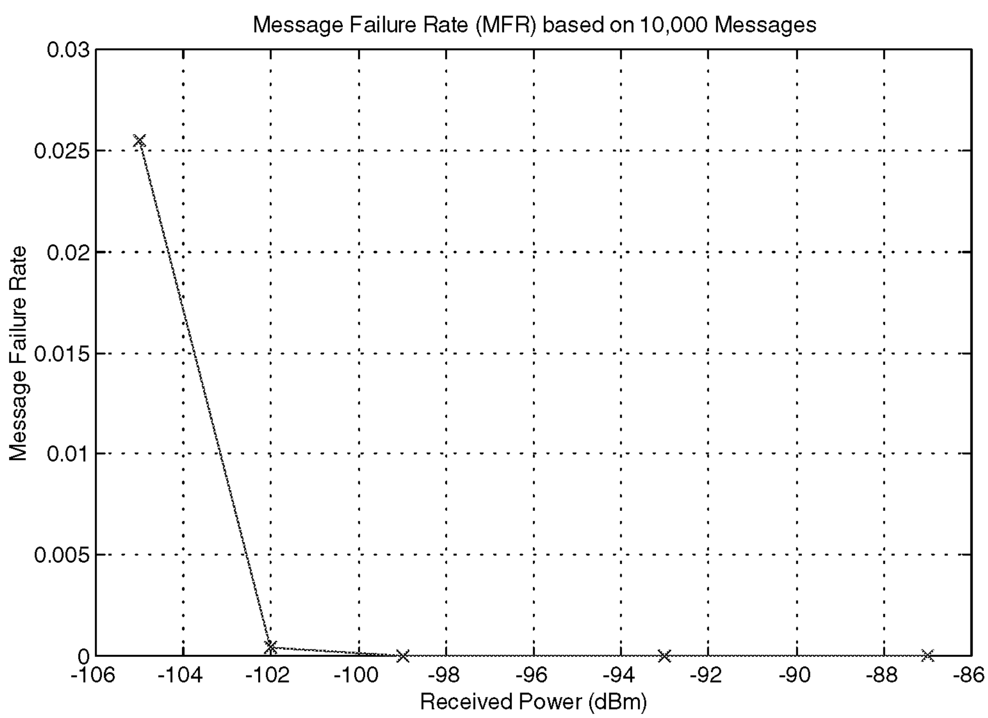
Tx Characteristics

- Tx computer generates test messages
  - 223 bytes in length
  - Message counter for determining message count
  - GPS location of Tx station
  - Random fill bits
  - 32-bit checksum
  - Weather-related messages will be used eventually
- Messages rate = approx. 3/2 seconds = 1.5 Hz
- Power measured with HP8591E Spec Analyzer
  - Resolution Bandwidth (RBW) = 1 kHz for trace
  - RBW = 30 kHz for sensitivity measurements

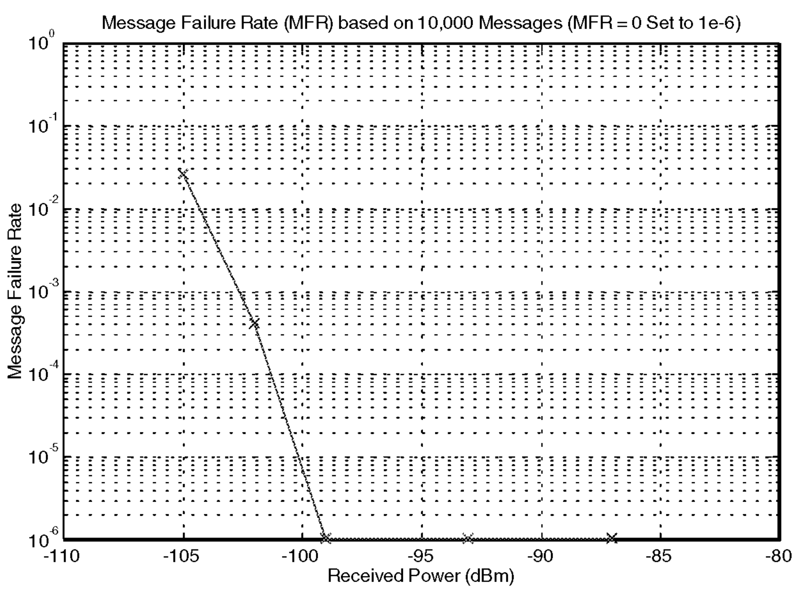
Rx Mode Characteristics

- PAR VDLM2 equipment does not output "bad" messages
  - Raw Bit Error Rate (BER) not readily available
  - Use Message Failure Rate (MFR)
  - Determine sensitivity by post-processing data
- Reported MFR based on 10,000 messages
  - Test time per data point was approximately 2 hours
- Screen displays GPS time, range, message count, and count difference

Measured Sensitivity (view 1)



Measured Sensitivity (view 2)



- Set MFR=1e-6 for plotting purposes
- Interpolated Sensitivity Points

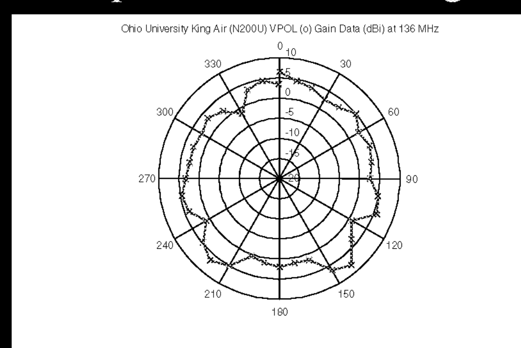
Power (dBm)	Approx. MFR
-101	1e-5
-102	5e-4
-103	1e-3
-104	1e-2

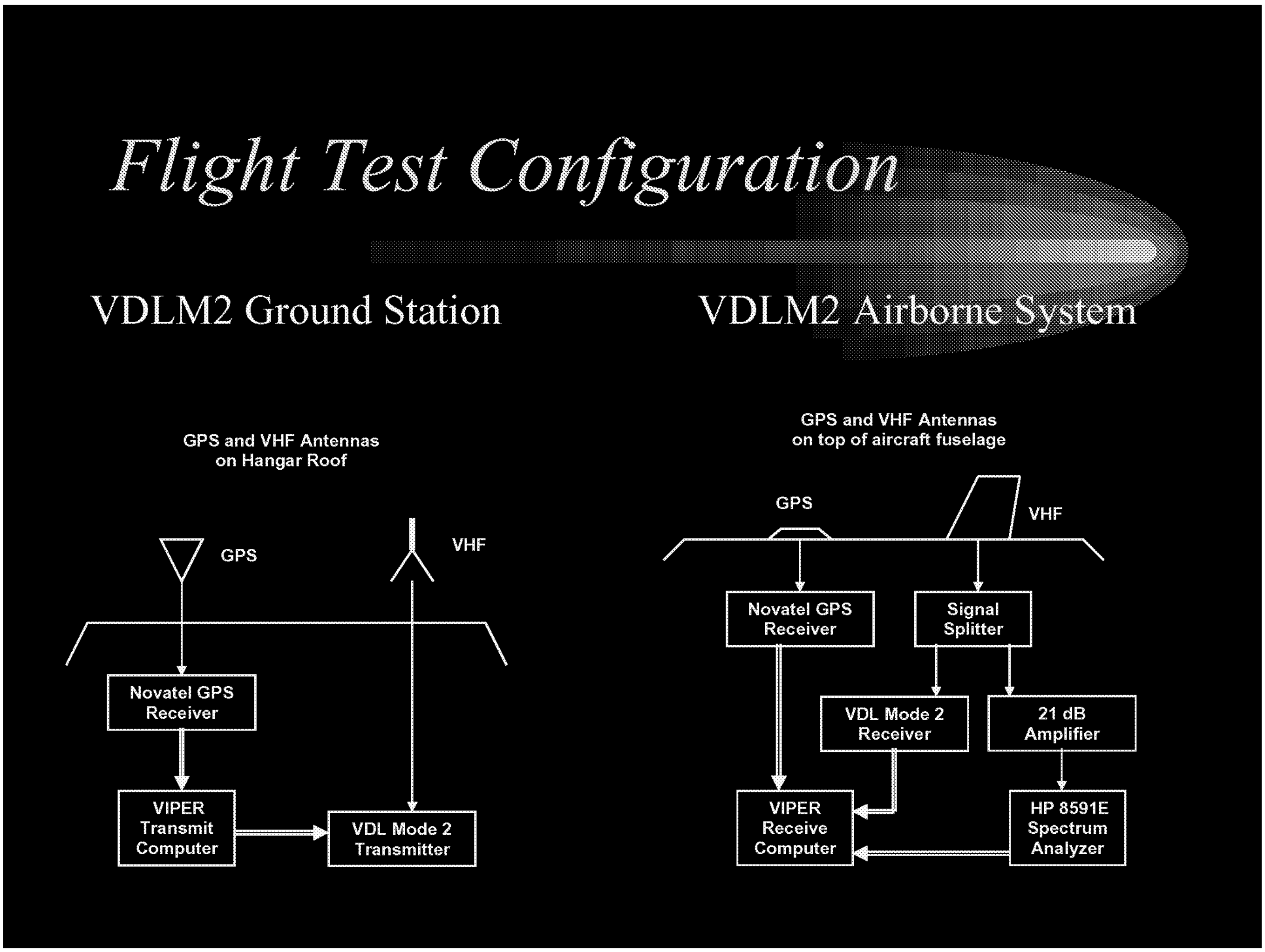
Measured sensitivity compares well with -103 dBm claimed by manufacturer.

Flight Test Preparation

King Air C-90 (N200U) Aircraft

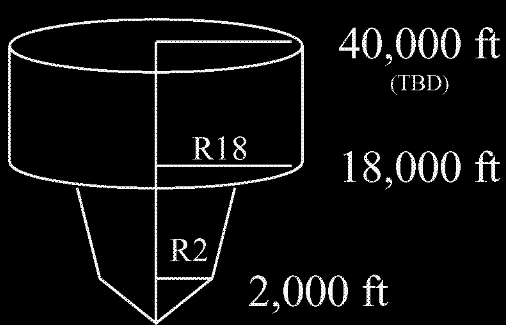
- Vertically Polarized (VPOL) Rx antenna on top of aircraft fuselage

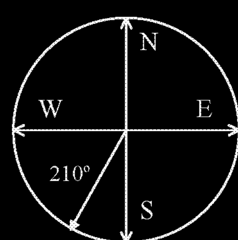



Flight Test Configuration
VDLM2 Ground Station
VDLM2 Airborne System
GPS and VHF Antennas
on Hangar Roof
GPS
VHF
Novatel GPS Receiver
VIPER Transmit Computer
VDL Mode 2 Transmitter
GPS and VHF Antennas
on top of aircraft fuselage
GPS
VHF
Novatel GPS Receiver
Signal Splitter
VDL Mode 2 Receiver
21 dB Amplifier
VIPER Receive Computer
HP 8591E Spectrum Analyzer

Flight Test Profile

- Tested the 210º compass radial to the extent of coverage at two altitudes above ground level:
  - 2,000 ft. AGL (typical minimum vectoring altitude)
    - Timely weather should not be needed below this altitude
  - 18,000 ft. AGL (bottom of current ARINC coverage)





Compass Radials

210º radial chosen from Ohio University Airport (UNI) to minimize traffic-based course deviations

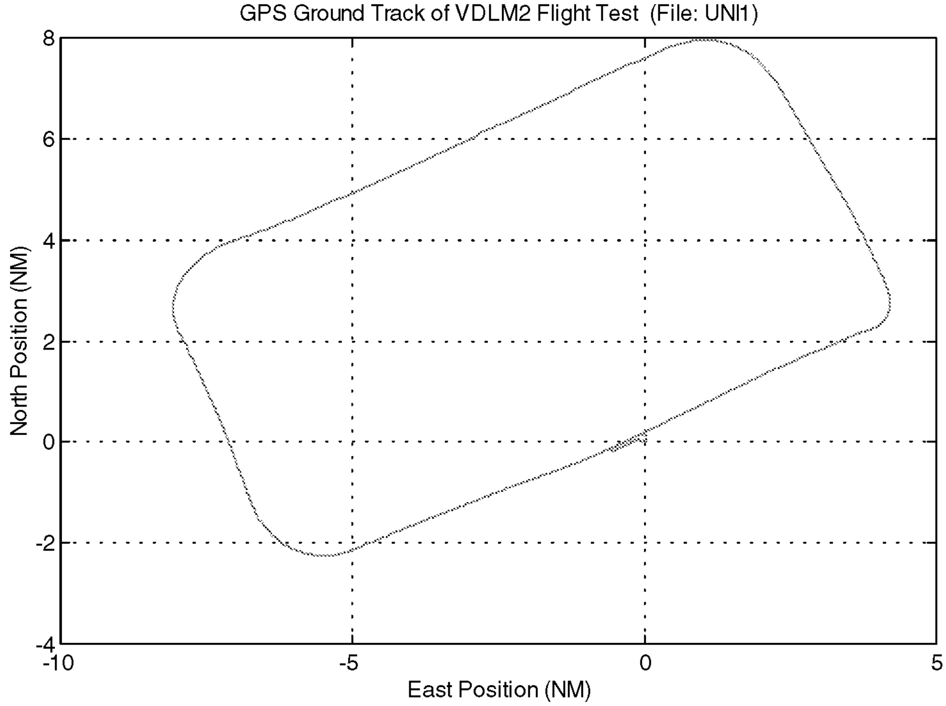
Current Method for Measuring In-Flight Received Power

- Use HP8591E Spectrum Analyzer (SA)
  - Power Measurement Settings
    - Resolution Bandwidth = Video BW = 30 kHz
    - Center measurement on known Tx frequency
      - Max Hold for 3 seconds
        - Allows for non-synchronized operation (SA & VDLM2)
    - Peak Search and record value at center frequency
- Customized Ohio U. data logging software
    - Multitasks with VIPER software under Windows 2000
    - Time tags power measurement with GPS time for post processing

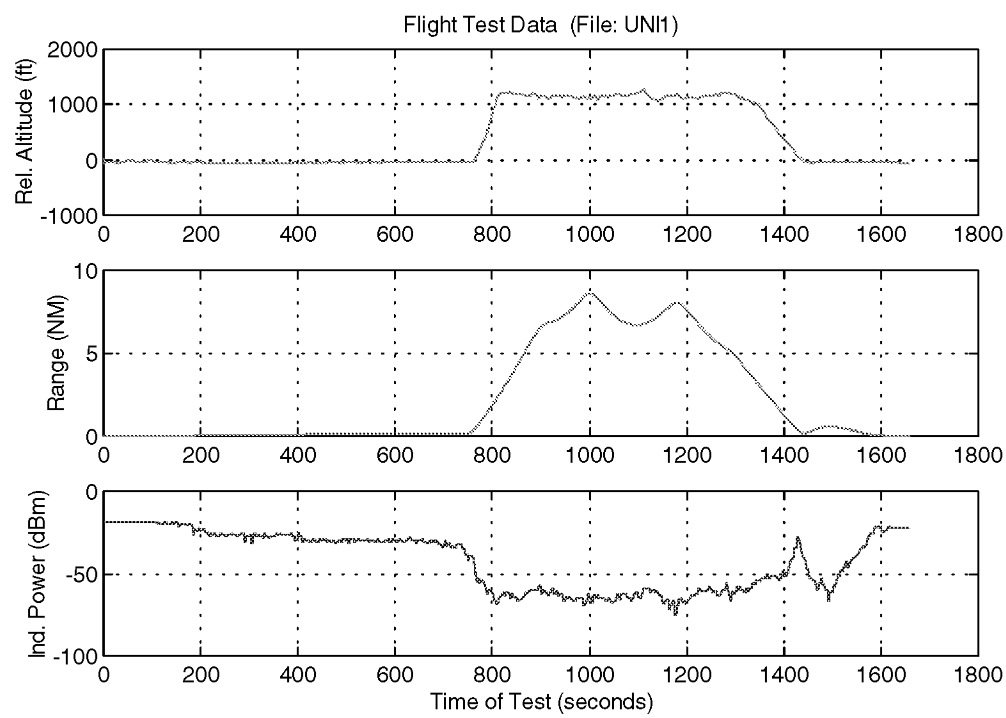
A Collection of Interesting Pictures

Data File 1
Shakedown Flight

GPS Ground Track of VDLM2 Flight Test (File: UNI1)



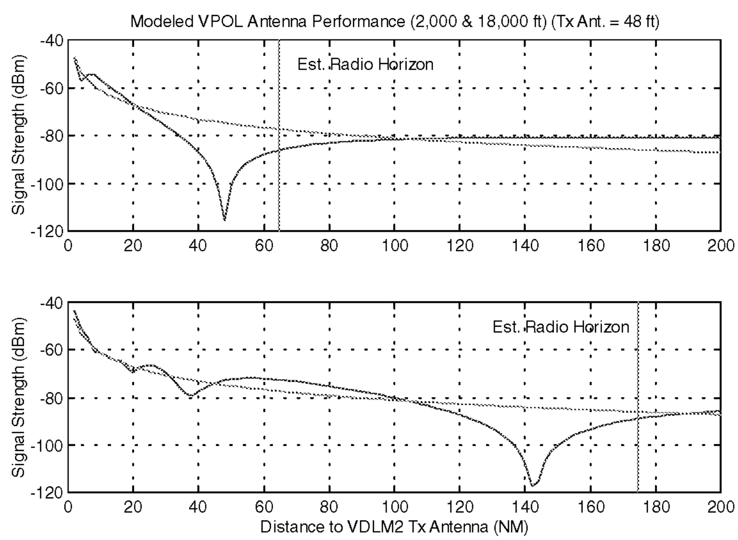
Data File 1
Shakedown Flight (2)



Predicting Performance at 2,000 ft and 18,000 ft (AGL)

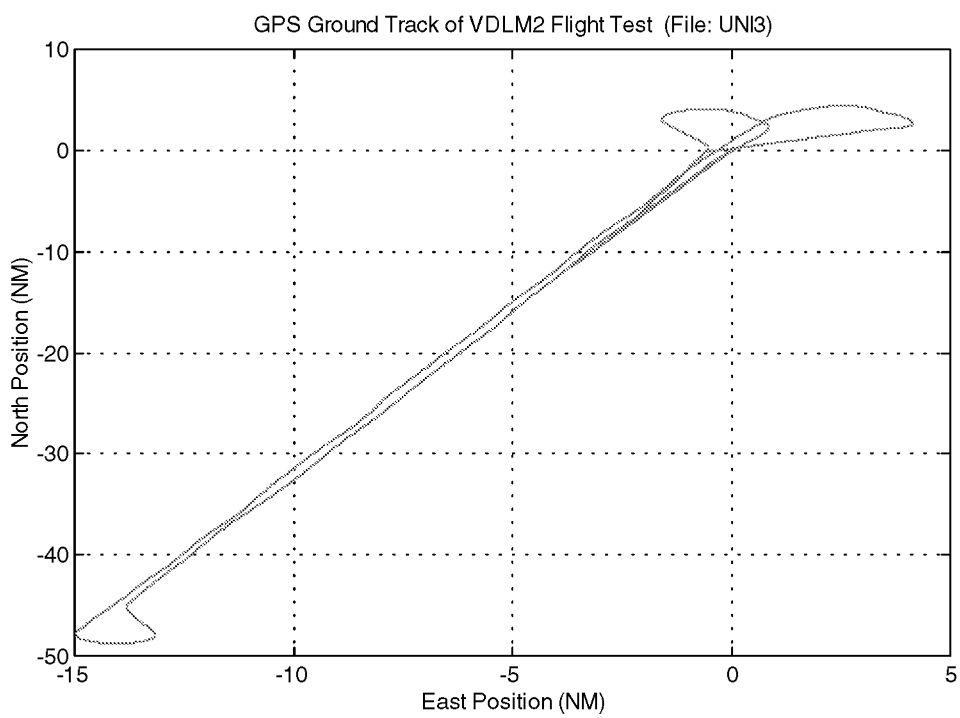
- Model written by Ohio University
- Models terrain as uniform spherical earth
- Can vary surface conditions
  - Salt water - Swamp
  - Fresh water - Desert
  - Average earth (used in this analysis)
- Assume isotropic VPOL Tx antenna
- Coverage performance varies from free space due to multipath and path length difference

Predicting Performance (2)

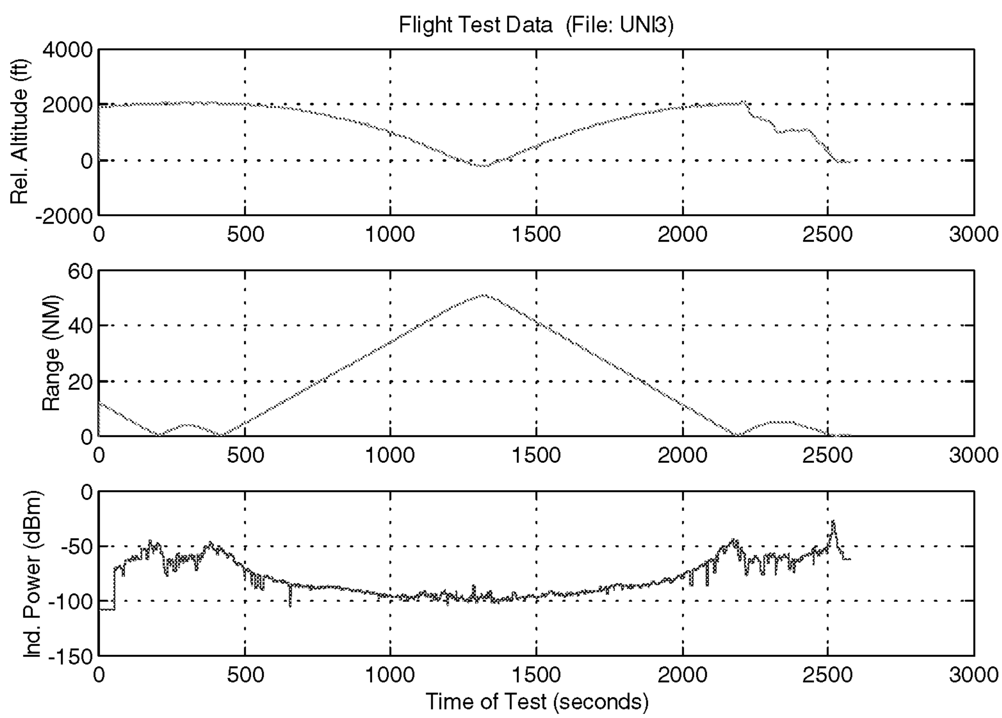


- Rx at 2,000 ft
  - Signal expected to be lost at ~45 NM
- Rx at 18,000 ft
  - Signal expected to be lost at ~140 NM
- Signal increase beyond loss region is artificial (need model update)
- Radio horizon using 4/3 earth radius propagation estimate

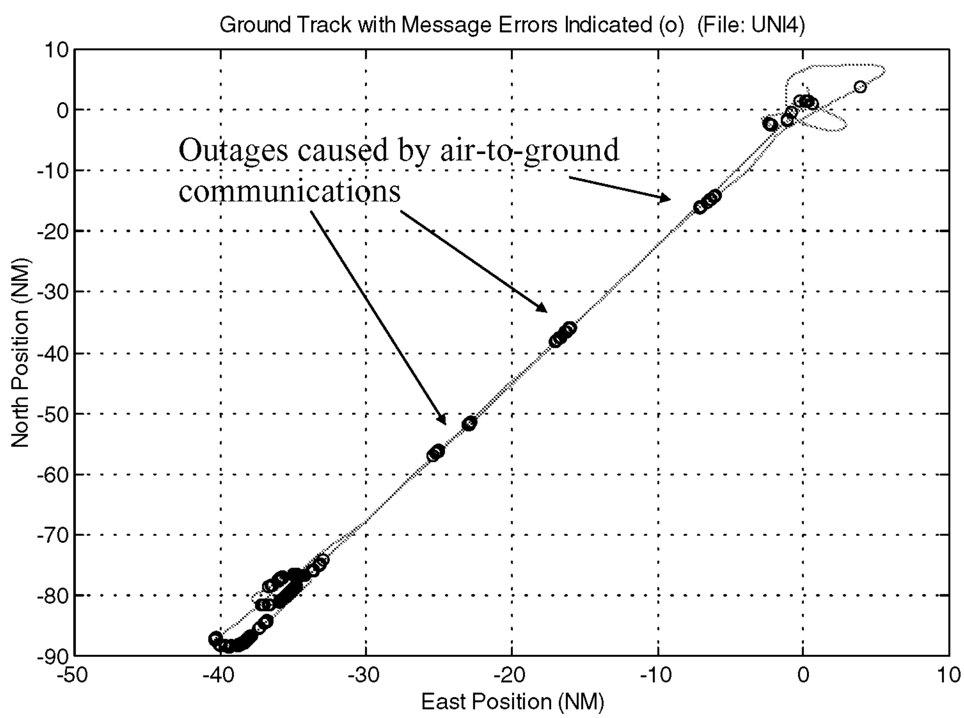
Data File 2
Radial at 2000 ft AGL



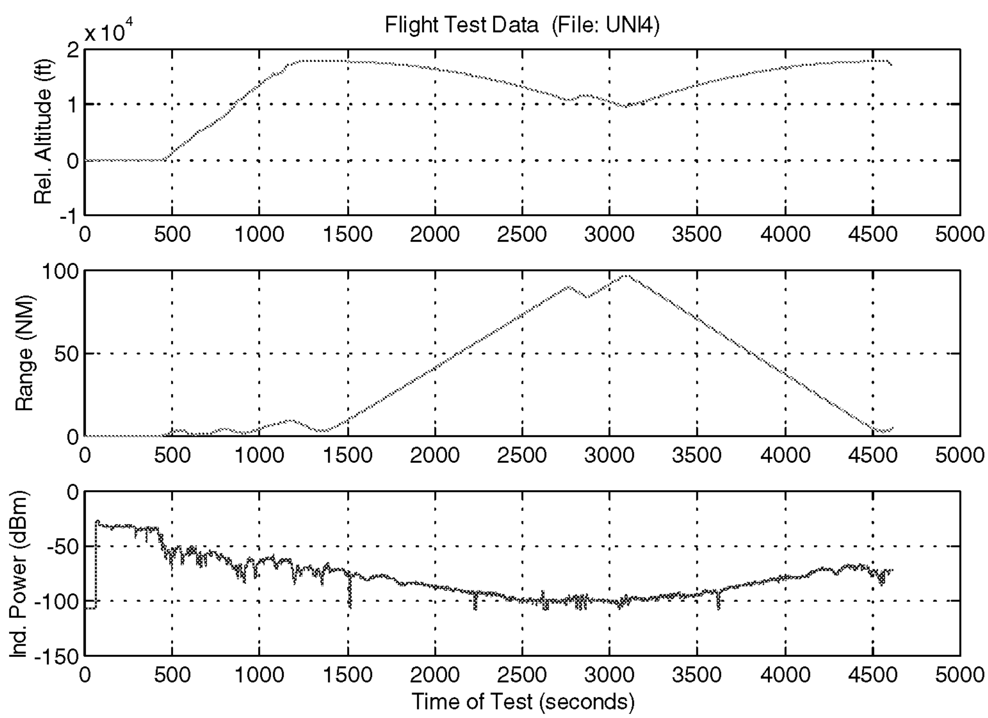
Data File 2
Radial at 2000 ft AGL (2)



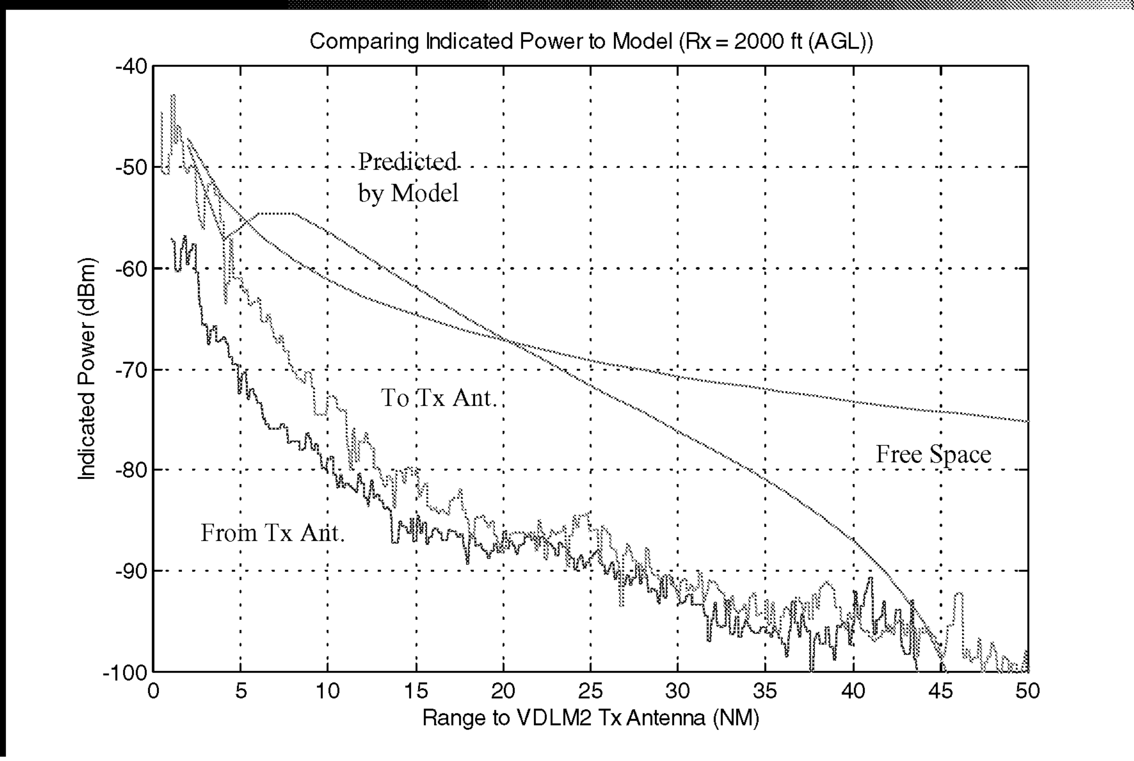
Data File 3
Radial at 18,000 ft AGL



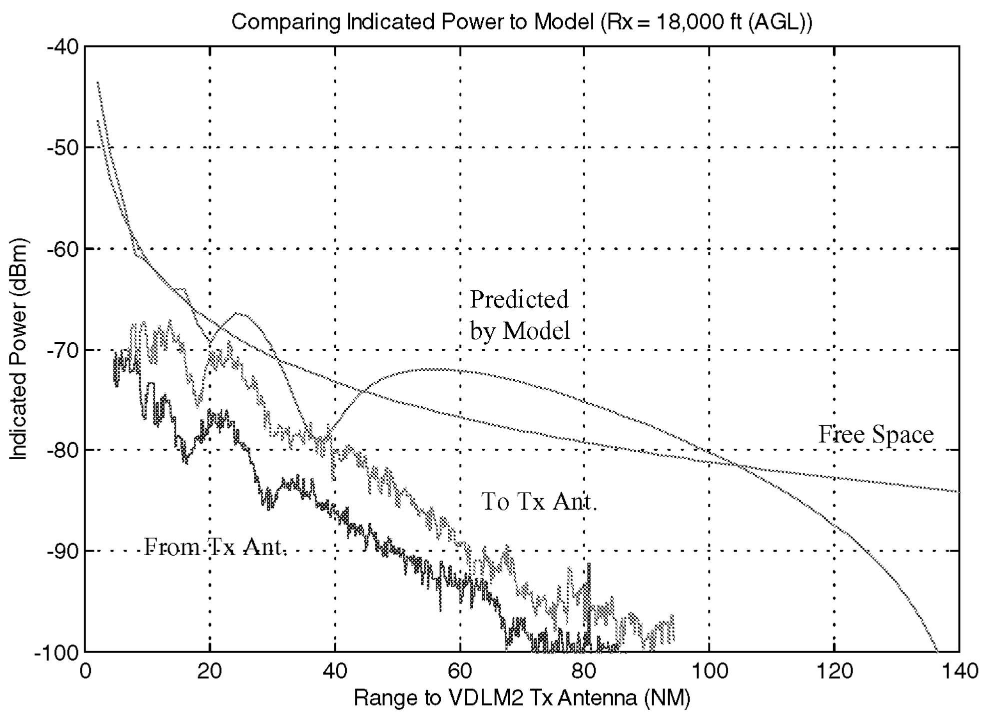
Data File 3
Radial at 18,000 ft AGL (2)



Comparing Received Signal Strength to Predicted (2,000 ft)



Comparing Received Signal Strength to Predicted (18,000 ft)



Comments on Received Data versus Model Prediction

- Flight test data and model are not in very good agreement (yet) - still under investigation
  - Flight data is biased from model (6 - 16 dB)
  - Model predicts location of fades at 18,000 ft AGL
- Potential sources of model mismatch
  - Rx and Tx antenna calibration error
  - Tx antenna on hangar edge
  - Non-uniformity of local terrain

Flight test data & model agreement with Horizontal Polarization and the LAAS VDB has been very good.

NASA/CP—2002-210964

Decision-making in flight with different convective weather information sources:

Preliminary Results
from
the Langley CoWS Experiment
(COnvective Weather Sources)

Jim Chamberlain
Crew Systems & Operations Branch

Kara Latorella
Crew/Vehicle Integration Branch

NASA Langley Research Center

Presented at the NASA Weather Accident Prevention Workshop~ 2001 ~ Chamberlain & Latorella

Outline

- CoWS Experimental Apparatus Development
  - Ground Station
  - B200 Aircraft
  - Airborne System
- CoWS Experiment
  - Experimental Conditions & Objectives
  - Procedures
  - Preliminary Results
  - Conclusions
  - The Future of CoWS

Experimental Apparatus

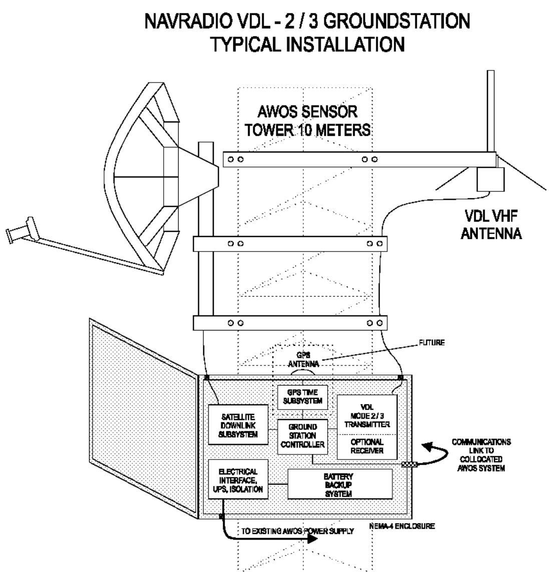
Approach

Use CRA-developed, removable tethered-display AWIN system in B200

Apparatus

- Honeywell CRA AWIN ground stations
- Langley B200 Super King Air
- Honeywell CRA tethered AWIN system

Ground Infrastructure



Typical Honeywell CRA

AWIN Ground Station

- •Satcom antenna & receiver
- •Processor & power supply
- •VDL transmitter & antenna

Ruggedized, Compact, Self-Contained

AWIN Receiver/Processor at RTI/Hampton can record Wx

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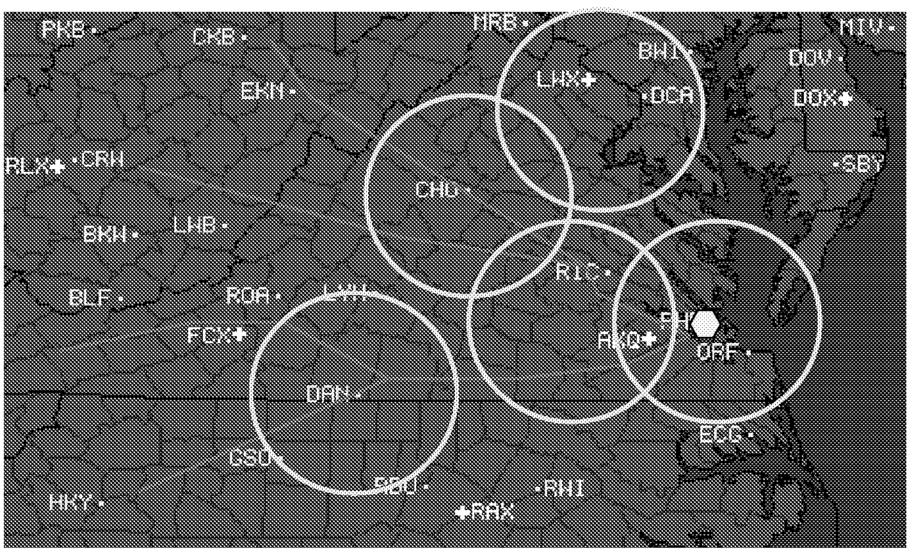
Test Range

- Five ground stations, 40nm radius
- Four destinations & flight paths



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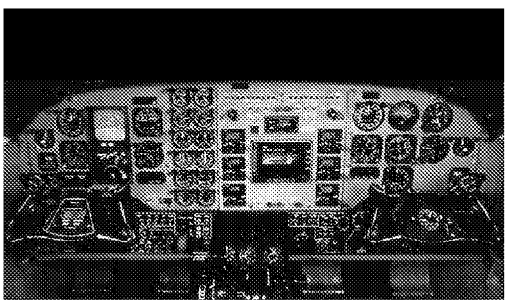
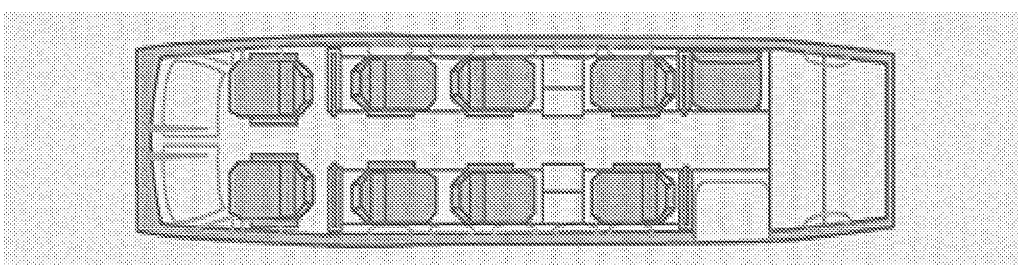
B200 Super King Air





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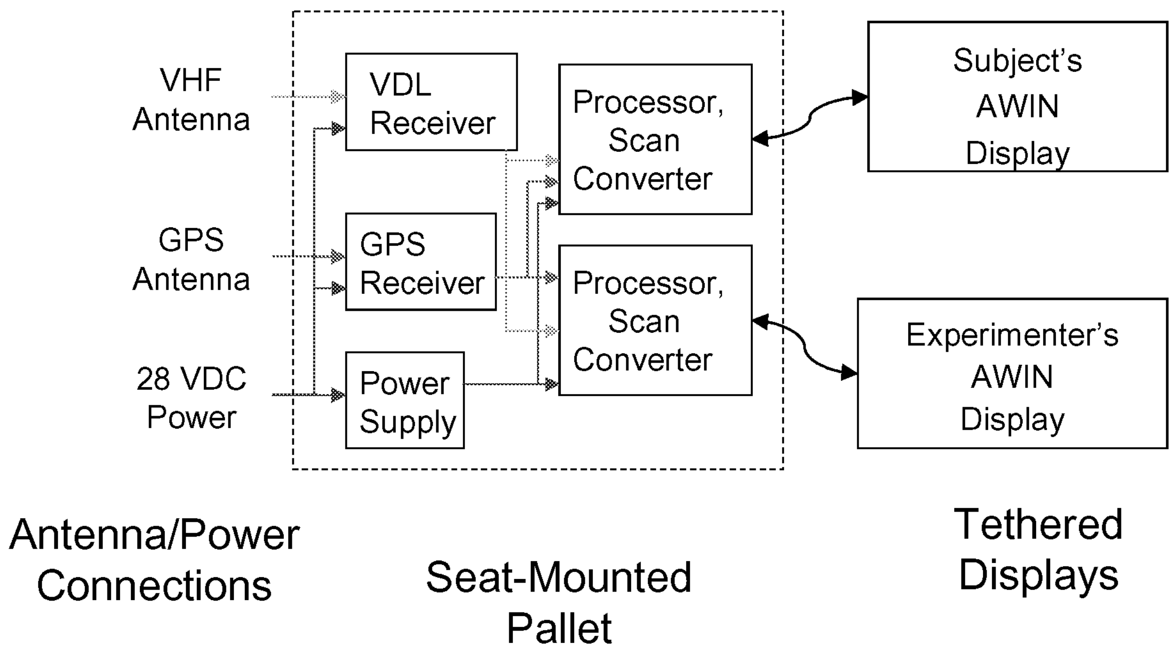
AWIN Architecture



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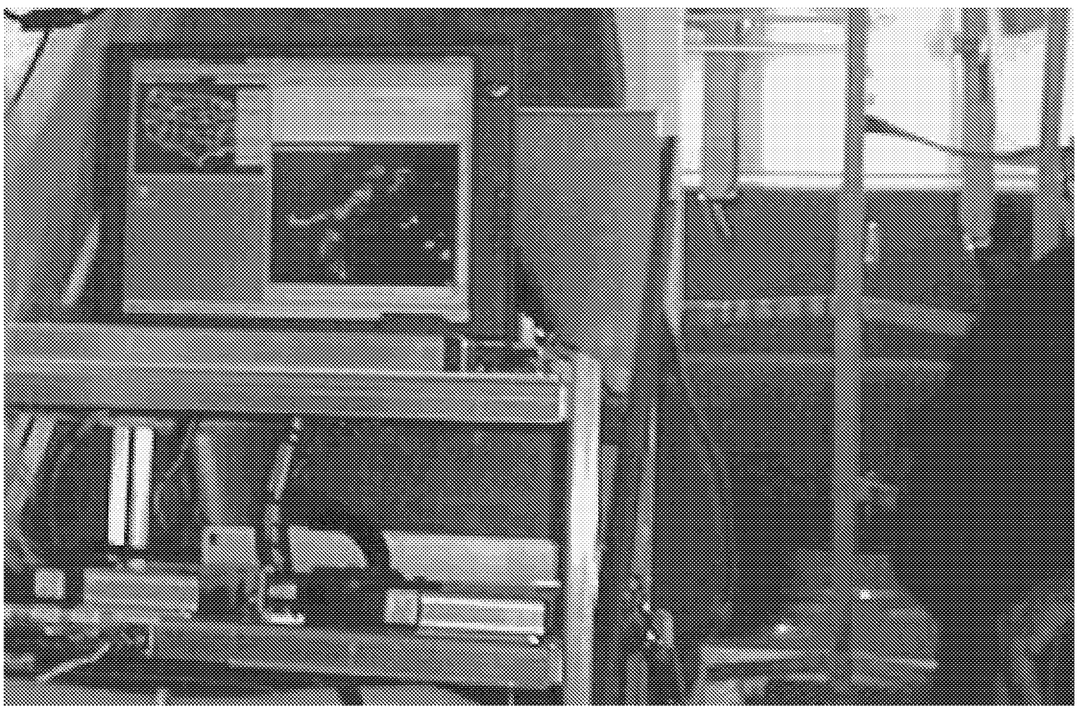
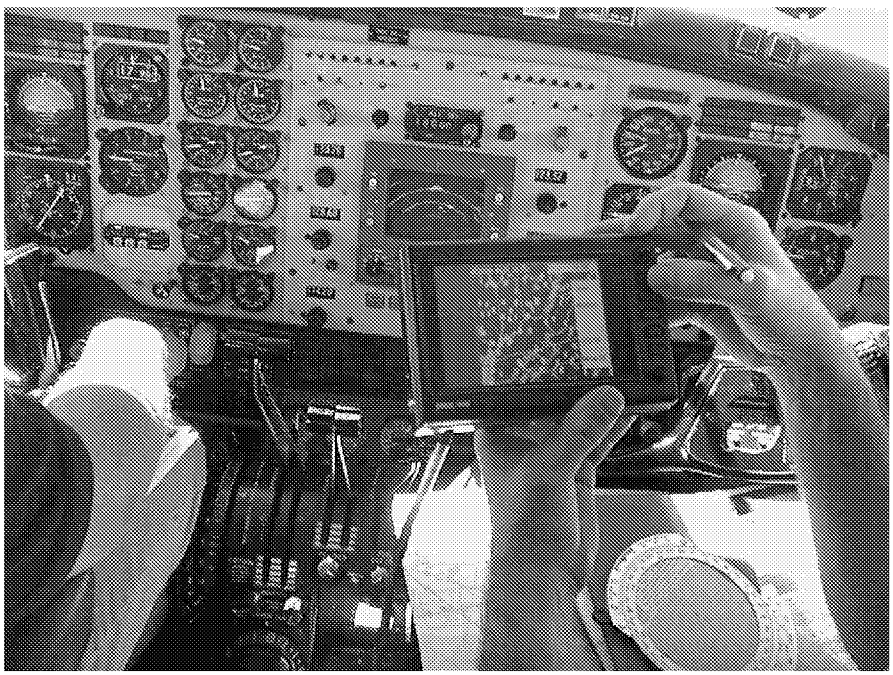
Equipment Pallet in the B200



AWIN Display in B200



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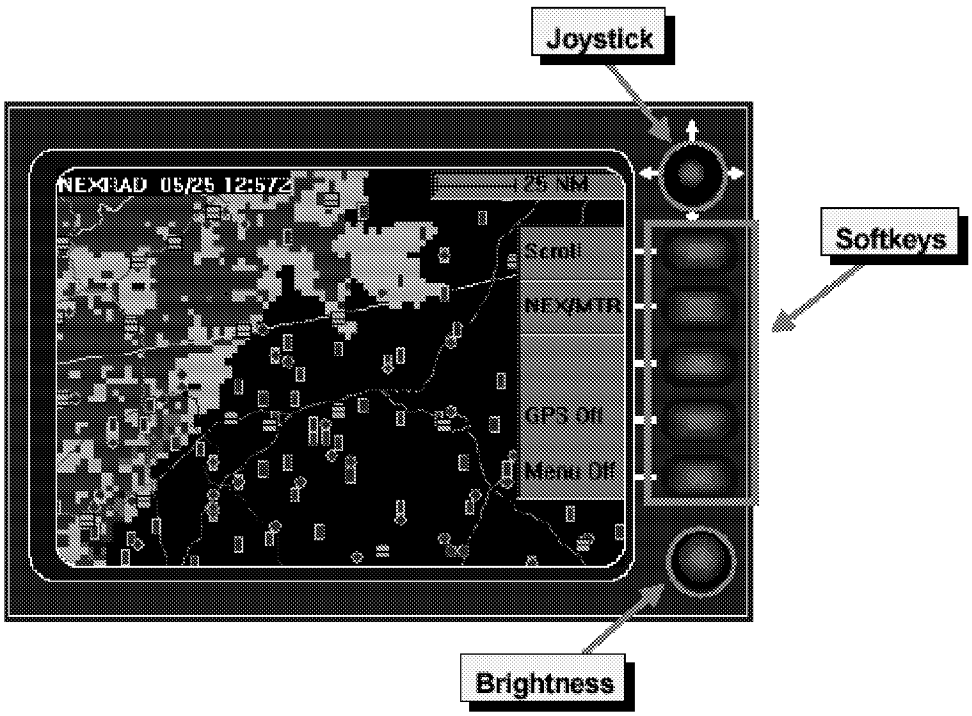
AWIN Input Devices



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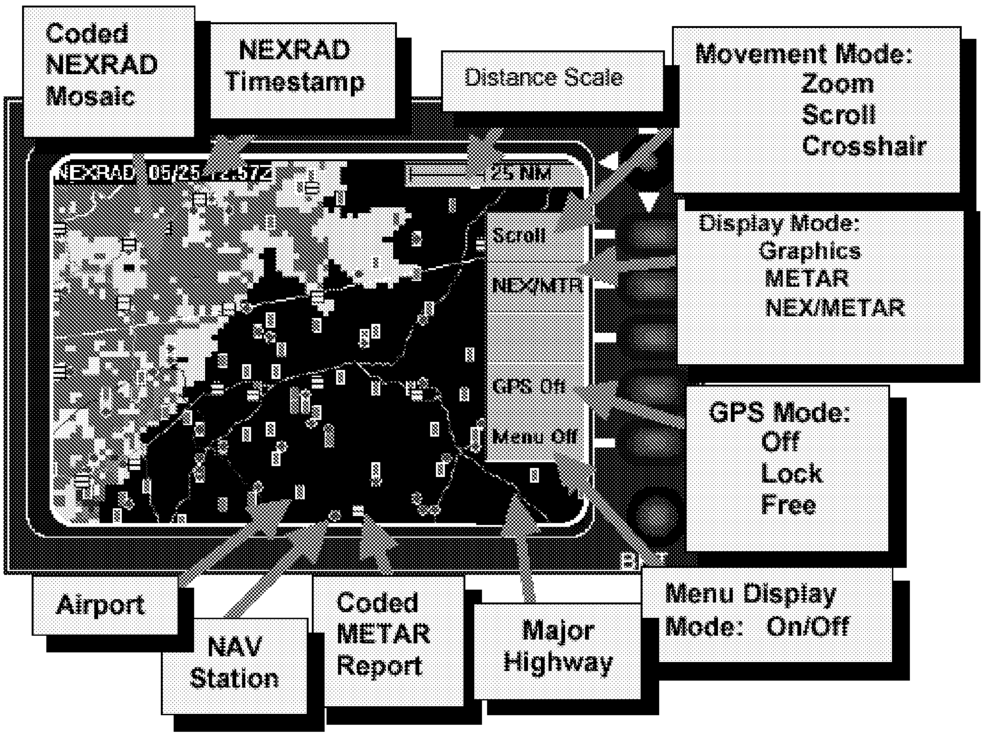
AWIN Display Elements



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CoWS Experiment

- Motivation
- Objectives

- Participants
- Experimental Design
- Experimental Protocol

- Preliminary Results
- Conclusions

Experimental Motivation

- General aviation accident statistics
- The hazards of convective weather
- Aviation Weather INformation (AWIN) systems

Experimental Objectives

How do GA pilots use
different weather information sources
when approaching convective weather situations?

- Sources
  - Conventional aural (ATC, HIWAS, Flight watch),
  - Out-the-window visual scene + aural
  - AWIN display + aural
- Effects
  - Confidence, Workload, Information Sufficiency
  - *Situation awareness, decision quality, individual differences*

Participants

- 8 Check-out, 12 Experimental, 6 reported here
- Subject Requirements
  - local GA pilots
  - instrument rating
  - 50-1000 cross-country or 250 - 1000 total flight-hours
  - Has not worked for a scheduled air-carrier in prior year
  - Has not participated in the RTI FISDL simulation study
- Subjects clustered by cross-country hours
  - low (135), medium (379), high (738) *($p<.0001$)*
  - 4 teams of 3 subjects (one of each level)

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Inflight Experimental Conditions

- For each flight

	"IMC"	VMC
Without AWIN	Aural Cues	Aural + Window
With AWIN	Aural + Display	Aural + Display + Window (crossed out with X)

- For each subject (cue set condition)
  - 6 "proximity" observations of confidence
  - 1 observation of workload & information sufficiency
- Three flights per team

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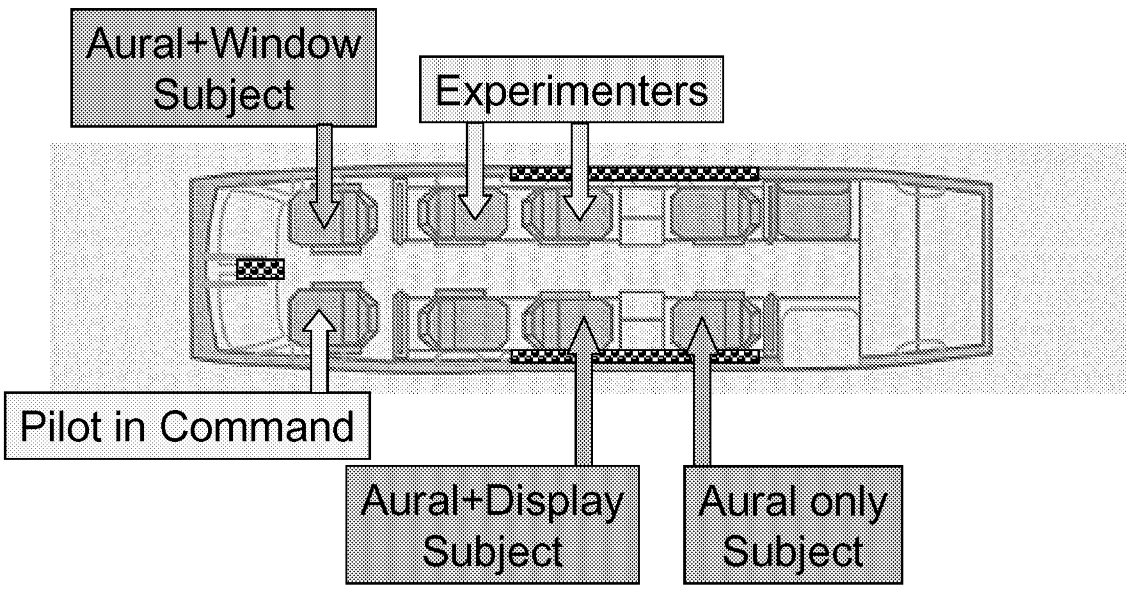
Experimental Conditions in B200



= Opaque covers for side windows & onboard radar

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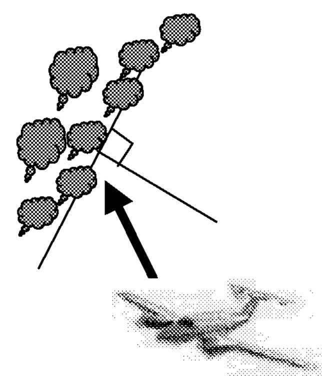
Scenarios

- Mission Motivations
  - wedding, graduation, job interview
- Flight Scenario
  - Flying IFR, but in VMC
  - NASA to destination, 1.5-2 hours
  - Convective fronts, moderate$^+$ intensity
  - Approach front ~45^o



- Aircraft Performance ~ small single-engine
  - Cruising Altitude = 14000’, above haze layer
  - Cruising Speed ~ 170kts true airspeed
  - not radar-equipped, no deicing equipment
  - not pressurized, but does have Oxygen

Scenario Flight Paths

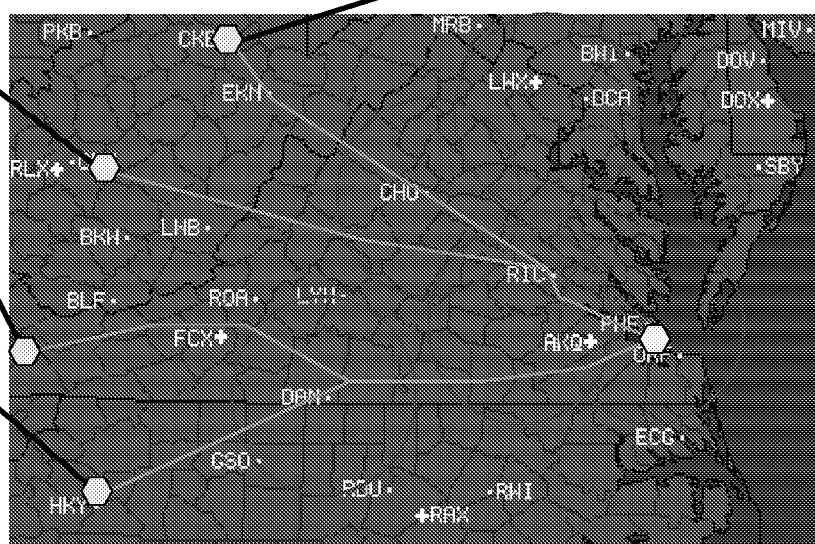
- Test range: 5 ground stations, 40nm radius
- Four destinations & flight paths

Charleston, WV

Clarksburg, WV

Abingdon, VA

Hickory, NC

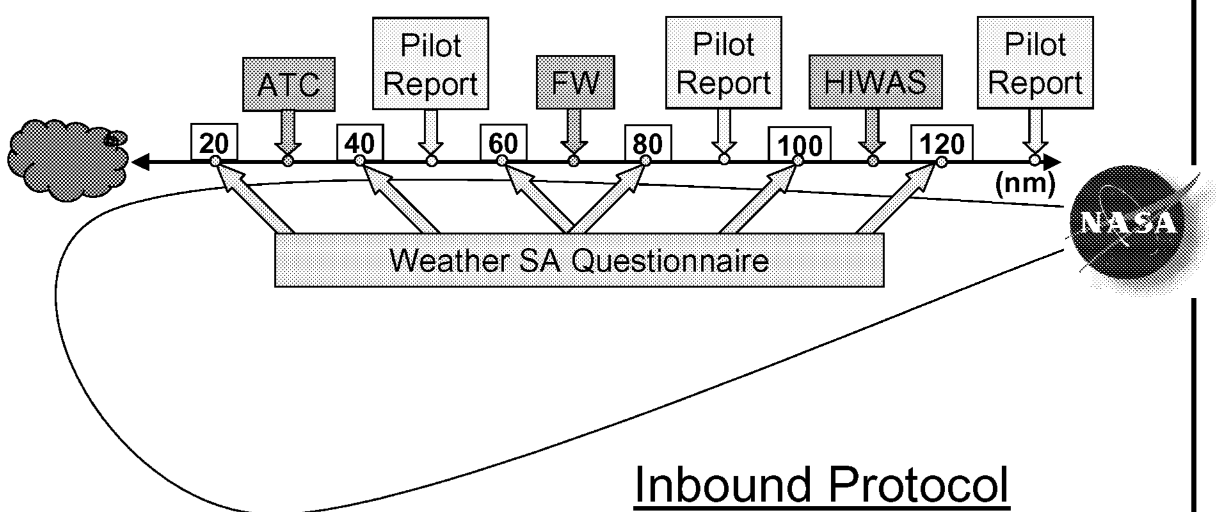


Experimental Protocol

- Preflight
  - Introduction to CoWS, assignment to conditions
  - Mission, route, and regional information briefing
  - Weather briefing
    - » *DUATS text & graphics,*
    - » *Audiotaped FSS briefing, twice*
    - » *Review*
    - » *Preflight SA questionnaire*
  - Intervening tasks
    - » *AWIN training, personality, risk, weather knowledge test*
- Flight
  - Outbound phase
  - Inbound phase
- Debriefing

In-flight Protocol

Outbound Protocol



Inbound Protocol

- *Draw position & weather*
- *Inbound questionnaire*
- *Usability questionnaire*

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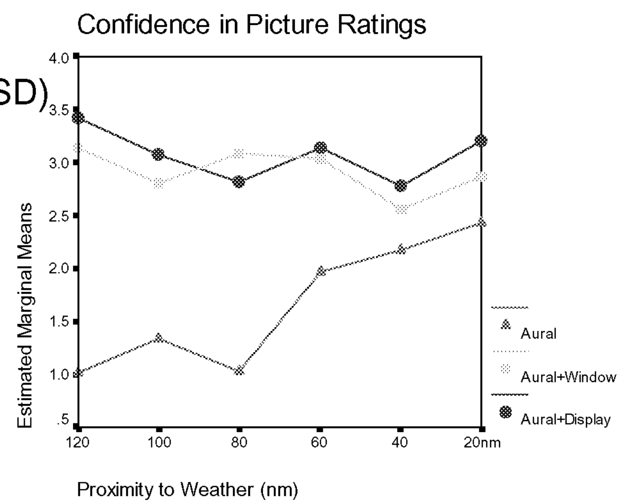
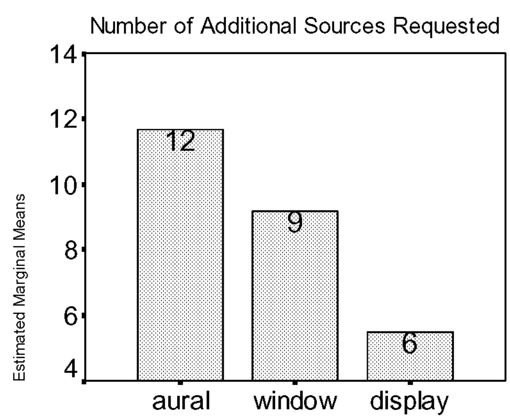
Preliminary Results - Confidence

- Summary of ANOVA
  - Cue set ~ Highly significant (*p*<.0001)
  - Proximity to weather ~ Not significant (*p*=.691)
  - Cue set X Proximity ~ Not significant (*p*=.275)
- Pair-wise comparisons (LSD)
  - Aural *v.* Window (*p*<.0001)
  - Aural *v.* Display (*p*<.0001)
  - Window *v.* Display (*p* = .491)



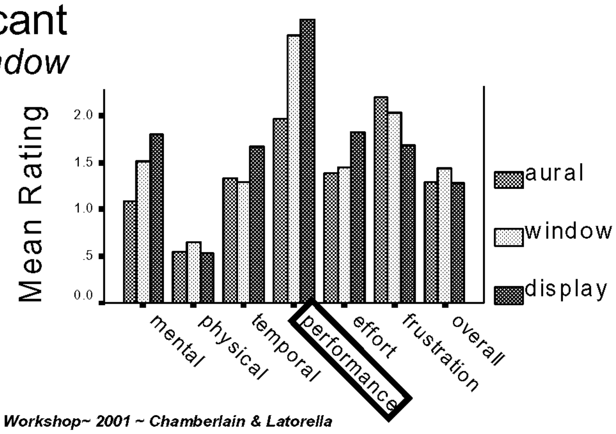
Preliminary Results - Information Sufficiency

- Summary of ANOVA
  - Cue set ~ Significant (*p<.061*)
- Pair-wise comparisons (LSD)
  - Aural *v.* Display *(p=.009)*
  - Window *v.* Display *(p=.094*
  - Aural *v.* Window *(p=.242)*



Preliminary Results - Workload

- Summary of ANOVA
  - Performance Rating
    - » *Cue set ~ Significant (p<.091)*
    - » *Subjects ~ Significant (p<.03)*
  - Physical Rating
    - » *Subjects ~ Significant (p<.02)*
- Pair-wise cue set comparisons (LSD)
  - Performance ~ not significant
    - » *Trend: Aural < Display, Window*
- *Subjects did report that workload was similar to that when actually flying.*



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Conclusions

- Reliance on AWIN in IMC and close to hazards
  - As confident as visuals - possibly over-confident
  - Less likely to seek information from ground sources
  - Perceived performance similar to window condition
  - *Data is at least 6 minutes old, was as old as 30 minutes*
- Implications: design, training, & use guidelines
  - » ***RTCA FIS-B Minimum Aviation System Performance Standards.***
    - » Document: DO-267
    - » note added to indicate need for age v. timestamp
  - » ***Need more salient indication or alerting***

The Future of CoWS

- Other Experimental Results
  - Full data set - Effects of cues on inflight SA & decisions
    - » *proximity to convective frontal weather*
  - Effects of individual characteristics
    - » *personality, risk tolerance, weather knowledge*
  - Effects of weather graphics on preflight SA
- Usability Assessment of an available AWIN system
- Canned cues for subsequent comparative analysis
  - Onboard weather radar, AWIN radar mosaic,
  - Pilot observations, ground sources (ATC,FW, FSS),
  - HIWAS, video of external view.

Presented at the NASA Weather Accident Prevention Workshop~ 2001 ~ Chamberlain & Latorella

CoWS

Convective Weather Sources

Questions?

Presented at the NASA Weather Accident Prevention Workshop~ 2001 ~ Chamberlain & Latorella

General Aviation Cockpit Weather Information System Simulation Studies

Ray McAdaragh, Ph.D.
FAA Human Factors Division / NASA AWIN Program

Paul Novacek
Research Triangle Institute (RTI)

FAA / NASA Cooperative Research

June 5, 2001

NASA/CP—2002-210964

Project Goals

- Develop a Better Understanding of the Use of Data-Linked Weather Information
- Provide Guidance to FAA/Manufacturers on the Use of Data-Linked Weather Information
- Recommend Guidelines for Inclusion in the AIM and ACs

RTI

Description

- A Series of Rigorous Investigations Using Piloted Simulation of the Effects of Various Data-Linked Cockpit Weather Information Treatments

RTI

Research Triangle Institute (RTI) Completed Experiments

- Use of a Data-Linked Weather Information Display and the Effects on Navigation Decision Making in a Piloted Simulation Study
- The Effects of Ownship Information and NEXRAD Resolution in use of a Weather Information Display

RTI

NASA/CP—2002-210964

Research Triangle Institute (RTI) Current Experiment

- An Investigation into the Use of NEXRAD Image Looping and the Use of the National Convective Weather Forecast Product on a Moving Map Display for General Aviation

RTI

First RTI Experiment

June 1999 to August 2000

Investigate the use of a Data-Linked Weather Information Display and the Effects on Navigation Decision Making in a Piloted Simulation Study

RTI

Objective & Hypothesis

- ***Objective:*** To investigate the potential for misuse of weather information, and thus provide guidance to the FAA
- ***Hypothesis:*** Delayed weather information datalinked to a cockpit display may lead to navigation decision errors

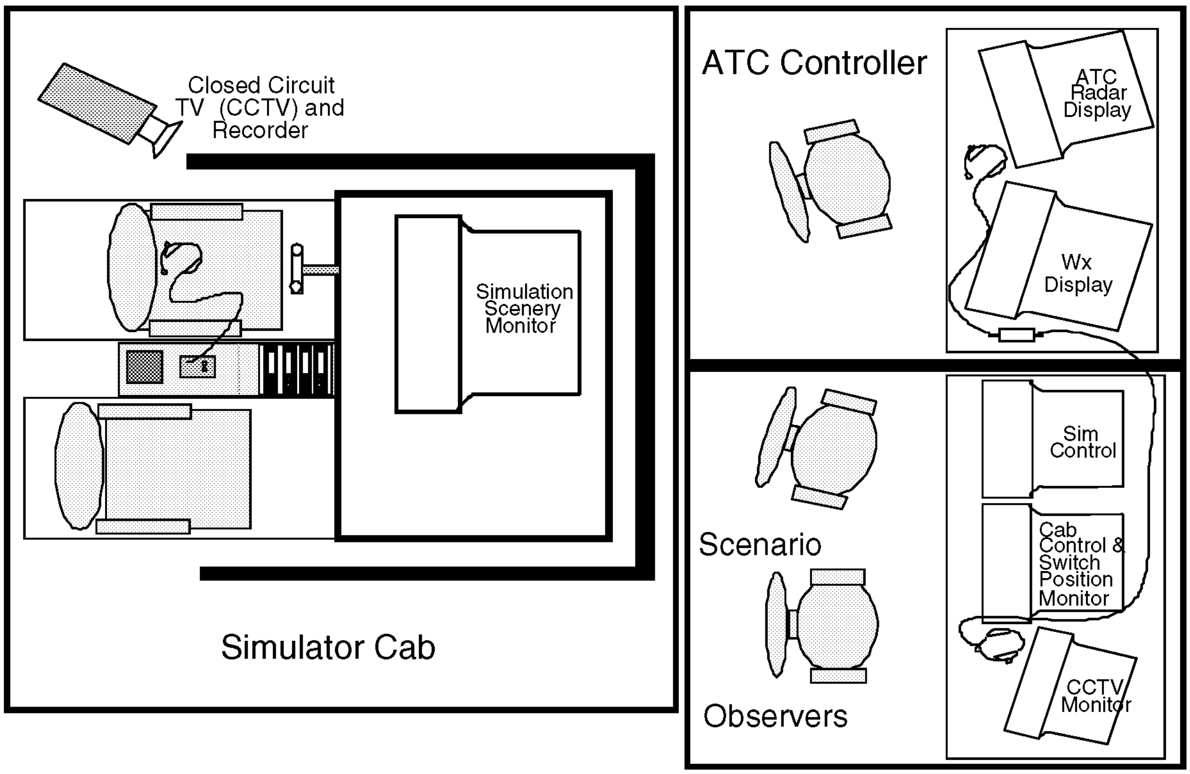
RTI

Experiment Design

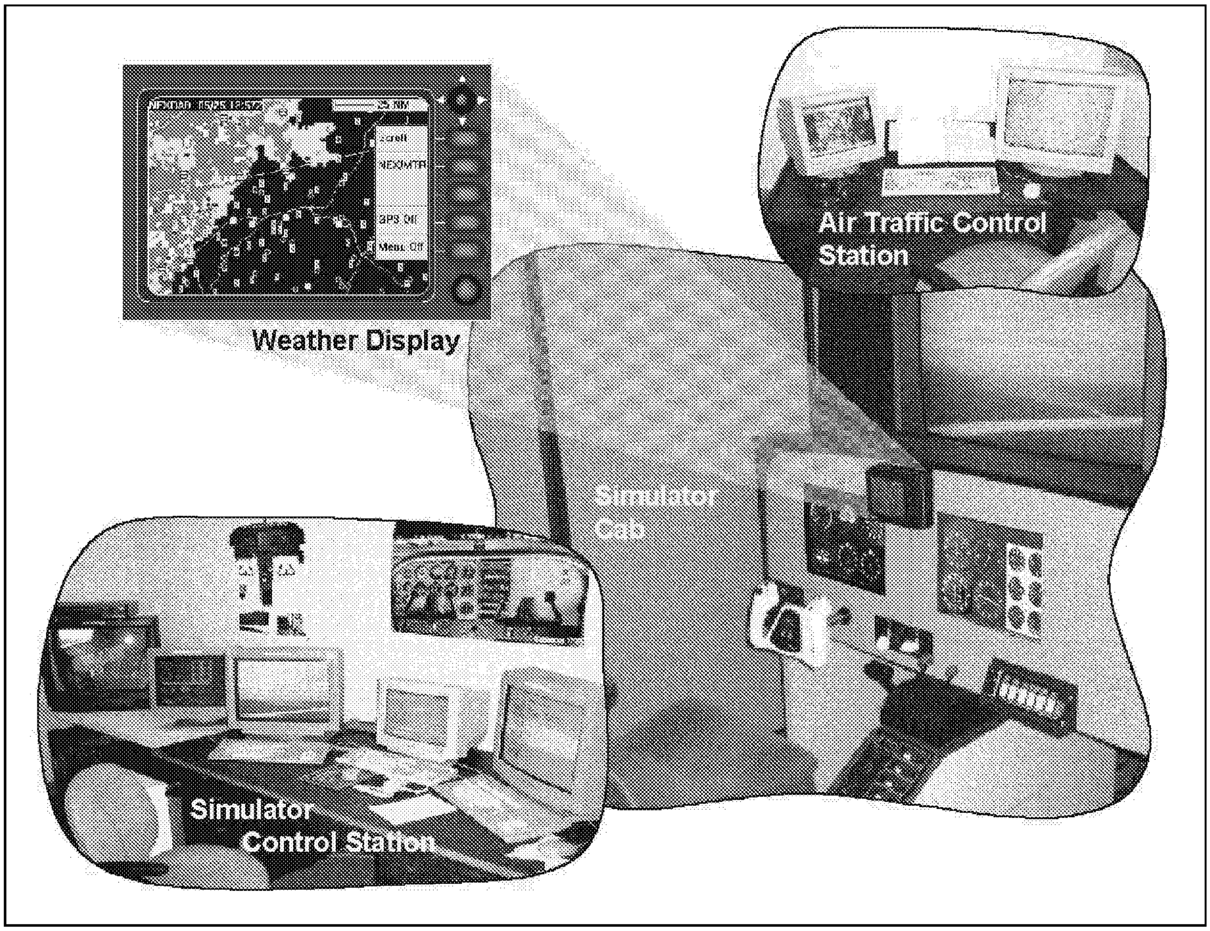
- Two groups of pilots, 12 with a datalinked weather display and 12 without a weather display
- The simulator mission consisted of a two-leg mercy flight with convective weather along the route
- All subjects were current Instrument Flight Rules (IFR) qualified pilots
- Primary data collected consisted of weather related navigation decisions.

RTI

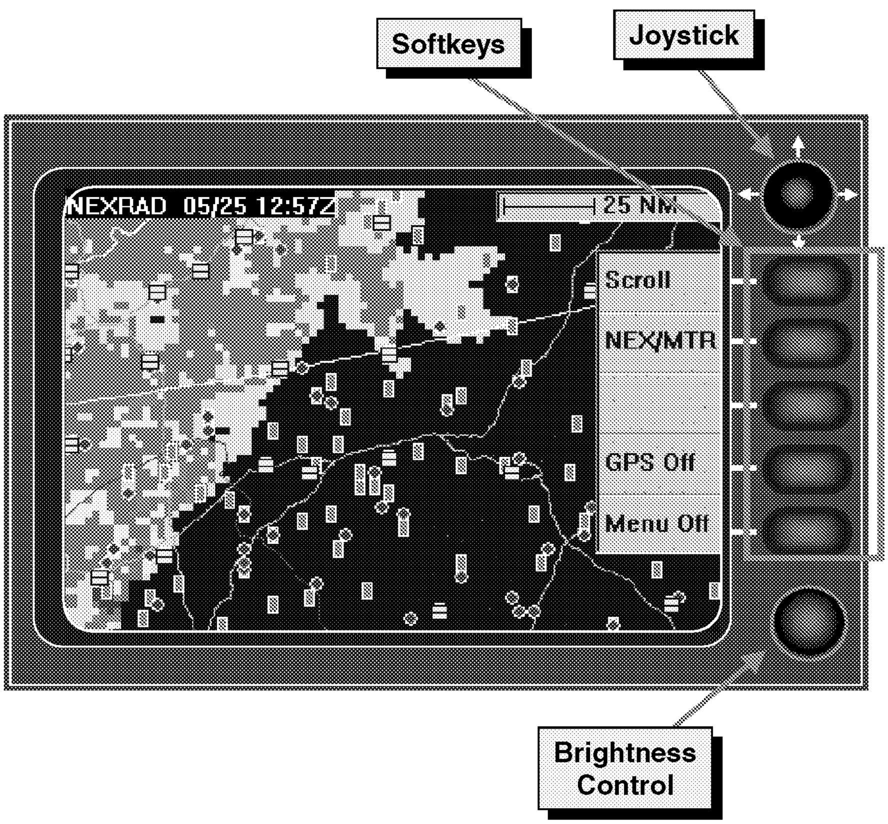
RTI Simulation Hardware Configuration



RTI Cockpit Research Facility

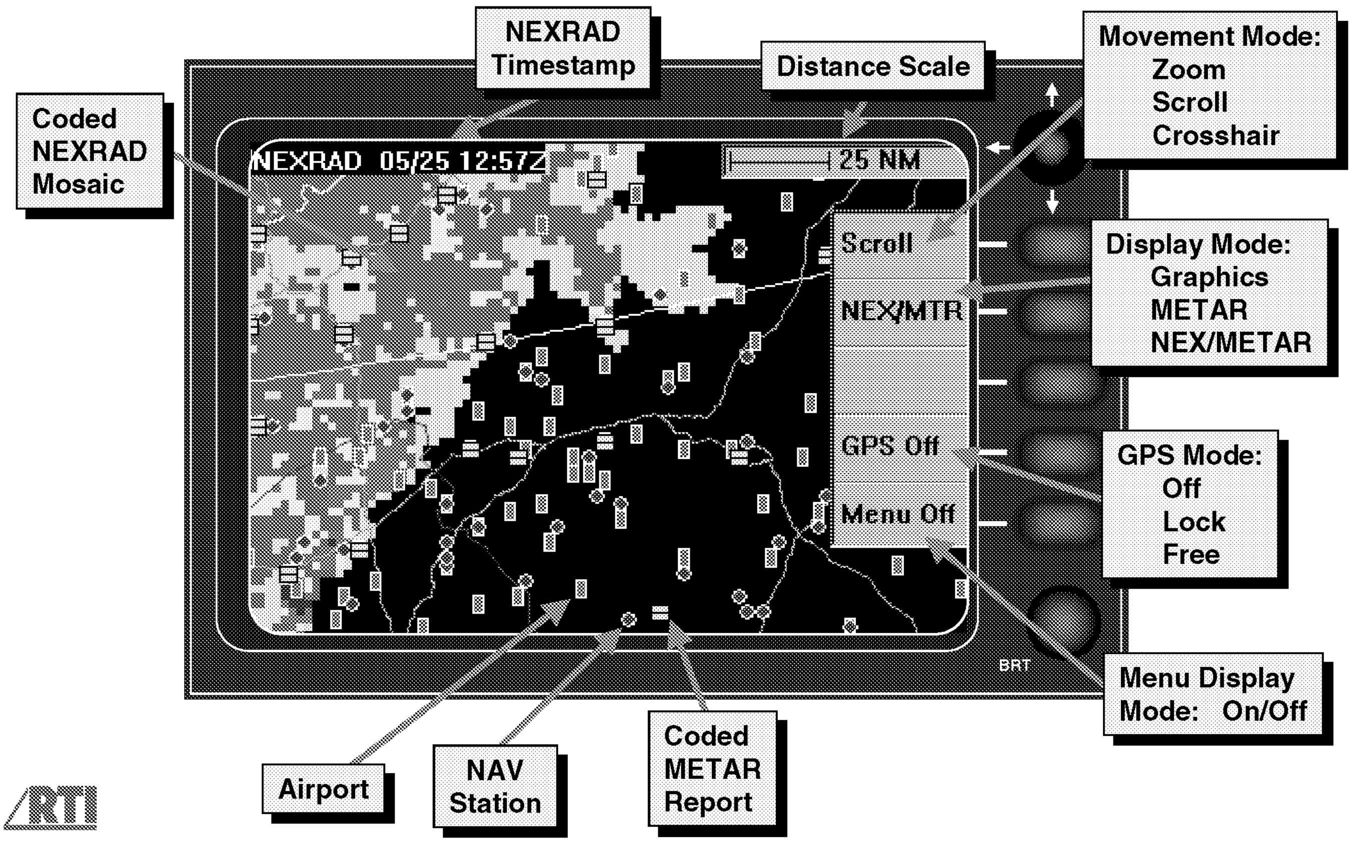


Datalinked Weather Display Configuration



RTI

Datalinked Weather Display Screen Layout



Mission Scenario

Take-off from Newport News

Pick-up medicine at Richmond

Encounters thunderstorm that prevents landing at Richmond (decision 1)

Divert or waved off from Richmond

Continue flight to Wallops Island with medicine.

Encounters thunderstorms enroute to Wallops (decision 2)

Lands successfully at Wallops Island Airport

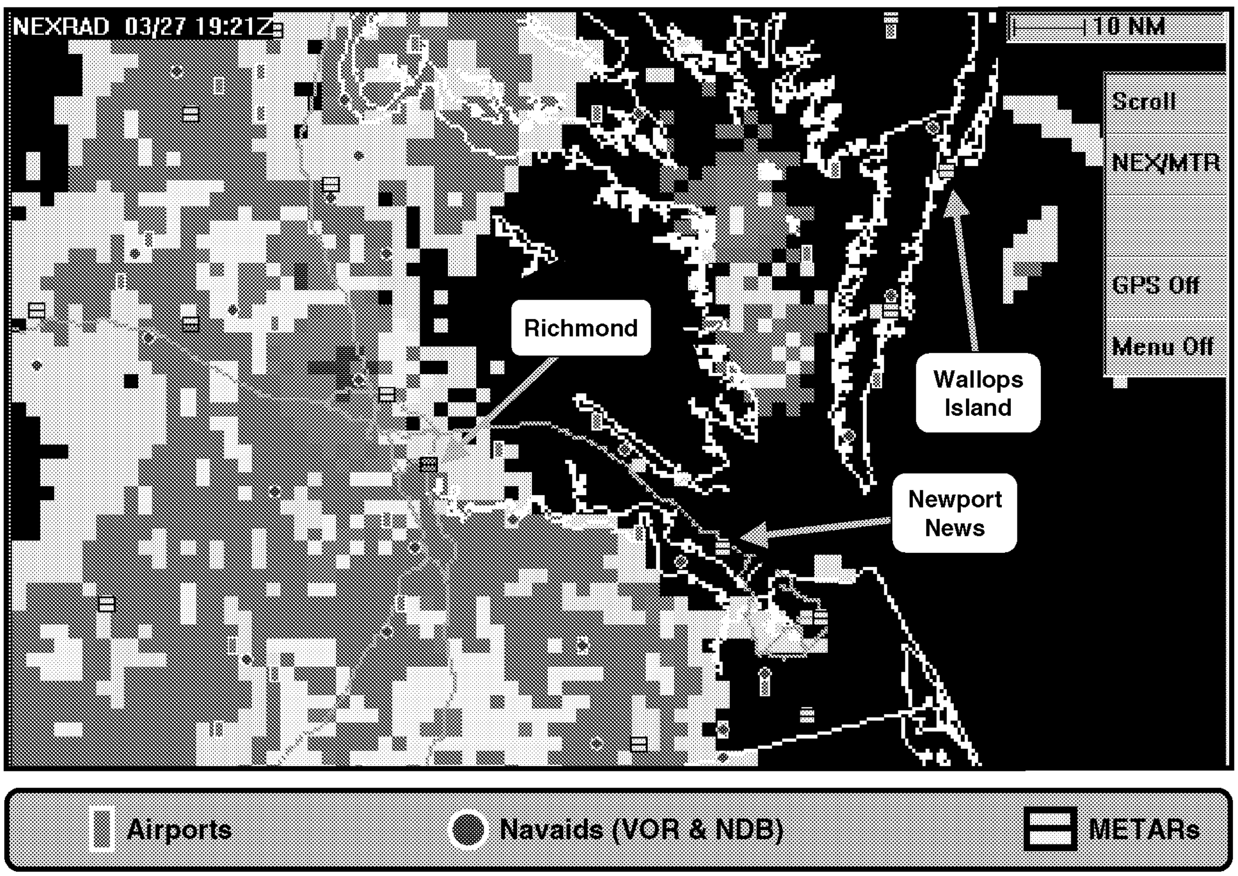
RTI

Experiment Procedure

1. Pilot given Risk Aversion and Weather Knowledge tests
2. Pilot briefed on mission, simulator and weather display
3. Pilot provided instruction and practice in the simulator
4. Pilot planned flight (charts, weather reports provided)
5. Pilot performed the mission, data was collected
6. Pilot completed Immediate Reaction Questionnaire
7. Pilot participated in structured interview, data was collected
8. Pilot completed open-ended questionnaire

(each experiment session took approximately 5 hours)

RTI


NEXRAD 03/27 19:21Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off
Richmond
Wallops
Island
Newport
News
Airports
Navaids (VOR & NDB)
METARs

Conclusions

- The weather display system used in this study did not improve pilot decision making
  - Situational awareness increased but at a cost of higher workload
  - Pilots were unable to easily perceive their proximity to potentially hazardous weather conditions
  - Pilots had difficulty determining storm movement
  - Display caused less reliance on other weather sources

RTI

Recommendations

- Provide the following features
  - Ownship information symbology
  - Direction and rate of hazardous weather
  - Intuitive NEXRAD image age information
  - Provide METAR code translation
  - Develop training curriculum
  - Emphasize that a weather display not to be used for navigation

RTI

NASA/CP—2002-210964

Second RTI Experiment

September 2000 to April 2001

Investigate the Effects of Ownship Information and NEXRAD Resolution in the use of a Weather Information Display

RTI

NASA/CP—2002-210964

Objective & Hypothesis

- ***Objectives:*** Explore the relationship between delayed uplinked weather information and aircraft ownship. Explore the effect of differing sizes of NEXRAD cell size on pilot judgement.

- ***Hypothesis:*** There is a potential for misuse of delayed weather information superimposed onto a moving map display with aircraft ownship.

  Additionally, weather display resolution is an integral element of weather situational awareness, and has a significant effect on pilot judgement.

RTI

Comparisons of follow-on experiment to previous baseline experiment

Experiment similarities:

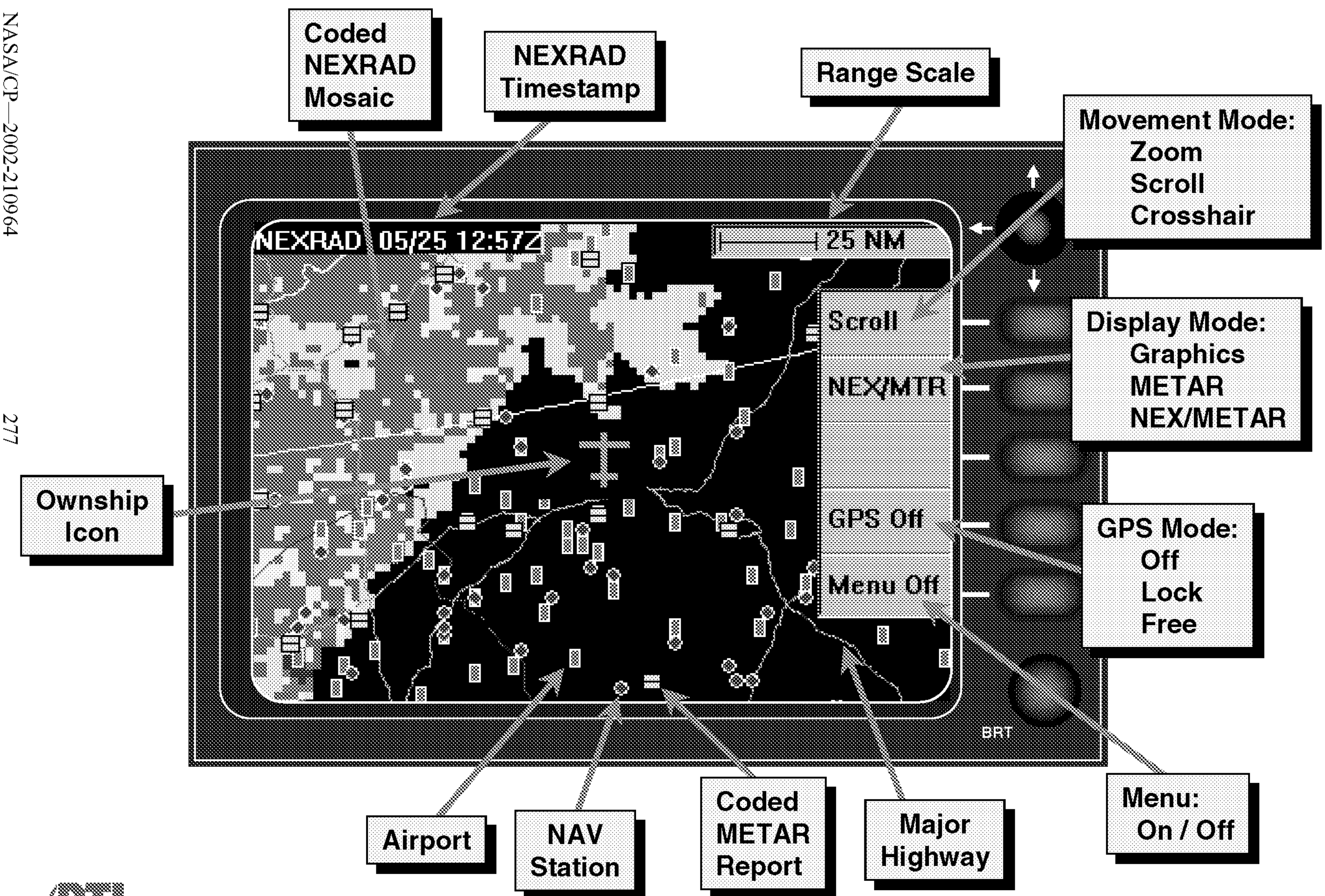
- Identical facilities
- Similar subject pilot selection process
- Similar data collection (expanded)
- Identical materials and procedures
- Similar data analysis (expanded)

Experiment differences:

- Addition of ownship symbology to weather display
- One group of 12 pilots used 4 km NEXRAD cells
- The other group of 12 pilots used 8 km NEXRAD cells

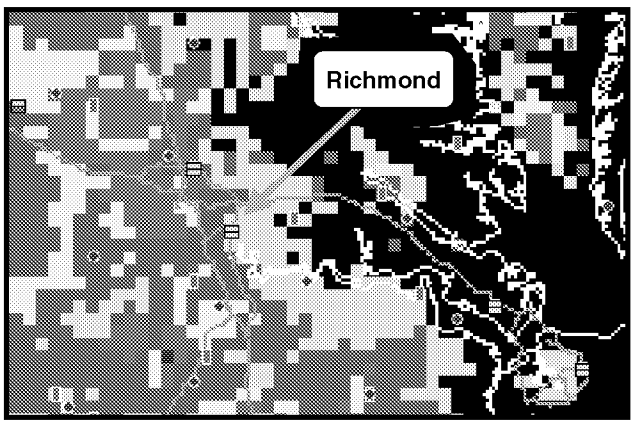
RTI

Datalinked Weather Display with Addition of Ownship Symbology

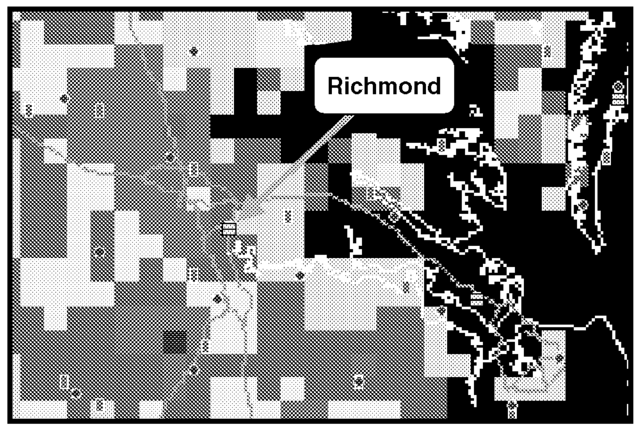


RTI

Comparison of Small and large NEXRAD cells



1914Z NEXRAD Image
Small Cells (4 km sides)

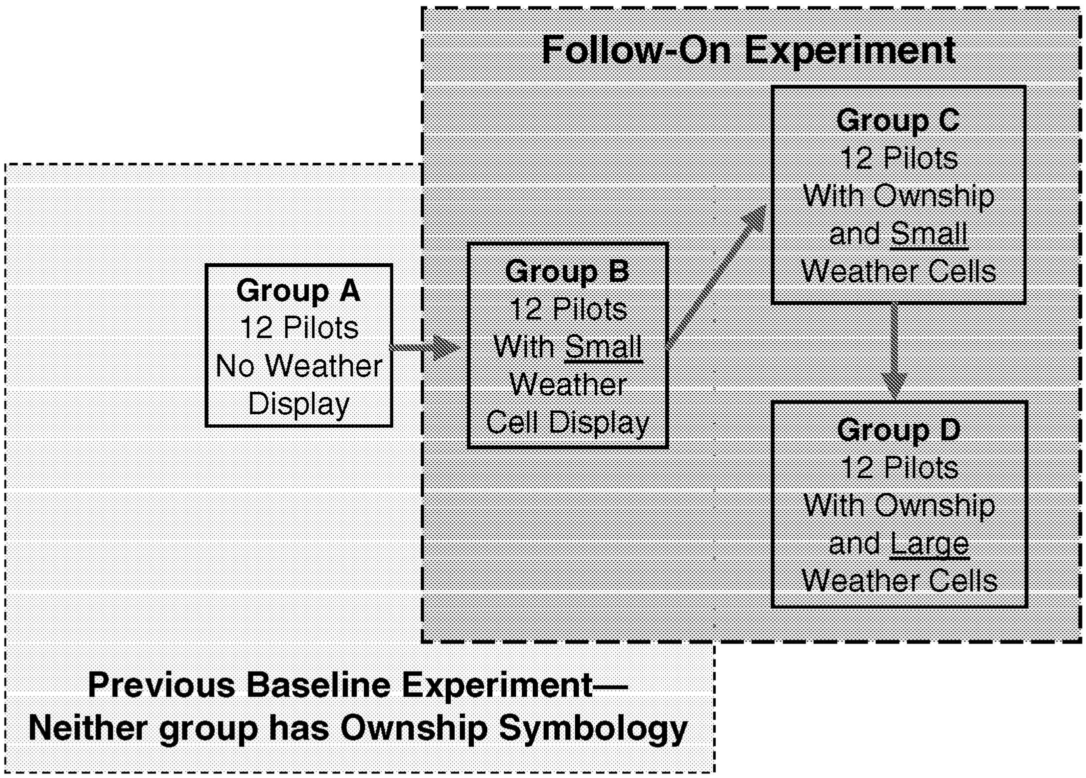


1914Z NEXRAD Image
Large Cells (8 km sides)

(both maps cover identical geographical areas)

NASA/CP—2002-210964

Relationship to Previous Baseline Experiment



(red arrows denote statistical comparisons)

RTI

Mission Scenario

(identical to baseline experiment)

Take-off from Newport News

Pick-up medicine at Richmond

Encounters thunderstorm that prevents landing at Richmond (decision 1)

Divert or waved off from Richmond

Continue flight to Wallops Island with medicine.

Encounters thunderstorms enroute to Wallops (decision 2)

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RTI

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5. Pilot performed the mission, data was collected
6. Pilot completed Immediate Reaction Questionnaire
7. Pilot participated in structured interview, data was collected
8. Pilot completed open-ended questionnaire

(each experiment session took approximately 5 hours)

RTI

Data Collection

The primary data collected consisted of weather related navigation decisions...

— good or poor, based on objective criteria

... and the weather information gathering methods used to arrive at those decisions.

— weather services used, and how the pilot integrated the information

RTI

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Conclusions

- Datalinked weather display increased situational awareness of hazardous weather
- Introduction of ownship symbology did not increase number of good decisions, but did decrease workload
- Introduction of larger NEXRAD cells did have a positive effect on decision making
- Use of datalinked weather display compelled some pilots to forgo use of corroborating weather sources
- Textual METAR teletype codes were difficult to decipher in high workload situations
- Pilots questioned validity of METAR data due to age
- Larger NEXRAD cells contributed to stimulus area effect

RTI

Recommendations

- Provide ownship information symbology
- Provide more effective means of distance determination
- Provide intuitive NEXRAD image age information
- Train pilots in the use and limitations of datalinked weather displays
- Provide METAR teletype code English translations
- Investigate depiction of direction and rate of hazardous weather movement

RTI

Overview of Continuing Research

(started May 2001)

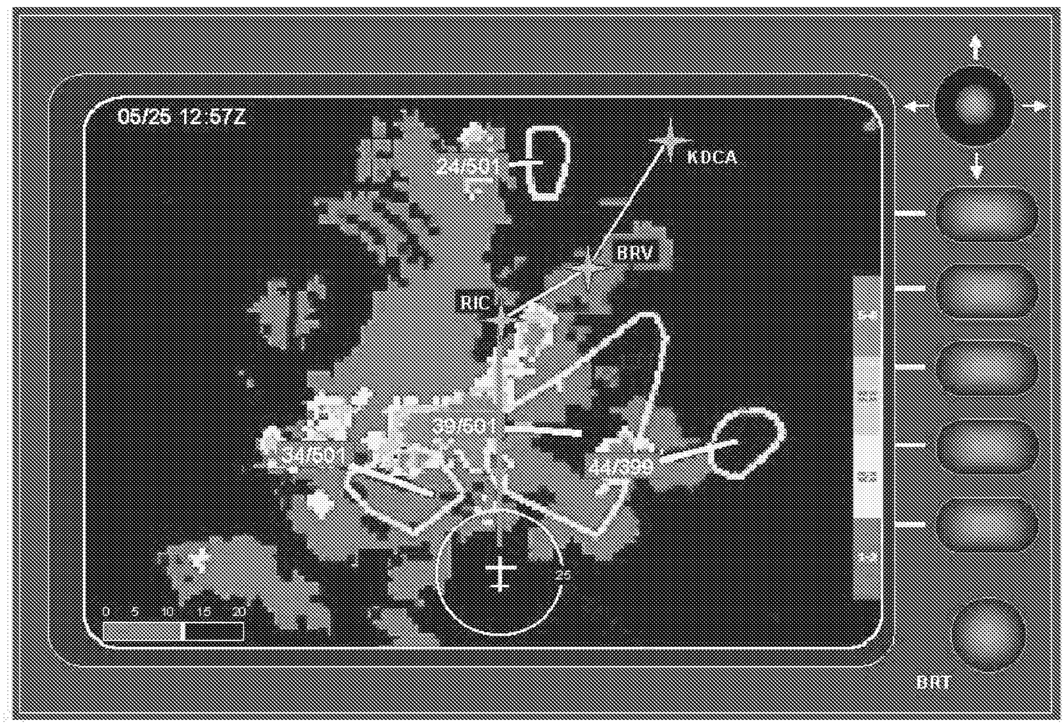
An Investigation into the Use of NEXRAD Image Looping and the Use of the National Convective Weather Forecast Product on a Moving Map Display for General Aviation

- Determine the effects of NEXRAD looping on pilot decisions and workload
- Determine the effects of using a nowcast product on pilot decisions and workload

The experiment will be similar in design, procedures, equipment, mission and analysis to the previous two experiments

RTI

Datalinked Weather Display with the National Convective Weather Forecast Product



(blue outlined areas indicate one-hour forecast of cell movement)

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Some Possible Future Experiments

- Investigation into the use of Data-Linked Weather Information Display with Enhanced Weather Products and Decision Aids during Collaboration with Weather Service Providers (Collaborative Decision-Making Training Issues)
- Investigation of the Effect of Information Search Prompting upon use of Weather Displays in Decision Making.
- Investigation into Workload and Decision-Making Effects of an Integrated Weather and Navigation Display System

QUESTIONS?

General Aviation FIS Broadcast System

Honeywell International

AWIN System Project Overview

Honeywell

AWIN Phase I Overview

AWIN Phase II Plans

FIS Overview

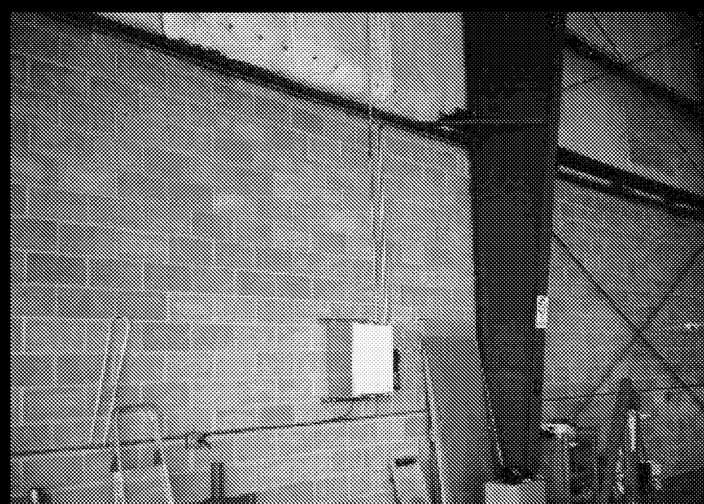
Honeywell

AWIN Phase I Overview

- Developed Airborne Receivers and Displays
- Developed and built Ground Stations
- Deployed VDL Mode II Ground Stations
  - MN, WI, CO, KS, VA
  - VA stations used for CoWS Experiments
- Provided technical support for the Ground Station network.

