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Automated Turbulence Reporting in National Air Space (NAS) Operations

Presented to NTSB PIREP Forum

June 22, 2016

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Automated Turbulence Reporting in NAS Operations
Overview

- Motivations
  - Turbulence impacts on NAS operations
  - Turbulence Concerns for Users
  - Shortfalls with manual turbulence PIREP reports
- Automated *In Situ* Turbulence Reporting: FAA-Sponsored Development
  - National Center for Atmospheric Development (NCAR) Eddy Dissipation Rate (EDR) Algorithm
- Integration into NAS Operations
  - Delta Air Lines (DAL) Flight Weather Viewer
- Future challenges
  - Tech transfer (global expansion of program)
  - Standardization
  - Data Access

Automated Turbulence Reporting in NAS Operations
Turbulence impacts on NAS Operations

- **SAFETY:** In non-fatal accidents, turbulence is leading cause of injuries to passengers and flight crews for Part 121 Air Carriers[1]
  - [2]1998-2013: 432 turbulence events; 225 serious injuries; 1,109 minor

- **CAPACITY**: Turbulence is the 2nd leading cause of impact to NAS capacity
  - Degraded acceptance/departure rates from terminals
  - Reroutes, delays, diversions, cancellations
  - Increased controller workload

- **FUEL CONSUMPTION/EMISSIONS:** Pilot initiated altitude deviations
  - ATC "Chat Room" - Pilots & controllers on center frequencies drive often unnecessary altitude deviations as pilots seek smoother rides
  - Significantly reduces airline fuel economy and increases carbon emissions.
    - Estimates that 40-159 million gallons of fuel are wasted annually[3]

[1]http://www.faa.gov/passengers/fly_safe/turbulence
[2]*NTSB Briefing to Turbulence Workshop, Washington DC, September, 2014*
[3]*NASA Turbulence Reporting Technologies In-Service Evaluation: Delta Air Lines Report Out, April 2007*

Turbulence Concerns for Users

Flight Crews • Multiple data sources (ATC "Chat" room, dispatchers, company-specific forecast products, on-board radar) • Strategic vs tactical decisions • Reporting subjectivity, inaccuracy • Cabin management • Tolerance for risk • Company policies	**Dispatchers** • Multiple data sources • Subjectivity, inaccuracy • Tolerance for risk • Workload
ATC • No access to real-time turbulence data at work area • Reporting subjectivity, inaccuracy • PIREPs communicated via "sneaker net" • Ride reports passed from controller to controller during shift change • Altitudes "blocked" out with repeated turbulence reports, can persist for hours	**Flight Attendants** • Cabin management • Insufficient info from flight crews • Obligation to continue duties when seatbelt sign is on • 300 lb beverage cart • Uncooperative passengers

Shortfalls in Manual Turbulence PIREPS

- PIREPS are subjective in nature
  - What is “light” for one pilot may be “moderate” for another
  - Pilot tolerance for turbulence varies with phase of flight
- PIREP thresholds are aircraft-dependent
  - “Light” for a large aircraft may be “moderate” or even “severe” for smaller planes
- Due to various reasons, manual turbulence PIREPs are often inaccurate in space and time:
  - A 2012 study by the National Center for Atmospheric Science (NCAR) found*:
    1. PIREPS, on average, have distance errors of 35-45 km
    2. Average PIREP timing error can range from a few seconds to a few minutes

