Appendix O

STAR-CCM+ for Complex CAE Design Problems

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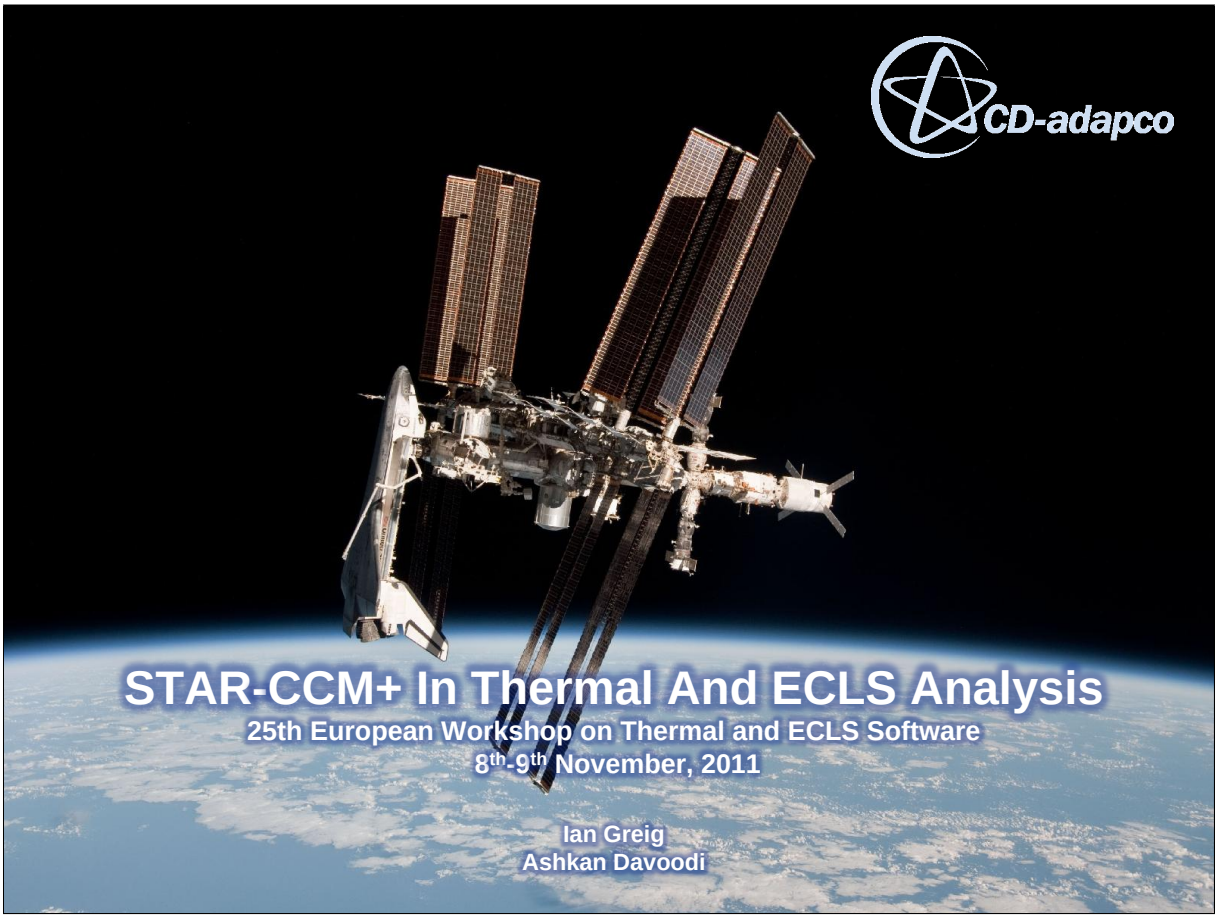
Abstract

CD-adapco has a long history of working with the aerospace and space industry, tackling their toughest problems. CD-adapco'si new generation CAE software, STAR-CCM+, is used in industry every day to perform a full suite of fluid, thermal, mechanical and electro-magnetic analysis. STAR-CCM+ leverages modern software languages and architecture to take advantage of ever larger computing resources via a client-server architecture using JAVA and C++ respectively. STAR-CCM+ is based on the finite volume methodology, with additional capabilities to solve in the Lagrangian, particle framework and others. This presentation will provide an overview of some of the physics available within STAR-CCM+ to perform complex thermal and ECLS type analyses as well as supporting examples.



