PARTNER

Partnership for AiR Transportation Noise and Emission Reduction

An FAA/NASA/TC-sponsored Center of Excellence

Overview of PARTNER's Emissions-Operations Research

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PARTNER Director

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Outline

- Description of PARTNER
- Overview: Emissions-operations research
- Example: improving emissions modeling/RVSM study
- Summary

PARTNER vision

William James Warren/CORBIS

- A world-class research organization…

…closely aligned with national and international needs

…leveraging a broad range of stakeholder capabilities

…fostering breakthrough technological, operational, policy and workforce advances

…for the betterment of mobility, economy, national security and the environment

PARTNER universities
10 schools 90+ students

- Boise State University (BSU)
- Florida International University (FIU)
- Georgia Institute of Technology (GT)
- Massachusetts Institute of Technology (MIT)
- Pennsylvania State University (PSU)
- Purdue University
- Stanford University
- University of Central Florida (UCF)
- University of Missouri at Rolla (UMR)
- York University

(with additional work by Harvard University, University of North Carolina, and Reading University)

Sponsors

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FAA Office of Environment and Energy (AEE)

NASA Vehicle Systems Program

Transport Canada   Transports Canada

$2.7M for FY03/04

$4.2M for FY05

$6.4M for FY06

1:1 Cost sharing for all US federal grant funds

Advisory board: 47 organizations

Industry/professional/community (38) + FAA (6), NASA (2) and Transport Canada (1)

- Aerodyne Research Inc. (ARI)
- Aerospace Industries Association (AIA)
- Airbus
- Air Transport Association of America (ATA)
- Airports Council International – North America (ACI-NA)
- American Institute of Aeronautics and Astronautics (AIAA)
- Bay Area Air Quality Management District (BAAQMD)
- Bell Helicopter Textron
- The Boeing Co.
- Bombardier
- Cessna Aircraft, A Textron Company
- Delta Airlines
- Environmentally Compatible Air Transport System Network of Excellent (ECATS)
- FAA Airports and Environmental Law Division (FAA AGC)
- FAA Air Traffic Environmental Programs Division (FAA ATA-300)
- FAA Centers of Excellence (FAA AAR-400)
- FAA Community and Environmental Needs Division (FAA APP-600)
- FAA Flight Standards (FAA AFS)
- FAA Office of Environment and Energy (FAA AEE)
- General Electric Aircraft Engines (GEAE)
- Gulfstream Aerospace Corp.
- Harris, Miller, Miller & Hanson, Inc. (HMMH)
- Indiana Dept. of Transportation (INDoT)
- Lockheed Martin Aeronautics Co. (LMCO)
- Logistics Management Institute (LMI)
- Lyons, Richard, Consultant
- Massachusetts Port Authority (Massport)
- Metron Aviation
- Metropolitan Washington Airport Authority (MWAA)
- NASA Radiation Sciences Program
- NASA NASA Aeronautics Research Mission Directorate
- National Organization to Insure a Sound-controlled Environment (NOISE)
- O'Hare Noise Compatibility Commission
- Palisades Citizens Association
- Pratt & Whitney (P&W)
- Raisbeck Engineering
- Rannoch Corp.
- Regional Airport Authority of Louisville and Jefferson County (RAA)
- Rolls Royce (RR)
- San Francisco International Airport/Community Roundtable
- Sikorsky Aircraft
- Snecma
- Transport Canada
- United Parcel Service (UPS)
- United States Dept. of Transportation (US DoT) Volpe National Transportation Systems Center (TSC)
- United States Environmental Protection Agency (US EPA) National Risk Management Research Laboratory (NRMRL)
- Wyle Laboratories

Research portfolio: three detailed plans
(Drivers, Goals, Objectives, Challenges, Approaches)

Noise

Provide quantitative predictions and qualitative assessments of aviation noise and its impacts, and contribute to mitigation strategies considering all inter-relationships

Emissions

Provide quantitative predictions of aviation emissions & their impacts that contribute to mitigation strategies considering all inter-relationships

Interdependencies

Enable better communication and decision-making in addressing the interdependent environmental effects of aviation by being able to fully assess the benefits and costs of interdependent policies, technologies, operational procedures and market conditions

