ASCENT Project 050

Over-Wing Nacelle (OWN) Placement Evaluation

Georgia Institute of Technology

PI: Dimitri Mavris, Chung Lee
PM: Chris Dorbian
Cost Share Partner: Georgia Institute of Technology

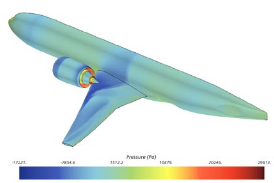
Objective:

- Use multidisciplinary design analysis and optimization (MDAO) methods to assess environmental impact of over-wing nacelle (OWN) placement
- Emphasis on high fidelity aerodynamics to capture drag penalty

Project Benefits:

- Enable accurate tradeoffs between noise benefits and fuel burn penalties
- Demonstrate computationally efficient methods for aircraft design studies

Research Approach:



- Computational efficiency is key challenge
- Numerical uncertainty is a major theme
- Fair comparison requires two optimization processes: OWN vs under-wing nacelle (UWN)

Major Accomplishments (to date):

- Developed coupled aero-propulsion analysis method
- Optimization comparison of OWN vs UWN for fixed size and engine cycle
- Initial comparisons of fuel burn predictions from different trajectory analysis methods

Future Work / Schedule:

- Engine sizing optimization study (Dec 2023)
- High lift / low speed study (Dec 2023)

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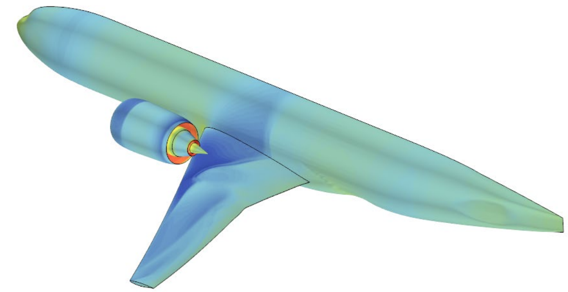
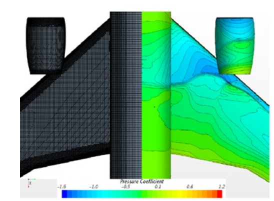
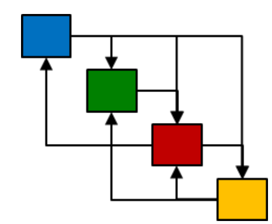
Do over-wing nacelle (OWN) benefits outweigh its disadvantages?



- Focus is **forward-mounted OWN** for single-aisle transports
  - Clearance for larger engines
  - Noise shielding
  - *Complex aero-propulsion coupling*



