ICAO Symposium on Non-CO_2 Aviation Emissions

16 — 18 September 2024

Montréal, Canada

Peter de Bock

Program Director

US Department of Energy, Advanced Research Projects Agency – Energy (APRA-E)

Speaker

Session 3: Mitigating Non-CO_2 Aviation Emissions – What is possible

Part I – Innovative Technologies

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Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS)

Dr. Peter de Bock, Program Director

US Department of Energy

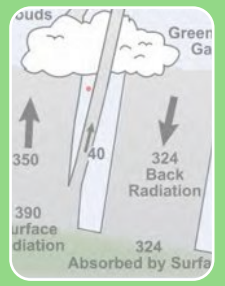
Advanced Research Projects Agency - Energy

ICAO

PRE-TRAILS, Can we predict with high certainty, if a contrail will be persistent ~5-10 hours later and form Aircraft

1. Contrail formation Does it lead to persistent Aircraft Induced Cirrus clouds?

PRE-TRAILS



2. Is the persistent contrail leading to additional radiative forcing?

3. Mitigation

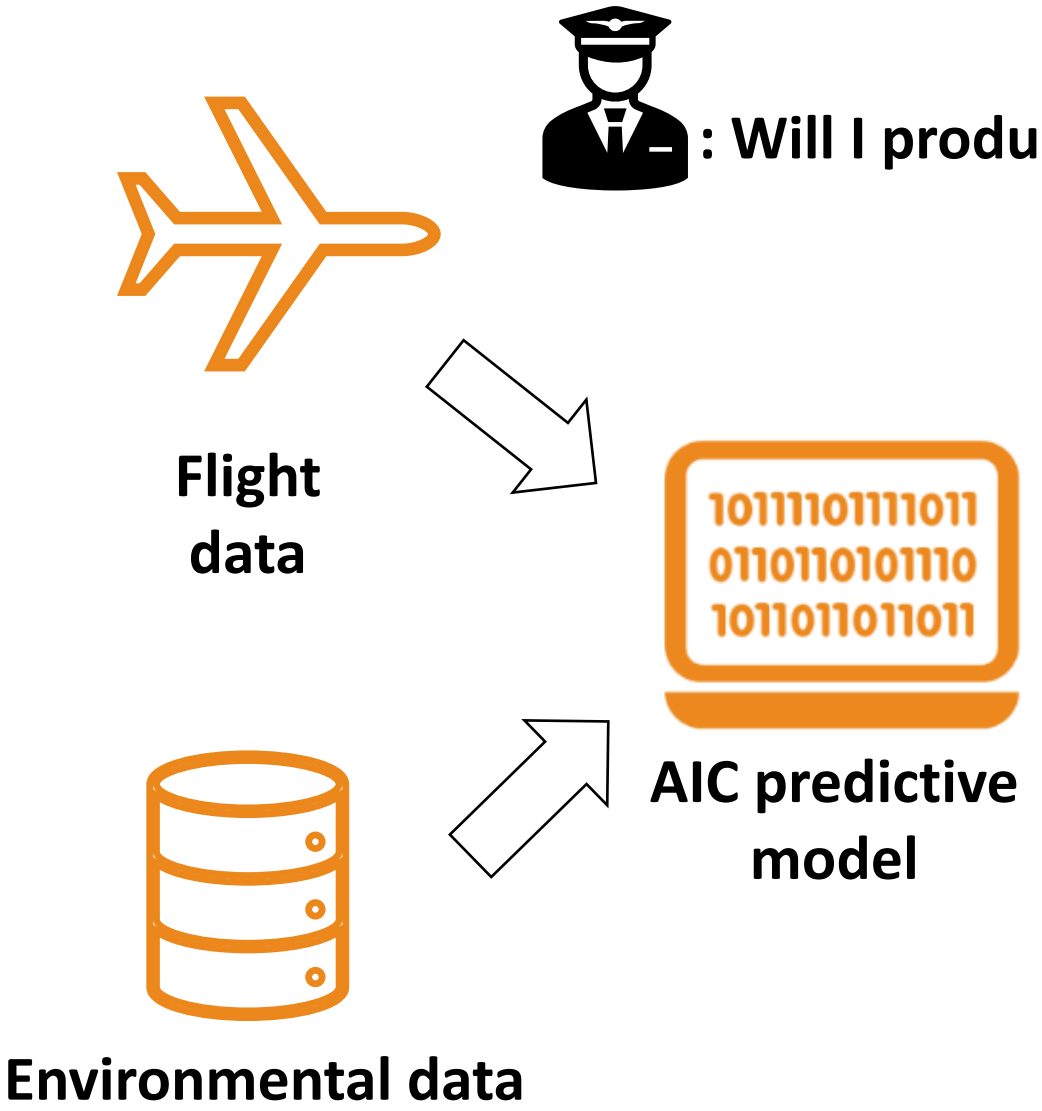
Boeing 787 at high altitude– big contrails but are they persistent or dissipate?