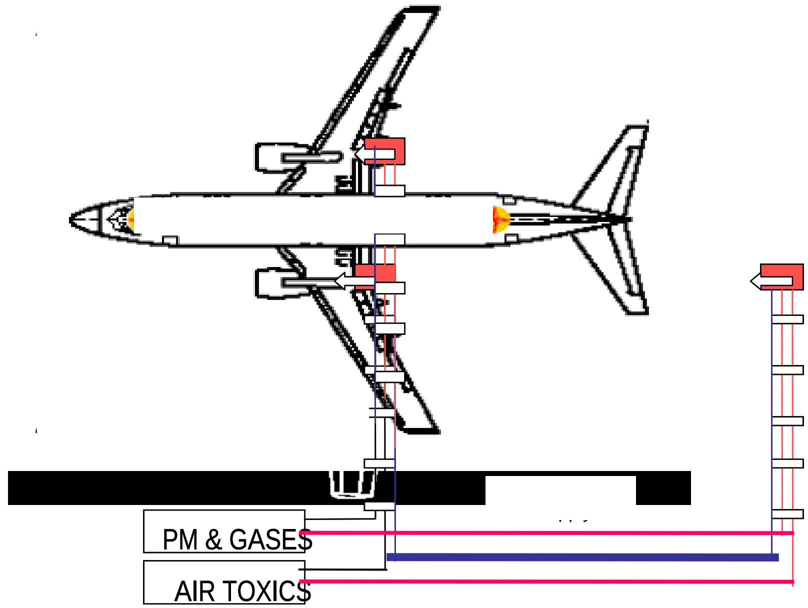
Selected emissions activities

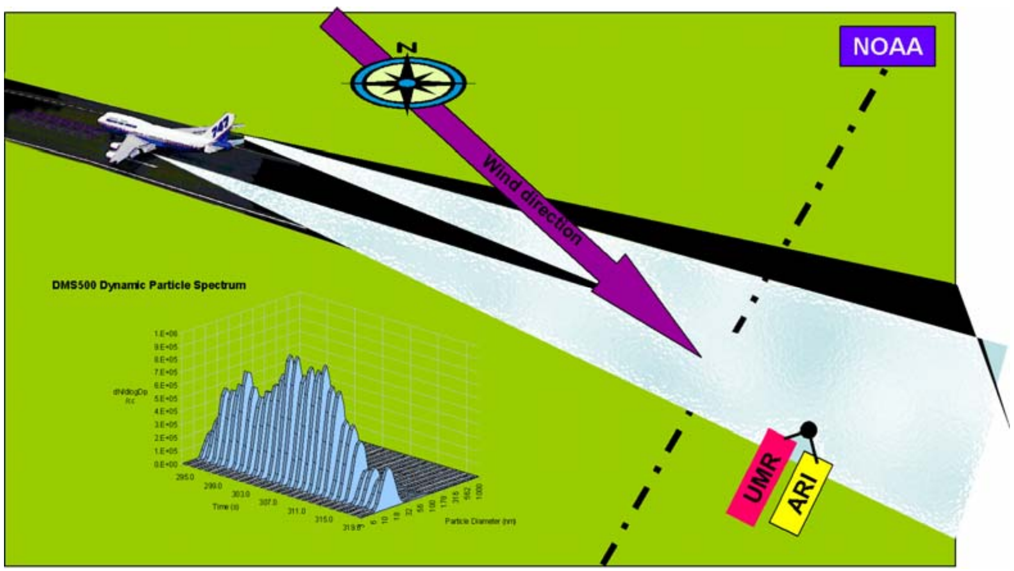
- PM and gaseous emissions measurements and modeling
- Continuous descent approach studies
- Enroute operations study
- Energy Policy Act study
  - Ground and terminal area operations
- Aviation Environmental Portfolio Management Tool
  - Reduced thrust sample problem
- Analysis of reduced thrust for AA B777 operations at Heathrow and Gatwick
- Contributing to development and application of FAA System for assessing Aviation's Global Emissions (SAGE)
  - Fuel burn and emissions modeling
  - Contrails estimation
  - Reduced vertical separation minimum analysis

Aircraft emissions measurements

(contact: Phil Whitefield, pwhite@umr.edu)

- Major U.S. Airlines
- Major U.S. Airports
- Measured hundreds of aircraft
  - Operational
  - After hours
- Compared and assessed measurement methods
- Modeled PM and precursor behavior
- Measured and modeled plume behavior
- Used to improve FAA EDMS tool





Continuous descent approach

(contact: John-Paul Clarke, john-paul.clarke@ae.gatech.edu)

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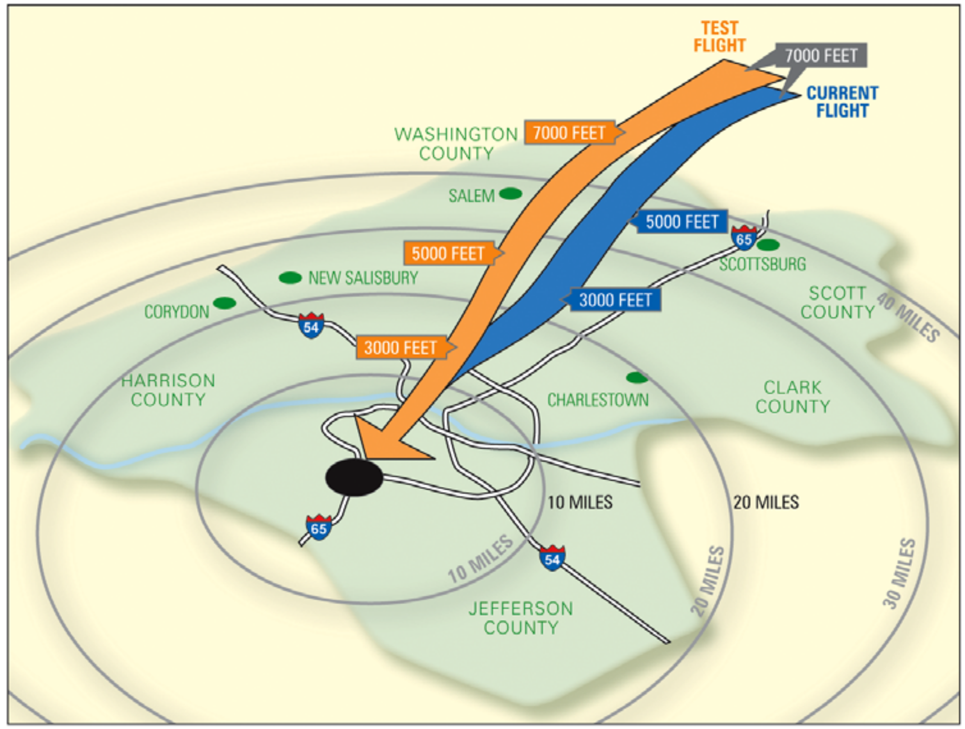
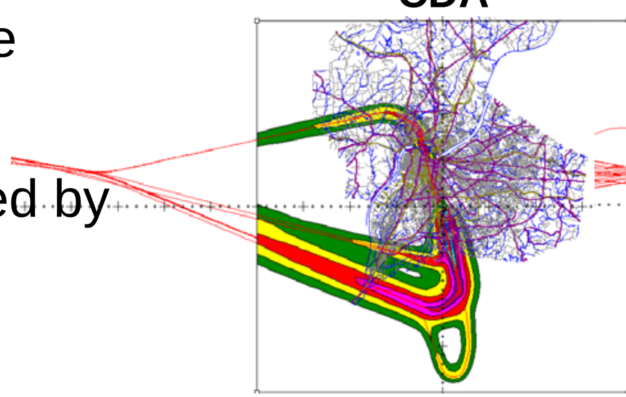
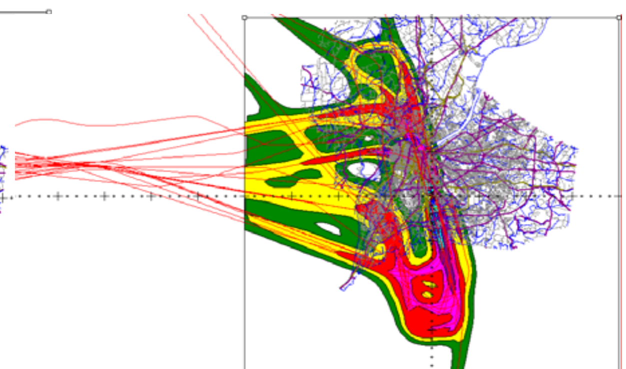
- MIT, FAA, NASA, UPS, Louisville Airport
- 125 UPS aircraft
- 3-6 dB noise reduction
- 35% NOx reduction
- 13-20% CO reduction
- 11-25% UHC reduction
- >120 lbs fuel reduction
- 2-3 min. flight time reduction
- Being implemented by UPS



