# Turbulence PDT core members

**NCAR/RAP**
- Bob Sharman (lead)
- Barb Brown
- Larry Cornman
- Tenny Lindholm

**NOAA/FSL**
- Steve Koch (alternate)
- Cec Girz
- Jennifer Mahoney
- Fernando Caracena

**AWC**
- Ron Olson
Turbulence PDT Overview: Major Work Areas and Funding

22 task areas in all
1. Develop and implement in-situ measuring system (16%)
2. Improve turbulence remote sensing (10%)
3. Develop and implement automated turbulence forecasting techniques (74%)
   - ITFA testing & tuning (24%)
   - Verification of forecast products (17%)
   - New diagnostic+prognostic development, including r&d leading to better understandings of turbulence and forecastability (33%)
152. Generation of turbulence by a grid. Smoke wires show a uniform laminar stream passing through a $\frac{1}{16}$-inch plate with $\frac{3}{8}$-inch square perforations. The Reynolds number is 1500 based on the 1-inch mesh size. Instability of the shear layers leads to turbulent flow downstream. Photograph by Thomas Corke and Hassan Nagib.
**Turbulence PDT Overview: In-situ**

**Goal:** To augment/replace pireps of turbulence

**Features:**
- Automatically records turbulence (peak and average)
- Aircraft independent (edr)
- Automatically downloads data periodically during flight using ACARS network
- Software mod to ACMS, no hardware mods
- Adopted as ICAO Standard

**Status:**
- On-board ~80 UAL 737’s, 757’s
- Off-line testing very positive
- End-to-end testing shows some discrepancies => FOQA
In-situ potential to replace pireps
In-situ status - off-line calibration studies

Measured vertical acceleration from NASA flight test

Wind derived vs in-situ algorithm
**Turbulence PDT Overview: Remote Sensing of Turbulence**

**Goal:** To observe turbulence using remote sensing techniques

**Research areas:**
- Refine algorithms for retrieving reliable turbulence estimates from WSR-88D moments and reflectivity data
- Develop methods to infer upper level turbulence from lidar, GPS or other measurements
- Use combinations of simulations and field data for algorithm development and verification
Remote sensing status - WSR88D radar

RAPS-92 Mile High Radar/T-28 EDR comparison

Existing WSR-88D Algorithm

Improved WSR-88D Algorithm
GPS Feasibility study:

- Turbulence causes GPS signal scintillations
- Ground-based GPS scintillation dominated by low level humidity fluctuations
- GPS to
  - low-earth-orbiting (LEO) satellite
  - cruise altitude aircraft occultation data may allow mapping of upper level turbulence
Goal: To provide automated gridded turbulence nowcasts/forecasts

Research areas:
• Integrated Turbulence Forecasting Algorithm (ITFA)
• Development and testing of new/improved diagnostics/prognostics of turbulence
  – Research leading to better understandings of nature and causes of turbulence in the free atmosphere
• Development and testing of methods to combine diagnostics to achieve better performance
• Verification of forecast products
Integrated Turbulence Forecasting Algorithm (ITFA)

Fully-automated semi-empirical forecasting tool for upper level CAT

• Inputs
  – Most recent observations of turbulence (PIREPs, in-situ measurements, remote sensors)
  – Synoptic-meso-scale forecast data (RUCII) => diagnostics
  – Clouds, lightning and others

• Integrate many diagnostics with observations using fuzzy logic to get best agreement to current turbulence observations

• Output
  – Best guess of turbulence locations and intensities due CAT
  – Limited to RUCII domain and forecast cycles
Example of diagnostic merging into ITFA
ITFA - Status

• Revised operational ITFA
  – Fewer indices (12 instead of 16)
  – Graphical threshold changes
• RTVS winter 2001 evaluations
• Offline testing and tuning
  – Winter 2000-2001 statistical evaluations and case studies of various thresholding, weighting, and scoring schemes
  – WJHTC winter 2000 case studies
• Subjective evaluations
ITFA - Advantages

- Verifications show algorithm is competitive
  - Internal scoring
  - Independent verification team (NCAR/FSL) statistical analyses (‘98-’02 RTVS and post-season analyses)
  - AWC, airlines subjective analyses (winter 00, 01, 02)
  - MCR case studies based on NTSB data (1999)
  - FAA Tech Center winter ‘00 severe cases
- Adaptive architecture allows for easy enhancements
  - New predictive algorithms easily included
  - Options are scripted
  - More pireps sources/in-situ easily accommodated
- Frequent updates (RUCII cycle)
ITFA - AWTT Status

- “Grandfathered” at D3
- Freeze winter 01-02 version
- D4 scheduled for Nov. 2002
- FAA WJH Tech Center usability study scheduled for winter 2001-02
  - Based on ADDS graphics
  - Comair Dispatch
  - UAL Meteorology
- RTVS and post-season statistical evaluations
- Some recoding in preparation for transition to AWC
ITFA Performance Improvements
Research Areas

- **Turbulence diagnostic development**
  - Unbalanced flow diagnostic under development (Steve Koch, FSL)
  - Tropopause gradient feature detector developed; testing underway
  - “Empirical” mountain wave algorithms developed; testing underway
  - NASA/NCSU diagnostic codes; testing underway
  - NVA (Negative Vorticity Advection) index coded; testing underway
  - Effect of clouds

- **Optimization strategies**
  - Robust thresholds difficult to establish
  - Mappings and weightings are regional, altitude dependent
  - 3 research areas
    1. regional weightings
    2. Global minimization techniques
    3. Other regression techniques, neural nets, etc.
COMPARISON OF FLOW IMBALANCE INDICATOR TO ITFA
AS TURBULENCE PREDICTOR: CASE OF 11 MARCH 2000

Evolution of 3-hourly PIREPS

Turbulence Diagnostic from 3h RUC Forecast
valid at 1800 UTC 11 March 2000

Predicted Turbulence from Imbalance Indicator
valid at 1800 UTC 11 March 2000

Pressure Perturbation Mesoanalysis at 1930 UTC
ITFA empirical mountain wave example

EXPERIMENTAL PRODUCT
16:30 UTC 14 Mar - 19:30 UTC 14 Mar 2001

- null
- smooth-light
- light
- light-mod
- moderate
- mod-severe
- severe
- extreme
Thresholding difficulties

IDEAL (pireps)

VWS (pireps)
Optimization studies
(3 hr forecast statistics)
Other forecast activities

• Field programs:
  – SCATCAT Northeastern Pacific field program (Jan-Feb ‘01) (with Mel Shapiro, MMM)
  – Provides high resolution atmospheric measurements plus in-situ turbulence observations
  – Allows testing of diagnostic performance on operational system with research grade turbulence verifications (NOT PIREPs)
  – May lead to better diagnostics

• Convectively-induced turbulence (CIT) studies
  – Very high resolution numerical simulations of CIT encounters
  – May lead to better CIT diagnostics
  – May lead to better cloud avoidance strategies
18 Feb 2001 case
upper: 300 mb heights, winds
right: isentropic cross section
CIT Simulation

- Use computer models to recreate out-of-cloud turbulence encounters
- Can be used for cloud avoidance strategies
- Example case
  - 757 severe CAT encounter at FL370 above cloud tops
  - 10 July 1997
  - N. Dakota
  - 22 injuries
  - Simulation showed vorticity burst, gravity waves at cloud top
  - Good agreement with observations

**Turbulence near penetrating updraft.**

Potential temperature - 1 K intervals

**Eddy diffusion coefficient** - > 0.1 m^2/s

Cloud water + ice - > 0.05 g/kg

Todd Lane June 2001.