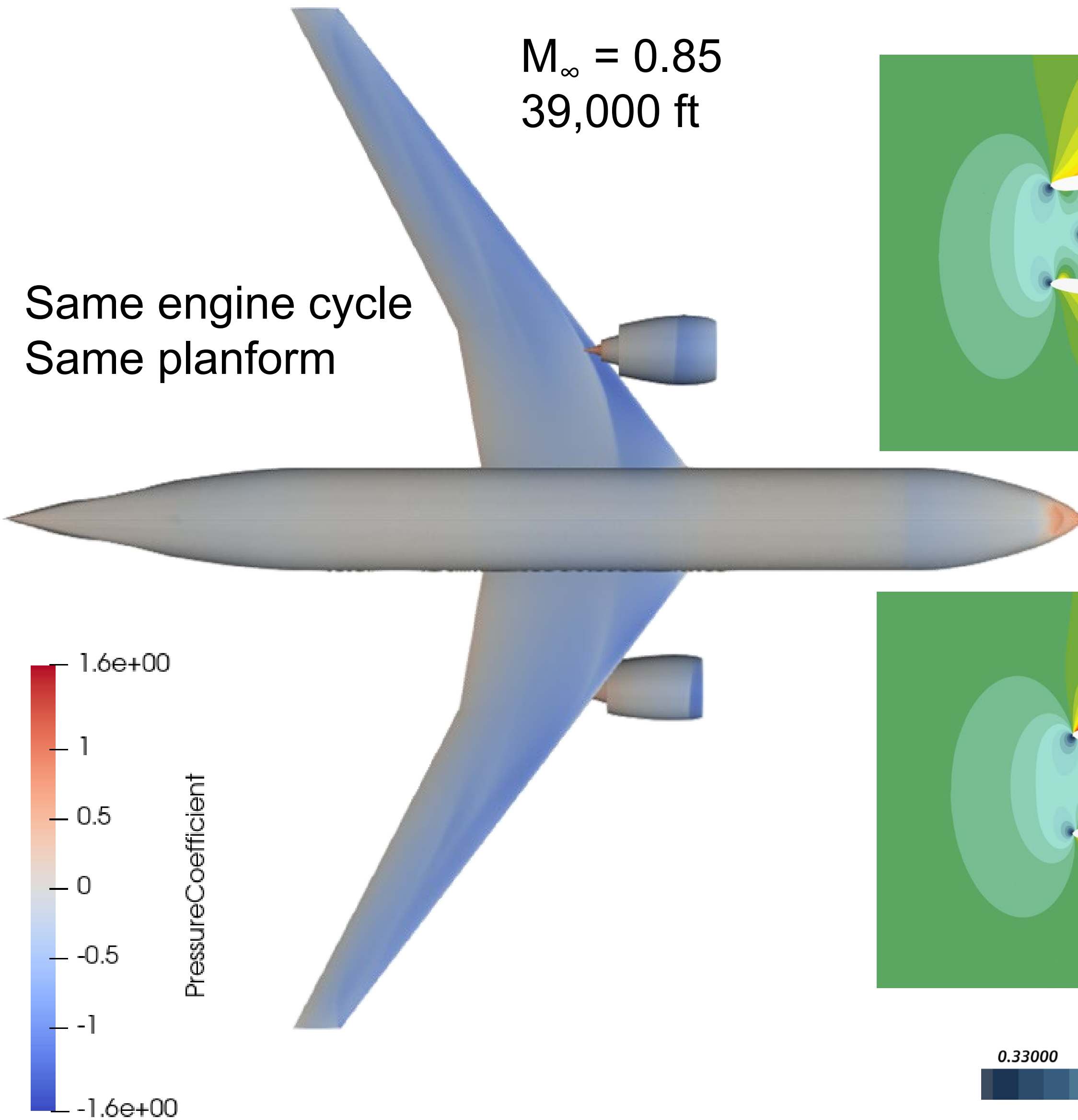


- Less focus on numerical outcome; more emphasis on **methodology** and **lessons learned**
  - Computational cost and efficient MDAO
  - Error and uncertainty

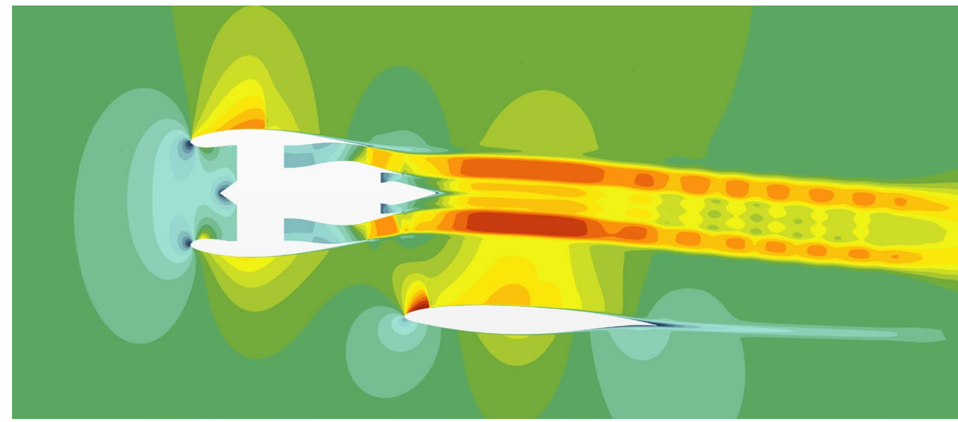
Last time: OWN had 4% higher fuel burn at cruise (in a controlled comparison)