Honeywell

Charlottesville VA



Petersburg VA

Honeywell

AWIN Phase II Overview

- Support Mid-Atlantic Test Range
- VDL Mode 2 RF Propagation Study
- Bi-directional FIS Study
- FIS Lightning Data Product Study
- Miniaturized VDL Mode 2 Radios

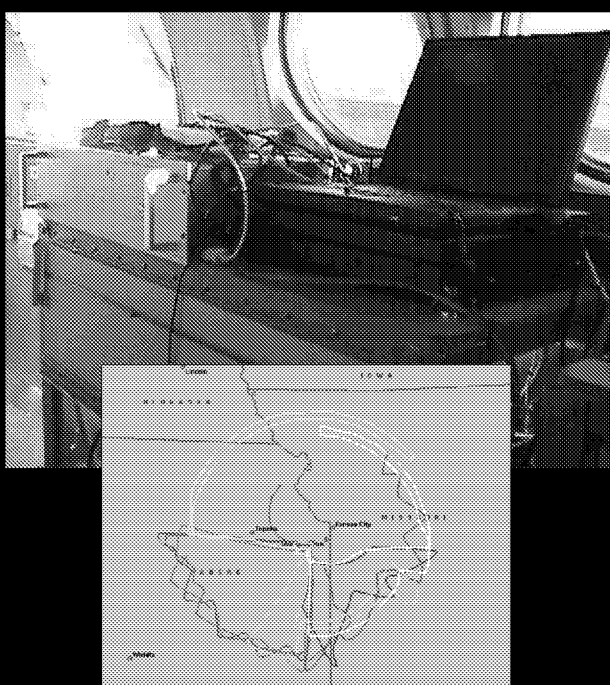
Honeywell

Test Range Support

- Continuation / Enhancement of AWIN VDL Mode 2 Network
  - Technical support for VA Ground Stations
  - Exploring transition to FIS network by implementing a Private Experimental Channel
    - Leverage FIS Subscription Control Encryption
    - Only NASA will be able to read the data
    - Allows the continuation of experiments and new data product evaluations
- License Display Software

Honeywell

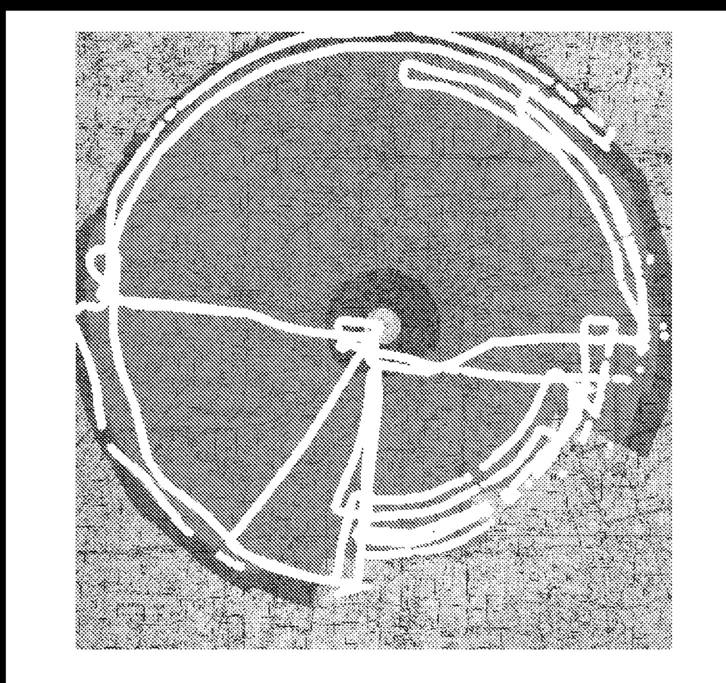
Flight Testing Program



- RF system performance tests
  - Single transmitter located in Olathe
  - Transmitted packets with known data
  - Aircraft flew at 5000 ft AGL
  - 19” rack Rx in Aircraft
  - Multi-flight test (>40 hours total)
- Data Collection
  - Time
  - GPS Position
  - Bit Error Rate (BER)
- Data Usage
  - “Calibrate” RF simulation tool
  - Refine Ground Station placement

Honeywell

VDL Mode 2 RF Propagation Analysis



White lines show the aircraft position where BER was less than 10^{-3}

Honeywell

Bi-Directional FIS Study

- Bearer System Evaluation
  - Focus on GA market parameters
- Return Path Usage Analysis
  - User requests tailored service
  - Response uplinked via FIS-B system
- VDL 2 Augmentation
  - Geographical footprint
  - Altitude

Lightning Data Product Analysis

- Examine the differences between lightning data collected by on-board systems and terrestrial network data
  - Cloud-to-cloud vs ground strike
  - Data latency
  - Position accuracy
- Leverage the study to determine education parameters for FIS users

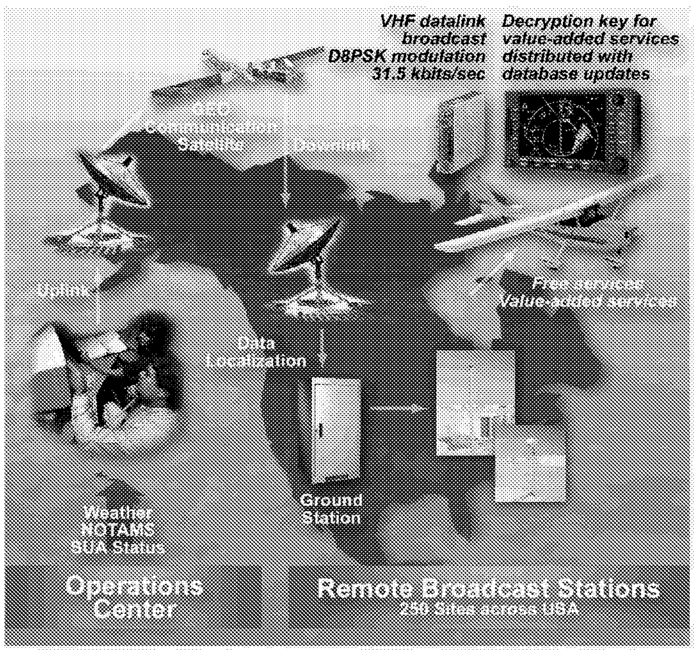
Honeywell

Miniaturized VDL Mode 2 Radio

- Increment 1
  - Mini VDL2 Receiver
  - Increase integration of safety products
  - Generate platform for portable FIS receiver
- Increment 2
  - D8PSK "Radio on a Chip"
  - Transceiver
  - Enable further integration, create a next-generation portable platform core

FIS Overview

Honeywell



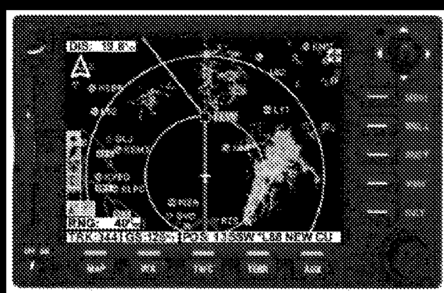
BASIC Products

- METARs
- PIREPs (pilot reports), urgent and routine
- SPECI surface observations
- TAF terminal forecasts
- AIRMETs
- SIGMET
- Convective SIGMETs
- Alert weather watches

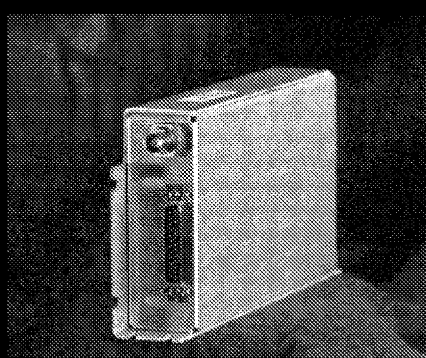
Value-Added Products

- NEXRAD
- Graphical METARs
- NOTAMs
- Graphical SIGMET and AIRMET display
- NLDN lightning data
- Special use airspace status
- Winds aloft information
- Convective nowcast
- Icing nowcast
- Turbulence nowcast

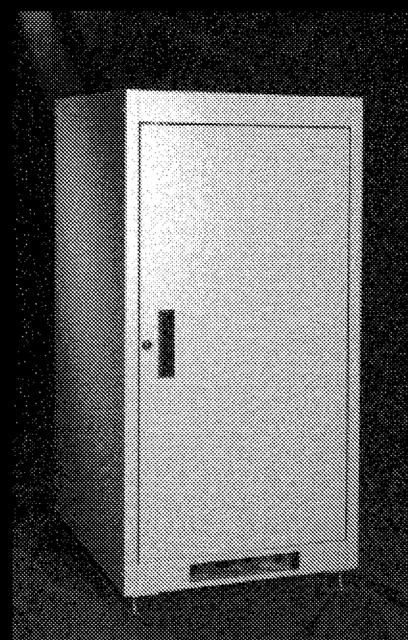
Honeywell



KMD 550 Multi function Display



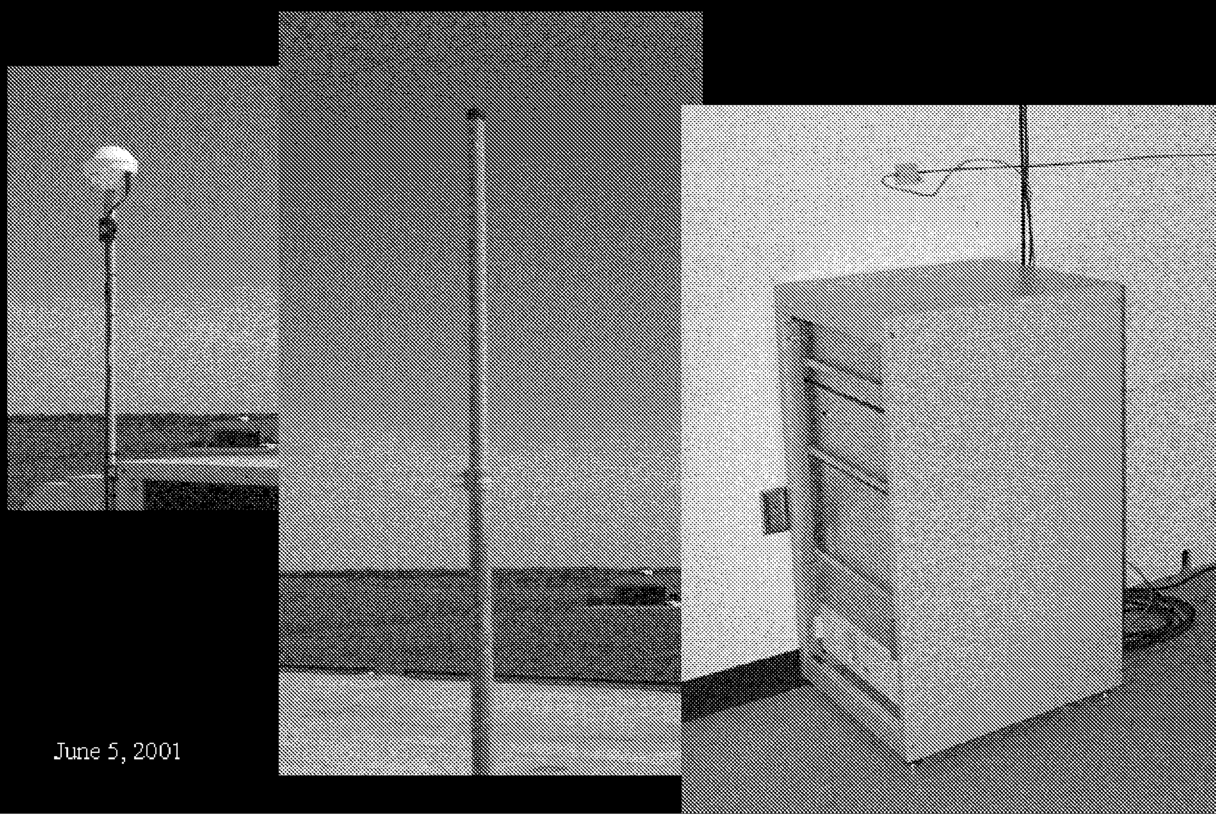
KDR 510 FIS Receiver



KGS 511 Ground Station

Honeywell

Independence KS

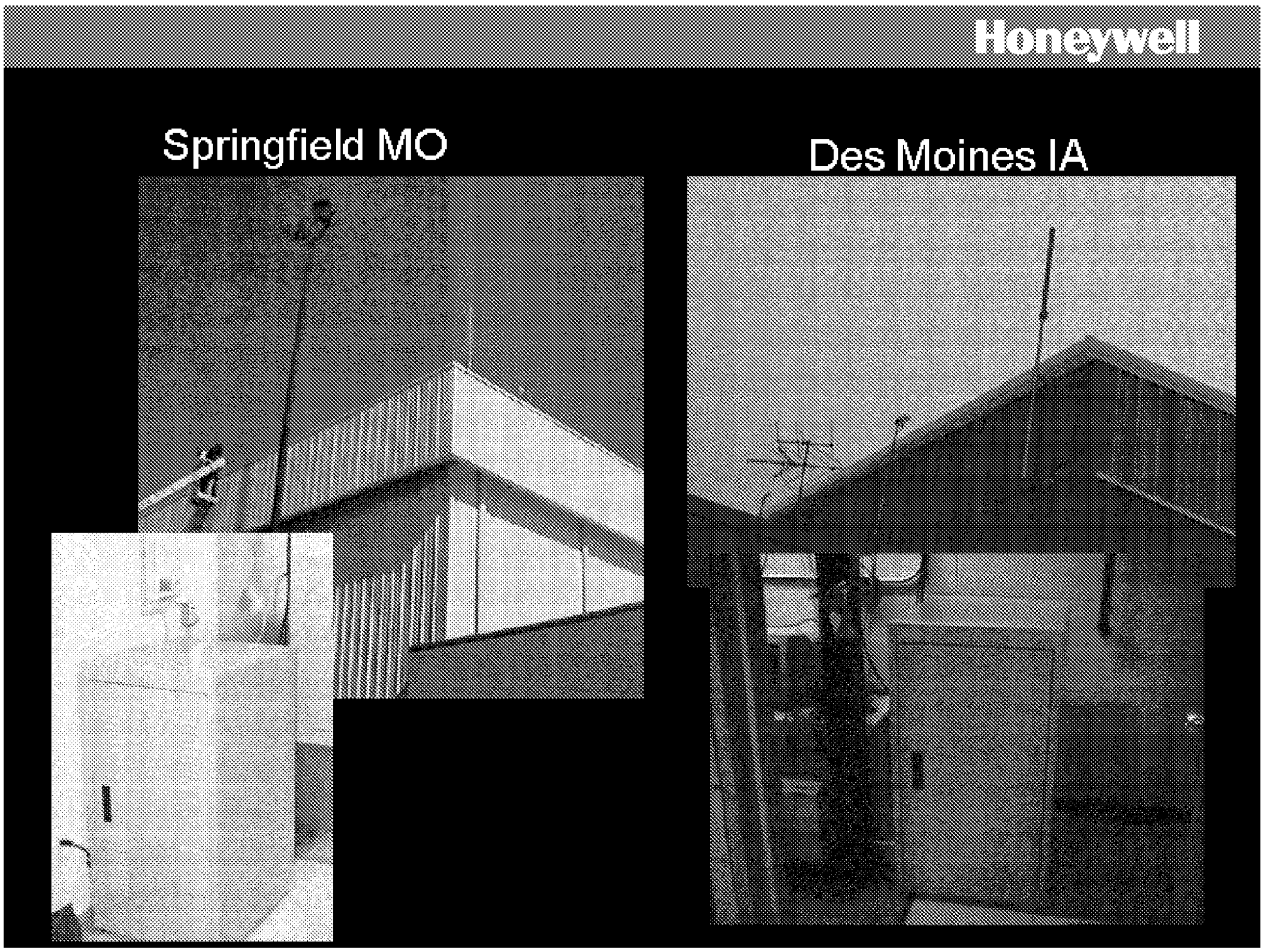


June 5, 2001

Honeywell

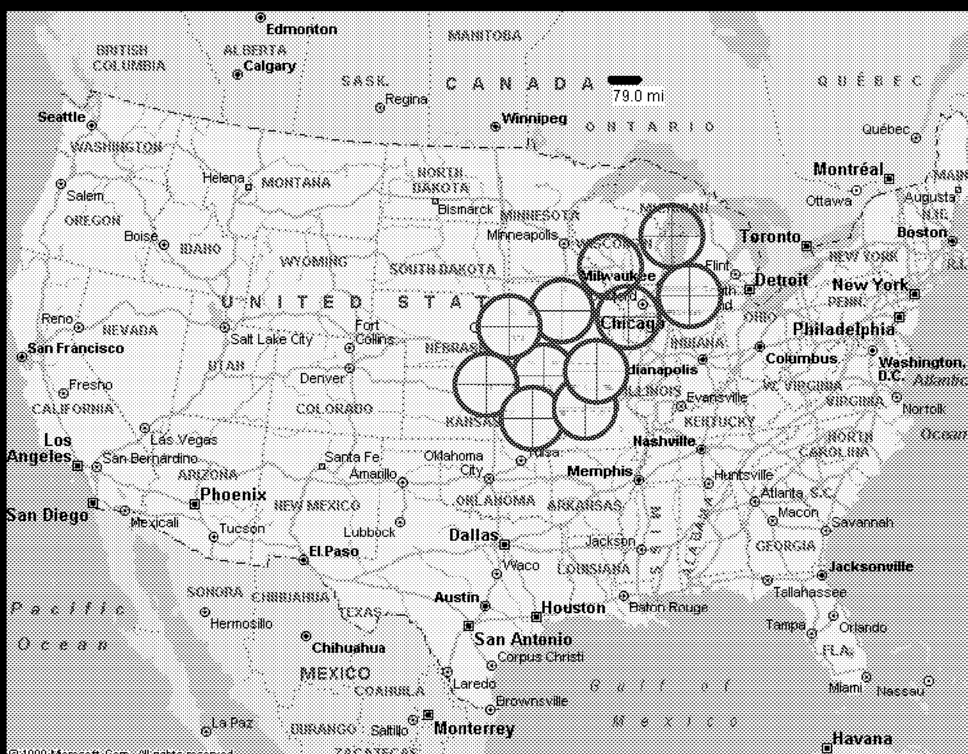
Lyons KS

June 5, 2001


Honeywell
Springfield MO
Des Moines IA

Honeywell

FIS Installations



Installation Complete

Installation In Process

NASA/CP—2002-210964

FIS Architecture Study Plan

JHU/APL

Robert Nichols and William Kasch
Information Transfer Group
JHU Applied Physics Laboratory
Laurel, MD

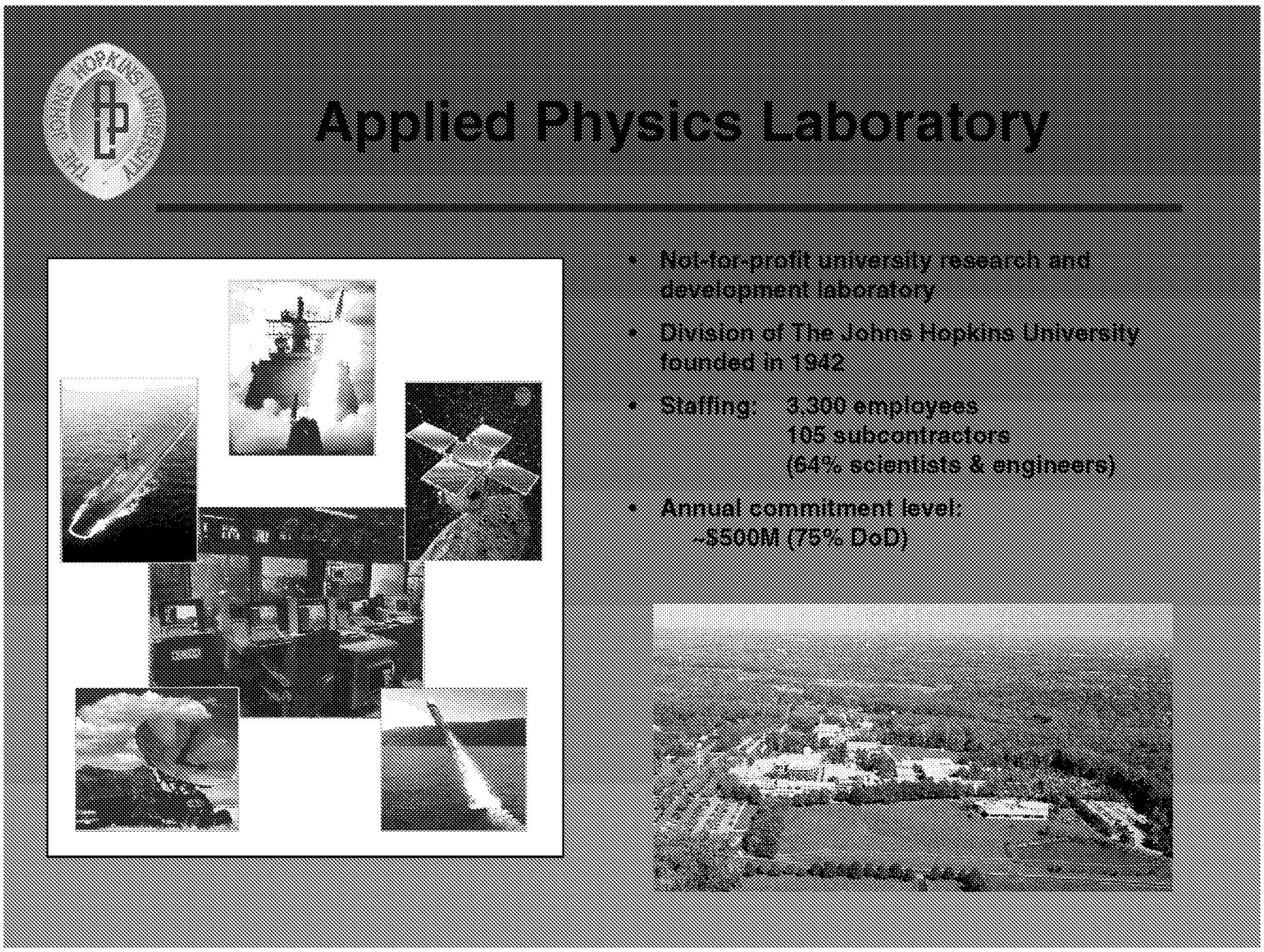
robert.nichols@jhuapl.edu
william.kasch@jhuapl.edu

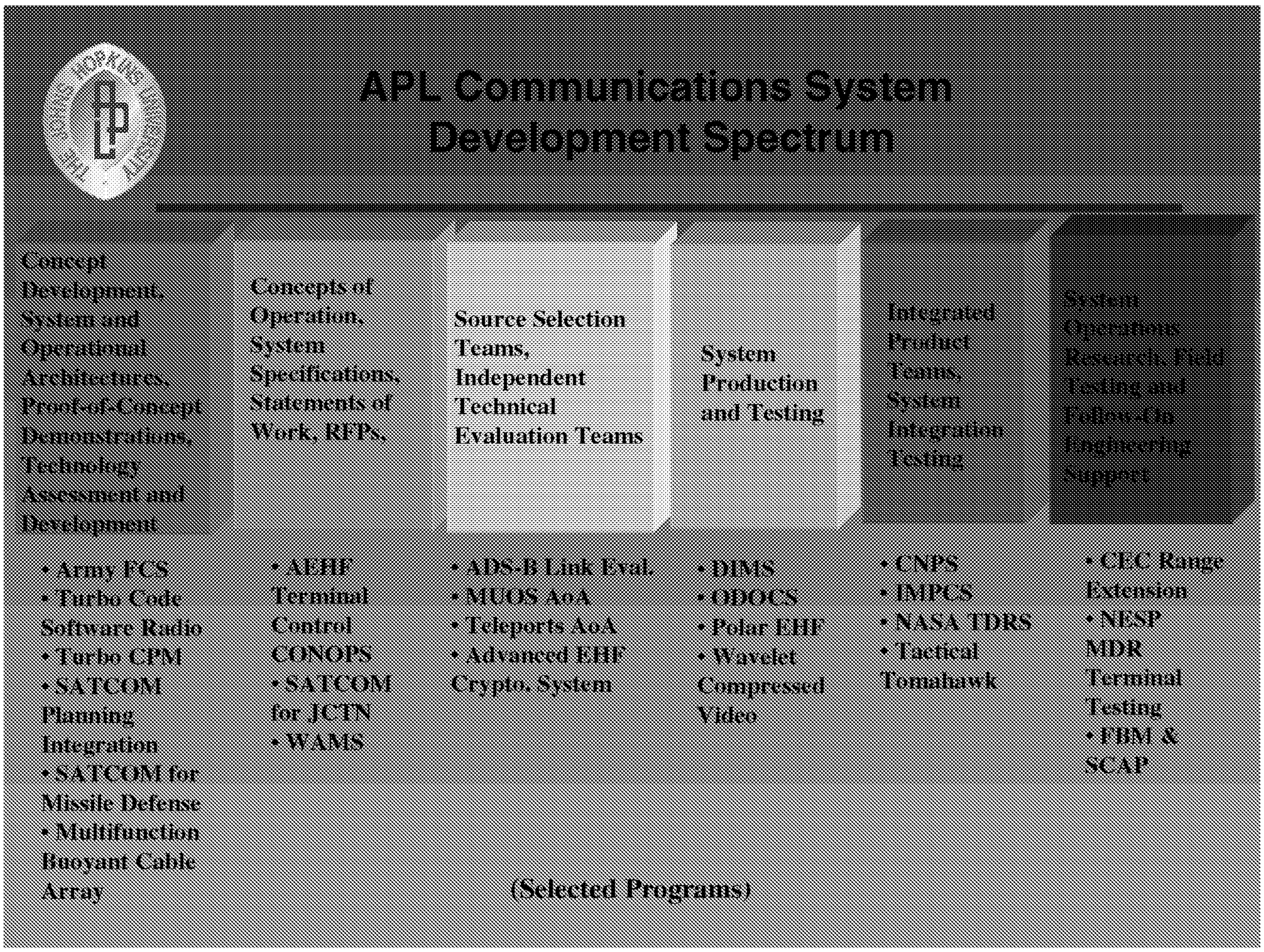
Outline

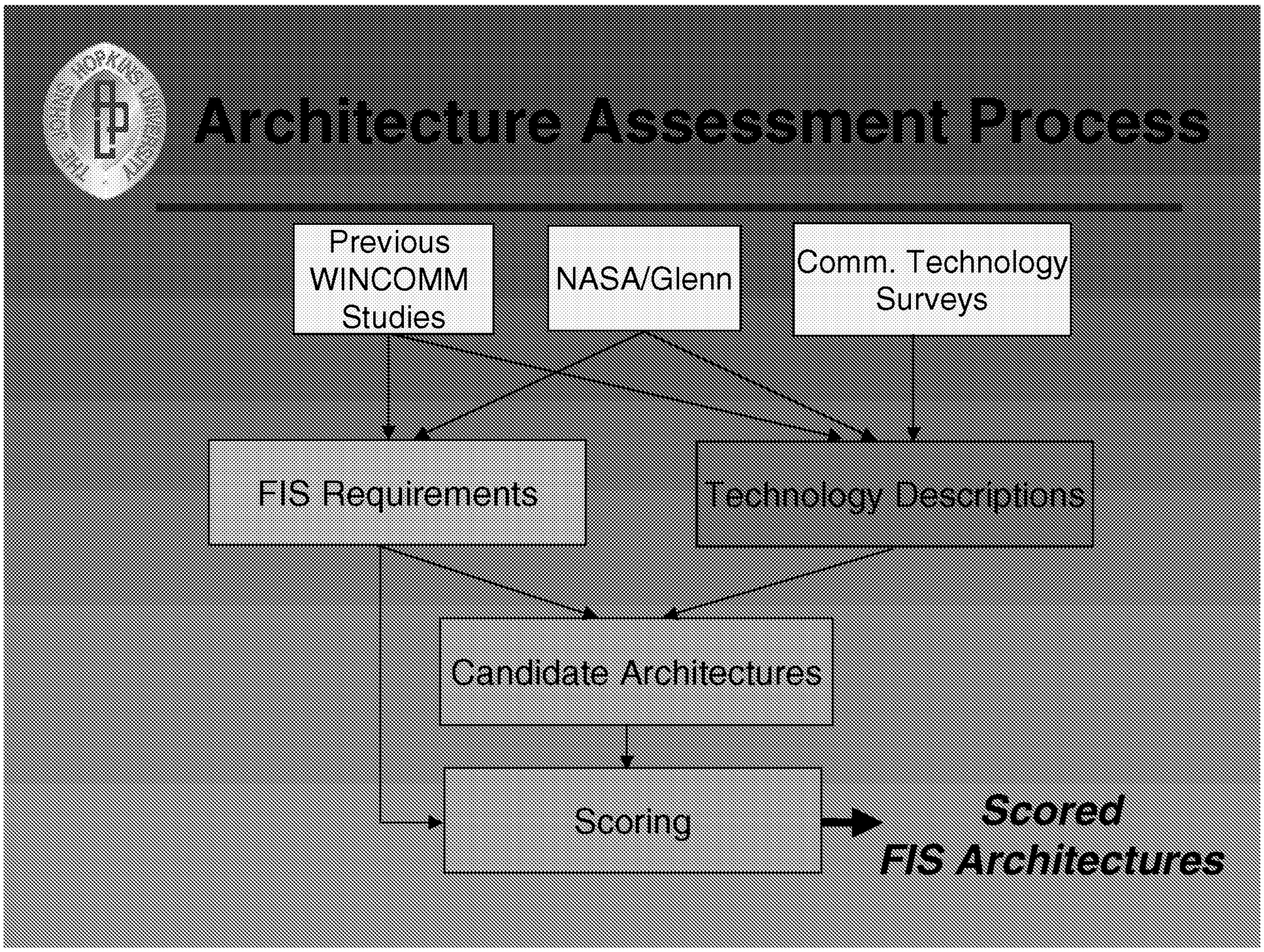
- Study Background
  - NASA/Glenn Tasking
  - APL Overview
- Architecture Process
  - Schedule
  - Requirements
  - Technology
  - Candidate Architectures
  - Scoring
- Summary

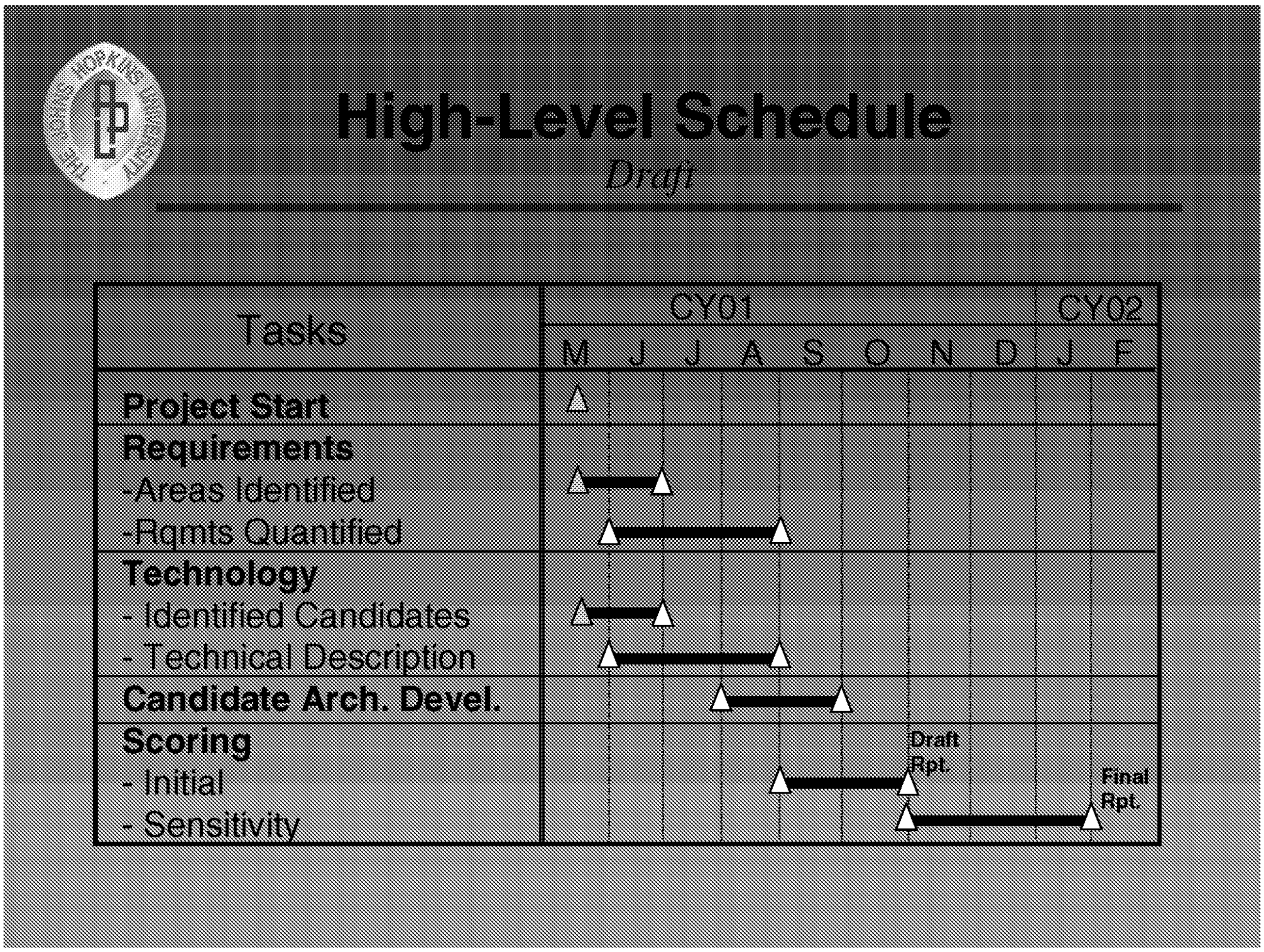
NASA/Glenn Tasking

- NASA/Glenn has tasked APL to "support the investigation of systems and architectures, currently under development, that have the potential to support the dissemination of timely weather information to aircraft"
  - VDL Mode-4, Mode-S (1090), UAT modeling/simulation for TAMDAR (EPIREP) and FIS-B
  - FIS architecture: independent assessment to determine a single optimum WINCOMM architecture
- Focused on 2007 - 2015 implementations
- Period of performance - 9 months


Applied Physics Laboratory
• Not-for-profit university research and development laboratory
• Division of The Johns Hopkins University founded in 1942
• Staffing: 3,300 employees
105 subcontractors
(64% scientists & engineers)
• Annual commitment level:
~$500M (75% DoD)


APL Communications System
Development Spectrum
Concept Development, System and Operational Architectures, Proof-of-Concept Demonstrations, Technology Assessment and Development
Concepts of Operation, System Specifications, Statements of Work, RFPs,
Source Selection Teams, Independent Technical Evaluation Teams
System Production and Testing
Integrated Product Teams, System Integration Testing
System Operations Research, Field Testing and Follow-On Engineering Support
• Army FCS
• Turbo Code Software Radio
• Turbo CPM
• SATCOM Planning Integration
• SATCOM for Missile Defense
• Multifunction Buoyant Cable Array
• AEHF Terminal Control CONOPS
• SATCOM for JCTN
• WAMS
• ADS-B Link Eval.
• MUOS AoA
• Teleports AoA
• Advanced EHF Crypto. System
• DIMS
• ODOCS
• Polar EHF
• Wavelet Compressed Video
• CNPS
• IMPCS
• NASA TDRS
• Tactical Tomahawk
• CEC Range Extension
• NESP MDR Terminal Testing
• FBM & SCAP
(Selected Programs)


Architecture Assessment Process
Previous WINCOMM Studies
NASA/Glenn
Comm. Technology Surveys
FIS Requirements
Technology Descriptions
Candidate Architectures
Scoring
Scored FIS Architectures


High-Level Schedule
Draft
Tasks
CY01
CY02
M J J A S O N D J F
Project Start
Requirements
-Areas Identified
-Rqmts Quantified
Technology
- Identified Candidates
- Technical Description
Candidate Arch. Devel.
Scoring
- Initial
- Sensitivity
Draft Rpt.
Final Rpt.

Requirements

- The assessment of WINCOMM architectures will require a precise description of requirements
- Requirements will be generated from:
  - Existing studies when possible
  - NASA/Glenn and APL in cases of new requirement areas
- The requirement areas to be considered will include (in no specific order):
  - Capacity
    - What are the information exchange requirements?
    - What are the per aircraft and aggregate data rates to be supported?
  - Connectivity/Topology
    - What topology will be suitable/achievable for WINCOMM (e.g., hub/spoke, flat)?

Requirements (cont'd)

- Requirements areas (cont'd)
  - Number of elements
    - How many aircraft must be supported in the architecture?
    - How many other elements (ground nodes) are required?
  - Platform constraints
    - What aircraft constraints exist in terms of size/power/weight?
    - What ground node constraints exist?
  - Coverage
    - Is global or regional coverage required?
    - Will requirements change with aircraft flight phase?
  - Link availability
    - What is the expected percentage of time that the link will need to be available?
    - Is this characterized by successful message receipt?

Requirements (cont'd)

- Requirements areas (cont'd)
  - Latency
    - What are the required timing constraints on information receipt?
    - How does this vary by information type, aircraft type and flight phase?
  - Cost
    - What is the targeted aircraft cost?
    - What are the constraints on infrastructure cost?
  - Traffic type
    - Is the traffic expected to be continuous or bursty?
    - If bursty, what are appropriate statistics?
  - Protection
    - Should the link information be encrypted and/or protected in particular ways?

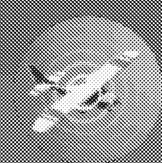
Technology

- Technologies will be identified from previous studies and APL surveys
- Possibilities include both LOS and SATCOM systems projected to be mature in the time frame of interest
- All possess advantages and disadvantages. Examples:
  - Existing aviation links may have lower cost due to current equipage and infrastructure
  - SATCOM provides large coverage and broadcast capabilities
  - Cellular infrastructure in place but coverage limitations exist
  - Etc.

Technology (cont'd)

Example Technologies for Consideration

- Aviation Links
  - **ADS-B candidates**
    - **VDL Mode 4**
    - **Mode S "1090"**
    - **UAT**
  - **ACARS**
  - **EFAS**
  - **VDL Modes 2 & 3**



- Satellite Communications
  - GEO/MEO/LEO constellations
  - S-DARS

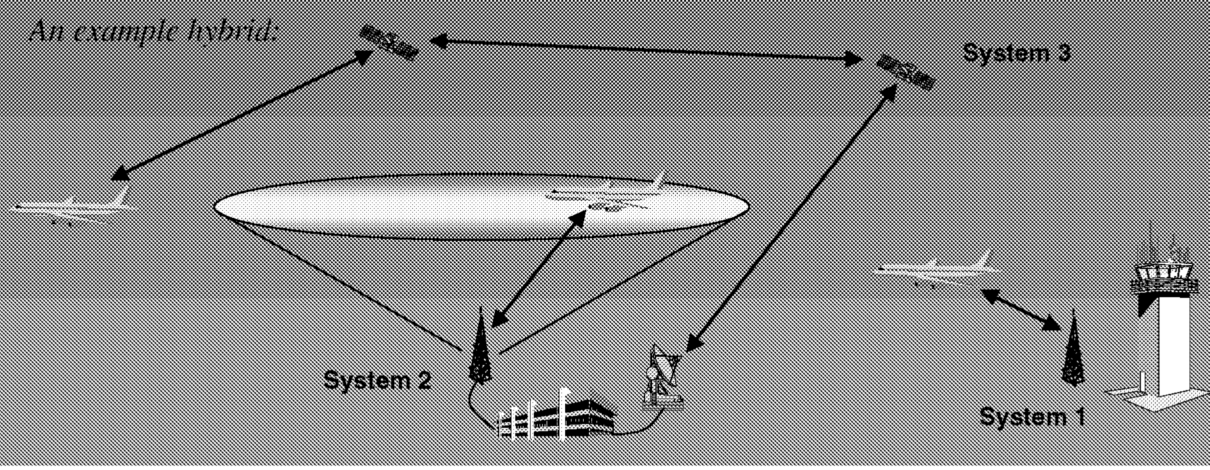
- Cellular Networks
  - AMPS
  - IS-95
  - GSM
  - UMTS

- Related Technologies
  - Compression
  - Software-Defined Radios

Candidate Architectures

- Architectures will be developed using the technologies with input from the requirements
- Architectures may consist of a single communications technology or hybrid concepts

An example hybrid:



Scoring

- Scoring necessary for two reasons:
  - To quantitatively determine the ability of an architecture to support each requirement (quantify the advantages and disadvantages)
  - To combine the varied requirements into a single score for ranking purposes
- Quantitative approach will be developed by APL and NASA/Glenn
- Sensitivity analysis will be conducted to examine the dependencies of different scorings and weightings
- Similar approaches used by APL in recent DoD Analysis of Alternatives

Summary

- Goal of task is to determine the best communications architecture to support FIS
- A process has been developed to enable an independent assessment while leveraging the substantial investments already made

TAMDAR Development Strategy

Tri-Agency Team

Prepared for the

NASA Weather Accident Prevention Annual Project Review

June 5-7, 2001

Sandra Schmidt
FAA Aviation Weather Policy Division, ARW-100
202-366-4437

Background

- Formed TAMDAR Interagency Team
  - FAA/NASA/NWS
- Developing Operational Concept for collection and distribution of Aircraft Derived Meteorological Information below FL200
- Conducting TAMDAR studies to provide input to the FAA alternatives analysis.
  - NASA Langley - Sensors & Incentives
  - NASA Glen - Communication Alternatives
  - FSL - Data Quality

Government Initiatives

- FAA/NWS partners in current Meteorological Data Collection and Reporting Service (MDCRS)
  - MDCRS data is basis for quality of current RUC model forecasts
  - TAMDAR data could fill current data void regions leading to even better RUC model forecasts
- FIS Data Link Policy addresses the need to conduct investment analysis
- FAA Safer Skies recommended study of government/industry role in the development/implementation of TAMDAR system

Benefits

- Improve quality of Models/Forecasts to include warnings/advisories
- Alert NAS users of weather hazards
- Confirm existing weather conditions

Issues/Concerns

- Quality and Coverage of Aircraft Derived Meteorological Data
- Accuracy of Sensors
- Development of Business Case to support system architecture

NASA/CP—2002-210964

TAMDAR Capabilities Development

June 6, 2001

Taumi Daniels
NASA Langley Research Center
Hampton, Virginia

(757) 864-4659
t.s.daniels@larc.nasa.gov

Outline

- Goal & Background
- TAMDAR Sensor Development & Testing
- Coverage Analysis
- Related FAA & NOAA Activities
- Fleet Operational Evaluation
- Alternate Method
- Summary

Goal of TAMDAR

"Demonstrate a TAMDAR system capability through a fleet evaluation in the NAS under a FAA, NOAA, NASA, and Industry joint effort."

TAMDAR Background

National Aviation Weather Program Council (Federal Coordinator for Meteorology, NASA, FAA, NTSB, NWS, DOD, Department of Agriculture)

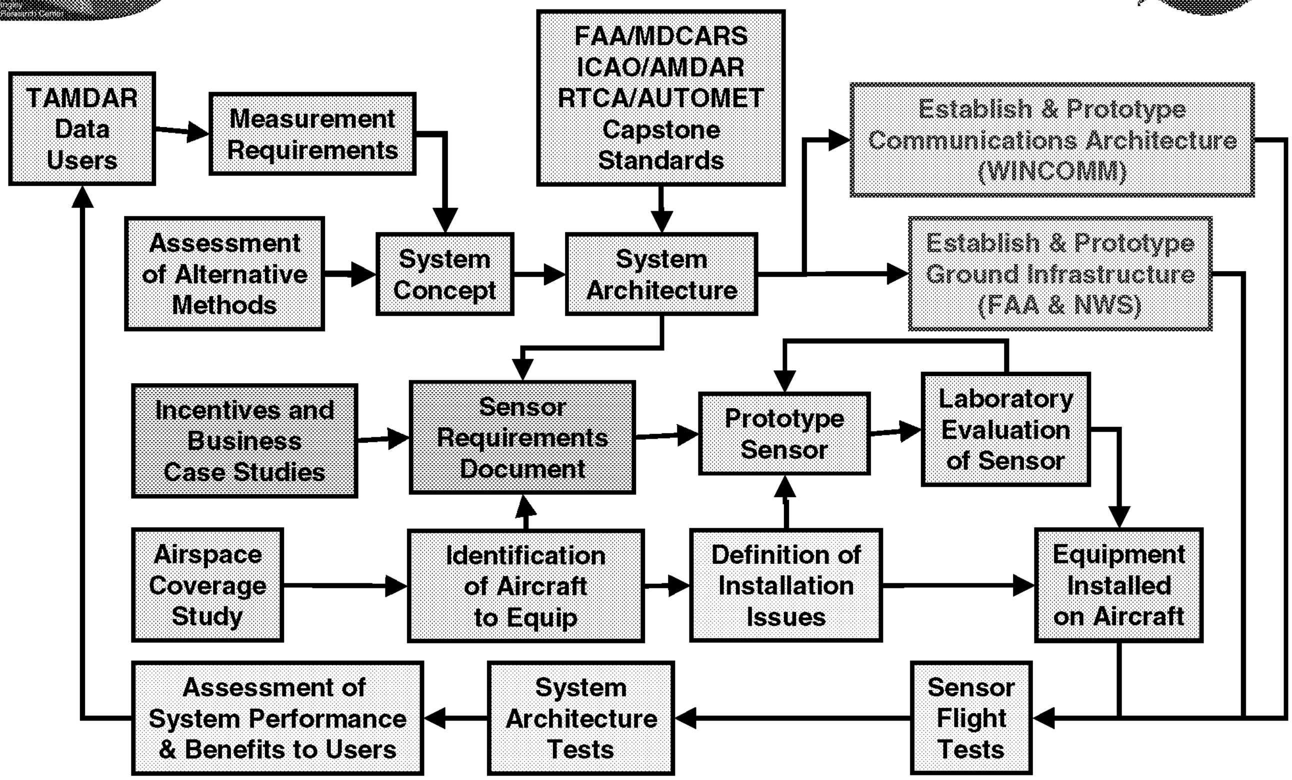
- National Aviation Weather Program Strategic Plan, April 1997
- National Aviation Weather Initiatives, January 1999

- Implement data link capabilities for Flight Information Services (FIS)
- Develop and implement multifunctional color cockpit displays incorporating FIS products
- Expand and institutionalize the generation, dissemination, and use of automated **PIREPS** to the full spectrum of the aviation community, including general aviation
- Improve underlying weather forecasting services
- Require, develop, and implement aviation weather-related training packages for users
- Improve aviation weather information telecommunications capabilities for ground-ground dissemination of aviation weather products
- Establish objective standards for characterizing various weather phenomena for national and international use

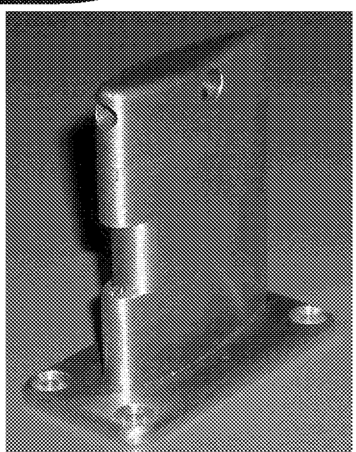
TAMDAR Background

- NavRadio Team Phase I CRA propose low cost electronic pilot report capability
- Transmitter design stymied by lack of frequency allocation; effort focused on sensor
- After many acquisitions, NavRadio ⇨ Honeywell, Int.
- Phase II CRA not pursued by Honeywell, Int.
- Effort becomes project under AWIN
- Tri-Agency Team formed to develop concept of operations
- GTRI / ODS task contract in place to complete sensor development
- ARNAV Phase II CRA to deploy sensors and test data link

TAMDAR Flowchart



TAMDAR Sensor



ODS Sensor

Icing
Temperature
Pressure Altitude
Humidity
Magnetic Heading
Eddy Dissipation Rate*
True Airspeed*
Dew point*
Density Altitude*
Winds at Altitude*

*can be computed

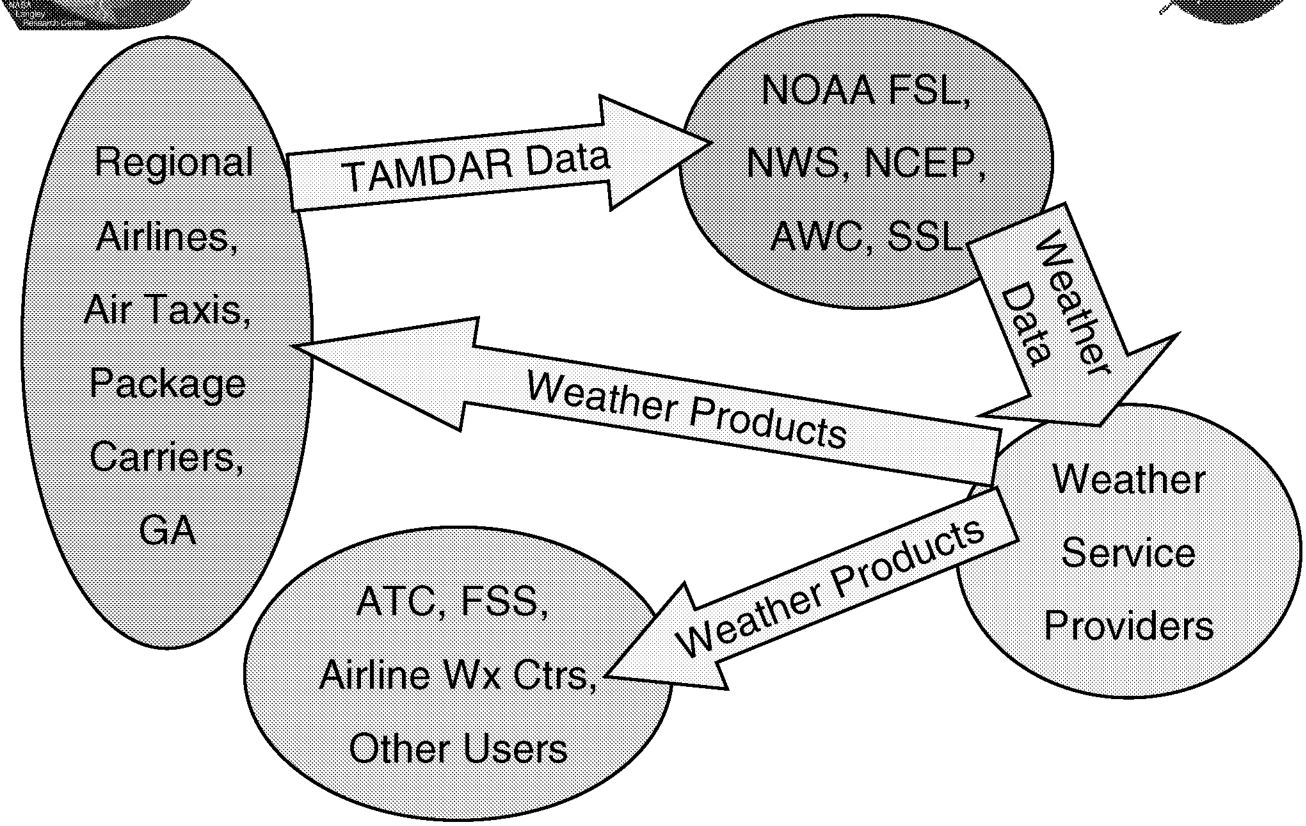
→ Cockpit Display

→ Ground Station

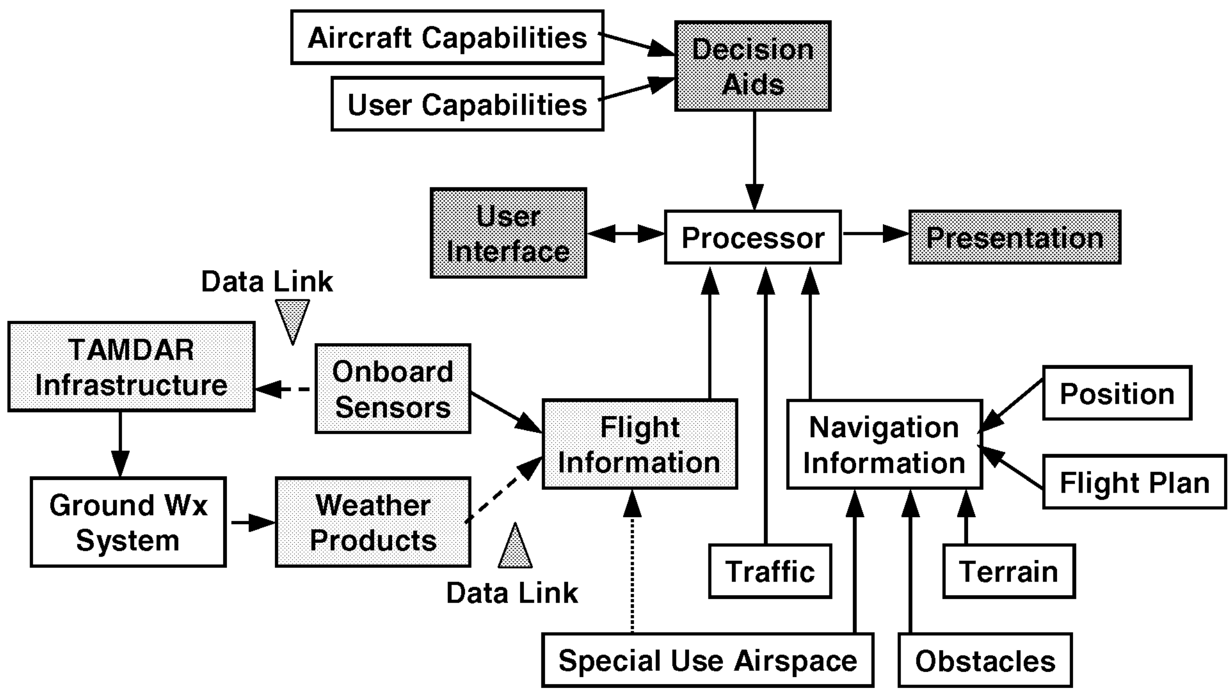
→ Other Aircraft

TAMDAR is envisioned to downlink weather data from non-jet aircraft. The weather data will be sent to FSL, FSS, ATC, AWC, and others via a ground-based infrastructure and to other aircraft. New weather products will be generated and uplinked to the cockpit.

TAMDAR System Concept



AWIN System


Aircraft Capabilities
User Capabilities
Decision Aids
User Interface
Processor
Presentation
Data Link
TAMDAR Infrastructure
Onboard Sensors
Flight Information
Navigation Information
Position
Flight Plan
Ground Wx System
Weather Products
Data Link
Traffic
Terrain
Special Use Airspace
Obstacles

Sensor Development

- Task Contract with GTRI and subcontractor ODS
- Subtask 1: Requirements Definition and Design Review
- Subtask 2: Sensor Fabrication
- Subtask 3: Flight test on research aircraft
- Future Tasks: Evaluate flight test results; make design modifications as needed, fabricate additional units; conduct fleet evaluation; evaluate results

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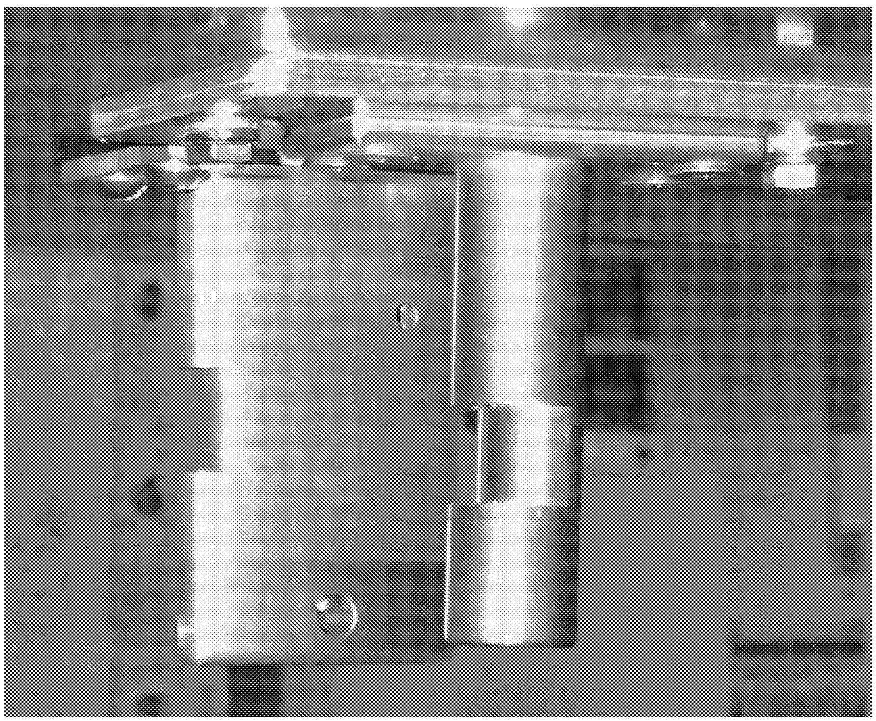
Sensor Development

- Current version of sensor ground tested and flight tested
- Next version of sensor currently under development
- Flight test of next version planned for 10-11/01 on-board University of Wyoming B200 atmospheric research aircraft
- Possible flight testing during International Water Project (IHOP) 5-6/02

NASA Ground Tests

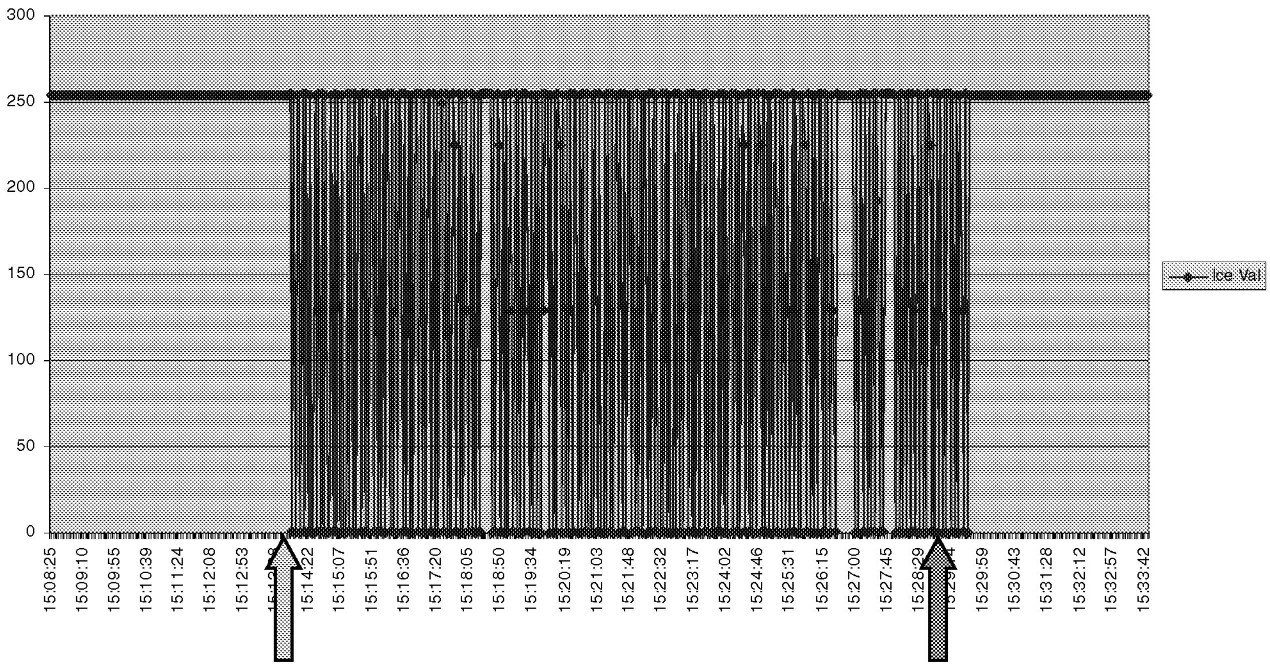
- Langley 7 x 10 Inch Low Speed Tunnel (5/2001 – 6/2001)
  - Air speed, temperature, pressure comparison
- Langley Test & Dynamics Branch Facilities
  - “Shake and Bake” testing includes temperature, pressure, and vibration
  - Testing to be conducted May – June 2001
- Glenn Icing Research Tunnel Test (3/21 – 3/23)
  - Piggyback on another test
  - ODS also tested Model 1000 Icing Sensor

NASA Ground Tests

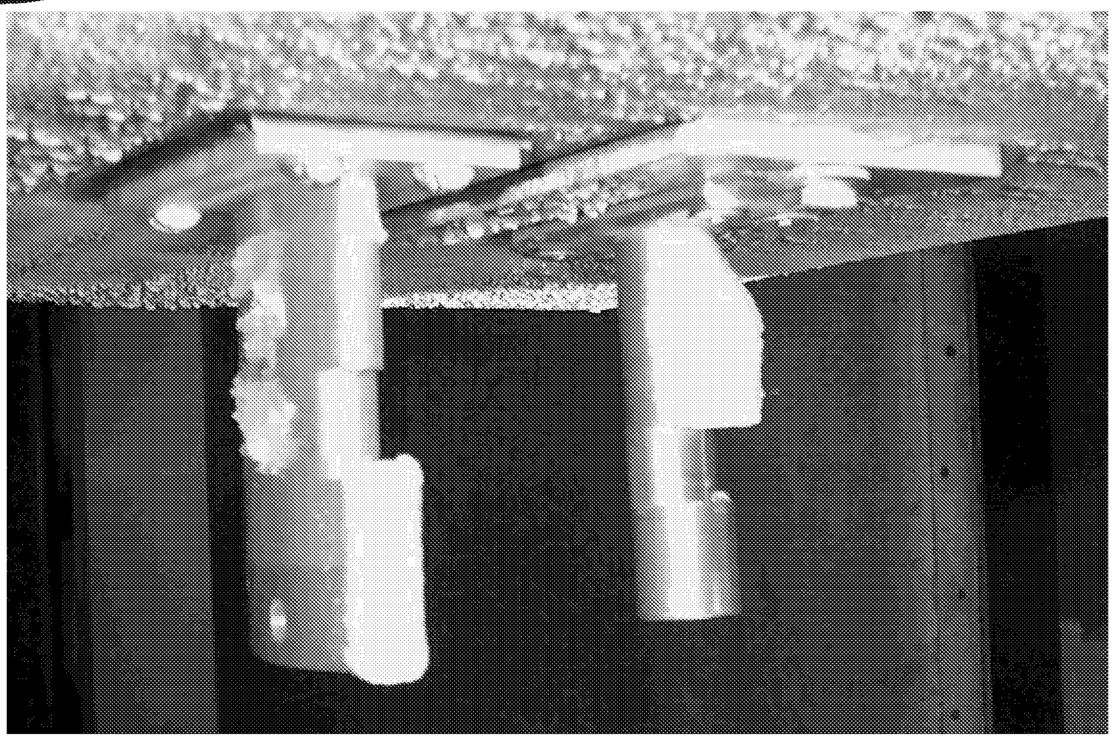


NASA Ground Tests

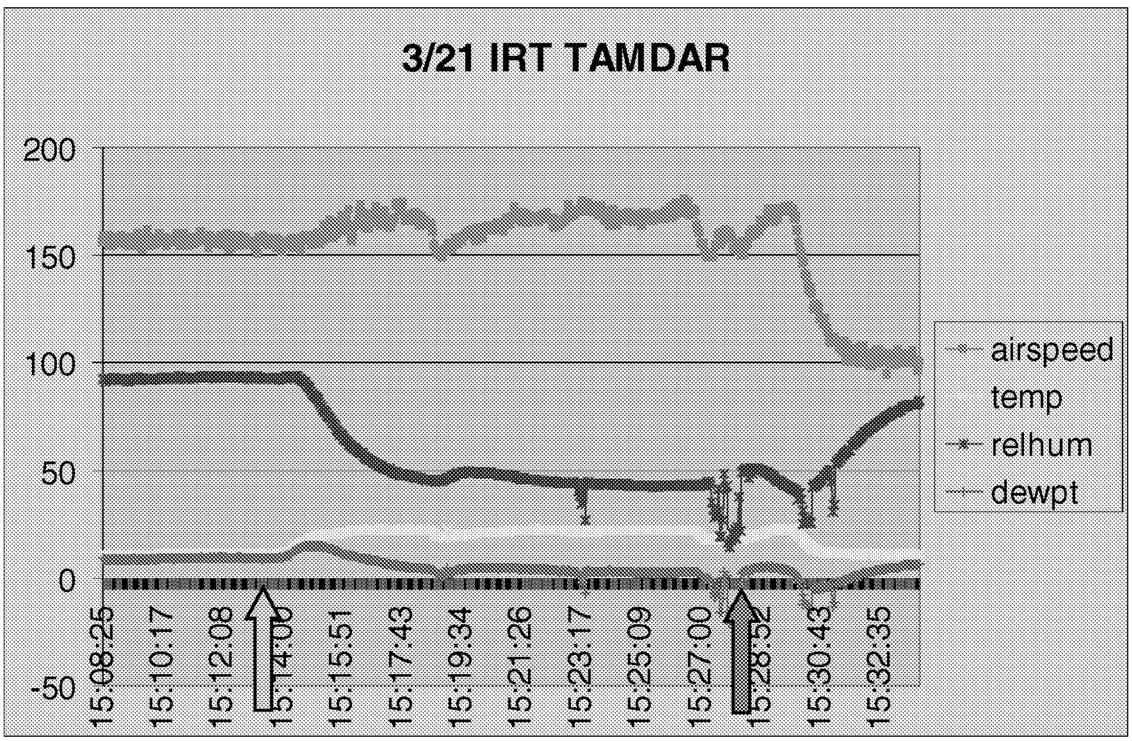
3/21 First Run Icing Response



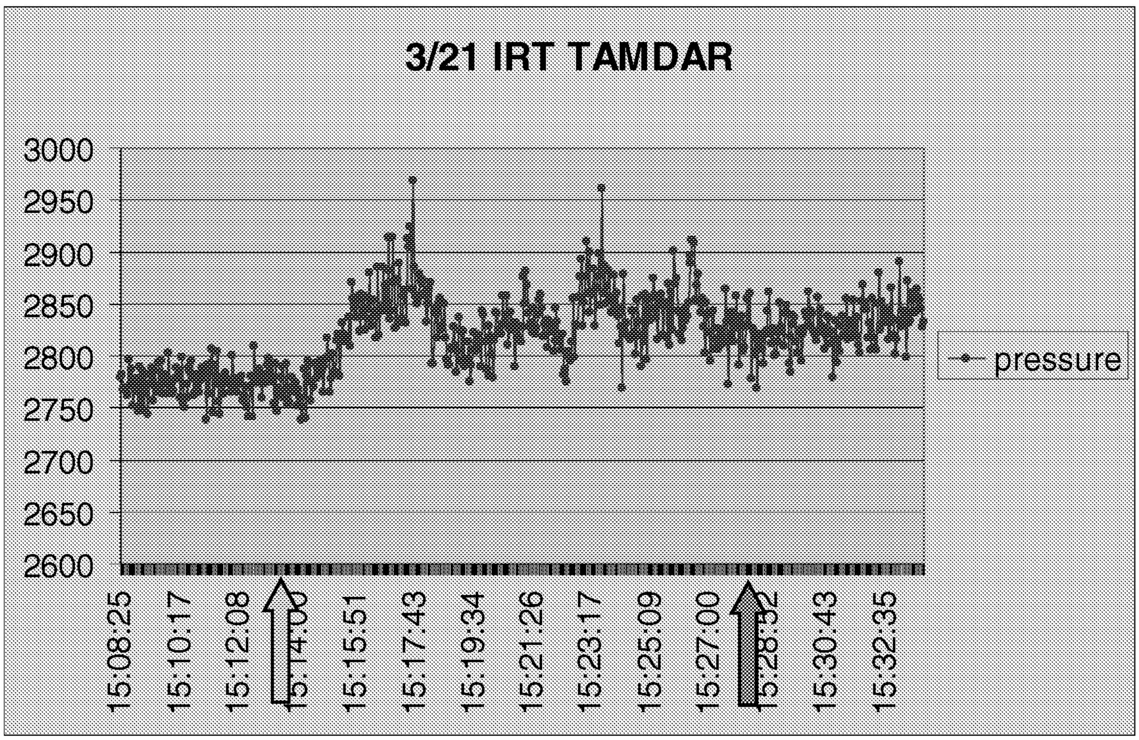
NASA Ground Tests



NASA Ground Tests



NASA Ground Tests

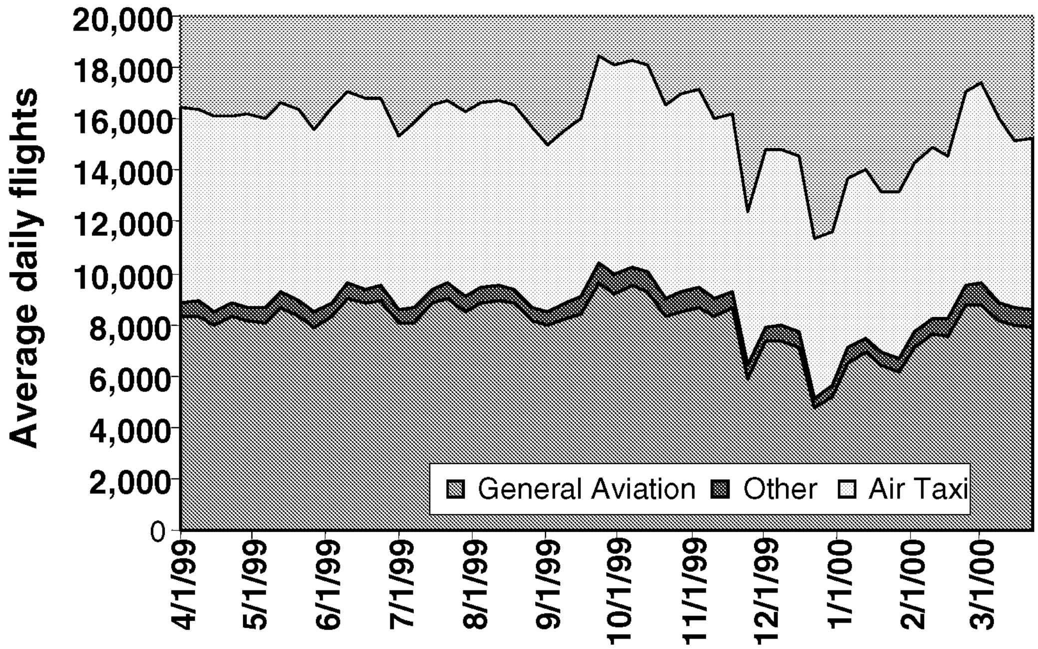


NASA Flight Test

- Three flight test series scheduled, August – November 2001
- AWIN, WINCOMM coordination for data link testing
- Goal: To provide support to WINCOMM for TAMDAR system architecture tests (Cessna 206H)
- TAMDAR in support role, not central research effort

ETMS Analysis of IFR Flights

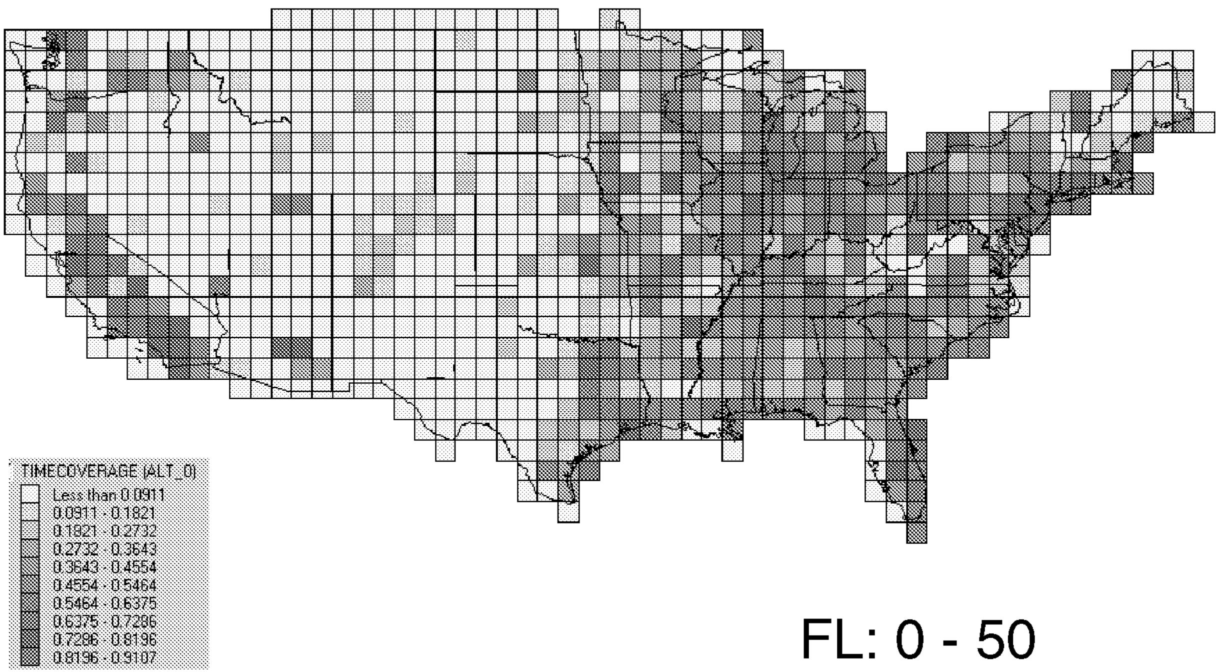
Average weekly operations over 12 months



Source: FAA ATA-200 AT Airspace Lab Brent Brunk

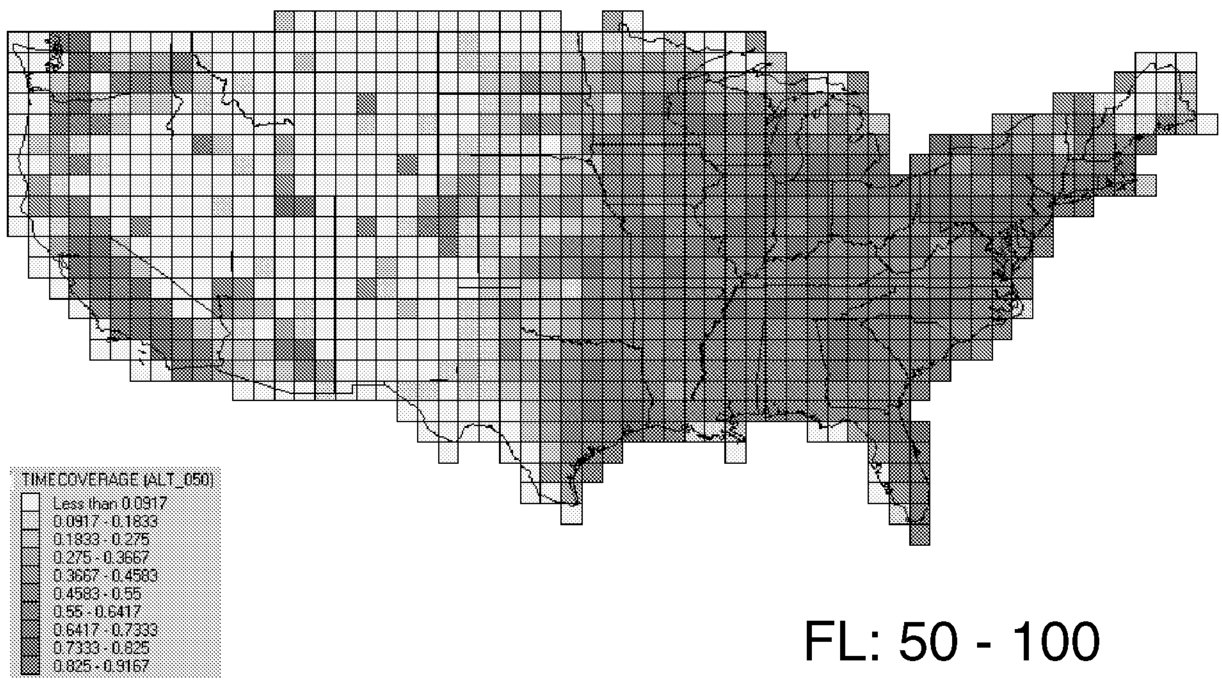
Many thanks to Nancy Kalinowski, ATA-2

ETMS Analysis of IFR Flights



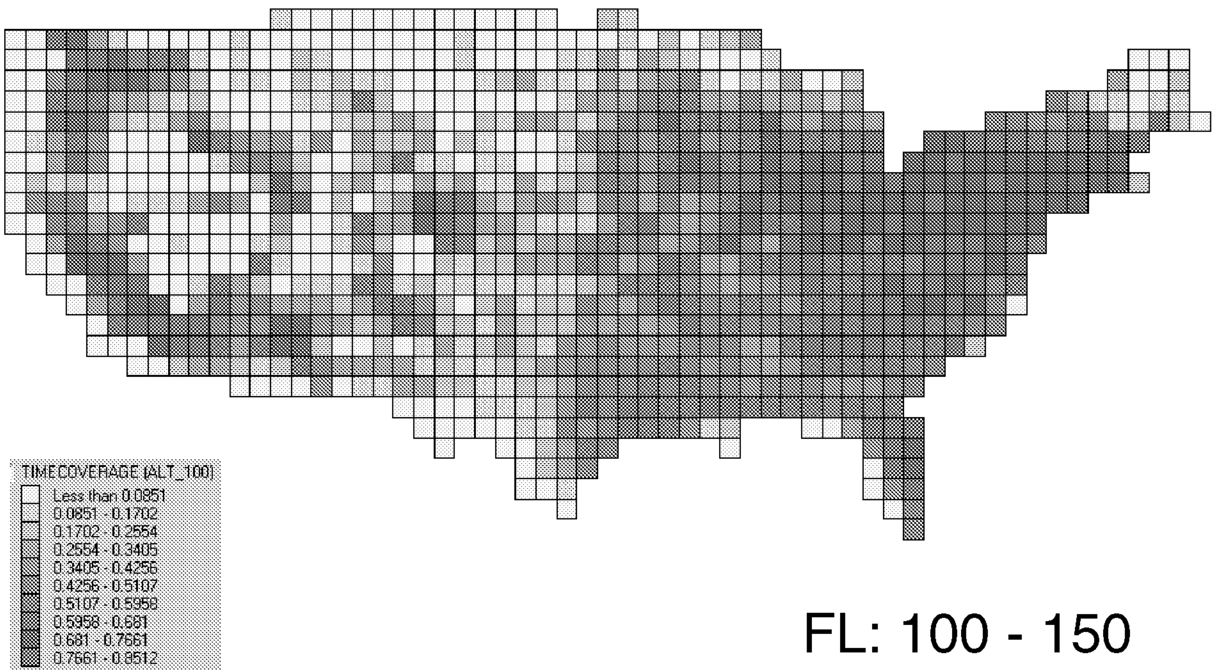
FL: 0 - 50

ETMS Analysis of IFR Flights



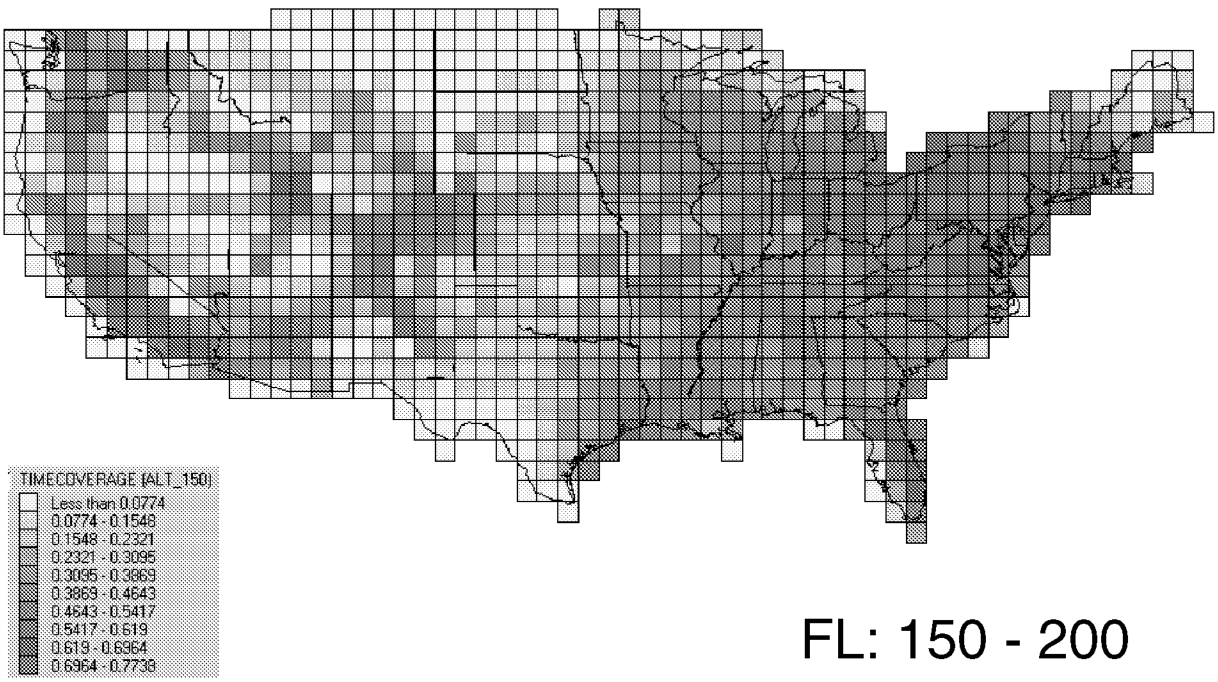
FL: 50 - 100

ETMS Analysis of IFR Flights



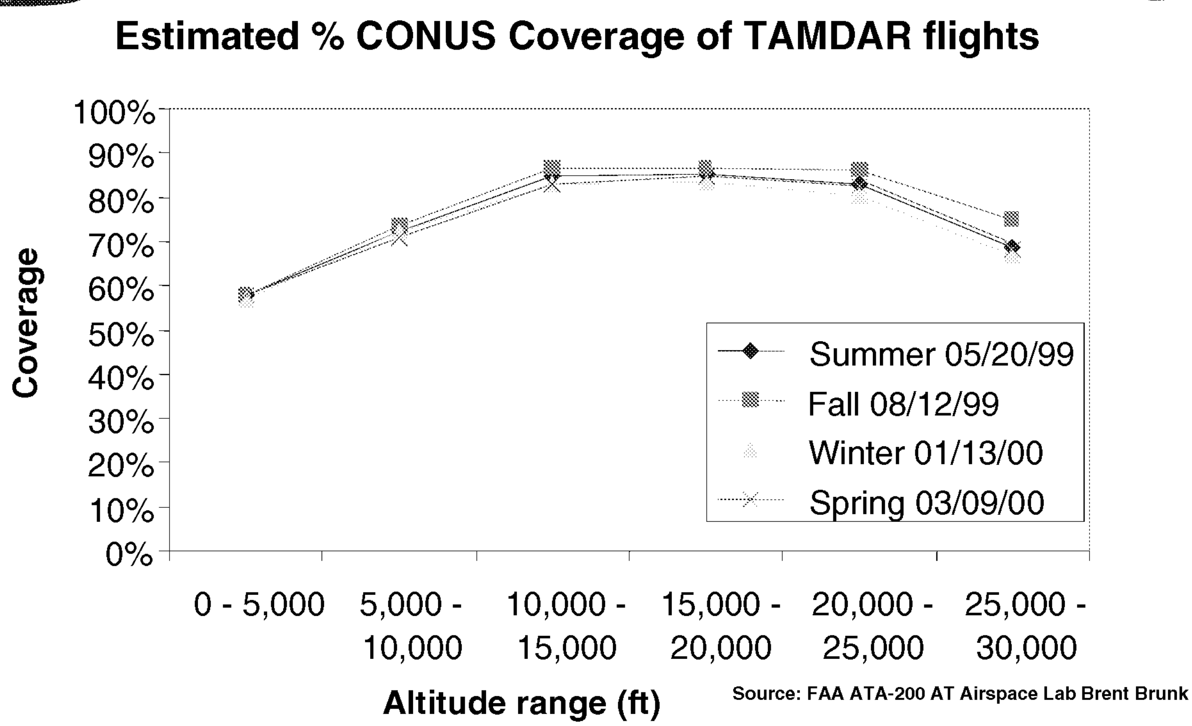
FL: 100 - 150

ETMS Analysis of IFR Flights



FL: 150 - 200

ETMS Analysis of IFR Flights



Capstone and TAMDAR

- FAA Capstone agreed to AWIN proposal to include TAMDAR into Bethel Area operational evaluation
- NASA to deliver 10 certifiable sensors
- FAA Capstone to support equipage, certifications, installations, and modifications to communications infrastructure
- ODS to support installations and calibrations

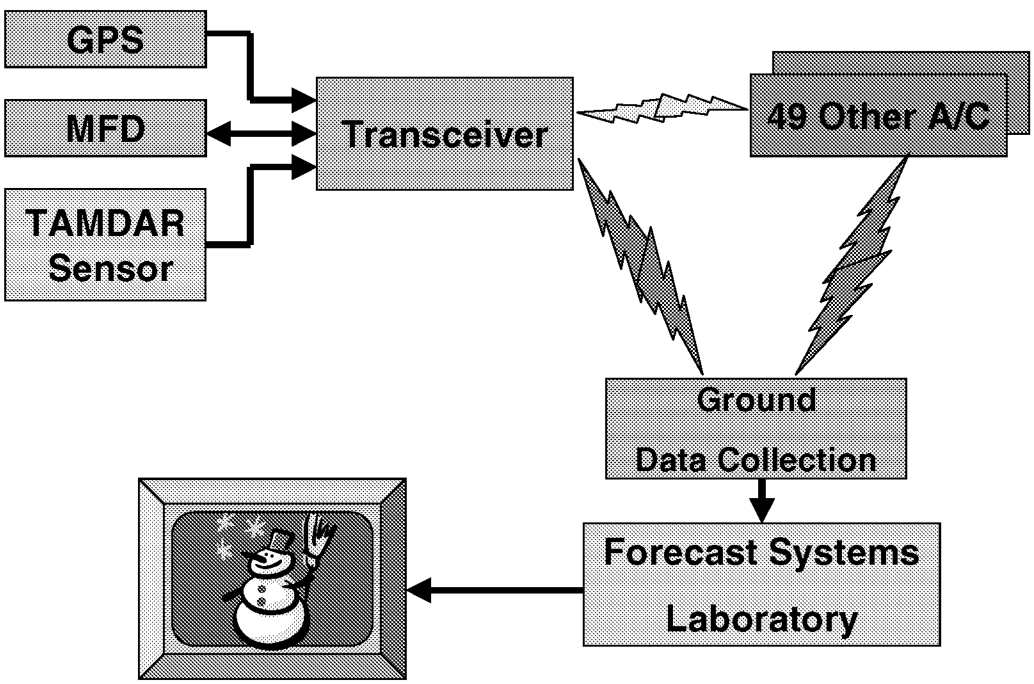
Tri-Agency TAMDAR Team

- Representatives from NASA Langley, NASA Glenn, FAA ARW-100, FAA AUA-400, NOAA FSL, NOAA NWS meet to coordinate activities related to TAMDAR
- First action: No longer use term “E-PIREP”
- Currently drafting “Concept of Operations”

NOAA FSL Activities

- Goal of Fleet Operational Evaluation is to get the data to NOAA Forecast Systems Lab
- Challenges for FSL:
  - Provide consultation on sensor development
  - Identify and establish sources of corroborative weather information
  - Perform data validation, collection, storage and archival
  - Investigate meteorological phenomena revealed by this new high resolution data
  - Develop new weather products

Fleet Operational Evaluation Concept



Candidate Communications Links

Disseminate data to NOAA FSL via one of the following:

- ARNAV
- Honeywell
- UPS AT
- EchoFlight
- ARINC
- Cellular Modem
- FlyTimer
- Orbcomm
- SITA

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Fleet Operator Selection Criteria

- Two or more fleet operators
- At least 50 aircraft of same type
- 24 x 7 operations
- Extensive routes in geographically diverse regions
- Can be FIS & TAMDAR equipped
- Can participate in 6 month duration research project
- Candidates: UND, ERAU, OU, United Express, UPS, Federal Express

Calibration Issues

- Sensors are factory calibrated
- Capability to perform field calibration with external connection to instrumentation
- Possibly perform self-checking via ASOS or other sources via data link
- Ground truth checking at FSL
- Need to establish calibration schedule and standards
- Some pilot training may be involved

Certification for Fleet O. E.

- Fleet Operational Evaluation would require:
  - FAA Certification of sensor
  - Selection of fleet operator and aircraft type
  - Certification Plan
  - RTCA DO-160E testing

National Demonstration

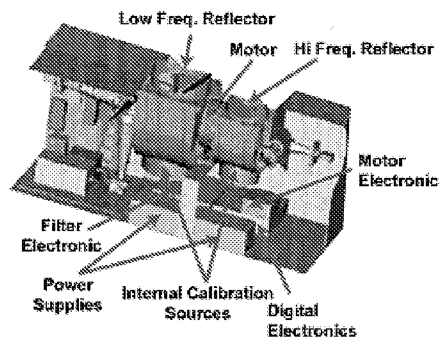
- AvSP goal for a 2002 National Demonstration
- Some Potential Activities Include:
  - Cessna 206H cross-country flight with data link
  - B200 King Air (NASA 8) flights with data link
  - International Water Vapor Experiment (IHOP) using University of Wyoming King Air with data link
  - Planned Fleet operational evaluation most likely to occur in 2003

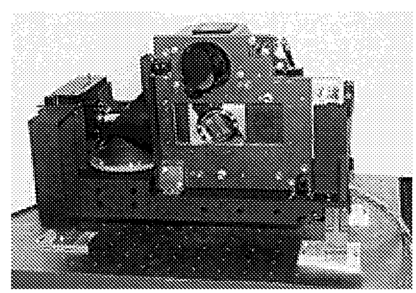
Alternate Method

- NPOESS – National Polar Orbiting Operational Environmental Satellite System – DoD, NASA, NOAA team with partners EUMETSAT and NASDA
- 5 NPOESS satellites, deployed from 2008 to 2011, operational through 2018, each equipped with a subset of ten different sensors.
- ATMS – Advanced Technology Microwave Sounder
- VIIRS – Visible Infrared Imaging Radiometer Suite
- CrIS – Cross-track Infrared Sounder

Alternate Method

- ATMS – Advanced Technology Microwave Sounder
  - Ten altitude bands, from 4 to 37 Km
  - Measures water vapor and temperature
  - 32 Km spot size
- CrIS – Cross-track Infrared Sounder
  - Measures water vapor, temperature and pressure
- VIIRS – Visible Infrared Imaging Radiometer Suite
  - Measures temperature and pressure





Summary

- NASA FAA NOAA Industry Collaborative Effort
- TAMDAR Sensor Development
- Ground/Flight Testing
- FAA Capstone
- NOAA FSL
- WINCOMM Datalink Evaluation
- Fleet Operational Evaluation
- AWIN National Demonstration

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TAMDAR Datalink Development
For
Weather Accident Prevention Annual Project Review
Cleveland, Ohio, Hilton South
June 5-7, 2001

Monty Andro/Stephen C. Wiersma

NASA Glenn Research Center
Cleveland, OH 44135
(216) 433-3492
mandro@grc.nasa.gov

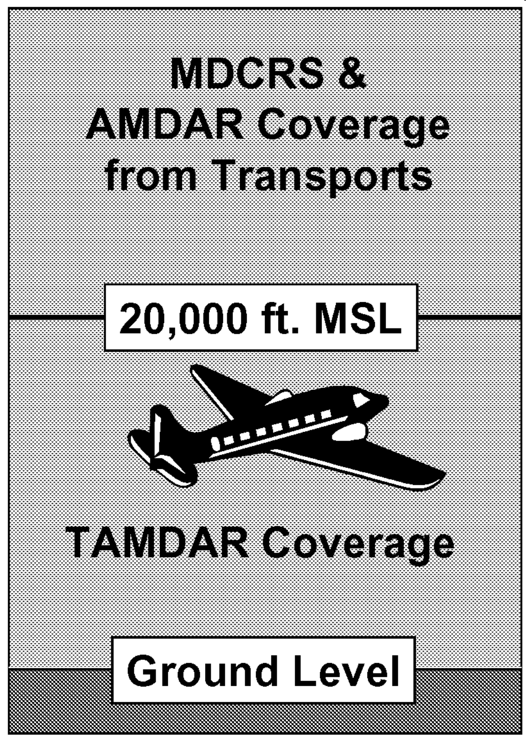
TAMDAR Objectives

WxAP - Weather Information Communications

Use aircraft operating below 20,000 ft altitude to sense and report
- Moisture
- Temperature
- Winds

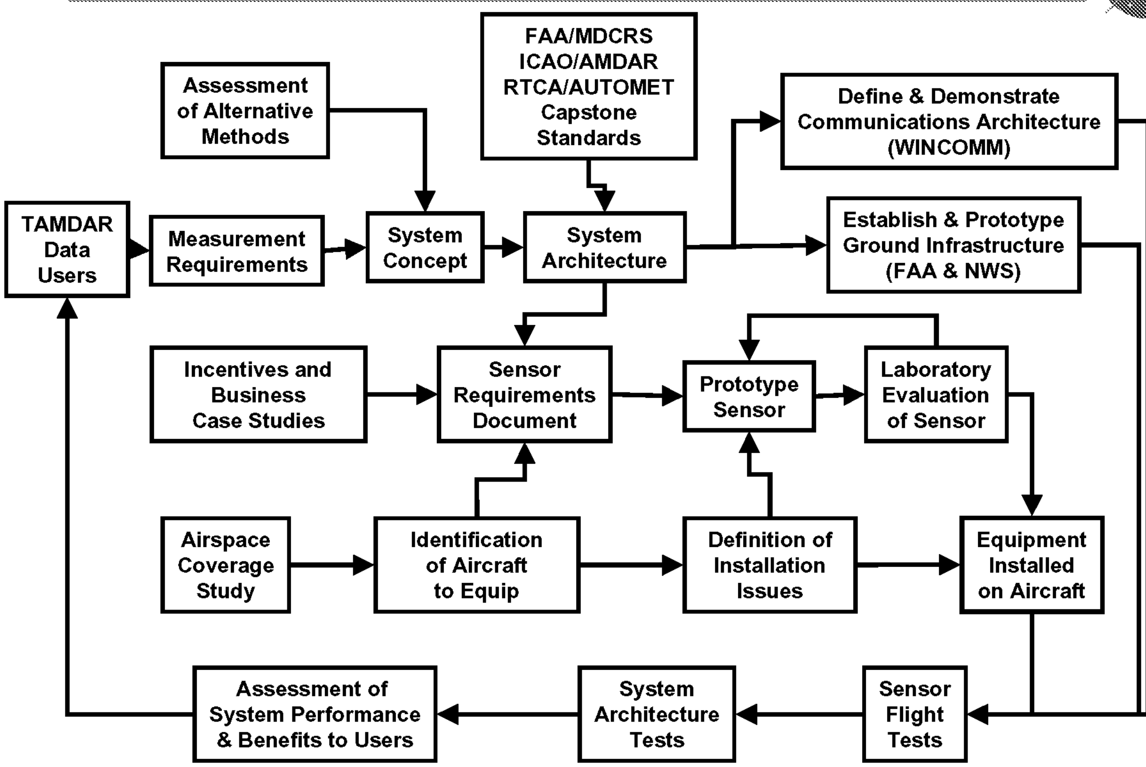
to be used by
- Forecast models
- Weather briefers
- Controllers
- Other aircraft

NASA Inter-Agency Effort
- NASA Glenn Research
- NASA Langley Research



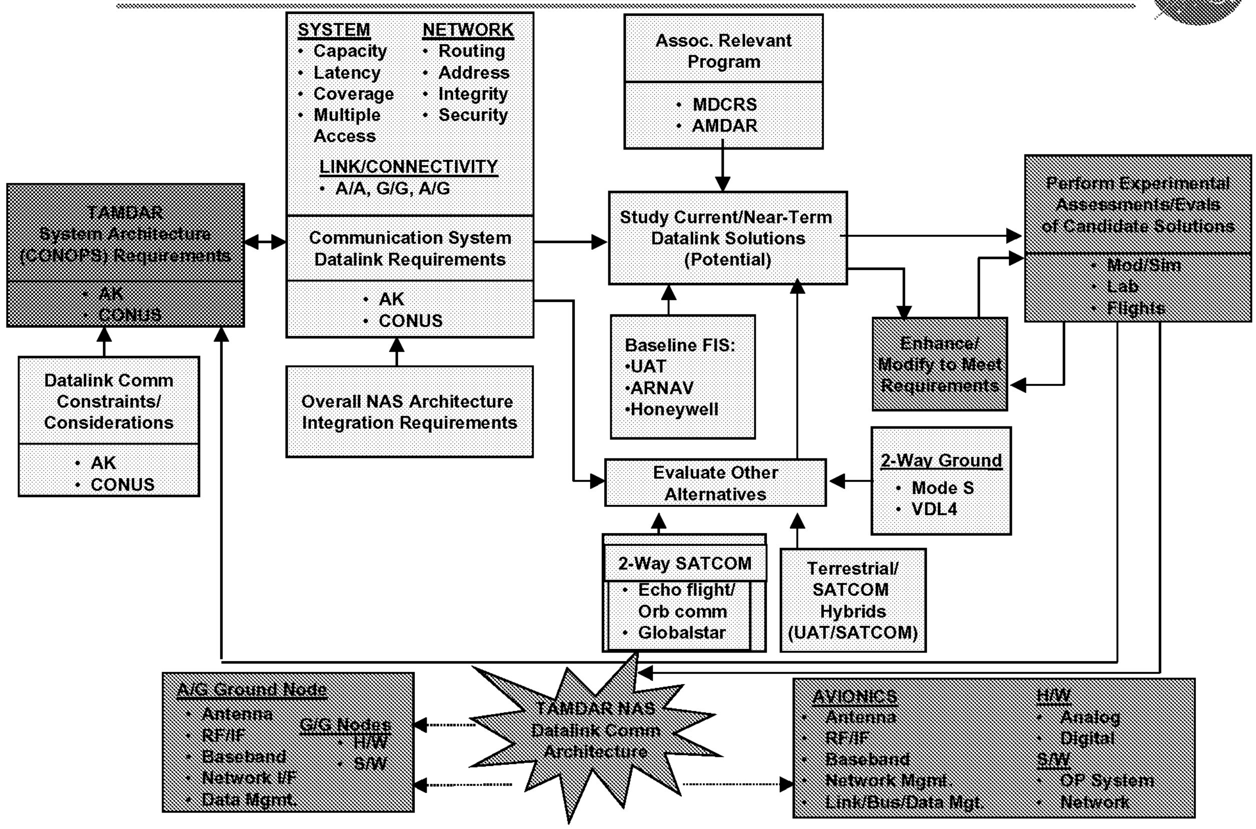
TAMDAR Flowchart

WxAP - Weather Information Communications



TAMDAR Datalink Architecture Development

WxAP - Weather Information Communications



TAMDAR Conops

WxAP - Weather Information Communications

Conops Development by team of FAA, NASA, NOAA, and NWS.

- Based on the RTCA DO-252, Minimum Interoperability Standards (MIS) for Automated Meteorological Transmission (AUTOMET)

General Communication Considerations

- Support plane to plane communications
- Ascent, descent and en-route sensitive sampling rates.
- Immediate updates of HAZMET type reports (icing)
- 5 min latency from sample time to weather processing center
- Data rate based on precision, sample rate, and update rate.

TAMDAR Com Activities

WxAP - Weather Information Communications

Studies

ADS-B Candidates: UAT, MODE S, VDL 4
Issue: Surveillance band (UAT and MODE S), VDL4 questionable near term solution.

FIS G-IPPA's Honeywell, ARNAV
Issue: Broadcast only license.

2 Way VDL-2 ARINC, SITA
Issue: targeted towards carriers.

Satellite Based Globalstar, Orbcom/Echoflight, Generic Satellite Systems
Issue: Financial stability.

TAMDAR Com Activities

WxAP - Weather Information Communications

FAA TAMDAR Architecture Study

Flight Experiments

- UAT Cessna Demonstration
- Orbcom/Echoflight Cessna Demonstration

Capstone Collaboration

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CAPSTONE

WxAP - Weather Information Communications

Roles and Responsibilities

(Task A: TAMDAR Datalink Architecture)

NASA WINCOMM will:

- Perform UAT laboratory assessment
- TAMDAR flight sensor
- UAT flight assessment
- UAT for TAMDAR datalink assessment/evaluation
- Jointly develop plans for TAMDAR insertion into Capstone
- Overall TAMDAR datalink architecture validation in Capstone environment

FAA Capstone will:

- Provide a UAT flight transceiver and associated support avionics
- Provide a UAT ground station
- Jointly develop plans for TAMDAR insertion into Capstone for a multi-aircraft demonstration
- Provide field assistance for TAMDAR field testing in Capstone
- Provide demonstration aircraft and integration of TAMDAR and Capstone equipment.
- Provide field performance data for analysis

CAPSTONE

WxAP - Weather Information Communications

Roles and Responsibilities

(Task B: SATCOM FIS Augmentation)

NASA WINCOMM will:

- Perform analyses of potential candidate SATCOM systems for AK. Analyses will investigate footprint coverage, link budgets, and system information capacity, latency and integrity.
- As necessary, provide access to NASA-owned facilities, communications system hardware such as SWIS, Globalstar, and Echoflight and test instrumentation for the investigation.
- Jointly develop necessary test plans
- Perform end-end system assessment of SATCOM augmentation scenarios.

FAA Capstone will:

- Provide AK region operational datalink requirements
- As necessary, provide access to Capstone infrastructure and integration of SATCOM hardware for end-to-end field evaluation
- Jointly develop necessary test plans
- Provide field performance data for analysis and final documentation

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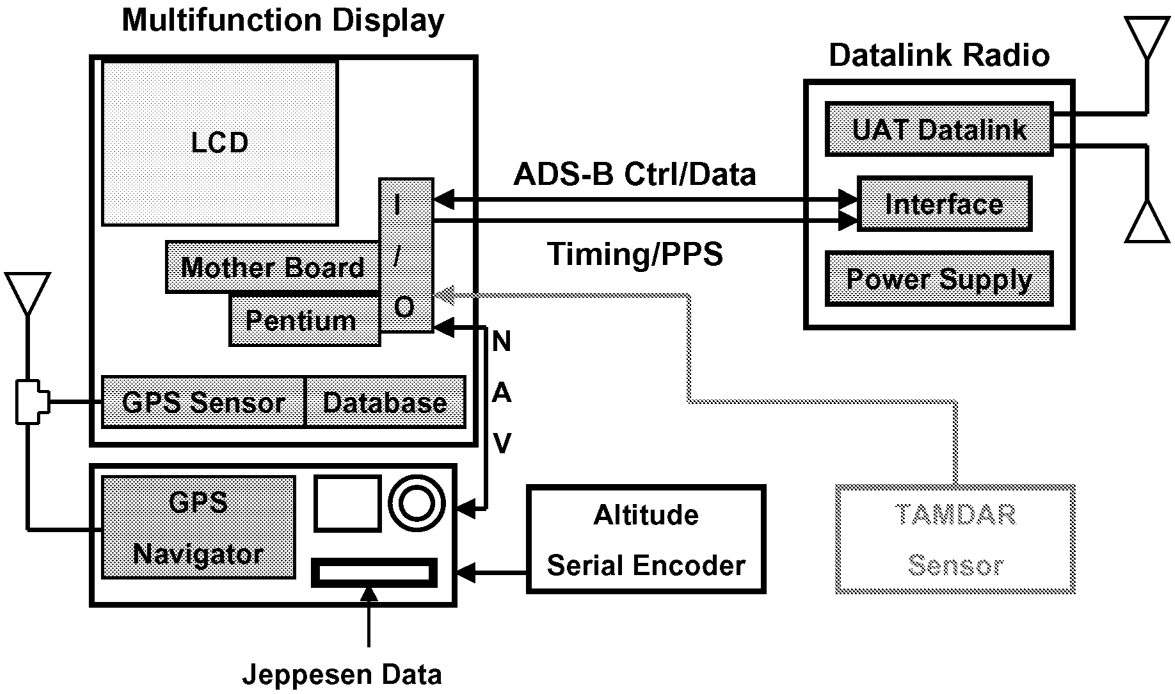
UAT Avionics Architecture

WxAP - Weather Information Communications



UAT TAMDAR Flight Experiment

WxAP - Weather Information Communications

UPS AT assisting in software modifications to avionics and ground station (GBT)

- **Combined avionics, ground station, and sensor demonstration**
- **Modify avionics to accept 15.5 byte TAMDAR data**
- **Encapsulate TAMDAR data in a extended type message**
- **Modify GBT to output TAMDAR data**
- **Maintain current UAT framing and signaling**

Orbcom/Echoflight Flight Experiment

WxAP - Weather Information Communications

- **TAMDAR messages encapsulated into email messages and transmitted through Echoflight system.**
- **Ground based systems receive and store email messages with TAMDAR data.**
- **Evaluate message reliability and delay**

ADS – B Studies

WxAP - Weather Information Communications

UAT, MOD-S, VDL 4 assessment will be accomplished by JHU-APL

- **Leverage existing JHU-APL work for ADS-B simulations**
- **Will evaluate air communication only**
- **Ground communication assessment will accomplished at NASA Glenn**
- **Transfer models to NASA Glenn**

WINCOM Studies

WxAP - Weather Information Communications

ARINC Study

- Assess current MDCRS architecture in supporting new participants (part 121, part 91)
- Investigate data link coverage and availability
- Investigate ground distribution and loading
- Assess and propose plans for improvement

Honeywell and ARNAV

- Leverage existing Cooperative Research Agreements
- Work with vendors to complete assessment

Satellite Based

- Leverage existing and on-going in-house architecture studies
- Include assessment of in-house laboratory experimentation

FAA Task

WxAP - Weather Information Communications

Task 3 FISDL Communications Assessments:

Subtask 1 of 2

"… provide assessments of communications alternatives for implementing a national system for collecting, processing and disseminating electronic pilot report data …"

FAA Needs:

- Assessment and recommendations of data link communications technology and ground communications infrastructure that supports national downlinking of electronic pilot reporting.

Schedule

- Final Report 9/01

Overview: Business Feasibility of the TAMDAR System

Paul Kauffmann
Erol Ozan

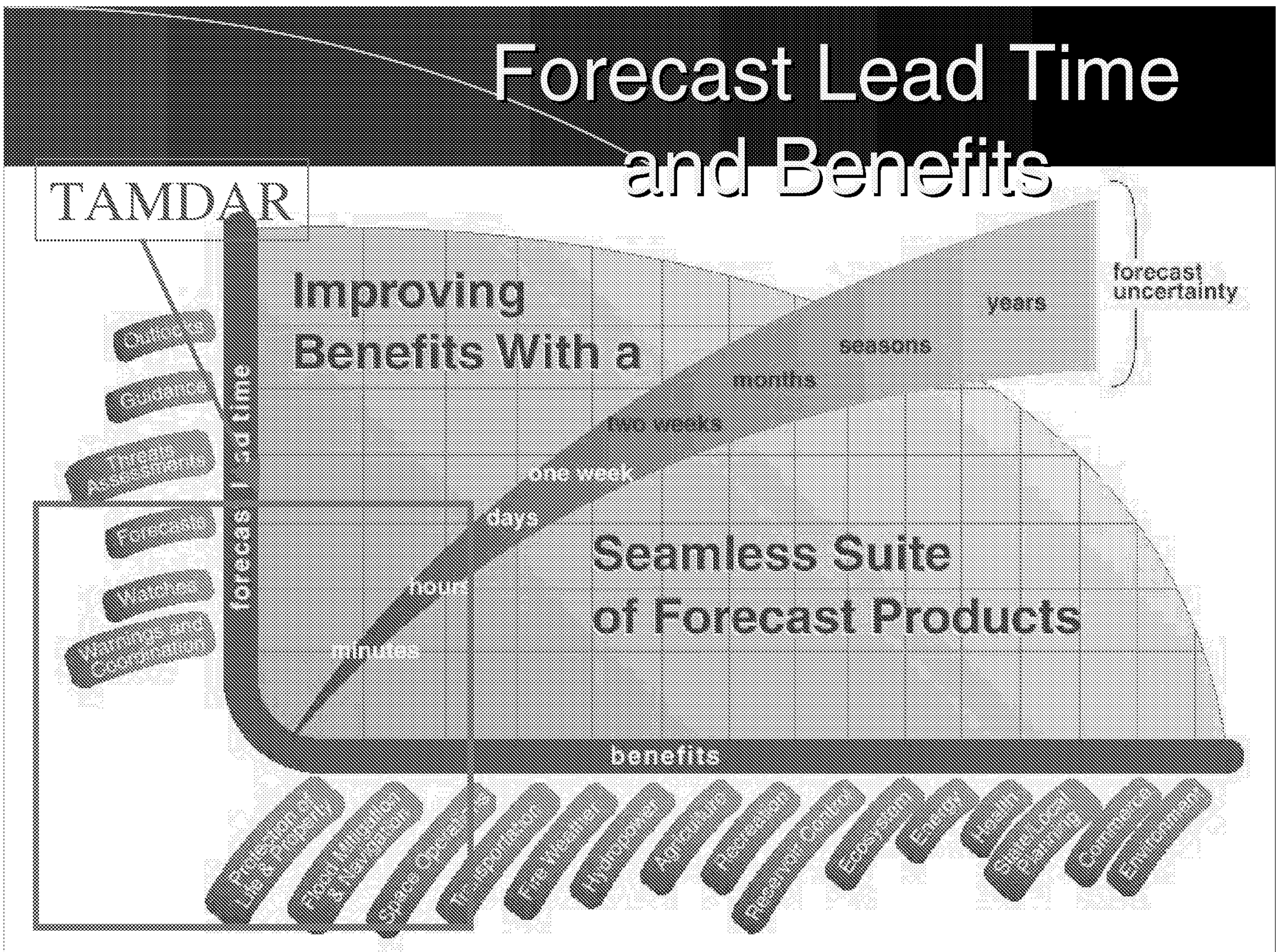
Department of Engineering Management

Agenda- Current Status

- Introduction: Study Objectives and System Description
- General Aviation Market Analysis
- Carrier Market Analysis
  - Commuter, business, package
- Competitive Weather Source Analysis
- Weather Information Providers
- Policy Issues and Implications
- Conclusions

What is TAMDAR?

- Tropospheric Airborne Meteorological Data Reporting
  - Past reincarnations: EPIREPS, AUTOMET
- Components: sensor package, signal processors, and communications equipment
  - Operational Concept: Carried aloft by participating aircraft to report weather conditions to ground-based receiving stations for distribution into a national system.

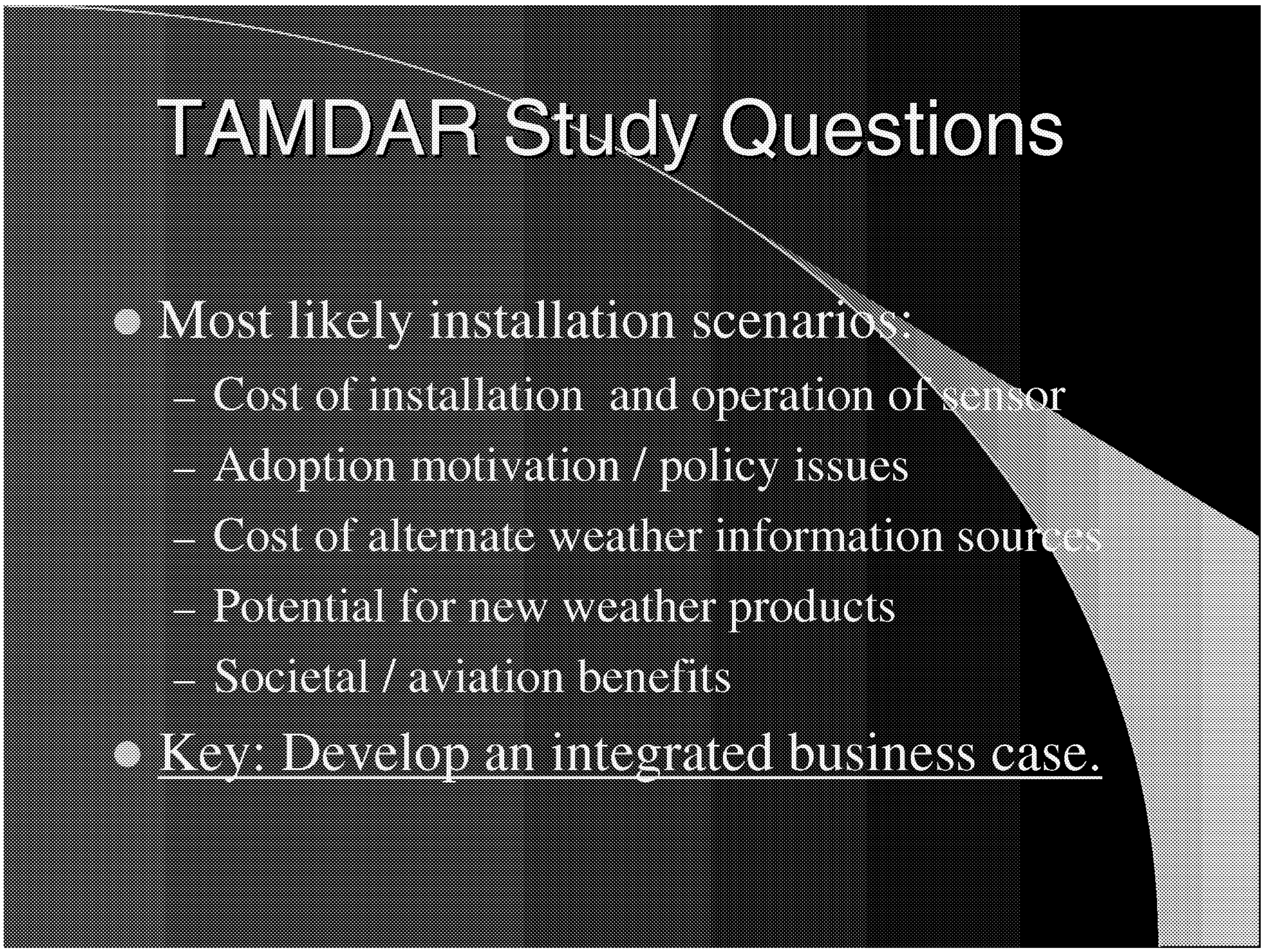

Forecast Lead Time and Benefits
TAMDAR
Improving Benefits With a
Seamless Suite of Forecast Products
forecast uncertainty
years
seasons
months
two weeks
one week
days
hours
minutes
Outlooks
Guidance
Threats Assessments
Forecasts
Watches
Warnings and Coordination
benefits
Protection of Life & Property
Flood Mitigation & Navigation
Transportation
Fire Weather
Hydropower
Agriculture
Recreation
Reservoir Control
Ecosystem
Energy
Health
State/Local Planning
Commerce
Environment

Sensor Package: General Concept

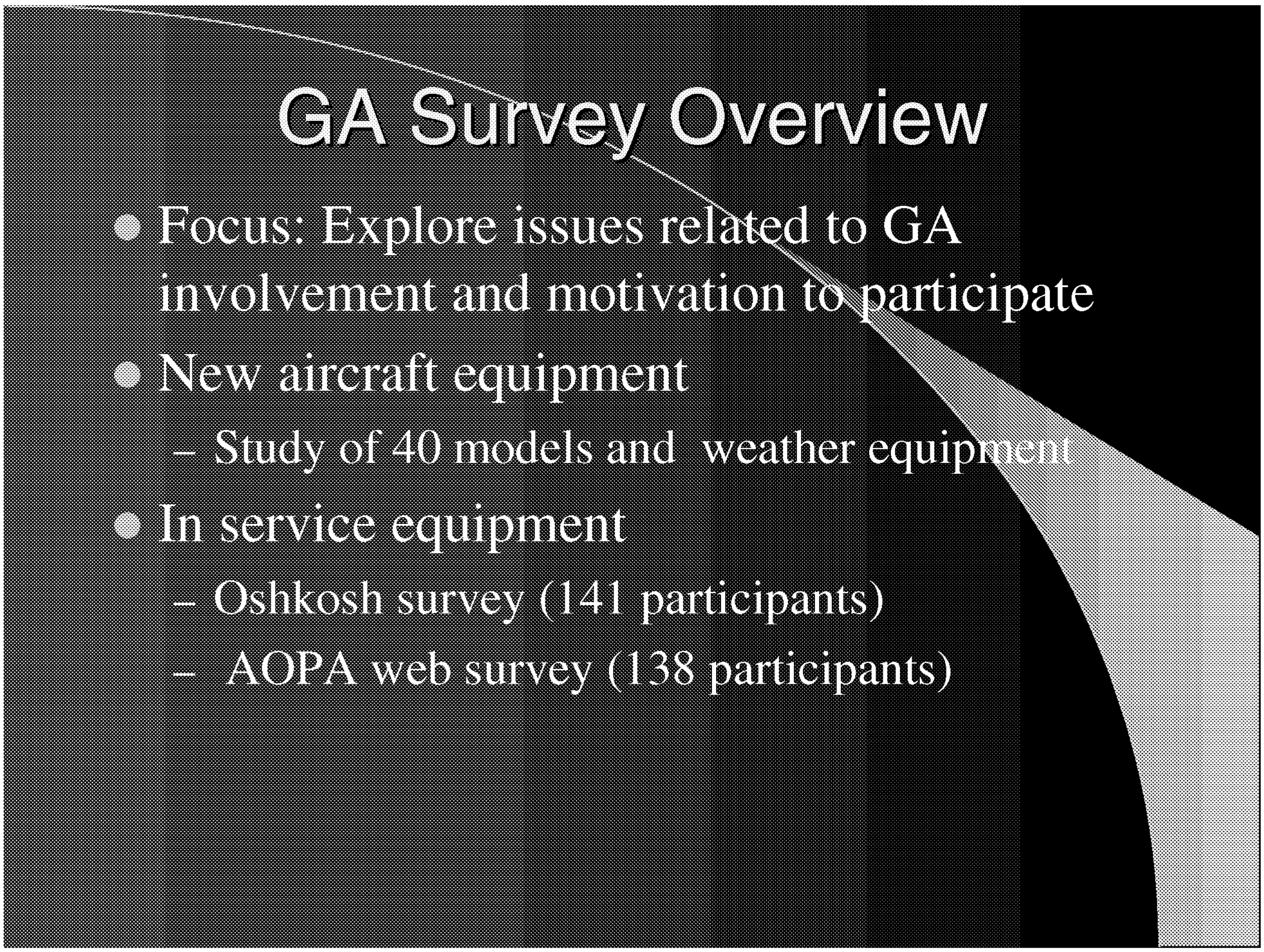
- GPS location
- Indicated Airspeed
- Pressure Altitude
- Temperature
- Relative Humidity
- Magnetic Heading
- Winds aloft (direction & speed)
- Accelerometer (Turbulence)
- Ice detection and warning

Target price of one manufacturer: $5,000

Market target: 2003


TAMDAR Study Questions
Most likely installation scenarios:
– Cost of installation and operation of sensor
– Adoption motivation / policy issues
– Cost of alternate weather information sources
– Potential for new weather products
– Societal / aviation benefits
Key: Develop an integrated business case.