CDA



Baseline



Enroute traffic optimization

(contact: John-Paul Clarke, john-paul.clarke@ae.gatech.edu)

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- Objective
  - Develop algorithm to and demonstrate the benefits of en route traffic optimization
- Research Approach
  - Develop mathematical model of the air routes through the Cleveland ARTCC
  - Develop prototype optimization algorithm by enhancing an existing Mixed-Integer Linear Program (MILP) within an A* Search-based Branch & Bound framework
  - Conduct simulation study based on existing and potential future traffic levels
- Output
  - Prototype algorithms
  - Estimates of emissions, fuel burn and time benefits

Energy Policy Act study

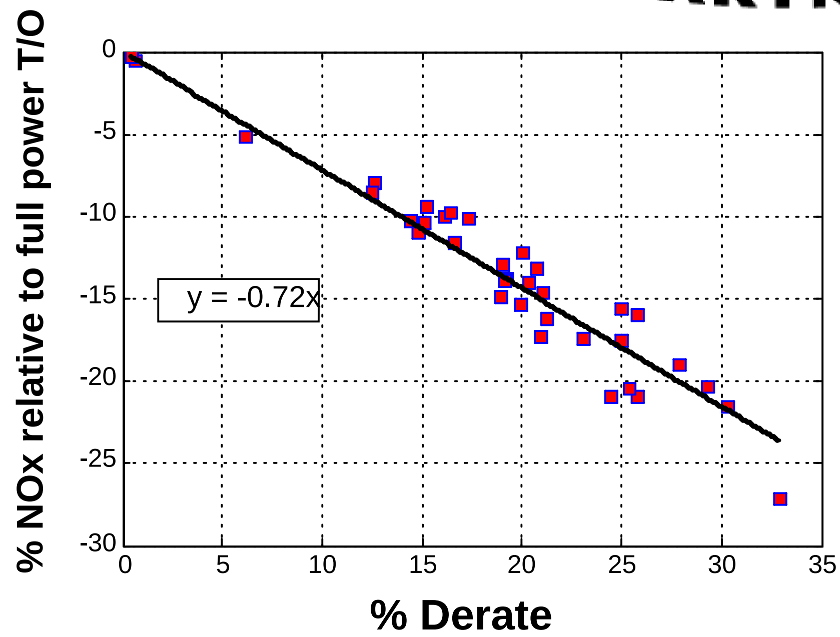
(Ian Waitz, iaw@mit.edu, Warren Gillette, warren.gillette@faa.gov)

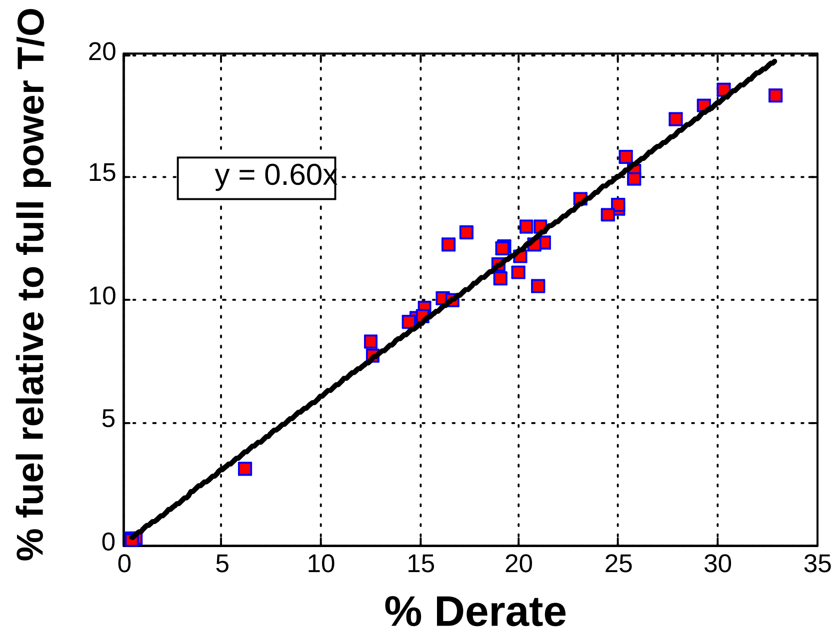
- *Energy Policy Act of 2005* requires the FAA and EPA to identify:
  1. The impact of aircraft emissions on air quality in nonattainment areas;
  2. Ways to promote fuel conservation measures for aviation to enhance fuel efficiency and reduce emissions; and
  3. Opportunities to reduce air traffic inefficiencies that increase fuel burn and emissions.
- CSSI, Metron, MIT, EPA, FAA, UNC, Harvard, US DoD
- EDMS + local air quality modeling + health impact assessment
- Study to be completed early 2007