Agenda

1. Introduction to CD-adapco
2. What is STAR-CCM+?
3. Validation of Li-Ion Battery Electro-Thermo Model
4. Aircraft Cabin Comfort Modelling
5. Presentation Conclusion

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Introduction

- CD-adapco's state of the art multi-physics code STAR-CCM+ has found a wide range of applicability across the aerospace and space community
- STAR-CCM+ has been used across the space flight envelope and throughout spacecraft themselves, to simulate everything from re-entry to battery thermal management
- This presentation describes what STAR-CCM+ is, how it has been used, and it's capabilities, for thermal and ECLS analyses

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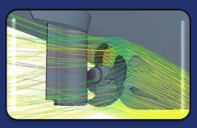
CD-adapco: *Engineering Success*

Our purpose is to ensure the customer's *success* through the use of engineering simulation

- Enable & inspire innovation
- Reduce engineering time & costs



We provide *successful* engineering simulation solutions

- Software products like STAR-CCM+ that are accurate, efficient, and easy to use
- Local dedicated support
- Engineering services: technology transfer, burst engineering resources, custom software tools

We are a growing and *successful* engineering simulation company

- 17% growth in FY2010 global software sales
- >480 employees in ~25 offices
- >8000 users worldwide

Our independence breeds *engineering success*

- Largest independent CAE/CFD provider
- Heavily invest in employees
- Continuously invest in development of new technology

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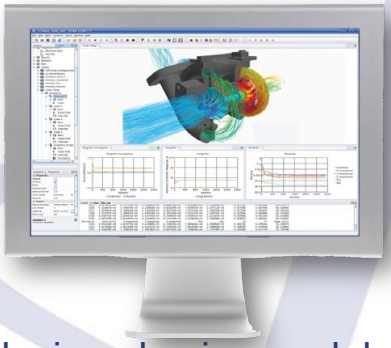
What is STAR-CCM+?

- Modern, fully parallel mutli-physics CAE software
- Client - Server architecture using JAVA - C++ respectively
- Complete process
  - CAD import/Generation
  - Meshing
  - Solving
  - Post Processing



- A comprehensive range of inclusive physics models and links to other packages of different dimensionality (1D, 2D, 3D)

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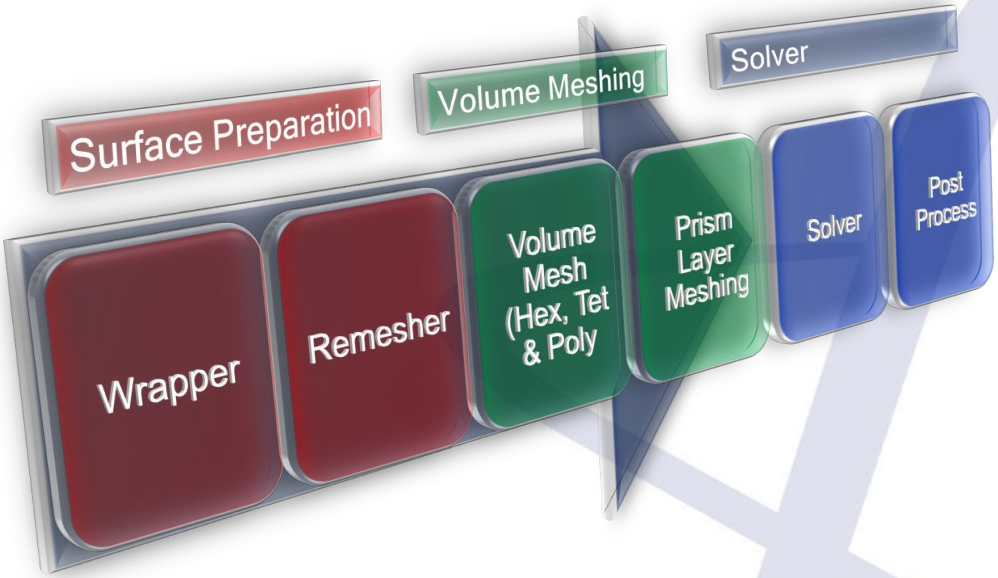
Mesh Generation in STAR-CCM+