Integrated Team Approach
Forgive me if I left anyone out!
Communication Link
Package Carriers
AOPA
Commercial Carriers
Commuter airlines
GA
Weather Service
ATA
Weather Information Providers

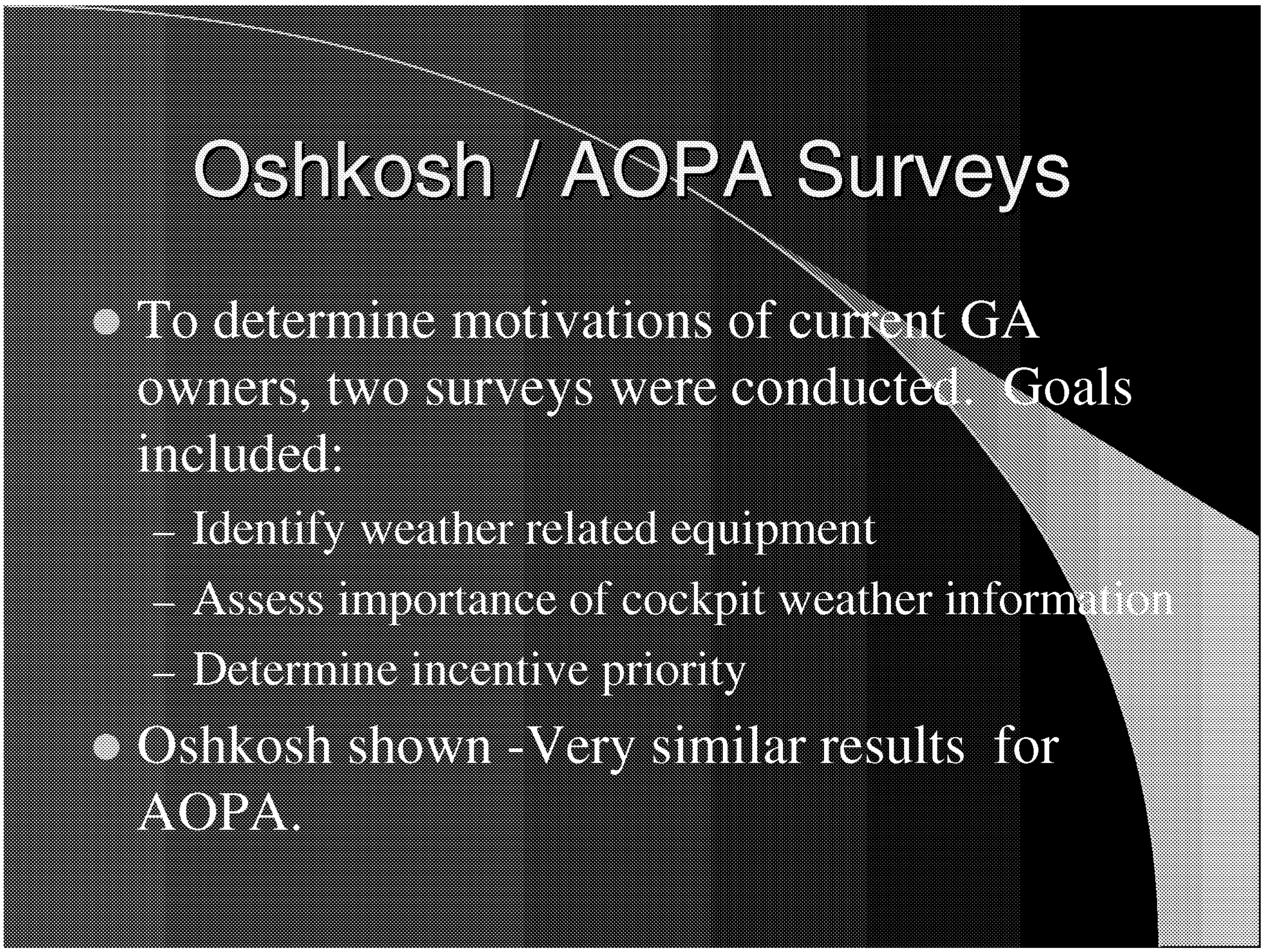

GA Survey Overview
Focus: Explore issues related to GA involvement and motivation to participate
New aircraft equipment
– Study of 40 models and weather equipment
In service equipment
– Oshkosh survey (141 participants)
– AOPA web survey (138 participants)

New Aircraft Weather Equipment

- Examined standard weather information equipment on 40 models of new aircraft.

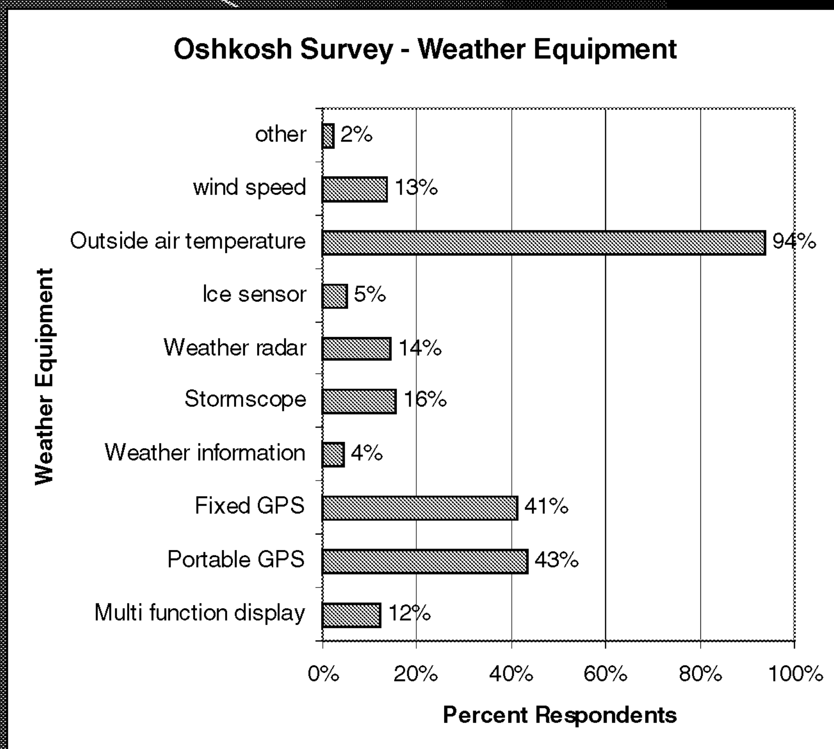
With weather instruments	47.5%
Models with weather radar	17.5%
Models with stormscope	27.5%
Without weather instruments	52.5%

- Conclusion: opportunity to offer weather information even to new aircraft owners as incentive to participate.


Oshkosh / AOPA Surveys
To determine motivations of current GA owners, two surveys were conducted. Goals included:
– Identify weather related equipment
– Assess importance of cockpit weather information
– Determine incentive priority
Oshkosh shown -Very similar results for AOPA.

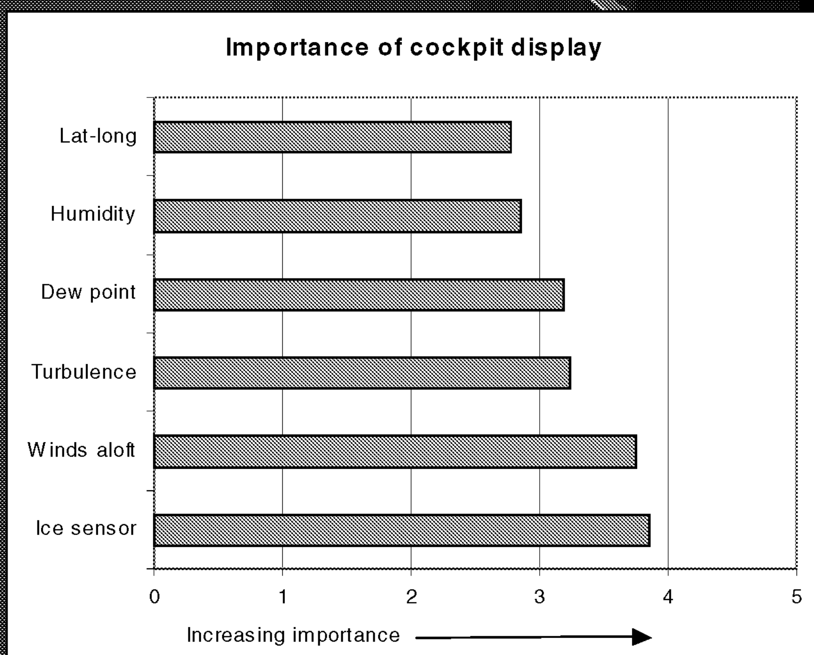
Weather Related Equipment

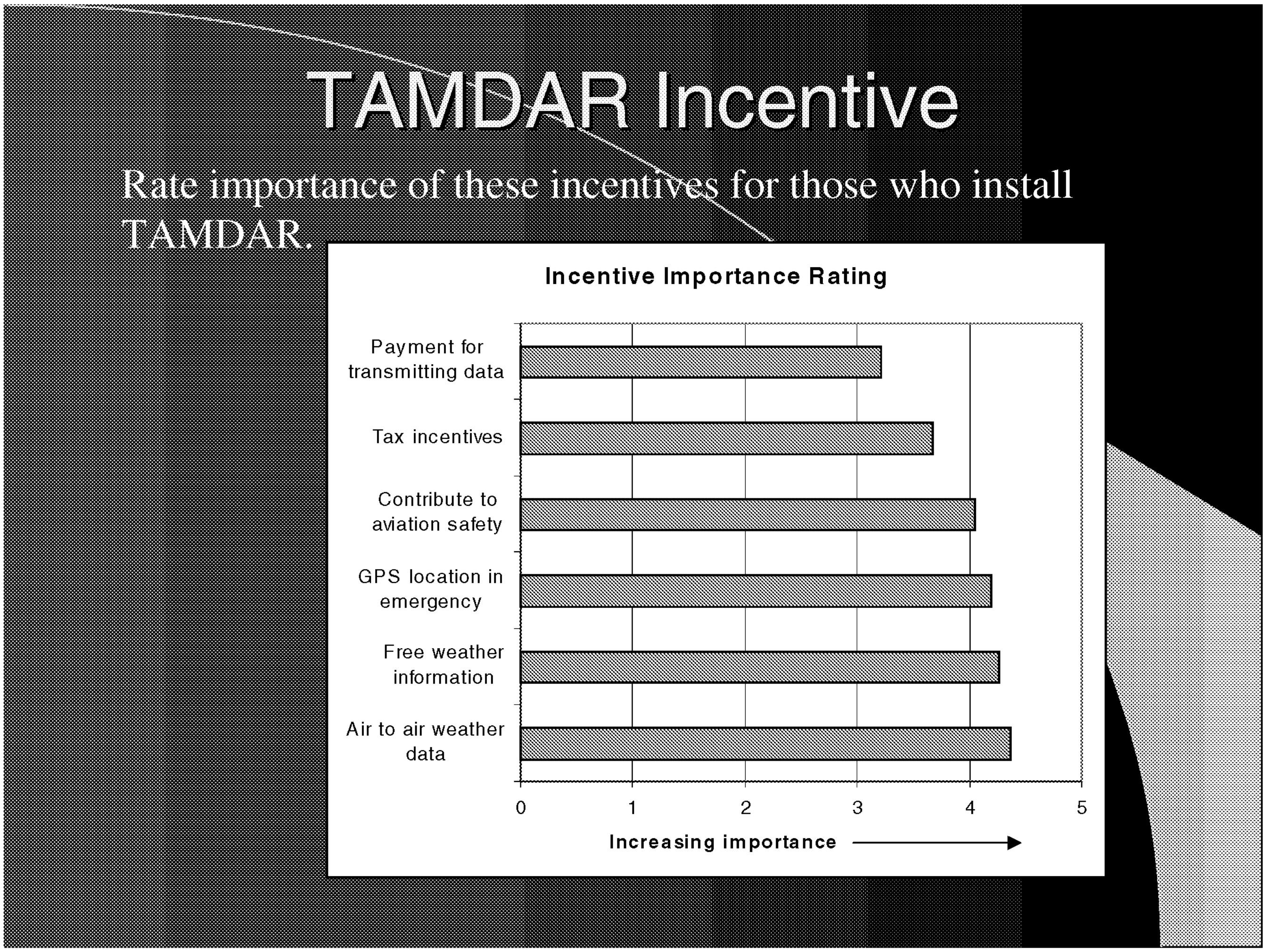
- 75% below 18,000 ft.
- 89% single or multi engine piston
- 79% less than 20 hours per month



Cockpit Weather Data

Rate importance if you could select TAMDAR data for display in the cockpit (1-5very important):



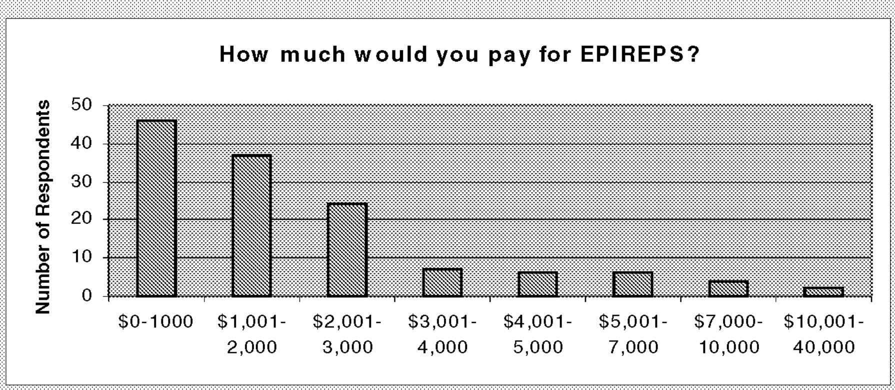

TAMDAR Incentive
Rate importance of these incentives for those who install TAMDAR.
Incentive Importance Rating
Payment for transmitting data
Tax incentives
Contribute to aviation safety
GPS location in emergency
Free weather information
Air to air weather data
0
1
2
3
4
5
Increasing importance

Oshkosh-Willingness to Pay

- For weather data items rated 4 or 5:

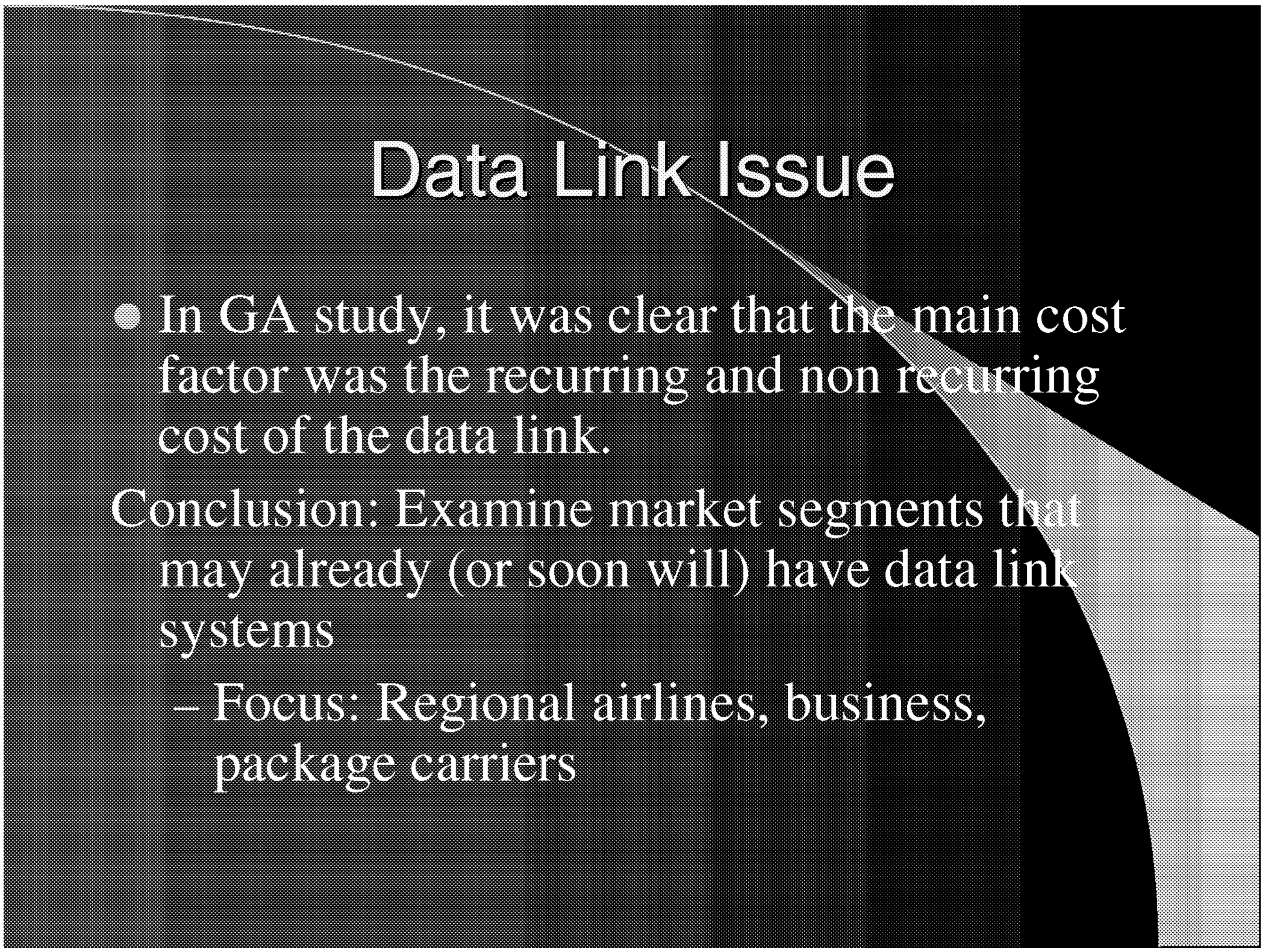
Price		%
$0-1000	46	34.8
$1,001-2,000	37	28.0
$2,001-3,000	24	18.1
$3,001-4,000	7	5.3
$4,001-5,000	6	4.5
$5,001-7,000	6	4.5
$7,000-10,000	4	3.0
$10,001-40,000	2	1.5

Non recurring cost that Participants are willing to pay for weather data rated 4 or 5.



Summary - GA Analysis

- Owners motivated for weather information
  - Opportunity for new aircraft and current fleet
- Low cost threshold for instrument purchase plus data link costs
- Operational issues
  - Data quality, instrument repair
  - Consistency of data input and transmission format
  - System management and control

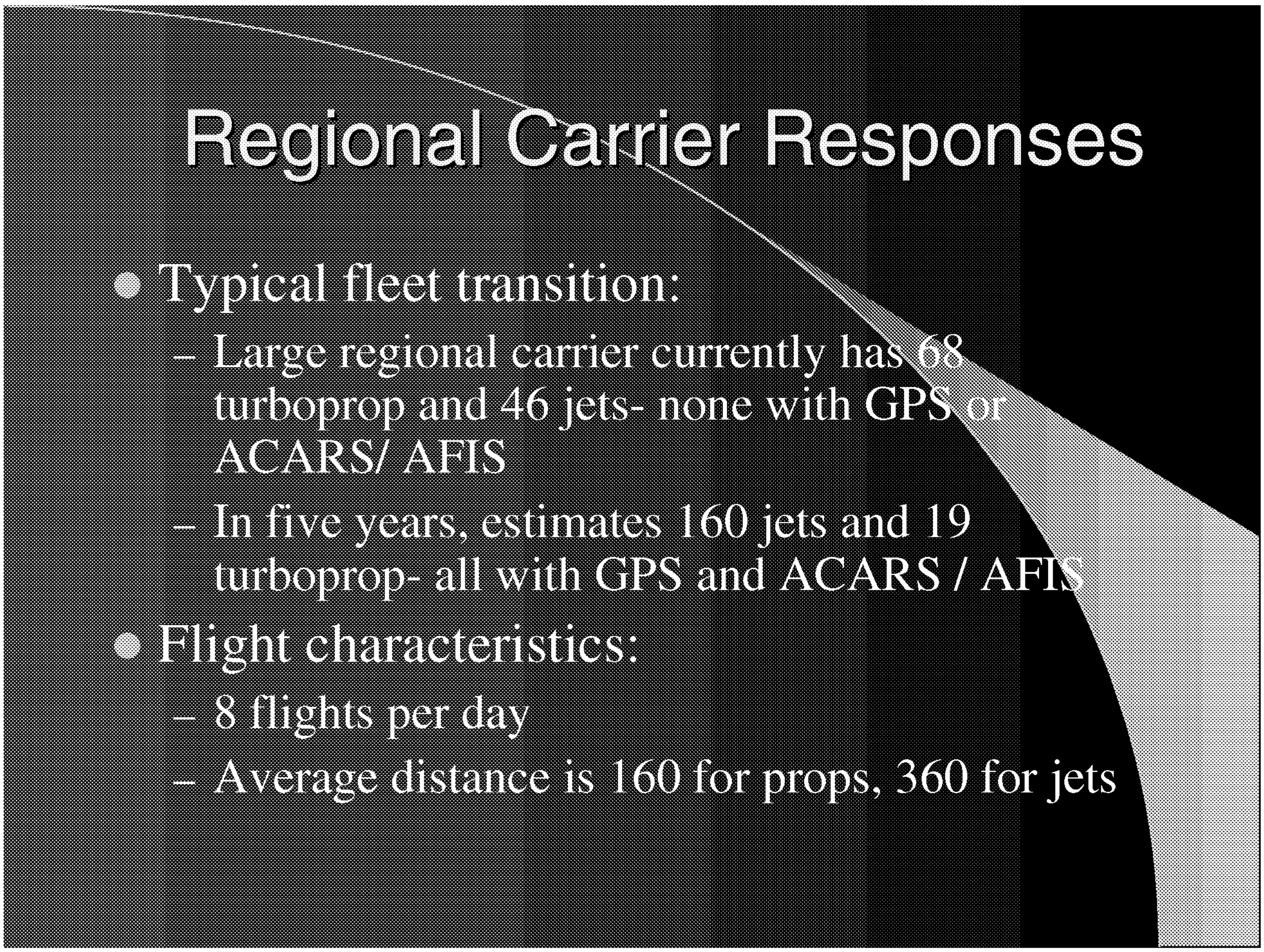

Data Link Issue
In GA study, it was clear that the main cost factor was the recurring and non recurring cost of the data link.
Conclusion: Examine market segments that may already (or soon will) have data link systems
– Focus: Regional airlines, business, package carriers

Current ACARS Status

- Estimates of current fleet
  - 6500 aircraft currently ACARS equipped
  - 1500 are high end GA
- Current message cost (hesitation!):
  - Automet message with identifier data: 103 characters
  - Typical transmission costs \$0.07-\$0.08 per kilo character (1000 characters)
  - For one data point ≈ \$0.01
  - Commonly quoted ranges \$0.04 to \$0.10 appear high.

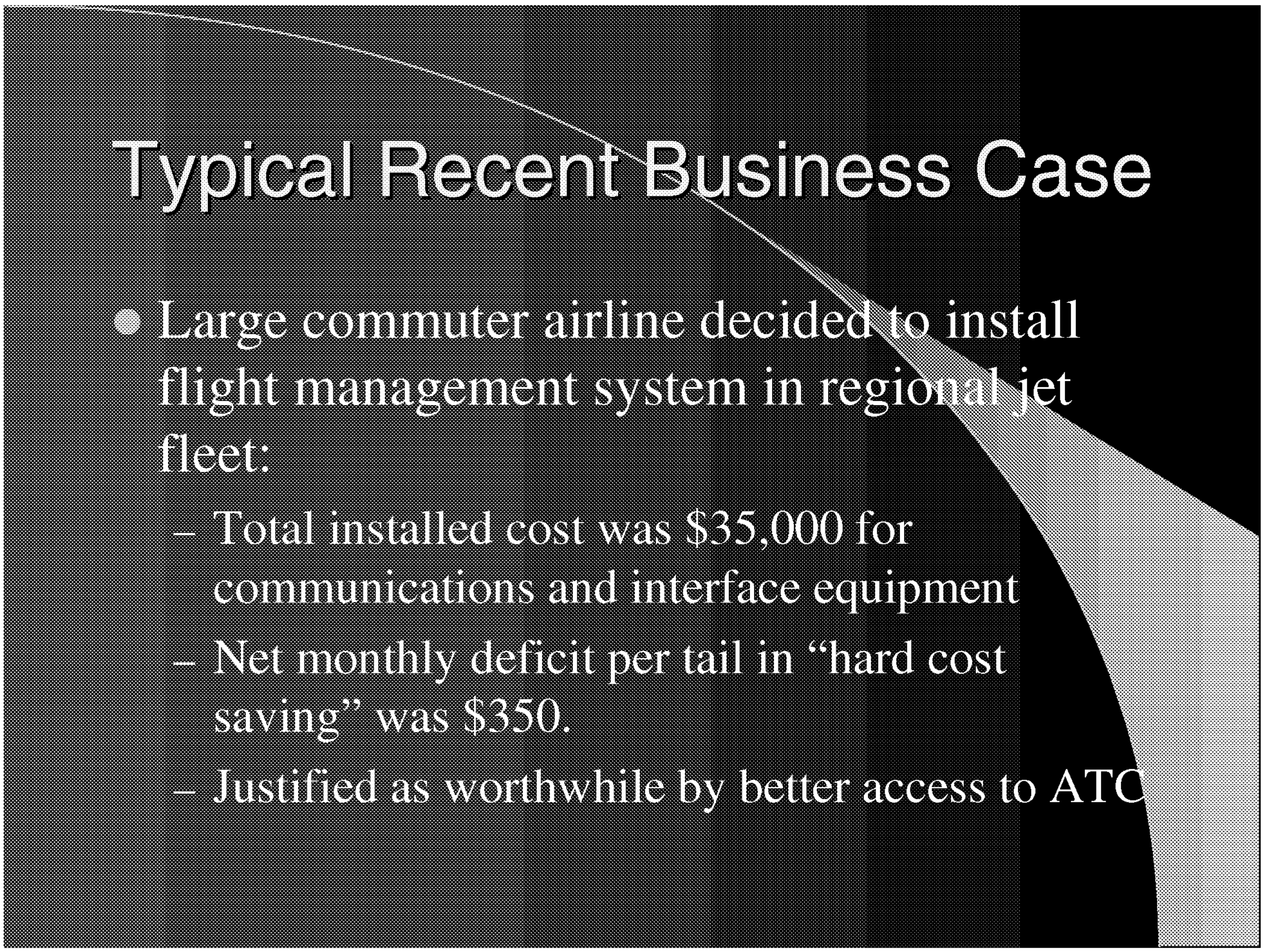
Current Market Analysis

- Current surveys under way to analyze:
  - Regional airlines, package carriers, business operators
- Areas of interest:
  - Current Fleet characteristics and changes in next five years (issue of regional jets)
  - Typical flight characteristics
  - Current fleet management / communications equipment
  - Motivations to participate


Regional Carrier Responses
Typical fleet transition:
– Large regional carrier currently has 68 turboprop and 46 jets- none with GPS or ACARS/ AFIS
– In five years, estimates 160 jets and 19 turboprop- all with GPS and ACARS / AFIS
Flight characteristics:
– 8 flights per day
– Average distance is 160 for props, 360 for jets

Fleet Management / Communication

- As noted, many aircraft are not equipped with GPS and / or ACARS / AFIS (airborne flight information system).
- Transition discussed with change to jets.
- High priorities for change include:
  - Cost reduction (automate OOOI data- out, off, on, in)
  - ATC communications (e.g. pre departure clearance)
  - Future services (free flight requirement, ADSB, etc.)


Typical Recent Business Case
Large commuter airline decided to install flight management system in regional jet fleet:
– Total installed cost was $35,000 for communications and interface equipment
– Net monthly deficit per tail in "hard cost saving" was $350.
– Justified as worthwhile by better access to ATC

Weather Information Providers

- Survey of viewpoint of weather information providers (for profit):
  - Goal: Is there commercial potential in TAMDAR?
- Packaged data set: Aviation, DOTS, military
- Improved forecast products: Above + broadcast
- Several comments focus on cost effective selection of data points.

Competitive Weather Sources

- TAMDAR complements other weather data
  - Provides opportunity for data correlation (e.g. satellites).
- However there is an issue of cost saving in other data gathering areas and cost effectiveness.
- Example: Weather balloons gather data for many purposes. Could the number be reduced?

Canadian AMDAR Case

- Weather balloon replacement considerations in Canada:
  - Cost of AMDAR flight: 30 observations @$0.04 each = $1.20 (VHF transmission- satellite higher)
  - Annual cost = 365*$1.20
  - Annual cost of a weather balloon launching is over $300
- Is a daily AMDAR flight worth more than a balloon launch? Is this a trade off that is appropriate in some cases or many cases?

Cost Summary- Estimates

- Sensor Suite: Target- $3500-$6500 including installation
- Communication system: $10,000-$35,000
  - Prefer to build on existing or planned flight information systems (e.g. ACARS)
- Data link costs: $0.01 per data point

How to Structure the Business Case?

- Program is aviation focused but societal benefits.
- Current issues in NAS, crowding, delays, etc.
  - TAMDAR can improve this
- Conclusion: build base business case on aviation impact
- Issue: How far can this move us forward?

TAMDAR Forecast Impact

- TAMDAR should improve short term forecasts in the following areas:
  - •Significant convection / severe weather
  - •Cloud cover / ceiling / fog / visibility
  - •Low level winds direction / shift
  - •Low level temperature structure
  - •High level winds, jets
  - •Precipitation type (icing, snow, rain)
  - •Maximum / minimum temperature
  - •Turbulence and wind shear
  - •Other: ______________________________

Current survey areas under discussion.

TAMDAR Terminal Operation Impact

Quantify delays from:

- Convection or severe terminal area weather.
- Terminal cloud cover, ceiling, visibility or fog
- Anticipation of wind direction or wind shift in the terminal area.
- Icing and snow in the terminal area
- Terminal area turbulence and wind shear
- Weather activity in arrival paths or departure gates into or out of the terminal area
- General precipitation conditions in the terminal area
- At smaller airports due to “ripple” effect of delays at hubs.

TAMDAR Airline Operations Impact

- Costs from reduced flight time or fuel use from improved flight planning prior to take off.
- Costs from reduced fuel consumption due to improved flight rerouting en route.
- Costs related to carrying excessive fuel as a precaution for forecast inaccuracy.
- Costs related to diversion or hold decisions for aircraft in flight.
- Costs related to hold decisions for aircraft on the ground.
- Costs due to improved ground operations.
- Costs related to improved traffic flow management.

Policy Issues and Implications

- Also studying possible policy implications - objective measures needed:
  - ***Input measures*** (Incentive and operating cost of the TAMDAR system).
  - ***Output measures*** (the number of data points).
  - ***Outcome measures*** (the amount of improvement in weather aviation delay and operating costs).
  - ***Impact measures*** (the decrease of weather related aircraft accidents in which TAMDAR weather data played a significant role, the improvement of aviation efficiency which resulted from TAMDAR data, increase of quality and efficiency of product and services which are weather related).

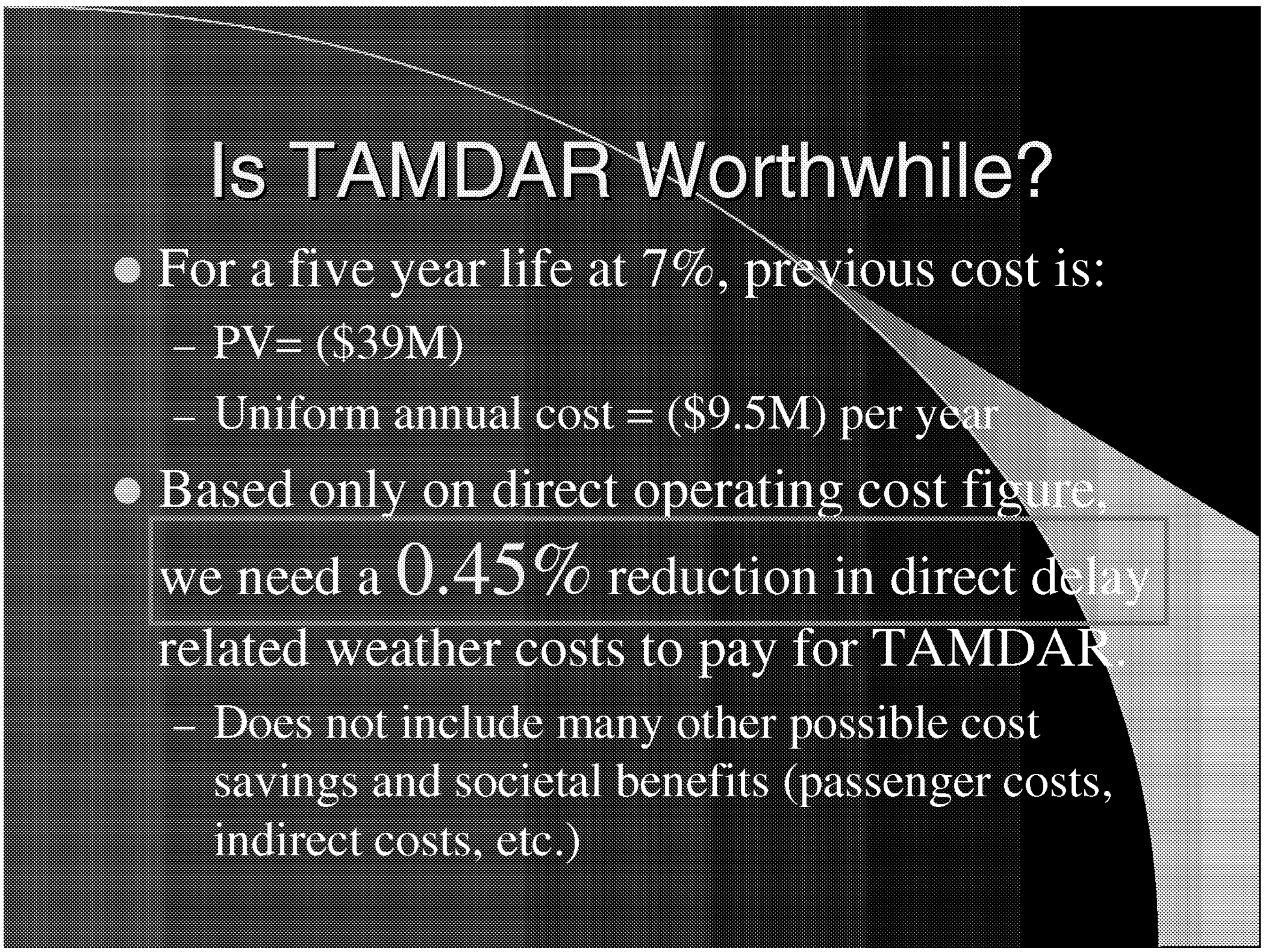
The Policy Investment Role in TAMDAR Technology: Principles

- There will always be areas where public benefits … substantially exceed the returns that can be realized by private investment alone. Federal investment is essential in these areas. The President's Committee of Advisors on Science and Technology provides the following criteria for government investment in technology
- "Areas of national importance where the marketplace alone cannot justify a sufficient level of technology investment by private industry "
- "...Where the benefits are too widely spread for any one company to recover its investment at a profit... "

(President's Committee of Advisors on Science and Technology (PCAST) *Executive Office of the President's Committee of Advisors on Science and Technology, Washington, D.C. 20500, June 18, 1996)*:

Business Case Example

- Per FAA, direct operating cost of 89M delay minutes was $3B in 1999.
  - Weather is a causal factor in about 70% or $2.1B.
- Cost range-equipping 2000 TAMDAR aircraft (WORST CASE) :
  - Non recurring cost: $33M (as incentive, TAMDAR pays half of $20k / unit plus sensor).
  - Recurring cost: Two flights per day at $1 each*2000*365 =$1.5M (Optimization model: Erol Ozan dissertation focus)


Is TAMDAR Worthwhile?
For a five year life at 7%, previous cost is:
– PV= ($39M)
– Uniform annual cost = ($9.5M) per year
Based only on direct operating cost figure, we need a 0.45% reduction in direct delay related weather costs to pay for TAMDAR.
– Does not include many other possible cost savings and societal benefits (passenger costs, indirect costs, etc.)

Conclusions -Next Steps

- TAMDAR appears to have great potential to impact forecasting and aviation operations
- Significant challenge to document the savings impact of TAMDAR
  - Working group: NWS and ATA
- Things we don't know are diminishing
- Many thanks to all who have helped us get this far!


National Weather Service
Aviation Services Branch
Impact of Meteorological Data Collection and
Reporting System (MDCRS) / Tropospheric
Airborne Meteorological Data Reporting (TAMDAR)
Data on National Weather Service (NWS) Operations
Carl Weiss

MDCRS / TAMDAR Topics

- MDCRS Overview
- Value of MDCRS Observations to Numerical Weather Prediction (NWP)
- Value of MDCRS Observations in Operational Settings
- Added Value of TAMDAR Observations
- Recommendations

MDCRS Overview

- Participating airlines: United, UPS, American, FedEx, Northwest, Delta
- More than 80K observations daily over continental United States (CONUS)
  - *~ 1450 Aircraft*
- 30 UPS aircraft making moisture measurements
- Aeronautical Radio, Inc. (ARINC) contracted by the Federal Aviation Administration (FAA) and NWS to:
  - *Separate meteorological data from Aircraft Communications Addressing and Reporting System (ACARS) messages*
  - *Process data into Binary Universal Form for data Representation (BUFR) format*
  - *Send data to NWS and Federal Aviation Administration (FAA) via Global Telecommunications System (GTS)*

MDCRS Overview (Continued)

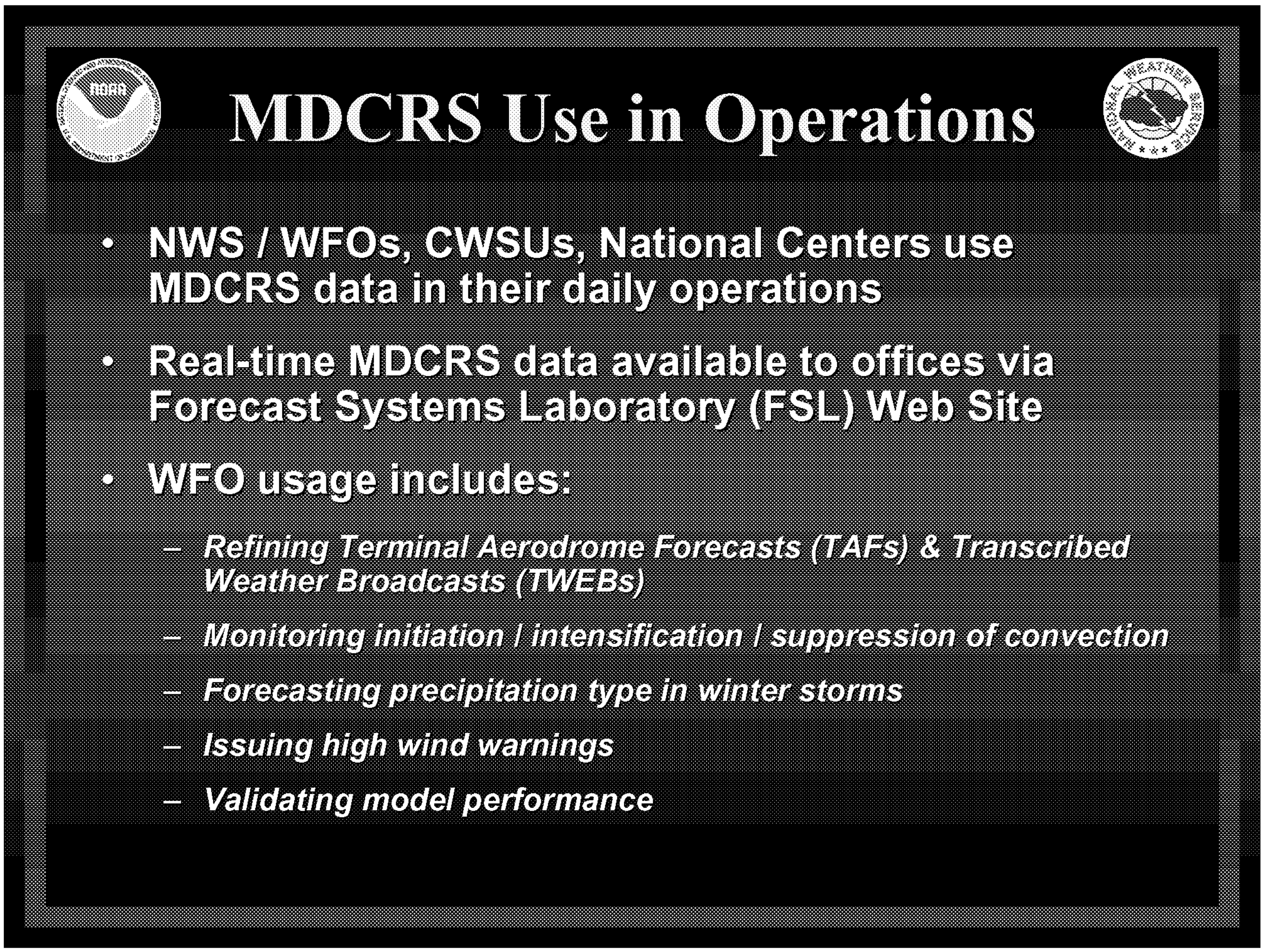
- NWS / National Centers for Environmental Prediction (NCEP) uses MDCRS data for NWP
- NWS / Weather Forecast Offices (WFOs), Center Weather Service Units (CWSUs) and National Centers use MDCRS data in daily operations

MDCRS Use in NWP

- Accurate forecasts depend upon accurate analyses which, in turn, depend on accurate observations
- NCEP has been using automated aircraft observations for NWP since mid-1980s
- MDCRS wind / temp data included in both NCEP global & regional models since early 1998
- NCEP receives ~65K MDCRS reports daily
  - *Average hourly totals of MDCRS reports range from ~1000 reports (non-peak) to ~3200 reports (peak)*
  - *45% of these reports arrive within 10 minutes of observation time*
  - *65% within 15 minutes*
  - *70% within 20 minutes*

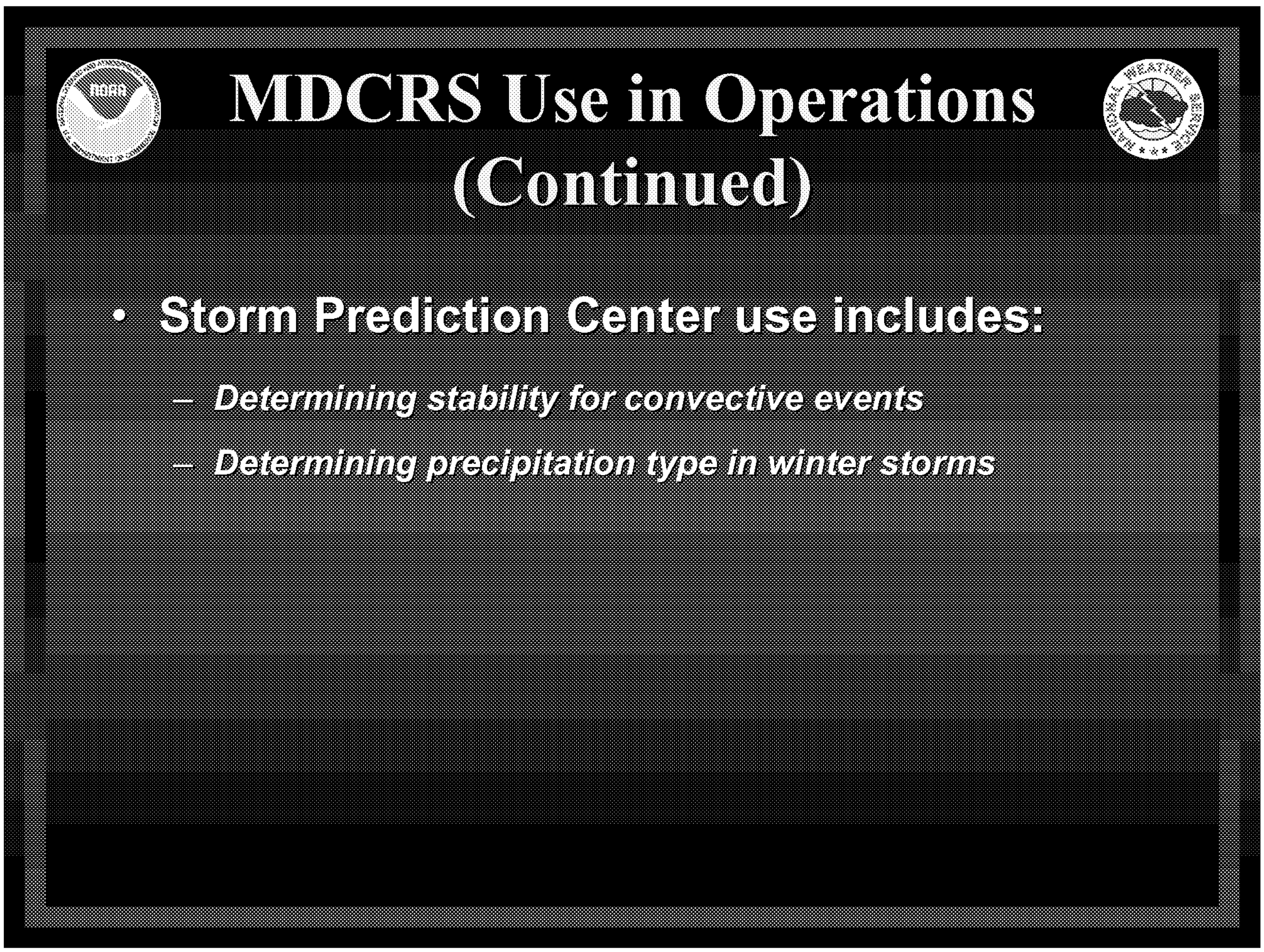
MDCRS Use in NWP (Continued)

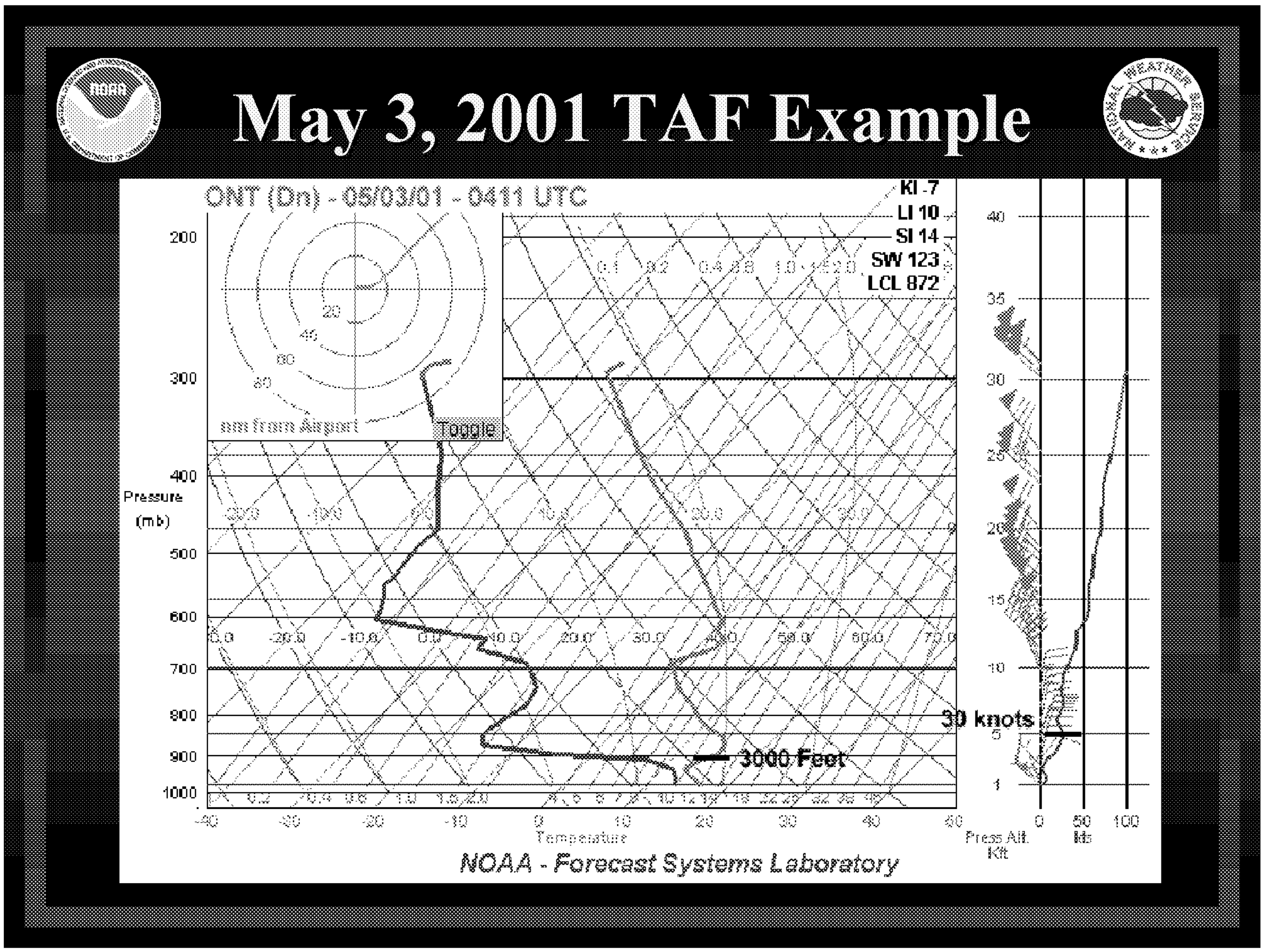
- MDCRS usage in Rapid Update Cycle (RUC) model
  - *Continuous availability of high-quality aircraft data led to development of RUC*
  - *Currently, RUC runs hourly*
  - *MDCRS data comprises up to 62% of the total observations used in an hourly RUC model run*
- MDCRS usage in Global and Meso-eta models
  - *Both model runs increased from twice (every 12 hrs) to 4 times (every 6 hrs) daily because of MDCRS data availability*


MDCRS Use in Operations
• NWS / WFOs, CWSUs, National Centers use MDCRS data in their daily operations
• Real-time MDCRS data available to offices via Forecast Systems Laboratory (FSL) Web Site
• WFO usage includes:
– Refining Terminal Aerodrome Forecasts (TAFs) & Transcribed Weather Broadcasts (TWEBs)
– Monitoring initiation / intensification / suppression of convection
– Forecasting precipitation type in winter storms
– Issuing high wind warnings
– Validating model performance

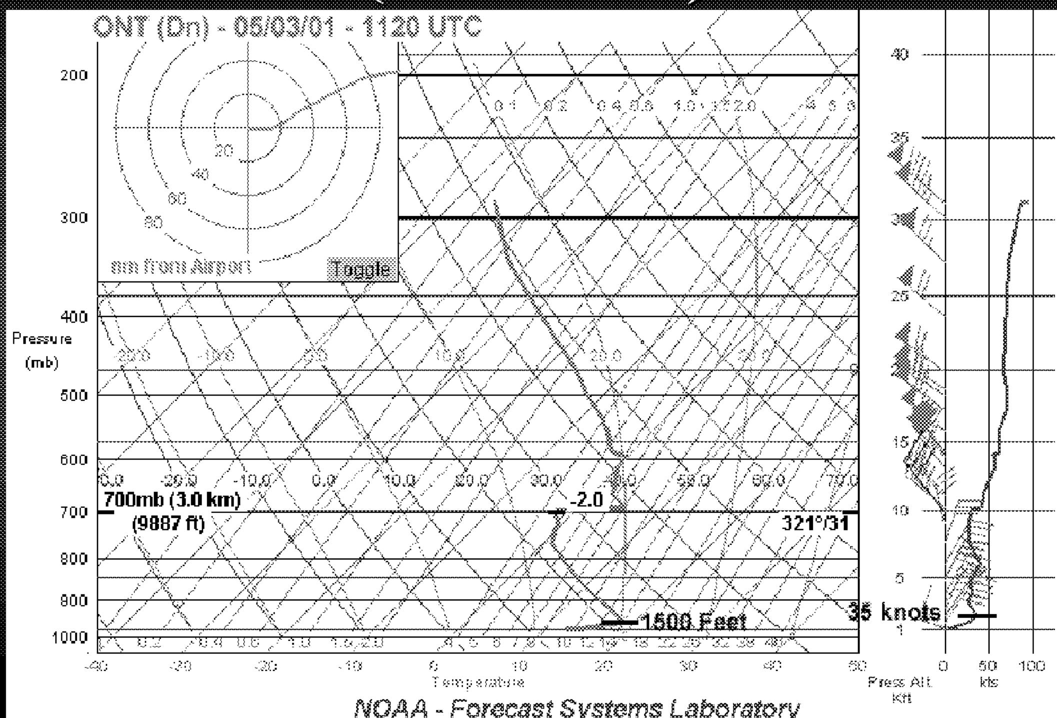
MDCRS Use in Operations (Continued)

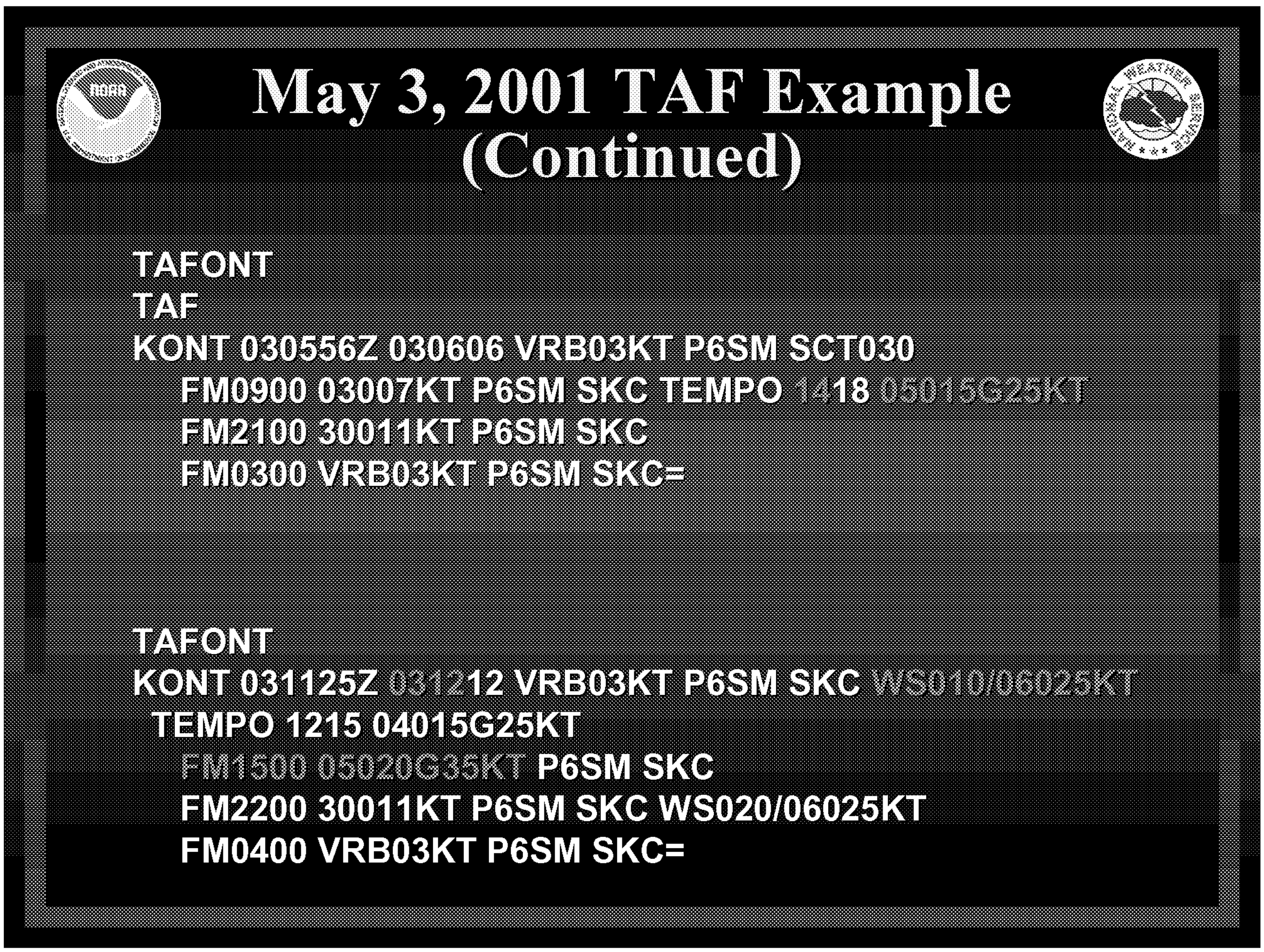
- CWSU use includes:
  - *Supporting air traffic flow to busy airports*
  - *Refining areas of icing and turbulence*
- Aviation Weather Center use includes:
  - *Utilizing data via RUC analysis*
- Tropical Prediction Center use includes:
  - *Supplementing hurricane recon flight data over land areas*
  - *Supporting marine & aviation forecasting for Gulf of Mexico, tropical Atlantic*

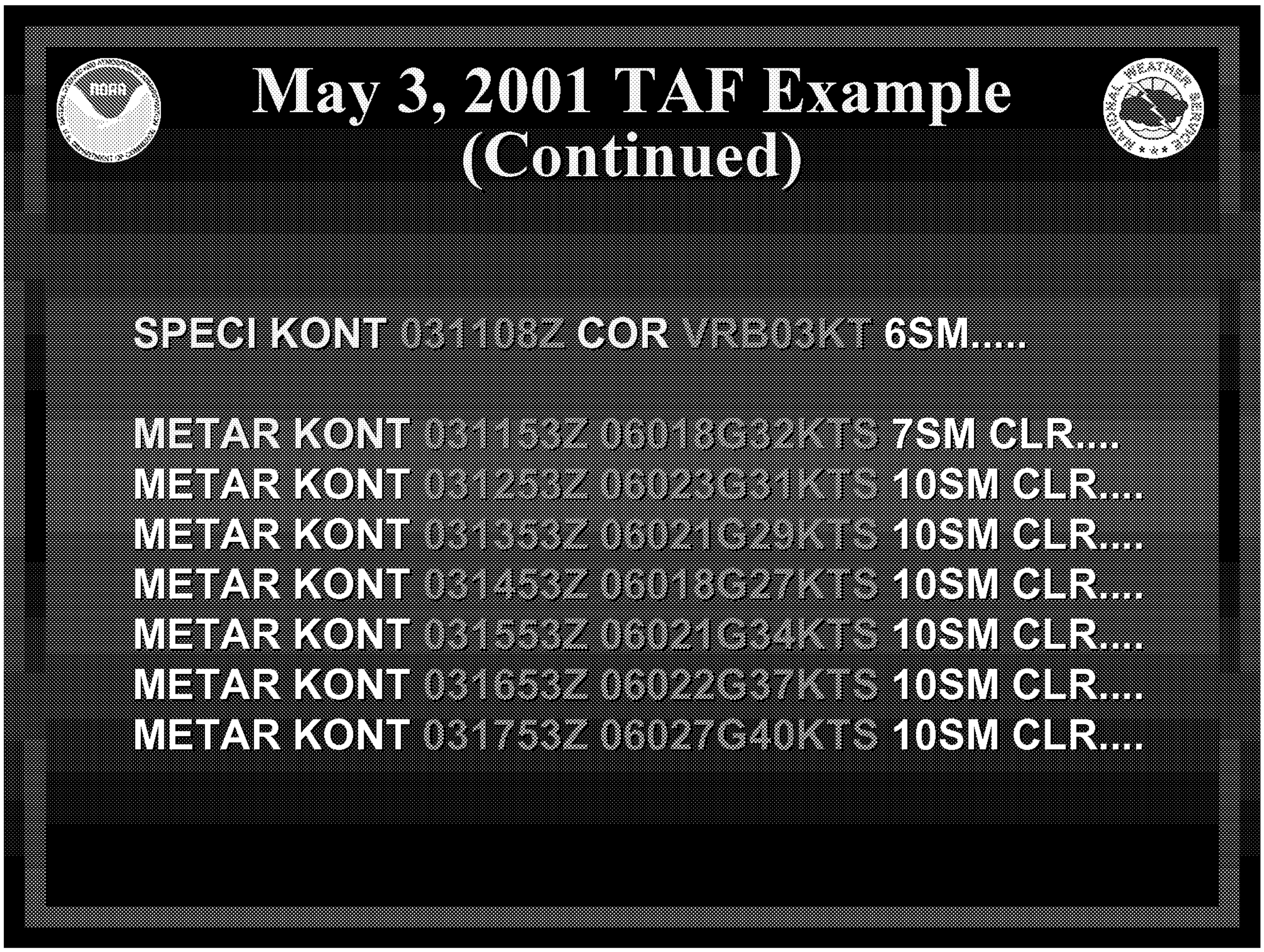

MDCRS Use in Operations (Continued)
• Storm Prediction Center use includes:
– Determining stability for convective events
– Determining precipitation type in winter storms


May 3, 2001 TAF Example
ONT (Dn) - 05/03/01 - 0411 UTC
KI -7
LI 10
SI 14
SW 123
LCL 872
Pressure (mb)
nm from Airport
Toggle
30 knots
3000 Feet
Temperature
Press Alt. Kft
kts
NOAA - Forecast Systems Laboratory

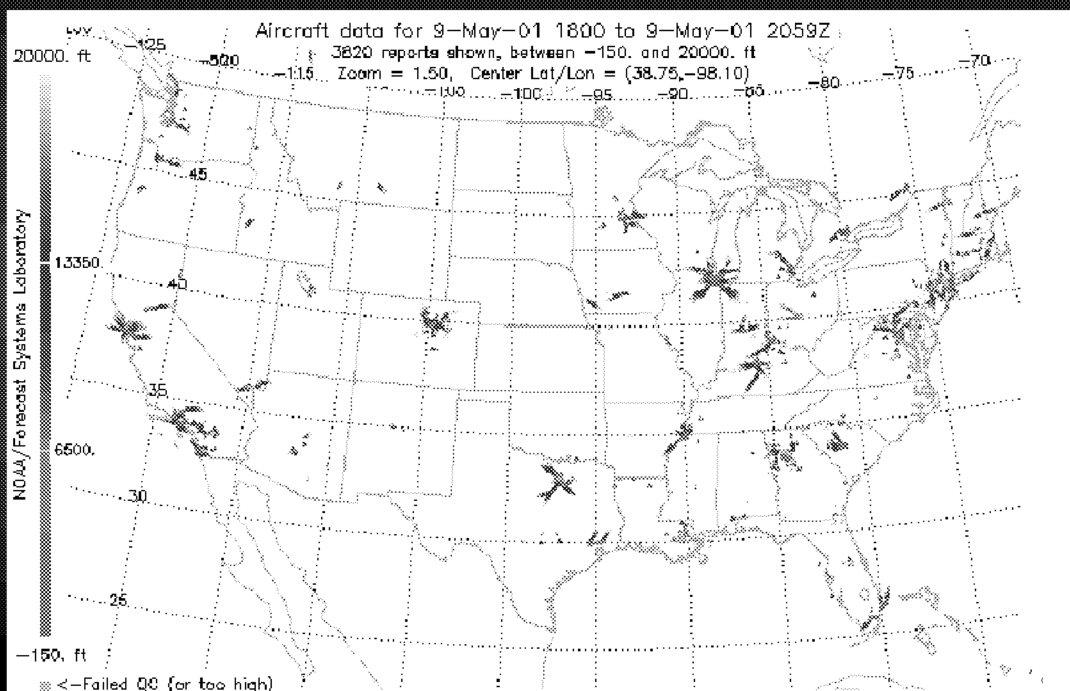
May 3, 2001 TAF Example (Continued)

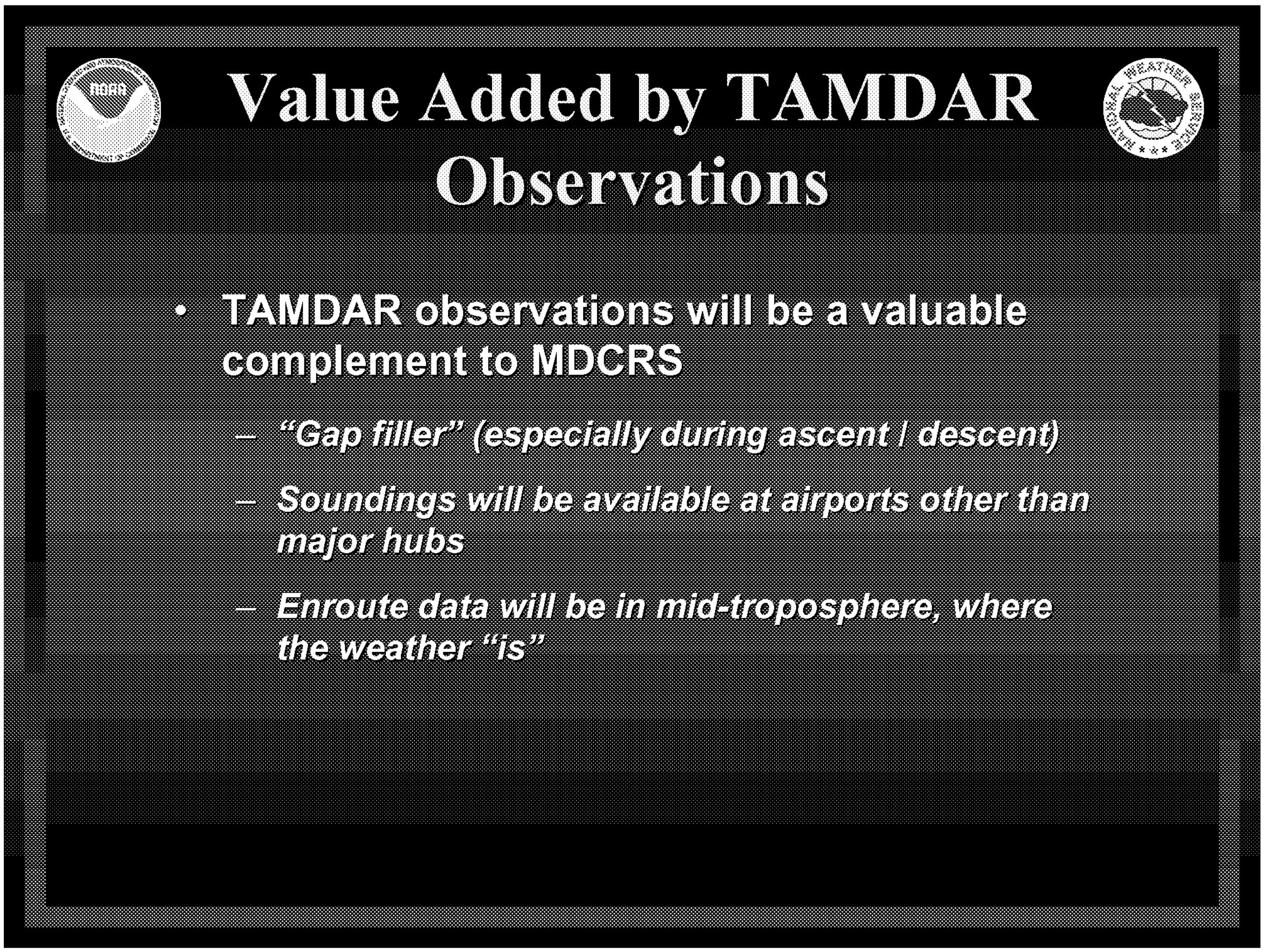


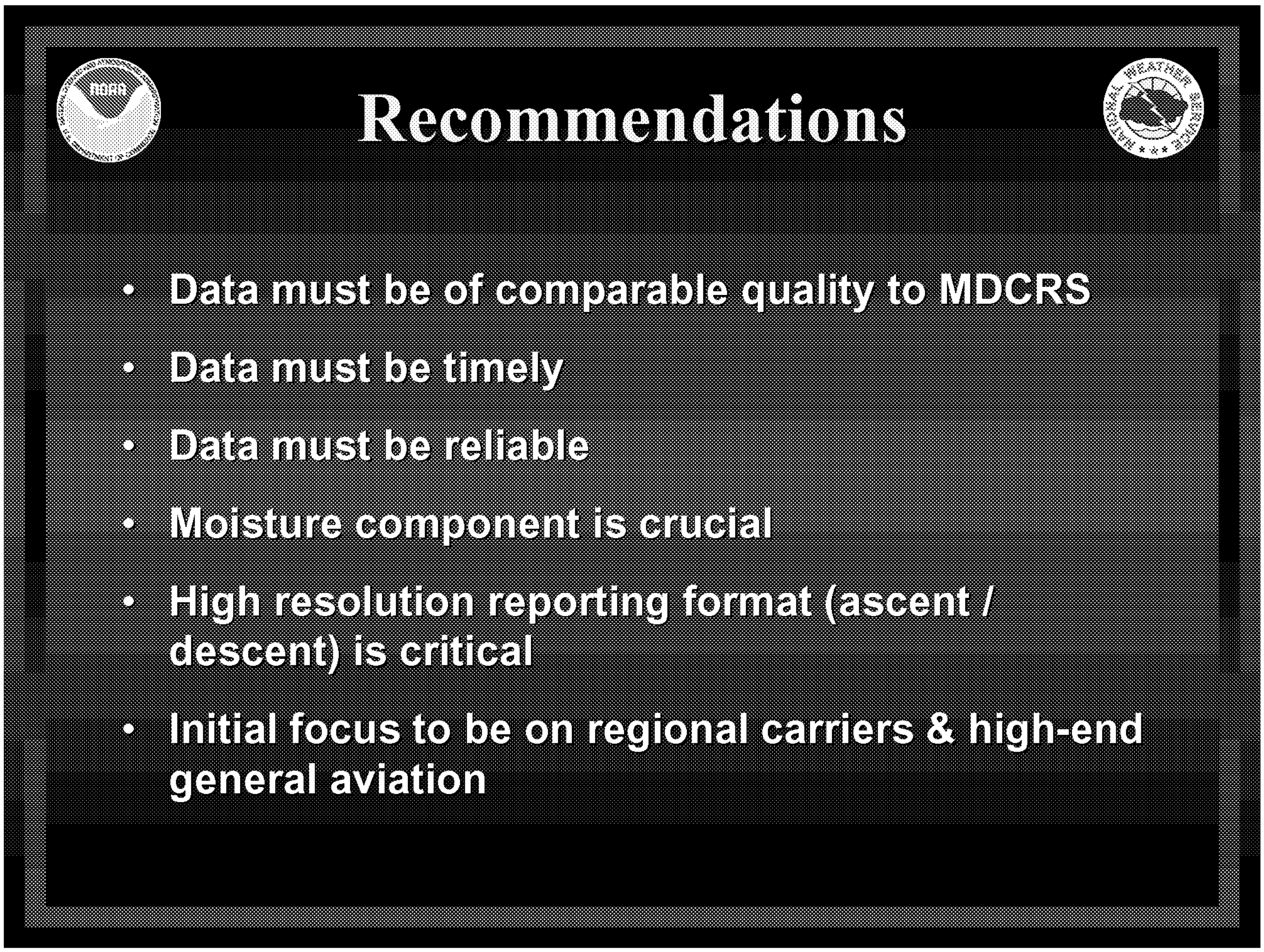

May 3, 2001 TAF Example
(Continued)
TAFONT
TAF
KONT 030556Z 030606 VRB03KT P6SM SCT030
FM0900 03007KT P6SM SKC TEMPO 1418 05015G25KT
FM2100 30011KT P6SM SKC
FM0300 VRB03KT P6SM SKC=
TAFONT
KONT 031125Z 031212 VRB03KT P6SM SKC WS010/06025KT
TEMPO 1215 04015G25KT
FM1500 05020G35KT P6SM SKC
FM2200 30011KT P6SM SKC WS020/06025KT
FM0400 VRB03KT P6SM SKC=


May 3, 2001 TAF Example (Continued)
SPECI KONT 031108Z COR VRB03KT 6SM.....
METAR KONT 031153Z 06018G32KTS 7SM CLR....
METAR KONT 031253Z 06023G31KTS 10SM CLR....
METAR KONT 031353Z 06021G29KTS 10SM CLR....
METAR KONT 031453Z 06018G27KTS 10SM CLR....
METAR KONT 031553Z 06021G34KTS 10SM CLR....
METAR KONT 031653Z 06022G37KTS 10SM CLR....
METAR KONT 031753Z 06027G40KTS 10SM CLR....

MDCRS Ascent / Descent Coverage




Value Added by TAMDAR Observations
• TAMDAR observations will be a valuable complement to MDCRS
– "Gap filler" (especially during ascent / descent)
– Soundings will be available at airports other than major hubs
– Enroute data will be in mid-troposphere, where the weather "is"


Recommendations
• Data must be of comparable quality to MDCRS
• Data must be timely
• Data must be reliable
• Moisture component is crucial
• High resolution reporting format (ascent / descent) is critical
• Initial focus to be on regional carriers & high-end general aviation

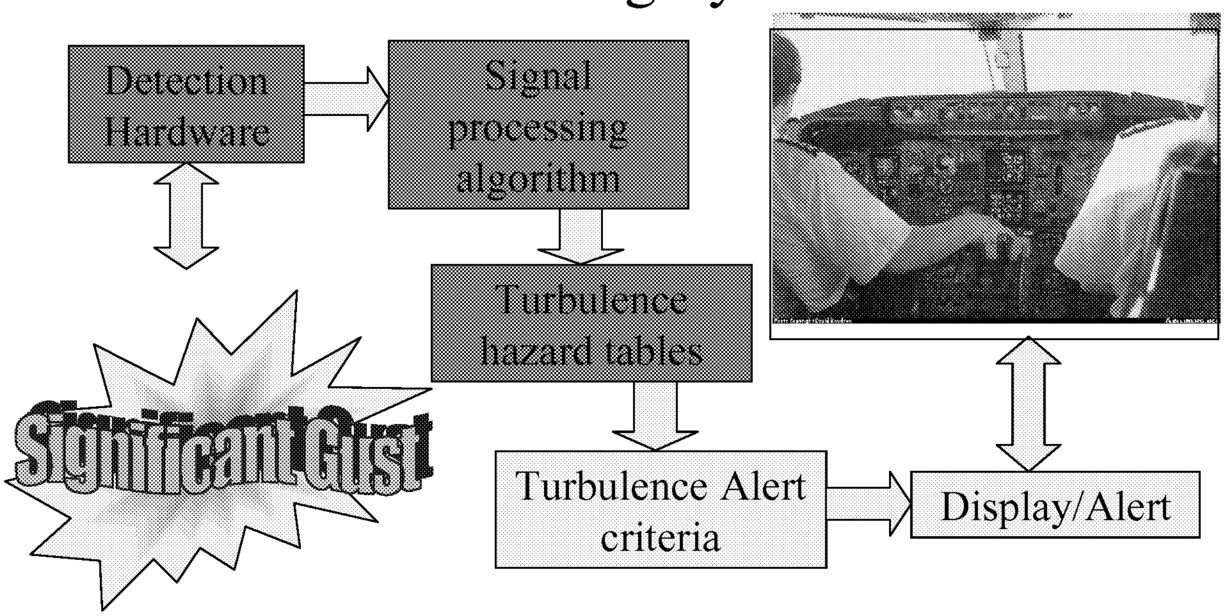
NASA/CP—2002-210964

Airborne Turbulence Warning System Development

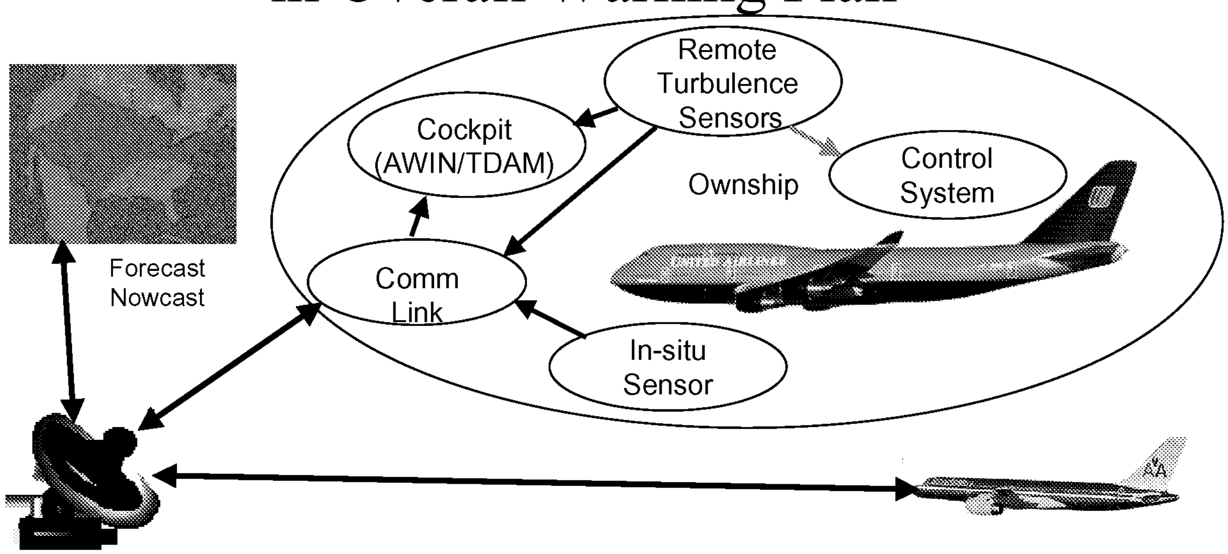
Weather Accident Prevention
Second Annual Review
June 5-7, 2001

Rod Bogue
NASA Dryden Flight Research Center

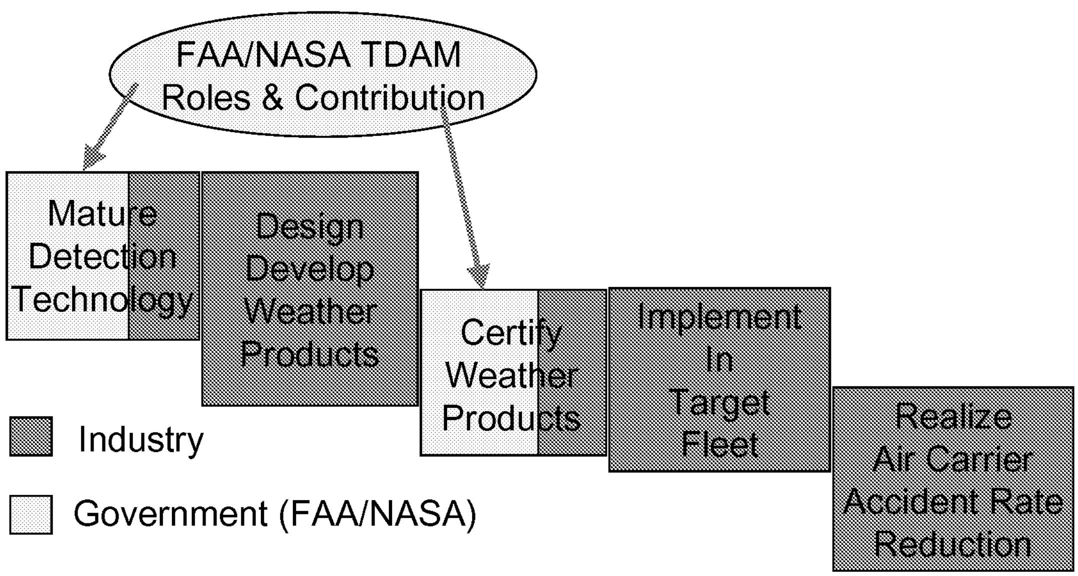
An End-to-End Tactical Turbulence Warning System



Turbulence Detection & Mitigation Role in Overall Warning Plan



Model for Reducing Air Carrier Turbulence Accident Rate



NASA/CP—2002-210964

Meteorological Case Studies of Turbulence Encounters

Richard Ferris

Outline

- Basis for Investigations
- Data Collection
- Case Studies
  - West Palm Beach, FL (Convective)
  - Wilmington, DE (Convective)
  - Cross City, FL (Convective)
  - Cape Girardeau, MO (CAT)
  - Houston, TX (Inconclusive)
- Conclusions
- Future Work

Basis for Investigation

- **Assistance to:**
  - National Transportation Safety Board (NTSB)
  - Dryden Flight Research Center (DFRC)
- **NTSB**
  - Analyses to help determine cause of upsets
- **DFRC**
  - Flight Operations Quality Assurance (FOQA) data
  - Weather analysis of selected turbulence cases
  - Safeguards taken to prevent unauthorized disclosure

Basis for Investigation

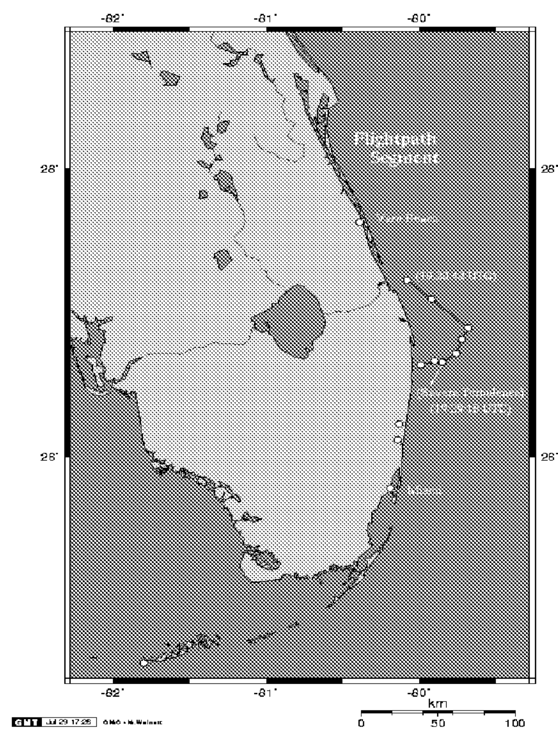
- Flight data recorder data alone will not suffice to determine causality
- Need to understand meteorological phenomena to develop an overall avoidance system
- Results will provide insights into issues that arise in both encounter analysis and development of automated systems
- Unclear if one would have identified operationally significant turbulence without apriori knowledge of upset location

Data Collection

- Mishap locations and flight profiles provided by NTSB and FOQA data
- Weather data obtained from National Climatic Data Center
  - NEXRAD Archive Level II
  - Satellite imagery
  - Upper air charts/soundings
  - Surface charts
- Data processed, generated, and analyzed locally

Case Study 1 (NTSB)

- Severe turbulence near West Palm Beach, FL
- One pax seriously injured
- Initially at 16,000 ft
- Loss of over 3000 ft in 30 sec
- Recovered and landed at MIA



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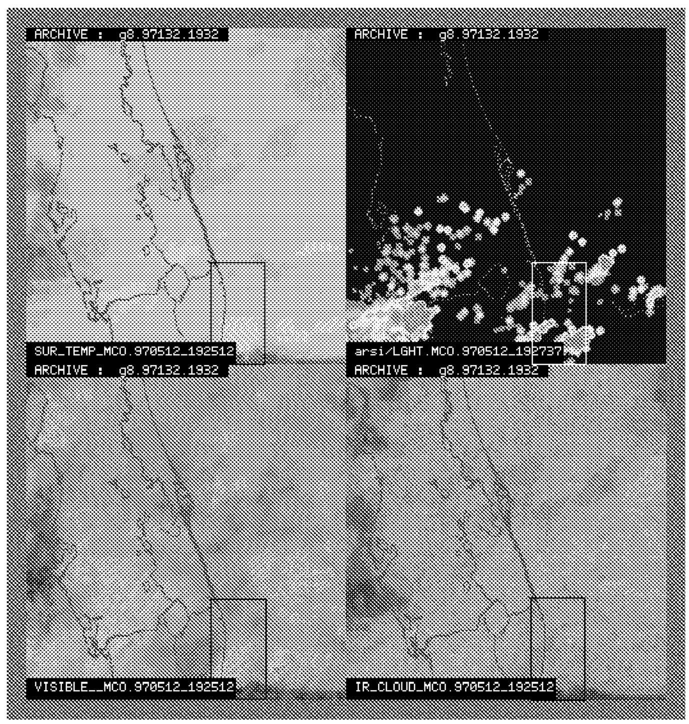
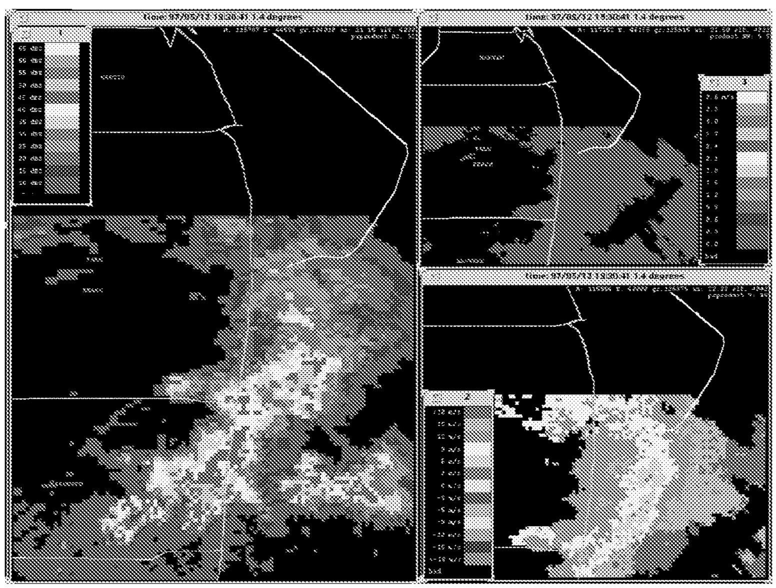
Case Study 1

- Frontal boundary
- Multi-layered clouds
- Widespread convection
- Winds at altitude: 240/35
- Only available radar-KAMX



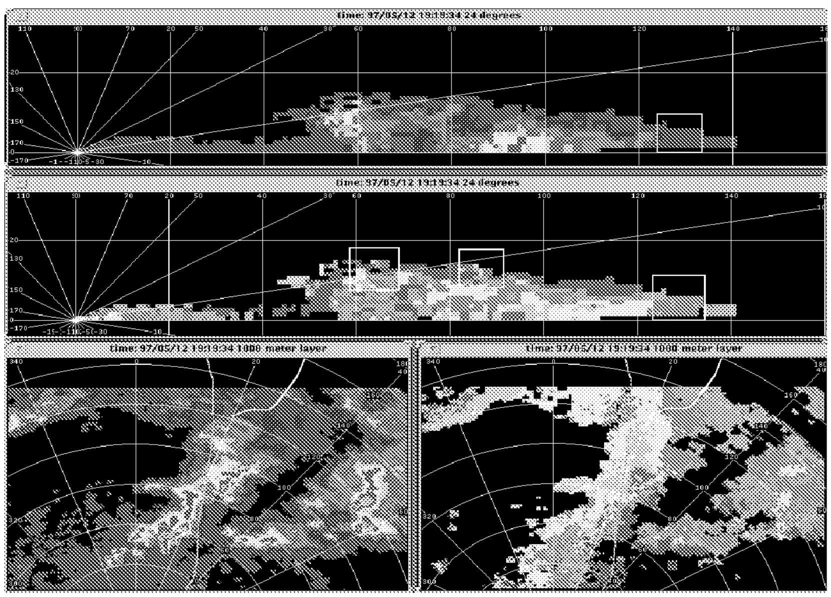
Case Study 1

- Plan view at incident time
- Nearest convection: 42 dBZ cell approximately 20 km to SSW
- Nothing indicative of severe turbulence



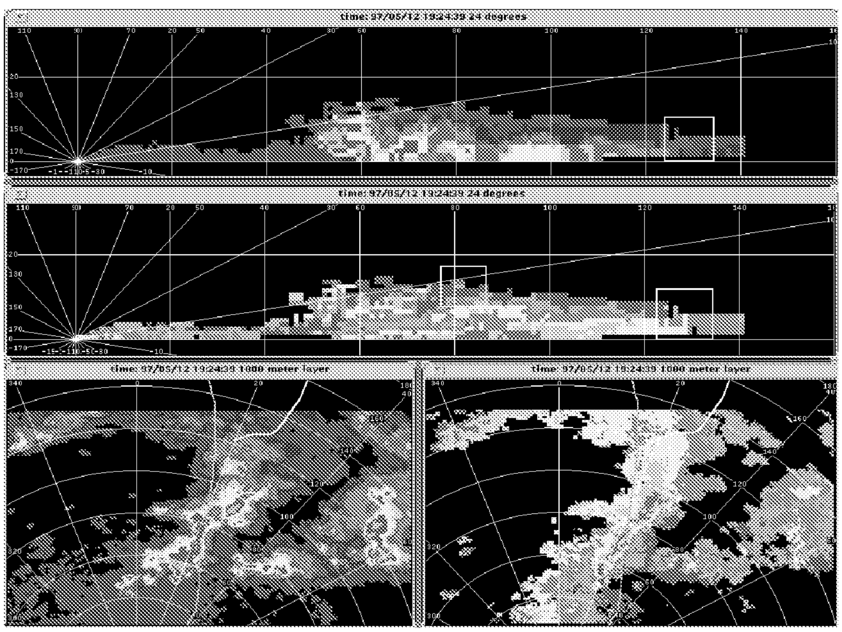
Case Study 1

- Incident along 24 degree radial at 128 nm
- Time: Approximately 10 minutes before upset
- Shear zones visible



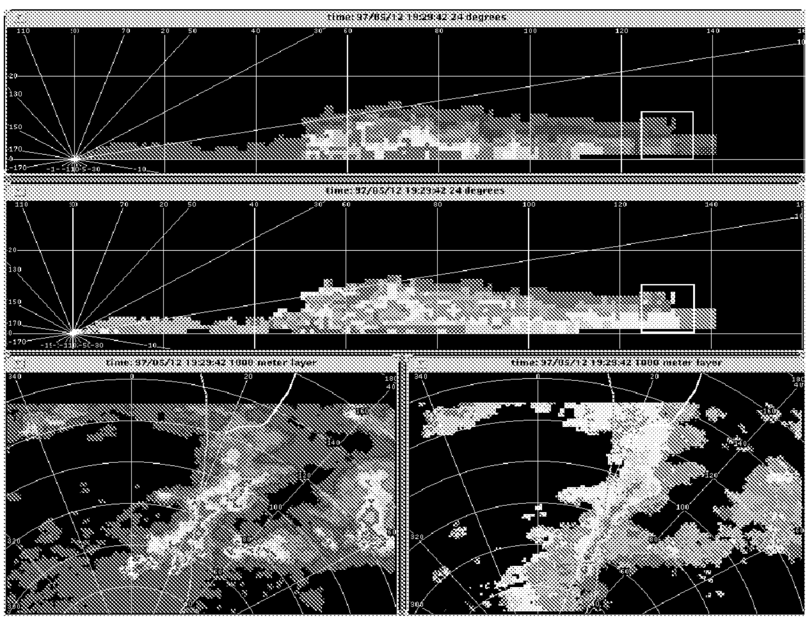
Case Study 1

- **Time: Approximately 5 minutes before upset**
- **Shear zones remain visible**



Case Study 1

- **At time of upset**
- **16.5 m/s couplet present approximately 3 km from aircraft**

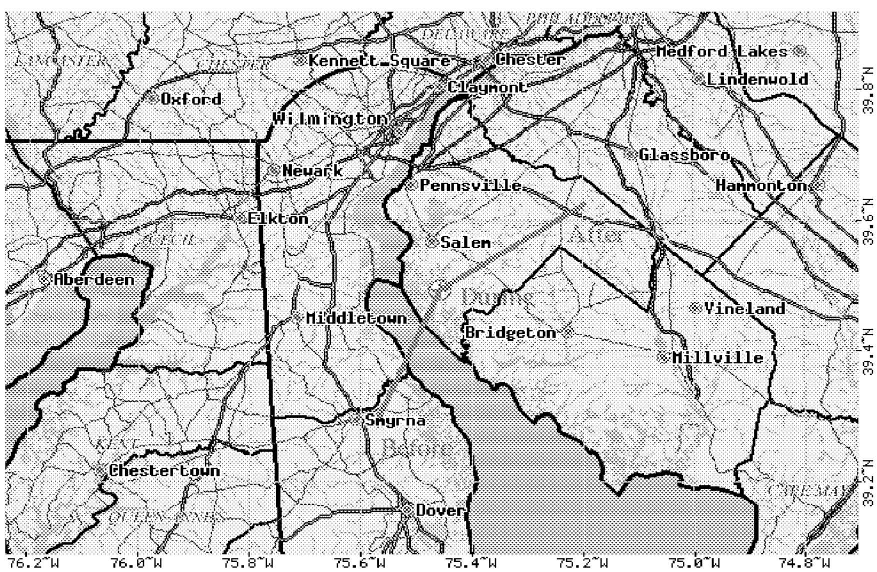


Case Study 1 Conclusions

- Aircraft was flying outside and downwind of convection
- Aircraft experienced upset indicative of severe turbulence
- Initial data revealed nothing exceptional
- Cross-sectional analysis and supporting evidence suggest a convectively induced mid-level windshear may have impacted the aircraft's flight path
- Aircrew flight control inputs were also a major factor

Case Study 2 (FOQA)

- Near Wilmington, DE
- Heading: 49.6 degrees
- Comp. airspeed: 266.0 kts
- Altitude: 7712 ft
- Auto Pilot: On
- Max G: +1.98



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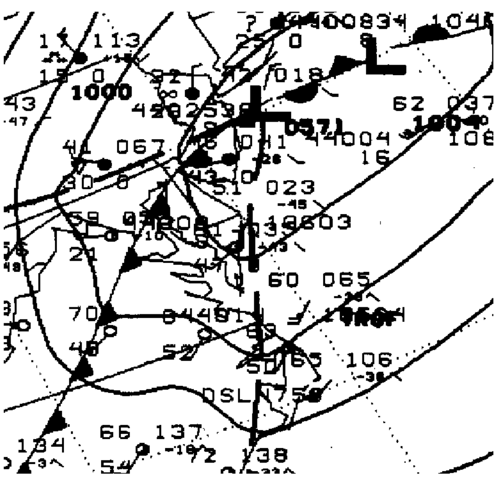
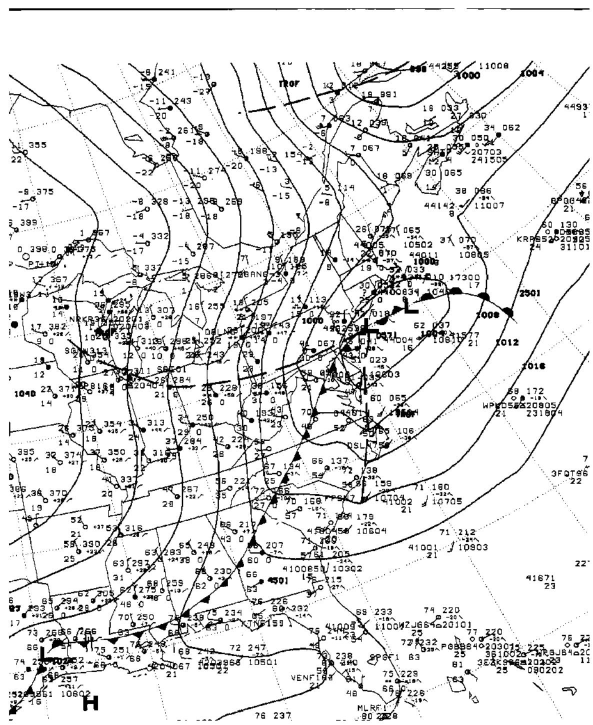
Case Study 2

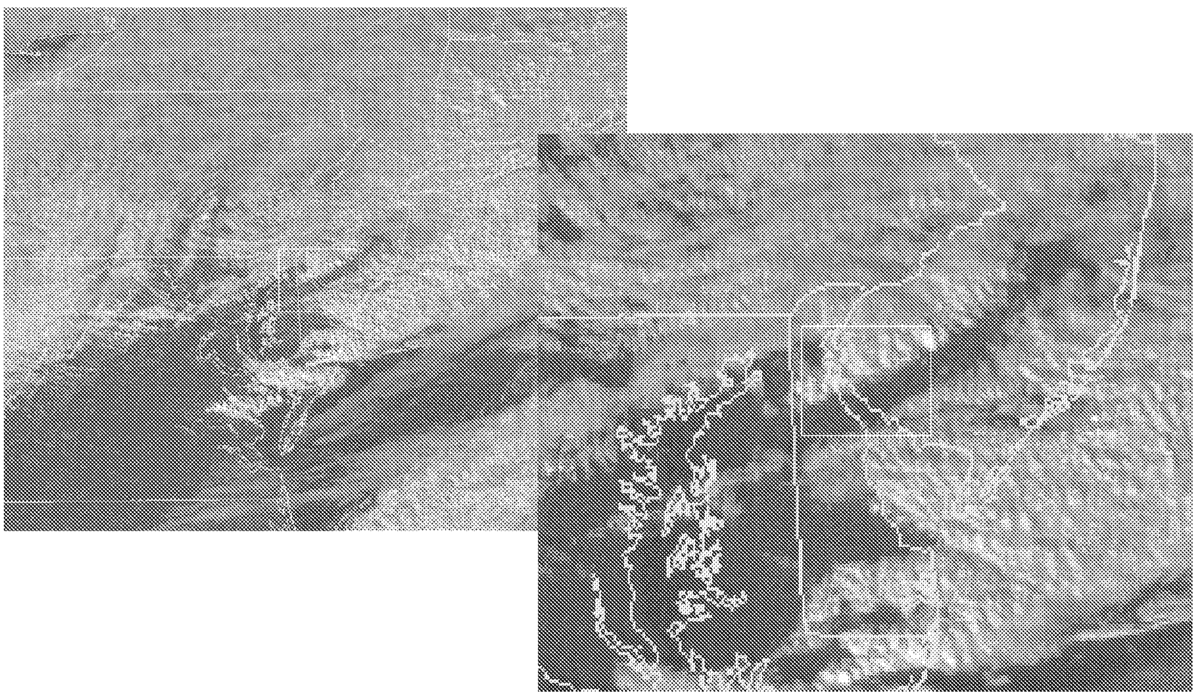
- Sfc chart at Incident - 91 min.
- Complex low off NJ coast
- Cold front/trough moving through area
- Snow and rainshowers from NE to Virginia





Case Study 2

- **Satellite images approximately 1 minute after Incident (I)**



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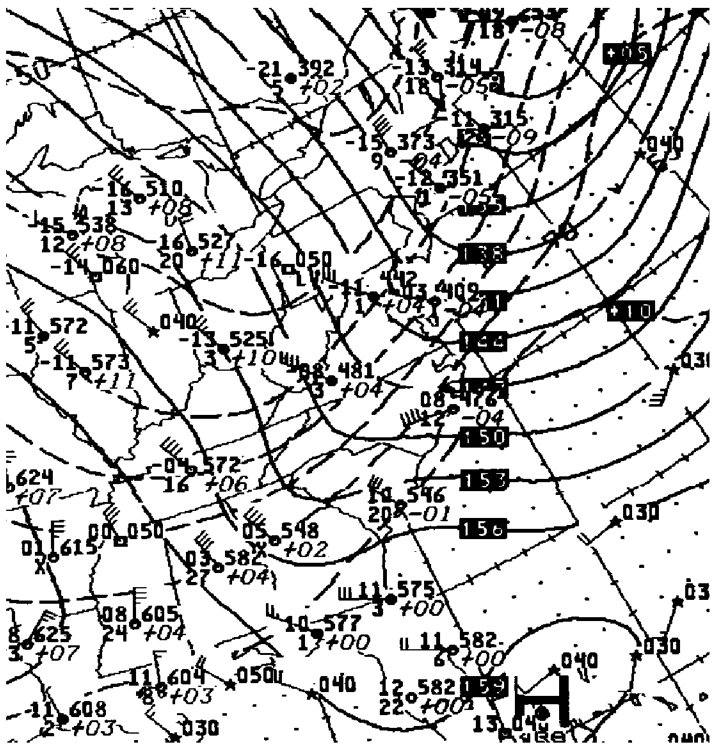
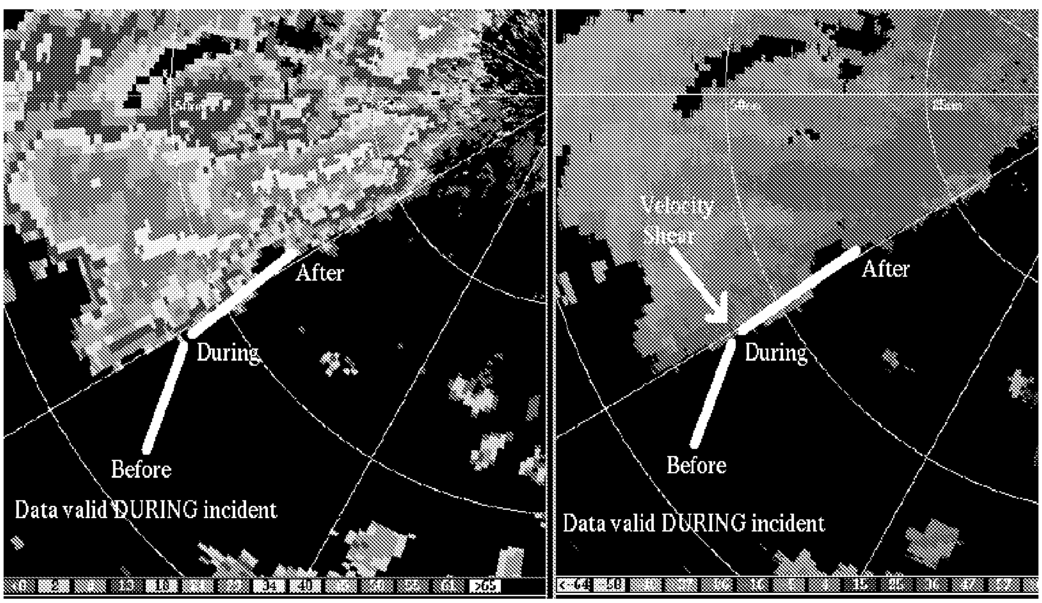
Case Study 2

- **850 mb (5000 ft) winds at I+4.5 hrs. (310/45)**
- **Trough in area**
- **Strong cold air advection**



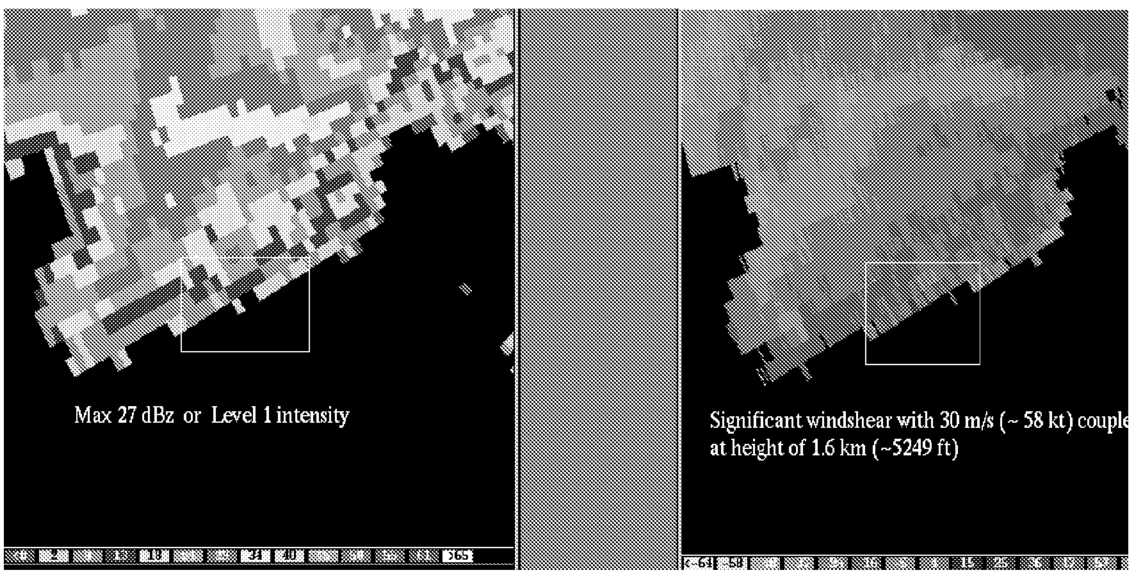
Case Study 2

- **NEXRAD reflectivity (left) and velocity (right) during Incident**



Case Study 2

- **Enlarged version of previous images during Incident**



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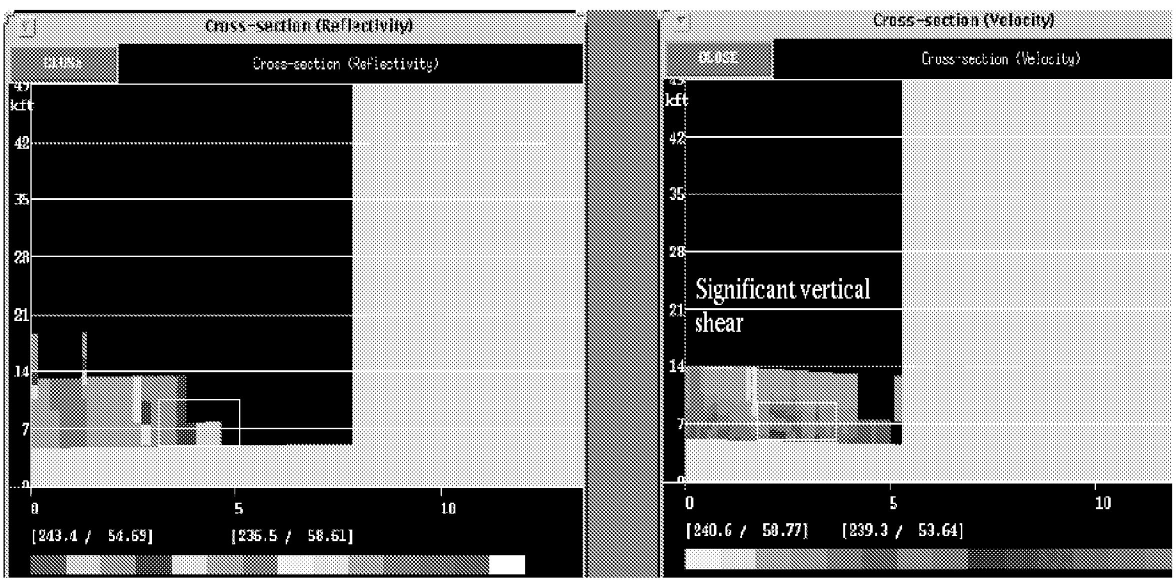
Case Study 2

- **Vertical cross section at I - 2 min.**
- **Significant velocity shear**



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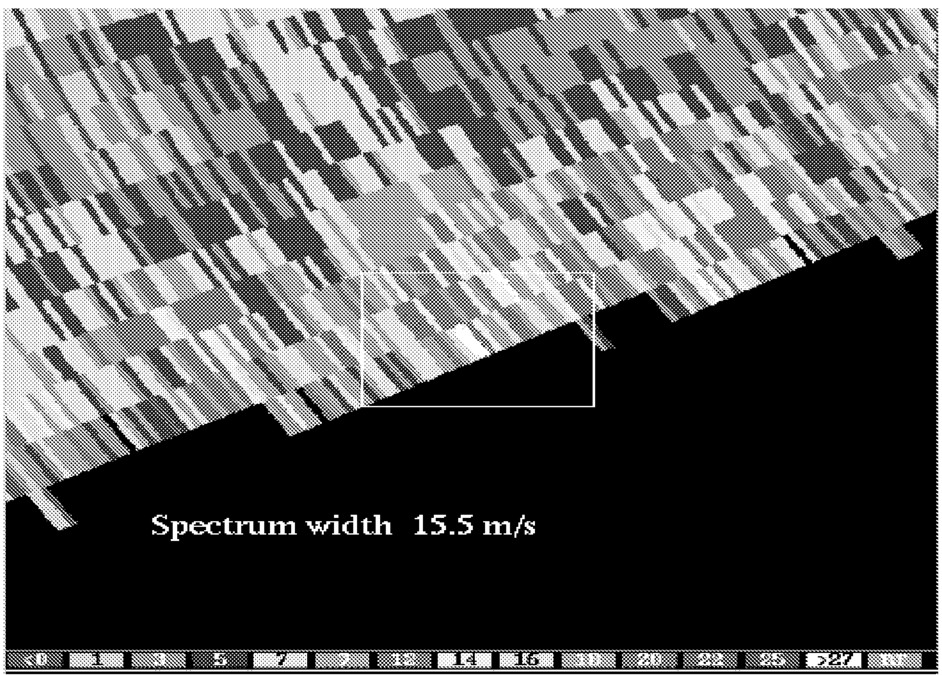
Case Study 2

