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FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Aircraft Engine Performance Modeling using FDR Archives

Yashovardhan S. Chati, Hamsa Balakrishnan

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Berkeley
UNIVERSITY OF CALIFORNIA

Massachusetts Institute of Technology

NSF

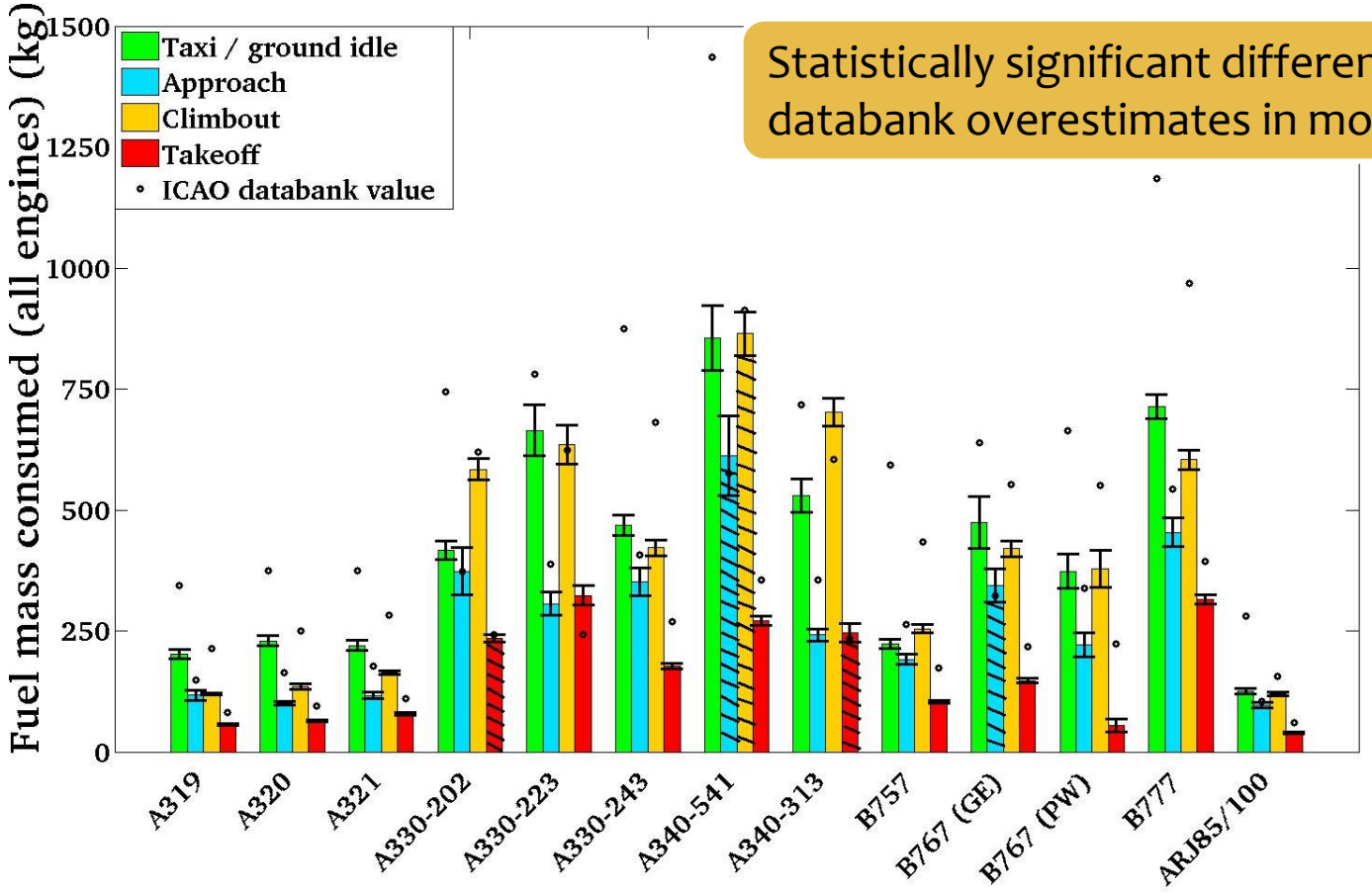
MICHIGAN

VANDERBILT UNIVERSITY

Motivation

* Aircraft emissions – significant source of air pollution, take place over a range of altitudes
* Total aviation traffic in 2050: 6.5 – 15.5 times that in 1990; total fuel burn: 1.5 - 9.5 times; CO_2 emissions 1.6 – 10 times ***(IPCC 1999)***
* Emissions depend on engine characteristics (like fuel burn) – important to estimate them accurately to come up with accurate emission inventories
* Current models use the ICAO databank to estimate fuel burn and emissions
* **Want to develop engine fuel burn and emissions models (with variability estimates) based on operational data**

Comparison of ICAO Databank and Operational Values



Statistically significant difference; ICAO databank overestimates in most cases

Chati, Y.S., and Balakrishnan, H., "*Analysis of Aircraft Fuel Burn and Emissions in the Landing and Take Off Cycle using Operational Data*," ICRAT 2014.

