Better Designs Faster in the Aerospace and Defense Industry

Durrell Rittenberg

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AMS Seminar Series
NASA Ames Research Center
August 29, 2017

Aerospace and Defense Industry Trends

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We are entering the 3rd aerospace revolution

- 1200 Aerospace Active Aerospace Start-ups
- 50% of MIT Aerospace grads going to non-traditional aerospace companies
- $5 Billion in VC funding in 2017
- Are we moving fast enough?

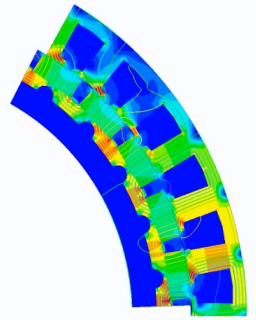
New Propulsion Strategies

- Electrification and new propulsion methods
- New strategies, new opportunities



The Green Skies Initiative

- Siemens 330LE
- Airbus E-FAN X 20 MW commercial regional jet
- New motor designs



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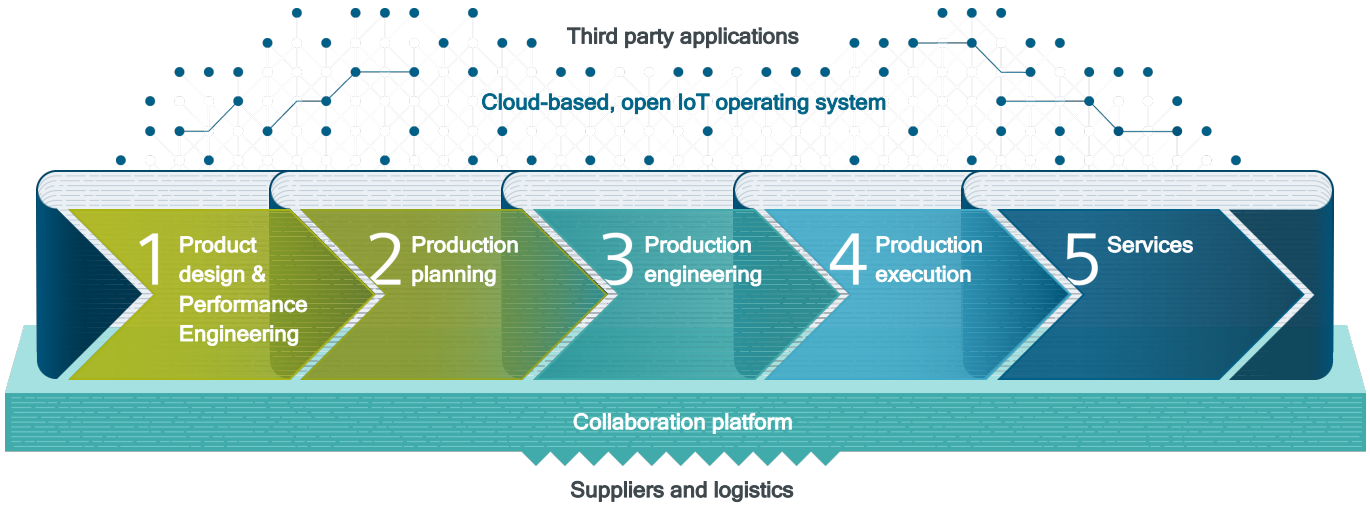


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Digitalization
changes
everything

Integrating and digitalizing the entire value chain is key to staying competitive in the future

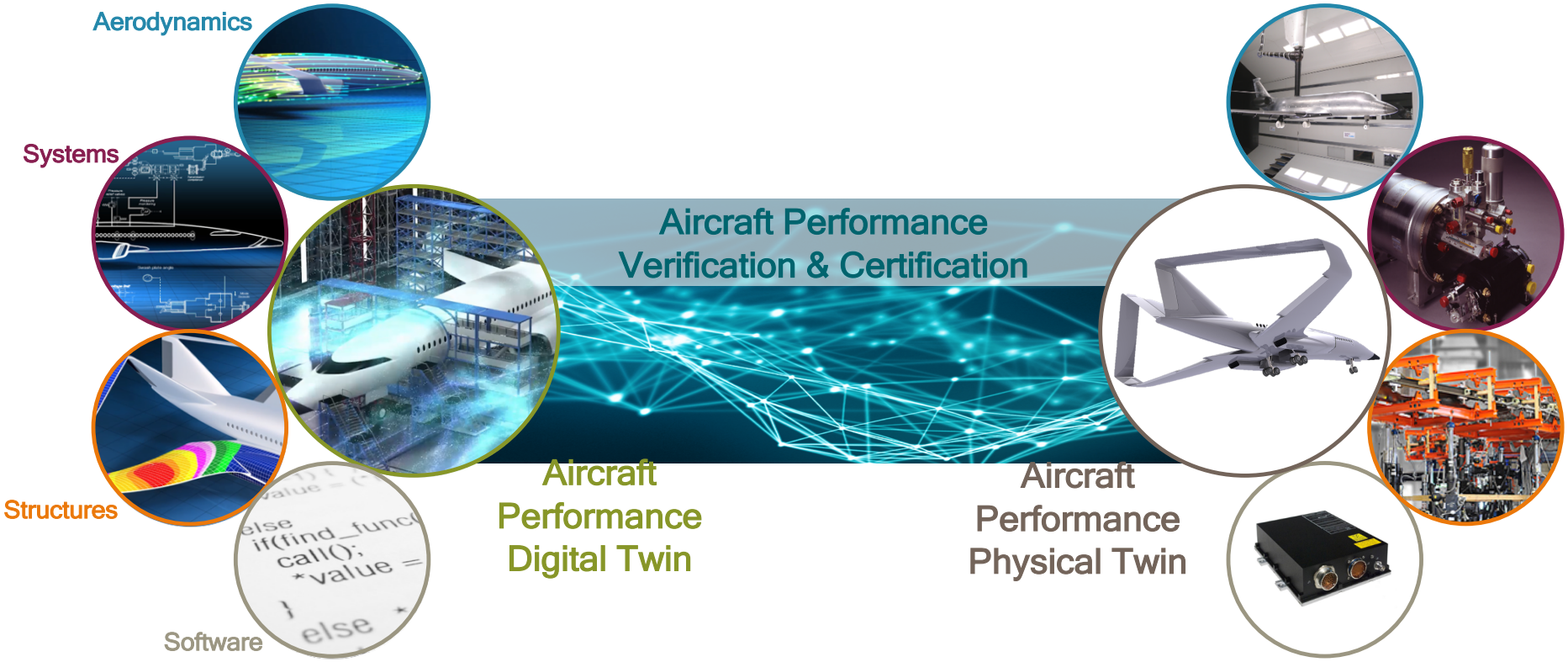
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The Digital Twin in detail

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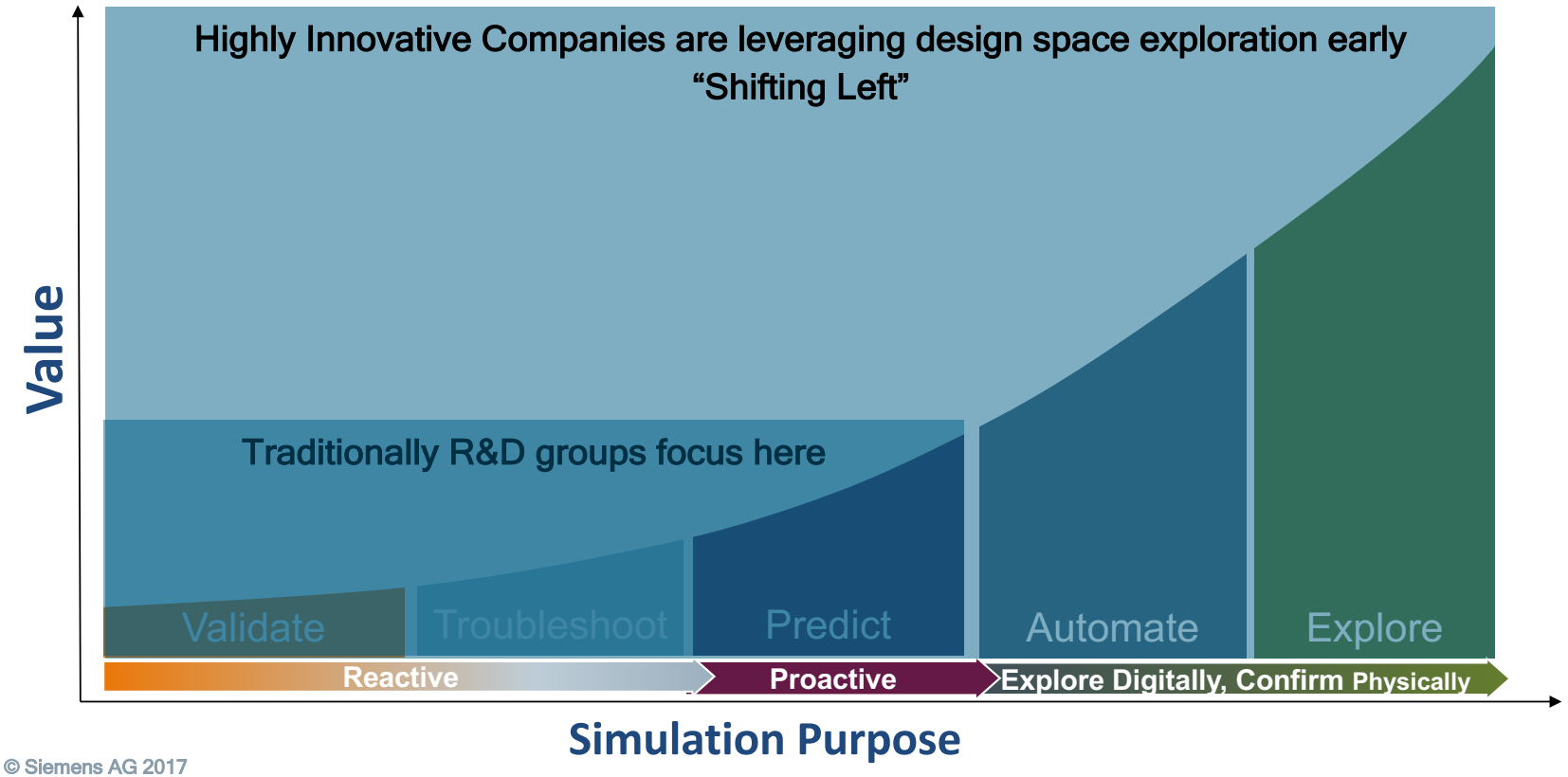


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Idea
Technology
INNOVATION
Invention
Creativity
Improvement
"Any company that ... stays stationary with their technology will be exceeded by their competitors"
Elon Musk
Tesla-SpaceX

Redefining Simulation Strategy for Innovation

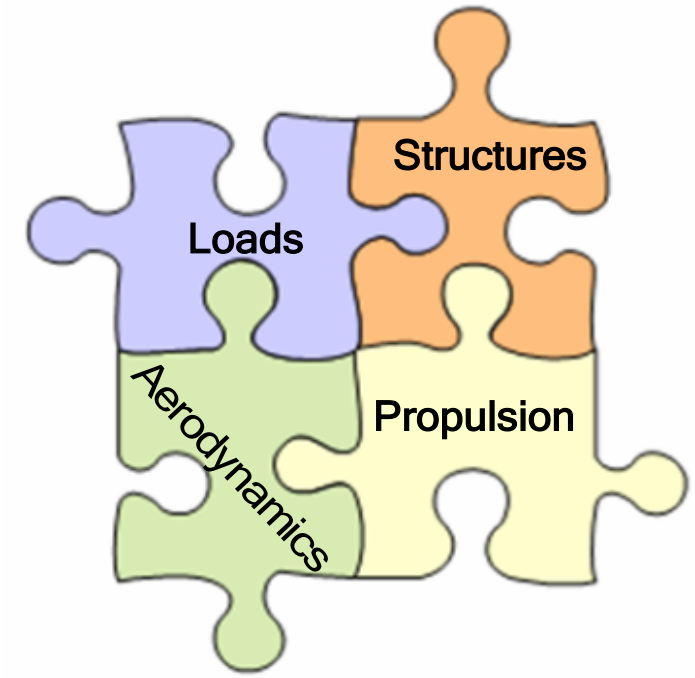
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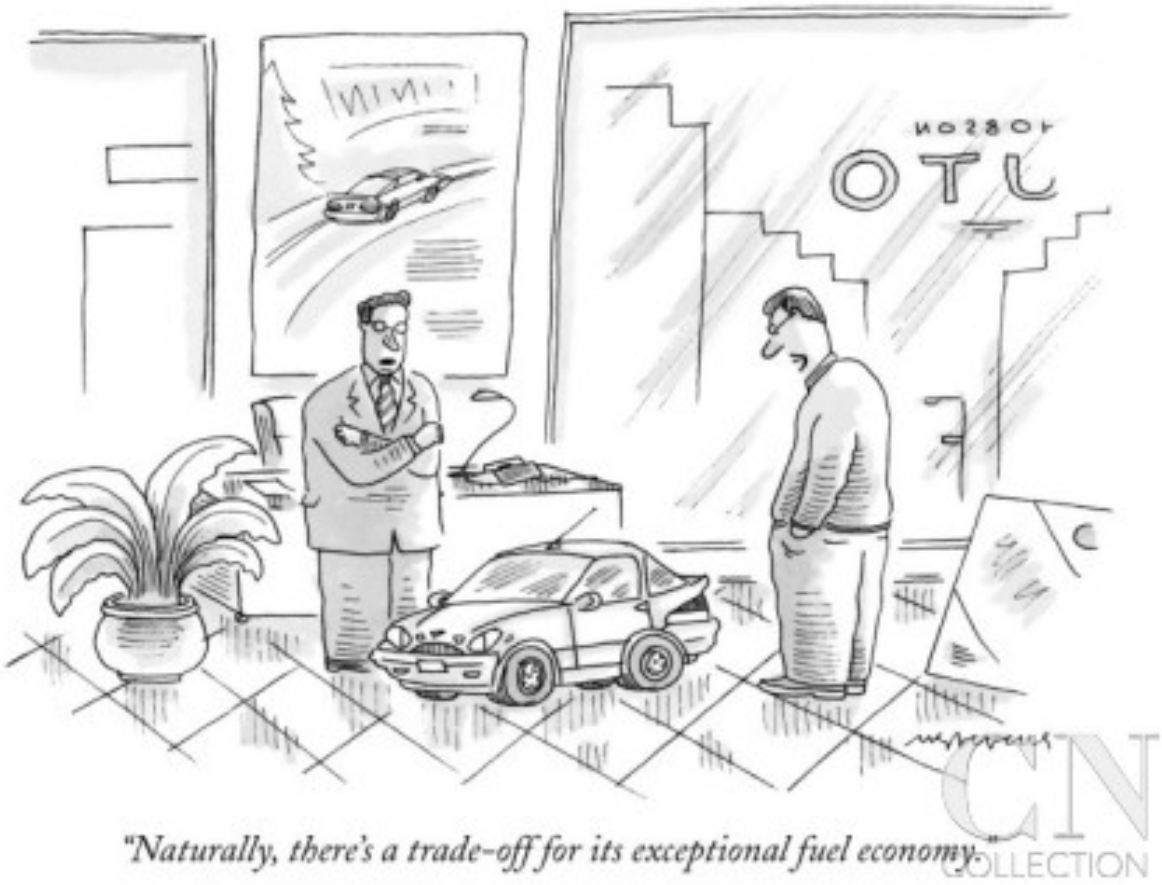


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What is the “real” value in design space exploration?

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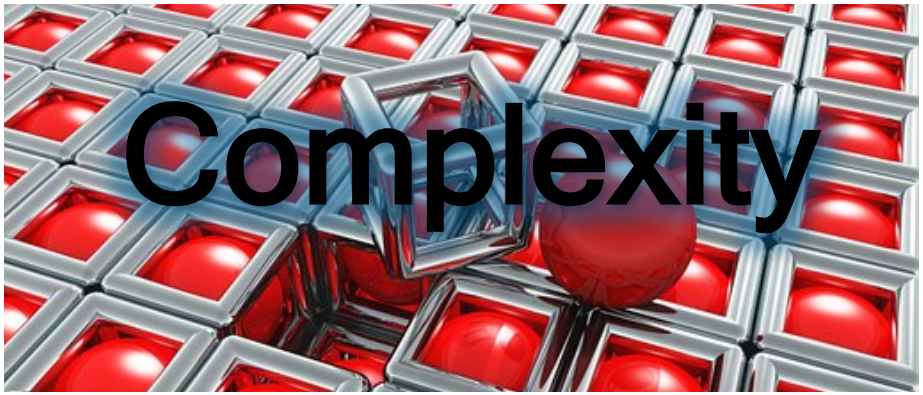




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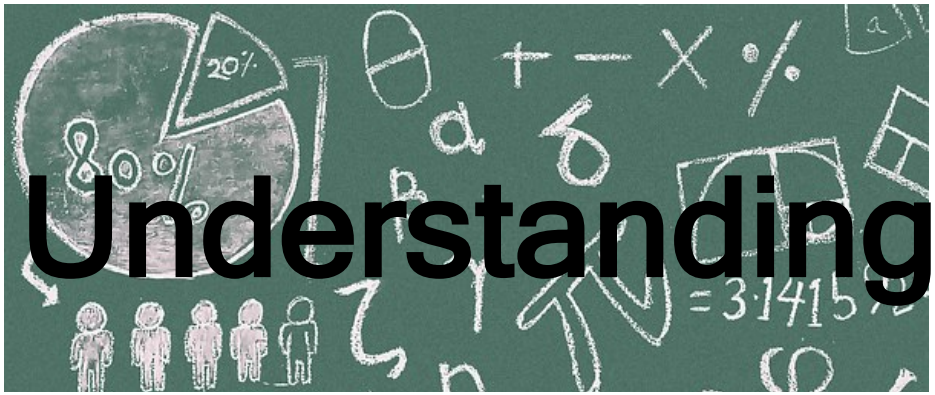
What holds organizations back from adopting design space exploration?

