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Partnership for AiR Transportation Noise and Emission Reduction

An FAA/NASA/TC-sponsored Center of Excellence

Assessment of CO_2 Emission Metrics for Commercial Aircraft Certification and Fleet Performance Monitoring

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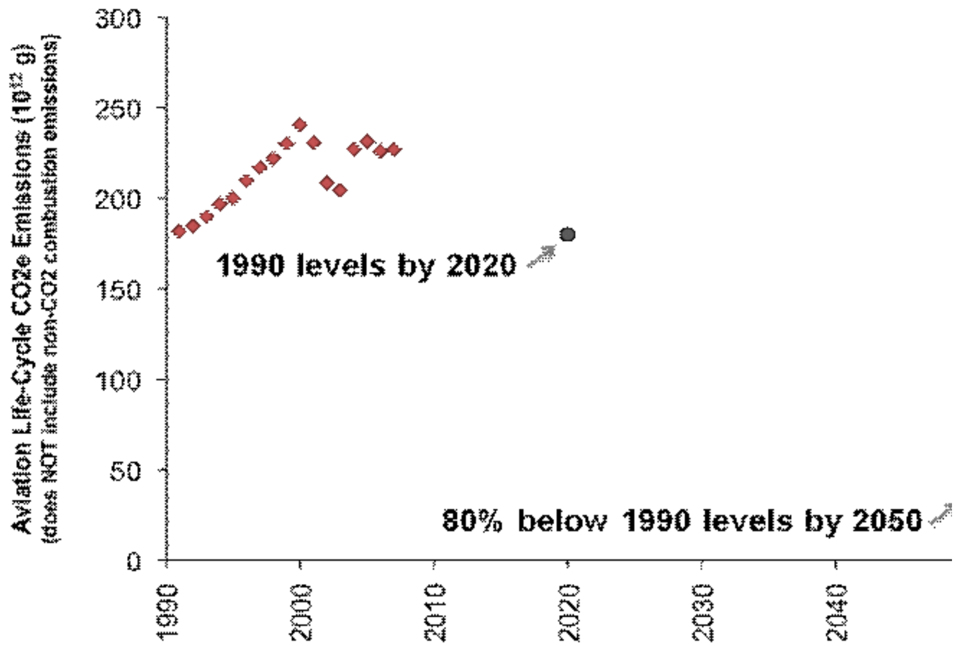
Motivation

- Growing concerns over CO_2 emissions and climate change
- Ambitious goals for CO_2 emission reductions across sectors
  - E.U.
    - 20% reduction by 2020 (1990 baseline)
  - United States:
    - neutrality by 2020
    - 80% reduction by 2050 (1990 baseline)
- Aviation specific “aspirational goals”:
  - ICAO:
    - 26% fuel efficiency improvement by 2020 (2005 baseline)
  - IATA:
    - Carbon neutral by 2020
    - 50% reduction by 2050 (2005 baseline)



Motivation (cont.)

- Several policy mechanisms and tools to reduce CO_2 emissions:
  - Voluntary actions
  - Emission taxes
  - Cap and trade
  - Standards
- This project/research focuses on aircraft certification standards
- Standard = Metric + Scope of Applicability + Certified Level
- Objective:

Identify robust metrics that objectively and accurately reflect CO_2 emissions at the aircraft and fleet levels

Rationale for Generating Candidate Metrics

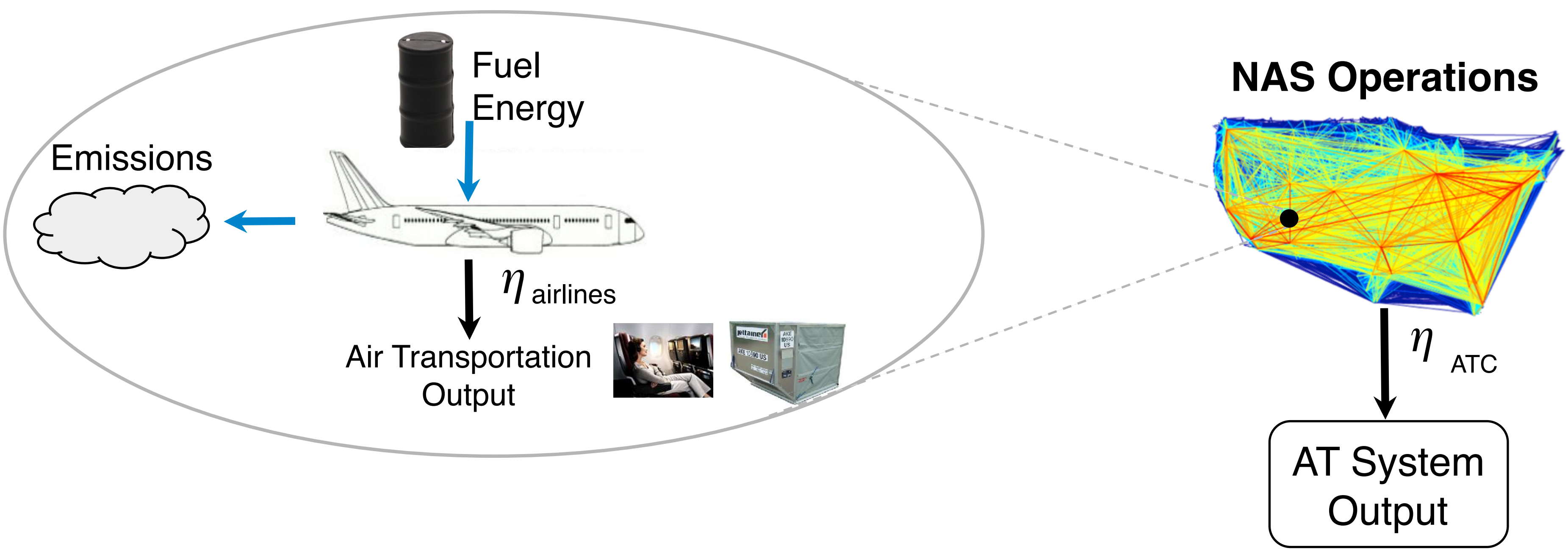
- Total CO_2 emissions function of several factors