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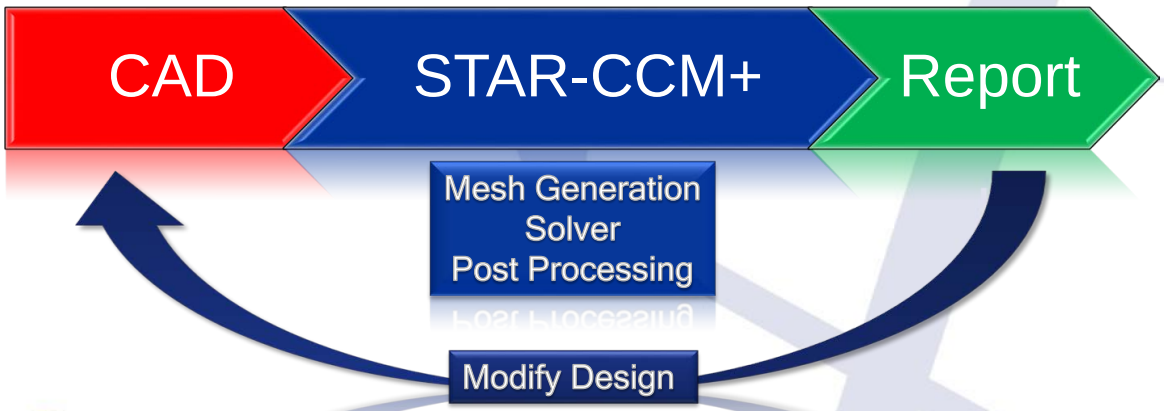
The STAR-CCM+ Advantage

- Meshing & post processing integrated with the solver in a single environment
  - Full CAE process scripted in a single code.
  - Full process can be run in batch or fully interactively.



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Validation of Li-Ion Battery Electro-Thermo Model

- This validation example*, from JAXA, compares temperatures calculated in two different ways with STAR-CCM+ with experimental cell temperatures on a COTS battery cell designed for space applications
- 2 different methods of simulation were used
  - Using Battery Design Studio to calculate the thermal heat sources and then performing a thermo-fluid analysis in STAR-CCM+
  - Using STAR-CCM+ Battery Design Module to calculate the coupled thermo-fluid and electro-chemical analysis

**Fundamental Study of Thermal Numerical Modeling of large Scale Li-Ion Battery for Space Application*, M. Kawase, H. Naito & K. Nishikawa, C5, ESPC 2011

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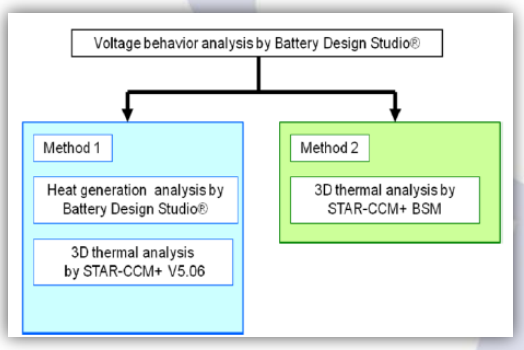
Analysis Methods

- Battery Design Studio® is used in both cases to characterise the battery cell as input for both of the thermal analyses
- Method 1 calculates thermal heat sources for STAR-CCM+
- Method 2 uses the cell characteristics as input and then performs a coupled thermo-electro-chemical analysis to determine heat generation and hence temperatures



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Geometry

- The analysis is conducted on an equivalent pouch cell of the elliptical, jellyroll cell below in both cases
- The elliptical cell geometry is used as geometry in STAR-CCM+ for calculating temperatures in Method 1
- The equivalent pouch cell geometry is used for Method 2 in STAR-CCM+

Model Cell
P/N : JMG100
Cell type : Elliptic cylinder
Cathode : LiCoO2
Anode : Graphite
Nominal Capacity : 100Ah(Rated)
Nominal voltage : 3.7V
Weight : 2,800g
Dimensions (W x L x H) : 50mm x 130mm x 208mm
Energy density : 132Wh/kg , 273Wh/l