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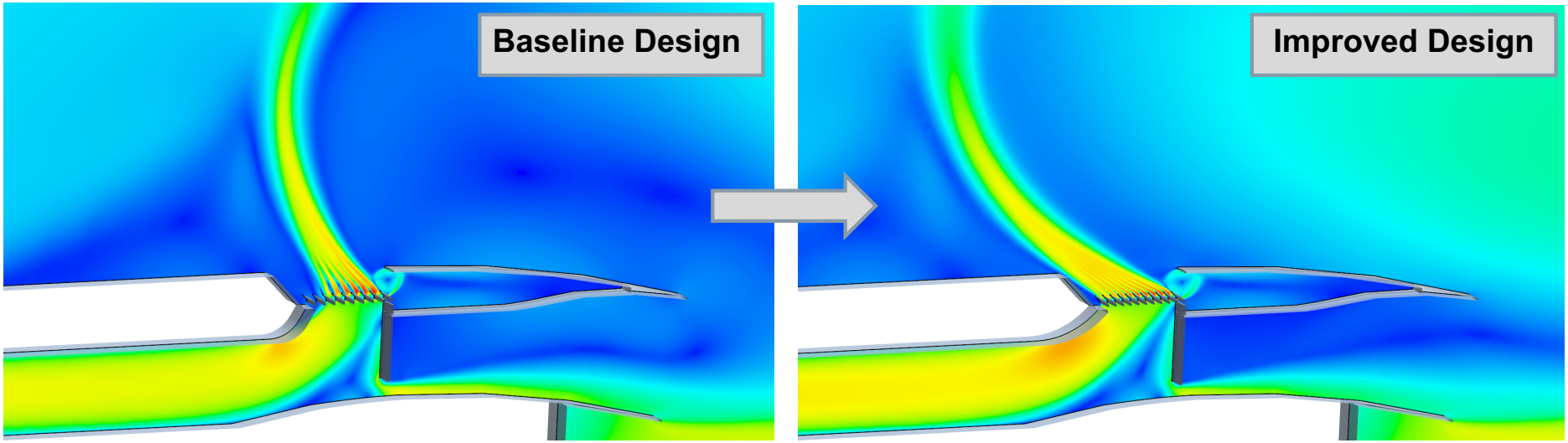


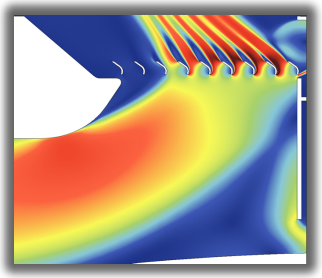


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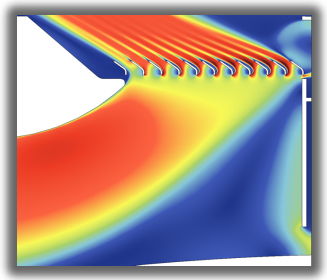
Driving Innovation through Simulation

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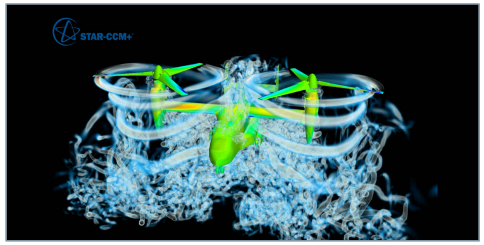
- 49% improvement in reverse thrust
- 18% increase in plume angle

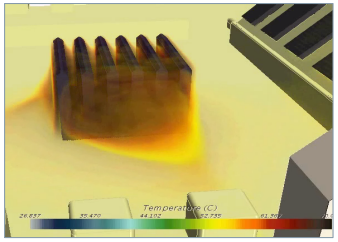


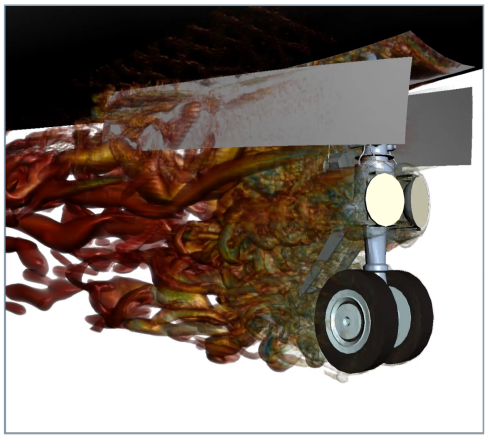
STAR-CCM+

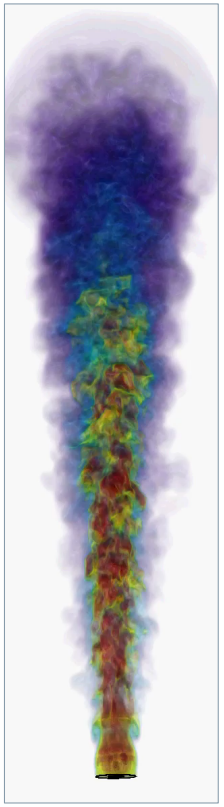
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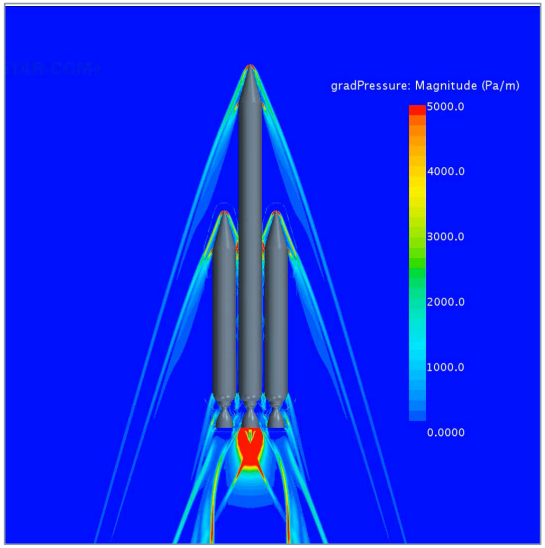
- Fluid Dynamics
- Solid Mechanics
- Fluid-structure Interaction
- Heat Transfer
- Particle Flows
- Reacting Flows
- Multiphase
- Electrochemistry
- Electromagnetics
- Acoustics
- Rheology



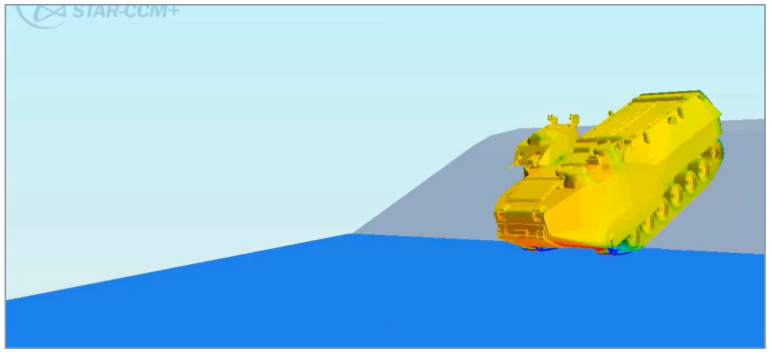








Multiphysics



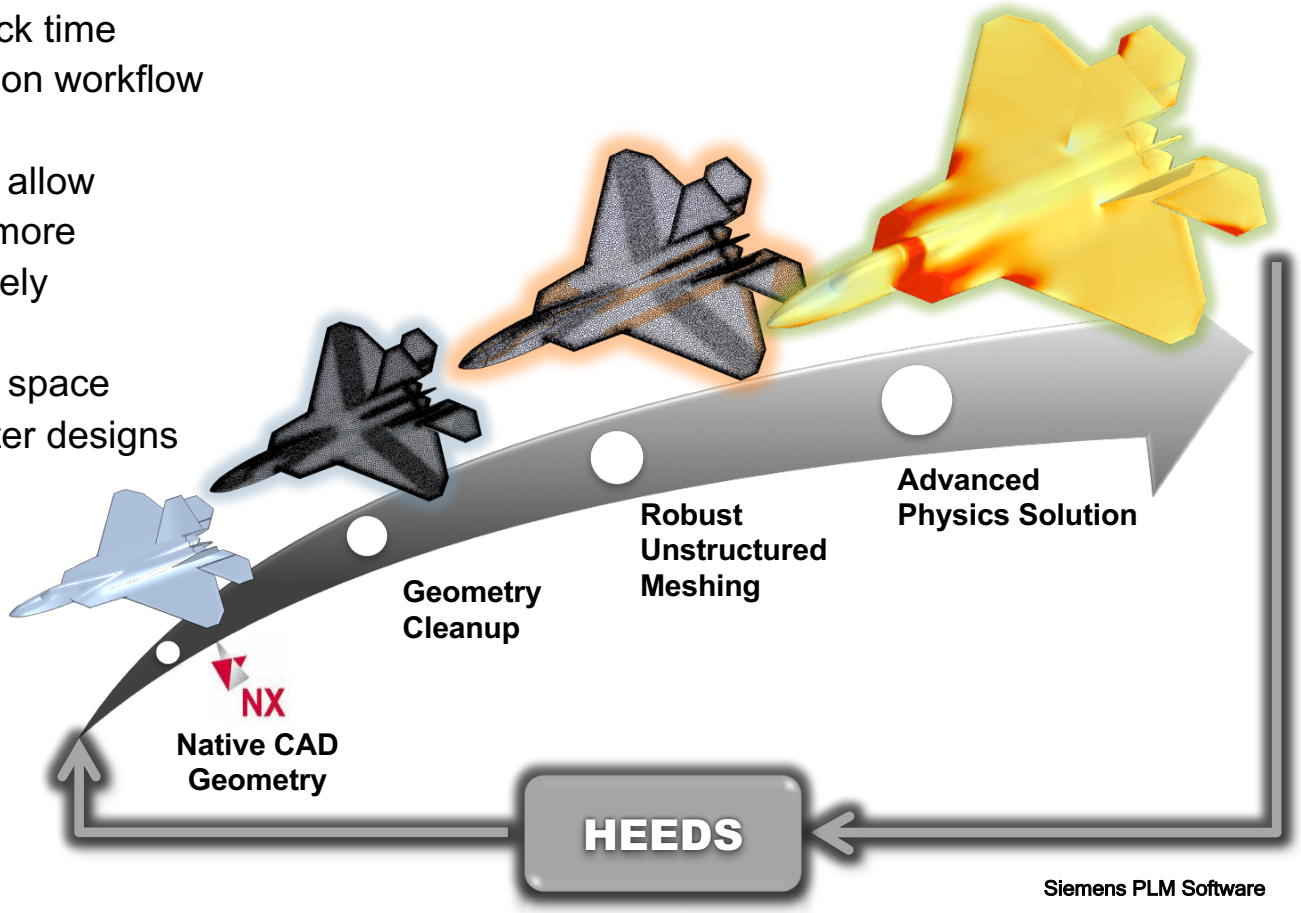
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Simcenter™ Portfolio for Predictive Engineering Analytics

STAR-CCM+

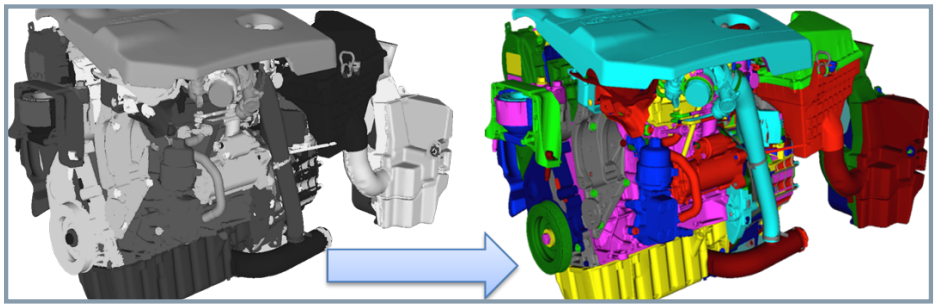
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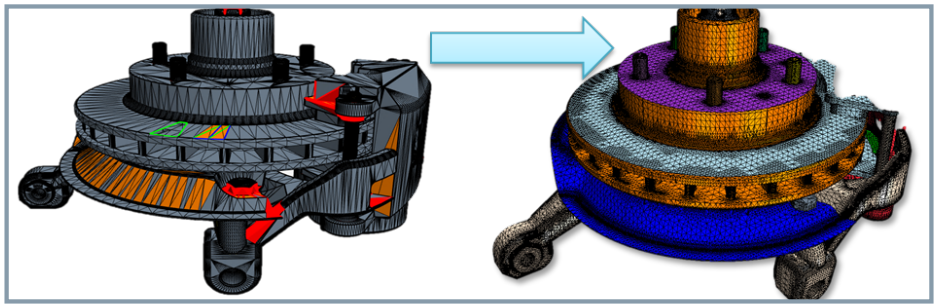
- Our main goal is reduce wall clock time thought robust pipelined simulation workflow
- Increased simulation throughput allow engineering groups to evaluate more designs faster and more accurately
- Leverage market leading design space exploration tools to discover better designs faster



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Reliable Geometry and Surface Preparation





Built-in 3D-CAD Modeler
- CAD cleaning tools
- Build CAD models

Integrated parametric solid & surface modeling

Direct link to most CAD packages

SPACECLAIM

CATIA

SolidWorks

NX

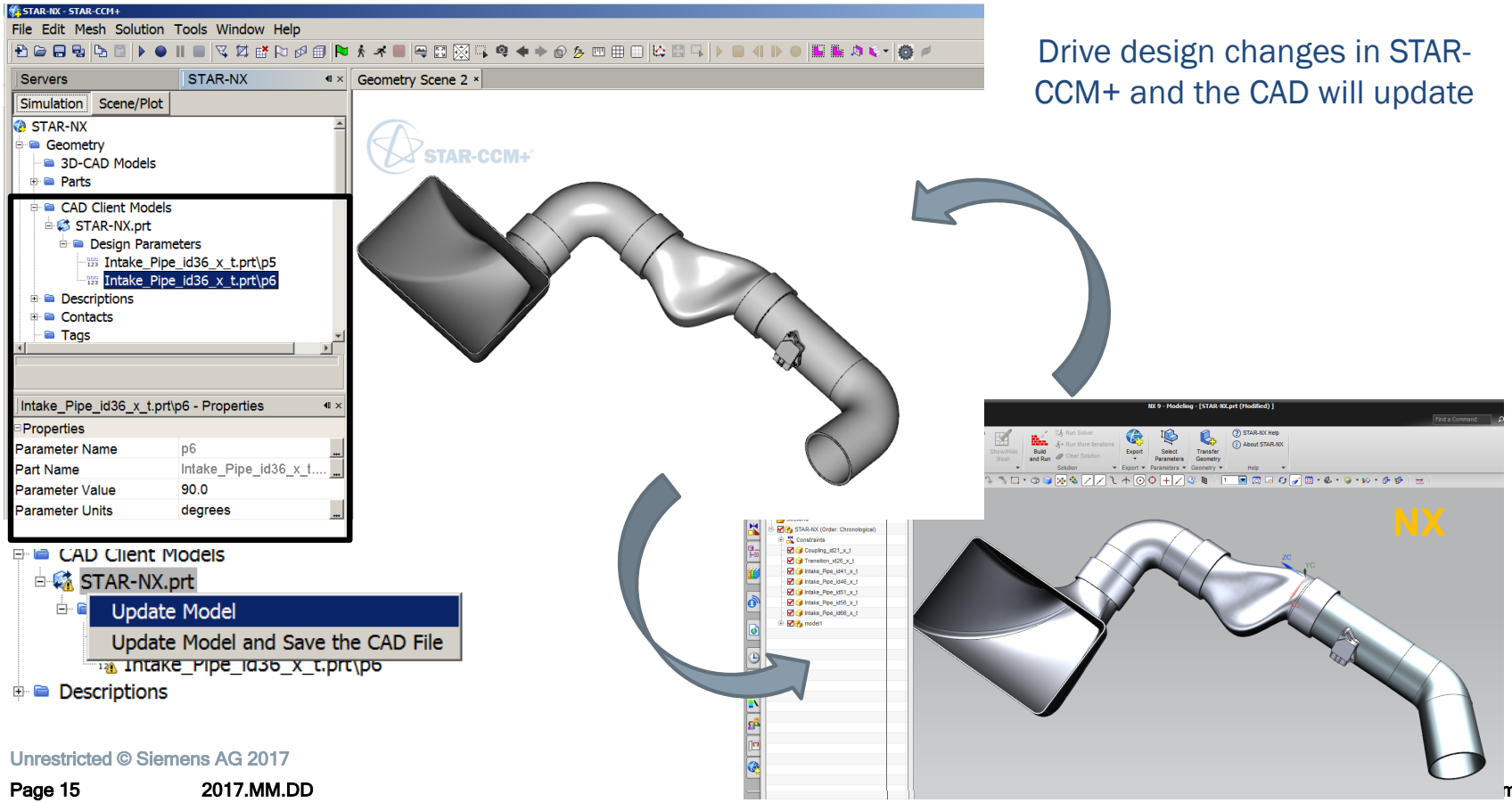
Industry leading surface wrapper
- Fast, Reliable, Automatic
- Address conglomerates of parts

Automated process for any geometry
- Fully featured surface repair toolset
- Automated flow domain creation

Tools for surface repair
- Pipelined corrections for design studies

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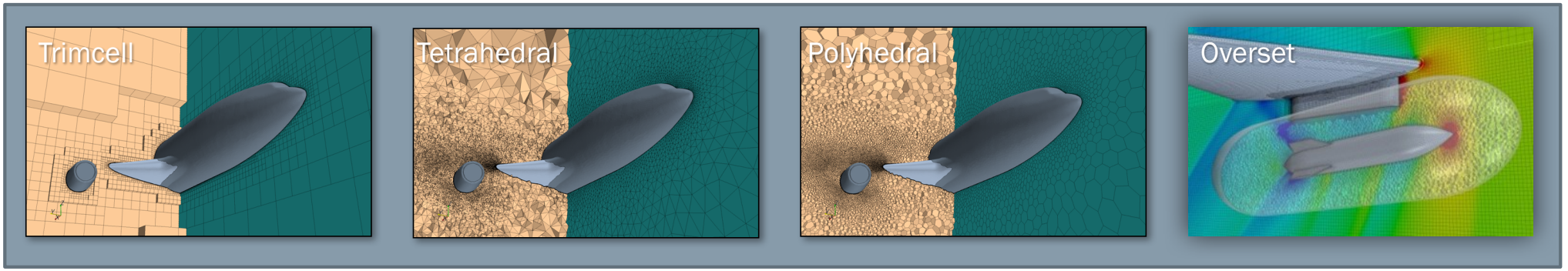
Direct CAD Integration



Drive design changes in STAR-CCM+ and the CAD will update

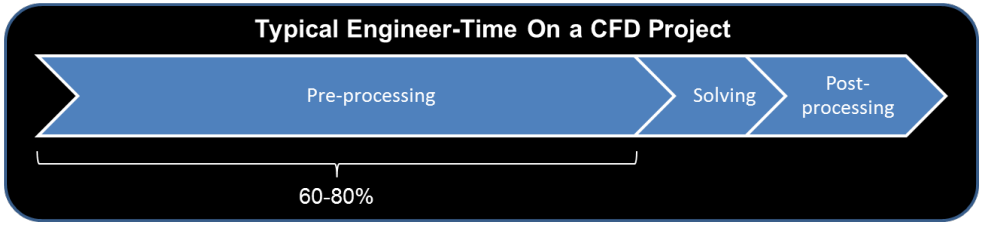
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Flexible, Automated Meshing



- Complete mesh control to full automation
  - Directed meshing of swept geometries
  - Arbitrary polyhedral, trimmed hexahedral, tetrahedral
  - Prism layer, Boundary extrusion
  - Specialized meshers:
    - Thin
    - Advancing Layer
    - Extruder
    - Generalized Cylinder

- Parts-Based and Region-Based Meshing
- Fast reliable meshing
  - Concurrent
  - Parallel Meshing
- Overset Meshing for complex motion



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Commercial Regional Jet

Increased simulation throughput of complex geometry

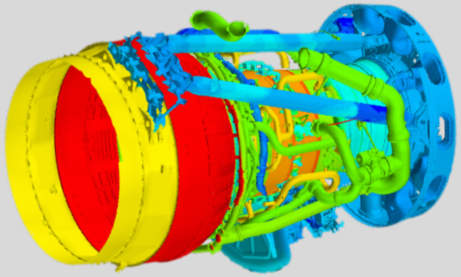
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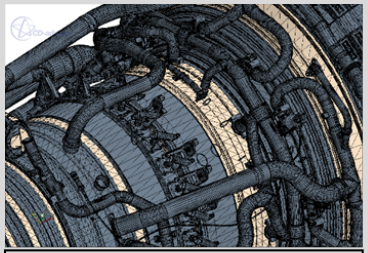


- Increased meshing through put time by 428% for a typical model
- Improved solution accuracy through modeling true geometry

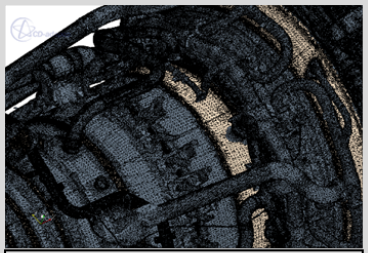
Thermal management issues with engine integration are due to complex environments.