$$CO_2Emissions = \sum_{AT\_Output_{As\_operated}} \left(\frac{CO_2Emissions}{Fuel\_Energy}\right)_{"As\_designed"} * \left(\frac{Fuel\_Energy}{AT\_Output}\right)_{"As\_designed"} * \left(\frac{AT\_Output_{"As\_designed"}}{AT\_Output_{"As\_operated"}}\right) * \left(\frac{1}{\eta_{ATC} * \eta_{airlines}}\right)$$

Fuel CO_2 Content
(measures fuel performance in terms of CO_2 per MJ)

Aircraft Energy Intensity
(measures aircraft performance in terms of Energy per Unit of Air Transportation Output)

Operational Factors
(i.e. Load Factor, ATC and Airlines Efficiencies)



Rationale for Generating Candidate Metrics

- Need to decouple Fuel Performance (i.e. Fuel CO_2 content) from Aircraft Performance (i.e. Aircraft Energy Intensity)

$$CO_2Emissions = \sum_{AT\_Output_{As\_operated}} \left(\frac{CO_2Emissions}{Fuel\_Energy}\right)_{"As\_designed"} * \left(\frac{Fuel\_Energy}{AT\_Output}\right)_{"As\_designed"} * \left(\frac{AT\_Output_{"As\_designed"}}{AT\_Output_{"As\_operated"}}\right) * \left(\frac{1}{\eta_{ATC} * \eta_{airlines}}\right)$$

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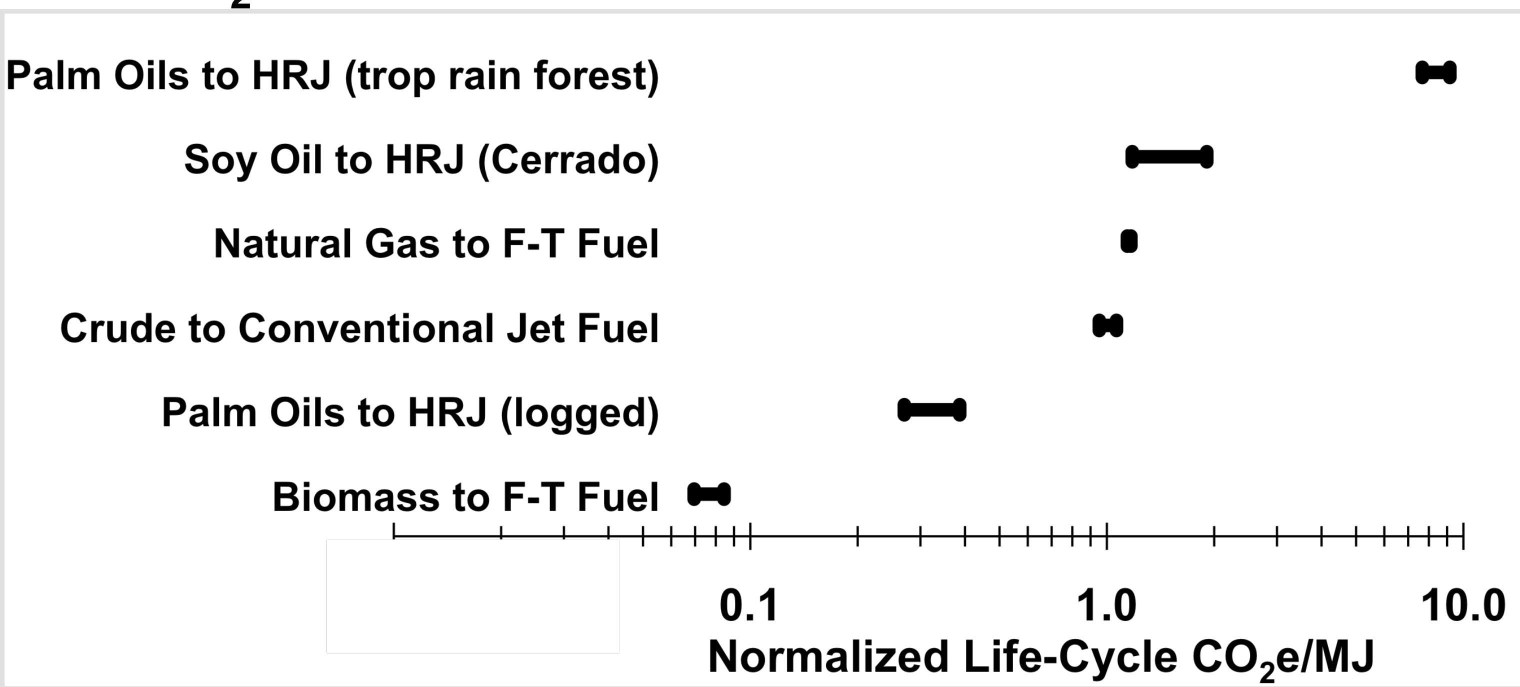
Fuel CO_2 Content



Rationale for Generating Candidate Metrics

- Aircraft certification metrics will focus on aircraft energy intensity

$$CO_2Emissions = \sum_{AT\_Output_{As\_operated}} \left(\frac{CO_2Emissions}{Fuel\_Energy}\right)_{"As\_designed"} * \left(\frac{Fuel\_Energy}{AT\_Output}\right)_{"As\_designed"} * \left(\frac{AT\_Output_{"As\_designed"}}{AT\_Output_{"As\_operated"}}\right) * \left(\frac{1}{\eta_{ATC} * \eta_{airlines}}\right)$$

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Operational Factors
(i.e. Load Factor, ATC and Airlines Efficiencies)

- How to define "Air Transportation Output" (i.e. productivity)?

