Computational Evaluation of an OML-based Heat Exchanger Concept for HEATheR

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AIAA/IEEE Electric Aircraft Technologies Symposium (EATS), Aug 2020

Motivation

- The High-efficiency Electrified Aircraft Thermal Research (HEATheR) project
  - Conceptual study looking into improving the efficiency of hybrid/electrified aircraft
  - Project seeks to minimize waste heat generated by electrical components
  - Also looks into novel solutions to avoid use of heavy thermal management systems that cause drag

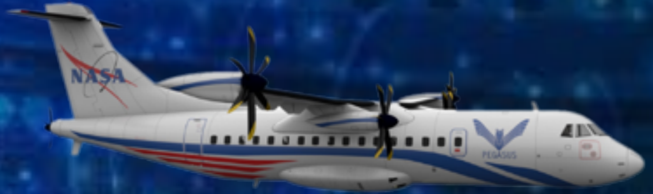
- In this work, an Outer Mold Line (OML) heat exchanger solution is considered
  - Component waste heat is rejected via convection through the outer skin of the aircraft
  - No air ducting, or any geometrical change in flow path: virtually no effect on vehicle drag
  - Challenge: Electrical component temperature limits, as well as outer skin structural considerations constrain the rejection temperature (<200C)

HEATheR Scope

- **STARC-ABL**: Single-aisle Turboelectric AiRCraft with Aft Boundary Layer ingesting propulsion
    - 150-passenger plane with an 3500hp, electric aft fan
    - The aft fan is driven by an electric motor
    - Generators on low pressure shaft of underwing turbofans power the fan

- **RVLT**: Revolutionary Vertical Lift Technologies
    - 15-passenger tilt-wing concept
    - One turboshaft engine drivers a generator to power 4 fans

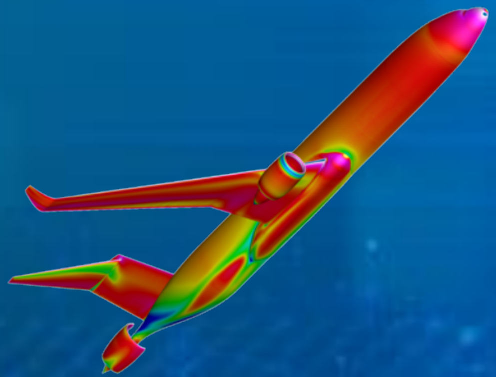
- **PEGASUS**: Parallel Electric-Gas Architecture with Synergistic Utilization Scheme
    - 48-passenger concept with a short fully-electric mission
    - Turboelectic architecture for longer range missions



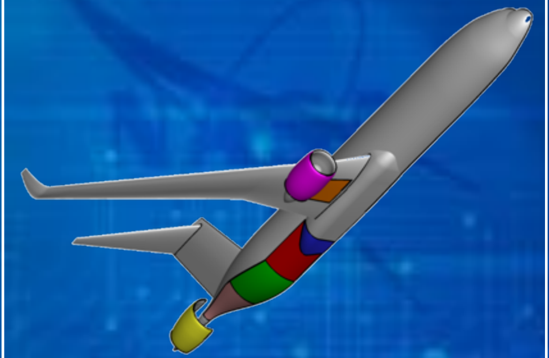
Goal

Help assess the feasibility and practicality of OML-based heat rejection

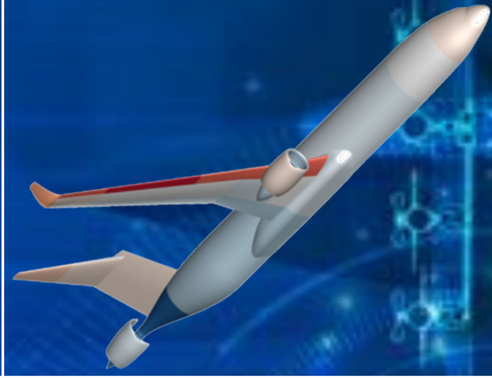
How much heat can we reject?



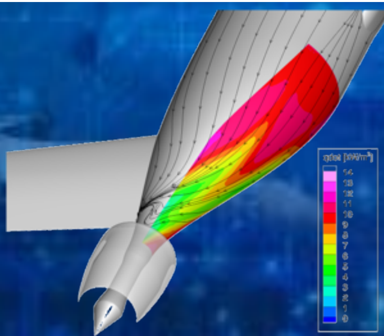
Where to place the OML heat exchangers?

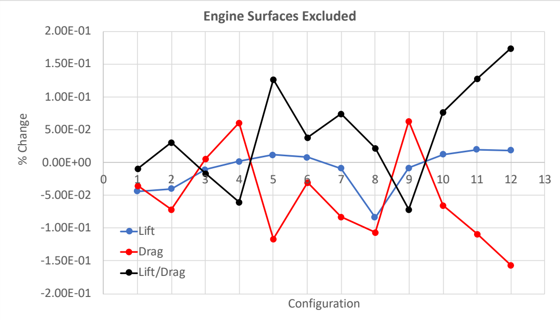


How sensitive is the cooling performance?



What is the effect on vehicle aerodynamics?



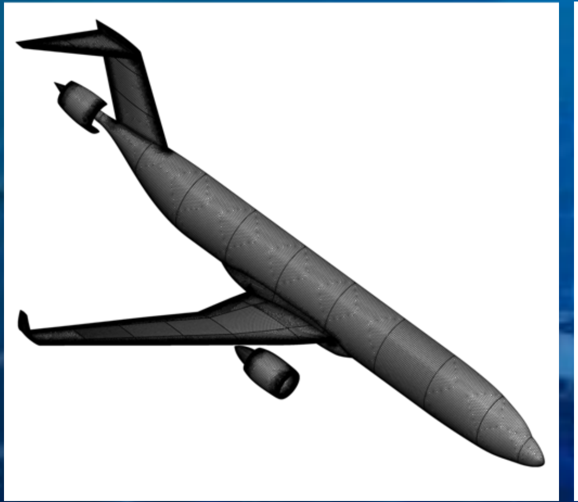


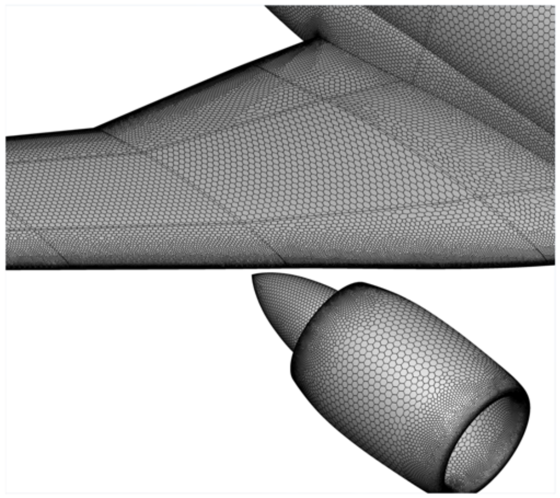
Method

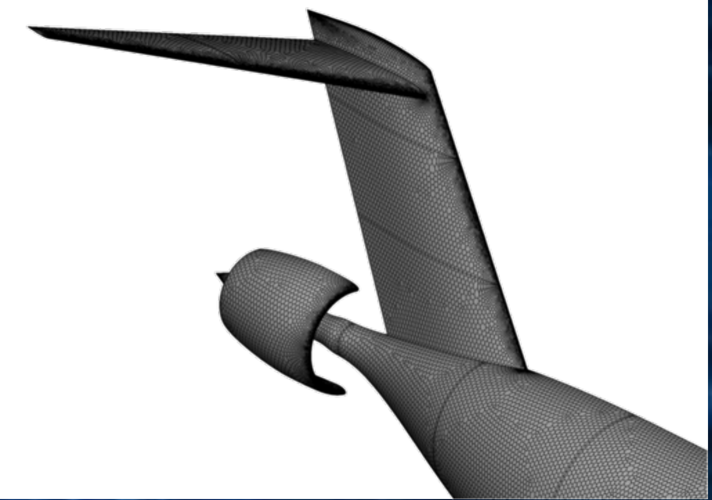
- Launch Ascent and Vehicle Aerodynamics (LAVA) Unstructured code is used
  - Developed in-house at NASA-Ames
  - Operates on arbitrary polyhedral unstructured meshes
  - RANS solver with Spalart-Allmaras (SA) turbulence model
- Boundary layer is resolved down to viscous sublayer (y+<1)
- Propulsors are modeled using an actuator zone model
  - Total thrust and torque of propulsors are imposed as momentum and energy sources in a volumetric zone spanned by propeller blades or fan
- OML-cooling surfaces are modeled as isothermal
  - With 200F surface temperature
  - Temperature choice respects structural limits for long term operation