- **No need to reduce model fidelity**
- **Accurately predict metal temperatures**
- **Model cooling strategies without costly testing**

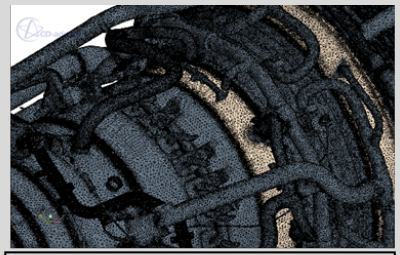




IMPORTED CAD



WRAPPED SURFACE



REMESHED SURFACE

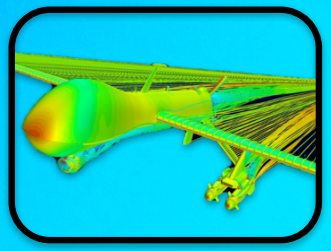
"STAR-CCM+ increased our modeling throughput for by more than we could have imagined. We can now look at design candidates in just a few days rather than several weeks"

Sr. Propulsion Engineer at Large Commercial Airframer

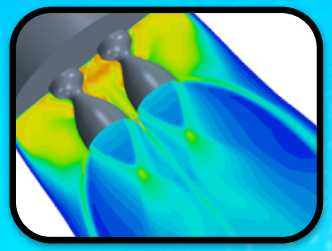
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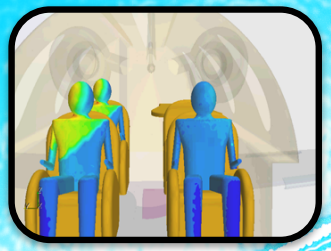
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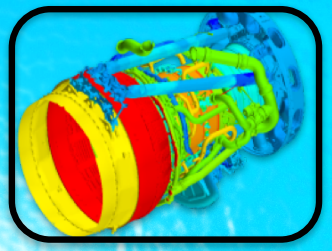
External Aerodynamics



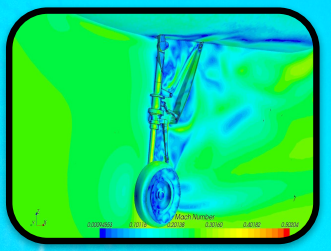
Rocket Propulsion



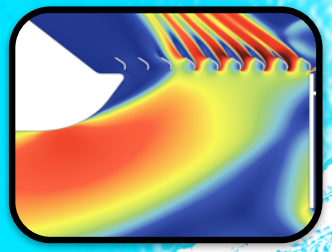
Environmental Control Systems



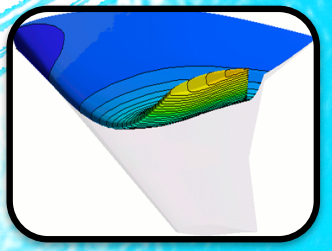
Thermal Management



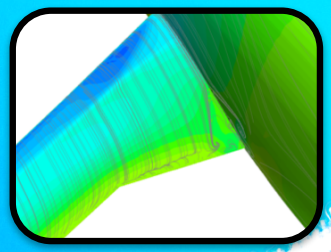
Aeroacoustics



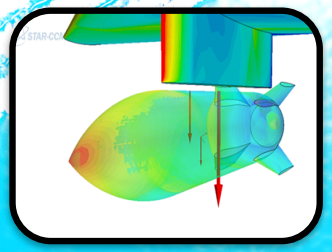
Design Exploration



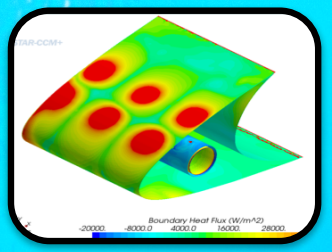
Fluid Structure interactions



Validation



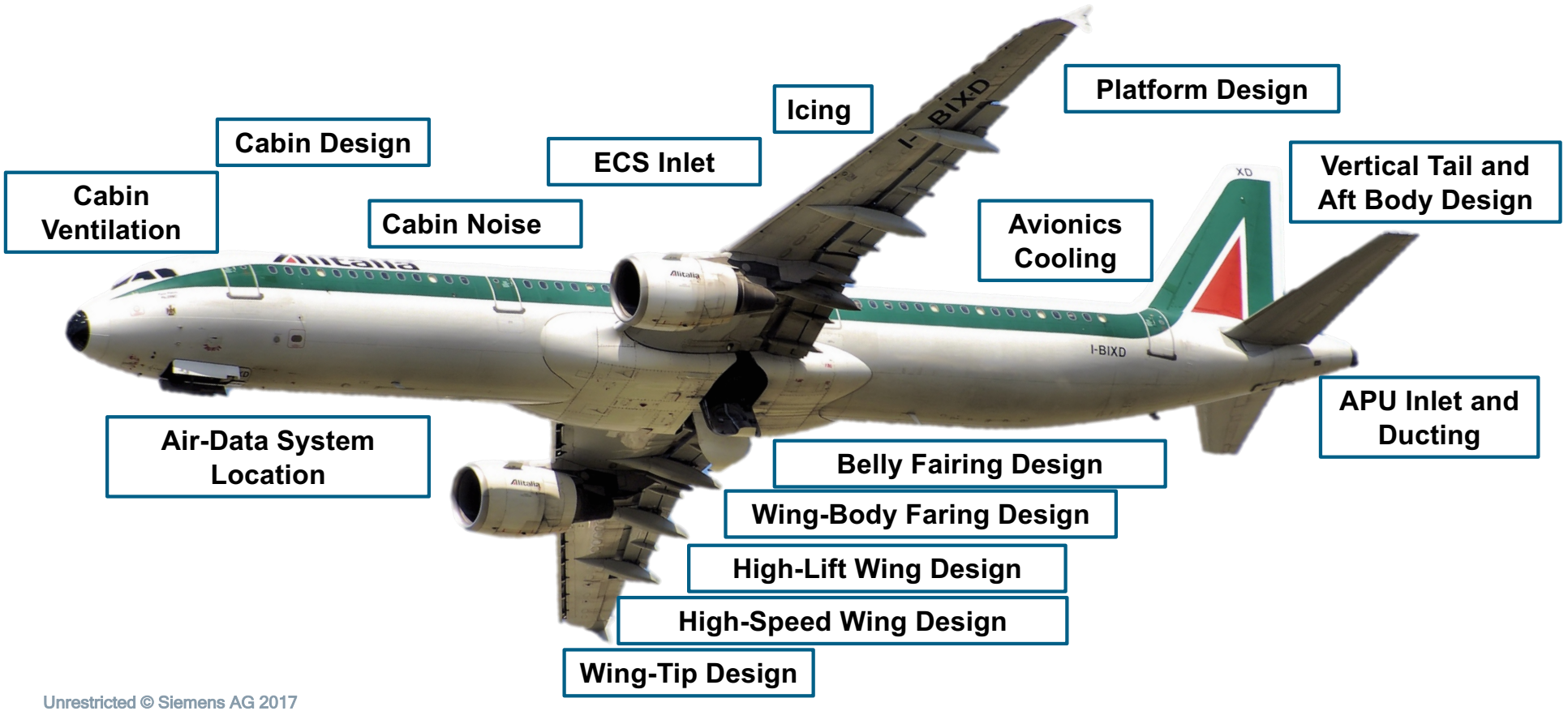
Store Separation



Ice Accretion and Protection

STAR-CCM+ is used throughout the aircraft design process

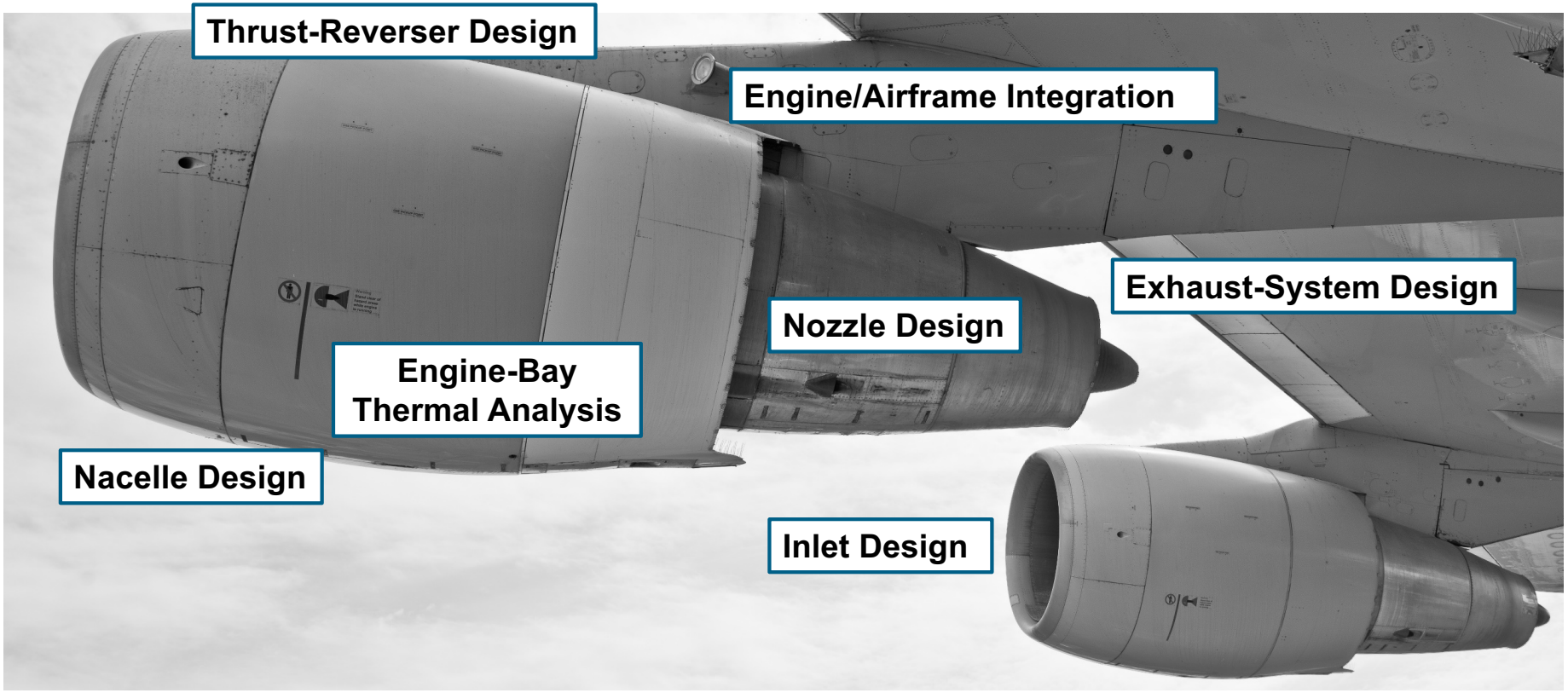
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STAR-CCM+ is used throughout the aircraft design process

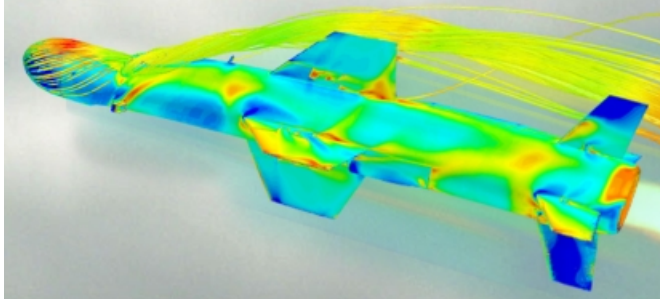
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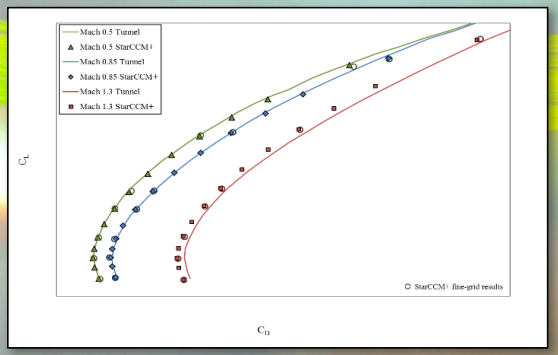
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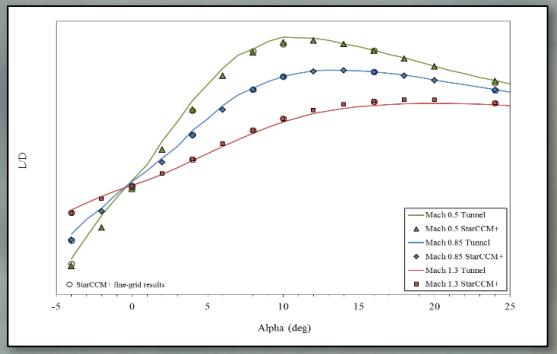
With STAR-CCM+ companies are tackling todays aerodynamic problems

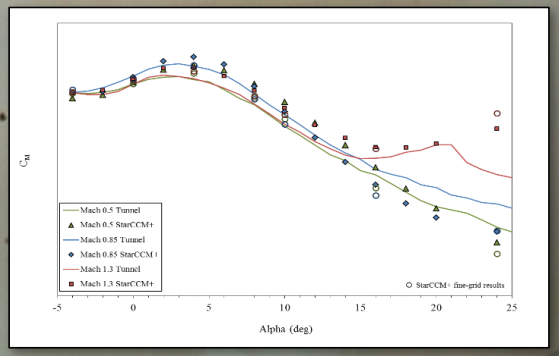
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- Aerodynamic Optimization
- Drag Prediction
- Stability and Control
- Aero Loads Generation
- Engine Airframe Integration
- Fairing Design
- Aeroelastic Calculations







Leverage STAR-CCM+ and HEEDS to develop aero performance databases

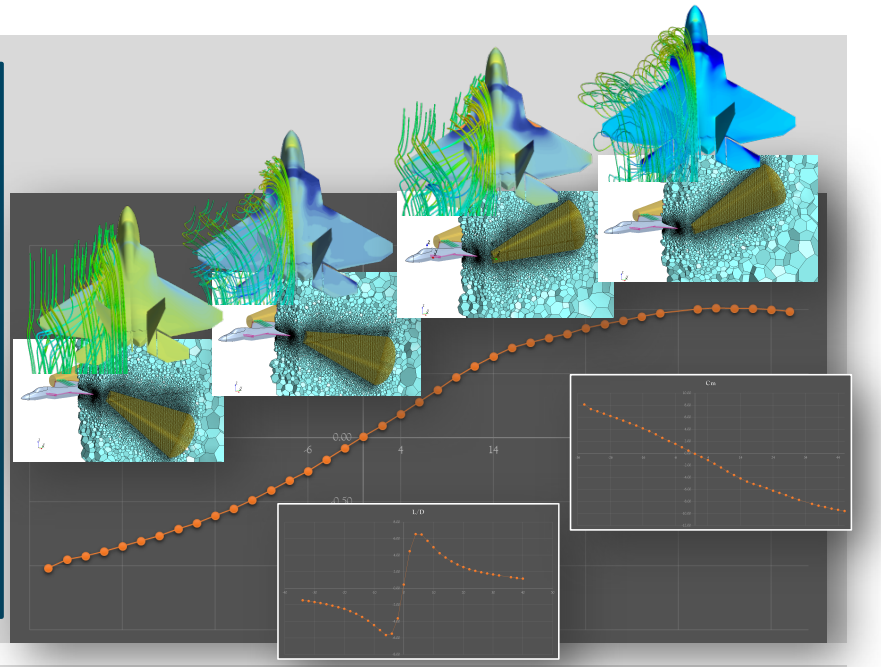
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Leverage Validated Physics

- STAR-CCM+ used in common AIAA aerodynamic workshops including DPW, HLW, SBP, AEP
- Automated design sweeps allow for quick database population
- Grid sequencing for quick convergence
- Automatic meshing and Adjoint based grid refinement

- Automate aero-performance data base development
- Capture key aerodynamic features with automatic solution refinement
- Identify potential aerodynamics issues
- Evaluate high speed and low speed performance



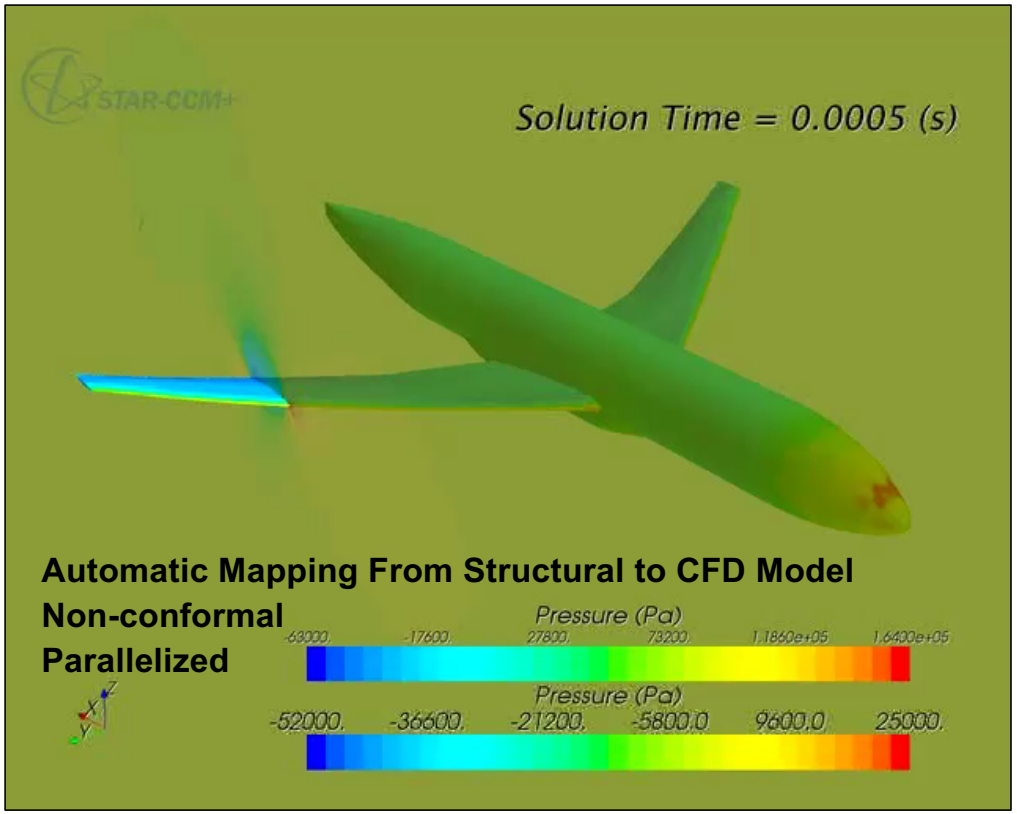
"With STAR-CCM+ we were able to decrease the amount of costly wind tunnel testing by a factor of 4 which lower of project cost substantially."

