SESA6085 – Advanced Aerospace Engineering Management

Lecture 14

2024-2025

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Recap

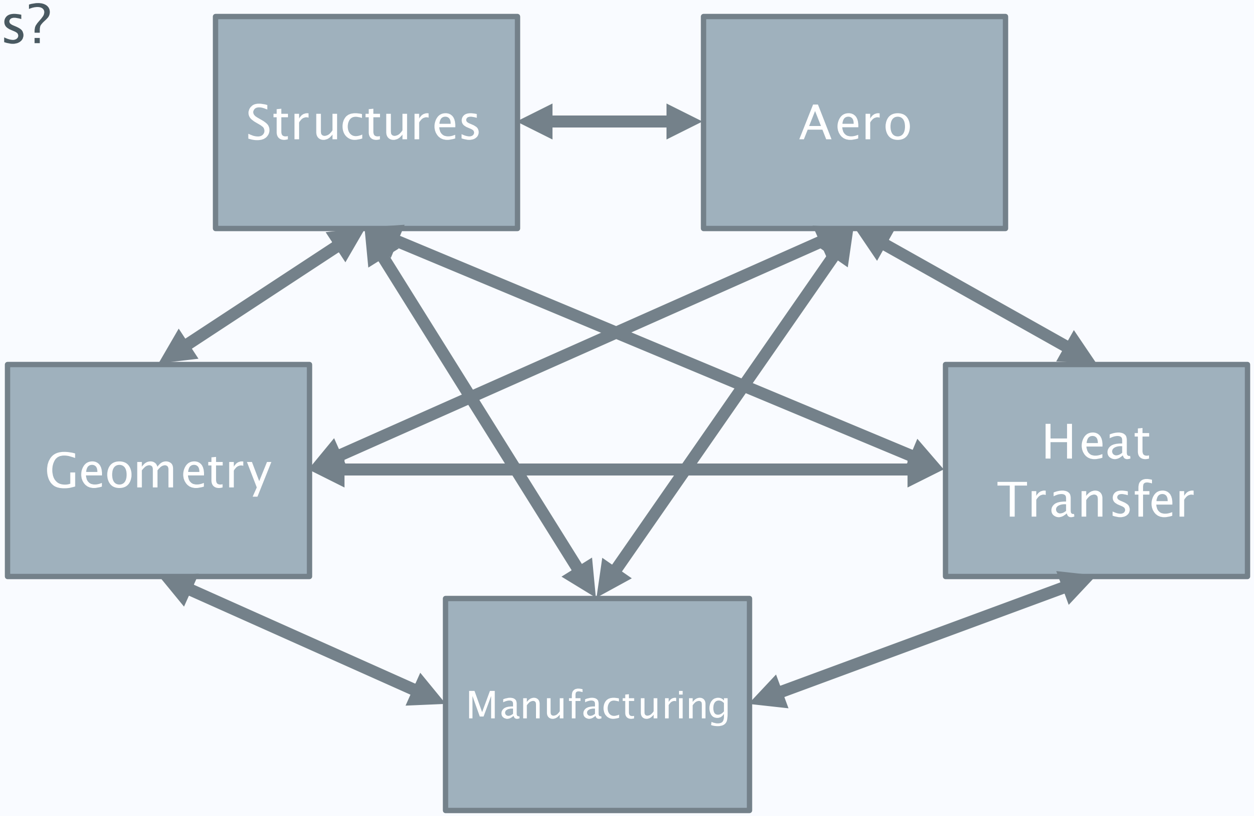
- So far, we have…
  - Considered the mathematical foundations of uncertainty
  - Addressed component and system reliability
  - Considered designing in the presence of uncertainty
- Today we will address another form of risk/uncertainty within design

A Single Component

- Consider the illustrated turbine blade
- What technical disciplines are involved in its design?
  - Geometry generation/manipulation
  - Aerodynamics
  - Heat transfer
  - Structures
  - Manufacturing
- Can a single engineer tackle all of these aspects?
  - Probably not, a team is required
- Are these aspects of the design independent?
  - No! They are heavily coupled

A Single Component

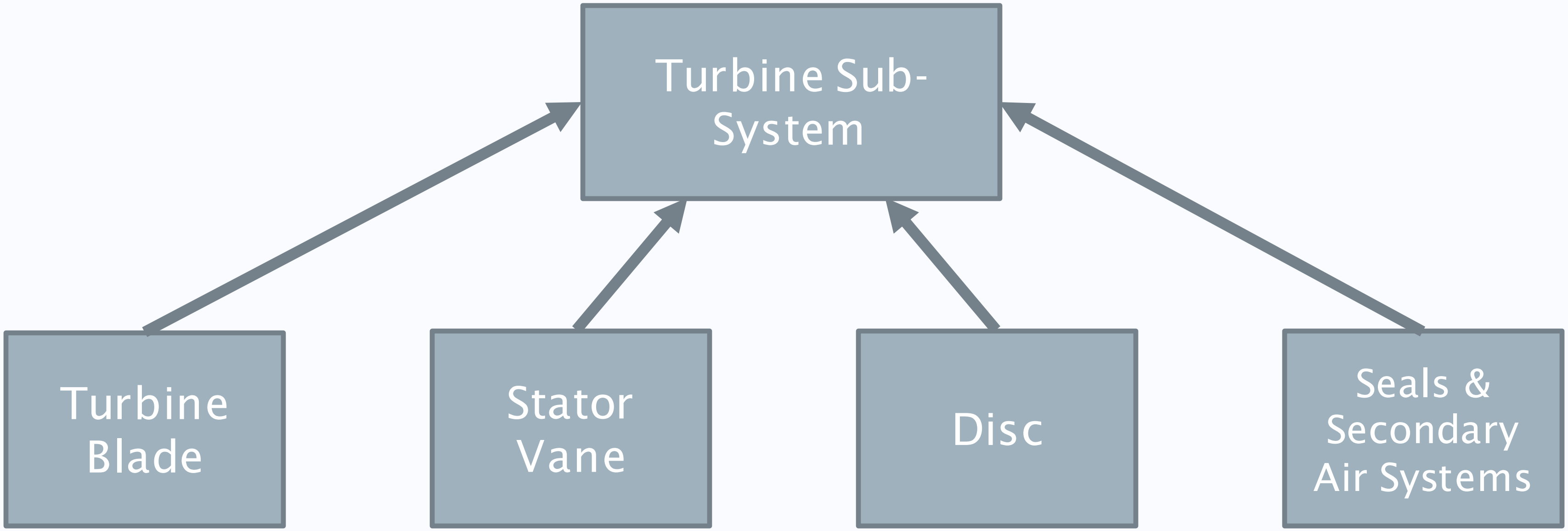
- What are the implications for this coupling on the design process?



- Communication!