STARC-ABL

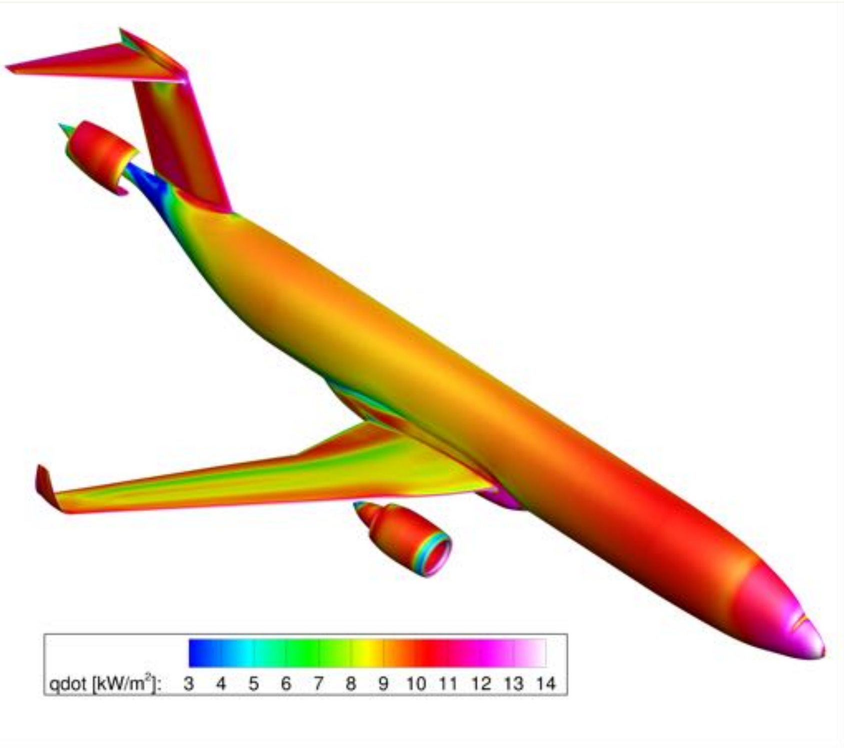
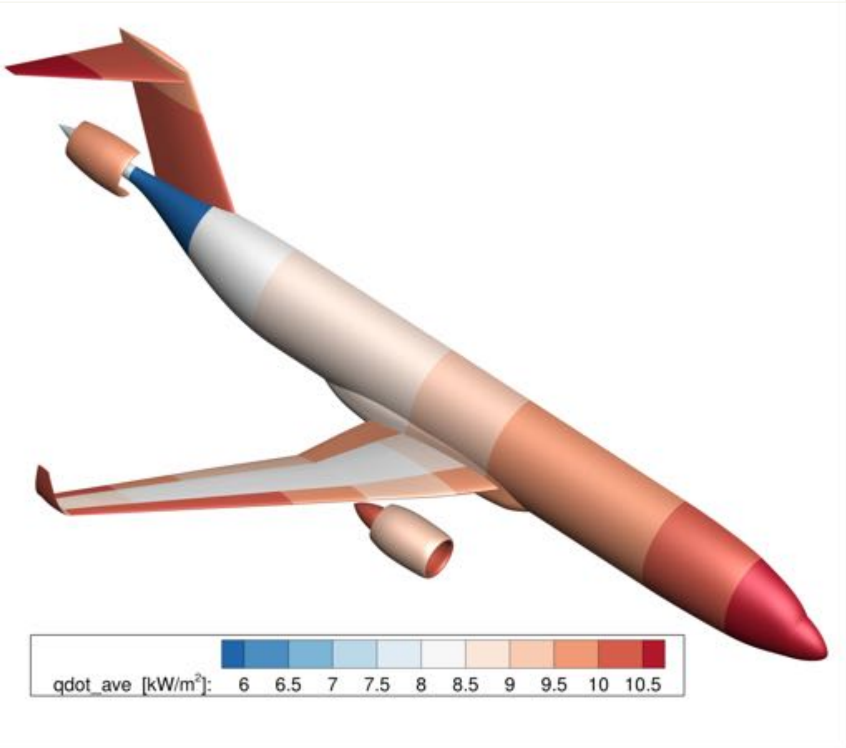
- Half airplane is modeled, taking advantage of the symmetry
- Initial grid contains 25.6 million polyhedral cells
- For preliminary analysis, the entire aircraft is considered as a heat rejection surface
- The surface is split into logical patches to measure average heat rejection capability
- The preliminary simulations did not include the thrusters



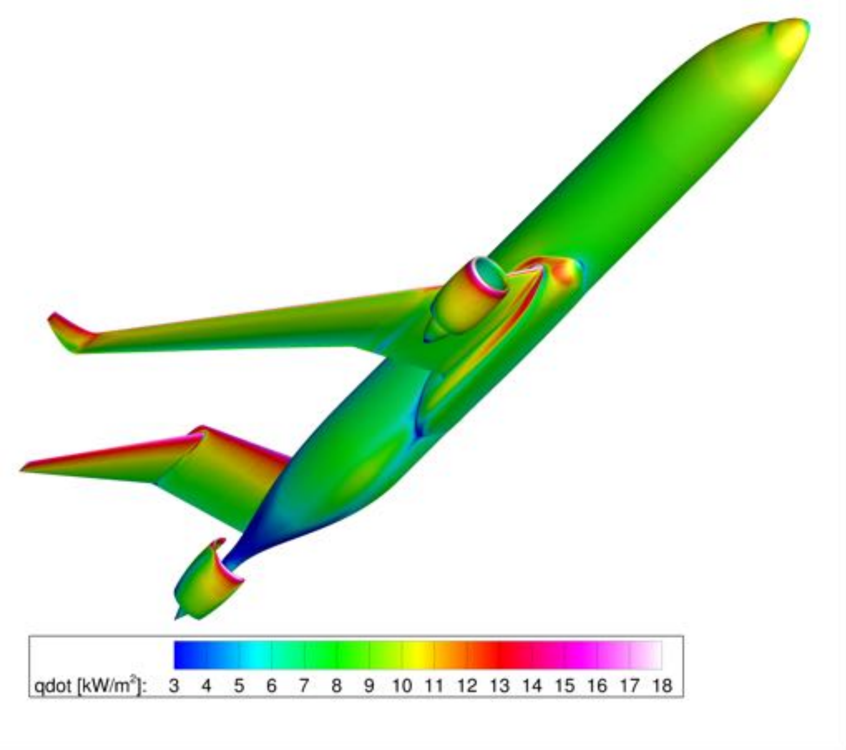
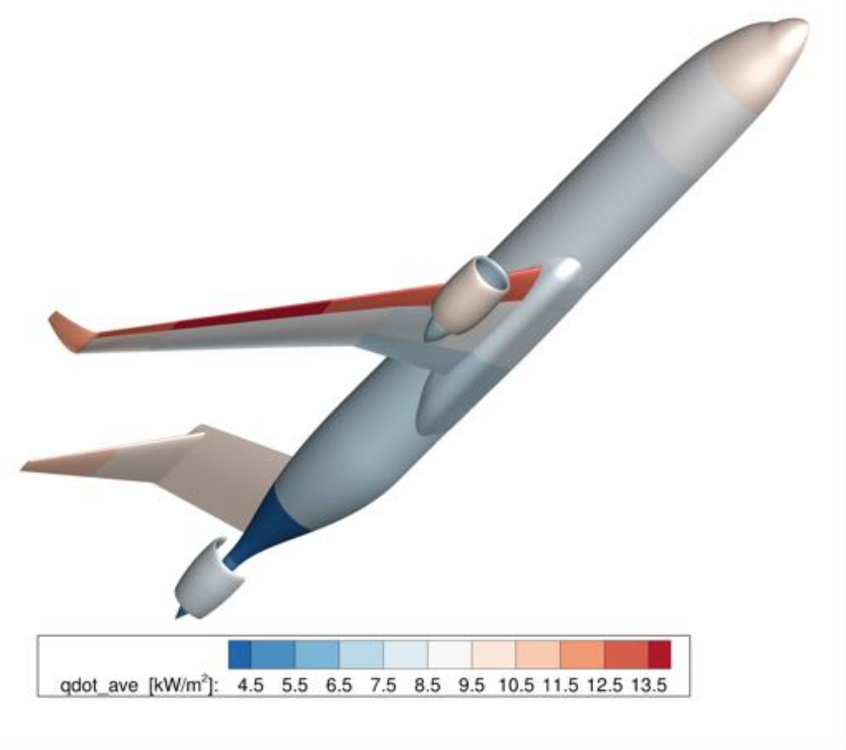




STARC-ABL cruise (alpha = 0)

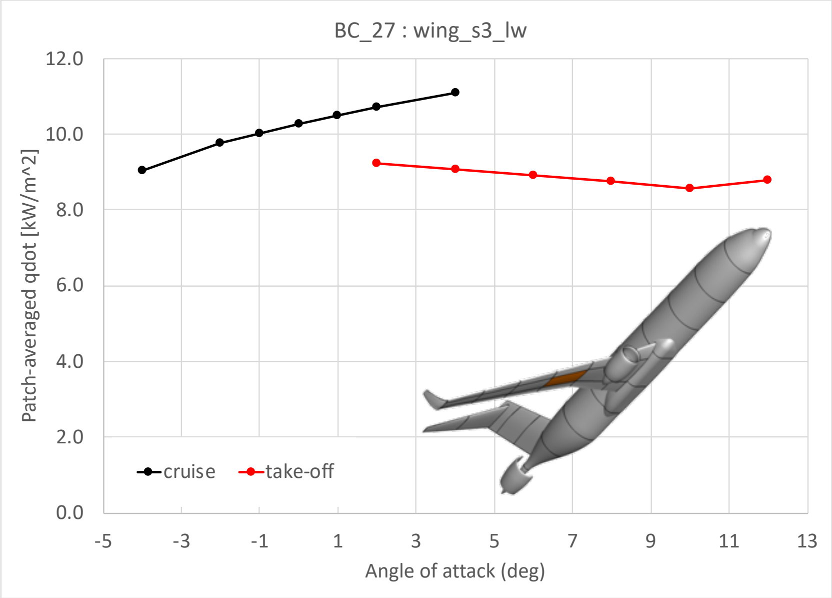
Distribution	Patch-averaged
	

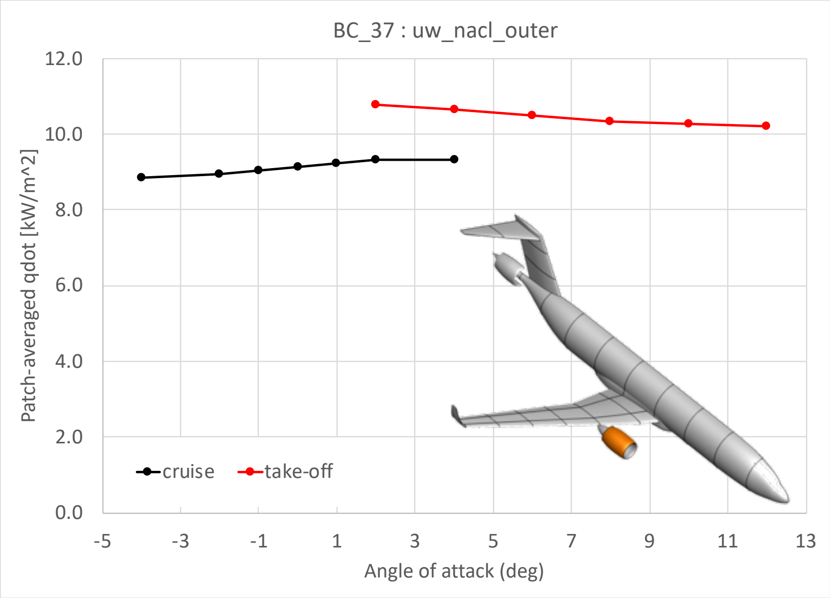
STARC-ABL take-off (alpha = 8)