Director of Flight Sciences, ADD

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Fluid-Structure Interaction for aerospace applications

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Tightly Coupled / Co-Simulation

- STAR-CCM+ 2 way coupled CSM
- STAR-CCM+ DFBI
- STAR-CCM+ FV Stress
- Abaqus

Loosely Coupled Options:

- Nastran, ANSYS, Abaqus

Common Applications:

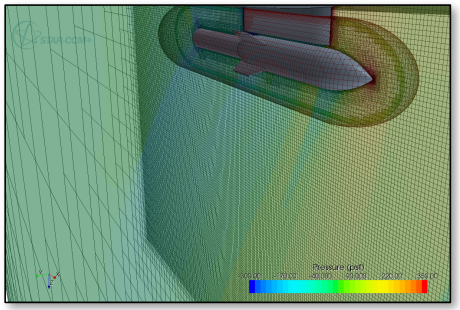
- Aeroelastic prediction
- Flutter: Wing, Turbine / Compressor Blade, Fans
- Landing gear doors
- Fuel pumps
- Propellers

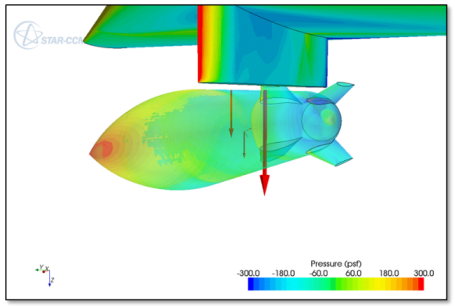
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Modeling separation and movement with Overset grids

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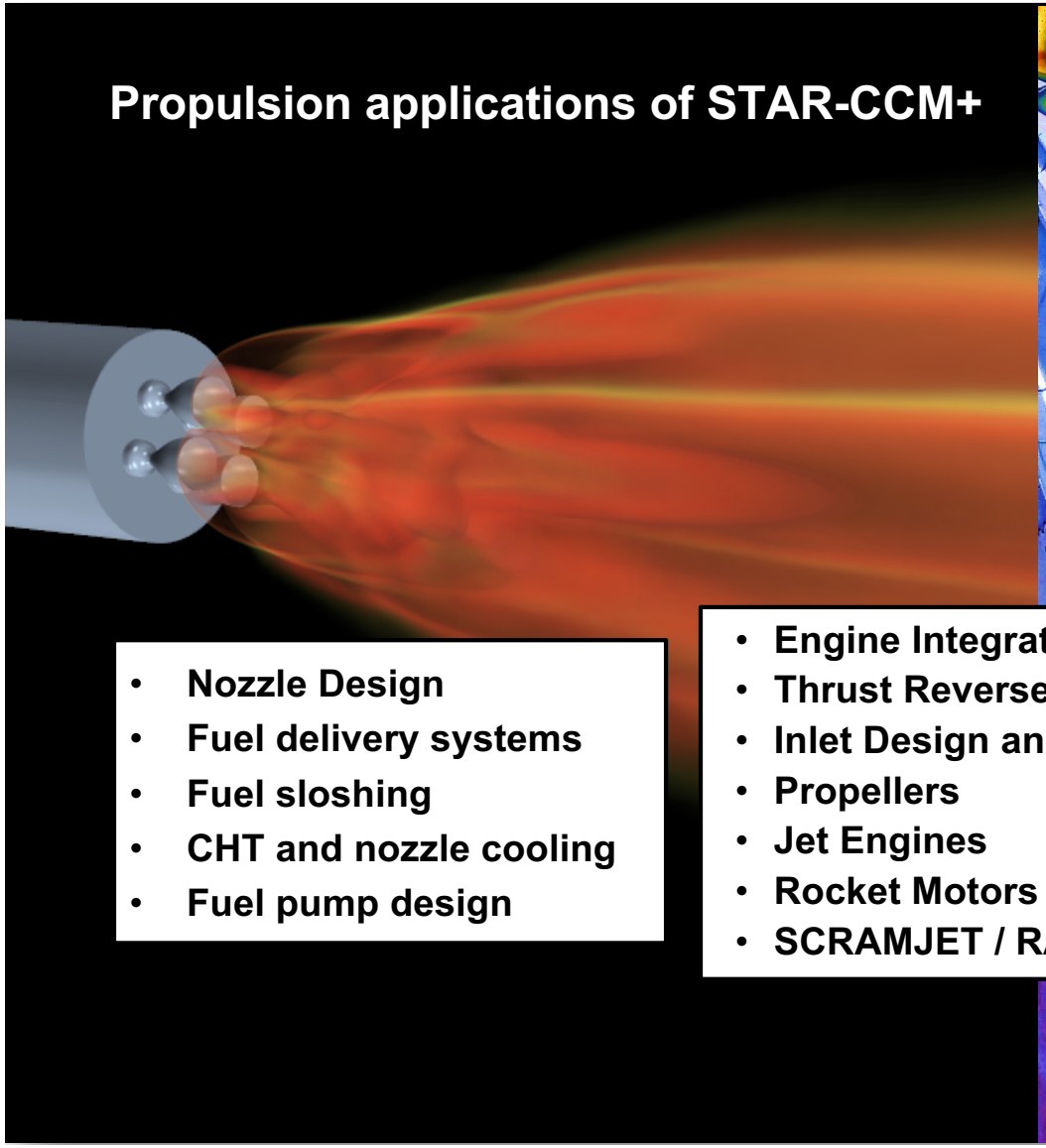


Overset Mesh

- "Grid" Approach
  - Aerodynamic database built from many steady-state solutions at different relative positions / orientations
- CFD-in-the-loop
  - Unsteady coupling of CFD and 6DOF motion
  - Built-in motion constraints
  - Can apply and visualize external loads

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Propulsion applications of STAR-CCM+



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- Nozzle Design
- Fuel delivery systems
- Fuel sloshing
- CHT and nozzle cooling
- Fuel pump design

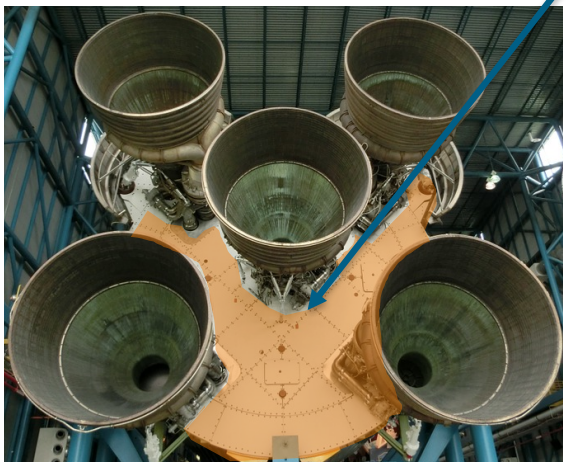
- Engine Integration
- Thrust Reversers
- Inlet Design and Analysis
- Propellers
- Jet Engines
- Rocket Motors
- SCRAMJET / RAMJET

- Blade Cooling
- Combustor design
- Cowling and exhaust
- Fuel system design
- Heating and Cooling

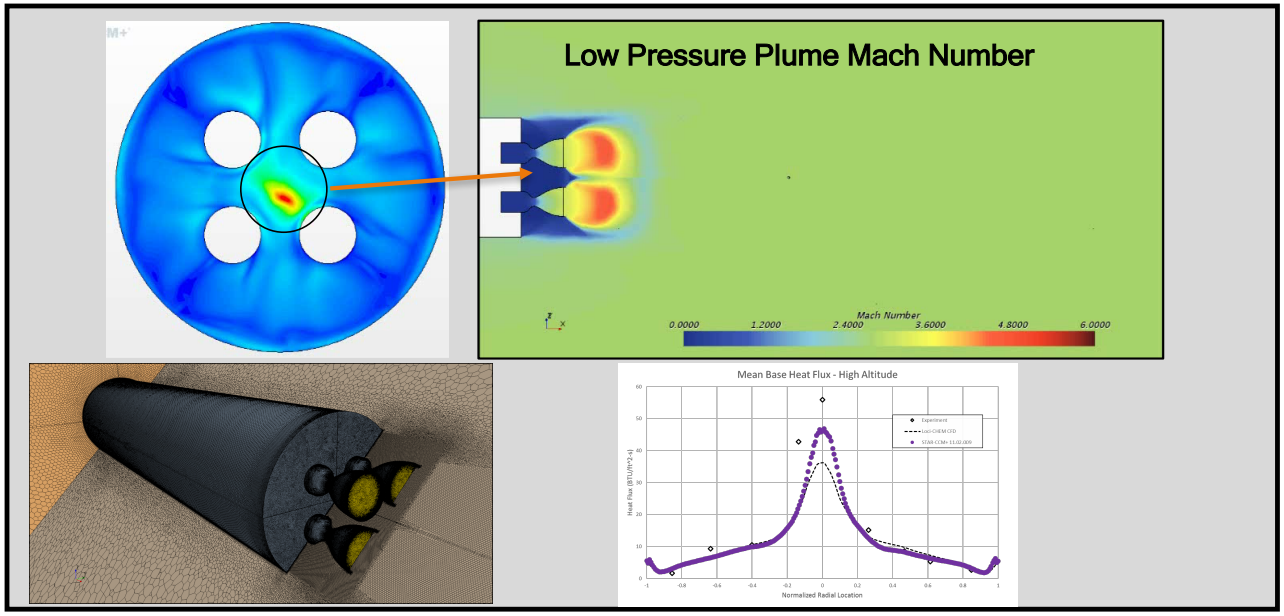
Avoiding Rocket Base Heating problems

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Base heating is a significant problem



- Accurate prediction of Base heating
- Complete analysis less than 17 hours



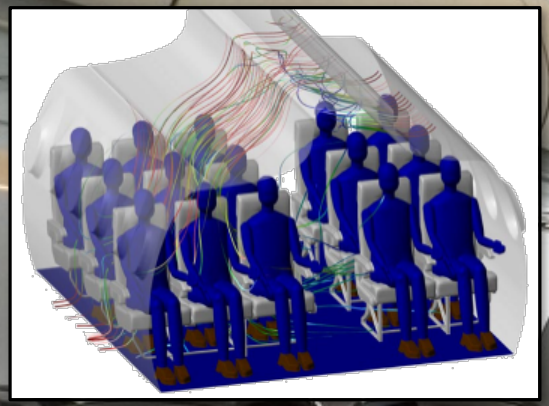
"Our results were in good agreement with the NASA predictions and we identified potential issues with steady state simulations"

Trevor Blanc, Support Engineer, CD-adapco

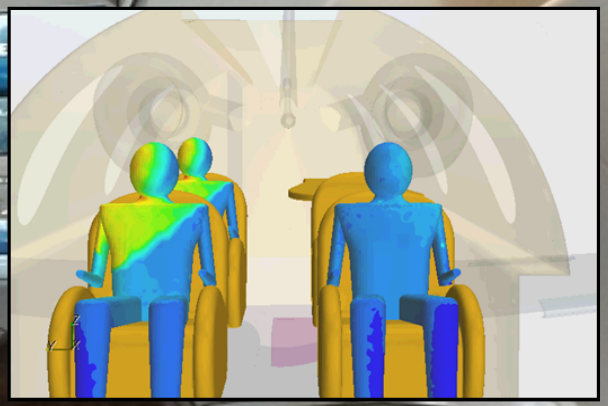
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ESC design and characterization

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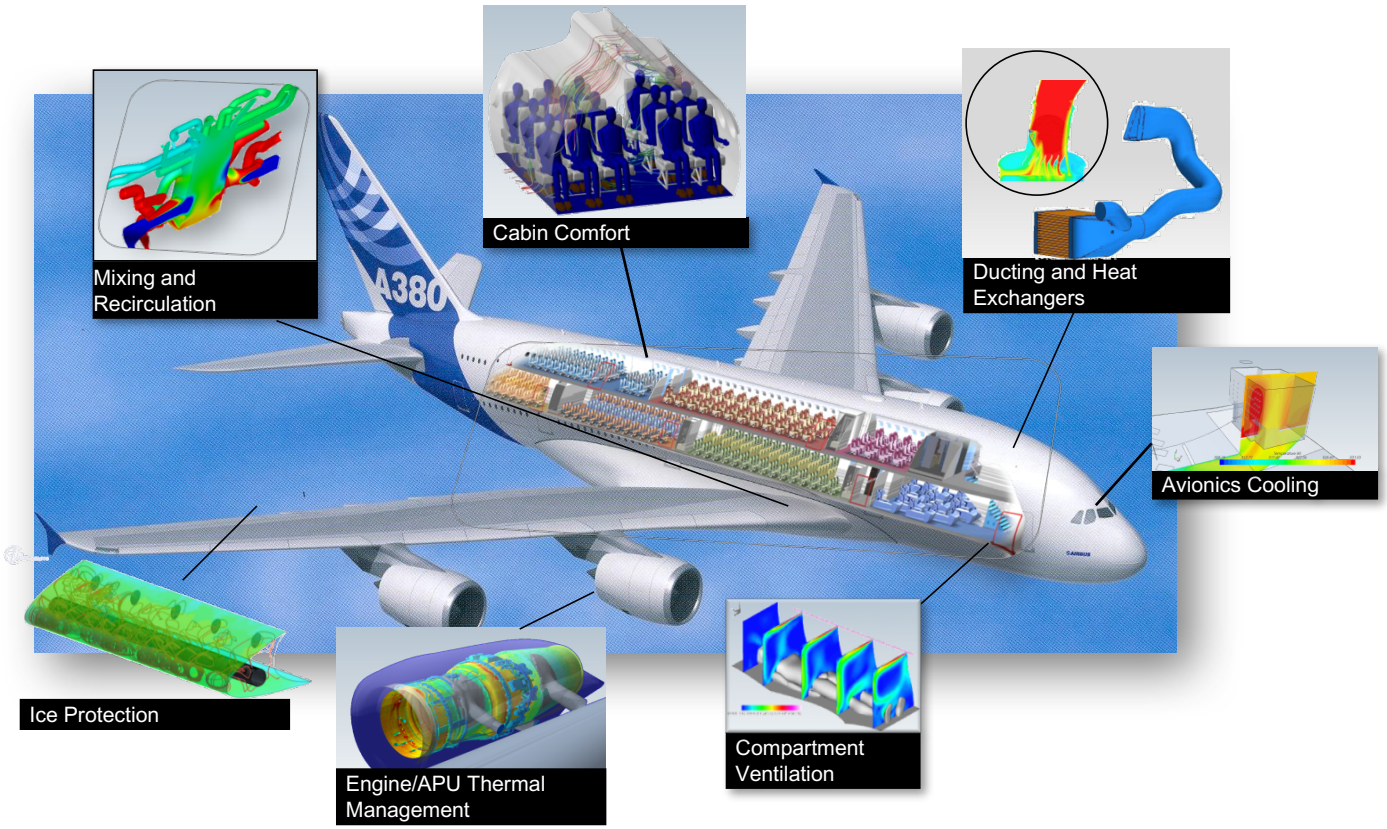


- Bleed air systems design
- Heat-exchanger
- Cabin ducting
- Passenger comfort modeling
- Duct noise prediction
- HVAC system performance and design



Key Aerospace Application Area: ECS / Aircraft Systems

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- Engine integration
- Cabin comfort models
- Ducting and heat exchangers
- Avionics cooling
- APU integration
- Ice protection systems
- Compartment ventilation
- Thermal comfort models
- Fogging and defogging
- Cabin acoustics

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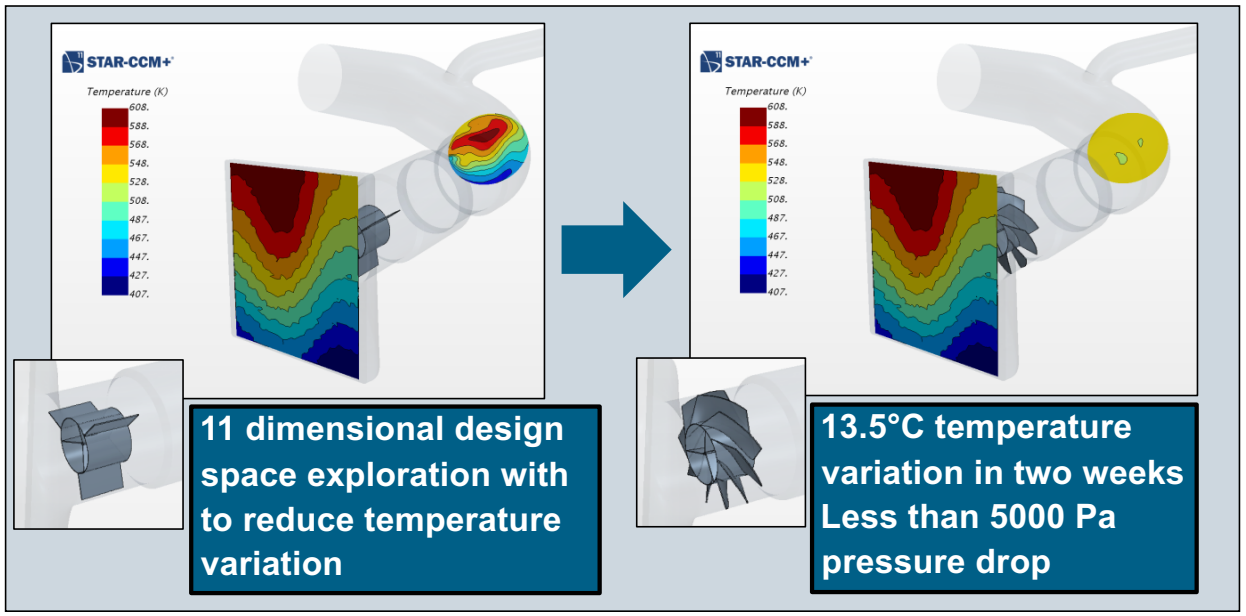
Airbus

STAR-CCM+ design exploration delivers significant improvements for air bleed system

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- Reduced design cycle time from 6 month to 2 weeks
- Reduced temperature variation by 91%

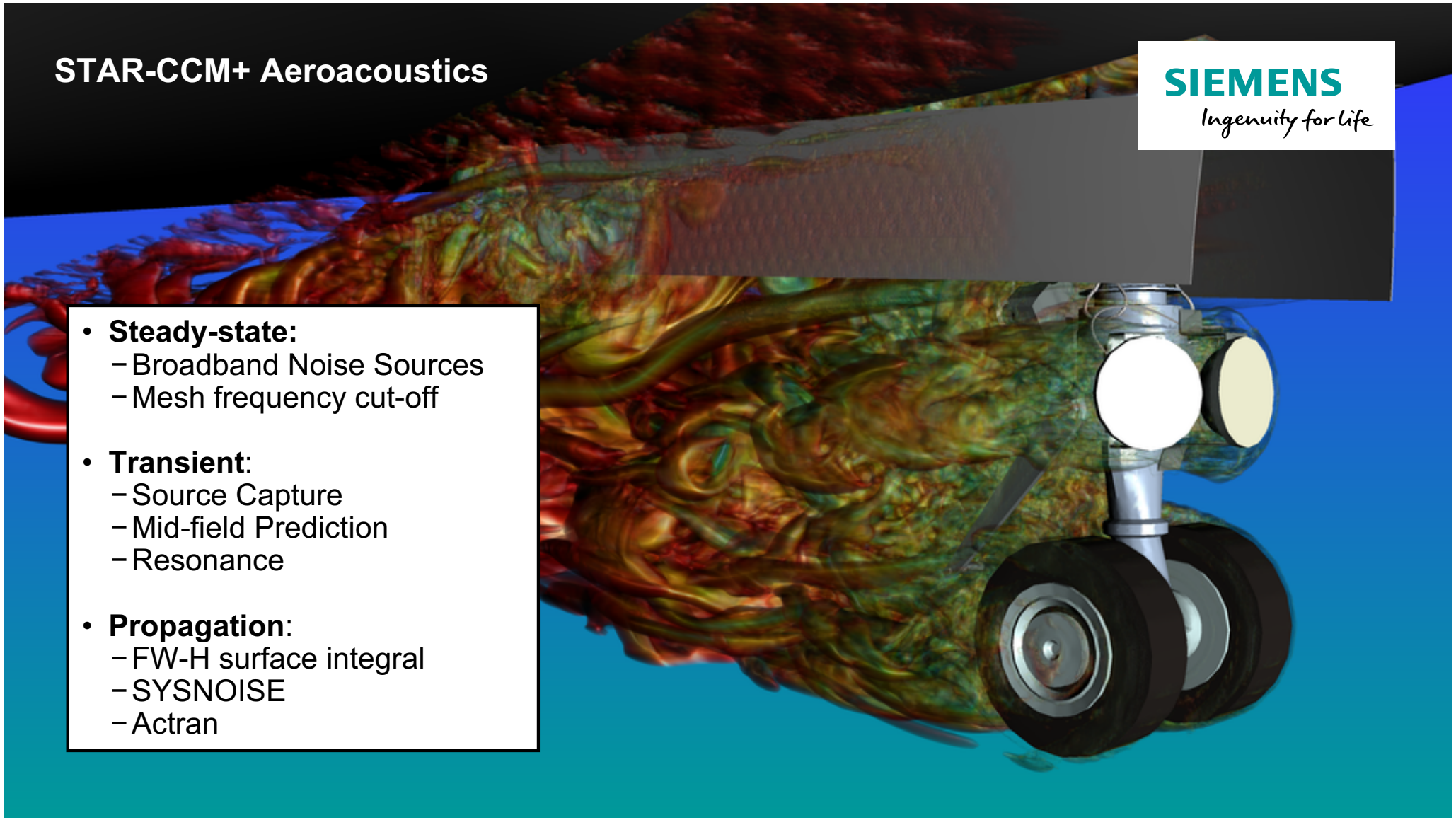


"With STAR-CCM+ and Optimate we learned what makes a good design and how to improve the performance of the system"