A Sub-System

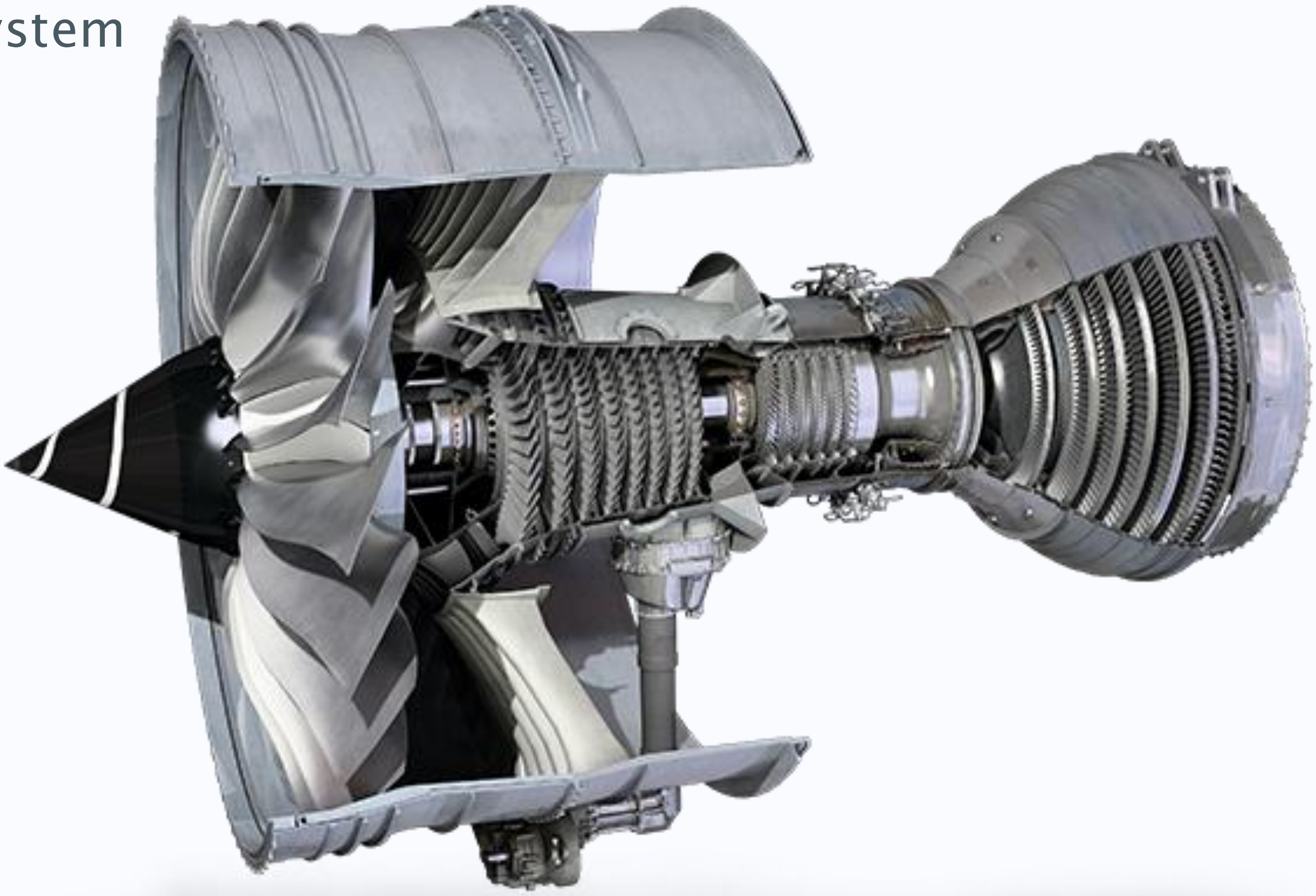
- Let's expand our example to the entire turbine sub-system



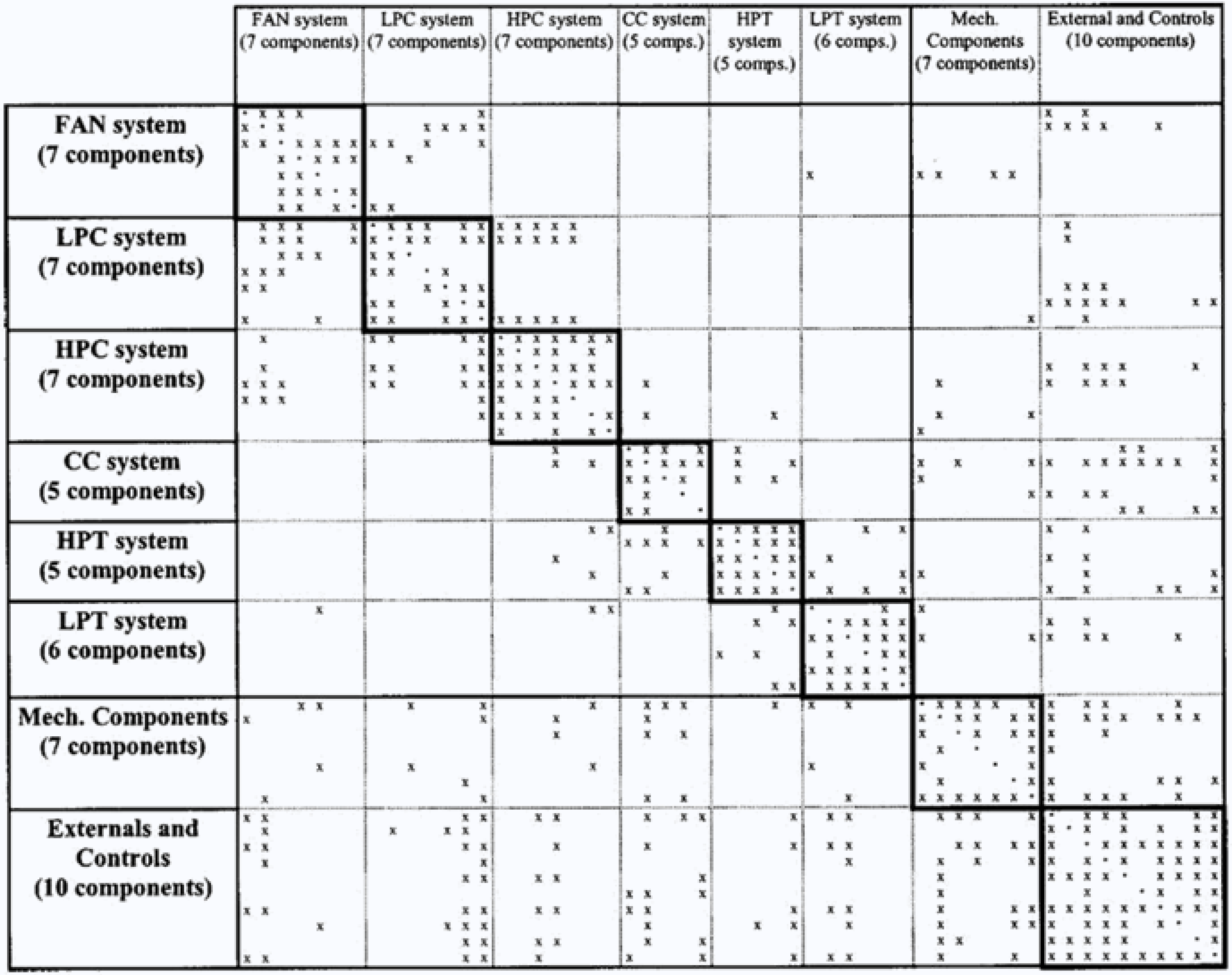
- Again, we have a communication issue but now across components

