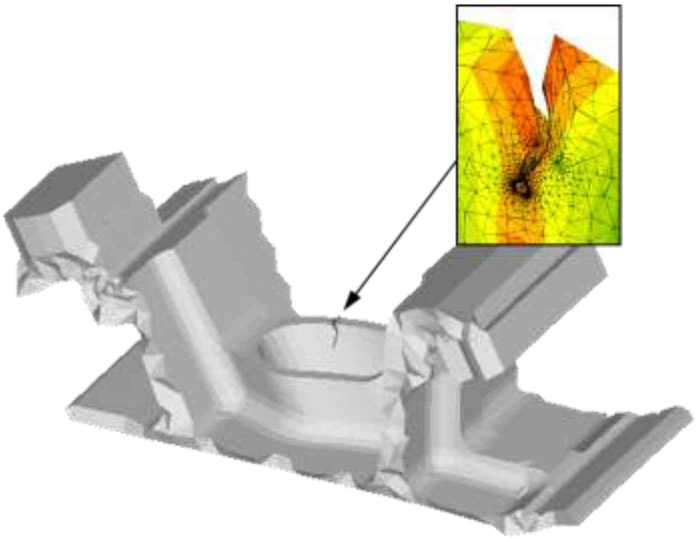
Department of Industrial Engineering
Faculty of Engineering University of Salerno - Fisciano (SA)

WORKSHOP

24-5-2019
room “118”

Recent developments in Aircraft turbine design



Program

11.00 **Welcome** and **Workshop introduction** (***Prof. Renato Esposito*** – Machine Design Group, Faculty of Engineering, University of Salerno; ***Eng. Oscar Carrozzo*** – Aeropolis.it)

11.20 CalculiX®: a free software finite element program for three-dimensional thermomechanical calculations (***Dr. Guido Dhondt - MTU Aero Engines AG***)

12.10 coffee break

12.20 Thermomechanical design of rocket engine thrust chambers (***Dr. Michele Ferraiuolo – CIRA*** *(Italian Center for Aerospace Research)*)

13.10 Discussion

13.20 **End of seminar**

Workshop organisation

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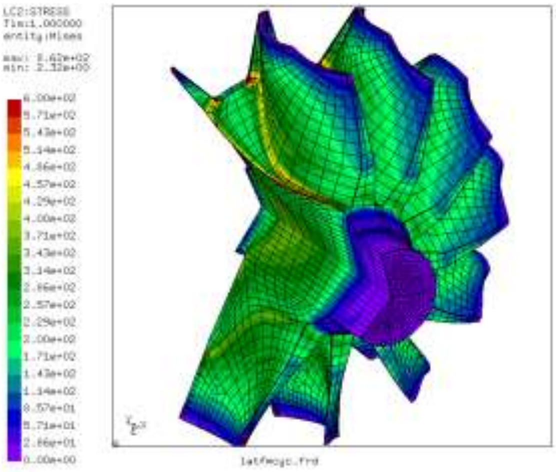
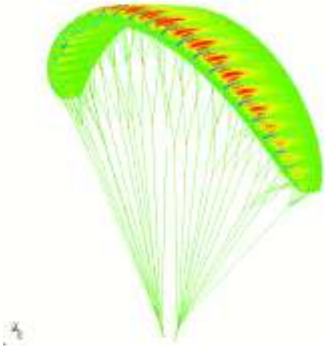
Abstract (dr. Guido Dhondt)

CRACKTRACER3D is a tool developed at MTU Aero Engines AG to calculate cyclic crack propagation in isotropic and anisotropic materials subject to mixed-mode loading. It is based on an iterative procedure by repeatedly inserting the actual crack shape into the uncracked mesh. To that end a flexible cylinder about the crack is remeshed with (partially collapsed) hexahedral elements and attached to the remaining structure using tetrahedral elements. The procedure allows for arbitrary loading, including combinations of LCF-loading and HCF-loading (the latter due to vibrations).
The fracture propagation procedure in CRACKTRACER3D is linear elastic and makes use of the stress intensity factor concept (K). The calculation of the K-factors is based on a comparison of the singular stress field at the crack tip with the stresses calculated by the finite element program CalculiX at the integration points in the collapsed elements ahead of the crack tip. For isotropic materials the singular stress field is known analytically. For anisotropic materials, however, this is not the case and the singular stresses have to be calculated numerically. To that end the governing equations of motion are solved at the crack tip by the finite difference method. Since the local orientation of the crack front the material orientation changes continuously, this calculation has to be repeated in each iteration. The method has been applied to several specimens and was compared with the Interaction Integral Method in ABAQUS. The results showed good agreement. The method is being applied on a daily basis for all single crystal crack propagation calculations at MTU.
CalculiX® is a free software finite element program (the GNU-license applies) developed by Guido Dhondt and Klaus Wittig. It consists of a preprocessor, a finite element program and a postprocessor. The source code and a Linux executable can be downloaded from www.calculix.de. Windows executables are also available on the internet. With the preprocessor the geometry of a structure can be created, boundary conditions can be defined and a mesh generated. Furthermore, the STEP format can be read in order to import points and lines from a CAD file. Due to the similarity between a CalculiX® input deck and an Abaqus® input deck any other preprocessor capable of generating Abaqus® input can be used as well.