Andreas Ruch, ECS Analysts Airbus

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STAR-CCM+ Aeroacoustics



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- **Steady-state:**
  - Broadband Noise Sources
  - Mesh frequency cut-off
- **Transient**:
  - Source Capture
  - Mid-field Prediction
  - Resonance
- **Propagation**:
  - FW-H surface integral
  - SYSNOISE
  - Actran

Bombardier Aerospace

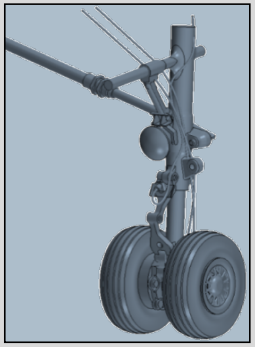
Reduces airport noise through aeroacoustics simulation with STAR-CCM+

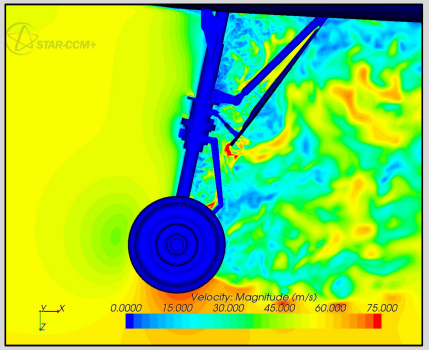
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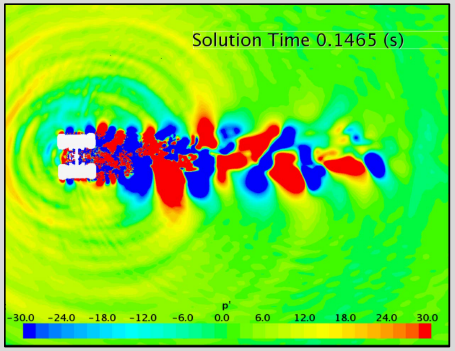


Multi-Physics Simulation Improves Design

- Aeroacoustic predictions matched measured data.
  - location of noise sources and frequency spectra identified
- Lowered overall development cost







- Mitigate the main sources of noise leveraging computational aeroacoustics with STAR-CCM+ and the full fidelity CAD of target landing gear geometry.
- Approach must be validated with measured data
- Impact of design changes need to be determined in weeks not months

"Using the high fidelity CAD model and STAR-CCM+ we were able to predict the source of landing gear noise with high accuracy"

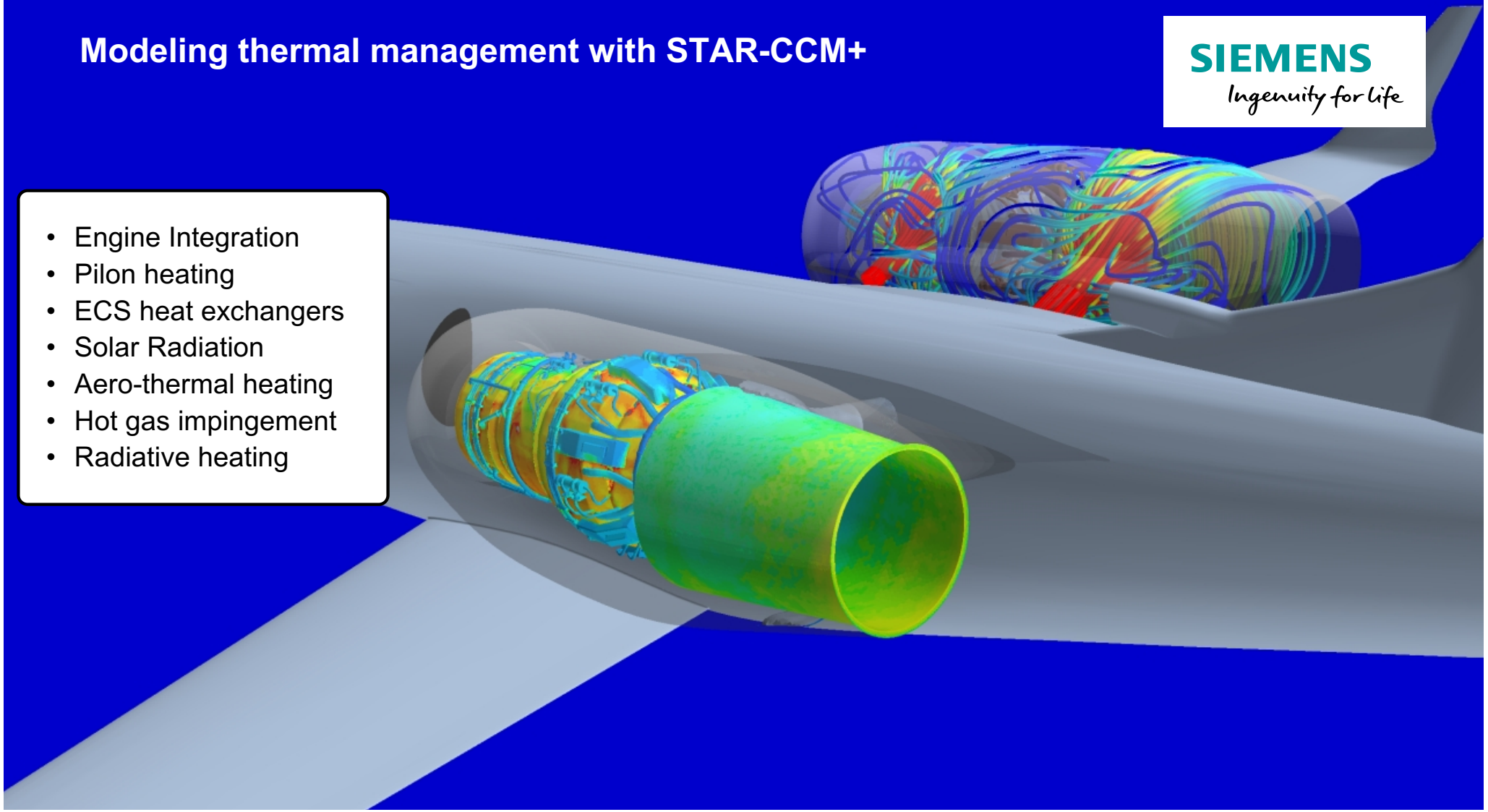
Mohammad Tabesh - Bombardier Aerospace

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Modeling thermal management with STAR-CCM+

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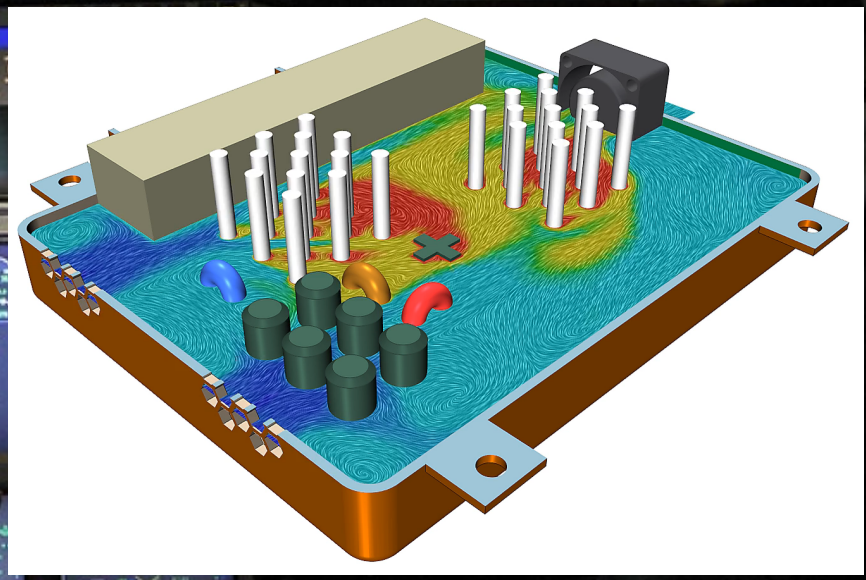
- Engine Integration
- Pilon heating
- ECS heat exchangers
- Solar Radiation
- Aero-thermal heating
- Hot gas impingement
- Radiative heating

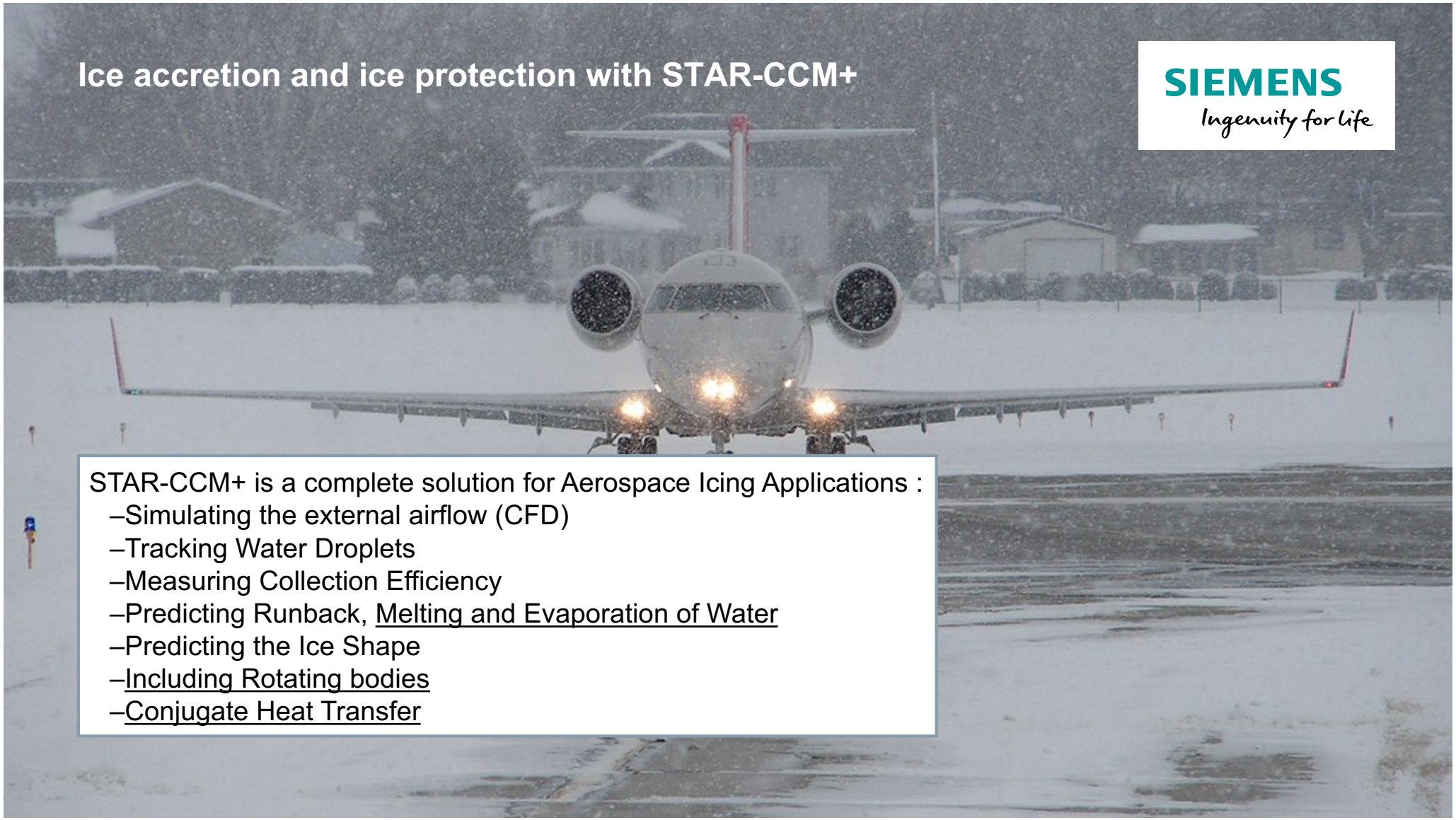


Avionics / Payload / Electronics Cooling

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- Complex geometry and flow paths
- Including wires, cables, connectors, etc.
- Conjugate heat transfer
- Forced or passive cooling
- Fan Performance
- Acoustics
- Dust Accrual
- From individual component to full system





Ice accretion and ice protection with STAR-CCM+

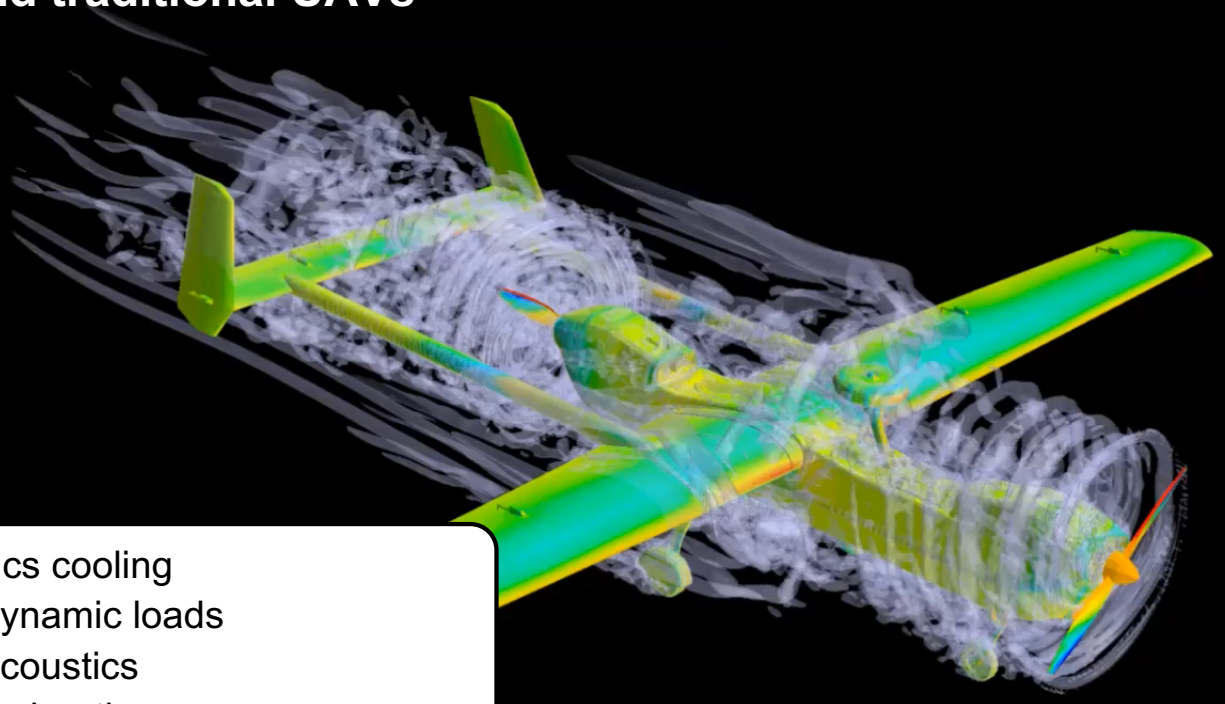
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STAR-CCM+ is a complete solution for Aerospace Icing Applications :

- –Simulating the external airflow (CFD)
- –Tracking Water Droplets
- –Measuring Collection Efficiency
- –Predicting Runback, Melting and Evaporation of Water
- –Predicting the Ice Shape
- –Including Rotating bodies
- –Conjugate Heat Transfer

VTOL and traditional UAVs

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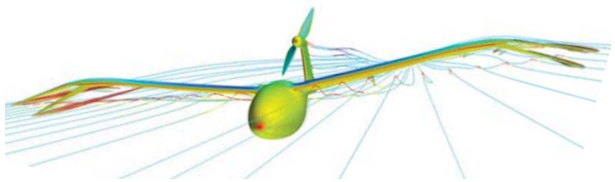
- Avionics cooling
- Aerodynamic loads
- Aeroacoustics
- Battery heating
- Electric motor design
- Propeller performance

JOBY Aviation

Revolutionizing Aircraft Propulsion Through Digital Exploration

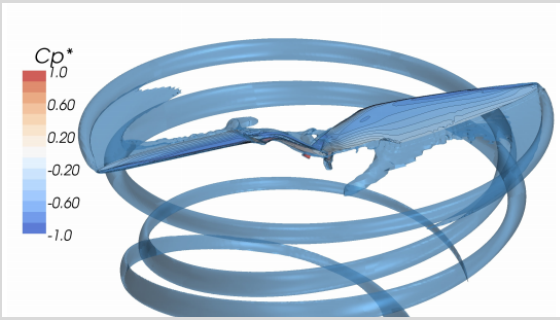
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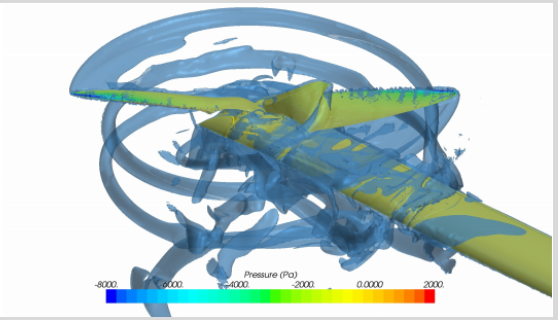


Digital Exploration

- Reduced need for propulsion testing for preliminary designs
- Accelerated project timeline 2X
- Discovered Innovative new more efficient propulsion designs that are changing modern aviation



Determine aerodynamic performance of proposed rotor configuration under perfect conditions



Validate Lifting thrust with on wing configuration prior to costly test.