$M_\infty = 0.85$
39,000 ft

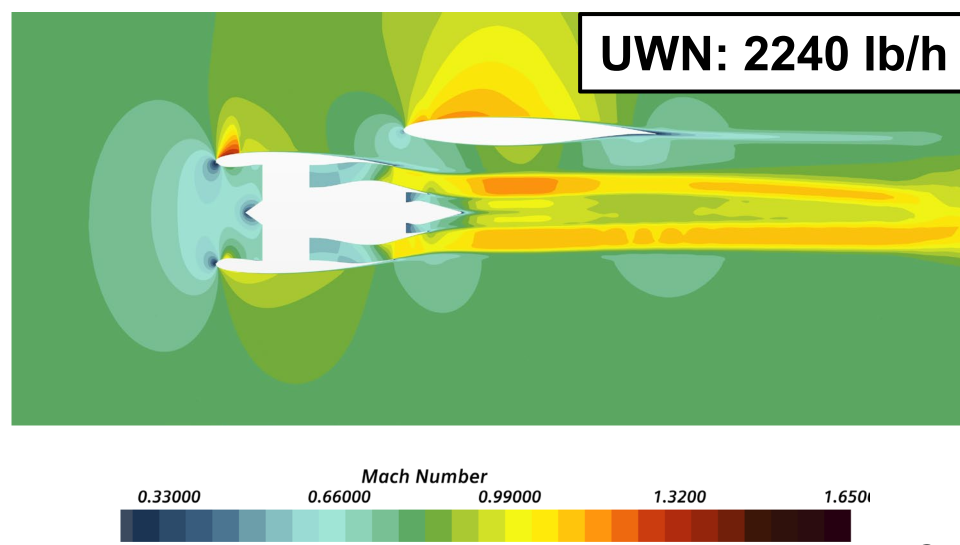
Same engine cycle
Same planform



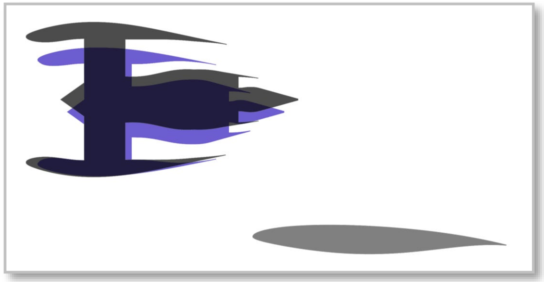
OWN: 2330 lb/h



UWN: 2240 lb/h

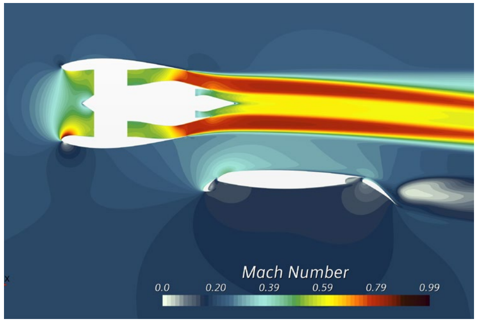


2023 effort includes three parts



- Engine sizing study

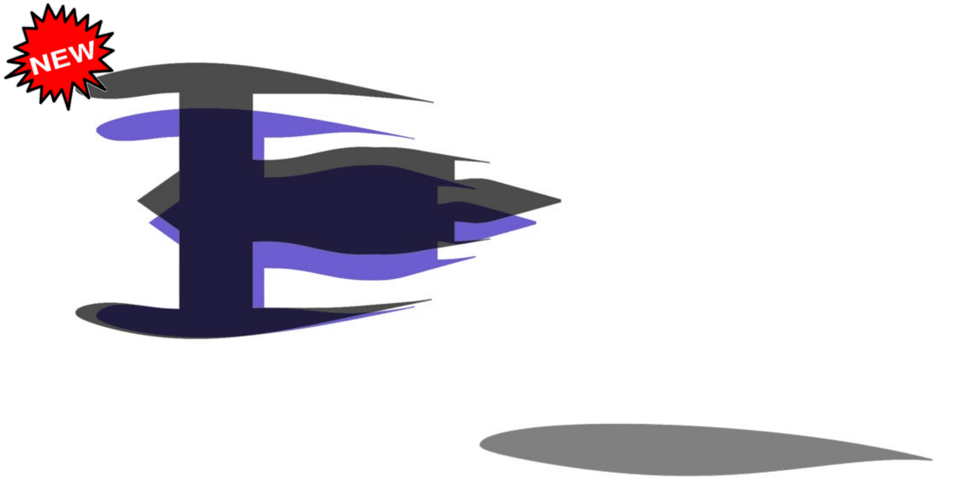
- Higher fidelity mission analysis



- High lift / takeoff physics study

2023 work focuses on engine sizing study

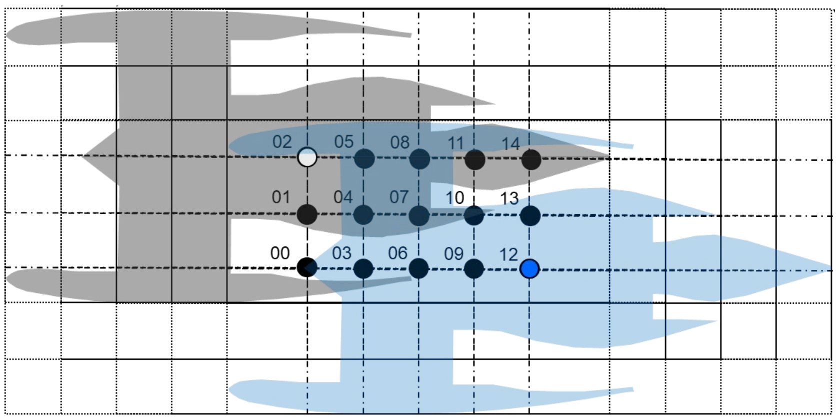
- OWN potentially allows clearance for higher bypass ratio engines
- Methodological issues:
  - Under-constrained scope of aero-propulsion optimization may lead to unrealistic results
  - We are ***selecting*** a larger engine size for study

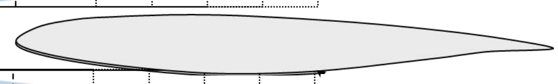


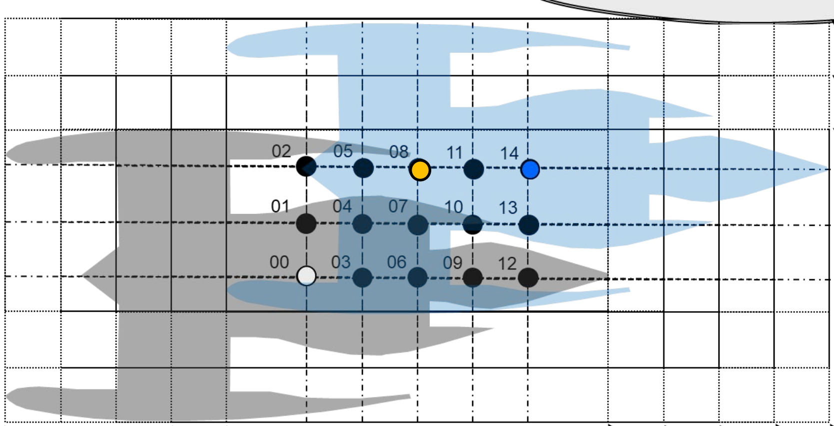
We will first perform a nacelle location study with larger engine