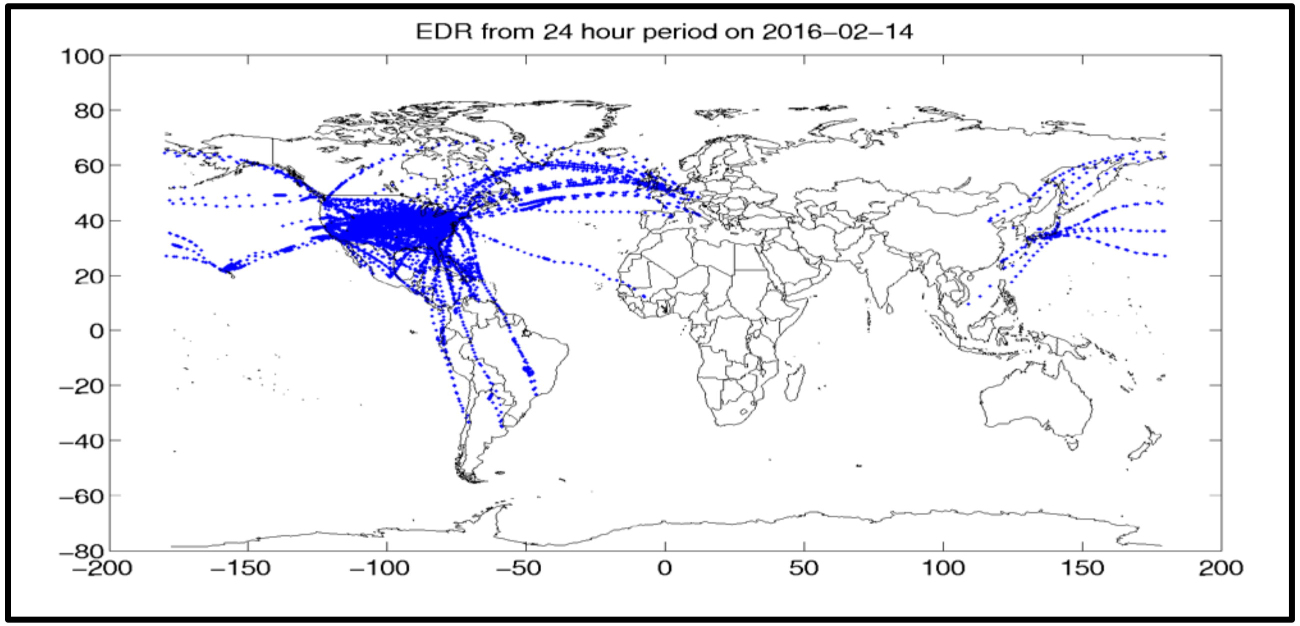
*Pearson, J. and Sharman, R., 2013: “Calibration of in situ eddy dissipation rate (EDR) severity thresholds based on comparisons to turbulence pilot reports (PIREPs)”, presentation at 93rd American Meteorological Society Annual Meeting, 16th Conference on Aviation, Range, and Aerospace Meteorology, Austin, Texas.

Automated In Situ Turbulence Reporting
NCAR EDR Algorithm

EDR

- Development began in 1990s under FAA's Aviation Weather Research Program (AWRP)
- Software loaded on the Aircraft Condition Monitoring System (ACMS), uses existing sensors (accelerometer/ winds) to derive a measure of the turbulent state of the atmosphere
- Aircraft independent, not a direct measurement of g- loads
- Provides atmospheric turbulence metric: eddy dissipation rate (EDR), actually $\varepsilon^{1/3}$ ($m^{2/3}$ / s), scaled 0.0-1.0
- International Civil Aviation Organization (ICAO) standard for turbulence reporting

Automated In Situ Turbulence Reporting
NCAR EDR Algorithm



U.S. Carriers: ~190 reporting a/c

DAL – 162 (B-737/767's)

A-330s in progress

SWA – 34 (B-737s)

UAL – 1 (B-757)

Average number of measurements = 11,731/day

Foreign carriers

XiamenAir (China): ~57 B-737s, looking into outfitting B-787s
Qantas (Australia): Looking into outfitting ~30 A-330s
Air France: Looking into outfitting B-777s
Lufthansa (Germany): Looking into outfitting Airbus

Integration of In Situ Turbulence Reports into NAS Operations

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Dispatch Demo

Sep 08-Jan 10

Focused on:

- Dispatchers
- Flight Operations
- Atlanta Air Route Traffic Control Center Weather Support Unit (CWSU)

Flight crews did not have direct access to the data. Demo was strategic in nature, not tactical.

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Dispatch Demo Sep 08-Jan 10	Uplink Demo May 13-Jul 14
Focused on: • Dispatchers • Flight Operations • Atlanta Air Route Traffic Control Center Weather Support Unit (CWSU) ***Flight crews did not have direct access to the data. Demo was strategic in nature, not tactical.***	***Operational flight demonstrations of the turbulence tablet with Line Check Airmen in the cockpit.*** • Is it feasible to provide and displaying the information on the flight deck through existing WiFi link? • What human factors considerations exist? • Can we quantify the efficiency and capacity benefits to the NAS? ***Conclusion: Overwhelming approval by LCA. DAL recommended implementation airline-wide as supplementary information.***