(1) "Measure of distance traveled"
  - Range

(2) "Measure (or proxy) of what is transported"
  - Payload
  - Useful load (= MTOW – OEW or MTOW-MEW)
  - Maximum Takeoff Weight (MTOW)
  - Floor Area
  - Available Seats

(3) "Measure of speed"
  - Speed: MRC, LRC, etc.?
  - Time: Block time, Air time, etc.?

Candidate Metrics

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- Ruled out **single parameter metrics** (based solely on distance)
  - Automobile standards (e.g. CAFE) are based on distance only
    - Measure of “what is transported” does not significantly vary (i.e. most cars have a 5 pax. capacity)
    - Most cars have approximately the same speed capabilities (limited by operational speed limits)

- **Two parameter metrics** (combining distance and a measure of “what is transported”)
  - Investigating 5 candidate metrics*

Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy
-----------------	-----------------	-----------------	-----------------	-----------------
Payload * Range	**Useful Load** * Range	**MTOW** * Range	**Floor Area** * Range	**Av. Seats** * Range

- Should speed (or airtime) be included in a **three parameter metric?**

Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy
-----------------	-----------------	-----------------	-----------------	-----------------
Payload * Range*Speed	**Useful Load** * Range*Speed	**MTOW** * Range *Speed	**Floor Area** * Range *Speed	**Av. Seats** * Range *Speed

Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy	Fuel Energy
-----------------	-----------------	-----------------	-----------------	-----------------
Payload * Range/Time	**Useful Load***Range/Time	**MTOW** * Range/Time	**Floor Area***Range/Time	**Av. Seats** * Range/Time

Rationale for Not Pursuing the In-Depth Evaluation of Speed Based Metrics

$$\text{Fuel Intensity} = \frac{\text{Block Fuel Energy}}{f(\text{Items Transported, Distance, Speed}^{\alpha})}$$

- "Block Fuel Energy" and "Speed" are coupled
- Coupling implies a trade (i.e. relative value) between these two parameters
- What should be the relative weight on "speed" vs. "block fuel"?
  - Inclusion of a Cost Index
  - Historically, cost index has not been constant over time
  - Inclusion of a speed parameter would require forecasting a cost index
- Not clear how aircraft cruise speed will evolve in the future? Perverse effects of speed based metrics?
- Speed variations probably best dealt with by limiting scope of applicability
  - e.g. certification requirement for subsonic, supersonic, etc.

Attributes of Metrics and Evaluation Criteria

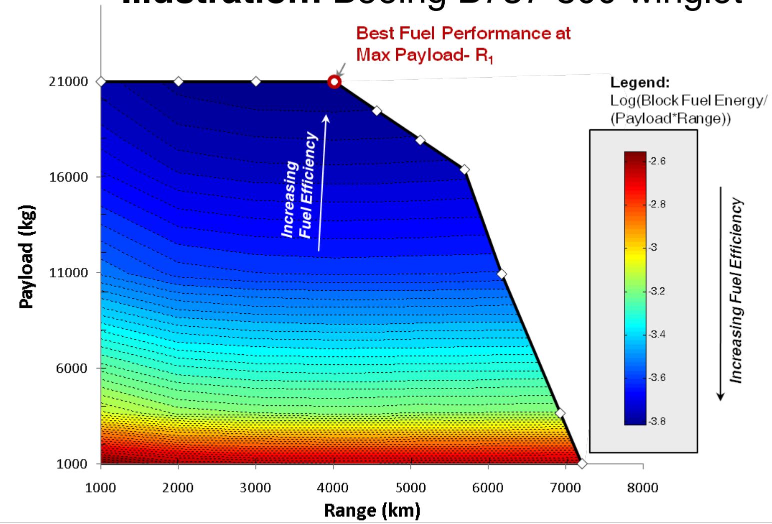
Metrics should:

