Development of Flight Inefficiency Metrics for Environmental Performance Assessment of ATM

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Motivation

- ATM has important role in reducing environmental impacts of aviation: ***ATM affects ALL aircraft***
- Increasing efforts to quantify ATM's current impact
- Concept of "Flight Inefficiency" commonly used
- This study designed to complement these activities

Outline

1. Identify sources of Flight Inefficiency
2. Describe Flight Inefficiency metric options
3. Analyse data with key Flight Inefficiency metrics
4. Discuss insights enabled through this approach

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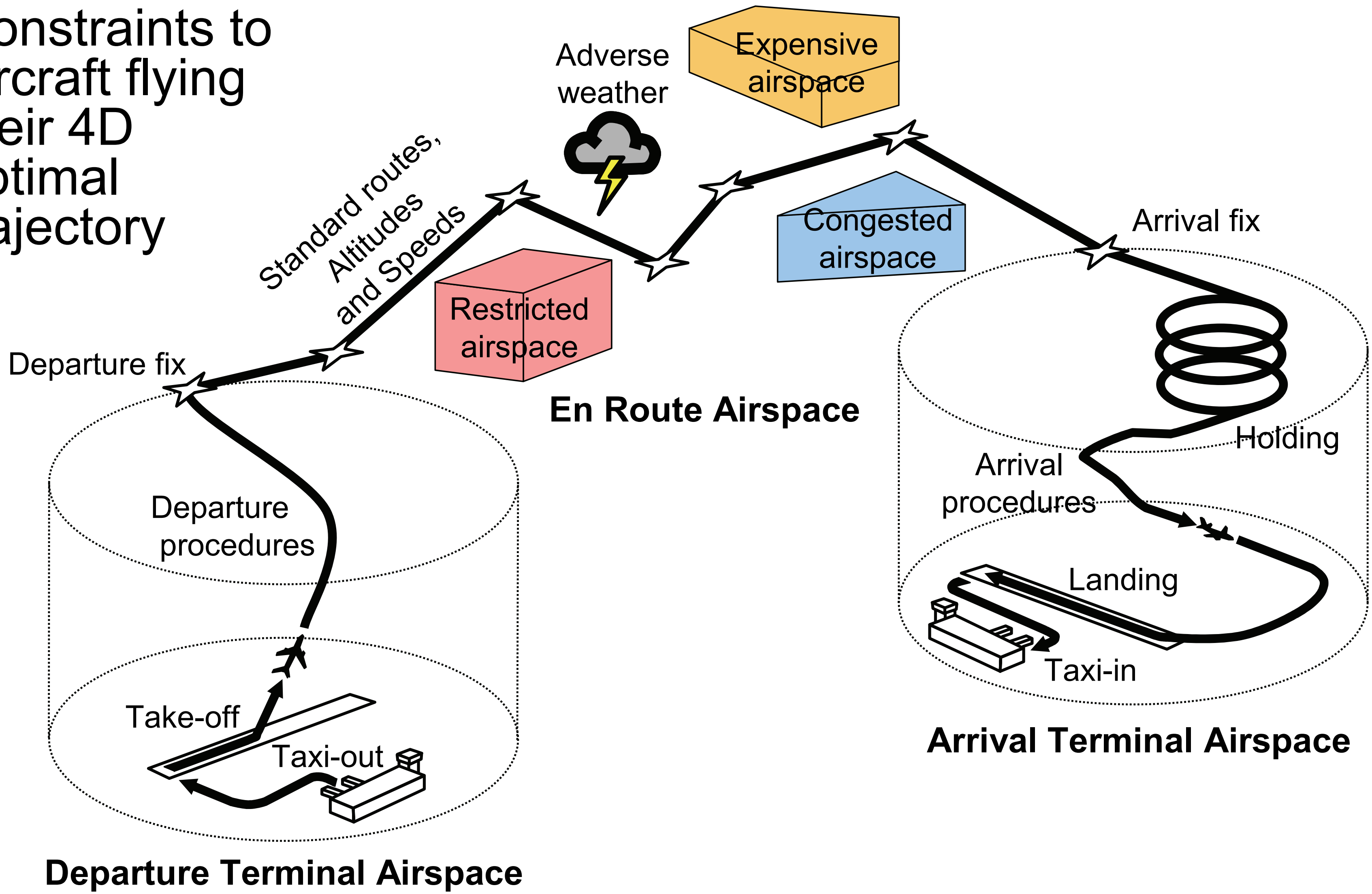
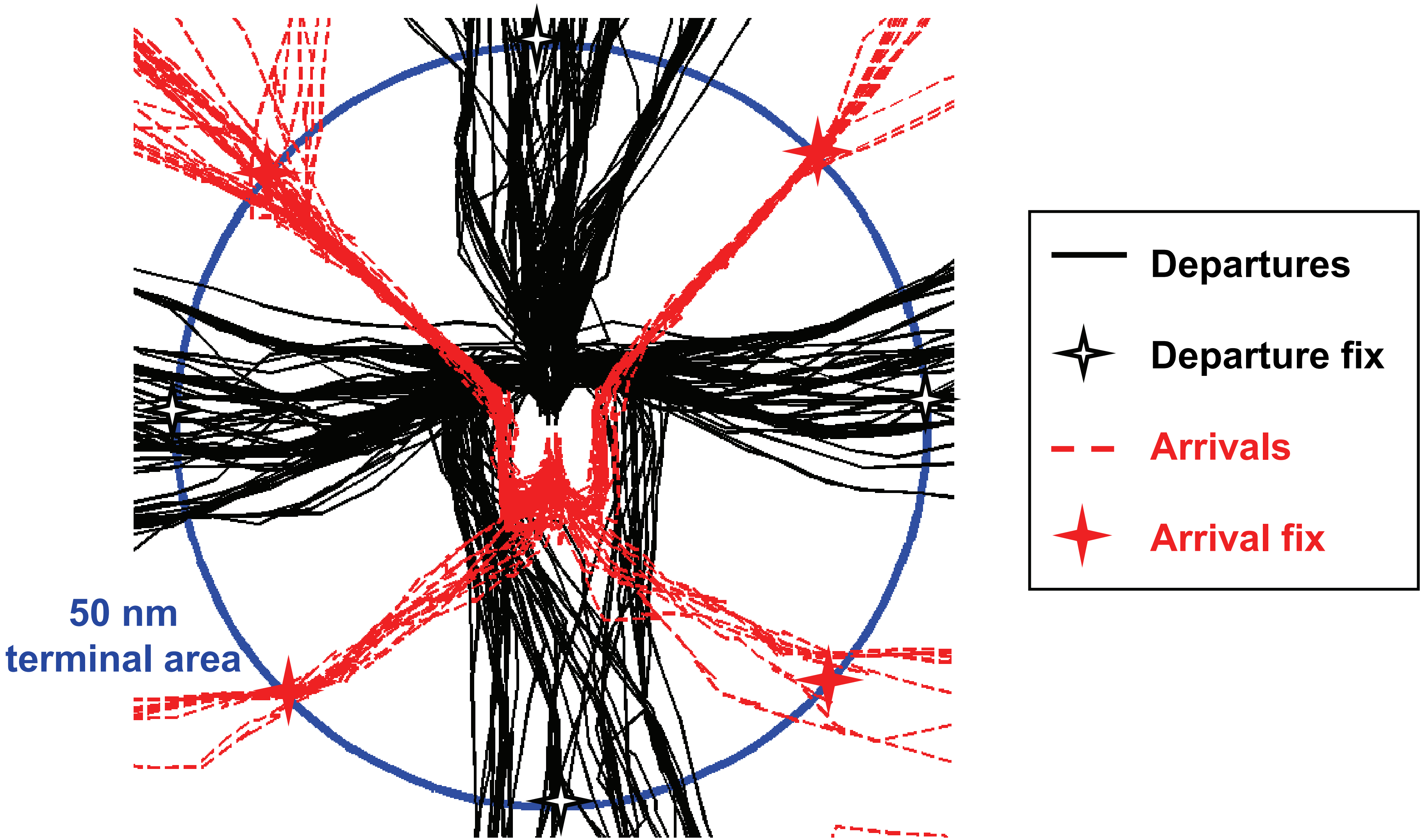
Flight Inefficiency Sources