- We will vary nacelle locations as done previously:

OWN



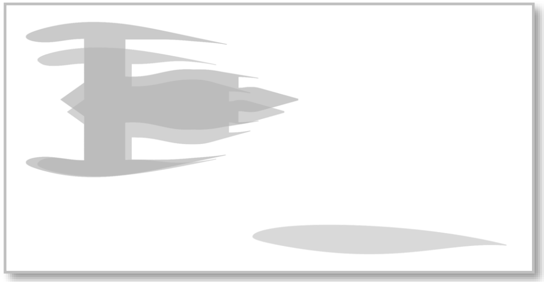




UWN

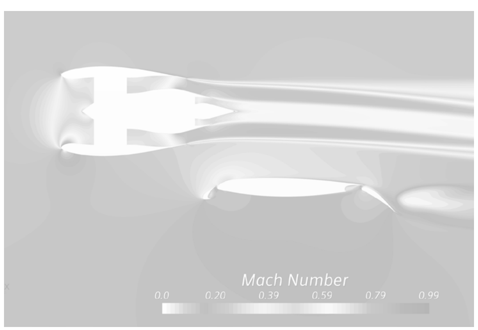
Final locations to be selected for more detailed shape optimization in summer 2023

2023 effort includes three parts



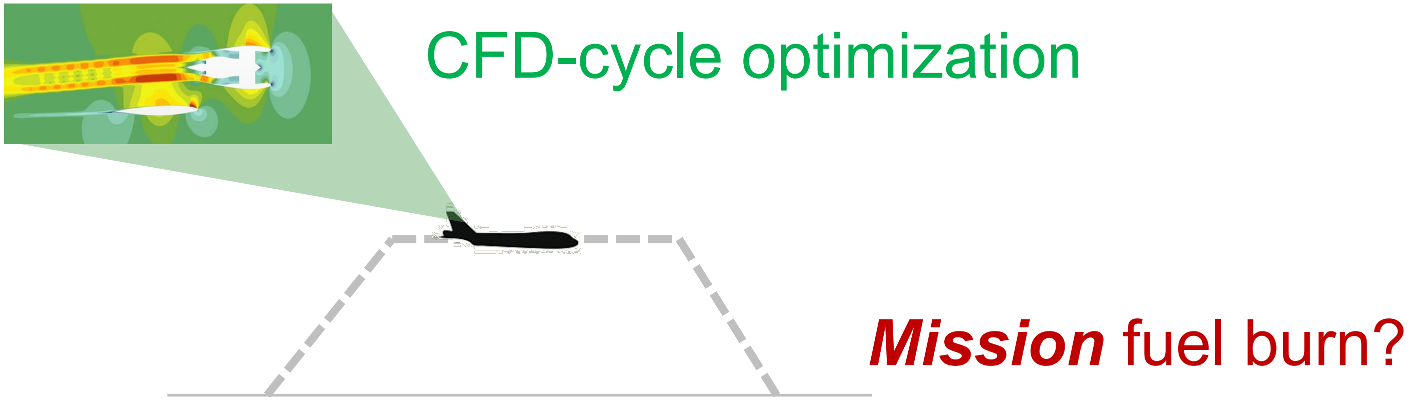
- Engine sizing study

- Higher fidelity mission analysis



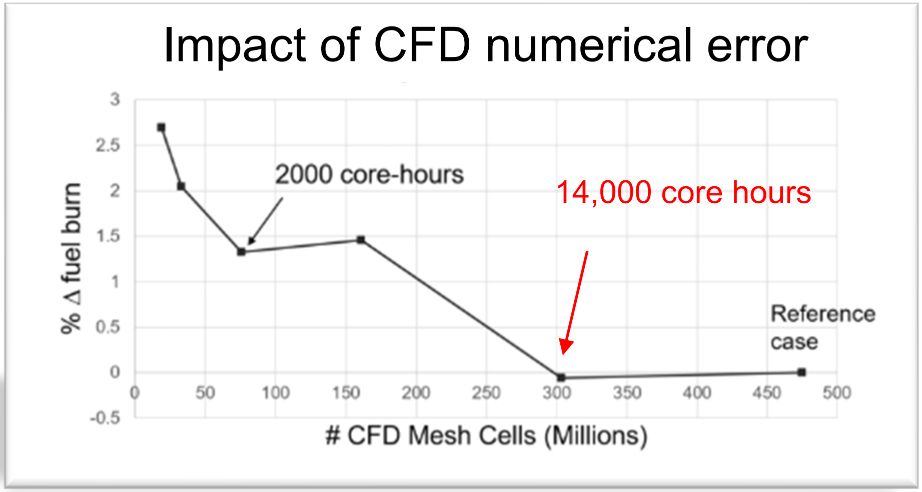
- High lift / takeoff physics study

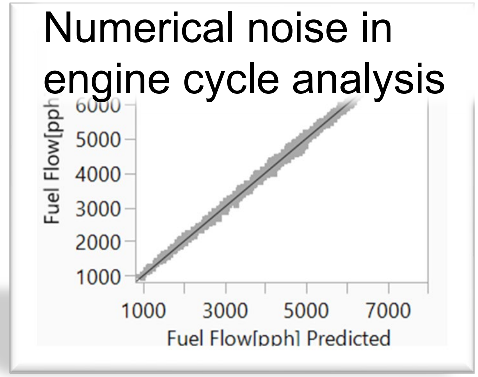
Higher fidelity aero-propulsion needs to be linked to system level metrics