Analysis of reduced thrust for AA B777 ops at LHR and LGW

(contact: Ian Waitz, iaw@mit.edu)

- Analyzed CFDR data from American Airlines
- Reports:
  - CAEP/7-WG2-TG2/4-5-IP4
  - PARTNER-COE-2005-001 (at http://www.partner.aero)





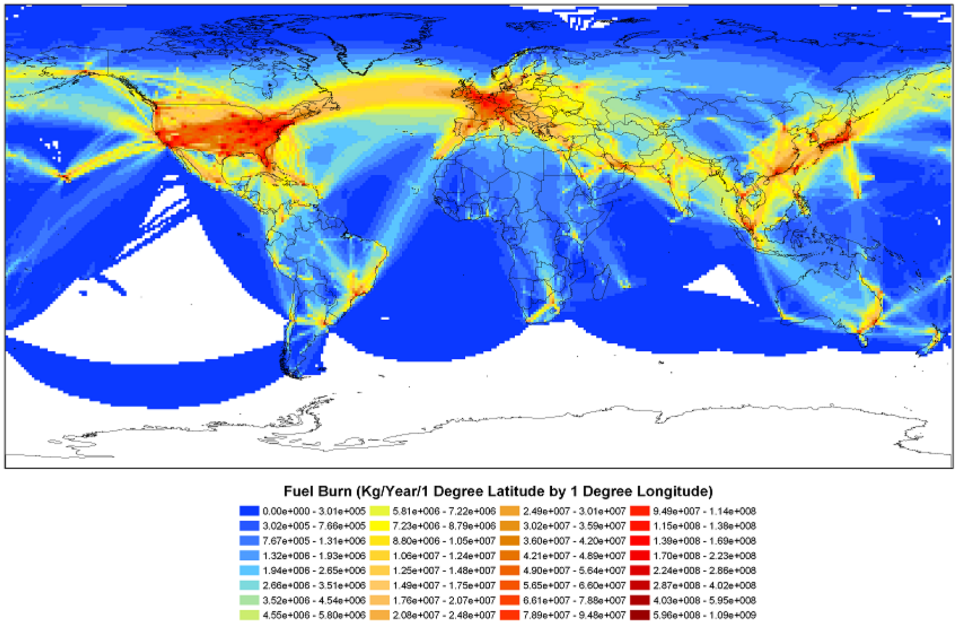
System for assessing Aviation's Global Emissions (SAGE)

(Ian Waitz, iaw@mit.edu, Gregg Fleming, fleming@volpe.dot.gov)

- Fuel burn and emissions estimates for commercial aircraft
  - Developed for FAA by Volpe, MIT, and LMI
  - 30 million flights, 450 aircraft types
  - 40% of flight trajectories from radar data, 60% from OAG with dispersion routing
  - BADA aircraft performance & BM2 emissions estimation

PARTNER activities:

- Improving fuel burn and emissions modeling
- Estimating contrail formation
- Assessing Reduced Vertical Separation Minimum



Example: RVSM/fuel & emissions

(contact: Ian Waitz, iaw@mit.edu)

- Prior studies: FAA ATO (2005), Eurocontrol (2002)
  - Small increase in average altitude: 400 ft
  - Small fuel burn benefits: 17-35 kg/flight
  - Small emissions benefits: 0.7%-1% NOx reduction
- Prior studies flew aircraft on radar trajectories through standard atmosphere
- Prior studies used the Eurocontrol Base of Aircraft Data (BADA)
  - BADA widely used for similar studies within EU and US

Fuel & emissions: missing elements

- Influence of weather
- BADA
  - Two components of drag (induced and viscous), but missing drag due to compressibility
  - Specific fuel consumption (sfc) model does not have appropriate dependence on altitude or thrust level
- When BADA is applied for fleet average assessments and compared to airline data
  - It has been shown to be accurate (within 5%),
  - But not precise (up to 30% error for individual a/c types and flights)
- **Concern:** methods may not be suitable for investigating small changes in operations
  - E.g. small percent change in fuel burn due to a *change* in altitude

Volpe/MIT RVSM study

- Develop and apply improved performance model
  - Include compressibility drag model
  - Analyze 2000+ flights of flight data recorder
    - Develop improved SFC Model
    - Derive more accurate drag coefficients
  - Aircraft types analyzed thus far
    - A319, A320, A321, A330, A340, B757, B767
- Use assimilated weather data
  - Source: NASA Goddard
  - Coverage: Global, 1 x 1.25 degree grid
- Utilize ETMS radar tracks, one month prior to and following RVSM, to determine effect on:
  - Fuel burn
  - Emissions
  - Vertical distribution of emissions