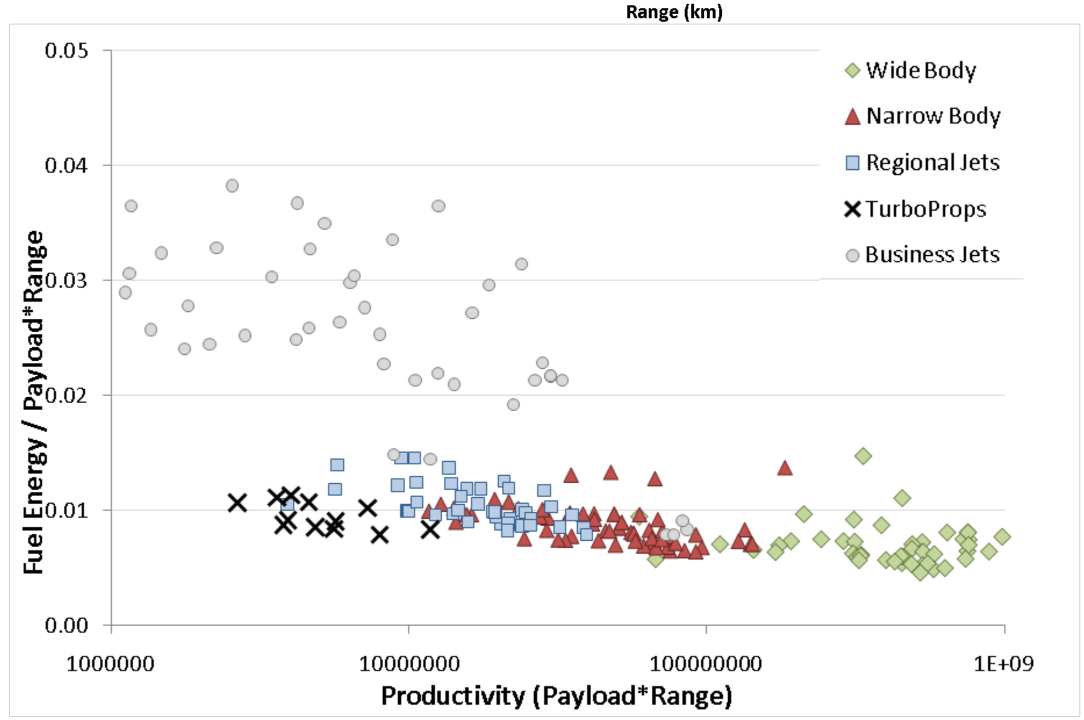
- Decouple effects of fuel performance from aircraft performance
- Include a measure of productivity
- **Accurately reflect CO_2 emissions and fuel burn at aircraft level**
- Be easily measurable
- **Be fair (equitable) across set of stakeholders**
- **Limit unintended consequences**
- Exhibit a degree of equivalence between "aircraft certified performance" and "aircraft reported performance (by operators)"
- Limit cost of implementation
- Limit interdependencies with other standards

Illustration of Metric Evaluation: Aircraft Fuel Efficiency Analysis based on Piano-X

- **Analyzed fuel efficiency performance of 217 aircraft types:**
  - aircraft types:
    - Wide body, Narrow body, Regional jets, Turboprops, Business Jets
  - status of production:
    (consistent with WG3 breakdown – potentially used for certification requirement applicability)
    - "out of production/in service",
    - "in production",
    - "new aircraft types"
- **based on Piano-X aircraft performance models:**
  - "Flew" aircraft at various reference mission points (e.g. Max. Payload-R1) using several assumptions accounting for operational constraints

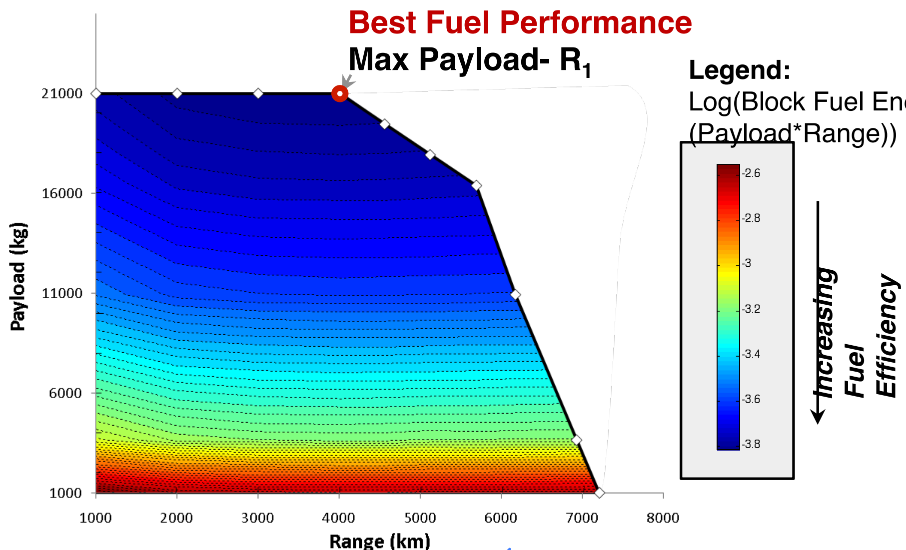
Illustration: Boeing B737-800 winglet



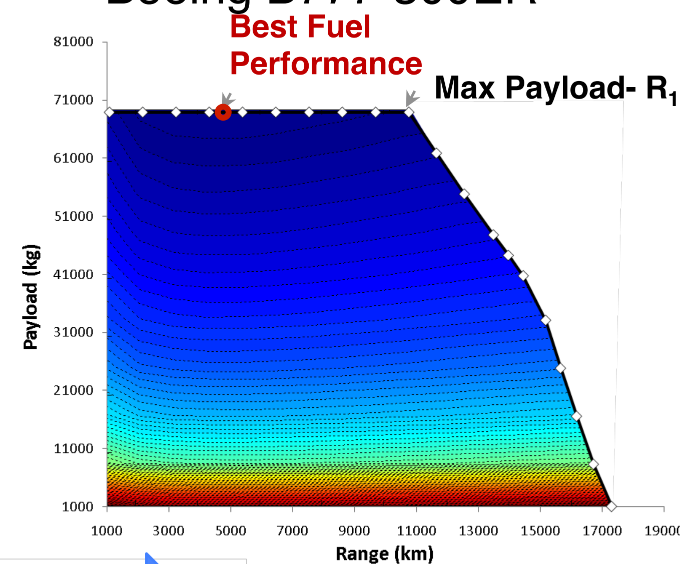


Robustness of Metric Measurement to Operational Deviation
(i.e. Operating at less than optimum ranges)