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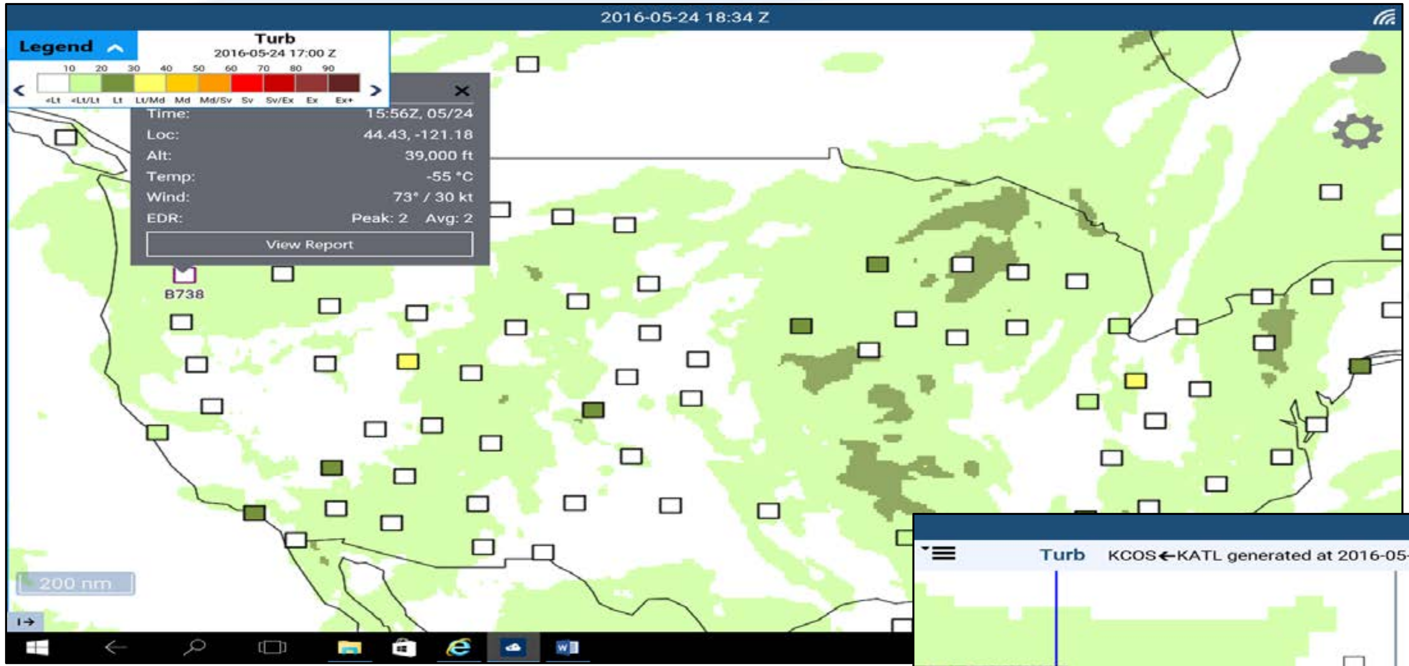
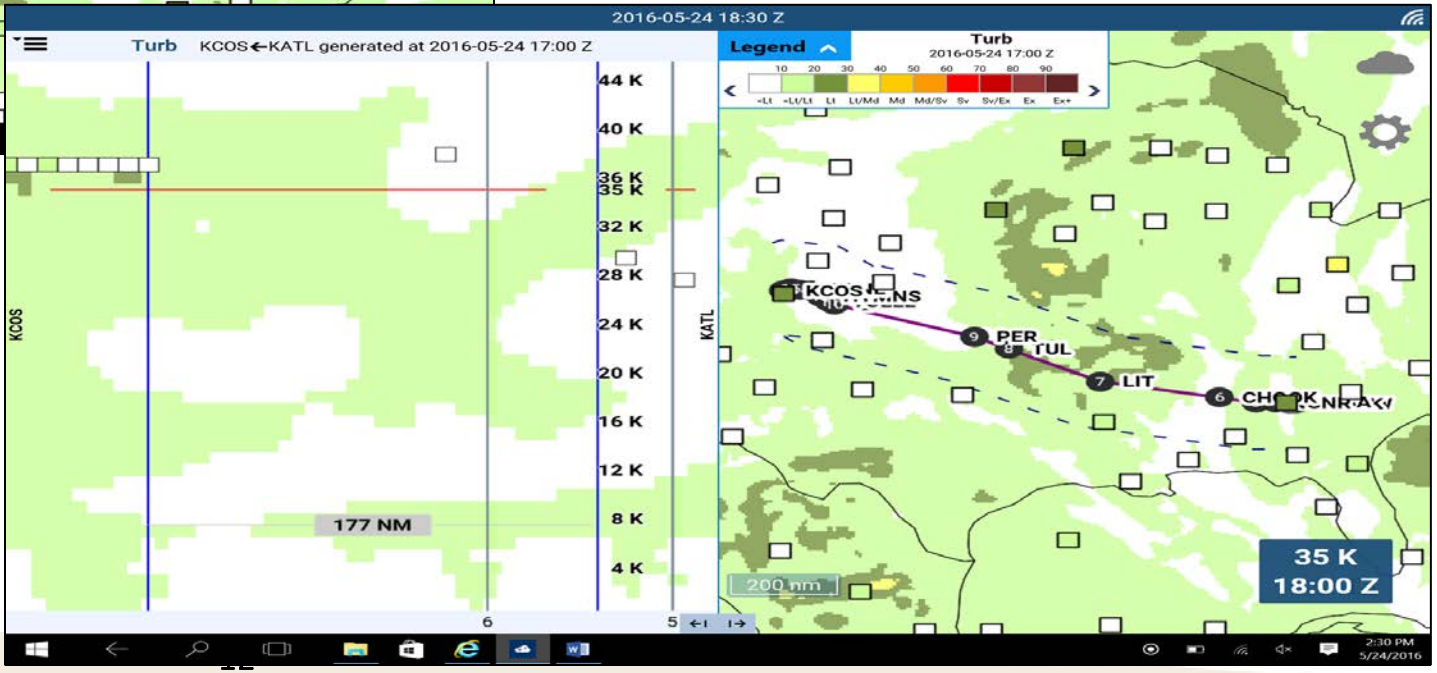
Delta Air Lines Flight Weather Viewer