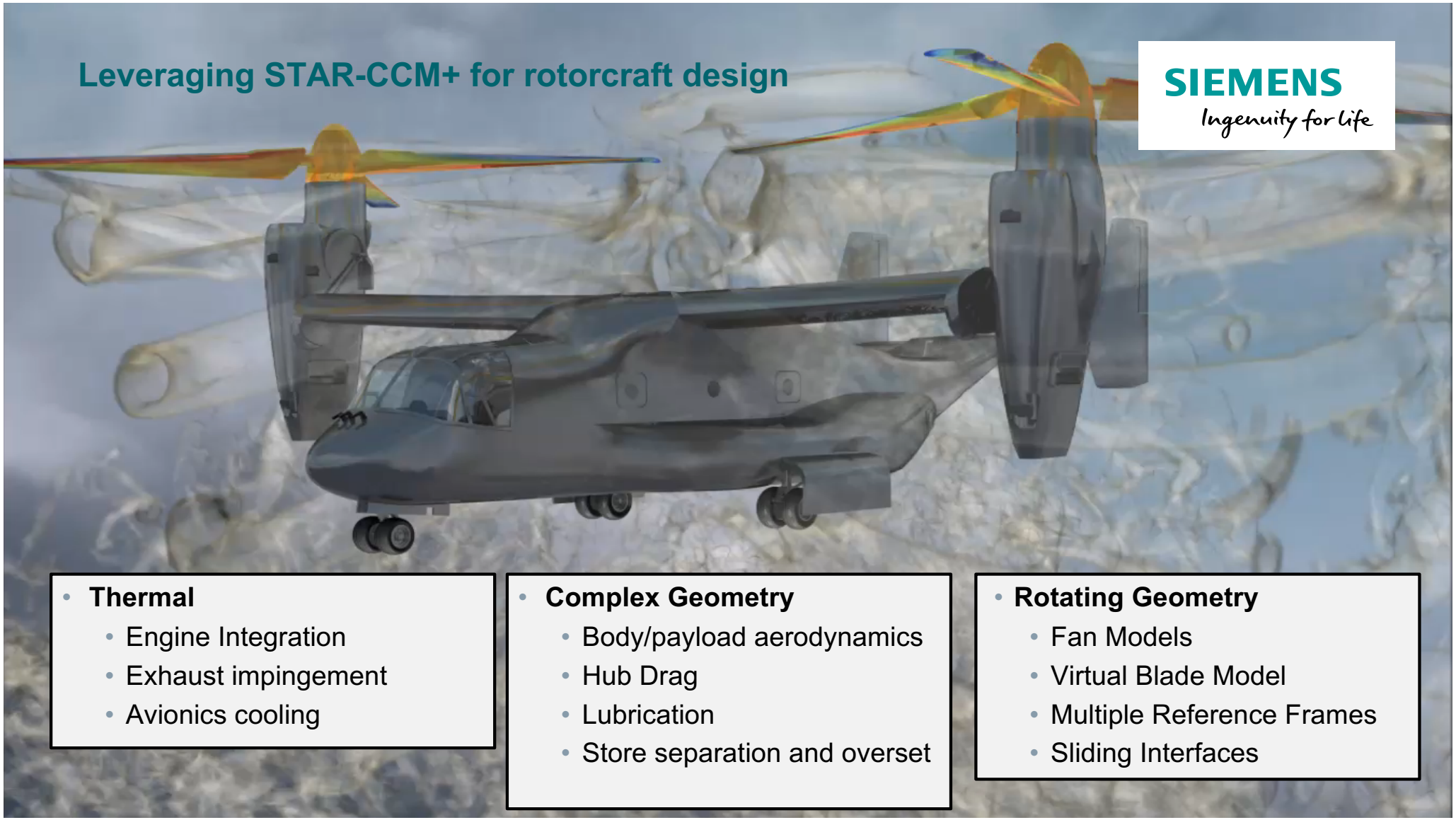
"STAR-CCM+ has been an extremely valuable component of our design and analysis toolkit as low-order tools are not powerful enough and statistical methods are less useful due to the lack of significant historical data."

Alex Stoll aeronautical engineer at Joby Aviation

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Leveraging STAR-CCM+ for rotorcraft design

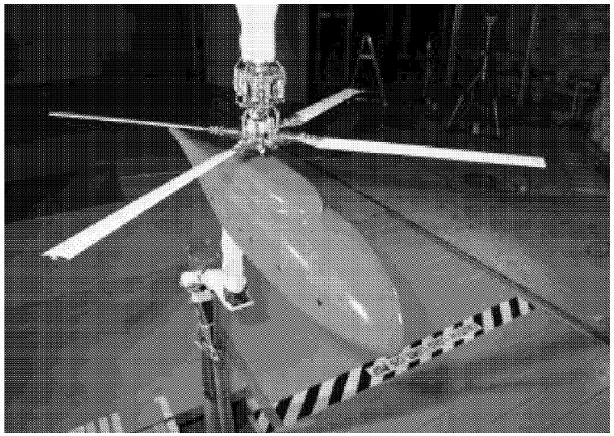
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- **Thermal**
  - Engine Integration
  - Exhaust impingement
  - Avionics cooling
- **Complex Geometry**
  - Body/payload aerodynamics
  - Hub Drag
  - Lubrication
  - Store separation and overset
- **Rotating Geometry**
  - Fan Models
  - Virtual Blade Model
  - Multiple Reference Frames
  - Sliding Interfaces

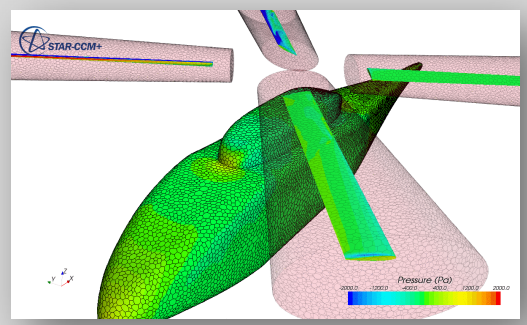
Validation: NASA Rotor Body Interaction [ROBIN]

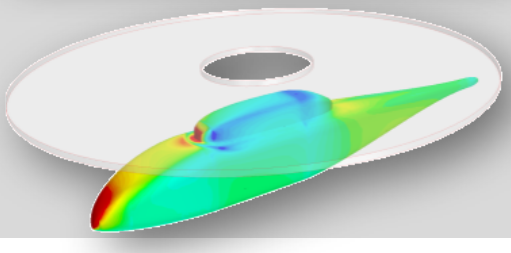
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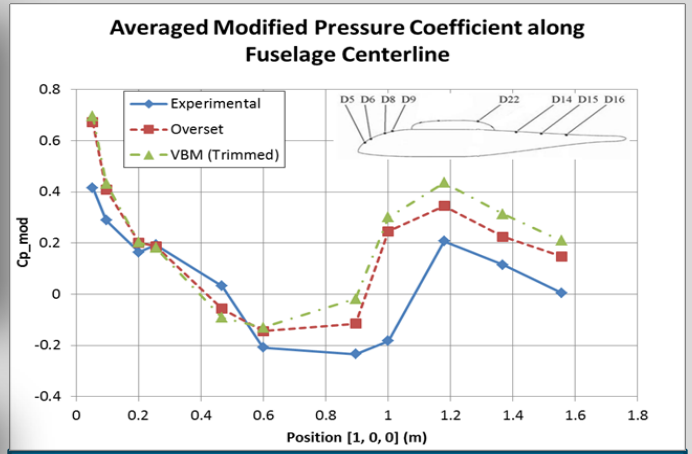


Results:

- Both methods predict thrust coefficient within 6% of experimental data
- Pressure coefficient along the centerline of fuselage
- VBM approach 12x faster than Overset method







- STAR-CCM+ with Overset mesh and sliding domain for high fidelity prediction
- Take advantage of the Virtual Blade Element Model for fast low fidelity modeling
- Reduce simulation time with overset grids

"Knowing when and how to use VBM and overset can reduce engineering effort as much as an order of magnitude for the right type of problem."

Ritu Maripu, Senior Support Engineer, CD-adapco

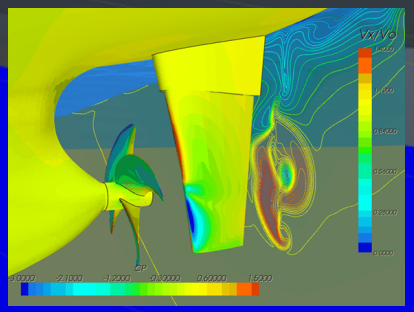
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STAR-CCM+

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STAR-CCM+ for Marine Defense

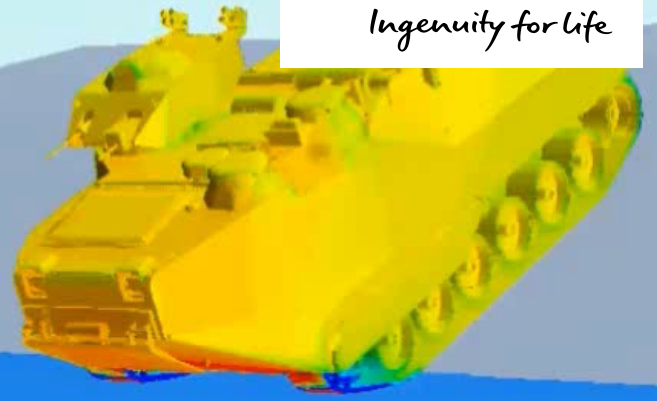
- Hydrodynamics
  - VOF Free Surface
- Seakeeping & Maneuvering
  - Coupled 6DOF motion
- Propulsion
  - Unsteady rotating geometry
  - Cavitation
- Aerodynamics



Ground Vehicle Defense

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- **Vehicle Aerodynamics**
  - Aerodynamic Performance
  - Aeroacoustics
  - Water/Dirt Management
- **Auxiliary/Secondary Flows**
  - Air Intakes
  - Exhaust
- **Vehicle Thermal Management**
  - Engine/Transmission Cooling
  - Underhood Components
  - Electronics Cooling
- **Cabin Simulations**
  - HVAC
  - De-ice/Defog
  - Human-Effects
- **Batteries and Electric Machines**




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Airbus improves ECS system performance through gasper valve design

Gasper Design Space Study

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Individual air nozzles – Purpose

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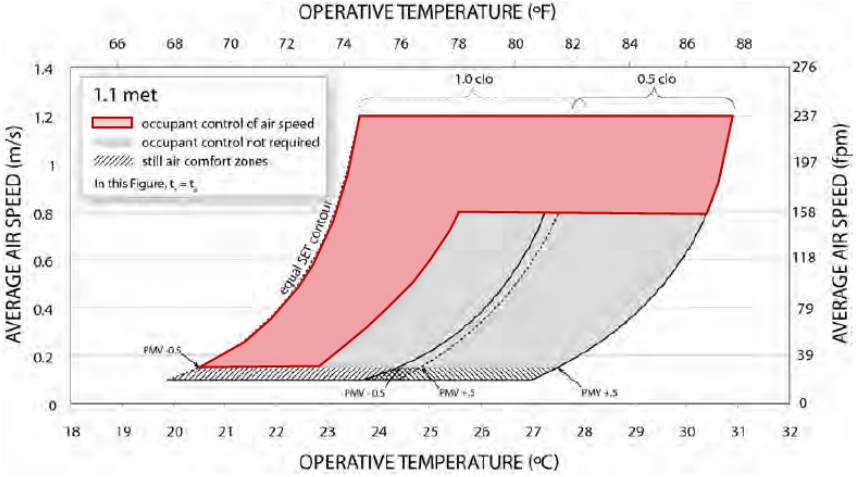
- Individual air outlets can be found in many aircraft models flying today in many forms
- Main reason given for use of nozzle:
  - After boarding (first 30min) 70% of occupants open nozzle
  - Use of nozzles reduces to 62% after 40min, then constant
  - Most occupants target nozzle to upper body part (52%), 32% to lower body, 15% to head
  - (Source: “Experimental investigation of personal air supply nozzle use in aircraft cabins”; Zhaosong Fang, Baizhan Li, Andrew N. Baldwin; 2015)



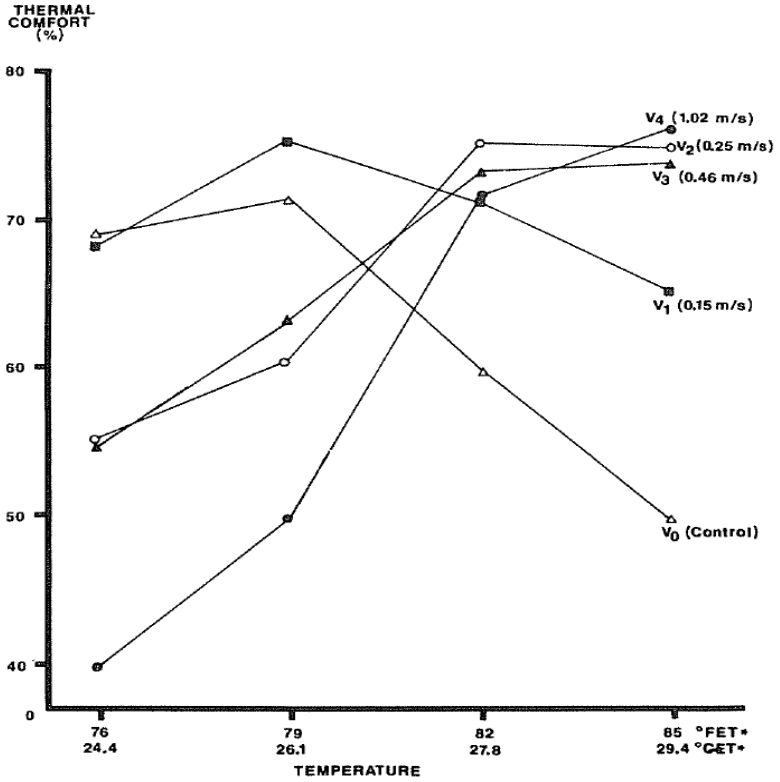
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Individual air nozzles – Purpose

With ambient temperatures of >27°C, average velocities of 0.8 m/s are perceived as comfortable
Air velocity is an important factor



Source: ANSI/ASHRAE Standard 55-2013



Source: Ceiling Fans as Extenders of the Summer Comfort Envelope; F.H. Rohles, F.H., S.A. Konz, B.W. Jones; 1983;

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Individual air nozzles – Motivation for design improvements

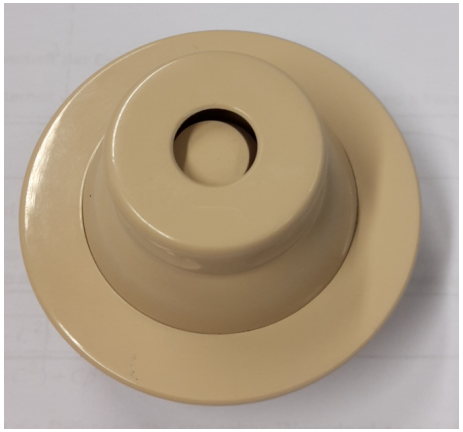
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Amount of air that can be supplied to the individual air nozzles is limited by the overall air system performance

Maximum pressure loss of the individual air nozzles is also limited:

- Pressure in supply manifold is driven by overall air system performance
- Generally, less pressure loss also means less noise generation







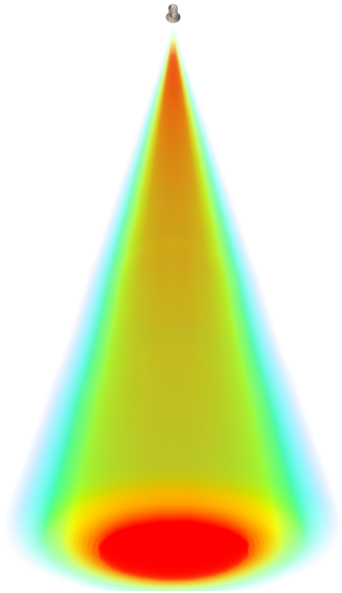
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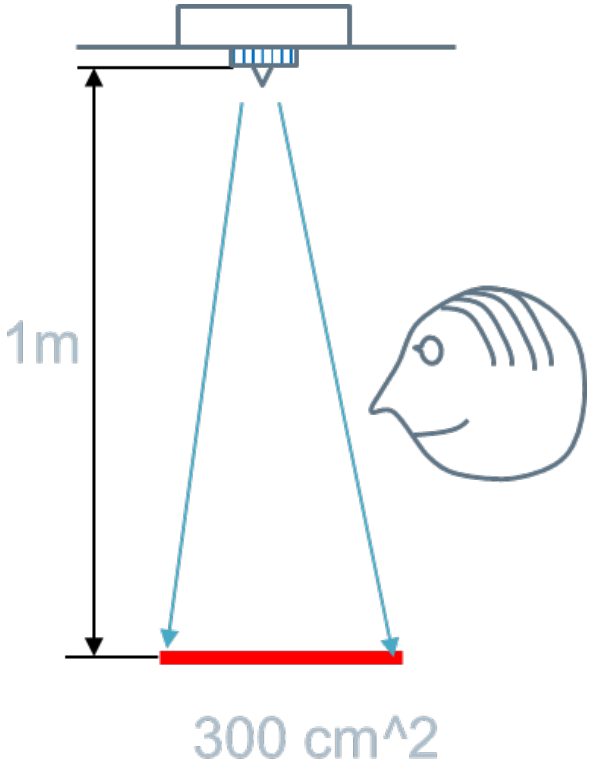
Individual air nozzles – Requirements

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Objective	Minimize pressure drop	>300 Pa
Constraint	Velocity Magnitude	>= 0.8 m/s
Constraint	Area at 1M of 300 cm^2	> 0.5 m/s

STAR-CCM+

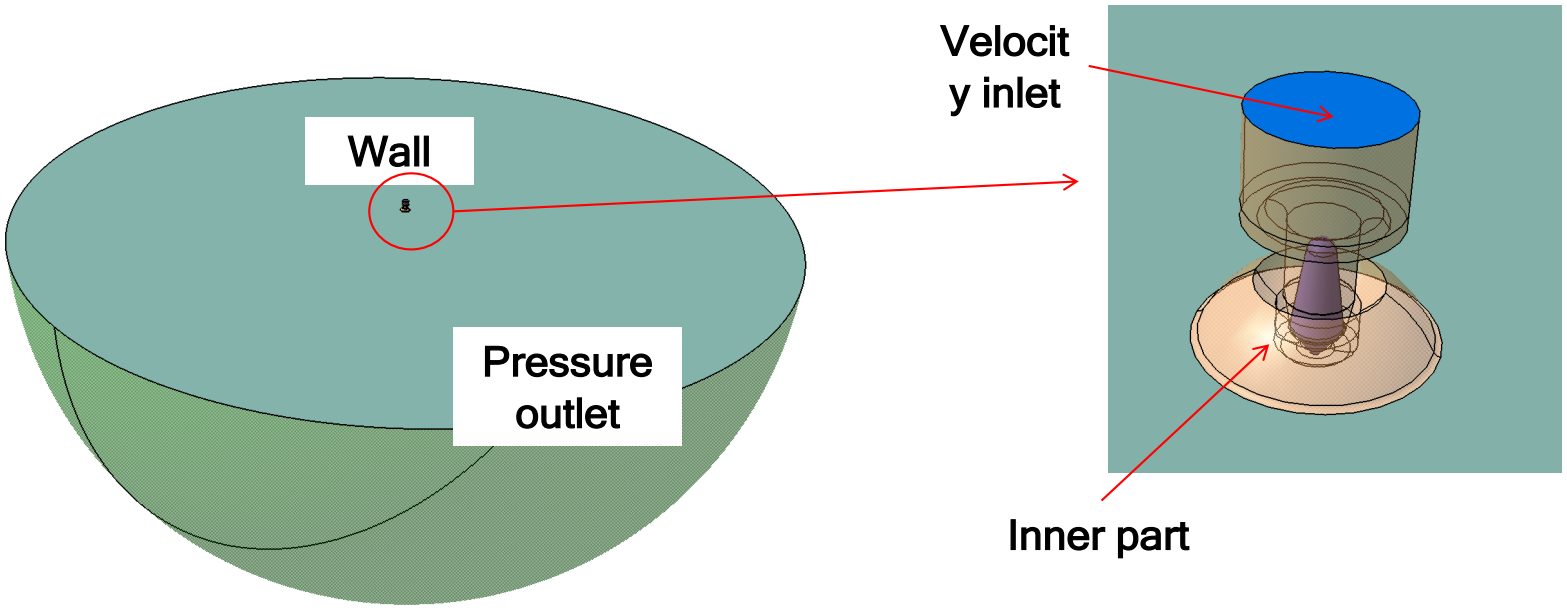




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Parametric model – Geometry

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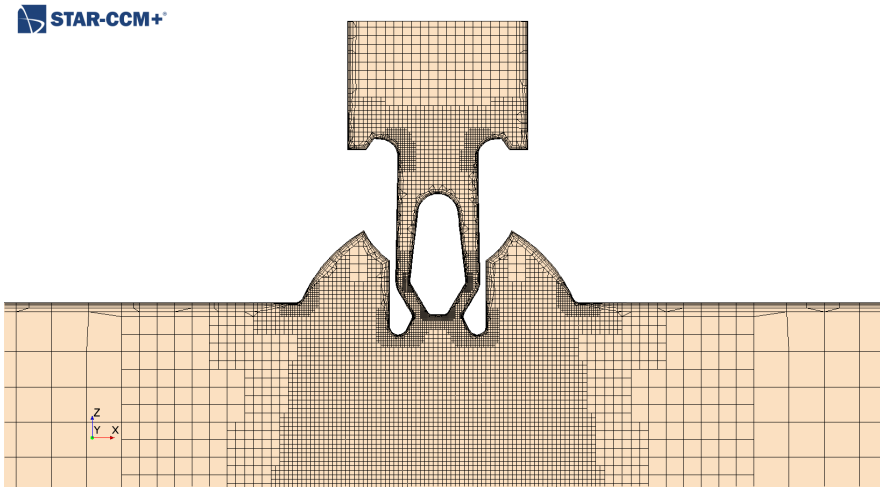