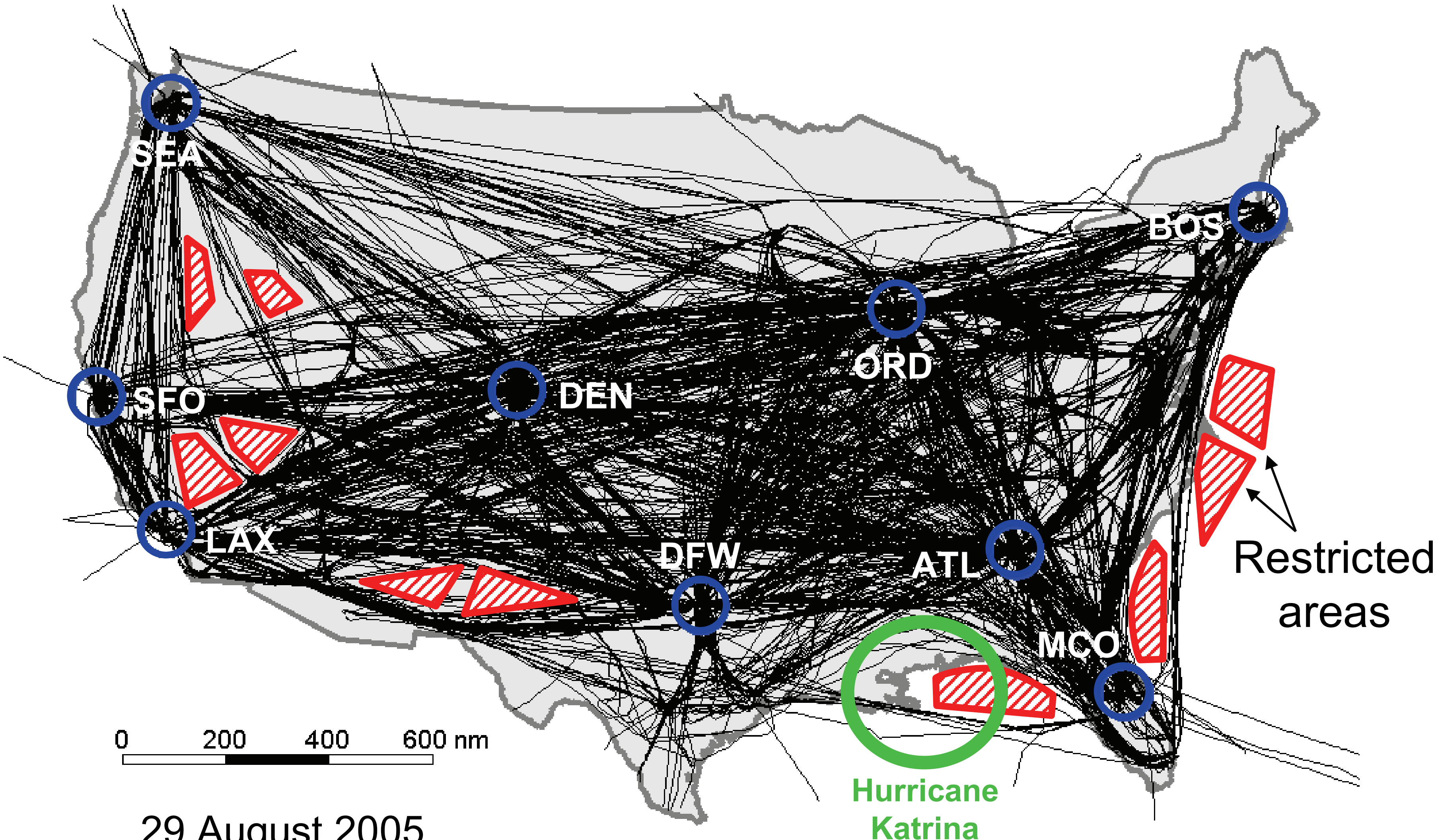
- Constraints to aircraft flying their 4D optimal trajectory