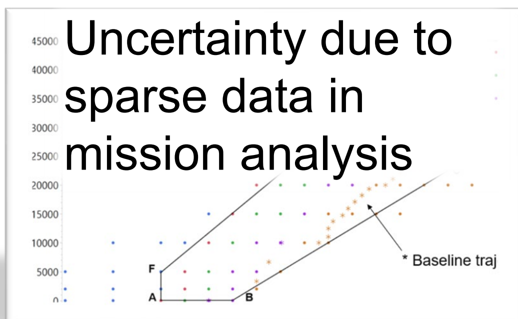


- Optimization and initial fuel comparison performed at cruise
- Mission fuel burn prediction raises new challenges:
  - Limitations of dynamics models in legacy trajectory analyses ☆
  - Sampling of computationally intensive simulations

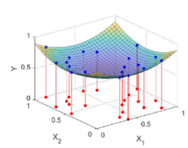
Recall: we must address several types of uncertainty to make credible predictions

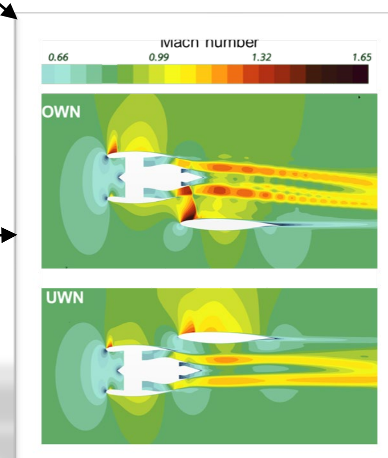






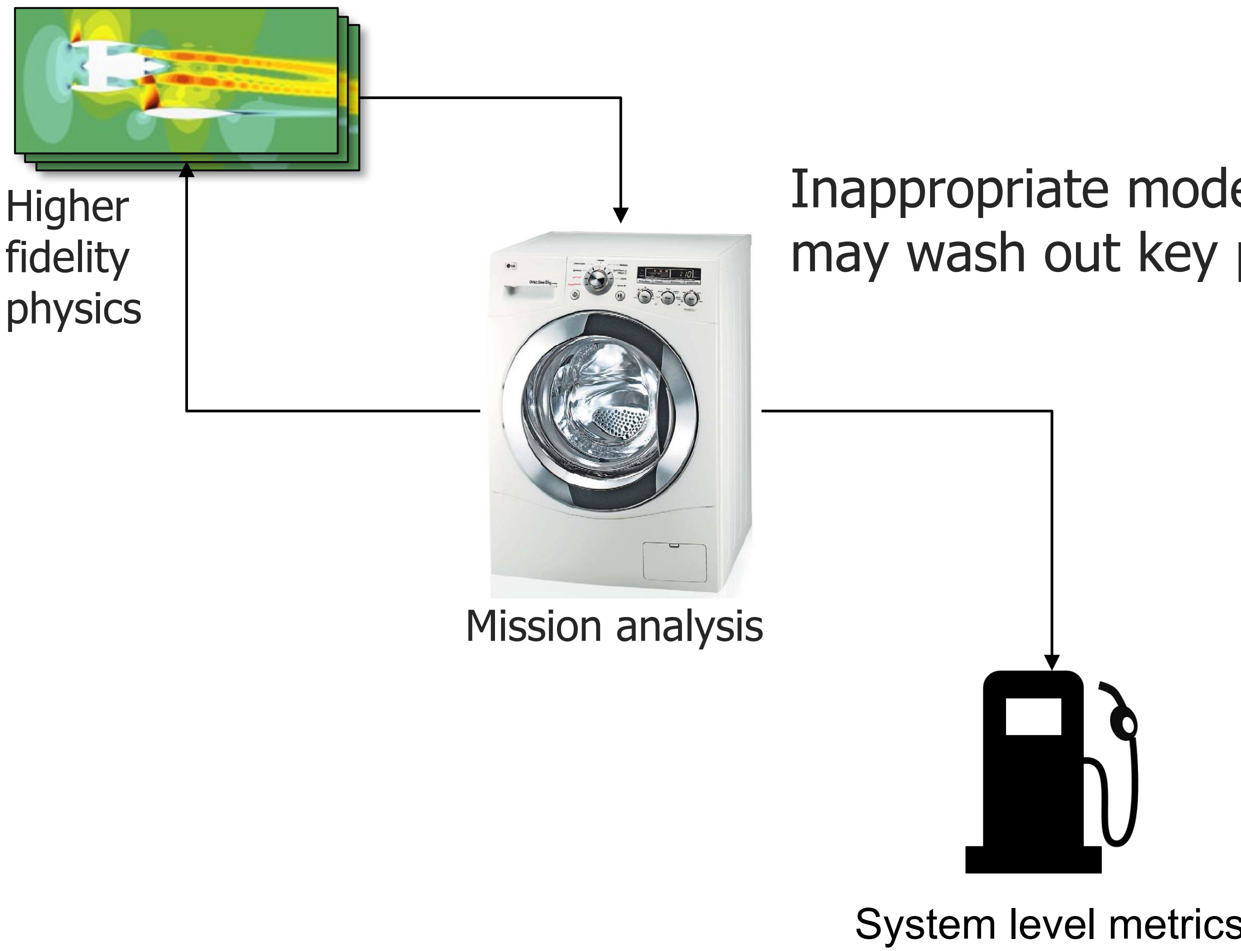
Uncertainty due to incomplete optimization