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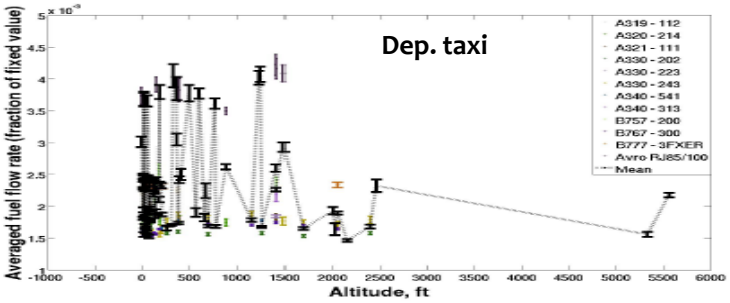
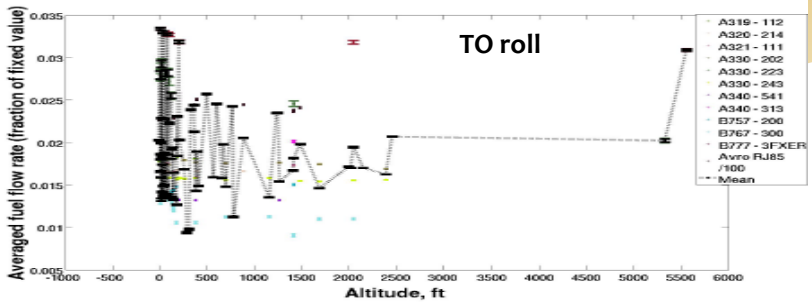
Trends in Fuel Flow Rates



a)



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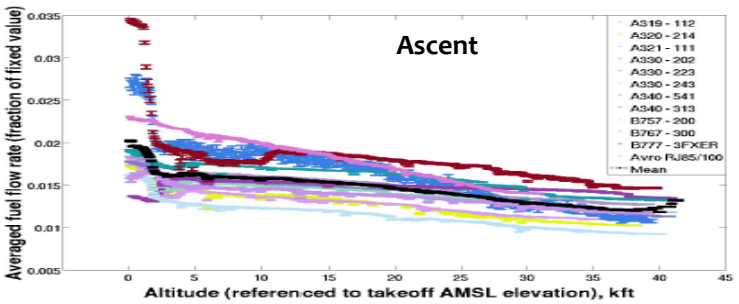

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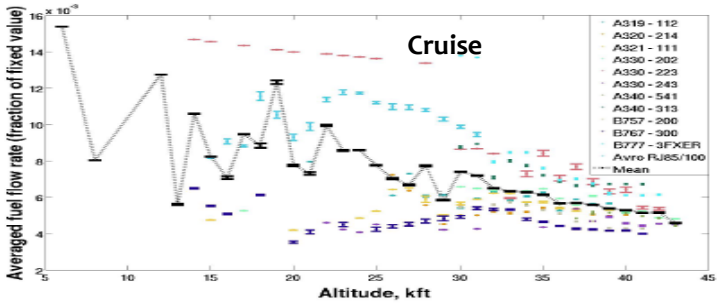
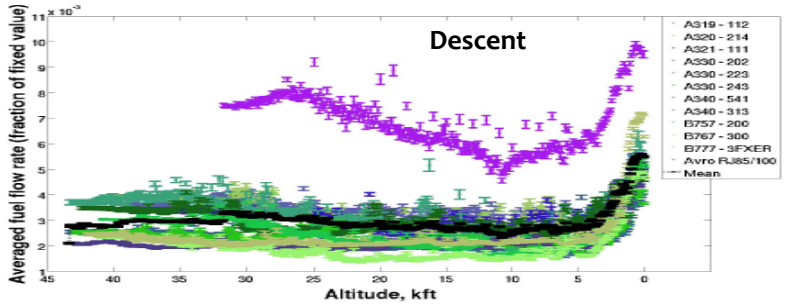
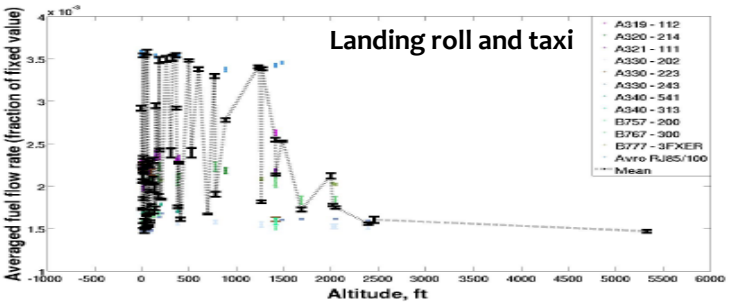


d)



e)



f)