An Entire System

- Of course, we can expand our example to that of an entire system

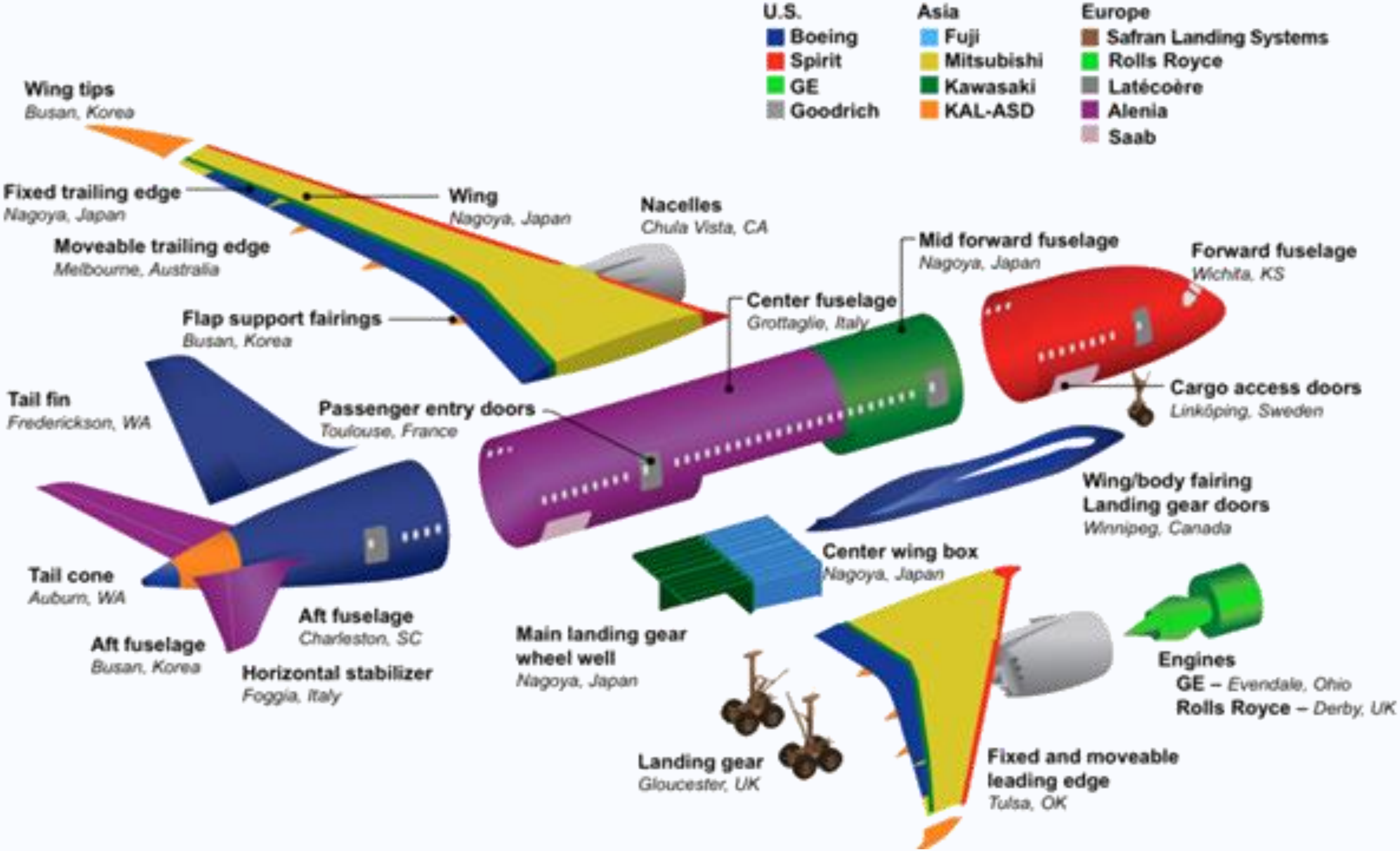


Gas Turbine Sub-system Dependencies

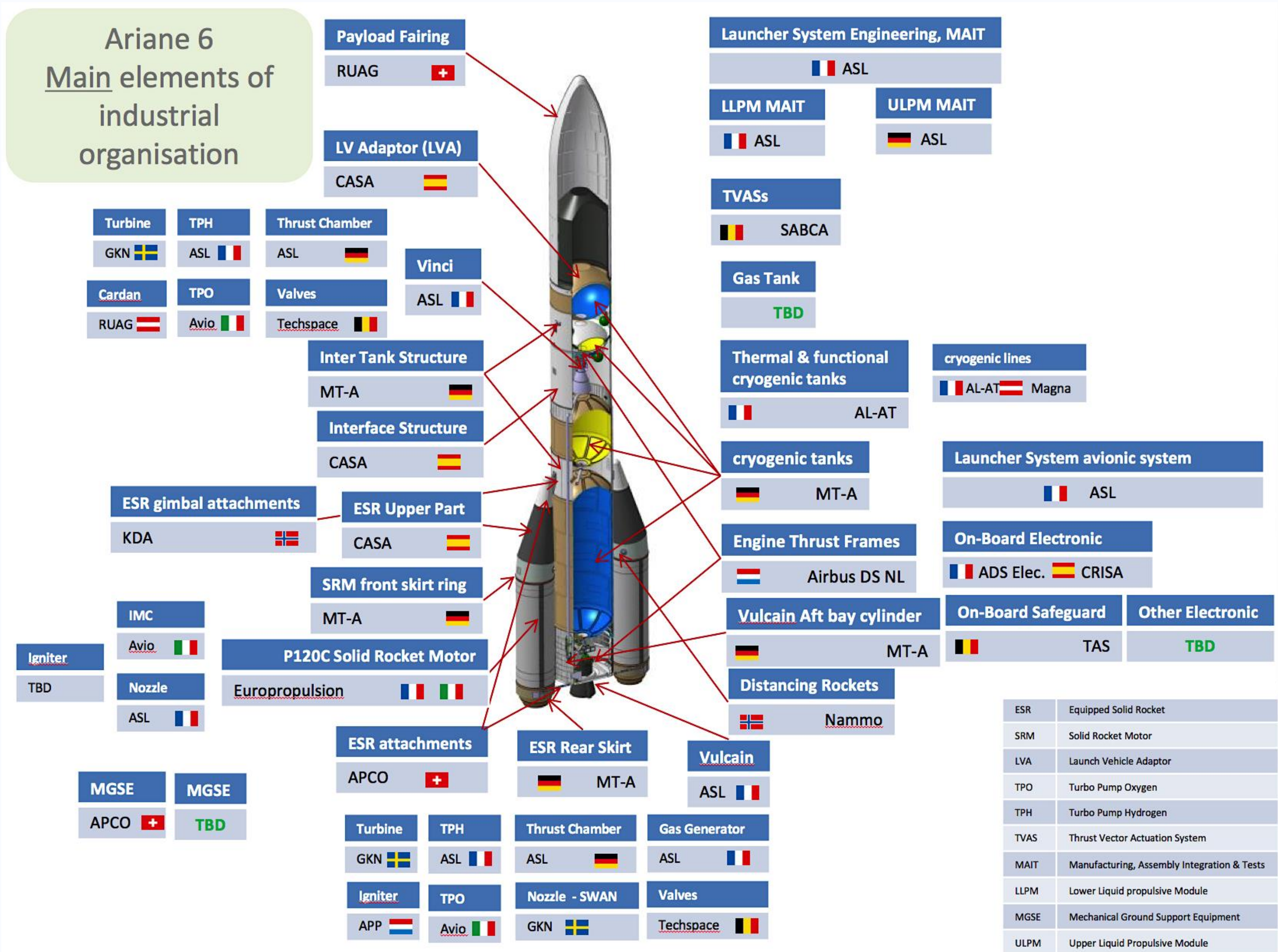


Boeing 787

- Now we have different companies involved…



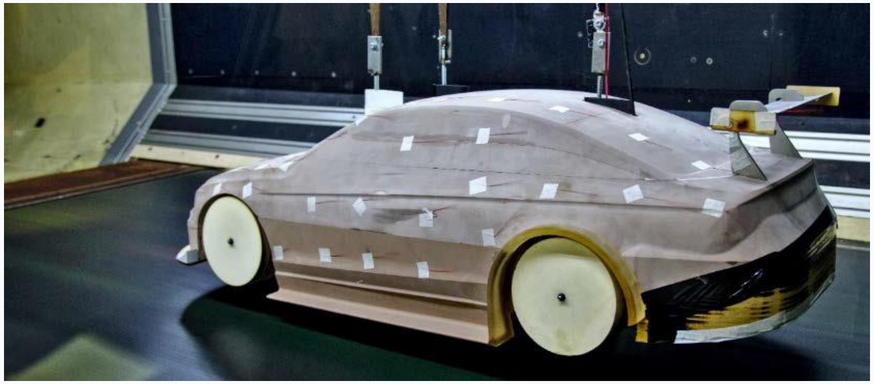
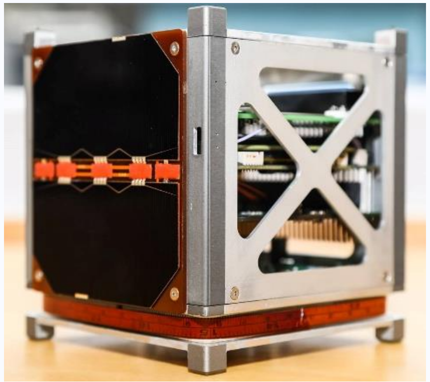
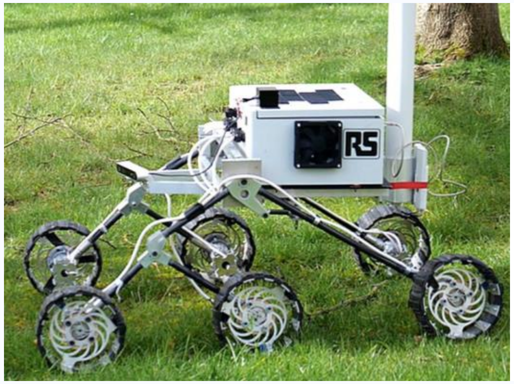
Ariane 6



Ariane 6
Main elements of industrial organisation
Payload Fairing
RUAG
LV Adaptor (LVA)
CASA
Turbine
GKN
TPH
ASL
Thrust Chamber
ASL
Cardan
RUAG
TPO
Avio
Valves
Techspace
Vinci
ASL
Inter Tank Structure
MT-A
Interface Structure
CASA
ESR gimbal attachments
KDA
ESR Upper Part
CASA
SRM front skirt ring
MT-A
IMC
Avio
Igniter
TBD
Nozzle
ASL
P120C Solid Rocket Motor
Europropulsion
ESR attachments
APCO
ESR Rear Skirt
MT-A
Vulcain
ASL
MGSE
APCO
MGSE
TBD
Turbine
GKN
TPH
ASL
Thrust Chamber
ASL
Gas Generator
ASL
Igniter
APP
TPO
Avio
Nozzle - SWAN
GKN
Valves
Techspace
Launcher System Engineering, MAIT
ASL
LLPM MAIT
ASL
ULPM MAIT
ASL
TVASs
SABCA
Gas Tank
TBD
Thermal & functional cryogenic tanks
AL-AT
cryogenic lines
AL-AT Magna
cryogenic tanks
MT-A
Launcher System avionic system
ASL
Engine Thrust Frames
Airbus DS NL
On-Board Electronic
ADS Elec. CRISA
Vulcain Aft bay cylinder
MT-A
On-Board Safeguard
TAS
Other Electronic
TBD
Distancing Rockets
Nammo
ESR Equipped Solid Rocket
SRM Solid Rocket Motor
LVA Launch Vehicle Adaptor
TPO Turbo Pump Oxygen
TPH Turbo Pump Hydrogen
TVAS Thrust Vector Actuation System
MAIT Manufacturing, Assembly Integration & Tests
LLPM Lower Liquid propulsive Module
MGSE Mechanical Ground Support Equipment
ULPM Upper Liquid Propulsive Module

GDP

- Of course, you are all in the midst of tackling this exact problem yourselves to varying degrees…

Overview

