VOLVO AERO

Simulation thoughts

One of the ideas of Nafems is to encourage discussion within the simulation community and thereby stimulating the process of improving simulation capabilities and results. The community of simulation according to Nafems: •Industry, •Education&research, •Software suppliers.

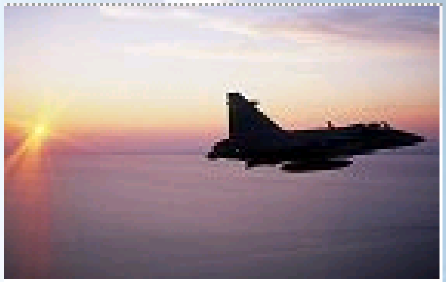
In line with this strategy this presentation aims to:

- Provide industry side input to the “community of simulation”

which will be done by:

Stepping through the simulation process from Volvo Aero perspetcives, highlighting strong and weak points and pondering on future needs

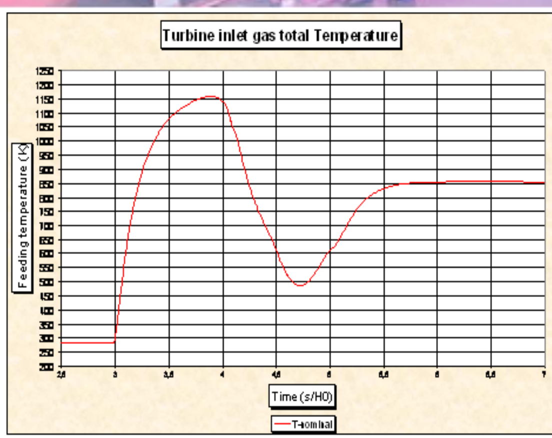
Just an introduction ….



- Per Ekedahl, Volvo Aero Corporation, Trollhättan - Sweden

- Company within the Volvo Group
  - ❑ Main products / businesses:
  - ➢ Design and life-time service of the RM12 jet engine for the JAS 39 Gripen fighter (derivative of the GE F404 engine)
  - ➢ Partnership with component responsibility in several commercial jet engine industry projects
  - ➢ Overhaul of commercial jet engines
  - ➢ Turbines and nozzle extensions for the Ariane launcher programs

Introduction (cont'd)



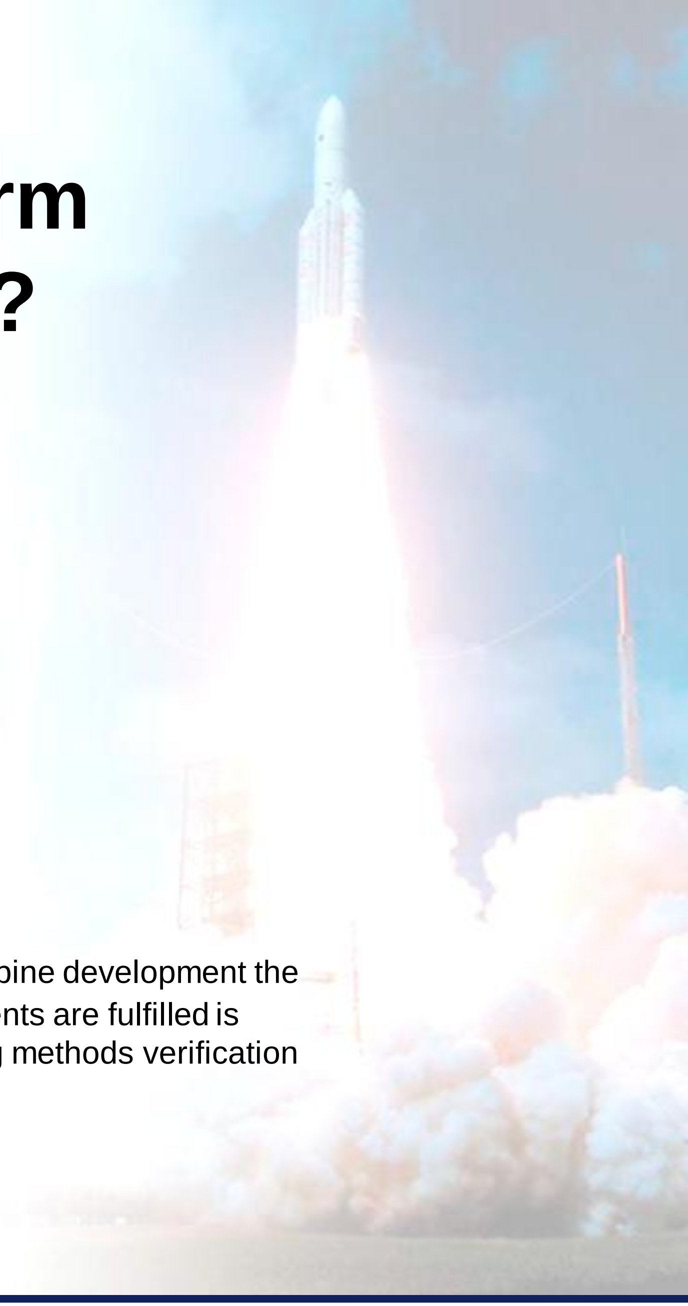
- Gas turbines for liquid propellant space rocket propulsion systems (Ariane 5)
- Provide torque to pump of fuel and oxygen (power: ~15MW)
- 2 stage supersonic aerodynamic design
- Super alloy structures (Inconel 718, etc)
- Severe thermal gradient loads in combination with pressure / rotational speed (960K, 122bar, 39800rpm)
- 3D complex stress / high amplitude loads
- Few cycles service life (five), few hardware (6-8 per year)