Sample Inefficiencies: Terminal Airspace Standard Procedures



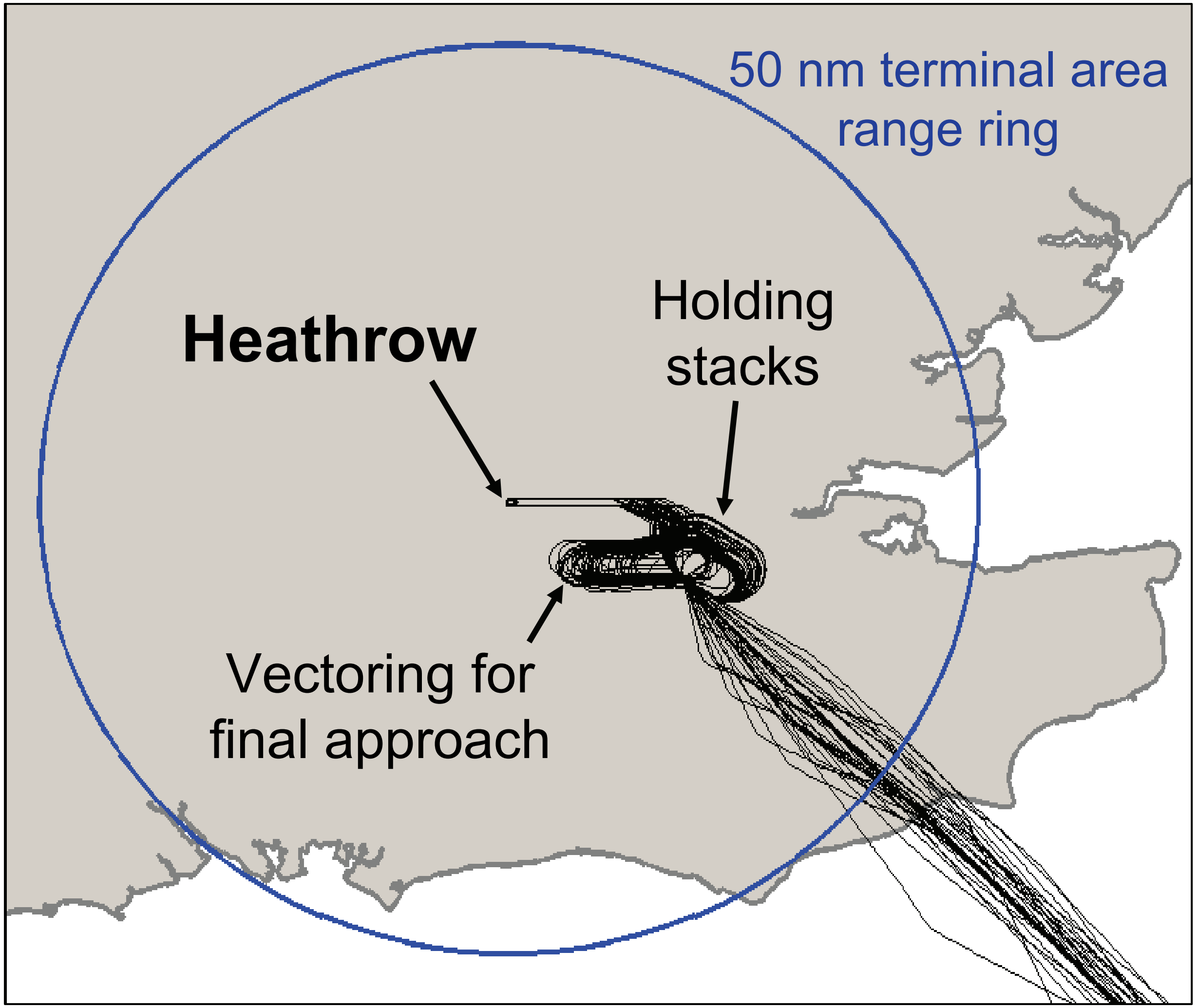
Sample Inefficiencies: En Route Airspace



29 August 2005

Sample Inefficiencies: Arrival Terminal Airspace

- Holding absorbs delay & maximises runway capacity
- Vectoring for spacing and sequencing on final approach



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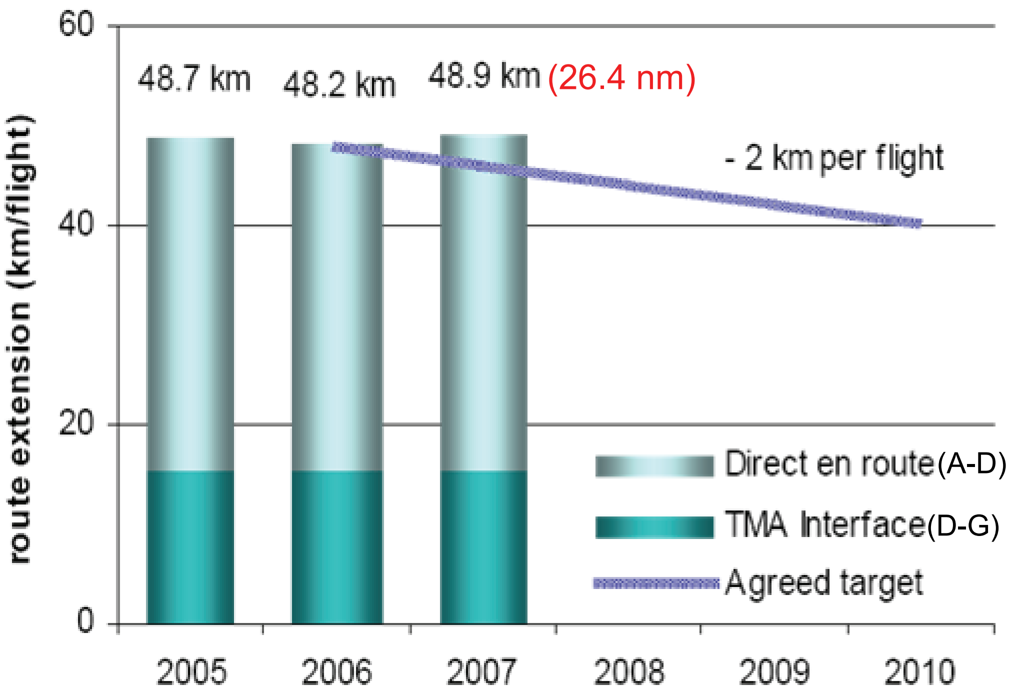
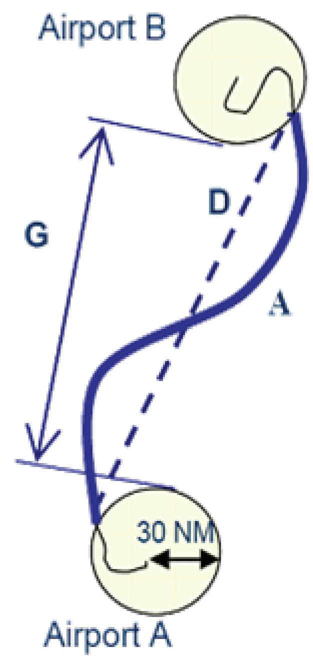
Flight Inefficiency Metrics

- Concept commonly used as ATM performance indicator
  - Quantify difference between “ideal” and “actual” performance
- Focus has been on average route extension over great circle

Flight inefficiency metric:

$$\frac{Actual - Optimal}{Optimal} \times 100\%$$





Source:

Flight Inefficiency Metrics

- Route extension is simple and compatible with current surveillance systems, but neglects effects in other flight dimensions
- Fuel-based metrics (e.g. excess fuel burn) capture these effects and directly relate to emissions, but…
- …are more challenging due to need to determine optimum fuel burn and access to more aircraft info

Metrics in Different Flight Dimensions

Dimension	Sample "actual"	Sample "optimal"	Advantages	Dis-advantages
Lateral	Flown ground distance	Great circle distance	Simple	No info from other flight dimensions
Vertical or Speed	Average cruise altitude or speed	Optimal en route altitude or speed	Captures vertical or speed elements	More complex & No info from other flight dimensions
Fuel	Average block fuel	Optimal block fuel	Proportional to emissions	More complex