- Design of any complex system cannot be carried out (usually) by a single person
- This starts to introduce issues
  - Complex systems can be tightly coupled
  - Communication of the coupled information introduces an uncertainty
  - The design “drum beat” can be different between sub-systems, components or disciplines
- We need a way of managing these uncertainties

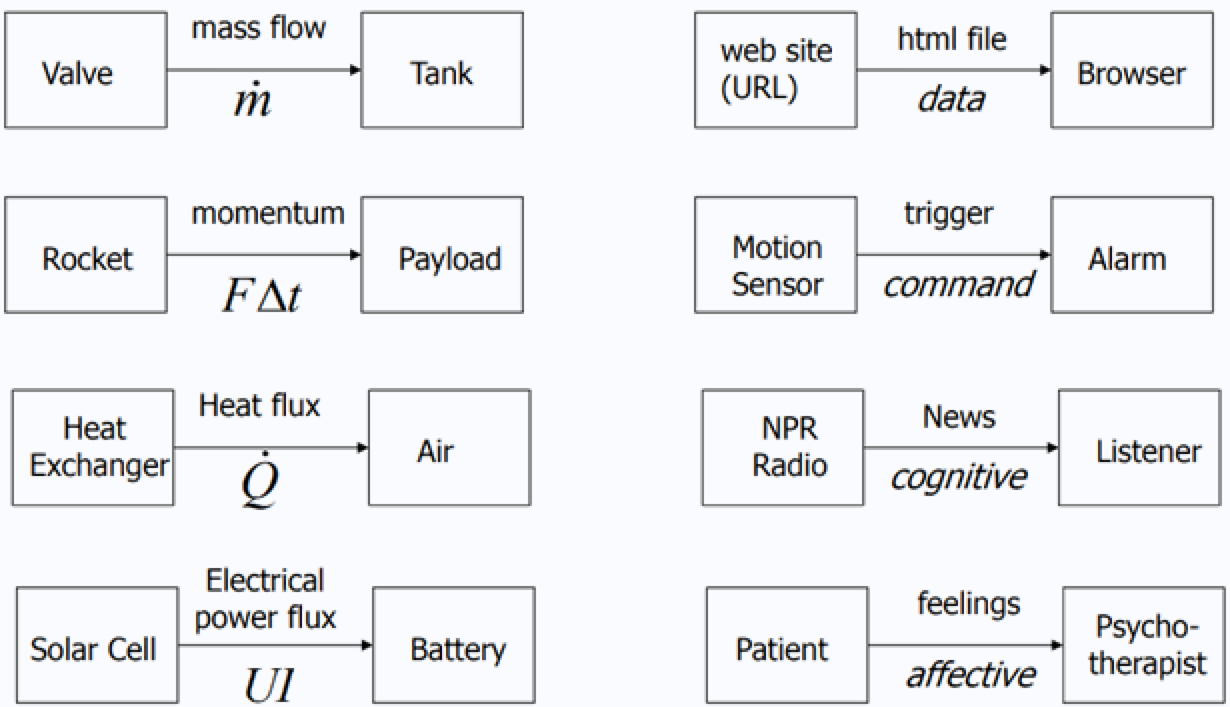
Concurrent & Collaborative Design

Design Decomposition

- Decomposing a design problem into sub-systems can:
  - Exploit sub-system specific expertise
  - Reduce the number of design variables that are controlled
  - Reduce the scope of the analysis models used
- However, sub-systems can:
  - Be tightly coupled
  - Have conflicting requirements
  - Contribute differently to the overall system performance
- Such decomposition is at the heart of concurrent design, where many design (& manufacturing) tasks are completed concurrently
  - Requires extensive coordination and communication

Coordination Through Interfaces

- Traditionally coordination is achieved through communication at sub-system interfaces
- Information at these interfaces can be in a variety of forms



Coordination Through Interfaces

- Interfaces are agreed at the outset of the design process, based on a system-level conceptual/preliminary design
  - Therefore, an initial system-level view is very useful!
  - Without such a view defining appropriate interfaces is difficult and can hamper designers significantly
- Normally these act as constraints to the sub-system designers e.g.
  - Pressure ratio agreed
  - Combustor exit temperature profile is agreed
  - Stiffness of casing is agreed
- A designer may be forced to satisfy these interface constraints before a design is accepted