Starting point: Product development is of type "design by simulation"

- Requirement fulfilment is to be demonstrated based on
  1. Simulations
  2. Subscale testing
  3. Full-scale qualification testing
- Where no loops are expected*; i.e. the simulations must be accurate the first time and testing is only performed for validation of the simulation results

*I.e. at least the requirement is that 3) is passed only once, some looping of 1) and 2) is mostly acceptable

What is needed to perform successful simulations*?



- Concept solution (geometry)
- Failure modes
- Loads
- Material behaviour
- Simulation method

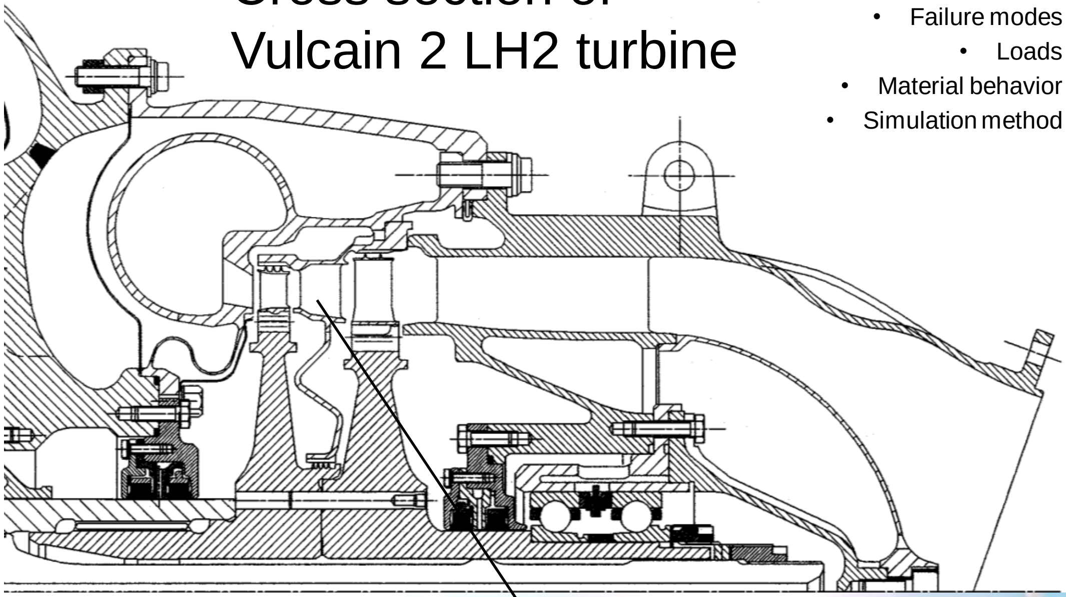
*in this overview limited to mechanical integrity issues, in a real turbine development the aerodynamic design to ensure that power and efficiency requirements are fulfilled is performed in parallel, of course also concurrent with manufacturing methods verification