Source: Youtube - LouB747 - RARE Contrails | Early morning 787 Dreamliner

Will the flight produce Aircraft Induced Cirrus 5hrs later?

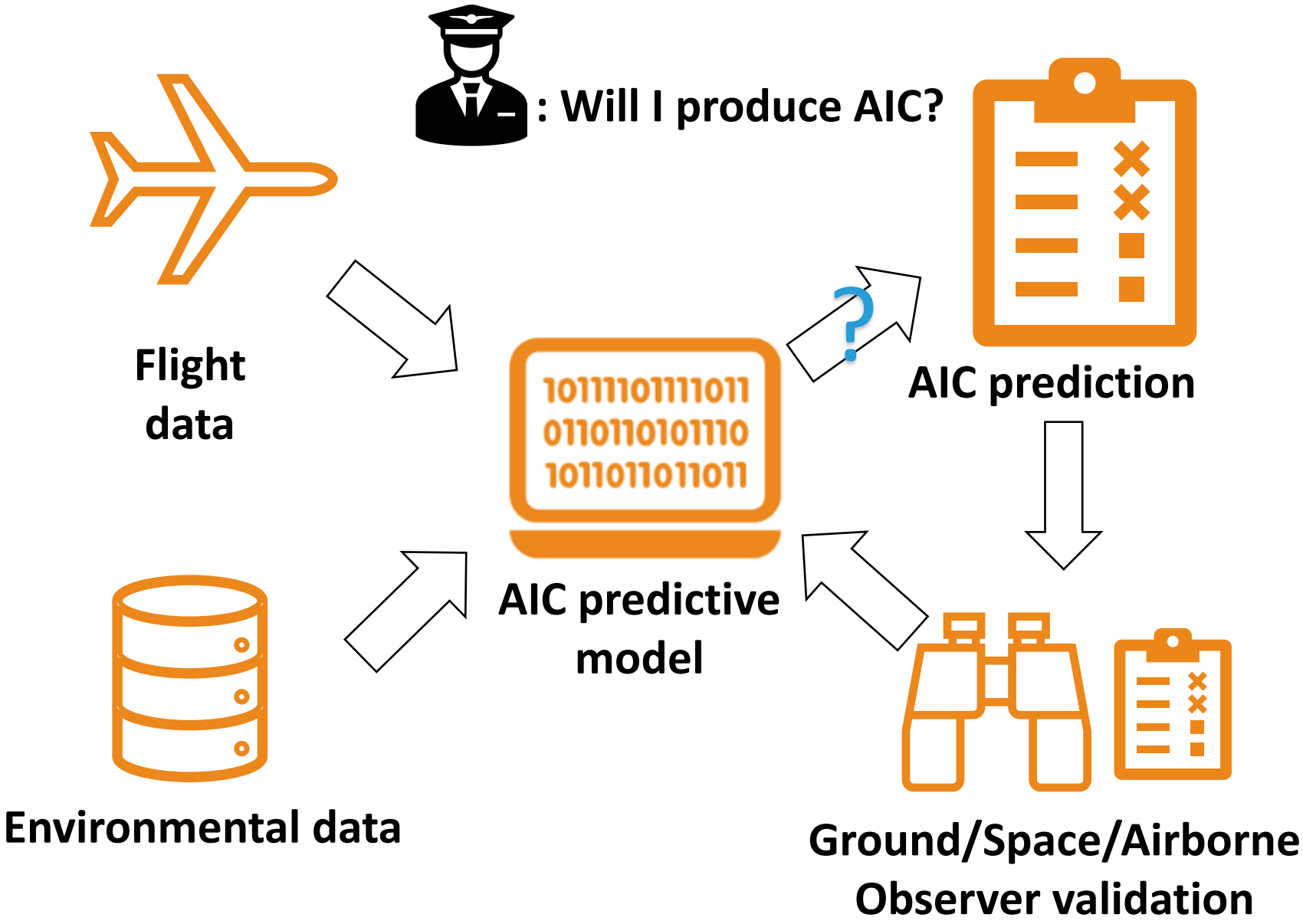
: Will I produce AIC?