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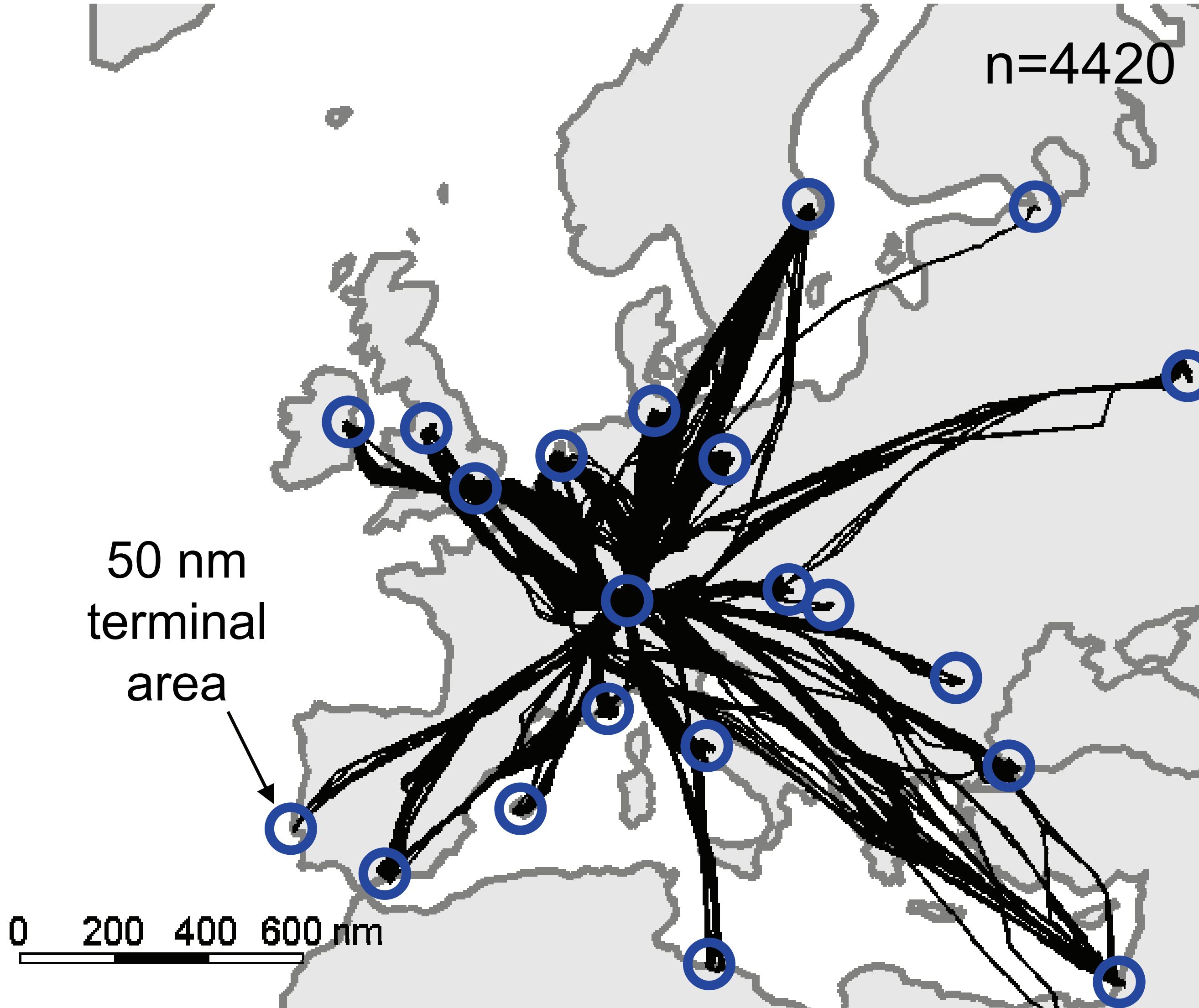
European Flight Data Summary

- Flight data from European airline A320 family during early 2008
- Lateral & fuel-based analysis



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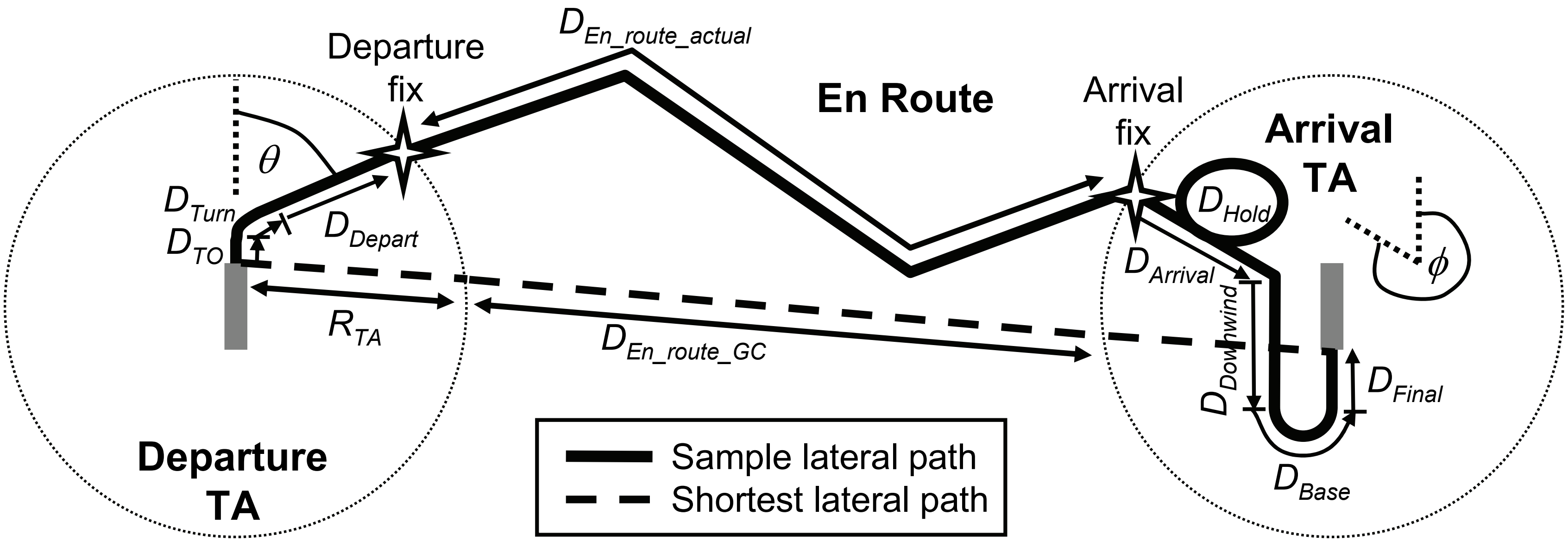
Lateral Analysis: Route Extension