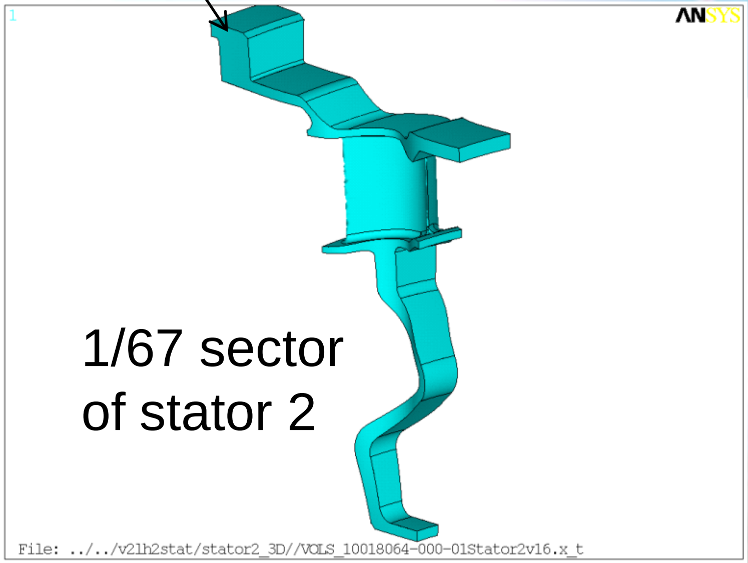
- Concept solution (geometry)
- Failure modes
- Loads
- Material behavior
- Simulation method

Concept

- The industry produces the best concept given a “Technical Specification and Requirements” document from its customer (this is exactly this skill we as a product developing company claim to possess)
- In the beginning of a product development project, the concepts are defined by drawings (and/or CAD models)
  - Soft ware suppliers are much involved in concept definition activity by providing tools for creation of CAD models
  - Performance of these CAD-tools are assessed based on
    - ✓Efficiency (including learning of CAD personnel)
    - ✓Capability (ease of communication with (other) CAM/CAE tools)

Cross section of Vulcain 2 LH2 turbine

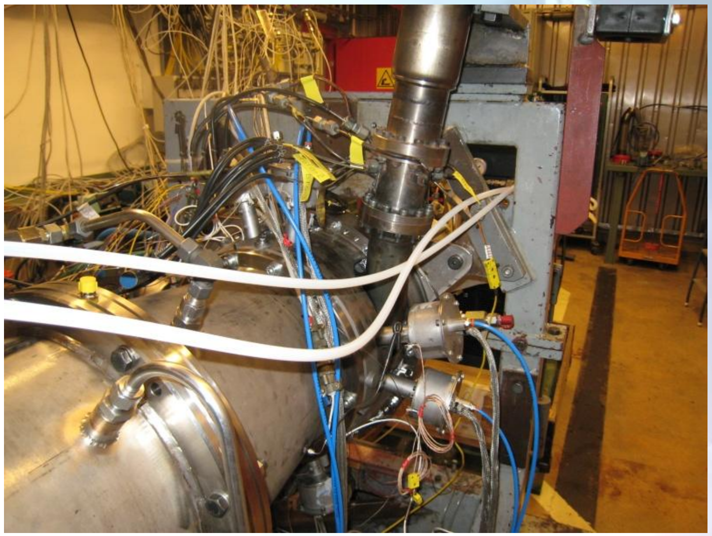


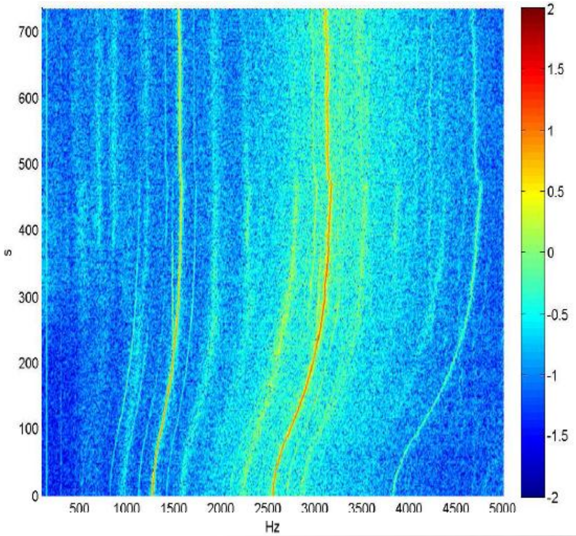


Failure modes

➢How may the product loose, or partially loose, its functions

1. Static breakage or excessive deformation (including creep, and buckling)
2. Fatigue (LCF and/or HCF)
3. Combinations of 1) and 2)
4. Leakage (which is normally consequence of 1) thr. 3))