- Updated tablet application is now in use in the cockpit by over 12,000 DAL pilots through GoGo WiFi network
- Depicts graphical views of forecast and actual turbulence along route of flight
- Greatly enhances cockpit situational awareness
  - Enhances pilot's ability to anticipate and react to possible turbulent conditions
  - Better decisions based on not only cabin safety, but ride comfort and fuel-burn efficiency (reduced emissions)
- Reduction in ATC workload
  - Less requests for altitude changes
  - Improved NAS capacity

Delta Air Lines Flight Weather Viewer



Graphical Turbulence Guidance (GTG) forecast product along with actual automated turbulence reports



On the left: Atmospheric profile view
On the right: Route of flight

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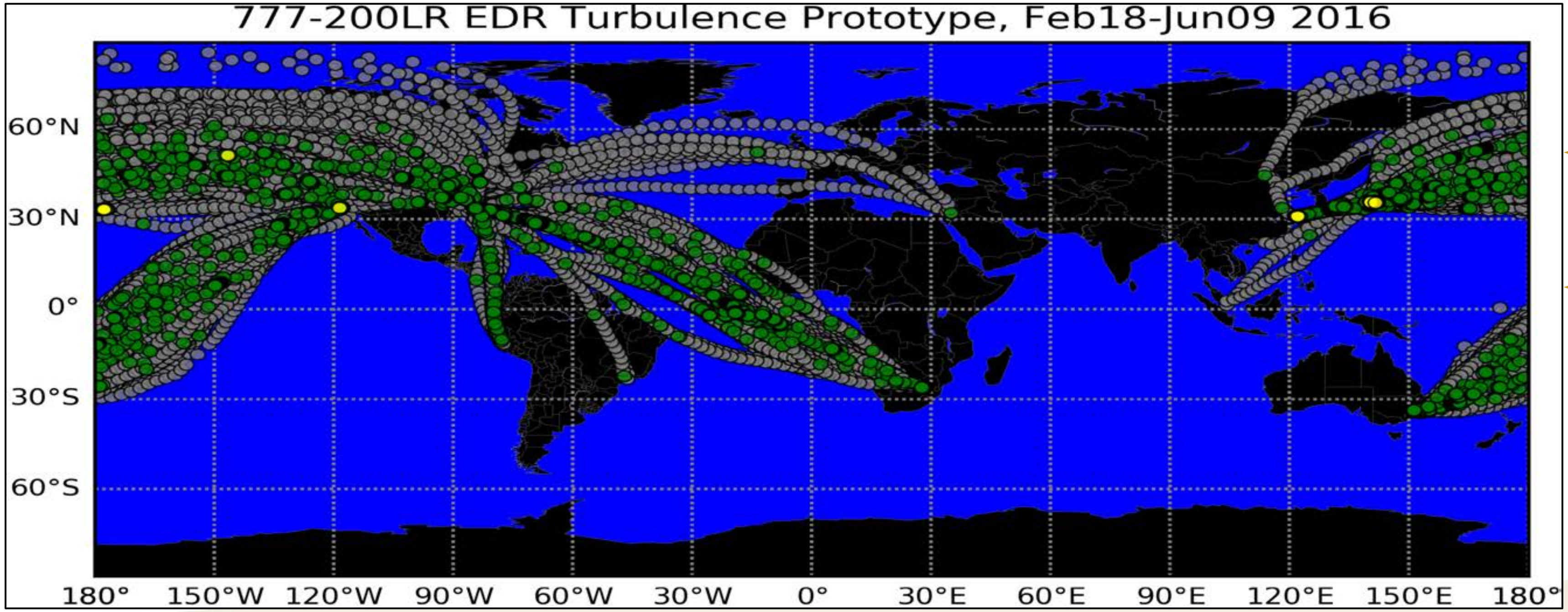
Future Challenges