Distribution	Patch-averaged
	

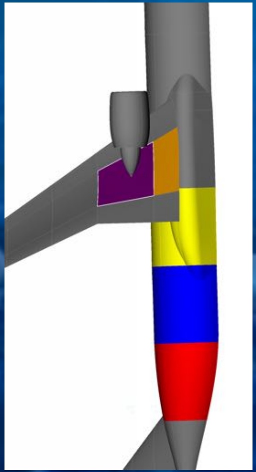
STARC-ABL Sensitivity to Angle of Attack

- Angle of attack sweep was simulated for both cruise and take-off
- Sensitivity of cooling at each surface patch was observed
- Most patches of interest exhibited robust performance with angle of attack variation





STARC-ABL Grid Sensitivity



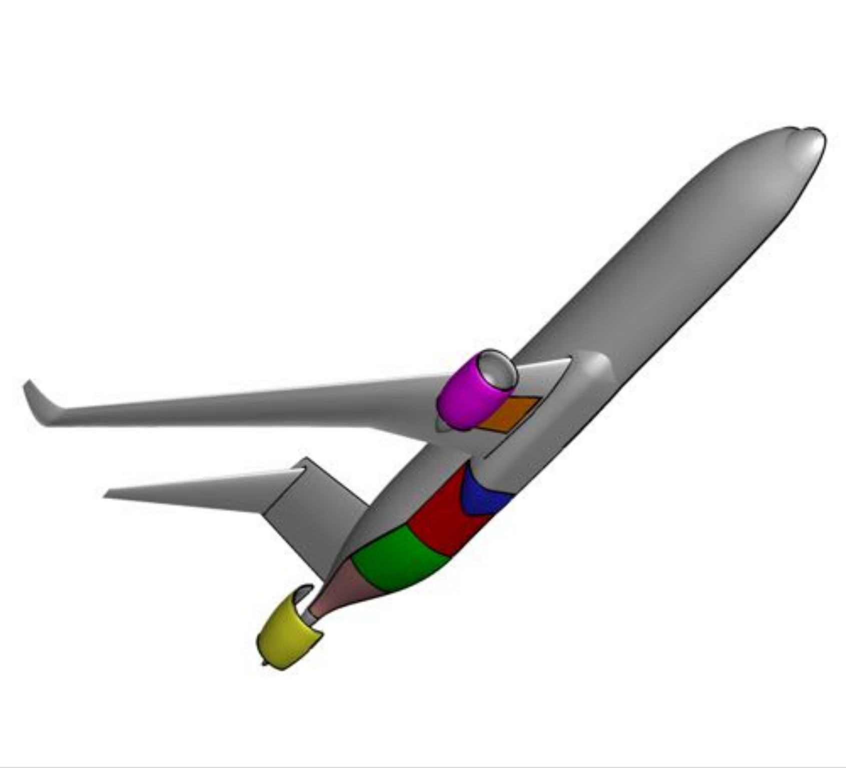
Patch	% Difference in average heat flux		
	Refinement 1 (0.75x)	Refinement 2 (0.5x)	Boundary layer refinement
Wing patch	0.36	0.68	1.66
Fuselage patch 1	1.02	1.91	0.46
Fuselage patch 2	0.77	1.99	0.49
Fuselage patch 3	1.49	2.92	0.44

STARC-ABL Down Selection of Surfaces

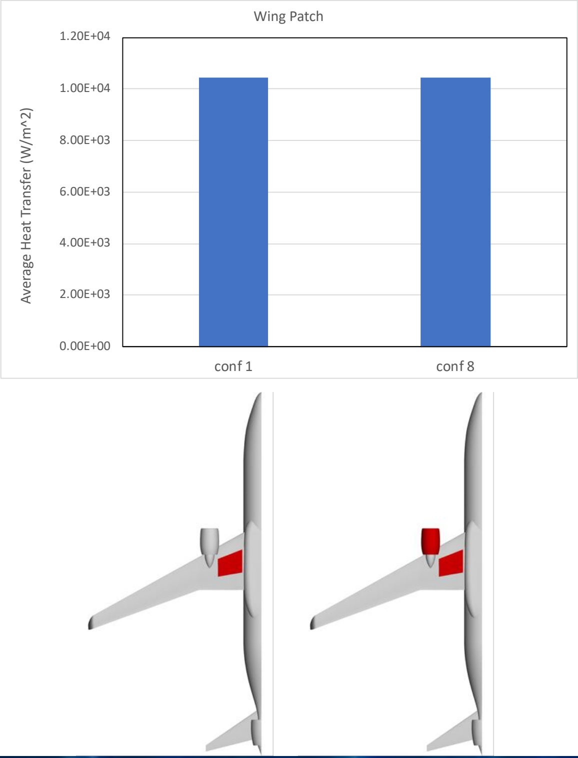
- Candidate OML cooling surfaces are narrowed down according to:
  - Consistent cooling performance
  - Proximity to electrical components
  - Away from critical stress areas
  - Ease of implementation

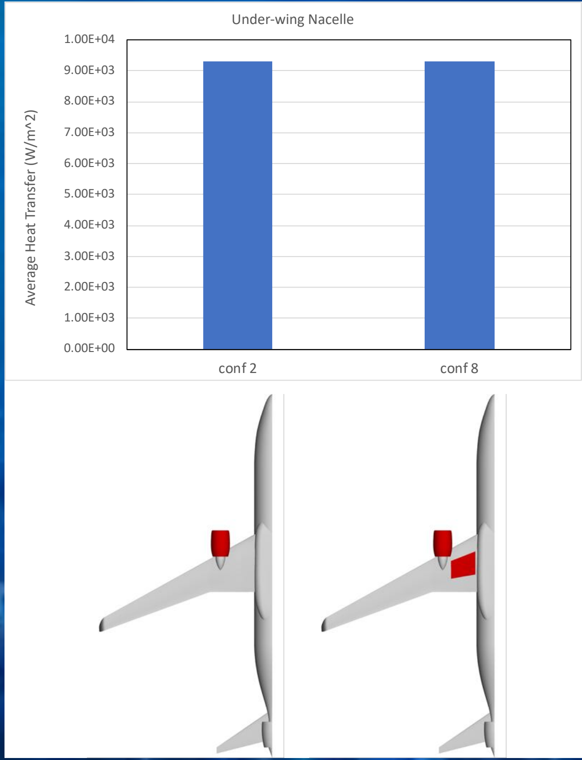
- Grid was updated with additional refinement at patch boundaries
  - 28.5 million polyhedral cells

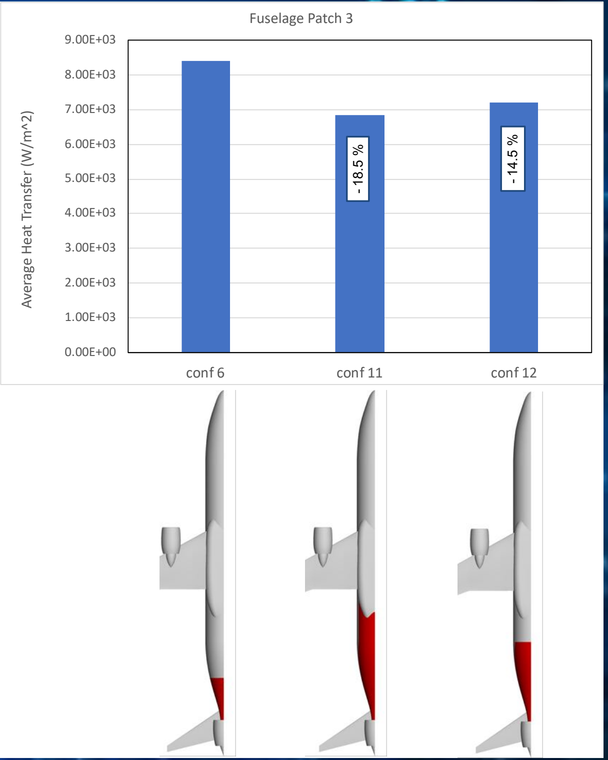
- The final set of simulations were run with thrust-on