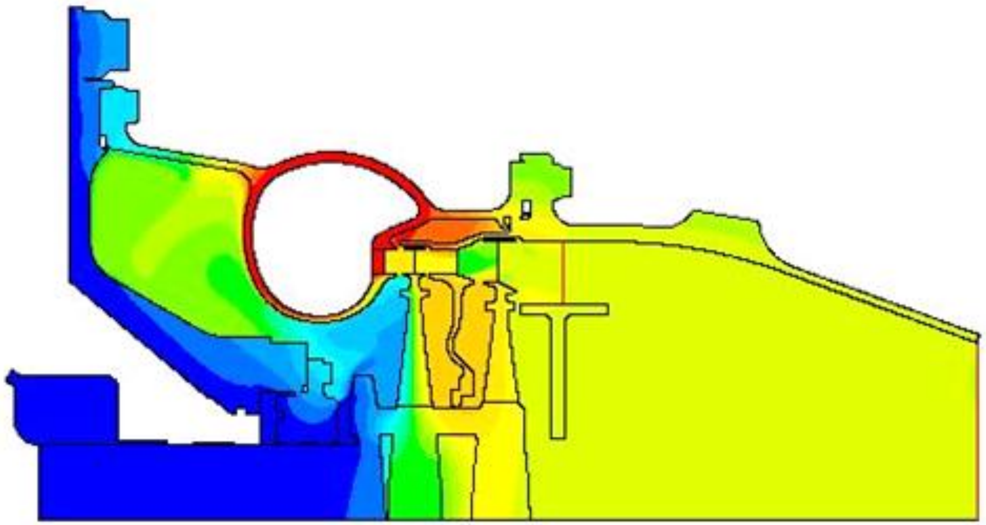


Loads

- Loads in a space launcher vehicle typically arises by:
  1. Operating the vehicle (accelerations)
  2. Engine function; i.e. the combustion process to generate thrust to the vehicle (heat, pressure and rotational speeds)
  3. Environment (friction from passing through the air, shocks by breaking the speed of sound barrier, surrounding temperatures)

  Changes of thermal loads generates a load by itself – transients
- Simulations are often needed to compute loads on system level and how these loads transfer to individual components. For a space launcher turbine this means that loads of type 1) and 3) together with the domain of operation of the turbine in terms of inlet gas temperature and pressure as well as turbopump rotational speeds are given as inputs.
  - At Volvo Aero we have to derive the internal turbine loads from these inputs, which is done by simulations

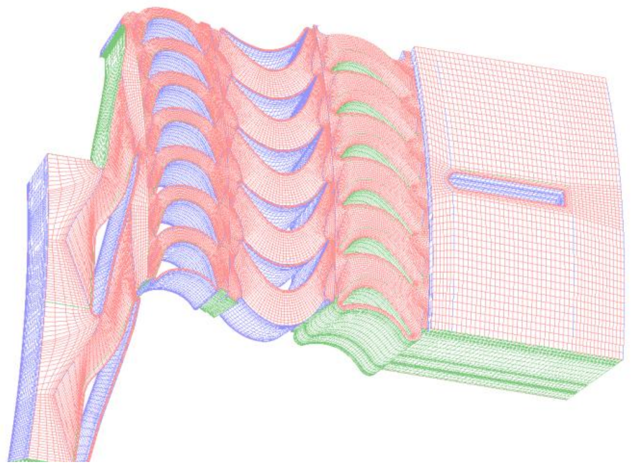
Loads (cont'd)

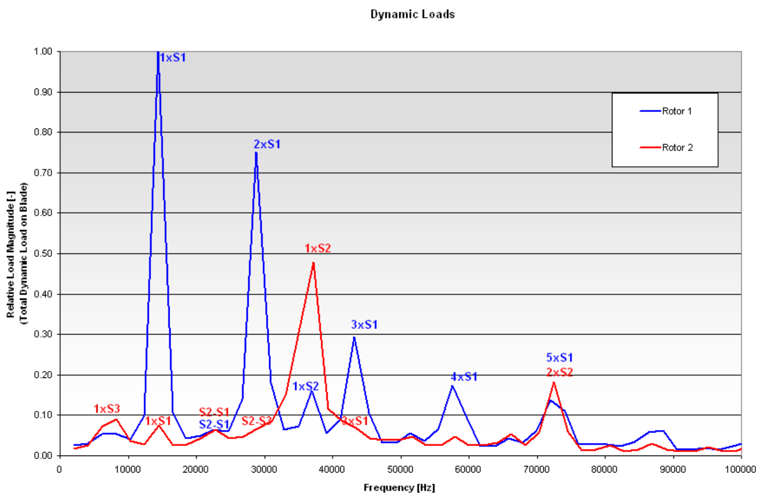


- Loads in terms of distributed temperatures, pressures and heat transfer coefficients (HTC) together with flow impulse loads are derived from steady state CFD simulation of the turbine per operating condition (Tinlet, Pinlet and shaft speed)
  - The performance of CFD simulation is assessed based on
    - ✓Efficiency/accuracy
    - ✓Capability (ease of communication with (other) CAE tools)