Von Mises stress in a turbine segment

Maximum principal stress in a paraglider (thanks to Thomas Ripplinger)

The finite element program is a three-dimensional versatile code which can be used to (not exhaustive):
- calculate **static** calculations for structures (displacements, strains, stresses, energy..)
- perform **frequency** calculations in order to determine the eigenmodes (with or without cyclic symmetry) of a structure
- use these eigenmodes for **modal dynamic** calculations (time domain) or **steady state dynamic** calculations (frequency domain)
- determine the eigenmodes for structures subject to **Coriolis forces** (e.g. in rotor dynamics)
- perform **implicit or explicit dynamic** calculations for structures.
- calculate **temperatures** and heat fluxes in structures subject to heat conduction and convection/radiation interactions with the environment
- determine the fluid flow parameters such as mass flow, total temperature and total pressure in **one-dimensional fluid networks**
- perform **coupled calculations** involving structures and fluid networks
- determine the **sensitivity** of a target function (such as stress, energy, frequency ..) w.r.t. design variables (such as the outer geometry of a structure)
- perform **adaptive tetrahedral meshing** based on some user-defined field

The following features are yet in an experimental stage:
- the calculation of **electromagnetic fields** for heat induction applications
- three-dimensional fluid flow applications (full **3D Navier-Stokes equations** including the SST turbulence model)

The postprocessor is used to visualize the results such as displacements, stresses etc.

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Abstract (dr. Michele Ferraiuolo)

Liquid Rocket engines for aerospace applications work at very high heat fluxes (1–10 MW/m2) and pressures (50– 100 bar); then, in order to preserve the hot gas side wall from melting, the thrust chamber must be actively cooled. The most common cooling technique is based on regenerative cooling, that is, the fuel itself acts as a coolant and is passed through the coolant channels, provided in the periphery of the chamber wall. The thermomechanical design of regeneratively cooled thrust chambers employed for liquid rocket engines is very challenging since it involves the adoption of very complex non linear structural models. In fact, the high heat fluxes generated by the combustion gases chamber cause elevated temperatures in the copper structure which is composed of ligaments separating the coolant flow from the combustion gases. Those thermal loads together with the mechanical loads (pressure of the coolant and pressure of the combustion gases) are responsible for high thermal stresses in the inner copper structure. As a result, plastic strains and rate/time dependent phenomena are expected during the service life of the thrust chamber. More specifically, the material of the inner liner is constrained by the cold side wall of the liner. In particular, as stress and strain levels rise the material behavior may become viscoplastic, and time dependent when quick loading or high temperature values are detected. When plastic behavior is coupled with creep and hardening phenomena, viscoplastic models must be taken into account. In the present work an investigation of the viscoplastic models able to capture the thermomechanical behavior of the thrust chamber is given. Furthermore, details on the failure phenomena occurring during the service life of the chamber is illustrated highlighting how they impact the design of the cooling channel and the Nickel closeout structure. Finally, further developments currently on going in order to reduce as much as possible the computational cost of those non linear models, will be shown.

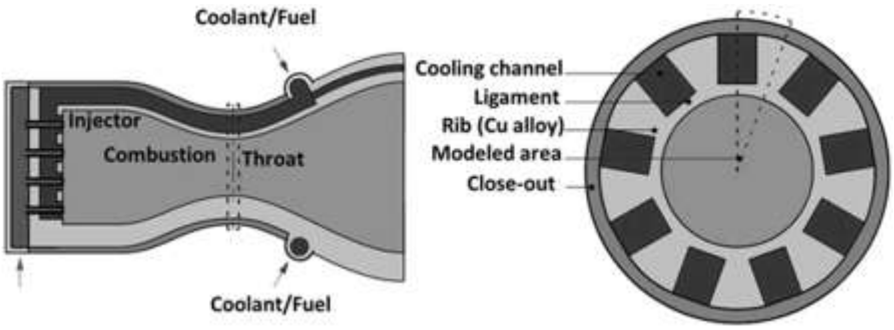

Figure 1: scheme of a regeneratively cooled thrust chamber

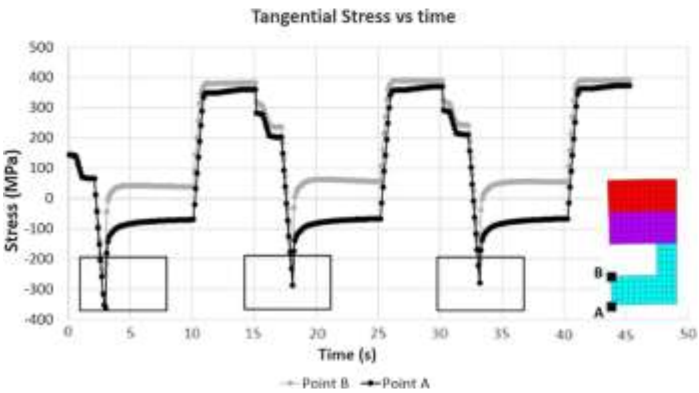

Figure 2: tangential stress vs time cooling channel

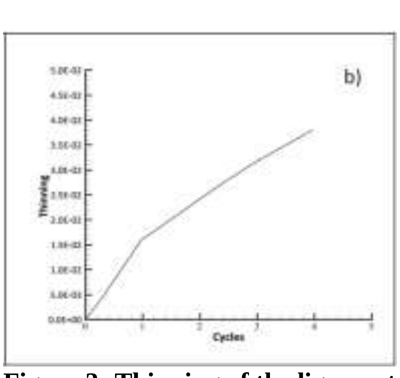

Figure 3: Thinning of the ligament