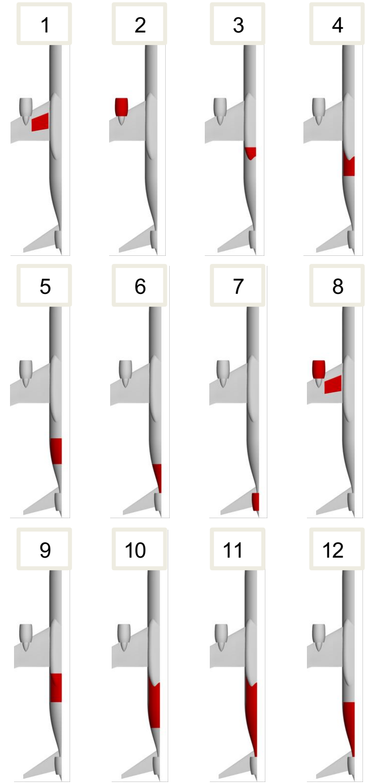
STARC-ABL Patch-to-Patch Interactions

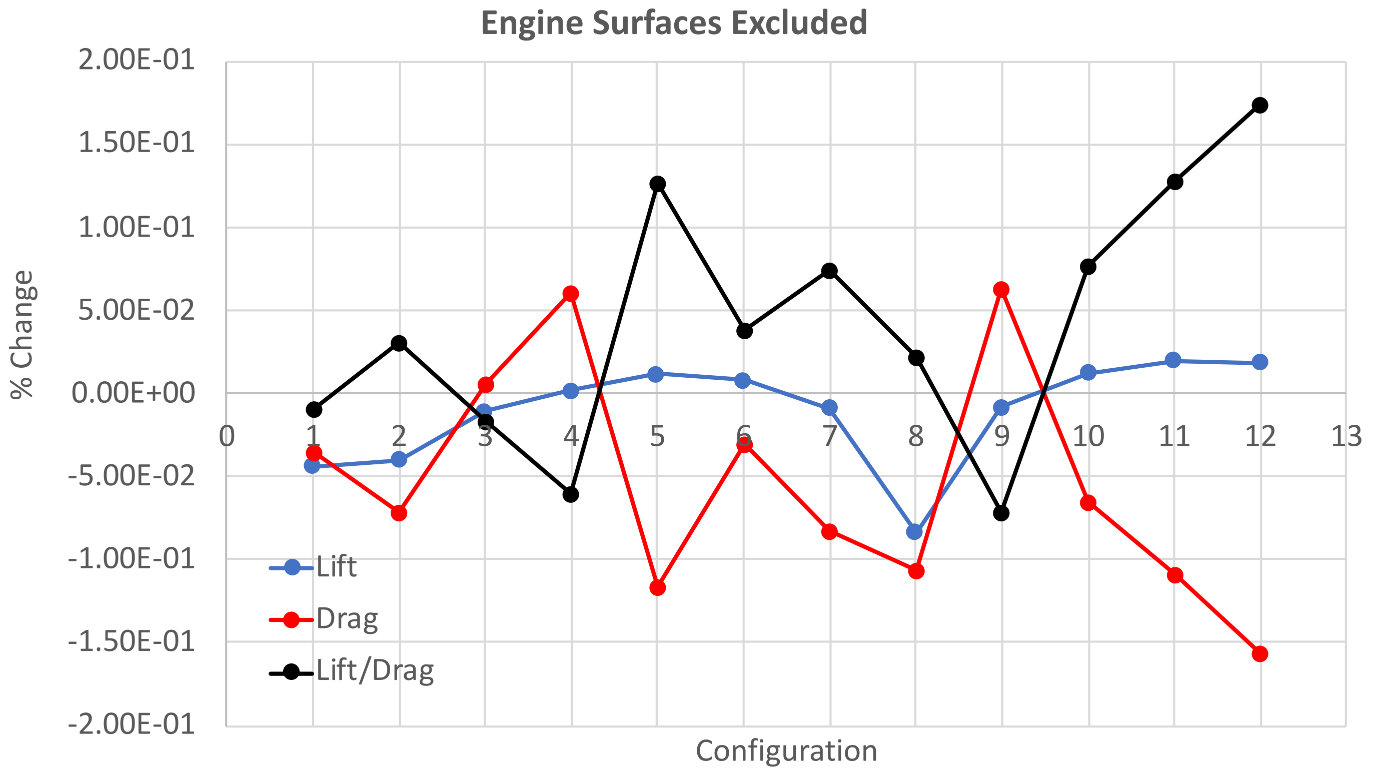




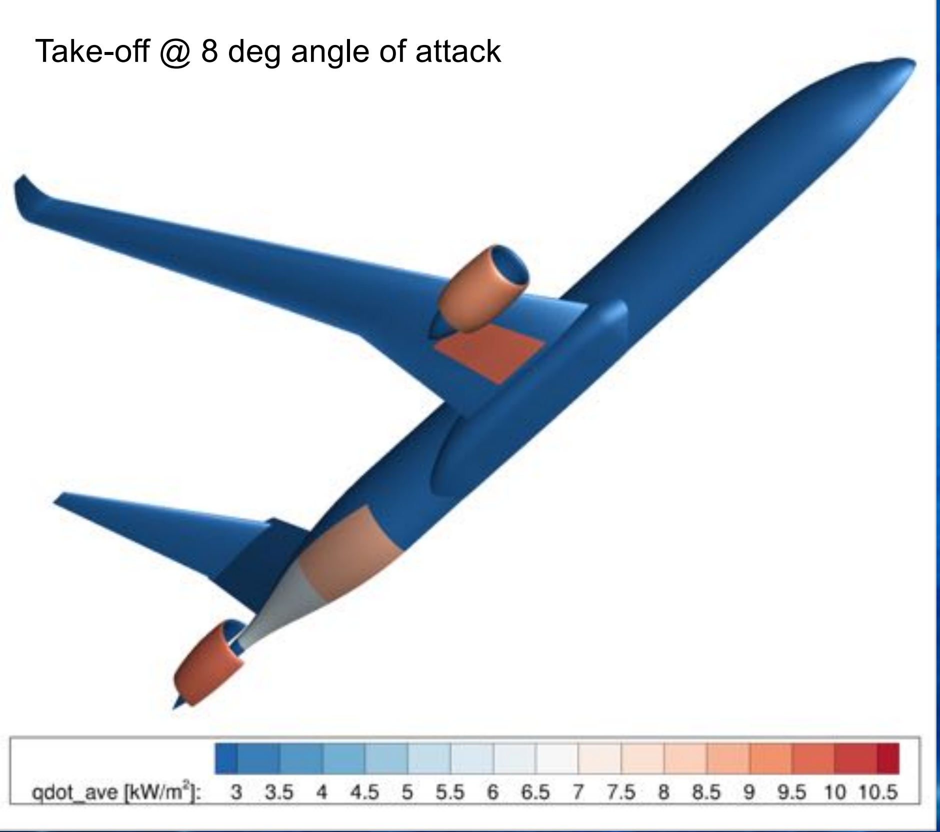


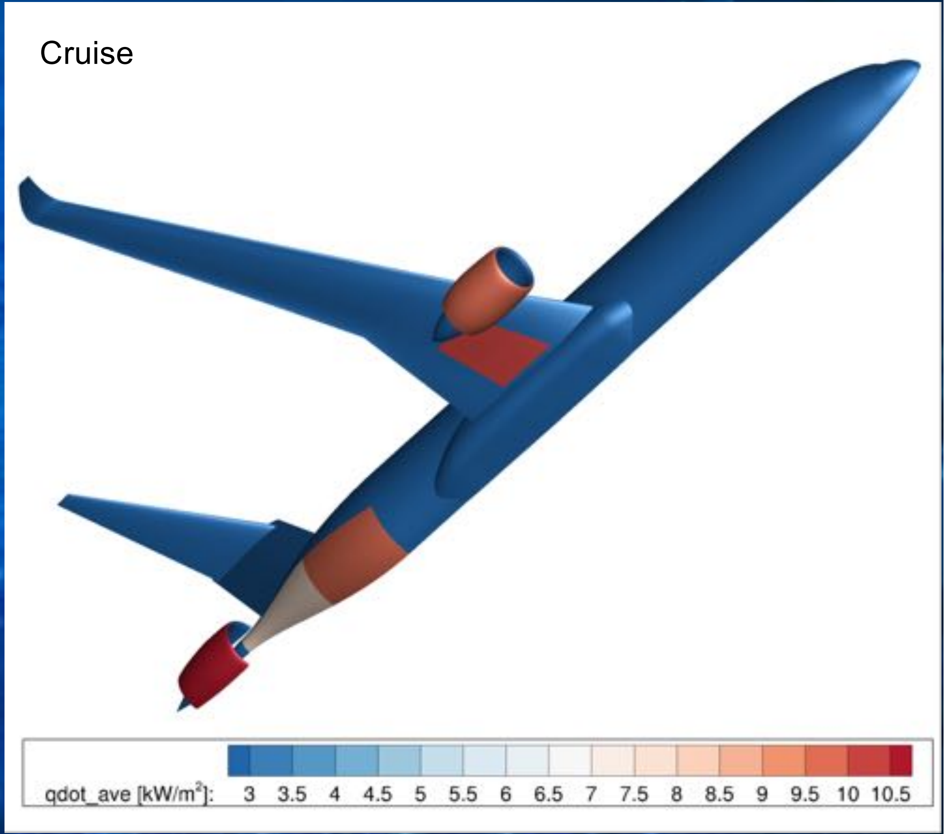
STARC-ABL Effect on Aerodynamics





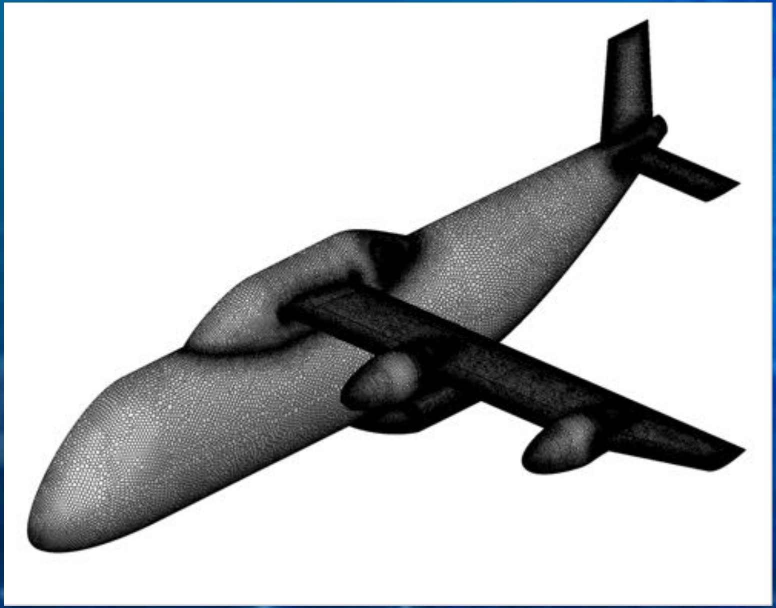
STARC-ABL Final Results

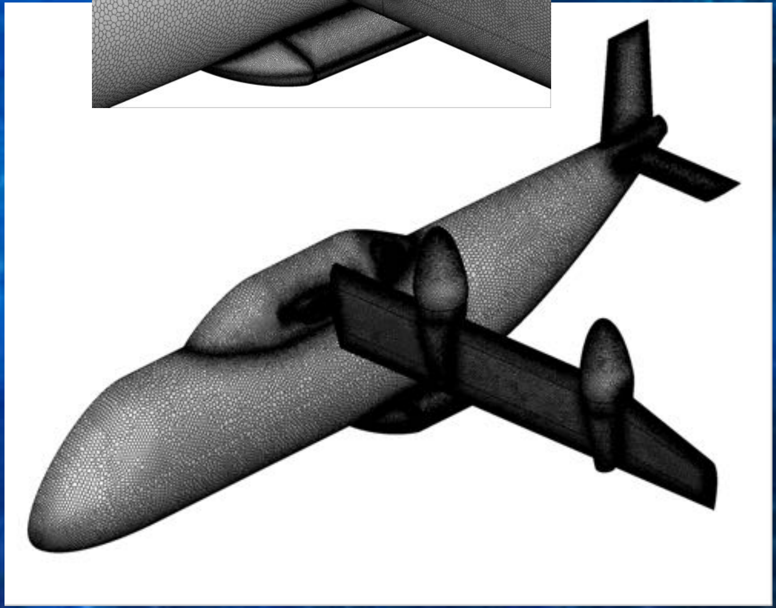


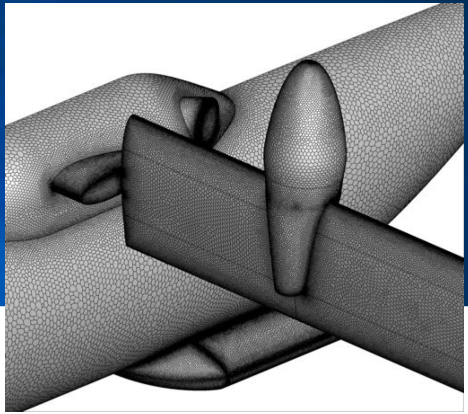


RVLT Grid

- ~24M polyhedral elements
- Half airplane is modeled
- Wall spacing selected to achieve y+ < 1