- **Spectrum width value of 15.5 m/s**



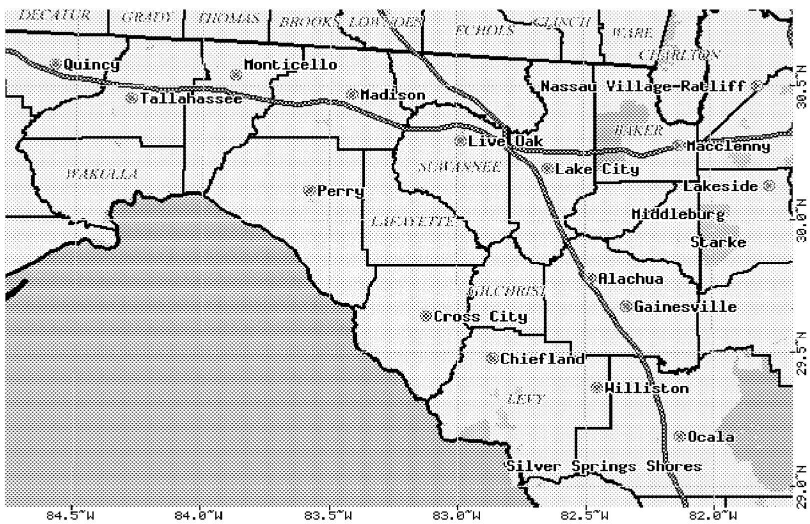
Case Study 2 Conclusions

- **Aircraft entered line of convection induced by front/trough**
- **Reflectivity values in area of 27 - 39 dBZ**
- **Small but significant velocity shear of 30 m/s present**
- **Spectrum width indications of severe turbulence**
- **Upset likely caused by penetration of boundary between line of convection (rising air) and dry slot (sinking air)**

NASA/CP—2002-210964

Case Study 3 (NTSB)

- Near Cross City, FL
- IMC at cruise altitude of FL330
- One second of moderate turbulence
- Max G: +1.75, -0.28
- One FA seriously injured, two FA and one pax - minor injuries



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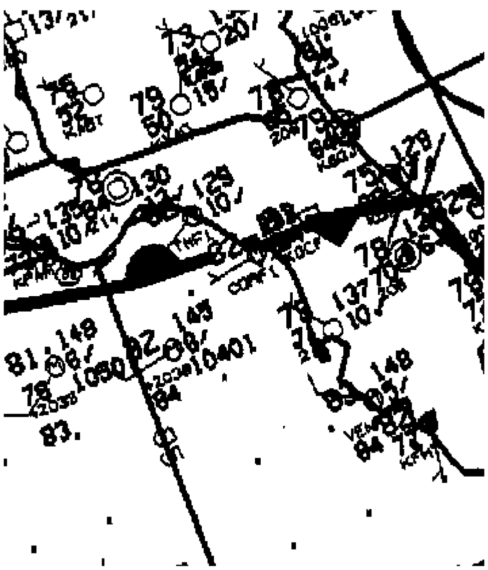
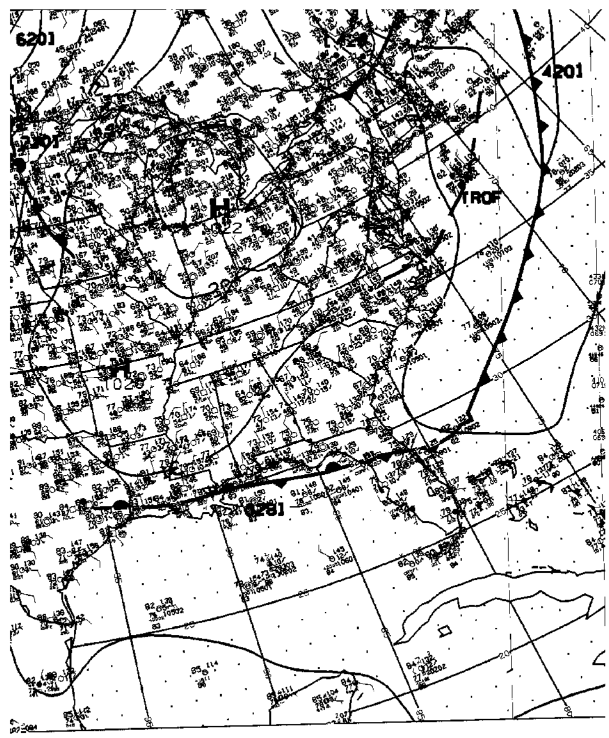
Case Study 3

- Sfc chart at I - 44 minutes
- Stationary front through area
- High temps/dew points





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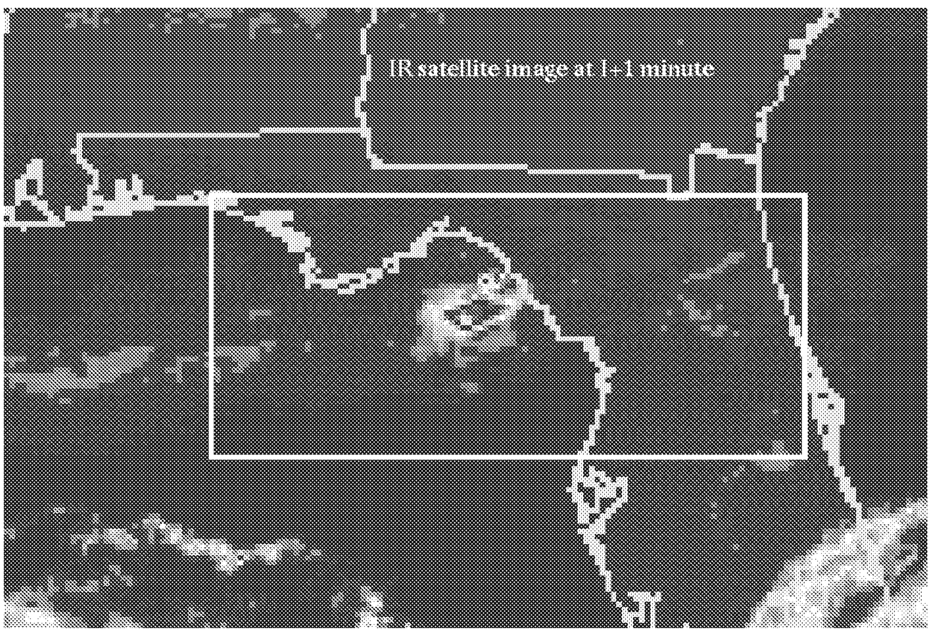
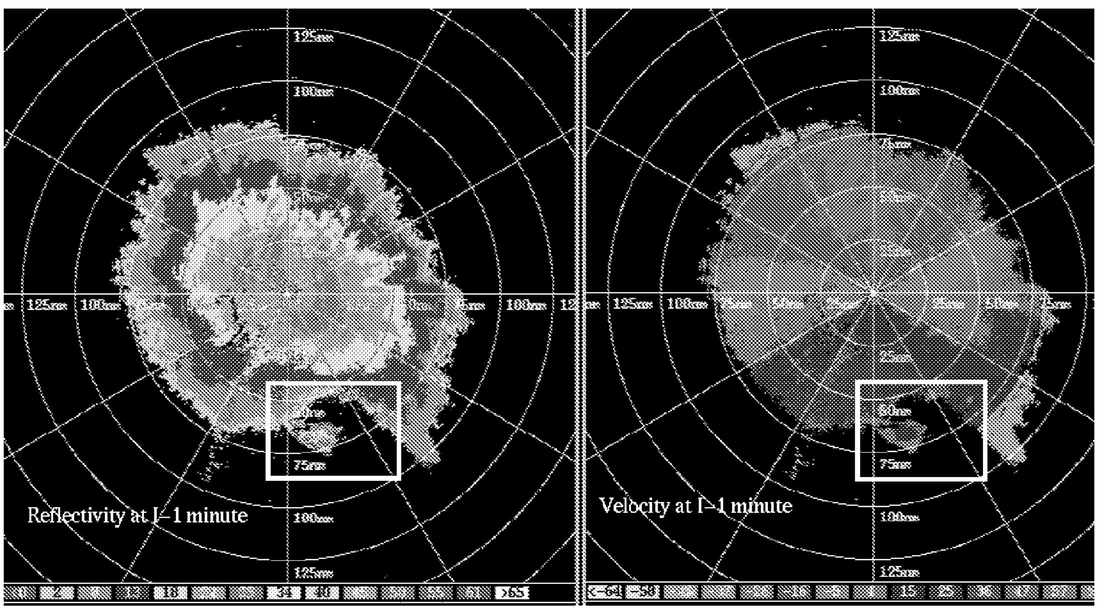
Case Study 3

- IR satellite image at I + 1min



Case Study 3

- **Level 5 thunderstorm just west of aircraft 1 min <u>before</u> upset**
- **Rapid motion to southeast**



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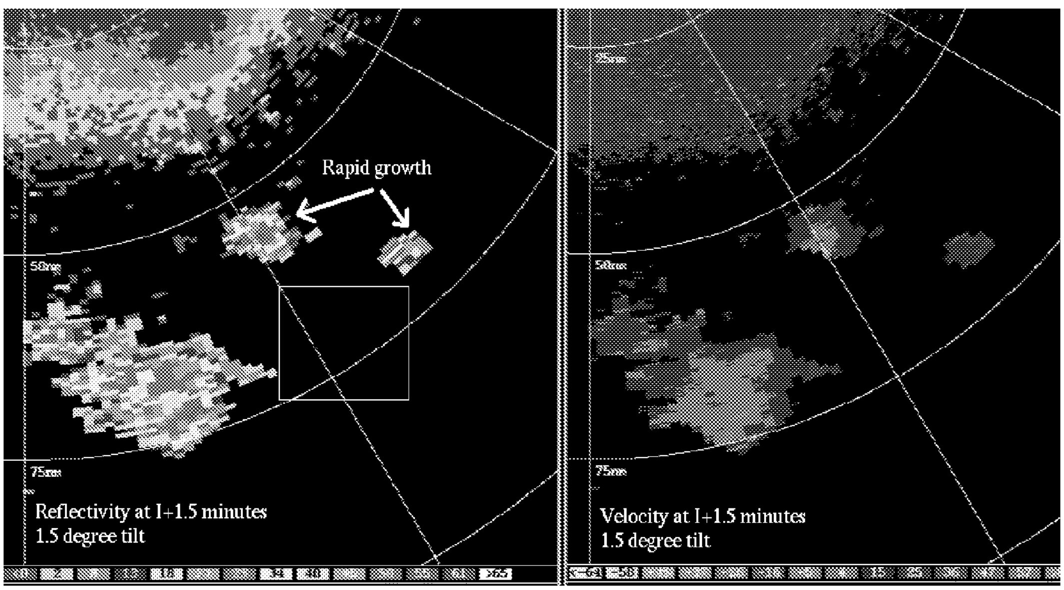
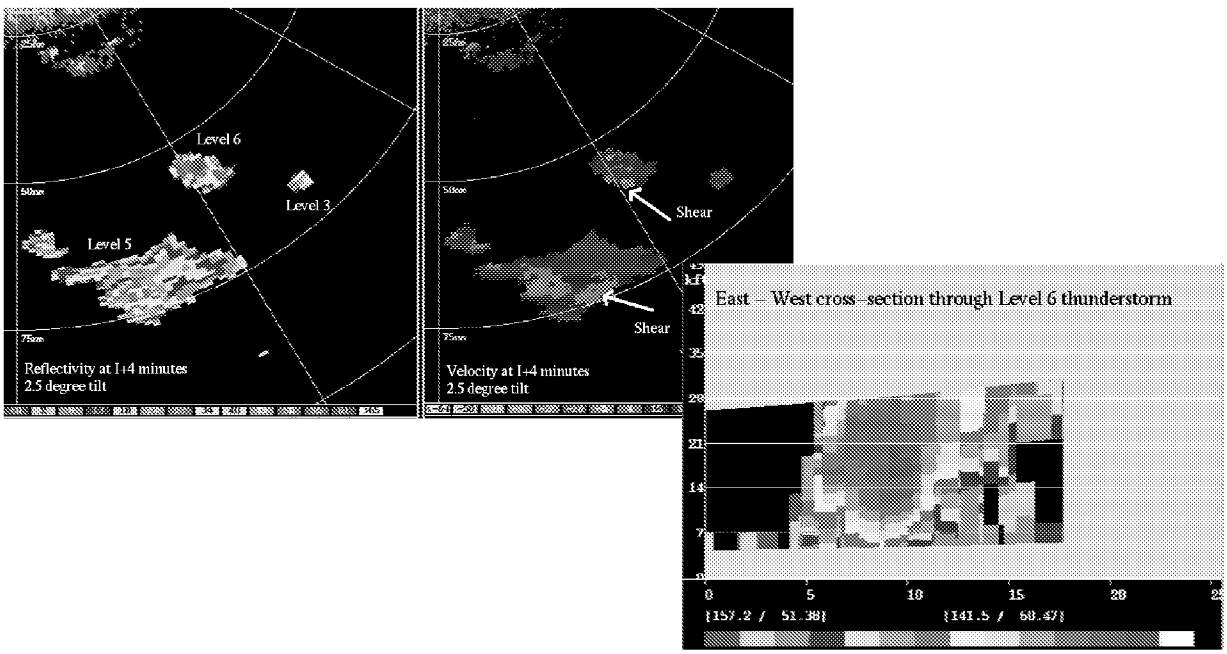
Case Study 3

- New thunderstorms at 1.5 minutes <u>after</u> upset to N and NE
- Confirmed by pilot



Case Study 3

- **Upper level shear noted in both major storms at I + 4 min.**
- **Max shear of 16.5 knots**



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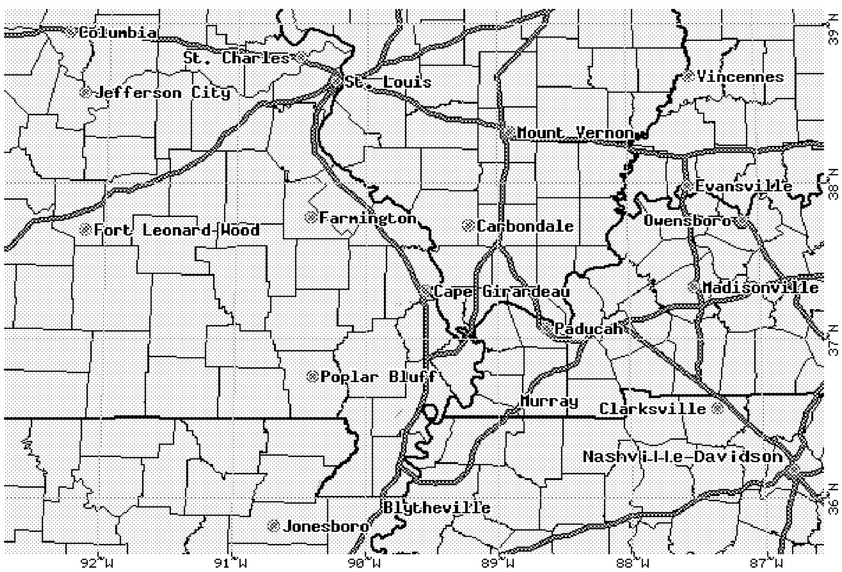
Case Study 3 Conclusions

- Original level 5 thunderstorm produced outflow
- Explosive secondary growth, especially at mid-levels
- Level 6 thunderstorm in area likely produced upset

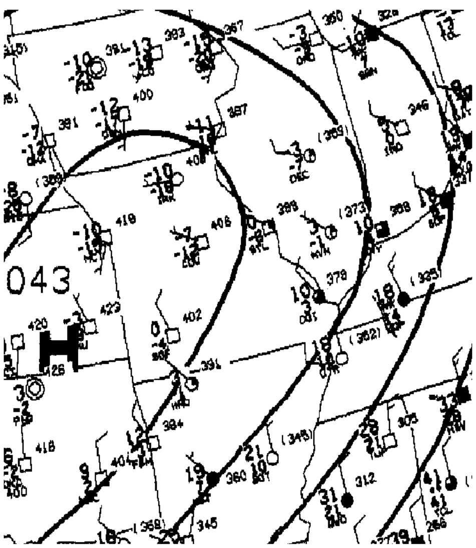
Case Study 4 (NTSB)

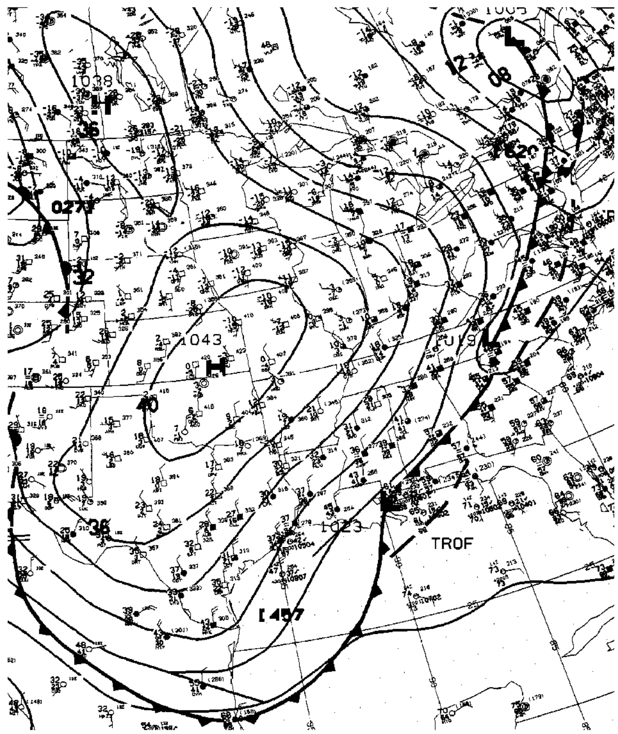
- Near Cape Girardeau, MO
- Initial descent from FL230
- "Intense" turbulence for 30 sec
- Max G: +2.5, -0.79
- Two FA hurt, one seriously



Case Study 4

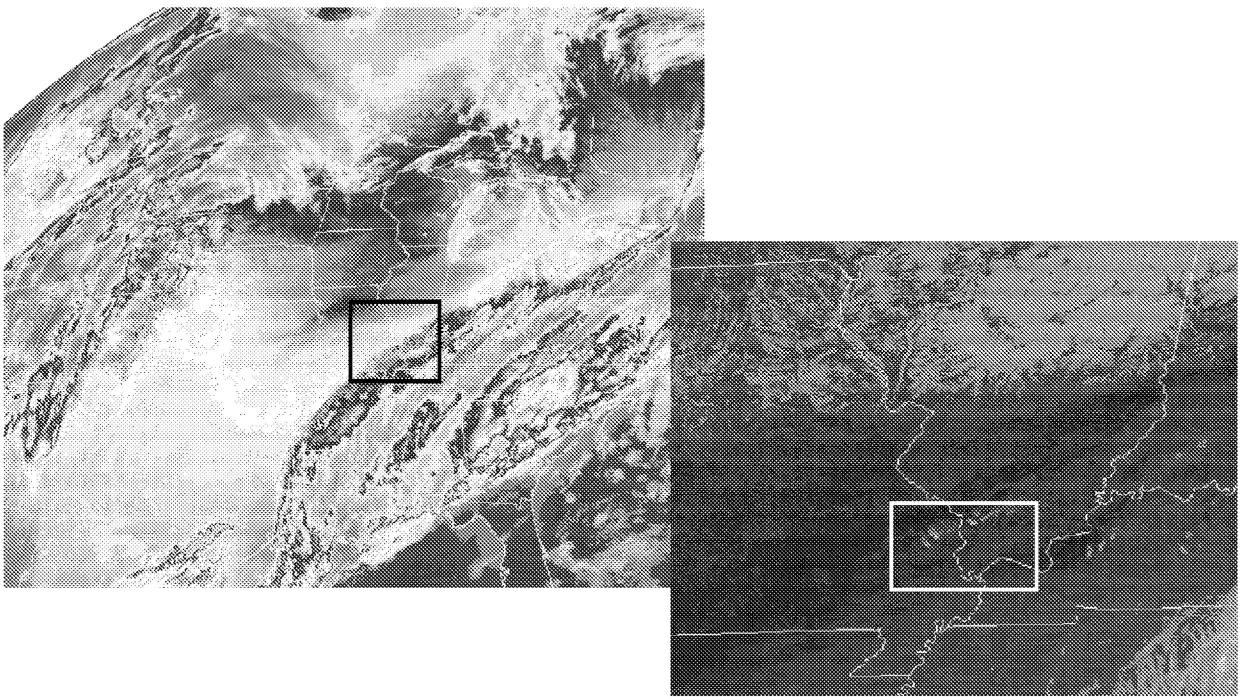
- **Sfc chart at I + 10 minutes**
- **Strong surface high over KS/MO**
- **Fair weather in area**





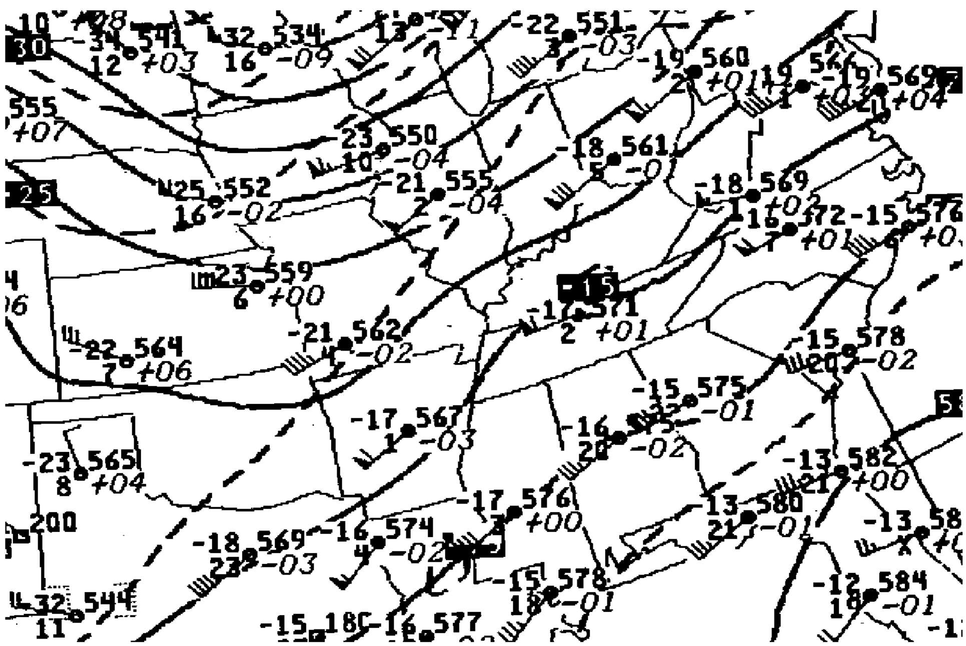
Case Study 4

- **Satellite images at I - 5 minutes**



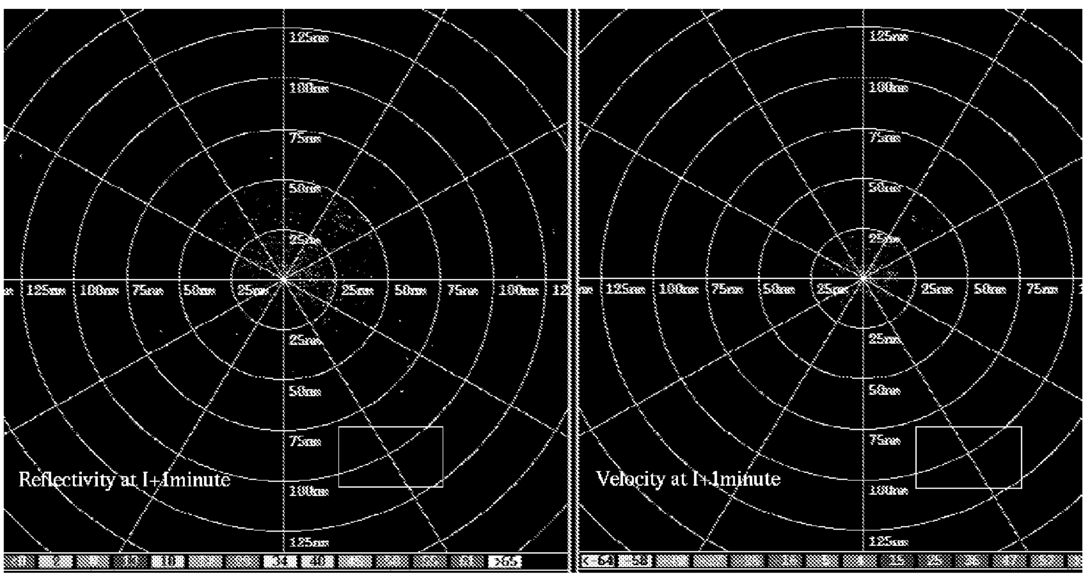
Case Study 4

- **500 mb (18,000 ft) winds at I - 4 hours (250/55 kts)**



Case Study 4

- **NEXRAD data 1 minute after upset**
- **No significant returns**

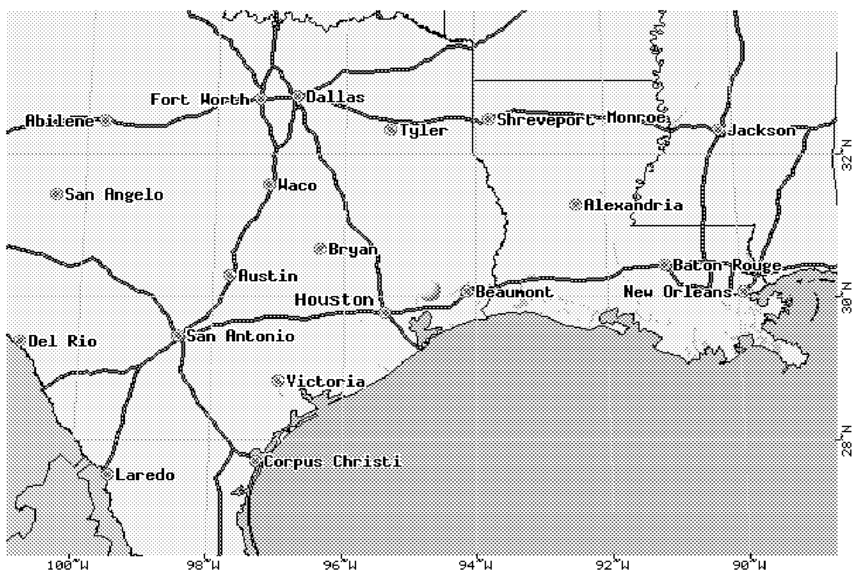


Case Study 4 Conclusions

- **Aircraft likely experienced severe CAT associated with jet stream and converging winds at altitude.**

Case Study 5 (FOQA)

- Near Houston, TX
- Heading 179.8 degrees
- Comp. airspeed: 232.0 kts
- Altitude: 7648 ft
- Auto Pilot: On/Off
- Max G: +1.74



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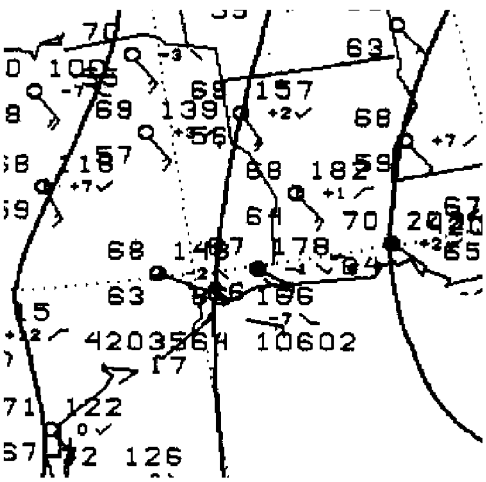
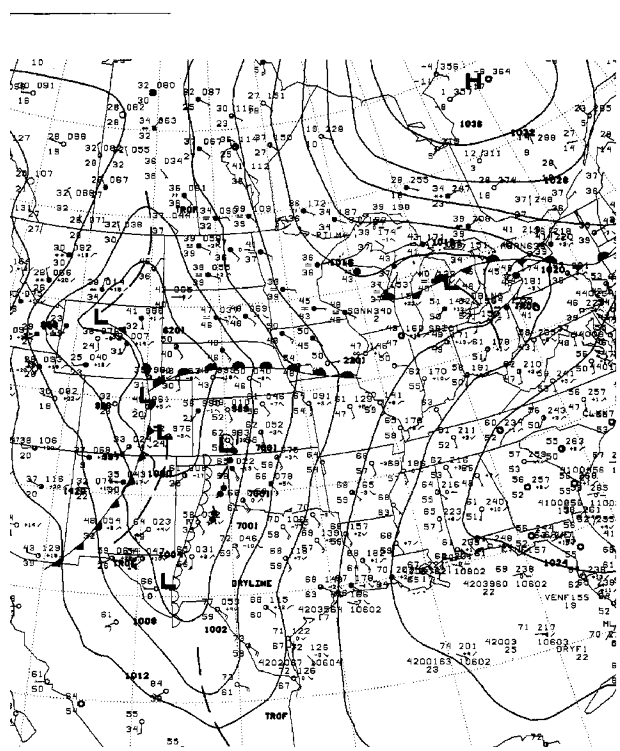
Case Study 5

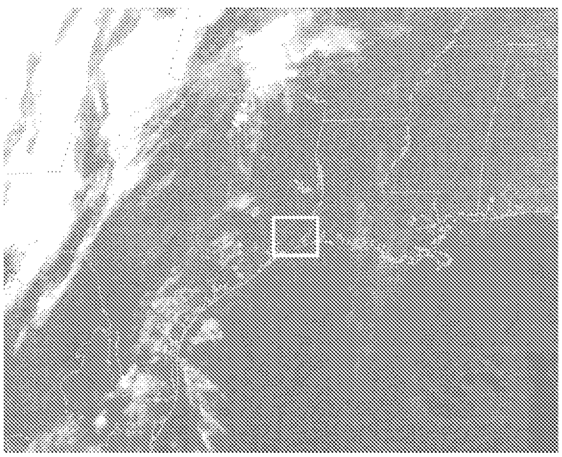
- Sfc chart at I - 1 minute
- Large high off mid-Atlantic
- Cold front exiting Rockies
- Dry line in west Texas
- No sig wx in airspace

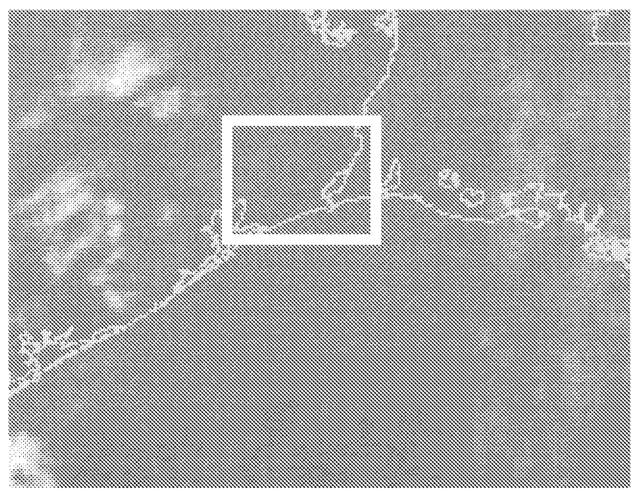




Case Study 5

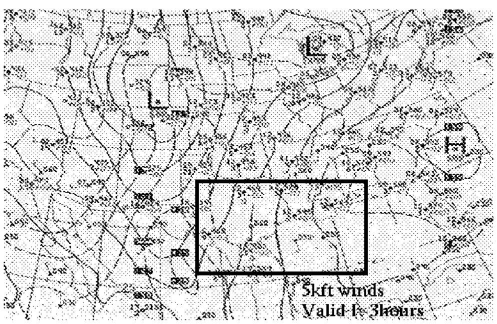
- **IR satellite images taken at I - 16 minutes**

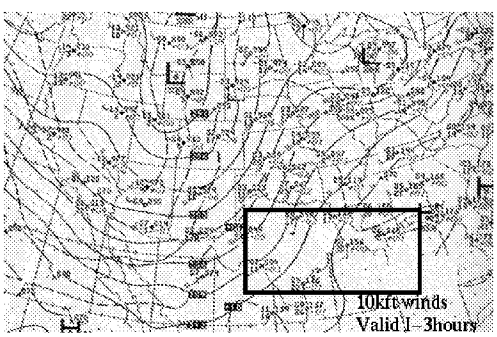


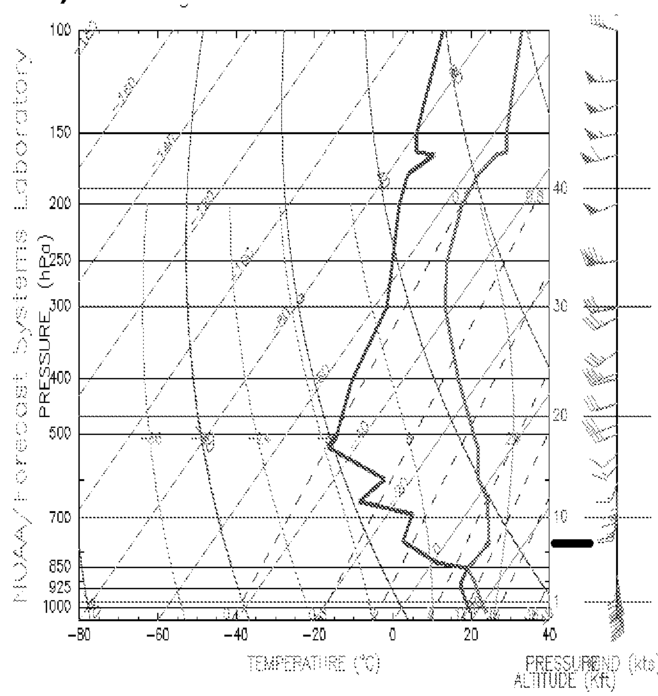


Case Study 5

- **Upper air charts at 850 and 700 mb at I - 3 hours**
- **Vertical profile at I - 3 hours (LCH)**







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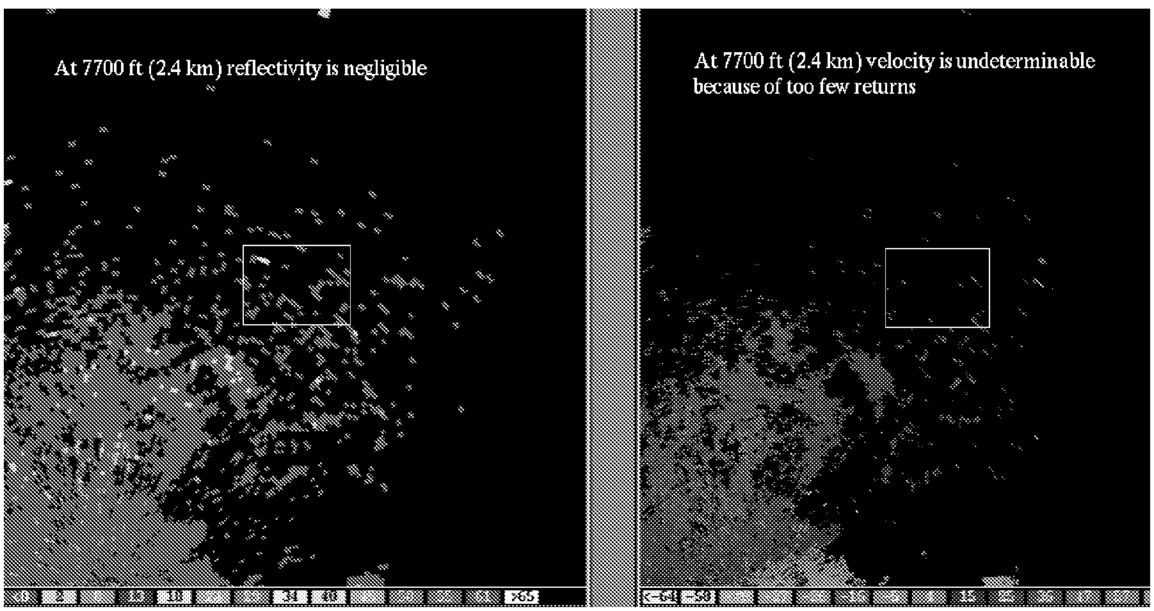
Case Study 5

- NEXRAD data at I + 1 minute
- Normal clear air returns



Case Study 5 Conclusions

- Deep convection / thunderstorms ruled out
- Aircraft heading directly into warm / moist southerly flow
- At or just above cloud deck
- Possible wind surge not detectable in radar data

Overall Conclusions

- **Wide range of causes for in-flight turbulence from convection to the jet stream**
- **Upsets can be captured by DFDR data but explanations may remain elusive**
- **High resolution data can assist in determining cause in many instances**
- **Pilots should continue to adhere to well known thunderstorm and CAT avoidance rules-of-thumb.**

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Future Work

- **Automated turbulence detection needs to integrate:**
  - ground and airborne radar
  - thermodynamic and wind profiles
  - satellite data

- **Systems to warn of turbulence using airborne radars need to use winds aloft information to determine region of hazard "down wind" of convective cells (Case 1)**

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Future Work

- **Fast update information sensors/systems needed to avoid rapidly developing convective cells (Case 3)**
  - **ASR9 and ARSR4 (Corridor Integrated Weather System)**
  - **High update rate convective initiation forecasts**

- **Convective forecast algorithms can facilitate convective turbulence avoidance**
  - **Terminal Convective Weather Forecast (TCWF)**
  - **Regional Convective Weather Forecast (RCWF)**
  - **National Convective Weather Forecast (NCWF)**

NASA/CP—2002-210964

Weather Associated with the Fall-2000 Turbulence Flight Tests

David W. Hamilton and **Fred H. Proctor**

NASA Langley Research Center

Hampton Virginia

Session: Airborne Turbulence Warning System
Weather Accident Prevention Annual Project Review
5-7 June 2001, Cleveland, Ohio

Outline

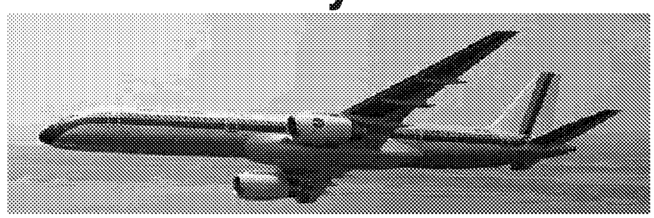
- Introduction
- Flight Experiments
  - Equipment for turbulence detection
  - Flight requirements
  - Flight preparations
- Turbulence Metrics
- Research Flights
- Summary

Turbulence Threat

- Sudden, unexpected encounters with turbulence, usually lasting 10-30 seconds, have led to frequent injuries aboard commercial aircraft
- A recent study of 44 turbulence encounters resulting in injuries:
  - 82% were found to be near or within convective activity
  - Mountain wave (2%), CAT (16%)

Flight Experiments

- **NASA-Langley's ARIES B-757 flew into regions favorable for convectively-induced turbulence**



- **ARIES equipment**
  - ***In situ* sensors measure wind, temperature and acceleration**
  - **Onboard Doppler radar for forward turbulence detection**

- **Data collected for events ranging from smooth air to severe turbulence**

Flight Requirements

- **Flight days were chosen based on likelihood of convectively-induced turbulence within flight range of NASA Langley**
  - **Test days limited by availability of B-757**
- **Altitudes of interest: between 18,000 and 40,000 ft**
- **Direct penetration into regions with Level 3 radar reflectivity were avoided**

Flight Preparations

- **Meteorology team at NASA-Langley prepared: 2-day, 1-day, and day-of forecasts in support of flight tests**
  - Brief researchers
  - Brief pilots for flight planning
- **Products Used:**
  - NCEP models, i.e. RUC, ETA, etc.
  - NC State's operational mesoscale model
  - Airmets, Pireps, NCAR's ITFA
  - Satellite and Radar
- **Meteorologist on board provided guidance into turbulent regions**

Turbulence Metrics

- **Quantification of *in situ* turbulence:**
  - Root mean square of normal load acceleration: $\sigma_{\Delta n}$
  - Eddy dissipation rate: $\varepsilon^{1/3}$

- **Defined a significant turbulence event as:**

  $$\sigma_{\Delta n} > 0.15$$

  - $\sigma_{\Delta n} > 0.20$ moderate
  - $\sigma_{\Delta n} > 0.30$ severe

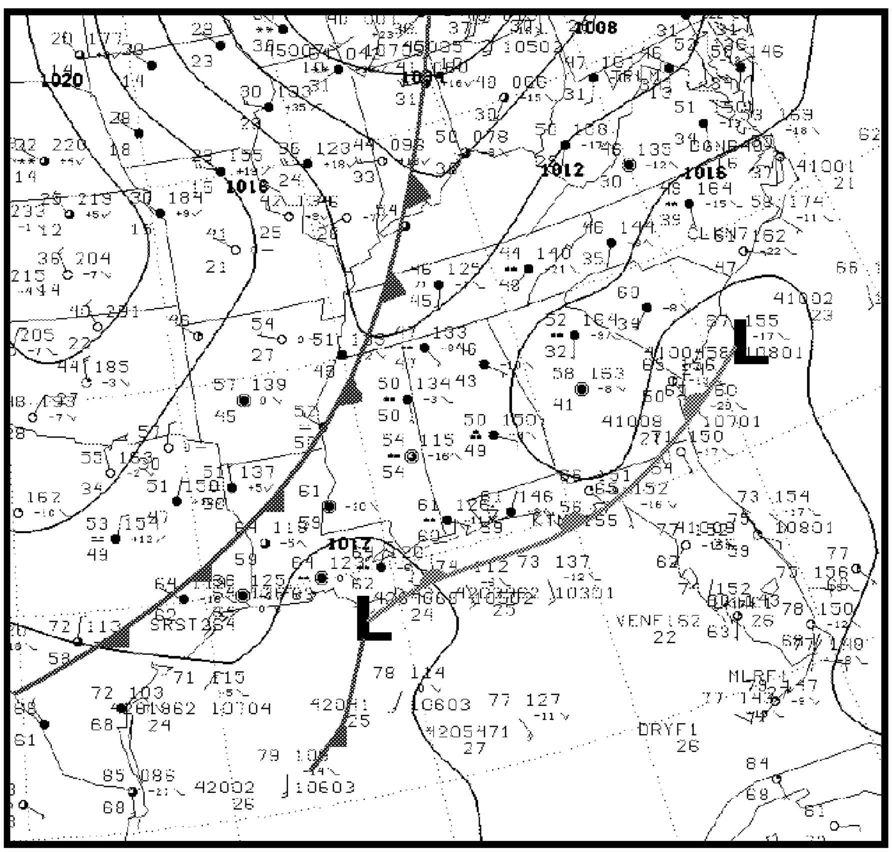
The Flight Experiments

- R-181, November 16, 2000
  - most events having levels below threshold for moderate turbulence
- R-190, December 13, 2000
  - severe turbulence; similar to NTSB accident accounts
- R-191, December 14, 2000
  - strongest encounter of the season; encounters with storm tops.

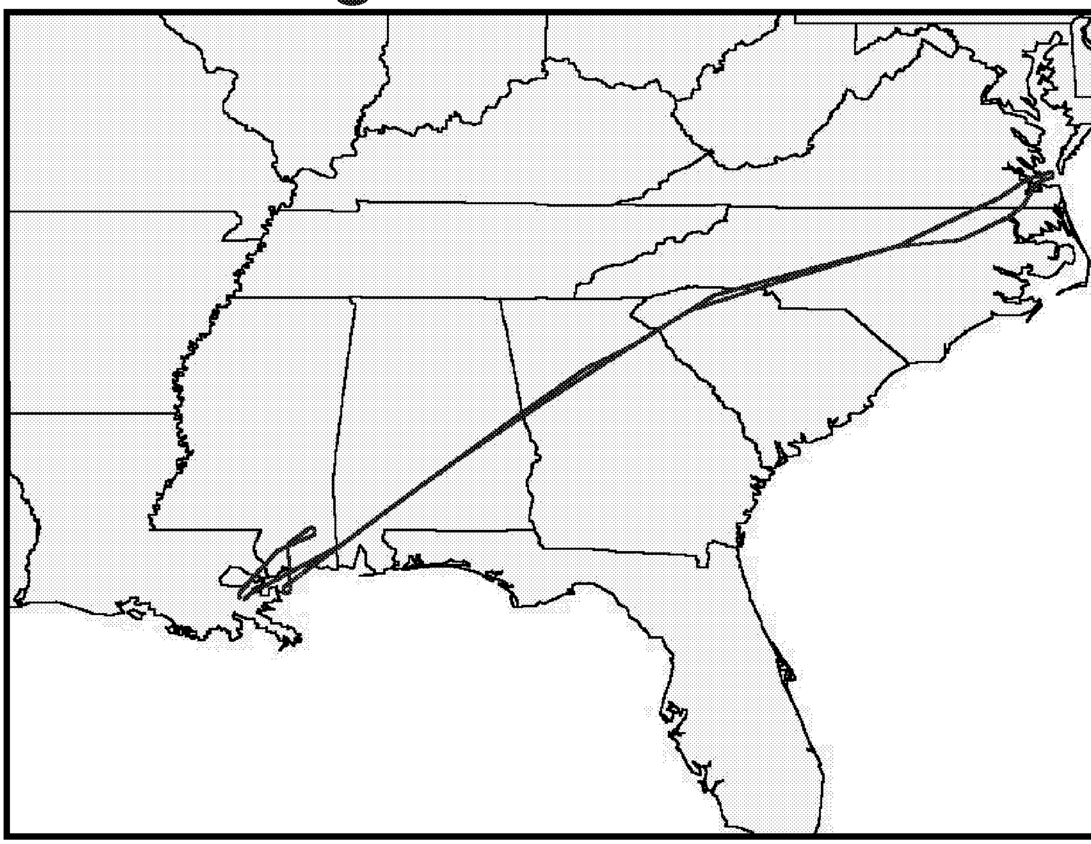
R 181 – Nov 16, 2000

- **Mississippi-Louisiana Gulf Coast region favorable for convective turbulence**
- **Broad overrunning of rain with embedded convective cells**
  - **Peak storm top: 30,000 *ft***
  - **Cell movement: from west-southwest at 45 *kts***
- **3 significant turbulence events with peak *in situ* measurement:**
  - $\sigma_{\Delta n} = 0.21$
  - $\varepsilon^{1/3} = 0.25$

21 UTC Surface Analysis
Nov 16, 2000

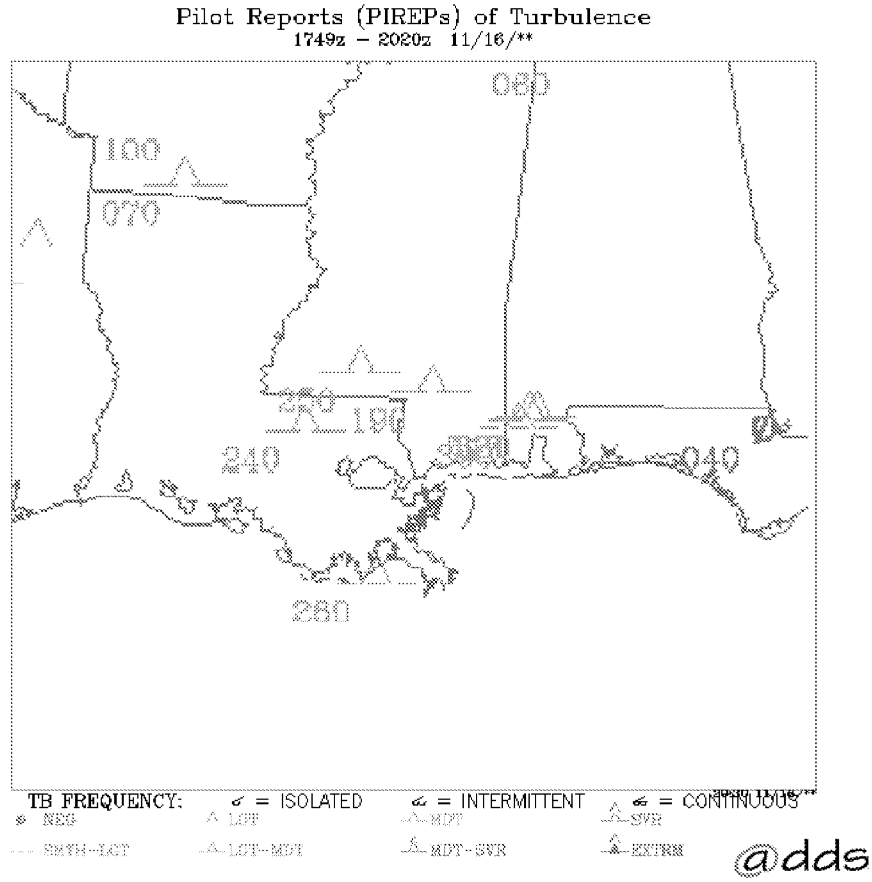


Flight Path for 181

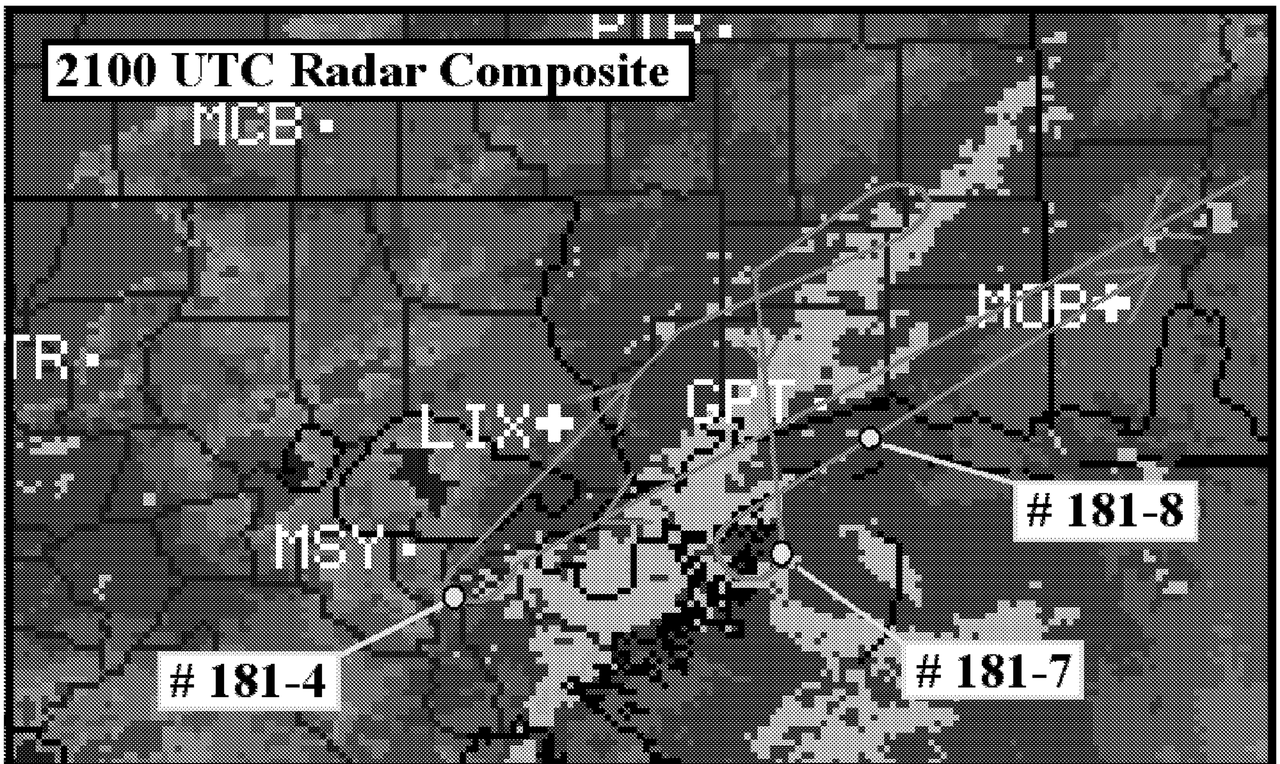


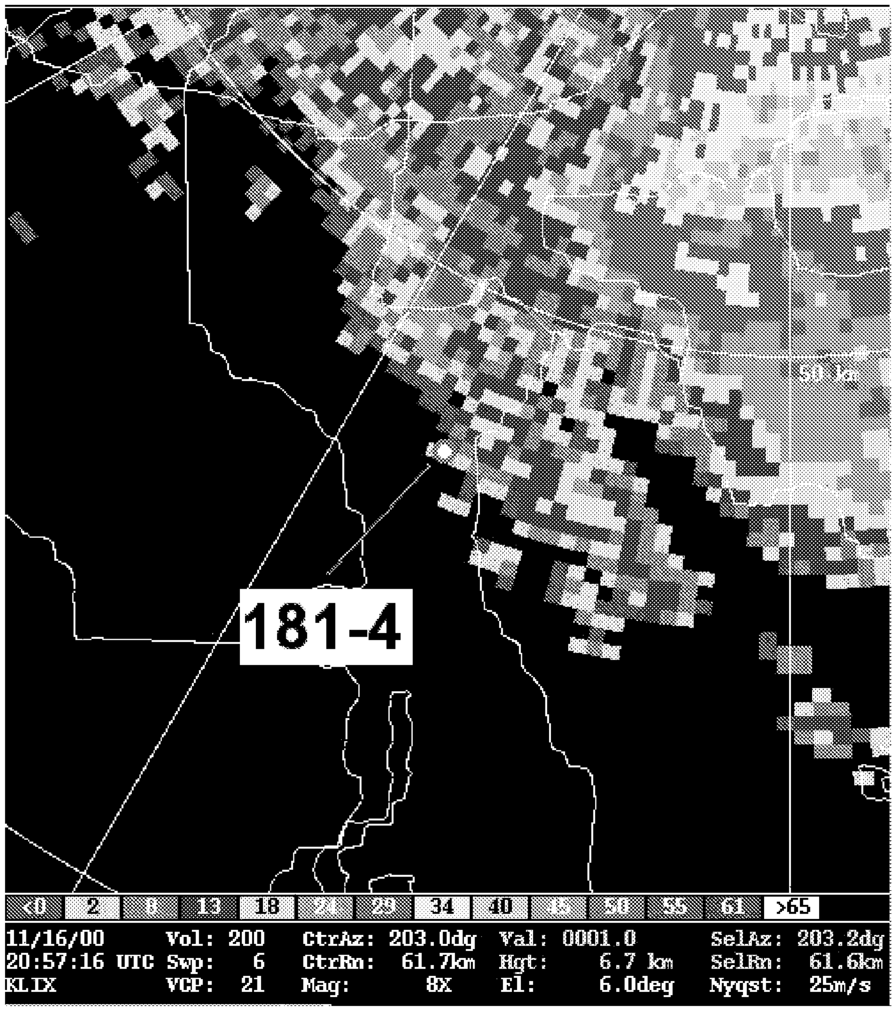
Reported PIREPS on Nov. 16, 2000

1749 – 2020 UTC



Flight 181 – Path with Nowrad

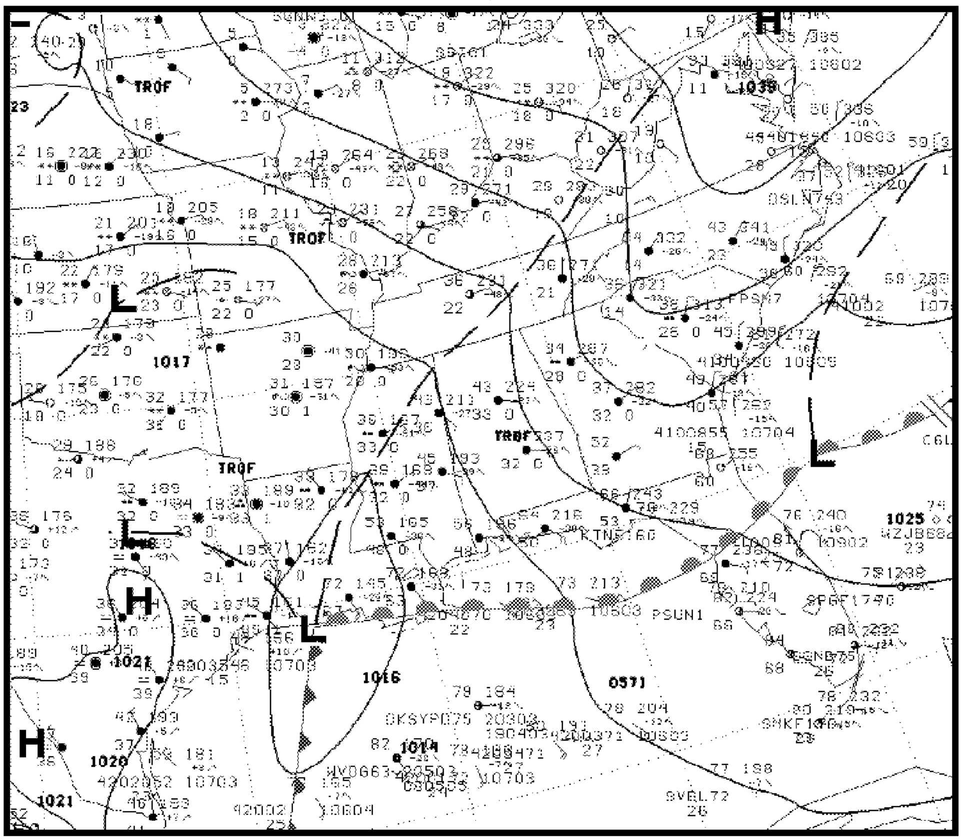


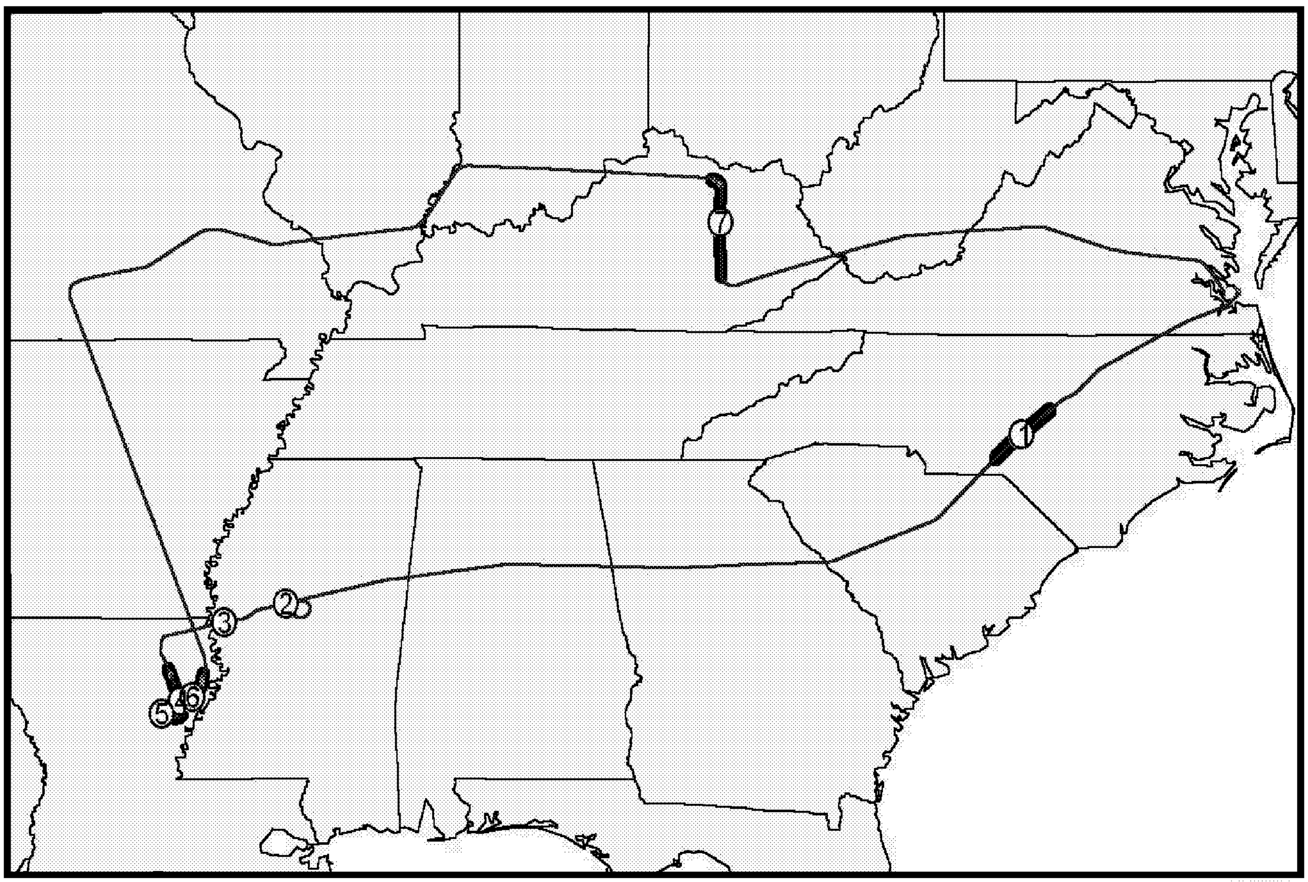

181-4
50 km
<0 2 8 13 18 24 29 34 40 45 50 55 61 >65
11/16/00 Vol: 200 CtrAz: 203.0dg Val: 0001.0 SelAz: 203.2dg
20:57:16 UTC Swp: 6 CtrRn: 61.7km Hgt: 6.7 km SelRn: 61.6km
KLIX VCP: 21 Mag: 8X El: 6.0deg Nyqst: 25m/s

R – 190 December 13, 2000

- **Along Gulf Coast; convective turbulence experienced in Central Mississippi and NE Louisiana**
- **Broad overrunning area of rain and convective cells with embedded thunderstorms**
  - Peak storm tops: 43,000 *ft*
  - Cell movement: from southwest at 65 *kts*
- **2 significant turbulence events with peak *in situ* measurement:**
  - $\sigma_{\Delta n} = 0.35$
  - $\varepsilon^{1/3} = 0.47$

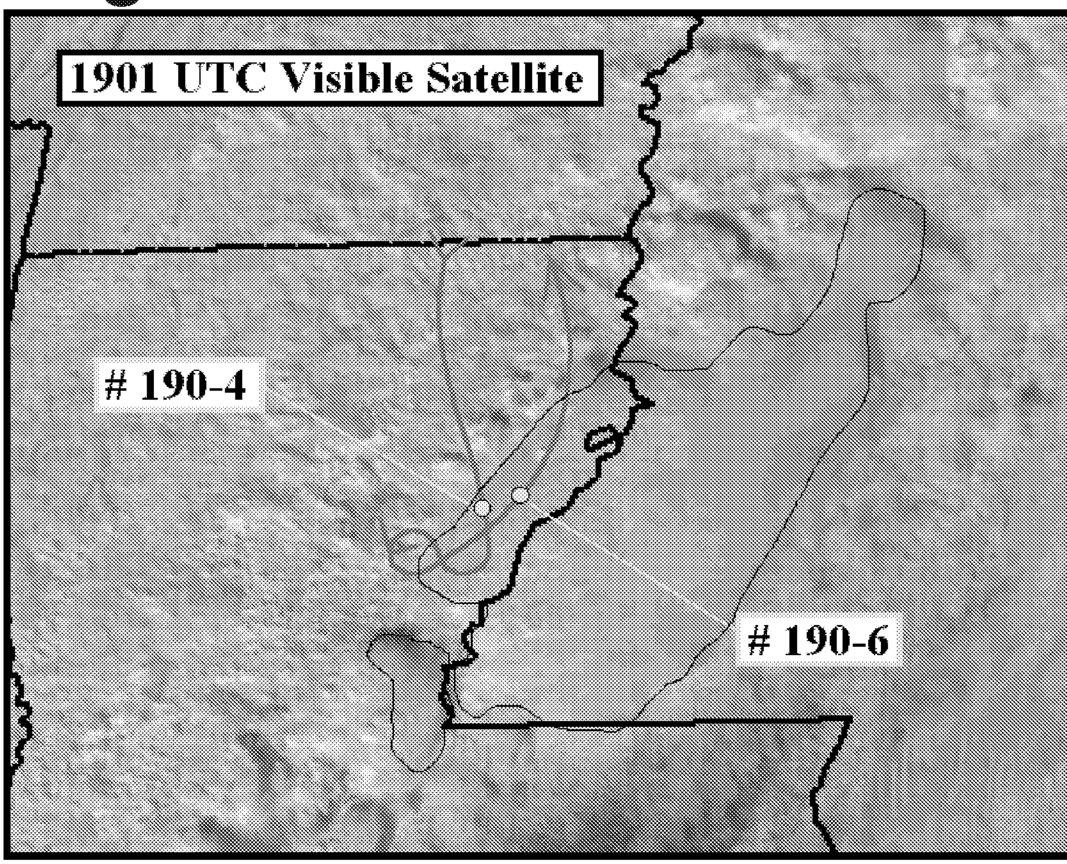
18 UTC Surface Analysis
Dec 13, 2000



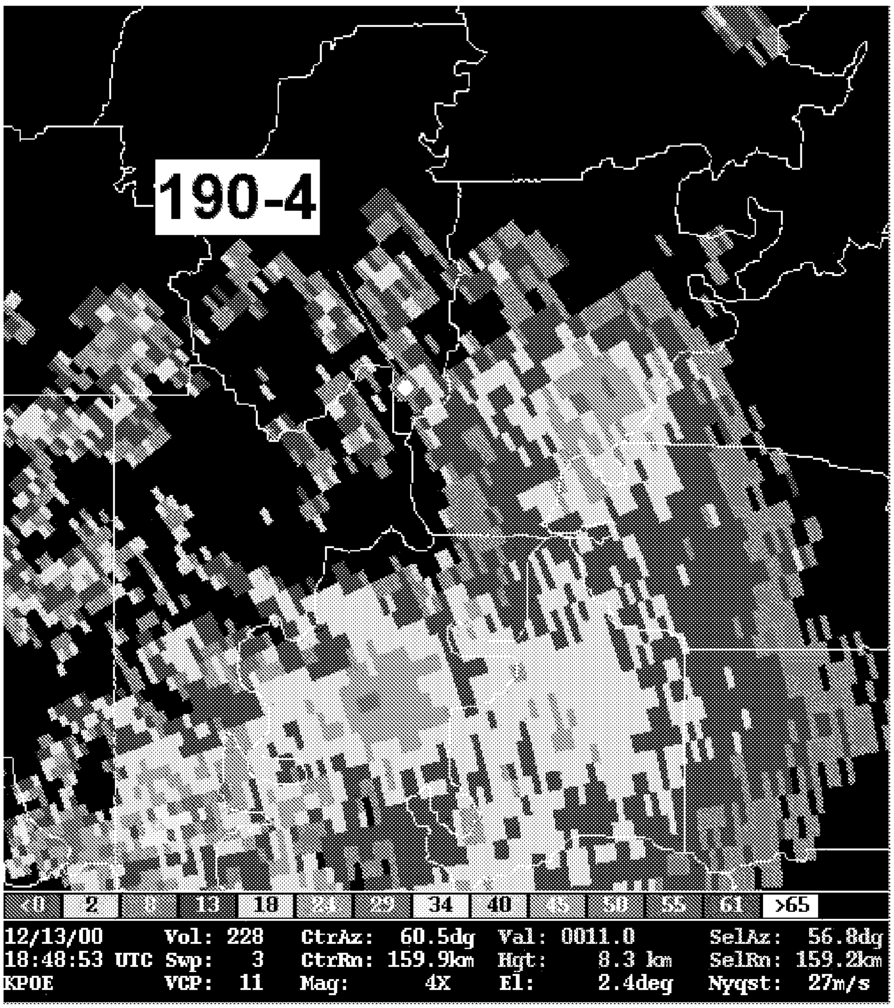


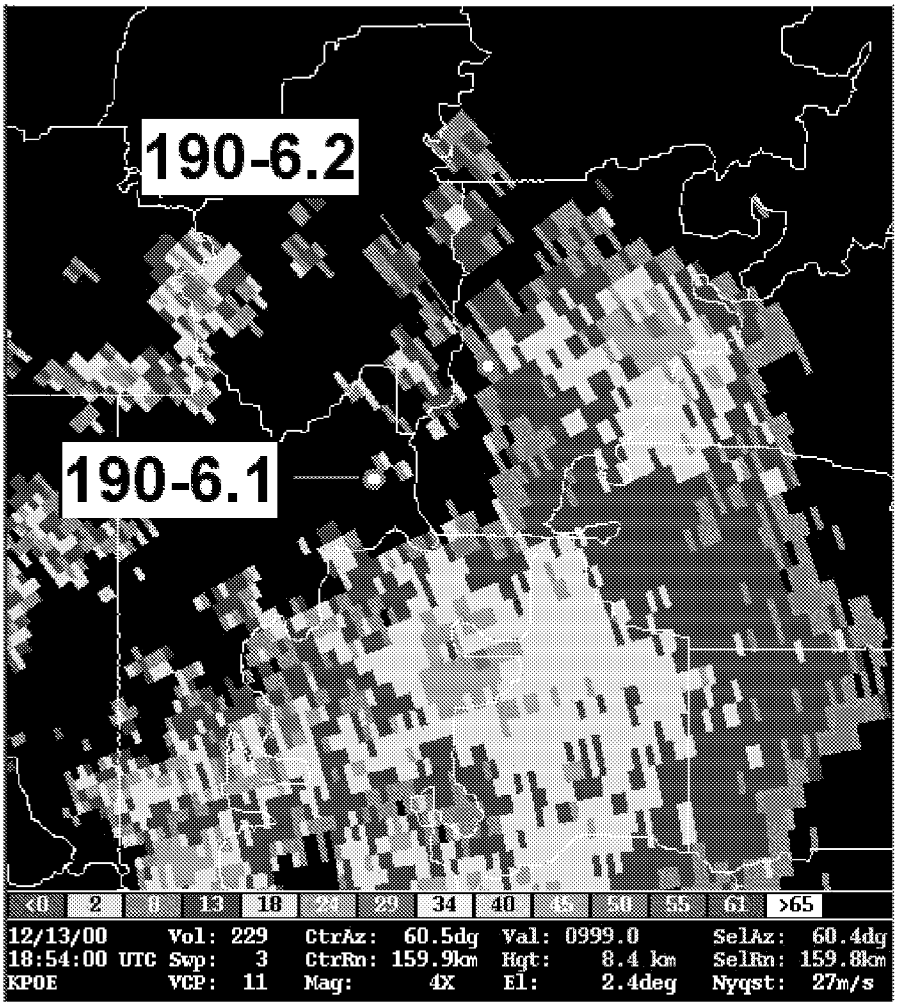
Flight 190 Dec. 13, 2000

Flight 190 – Path with Satellite



On Edge of Convection

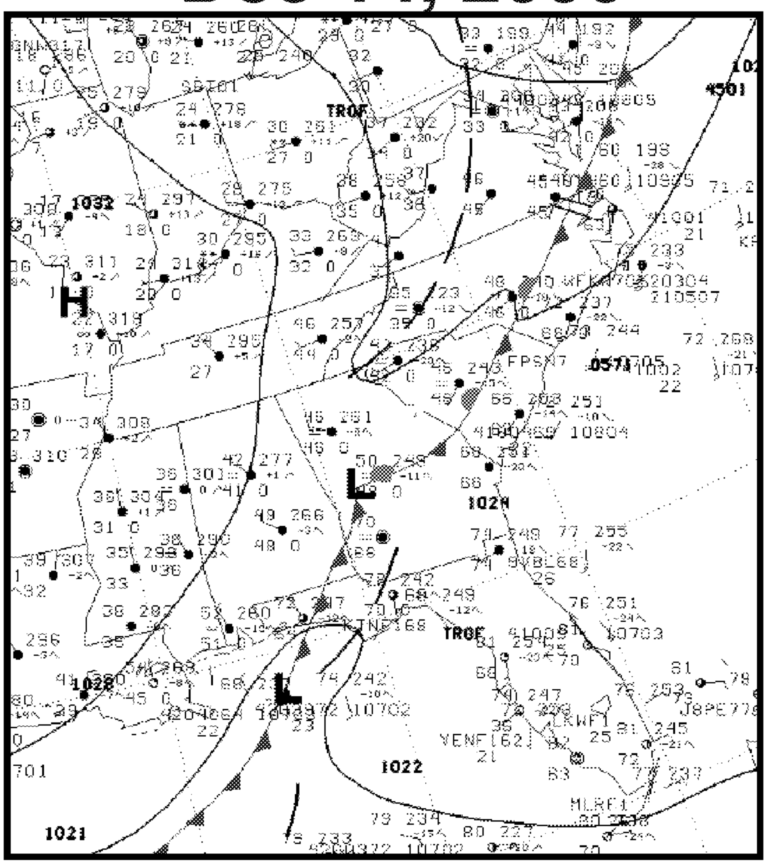

190-4
<0 2 8 13 18 24 29 34 40 45 50 55 61 >65
12/13/00 Vol: 228 CtrAz: 60.5dg Val: 0011.0 SelAz: 56.8dg
18:48:53 UTC Swp: 3 CtrRn: 159.9km Hgt: 8.3 km SelRn: 159.2km
KPOE VCP: 11 Mag: 4X El: 2.4deg Nyqst: 27m/s

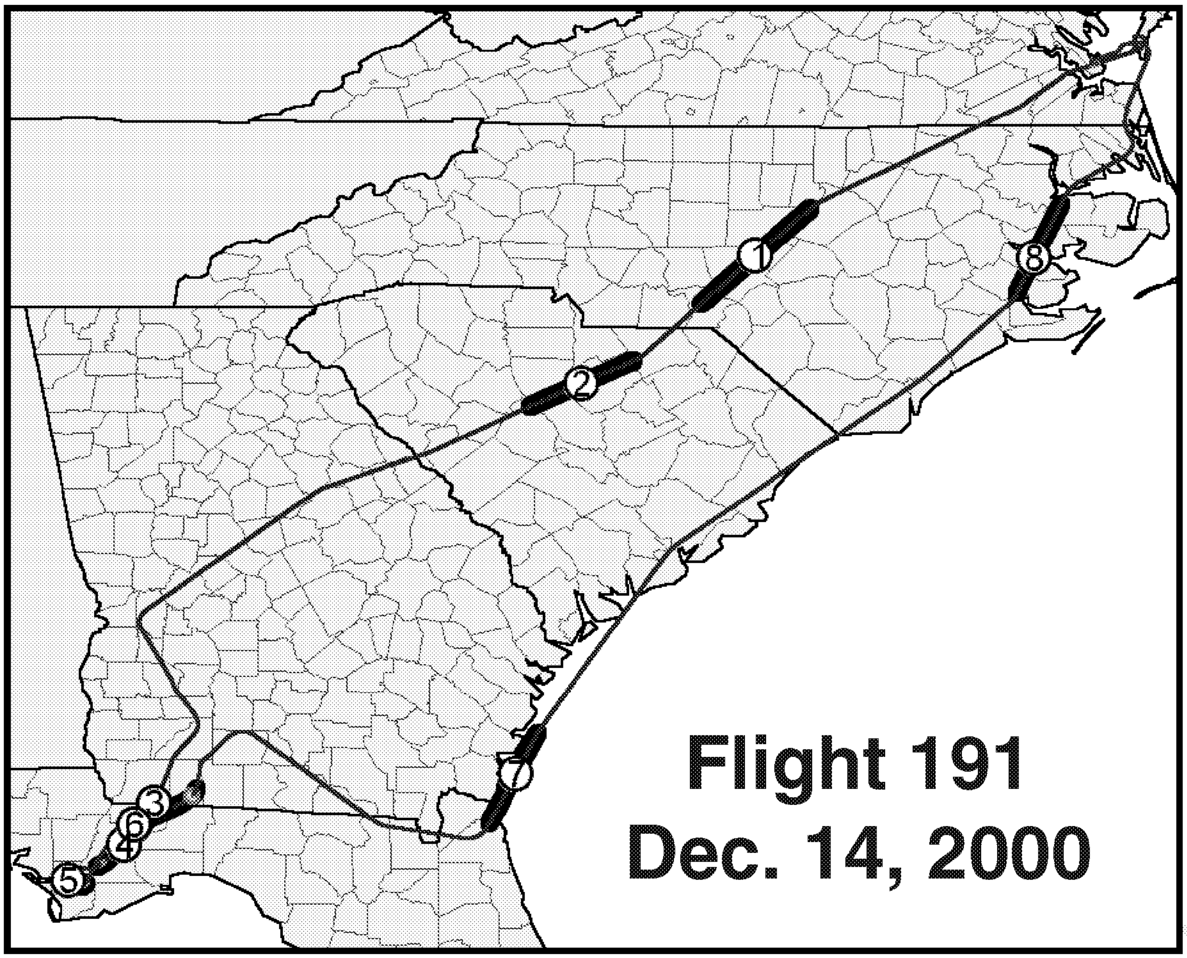

190-6.2
190-6.1
<0
2
8
13
18
24
29
34
40
45
50
55
61
>65
12/13/00
18:54:00 UTC
KPOE
Vol: 229
Swp: 3
VCP: 11
CtrAz: 60.5dg
CtrRn: 159.9km
Mag: 4X
Val: 0999.0
Hgt: 8.4 km
El: 2.4deg
SelAz: 60.4dg
SelRn: 159.8km
Nyqst: 27m/s

R – 191 December 14, 2000

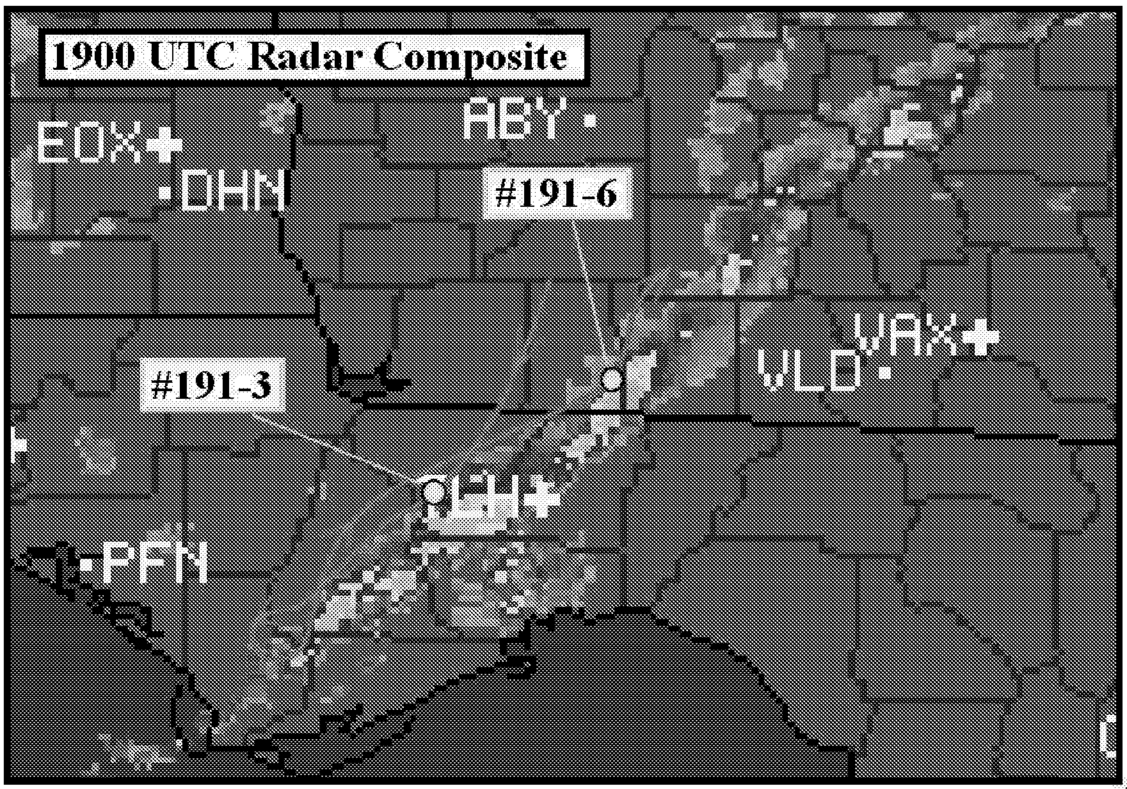
- **S Georgia and N Florida Panhandle; severe turbulence experienced near Tallahassee, Fl and Valdosta, Ga**
- **Narrow line of convective cells**
  - **Peak storm tops: 39,000 *ft* *(11.8 km)***
  - **Cell movement: from southwest at 40 *kts***
- **2 significant turbulence events with peak *in situ* measurement:**
  - $\sigma_{\Delta n} = 0.44$
  - $\varepsilon^{1/3} = 0.74$

18 UTC Surface Analysis
Dec 14, 2000



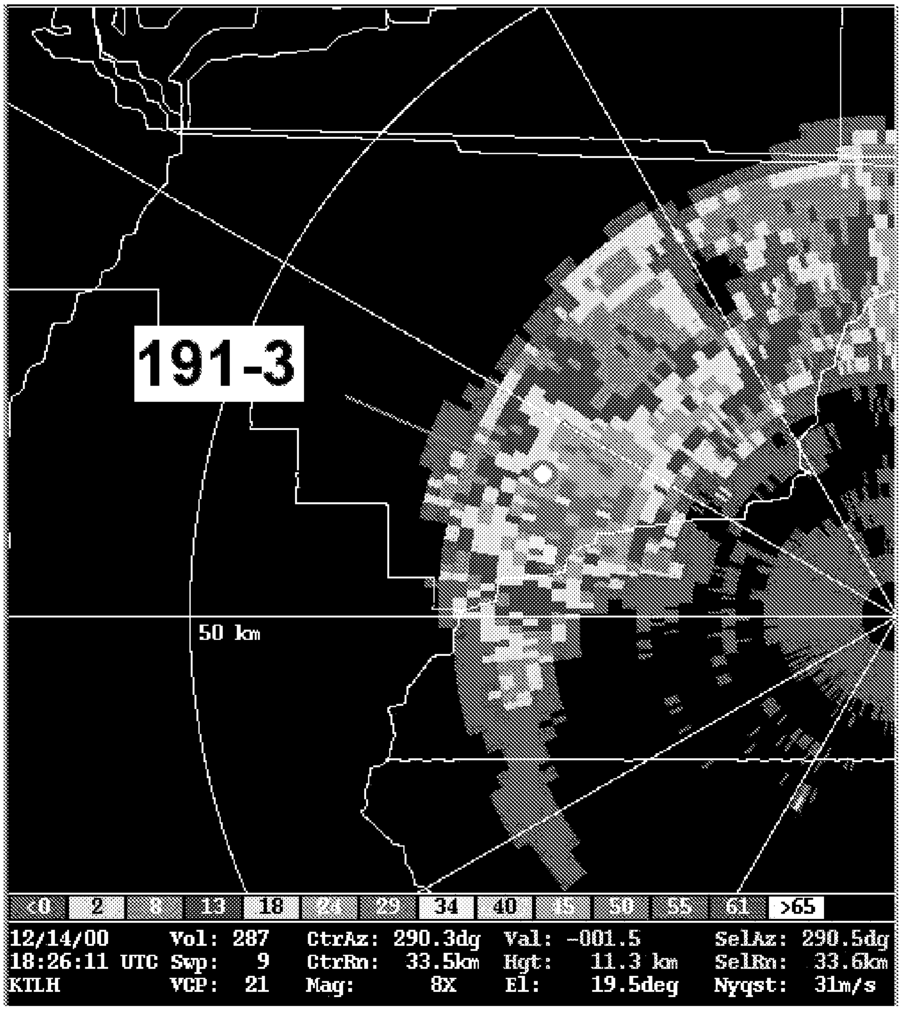

1
2
3
4
5
6
7
8
Flight 191
Dec. 14, 2000

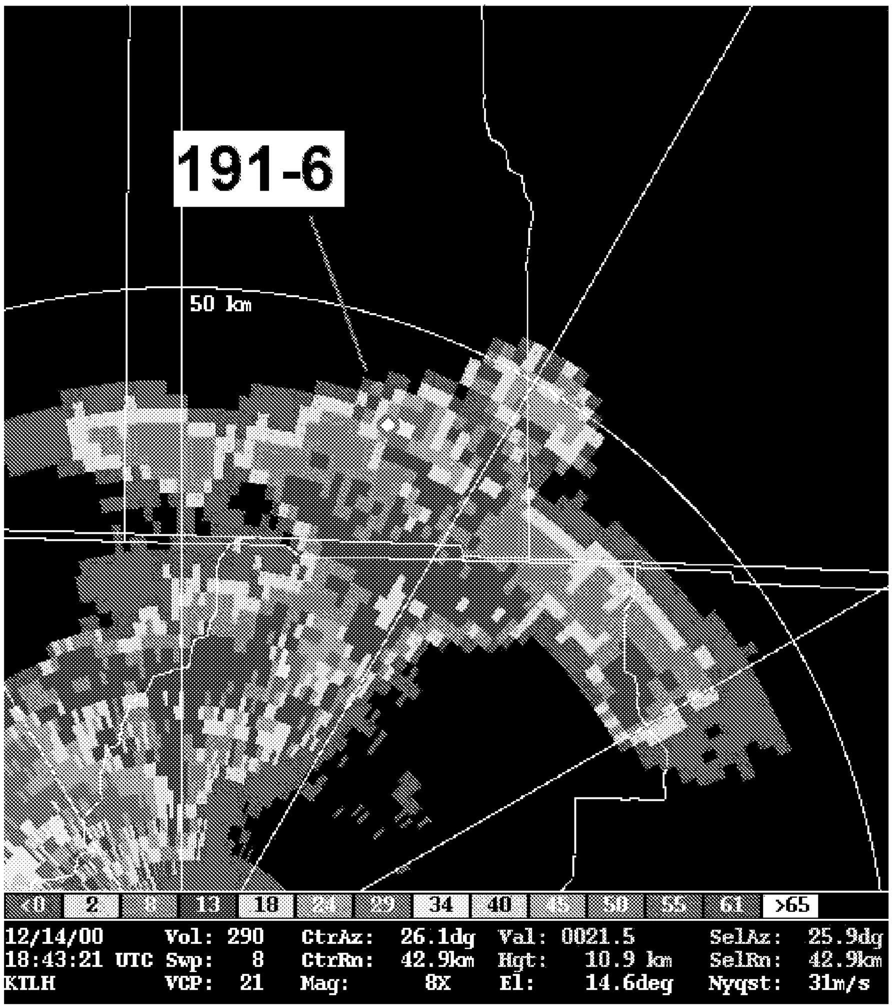
Flight 191 – Path with Nowrad



On Approach to Convective Line

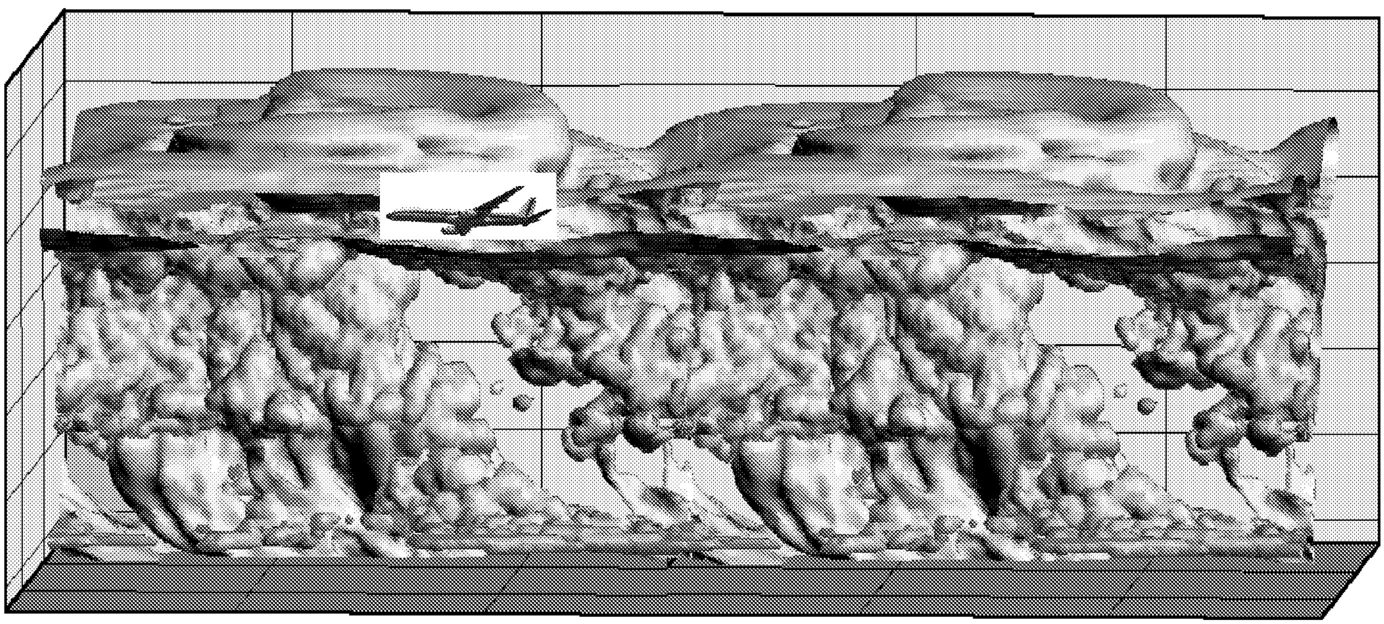
(viewed from northwest)


191-3
50 km
<0 2 8 13 18 24 29 34 40 45 50 55 61 >65
12/14/00 Vol: 287 CtrAz: 290.3dg Val: -001.5 SelAz: 290.5dg
18:26:11 UTC Swp: 9 CtrRn: 33.5km Hgt: 11.3 km SelRn: 33.6km
KTLH VCP: 21 Mag: 8X El: 19.5deg Nyqst: 31m/s


191-6
50 km
<0 2 8 13 18 24 29 34 40 45 50 55 61 >65
12/14/00 Vol: 290 CtrAz: 26.1dg Val: 0021.5 SelAz: 25.9dg
18:43:21 UTC Swp: 8 CtrRn: 42.9km Hgt: 10.9 km SelRn: 42.9km
KTLH VCP: 21 Mag: 8X El: 14.6deg Nyqst: 31m/s

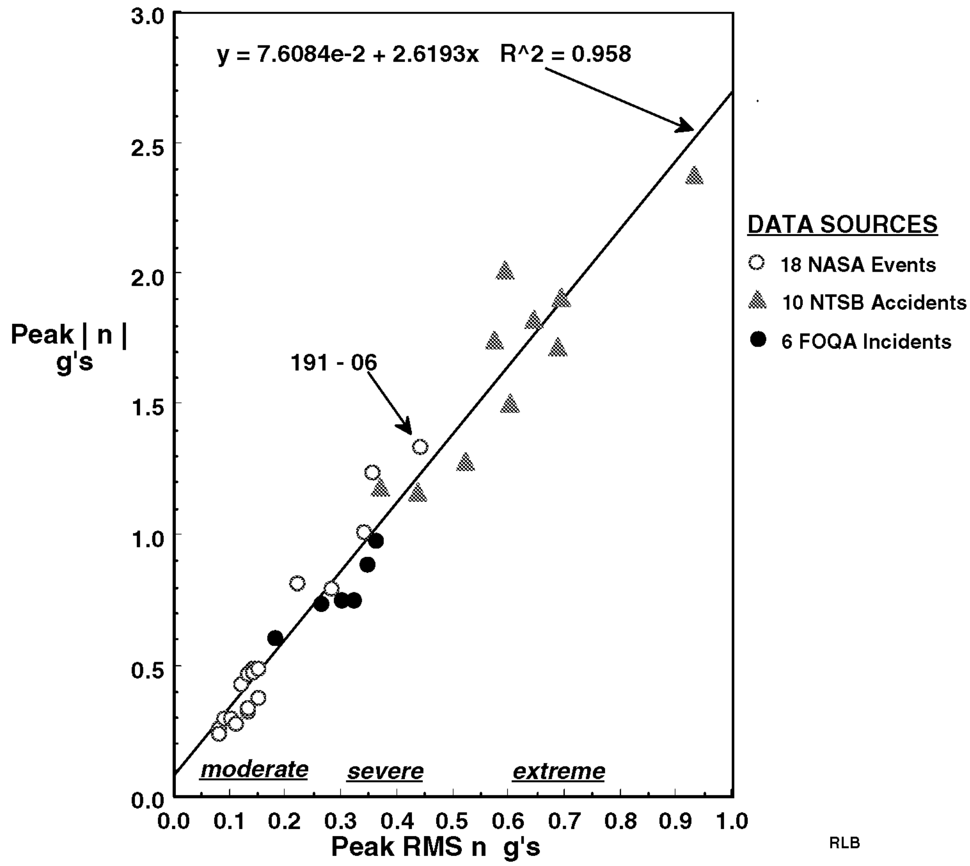
Event	Altitude (MSL) (k ft)	Peak *In Situ* Turbulence $\sigma_{\Delta n}$	$\varepsilon^{1/3}$ ($m^{2/3}/s$)	Peak Vertical Wind (m/s) *from 20 Hz data Max	Min	Horizontal Scale/ Duration of Event	Peak Radar Reflectivity (along flight path)
181-4	22	0.21	0.25	4 m/s	-4 m/s	7 km / 33 sec	NA
181-7	19	0.15	0.16	5 m/s	-1 m/s	10 km / 50 sec	25 dBz
181-8	19	0.16	0.18	6 m/s	-1 m/s	6 km / 30 sec	27 dBz
190-4	24	0.28	0.47	12m/s	-6.5m/s	15 km / 70 sec	20 dBz
190-6	24	0.35	0.45	11m/s	-6m/s	7 km / 32 sec	23 dBz
191-3	33	0.34	0.60	9 m/s	-15 m/s	7 km / 30 sec	35 dBz
191-6	33	0.44	0.74	18 m/s	-15 m/s	6 km / 25 sec	33 dBz

TASS 100 m Simulation



Correlation of Peak Load With Peak RMS Load (5 sec. window)

Based on Measurements for 34 Turbulence Encounter Cases



SUMMARY

- 3 flight experiments into regions favorable for convectively-induced turbulence
  - most events lasting ~30 seconds
  - 3 severe turbulence encounters (based on $\sigma_{\Delta n}$)
  - all severe events appeared discrete-like, although bathed in a continuous spectrum of turbulence.
  - all turbulence events associated with radar reflectivities < 35 dBz

SUMMARY (cont.)