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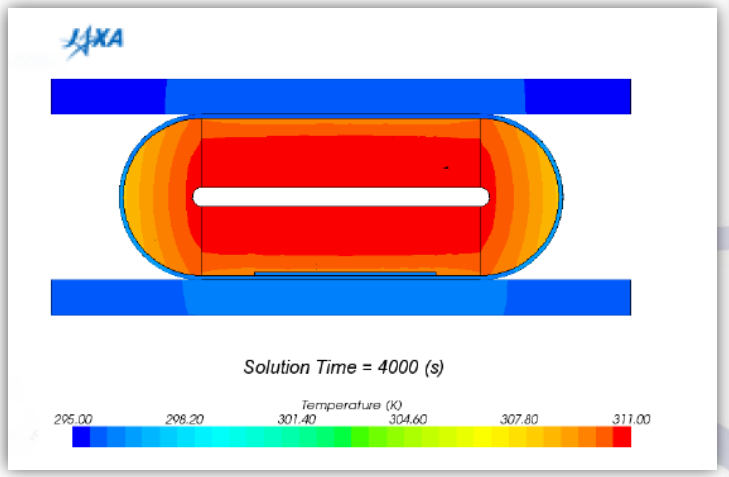
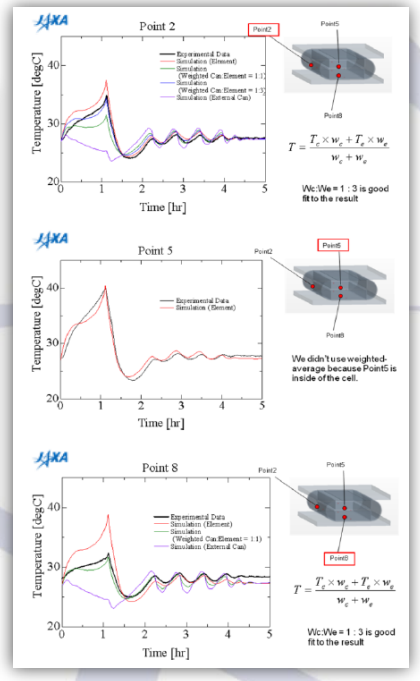
Method 1: Temperature Distribution in Jellyroll





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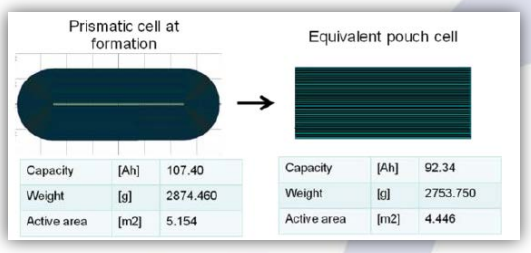
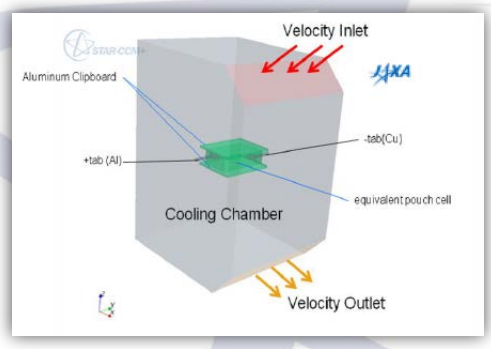
Method 2: Geometry

- For method 2, the elliptical cell is reduced to an equivalent pouch cell due to modelling requirements
- The analysis is conducted in an idealised cooling chamber with a velocity inlet, a pressure outlet and adiabatic walls, with the pouch cell, clipboards and air interfaced together





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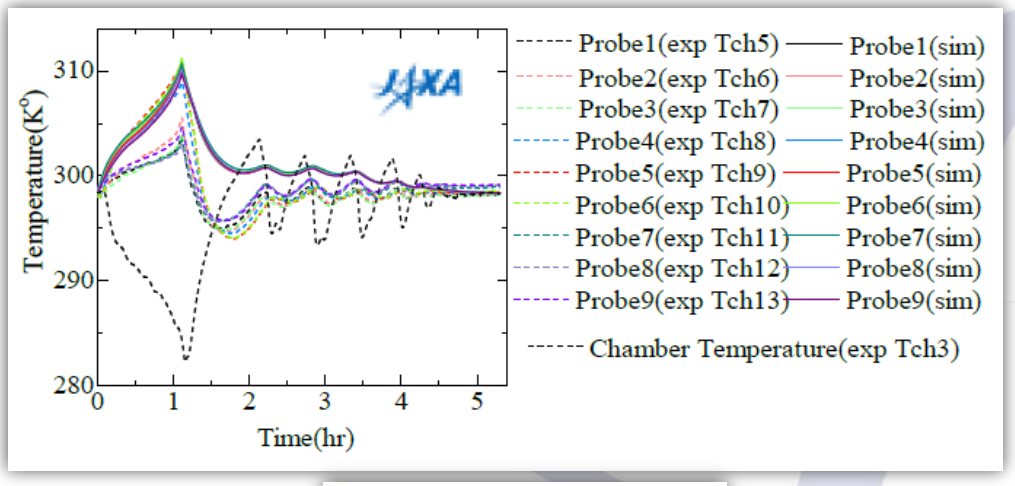
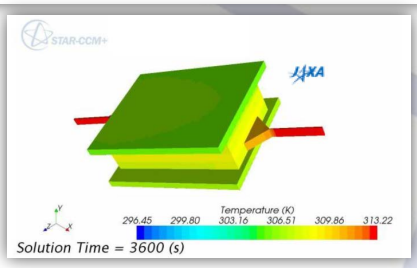
Method 2: Temp. Dist. In Equivalent Cell Pouch