Coordination Through Interfaces

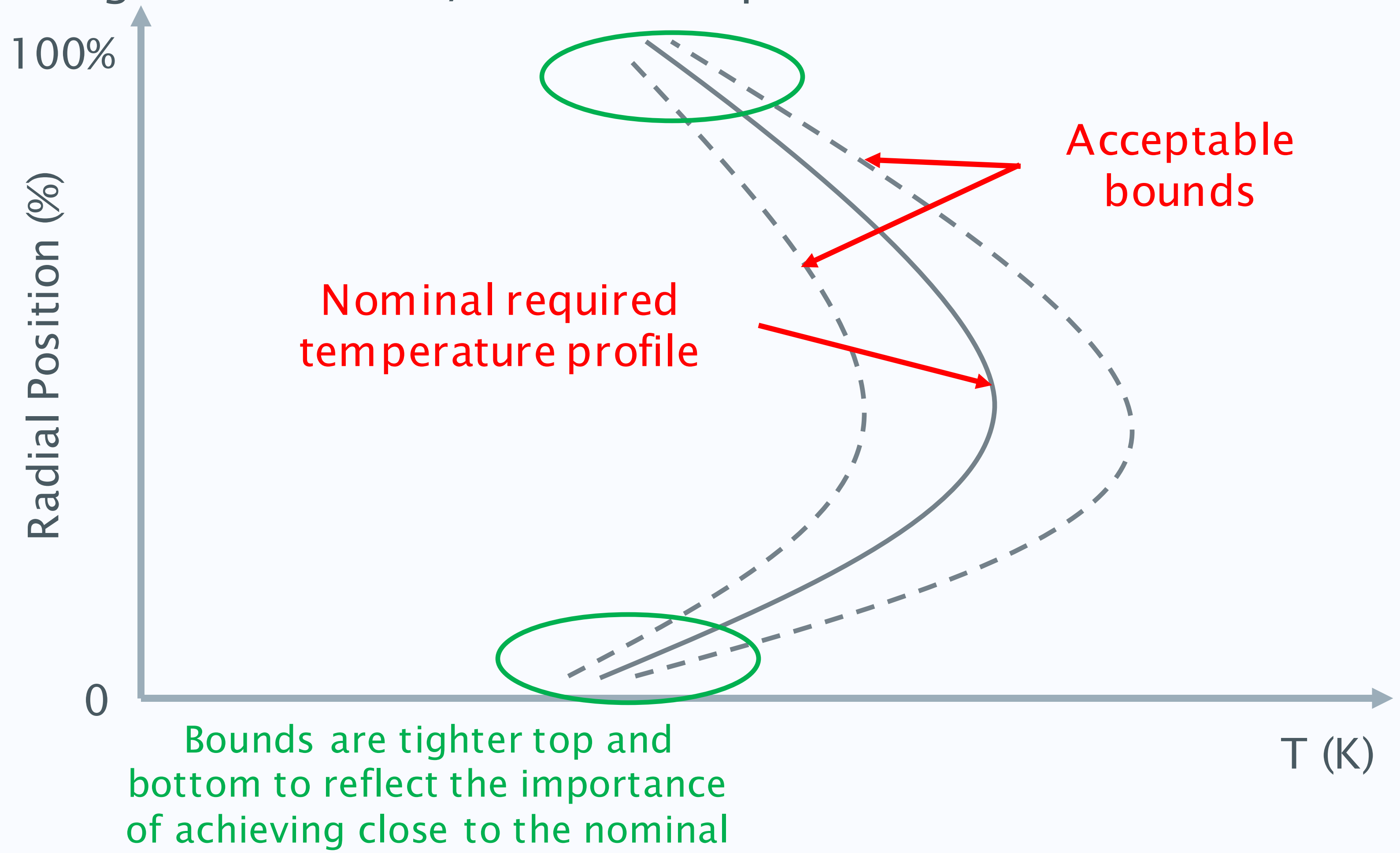
- What are the potential issues with such an approach?
- The constraints imposed may be difficult to satisfy
  - Sometimes impossible!
- Are rarely checked at the system level
  - System-level response of a sub-system with true representations of interface components can be different to the isolated system
  - Modelling assumptions can play a role in this e.g. imagine calculating the deflection of a wingtip in isolation
  - The interface may not capture enough information e.g. a bulk average velocity vs. a velocity distribution
- Can ignore the influence of changes in other sub-systems
  - For relatively uncoupled sub-systems this may be fine
  - But for coupled systems this can be a real problem – causing rework or a move away from a concurrent design to a more sequential process

Coordination Through Interfaces

- In reality these constraints are often not treated as black and white
  - Bounds of acceptance are placed on them e.g.
    - Pressure ratio ± 1%
    - Displacement ± 4 mm
  - These bounds can be field functions
  - These bounds reflect past experience and the relative importance of certain constraints

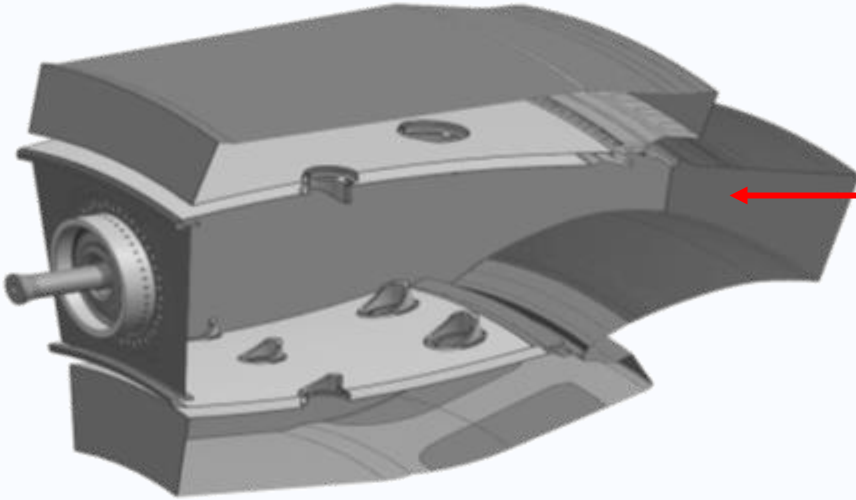
Coordination Through Interfaces

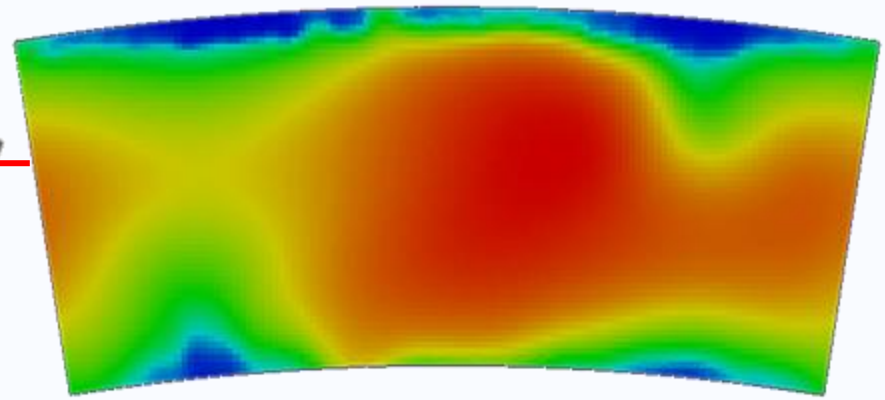
- E.g. a combustor/turbine temperature interface



Coordination Through Interfaces

- Of course, even seemingly complex interface constraints such as this have their issues…





- The circumferentially averaged temperature profile does not take into account where the peak is circumferentially

Coordination Through Interfaces

- Such bounds can also help the downstream designer
- How?
- The bounds can be used as part of a sensitivity study
  - Each new design will be tested with the ± bounds
  - If it still performs acceptably the design is accepted
- However, with multiple interfaces…
  - Do we consider combinations of all such bounds?
  - Do we ignore those that aren't important/influential and if so how do we consider which to leave out – preliminary system level design stage and experience can help
  - Do we just consider the two overall worst and best case scenarios