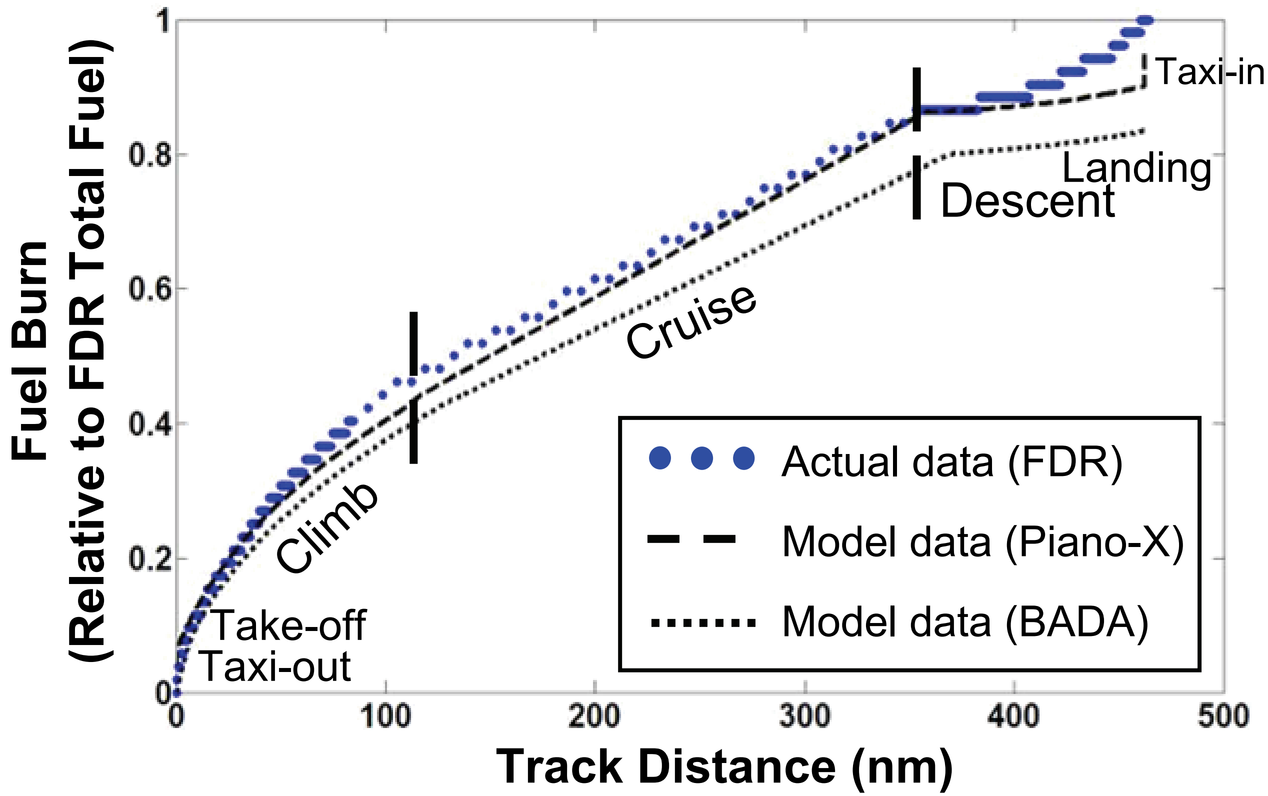
$$GTE_{DepTA} = (D_{TO} + D_{Turn} + D_{Depart}) - R_{TA}$$

$$GTE_{En\_route} = D_{En\_route\_actual} - D_{En\_route\_GC}$$

$$GTE_{ArrTA} = (D_{Arrival} + D_{Hold} + D_{Downwind} + D_{Base} + D_{Final}) - R_{TA}$$

Fuel Analysis: Aircraft Performance Modelling

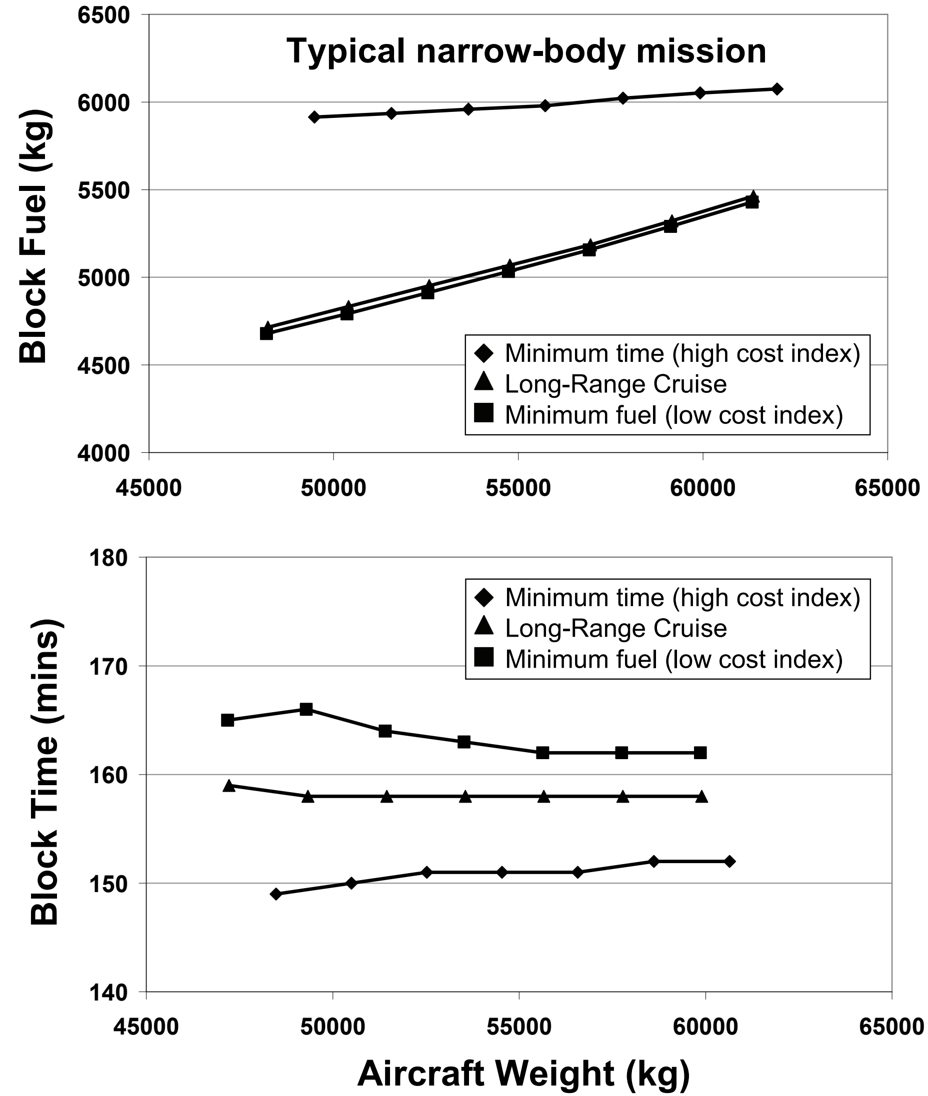
- FDR data used to validate candidate aircraft performance models to determine optimum fuel burn