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Validation Conclusion

- The experimental and simulation data match very well in both cases
- Discrepancies between the data are potentially down to incorrect boundary conditions, the equivalent pouch simplifications in the case of method 2 and the methods chosen for the cell characterisations
- STAR-CCM+ makes battery performance and lifetime analysis possible when thermal effects are an important consideration

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Aircraft Cabin Comfort Modelling

- An important consideration of human spaceflight is maintaining ideal working conditions for astronauts, and in the future commercial passengers, especially on long duration missions
- This process presentation* is an example of how STAR-CCM+ is currently being coupled to anatomical models to perform aircraft cabin comfort analysis

**Aircraft passenger cabin thermal comfort analysis by means of integrated mono dimensional-CFD approach*, P. Borrelli, A. Romano & D. Cannoletta, Alenia Aeronautica, STAR-European Conference 2011

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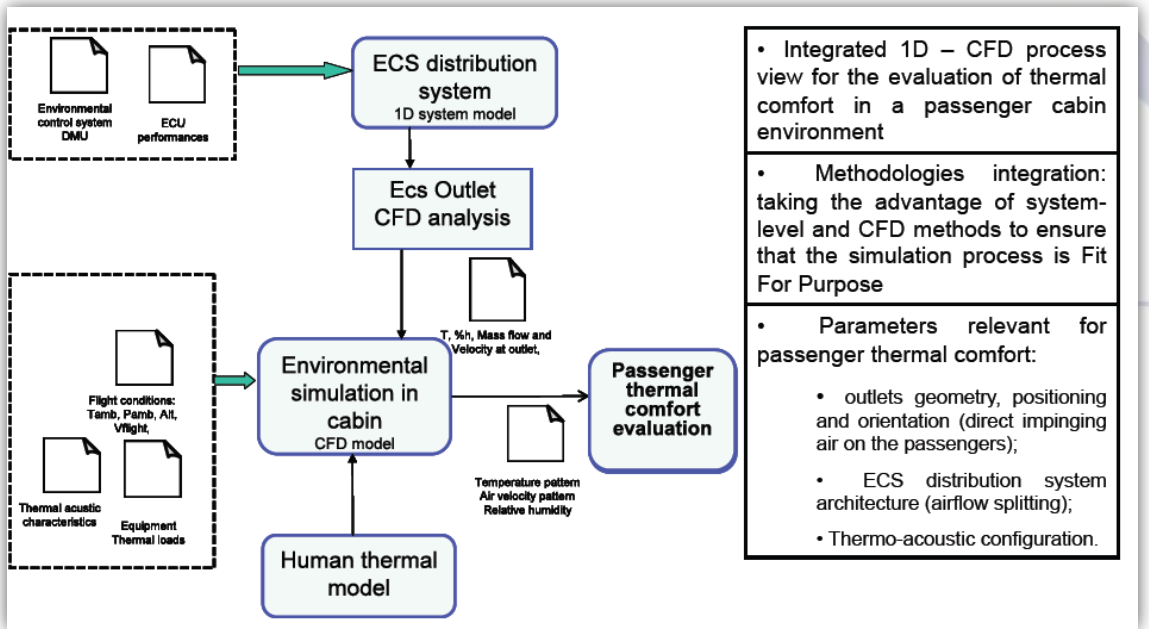
Process and Coupling Diagram