EDR Tech Transfer Package Development

(Global Expansion)

- Under FAA Weather Technology in the Cockpit (WTIC) funding, NCAR is developing an EDR Technical Transfer (EDR TT) package that will allow airlines to more readily implement standardized EDR reporting.
  - The EDR TT Package comprises both onboard data processing software and ground-based software to provide tuning and verification
  - Testing is being done in collaboration with Delta Air Lines and Boeing



- Still a prototype, but maturing quickly
- >45,000 reports between Feb and Jun

Future Challenges
Standardization

- There are currently three major EDR algorithm implementations, from different developers (NCAR, WSI, Panasonic), with different computational methods
- RTCA Special Committee 206, Aeronautical Information and Meteorological Data Link Services
  - Sub-Group 4: EDR Minimum Operational Performance Standards (MOPS)
    - Terms of Reference: *“Define requirements as necessary for input parameters and computational methodologies to facilitate the calculations of EDR by various algorithms such that the outputs are operationally comparable”.*
    - Scheduled to be presented to RTCA PMC for approval in December 2017
    - FAA Flight Standards expects to invoke the EDR MOPS in either a Technical Standards Order (TSO) or an Advisory Circular (AC).
    - Will apply to the algorithm developer, not the participating airlines.
  - Supported by FAA SE2025 funded EDR Standards Analysis Project
    - Providing RTCA with recommendations for performance standards

Future Challenges
Data Access Issues

- Efforts underway to process and store the NCAR EDR data on National Weather Service's MADIS system
  - Access will be controlled by NWS on a case-by-case basis
- Under current arrangement, EDR data is considered proprietary by the airlines (as well as by the private commercial vendors that provide separate services)
- Potential for cost-sharing/more open data access agreements between the government and airlines?
  - The discussions are on-going. Stay tuned.

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Questions?

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Projected GTG releases (updated March 2016)

Version	Capabilities	Op. date*/Enter QA
GTG1	Upper levels RUC20	3/2003*
GTG2	Improved GTG1 +Mid levels +Uses UAL in situ	2/11/2010*
GTG2.5	13 km WRFRR cutout grids +VWA insitu (UAL+DAL)	5/1/2012*
GTG3.0	13 km WRFRAP grids +MWT +low levels +1-18 hrs	10/2015*
GTGN-1	TRP *SRM*	3/2016 *???*
GTG3.X	General Improvements +Including Auto-tuning *QA Eval? TRP?*	11/2016
GTG-G	Global GFS-based/UKMO? +0-36 hrs +Upper-levels only	FY16-17
GTG-AK?	GTG WRF-RAP	FY17-18
GTG4	Improved GTG3.X + HRRR 3-km grid + CIT forecasts +GTGN2 (incl. sat. feature detectors) ?	FY18-19
GTG5	Improved GTG4 +Ensembles/Probabilistic forecasts	FY19-20
GTG6	Improved GTG5 +>FL650	FY20-21