Data Fusion: Flight, Radar, Weather, any… data

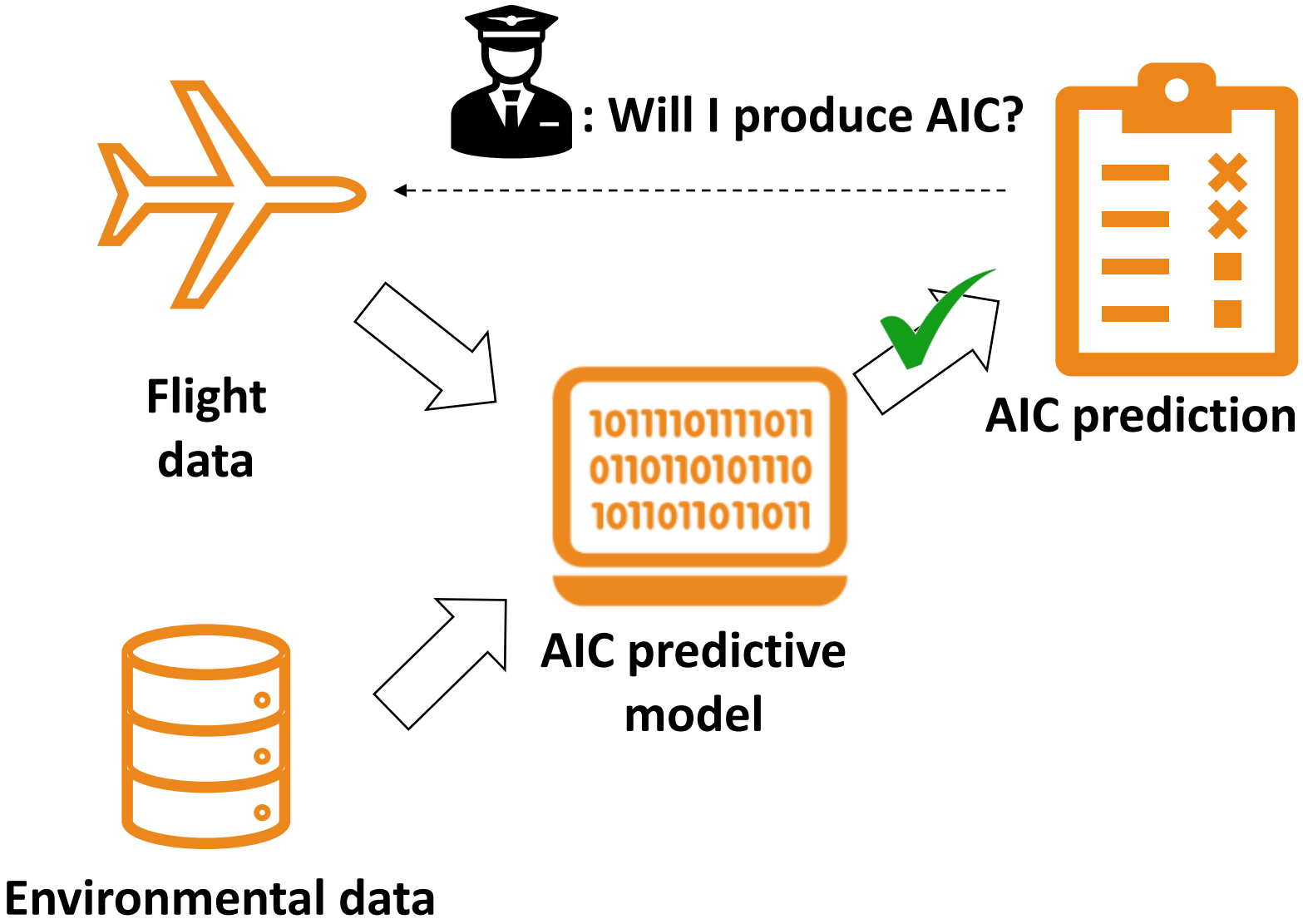


Use the Aircraft as a Sensor

Train model: Prediction and Observation/Validation



Achieve F_1-score > 0.8: accurate prediction



https://arpa-e.energy.gov/technologies/exploratory-topics/aviation-contrails

Contrail Information for Collaborative Operations (CINCO)