The Role of Robust Design

- Of course, we could recast this in the form a robust design problem
- How?
  - Rather than discrete upper and lower bounds we define the interface in the form of a PDF
  - We now take into account the likelihood of a constraint violation
- Where does the PDF come from?
  - Past experience and/or expert elicitation
  - Could be updated as the design iterations progress
- This gives us a final sub-system/component design robust to what happens around it

The Role of Robust Design

- But what’s the downside of such a strategy?
  - Evaluating the performance of a design in such a manner can be expensive
- Direct use of Monte Carlo simulations is normally impossible
- Quasi-Monte Carlo is also too expensive
- Other modern techniques may help e.g.
  - Sparse quadratures
  - Surrogate modelling methods
  - Multi-fidelity methods

MDAO-like Frameworks

- The literature contains a number of frameworks for the solution of Multidisciplinary Design Analysis & Optimisation (MDAO) problems
  - E.g. see openmdao.org for example
- Within this field collaborative design optimization is an active area of research
  - These methods were developed in response to the distributed way in which engineers actually work
  - E.g. Concurrent subspace optimization (CSSO)

Collaborative Design Methods

- These methods maintain a distributed framework
- The overall system problem is decomposed into multiple sub-problems
- Sensitivity equations can be created to define the impact of a designer changing their local variable on a non-local response
  - E.g. a designer changes the propeller diameter what is the impact (sensitivity) of the engine fuel consumption
- This information is used to solve a constraint on each interface by an overarching system-level coordination process

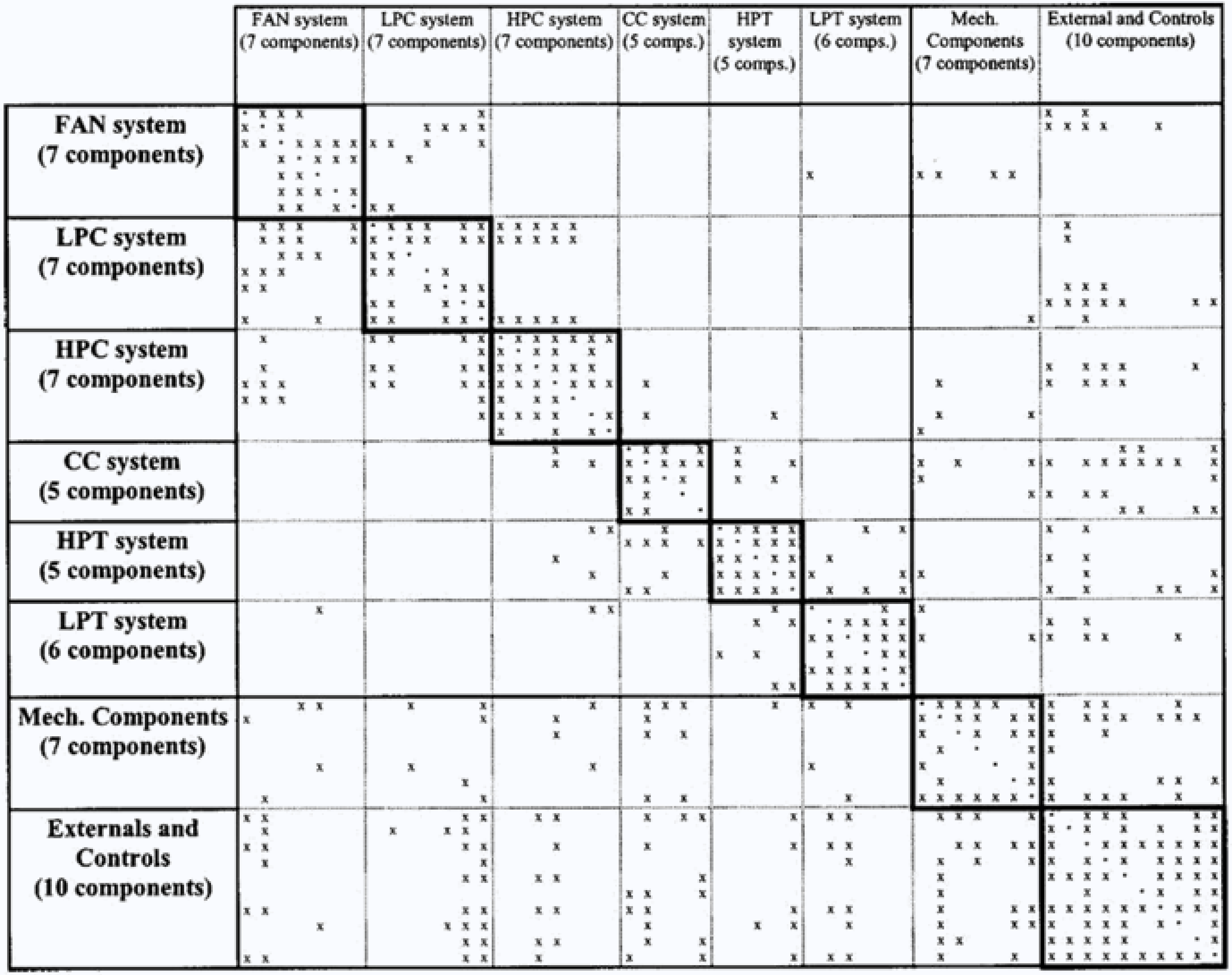
Collaborative Design Methods

- What are the downsides of such approaches?
- While respecting the distribution of activities it requires a considerable level of automation
  - Geometry creation
  - Simulation generation (meshing, simulation & post-processing)
  - This can be difficult and expensive to achieve and maintain (trade-off between design flexibility & automation)
- Assumes that designers will stick to a fixed set of design variables
  - In reality this is rarely the case!
  - Designers like to try new ideas and concepts – this does not fit within a structured MDAO environment

A Case Study At The Cutting Edge

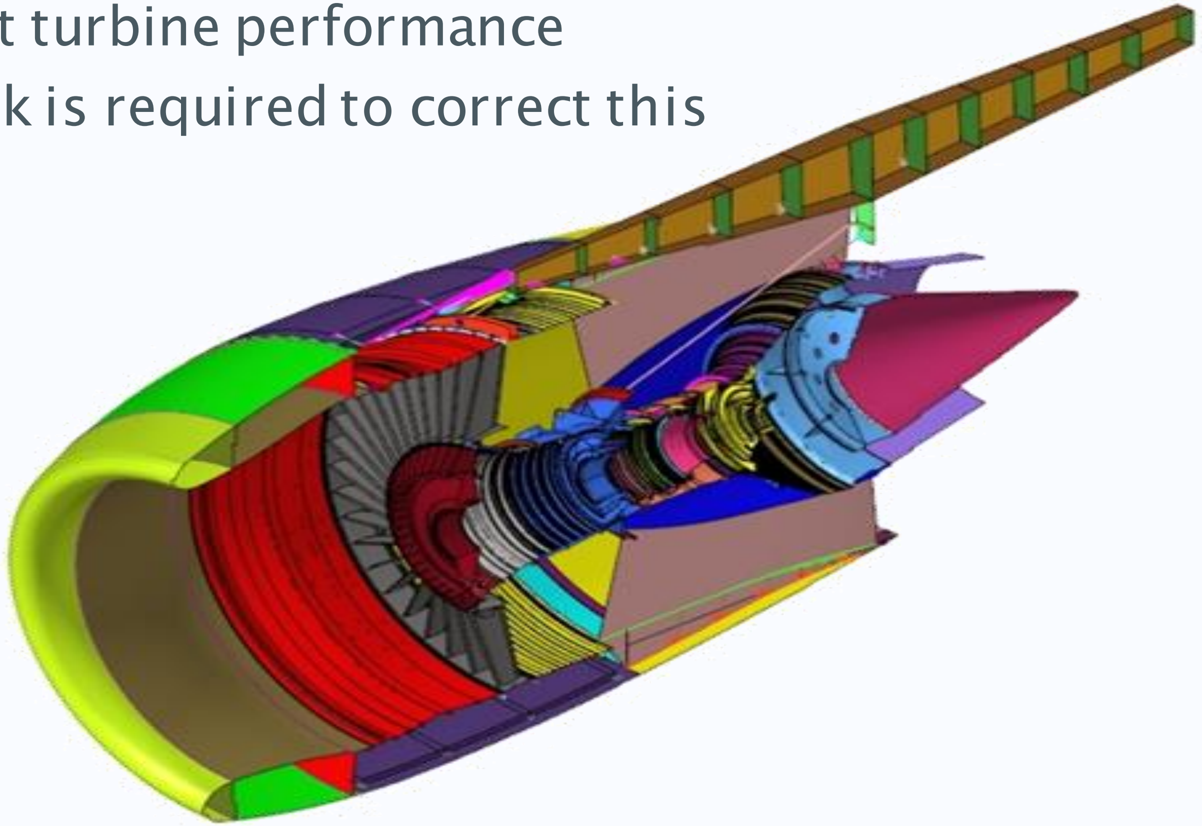
(Not Examinable)