Meaningful comparison must be above a “noise floor”

Risk: loss of information when propagating high fidelity physics to system level



Inappropriate model assumptions may wash out key physics effects

Trajectory analysis potentially introduces significant errors

- We currently suspect errors of O(1%) mission fuel burn
- Force accounting in many legacy codes cannot capture key aero-propulsion physics

<u>Ex</u>: Thrust = Drag*

Now depends on α

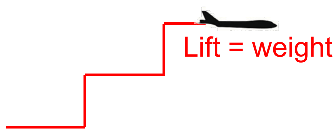
Now affected by engine throttle

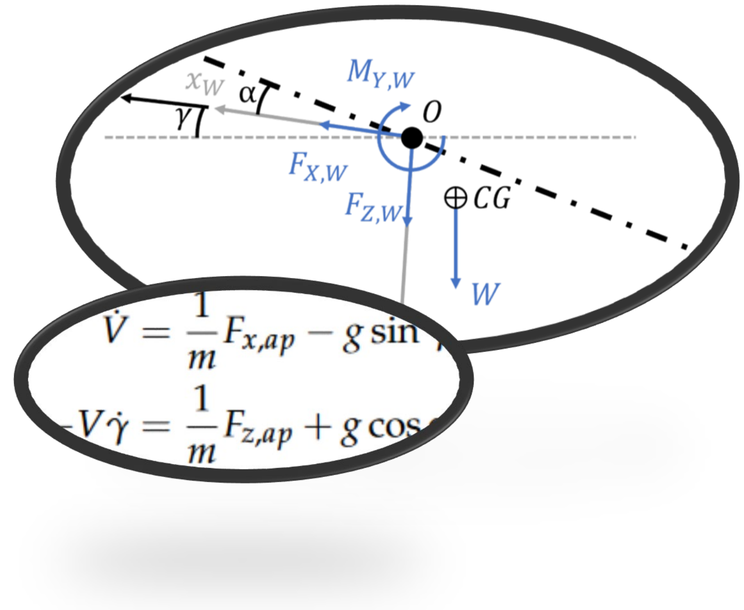
- Other sources of error due to dynamics model showcased today

* Yes, yes, for *steady, level flight*

To address fuel burn uncertainty, we implemented a more general trajectory model

- 3-DOF equations of motion
- As opposed to what?
  - **<u>Ex</u>**: NASA FLOPS models climb as a "step climb"

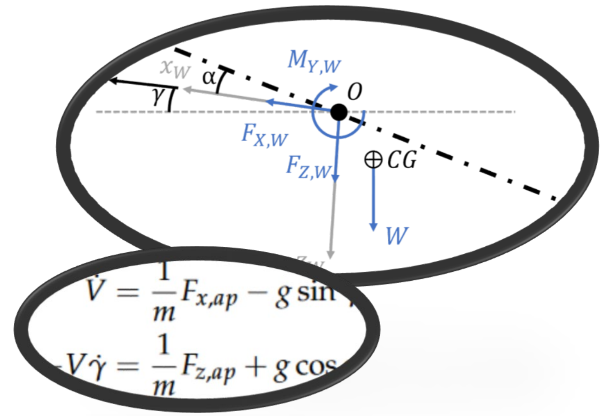




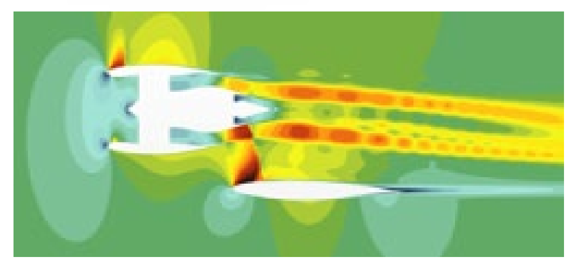
- Challenge: trajectory optimization is much more difficult
  - We have cooperated with NASA OpenMDAO/Dymos team