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Innovative Sensor Approach

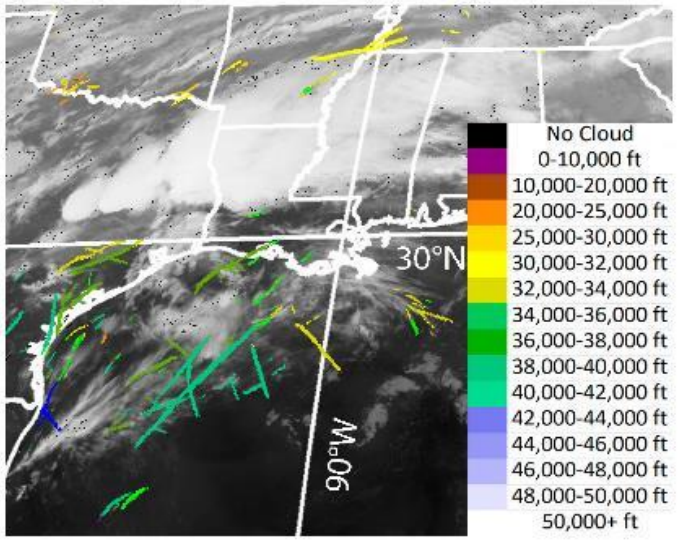
Develop water vapor sensors that meet upper tropospheric requirements, remaining cost effective in order to enter the commercial carrier market. Sensors should run unattended in extreme environments.

Observation method approach

Satellite-observation-based regression model with input from numerical weather prediction model(s) including ice supersaturated regions (ISSRs) and other variables as inputs. Ground based observations combined with ADS-B data.

Data Fusion Approach

Blend aircraft, satellite, and ground-based observations, deep learning and emerging observations from water vapor sensors



Hoffman et al., *Remote Sensing*, 2023, 15, 2854.
https://doi.org/10.3390/rs15112854

High level targets:

F1 score
Accuracy

Desired outcome &/or Partnering Opportunities:

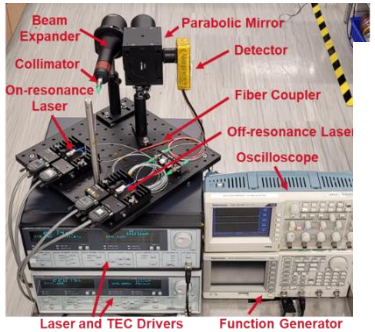
Boeing encourages collaboration with other companies as well!

RTX and Breakthrough

POC: miad.Yazdani@rtx.com

Innovative Sensor Approach

Seamless data integration and physics-informed real-time forecasting together with LIDAR-based stand-off humidify measurement



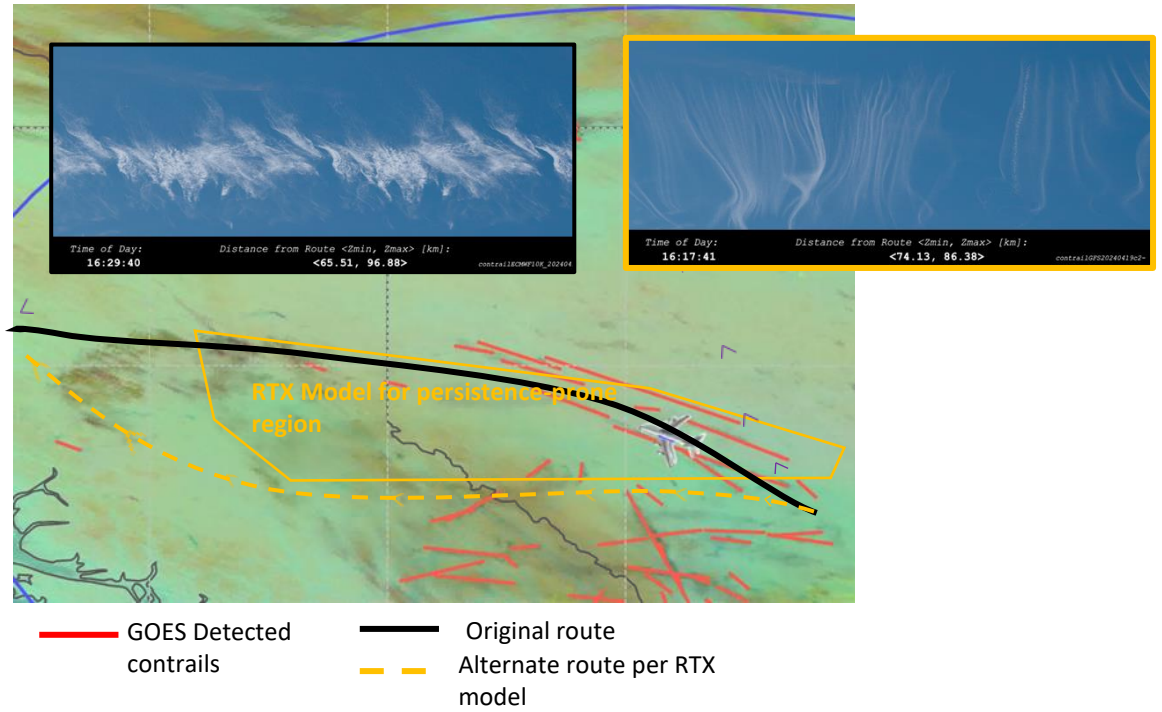
Collins OID Prototype (potential path to integration)

