10th ANKARA INTERNATIONAL AEROSPACE CONFERENCE **AIAC-2019-141**
18-20 September 2019 - METU, Ankara TURKEY

THERMOMECHANICAL ANALYSIS AND DESIGN MODIFICATION OF A ROCKET, MISSILE NOZZLE INSERT

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ABSTRACT

Nozzle designs are used to obtain specific thrust force for a time interval and to cause the munitions to reach high speed levels. The nozzle throat insert is subjected to high levels of temperature and pressure loads. Due to the high levels of temperature, selection of the material, design of the nozzle insert becomes more important and critical issue. It is a basic requirement to satisfy the structural integrity for the nozzle insert throughout the mission envelope. Structural integrity of the insert is checked by the thermo mechanical analysis for the mission period. Within this context, thermo mechanical analysis of the missile CASTOR II[Shields, 1976] is carried out by Abaqus software and design modifications are proposed to decrease the maximum and minimum principal stress levels.

INTRODUCTION

Nozzle insert is subjected to the high levels of temperature and pressure load during firing of a missile or maneuver of the munition [Lapp, Quaseda, 1992]. Structural integrity of the insert must be checked during all mission interval of a missile[Lapp, Quaseda, 1992]. The highest temperature level is appeared in insert region. Specific nozzle designs were made due to different mission requirements. Basically there are 2 types of nozzles according to placement of the design in the missile. These are external and submerged nozzles[Nasa, 1975]. External nozzle is shown in Figure 1 and submerged nozzle is shown in Figure 2. There are divergent and convergent sections in external nozzle and firing is occurred outside the nozzle section[Nasa, 1975]. Some part of the entry, throat and exit sections are located in the firing section for the submerged nozzle design. Maneuver capabilities can be added with the flexible joints to the nozzle design[Graves, Fonnesbeck and Roth, 1989]. Solid propellant rocket system designs use same principle to accomplish the space missions. Throat inserts are mostly produced by carbon composite materials having different mechanical, thermal properties with respect to the directions.

Within the scope of the this work, thermo mechanical analysis is carried out of Castor II[Shields, 1976] rocket nozzle which temperature and pressure data is found in literature. Analysis is made through finite element modelling software. Work covers the analysis of the

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structural in integrity of the throat insert except the nozzle insulation materials and metal casing. Insert is exposed to high levels of temperature and thermal expansion can cause a risk of a failure. Thermal expansion factor must be taken into consideration to overcome failure. For this problem, gap can be left between the interfaces of the contacting surfaces with the insert [Sun, Bao, Zhao, Hou, Zhang, Hui, Shi, 2017]. Gaps are found to reduce the stress levels in insert but can also cause the stresses to get higher on the corner points [Yu, Shi, Wang,Yang, 2018]. Special adhesives are used to obtain the integrity of the insert but adhesives can be assumed to be functionless over ≈200°C[Lin, Bao, Zhang, Xu, 2015] which means that interfaces can be accepted in a contact condition rather than bonded condition.

Insert material is assumed as polycrystalline graphite. Design modification and gap effect are proposed to decrease the maximum and minimum principal stress values. Additionally, comparison of the stress results with the original design is performed.