Initial comparison of new and legacy trajectory analysis reveals discrepancies

- FLOPS vs 3 DoF trajectory comparison
  - **Δ0.7% mission fuel burn** discrepancy attributable to equations of motion



- Upcoming work: include coupled aero-propulsion with trajectory optimization



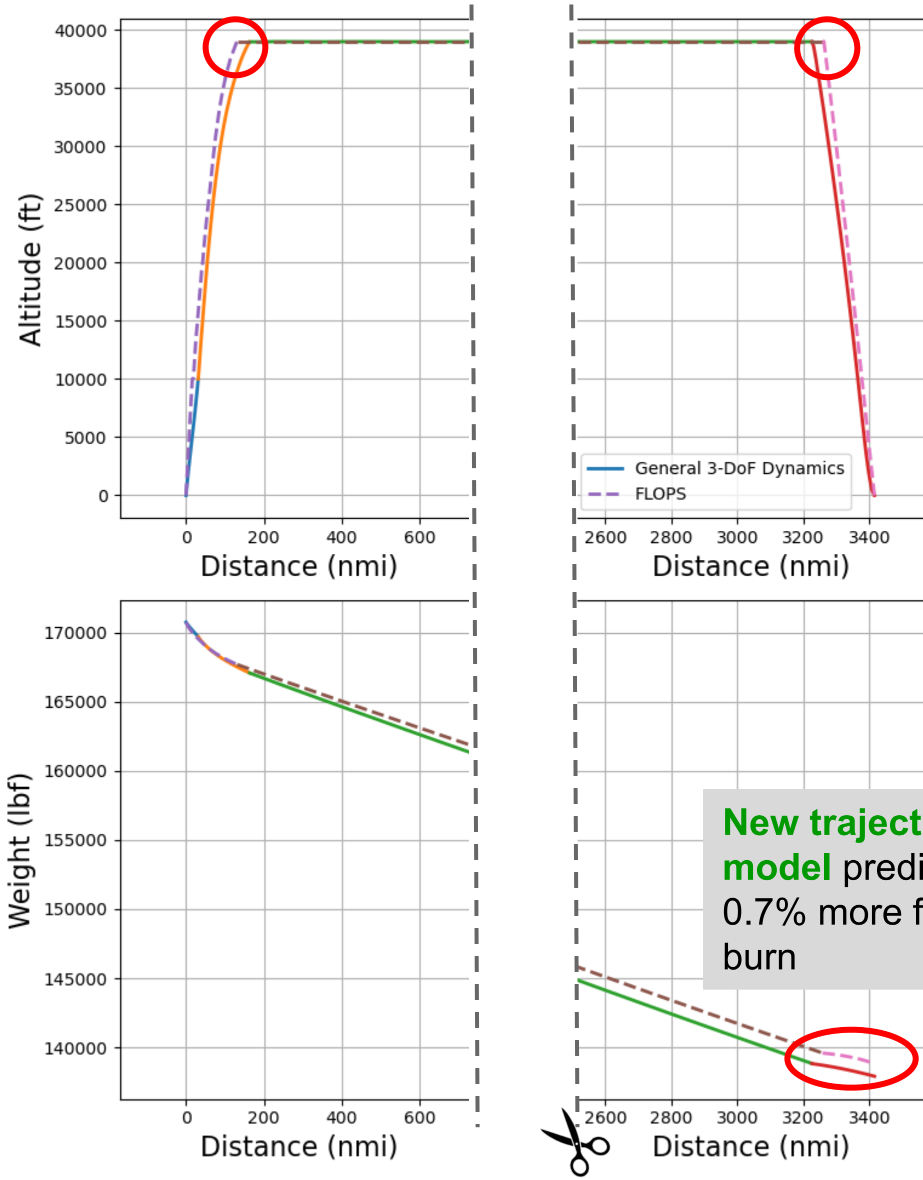
- Potential finding:
  - Mission analysis must have fidelity commensurate to aero-propulsion disciplines

(Some details) Trajectory comparison was a controlled numerical experiment

- Same values used for two trajectory analysis codes:
  - Weights
  - Aero polars
  - Engine deck
  - Range
  - TOGW
  - Mission segment speed and altitude boundary values

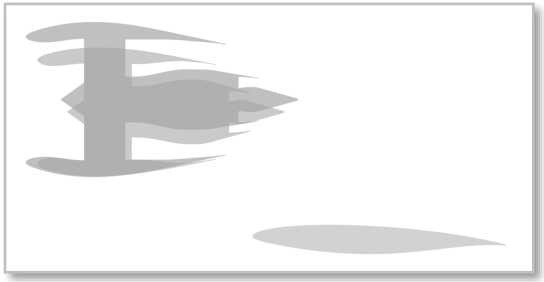
- We allowed optimizers to vary:
  - Time and distance spent in each segment