Observation method approach

GOES satellite observation for PIML validation and enhancement

Data Fusion Approach

On-board sensors fused with forecast data data for formation prediction and GFS and ECMWF forecast data to bound uncertainty of persistence prediction



High level targets:

F1 score: > 0.8

Accuracy: >80% confidence in persistence time and AIC optical depth over >6hr lifetime

Desired outcome &/or Partnering Opportunities:

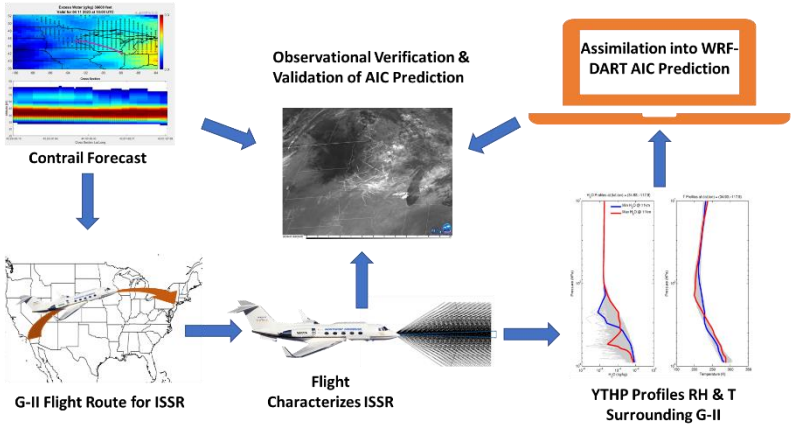
High-confidence persistence prediction and high-accuracy stand-off humidity measurement

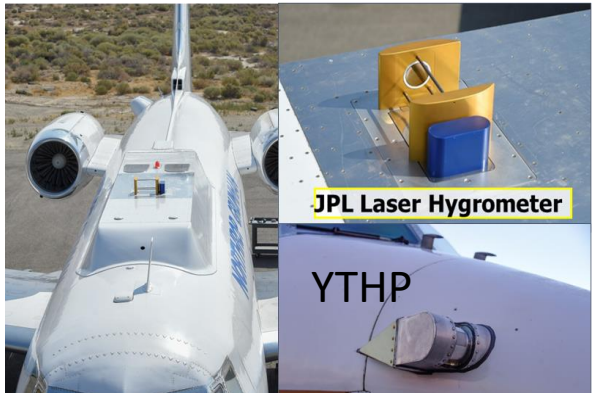
Contrail Avoidance System (CAS)

POC: william.deal@ngc.com

Innovative Sensor Approach

We use forward, vertically scanned microwave radiometer to measure a vertical temperature and humidity profile in front of the aircraft to provide vertical knowledge of contrail formation conditions





Observation method approach

Dedicated test flights will monitor temperature conditions. Human observers will be stationed along flight path to monitor AIC formation during multiple validation test flights