Gas Turbine Sub-system Dependencies



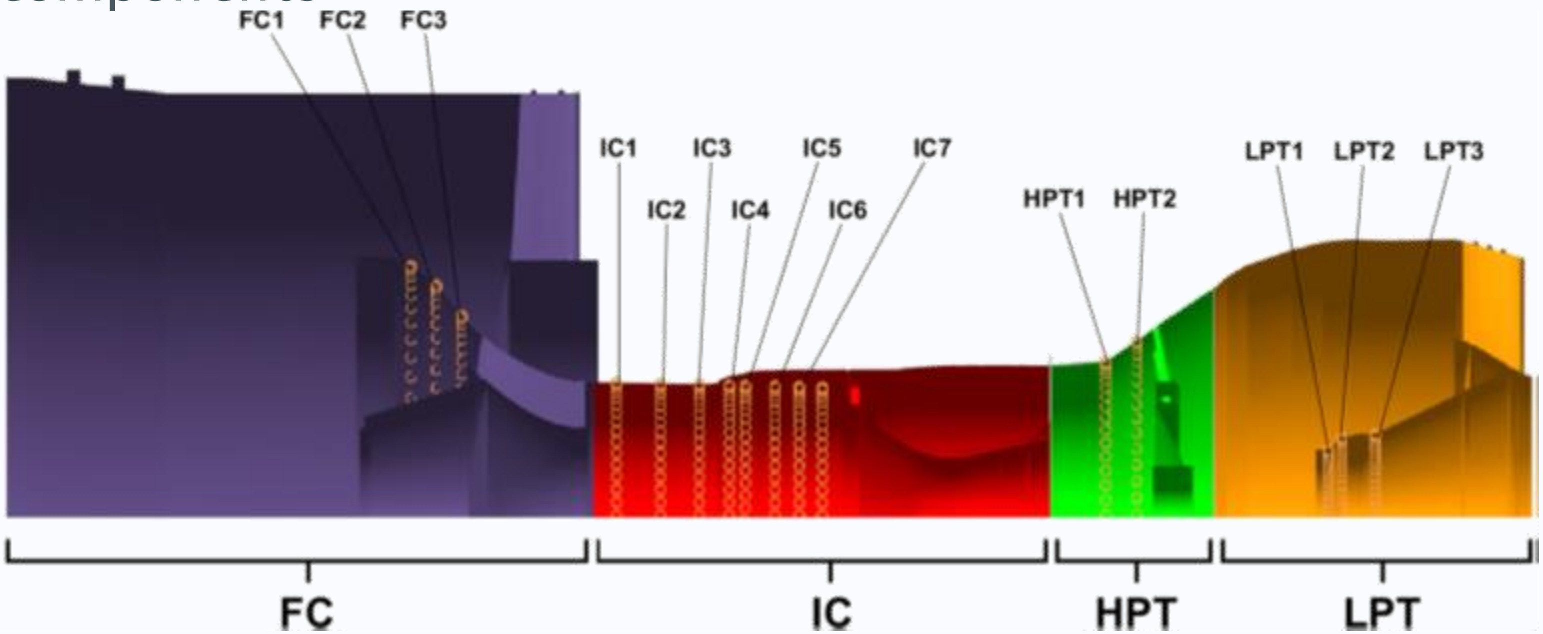
Engine Structural Design

- Changes in one part of the engine structure can have a dramatic effect on the stiffness of the entire engine
- Changes to the compressor casing, for example, could impact turbine performance
- Rework is required to correct this



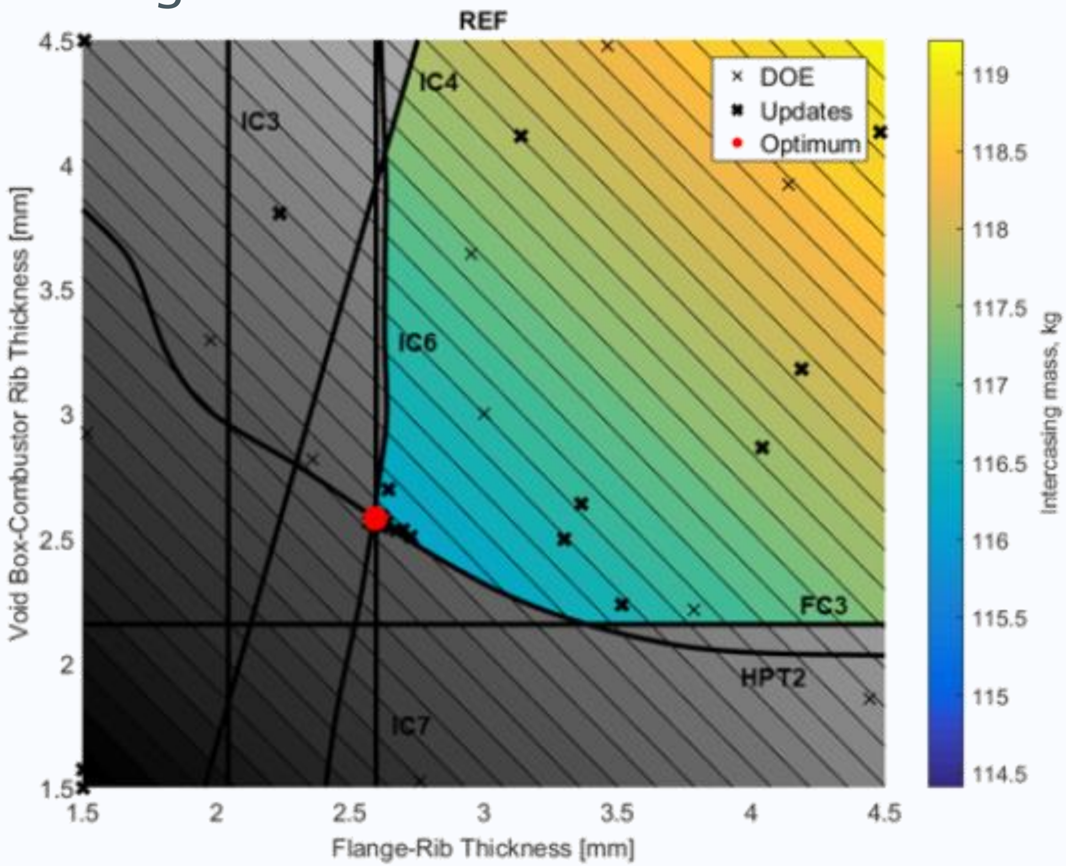
A Simple Example

- Consider a simplistic engine structure (see below)
- We are interesting in reducing the mass of the compressor intercasing (IC)
- We can do so by varying the thickness of two different casing components