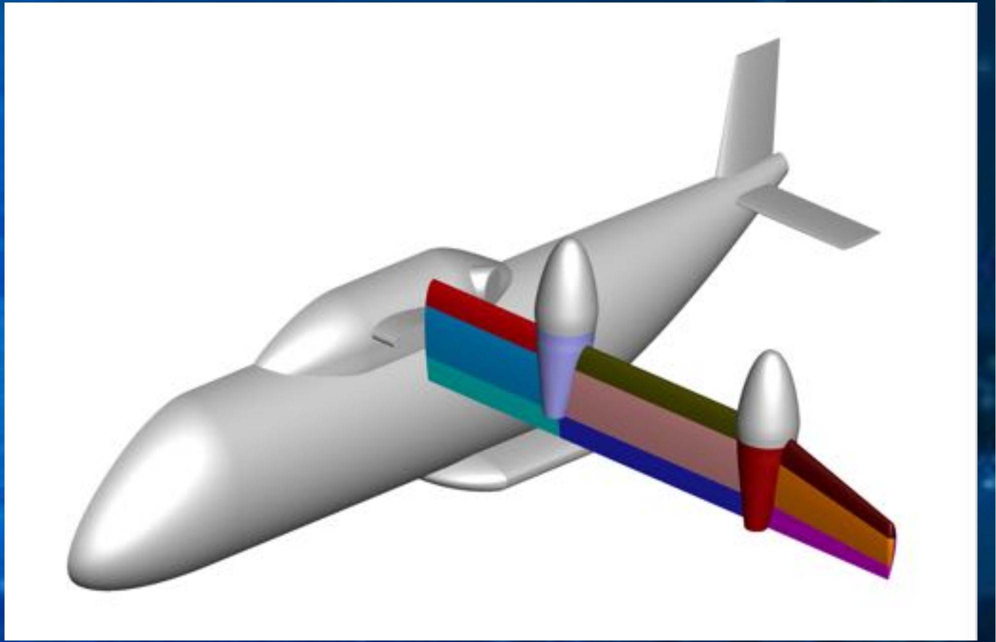




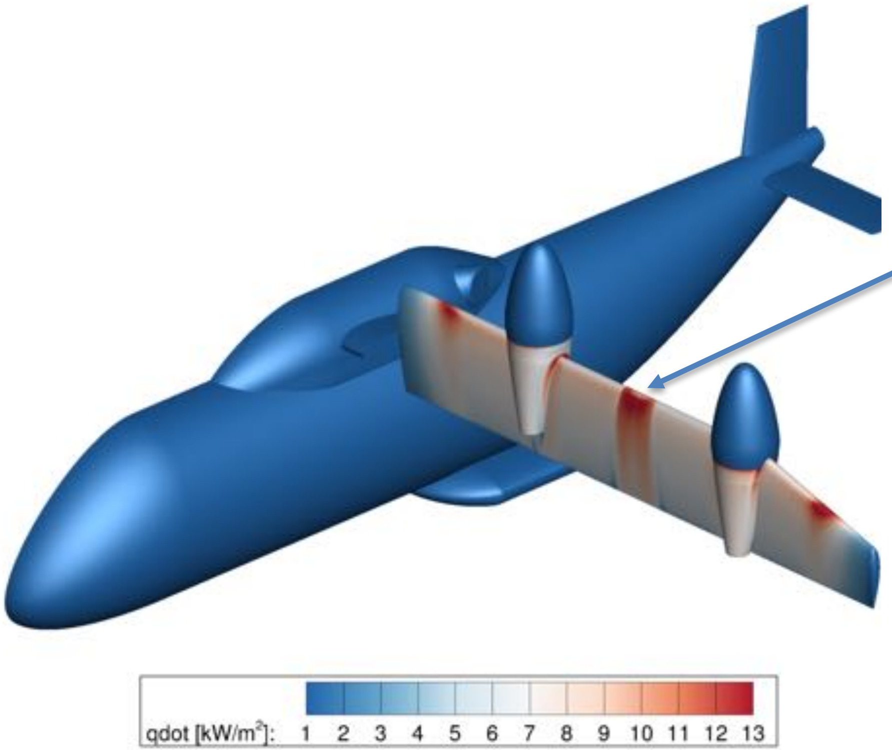


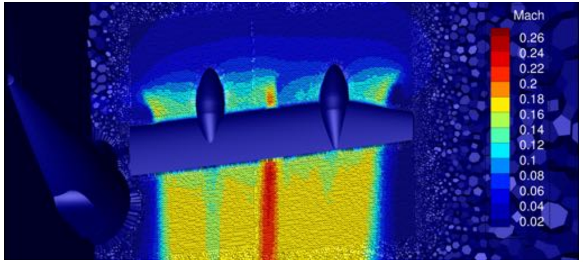
RVLT OML Patching

- Candidate OML cooling regions have been split into logical patches
- For RVLT, hover restricts the OML cooling application to wing surfaces, cooling due to prop downwash
- Wing leading edge, mid and trailing edges have separate patches for inboard, mid-board, and outboard
- Motor nacelles have been included as candidates