BADA vs. derived methods: drag

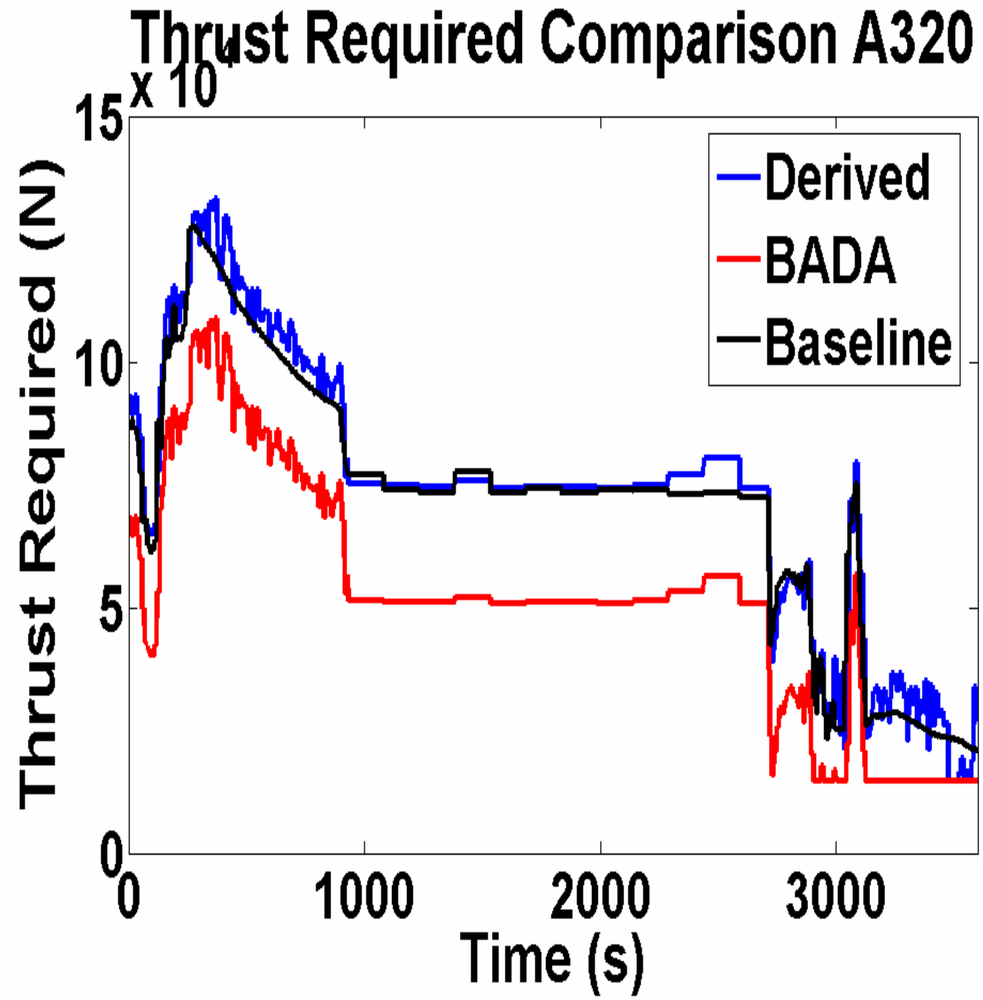
- Drag calculation method:

$$D = \left(C_{d0} + C_{d2}C_L^{\ 2} + \Delta C_{dC}\right)\left(\tfrac{1}{2}\rho V^2 S\right)$$

- Limitations
  - Error in coefficient magnitudes
- Example: A320

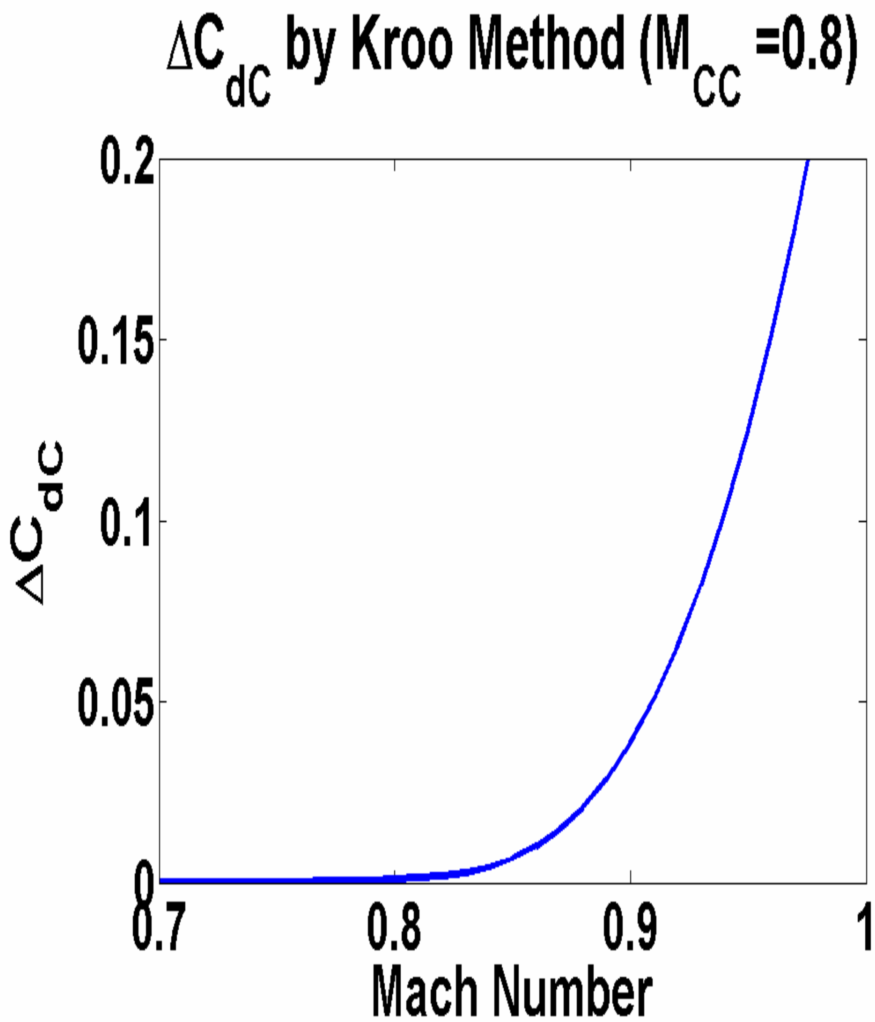
	Derived	BADA
C_{d0}	0.0316	0.0240
C_{d2}	0.0887	0.0375