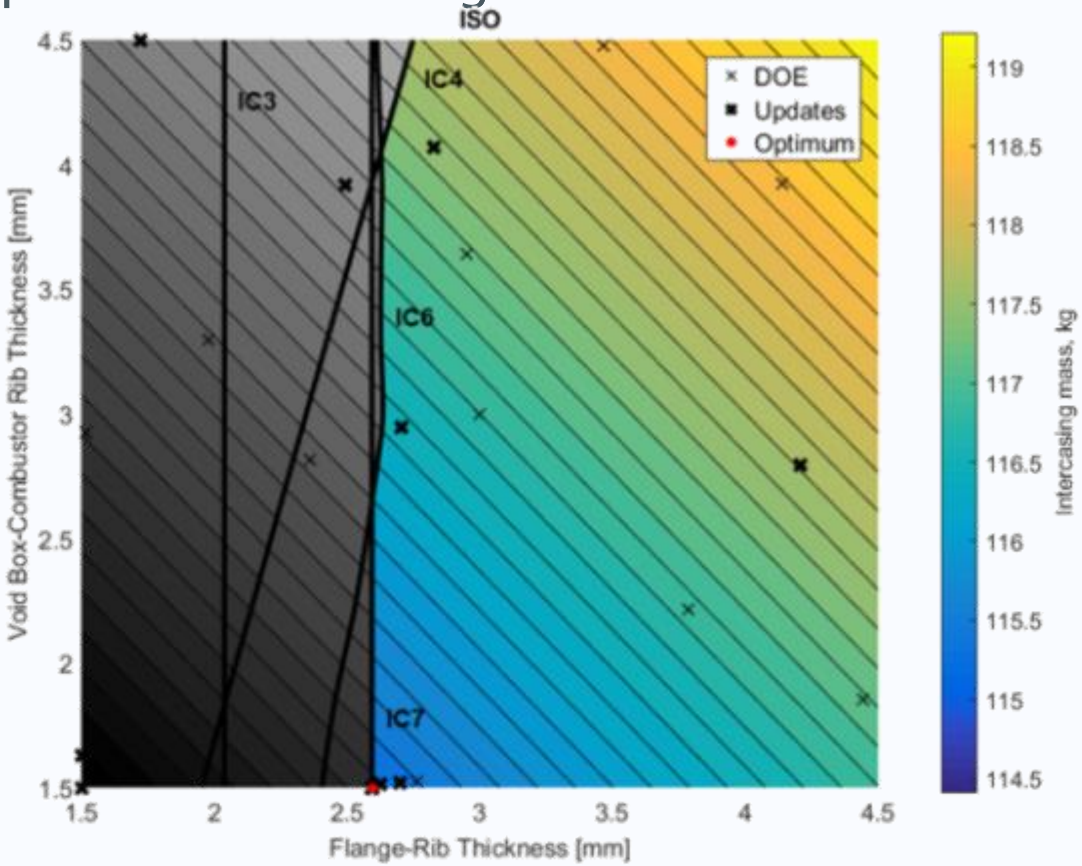
A Simple Example

- If we knew the impact of our changes in thickness on all parts of the engine…



A Simple Example

- However, normally this is not the case, the designer is blind to the impact of their changes…



A Simple Example

- Plainly without this additional knowledge the designer is led astray
  - Resulting in rework ($$$)
- How can we provide the designer with this additional information?
  - Simulate the entire engine?
  - Use a collaborative optimisation approach?
- What we actually did was something in between[†]

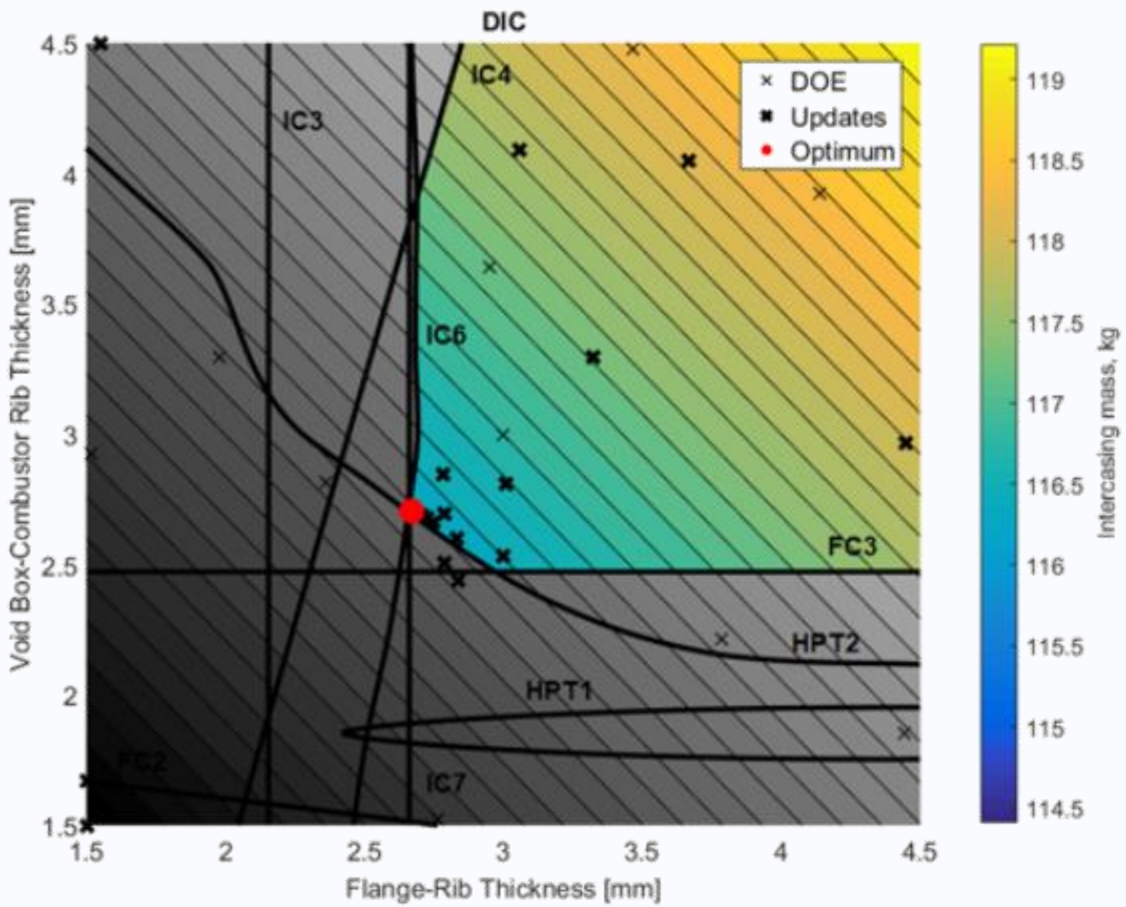
[†]Yong et al., "A medial-object-based design-in-context approach for the structural design of engine subsystems", AIAA Propulsion & Energy Forum, 2019

Design in Context

- We had available to us a way in which we could create a low fidelity (cheap) model of the entire engine
  - In this case a shell model
- A designer can therefore use the shell model of the rest of the engine within his own FE analysis
  - Little increase in simulation cost
  - But now the designer knows something about the wider impact of their changes

Design in Context

- With this low fidelity information…



Conclusions

Conclusions

- Complexity of modern engineering requires decomposition
- Defining interfaces offers a practical mechanism of managing such interactions
  - Can be extended to include bounds or PDFs
  - Sensitivity analysis and robust design methods offer a way to cope with interface uncertainties
  - Don't forget about the role of system-level preliminary design in defining sensible interfaces
- MDAO based methods offer an alternative solution
  - But require substantial effort to be spent in automation
  - Are not flexible enough to respond to radical design variations

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