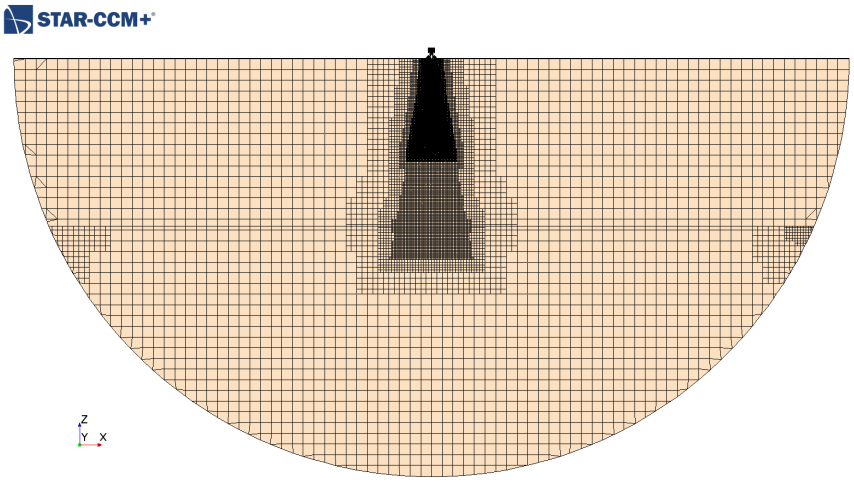
- CATIA V5 was used to create a rotational-symmetric model
- The inner part, which defines the shape of nozzle is defined by a parametric sketch

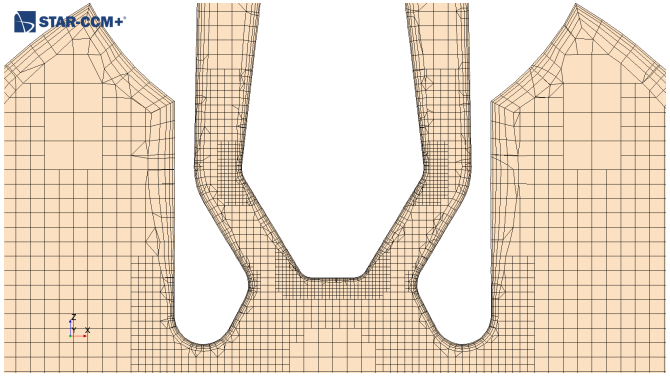
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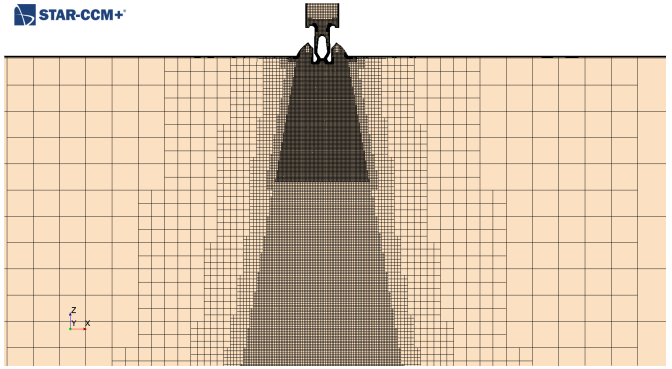
Computation mesh must be robust for study to succeed

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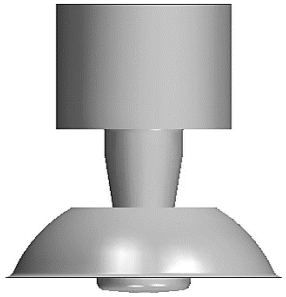


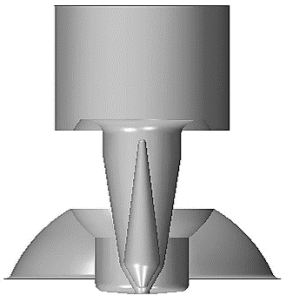
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Initial CAD Robustness of 11 dimensional space

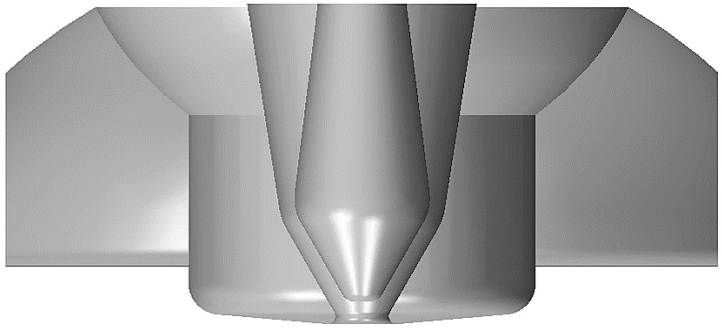
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Goal: Evaluate 160 designs with the objective of maintaining comfort and reducing pressure loss.





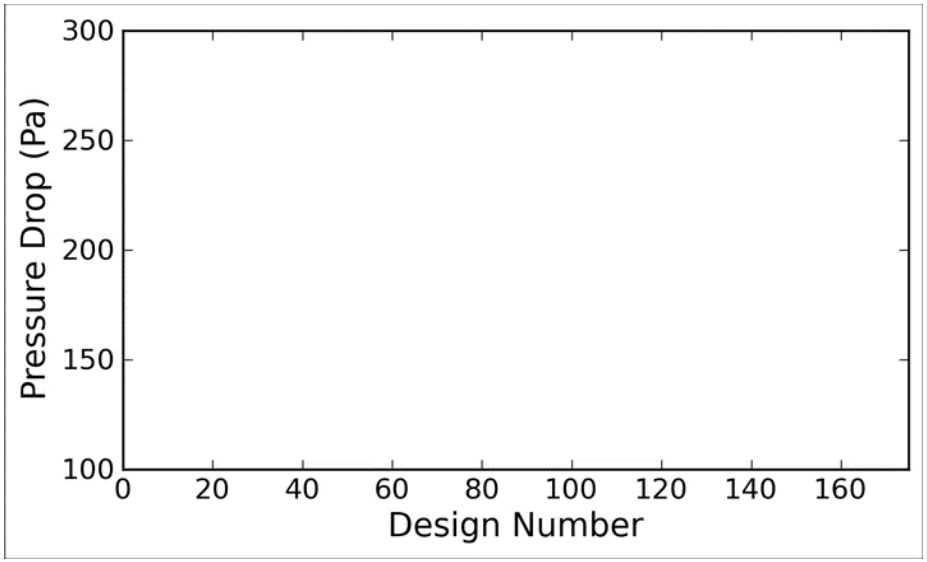


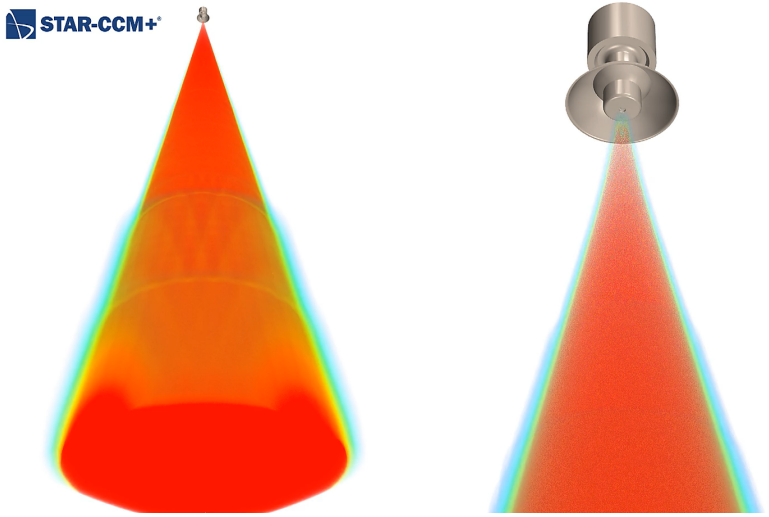


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Design search study results

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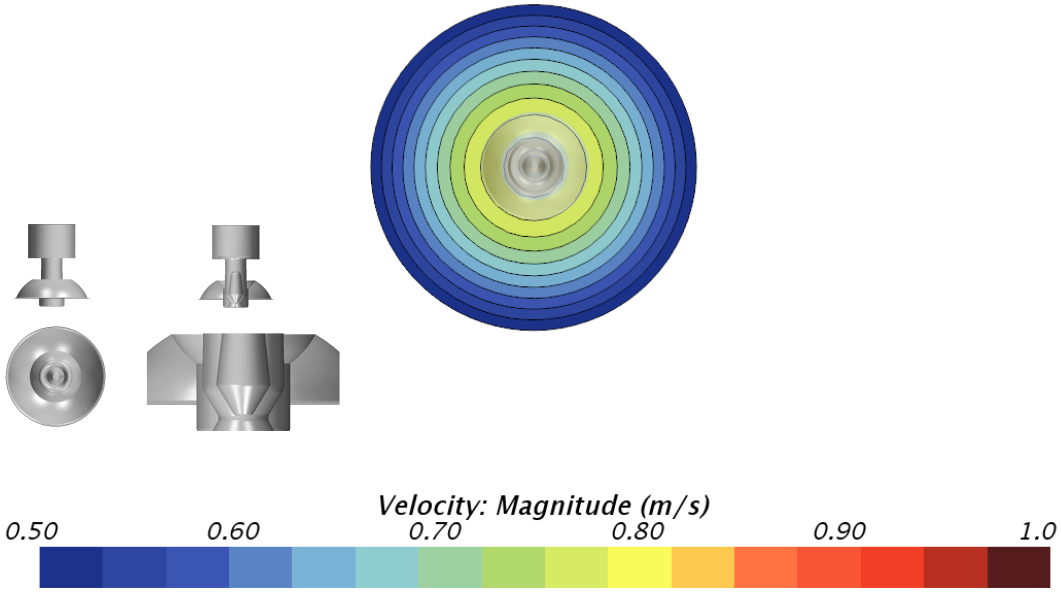


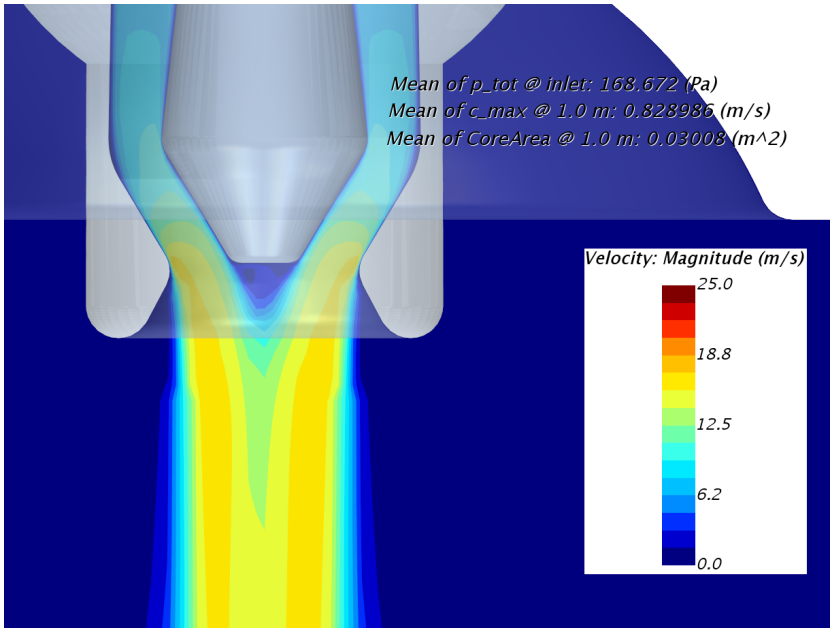
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Summary

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- Best designs show over a 50% improvement in pressure drop compared to existing design
- Evaluate new design strategies for air delivery systems






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Improving helicopter engine performance through dust separation: A study in Design Space Exploration

Agenda

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Problem Background

Engineering objectives

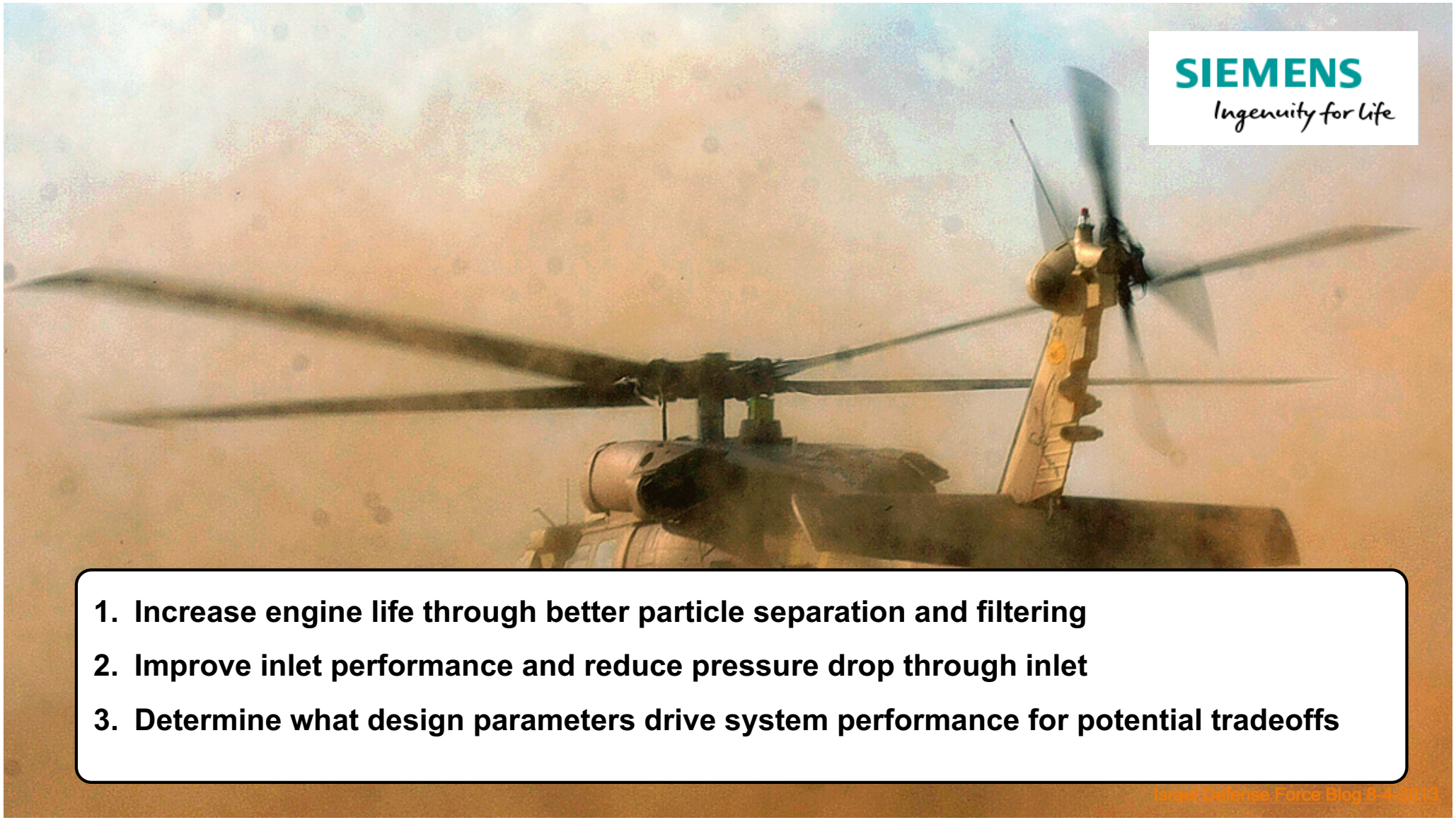
Computational set up

Design Space Exploration study

Results and discussion

Summary

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1. Increase engine life through better particle separation and filtering
2. Improve inlet performance and reduce pressure drop through inlet
3. Determine what design parameters drive system performance for potential tradeoffs

Israel Defense Force Blog 3-4-2013

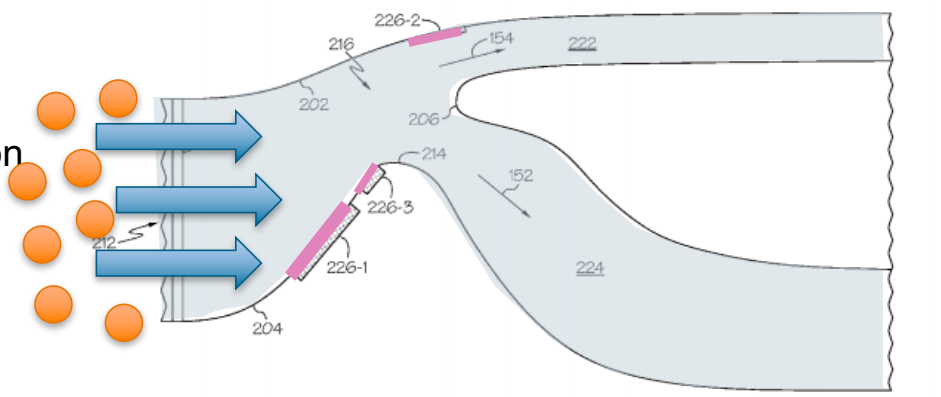
Inlet particle separation goals

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The main goal of the electrostatic separator is to remove 99.5% of the dust particles before they enter the engine

- Avoid costly damage to the engine
- Improve engine performance by reducing distortion





United States Application US20150198090

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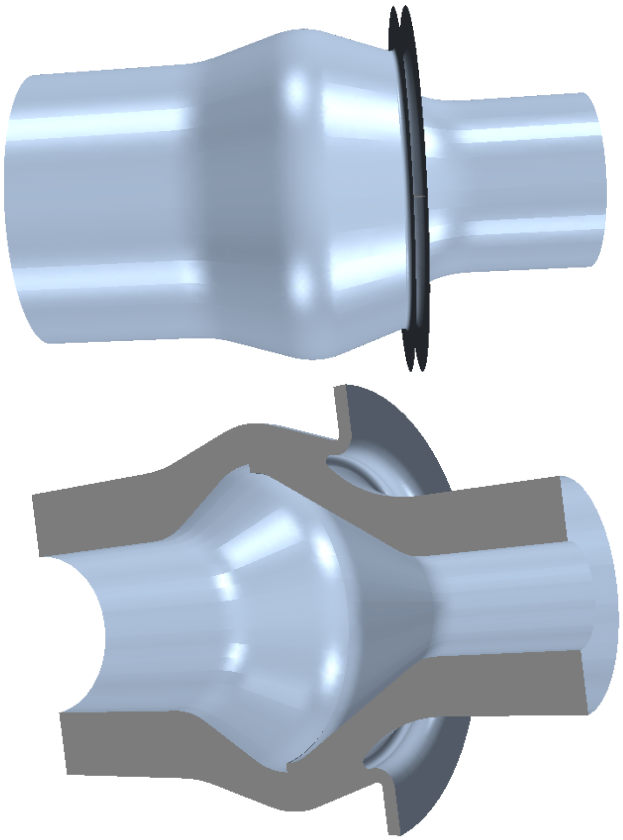
Levering design space exploration to improve particle separation

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Model: Based on loosely on existing electrostatic particle separators in the literature

Goal: Can we leverage intelligent search and design space exploration to improve the efficiency of a particle separator.