- Induced drag:
  - 0.0375 would theoretically require an aspect ratio of about 12, while it is actually 9.4



Compressibility correction ΔC_{dC}

- Correction calculation method:
  - Kroo Method
    - Piecewise defined
    - Third order as function of Mach number
  - Uses BADA to determine M_{cc}
- The analysis thus far indicates that the BADA cruise Mach numbers are a valid surrogate for M_{cc}



BADA vs. derived methods: fuel burn

- BADA Fuel calculation method:

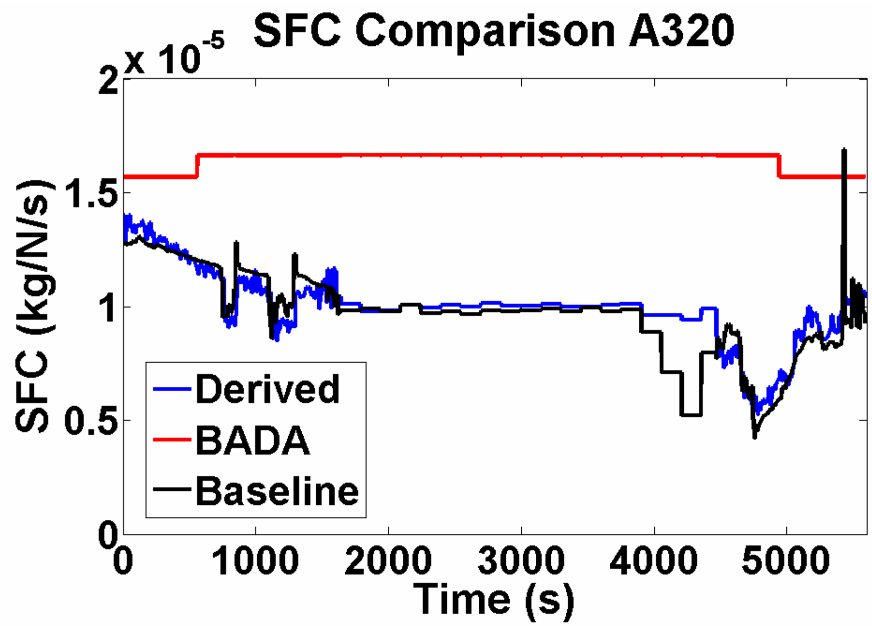
$$sfc = \frac{C_{f1}}{60000}\left(1+\frac{1.9438V}{C_{f2}}\right)C_{fcr}Thrust$$

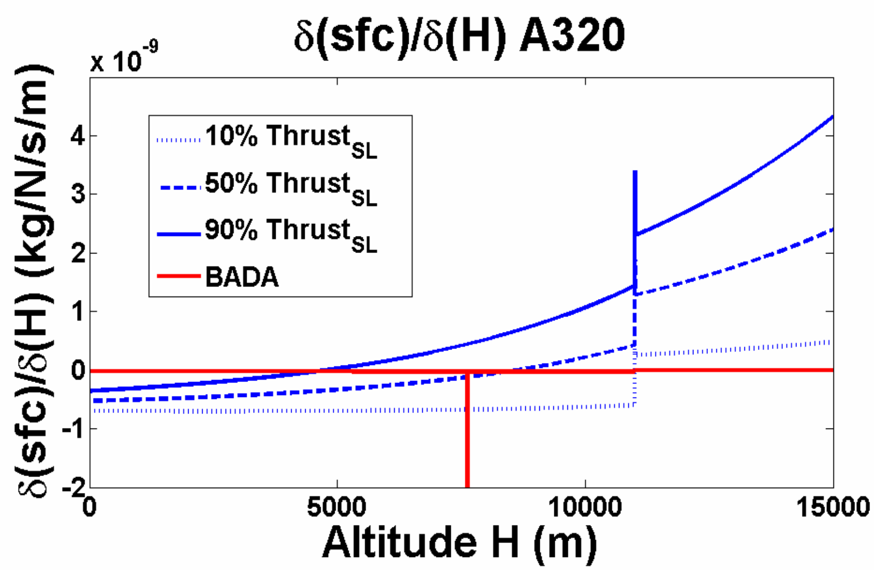
  - Limitation
    - No dependence on Altitude or Thrust level

- Derived Fuel calculation method;

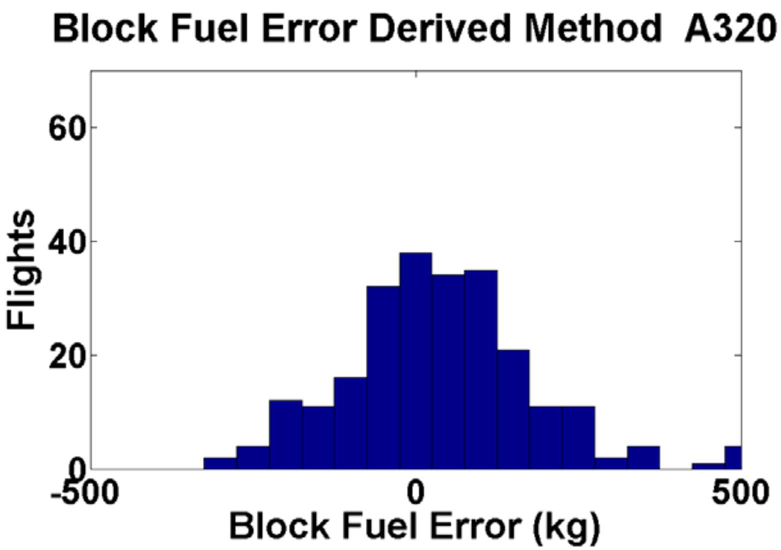
$$sfc = \alpha + \beta_1\left(\sqrt{\frac{T_i}{288.15}}\right) + \beta_2\left(\frac{V_i}{250}\right) + \beta_3\left(\frac{Thrust_i}{Max\_Thrust_{SL}}\frac{P_{SL}}{P_i}\right)$$