Boeing B737-800



Boeing B777-300ER



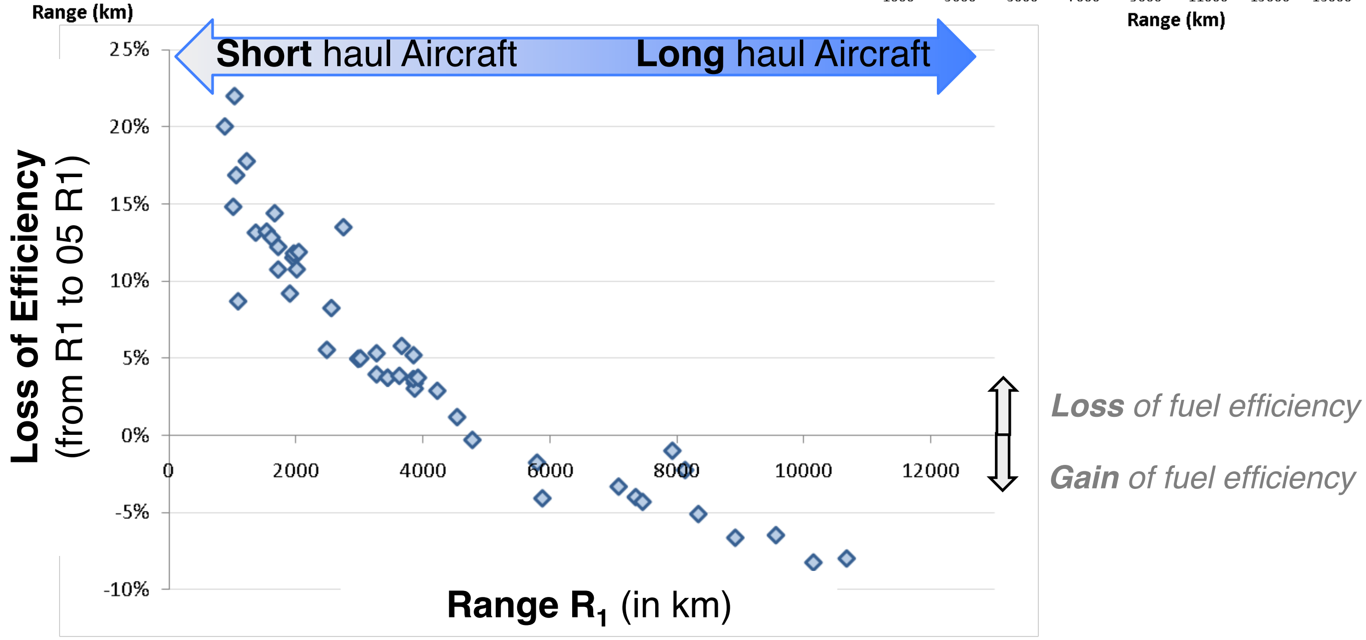


Illustration of Metric Evaluation: Temporal Robustness of Measurement

Metrics such as Fuel Energy / (**Seats***Range) can yield very different values between time of certification and time of operation

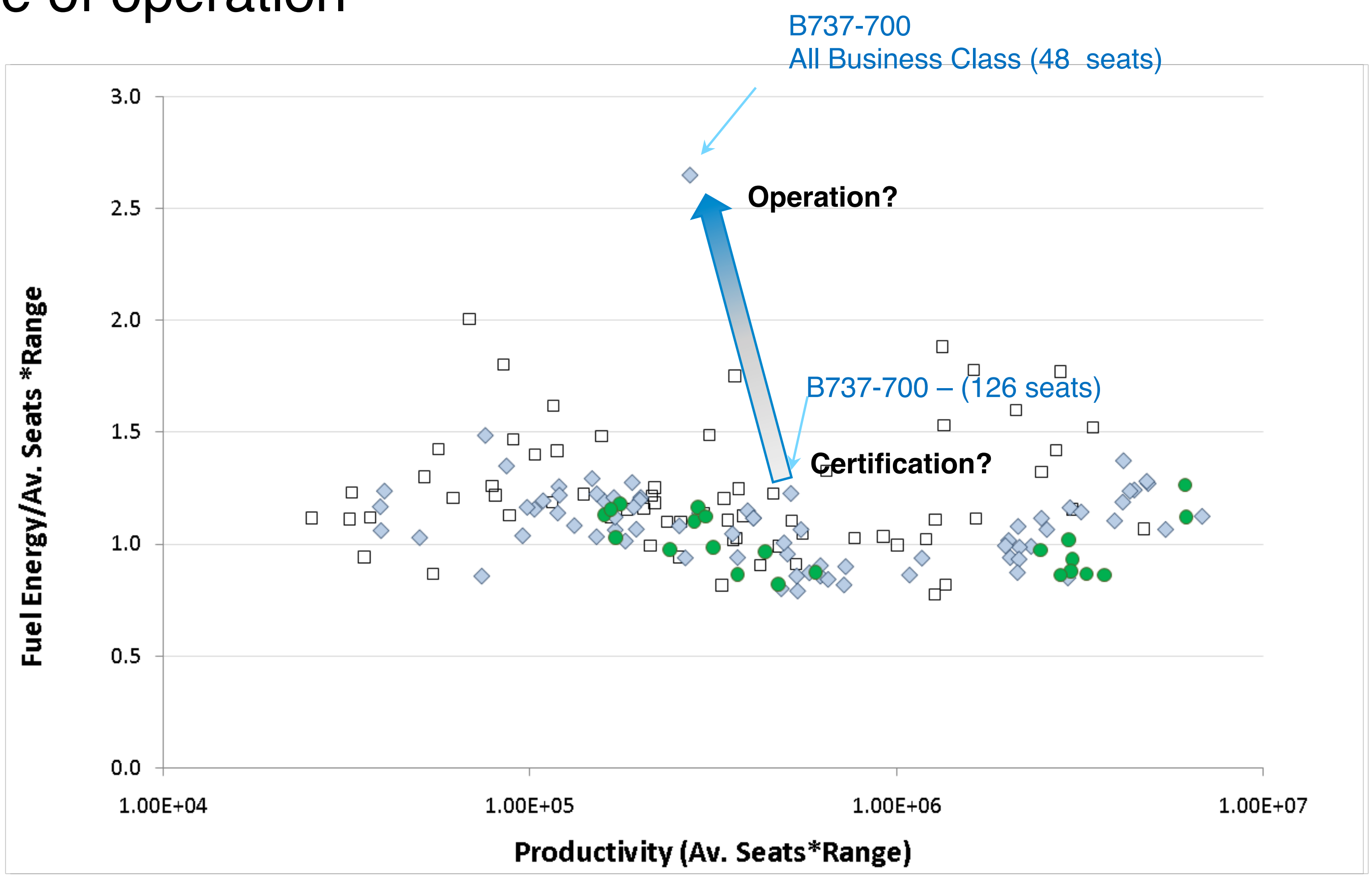
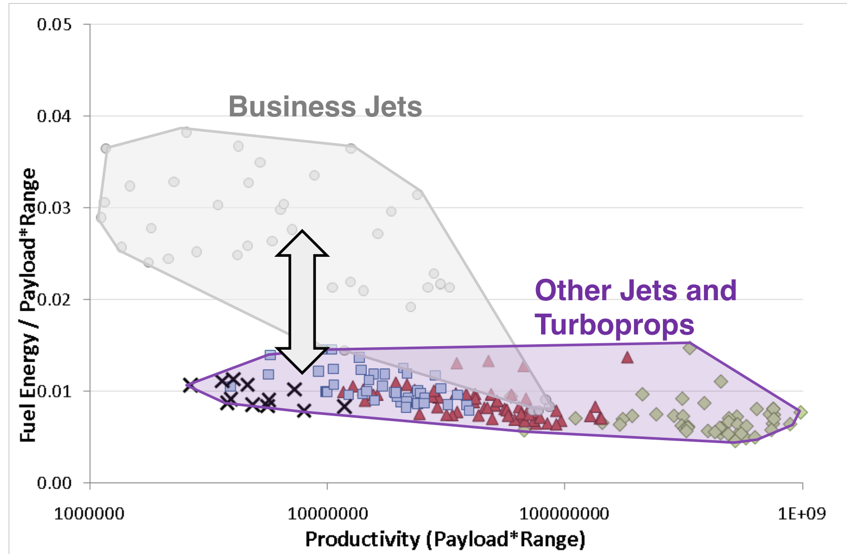