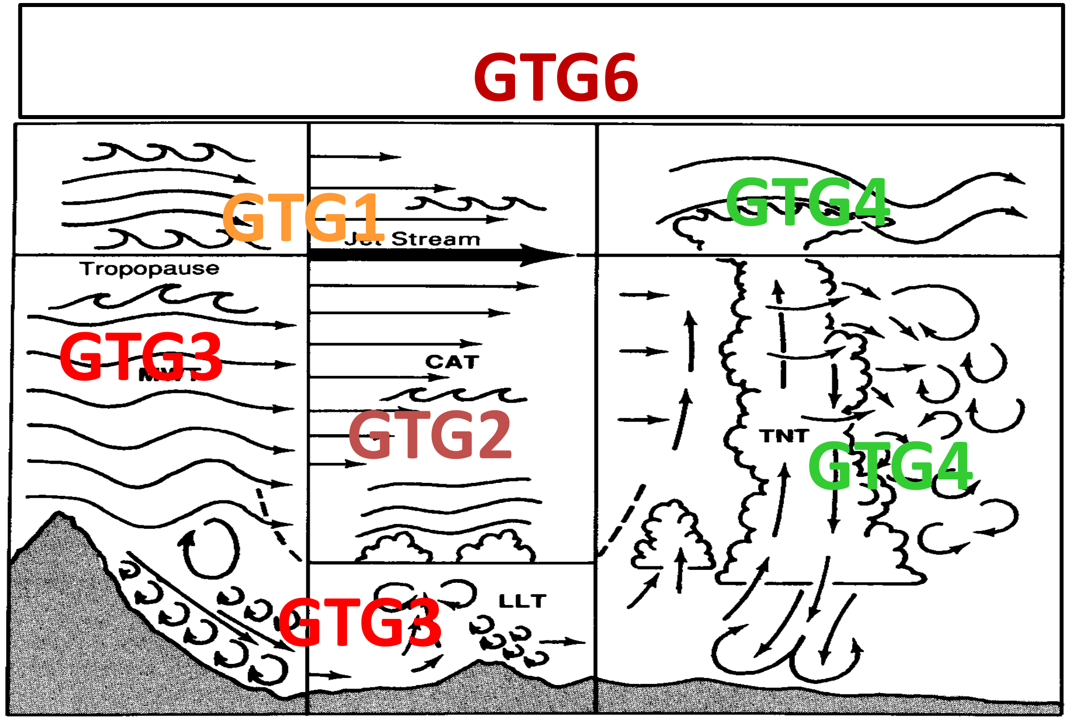

Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

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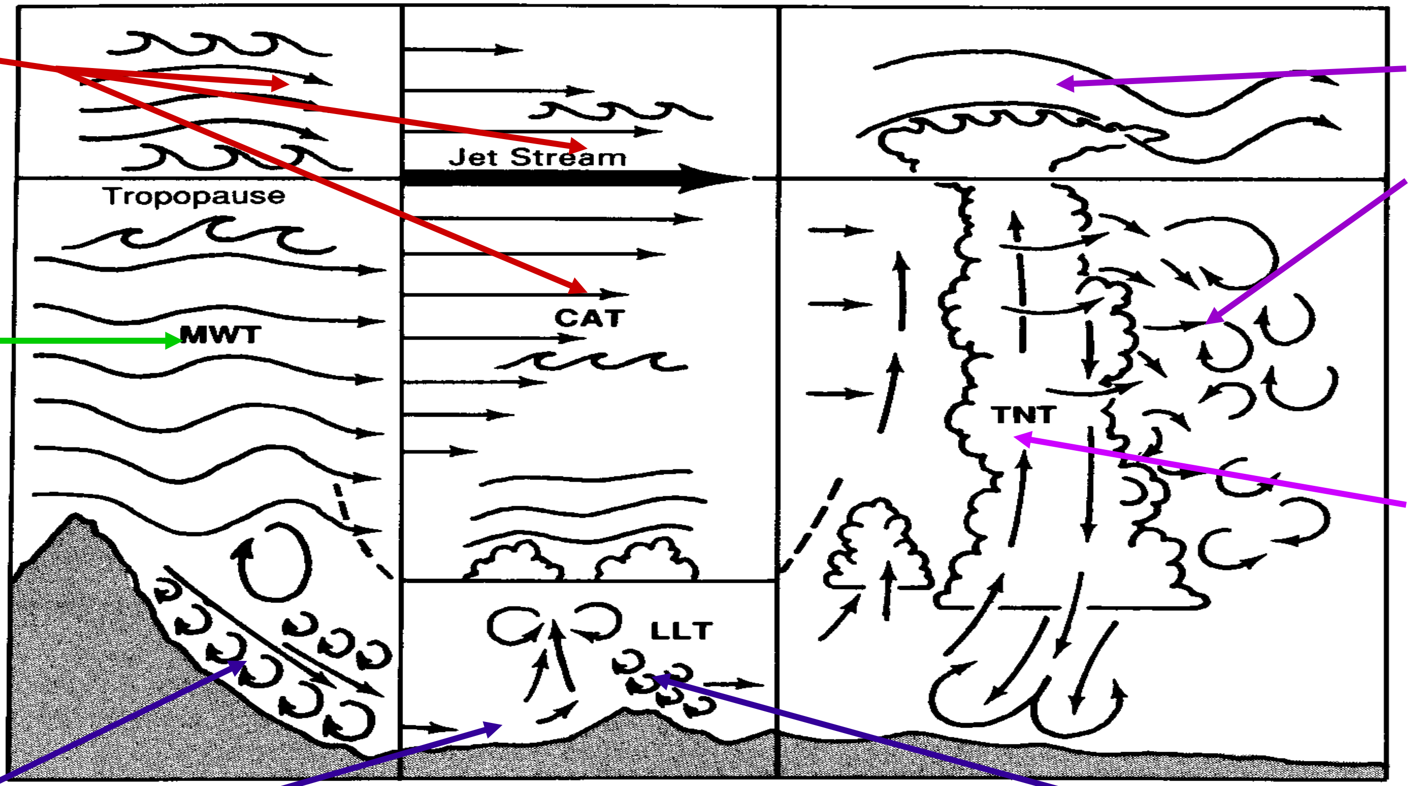
Turbulence Impact on Aviation