➢These inputs provide data to perform simulation of static and LCF type failure modes

Loads (cont'd)





- Dynamic loads (gas forces) to apply to rotor blades and stator vanes are derived in simplified 3D unsteady CFD simulation
  - The performance of CFD simulation is assessed based on
    - ✓Efficiency/accuracy
    - ✓Capability (ease of communication with (other) CAE tools)
- The natural frequencies of the structures is computed by FE simulation where the static loads (temperatures plus rotational speed of rotors) are produced by the "static and LCF" load procedure from the previous slide

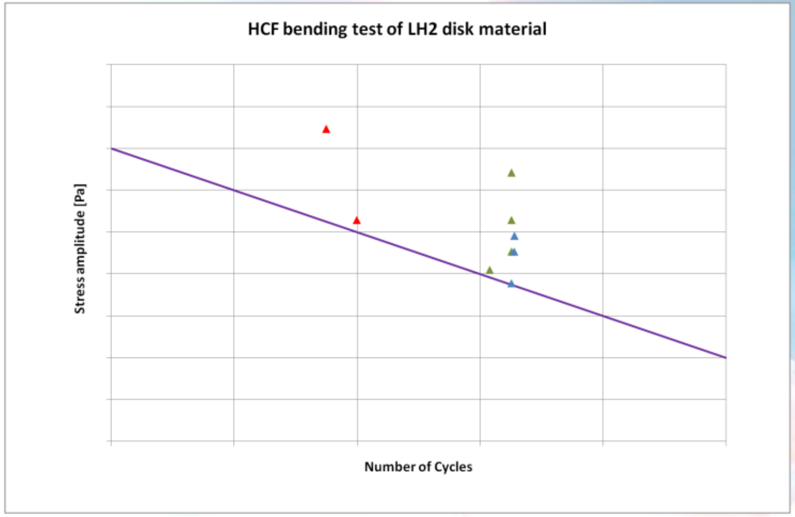
➢These inputs provide data to perform simulation of HCF type failure modes

- Load levels is the decisive factor for if a design is possible or not, yet they are difficult to establish as well qualitatively (what) as quantitatively (how much).

Material behavior

- Physical properties of metallic materials are almost without exception available in open data bases or suppliers information
- On the contrary mechanical properties are very expensive to produce
  - Longley studied issues:
    - environmental effects:
      - corrosion, oxidation, hydrogen embrittlement, friction & contact