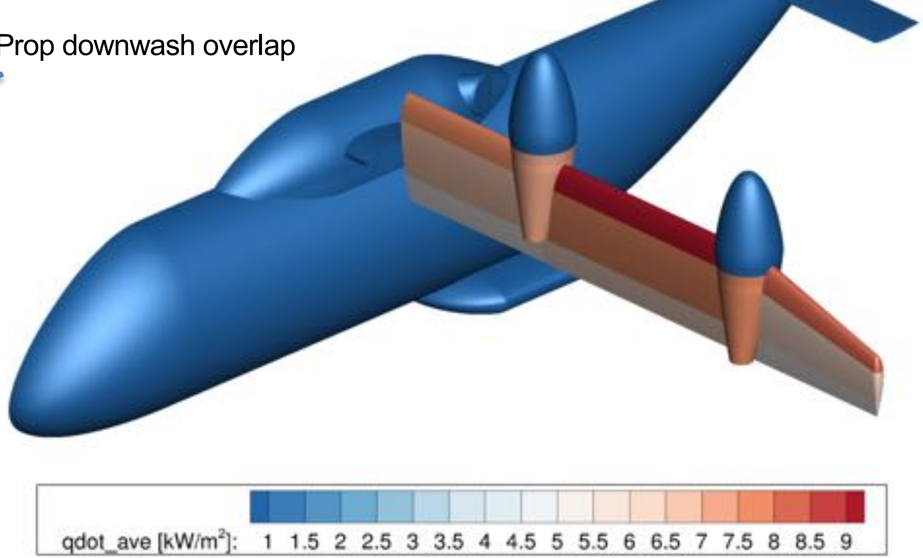


RVLT Results – Hover

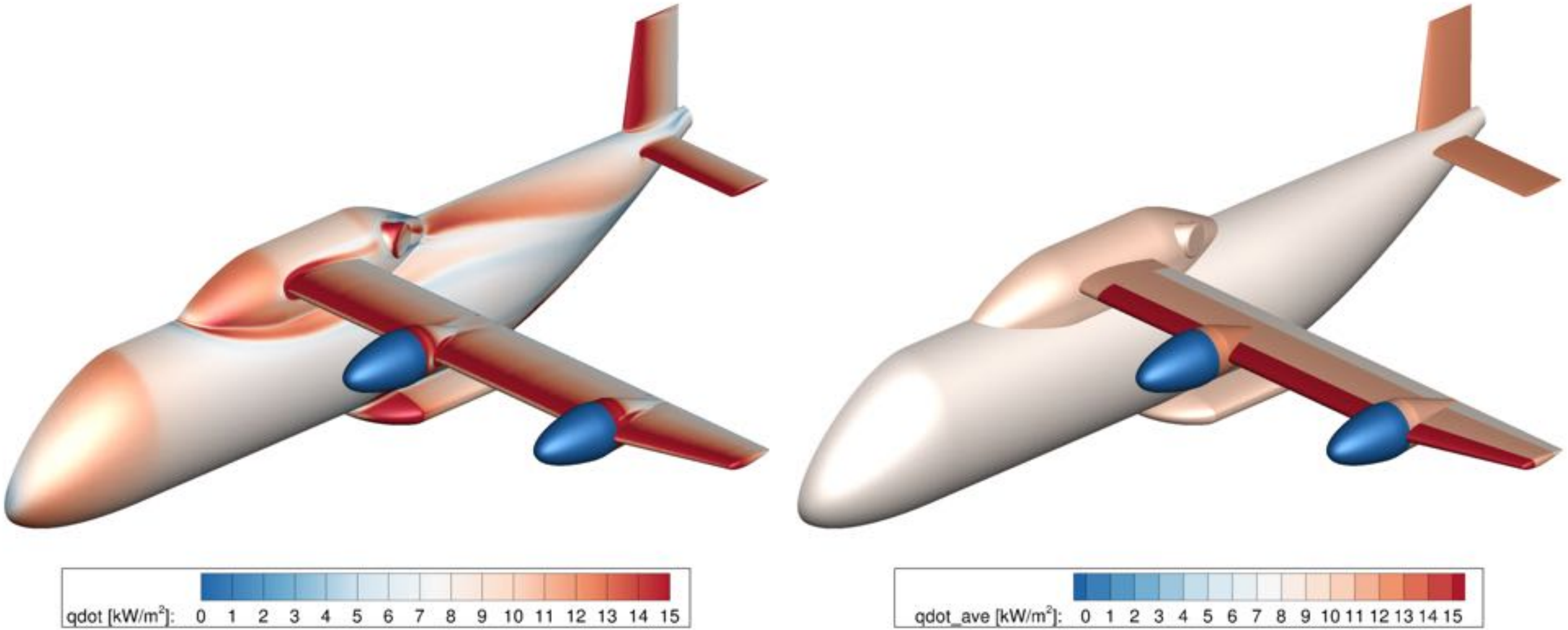




Prop downwash overlap

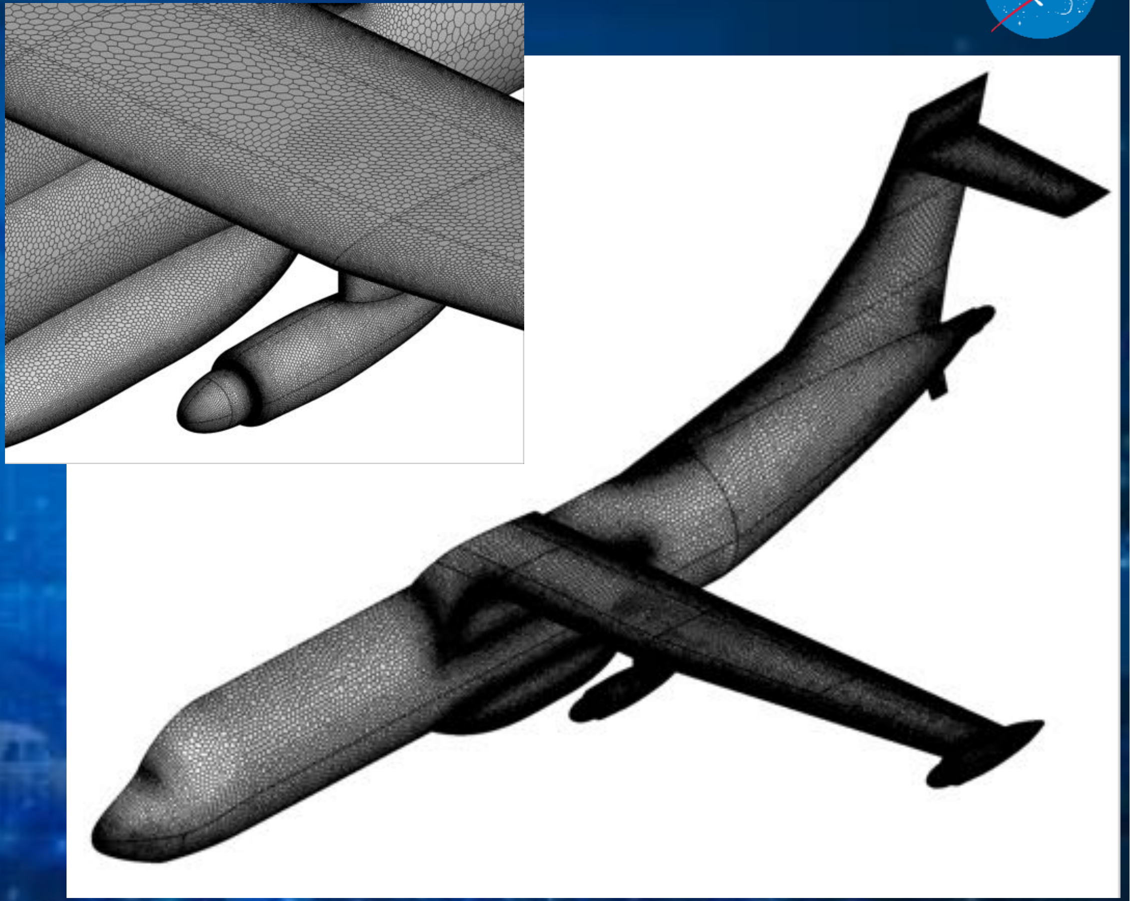


RVLT Results – Cruise



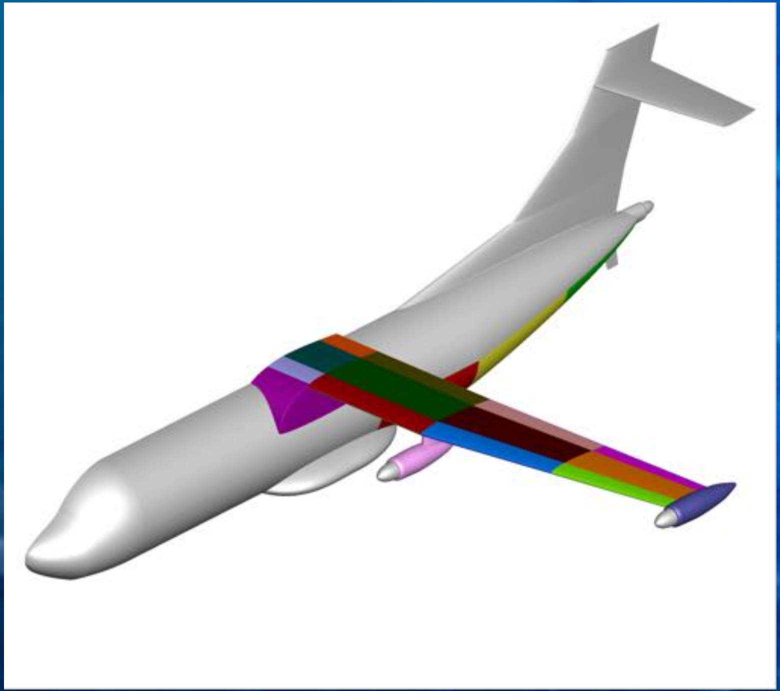
Pegasus Grid

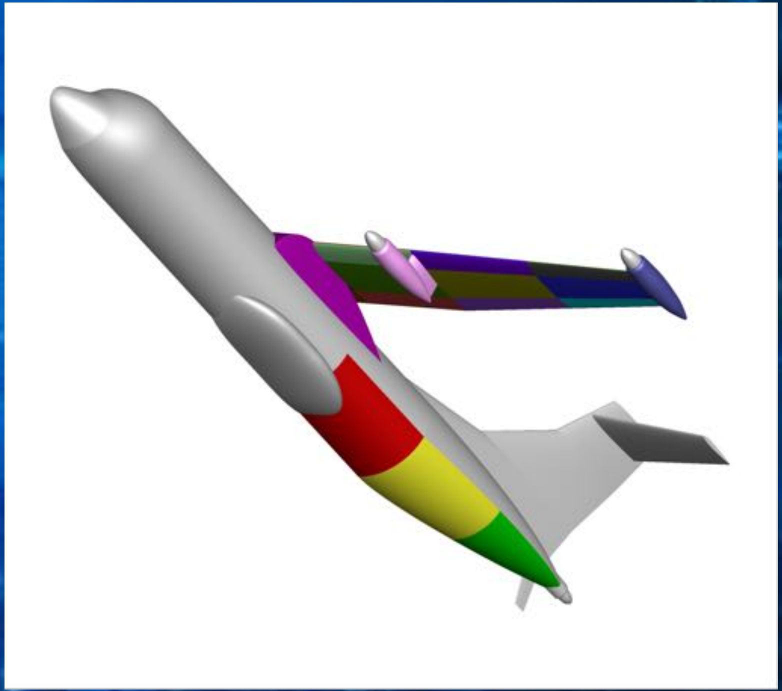
- ~22.4M polyhedral elements
- Half airplane is modeled
- Wall normal spacing set to ensure y+<1