•Clear-air Turbulence (CAT)

•Mountain wave Turbulence (MWT)

•Low level Terrain-induced Turbulence (LLT)



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•Cloud-induced or Convectively-induced Turbulence (CIT)

•In-cloud Turbulence

•Convective Boundary Lay Turbulence

FAA Airborne Obs (AO) Project

- Research Question: How can we help improve the NWS Numerical Weather Prediction models through optimizing AO coverage (spatial, temporal, latency and sampling rate)?
- NextGen-funded collaborative effort with NOAA's Earth Systems Research Lab (ESRL) modeling team (Stan Benjamin et. al.) and AvMet Applications.

Develop Airborne Observation Coverage, Operational Gaps/Mitigations, and Alternative Capability Assessment
Aircraft based data coverage optimization analysis report (ESRL)
Determine aircraft based spatial coverage required to optimize weather forecasts
Determine aircraft based temporal coverage required to optimize weather forecasts
Determine aircraft based parameters required to optimize forecasts
Determine aircraft based latency and sampling rate coverage required to optimize forecasts
Airborne Observations Capability Gap Report (AvMet)
Determine current AO coverage
Identify needed AO coverage
Determine capability gaps between current and needed AO coverage
Airborne Observations Capability Gap Mitigation Report (ESRL/AvMet)
Identify opportunities to meet current identified capability gaps.
Identify opportunities to meet future identified capability gaps.
AO Alternative Delivery Report (AvMet)
Determine alternative means to deliver needed airborne observations.
Determine alternative costs to deliver needed airborne observations.