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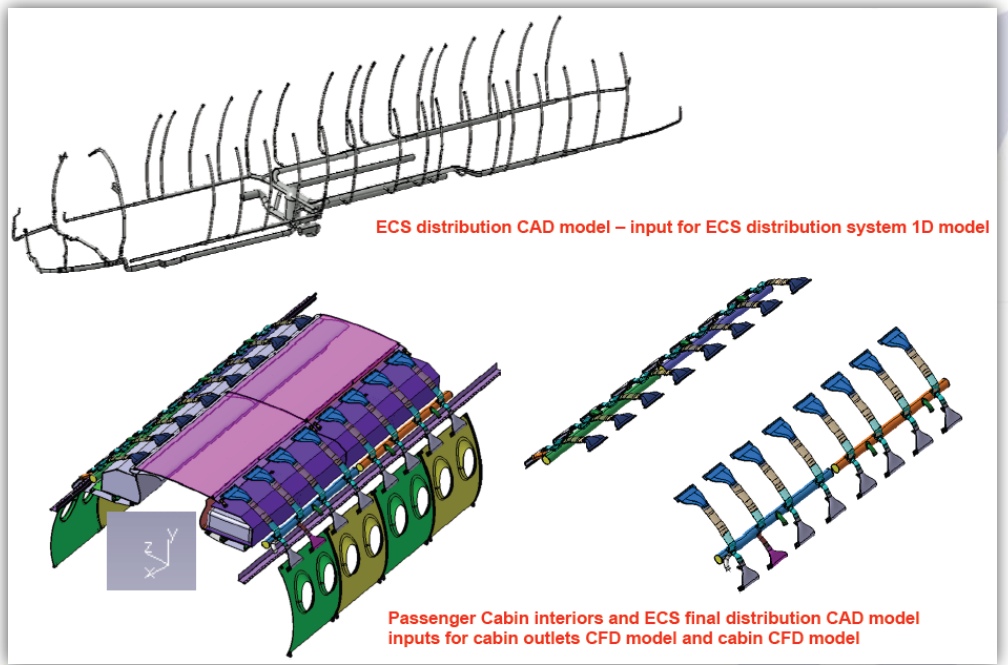
ECS and CFD Geometry Input



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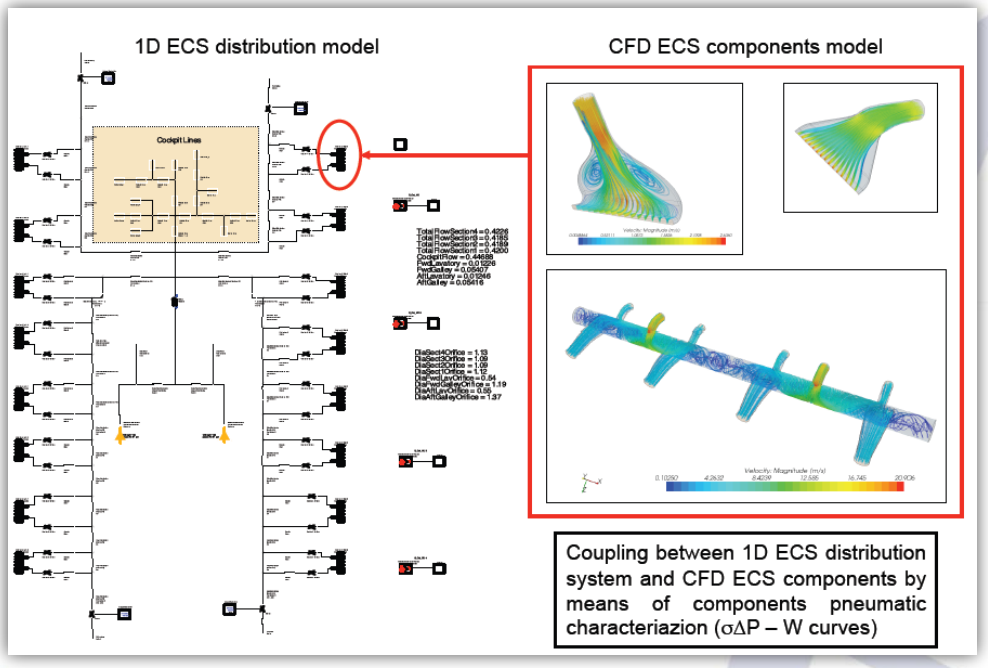
ECS Components Coupling