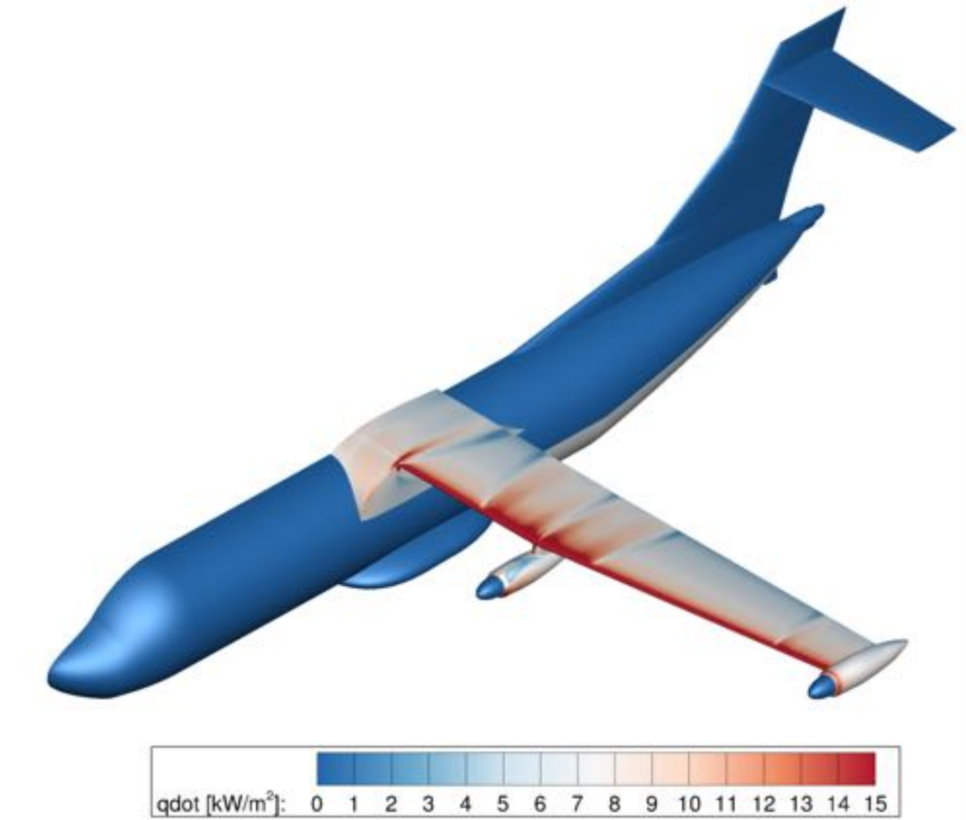
Pegasus OML Patching

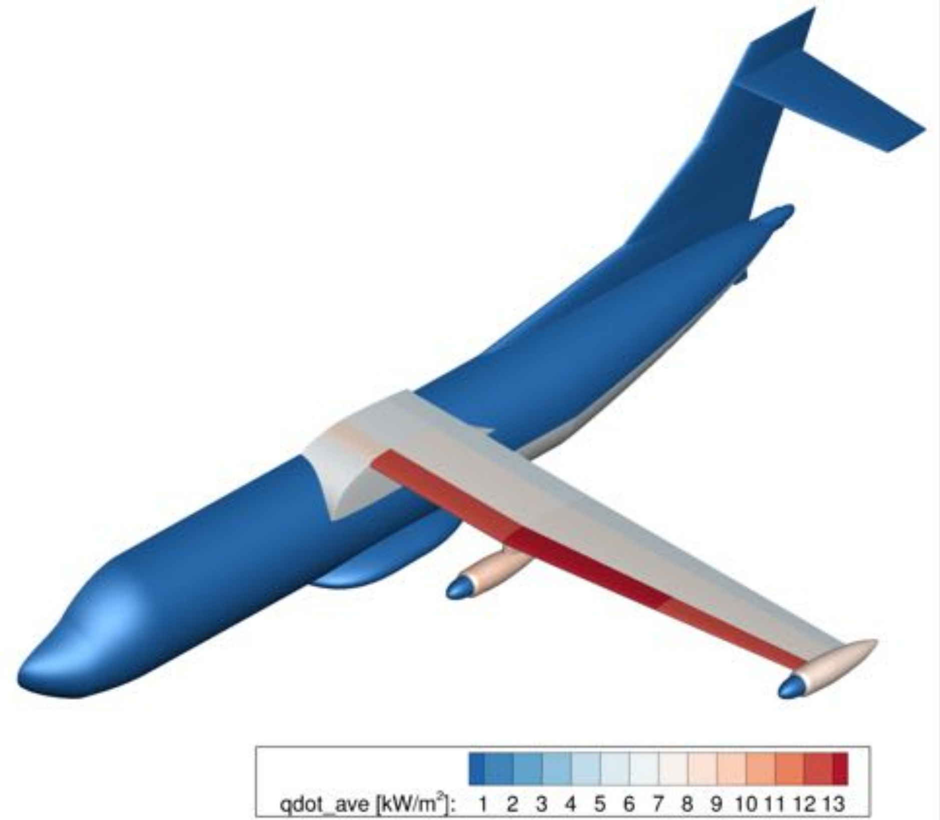
- Candidate OML cooling regions have been split into logical patches





PEGASUS Results – Take-off (alpha = 11 deg)





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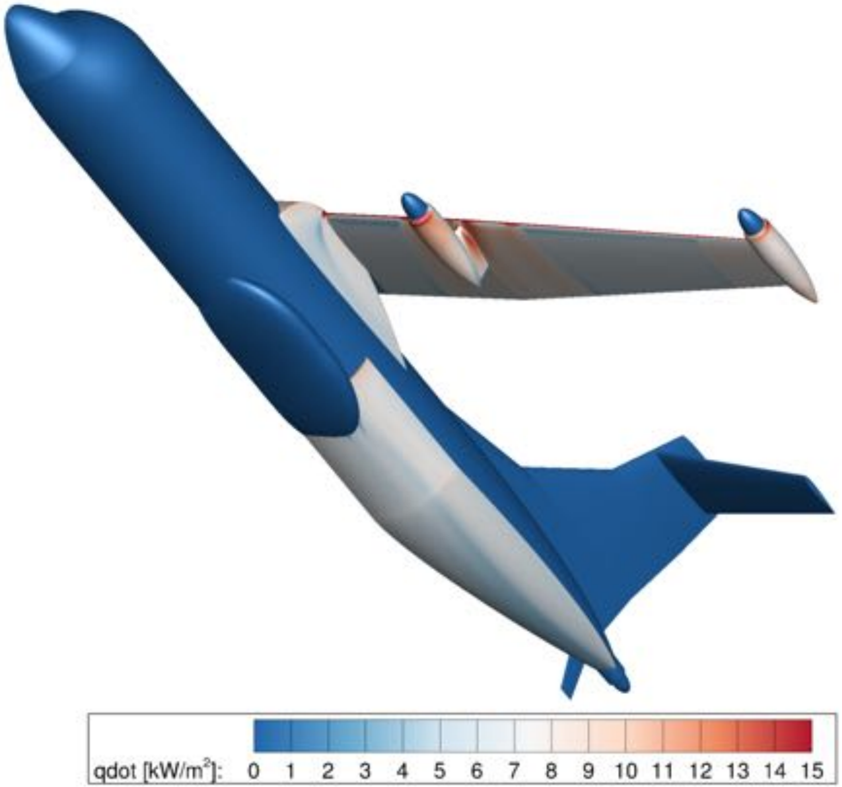
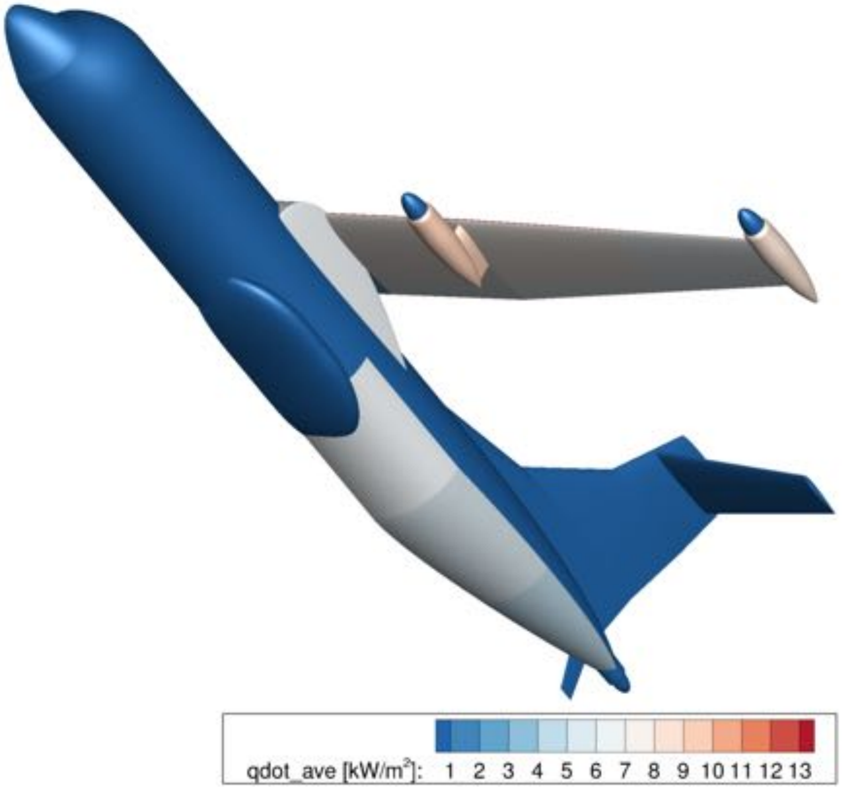
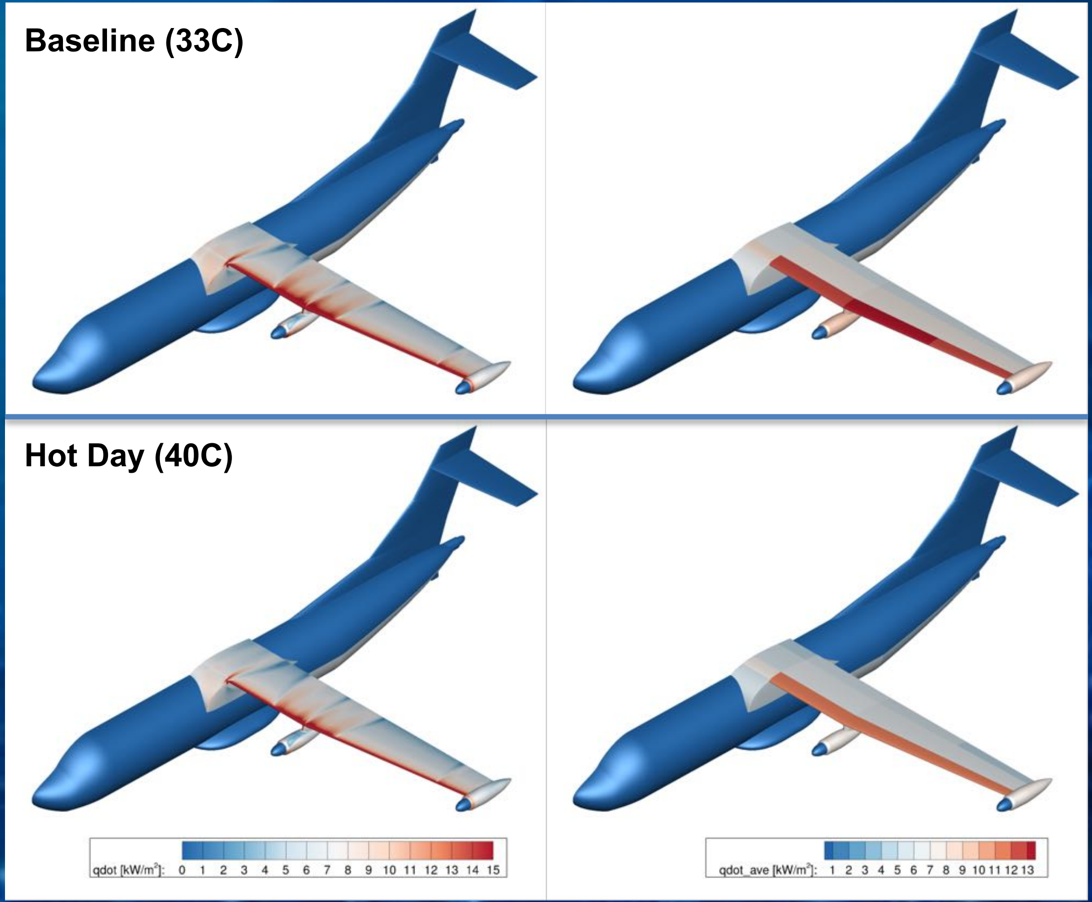
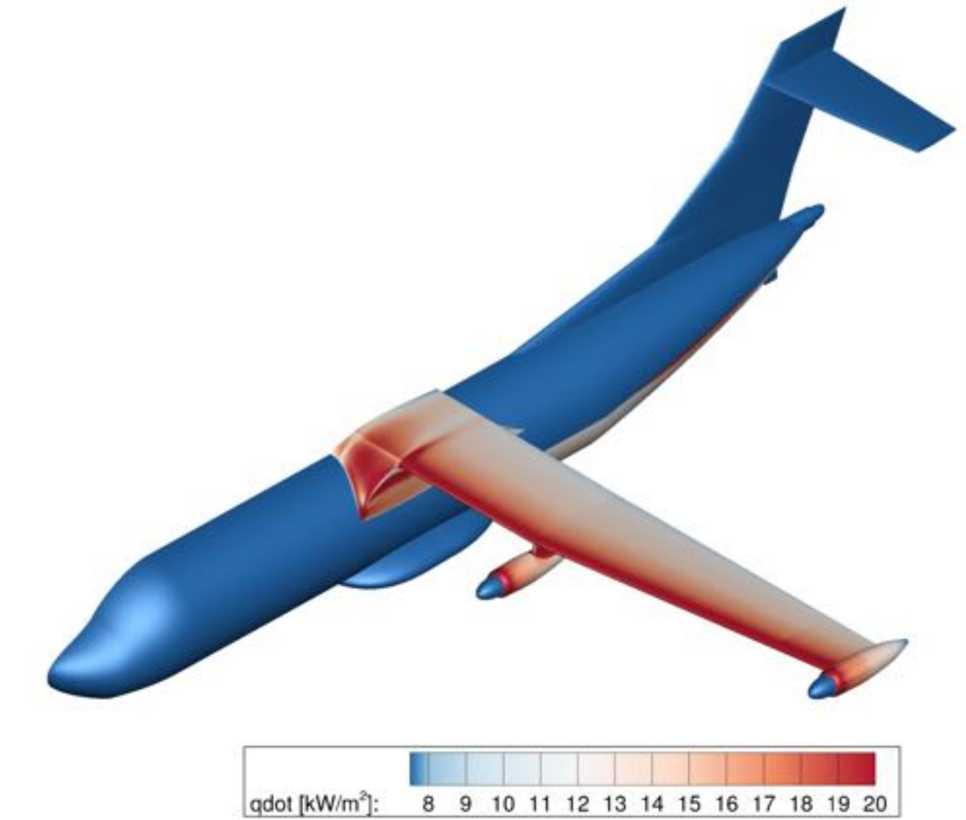