Data Fusion Approach

Predictive model will combine WRF data with aircraft engine signature and contrail formation model for initial flight planning. Fully designed system would update forecast with real-time sensor data to avoid contrail formation (post processing for Pre-Trails)

High level targets:

F1 score: >0.8

Accuracy: <1 Kelvin Temperature

<10 ppmv Water Vapor

Desired outcome &/or Partnering Opportunities:

- *Demonstration of YTHP and other sensors in AIC prediction and avoidance*
- *Partnering with FAA, airlines, NASA and sensor providers*

GE Aerospace

Engine-informed Prediction of aviation Induced Cirrus trails (EPIC-Trails)

POC: Saikat Ray Majumder
(raymajumder@ge.com)

Innovative (virtual) Sensor Approach

Develop Virtual Humidity Sensor (VHS):

- *use internal engine cycle simulations to examine sensor responses to humidity variations,*
- *use field data (engine data merged with humidity data) to build ML models to predict humidity*

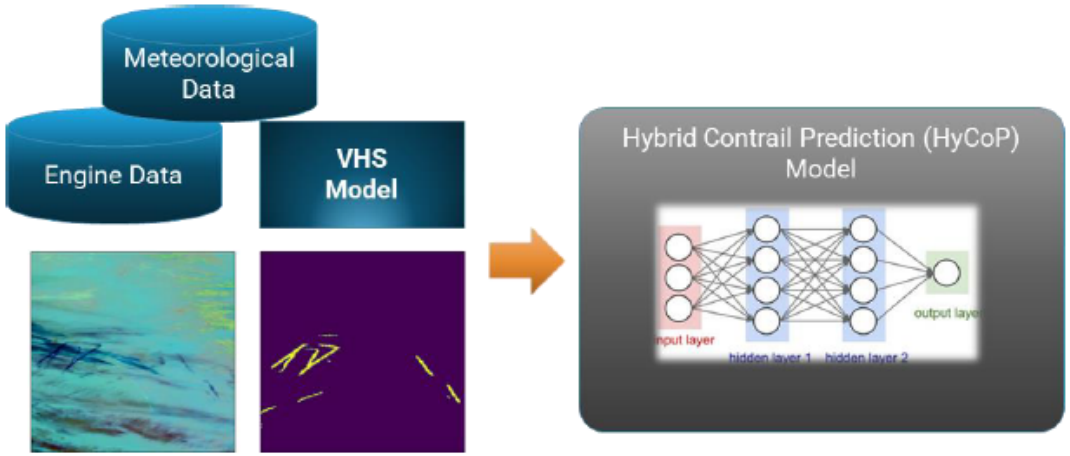
Observation method approach

Geostationary Satellite GOES-16 & GOES-18 + Meteorological data:

- *Contrail detection*
- *Contrail matching & tracking*
- *Flight attribution*

Data Fusion Approach

Contrail/plume physics models + multi-resolution geostationary satellite data + existing engine-specific sensor data with engine-specific NPSS => Hybrid Physics ML Model



High level targets:

- *At scale accurate observational validation of contrails*
- *F1-score >= 0.8 for up to 5-hours long-lived (LL) Aviation-Induced-Cirrus (LL-AIC)*

Desired outcome &/or Partnering Opportunities:

- *Facilitate development of engine-informed contrail, LL-AIC mitigation technology and commercialization of such systems.*
- *Enable scalable, low cost, robust virtual humidity and ISSR sensors.*
- *Enable novel contrail mitigation strategies that help reach our nation's net-zero goals.*

Physics & Machine Learning Based Contrail Prediction & Observation System

PI: Dr. David Bell (dbell@usra.edu), Universities Space Research Association (USRA)

Project Team

- **USRA Research Institute for Advanced Computer Science (RIACS)**
  40+ year history developing Artificial Intelligence (AI) solutions with NASA for Earth science, space science, space exploration & aeronautics
- **NASA's Ames Research Center – Aviation Systems Division**
  Decades of history developing Airspace Operations & Safety solutions including aviation contrail simulation
- **NASA's Langley Research Center – Climate Science Branch**
  Decades of history developing atmospheric science solutions including aviation contrail forecasts