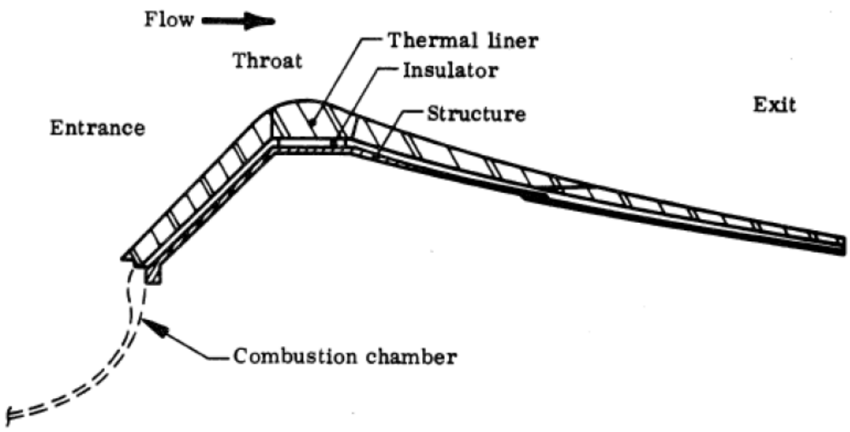

Figure 1: External nozzle design

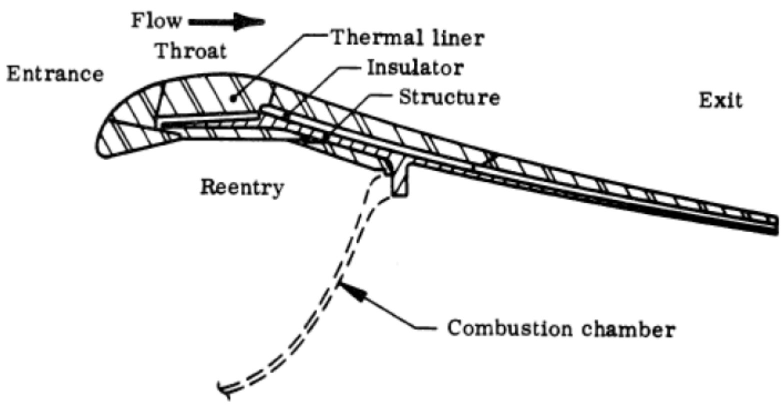

Figure 2: Submerged nozzle design

Geometry of the nozzle design is shown in Figure 3; dimensions are shown in Figure 4and materials used in nozzle assembly is shown in Figure 5 for Castor II[Shields, 1976] rocket.