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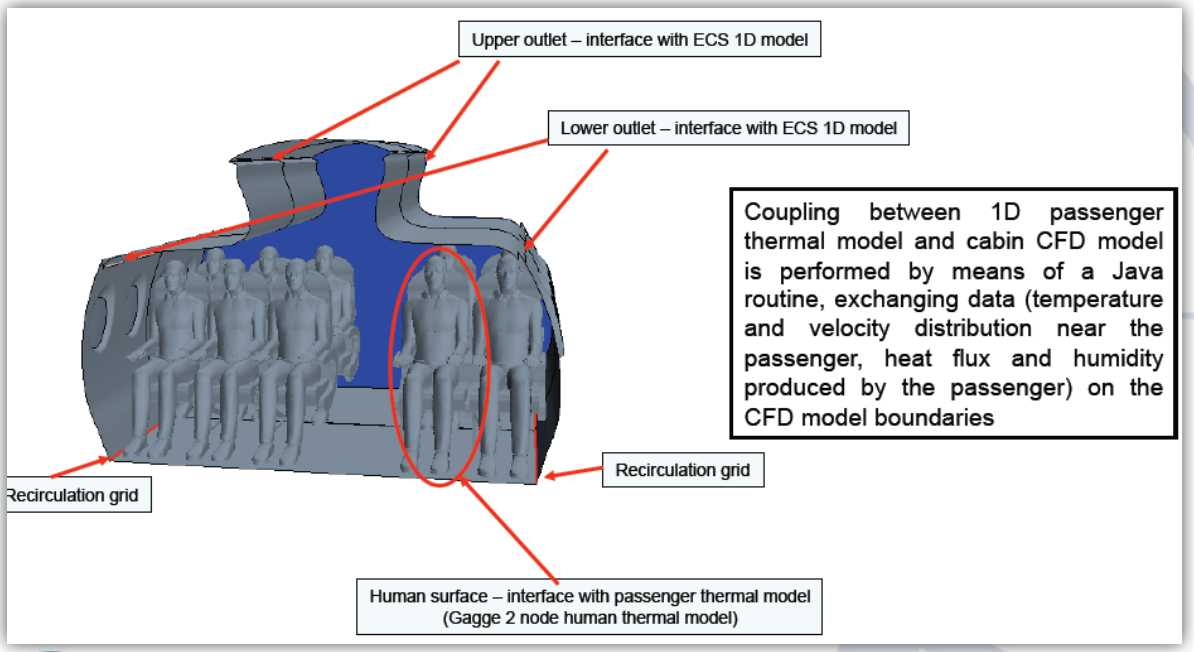
CFD Cabin Model



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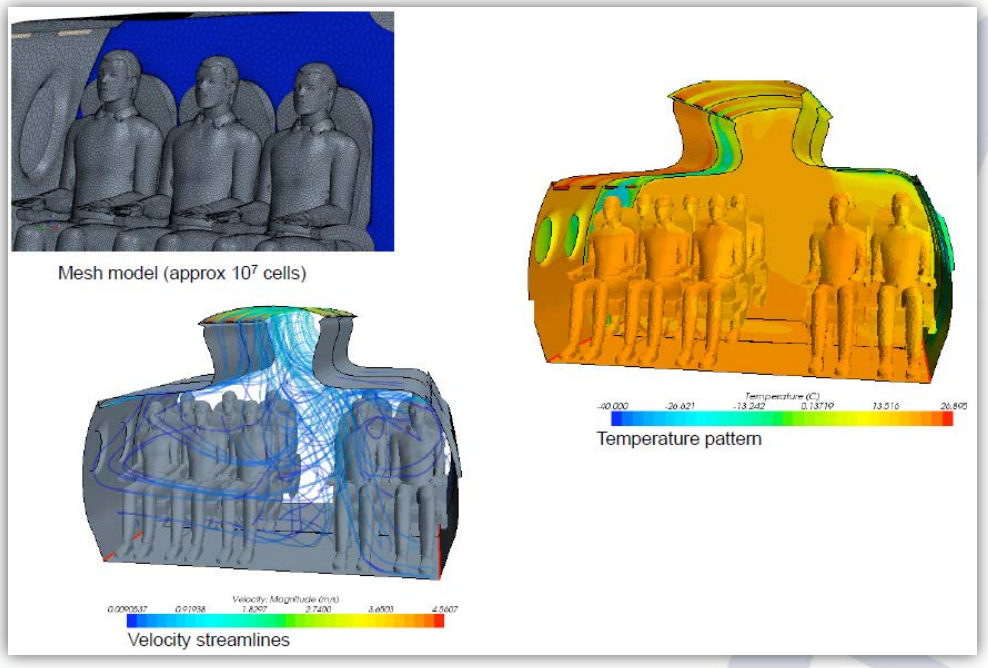
Coupled Fluid-Anatomical Model Results



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Conclusion

- Models such as these can include solar radiation effects, conjugate heat transfer and other important factors such as internal heat sources, electrical or mechanical
- Coupling with external codes of any dimensionality is made possible via STAR-CCM+'s JAVA macro faculties
- In the near future, STAR-CCM+ will come with it's own socket based coupling API so that users can program a coupling between STAR-CCM+ and potentially any other program