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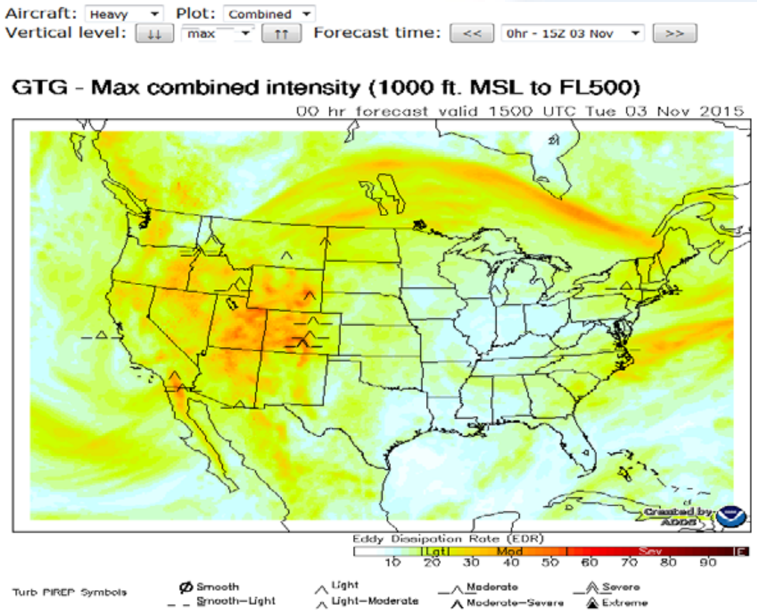
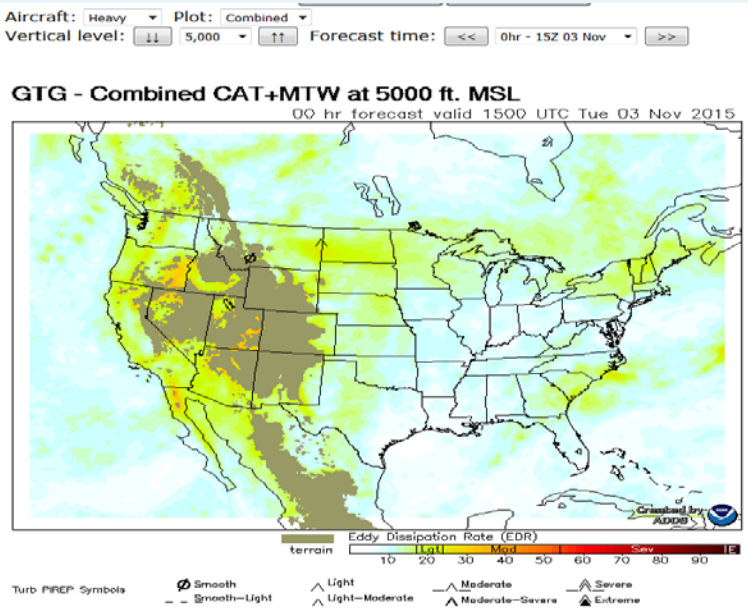
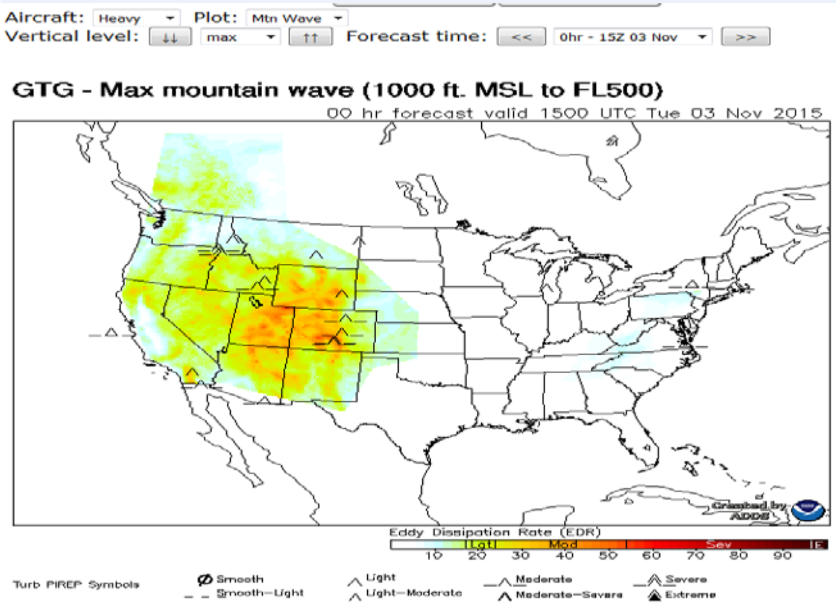
New Graphical Turbulence Guidance (GTG3) Product



Max Intensity CAT+MWT All Levels



CAT+MWT Low Levels (GA Users)



Explicit MWT Forecasts

- New product operational on Aviation Digital Data Service (ADDS) October 20, 2015
- Forecast output now in Eddy Dissipation Rate (EDR) [x10] with additional label of subjective intensity categories
- Users can select aircraft weight class (light, medium, heavy) to get specific intensities for their particular aircraft type
- Includes explicit forecasts for Mountain Wave Turbulence (MWT) that can be viewed separately
- Extended to low-levels (1000 ft – 10,000 ft) for use by General Aviation community
- Hourly forecasts now extend out 0-18 hours, updated hourly

GTG-Nowcast

- Nowcast: Designed to be used as a tactical turbulence avoidance product
  - Rapid update cycle of 15 minutes, valid for next 15 minutes
- Observation-centric
  - Nudges GTG3 to better agree with most recent turbulence observations
  - Uses both airborne (PIREPS, in situ EDR) and ground-based (NEXRAD Turbulence Detection Algorithm-NTDA) obs
- All sources of turbulence are represented – Low level, mountain wave, in and near-cloud, etc
- Outputs a 3D map of EDR, same grid as GTG3
- Product received unanimous approval of Technical Review Panel comprised of FAA, NWS, and airline met representatives on March 23
- Next Steps
  - Develop Conops: How will it be used? Where will it run?
  - Safety Risk Management assessment
  - Operational FY17?

GTG-Nowcast

Example: Dec 26, 2015, valid at 1500UTC FL3000