- Piano-X can be better tailored to observed operations

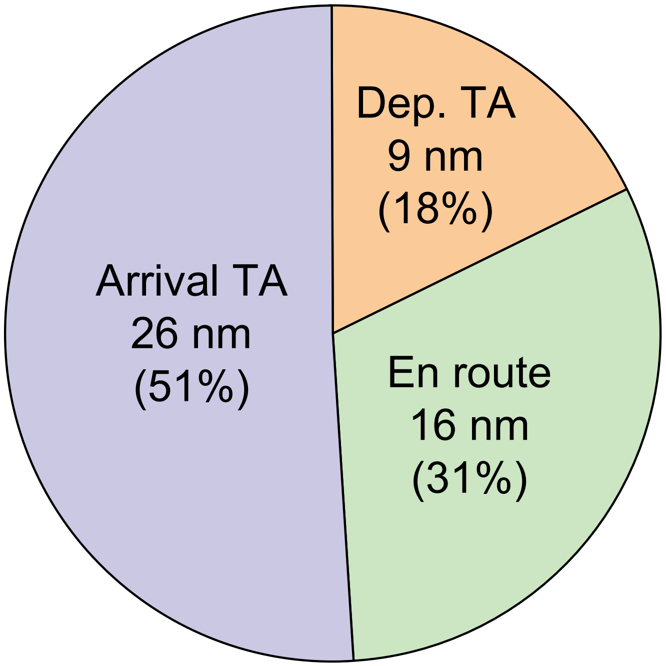
Fuel Analysis: Optimum Fuel Burn Challenges

- Function of many variables:
  - Aircraft type
  - Weight
  - Route length
  - Winds
  - Centre of gravity
  - Temperature
  - Operator "cost index", i.e. ratio of time-related costs to fuel-related costs



Lateral & Fuel Inefficiency Comparison

Lateral analysis
Average TGTE: 51 nm/13%



n=1794, A320 European flights only.
Average great circle distance 403 nm

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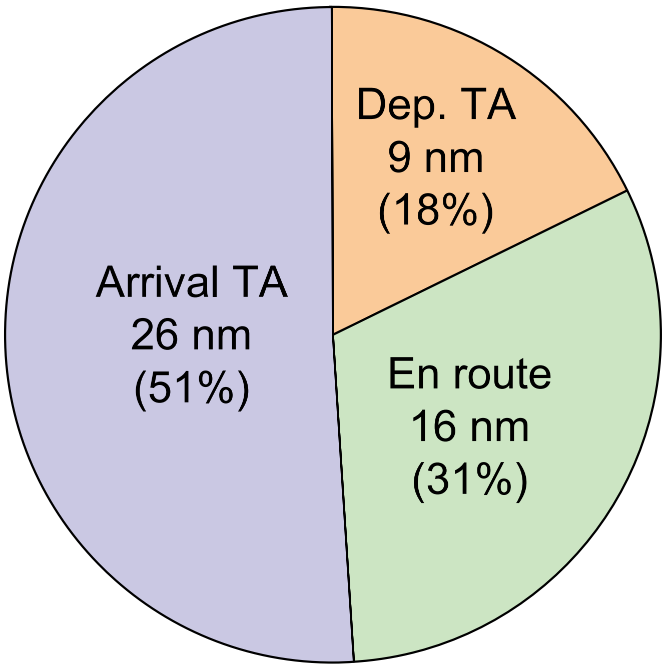
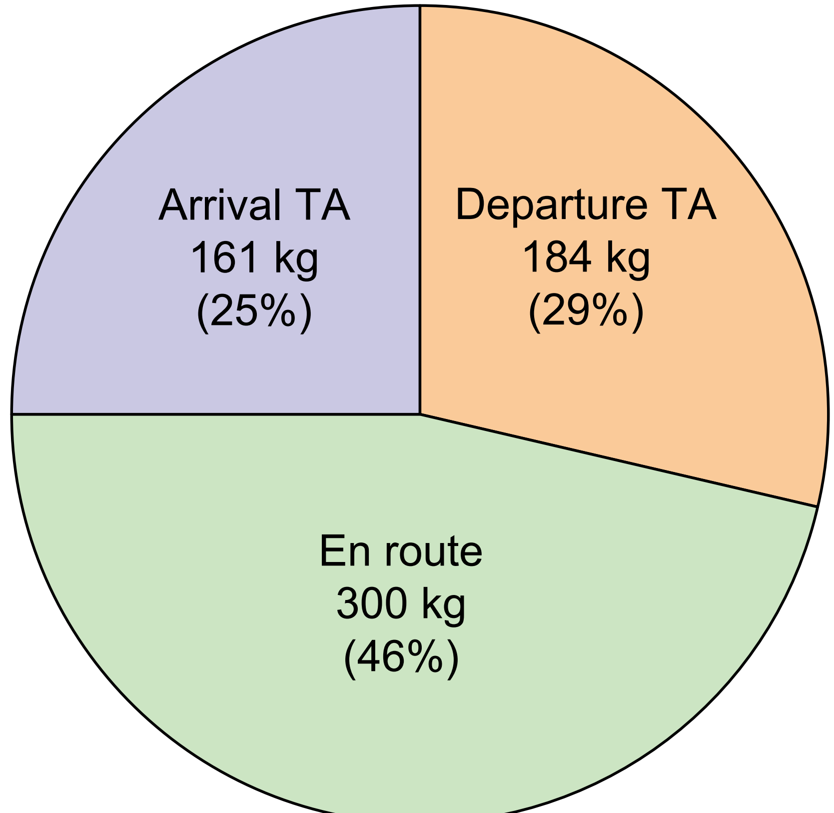


Fuel analysis
Average excess fuel burn*: 645 kg/23%



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*Relative to minimum theoretical fuel burn

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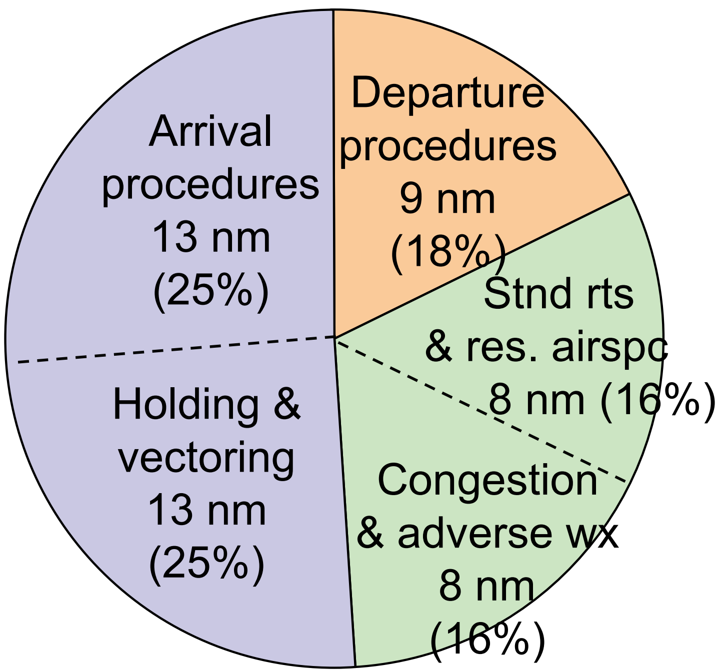