WHAT DRIVES GOOD DESIGN

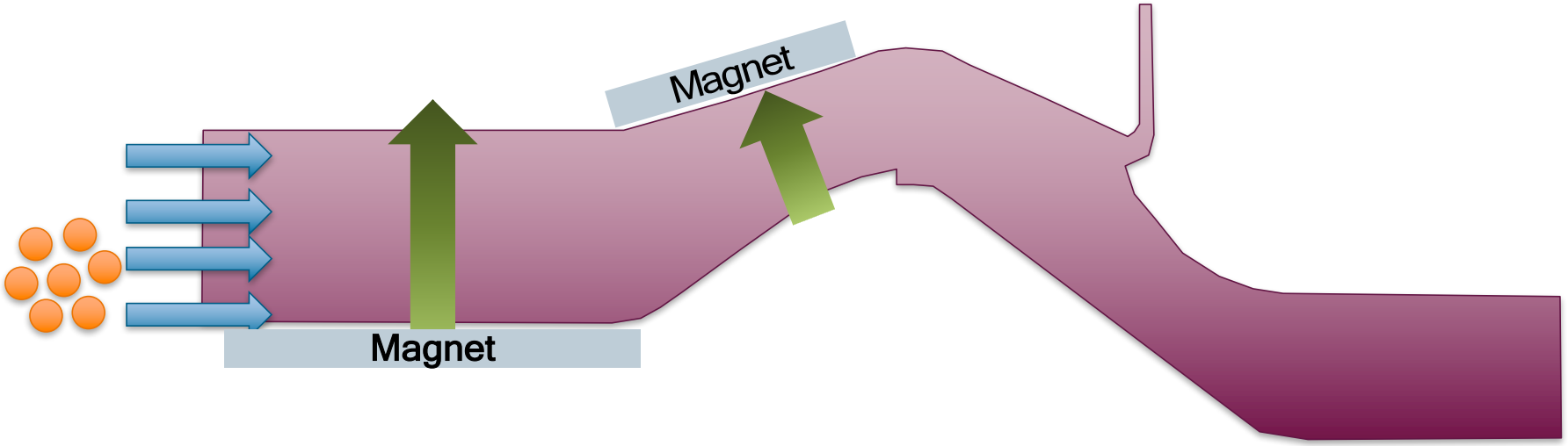


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Design Space Exploration Model Example

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- Reduce Dust in the engine air intake as much as possible
- Maximize air flow to engine
- Conform to the geometric design constraints
- Ensure design does not cause choking



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Study objectives and constraints

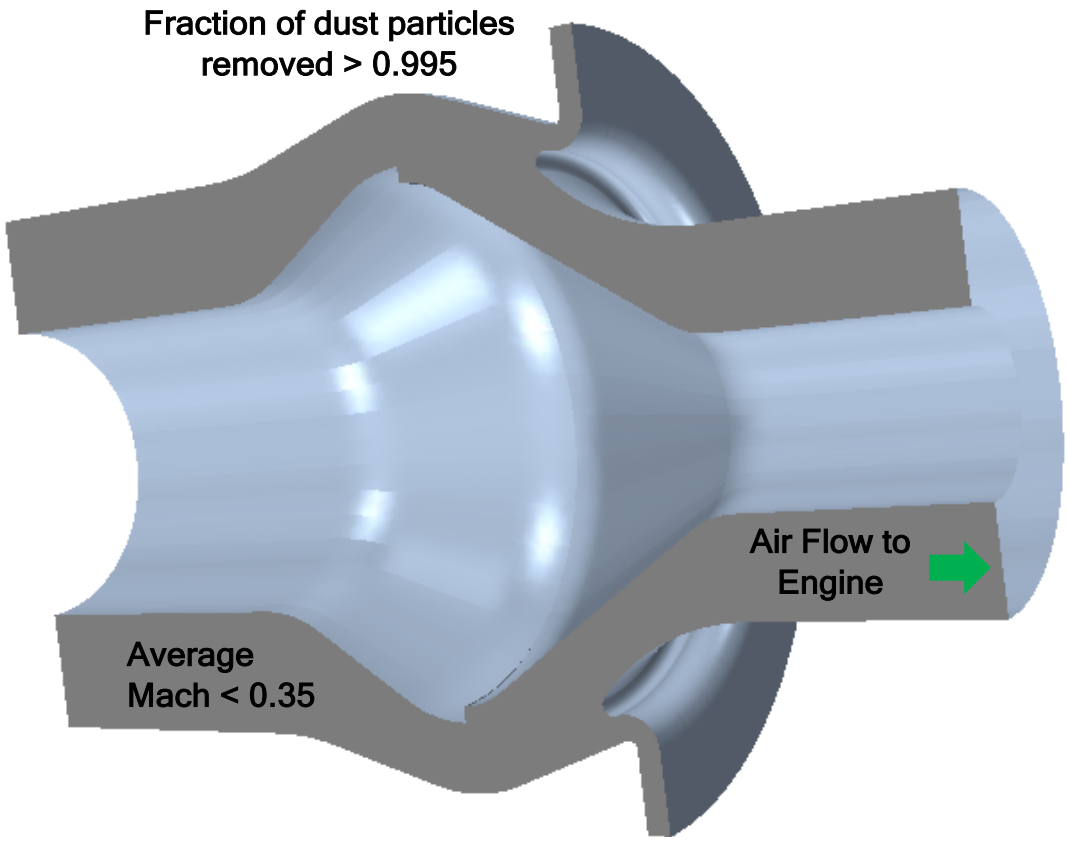
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Objective:

- Maximize air flow to the engine

Constraints:

- Fraction of removed dust > 0.995
- Average Mach < 0.35

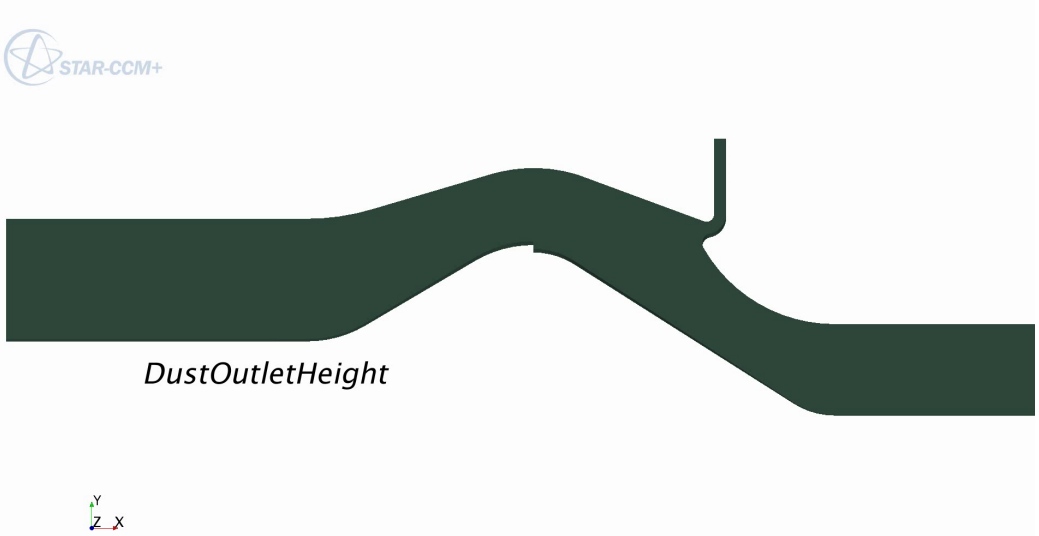


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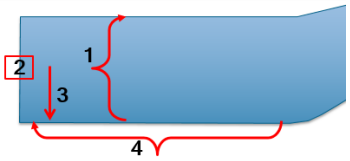
Geometric and Physics Parametrization (15 inputs)

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Parameter
Dust Outlet Height
Inlet Pipe Bottom Radius 1
Inlet Pipe Bottom Radius 2
Inlet Pipe Top Radius 1
Inlet Pipe Top Radius 2
Inlet Pipe Ratio
Step Height
Outlet Pipe Bottom Radius 1
Outlet Pipe Top Radius 1
Outlet Pipe Top Radius 2
Outlet Pipe Ratio



Physics Design Space: 4 Variables



- **1 – Electric potential field strength**
- **2 – Dust particle charge**
- **3 – Electric potential field starting point**
- **4 – Electric potential field length**

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Multi-Physics Computational Setup

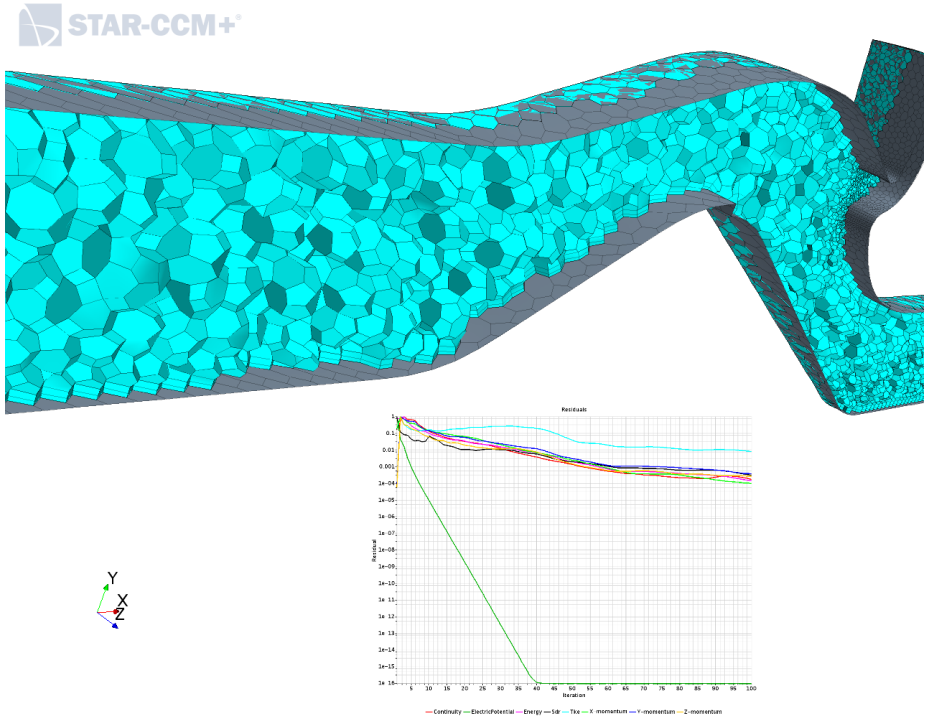
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CFD

- RANS
- SA turbulence model
- Polyhedral mesh average 0.5M cells per model
- Axisymmetric model
- Particles released in a steady solution

CEM

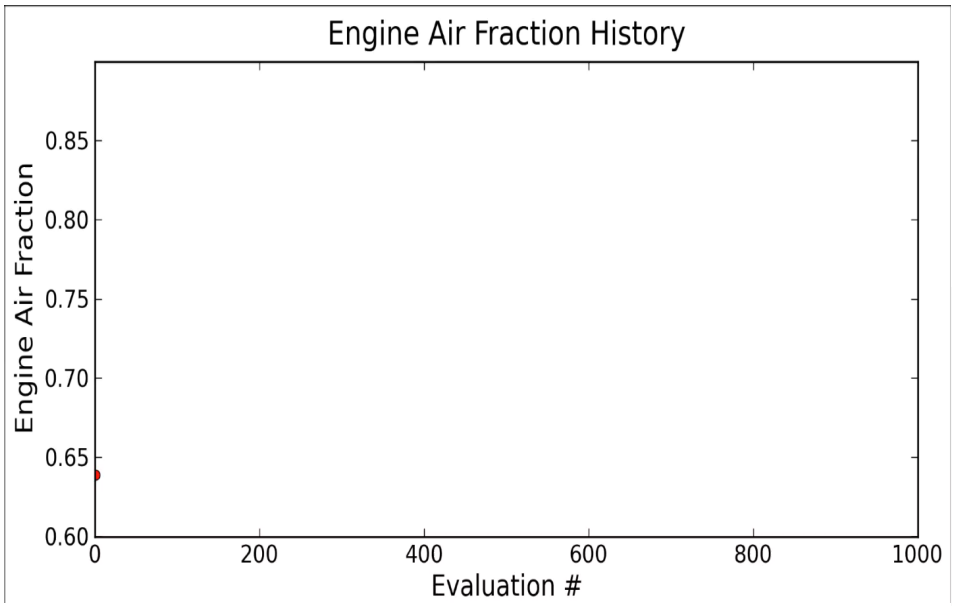
- STAR-CCM+

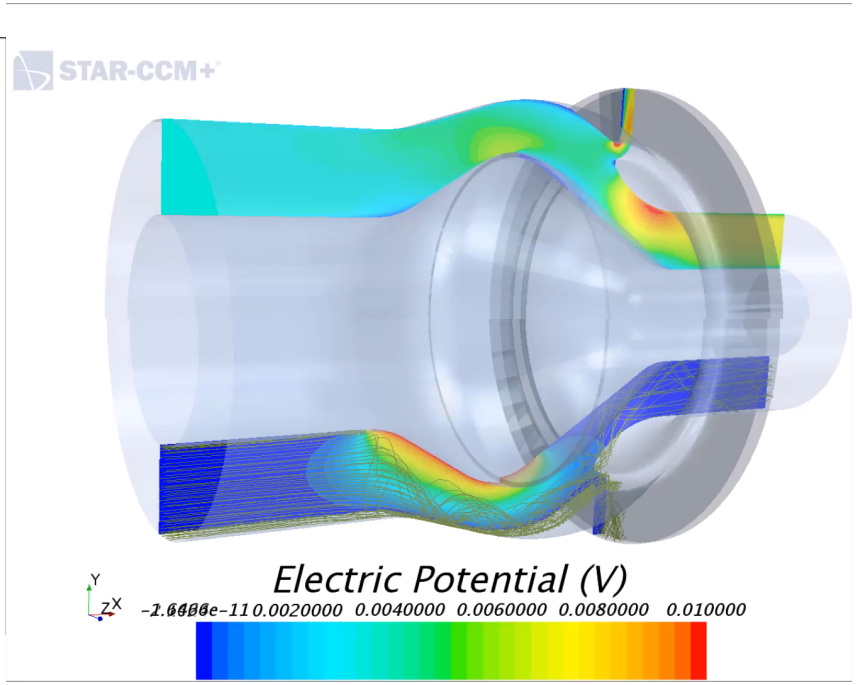


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1000 designs in 48 hours

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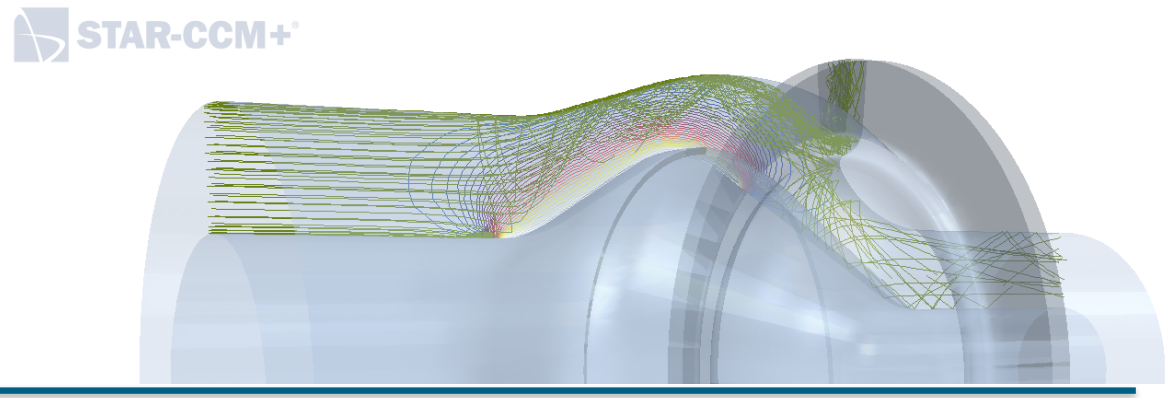


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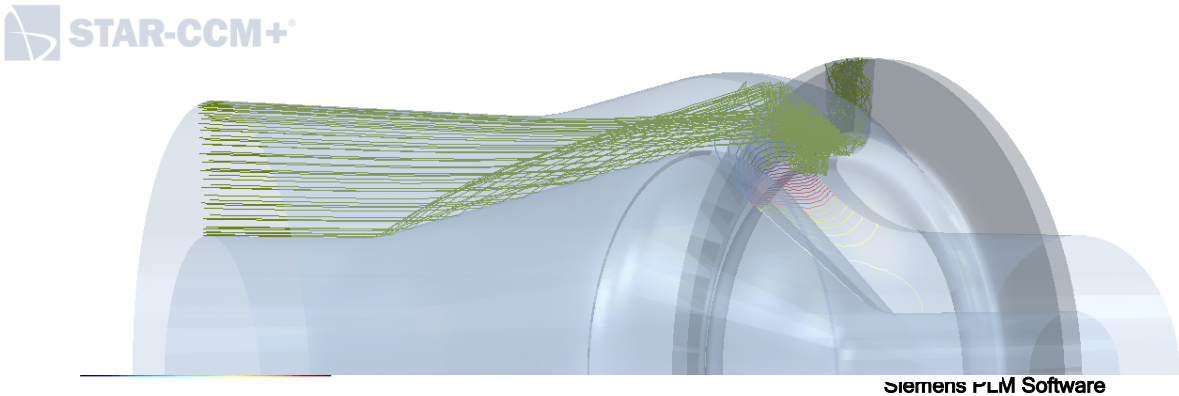
Design Exploration Search Results

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Baseline Design	
Average Mach	0.31
Separation Efficiency	0.48
Engine Air Fraction	0.643
Pressure Drop	8798

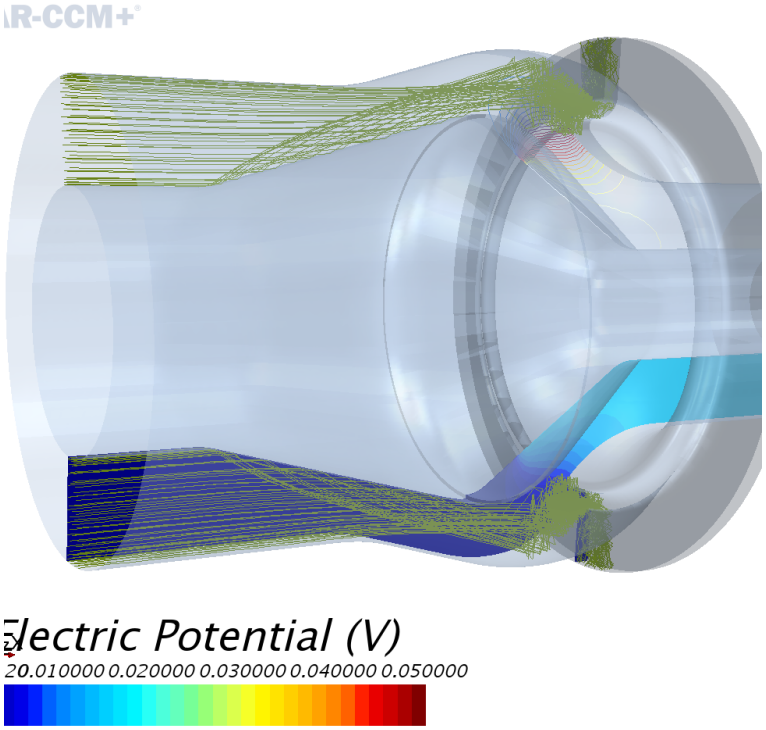


Best Design (947)	
Average Mach	0.321
Separation Efficiency	1.0
Engine Air Fraction	0.810
Pressure Drop	10860



Exploration Study Summary

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- Using design space exploration with intelligent search we improved the design of a electrostatic particle separator by 204%.
- Study was completed on a common engineering workstation in a total of 1/2 week to evaluate 1000 designs
- Identified 175 feasible designs all with improved separation and engine air fraction while maintaining acceptable pressure drop at the inlet
- 15 independent variables were included in the study

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STAR-CCM+ drives innovation for Aerospace and Defense

Durrell Rittenberg, Ph.D.

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Thank you for your kind attention

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