Illustration of Metric Evaluation
How to Evaluate "Fairness"?

- **Fairness depends on the definition of the metric and stakeholder view point (requires a value judgment)**
  - The same metric may be "fair" for one stakeholder but "unfair" for another
- **Fairness is dependent on the relative performance between groups of stakeholders**
- **The "performance spread" (i.e. standard deviation of performance across stakeholders) is used as a surrogate informational measure to evaluate potential fairness issues.**
- **The value judgment of determining how "fair" a metric should be left to the policy makers**



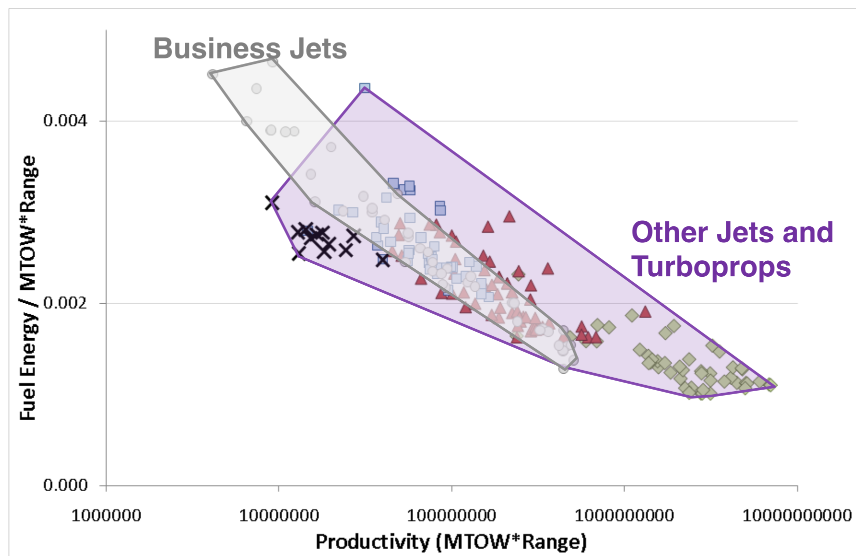
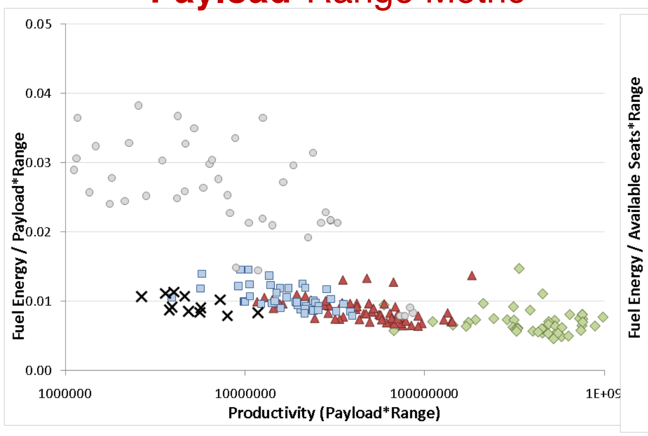