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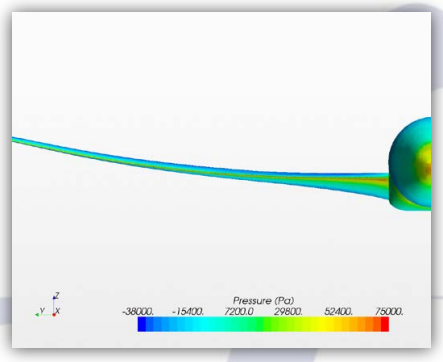
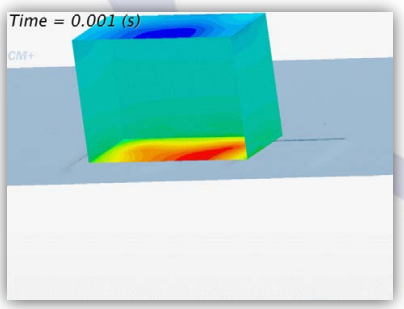
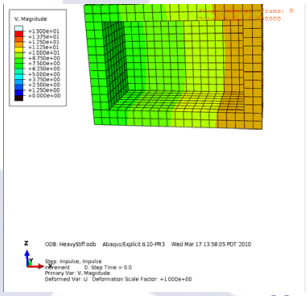
Advanced Simulation Capabilities

- Dynamic Fluid Body Interaction
- Particle dynamics
- Multiphase
- Fluid-Structure Interaction
- Electro-statics/Electro-magnetics
- Aeroacoustics
- Combustion
- Battery Modelling
- And More!







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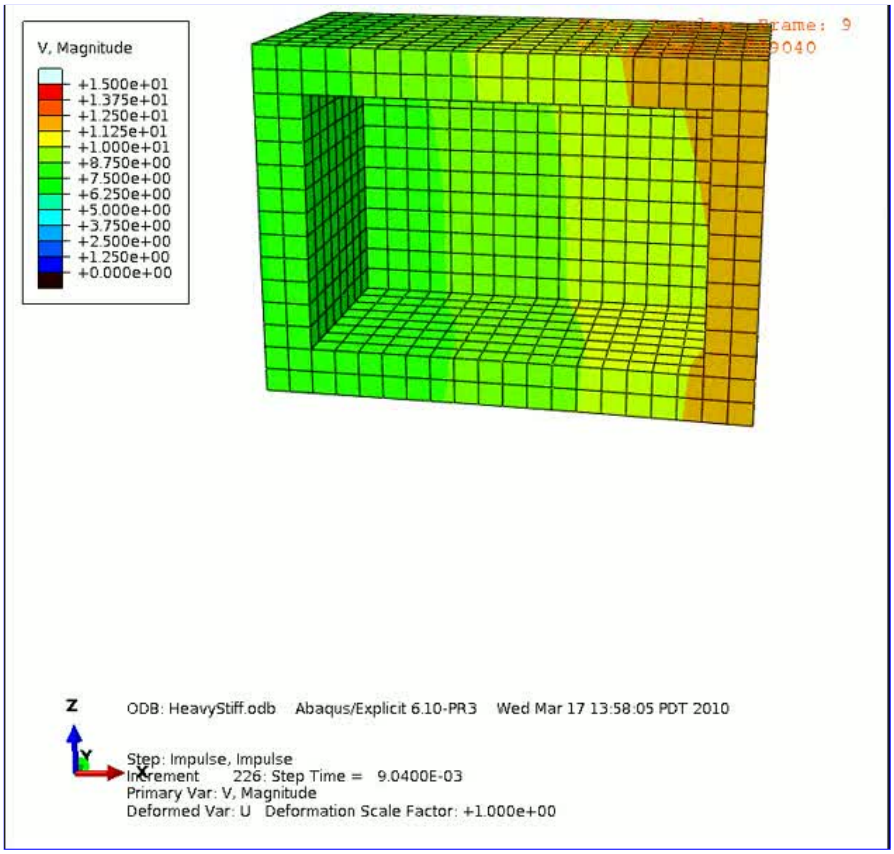

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Presentation Conclusion…

- STAR-CCM+ has found a wide user base in the missile, aerospace and space flight community for many applications
- The combination of advance physics and ease of use makes even the most challenging analysis manageable and possible within a reasonable timeframe
- CD-adapco's experts are always at hand to answer difficult questions and to expand the capabilities of the software to simulate the latest challenges

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…And a Request!

- CD-adapco is continually updated, improving and validating STAR-CCM+ against industrial benchmark cases, using industrial strength models the compare well with experiment/other data
- If there is such a case that you feel we should use to benchmark ourselves in this field, then please let us know!

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