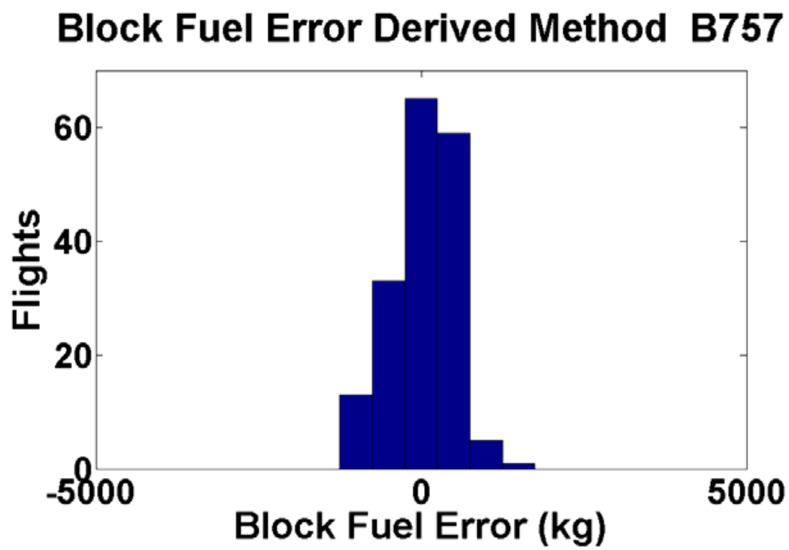
  - Dependent upon
    - Temperature
    - Pressure
    - Velocity
    - Thrust level