- **R-190 similar to NTSB accident accounts;**
  - **severe encounter occurred on periphery of large storm**
  - **encounter associated with weak radar reflectivity (< 22 dBz)**
- **R-191 being modeled with LES**

FUTURE FLIGHT PLANS

- Colorado – late Aug to early Sept
- Langley – late Sept to early Oct

NASA/CP—2002-210964

Numerical Simulation of Event 191-6 of NASA's Flight Tests

Fred H. Proctor and David W. Hamilton

NASA Langley Research Center

Hampton Virginia

Session: Airborne Turbulence Warning System
Weather Accident Prevention Annual Project Review
5-7 June 2001, Cleveland, Ohio

Outline

- Introduction
- Description of Turbulence Event
- TASS Model
- Initial Conditions
- Results from Model Simulation
- Summary

Introduction

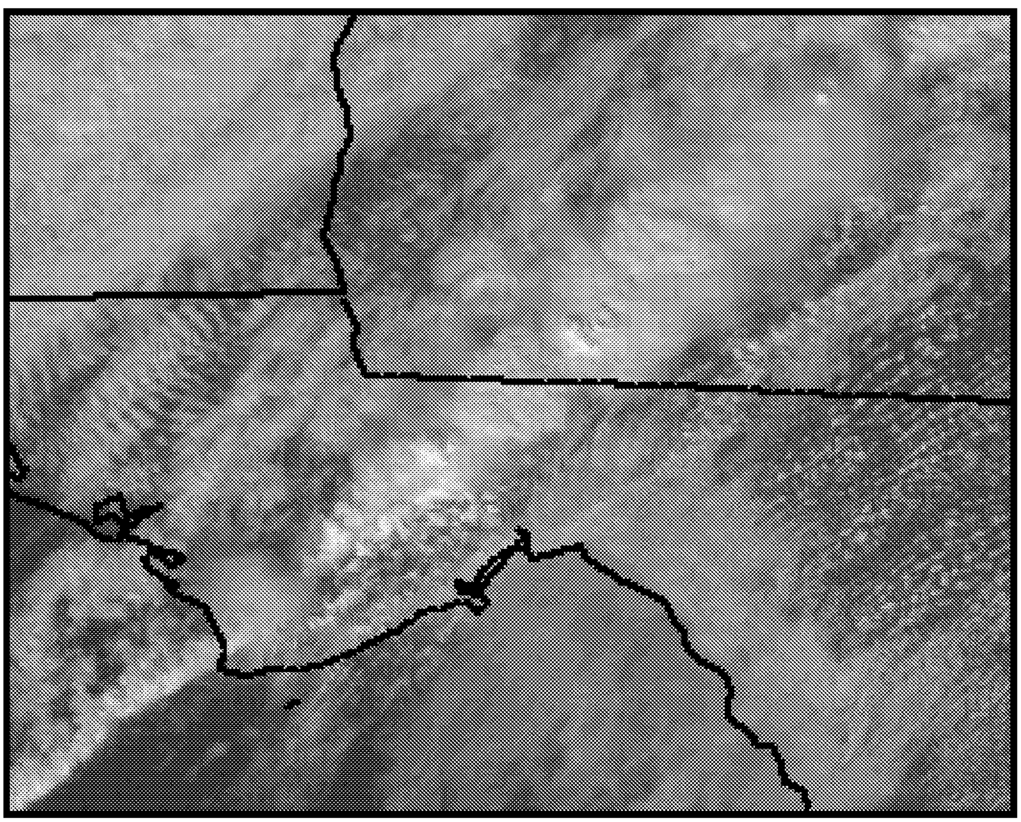
- **Numerical Simulation of Event 191-6**
- **Severe Turbulence Encountered by NASA Langley B-757 during Event 191-6**
- **Occurred as B-757 Penetrated Updraft Plumes Near Storm Top**
- **Data Available for Model Validation**
  - Ground Based Radar (i.e. Nexrad)
  - Satellite
  - NASA B-757
    - *In Situ* Winds and Accelerations
    - Onboard Doppler Radar
    - Eyewitness Accounts

NASA/CP—2002-210964

R – 191-6 December 14, 2000

- Severe turbulence encountered ~40 *km* NE of Tallahassee FL (TLH)
- Narrow line of convective cells
  - Peak storm tops: 39,000 *ft* *(11.8 km)*
  - Cell movement: from southwest at 40 *kts*
- 2 significant turbulence events with peak *in situ* measurement:
  - $\sigma_{ng} = 0.44$
  - $\varepsilon^{1/3} = 0.74$

1 km Visible Satellite
1845 Z December 14, 2000



MODELING ROADMAP

- **Step 1: Derive initial sounding based on mesoscale model prediction; configure domain; retrieve and prepare observed data for case verification.**
- **Step 2: Coarse-grid simulation: should capture large scale characteristics of storm: 125x125x70 grid points with horizontal grid size of 200 *m***
- **Step 3: Fine-grid simulation: 250x250x150 grid points, with grid size of 100 *m***
- **Step 4: Nested grid simulation**
  - **5 km region near cloud top**
  - **Minimum grid size less than 25 m.**
  - **Validate results**

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TERMINAL AREA SIMULATION SYSTEM (TASS)

- 3-D Large Eddy Simulation (LES) Model
- Meteorological Framework
- Prognostic Equations for:
  - 3-Components of Velocity
  - Potential Temperature
  - Water Vapor
  - Liquid Cloud Droplets
  - Cloud Ice Crystals
  - Pressure
  - Rain
  - Snow
  - Hail/graupel
  - Dust/insects/tracers
- 1st-order subgrid turbulence closure with Richardson-number dependency
- Surface friction layer based on Monin-Obukhov similarity theory
- Cloud microphysics

NASA/CP—2002-210964

TASS -- History

- Development began in 1983 for NASA/FAA Windshear Program
- Recently applied in NASA's Wake Vortex Program for improving airport capacity (i.e. AVOSS)
- Generation of data sets for Windshear Sensor Certification
- Supported NTSB Investigation of 1994 Charlotte and 1999 Little Rock Aircraft Accidents
- Simulations Applied to:
  - Cumulonimbus Convection
  - Tornadic Storms & Supercell Hailstorms
  - Microbursts & Microburst Producing Storms
  - Reconstruction of Microburst Windshear Encounters
  - Aircraft Wake Vortices
  - Atmospheric Boundary Layer
  - Flight Turbulence

R-191-6, 14 Dec 2000, Near Tallahassee FL

TASS Domain Configuration

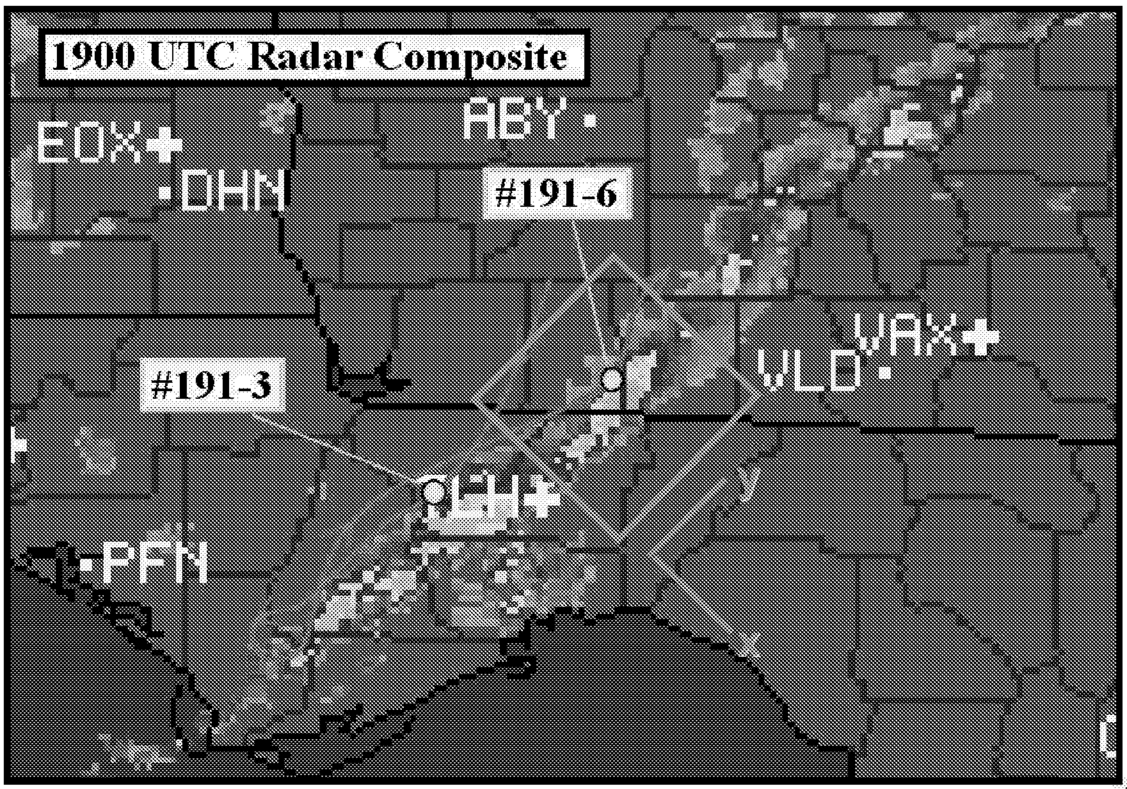
Physical Domain size

- Horizontal (X,Y): 25 x 25 km
- Vertical (Z): 14 km

Domain orientation and lateral boundary conditions

- Domain rotated 66° clockwise:
  - X – coordinate orthogonal to convective line
  - Y – coordinate along line
- Lateral BC:
  - Periodic boundary at $Y = \{0, X^*\}$,
  - Open at $X = \{0, Y^*\}$
- Computational resolution
  - Horizontal – 100 *m* (251 x 251 grid points); can resolve horizontal scales down to *400-200 m*
  - Vertical – 100 *m* , stretched grid at $Z<2100$ *m* with grid size decreasing to 50 *m* at $Z=0$ (148 levels)

TASS Domain Configuration



TASS Simulation of Event 191-6, 14 Dec 2000

TASS Input Data

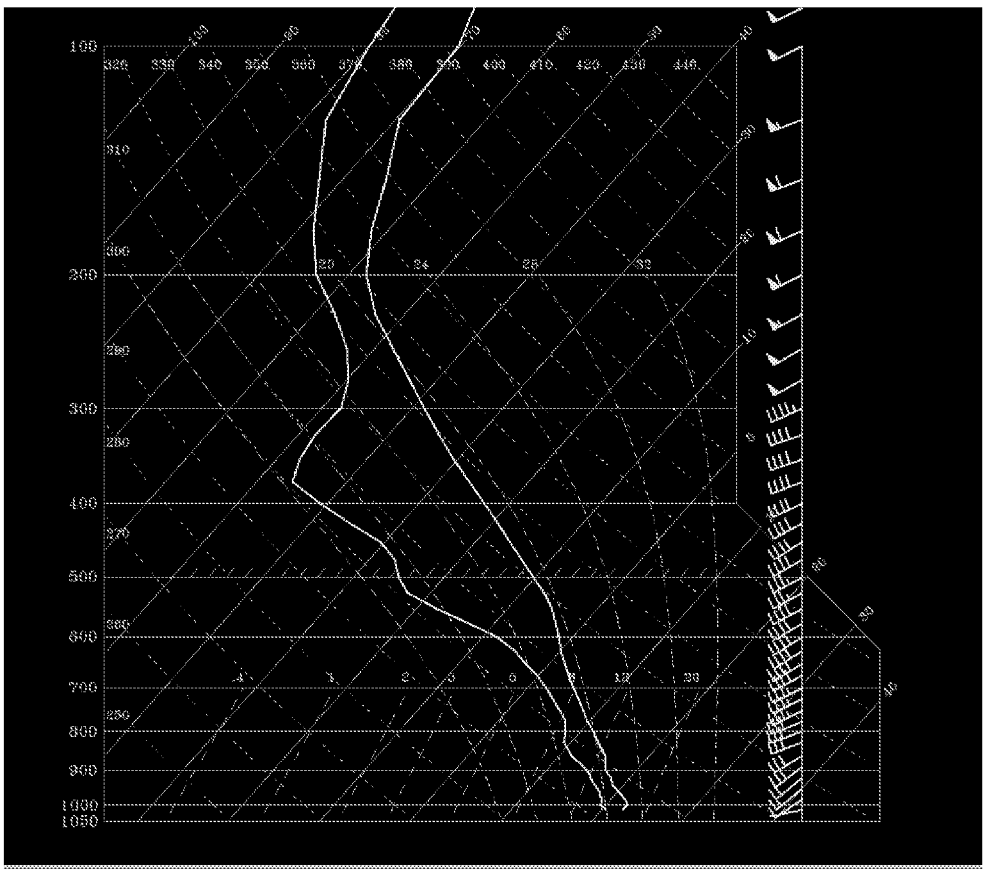
Input Sounding

- Environmental winds, temperature, dewpoint, & pressure
- From MASS 6-km forecast at time & location near event
- Boundary layer temperature & moisture from TLH observation

Convection initiated at model time zero

- Spheroidal thermal impulse
  - Peak amplitude 2.0° C
  - Dimensions – 4 km horizontal x 2.1 km vertical

MASS TLH sounding



TASS Simulation of Event 191-6, 14 Dec 2000

Simulated Storm Characteristics

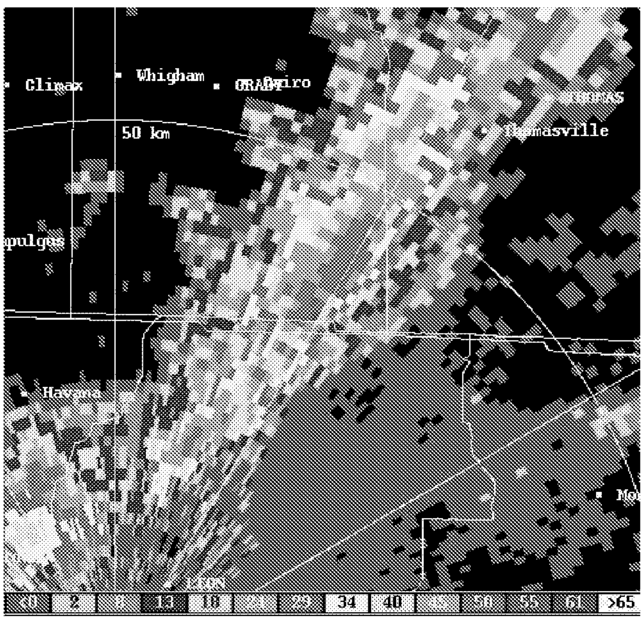
- Near solid line of convection
- Overshooting tops to 11.5 *km (38,000 ft)*
- Cell motion: 19 *m/s* (37 *kts*)
- Moderate rainfall at surface (no hail)
- Persistent multi-cell type convection
- Turbulence associated with storm tops
- Cloud top rise rates about 10 – 12 *m/s (30-40 ft/s)*

Table 3. Model Comparison

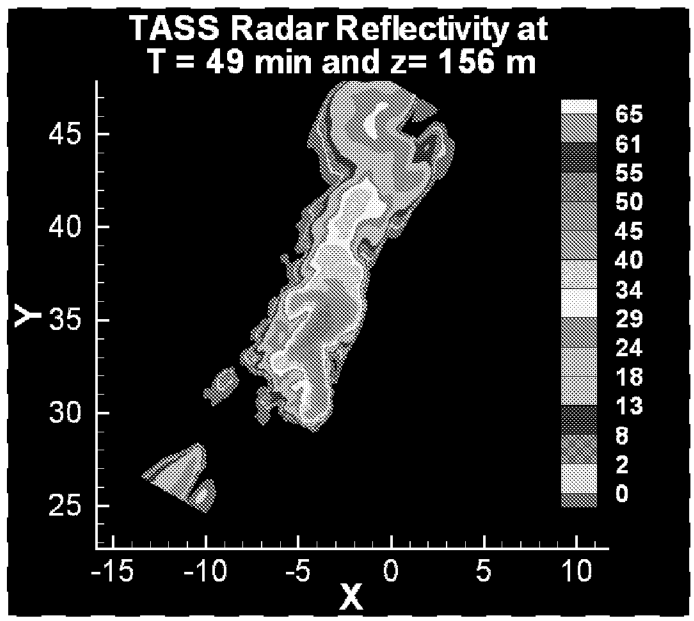
Variable	TASS		Observed	
Peak Storm Tops	11.5 *km*		11.8 *km*	
Peak Radar Reflectivity at Ground	53.5 *dBz*		55 *dBz*	
Peak Radar Reflectivity at *z*=9 *km*	38.9 *dBz*		40 *dBz*	
Cell Motion (toward)	ENE at 19 *m/s*		ENE at 17 *m/s*	
Width of Convective Line near Ground Level (based on 20 *dBz*)	6 *km*		8 *km*	
Peak Vertical Velocity at Flight Level (*z*~10.3 *km*)	Max 17 *m/s*	Min -11 *m/s*	Max 18 *m/s**	Min -15 *m/s**
Peak Eddy Dissipation Rate ($m^{2/3}/s$)	0.86		0.74	
Horizontal Scale of Turbulence Patch at Flight Level	5 *km*		6 *km*	

*from 1 *Hz in situ* data

Radar reflectivity near ground (*dBz*)

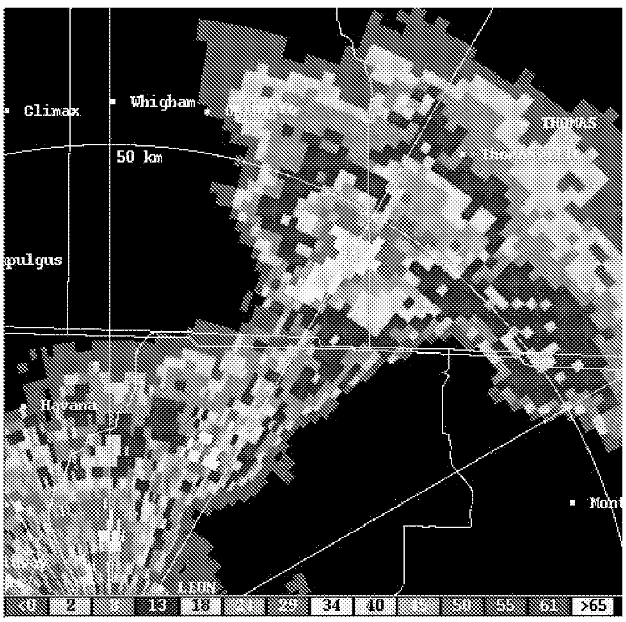


PPI Display From TLH Nexrad
(1.4° tilt)

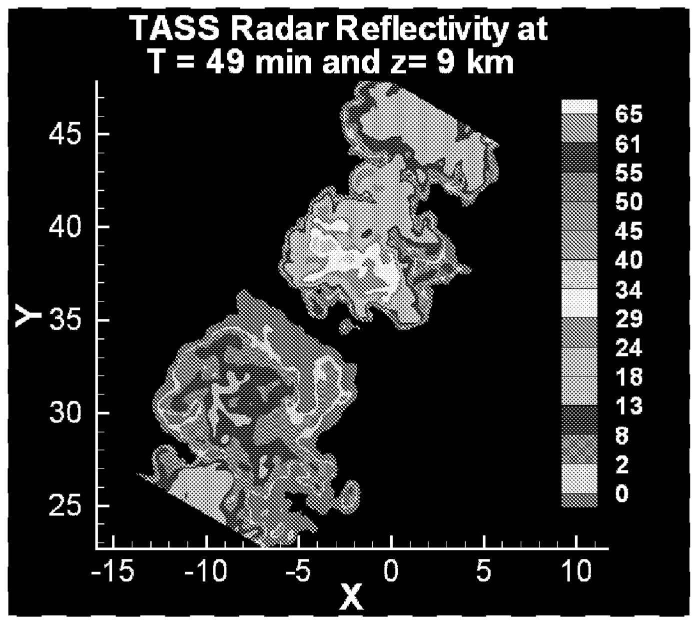


TASS
(Horizontal Cross Section)
(major tick every 5 *km*)

Upper-Altitude Structure of Convective Line



PPI Display From TLH Nexrad
(9.8° tilt)



TASS
(Horizontal Cross Section
at 9 *km* AGL)

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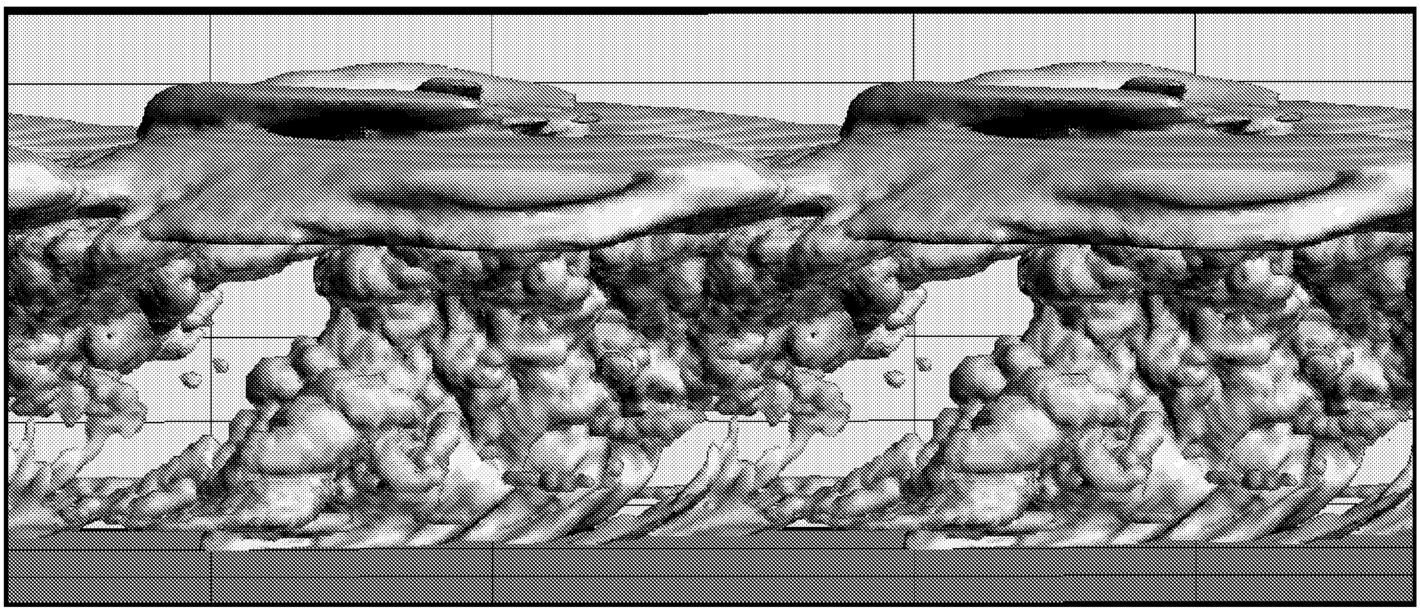
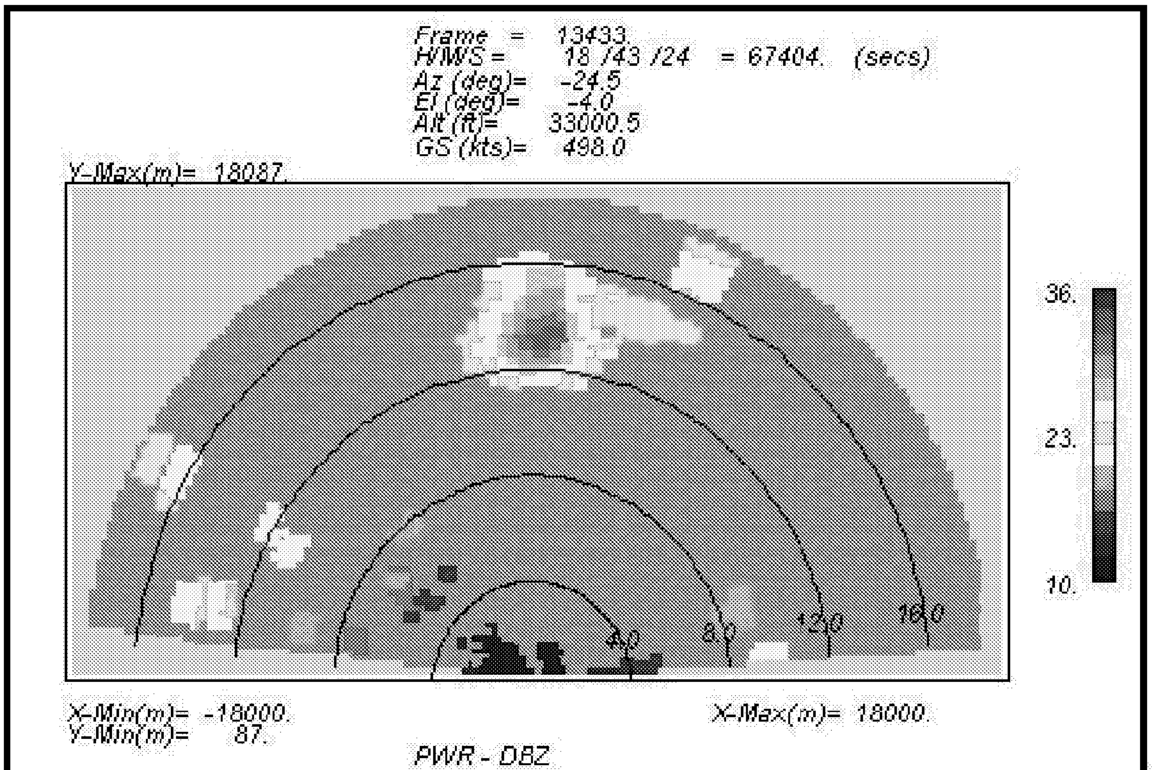
TASS Simulation of Convective Line
viewed from southeast
(cloud/precipitation surfaces)

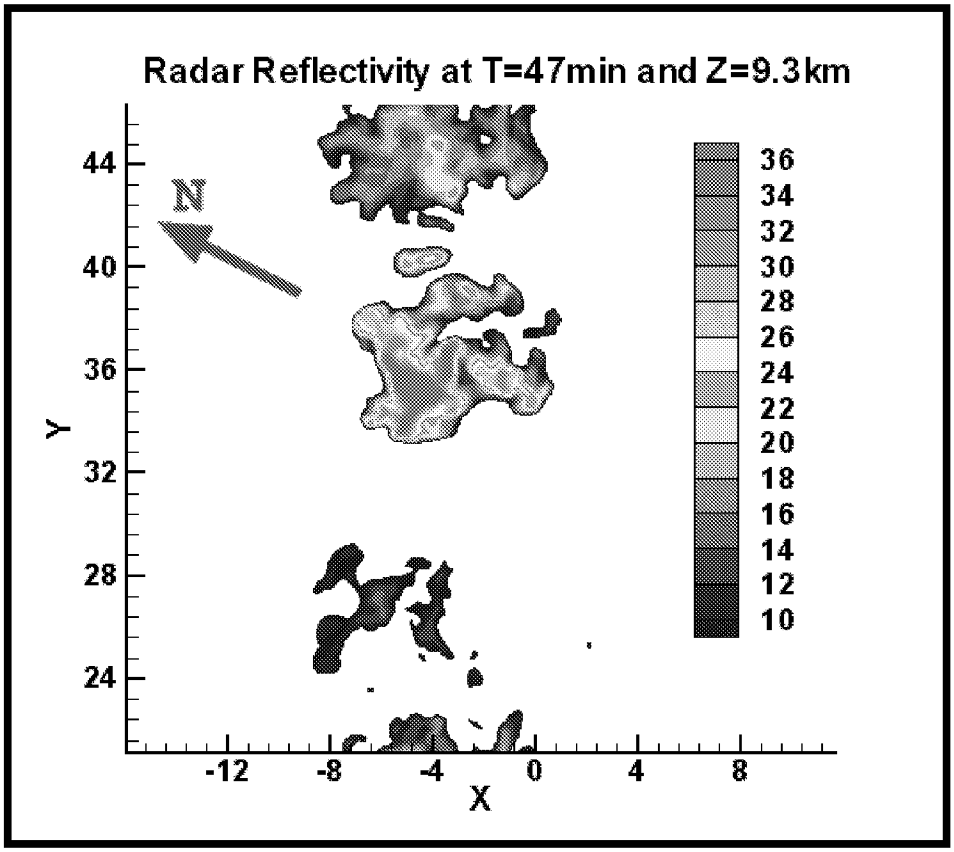


Radar reflectivity from onboard turbulence radar (dBz) at –4° tilt. (Range rings every 4 *km*)

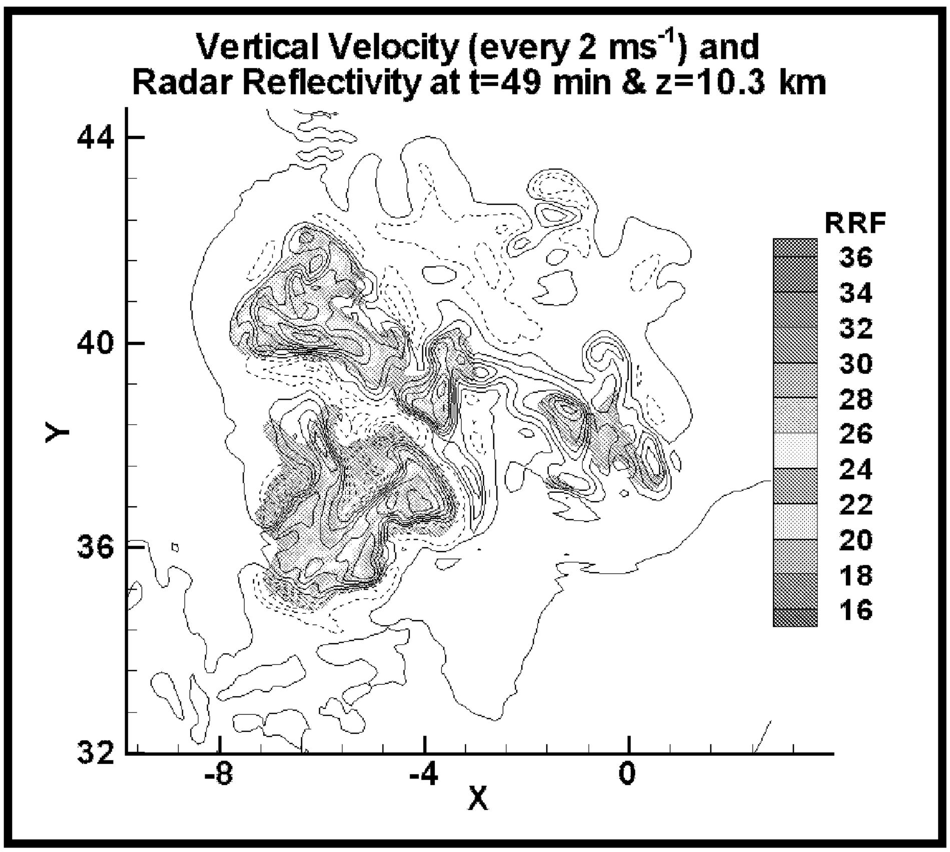


L. Britt

TASS radar reflectivity (dBz) at 9.3 *km* altitude corresponding to time and location of echo in previous slide (major ticks every 4 *km*)



TASS radar reflectivity (dBz) at 10.3 *km* altitude (major ticks every 4 *km*)



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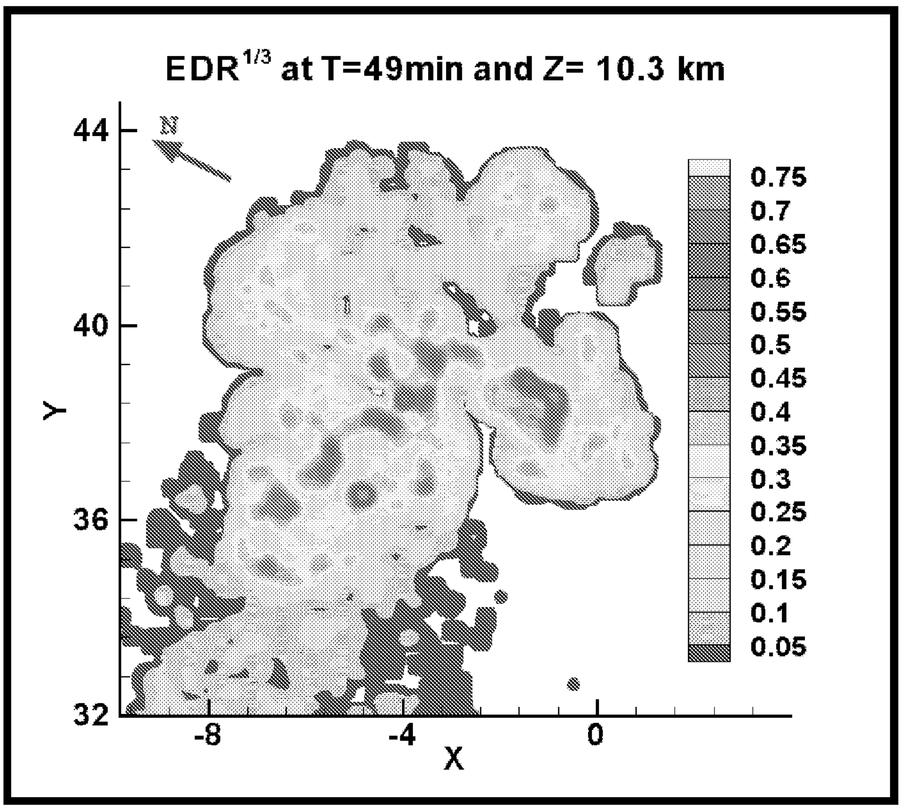
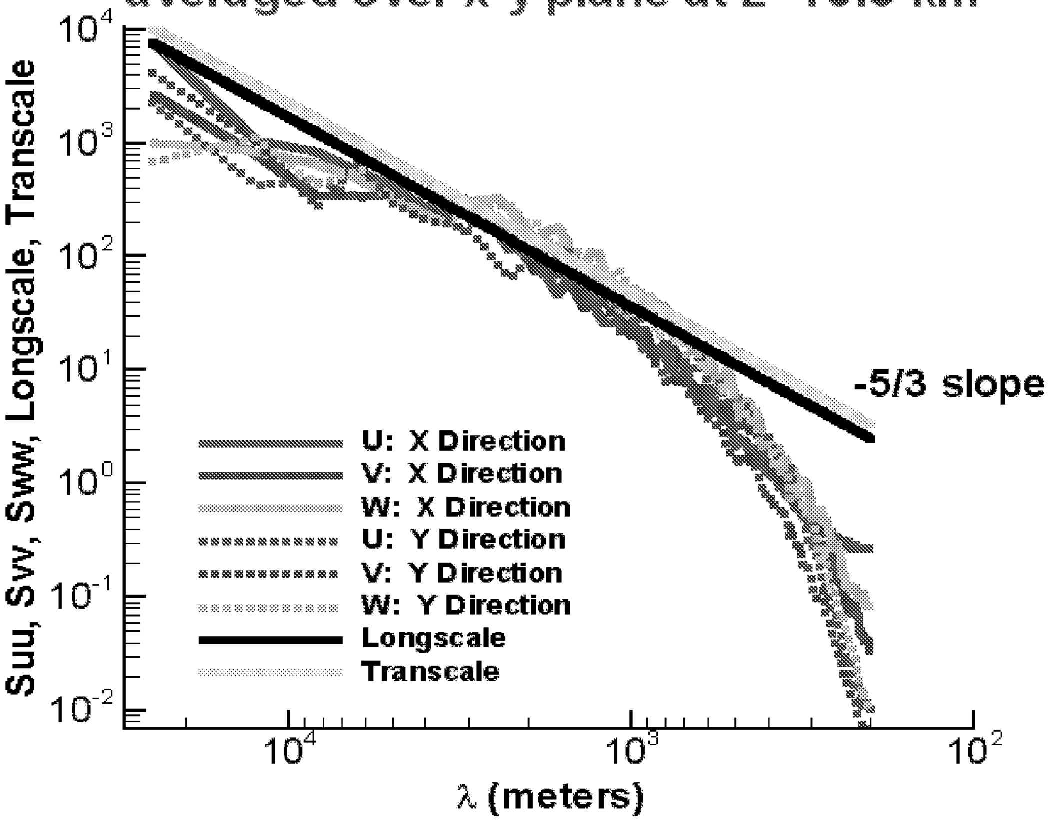
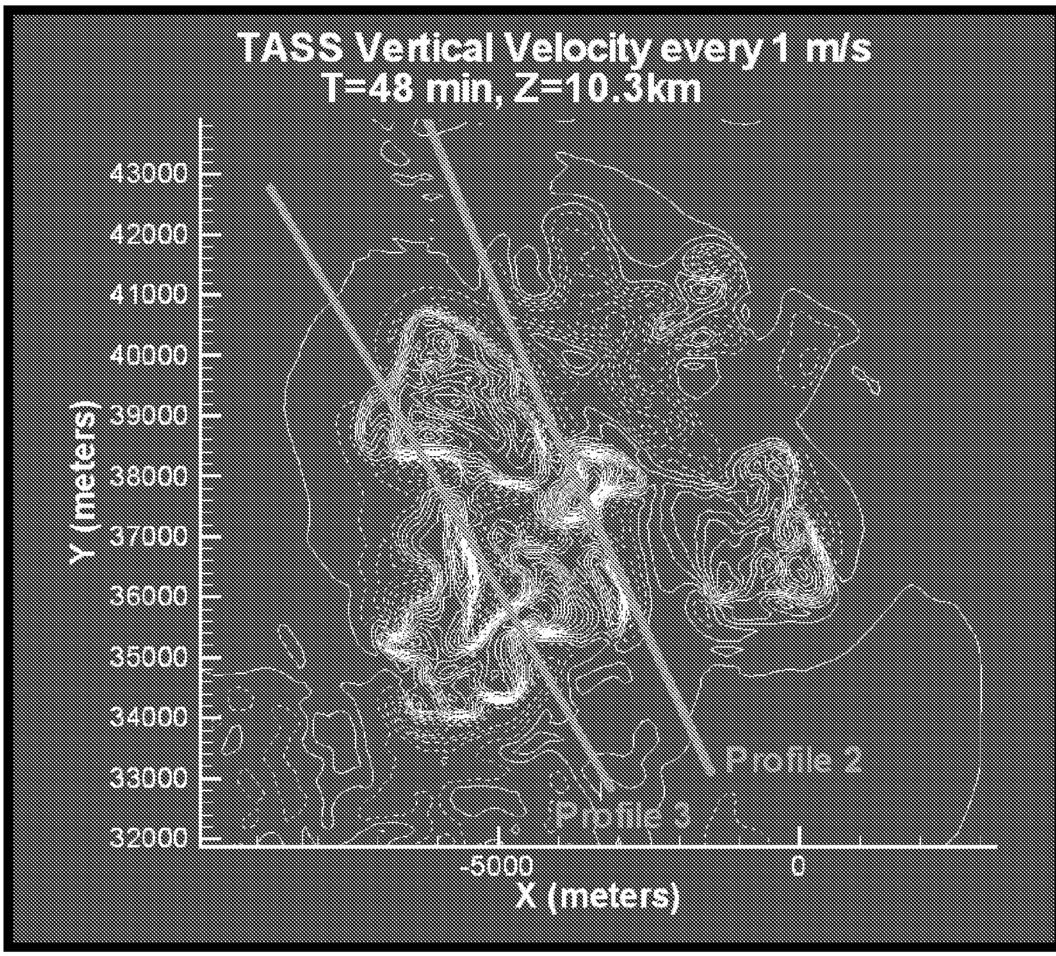
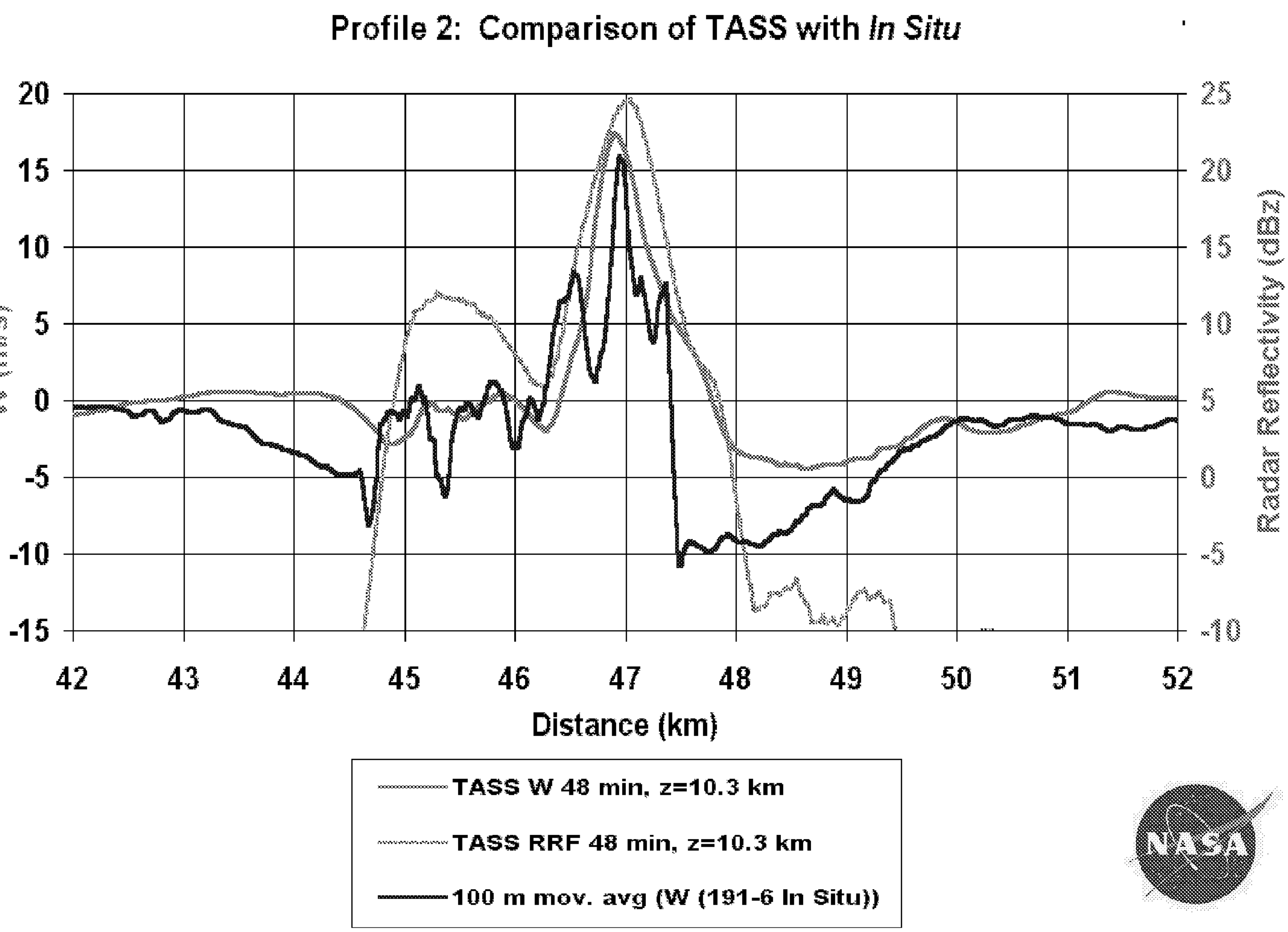
TASS Eddy Dissipation Rate to the 1/3 power ($m^{2/3}/s$) at time and location corresponding to previous slide.

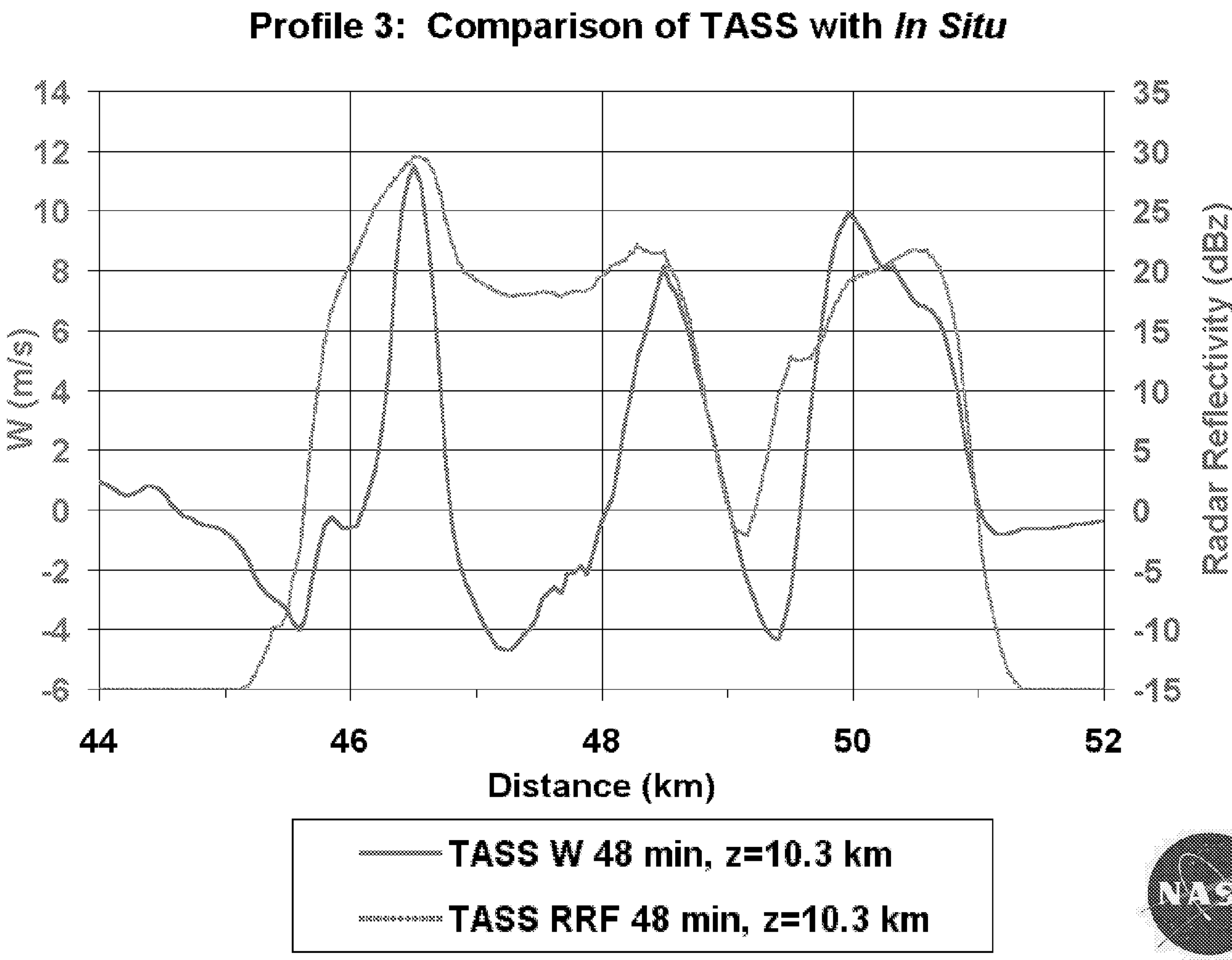


Spectra: TASS Simulation of R-191-6, Δ=100 m averaged over x-y plane at z=10.3 km




TASS Vertical Velocity every 1 m/s
T=48 min, Z=10.3km
Y (meters)
43000
42000
41000
40000
39000
38000
37000
36000
35000
34000
33000
32000
-5000
0
X (meters)
Profile 2
Profile 3


Profile 2: Comparison of TASS with *In Situ*
W (m/s)
Radar Reflectivity (dBz)
20
15
10
5
0
-5
-10
-15
25
20
15
10
5
0
-5
-10
42
43
44
45
46
47
48
49
50
51
52
Distance (km)
TASS W 48 min, z=10.3 km
TASS RRF 48 min, z=10.3 km
100 m mov. avg (W (191-6 In Situ))



Profile 3: Comparison of TASS with In Situ
W (m/s)
14
12
10
8
6
4
2
0
-2
-4
-6
Radar Reflectivity (dBz)
35
30
25
20
15
10
5
0
-5
-10
-15
44
46
48
50
52
Distance (km)
TASS W 48 min, z=10.3 km
TASS RRF 48 min, z=10.3 km

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Summary

- **Observed Large-Scale Features Captured by 100 m Simulation, Although Details of Storm Structure Differ from Measurements**
- **Turbulence Associated with Buoyant Plumes in Upper-Levels of Storm**
- **Turbulence and Strong Vertical Velocity may Occur within Weak Radar Reflectivity**
- **Downdraft Regions may Contain Weaker Radar Reflectivity than Updraft Regions (at flight level)**

Future/Ongoing Work

- Finer Grid Resolution Needed to Capture Important Scales of Motion that Affect Aircraft Normal Load Accelerations
- Data Set from this Case Delivered to NCAR for Addition of Small-Scale Karman Turbulence
- A Nested-Grid with Grid Size of 25 m to be Applied in Future Simulation

Unbalanced Supergradient Flow: Its Role in Organizing Severe Turbulence in Both Convective and Clear Air Case Studies

Michael L. Kaplan

North Carolina State University

NASA/CP—2002-210964

What is Supergradient Flow?
(Flow Which Exceeds Gradient Wind Balance)

(V**2/R)>(PGF+FV)

V=Horizontal Wind Velocity

R=Radius of Flow Curvature

PGF=Horizontal Pressure Gradient Force

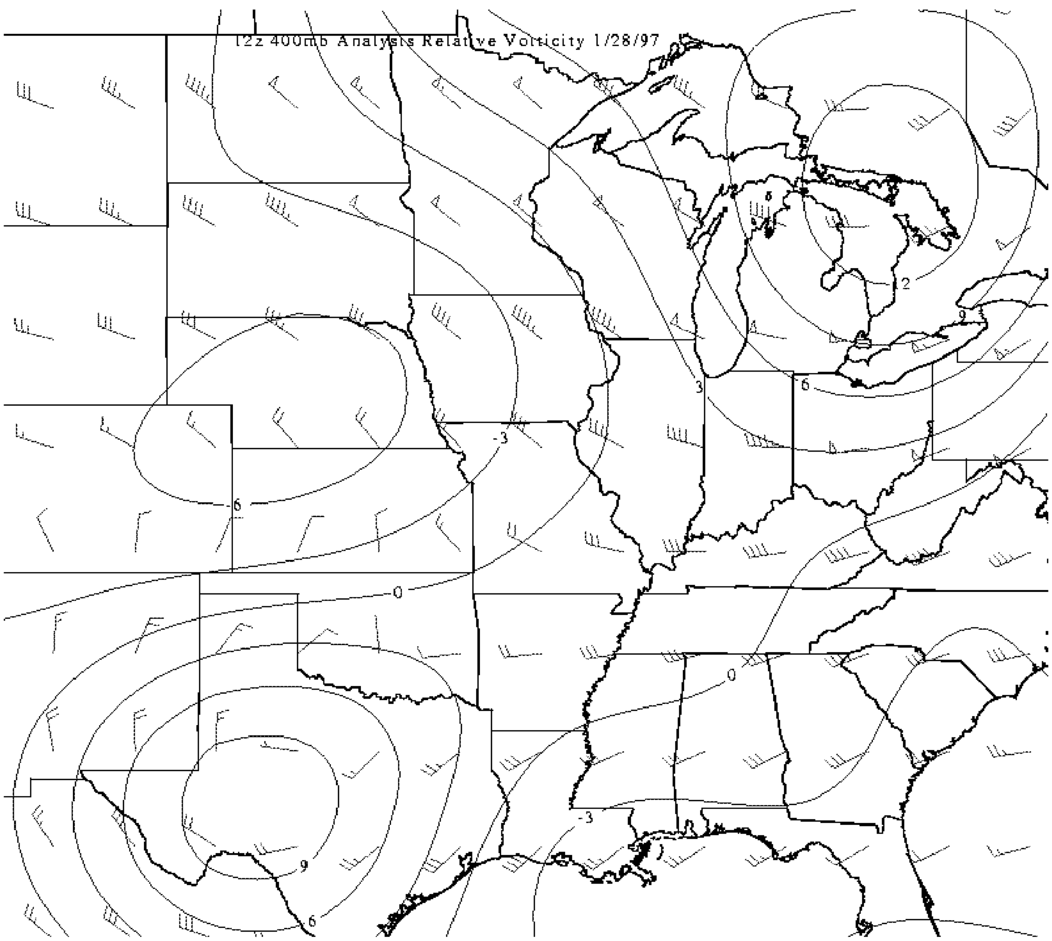
FV=Horizontal Coriolis Force

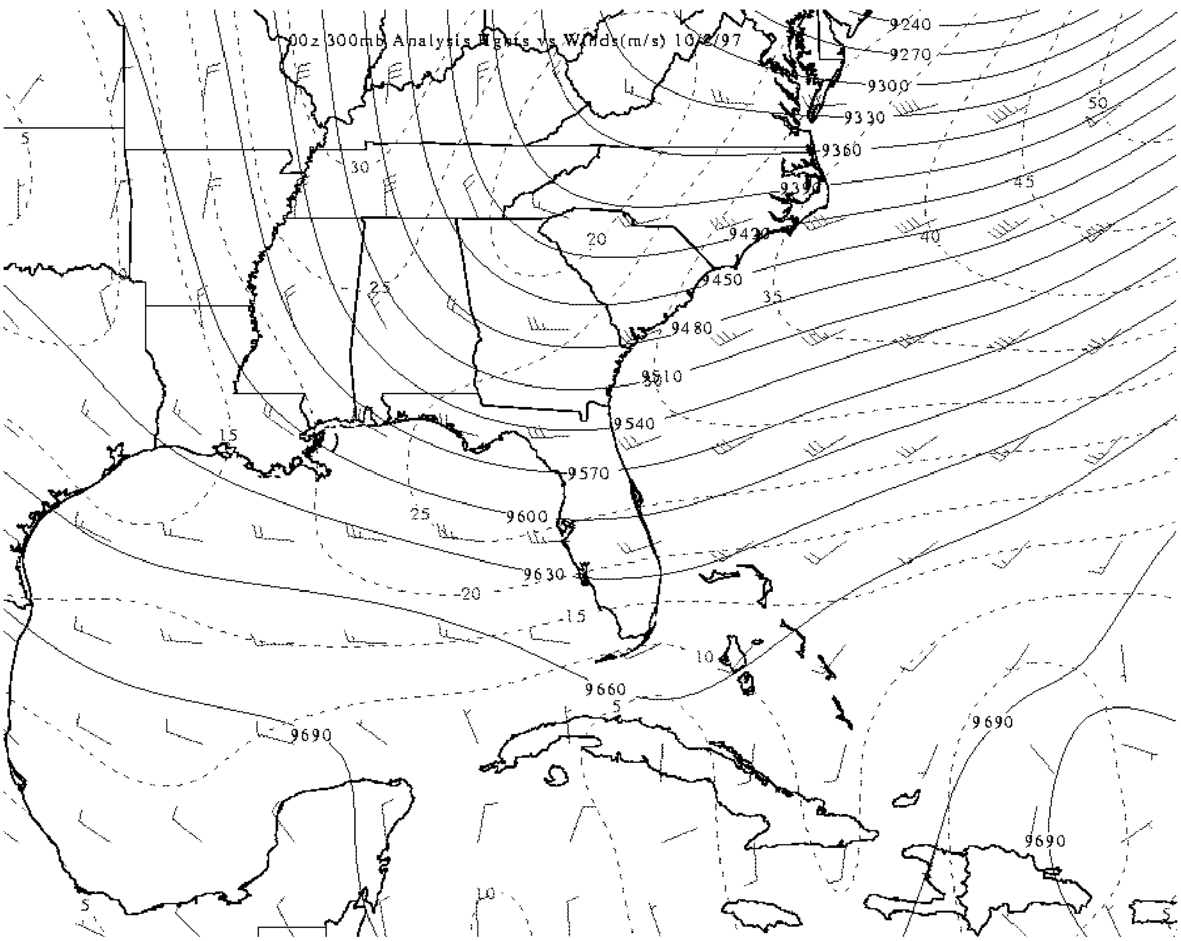
Presentation Overview

- 44 Case Synoptic Observational Signal
- Clear/Convective Accident Synoptic Signal
- Simulated Mesoscale Supergradient Flow
- Mass Perturbation/Supergradient Imbalance
- Flanking/Trailing Microvortex Genesis
- Single Characterization/Forecasting Index

Primary Observed Synoptic Signals in the 44 Case Studies

- 1. Immediate Upstream Curvature (98%)
- 2. Convection < 100 km Away (86%)
- 3. Upward Vertical Motion (82%)
- 4. Absolute Vorticity < 10-4 S-1 (80%)
- 5. Jet Entrance Region (77%)
- Indicates: Horizontally Changing Curvature in Proximity to a MASS Perturbation in the Entrance Region of 1 or More Jet Streams

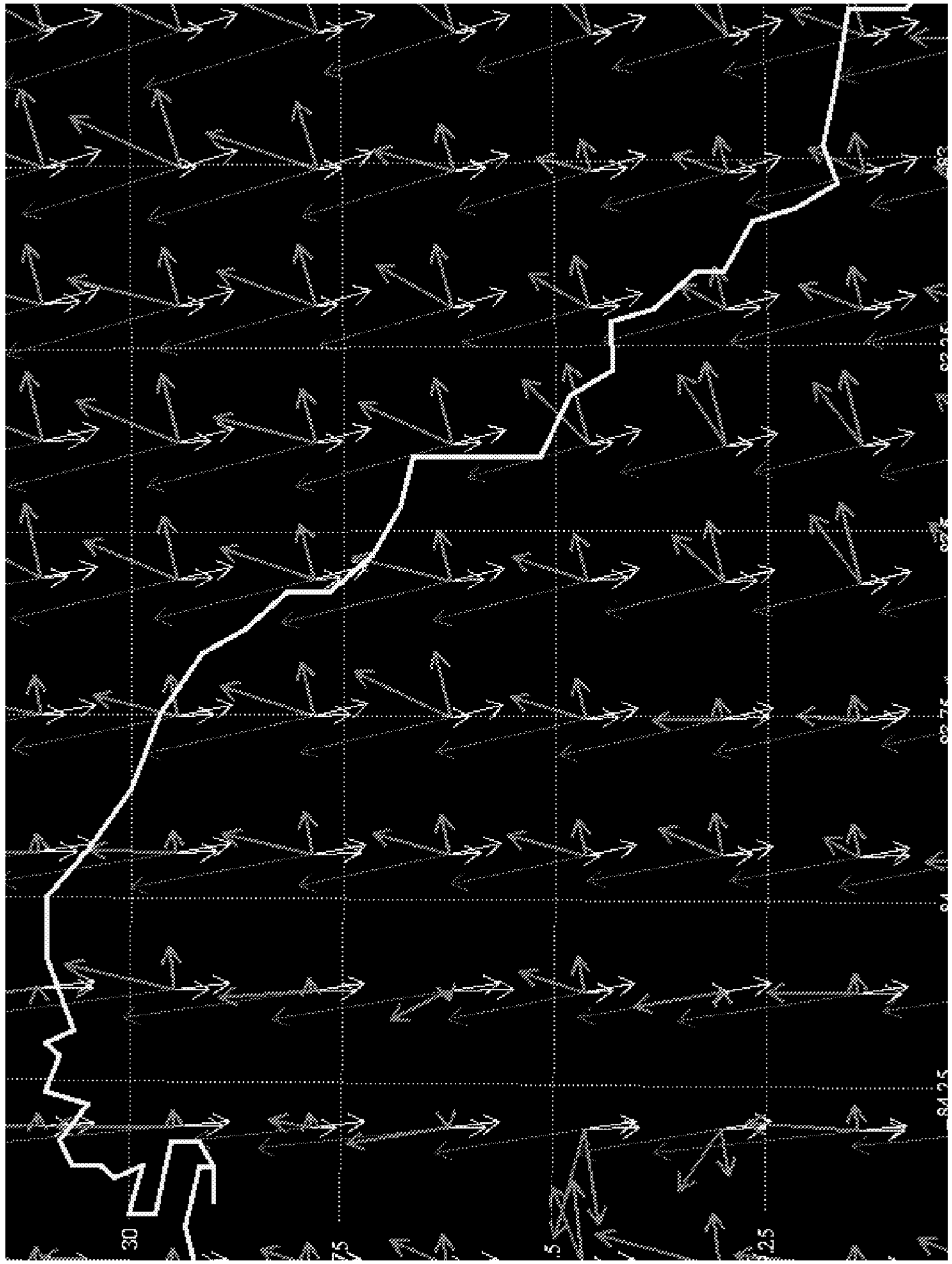

12z 400mb Analysis Relative Vorticity 1/28/97

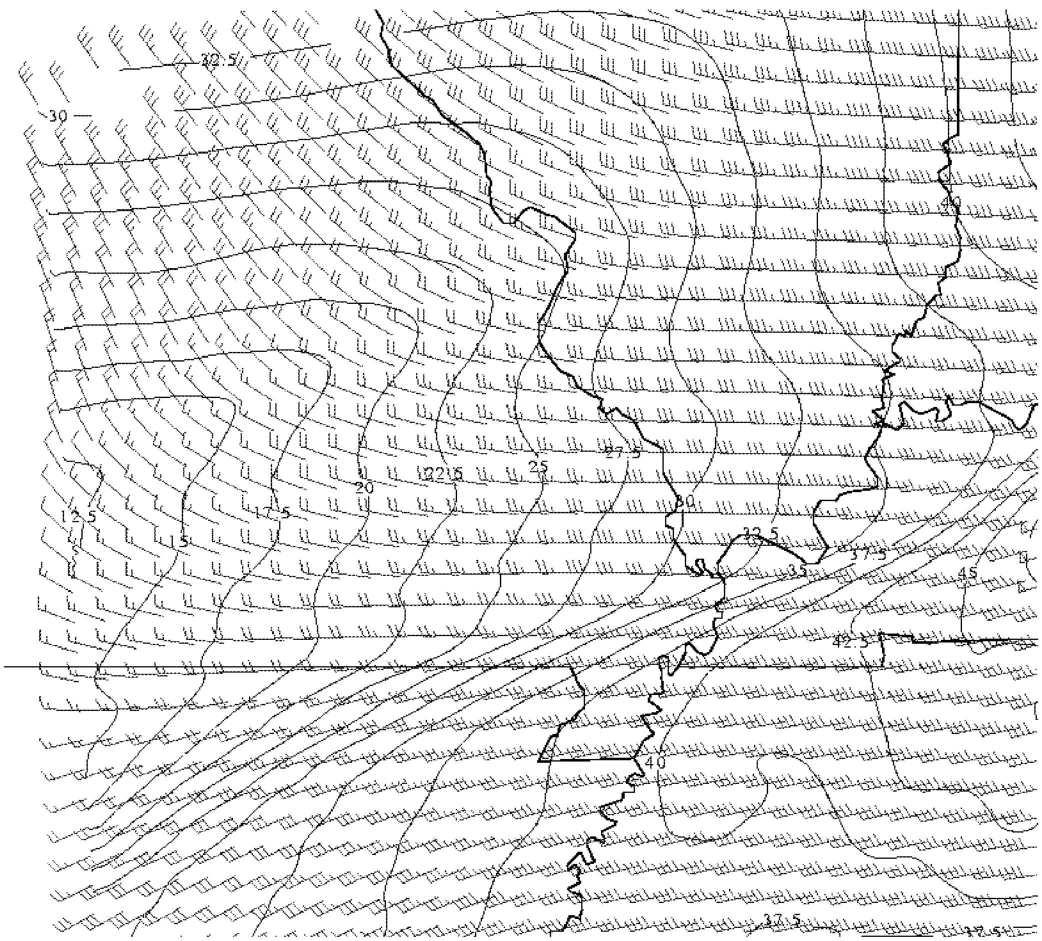

00z 300mb Analysis Hghts vs Winds(m/s) 10/2/97
9240
9270
9300
9330
9360
9390
9420
9450
9480
9510
9540
9570
9600
9630
9660
9690
9690
9690
50
45
40
35
30
30
25
25
20
20
15
15
10
10
5
5
5

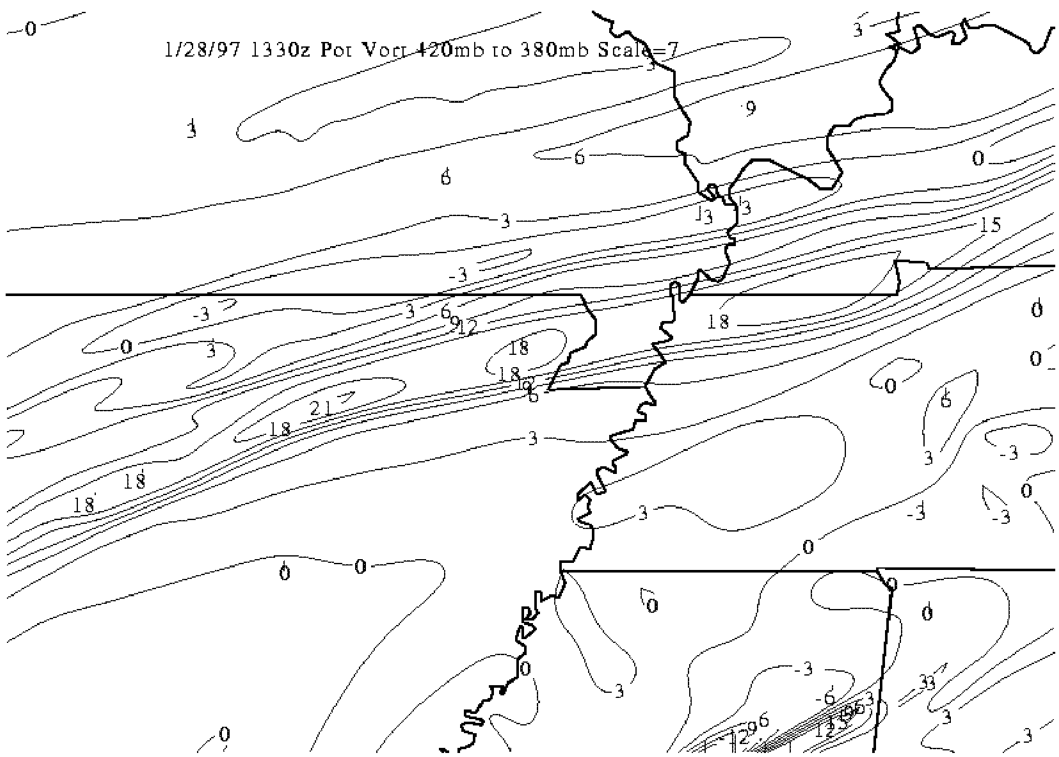
MASS Model Numerical Simulations

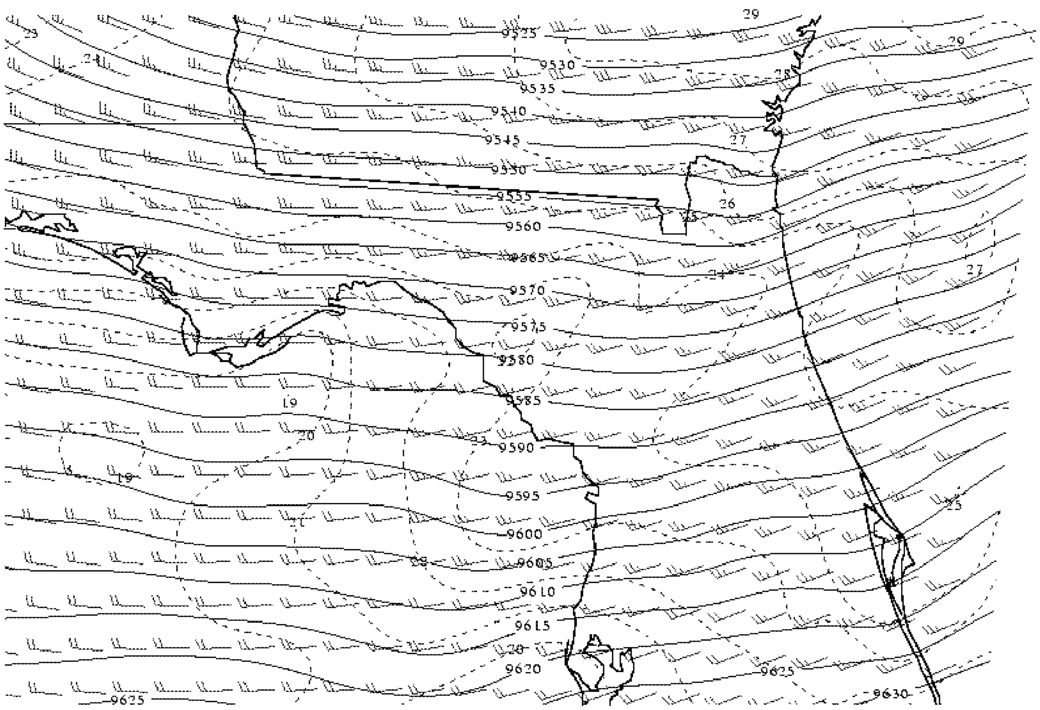
CGI Clear Air	CTY Convective
12 km Hydrostatic	18 km Hydrostatic
6 km Hydrostatic	6 km Hydrostatic
2 km Nonhydrostatic	2 km Nonhydrostatic
Enhanced Vertical	Bogus Raob RH
500m Nonhydrostatic	500m Nonhydrostatic
125m Nonhydrostatic	125m Nonhydrostatic
60m Nonhydrostatic	60m Nonhydrostatic


Resultant White
FV Yellow
Along PGF Blue

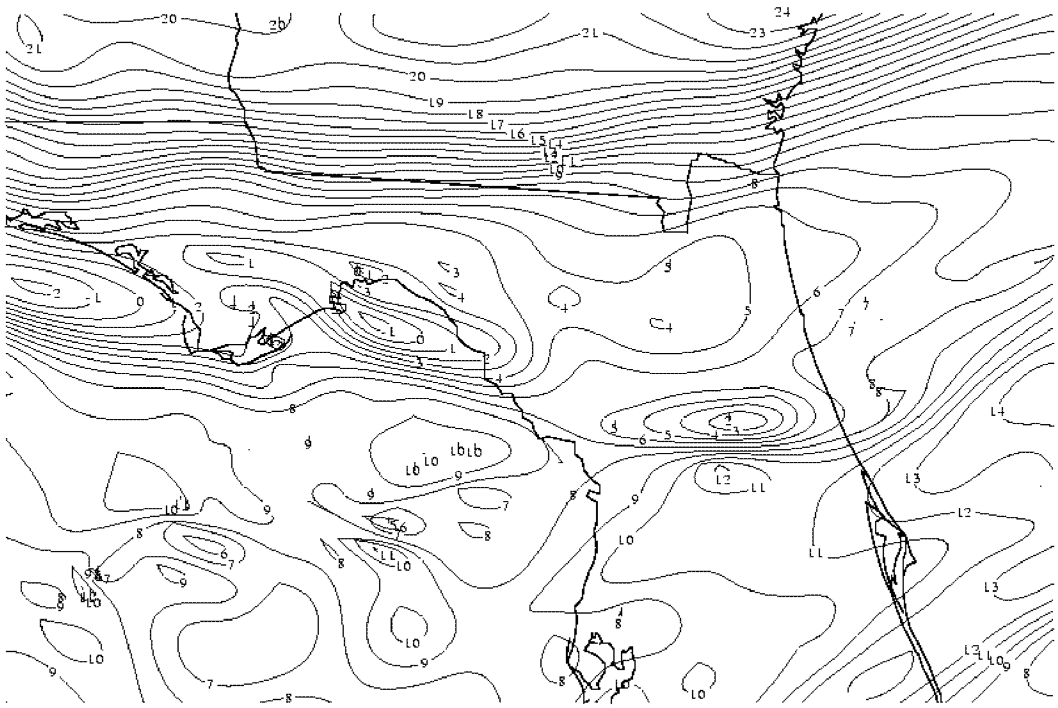

30


32.5
30
12.5
15
17.5
20
22.5
25
27.5
30
32.5
35
37.5
40
45
42.5
40
37.5

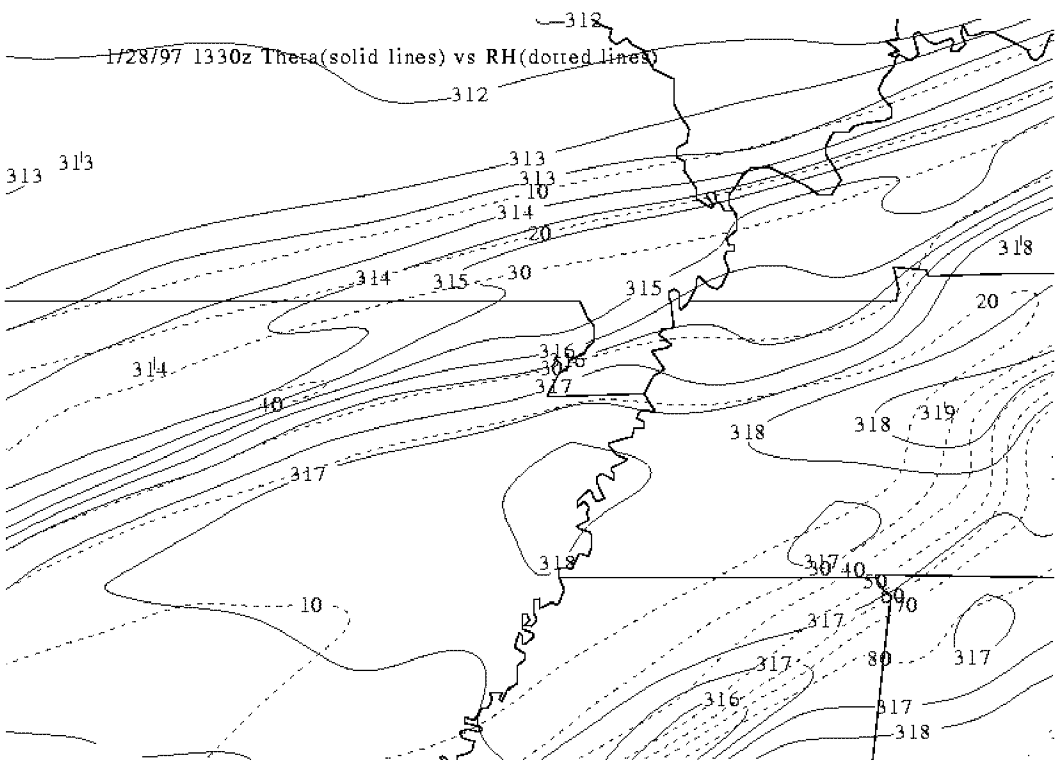

1/28/97 1330z Pot Vort 420mb to 380mb Scale=7

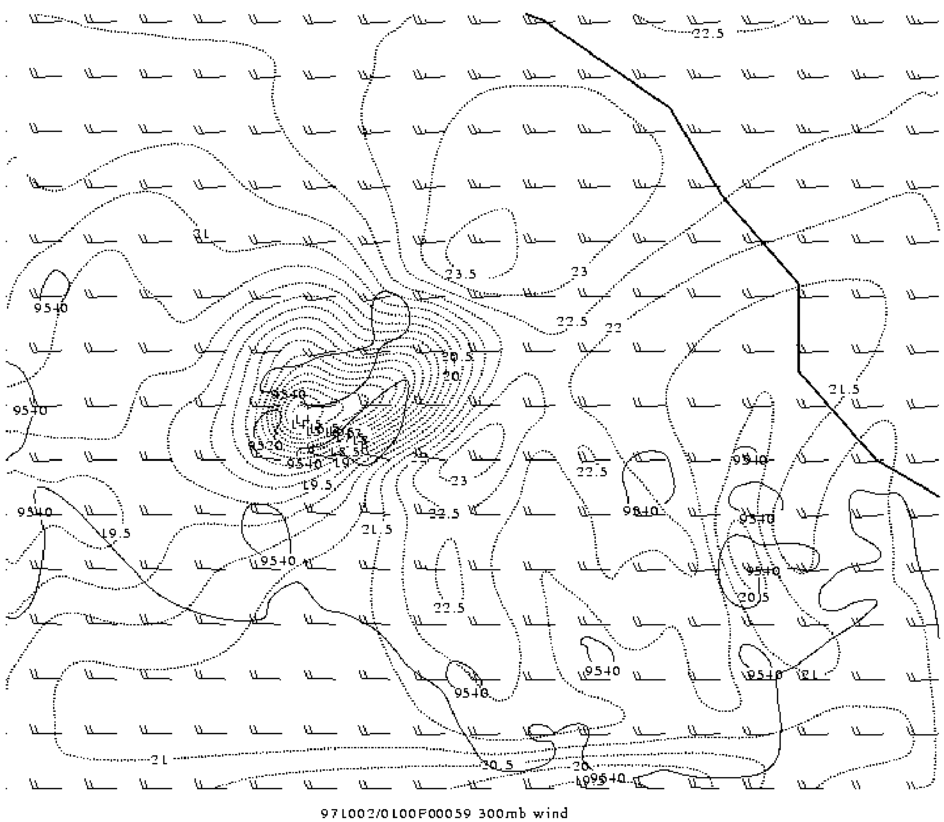


8/29/96 300 mb Heights vs Winds

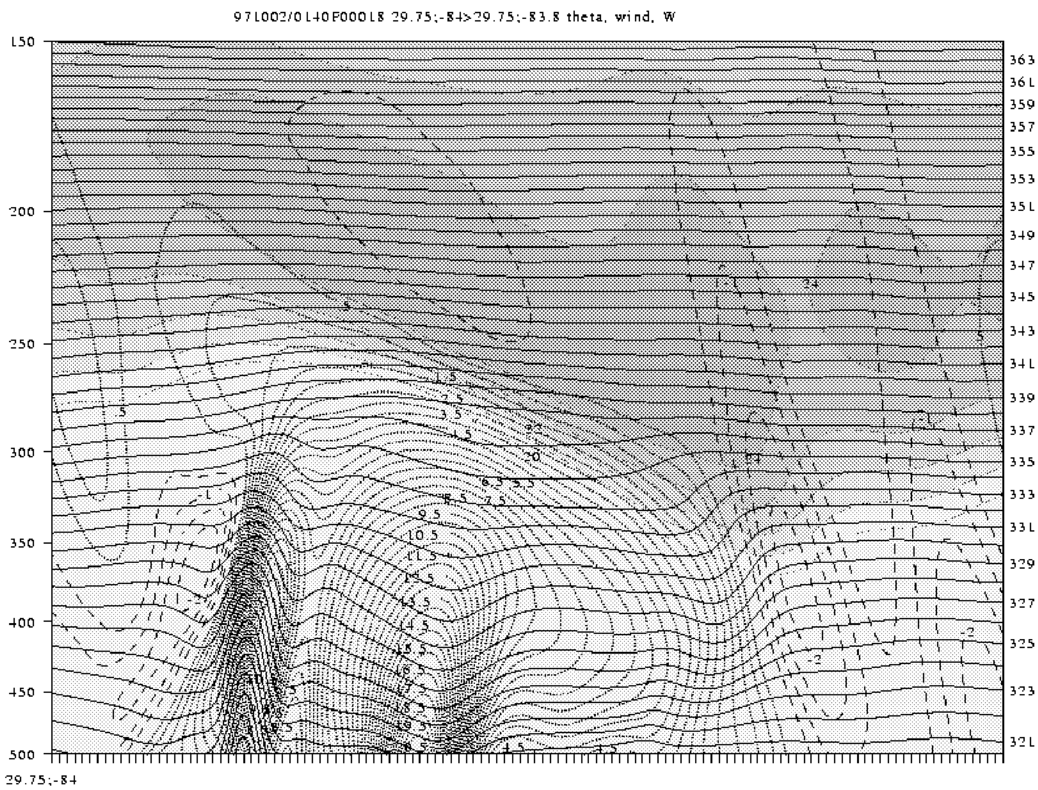


CTY Case PVOR with Theta, 0z 10/2/97


1/28/97 1330z Theta(solid lines) vs RH(dotted lines)



971002/0100F00059 300mb wind


97L002/0L40F00018 29.75;-84>29.75;-83.8 theta, wind, W
150
200
250
300
350
400
450
500
29.75;-84
363
361
359
357
355
353
351
349
347
345
343
341
339
337
335
333
331
329
327
325
323
321

Single Characterization/Forecast Index

- Cross Product of DEL(M) and DEL(ZETA)
- DEL(M) = Gradient (CpT+GZ)
- DEL(ZETA) = Gradient (DV/DX-DU/DY)
- PGF X DEL(ZETA) on Isentrope
- PGF Vector and Vortex Tube Intersect

Summary of the Organization of the Turbulence Environment

- Jet Streak Entrance Regions Merge In the Presence of Curved Flow
- Deformation Zone Forms As Momentum Converges and Centrifugal Force Increases
- Cross-Stream (Z) Vortices are Produced in Supergradient Flow Confluence Zone
- MASS Perturbation (Moist Convection /Frontogenesis) Modifies Along-Flow PGF
- (Y) Vortex Converges (Z) Vorticity=Hazard

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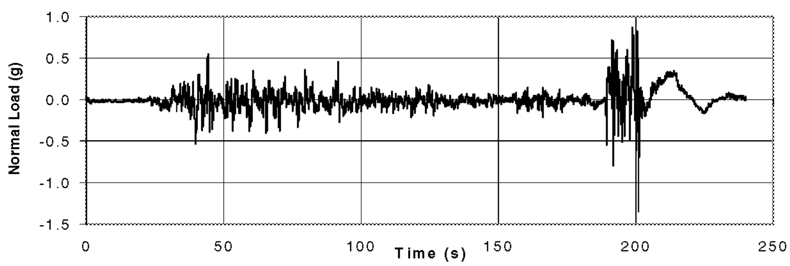
Simulations of continuous and discrete event turbulence

R. Sharman
National Center for Atmospheric Research
Research Applications Program
Boulder, CO

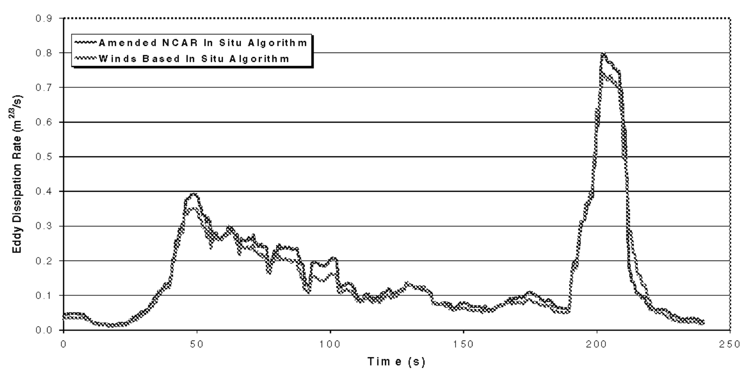
Second AvSP WxAP Annual Project Review
Cleveland, Ohio
6 June 2001

Continuous vs. discrete turbulence



☜ Measured vertical acceleration from NASA flight test

Wind derived vs in-situ algorithm



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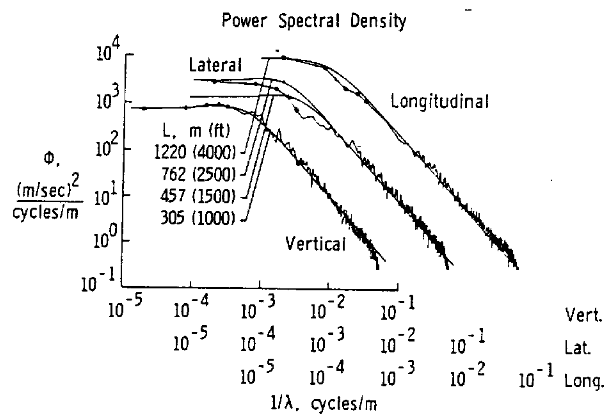
Continuous turbulence: Use of a von Karman representation

Advantages:

- Case studies show von Karman is a good representation
- Simple analytic formulation
- Only two parameters:
  - (correlation) length scale
  - intensity

Disadvantages:

- Larger scales may be misrepresented
- Computation that produces accurate spatial statistics is not so straightforward



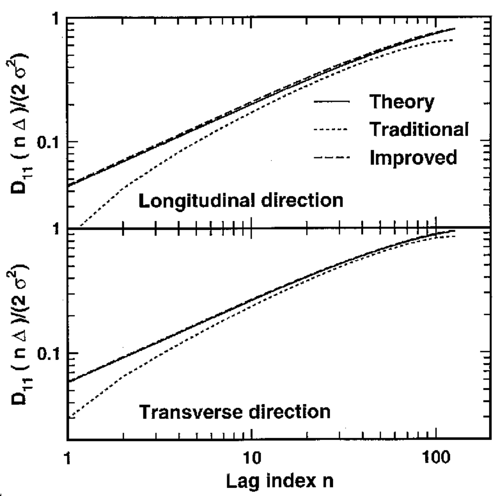
(b) Power spectral density.

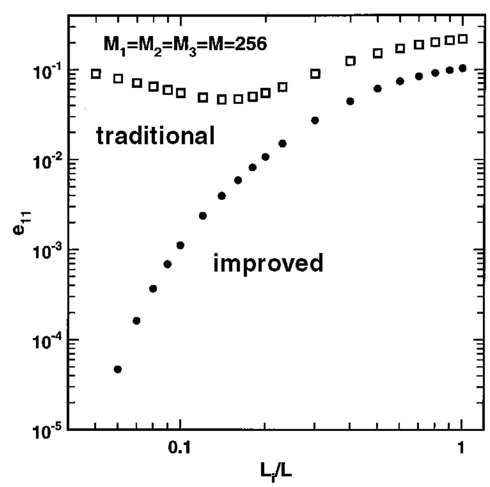
Figure 5. Convective case.

From Murrow, "Measurements of Atmospheric Turbulence", NASA CP-2468, 1986

von Karman Turbulence Simulations

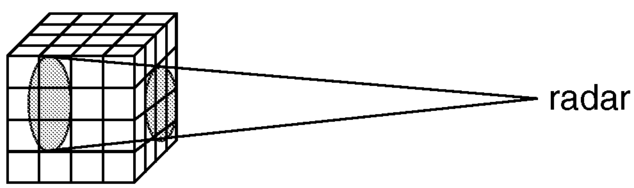
- Uses technique of Frehlich, Cornman, Sharman which minimizes errors in structure (correlation) functions





von Karman Turbulence Simulations: Applications to radar detection

- Using von Karman turbulence data with known statistics + radar simulation allows evaluation of radar turbulence estimation algorithms

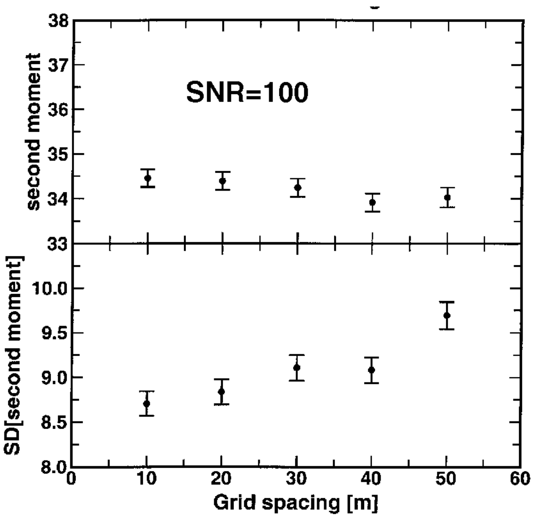


Von Karman
gridded 3d
fields of
velocity and
reflectivity

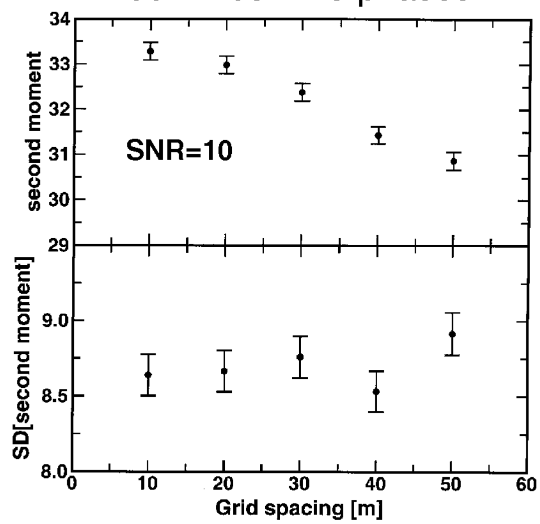
von Karman Turbulence Simulations: Applications to radar detection (cont.)

Q: What simulation grid resolutions are required?

A: It depends!



200 winds X 25 phases



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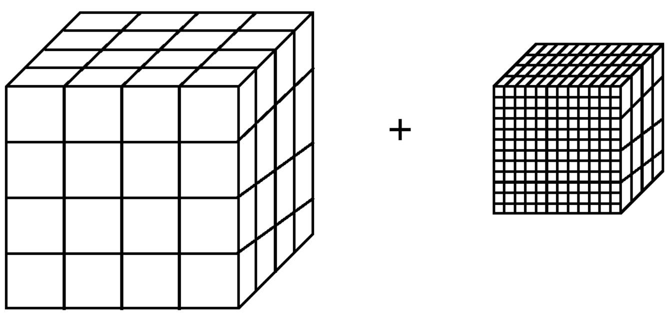
von Karman Turbulence Simulations: Applications to mesoscale cloud models

- Numerical simulations of clouds are good at resolving larger scales but smaller scales are misrepresented
- But von Karman is a good representation of smaller scales
- So add the two, modulating the von Karman intensities by the large scale resolved motion



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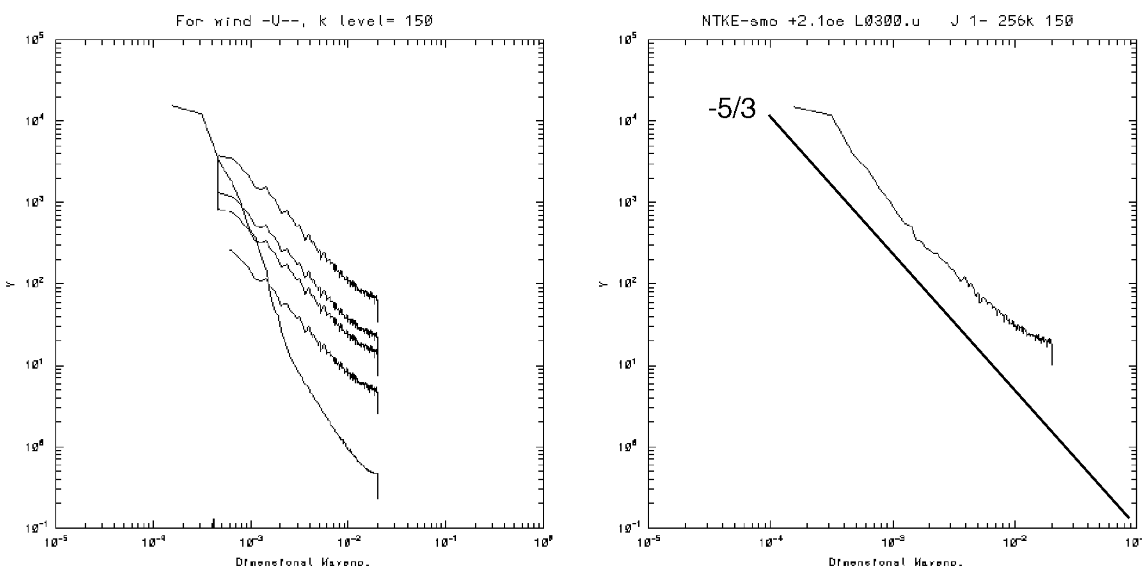
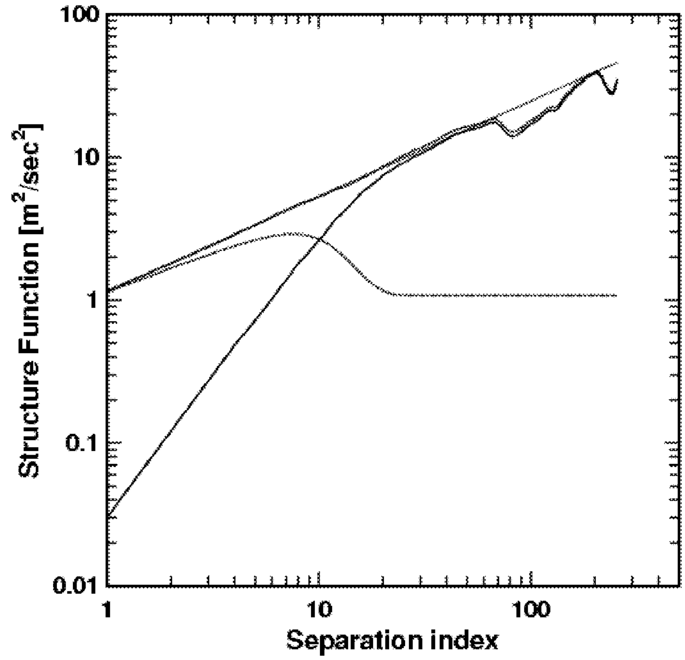
Numerical simulations + von Karman subgrid. Merged spectrum

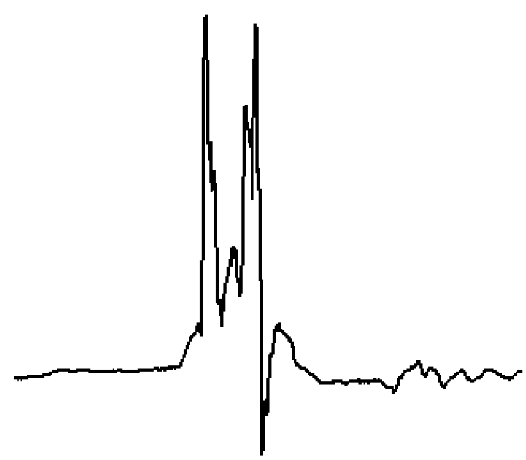


Numerical simulations + von Karman subgrid. Structure function fit and merger



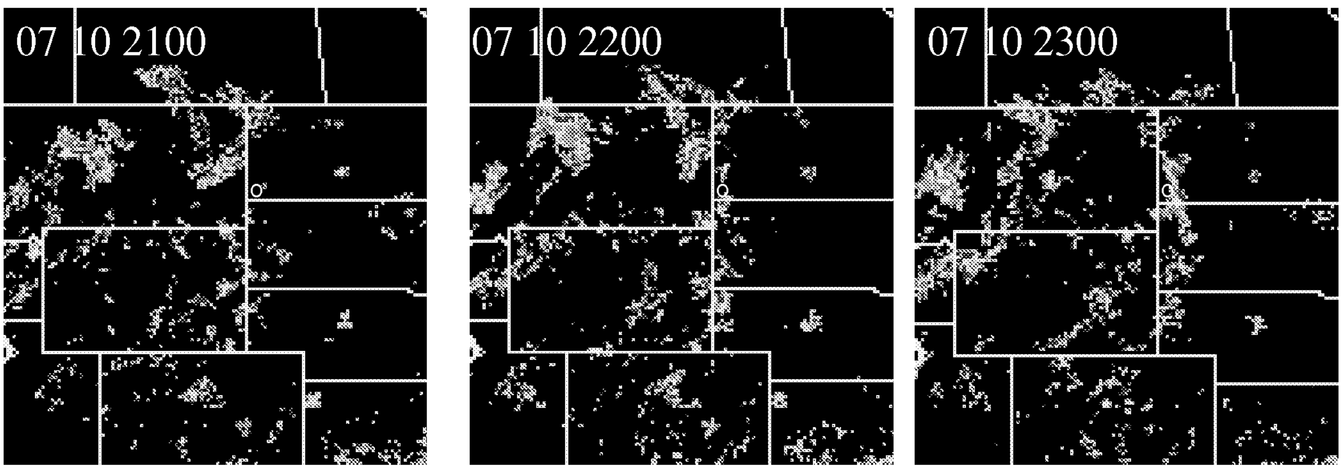
Discrete event simulation

- American Airlines 757 encountered severe clear-air turbulence at 37,000 ft enroute SEA-JFK 10 July 1997 2141 Z near Dickinson ND
- 12 sec, -.75 - + 2.01 g's
- 22 injuries, flight diverted to DEN
- No sigmet in area



Vertical velocity trace from FDR

Discrete event simulation (cont) - radar mosaic



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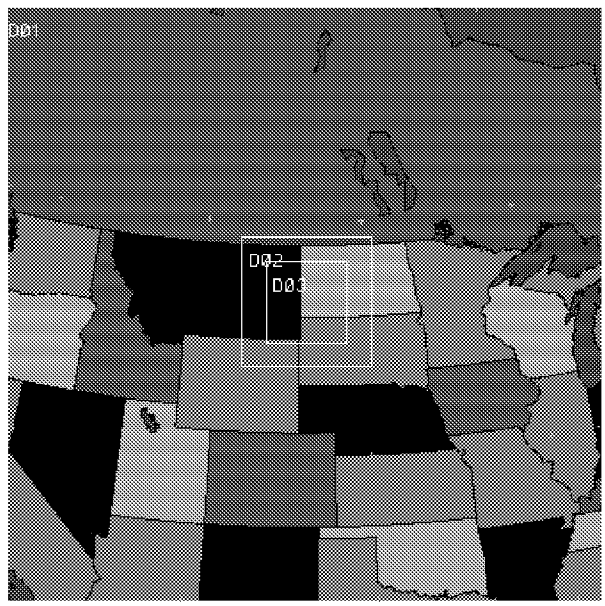
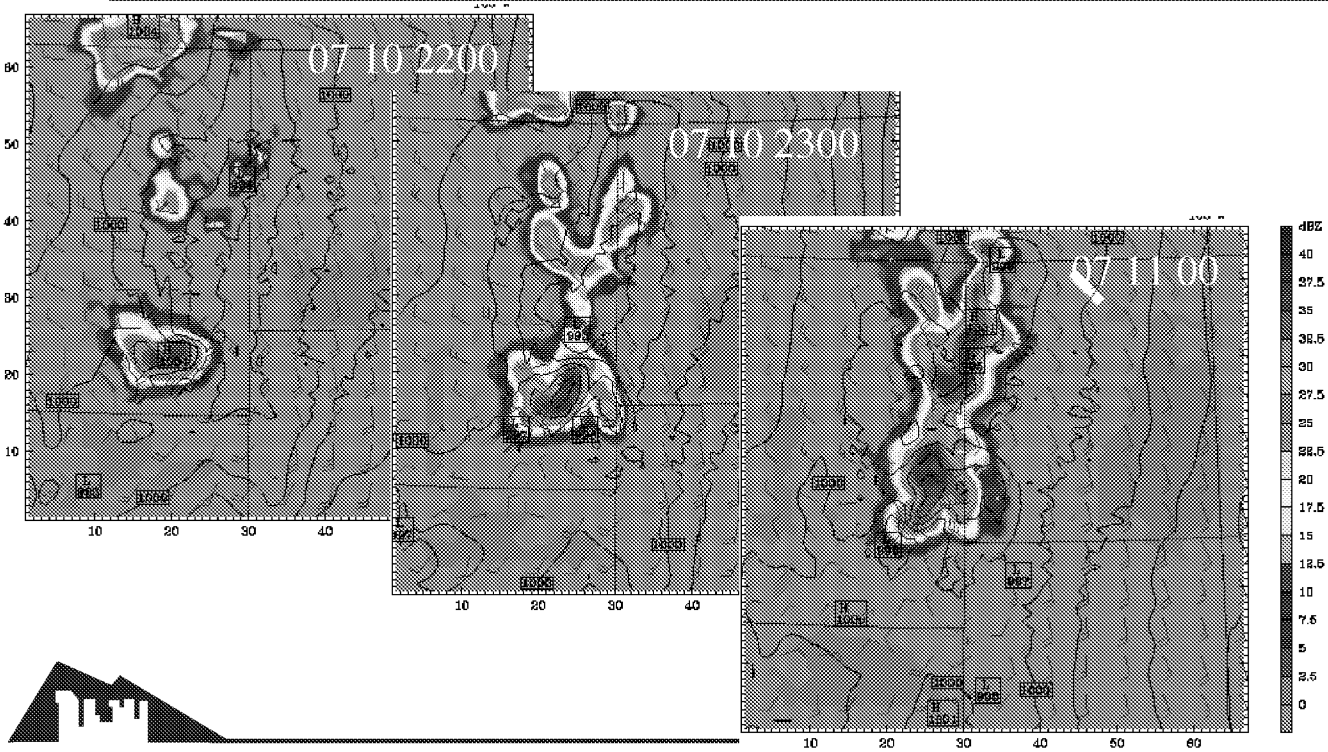
Dickinson,ND discrete event simulation

- **3 step procedure**
  - MM5 simulation
    - triply nested grid (27,9,3 km)
    - 35 vertical levels
  - Clark-Hall cloud model
    - nested grids, highest resolution 50 m
  - Add subgrid von Karman

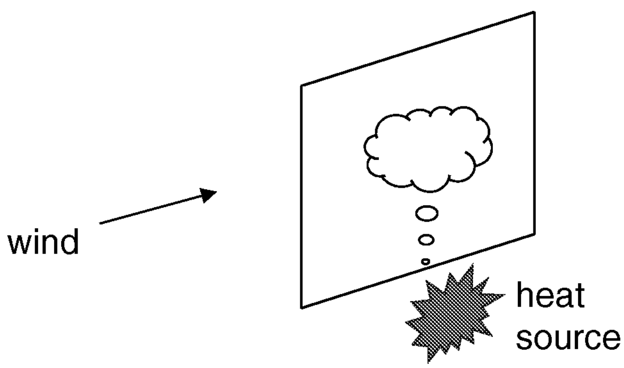


Dickinson,ND discrete event simulation - MM5 results

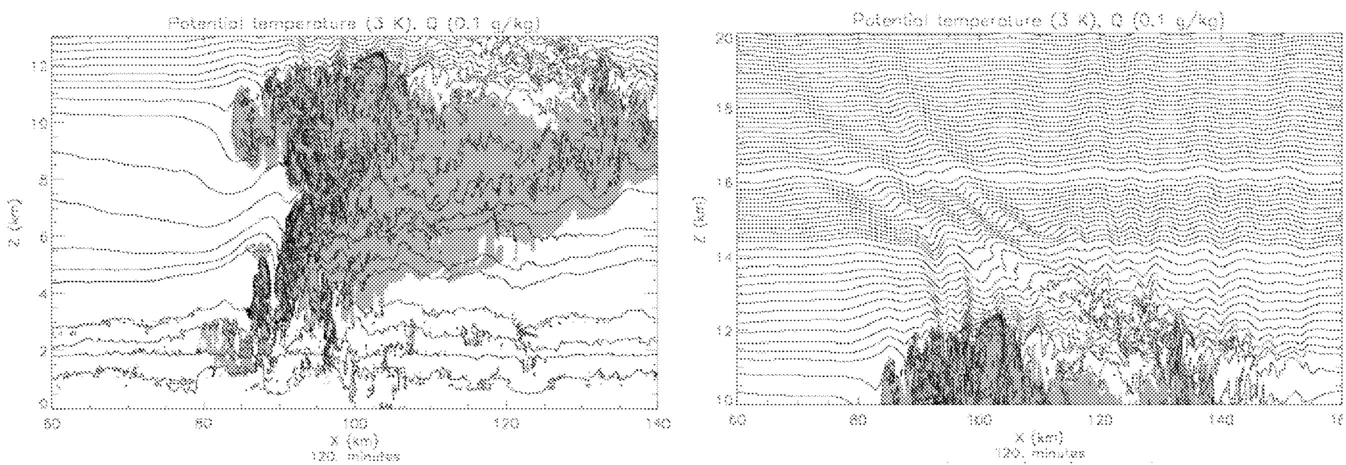


Dickinson,ND discrete event simulation - 2d high resolution simulations

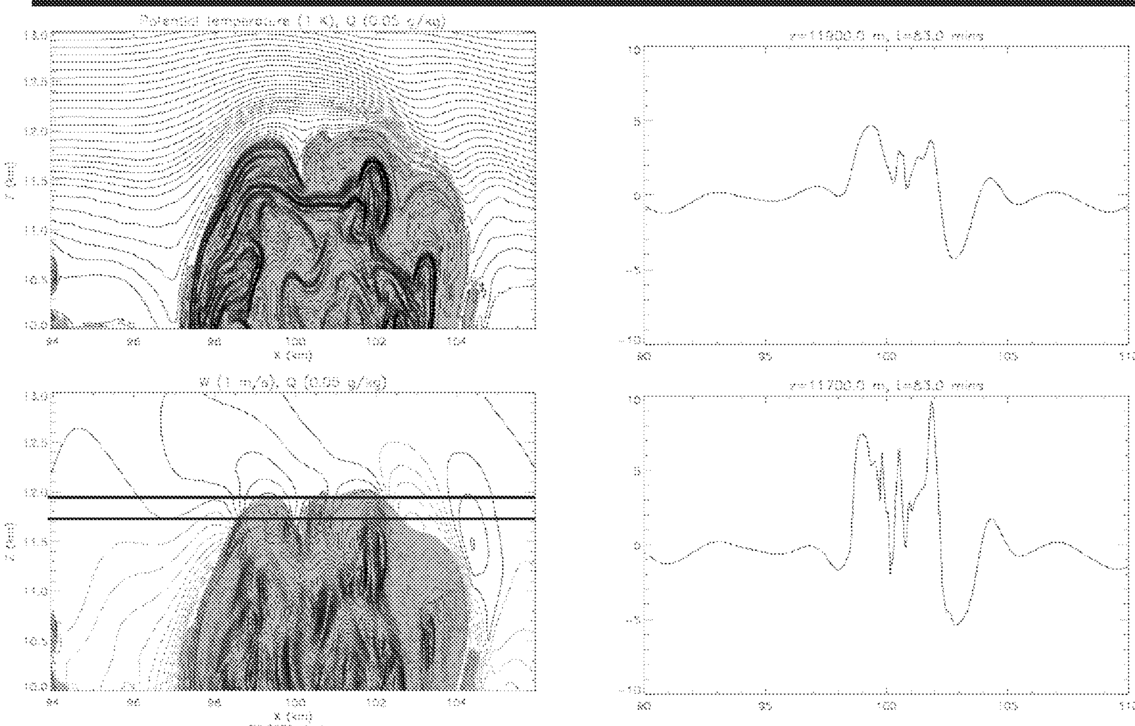
- 2d simulations aligned with flow
- High resolution (16m) Clark-Hall cloud model
- Clouds forced by heated surface
- Initialized with Bismarck, ND 0Z sounding



Dickinson,ND discrete event simulation - 2d high resolution simulations: results



Dickinson,ND discrete event simulation - 2d high resolution simulations: results



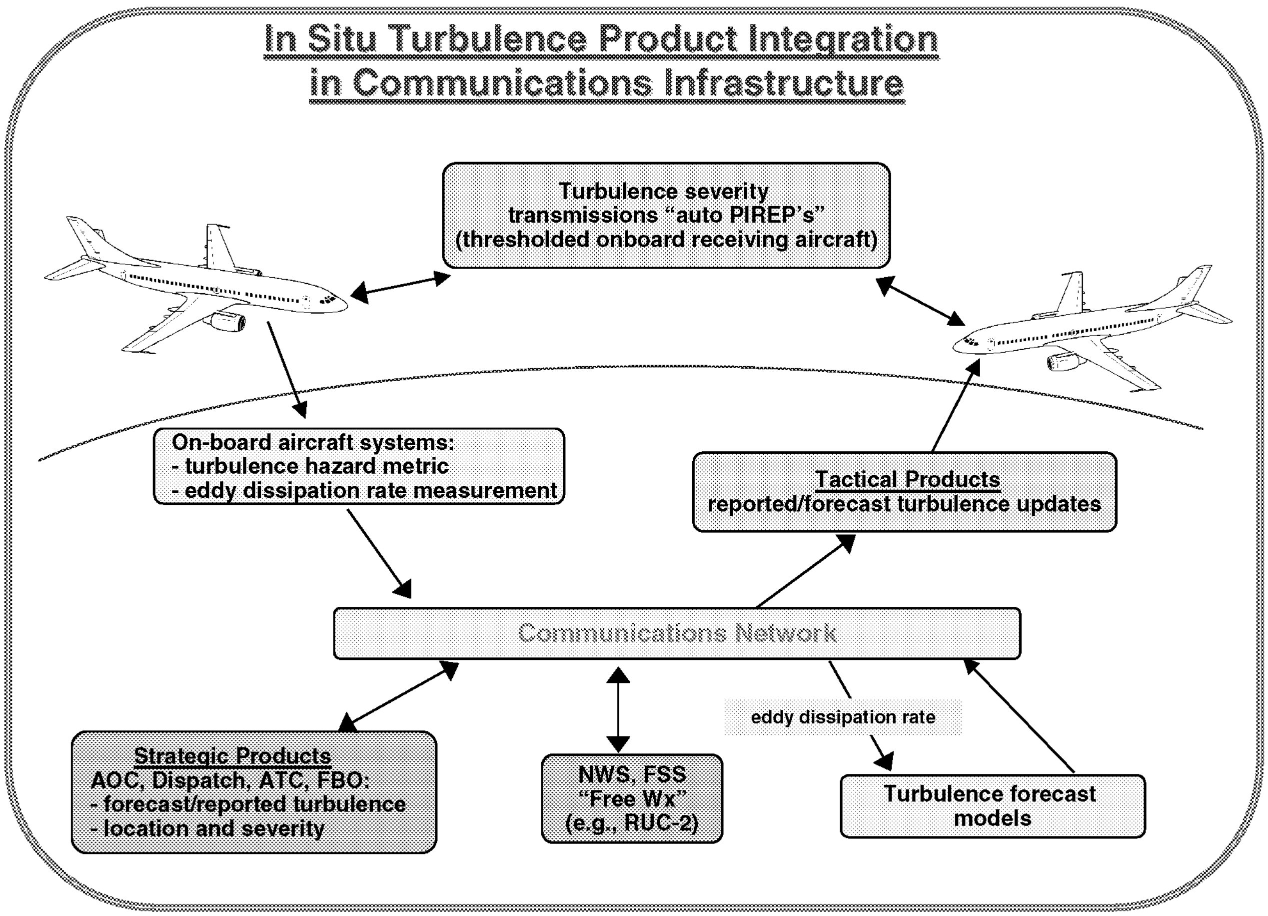
National Center for Atmospheric Research

Development and Flight Test of In Situ Turbulence Algorithms

Paul A. Robinson

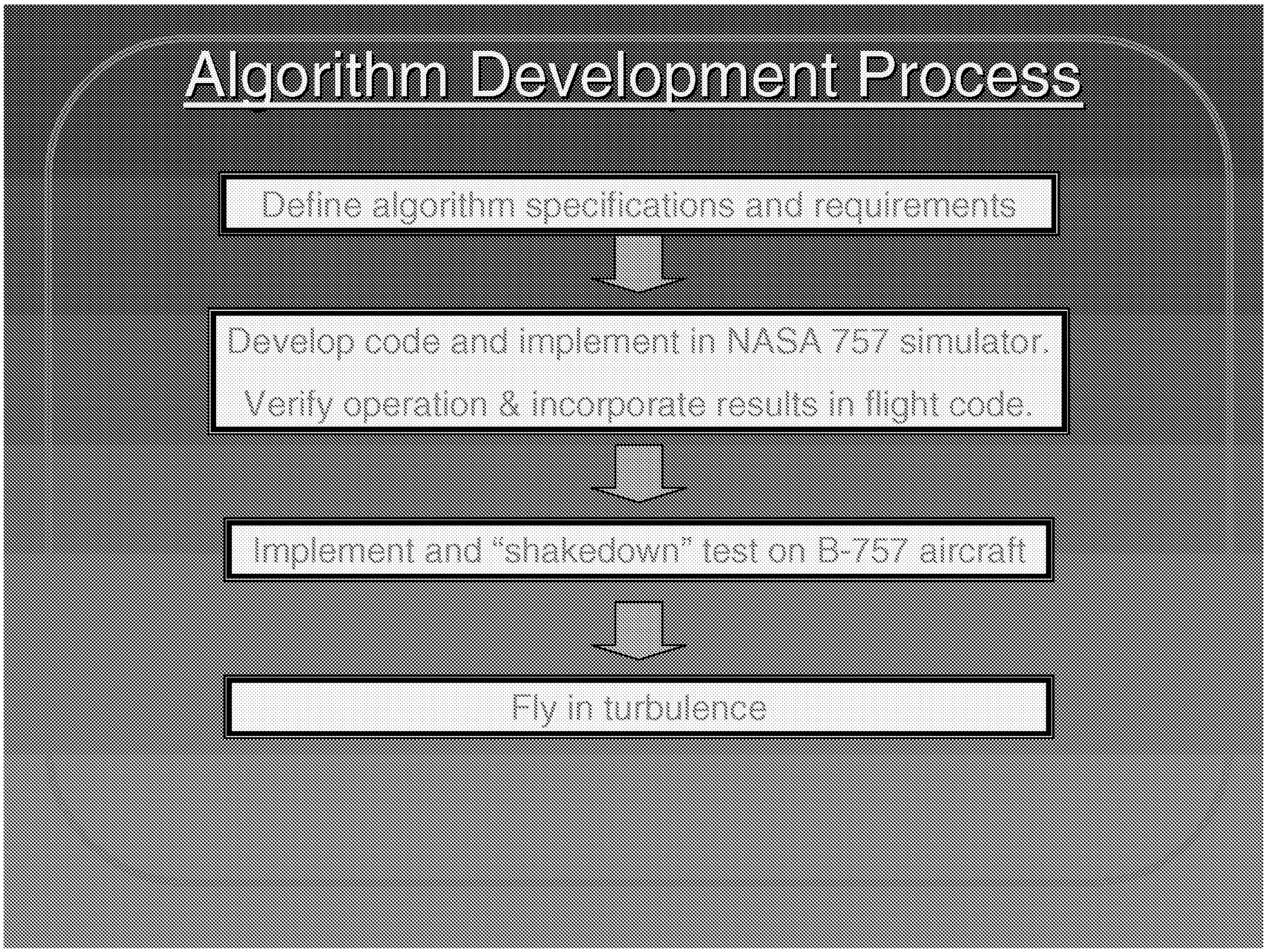
AeroTech Research (USA), Inc.
Hampton, VA 23666

2nd Weather Accident Prevention Annual Project Review
Cleveland, OH, June 5-7, 2001

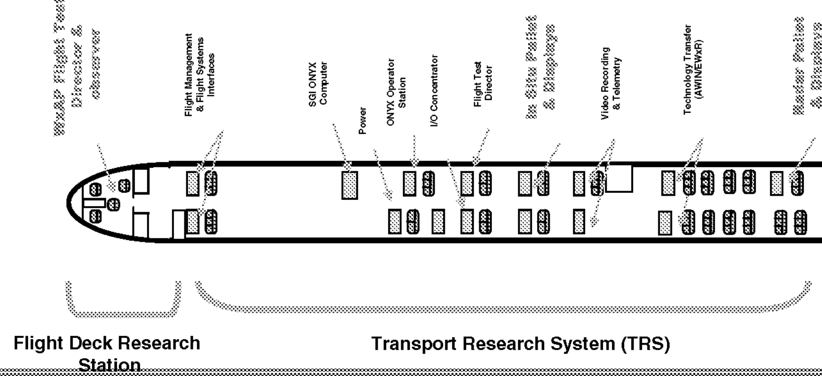

In Situ Turbulence Product Integration
in Communications Infrastructure
Turbulence severity
transmissions "auto PIREP's"
(thresholded onboard receiving aircraft)
On-board aircraft systems:
- turbulence hazard metric
- eddy dissipation rate measurement
Tactical Products
reported/forecast turbulence updates
Communications Network
eddy dissipation rate
Strategic Products
AOC, Dispatch, ATC, FBO:
- forecast/reported turbulence
- location and severity
NWS, FSS
"Free Wx"
(e.g., RUC-2)
Turbulence forecast
models

AeroTech's Task Areas

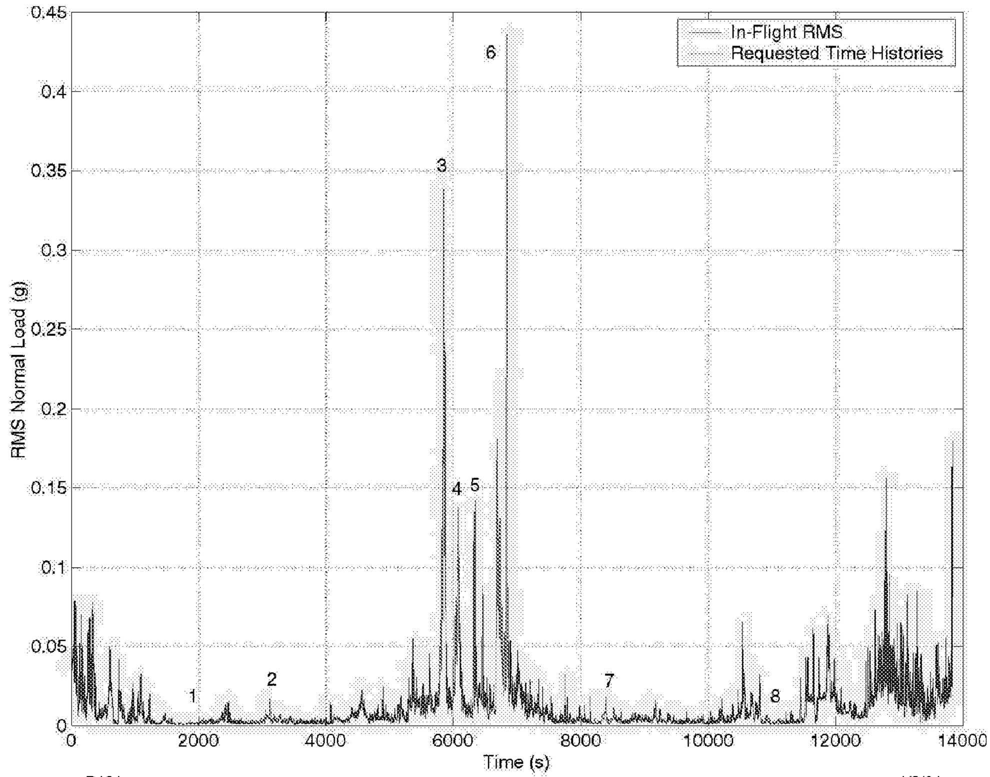
- **Develop, implement, and test in situ algorithms on NASA B-757 Research Aircraft:**
  - **3-D wind & turbulence recovery**
  - **atmospheric/meteorological diagnostics**
  - **distributed load analysis**
  - **hazard metric for radar**
- **Data analysis of flight test data**
- **Support radar algorithm development**


Algorithm Development Process
Define algorithm specifications and requirements
Develop code and implement in NASA 757 simulator.
Verify operation & incorporate results in flight code.
Implement and "shakedown" test on B-757 aircraft
Fly in turbulence