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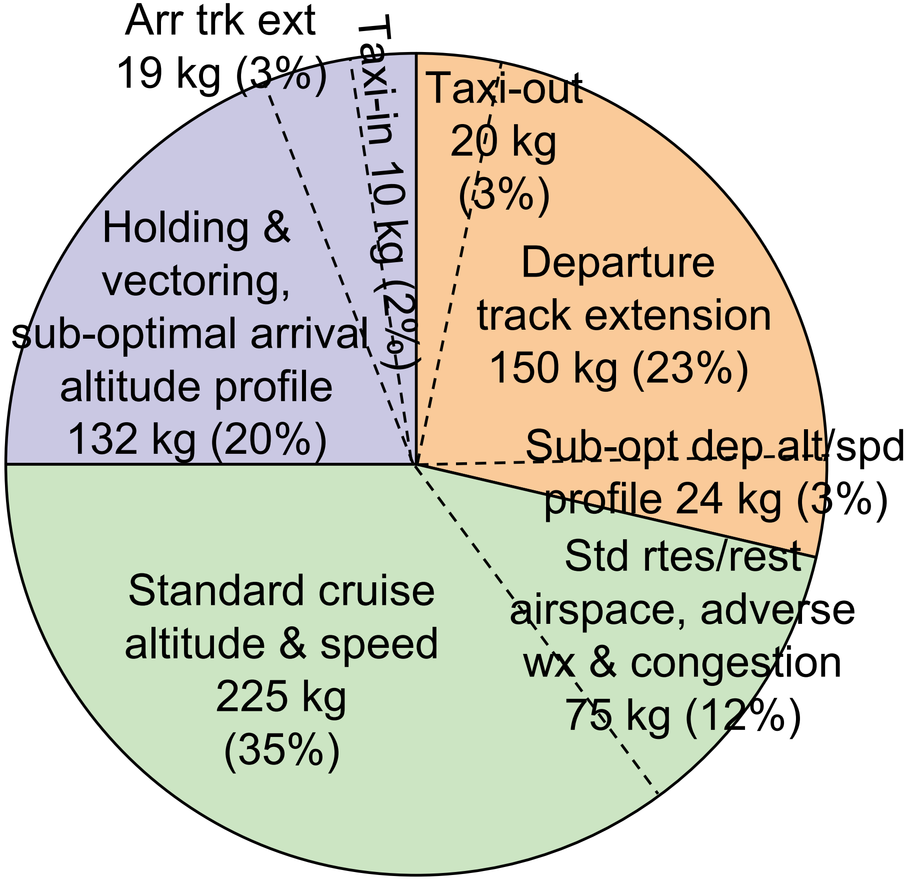

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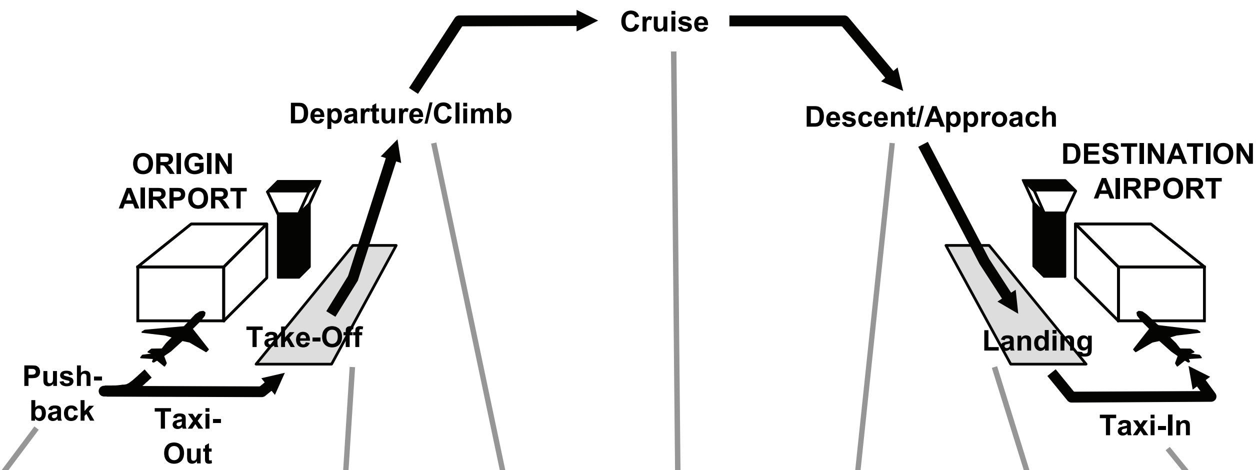
ATM Evolution Implications

