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ANALYSIS OF THE WELDING OF ARIANE 5 NOZZLE EXTENSION TUBES WITH A GENERAL PURPOSE FINITE ELEMENT PROGRAM

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Summary. The European Ariane 5 launcher is powered by two solid boosters and a cryogenic liquid core engine. A full analysis of the thermo-mechanical loading of the nozzle extension tubes of this engine has to model the production, the welding and the cyclic loading of the tubes during the hot run. In the current extended abstract, only the welding of the nozzle extension tubes is considered. At DLR Lampoldshausen, no dedicated welding analysis tool is available. Therefore, the welding of the nozzle extension tubes was modeled by a general purpose Finite Element code (ANSYS). A fully transient 3d thermal analysis of the welding provides the time dependent thermal boundary condition for the follow-on quasi stationary structural analysis of the welding of the nozzle extension tubes. This 3d elasto-plastic structural analysis is based on the von Mises yield function and rate dependency according to Peirce.

1 INTRODUCTION

The current Ariane 5 launcher with its new cryogenic upper stage (ECA) and an improved cryogenic core engine (Vulcain II) is so far the most powerful rocket of the ARIANE series. It is able to put a payload of up to 10 t weight into a geostationary orbit. The first successful flight of an Ariane 5 ECA took place on the 12th of February 2005.

The Vulcain II engine provides a vacuum thrust of 1340 kN with a total mass flow rate of about 320 kg/s. The nozzle extension is 2.3 m long with an inlet diameter of 0.59 m and an outlet diameter of 2.1 m. The main shell structure of the nozzle extension of the Vulcain II engine is made of a large number of nickel basis alloy tubes. These tubes have a rectangular cross section and are welded together during the production process of the nozzle extension.

A local deformation of the tubes (bulging) can be observed after the welding process and is increased during the hot run. Numerical analyses of the bulging phenomenon of the nozzle extension tubes due to the welding process are shown in the following sections.

2 THERMAL ANALYSIS OF THE WELDING OF NOZZLE EXTENSION TUBES

2.1 Basic equations

The applied heat equation for dynamic problems without internal heat sources can be found in [1].

2.2 Material Parameters

A temperature independent density of the tube material is assumed for the thermal analysis. The specific heat and the thermal conductivity are taken into account temperature dependent as specified in [1].

2.3 Boundary conditions

Boundary condition at the welding spot

At DLR, no dedicated welding analysis code is available. Therefore, the boundary of the molten area had to be identified from a cut out picture of already welded nozzle extension cooling channel tubes. In axial direction, a length of *l=2mm* is assumed for the welding area. For this brick shaped welding area, a prescribed temperature boundary condition with *T=1630K* is applied which is moving with the welding speed.

Far-field boundary conditions

Due to limitations in computing power, only a small section of the nozzle extension tubes could be analyzed. At the boundary of the modeled section (red symbols in Figure 1), a far-field boundary condition is applied.

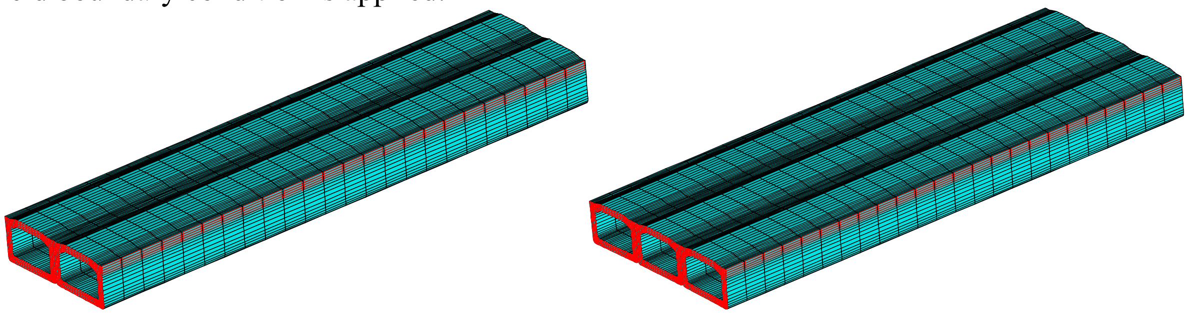

Figure 1: Two tube model (left) as used for checking the far-field coefficient h_f and three tube model (right) for thermal and structural analyses (length = 50mm).

At this far-field boundary, the following boundary condition is used:

$$\dot{q} = h_f (T_{wall} - T_f) \tag{1}$$

With:
- $\dot{q}$ heat flux
- h_f far-field coefficient
- T_{wall} wall temperature
- T_f far-field temperature of the remaining solid

A far-field temperature of $T_f = 300K$ is assumed. From a Finite Element analysis of the 3 D model shown in Figure 1 right, the heat flux $\dot{q}$ and the wall temperature T_{wall} can be determined for each internal welding boundary point of the model. For all these internal boundary points, the far-field coefficient h_f can be determined by equation (2) which is directly derived from equation (1):

$$h_f = \frac{\dot{q}}{(T_{wall} - T_f)} \tag{2}$$

Although the coefficients, determined by equation (2) show a significant variation in axial direction, a constant value is assumed for the thermal analyses.

2.4 Finite Element model

Finite Elements with quadratic shape functions are used for the analysis of the welding of the tubes. In axial direction of the tubes, an element length of 2mm is chosen (see Figure 1). In thickness direction, the Finite Element mesh is composed of 4 elements (see Figure 2).