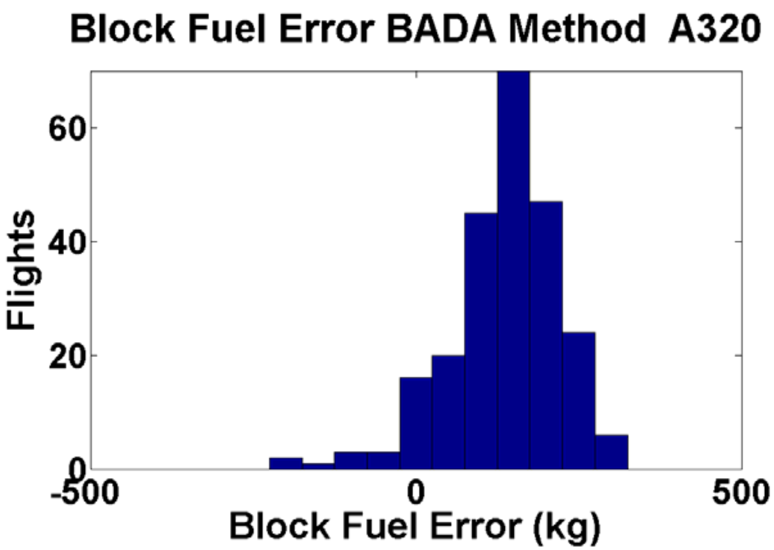


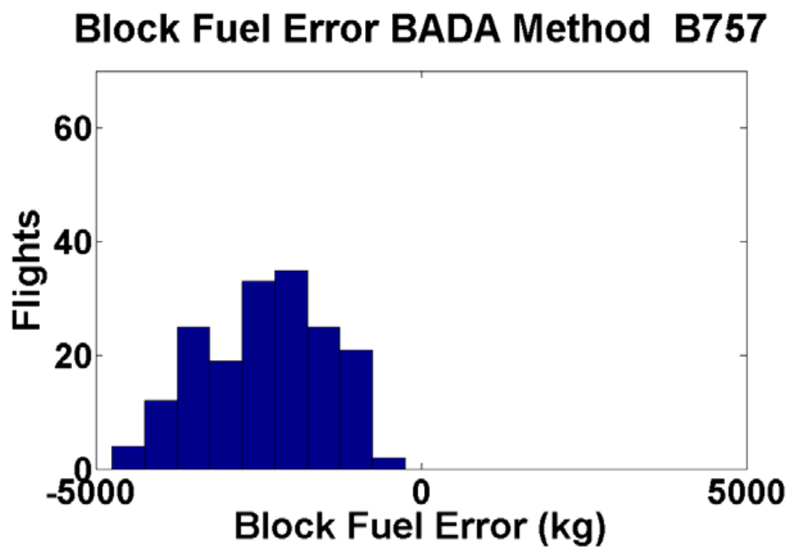


Comparison of block fuel

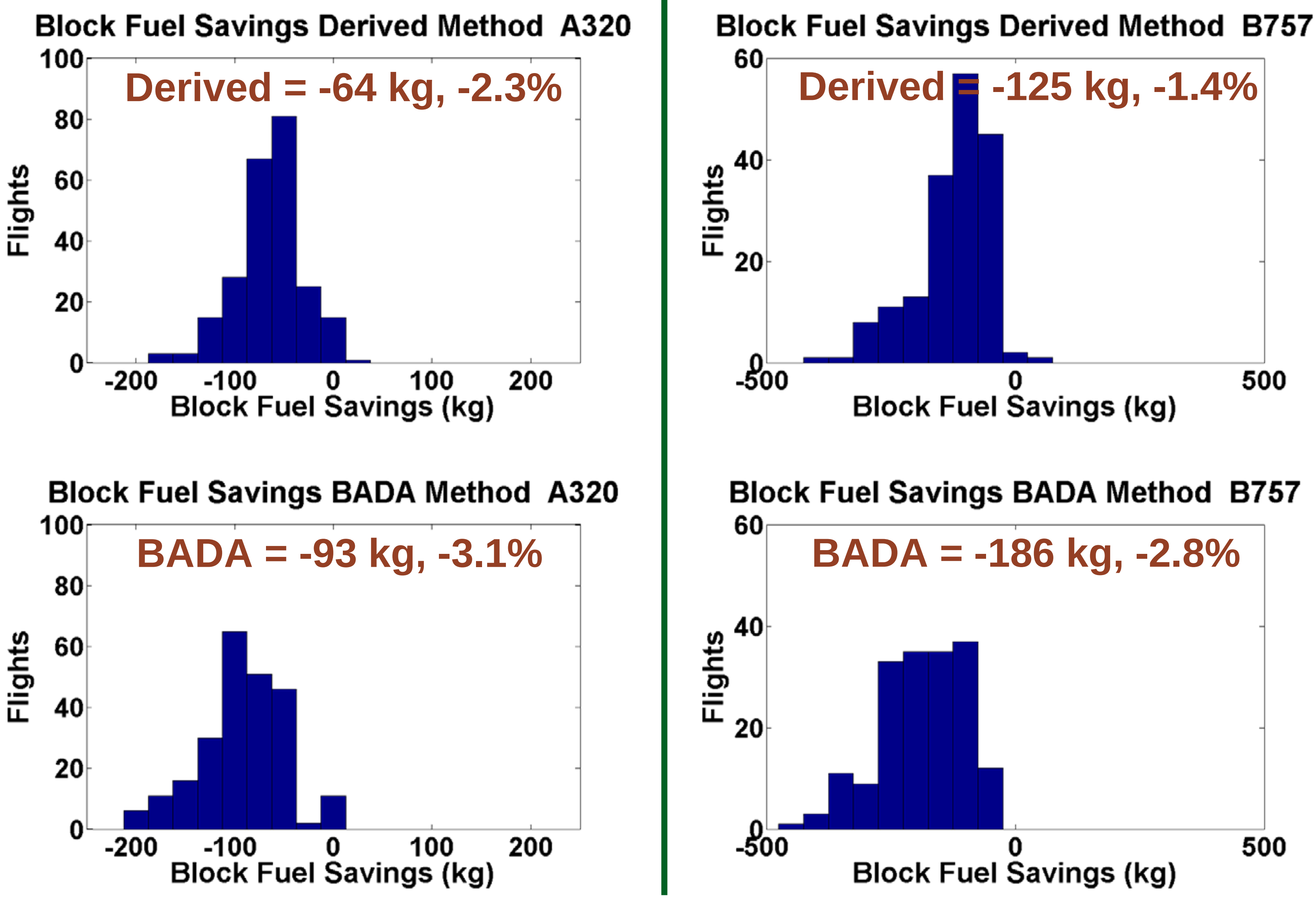








Example results for 1000 m increase in cruise altitude



Aviation Environmental Portfolio Management Tool (APMT)

(Ian Waitz, iaw@mit.edu, Maryalice Locke, maryalice.locke@faa.gov)

- Modular suite of tools to **better inform policy through rigorous environmental-economics analysis**
  - Noise, local air quality and climate
  - Interdependencies
  - More complete accounting of costs and benefits
- Includes
  - Partial equilibrium economic model of aviation markets
  - Environmental Design Space (EDS) for aircraft system-level trades
  - Aviation Environmental Design Tool (AEDT)
    - Global and local emissions (SAGE and EDMS)
    - Global and local noise (MAGENTA and INM)
  - Estimation of health and welfare impacts of noise, local air quality and climate change
- Development team
  - MIT, GaTech, MVA, Vital Link Policy Analysis, BB&C, Wyle Laboratories, U.S. DOT Volpe, Harvard School of Public Health, Univ. of North Carolina, MITRE, US FAA

APMT overview

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inputs

Policy scenarios
- Certification stringency
- Market-based measures
- Land-use controls
- Sound insulation

Market scenarios
- Demand
- Fuel prices
- Fleet

Environmental scenarios
- CO_2 growth

Technology and operational advances
- CNS/ATM, NGATS
- Long term technology forecasts

APMT

outputs

Cost-effectiveness
- $/kg NOx reduced
- $/# people removed from 65dB DNL
- $/kg PM reduced
- $/kg CO_2 reduced

Benefit-cost
- Net change in societal welfare ($)

Distributional analyses
- Who benefits, who pays
- Consumers
- Airports
- Airlines
- Manufacturers
- People impacted by noise and pollution
- Special groups
- Geographical regions

Global, Regional, Airport-local

APMT Prototype assessment and evaluation

- Comparison with AERO-MS
- Formal statistical analysis of uncertainties and propagation to system-level metrics
- Expert review of some components/modules
- Capability demonstrator problems
  - Fuel price changes (with and without EDS aircraft)
  - NOx technology stringency (with and without EDS aircraft)
  - Noise-phase out
  - **Reduced thrust take-offs** (consistent with sample problem defined by *CAEP-SG/20063-WP/30*)

Summary

- Critical needs exist in aviation and environment
- PARTNER has a strong team (~ 200 people)
- 3 years of operation
- Many research programs
  - Noise - emissions - interdependencies
- A growing forum for aviation and the environment

- ***Contact us about PARTNER***

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  - Bill Litant (Communications Director), wlitant@mit.edu

  - Web page: http://partner.aero