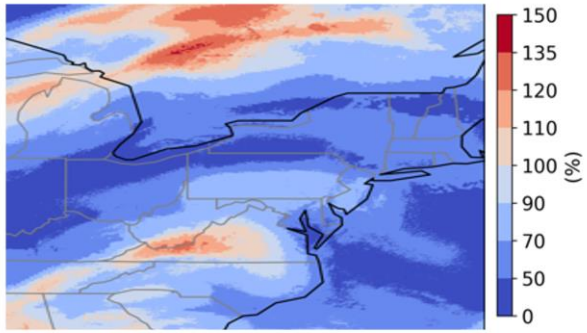
Project Team Contributions

- **USRA Research Institute for Advanced Computer Science (RIACS)**
  Developing integrated contrail prediction & observation services including development of advanced AI solutions
- **NASA's Ames Research Center – Aviation Systems Division**
  Providing access to the NASA Ames Contrail Simulation Model (ACSM)
  Providing access to the NASA Digital Information Platform (DIP)
- **NASA's Langley Research Center – Climate Science Branch**
  Developing environmental data nowcasts and forecasts of key atmospheric variables as inputs for contrail prediction and observation

Contrail Prediction

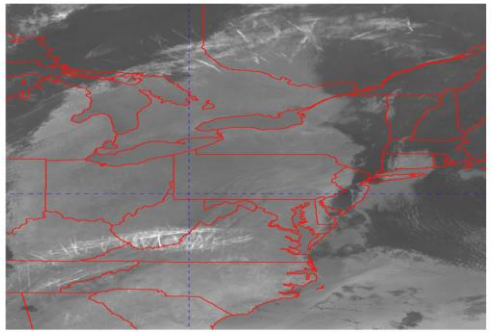
(Informed by Satellites)

Satellite-Based Forecasts



Max RHi above 30 Kft - 10/28/2019 18 UTC

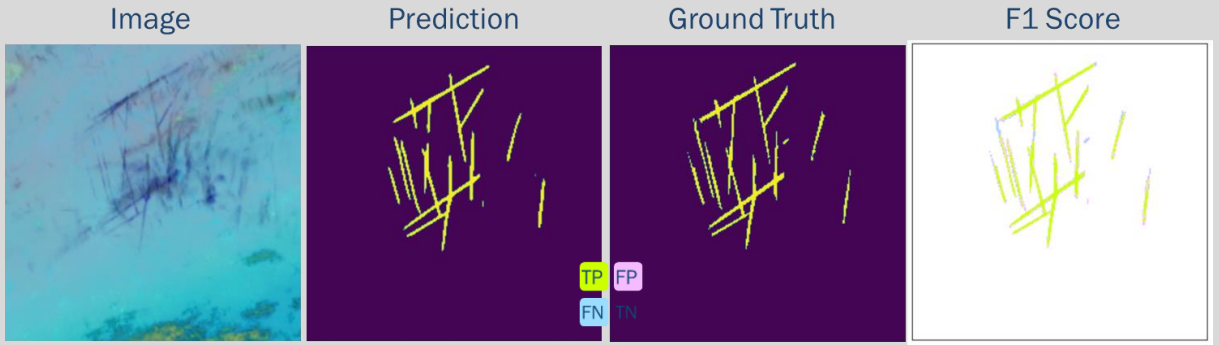
Persistent Contrails



GOES-16 Imagery - 10/28/2019 18 UTC

Contrail Observation

(Informed by Satellites)