Illustration of Metric Evaluation

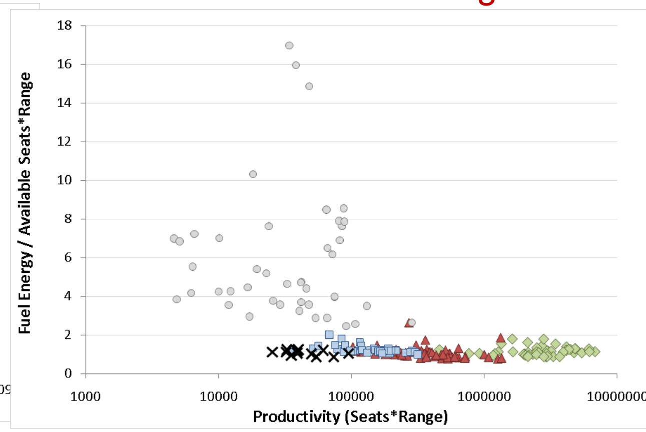
"Performance Spread" across Aircraft Type Categories

Business Jet category stand out on three of the metrics

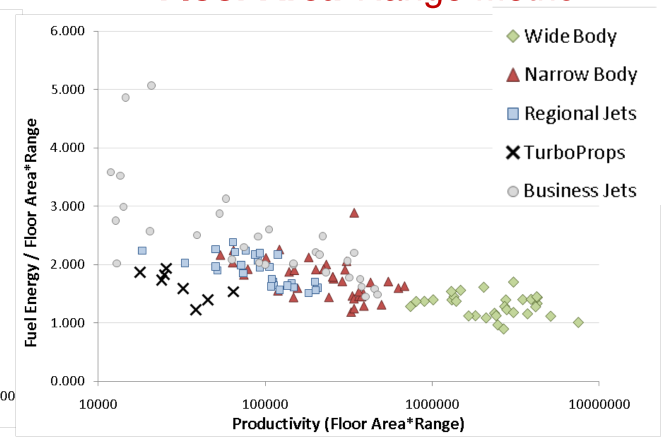
Payload*Range Metric



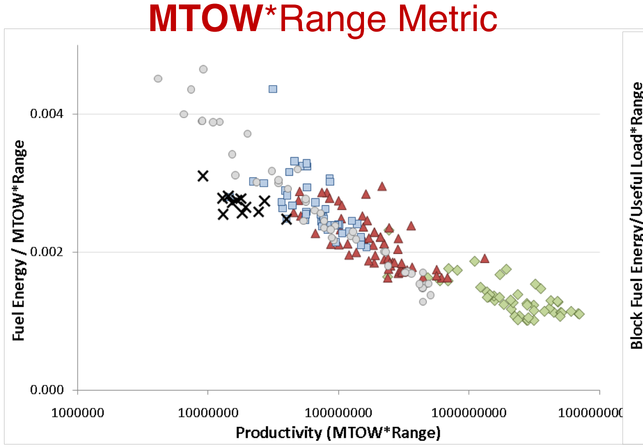
Available Seats*Range Metric



Floor Area*Range Metric



MTOW*Range Metric



Useful Load*Range Metric

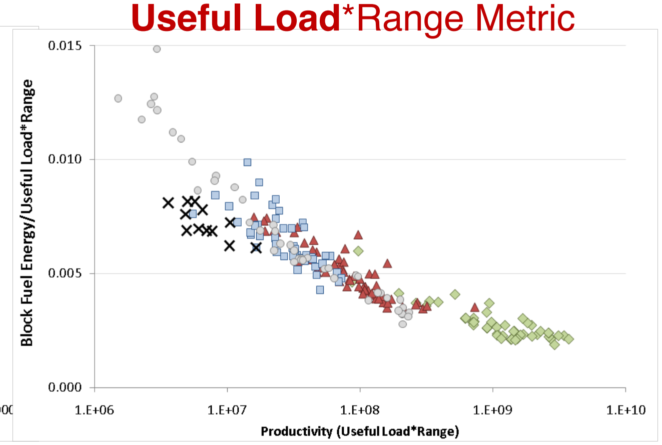
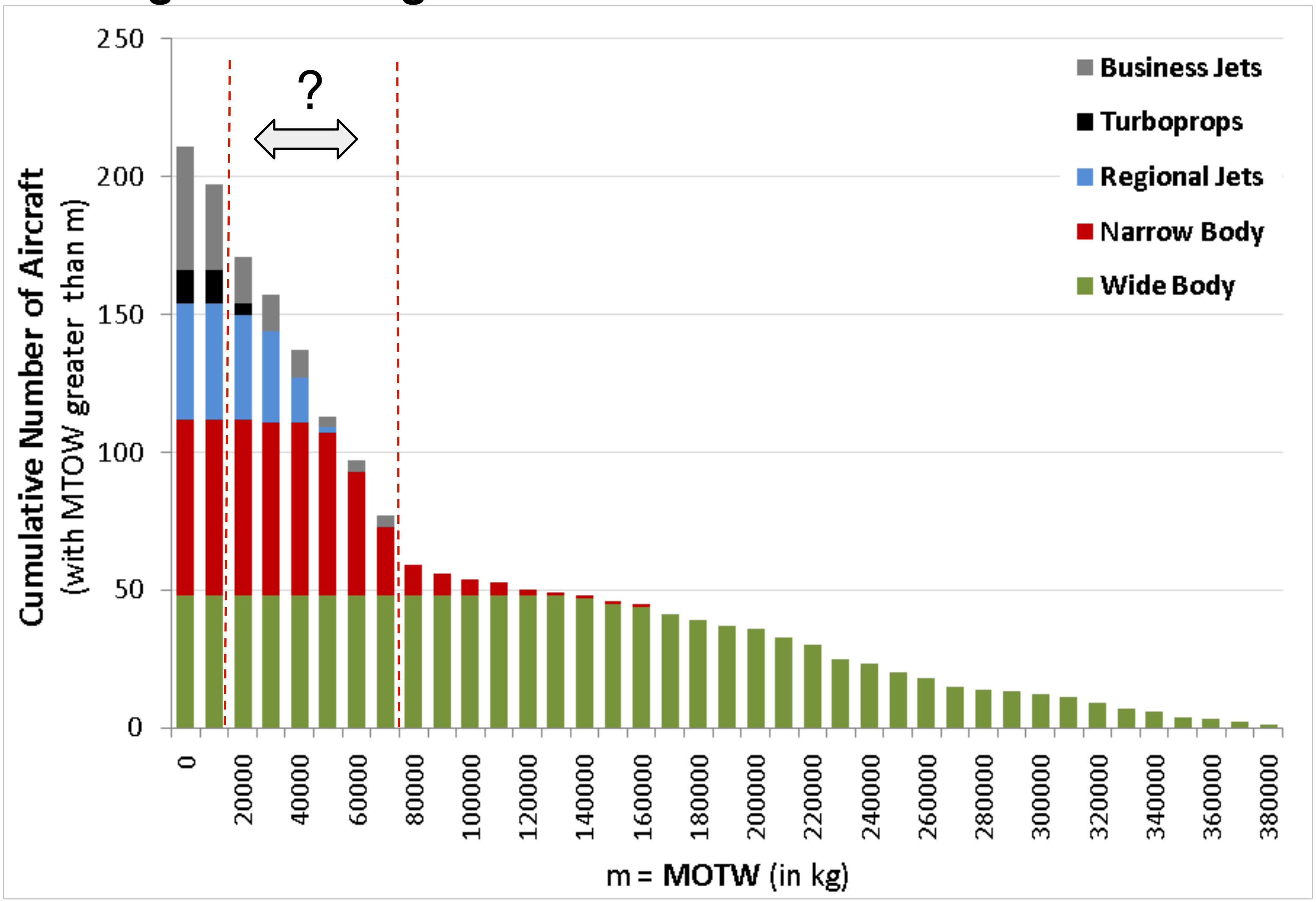
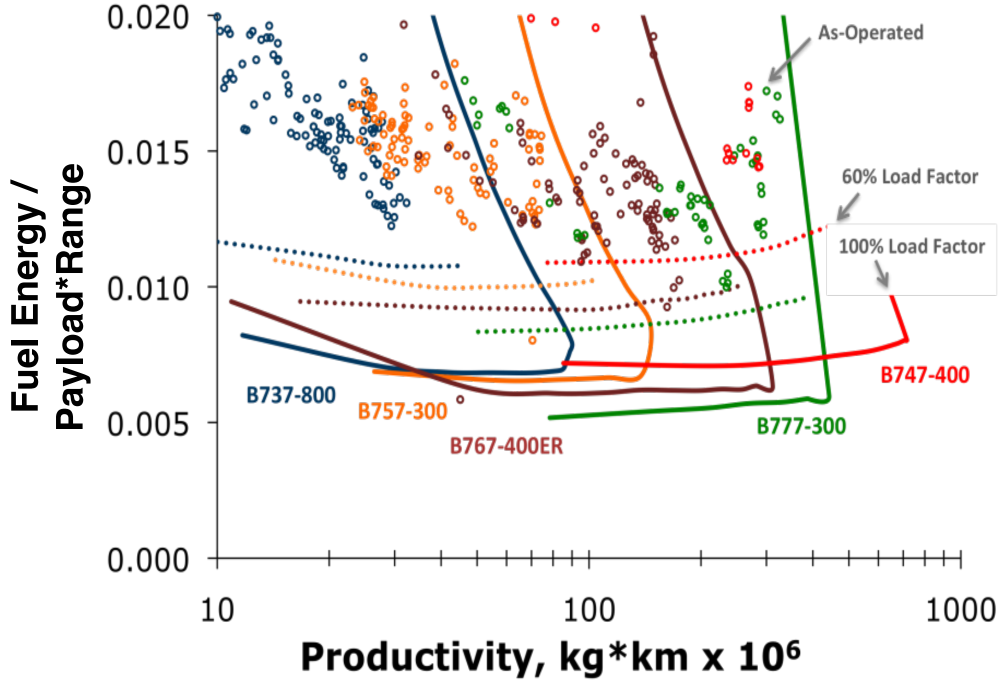


Illustration of Metric Evaluation: Potential Unintended Consequence

Difficult to Exclude Business Jets on the basis of MTOW without Excluding Regional Jets and Turboprops
-> Re-emergence of Regional Jets?



How to Account for Operational Inefficiencies?



- Solid lines are design data
  - Computed from payload-range
- Points are reported operational data (by airlines)
- Gap between as operated and as designed signifies total system operational inefficiencies

- Load Factor
  - Controlled by airlines
    - Fleet sizing
    - Aircraft Configuration
    - Revenue Management
- Air Traffic Control inefficiencies
  - Controlled by air navigation service providers (ANSP)
  - Also controlled by regulators that oversee ANSP
- Airline operational efficiency

Conclusions

- Definition of the metric is key to the development of an aircraft CO_2 emission certification standard
- Identified 15 candidate metrics
- Developed criteria for evaluating quantitatively and qualitatively each of the metrics
- Performing analyses of supporting the evaluation of each candidate metric
- Seeking input and participants for semi-structured interviews with airline industry stakeholders to understand:
  - potential equity issues,
  - potential unintended consequences,
  - gaming dynamics,
  - "airline perspective" on the potential impacts of CO_2 standards

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Questions
&
Comments