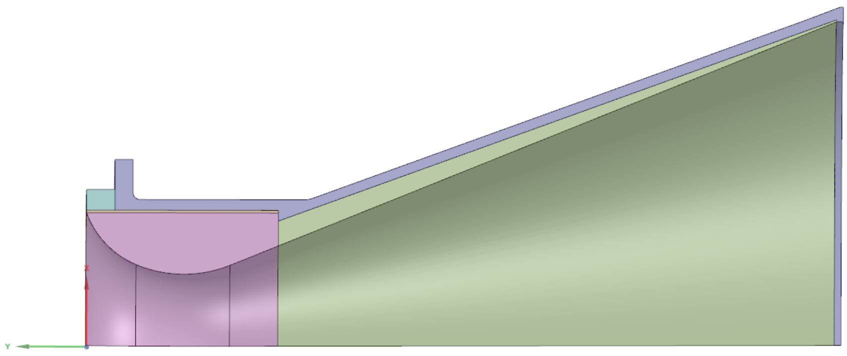

Figure 3: Castor II[Shields, 1976] nozzle design

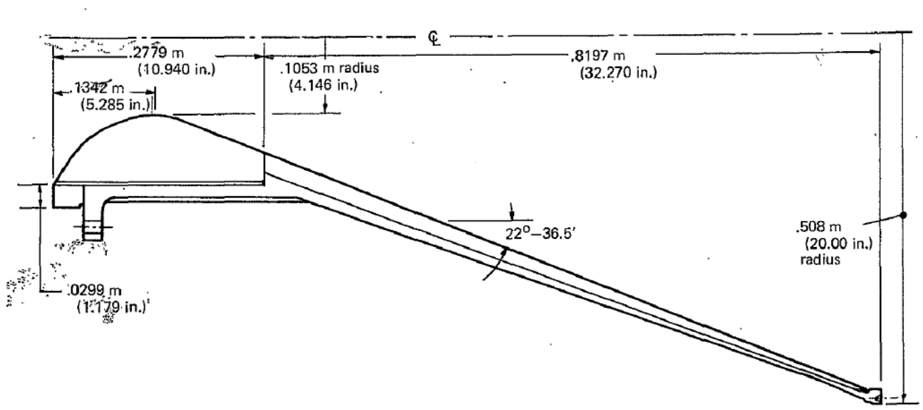

Figure 4: Dimensions of the Castor II[Shields, 1976] nozzle

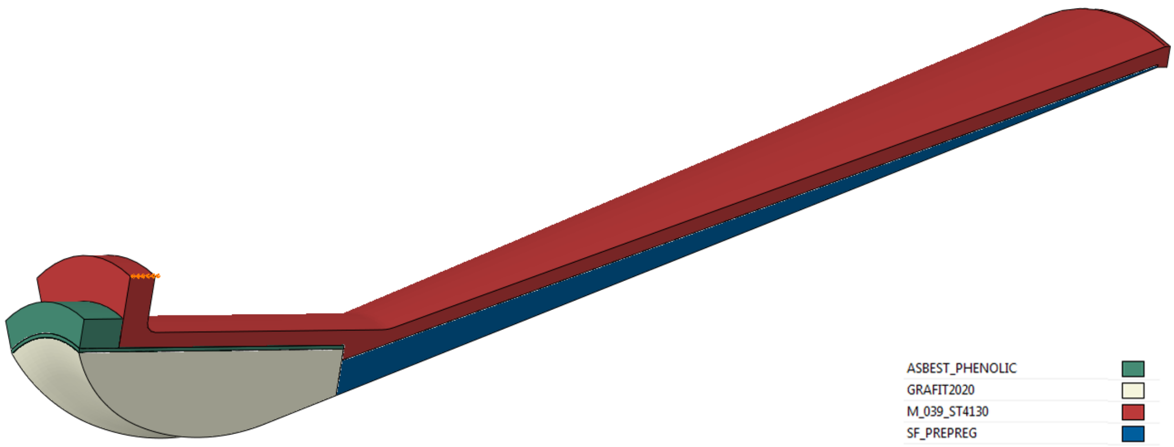

Figure 5: Materials for the Castor II[Shields, 1976] nozzle

METHOD

Subsequent to the application of the pressure load to the inner surface, temperature load is implemented to the finite element model nozzle of the Castor II[Shields, 1976] to obtain the analysis results. Finite element model is constructed by using full integration axisymmetric elements [Abaqus6141 Theory Guide]. Finite element model is shown in Figure 6. The pressure and temperature load are applied to the finite element model given in literature [Shields, 1976]. Pressure distribution is given in Figure 7 and temperature load (°C) is given in Figure 8.