NASA B-757 Turbulence Flight Experiment Setup



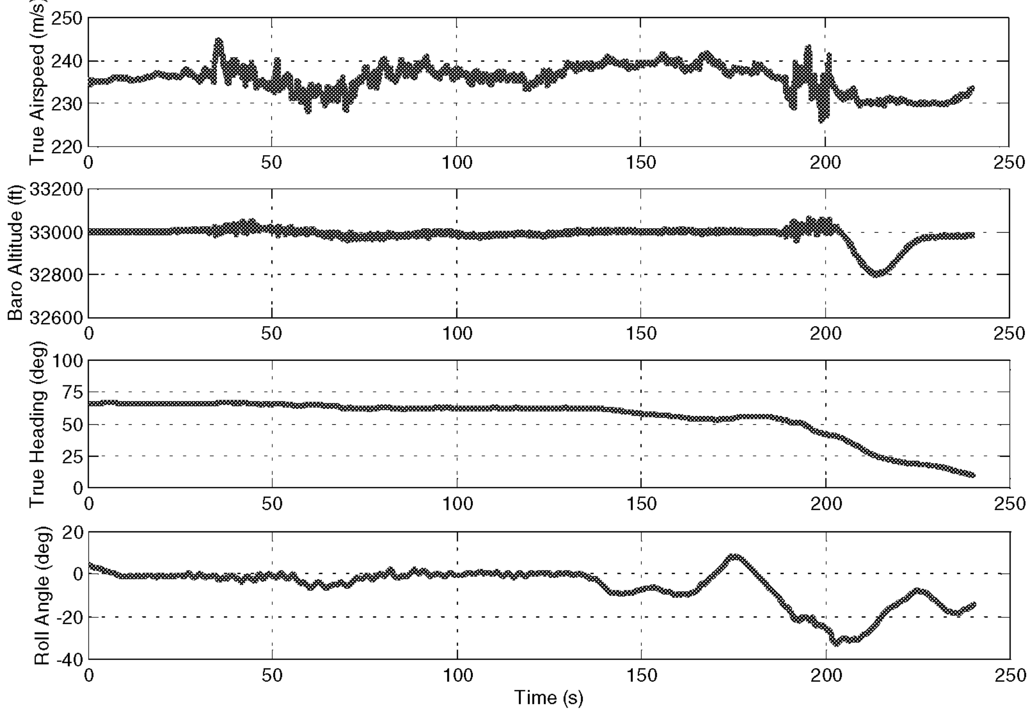
RMS Normal Load - Flight 191

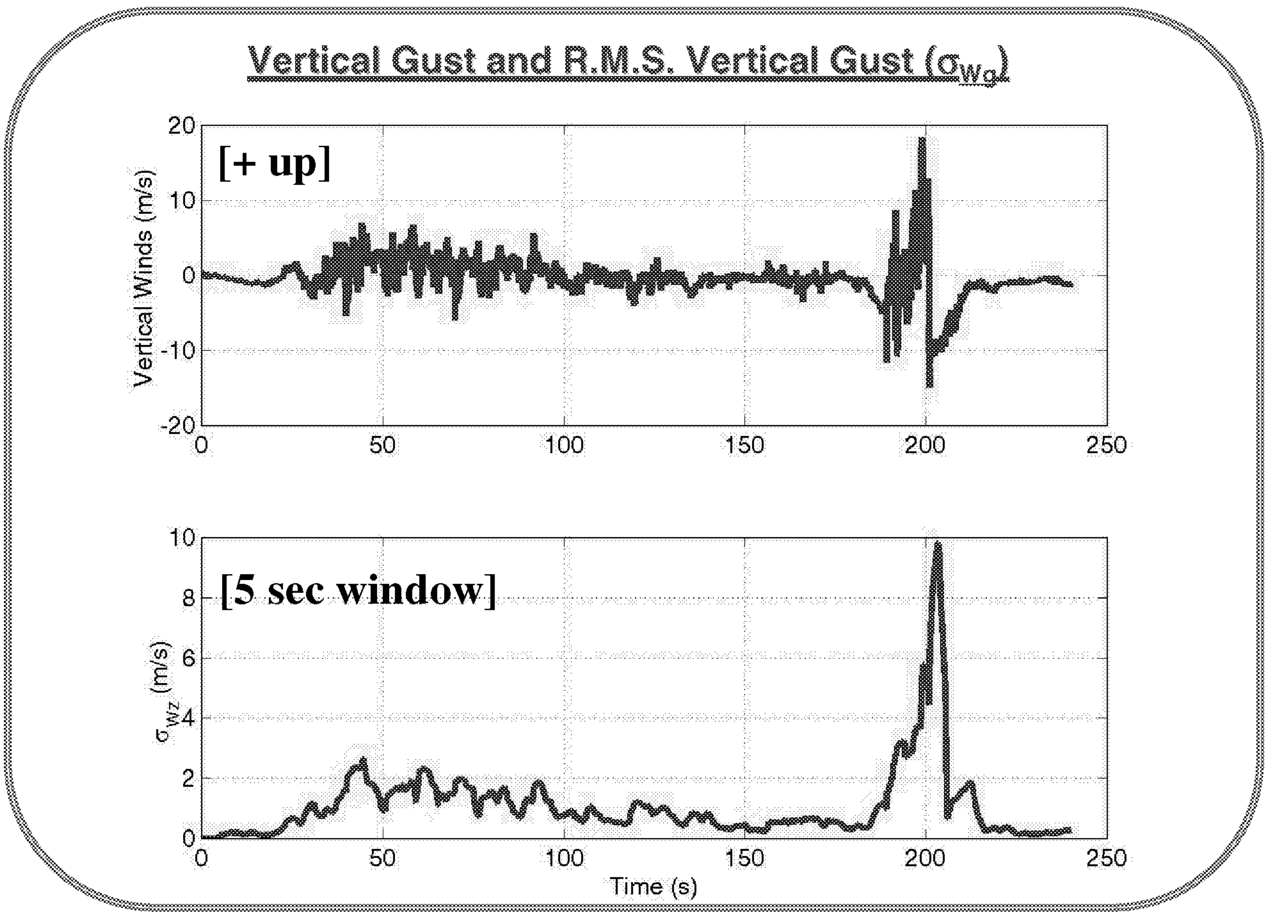


B191

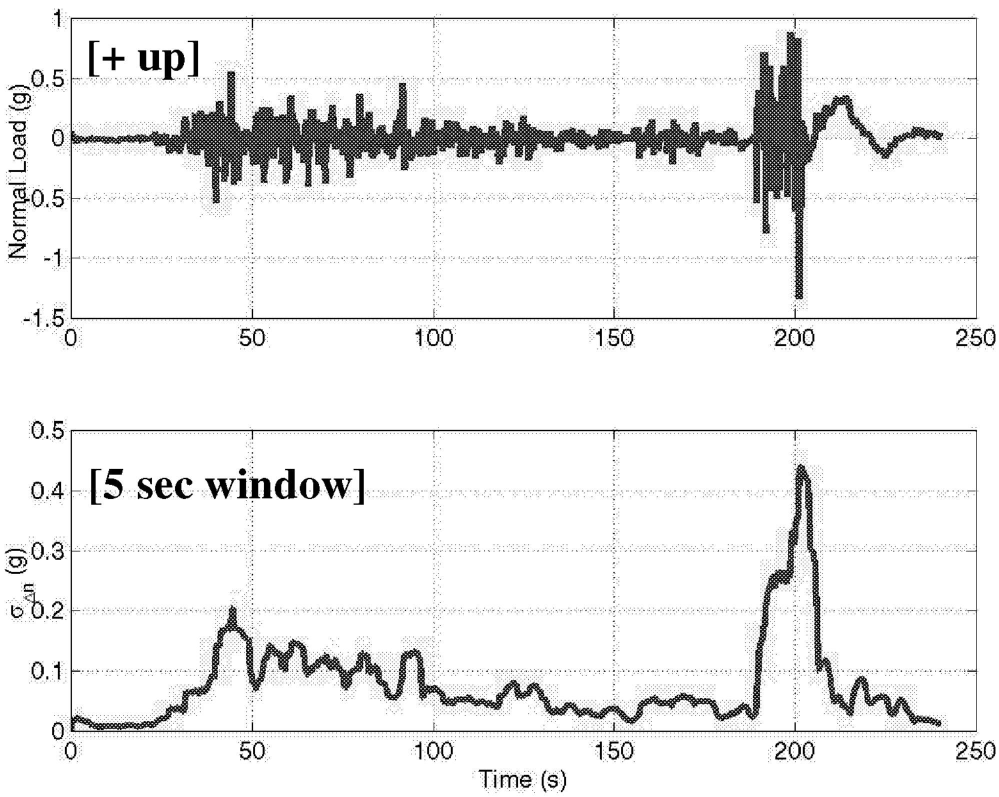
1/8/01

Flight Conditions: *R191-06*



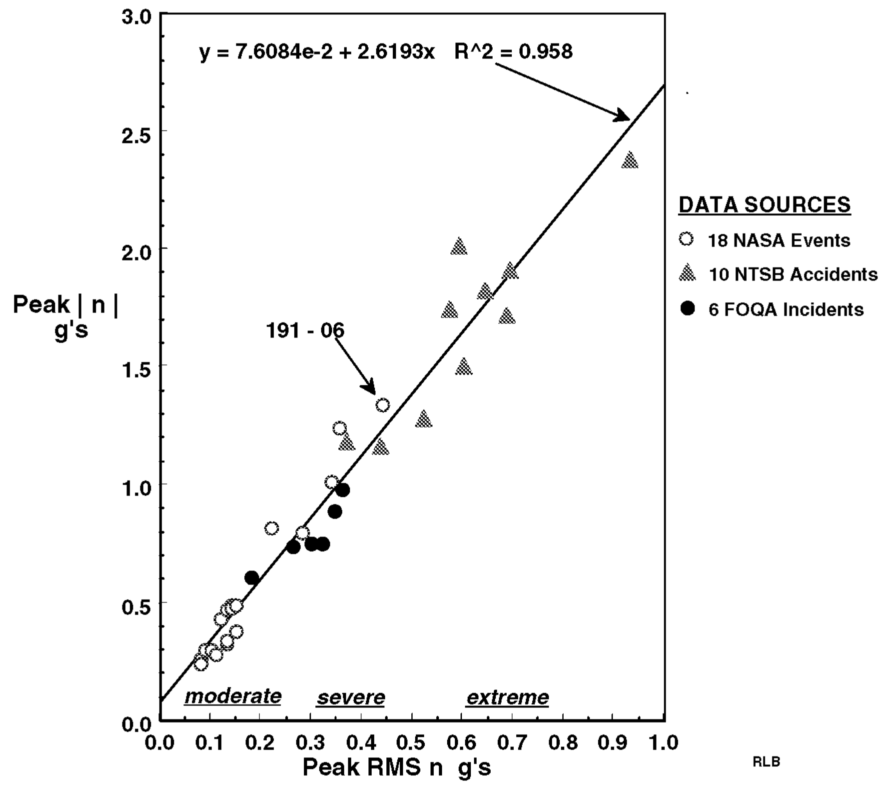

Vertical Gust and R.M.S. Vertical Gust (σ_{Wg})
[+ up]
Vertical Winds (m/s)
20
10
0
-10
-20
0
50
100
150
200
250
[5 sec window]
σ_{Wz} (m/s)
10
8
6
4
2
0
0
50
100
150
200
250
Time (s)

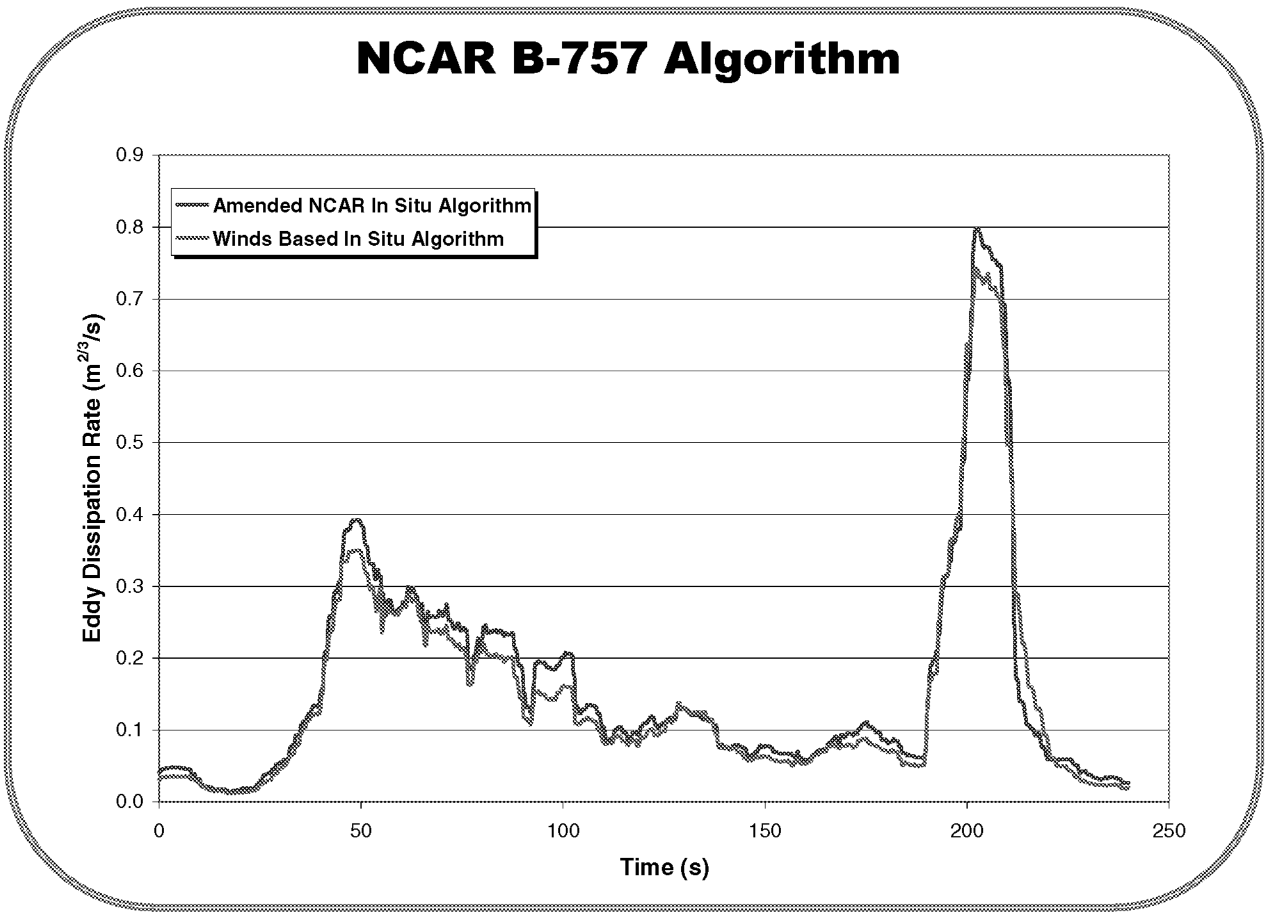
Normal Load and R.M.S. Normal Load ($\sigma_{\Delta n}$)



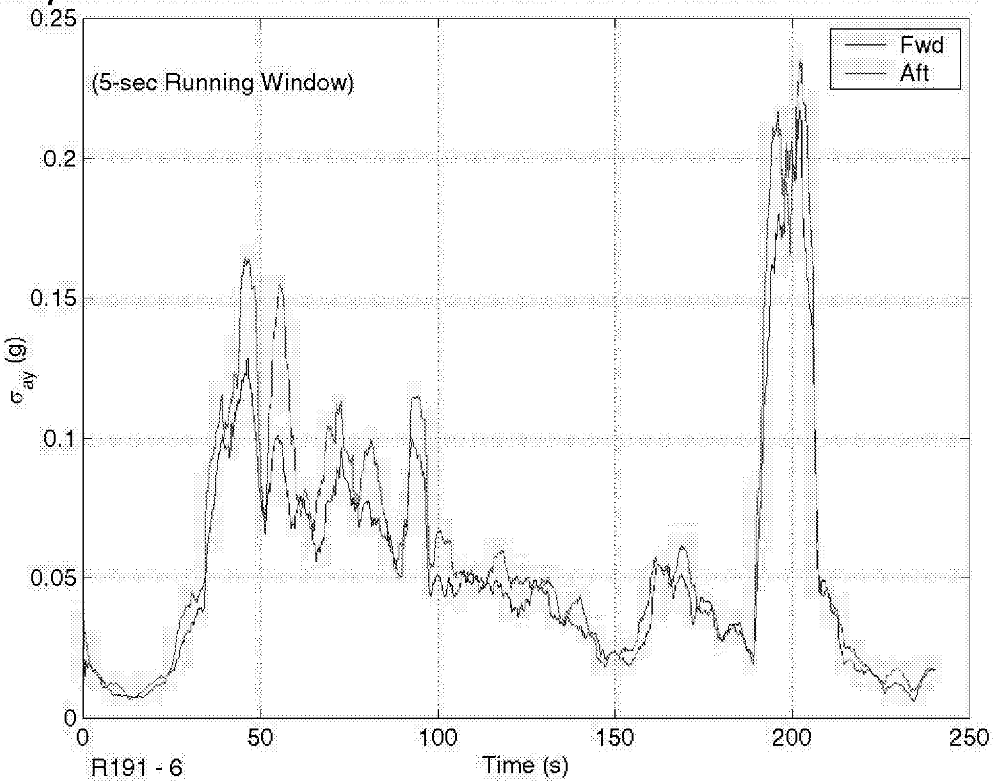
Correlation of Peak Load With Peak RMS Load (5 sec. window)

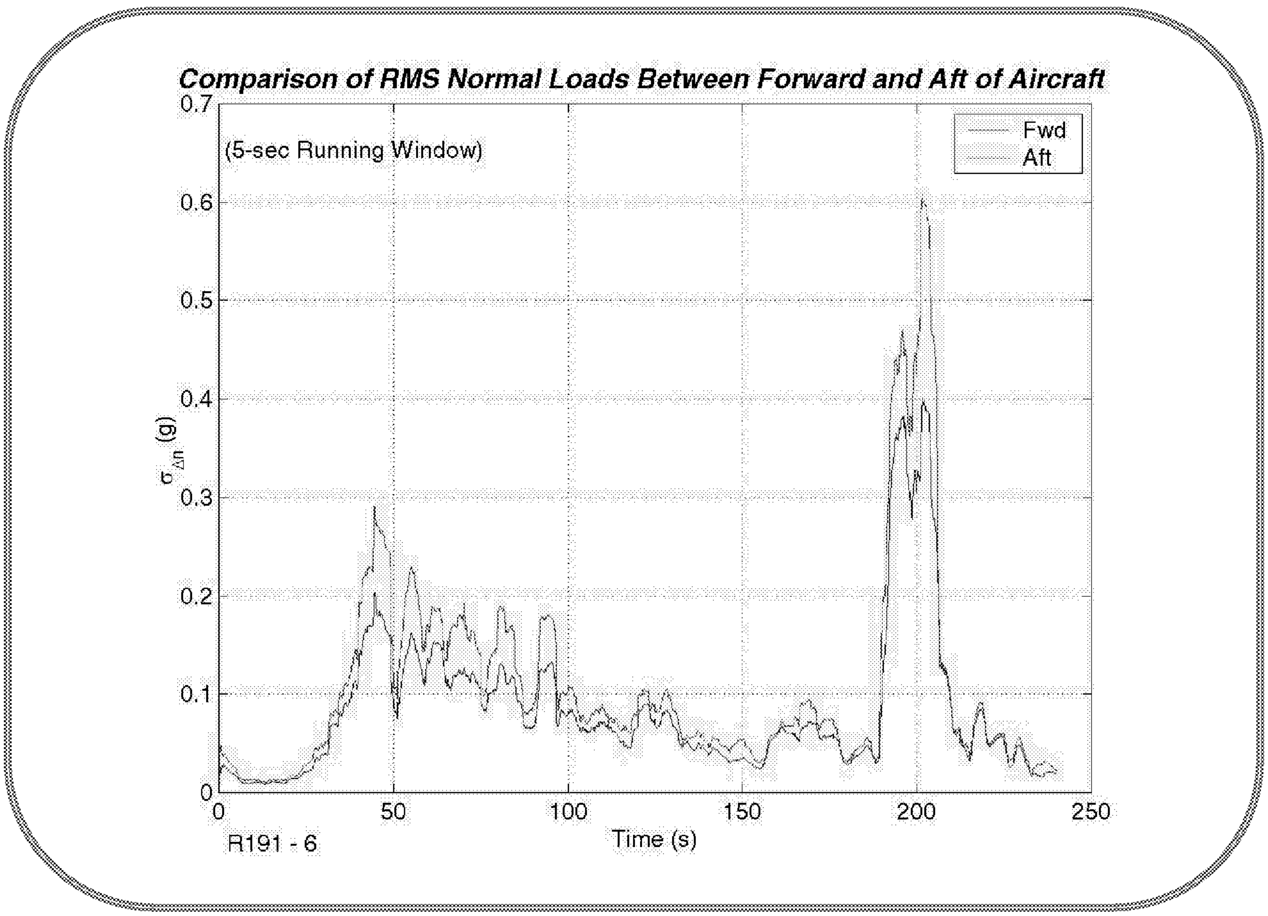
Based on Measurements for 34 Turbulence Encounter Cases



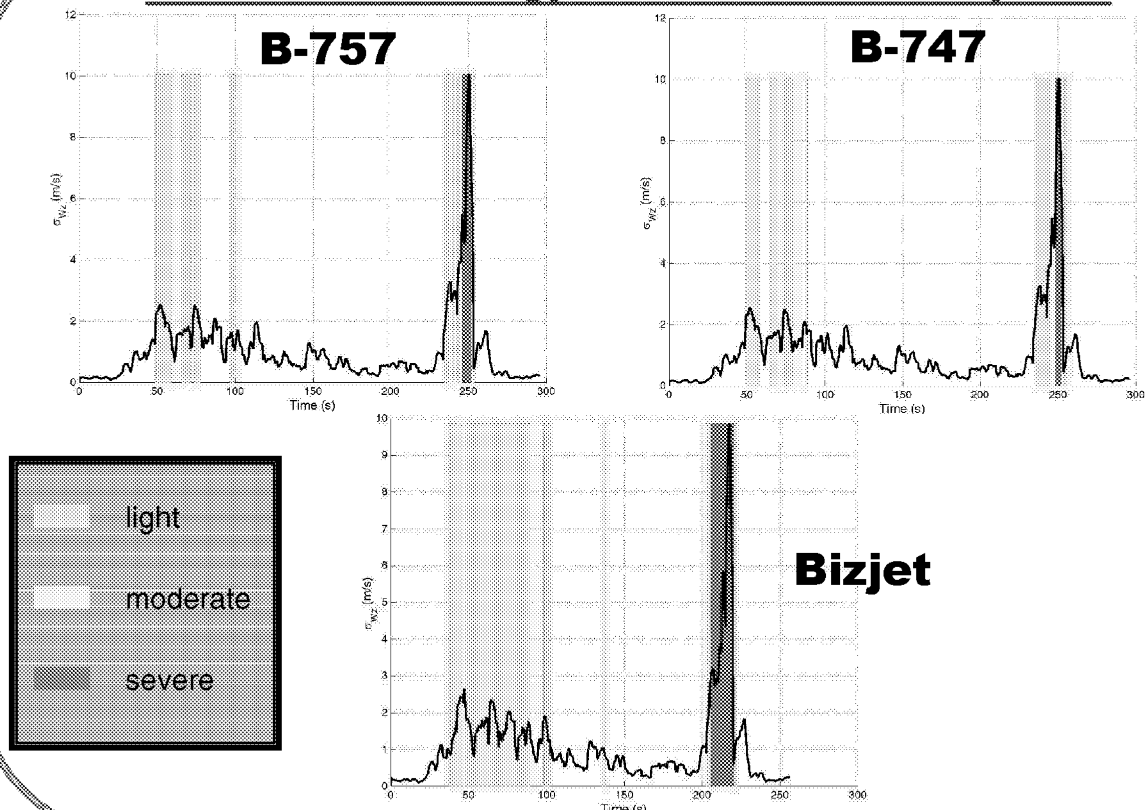

NCAR B-757 Algorithm
Amended NCAR In Situ Algorithm
Winds Based In Situ Algorithm
Eddy Dissipation Rate (m^2/3/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
50
100
150
200
250
Time (s)

Comparison of RMS Lateral Accelerations Between Forward and Aft of Aircraft




Comparison of RMS Normal Loads Between Forward and Aft of Aircraft
(5-sec Running Window)
Fwd
Aft
$\sigma_{\Delta n}$ (g)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
50
100
150
200
250
Time (s)
R191 - 6

Effect of Aircraft Type on Turbulence Response



Future Work

- Continue flight test of algorithms
- Support fleet implementation of NCAR algorithm
- Continue radar algorithm development support including certification process

NASA/CP—2002-210964

Turbulence Lidar Development Status

Weather Accident Prevention (WxAP)
Annual Project Review

Ivan Clark
NASA Langley Research Center

Philip Gatt and Stephen Hannon
Coherent Technologies, Inc.

Cleveland, OH, Hilton South
June 5-7, 2001

Overview

Aviation Safety Program

- Background information
- Technical accomplishments to date
  - ground and flight test activities
- Plans
  - flight test activities
  - algorithm development and performance simulation

Overview

Aviation Safety Program

- Background information
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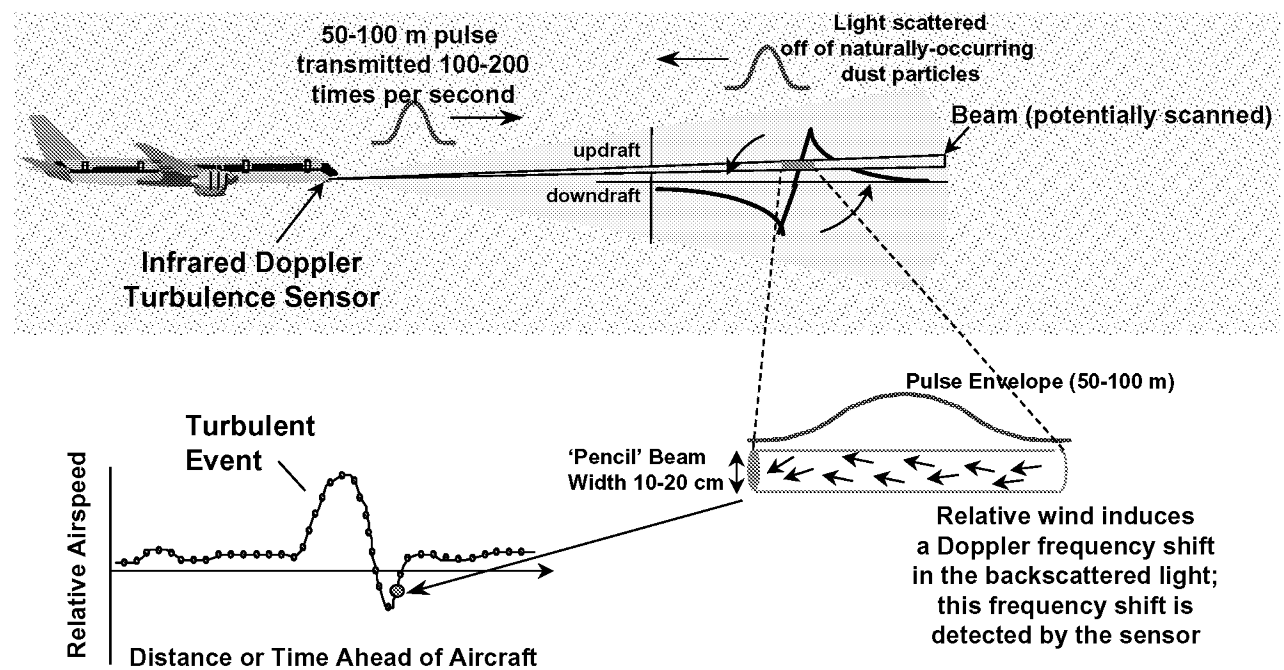
  - flight test activities
  - algorithm development and performance simulation

General Principle of Infrared Doppler Radar (Lidar) Turbulence Measurement

Aviation Safety Program



Turbulence Product Development Team Objective

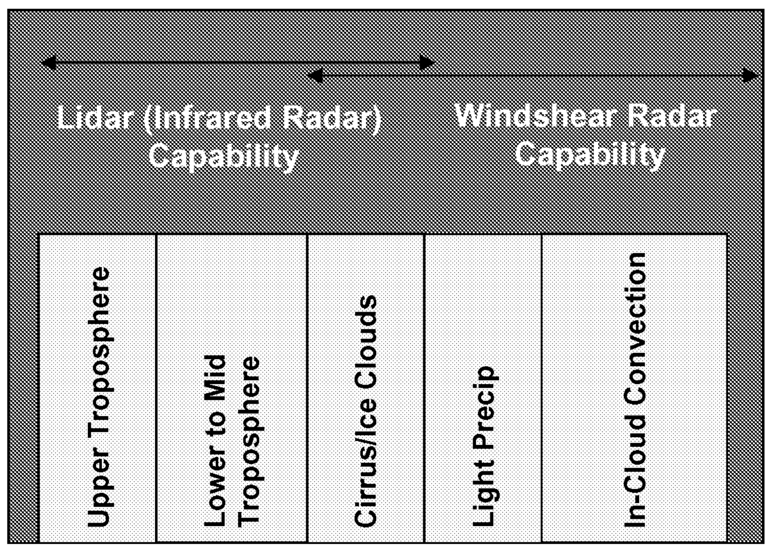
- **Develop a robust detection capability that spans the full range of turbulence environments**
  - Provide Timely Reliable Tactical Warning to:
    - Deviate,
    - Institute Cabin Safety Measures, and/or
    - Institute Mitigation Measures
  - Provide Real-Time Alerts to AWIN Network

Complete Detection Capability Provided through Dual Wavelength Radar

Aviation Safety Program

<u>TDAM Objective</u>: Develop a robust detection capability that spans the full range of turbulence environments

- **Convective Storms (within and as far as 40 miles away from visible clouds in clear air)**
- **Jet Stream (at confluence of multiple streams and near boundaries)**
- **Mountain Wave (upward propagating from disturbances near the surface)**



X-Band Radar			0 dBZ	10 dBZ		30 dBZ	50 dBZ	
Lidar units	-100 dBβ	-80 dBβ		-60 dBβ		-40 dBβ		

Reflectivity

Technology Readiness Development Needs

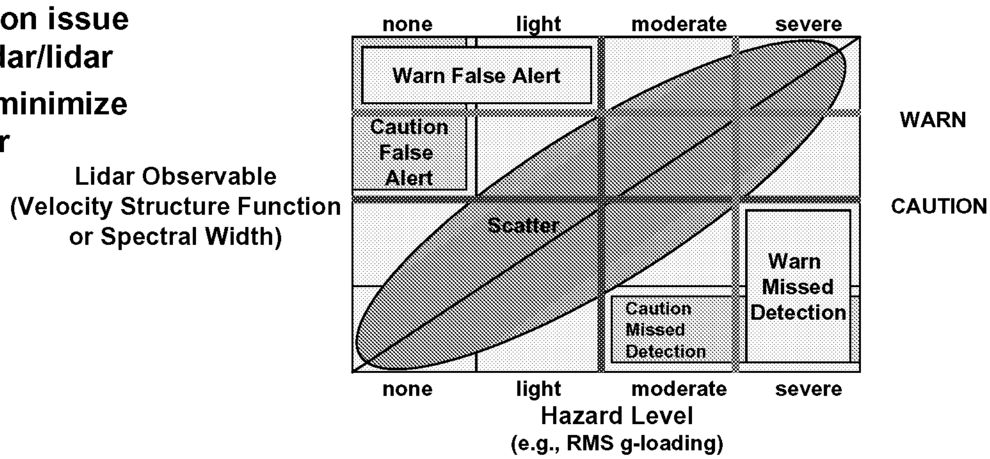
Aviation Safety Program

- **Lidar needs are similar to those for microwave radar and include:**
  - definition and characterization of hazard
  - hazard algorithm for quantifying the threat
  - validated algorithm(s) for using the IR radar to detect, discriminate, and quantify the threat
  - simulation test case development
  - validated system performance with properly designed field tests

Detection Issues

Aviation Safety Program

- **Detection/False Alert must consider the random nature of turbulence**
  - multiple turbulence warning levels
  - multiple turbulence classes/types
  - viewing longitudinal velocity behavior and inferring the vertical
- **Definition of errors required (not just Type I and Type II)**
  - common issue for radar/lidar
  - must minimize scatter



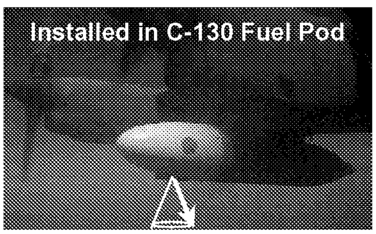
Flight Testing: Objectives and Needs

- **More flight hours at cruise altitudes**
  - identified as a major gap
  - measuring turbulence levels requires a large number of flight hours
- **More flight hours in moderate or stronger turbulence**
  - mid-level altitudes with focus on convective (storm) and breaking wave turbulence
  - performance envelope for onboard radar and lidar
- **Extended data sets for aerosol/turbulence correlation modeling**
- **Scanning versus single line of sight configuration**
  - scanning will enable better characterization of turbulent events
    - more direct comparison with radar for joint tests
  - include a mixture of both modes

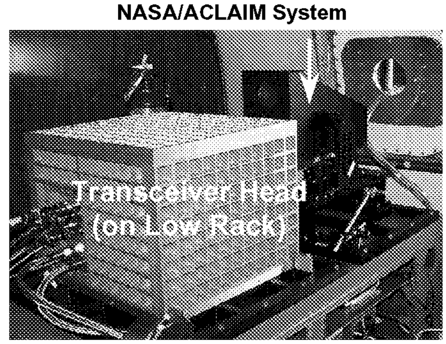
Program Assets and Resources:
Government Agency and Industry

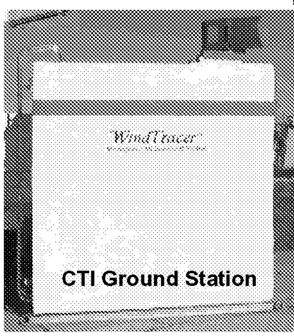
Aviation Safety Program

AFRL System for Precision Air Drop

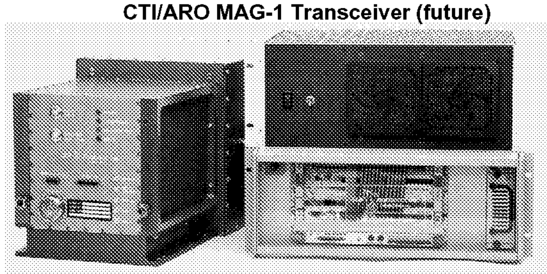


NASA/ACLAIM System

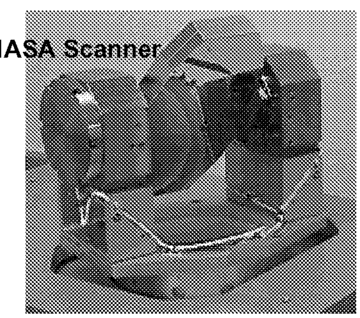




CTI/ARO MAG-1 Transceiver (future)



Control Electronics **Signal Processor**



Overview

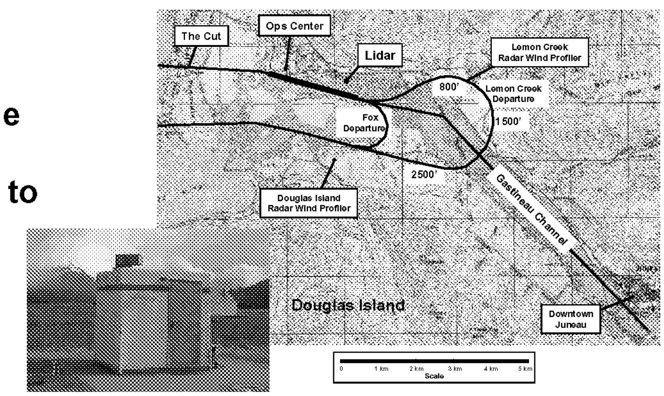
Aviation Safety Program

- **Background information**
- Technical accomplishments to date
  - ground and flight test activities
- **Plans**
  - **flight test activities**
  - **algorithm development and performance simulation**

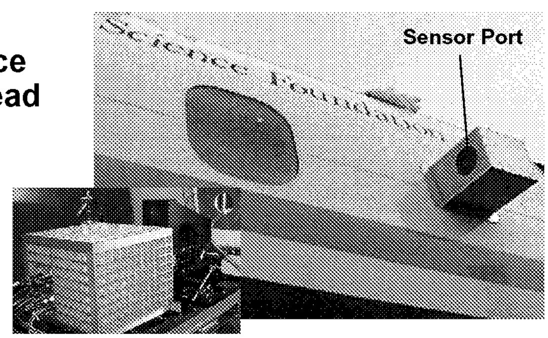
TDAM 1998 Accomplishments: Lidar

Aviation Safety Program

- **Juneau lidar deployment**
  - characterization of low altitude wind shear and turbulence
  - generated validated data sets to support development of lidar turbulence and wind shear detection algorithms

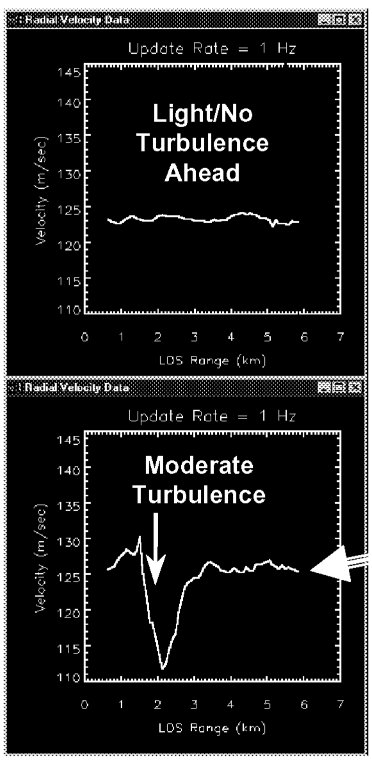


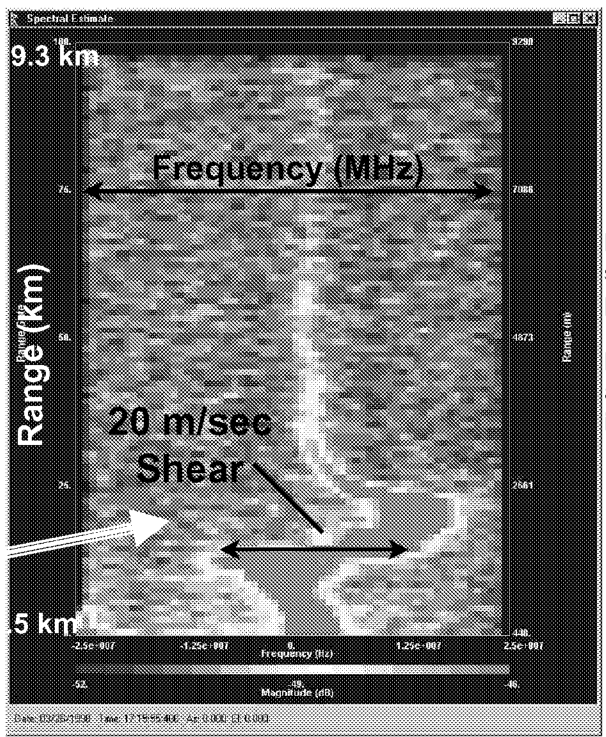
- **ACLAIM/Electra flights**
  - Detected light to moderate turbulence at ranges between 3 and 6 miles ahead
  - Penetrated turbulence to verify
  - Operated 15 hours in a variety of conditions from ground to 25kft



Sample Doppler Spectrum from ACLAIM/Electra

Aviation Safety Program





Isolated moderate to severe turbulence patch ahead

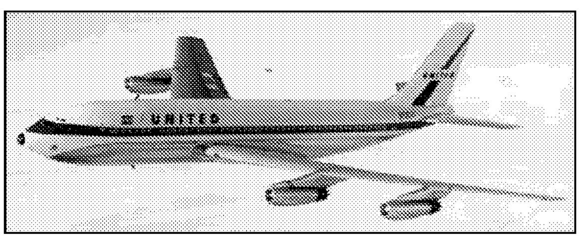
Detected turbulence and later penetrated it for confirmation

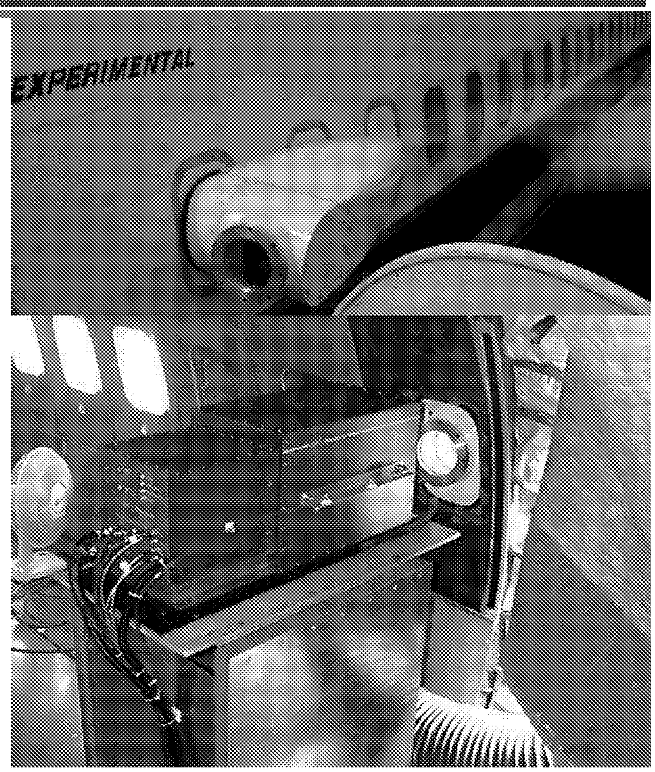
NASA/CP—2002-210964

B-720 Compact Lidar Flight Tests

Aviation Safety Program

- Collected lidar data to demonstrate CAT IR product capability at cruise altitudes
  - data consistent with performance model predictions
  - justified parametric system scaling for compact next-generation system
- Flights aboard Honeywell-owned B-720
- Conducted October, 2000
  - focus on cruise altitude operation
  - no significant turbulence encountered





Overview

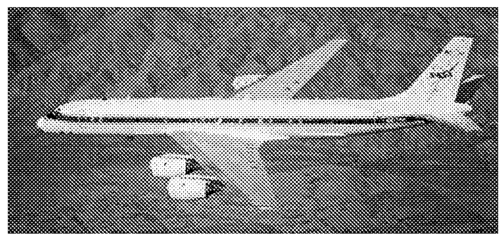
Aviation Safety Program

- **Background information**
- **Technical accomplishments to date**
  - **ground and flight test activities**
- Plans
  - flight test activities
  - algorithm development and performance simulation

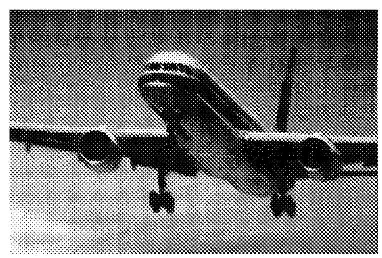
FY01/02 Lidar Flight Tests

Aviation Safety Program

- **DC-8 flight tests**
  - lidar operates in a piggy-back fashion
  - joint data for post-flight correlation with
    - in-situ
    - aerosol particle measurements
  - support lidar performance scaling and algorithm development efforts



- **B-757 flight tests**
  - joint with other WxAP tests
  - primarily focus on convective turbulence
  - joint data for post-flight correlation with
    - in-situ
    - radar measurements
  - support lidar performance scaling and algorithm development efforts
  - investigate scan strategy tradeoffs

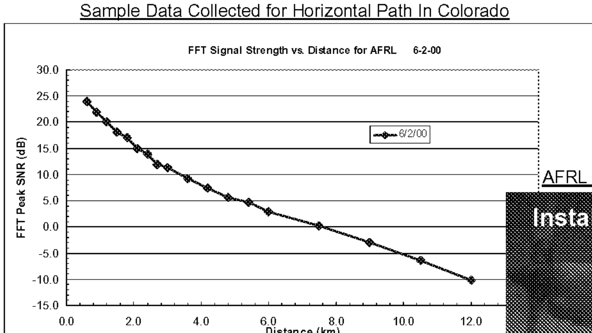


Transceiver Status

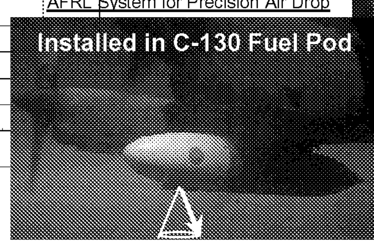
Aviation Safety Program

- **AFRL hardware delivered in March 2000**
  - **Specs after tune-up at CTI**
    - **2.0125 μm wavelength**
    - **9.3 mJ (out of telescope), 440 nsec pulse duration, 100 Hz PRF**
    - **8 cm beam diameter, 10 cm aperture, internal telescope focused at 1.5-2.5 km**
    - **20% small beam efficiency measured in June**
    - **horizontal path data show range performance to 10-12 km (Colorado data)**

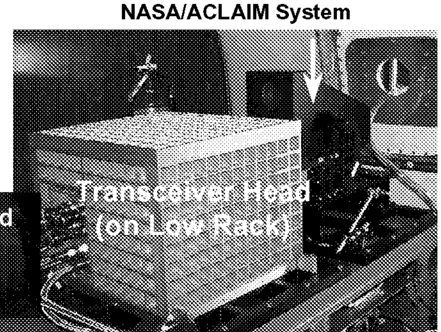
Sample Data Collected for Horizontal Path In Colorado



AFRL System for Precision Air Drop

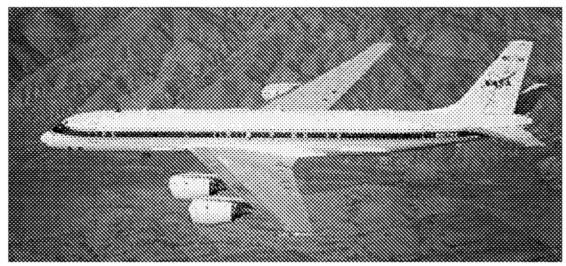


NASA/ACLAIM System

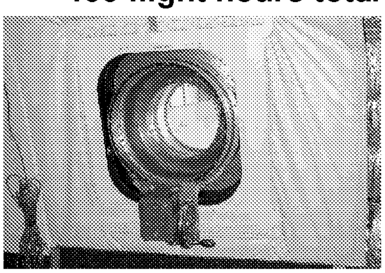


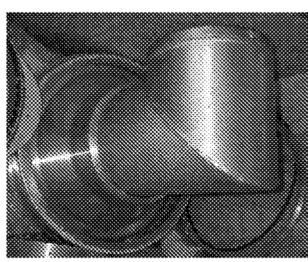
DC-8 Flight Test Status

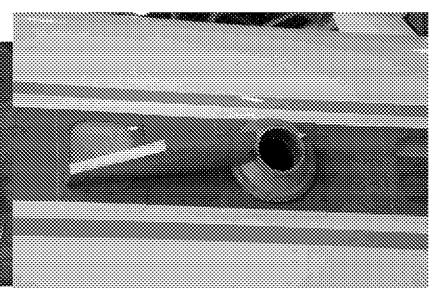
Aviation Safety Program



- **DC-8 volcanic ash encounter**
  - engine replacement required
- **Initial flight window (FY00) dropped**
  - Air-Sci program cancelled
- **CAMEX DC-8 flights scheduled for August-September**
  - piggyback status
  - ~100 flight hours total







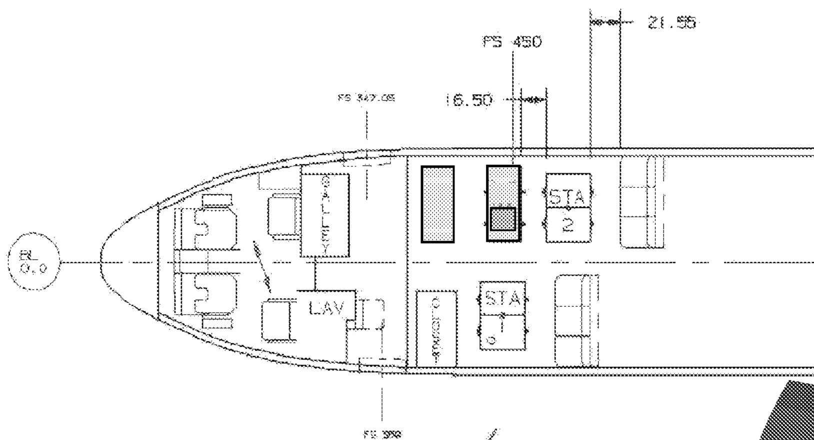
DC-8 Lidar Flight Test Status/Plans

Aviation Safety Program

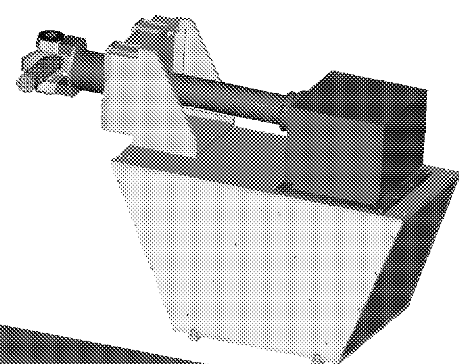
- Forward-looking periscope installed at FS1015
- Integrated AFRL / NASA Lidar system undergoing ground testing at LaRC
- Instrument upload scheduled for July
- Flights anticipated in August-September
  - piggyback on CAMEX includes in-situ turbulence and aerosol
- Research focused on:
  - cruise-condition flight data
  - correlation with atmospheric aerosols
  - correlation of wind shear measurements with other CAMEX measurements

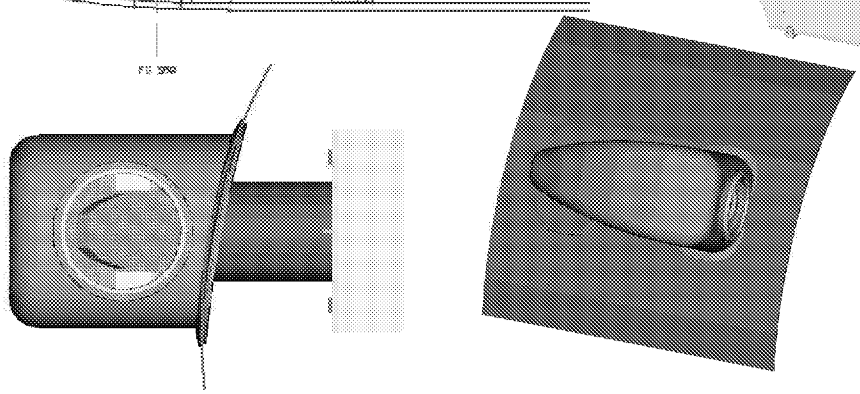
B-757 LIDAR Instrument Layout

Aviation Safety Program



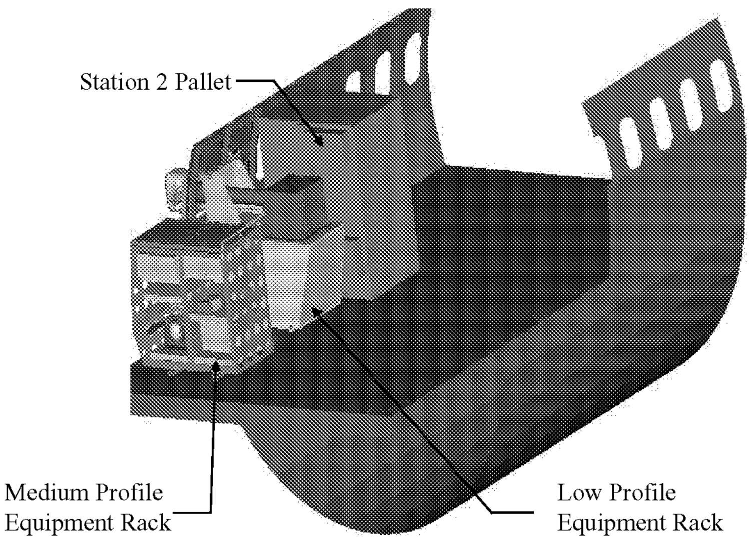
Rack Configuration





B-757 LIDAR Instrument Layout

Aviation Safety Program



B-757 Lidar Flight Test Status/Plans

Aviation Safety Program

- **NASA Critical Design Review held in May 2001**
- **Design for forward-looking scanner installation approved for FS450**
- **Integrated AFRL / NASA scanning Lidar system undergoing ground testing at LaRC**
- **Flights anticipated in early CY02**
  - joint with Turbulence Radar and Turbulence In-Situ
- **Research focused on:**
  - scanning effects and strategies
  - synergism with radar
  - convectively-induced turbulence

Lidar Algorithm Development Objective

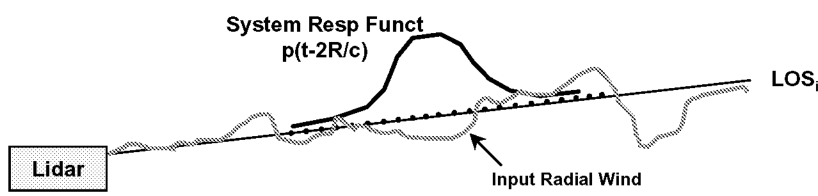
Aviation Safety Program

- **Develop reliable detection and discrimination algorithms for Doppler lidar prediction of turbulence hazard**
  - exploit understanding of unique aspects of lidar phenomenology
  - incorporate common aspects of radar developments

Lidar Algorithm and Simulation: FY00-02 Approach and Plans

Aviation Safety Program

- Maintain synergy with radar algorithm development
- Establish SNR requirements and averaging/resolution/performance trades for spectral width and structure function algorithms
- Establish link to hazard metric algorithm(s)
- Incorporate test cases in more sophisticated simulation
- Test on additional data sets (joint lidar/radar test data)
- Produce more robust performance predictions and feed back into algorithm development
  - false alarm mitigation

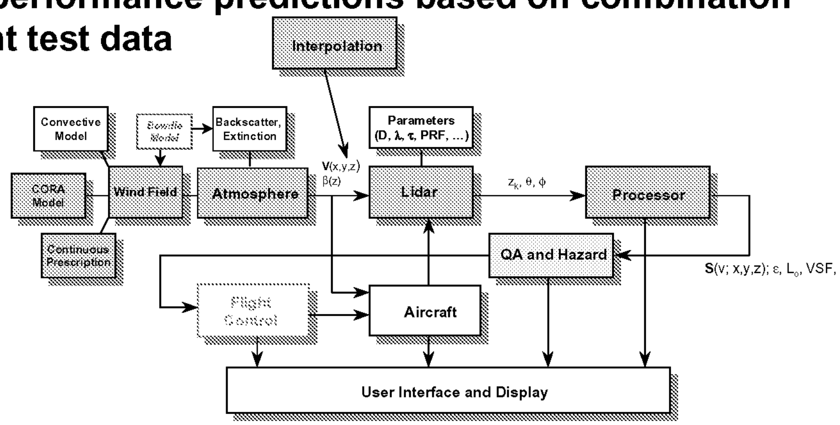


NASA/CP—2002-210964

Lidar Algorithm Development and Simulation: FY01/02 Activities

Aviation Safety Program

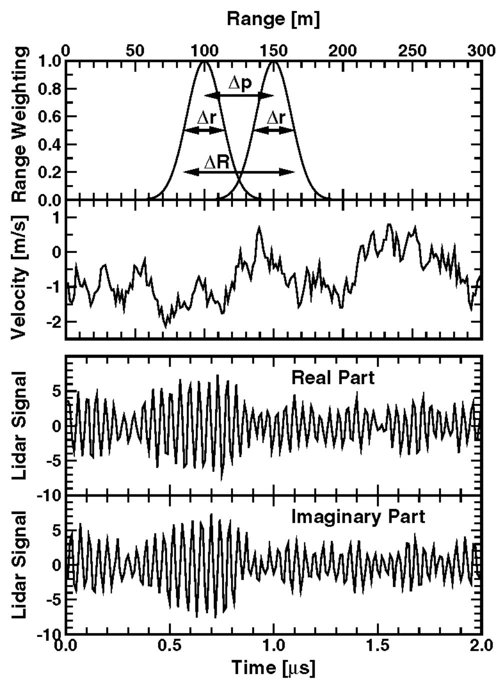
- **Focus on single line of sight algorithms/analyses and leverage existing tools**
- **Pursue structure function and spectral-width-based algorithms**
  - **small SNR regime: long range (longer warning times)**
  - **large SNR regime: correlation of vertical loading with longitudinal observations**
  - **investigate scan strategy impacts**
- **Develop preliminary performance predictions based on combination of simulated and flight test data**
- **Truth metrics initially limited (simulation using 2DOF a/c)**



Lidar Algorithm Development and Simulation: Leveraging

Aviation Safety Program

- **CIRES/NCAR:**
  - Space Lidar for NASA (SPARCLE)
  - extending detailed simulations
- **CTI**
  - simulation for wake vortex detection
  - existing real-time algorithms
- **Synergy with radar**
  - NCAR and RTI developments
- **Results in cost-effective development with near-term results**



Lidar Summary

Aviation Safety Program

- **Emphasis areas**
  - flight testing
  - algorithm development and associated performance analyses
- **Flight tests accomplished CY99-00**
  - NASA ACLAIM Electra flights
  - industry-funded B-720 flights
- **Flight tests planned for late CY01, early CY02**
  - DC-8 flights planned for August-September, piggy-back on CAMEX
  - B-757 flights in early CY02, joint with Turbulence Radar and In-Situ
- **Algorithm work highly leveraged**
  - NCAR and CTI developments
  - synergy with radar work (NCAR & RTI)
- **Parallel industry program to develop a clear air turbulence product**
  - focus is on cost reduction and reliability improvement

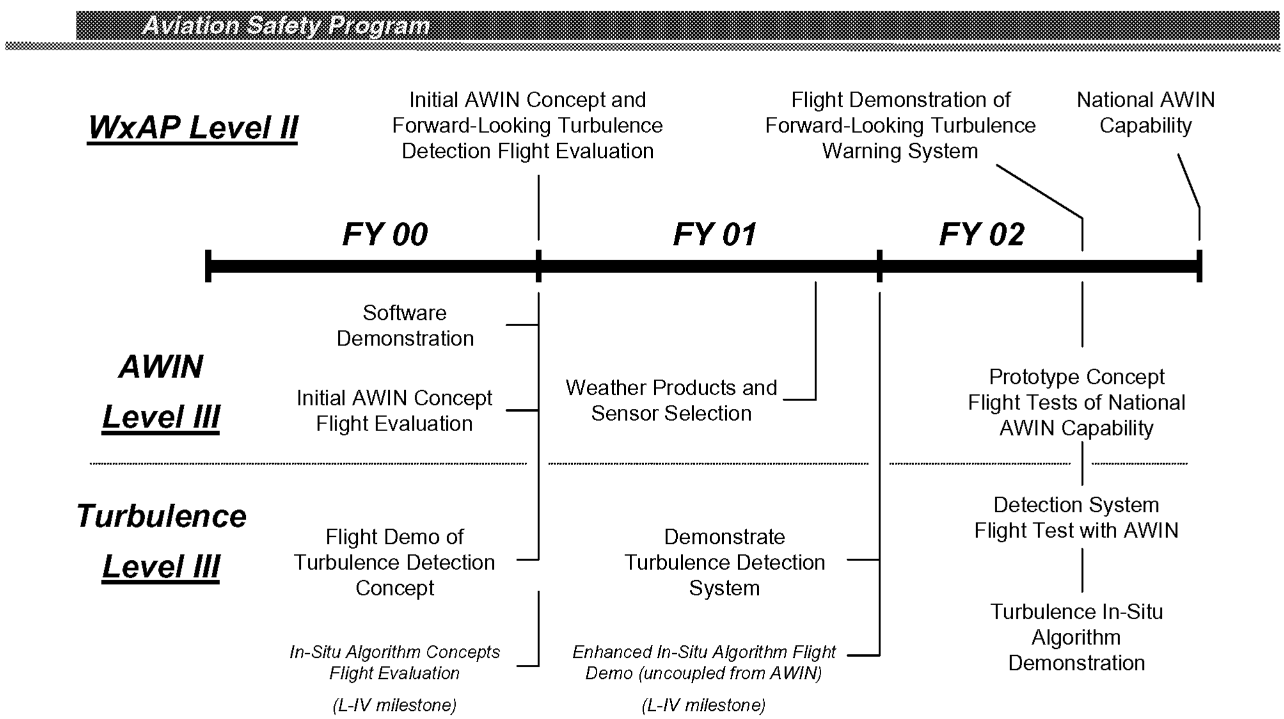
Turbulence Lidar Development Status

Aviation Safety Program

Reference Foils

SUPPORTED MILESTONES

(Through FY 02 only; Excludes WINCOMM)

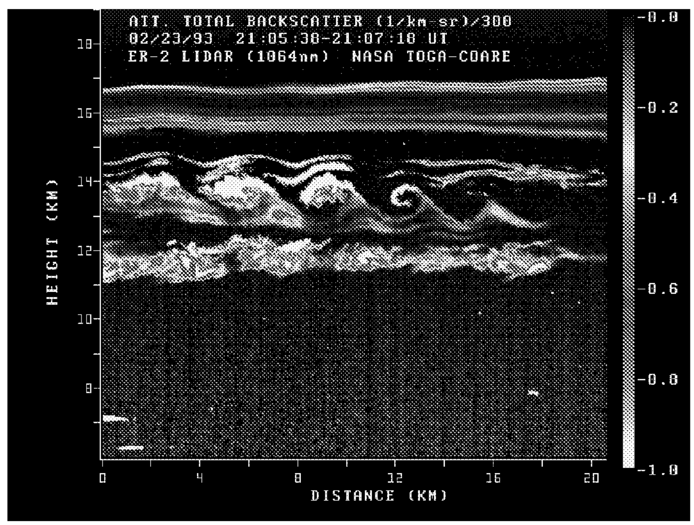


NASA/CP—2002-210964

Background

Aviation Safety Program

- **Turbulence Initiators**
  - **Convective Storms (within and as far as 40 miles away from visible clouds in clear air)**
  - **Jet Stream (at confluence of multiple streams and near boundaries)**
  - **Mountain Wave (upward propagating from disturbances near the surface)**

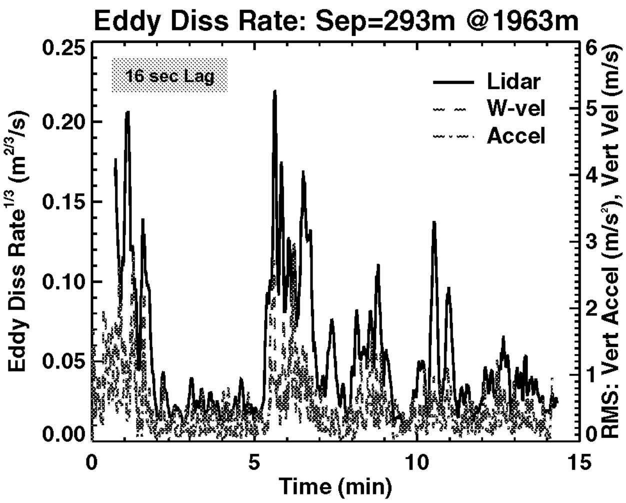


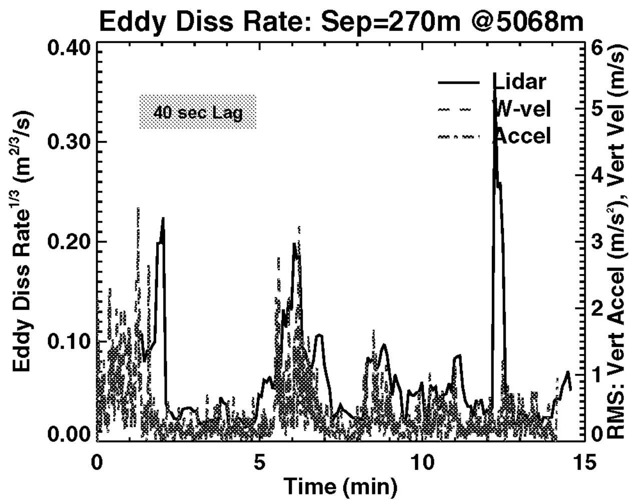
Localized "events" like these are extremely difficult to reliably forecast

Demonstration of Lidar Turbulence Detection

Good Correlation with Onboard Data out to 40 sec Lag (Flight 2)

Aviation Safety Program



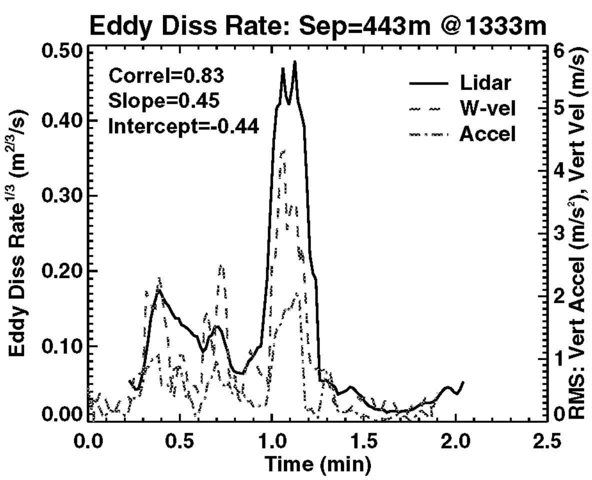


Time Evolution, Beam Pointing
Jitter (A/C Pitch) Can Reduce
Accuracy for Long Lags

Background: Demonstration of Lidar Turbulence Detection

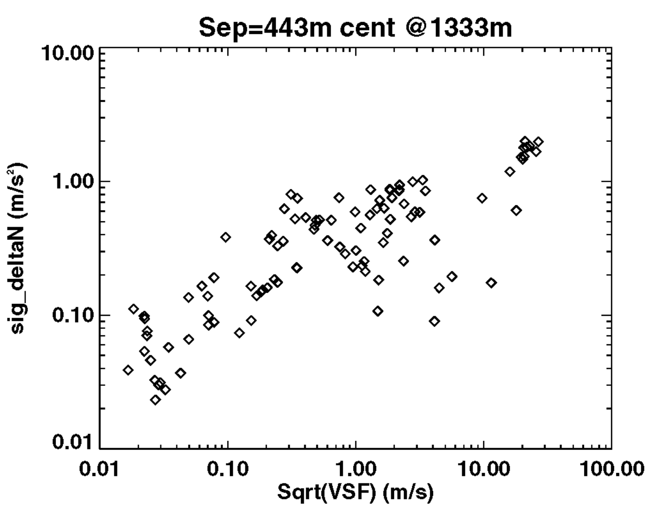
Good Correlation with Onboard Data (Flight 2)

Aviation Safety Program



Correl (a-w)=0.82 (0.89 linear)

LidarFile=d:\raspprd\electra\d3261702.prd.los
NavFile=d:\raspprd\electra\nav\802rf02_1646_1717.asc
StartTime=1715:05, EndTime=1717:00 IntegWidth= 5.0sec



LidarFile=d:\raspprd\electra\d3261702.prd.los
NavFile=d:\raspprd\electra\nav\802rf02_1646_1717.asc
StartTime=1715:05, EndTime=1717:00 IntegWidth= 5.0sec

Correlation of 1.3 km lagged structure function about as good as that between rms acceleration and rms vertical velocity

NASA/CP—2002-210964

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Flight Test Results for a Turbulence Detection Radar

Weather Accident Prevention Second Annual Review

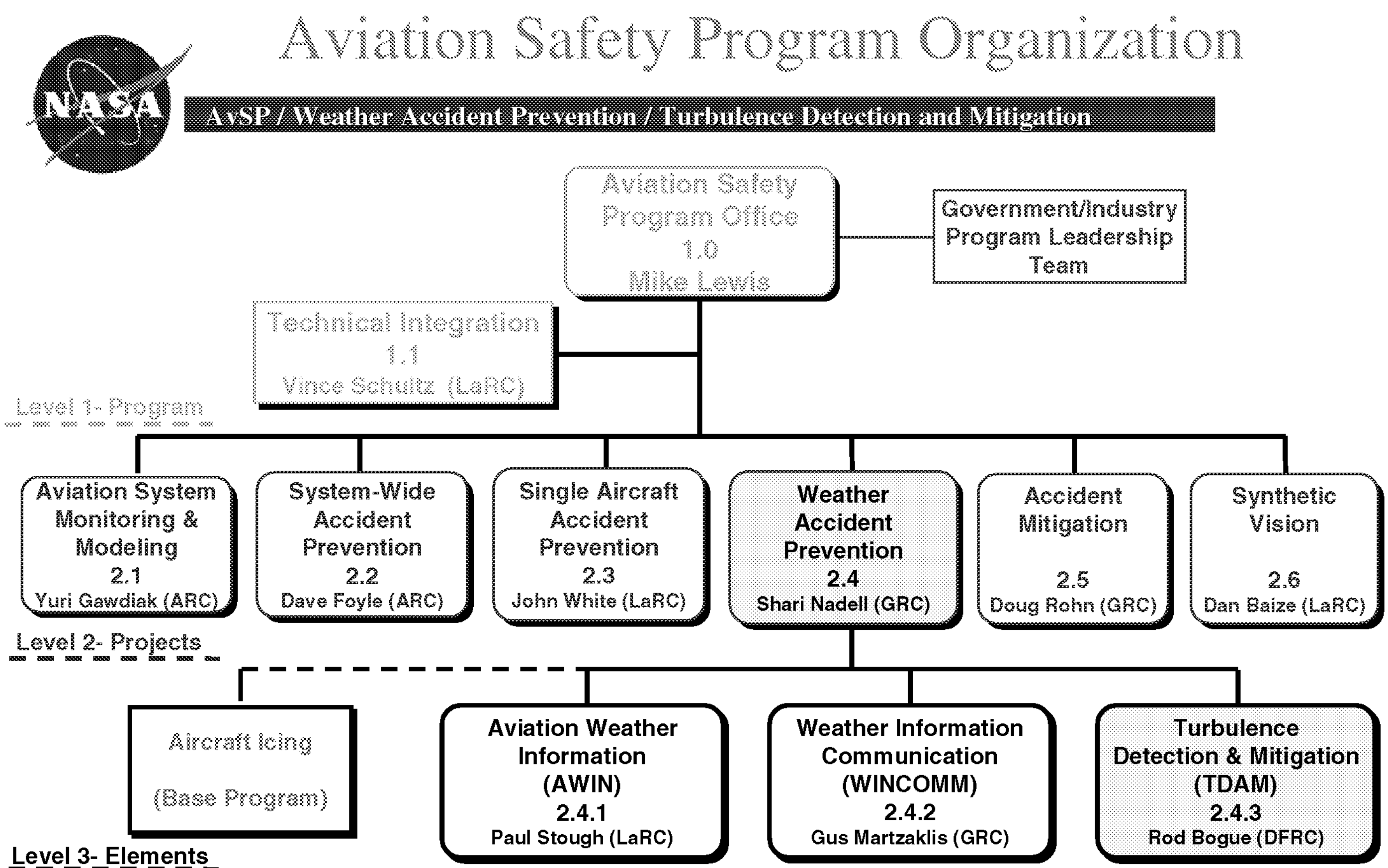
June 5-7, 2001

Phil Schaffner
Turbulence Radar Principal Investigator
Sensors Research Branch
NASA Langley Research Center
Hampton, VA 23681-2199
(757) 864-1809
E-mail: P.R.Schaffner@LaRC.NASA.gov

Presentation Outline

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Introduction
- Flight Configuration
- Flight Operations Summary
- Event Summary
- Data Report and Analyses by Flight
- Flight Test Summary
- CY01 Flight Plans


Aviation Safety Program Organization
NASA
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation
Aviation Safety Program Office 1.0 Mike Lewis
Government/Industry Program Leadership Team
Technical Integration 1.1 Vince Schultz (LaRC)
Level 1- Program
Aviation System Monitoring & Modeling 2.1 Yuri Gawdiak (ARC)
System-Wide Accident Prevention 2.2 Dave Foyle (ARC)
Single Aircraft Accident Prevention 2.3 John White (LaRC)
Weather Accident Prevention 2.4 Shari Nadell (GRC)
Accident Mitigation 2.5 Doug Rohn (GRC)
Synthetic Vision 2.6 Dan Baize (LaRC)
Level 2- Projects
Aircraft Icing (Base Program)
Aviation Weather Information (AWIN) 2.4.1 Paul Stough (LaRC)
Weather Information Communication (WINCOMM) 2.4.2 Gus Martzaklis (GRC)
Turbulence Detection & Mitigation (TDAM) 2.4.3 Rod Bogue (DFRC)
Level 3- Elements

Turbulence Detection Level 4 Sub-element

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Sensor Performance Assessment
- Sensor Development
- Algorithm Development
- Demonstration & Verification

Objectives

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

WxAP Objective #3

Provide commercial aircraft sensor with 90% probability of detection of severe Convective and Clear Air Turbulence thirty seconds to two minutes before encounter.

WxAP Milestone #2

Flight demonstrate certifiable forward-looking on-board turbulence warning system with Type-I and Type-II error probability commensurate with airborne wind shear technology. [TRL/IRL of 7/4]

Goal for NASA/FAA/Industry

Advance warning of ≥ 30 sec. with POD ≥ 80% for phenomena with reflectivity ≥ 15 dBz.

Flight Operations Summary

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

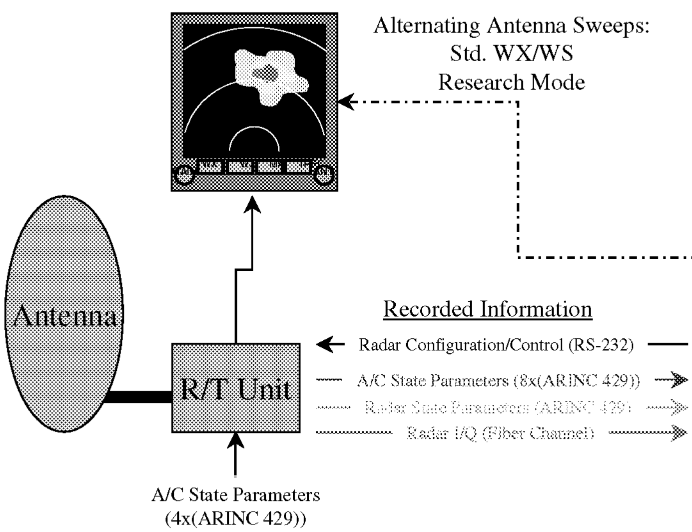
- Weather Support
  - Forecasting and pre-flight recommendations
    - 2-, 1-, and day of operation forecasts
  - Pilot briefings
  - Onboard tactical recommendations
  - Real-time observations
- *In Situ*
  - Data Collection
  - Real-time engineering displays
  - Post-flight processing
- Turbulence Radar
  - Data collection
  - Real-time engineering displays
  - Aircraft response algorithms
  - Post-flight processing

Radar Data Collection

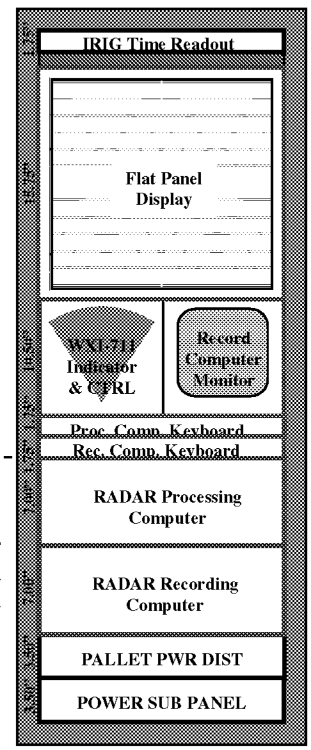
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

CY'00 Radar Flight Test Objectives

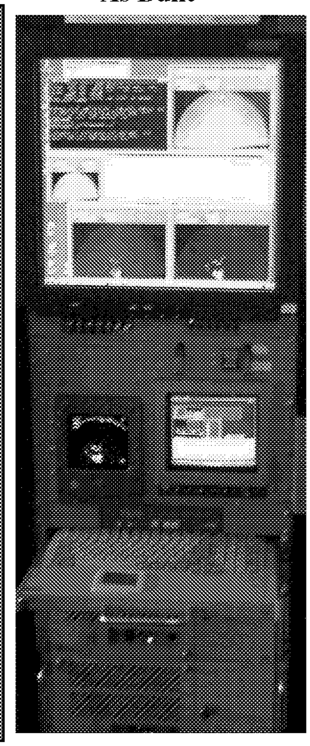
- **Collect airborne radar signatures of turbulence (along with aircraft response) to enable characterization and algorithm development/refinement.**
- **Assess the performance of the latest-generation turbulence detection and hazard estimation algorithms.**

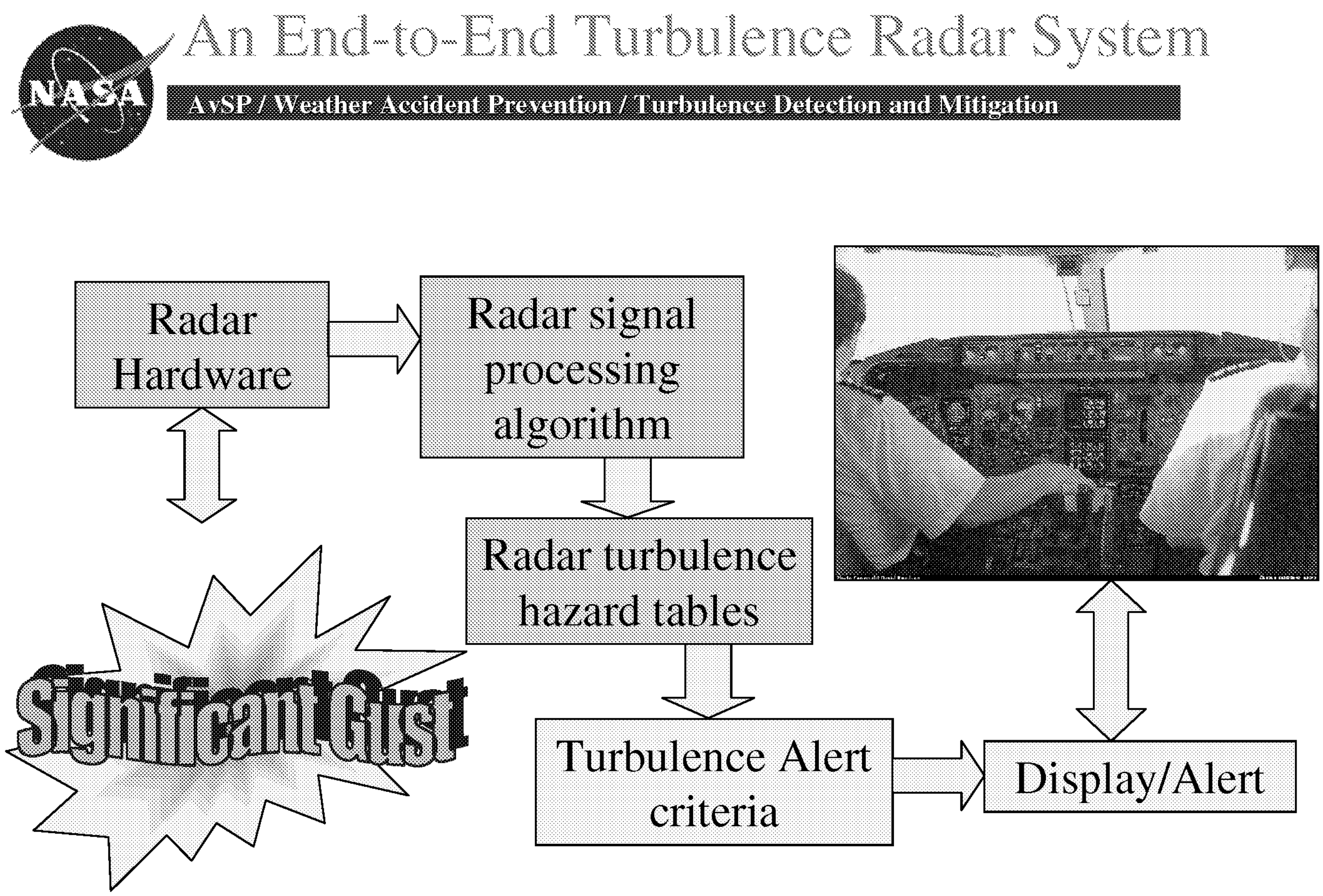


Design Layout



As Built




An End-to-End Turbulence Radar System
NASA
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation
Radar Hardware
Radar signal processing algorithm
Radar turbulence hazard tables
Turbulence Alert criteria
Display/Alert
Significant Gust

Baseline Algorithm Methodology

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Includes time-domain interference-rejection filter
- Frequency/Doppler-velocity domain spectral width estimation
- Optional averaging over range and/or azimuth
- Estimates turbulence correlation length
- Thresholding using CFAR (constant false alarm rate) threshold calculated from the spectra
- Estimates point variance from spectral width and bin-to-bin variance of average velocity
- Uses Hazard Tables to predict RMS accelerations from point variance

NCAR Algorithm Methodology

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- The NCAR Efficient Spectral Processing Algorithm (NESPA) is a multi-stage approach to finding high-quality Doppler moments in real-time.
- Data quality is improved by averaging the spectra over multiple azimuths and ranges.
- Hazard metrics are produced by scaling the second moment estimates using tables and combining the results from three elevation angles.
- Confidence measures based on many different indicators (e.g. SNR, continuity, etc.) of data quality are used in the multi-stage processing and are also used in the calculation of the hazard metrics.

Radar Hazard Tables

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Relate radar estimates of spectral width or point variance to predicted variance of aircraft accelerations
- Key part of system to go from radar data processing algorithm output to aircraft effects

Hazard Levels: RMS Vertical Acceleration

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

• Light	less than 0.2 g
• Moderate	0.2 to 0.3 g
• Severe	greater than 0.3 to 0.6 g
• Extreme	over 0.6 g

Proposed Alert Criteria

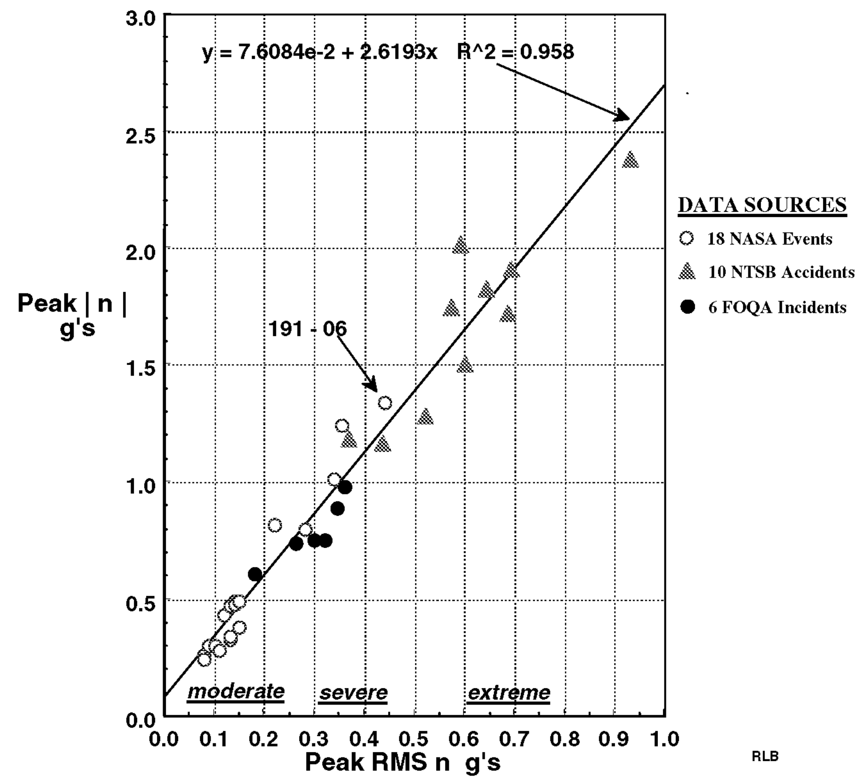
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Goal: Advance warning of ≥ 30 sec. with POD ≥ 80% for phenomena with reflectivity ≥ 15 dBz.

Alerts Based on Radar Observables	Predicted Hazard
No Alert	$\sigma_{\Delta n} < 0.2g$
May Alert	$0.2g \leq \sigma_{\Delta n} < 0.3g$
Must Alert	$\sigma_{\Delta n} \geq 0.3g$

Correlation of Peak Load With Peak RMS Load (5 sec. window)

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



Based on Measurements for 34 Turbulence Encounter Cases

Flight Test Summary

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Checkout/ferry flights (154, 155, 169)
- 3 Data flights
  - 181: 3 to 4 very low reflectivity encounters with light turbulence
  - 190 & 191: low reflectivity encounters with light to severe turbulence
- 18 *in situ* events identified from data flights
- 7 events selected for detailed radar analysis

18 Event Summary Table

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Flight-event	*No Alert < 0.2 g*	*0.2 <= Alert < 0.3 g*	*Alert >= 0.3 g*	*Notes*
181-01	X			
181-02	X			-10 deg roll
181-03	X			
181-04		X		+/- 30 deg roll
181-05	X			30 deg roll
181-06	X			-30 deg roll
181-07	X			+/- 30 deg roll
181-08	X			
190-02	X			
190-03	X			
190-04		X		30 deg roll
190-05	X			50 deg roll
190-06			X	40 deg roll
190-07	X			35 deg roll
191-03			X	30 deg roll
191-04	X			---
191-05	X			30 to 50 deg roll
191-06			X	30 deg roll

7 Event Summary Table

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Flight-event	In Situ $\sigma\Delta n$	NESPA	Baseline	Hazard
181-07	0.15	< 0.2	> 0.2	light
181-08	0.16	< 0.2	0.32	light
190-04	0.28	< 0.2	< 0.27	moderate
190-06	0.2 & 0.35	< 0.2	0.3	severe
191-03	0.34	0.2	0.32	severe
191-04	0.14	< 0.2	low reflectivity	light
191-06	0.44	0.32	near 0.4	severe

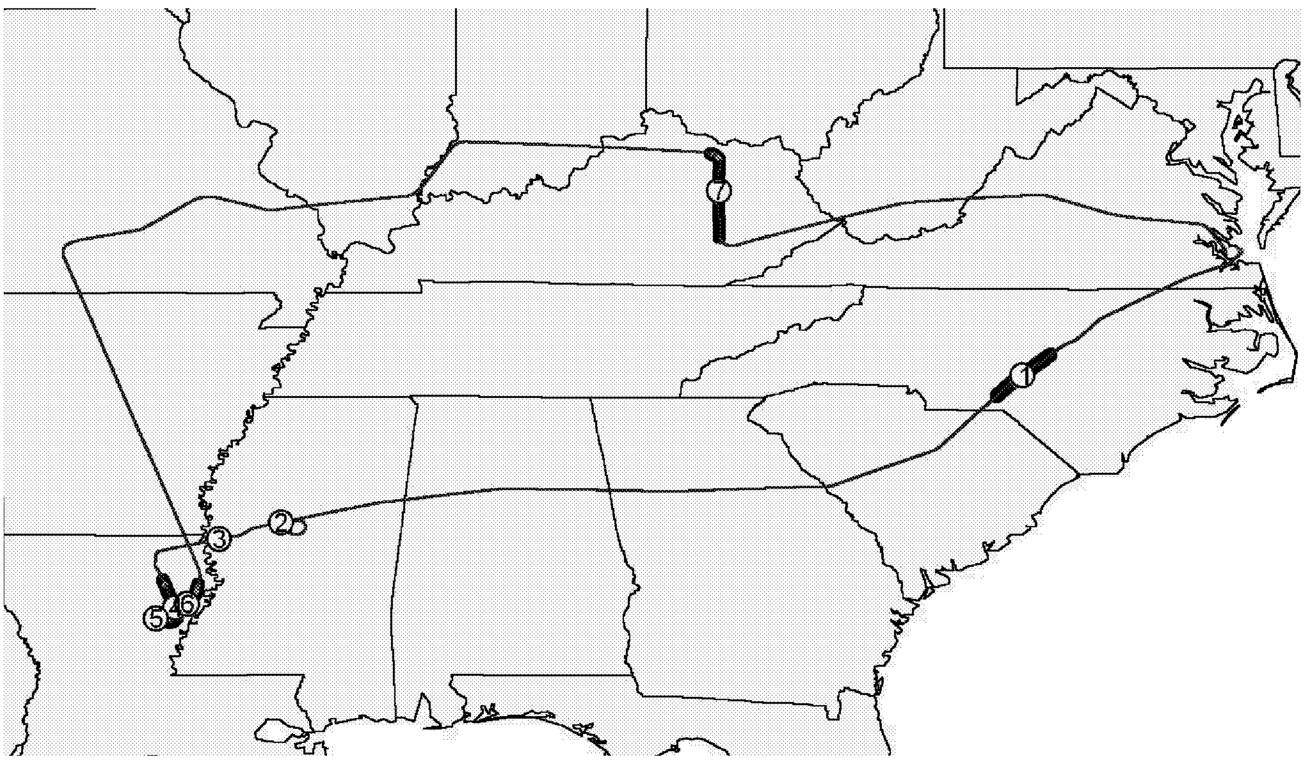
Weather Summary

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Flight/Day	Weather	Primary Region of Interest	Peak Storm Tops	Cell Movement (from)
Fl- 181 16 Nov 2000	Broad Area of Rain with Embedded Convective Cells	Southern Mississippi & Louisiana	30,000 feet	WSW at 45 kts
Fl -190 13 Dec 2000	Broad Area of Rain and Convective Cells with Embedded Thunderstorms	Northeast Louisiana	43,000 feet	SW at 65 kts
Fl -191 14 Dec 2000	Narrow Line of Convective Cells/Thunderstorms	Florida Panhandle & South Georgia	40,000 feet	SW at 40 kts

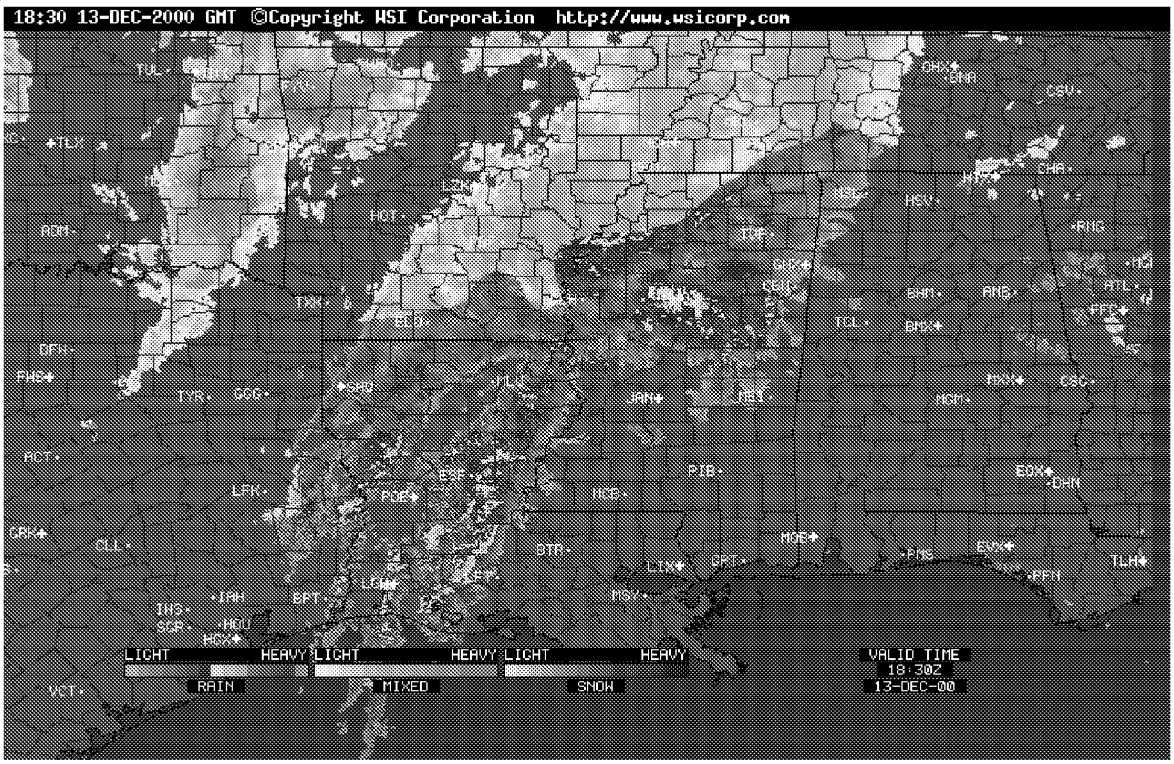
Flight 190 Path

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



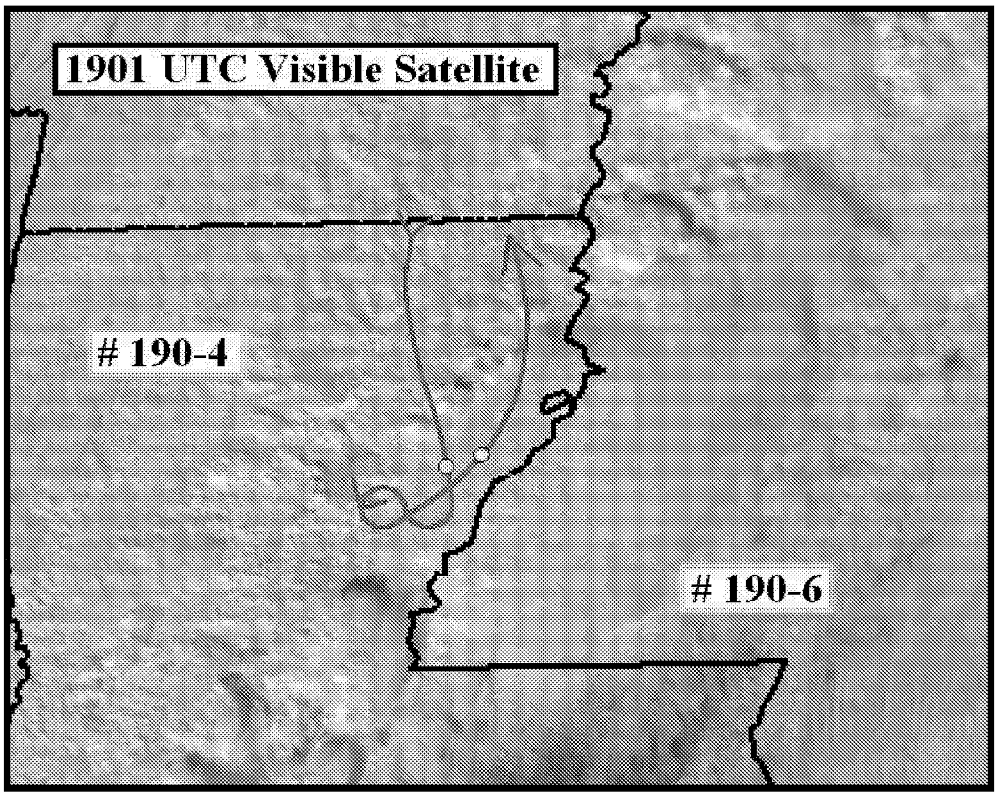
Flight 190 Weather

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



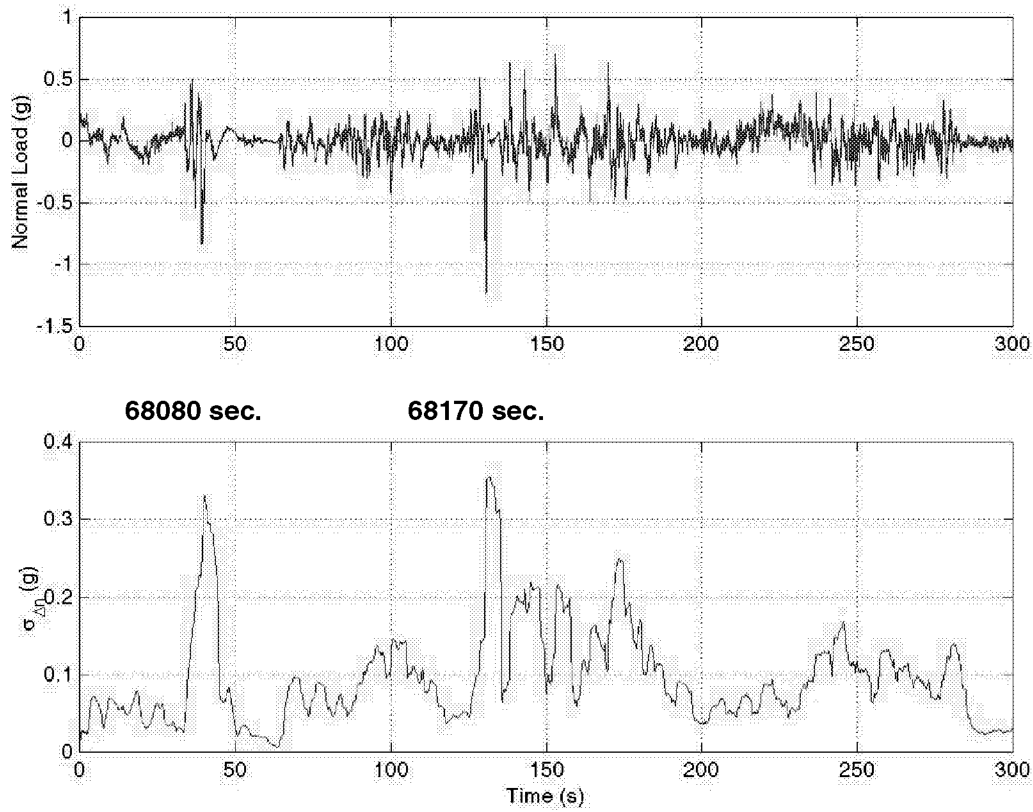
Flight 190 Satellite Weather

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



Flight 190 Event 06 Normal Loads

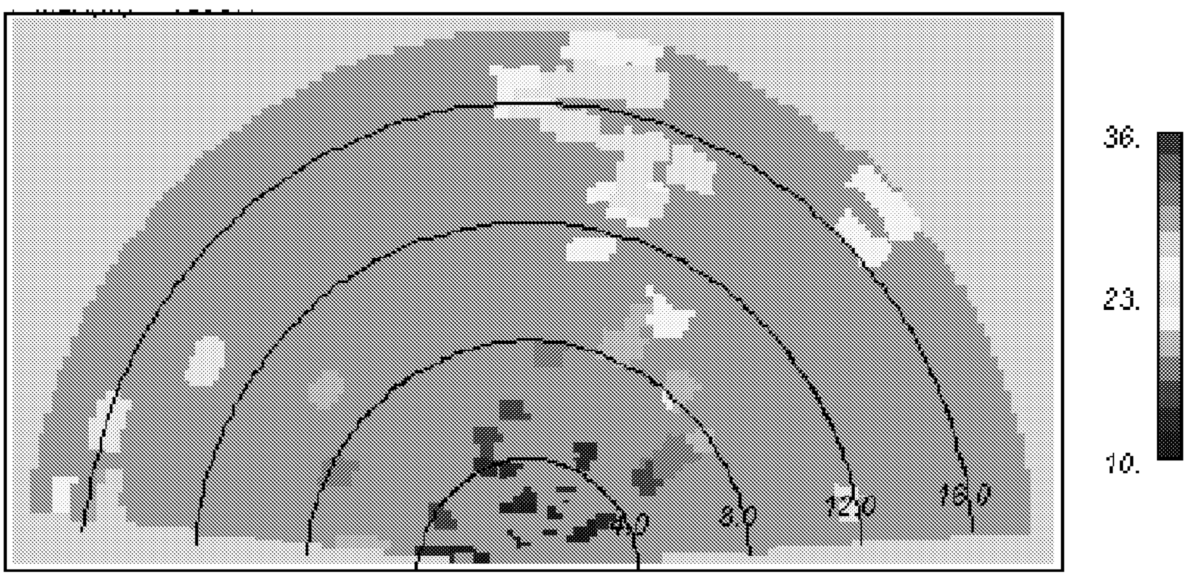
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



Reflectivity (dBZ) Event 190-06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

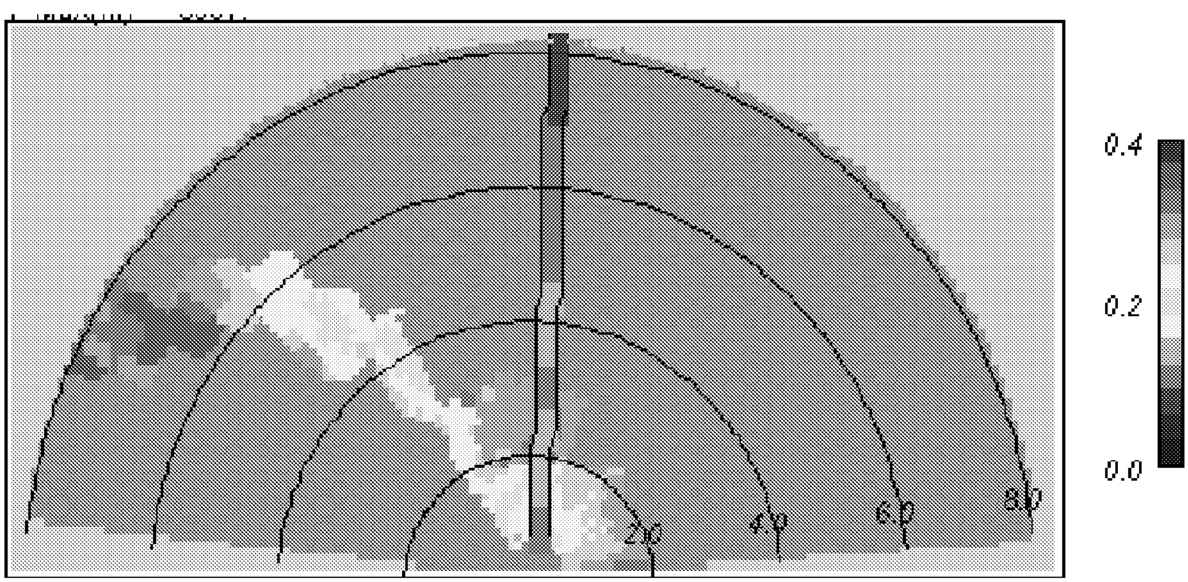
18:45:21 or 67521 seconds

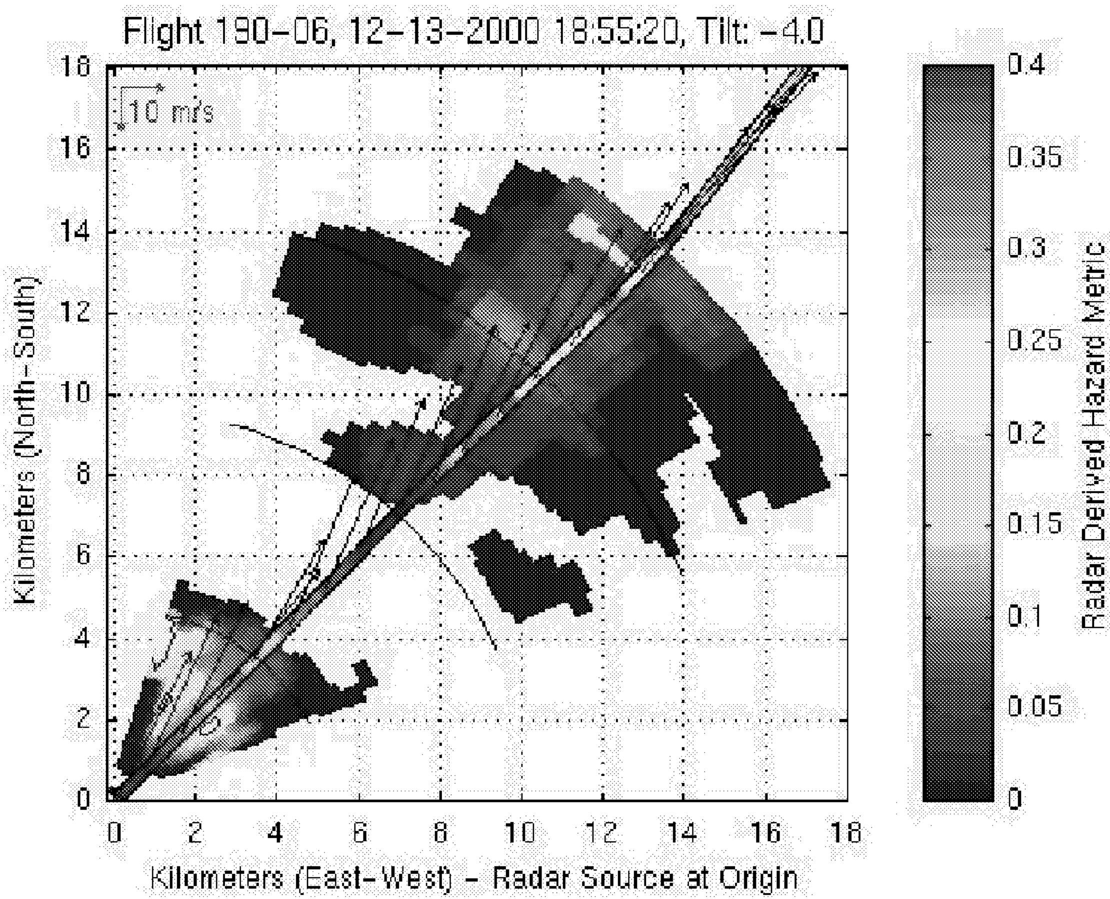


g-Loading (rms g) Event 190-06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:55:30 or 68130 seconds

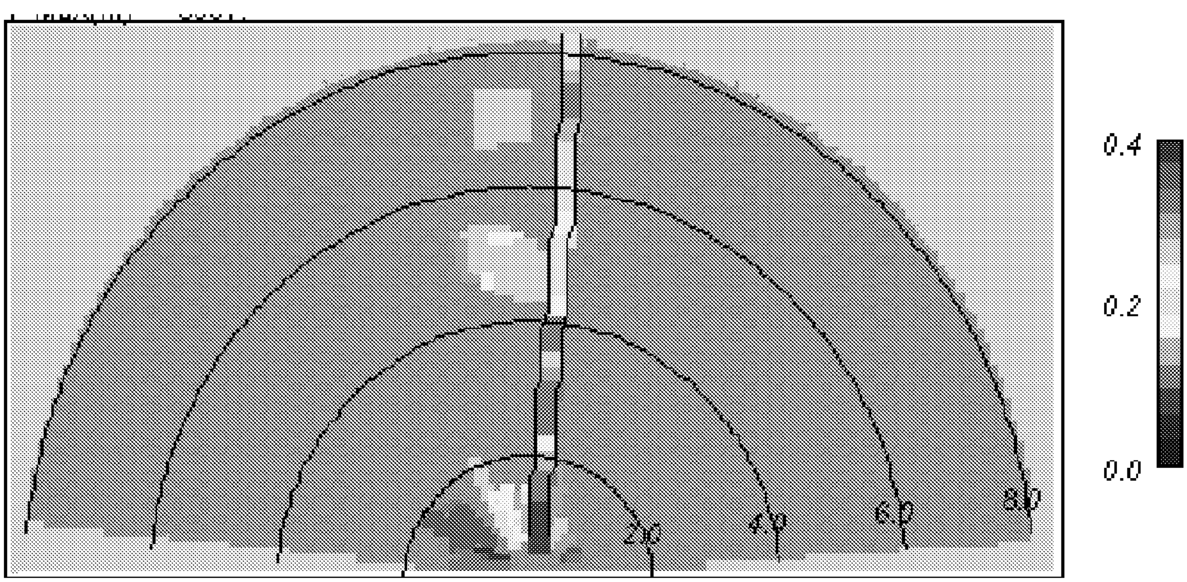


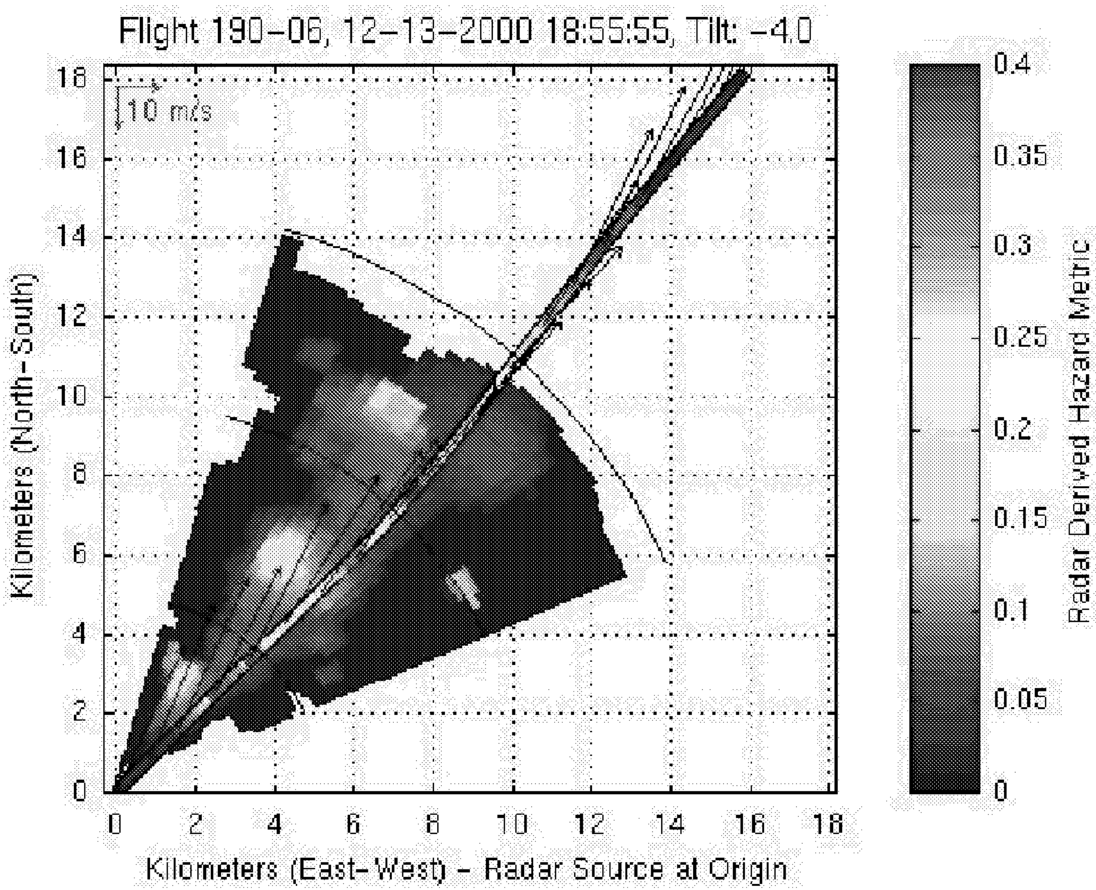

Flight 190-06, 12-13-2000 18:55:20, Tilt: -4.0
10 m/s
Kilometers (North-South)
Kilometers (East-West) - Radar Source at Origin
0
2
4
6
8
10
12
14
16
18
Radar Derived Hazard Metric
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

g-Loading (rms g) Event 190-06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:56:05 or 68165 seconds




Flight 190-06, 12-13-2000 18:55:55, Tilt: -4.0
10 m/s
Kilometers (North-South)
Kilometers (East-West) - Radar Source at Origin
Radar Derived Hazard Metric
0
2
4
6
8
10
12
14
16
18
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