2.5 Results of the thermal Finite Element analysis of the welding

In Figure 2 left, the thermal field in the middle cross section of the tubes during the first welding pass is shown. In Figure 2 right, the time dependent temperature during the welding process at selected points is shown. The very good coincidence of the results of the 2-tube model and the 3-tube model proves the validity of the choice of a constant farfield coefficient.

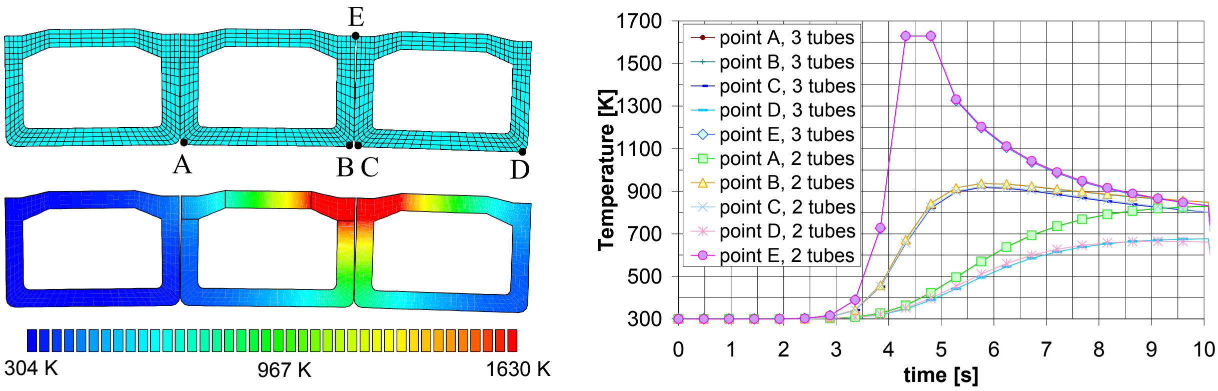

Figure 2: Temperature field during welding in the mid cross section of the tubes (left) and time dependent temperature during the welding process at selected points in the same cross section (right).

The time dependent thermal field can be used as a boundary condition for the structural analysis of the welding of the nozzle extension tubes as described in section 3.

3 STRUCTURAL ANALYSIS OF THE WELDING OF THE COOLING CHANNELS

3.1 Basic equations

The equations for elasto-plastic quasi stationary structural analyses can be found in [1].

3.2 Material parameters

Temperature dependent material parameters for the thermal expansion coefficient, the

Poisson's ratio, the Young's modulus and the non-linear stress-strain curve as specified in [1] are used for the structural analysis of the nozzle extension tubes.

3.3 Boundary conditions

At the front and back cross section and the welding boundary of the modeled part of the structure (red symbols in Figure 1), the tubes are clamped.

3.4 Finite Element Model

The same Finite Element mesh as shown in Figure 1 is used for the structural analysis as well.

3.5 Results of the structural analysis of the welding

The effective plastic strain after the first welding pass and the hot gas side mid-point deflection during the welding and cooling down phases of the tubes are shown in Figure 3.

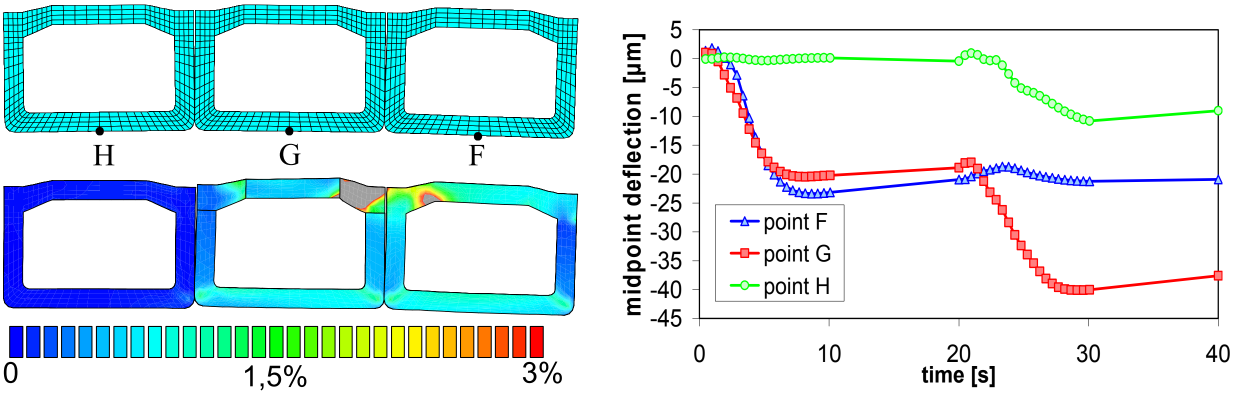

Figure 3: Effective plastic strain field after the first welding pass in the middle cross section of the tubes (left) and hot gas side mid point deflection of the tubes during the welding and cooling down phase of the first welding pass (0-20s) an the second welding pass (20-40s, right).

As shown in Figure 3, the hot gas side mid point deflection of the middle tube (point G) reaches a value of approximately 0.02 mm in the first welding pass and a value of about 0.04 mm in the second welding pass. The other two tubes show a lower bulging behavior.

4 OUTLOOK

Further welding analyses will simulate the welding of an outer stiffener to the already welded tubes.

REFERENCES

[1] J. Riccius and E. Zametaev, *Analysis of the welding of Vulcain 2 nozzle extension tubes with a general purpose Finite Element program*, DLR-IB 647-2005/06, DLR Lampoldshausen (2005).