- Helps prioritize ATM evolution concepts and tech-nologies

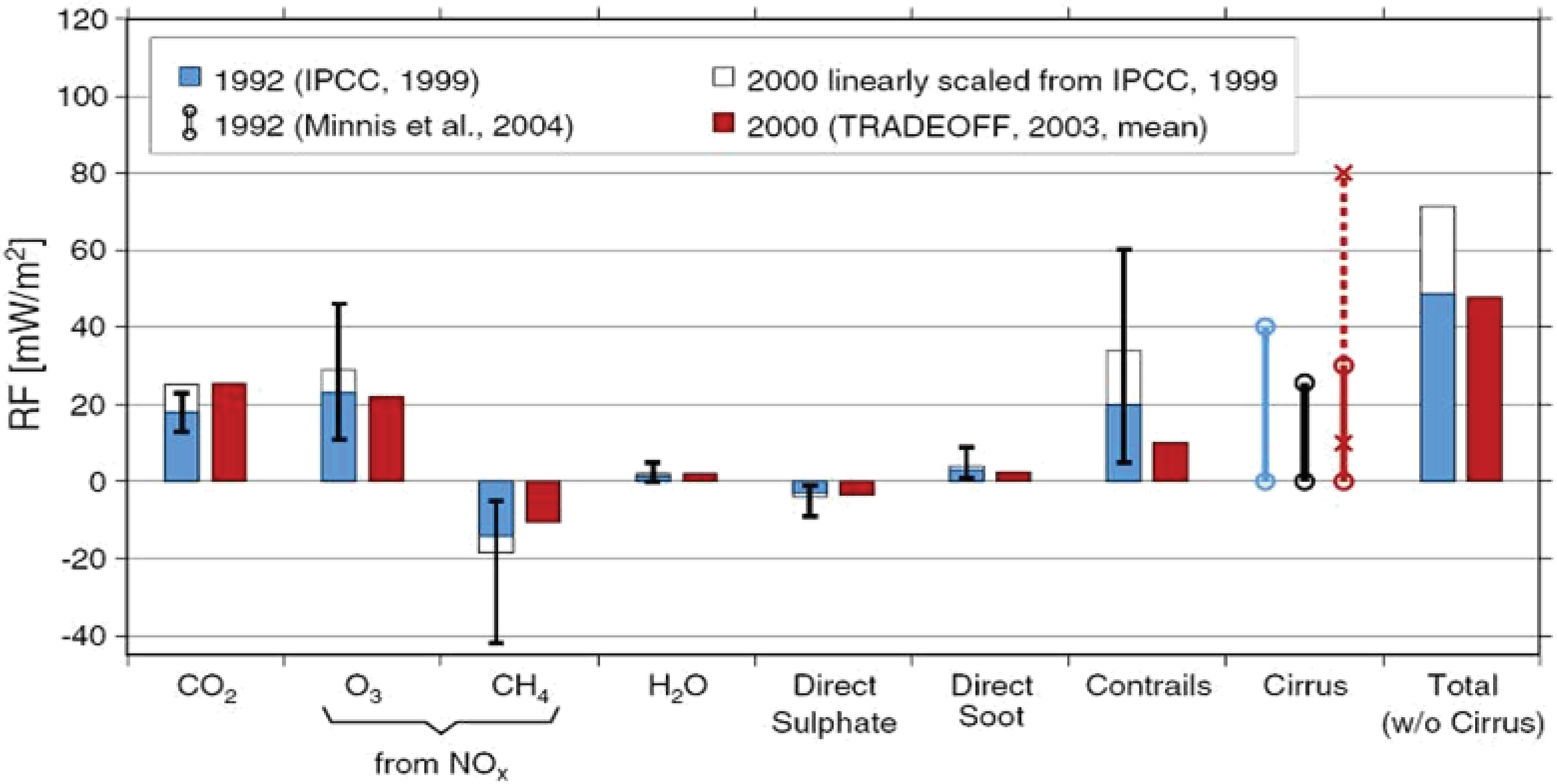


FUTURE OPERATIONAL CONCEPTS FOR IMPROVED LATERAL/FUEL-BASED ENVIRONMENTAL PERFORMANCE	• Optimised push-back time and sequence	• Single-engine optimal taxi routing with no holding	• Engine power optimisation	• Optimised lateral, vertical, speed profiles • Strategic de-confliction			• Displaced thresholds • Steeper glideslope angles • Runway allocation for optimal taxi routing	• Single-engine optimal taxi routing with no holding
				• e.g. Continuous Climb Departures	• e.g. wind-optimised ground track at optimal cruise altitude & speed	• e.g. full Continuous Descent Approach		
ENABLING TECHNOLOGIES	• Push-back optimisation algorithms (G) • Datalink (G-A)	• Taxi optimisation algorithms (G) • Datalink (G-A)	• Take-off power manage-ment (A)	• 4D trajectory management algorithms (G,A) • Advanced Communication: Datalink (G-A) • Advanced Navigation: P-RNAV (A) • Advanced Surveillance: ADS-B (G,A)			• Runway allocation algorithms (G) • Datalink (G-A) • P-RNAV (A)	• Taxi optimisation algorithms (G) • Datalink (G-A)
OTHER ENABLERS	• Modified standard operating procedures • CDM/CEM			• Airspace re-design • Modified standard operating procedures • CDM/CEM			• Modified standard operating procedures • CDM/CEM	

Key: (G) = Ground, (A) = Aircraft, (G-A) = Ground to Aircraft, ADS-B = Automatic Dependent Surveillance-Broadcast, CDM = Collaborative Decision Making, CEM = Collaborative Environment Management, P-RNAV = Precision Area Navigation,

Environmental Implications

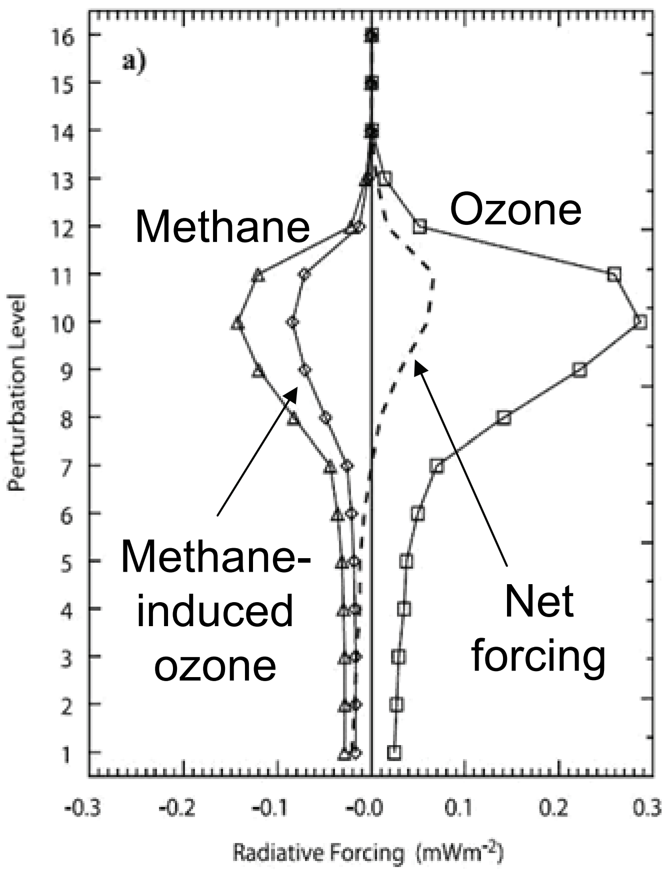
- Findings affect aviation environmental impact predictions
  - IPCC scaling factors of **1.15 on fuel burn, falling to 1.05 in 2015** to account for ATM inefficiencies and their improvement



Source: Sausen et al., 2005, "Aviation Radiative Forcing in 2000: An Update on IPCC", Meteorol. Z., 14 (4), pp. 555-561

Environmental Implications

- Findings affect aviation environmental impact predictions
  - Location of "non-CO_2" emissions affects climate response



- Radiative forcings due to changes in ozone, methane & methane-induced ozone as a function of the altitude of a 5% NO_x perturbation

- Much more work needs to be done: **Climate scientists and ATM researchers must collaborate**

Source: Köhler et al., 2008, "Impact of Perturbations to Nitrogen Oxide Emissions from Global Aviation", J. Geophysical Research, Vol. 113, D11305

Conclusions

- ATM has an important part to play in aviation environmental impact mitigation

- Flight inefficiency metrics effective at quantifying ATM performance
  - Importance of considering terminal area operations
  - Differences between track extension & excess fuel burn
  - Note: not all inefficiencies should be attributed to ATM

- Analysis provides important insights into:
  - ATM evolution priorities
  - Environmental impact assessment

Acknowledgements

- Funding bodies:

EPSRC
Engineering and Physical Sciences Research Council

NATURAL ENVIRONMENT RESEARCH COUNCIL

Omega

- Forthcoming publications at ATIO:
  - Effects of airspace charging on airline route selection
  - More detailed assessment of fuel inefficiency analysis

- Further information:
  - Tom G. Reynolds: tgr@mit.edu
  - www.AIMproject.aero