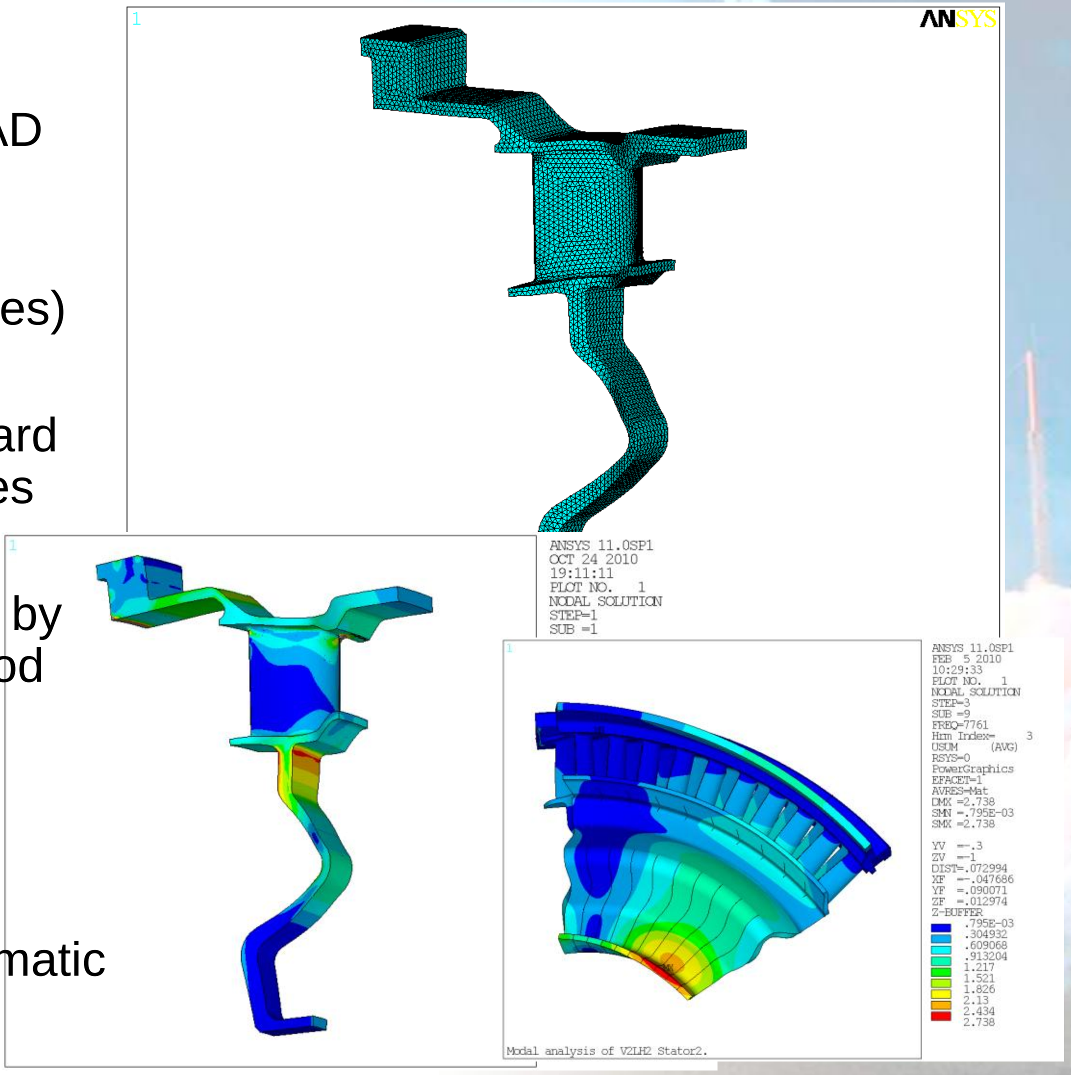
      Not to mention the ever debated load characteristics
      - R-value, multiaxiallity and load combinations, sequence effects etc
  - Areas of interest in recent years:
    - Life cycle management (optimize the metals journey mine to scrap yard)



- The material is an equally decisive factor as loads for if a design is possible or not, yet they are difficult to determine as well qualitatively (when) as quantitatively (how much and with what scatter).

Simulation method
(Finite element method is dominant)

- Trends (looking over 10 years)
  - Discretisation (meshing of CAD geometries (3D))
    - ↗Rapidness
    - ↗Quality (more brick meshes)
  - Solution
    - ↗Non-linear material standard for static and LCF analyses
    - ↗3D modeling standard
    - ↗Forced response analysis by mode superposition method and mapped loads from unsteady CFD
  - Post processing
    - ↗Results checking
    - ↗Plotting, animations, automatic report writing



Is the simulation process fit-for-purpose?

- Concept
  - Industry work flow
    - Improvement scope: computer aided conceptual work (KBE, optimization etc)
  - Concept definition by CAD
    - Improvement scope: efficiency and ease of data exchange
- Failure modes
  - Operational statistics, inspection and overhaul data
    - Improvement scope: virtual testing, real time failure simulations

Is the simulation process fit-for-purpose?