- Next time:
  - Fuel burn discrepancy due to aero-propulsion models

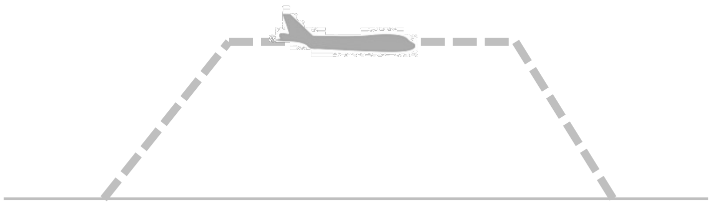


New trajectory model predicts 0.7% more fuel burn

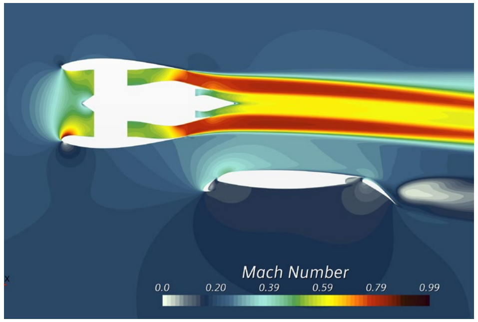
2023 effort includes three parts



- Engine sizing study



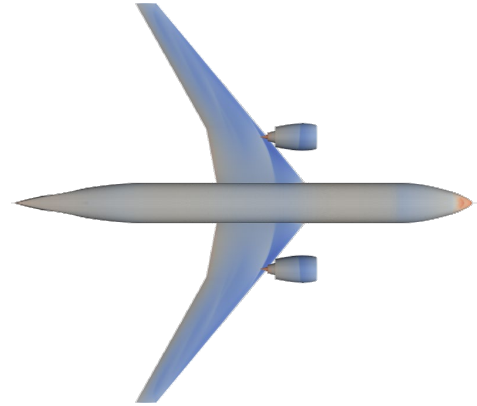
- Higher fidelity mission analysis



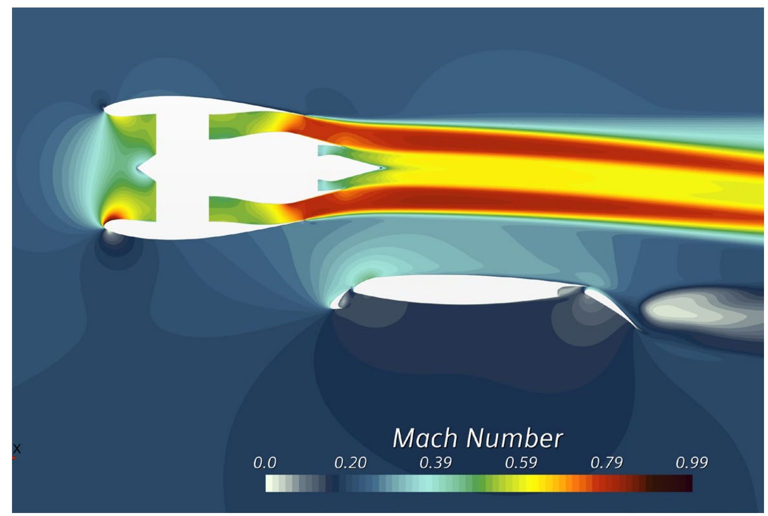
- High lift / takeoff physics study

High lift / low speed flight regime is potentially important for OWN sizing

- Current effort has focused more on cruise due to computational resources

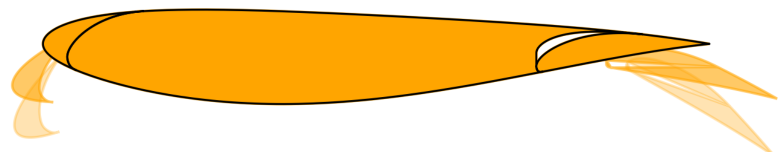


- But high lift regime influences both wing and engine sizing
  - Potential benefits of blowing
    - (*but don't count on it*)
  - Potential disadvantages
    - <u>Ex</u>: OWN placement spoils lift when one engine inoperative (OEI)

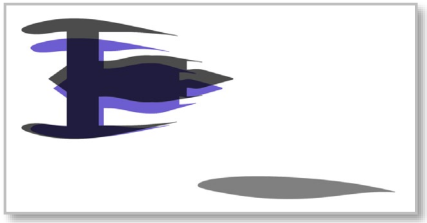


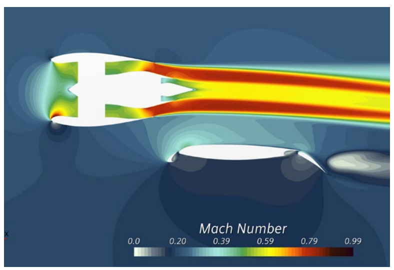
Currently setting up and running exploratory analyses for high lift OWN

- Parametric CAD models and kinematic constraints developed from scaled NASA High Lift Common Research Model



- Initial step is to compare OWN and UWN:
  - F_X, F_Z = f (α, flap and slat deflection, engine power code)
- These result will focus our future research steps (TBD)
  - Goal is physics understanding rather than design
  - Emphasis on potential "show-stoppers"





Thank you!

Questions?