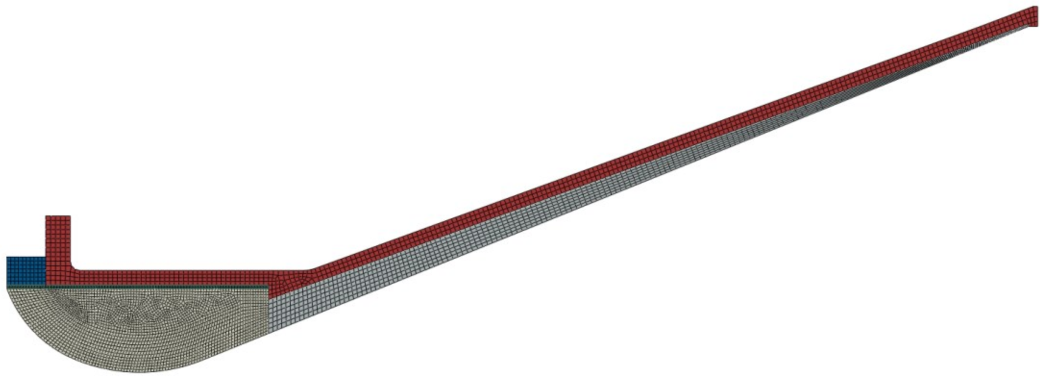

Figure 6: Finite Element Model of the Nozzle

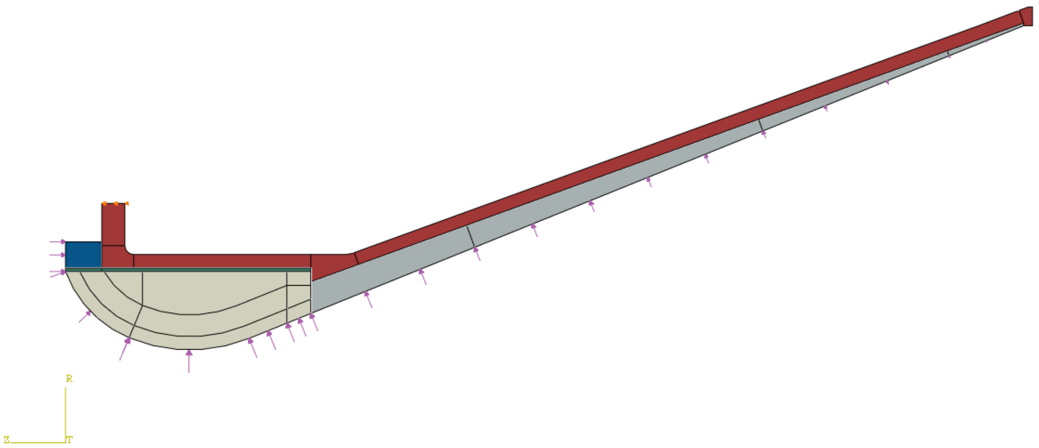

Figure 7: Pressure distribution

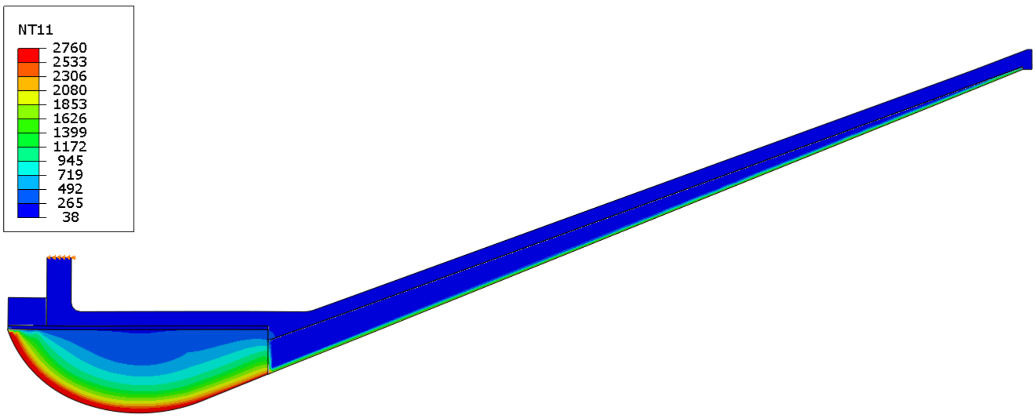

Figure 8: Temperature load

APPLICATIONS

After the application of the mechanical and thermal loads, stress distribution is obtained and the regions with high levels of maximum and minimum stresses are located. Due the fragile behavior of the graphite material, it is not suitable to evaluate the structural integrity with respect to the yield stress value. Tensile and compressive strength values must be taken into consideration to evaluate the structural integrity. Tensile strength value of 28MPa is taken into account and comparisons are made between the original and modified designs. Modified design is obtained with the division of the insert where maximum principal stress is high. Additionally, the effect of the gap is investigated and 0.25mm gap is left between the insert and the insulation material as shown in Figure 13. Maximum principal stress distribution is given in Figure 9; minimum stress distribution is given in Figure 10; shear stress distribution is given in Figure 11 for original model, modified design and modified design with a gap. Finally minimum principal stress distribution is shown in Figure 12 for modified design and modified design with a gap.