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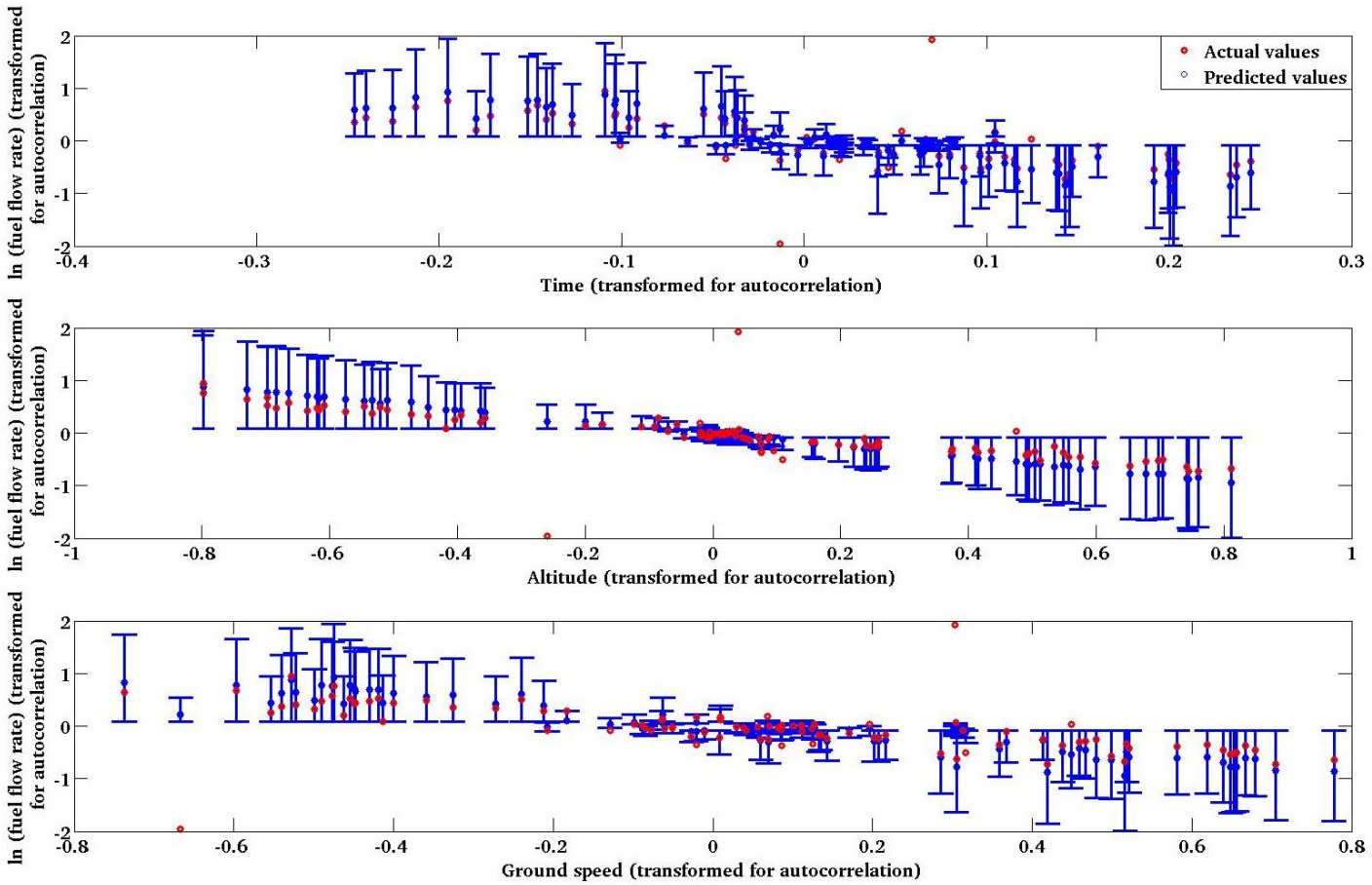
Regression

* Can we use regression to predict engine fuel flow rate from trajectory variables?
* Example study: aircraft - Airbus A320-214, 169 flights, ascent phase
* Independent/predictor variables:
  * Time since beginning of flight record (normalized by total flight time)
  * Pressure altitude (ref. TO airport AMSL elevation) (normalized by ceiling)
  * Ground speed (normalized by flight cruise speed)
  * Great circle flight range (normalized by aircraft range)
* Dependent/response variable:
  * Fuel flow rate (normalized by ICAO measured TO fuel flow rate)

Regression Model

ln (fuel flow rate) = (-0.2146, SE = 0.0100) + (-0.2187, SE = 0.0336) x time + (-1.2546, SE = 0.0119) x altitude + (0.2904, SE = 0.0134) x ground speed



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Summary

* FDR derived operational data being used to model fuel burn and emissions (with confidence intervals) => develop operationally accurate inventories
* Ongoing work: regression based models for predicting engine fuel flow rate and emissions from a handful of trajectory variables in all flight phases for all aircraft types
* Challenges:
  - Data not available for all aircraft types in operation (e.g. B737)
  - Tail numbers not known
  - Aircraft and engine age and maintenance information not known

THANK YOU