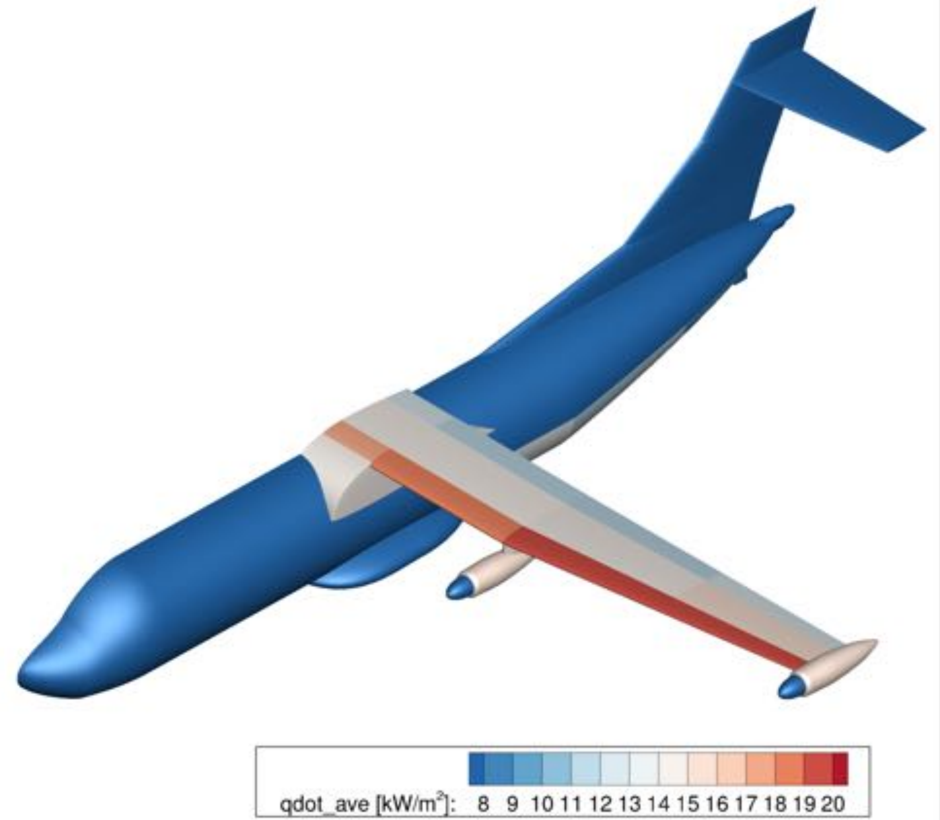


PEGASUS Results – Hot Day Take-off

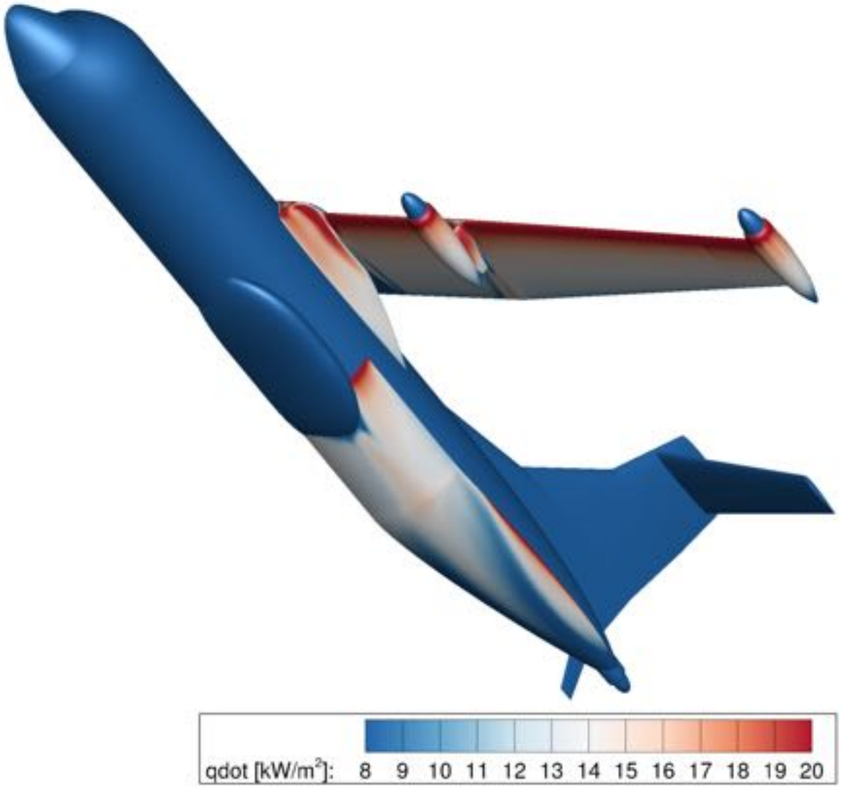


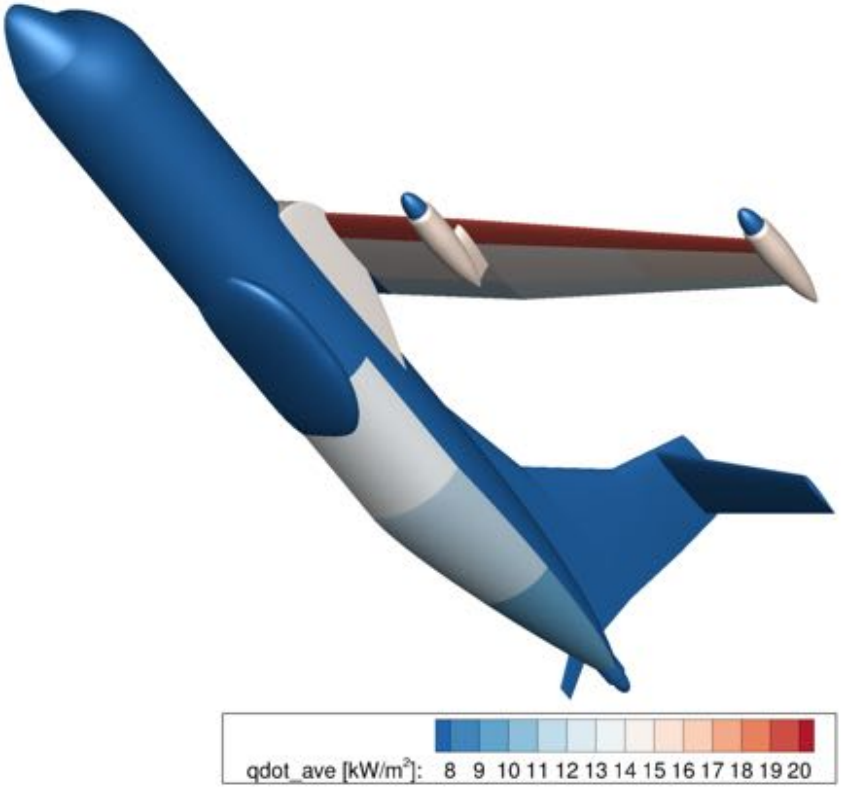
PEGASUS Results – Cruise





PEGASUS Results – Cruise





Conclusions

- Three different electrified aircraft concepts within HEATheR were considered for OML-based heat exchanger implementation
- OML cooling approach was predicted to produce robust, consistent performance for all 3 vehicles at various flight conditions
  - The decreased air density at higher altitudes is compensated by lower ambient temperatures
  - Cooling capacity at take-off (or hover) is still more restricted compared to cruise
    - Especially for a potential hot day
  - The largest variation was observed for PEGASUS, for which the cooling capacity is nearly halved compared to cruise
- The CFD results were used by project to size an OML-based thermal management system
- Future works includes further verification and validation studies of the CFD analysis
- As the concept designs mature, a higher fidelity conjugate simulation can be performed to predict surface temperature distribution along with heat flux

Acknowledgements

- The current work was funded by NASA's Convergent Aeronautics Solutions (CAS) project.
- The authors would like to thank James Jensen for contributions to geometry processing and Cetin Kiris for the valuable guidance.