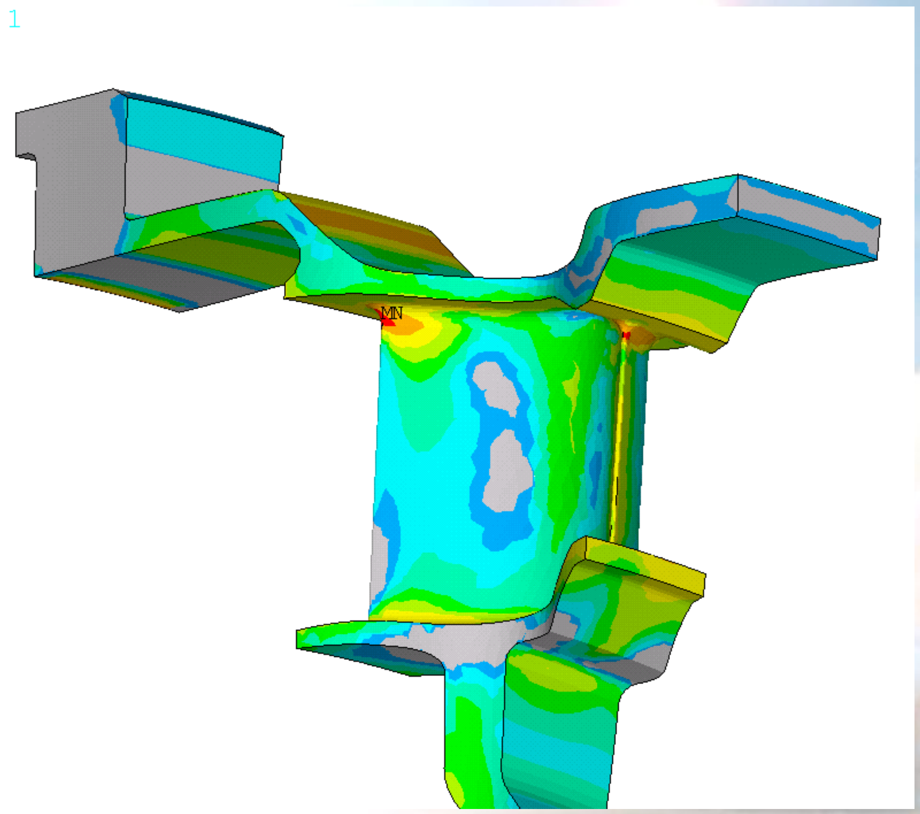
- Loads
  - Simulations (on a higher level in the system)
    - Improvement scope: efficiency and accuracy, ease of data transfer
- Material behavior
    - Simulation of effects of manufacturing processes
      - machining, welding, heat treatment, surface treatments
      - benefits of non destructive testing
    - Improvement scope: simulation of material life cycle behavior leading to optimization of fabrication processes, development of new manufacturing methods

Is the simulation process fit-for-purpose?

- Simulation model and methods
  - 3D, non-linear, transient, failure (all included)
    - Improvement scope: verification (understanding of results) and validation (physical testing correlations)

Feed-back from user - some obstacles

- Heat transfer coefficients



- Secondary flow simulations

Feed-back from user - some successes

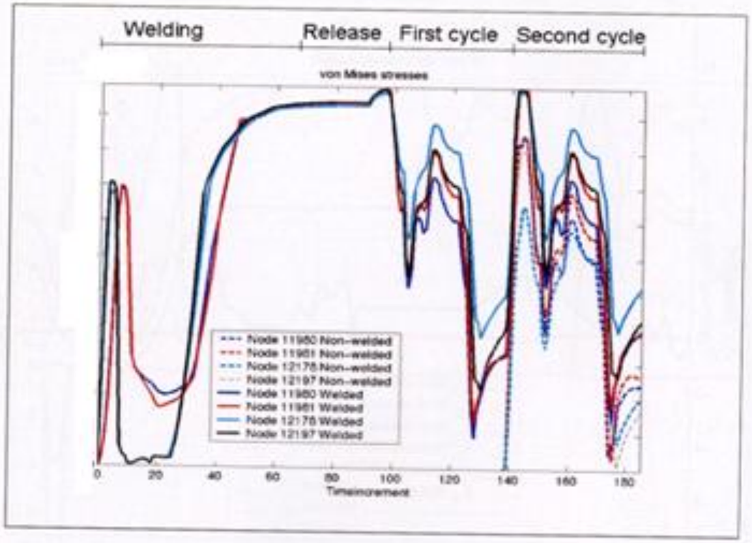
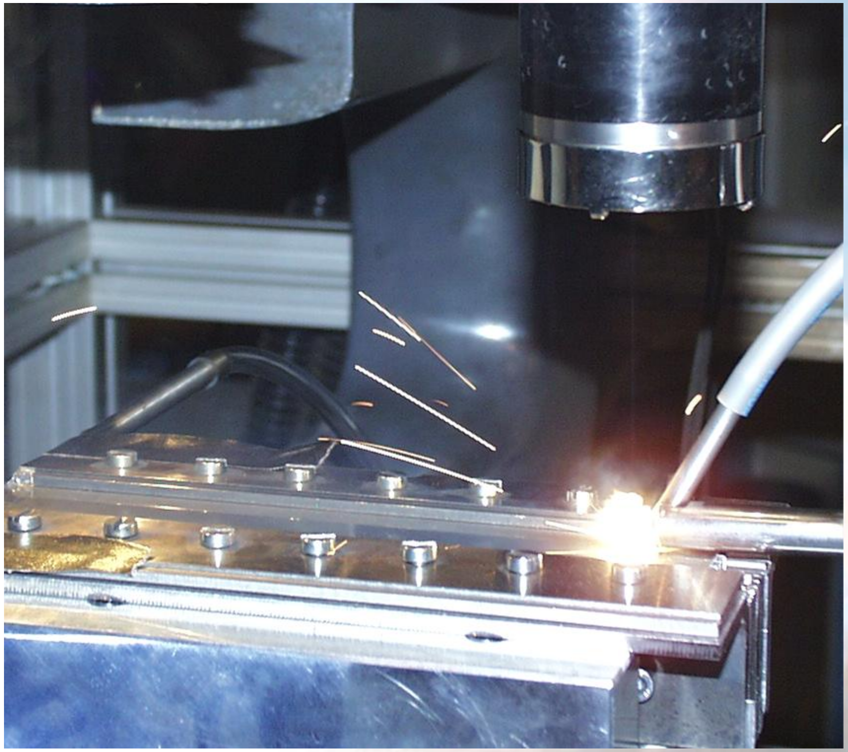