CHANGING WHAT'S POSSIBLE

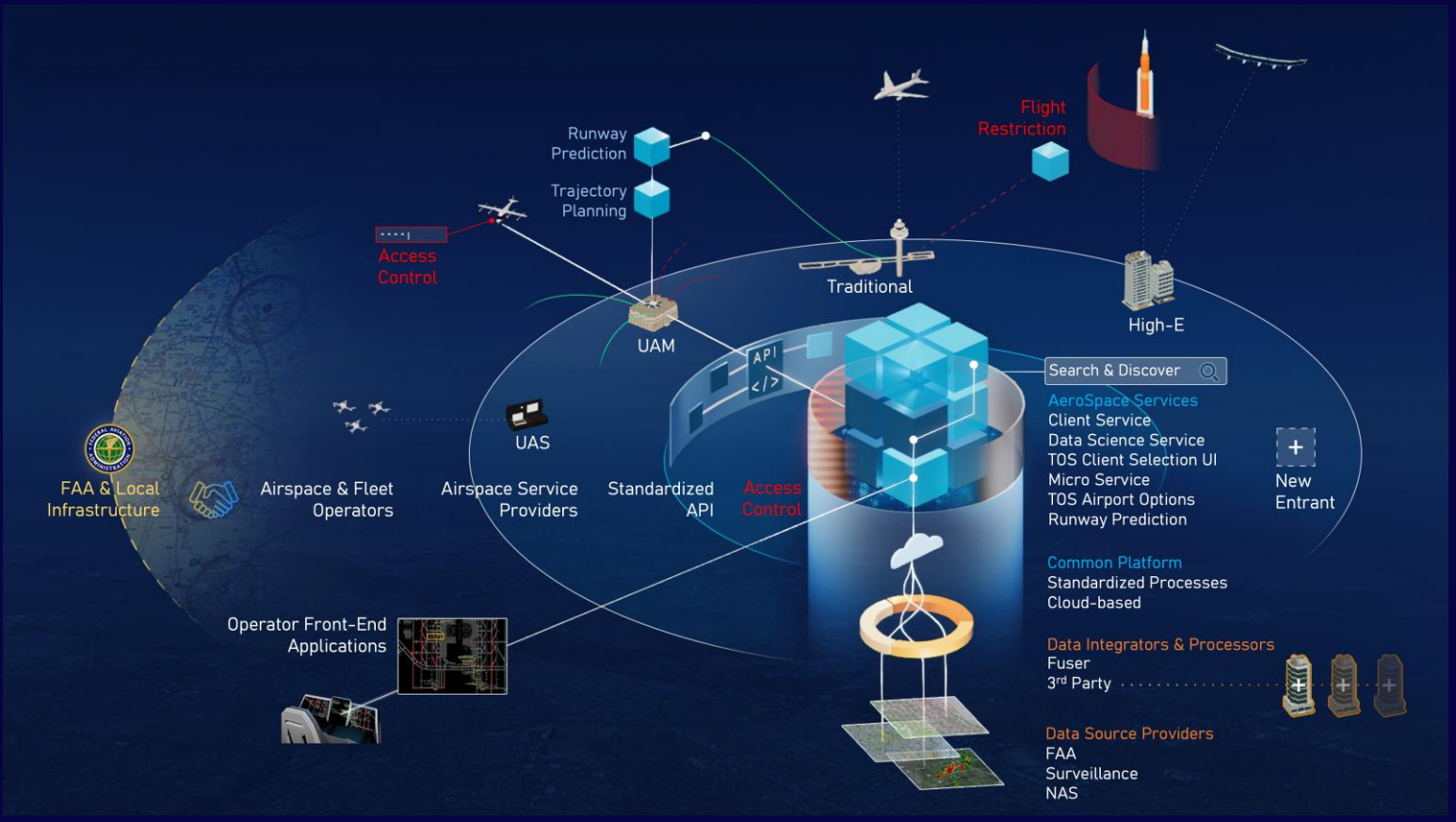
Mitigating climate impact of aviation contrails equivalent to CO2 emissions

Physics & Machine Learning Based Contrail Prediction & Observation System

Technology To Market (T2M) Path: Integration with the NASA Digital Information Platform (DIP)

Development and demonstration of a digital service-oriented framework to enable increasingly safe and sustainable operations for today and the future airspace system

Service-Oriented Cloud Based Infrastructure



Reference Platform
Informing platform interoperability requirements and best practices to enable innovative ecosystems

Predictive Services with ML Capabilities
Building reusable data integration services and AI/ML based predictive services for safe and sustainable operations.

SFNP Operations Demos
Demonstrating sustainability benefits derived using DIP services in today's NAS

OPERATIONS AND INFRASTRUCTURE

NASA

FEDERAL AVIATION ADMINISTRATION

jetBlue

DELTA

American

Southwest

UNITED

Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS)

Time of program: 2024Q2 – 2025Q4

- Novel sensors of unprecedented accuracy for troposphere measuring humidity and other gasses
- Community of performers working on understanding contrails and ISSR. Some open source/public
- Demonstration of F_1-score > 0.8 by 5 positive Aircraft Induced Cirrus cloud prediction
- Potential adjacent benefit: improved global warming and weather modeling & prediction

- Aircraft in program: RTX Challenger, NGC Hawker, Boeing EcoDemonstrator, Southwest Airlines
- PIs POC: https://arpa-e.energy.gov/technologies/exploratory-topics/aviation-contrails

Thank you: FAA, NASA, NOAA, ICAO

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Thank You

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