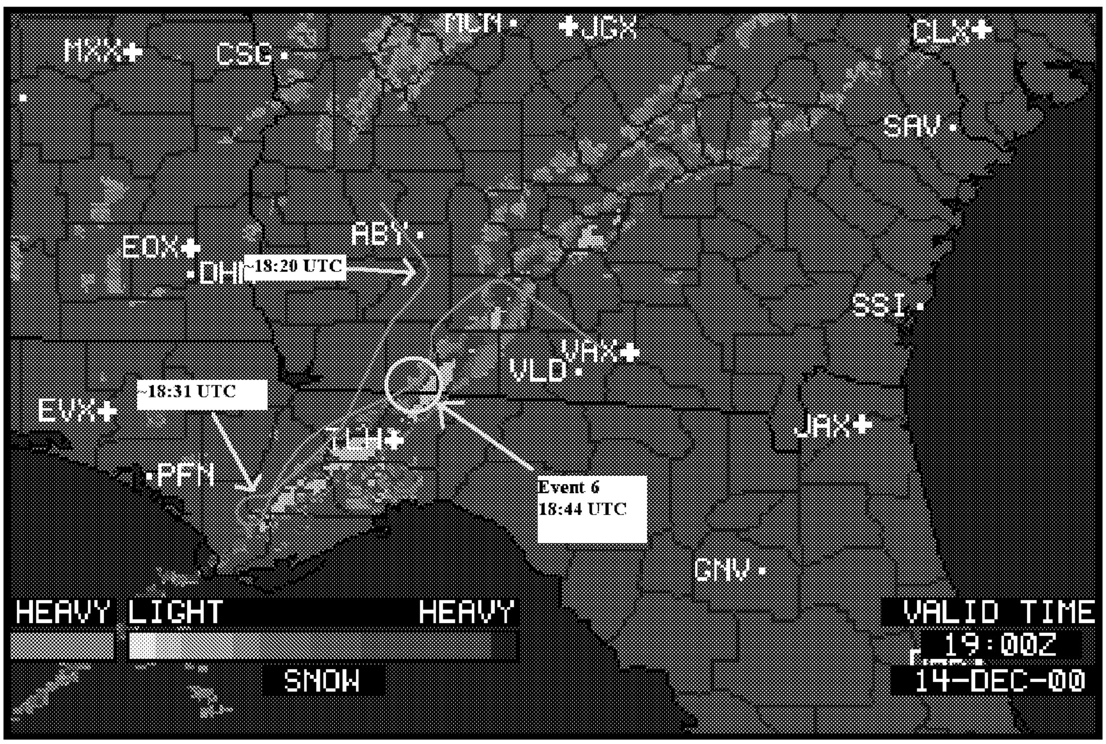
Summary - Case 190-06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- **Little reflectivity within scan range**
- ***In situ* peak rms g ~ 0.33 at 68170 seconds**
- **Missed prediction of in situ peak**
- **Detection of ~0.35 g 5 km (20 seconds) ahead at 68177 seconds where in situ shows ~0.25**
- **Many areas >0.3 off track**

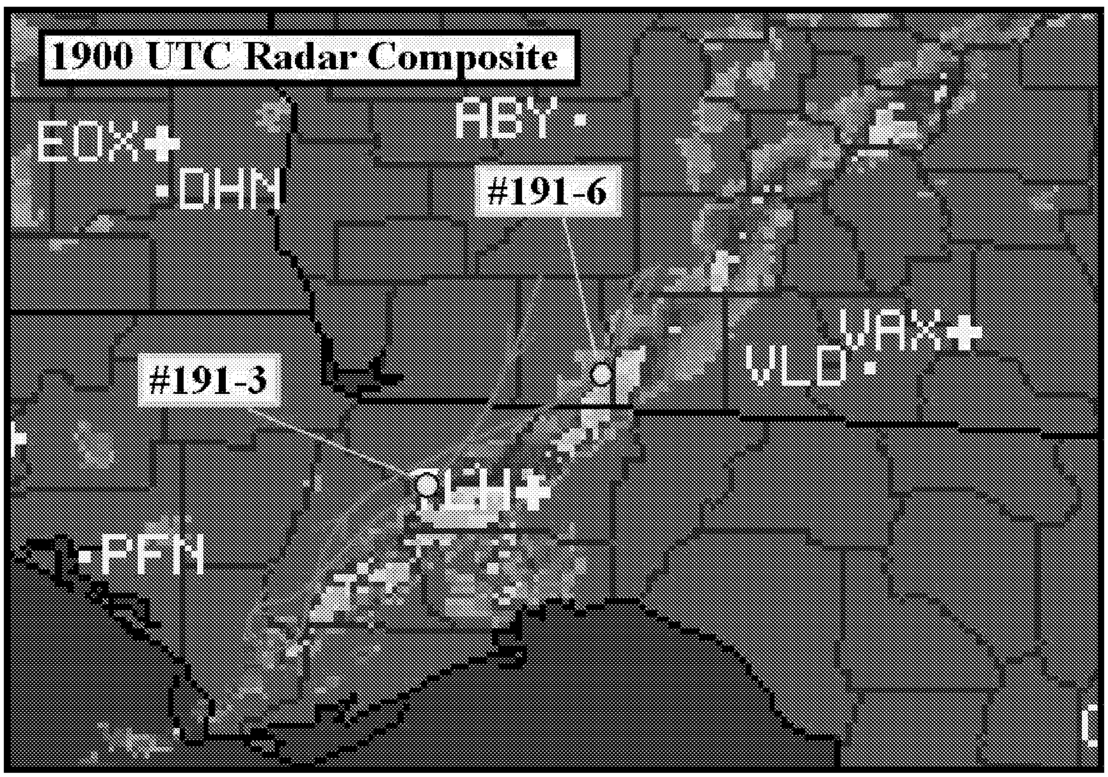
Flight 191 Weather

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



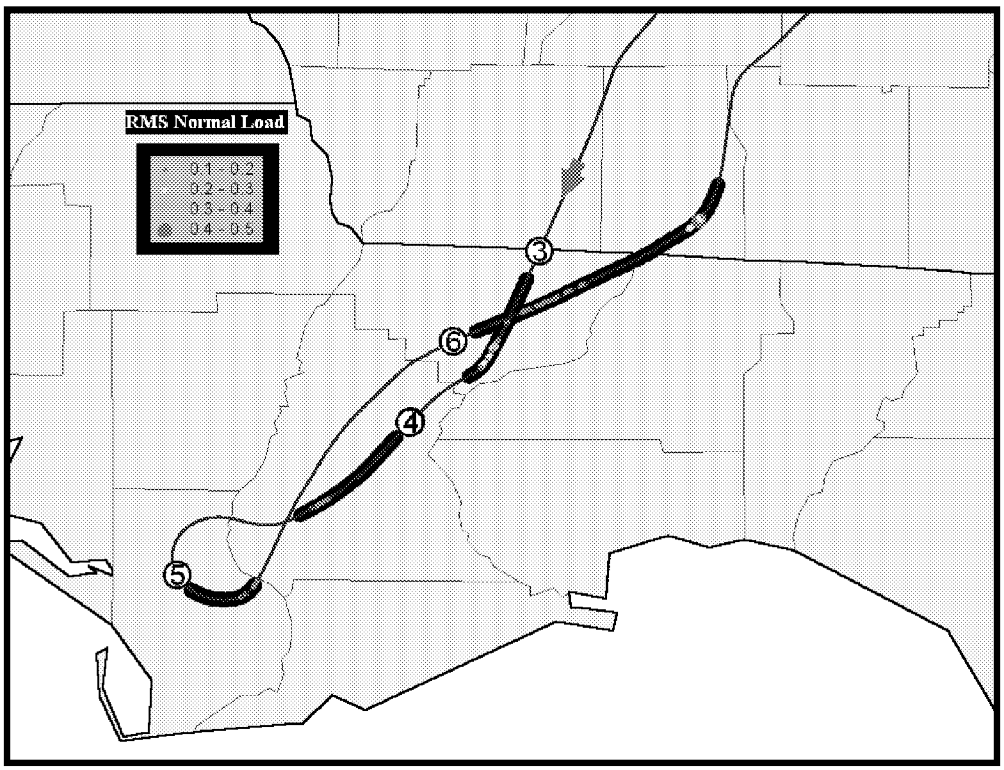
Flight 191 Weather

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



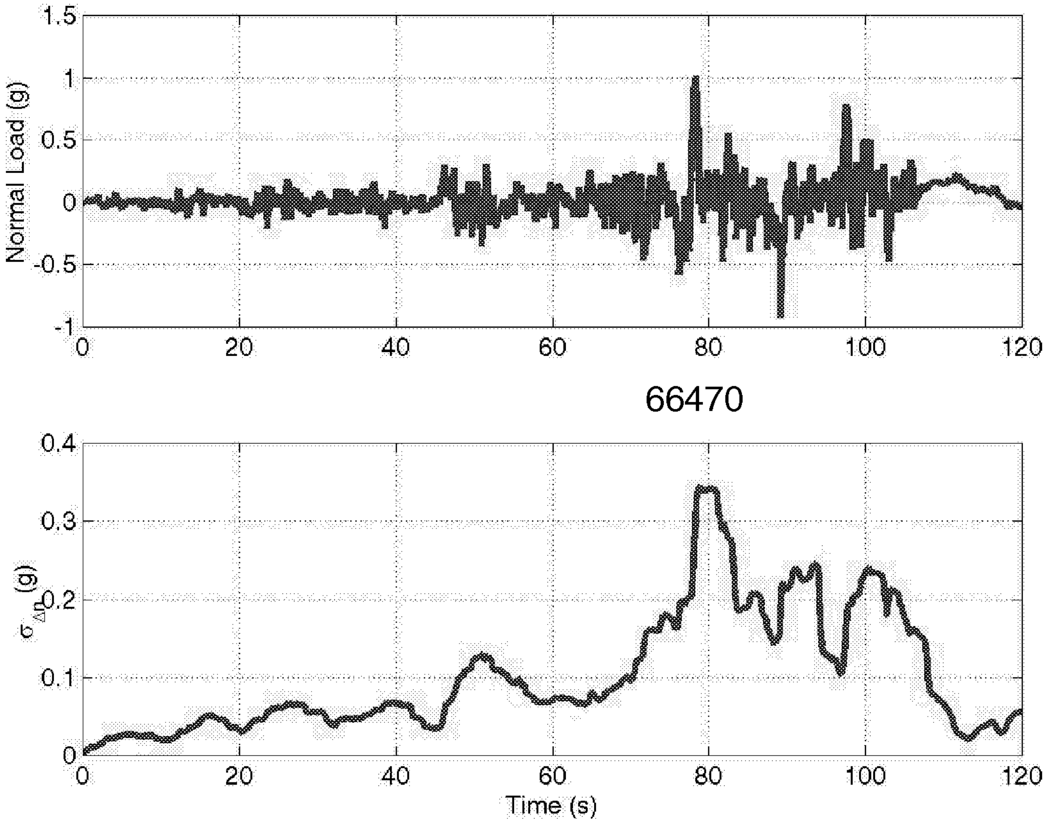
191 Path Flight

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation



Flight 191 Event 03 Normal Loads

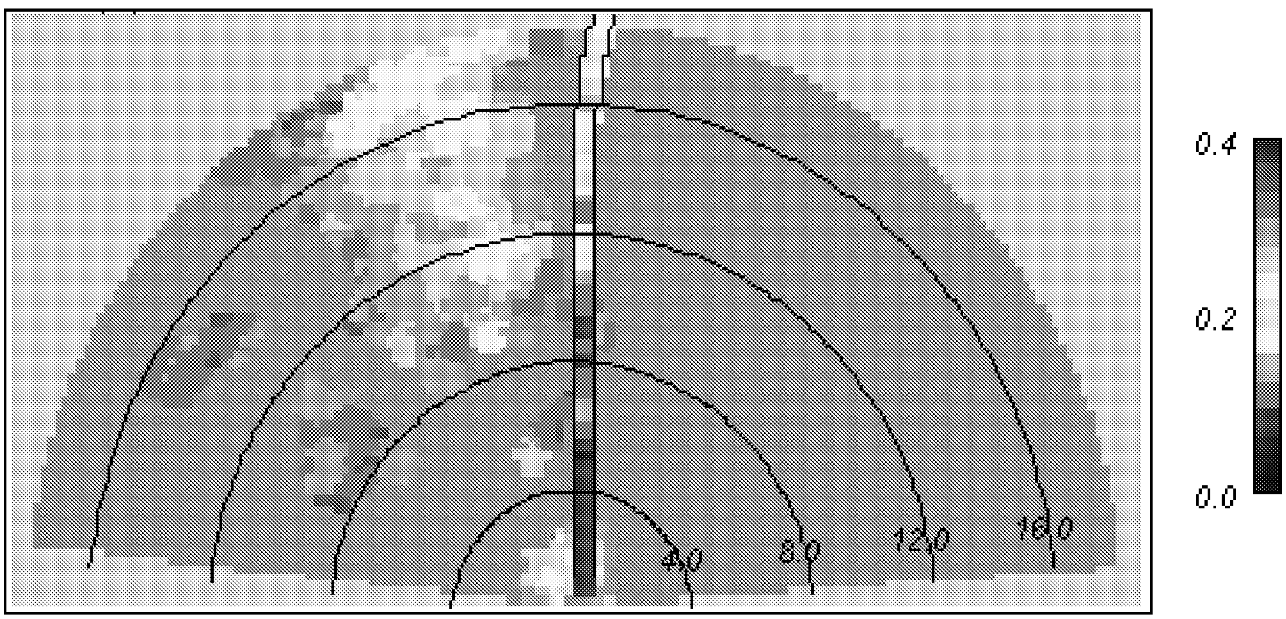
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

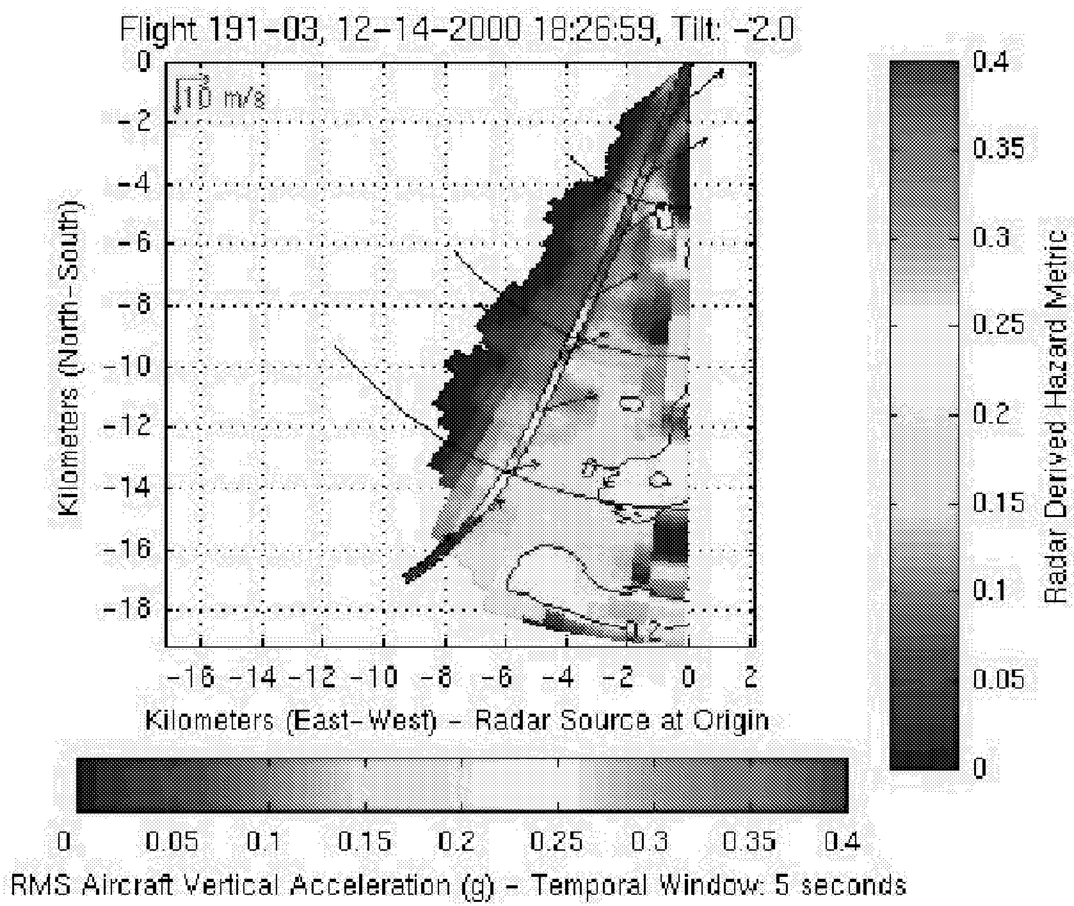


g-Loading (rms g) Event 191-03

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:26:54 or 66414 seconds

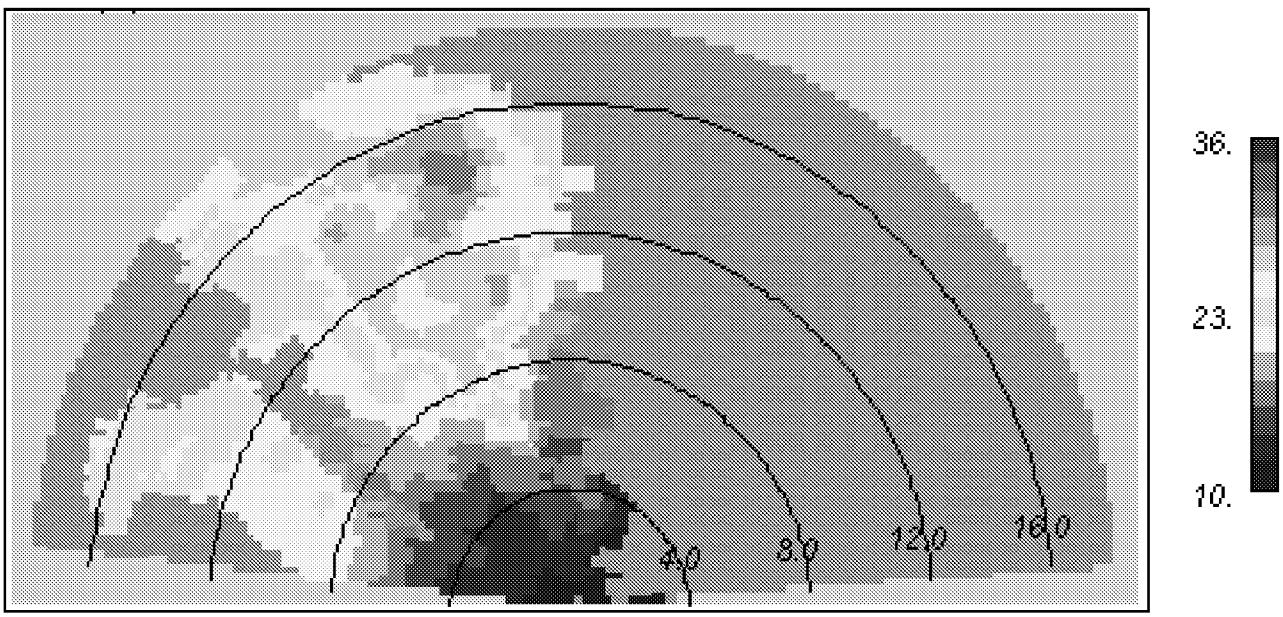



Flight 191-03, 12-14-2000 18:26:59, Tilt: -2.0
10 m/s
Kilometers (North-South)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0.2
-16 -14 -12 -10 -8 -6 -4 -2 0 2
Kilometers (East-West) - Radar Source at Origin
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Radar Derived Hazard Metric
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
RMS Aircraft Vertical Acceleration (g) - Temporal Window: 5 seconds

Reflectivity (dBZ) Event 191-03

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

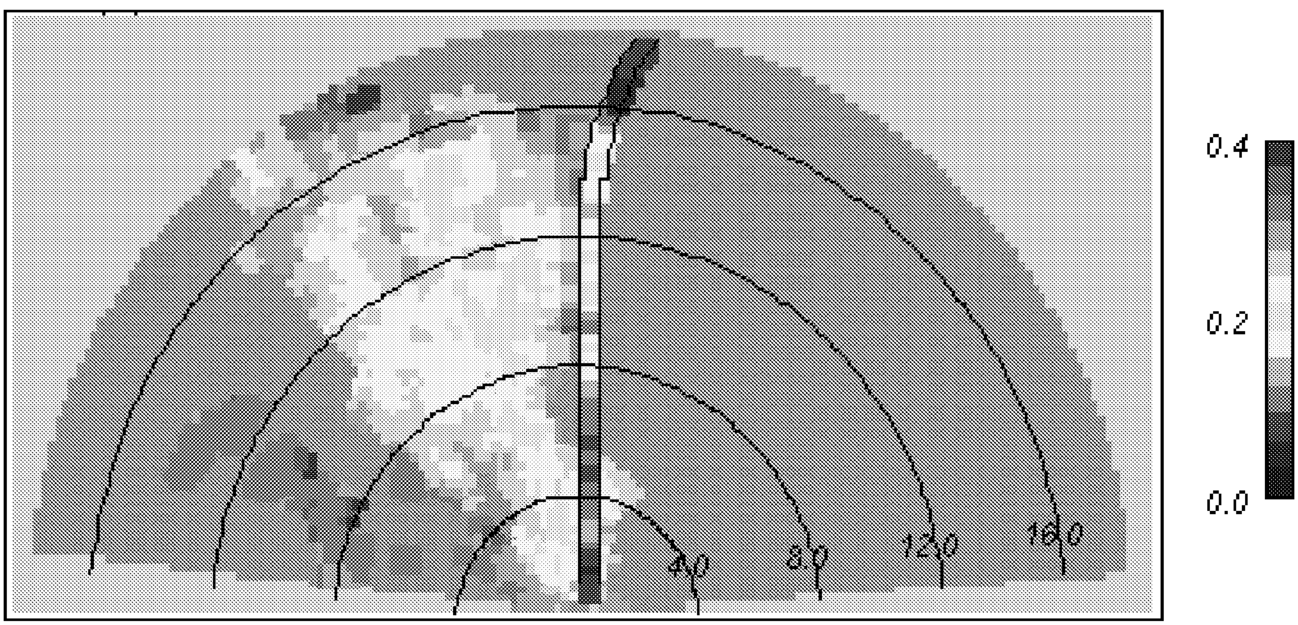
18:27:11 or 66431 seconds

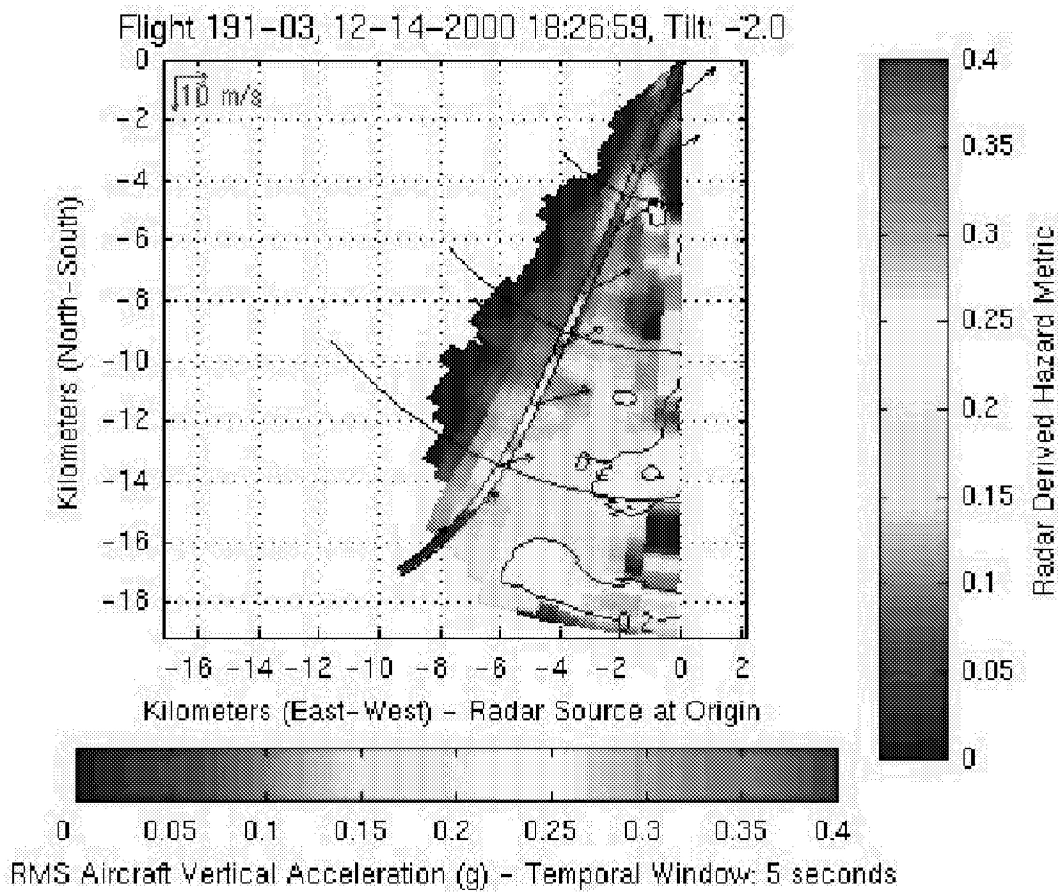


g-Loading (rms g) Event 191-03

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:27:09 or 66429 seconds




Flight 191-03, 12-14-2000 18:26:59, Tilt: -2.0
10 m/s
Kilometers (North-South)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-16 -14 -12 -10 -8 -6 -4 -2 0 2
Kilometers (East-West) - Radar Source at Origin
0.2
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Radar Derived Hazard Metric
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
RMS Aircraft Vertical Acceleration (g) - Temporal Window: 5 seconds

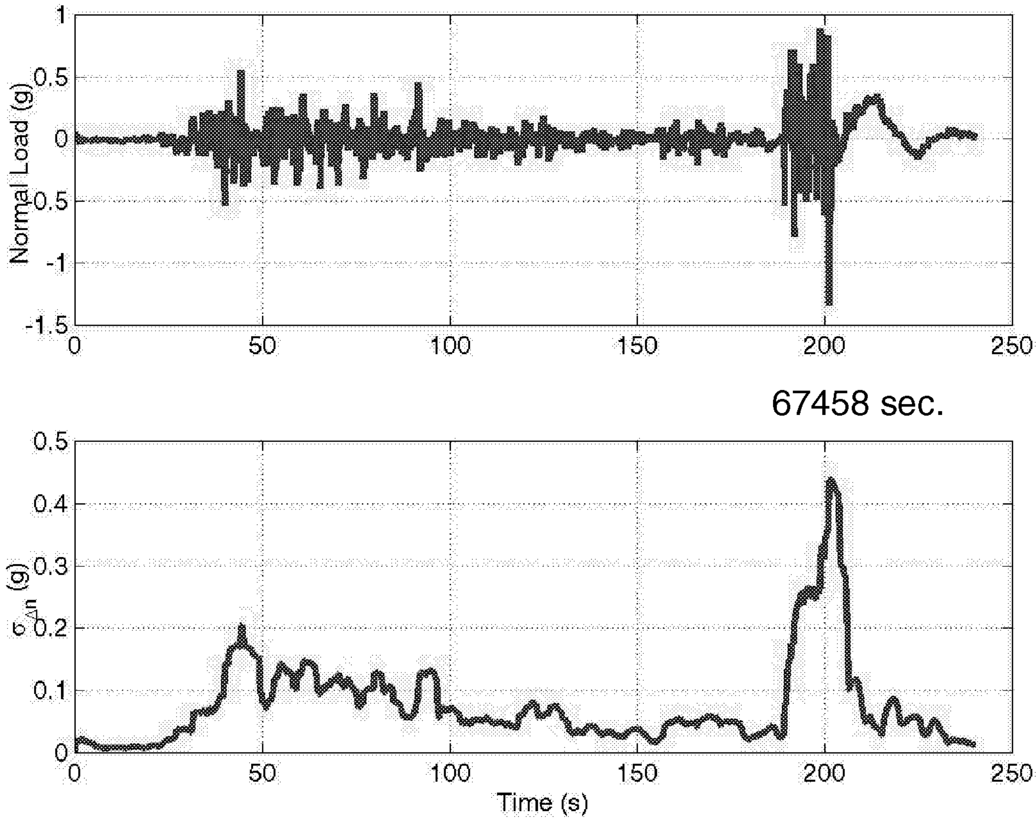
Summary - Event 191-03

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- **Good reflectivity on port side near path, low reflectivity along path at beginning of run**
- ***In situ* peak rms g ~ 0.33 at 66470 seconds**
- **Predictions of > 0.32 g along path at 66429 9.5 km (44 seconds) ahead**
- **Multiple hits on successive scans down to ~ 5 km**

Flight 191 Event 06 Normal Loads

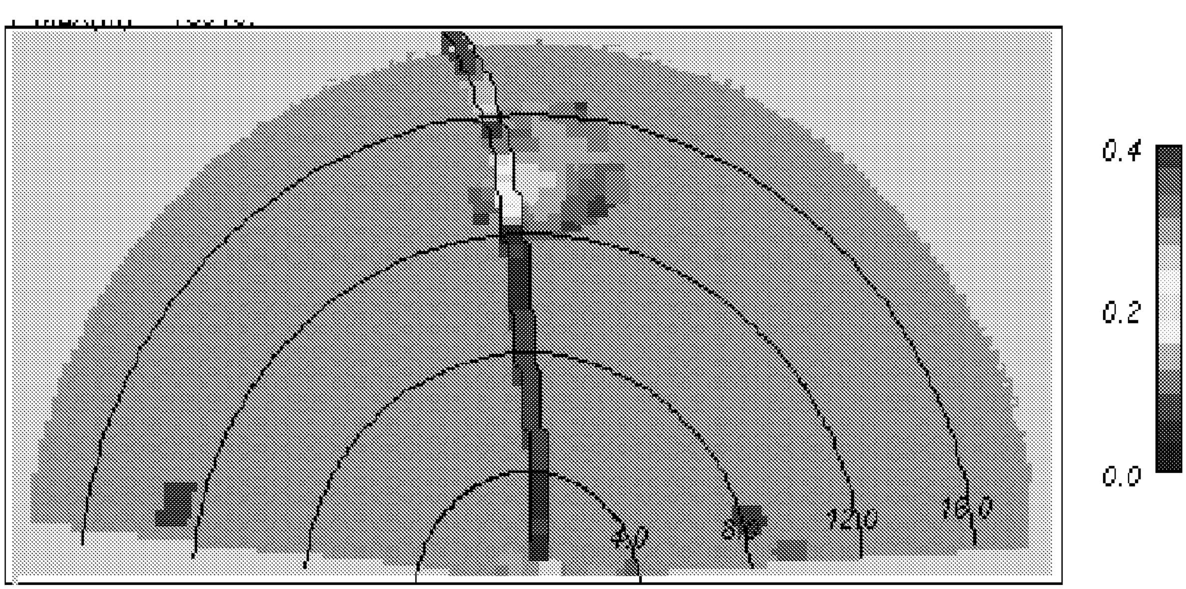
AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

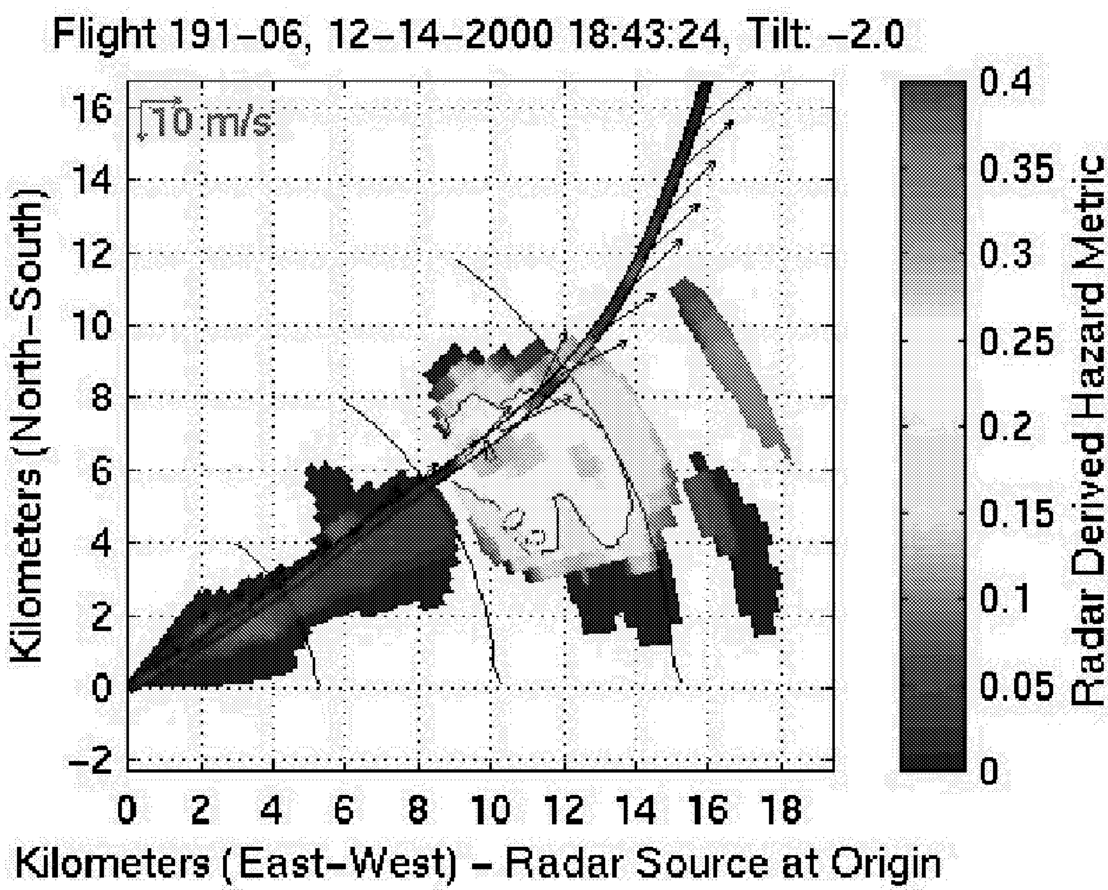


g-Loading (rms g) Event 191- 06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:43:22 or 67402 seconds

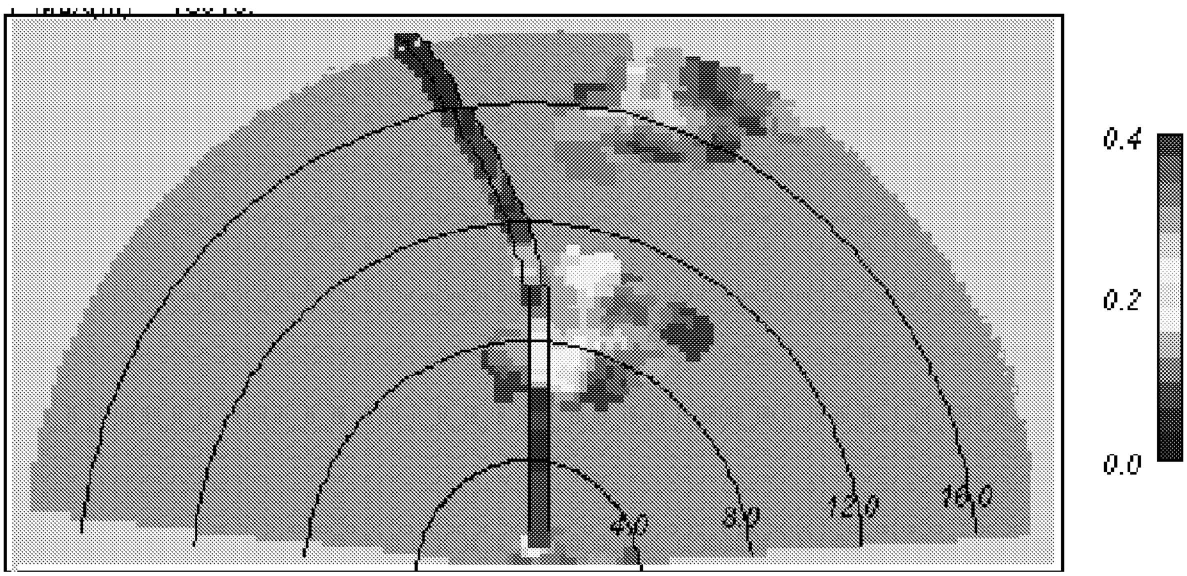


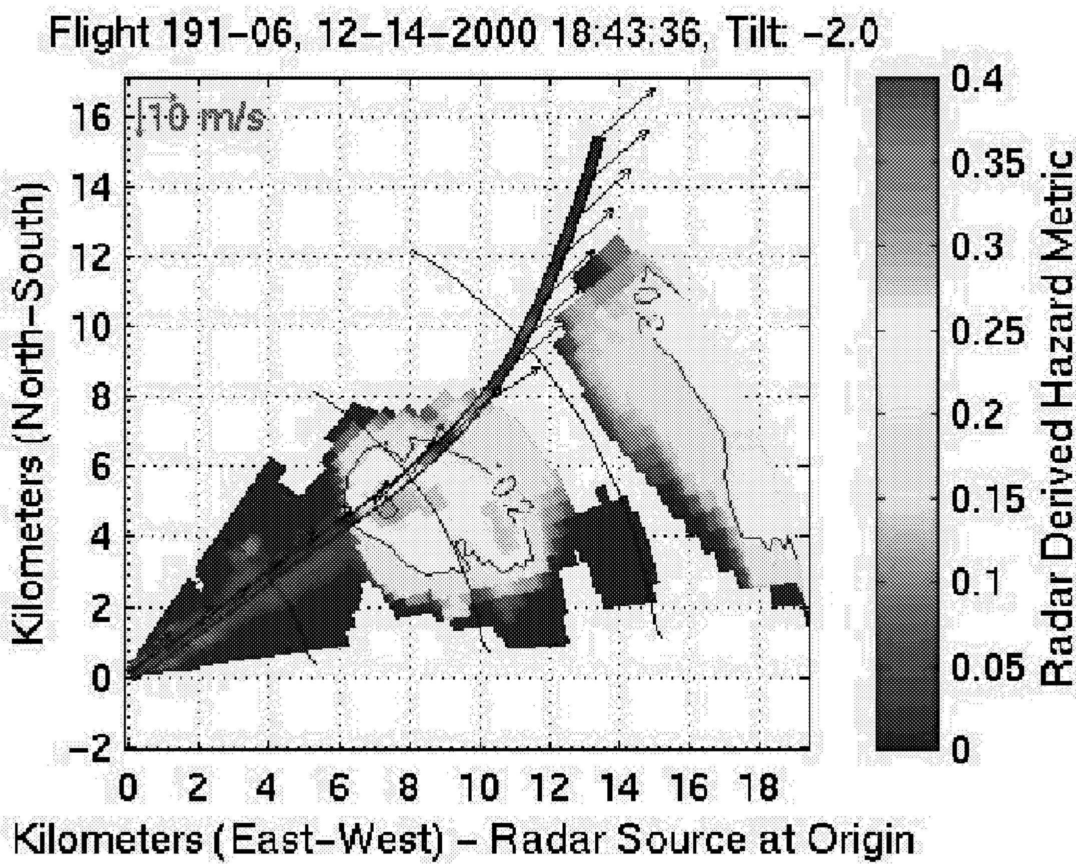

Flight 191–06, 12–14–2000 18:43:24, Tilt: –2.0
10 m/s
Kilometers (North–South)
Kilometers (East–West) – Radar Source at Origin
Radar Derived Hazard Metric
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
–2
0
2
4
6
8
10
12
14
16
18

g-Loading (rms g) Event 191- 06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

18:43:46 or 67426 seconds




Flight 191-06, 12-14-2000 18:43:36, Tilt: -2.0
10 m/s
Kilometers (North-South)
Kilometers (East-West) - Radar Source at Origin
Radar Derived Hazard Metric
0.2
0.2
16
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
16
18
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

Summary - Event 191-06

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- Two major "blobs" of reflectivity 25- 40 dBZ
- *In situ* peak rms g ~ 0.43 at 67458 seconds
- Prediction of ~ 0.4 g at 16km (63 seconds) ahead at 67402 seconds
- Multiple detections until 67450 seconds

Type I and Type II Errors

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- I: Missed Detections/Alerts
- II: False Detections/Nuisance Alerts
- Insufficient Data to Predict Performance
- Performance Predictions Will Require Modeling and Analysis
- Unlikely to Acquire Sufficient Experimental Data to Allow Statistical Analysis

Turbulence Radar Results Summary

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

Combined Event Based *A'Posteriori* Scoring for 7 Radar Events

	In Situ	Radar	Low dBZ
Bumps	5	4	3
Nulls	3	3	1

Conclusions

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- **Use and method of averaging/filtering will be a key factor in detection and reduction of false alarms**
  - **Lack of averaging may cause over-alerting**
  - **Averaging can reduce peak load estimates**
- ***In Situ* truth not available for large part of data**
  - **Validated models would enable more thorough algorithm evaluation**
  - **Modeling/simulation will support error analysis**
  - **Lidar can provide comparison data**

CY01 Flight Objectives

AvSP / Weather Accident Prevention / Turbulence Detection and Mitigation

- **S/W and H/W upgrades**
- **Flight objectives**
  - **40 events 0.2 g or better**
  - **Vary radar pulse configuration**
  - **Weather variety**
  - **Sufficient reflectivity for radar detection**
  - **Record I & Q and aircraft data**
  - **Test detection algorithms in real time**
  - **Research turbulence display for NASA pilots**

Market Assessment of Forward-Looking Turbulence Sensing Systems

Research Sponsor:

NASA Weather Accident Prevention Project (WxAP)

Paul Kauffmann, Old Dominion University

Overview

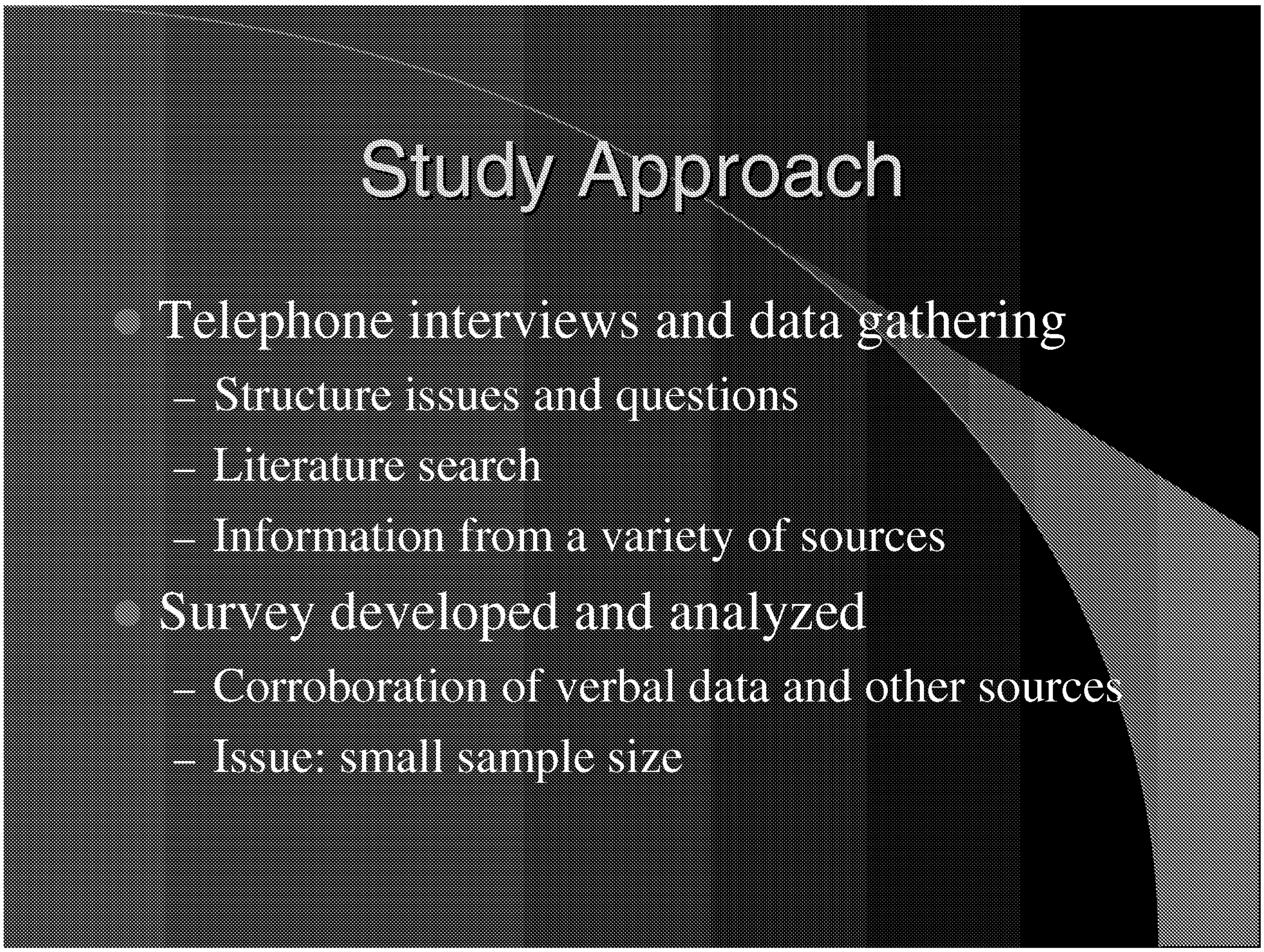
- Technologies and Study Objectives
- Study Approach
- Results:
  - Business Model: Injury rates, cost of injuries, indirect costs
  - Market penetration rate estimates
  - Product success characteristics

Objectives

- Identify cost and benefit data related to next generation of forward sensing turbulence technologies:
  - Enhanced X band, LIDAR, combined product
- Integrate into a business case that will evaluate feasibility of market success for the commercial transport fleet.

Technology Focus

- Examine three possible forward sensing turbulence system(s) that may achieve market success over the next 5-10 years:
  - 1) Next generation enhanced X band turbulence radar systems for convective turbulence.
  - 2) LIDAR based turbulence systems to sense clear air turbulence.
  - 3) A combined, hybrid system including both enhanced radar (X band) and LIDAR to sense both convective and clear air turbulence.

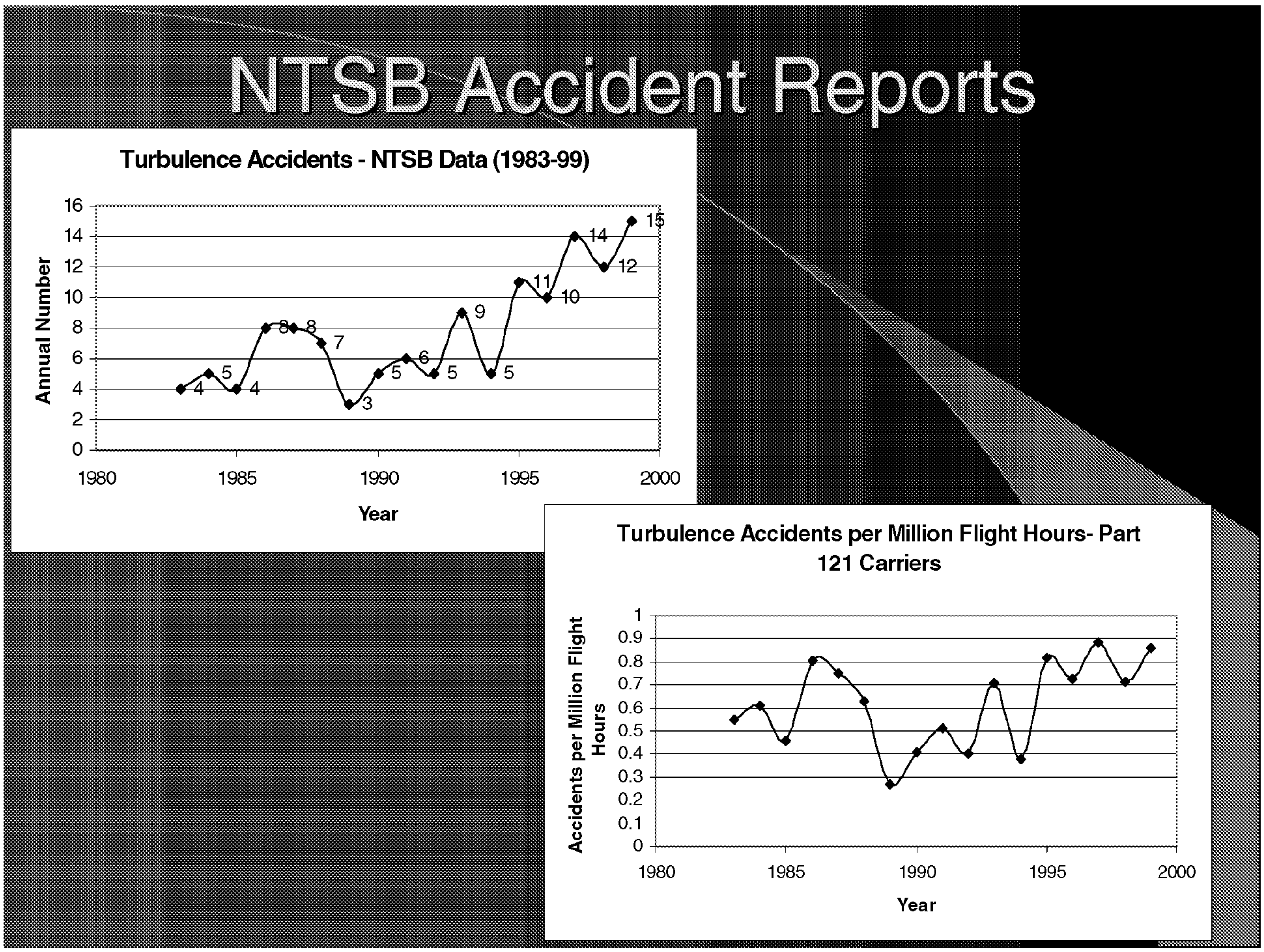

Study Approach
Telephone interviews and data gathering
– Structure issues and questions
– Literature search
– Information from a variety of sources
Survey developed and analyzed
– Corroboration of verbal data and other sources
– Issue: small sample size

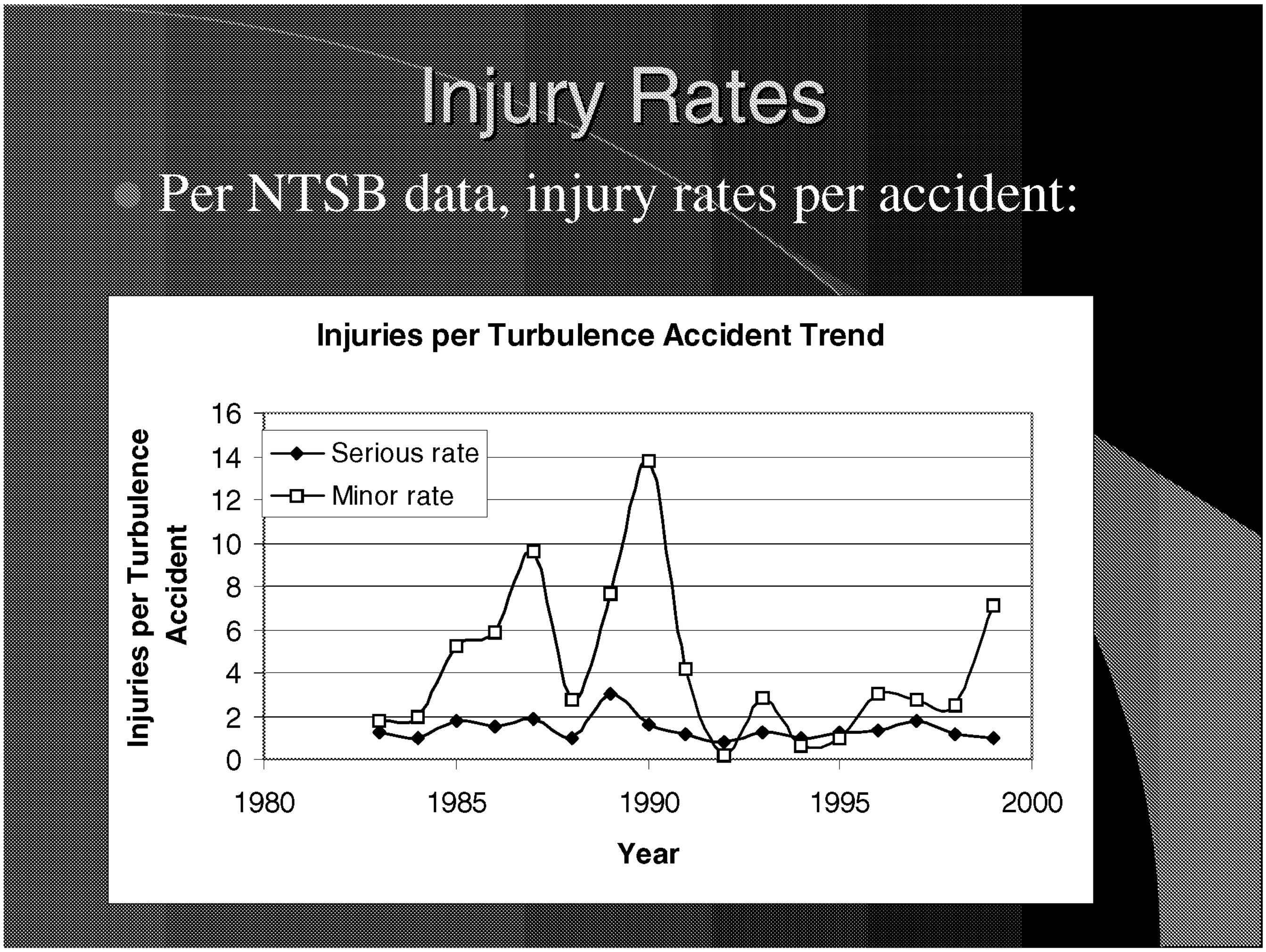
Business Case Equation

- Base Business Case defined by:
  - Net $ benefit of Turbulence System =
    - Investment – operating costs + savings from reduced turbulence accidents and incidents + savings from flight operations improvements (damage, diversions and flight time) + intangible benefits
  - Intangible benefits may be valued indirectly: the value to make case positive.

Accident / Incident Rates

- A variety of benchmarks:
  - AWS&T article: Part 121 carriers experienced an average of 130 events per year in a three - year period from 1994-96.
  - Study participant: 750 turbulence related events per year for Part 121 carriers.
  - FAA report: from 1981-1997, 342 reports of turbulence affecting major air carriers for an annual average of 27 events


NTSB Accident Reports
Turbulence Accidents - NTSB Data (1983-99)
Annual Number
Year
16
14
12
10
8
6
4
2
0
1980
1985
1990
1995
2000
4
5
4
8
8
7
3
5
6
5
9
5
11
10
14
12
15
Turbulence Accidents per Million Flight Hours- Part 121 Carriers
Accidents per Million Flight Hours
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1980
1985
1990
1995
2000


Injury Rates
Per NTSB data, injury rates per accident:
Injuries per Turbulence Accident Trend
Injuries per Turbulence Accident
Year
Serious rate
Minor rate
0
2
4
6
8
10
12
14
16
1980
1985
1990
1995
2000

Data from Crew Reports

- Crew report data analyzed to develop an estimated annual average, for Part 121 fleet:

	Clear Air	Wake	Convective	Total	1999 NTSB Accidents
Turbulence events	136.6	123.8	529.4	789.8	NA
Injury events	106.7	89.7	371.4	567.8	15
Minor FA injuries	123.8	132.3	431.2	687.4	20
Serious FA injuries	17.1	0.0	21.3	38.4	10
Minor PA injuries	17.1	12.8	89.7	119.5	87
Serious PA injuries	0.0	8.5	8.5	17.1	5

Airline executive: 200 passenger and 235 workers compensation claims for turbulence related injuries in 1997.

Survey Participant Estimates

- Survey participants estimate higher annual incidents:

Annual turbulence incidents for Part 121 Carriers		
Lower 90% interval	Most Likely	Upper 90% Interval
151	210	269

FAA Injury Costs

- "Willingness to Pay" approach:

Classification	Willingness to Pay	Emergency / Medical	Legal / court	Total Value
Death	$2.7M	Not a significant addition to WTP value		$2.7M
Minor injury	$34,000	$2,000	$2,500	$38,500
Serious Injury	$482,000	$27,600	$12,200	$521,800

Issue: Unclear how these costs relate to business case in industrial setting.

Other Benchmarks for Injury Costs

- Lindsey (2000): average FA injury cost is $10k-15k and average passenger injury between $50,000 - $60,000 (combined serious and minor).
- Search (2000): direct payment cost of $600k for serious passenger injuries and $100k for minor injuries. Total annual Part 121 cost of FA injuries is $11M.

Survey Results

- Survey response estimates:

	Survey: 90% Confidence Interval for mean cost of injury		
Injury Category	**Lower**	**Expected**	**Upper**
Serious Flight Attendant	64748	164286	263823
Minor Flight Attendant	9292	25000	40708
Serious Passenger	76587	170000	263413
Minor Passenger	3256	33333	63411

Total Injury Cost Estimate

- Using data from this study:

Injury Category	Annual Injuries (Table 4)	Expected Cost $	Total Cost $
Minor Flight Attendant	687.4	25,000	17,184,125
Serious Flight Attendant	38.4	164,286	6,312,536
Minor Passenger	119.5	33,333	3,984,725
Serious Passenger	17.1	170,000	2,903,157
	Total Annual Part 121 Industry Injury Cost		30,384,542

Industry Cost Benchmarks

- Turbulence costs are $30M- $60M:

	Survey	Lindsey	Search	FAA
	Table 9	Average flight attendant injury: $12,500	Flight attendant injury cost not estimated	Serious injury: $521,800
	Table 9	Average passenger injury: $55,000	Serious passenger injury: $600,000 Minor passenger injury: $100,000	Minor injury: $38,500
Minor Flight Attendant	17,184,125	9,072,364	$11,000,000 estimated as total flight attendant cost	Total serious injury cost: $28,960,694
Serious Flight Attendant	6,312,536			
Minor Passenger	3,984,725	7,514,052	11,954,174	Total minor injury cost: $31,065,910
Serious Passenger	2,903,157		10,246,435	
Total Part 121 Cost Estimate	**30,384,542**	**16,586,416**	**33,200,609**	**60,026,604**

Convective or Clear Air?

- What proportion of the costs are related to CAT? (LIDAR vs X Band)
  - For analysis: 2/3 incidents are convective

	Convective	Clear Air	Wake / Other
Table 4- Crew Reports	67%	17%	16%
Clark (1997)	50%	33%	17%
Lindsey (2000)	50%	34%	16%

Issue: Is CAT over reported?

Non – Recurring Investment

- From the survey data:

	OEM Purchase Cost			Retrofit Cost		
	-90%	Expected	+90%	-90%	Expected	+90%
X Band	25728	44643	63558	29865	43750	57635
LIDAR	48193	72500	96807	66182	87500	108818
Combined	59147	82500	105853	85823	97500	109177

Confidence intervals for mean cost shown

Differentiated based on original purchase on new aircraft and cost to retrofit existing fleet.

Operational Savings

- Operational Savings:
  - Fuel Savings: Search estimated $595 per aircraft per year
  - Diversions: Three found in the crew reports. Lindsey indicates that most continue.
  - Aircraft damage: Primarily cart and cabin related.
- Conclusion: Operational savings appear to be marginal decision factors

Business Case Injury Cost

- Consider investment for Part 121 carrier with 600 aircraft (per aircraft basis):
  - 80% success

	Total	Clear Air	Wake	Convective
Fatality events @ 0.2 /yr for industry	$108,000	$20,301	$17,053	$70,647
Minor Flight Attendant	$3,719,304	$669,937	$716,139	$2,333,228
Serious Flight Attendant	$1,366,277	$607,234	$0	$759,043
Minor Passenger	$862,439	$123,206	$92,404	$646,829
Serious Passenger	$628,354	$0	$314,177	$314,177
Total	$6,684,374	$1,420,677	$1,139,773	$4,123,924
Annual cost per aircraft	$11,141	$2,368	$1,900	$6,873

X Band Case -Possibly Favorable

- Using 12% rate, five years, retrofit option and 80% reduction:
  - Intangibles: diversion, damage, others

Percent injury cost reduction	80%	
Business decision based on single aircraft model	X Band Base Case	Value to Reverse Decision
Non Recurring Investment	$43,750	$21,966
Annual injury savings	$5,499	$11,542
Annual operating savings	$595	$6,638
Annual intangible benefits	NA	$6,043
Increased annual maintenance	0	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$21,784	

LIDAR Business Case-Unfavorable

- Possible market potential appears small:

Percent injury cost reduction	80%	
Business decision based on single aircraft model	LIDAR Base Case	Value to Reverse Decision
Non Recurring Investment	$87,500	$7,600
Annual injury savings	$1,894	$28,053
Annual operating savings	$595	$26,754
Annual intangible benefits	NA	$26,159
Increased annual maintenance	$4,375	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$94,298	

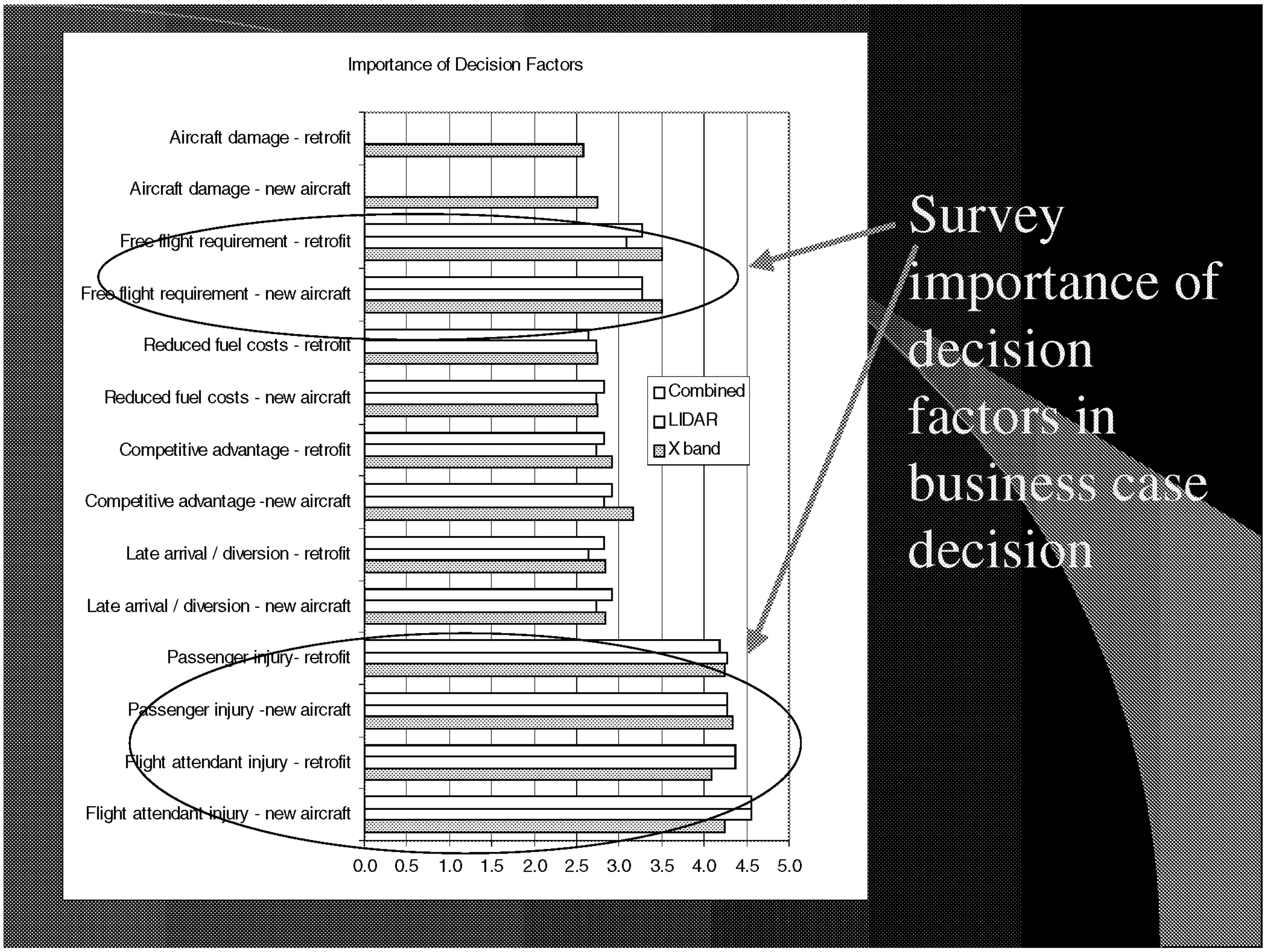
Combined Product Case- Unfavorable

- Incremental expenditure over X band appears unjustified:

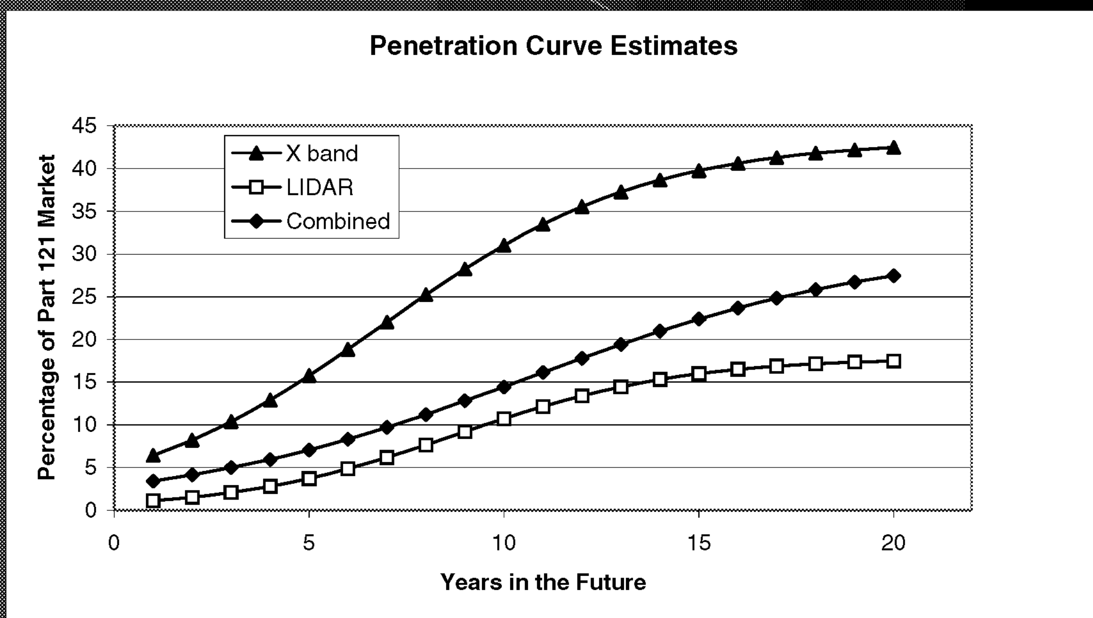
Percent injury cost reduction	80%	
Business decision based on single aircraft model	Combined Base Case	Value to Reverse Decision
Non Recurring Investment	$97,500	$11,221
Annual injury savings	$7,393	$31,327
Annual operating savings	$595	$24,529
Annual intangible benefits	NA	$23,934
Increased annual maintenance	$4,875	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$86,279	

Business Case Issues

- Influence of other factors:
  - Competition to own cockpits
  - Market leadership: Integrated suite of weather products
  - Demonstrated commitment to Safety
  - Competitive pressures if lead adopter purchases
  - Long flights and out of seat entertainment
  - Issue of free flight

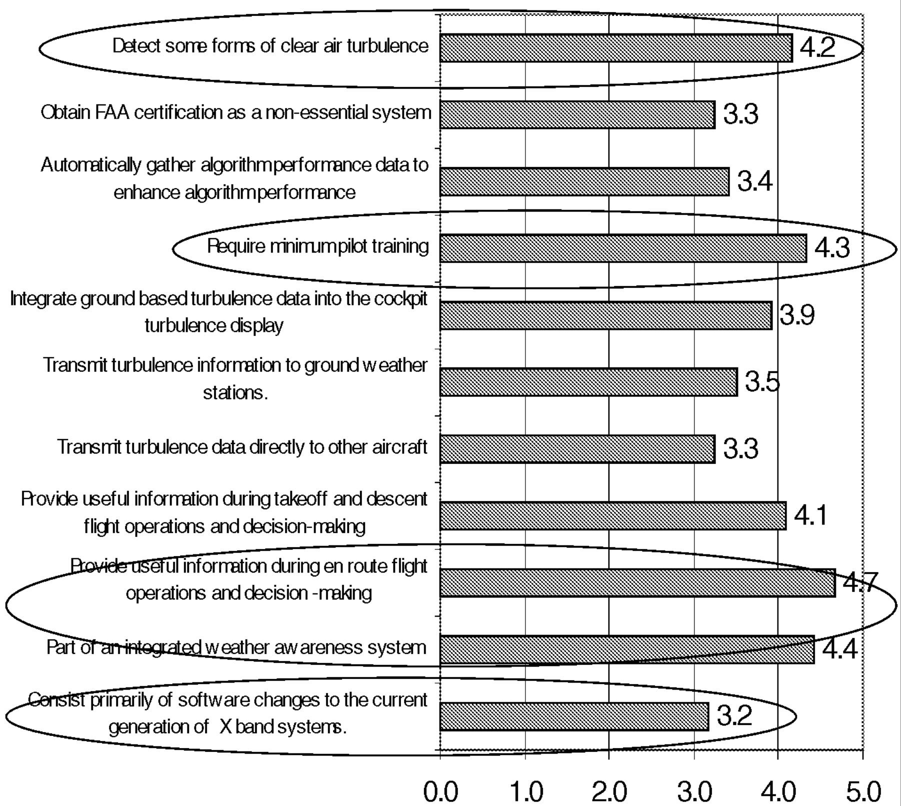

Importance of Decision Factors
Aircraft damage - retrofit
Aircraft damage - new aircraft
Free flight requirement - retrofit
Free flight requirement - new aircraft
Reduced fuel costs - retrofit
Reduced fuel costs - new aircraft
Competitive advantage - retrofit
Competitive advantage -new aircraft
Late arrival / diversion - retrofit
Late arrival / diversion - new aircraft
Passenger injury- retrofit
Passenger injury -new aircraft
Flight attendant injury - retrofit
Flight attendant injury - new aircraft
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Combined
LIDAR
X band
Survey importance of decision factors in business case decision

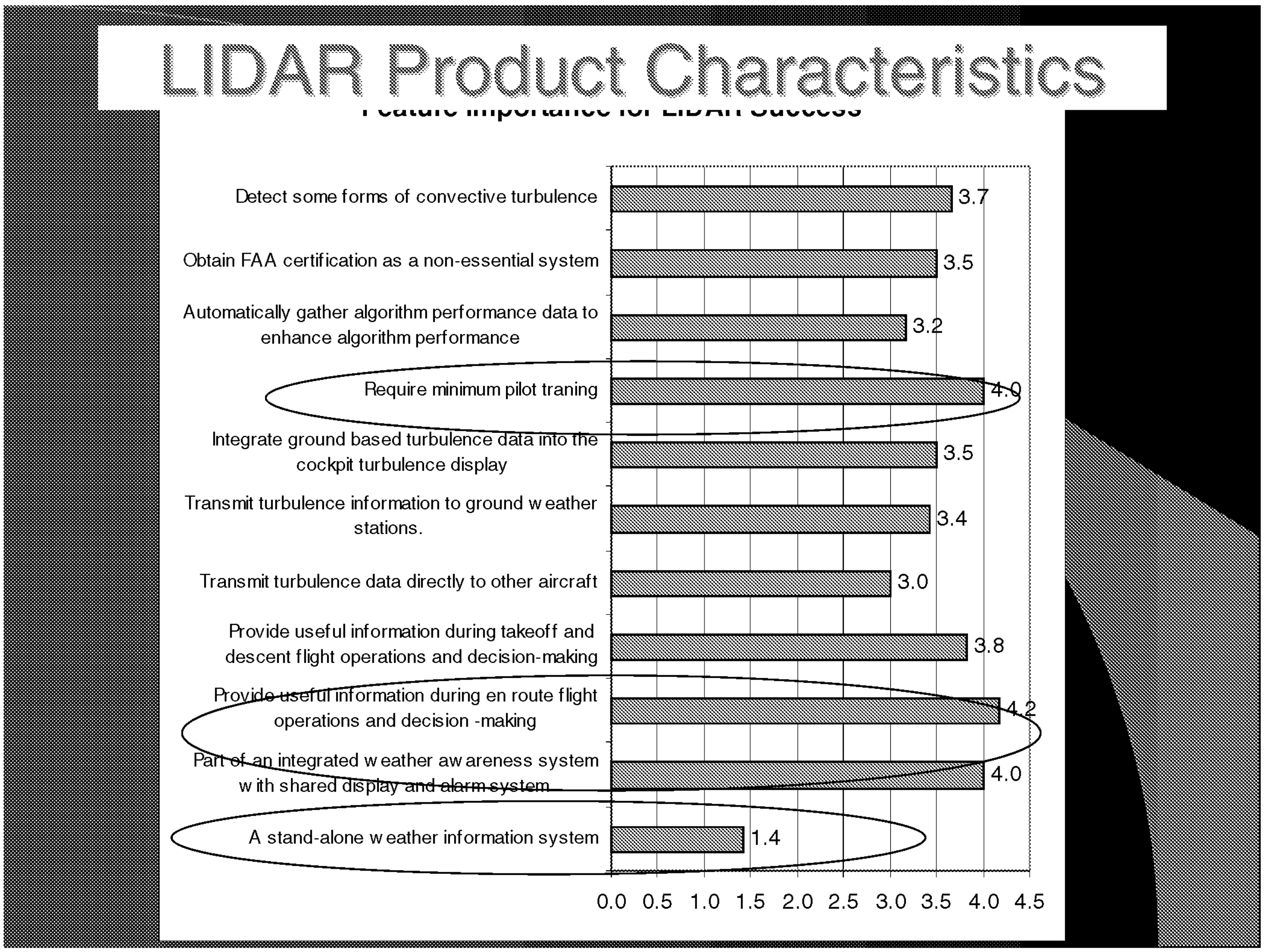
Market Penetration Estimates

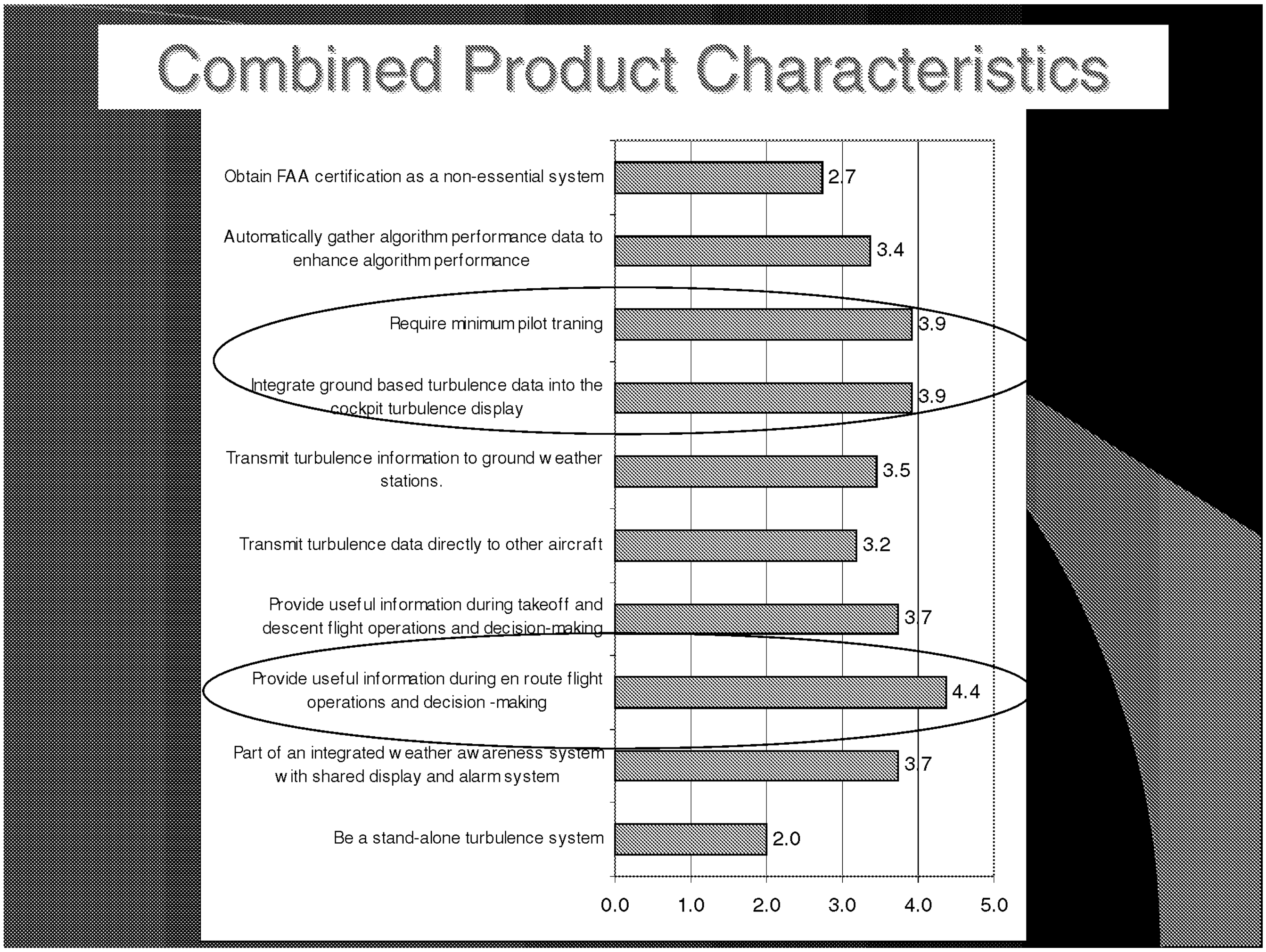


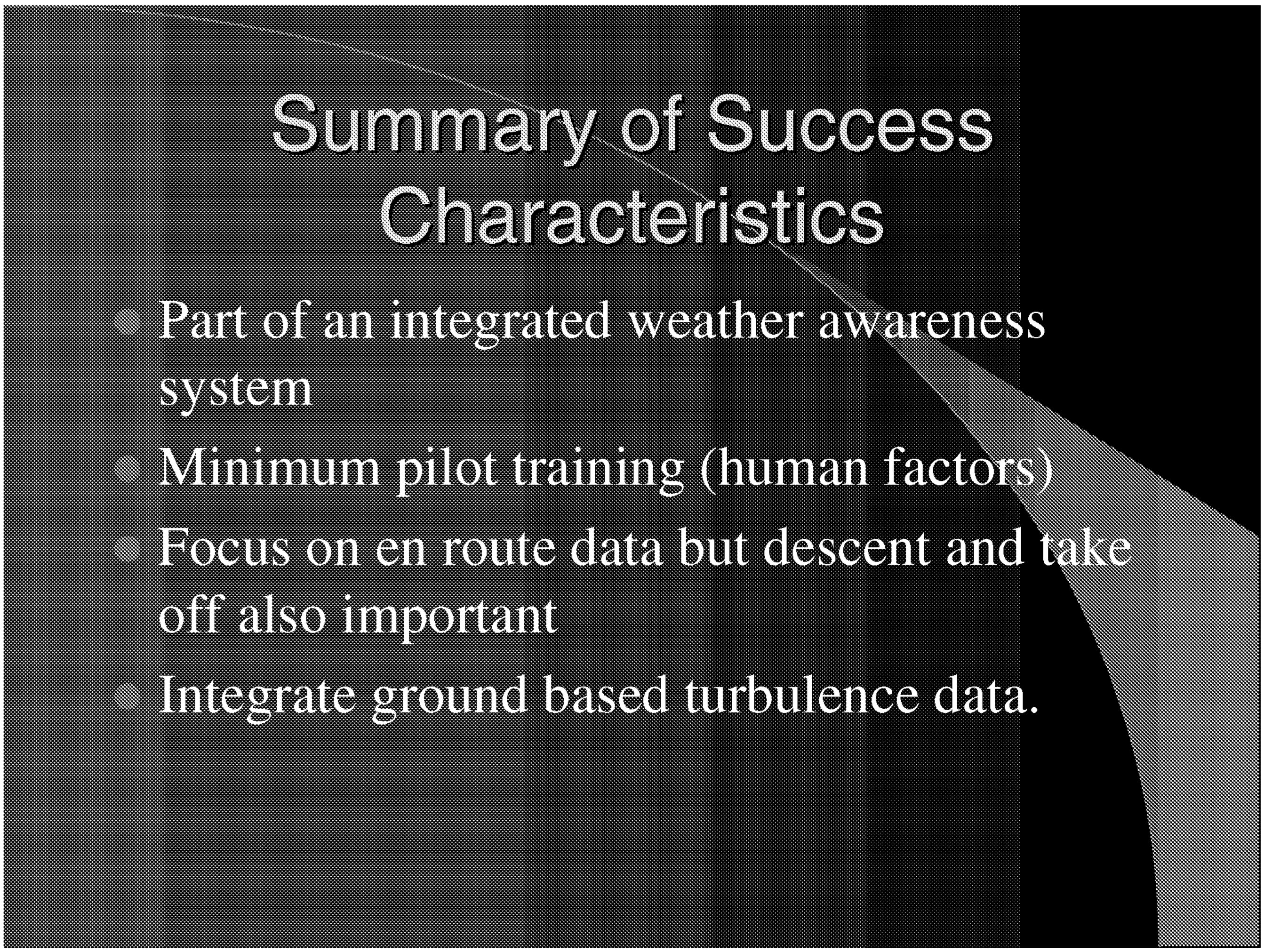
Penetration rates consistent with weak business case

X Band Product Characteristics




LIDAR Product Characteristics
Detect some forms of convective turbulence
3.7
Obtain FAA certification as a non-essential system
3.5
Automatically gather algorithm performance data to enhance algorithm performance
3.2
Require minimum pilot traning
4.0
Integrate ground based turbulence data into the cockpit turbulence display
3.5
Transmit turbulence information to ground w eather stations.
3.4
Transmit turbulence data directly to other aircraft
3.0
Provide useful information during takeoff and descent flight operations and decision-making
3.8
Provide useful information during en route flight operations and decision -making
4.2
Part of an integrated w eather aw areness system w ith shared display and alarm system
4.0
A stand-alone w eather information system
1.4
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5


Combined Product Characteristics
Obtain FAA certification as a non-essential system
2.7
Automatically gather algorithm performance data to enhance algorithm performance
3.4
Require minimum pilot traning
3.9
Integrate ground based turbulence data into the cockpit turbulence display
3.9
Transmit turbulence information to ground w eather stations.
3.5
Transmit turbulence data directly to other aircraft
3.2
Provide useful information during takeoff and descent flight operations and decision-making
3.7
Provide useful information during en route flight operations and decision -making
4.4
Part of an integrated w eather aw areness system w ith shared display and alarm system
3.7
Be a stand-alone turbulence system
2.0
0.0
1.0
2.0
3.0
4.0
5.0


Summary of Success Characteristics
Part of an integrated weather awareness system
Minimum pilot training (human factors)
Focus on en route data but descent and take off also important
Integrate ground based turbulence data.

Turbulence Warning

- Estimated minimum warning for market success:

	Expected Warning in Minutes		
	Severe Turbulence	Moderate Turbulence	Light Turbulence
X band	3.06	2.16	1.13
LIDAR	2.68	1.93	1.06
Combined	3.53	2.30	1.28

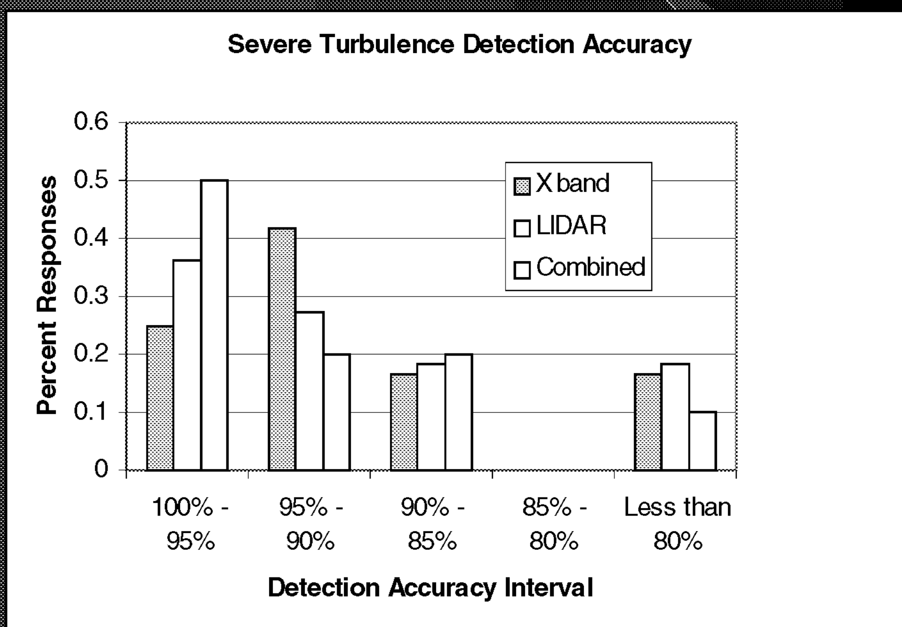
Detection Accuracy

- Accuracy threshold for market success:

	Expected Accuracy		
	Severe Turbulence	Moderate Turbulence	Light Turbulence
X band	90%	88%	83%
LIDAR	91%	88%	84%
Combined	93%	90%	85%

Example of Distribution

- The averages represent a range of accuracy estimates. For example:



Summary

- Market potential primarily based on injury cost reduction
- X band has the greatest market potential
  - Initial costs must be kept low
  - System integration, accuracy, and ability to detect some clear air turbulence are critical.
- LIDAR and a Combined product have a very weak business case
  - Market penetration potential: new aircraft for long flights.

Secure Cabin Exercise

Briefing

Rod Bogue
NASA Dryden Flight Research Center

NASA/CP—2002-210964

Secure Cabin Objective

- *To determine the estimated time required to configure a commercial aircraft cabin for safe transit of atmospheric turbulence.*

Cabin Secure Time

- **The time from first announcement of hazard until the cabin is declared secure.**

• Approach

- Conduct series of timed aircraft cabin preparation simulations on wide-body and narrow-body aircraft
  - Professional cabin crew staff from United and American
  - Paid passenger subjects
  - Guidance from Cabin Evacuation Drill experience
- Use team of experienced operational staff to develop plans and procedures

Secure Cabin Participating Organizations

- Flight Attendants
  - AFA, APFA
- Air Carriers
  - United, Jet Blue, American, Delta, Continental
- Airframe Manufacturers
  - Boeing
- Government Agencies
  - FAA/CAMI, NASA

Simulation Variables

- Passenger load and Flight Attendant compliment
- Cabin Class (first class, business class, main cabin)
- Cabin Activities (food service, beverage service, lavatory utilization, night conditions)

• Scenarios

- Full Meal Service
- After movie restroom call
- Long Haul night situation

Responsibilities

- Scenario Development - Secure Cabin Team
- Cabin Crew Staffing - UAL/American
- Pax Staffing - NASA funded
- Experiment Coordination - NASA
- Data Collection/Analysis - NASA/CAMI
- Report/Conclusions - Secure Cabin Team

Draft Plan

- Perform Wide-body exercise in the FAA/CAMI Cabin Evacuation facility at Oklahoma City in mid-September 2001
- Obtain passenger subjects from CAMI contractor
- Utilize CAMI Cabin Evac. facilities and expertise for exercise support (video, cabin set-up, test experience)
- Plan & conduct Narrow-body exercise at future date

CAMI 747 Cabin Evacuation Facility

Exercise Status

- Team Established and Functioning (3 meetings, conference calls)
- Approach defined, developing detailed scenarios
- Facilities Identified
- Experiment Protocol Approved
- Defining Space Act agreement
- Defining PAX participant staffing

Schedule

- Revise Draft Plan — 10 June 01
- Complete 747 Configuration — 1 July 01
- Finalize Plan — 15 July 01
- Conduct Wide-body Exercise — 10-14 Sept. 01
- Draft Report — 15 Nov. 01
- Final Report — 15 Jan. 02
- Conduct Narrow-body Ex. — 4Q FY-02

Risks/Mitigations

- Process Logistics
  - CAMI / NASA Ames IRB Approval
    - Closely coordinate with CAMI Staff
    - Expand/Augment CAMI Role in Exercise
  - Recent MOA funds transfer uncertainty
    - Located a second MOA for backup
- Exercise Injury Liability
  - IRB review of Exercise plan
  - CAMI partnership with Cabin Evac Experience
  - Injury insurance from Pax supply contractor

Risks/Mitigations

- **Passenger Seatbelt Unfamiliarity**
  - **Passenger training**
  - **Pre-exercise demonstrations**

"Feasibility Study of Transport-Aircraft Control Systems for Turbulence Effects Mitigation"

Christopher J. Borland
Vincent M. Walton

The Boeing Company
Commercial Airplane Group
Seattle, WA

NASA Weather Accident Prevention Review
June 5-7, 2001

Study Objectives

- Use turbulence inputs from injury-accident FDR data
- Assess capability of current aircraft control systems to reduce turbulence-induced acceleration response in the cabin
- Assess new control law strategies with current (on-board) and advanced (forward-looking) turbulence sensors
- Identify key issues to practical implementation

Analysis of Turbulence Accidents and Wind Field Determination

- NASA Ames provided FDR data from NTSB for five accidents (1975-85).
- Boeing Accident/Incident Investigation Group provided FDR data for five accidents (1997-99).

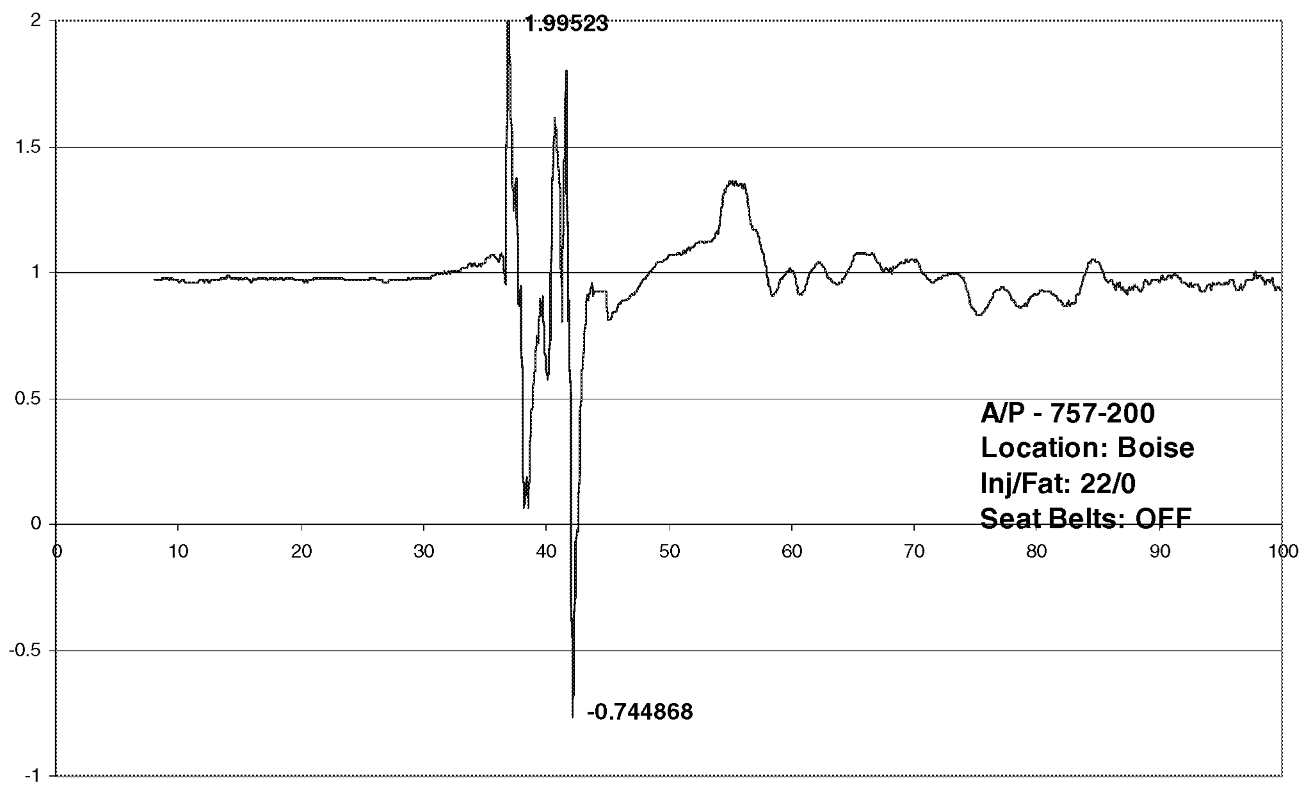
Most of these data show some interesting similarities:

- Severe turbulence onset often gives little or no warning.
- Positive and negative spikes in acceleration, with negative excursions to below 0 g, lasting about 1-2 seconds.
- Duration of severe turbulence is often brief, 5-10 seconds.

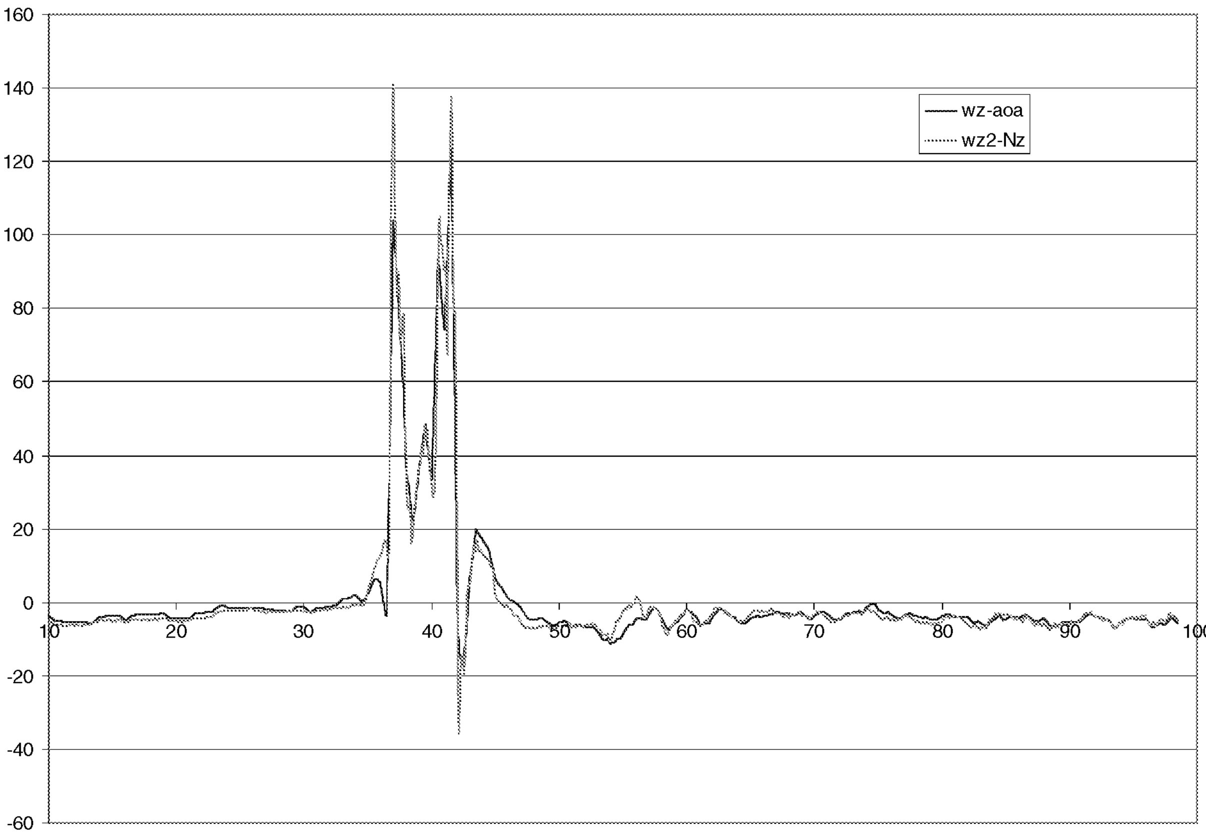
Analysis of Turbulence Accidents and Wind Field Determination (cont'd)

- FDR data can be used (sort of) to extract the wind field
  (Ref: Bach and Wingrove AIAA papers)
  - Alpha vane, Nz, θ, air data using kinematics only
  - Nz, θ, δe using aero characteristics from A/C model
- Peak velocities of over 140 ft/sec have been seen.
- Some time histories strongly suggest vortex encounters due to Kelvin-Helmholtz instabilities (shear layers from jet streams, thunderstorms, mountain waves).

Case B-1 - Nz (c.g.)

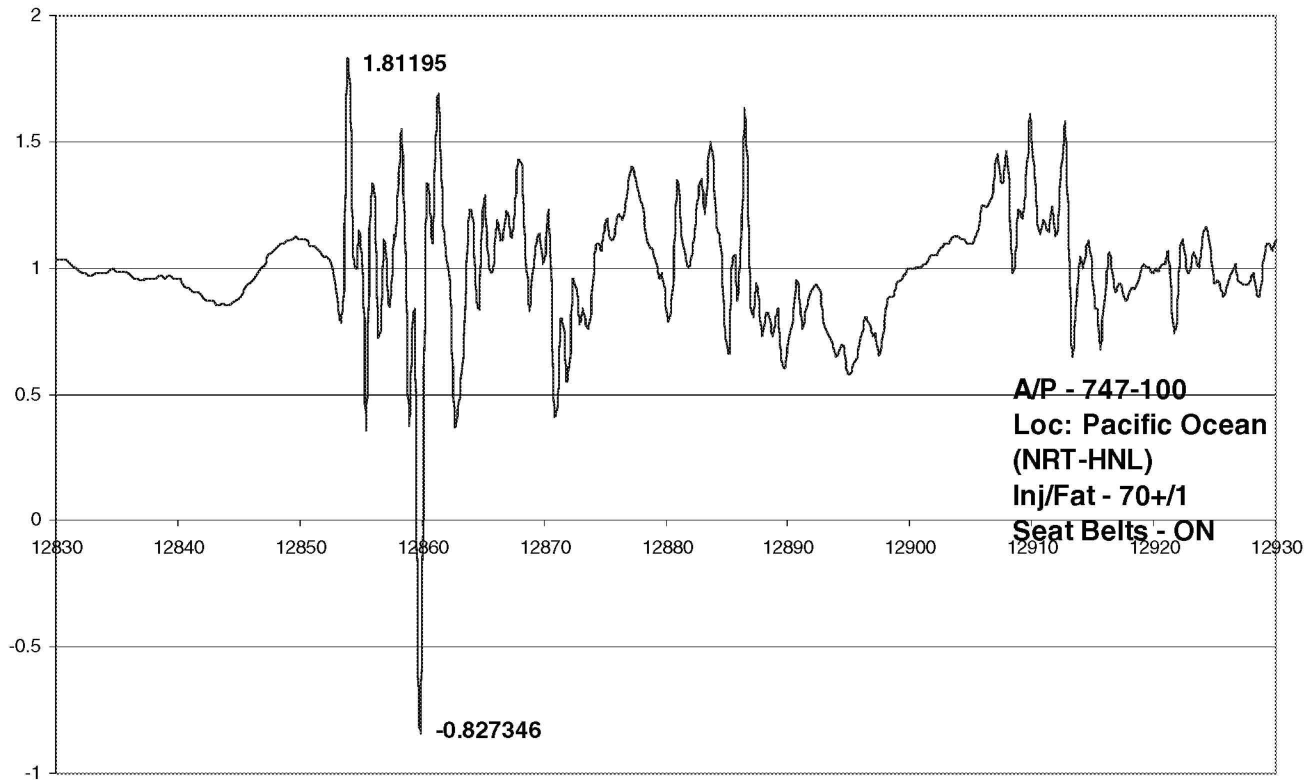

1.99523
-0.744868
A/P - 757-200
Location: Boise
Inj/Fat: 22/0
Seat Belts: OFF
2
1.5
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60
70
80
90
100

Case B-1 - Wz


160
140
120
100
80
60
40
20
0
-20
-40
-60
10
20
30
40
50
60
70
80
90
100
wz-aoa
wz2-Nz

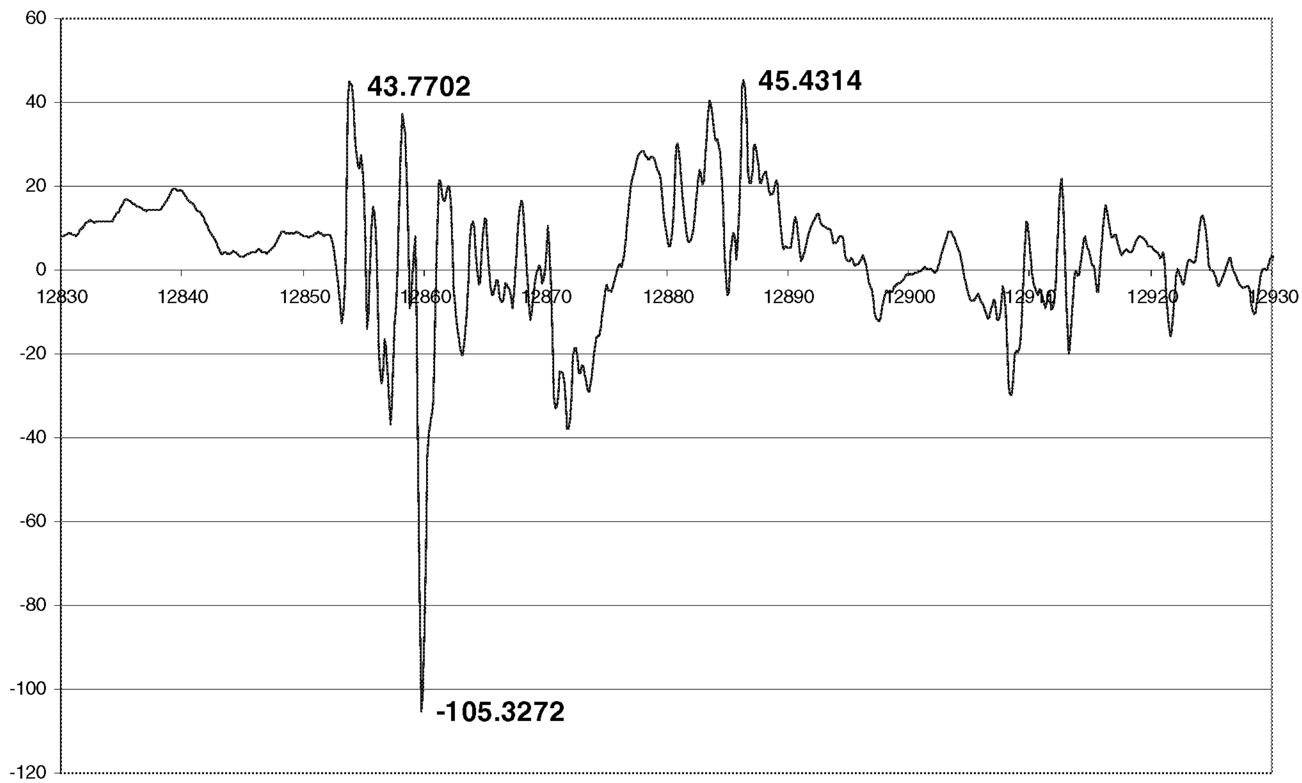
Aviation Safety Program

Case B-2 - Nz (c.g.)

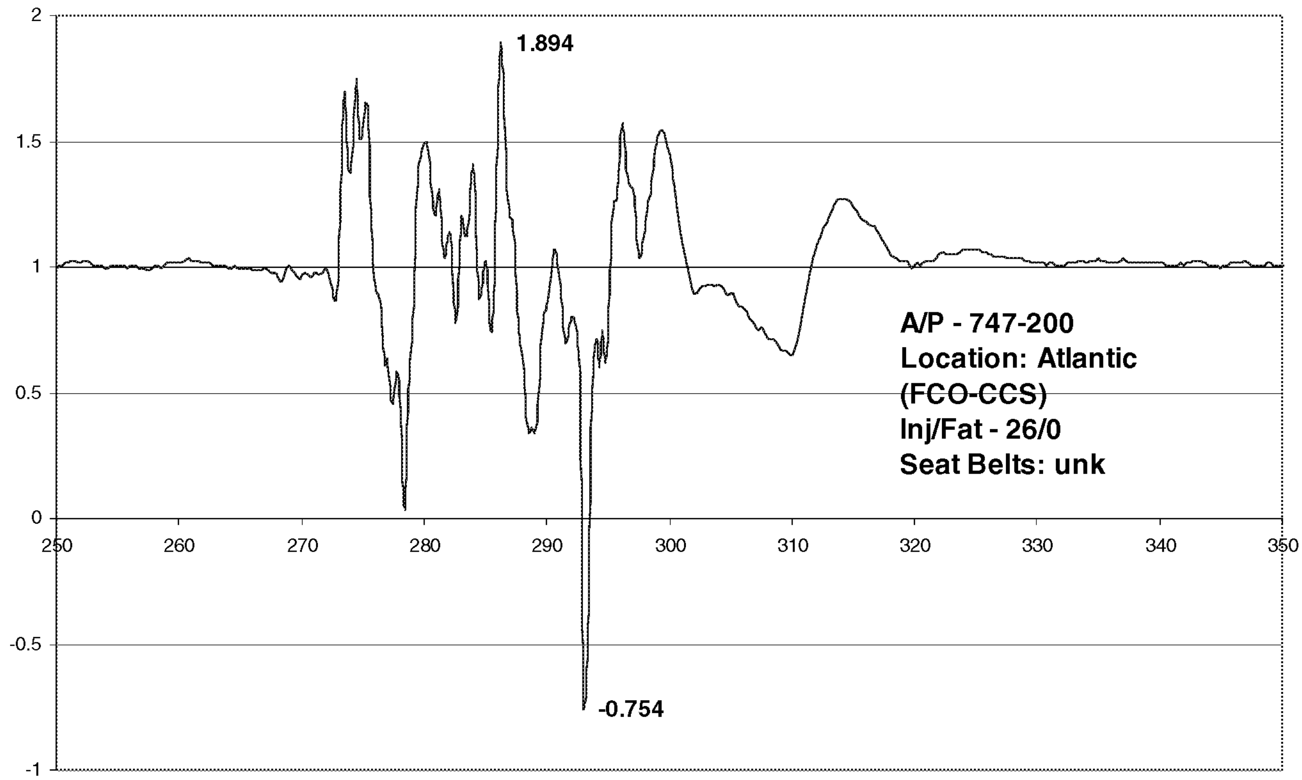


Aviation Safety Program

Case B-2 - Wz

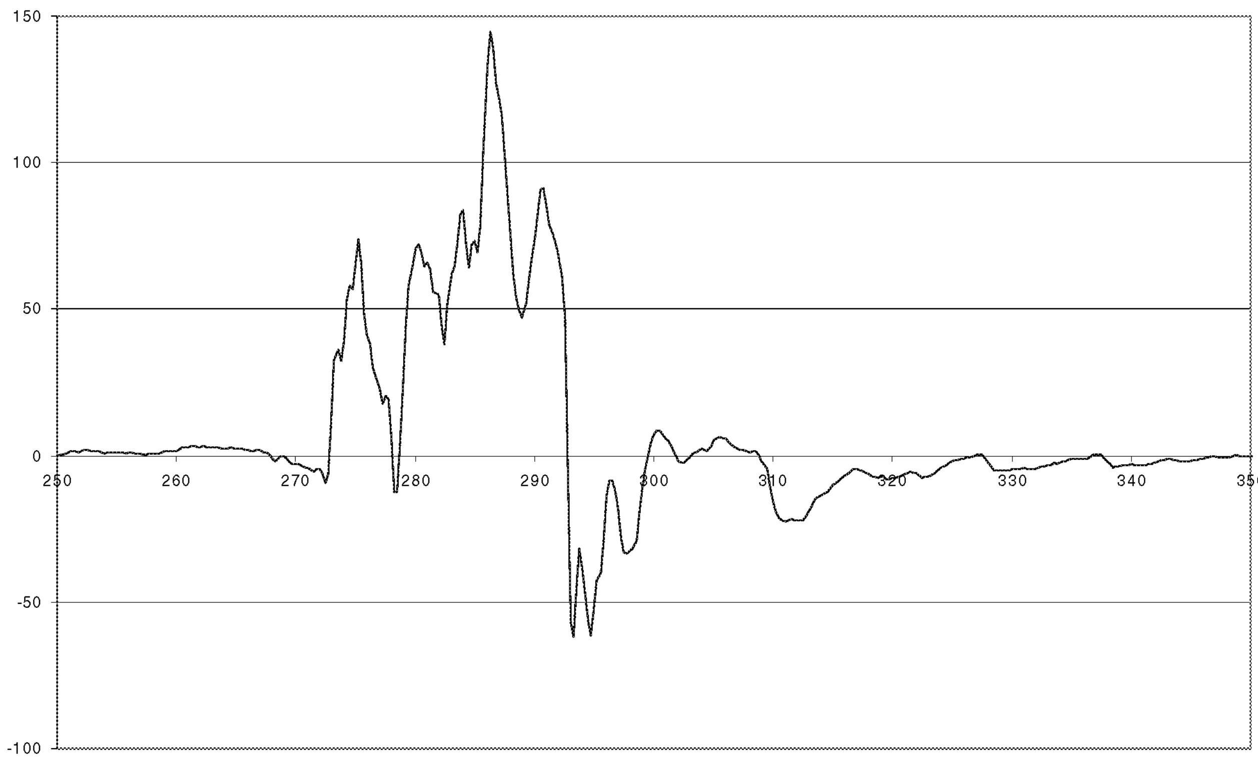


Case B-3 - Nz (c.g.)