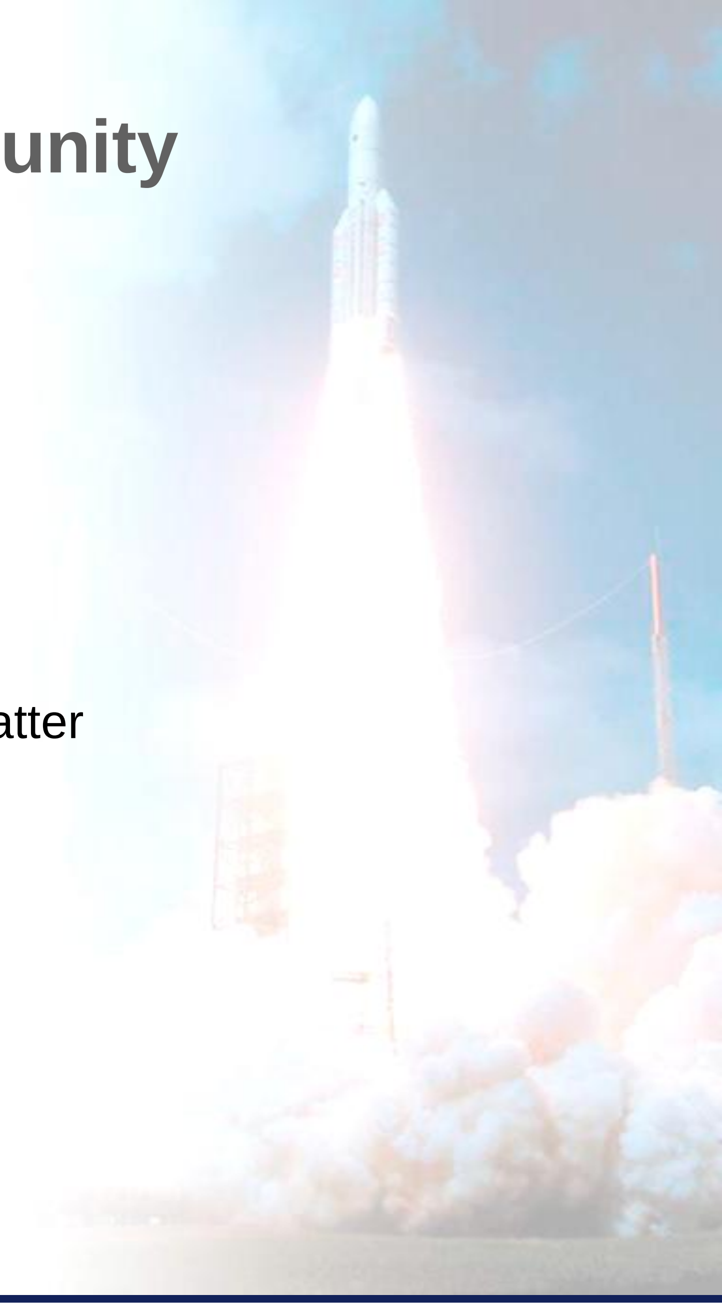
Figure 39 The evolution of von Mises stresses during simulation represented in four nodes. Two of them, 12178 and 12197, is located in the center of the weld, and the other two in the heat effected zone. The continous lines are for the welded simulation and the dashed lines are for the non-welded simulation

- Including welding in life calculation

- Weld sequence optimisation by simulation



Summary: Analysis community "to do list"



- Industry
  - Life time product philosophy
  - … (what more?)
- Education/research
  - Understanding material properties scatter
- Soft ware suppliers
  - Efficiency and robustness
- Hard ware suppliers
  - Could Moore's law be accelerated?