2
1.5
1
0.5
0
-0.5
-1
250
260
270
280
290
300
310
320
330
340
350
1.894
-0.754
A/P - 747-200
Location: Atlantic
(FCO-CCS)
Inj/Fat - 26/0
Seat Belts: unk

Aviation Safety Program

Case B-3 - Wz



NASA/CP—2002-210964

Current aircraft systems and requirements

- Turbulence Mitigation requires modification of the aircraft lift and pitching moment through:

- Direct lift control ; and / or
- Pitch Control

- Current non fly-by wire aircraft in the commercial fleet (737,747,757,767) have no direct lift control surfaces.

- For this study, pitch control alone has been used. Current elevator rate and deflection limits (with nonlinear limiting) have been used to set requirements.

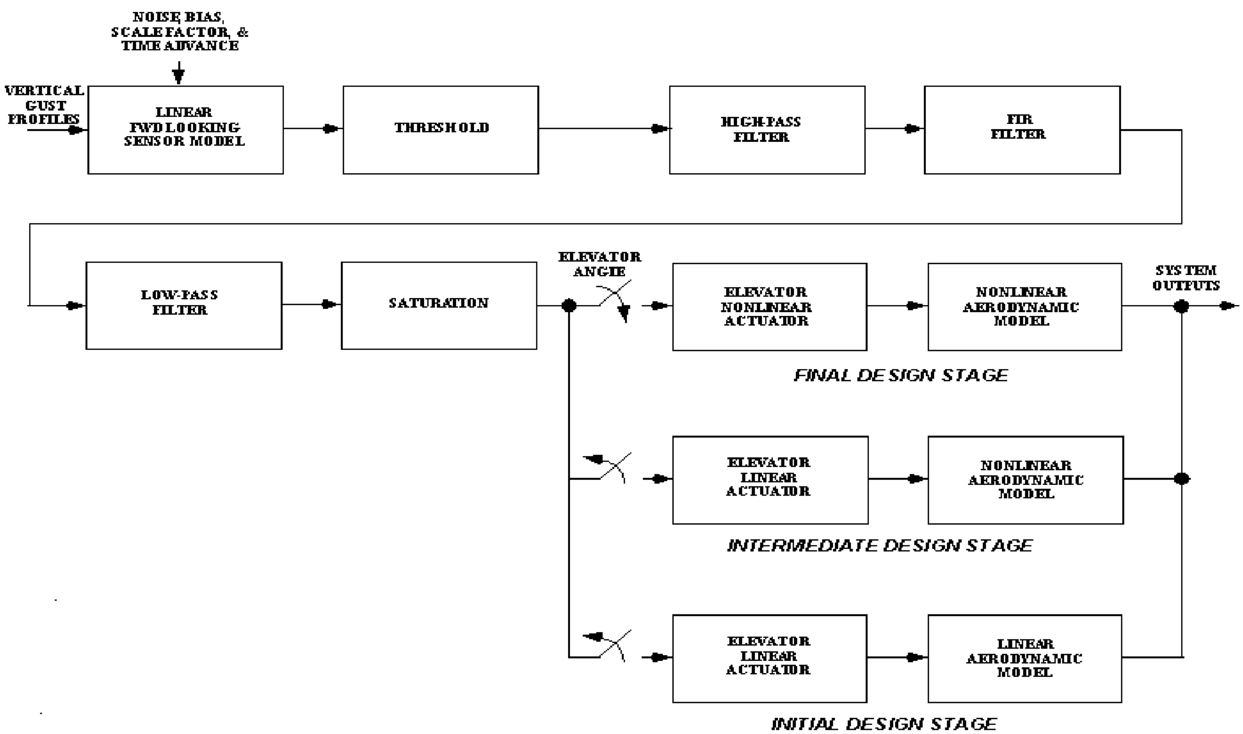
- Current autopilot modes do not effectively counteract severe turbulence.

- Autopilot actuator capabilities may be inadequate to provide mitigation.

Control System Development and Performance

Study Assumptions:

- Nonlinear aircraft model (757-200) with existing nonlinear actuators
- Knowledge of the vertical gust profile ahead of the aircraft
- Quasi-static elastic aircraft (no flexible mode dynamics)
- Feed-forward controller design to avoid stability issues
- Control law parameters varied for optimal performance
- Direct input to control actuator (not currently available)



CONTROL SYSTEM DESIGN MODEL

Sensitivity Studies

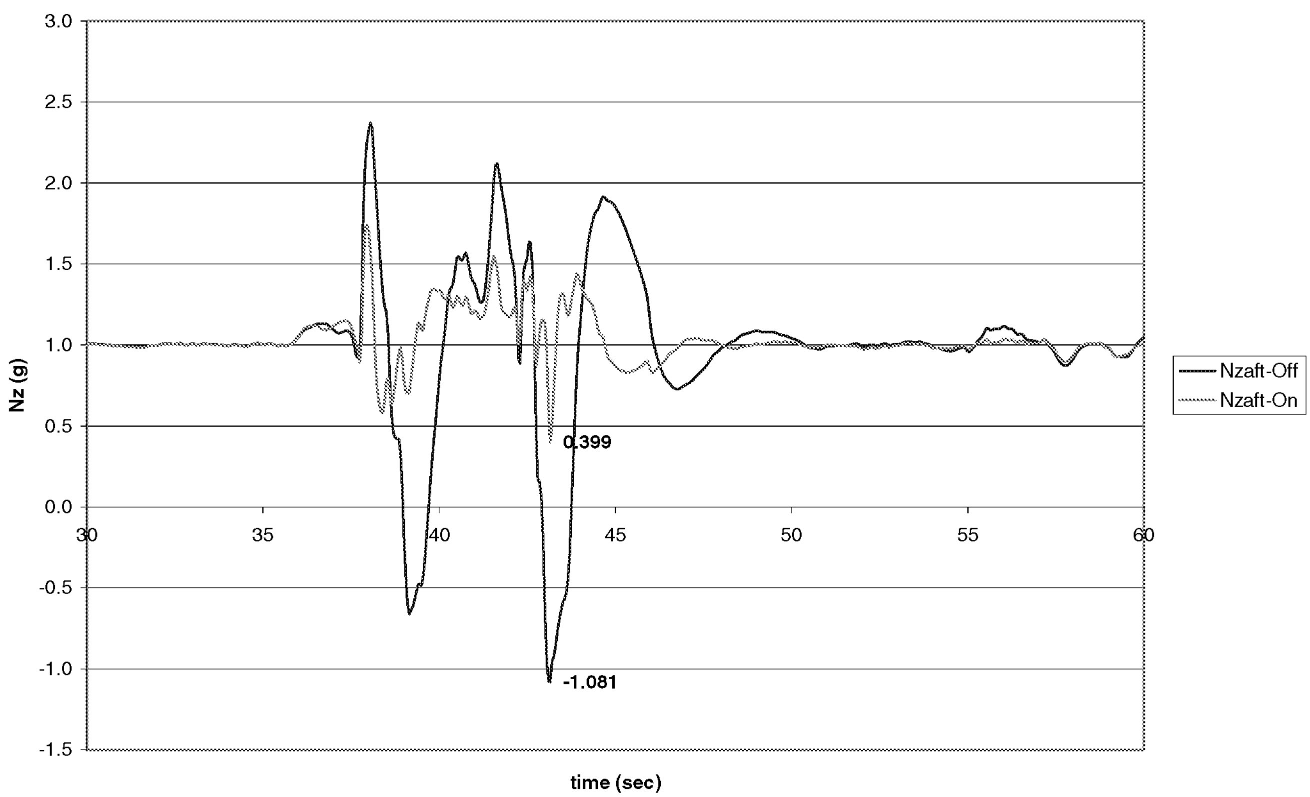
Turbulence input sensitivity

- 13 Time histories used as input to 757-200 nonlinear simulation model, control performance assessed
  - 5 NTSB Cases
  - 3 Boeing Cases
  - 5 Vortex Cases

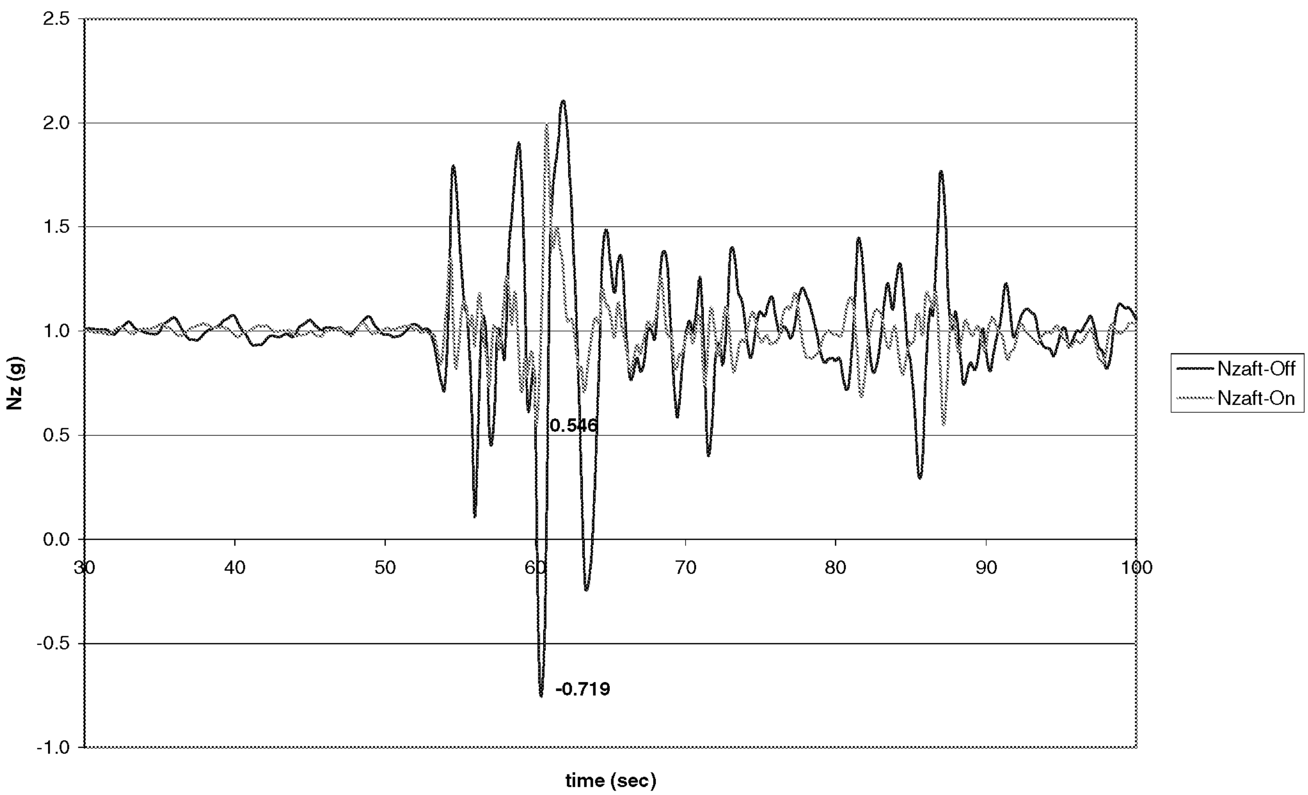
Sensor sensitivity

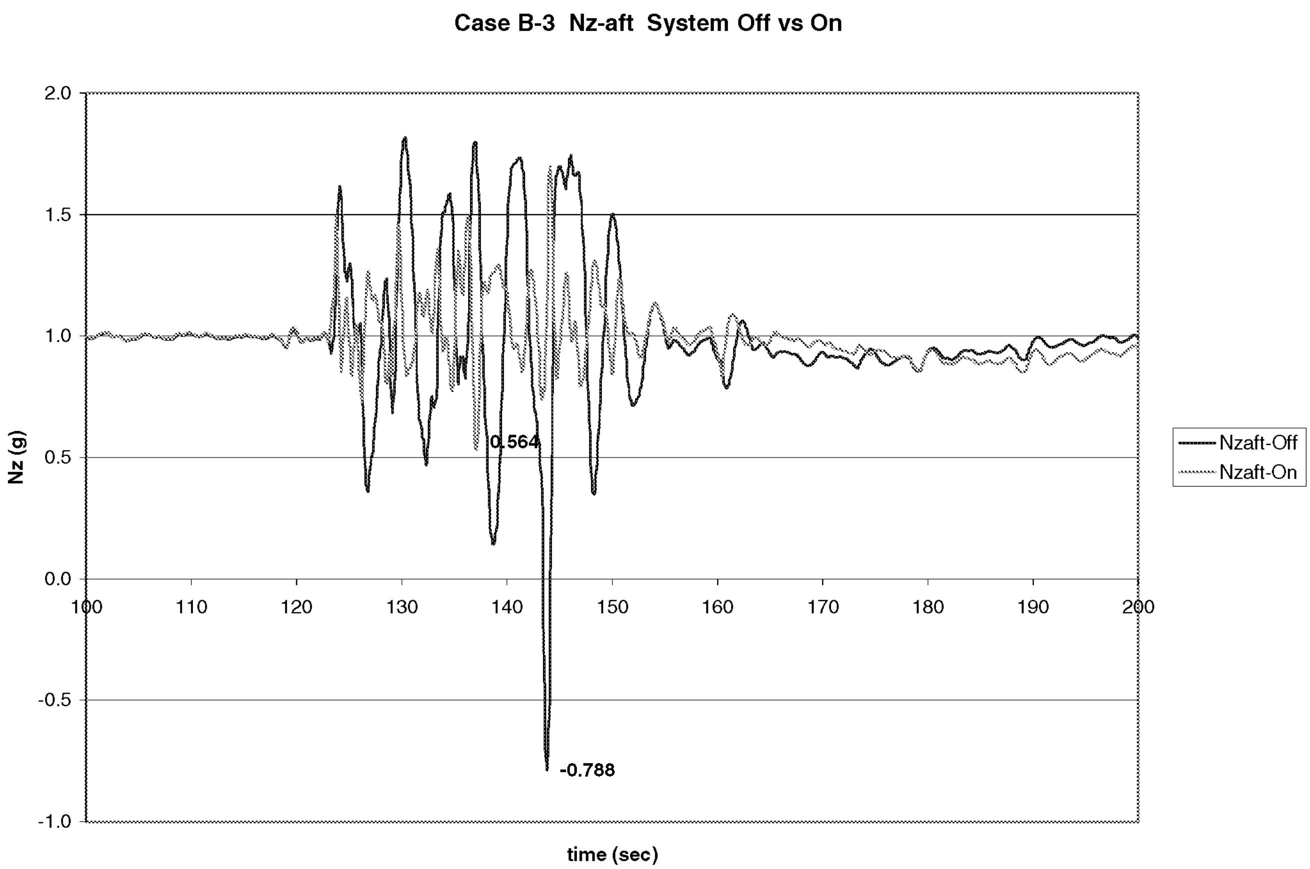
- Forward looking sensor compared with nose air data sensor for one case

Case B-1 Nz-aft System Off vs On

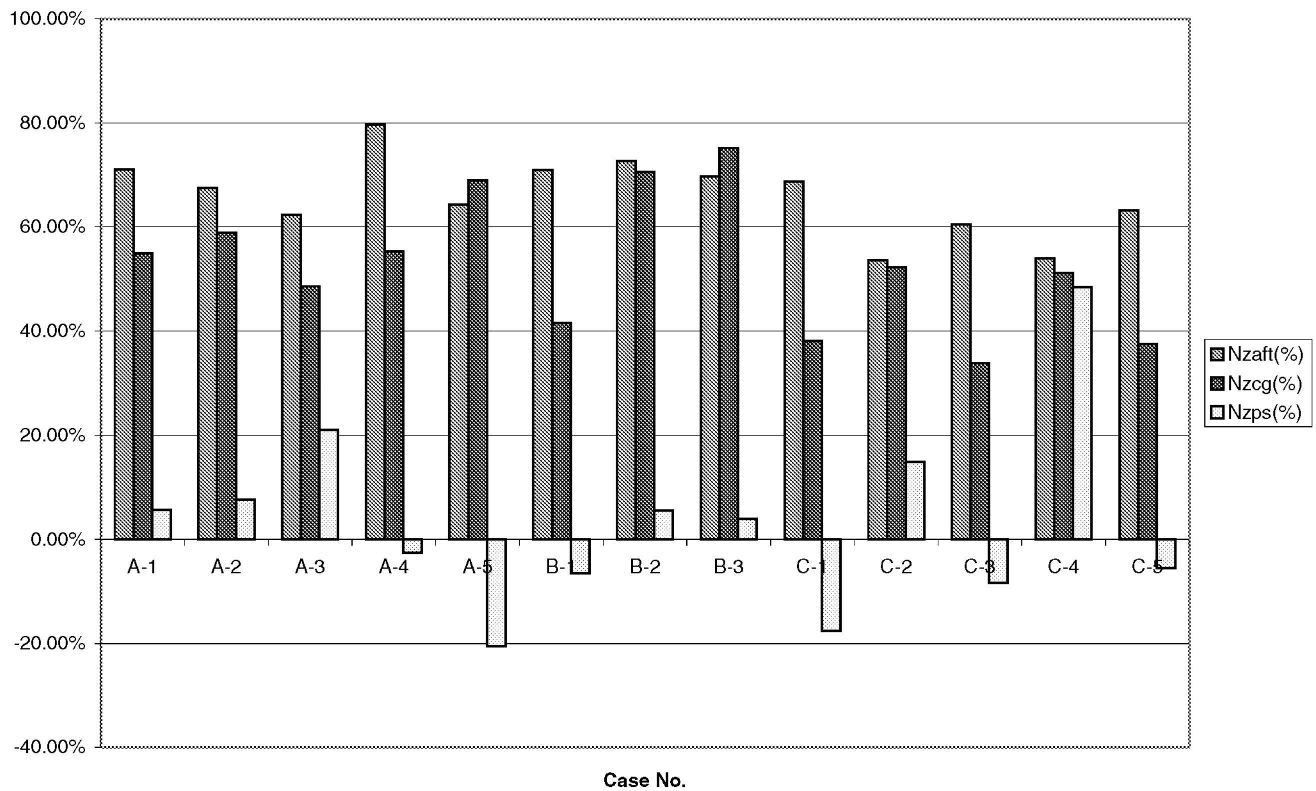


Case B-2 Nz-aft System Off vs On

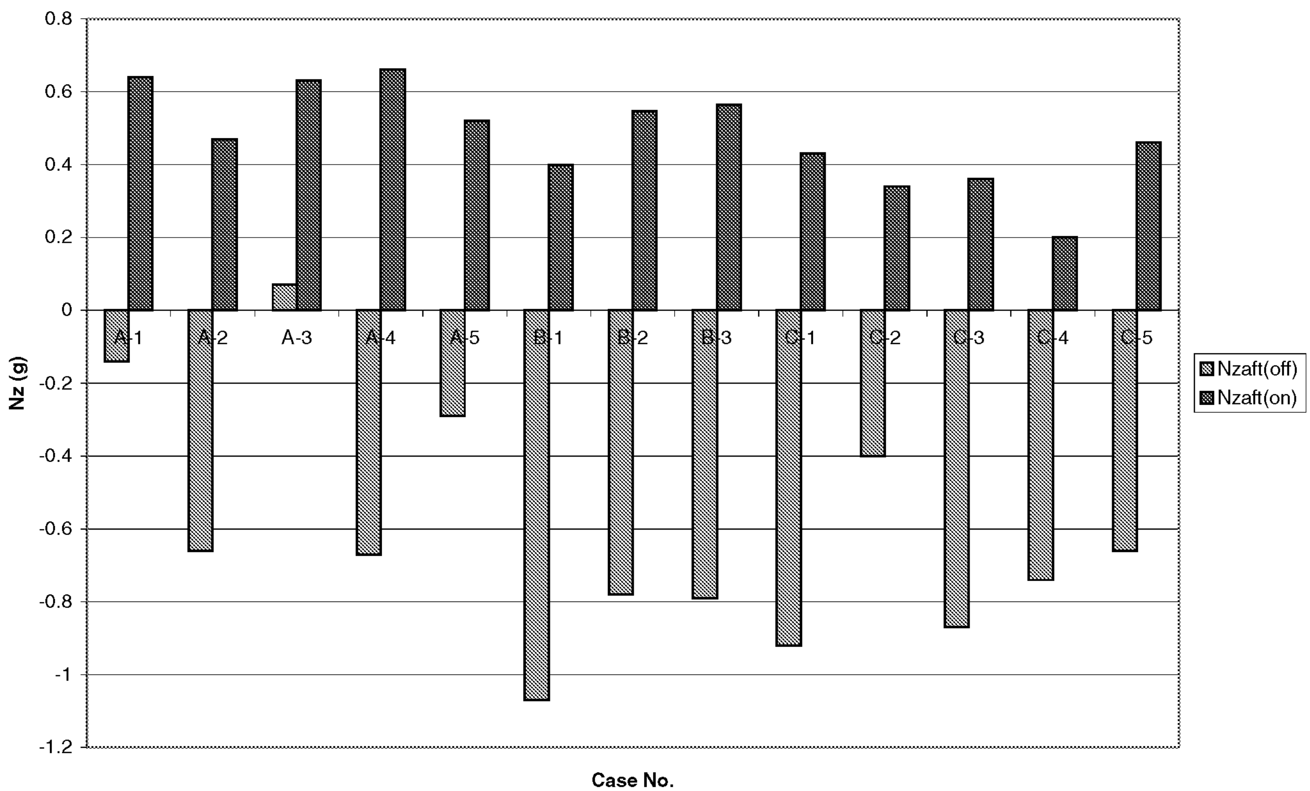



Case B-3 Nz-aft System Off vs On
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Nz (g)
100
110
120
130
140
150
160
170
180
190
200
time (sec)
0.564
-0.788
Nzaft-Off
Nzaft-On

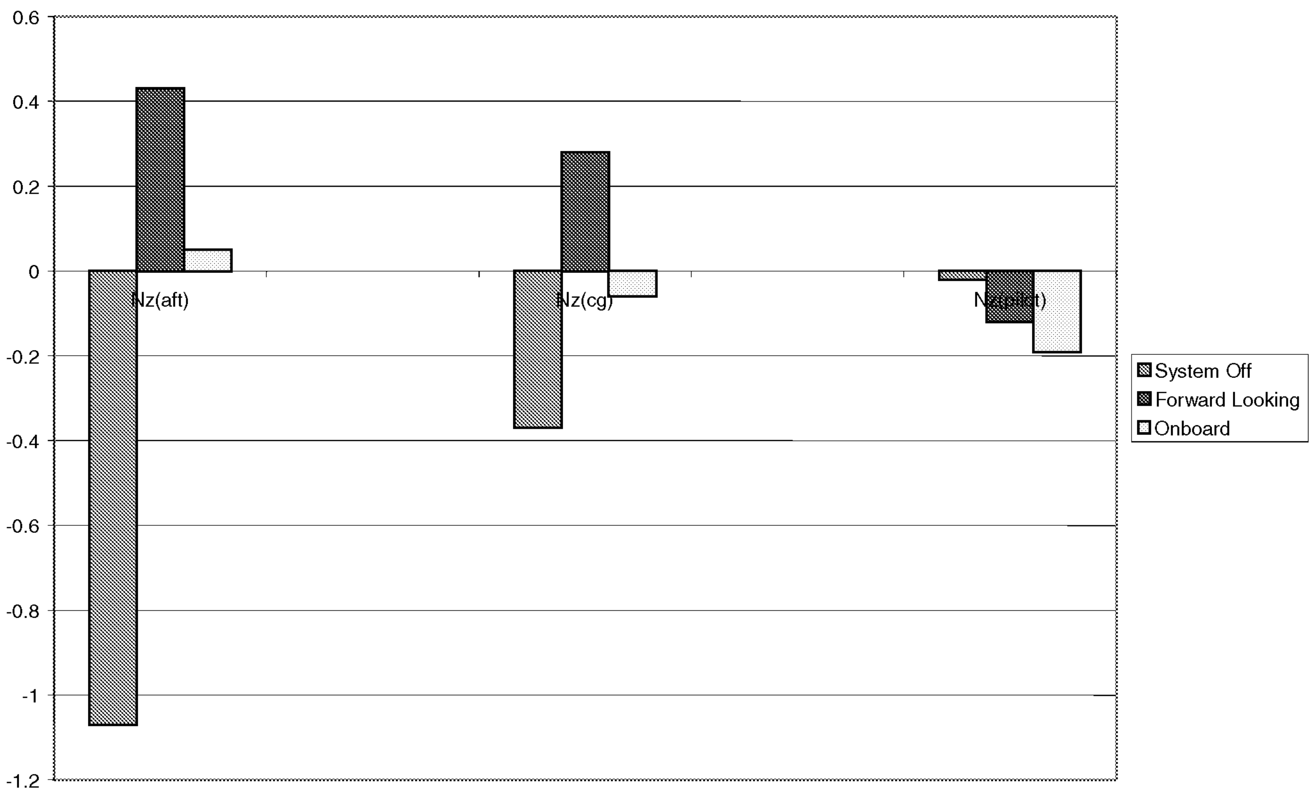
Percent Peak Negative Nz Reduction (1.1sec look ahead)



Aft Cabin Peak Negative Acceleration - System Off vs On



Forward Looking vs. Nose Air Data - System Off vs. On



Issues for Further Study

Aerodynamic Modeling Issues

- Nonlinear simulation data has limited negative angle of attack range
- Unsteady aerodynamics – angle of attack, control, gust lag functions
- Gradual gust penetration – wing sweep, wing to tail lag
- Stall Hysteresis – simulation is quasi-steady

Structural Modeling

- Dynamic Aeroservoelastic Model required for loads and flutter evaluation

Actuator Modeling

- "Physical model" required in place of "functional model"

Air Data System Modeling

- Need accurate measure of the "lead" for onboard air data

Issues (Cont'd)

Lidar Modeling and Accuracy

- Current simulation assumes "perfect" measurement of vertical gust velocity
- Lidar requires multiple off-axis measurements with spatial and temporal interpolation which will affect accuracy
- Additional errors such as bias and noise will affect accuracy
- Signal processing lags should be included
- Base motion "jitter" can be determined from structural dynamic model, isolation and/or motion compensation should be included

Multiple Flight Condition Modeling

- All simulation to date on single aircraft model at single flight condition. Effects of variations in altitude, Mach, gross weight, c.g. should be determined

Issues (Cont'd)

Autopilot / Manual Control Input Effects

- Current simulation models have no autopilot
- Need autopilot model to separate autopilot and manual inputs
- Need to assess whether autopilot and manual inputs make situation better or worse
- What is the effect of warning time on the pilot's reaction?
- What is the effect of various gust profiles on the pilot's reaction?
- How does the pilot react in the presence of a turbulence mitigation system?
- What do we show the pilot?
- These should be answered by a real-time simulation study.

Issues (Cont’d)

Control System Development Issues

- Redundancy Management
- Control Augmentation (SAS)
- Multiple Sensor Control
- Line of Sight Command for Maneuvering Aircraft
- Ride Quality vs Safety Requirements
- Gust Spectral Content Filtering
- Alternate Control Law Development Schemes
- New PCU Input vs Existing Autopilot Actuators (Autoland Mode)
- Direct Lift Control

NASA/CP—2002-210964

Recommendations for Further Work

Continue Modeling Improvements (aerodynamic, structural, sensor, control)

Evaluate Structural Load and Autopilot Effects

Continue Control Development Studies

Select Candidate Aircraft for Demonstration

Determine Forward Looking Sensor Accuracy by Flight Test

Perform Real-Time Simulation

Design and Installation of Required Aircraft System Modifications

- Sensors
- Computer
- Actuators

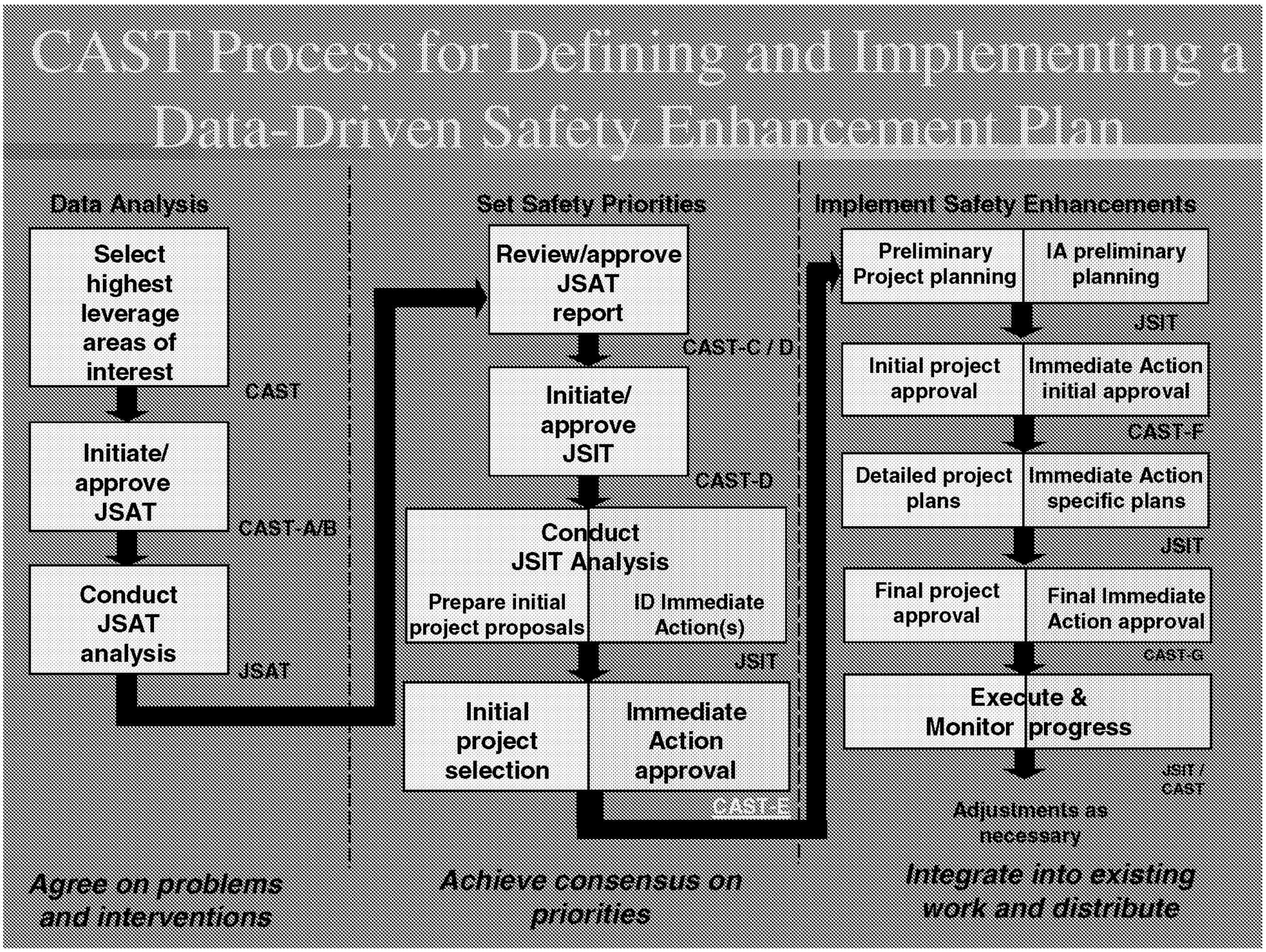
Flight Demonstration

Turbulence JSIT Status

Rod Bogue - NASA Dryden Flight Research Center

Outline

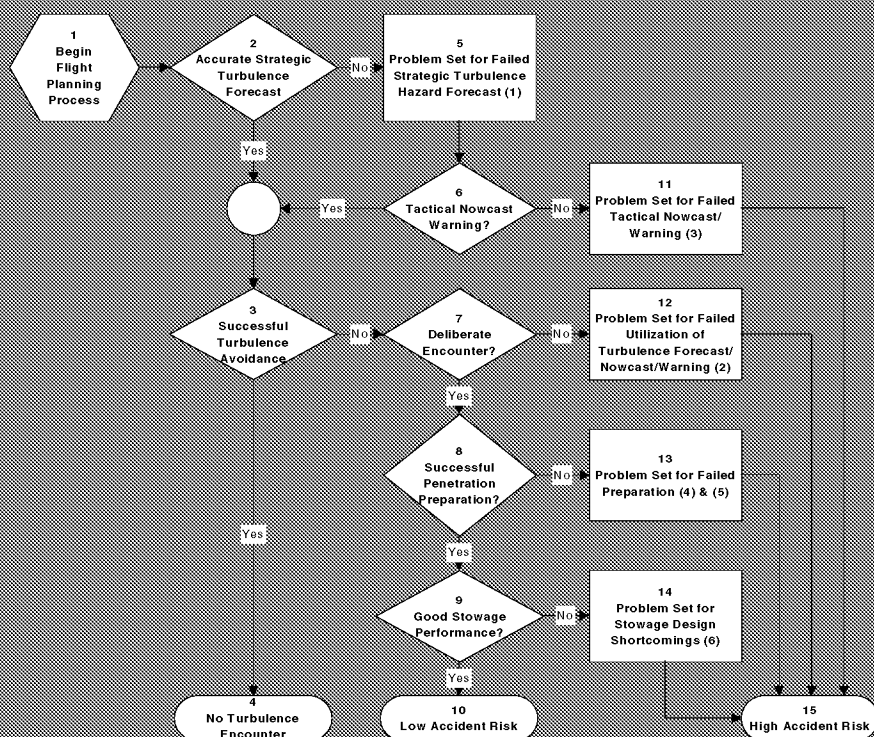
- **CAST Process**
- **Intervention & Project Statistics**
- **JSAT Turbulence Model**
- **Initial Project Subject Candidates**
- **Status**


CAST Process for Defining and Implementing a Data-Driven Safety Enhancement Plan
Data Analysis
Select highest leverage areas of interest
CAST
Initiate/ approve JSAT
CAST-A/B
Conduct JSAT analysis
JSAT
Agree on problems and interventions
Set Safety Priorities
Review/approve JSAT report
CAST-C / D
Initiate/ approve JSIT
CAST-D
Conduct JSIT Analysis
Prepare initial project proposals
ID Immediate Action(s)
JSIT
Initial project selection
Immediate Action approval
CAST-E
Achieve consensus on priorities
Implement Safety Enhancements
Preliminary Project planning
IA preliminary planning
JSIT
Initial project approval
Immediate Action initial approval
CAST-F
Detailed project plans
Immediate Action specific plans
JSIT
Final project approval
Final Immediate Action approval
CAST-G
Execute & Monitor progress
JSIT / CAST
Adjustments as necessary
Integrate into existing work and distribute

Intervention & Project Statistics

- **30 Interventions From JSAT**
- **16 Above the Line (53%)**
- **5 Projects**
- **2 Research Recommendations**

JSAT Turbulence Model



Initial Project Subject Candidates

- **Flight Attendant, Passenger and Cabin Secure Procedures**
- **Flight Attendant and Passenger Turbulence Injury Exposure**
- **Practices for Turbulence Avoidance**

Initial Project Subject Candidates (cont.)

- **Quality of Turbulence Information**
- **Turbulence Detection Technology**
- **Turbulence Displays and Data Dissemination**
- **Turbulence Effects Mitigation through Aircraft Control System Action**

Status

- JSIT Chartered 12 January 2001
- 3 Sub-Teams Organized
- 4 Full Meetings
- Obtained CAST E-Level Approval
- Finalizing Project Executive Summaries
- CAST added Cost/Benefit Assessment and Nationwide Facility Resource Needs Assessment
- Expect G-Level approval in early FY-02

NASA-FAA-NOAA Partnering Strategy

Weather Accident Prevention
Project Review
June 7, 2001

Dr. Ron Colantonio, Inter-Agency Coordination Manager

Content

Pros for Inter-Agency Collaborations

Pitfalls in Inter-Agency Collaborations

Partnership 101

Progress to Date

Summary

Glenn Research Center

Aeronautics

at Lewis Field

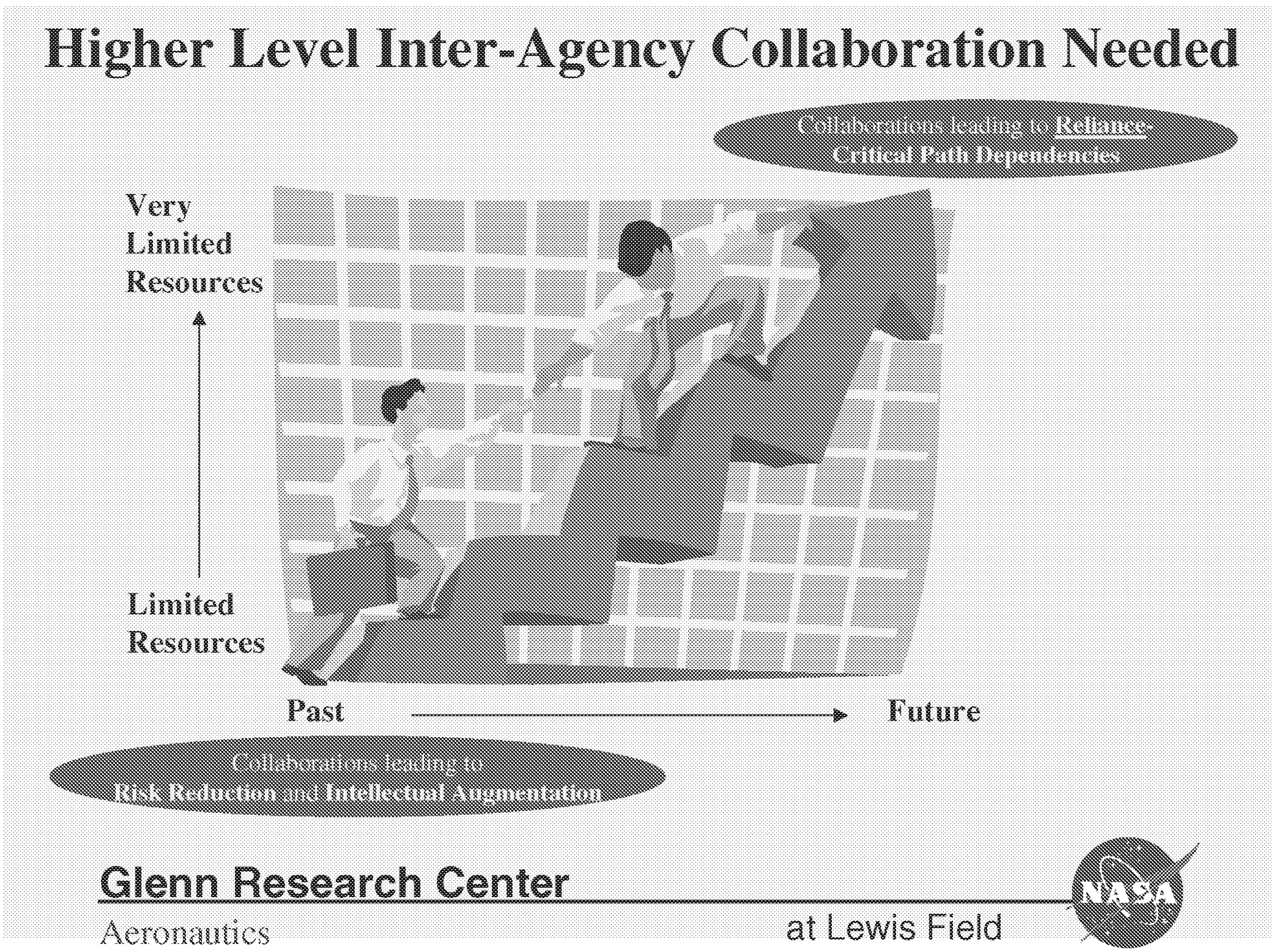
Resource Flows in Partnerships

- Pooling Arrangements- Two or more organizations combining similar resources
  - Cost and/or risk sharing
  - Gaining influence of stakeholders
  - Information sharing/benchmarking
  - Standard Setting

- Trading Arrangements: Two or more organizations exchanging dissimilar (but mutually valued) resources
  - Developing synergy through complementary competencies

Glenn Research Center

Aeronautics at Lewis Field



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What Defines a Good Partner

1. Resources- Do they possess the resources/capabilities we seek?

2. Incentives- Do they have adequate motivation and commitment to the success of the venture/partnership?

3. Cultural/Trust- Does it feel like their business approach fits well with ours?

Why Partnerships Fail

40-60% of all partnership/alliances fail

1. Environmental Reasons
   - Failure to anticipate changing R&D demands
   - Inability to reconcile macro-cultural issues

2. Strategic Reasons
   - Purpose not clearly articulated

3. Structural Reasons
   - Weak Incentive structure; ill suited for strategic purpose

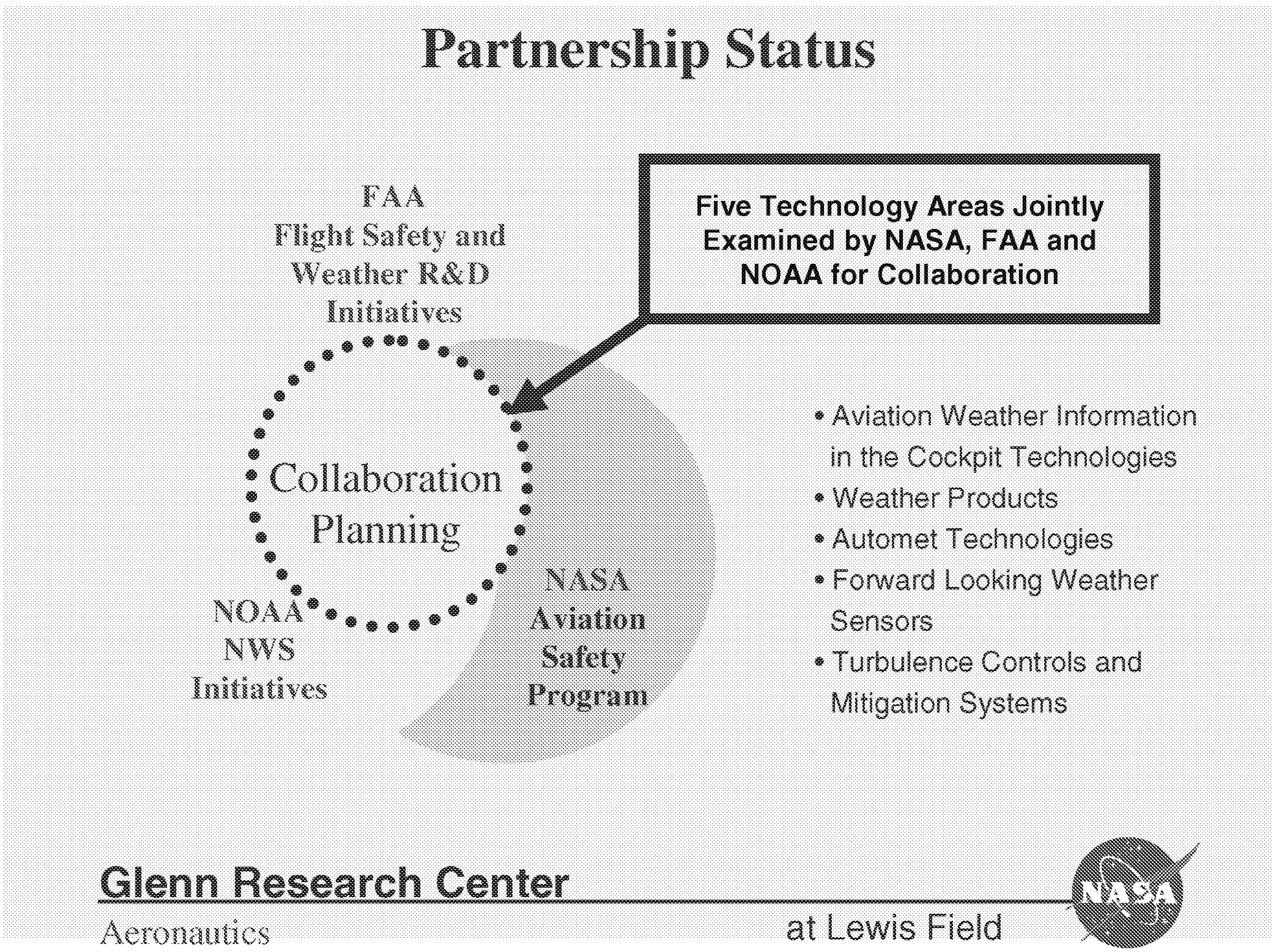
4. Behavioral Reasons
   - Egos and personal dislike (person versus organization)

Glenn Research Center

Aeronautics at Lewis Field

Current Inter-Agency Collaborative Activities

- **NASA-DOD-DOE Alliance in Propulsion & Power**
  - Completed five "Collaboration Workshops" during the past year
  - Generated detailed roadmaps for collaborative activities in 9 technology areas
- **NASA-Air Force Propulsion Collaboration**
  - Goldin/Peters agreement to increase collaboration
- **NASA GRC-Sandia Labs Collaboration**
  - MOU signed for broad suite of Aero/Space technologies
- **NASA-FAA Alliance under NASA-FAA Umbrella MOUs**
  - Aviation Weather Safety MOA signed
  - Aviation Air Emissions MOA being prepared
  - Accident Mitigation MOA being prepared
- **NASA-Canadian Agencies (CNRC, TC, MSC) Icing Alliance**
  - Aircraft Icing Research Alliance (AIRA) signed to do joint icing research per single strategic plan


Partnership Status
FAA
Flight Safety and
Weather R&D
Initiatives
Five Technology Areas Jointly
Examined by NASA, FAA and
NOAA for Collaboration
Collaboration
Planning
NOAA
NWS
Initiatives
NASA
Aviation
Safety
Program
• Aviation Weather Information in the Cockpit Technologies
• Weather Products
• Automet Technologies
• Forward Looking Weather Sensors
• Turbulence Controls and Mitigation Systems
Glenn Research Center
Aeronautics
at Lewis Field
NASA

NASA-FAA Partnership

Memorandum of Agreement between NASA and FAA concerning Weather Accident Prevention R&D Activities was signed in June 2000. The MOA states NASA and FAA will jointly develop the following products:

1. Aviation Weather Information Technologies for NAS and users
2. Aviation Weather Products
3. Electronic Pilot Reporting/Automet Technologies
4. Forward-Looking Weather Hazard Sensors
5. Turbulence Controls and Mitigation Systems

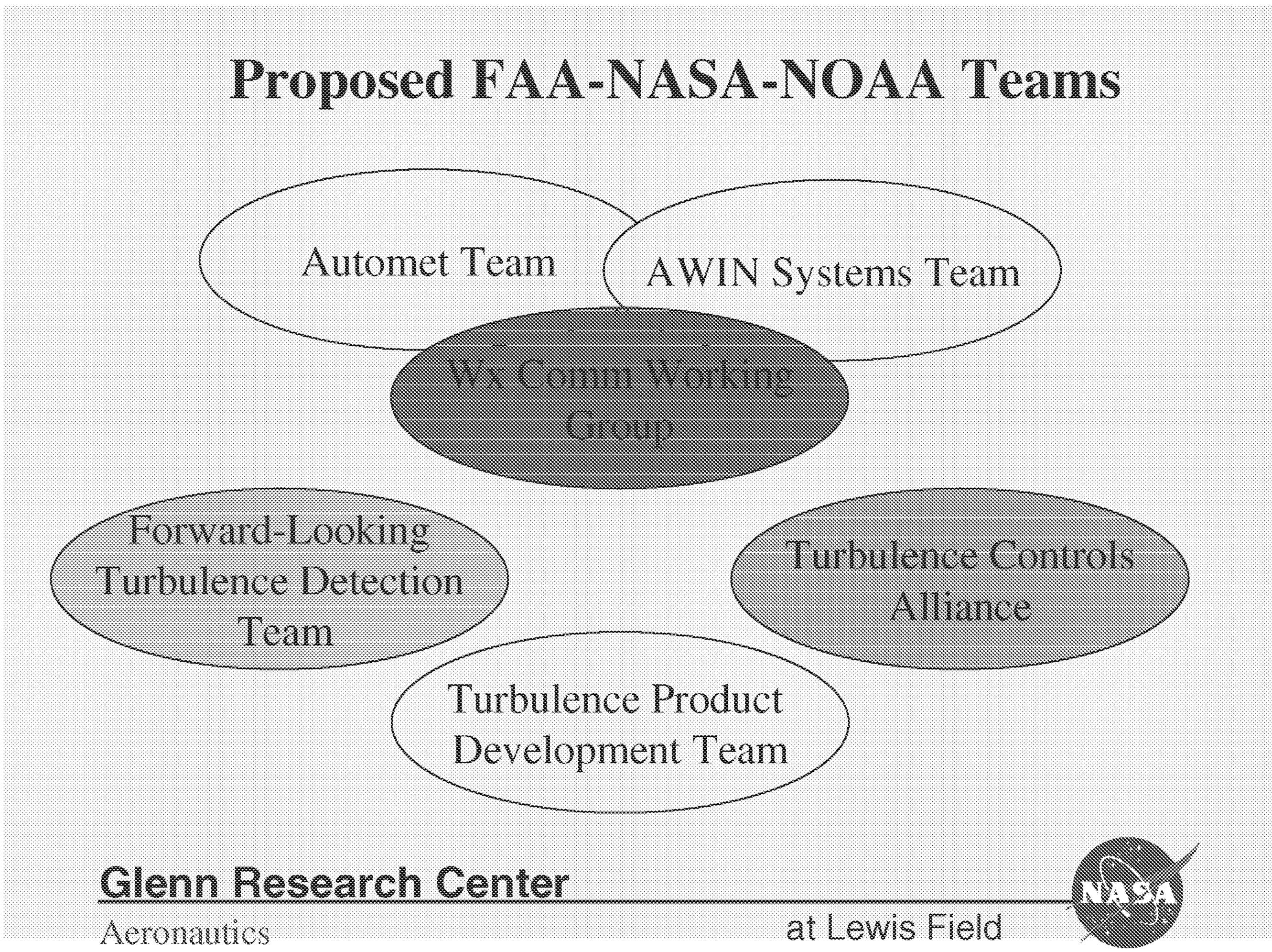
This MOA was signed by FAA Associate Administrator of Research and Acquisitions, Air Traffic Services and Regulation and Certification as well as NASA Associate Administrator for Aero-Space Technology

NASA/CP—2002-210964

NASA-NOAA/NWS Partnership

Memorandum of Agreement between NASA and NOAA/NWS concerning Weather Accident Prevention R&D Activities has been drafted and is under review. The MOA states NASA and FAA will jointly develop the following products:

1. Aviation Weather Information Technologies for NAS and users
2. Aviation Weather Products
3. Electronic Pilot Reporting/Automet Technologies
4. Forward-Looking Weather Hazard Sensors


Proposed FAA-NASA-NOAA Teams
Automet Team
AWIN Systems Team
Wx Comm Working Group
Forward-Looking Turbulence Detection Team
Turbulence Controls Alliance
Turbulence Product Development Team
Glenn Research Center
Aeronautics
at Lewis Field
NASA

Summary

- NASA, FAA, NOAA fully endorse the partnership vision and direction.
- Current NASA, FAA and NOAA collaboration activities going well.
- Interagency implementation agreements in progress toward integrating collaboration activities into agency program plans.

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Aeronautics at Lewis Field

NASA/CP—2002-210964

Flight Information Services Data Link (FISDL)

Alfred Moosakhanian

NASA Weather Accident Prevention Project Review

June 7, 2001

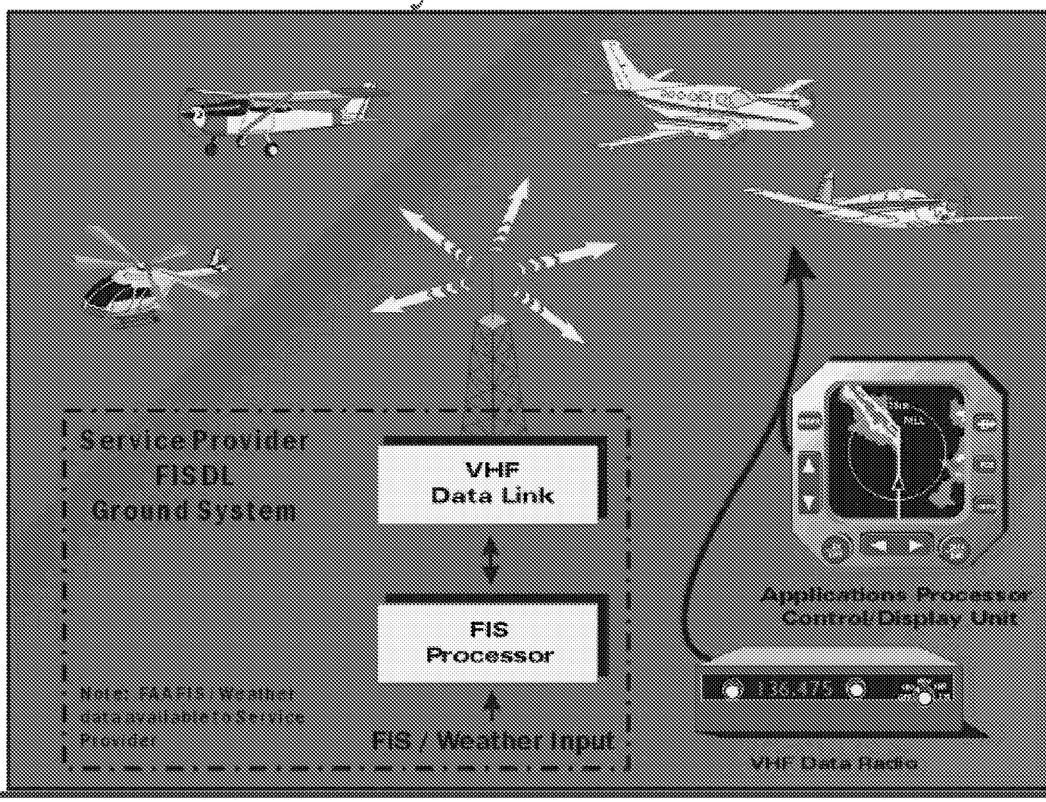
FIS Policy Implementation

- FAA published Airborne FIS Policy Statement based on industry petition through the GA Coalition:

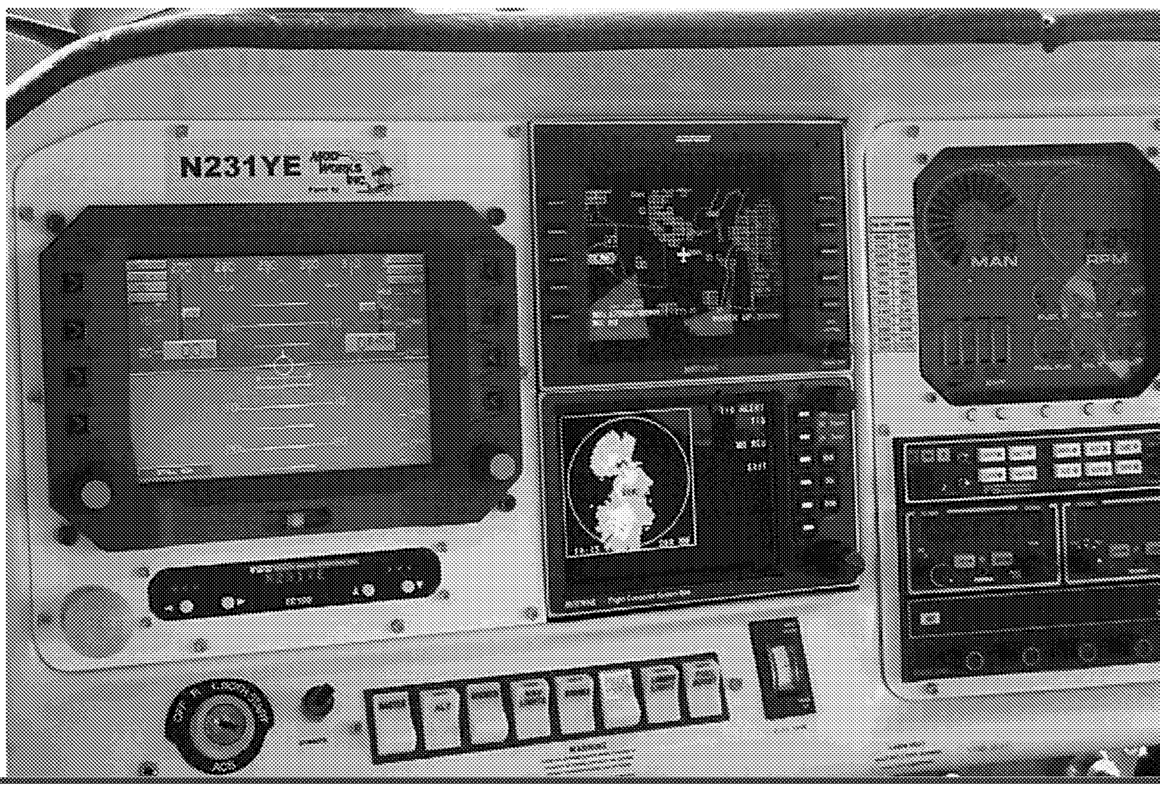
The FAA's goal "... is to use digital data link to deliver information to the pilot ... and will use the private sector's FIS capabilities ... to bring FIS services and products to the market place quickly and efficiently."

- FAA signed Government-Industry Project Performance Agreements (G-IPPAs) with two FISDL Service Providers
  - ARNAV Systems, Inc; Puyallup, WA
  - Honeywell International, Inc; Olathe, KS

FISDL System Overview



FISDL Cockpit Display



Unique G-IPPA Provisions

- Competitive strategy with two FISDL Service Providers designed to use "market pressure" to stimulate and control quality and cost of FISDL services
- No system specifications; rather based on:
  - FAA Statement of Objectives, and
  - SOW submitted by ARNAV and Honeywell
- FAA provides access to 4 VHF channels (136 MHz "protected" spectrum)
- ARNAV and Honeywell each provide independent system infrastructure and service at no cost to FAA

Key Provisions: *FAA Commitments*

- Five year agreement with opportunity for renewal
  - Access to 4 VHF channels (136 MHz “protected” spectrum) with spectrum engineering support
  - Access to FIS/Wx data within FAA systems; these data are also available to all other vendors as well
- Publish ACs, other publications, and necessary standards
- Sponsor studies to develop applications/benefits & NAS changes
- Evaluate implementation of GA Automet (TAMDAR / E-PIREPs)
  - Includes evaluation/validation of operations concepts and procedures for national deployment of downlink and possible crosslink of aircraft derived weather data from commuter, and low-altitude general aviation operations

Key Provisions: *Provider Commitments*

- System infrastructure and service at no cost to FAA
  - Full national coverage (CONUS + Hawaii; Alaska Optional)
    - Access from at least 5000' to 17,500'; sfc to 45,000' desired
- Products designed for aviation use and based on approved data sources
  - Conform to guidelines (ICAO, RTCA, SAE G10) for cockpit display
  - Basic products at no fee (METAR/SPECI, TAF/AMEND TAF, SIGMET, Conv SIGMET, AIRMET, PIREPs, Alert Wx Watches)
  - Valued-added products for fee
- Education/training materials for pilot users and FAA
- Archive all broadcast transmissions for at least 15 days
- Quality assurance that addresses system risks and user concerns

Implementation Status

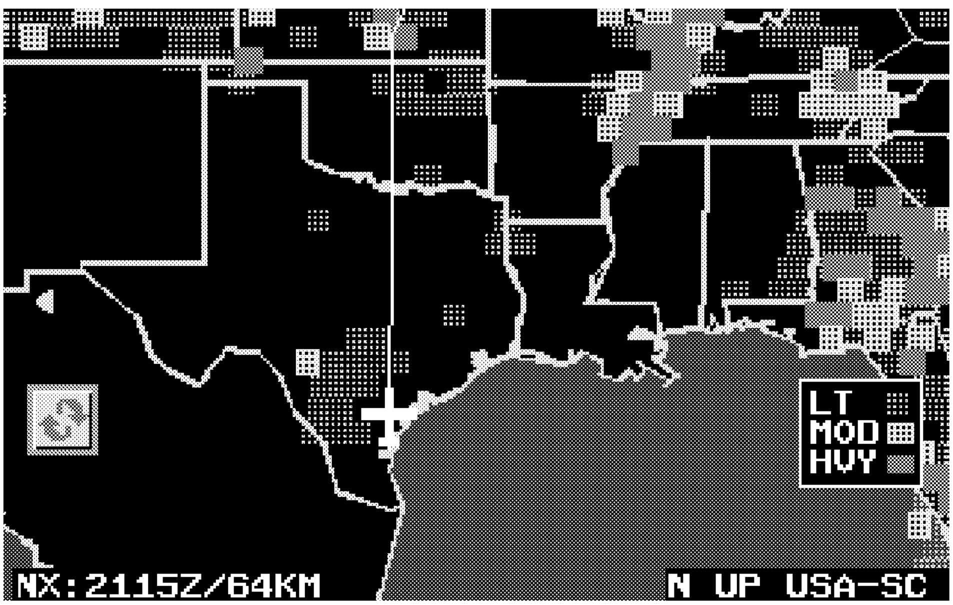
- Product review/approval procedures for value-added FISDL products established
  - ARW-200 (Weather Standards) Team Lead
  - Initial products (ARNAV and Honeywell) have been reviewed and accepted
- AIM Revision including FISDL overview in Section 7 published
- Advisory Circulars drafted by Flight Standards and Aircraft Certification
- FIS-B MASPS published by RTCA/SC-195
  - DO-267, March 27, 2001
  - Provides communications protocols and presentation guidelines for FIS digital broadcast and cockpit display

Implementation Status (Cont'd)

- ARNAV achieved operational status with GMSK data radio technology (July 2000)
  - TSO and STC have been issued

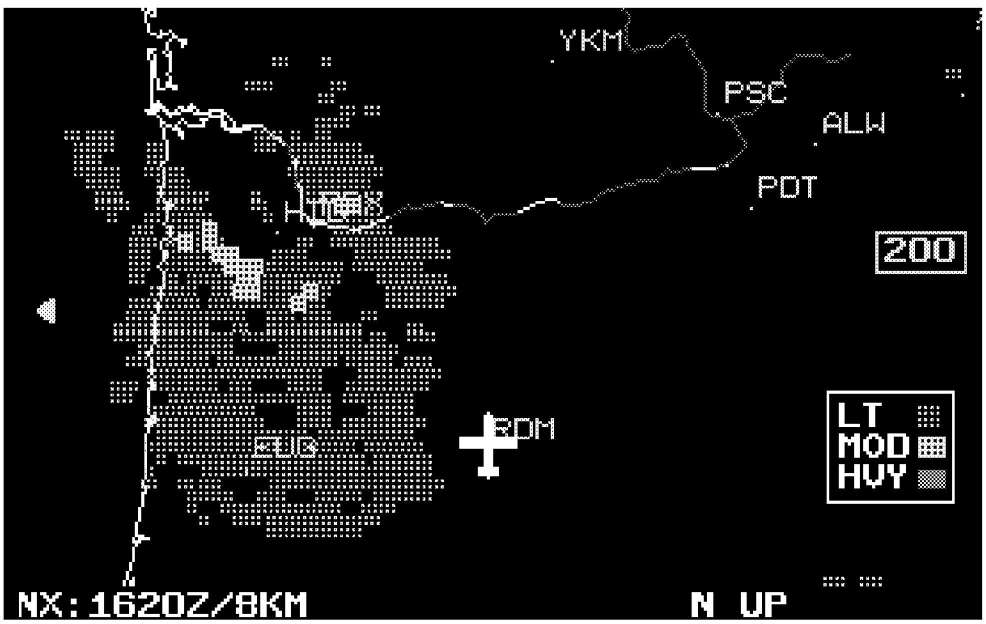
- Honeywell developing VDL Mode 2 data radio technology.
  - IOC of ground system scheduled for June 2001
  - Radio certification by 4th Quarter 2001

FISDL Examples - ARNAV



Regional NEXRAD

FISDL Examples - ARNAV



200 Nautical Mile NEXRAD

FISDL Examples - ARNAV

Full Text METAR Report


Airline Implementation of Cockpit Weather Systems
20
20
FLIGHT
OPERATIONS
TECHNOLOGY
Innovations in flight
Capt.David Sambrano
Flight Technical Manager

Background UAL ISE

- Just finished 40+ segments on A320 In-Service Evaluation
- Tested products of WINN program included:
  - CONUS Radar*
  - Worldwide Satellite*
  - Convection*
  - Nowcasting
  - Airports (METARS/TAFS)
  - Turbulence Forecast

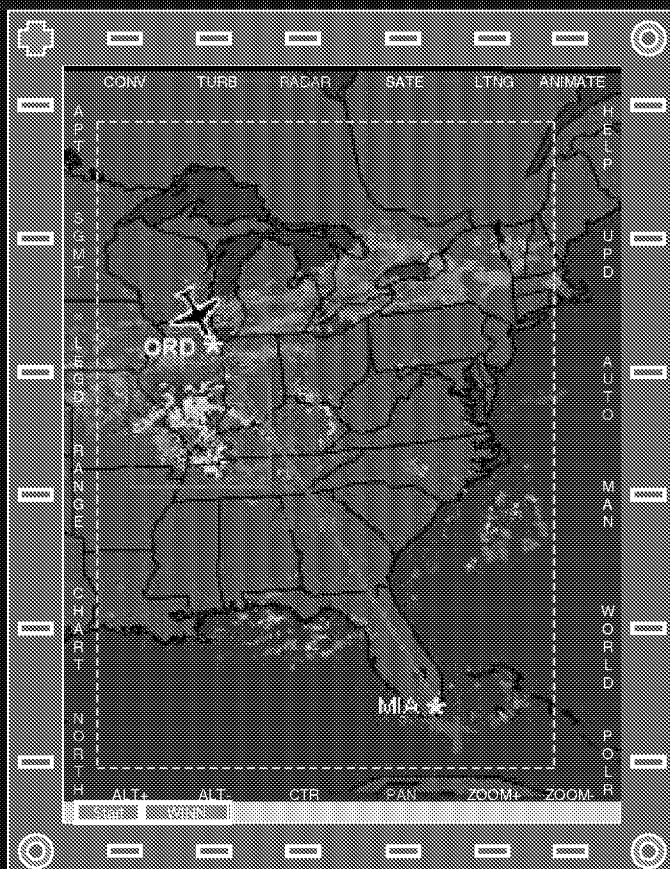
FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

Weather Information Network (WINN)

SIGMET, METARS, TAF, and airport ATIS information may be displayed in a graphic format and in text

The FMC's flight plan route is automatically displayed

Data is displayed in a "North up" format or in a "Track up" format



Covective, Volcanic Ash, Turbulence, Winds, Icing, Radar (conus only), Satellite, Lightning, and "Nowcasting" weather data are available world wide via automatic data link

Provides quality information for making better decisions

Enhances pilots' situational awareness

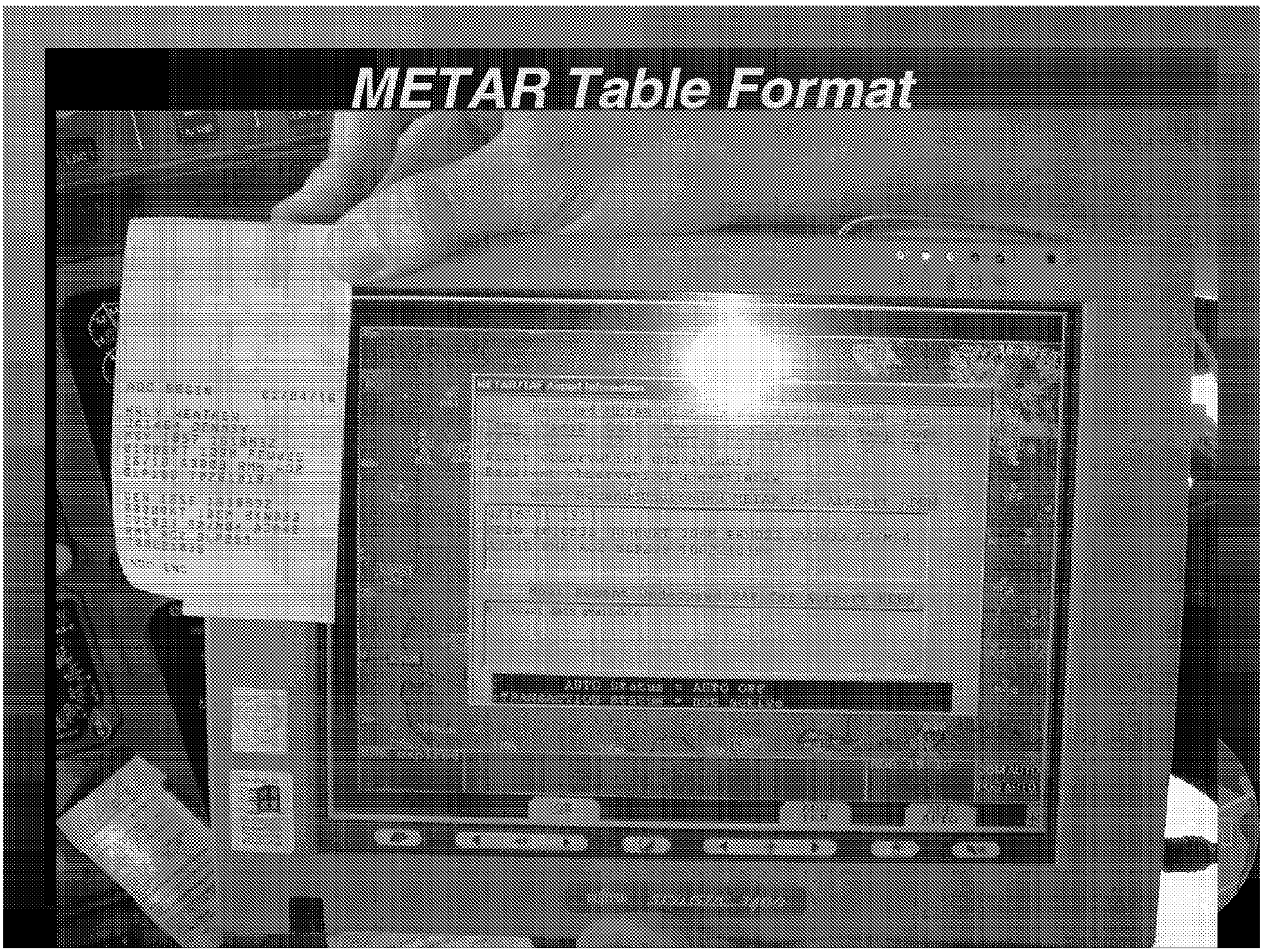
The WINN program automatically centers and tracks the aircraft's location or manually panning to any location

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

ISE Results

- Real time radar images.
- Turbulence predictions were accurate.
- Coded airport very effective in divert decision.
  - METAR Wx table format very good.
- SAT imagery results.
- Graphical Sigmets good.

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight


METAR Table Format

Net Results of Having Real Time Wx

- More accurate flight planning.
  - LAX-JFK 8am departure
- ATC ground stops.
- UAL size carrier can save est.1-2% fuel per year. (NASA Langley study)
- Est. 2% reduction in total block time
- Est. 80% reduction in all turbulence injuries.
- CAT/Wx predictions internationally.
- First phase towards true Free Flight.

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

Implementation Issues

- Display…where and what kind?
  - Removable PED display on adjustable simple mount. (Sky-Pad)
  - Not in primary field of view.
  - Cost effective for procurement to AT/GA.
- Certification Issues:
  - Supplemental information?
  - Collaborative decision making.
  - Other software driving certification?

FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

Implementation Issues

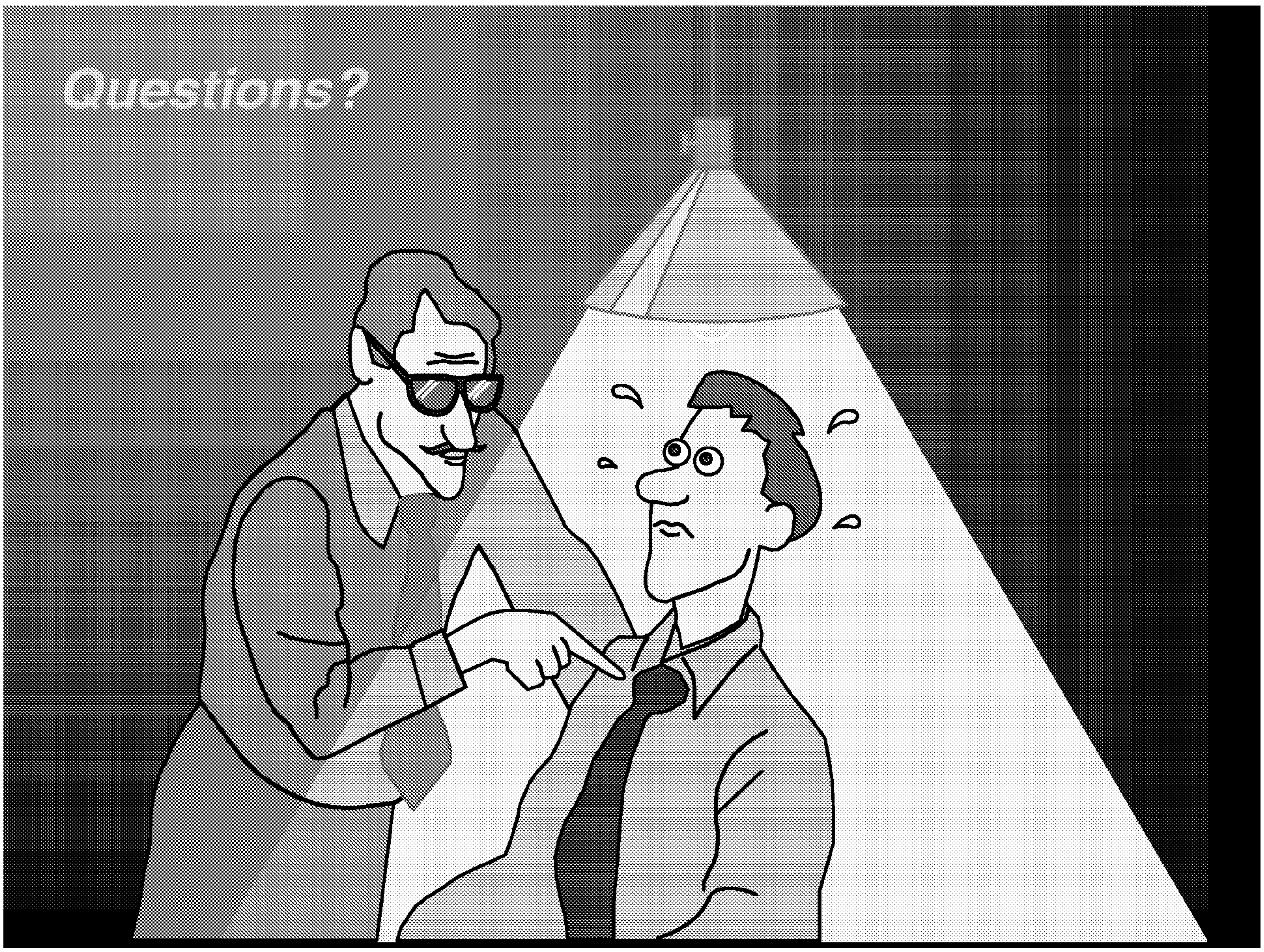
- Data pipe to the aircraft?
  - L-Band, Satellite, GTE Phone data receiver.
  - AT/GA solutions that are cost effective. $$$
- STC's of mounting unit.
- 80% of AOC communications

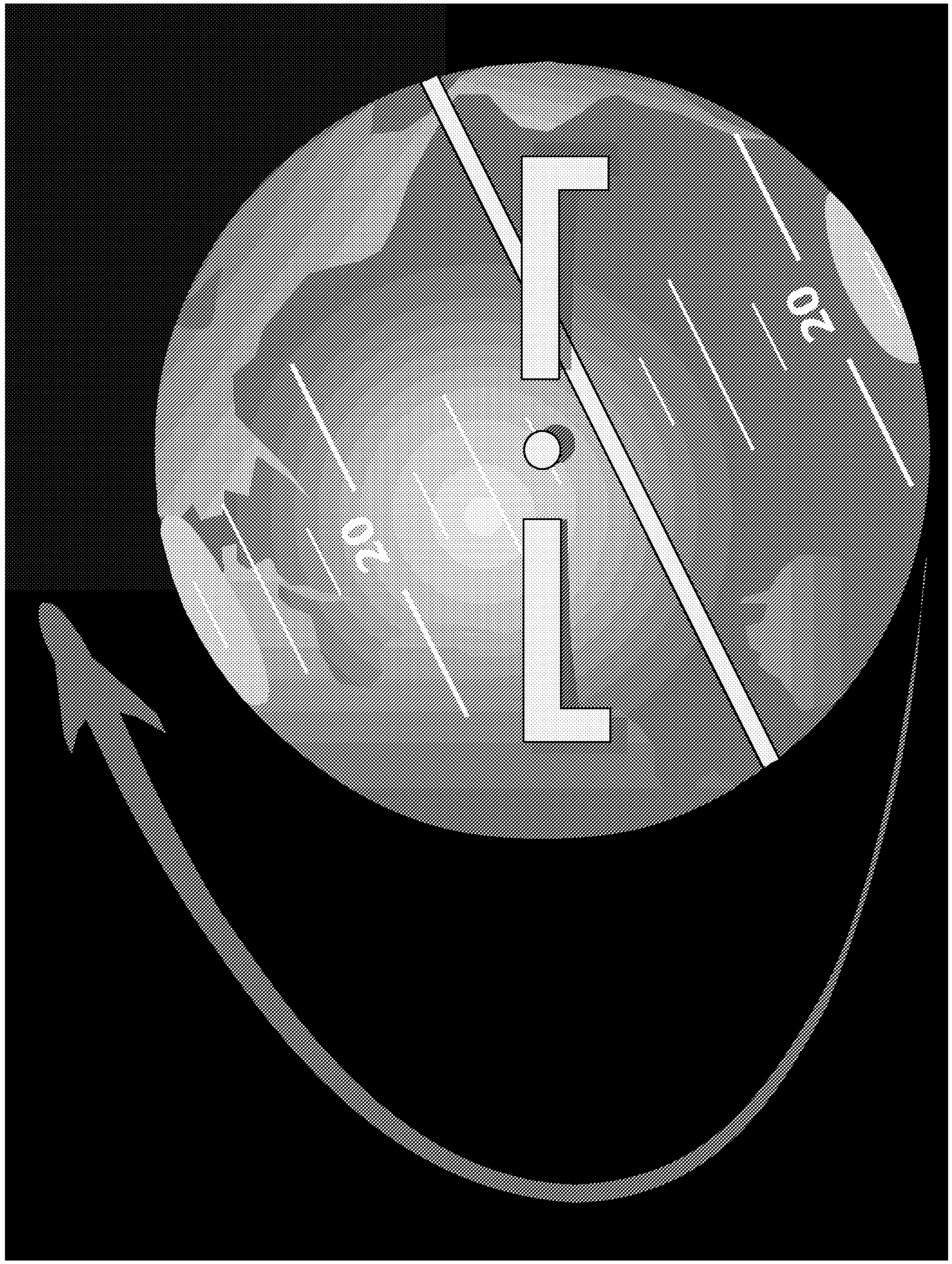
FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight

United Focus

- AT/GA solution.
- Solution must be cost effective.
- Safety makes this priority.

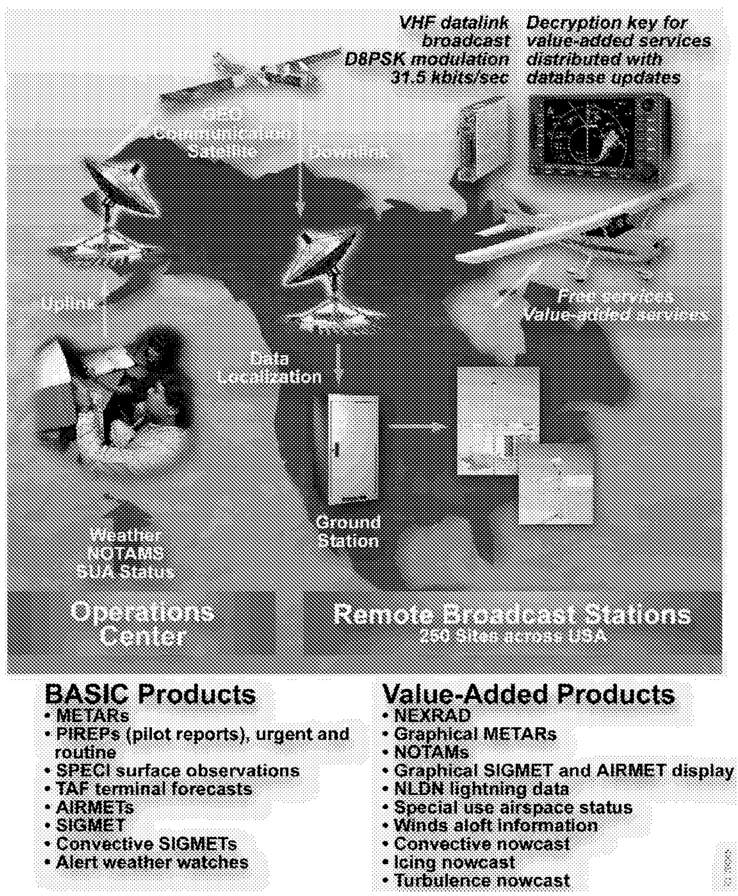
FLIGHT OPERATIONS TECHNOLOGY
Innovations in flight


Questions?


20
20

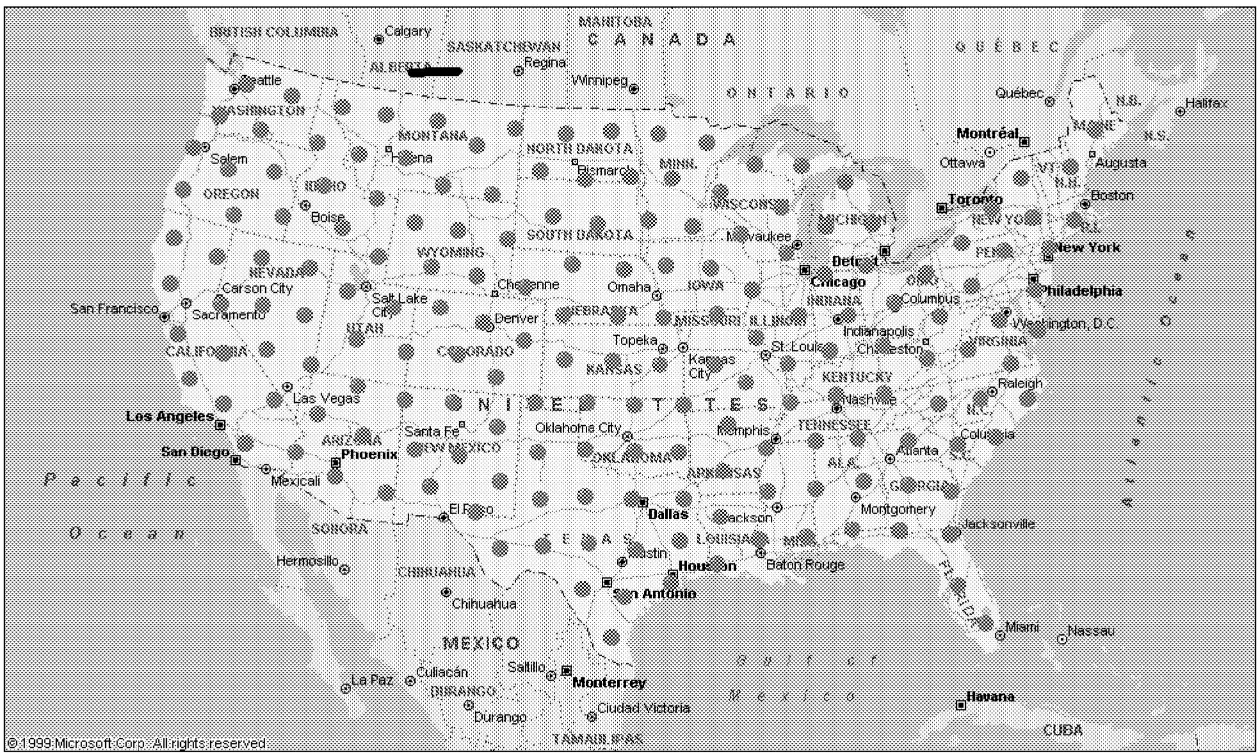
FIS Implementation

- Implementation
- Operation
- Future Technologies



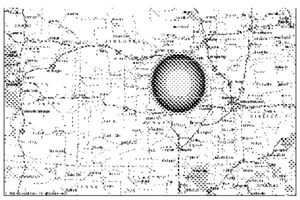
VHF datalink broadcast D8PSK modulation 31.5 kbits/sec
Decryption key for value-added services distributed with database updates
GEO Communication Satellite
Downlink
Uplink
Free services
Value-added services
Data Localization
Ground Station
Weather NOTAMS SUA Status
Operations Center
Remote Broadcast Stations
250 Sites across USA
BASIC Products
• METARs
• PIREPs (pilot reports), urgent and routine
• SPECI surface observations
• TAF terminal forecasts
• AIRMETs
• SIGMET
• Convective SIGMETs
• Alert weather watches
Value-Added Products
• NEXRAD
• Graphical METARs
• NOTAMs
• Graphical SIGMET and AIRMET display
• NLDN lightning data
• Special use airspace status
• Winds aloft information
• Convective nowcast
• Icing nowcast
• Turbulence nowcast

Preliminary Groundstation Site Map



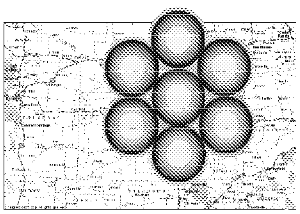
System Integration Efforts

"Turkey"



- "Turkey" Integration (Began in November 2000)
  - 1st End-to-End Integration Testing using Single Cell
  - Hub and Groundstation prototype testing.
  - Terrestrial network prototype testing.
  - Broadcast network RF performance testing.
  - Flight Testing to baseline RF performance
  - RF Propagation Analysis

"Frosty"

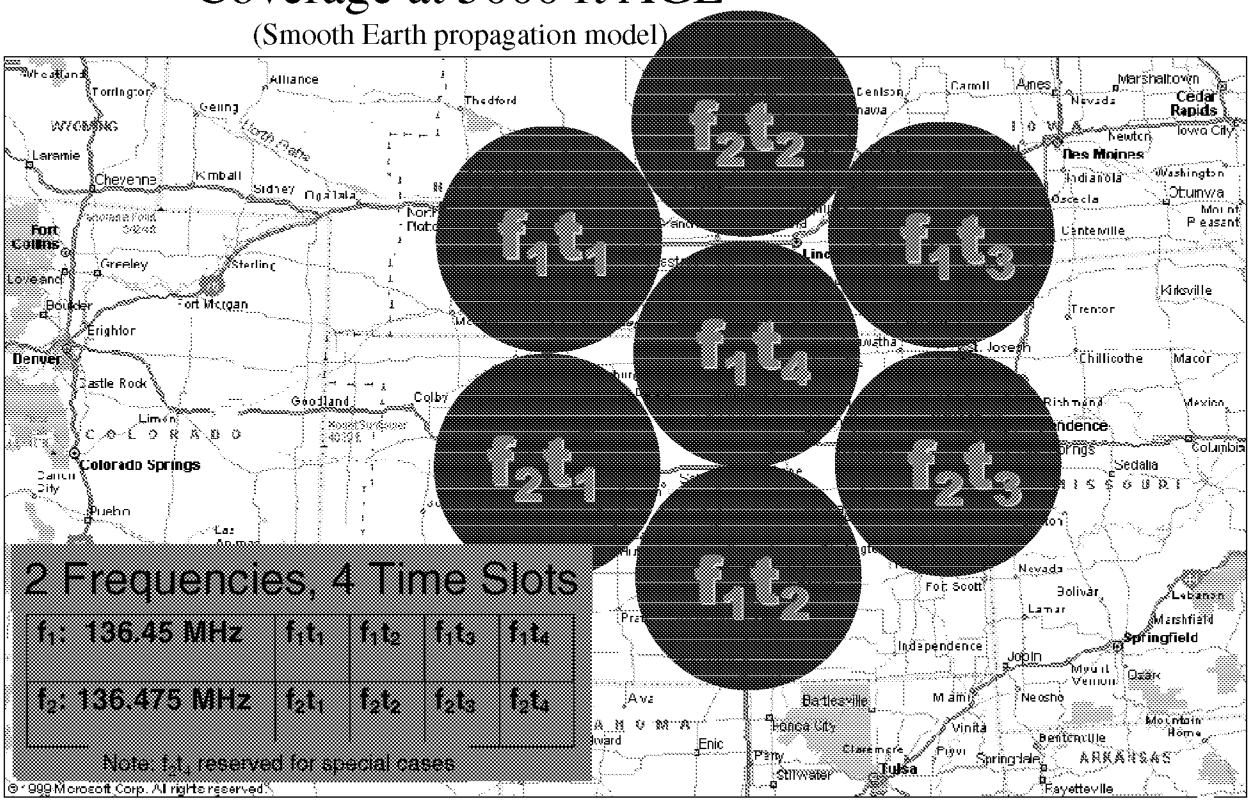


- "Frosty" Integration
  - Phase 1 (Complete Terrestrial Supercell)
    - Validate RF performance / Assess interaction between cells.
    - Test initial product package.
    - Validate terrestrial Wide Area Network (WAN) design and operation.
    - Achieve reliable 7x24 network operation.
    - Blue label VDR / Display tests.
    - Test ground station deployment process.
    - Perform Flight Testing
  - Phase 2 (Business Systems / Network Management)
    - Integrate and test WOC.
    - Subscription / Provisioning process integration and test.
    - Customer interface.
    - Integration of Billing systems.
    - Completion with IOC
    - Perform Flight Testing

FIS Supercell Frequency / Time Slotting

Coverage at 5000 ft AGL

(Smooth Earth propagation model)



2 Frequencies, 4 Time Slots

f_1: 136.45 MHz	f_1t_1	f_1t_2	f_1t_3	f_1t_4
f_2: 136.475 MHz	f_2t_1	f_2t_2	f_2t_3	f_2t_4

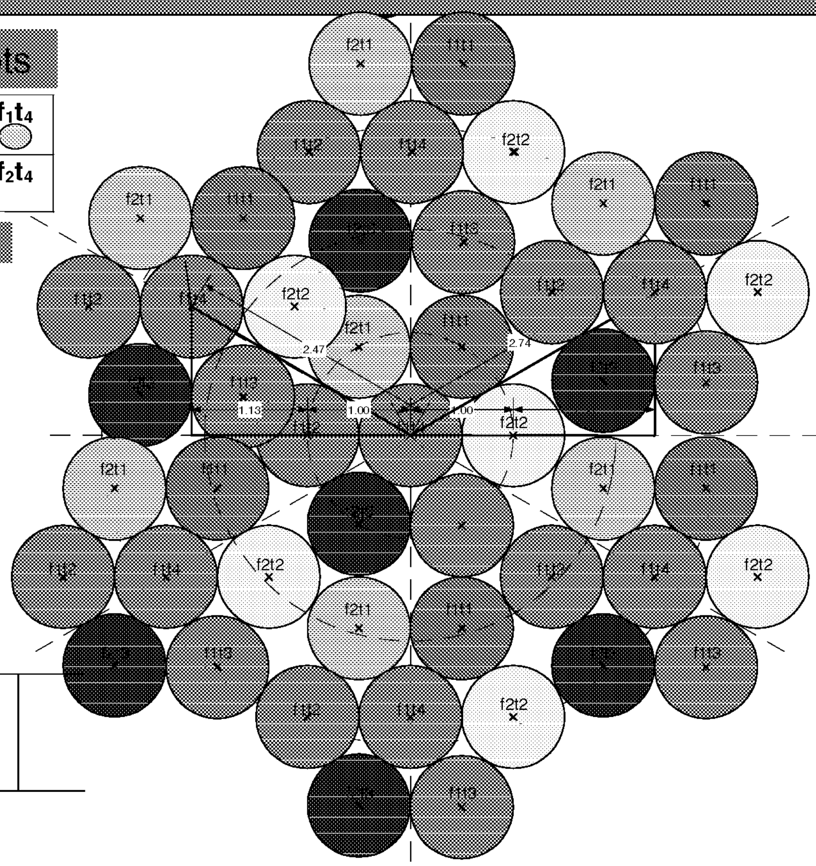
Note: f_2t_4 reserved for special cases

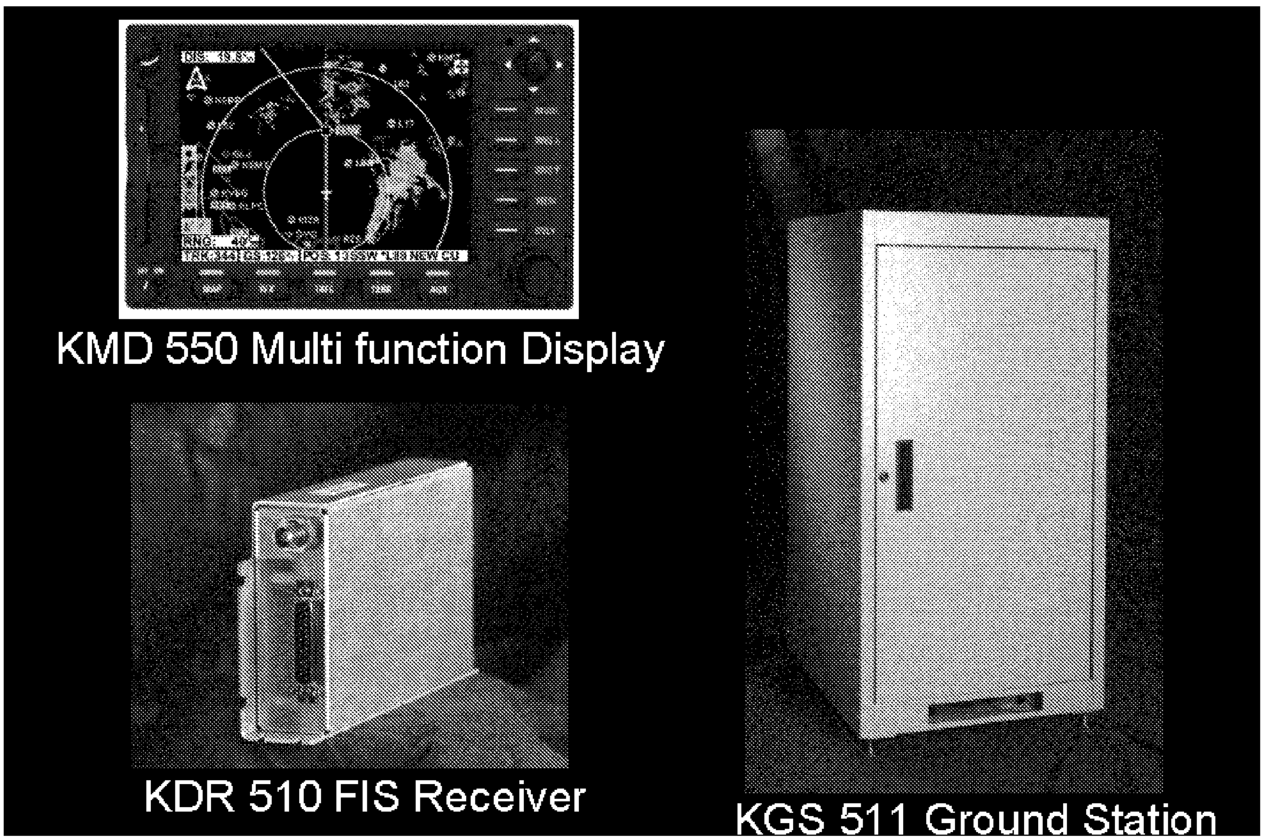
FIS Network Frequency / Time Slotting

2 Frequencies, 4 Time Slots

f_1: 136.45 MHz	**f_1t_1**	**f_1t_2**	**f_1t_3**	**f_1t_4**
f_2: 136.475 MHz	**f_2t_1**	**f_2t_2**	**f_2t_3**	**f_2t_4**

Note: f_2t_4 reserved for special cases




KMD 550 Multi function Display
KDR 510 FIS Receiver
KGS 511 Ground Station

Subscription Control

- Broadcast only system
  - No Handshaking
  - Free products vs Premium products
  - Subscription by year / month
  - Encryption solution

Operation Challenges

- Management of Ground Station Network
  - Network siting stability
  - Maintenance
    - Monitoring
    - Automation of monitoring
    - Logistics
- Manage Comm Link costs

Future Technologies

- Higher level of integration
- Portable Market
- 2 Way FIS

National Business Aviation Association (NBAA)

Tenny Lindholm
The National Center for Atmospheric Research
for
Bob Lamond
NBAA

What NBAA Wants…

- Shared situational awareness between the ground and flight deck
- Graphics (3-D if appropriate)
- Other FIS-B products (including current textual weather information)
- 3-4 year capability (not 2010)

National Center for Atmospheric Research

NBAA Operational Environment

- Service to many diverse major and smaller terminals
- Generally high-end equipment; however, there is a wide spectrum from helicopter to large bizjets
  - SATCOM
  - VHF digital radios
  - ACARS
  - FIS-B—yes
  - Display options
- Critical need to complete the mission
- Short-notice operations

Bottom Line for NBAA

- Access to data and information ASAP. That is,
  - NBAA has perhaps the best equipage in the industry; however, inflight operators cannot access weather information because the infrastructure is not in place
  - An incremental buildup of capability is okay, recognizing the infrastructure takes time
- A spectrum of capabilities
- Graphics
  - Mirror what is available on the ground for the flight deck
- Comprehensive national (and international) coverage
- Don't get too consumed with cutting edge development, unless there is a clear benefit
  - Technology has been demonstrated
  - Further focus on R&D vs. implementation will slow the introduction of needed capability

National Center for Atmospheric Research

Société Nationale de Constru[illegible]s Aéronautiques du Midi (SNCAM)

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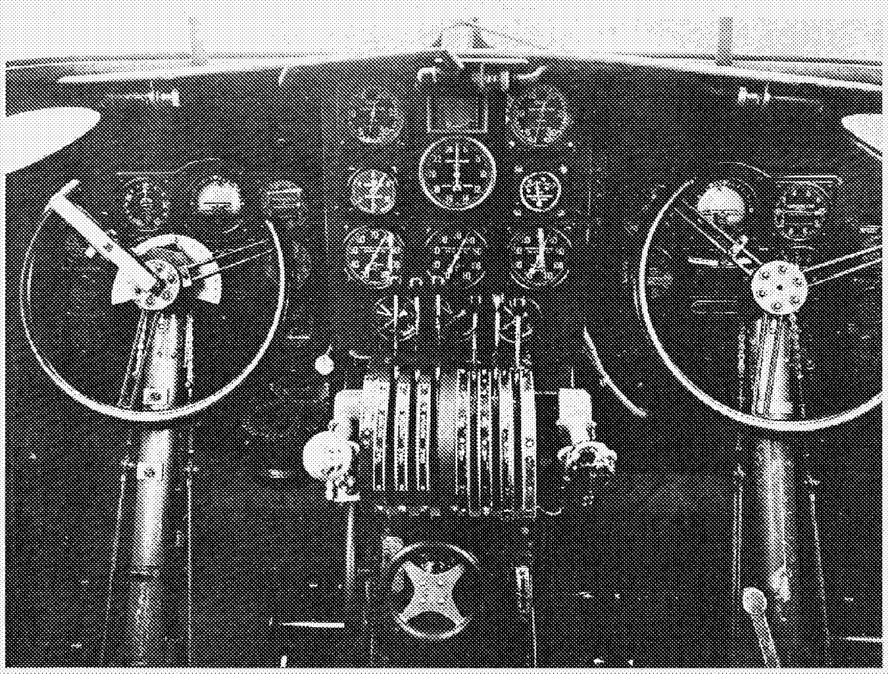
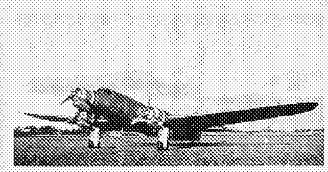


Premier vol / First flight

1939



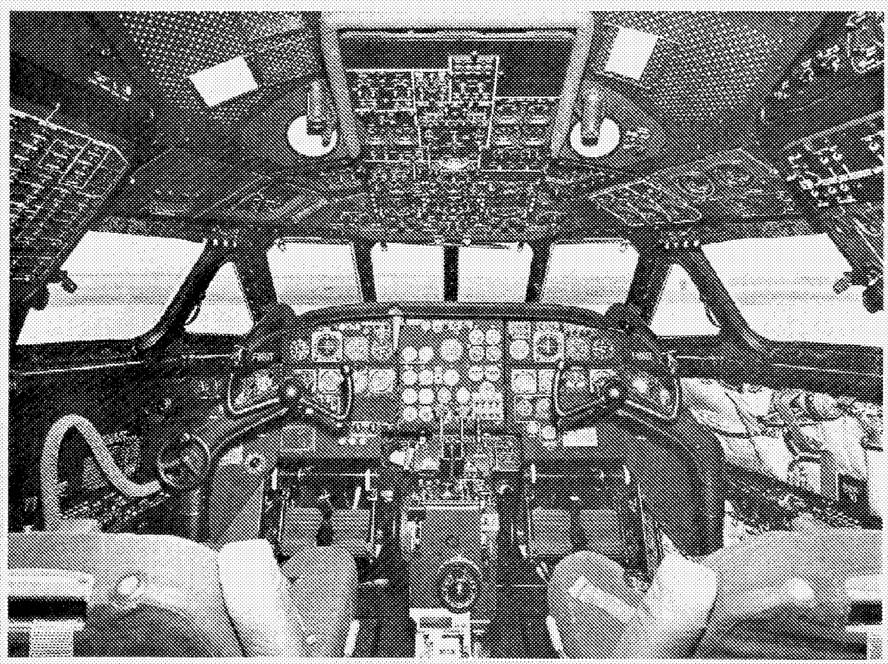
NASA/CP—2002-210964

Société Nationale de Constructions Aéronautiques du Sud-Est (SNCASE)

SE 210 "CARAVELLE"

Premier vol / First flight

1955

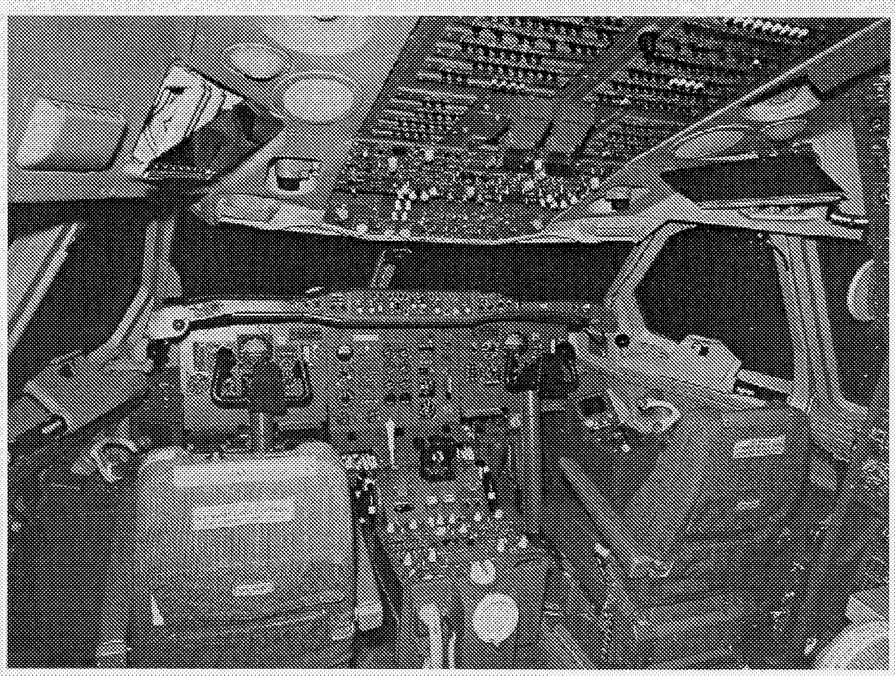


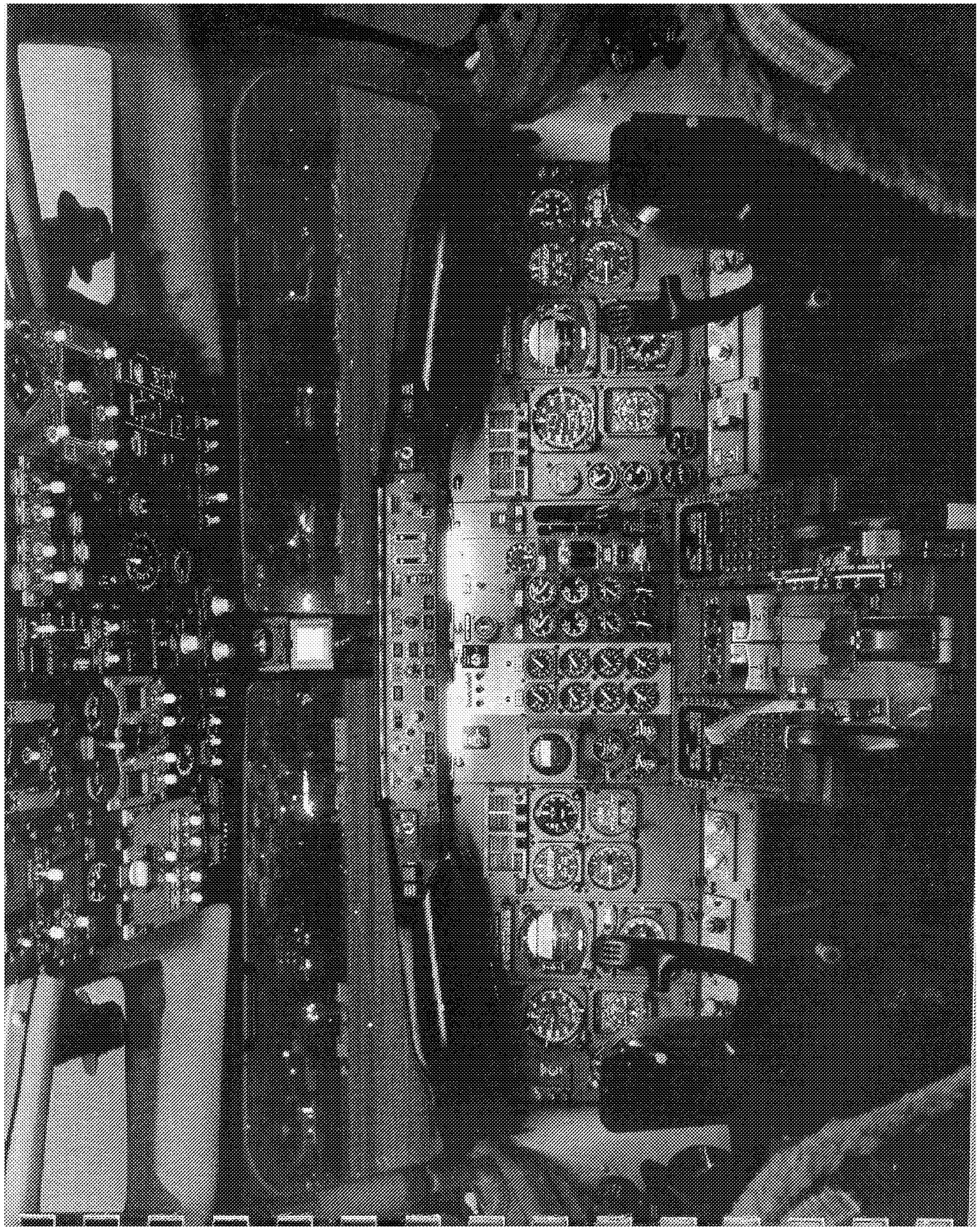
AIRBUS INDUSTRIE/AÉROSPA LE

AIRBUS A 300

Premier vol / First flight

1972





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13. ABSTRACT ***(Maximum 200 words)***

The Second NASA Aviation Safety Program (AvSP) Weather Accident Prevention (WxAP) Annual Project Review held June 5–7, 2001, in Cleveland, Ohio, presented the NASA technical plans and accomplishments to the aviation community. NASA-developed technologies presented included an Aviation Weather Information System with associated digital communications links, electronic atmospheric reporting technologies, forward-looking turbulence warning systems, and turbulence mitigation procedures. The meeting provided feedback and insight from the aviation community of diverse backgrounds and assisted NASA in steering its plans in the direction needed to meet the national safety goal of 80-percent reduction of aircraft accidents by 2007. The proceedings of the review are enclosed.

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