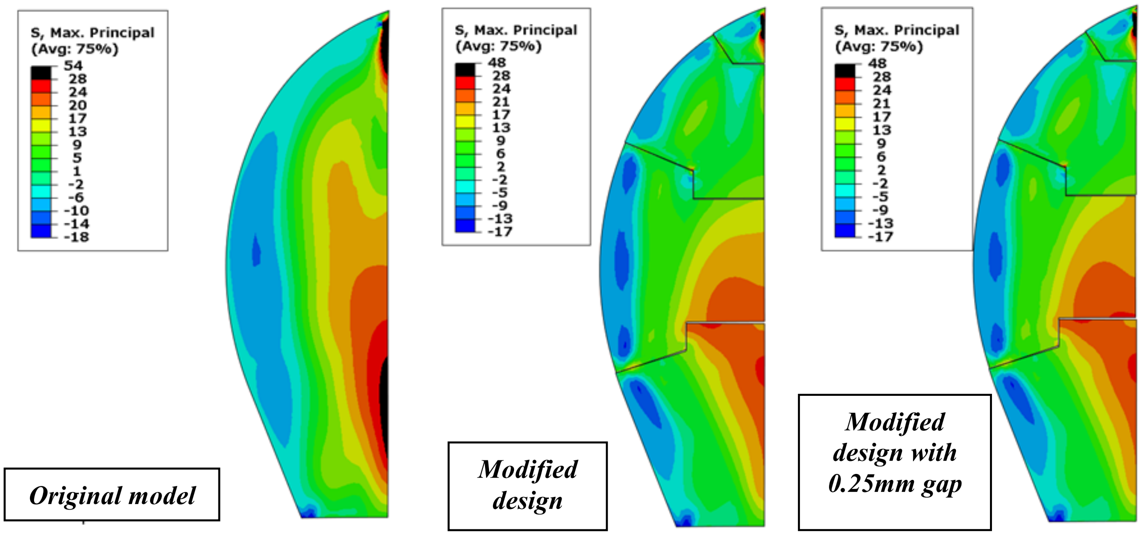

Figure 9: Maximum principal stress distribution

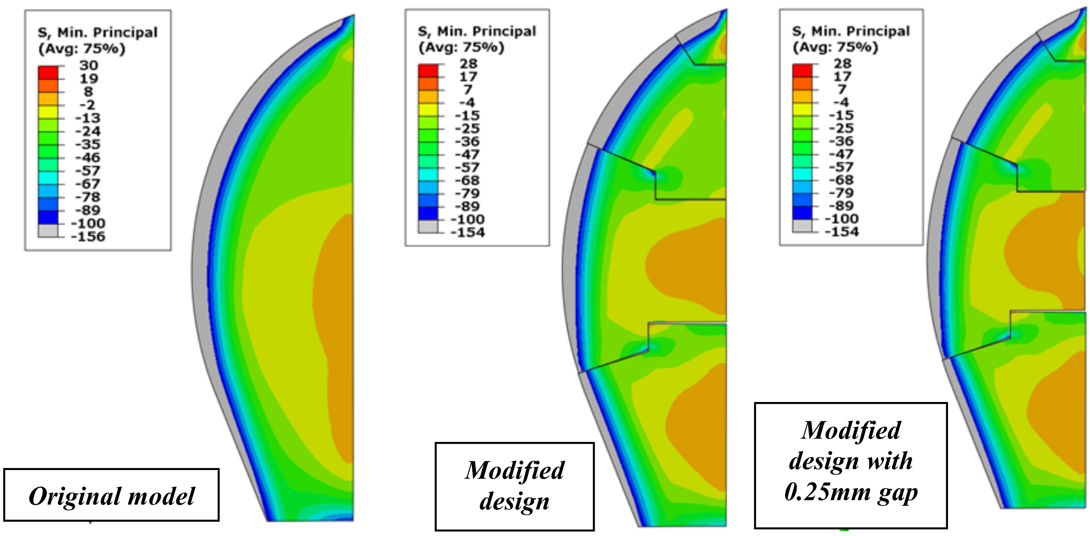

Figure 10: Minimum principal stress distribution

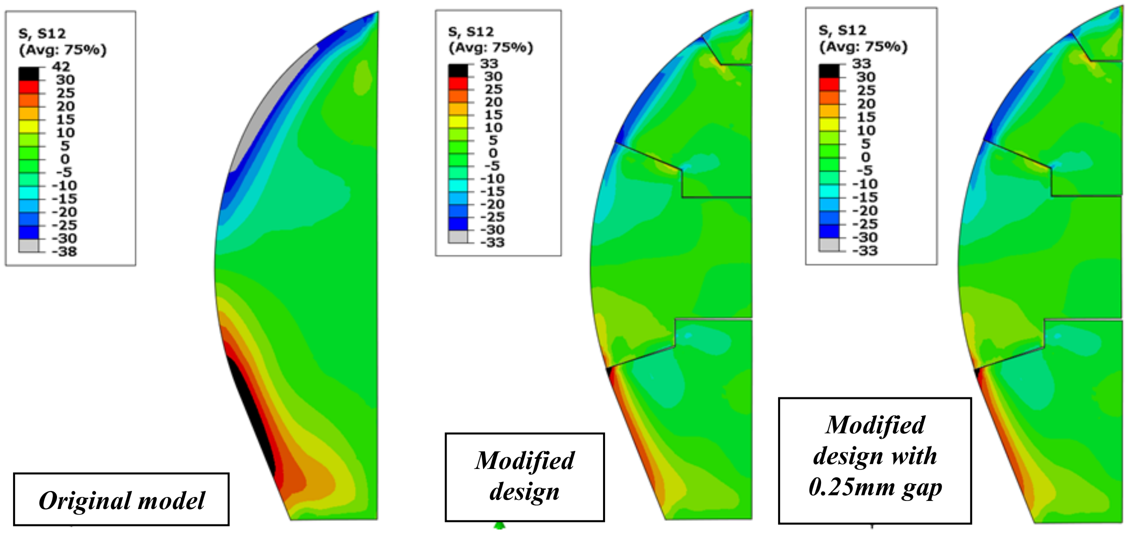

Figure 11: Shear stress distribution

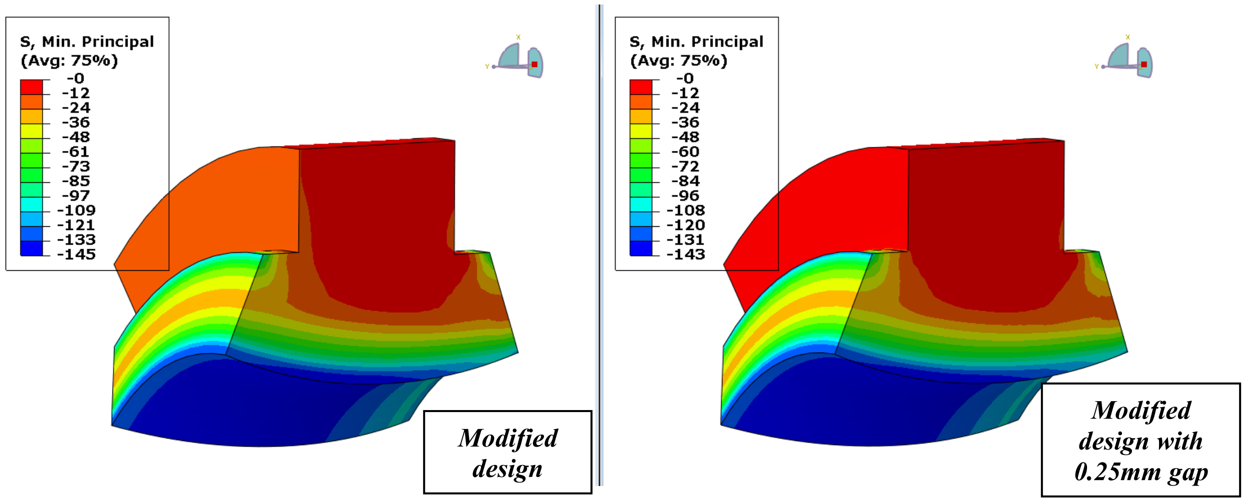

Figure 12: Minimum principal stress distribution

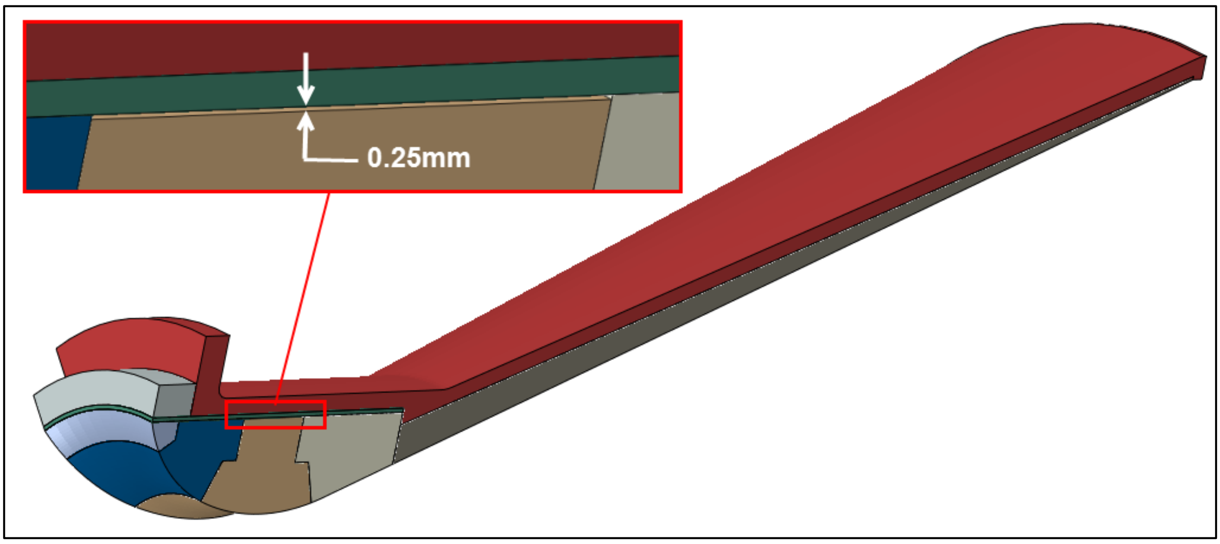

Figure 13: Radial gap distance

CONCLUSION

The thermo mechanical analysis of the Castor II nozzle is accomplished and insert design is investigated according to stress results assuming the structural integrity of the insulations, metal casing is protected. Due to the high temperature gradient on the insert, it is subjected to high principal stress levels. For this reason, if possible a material with high thermal conductivity and stable mechanical properties with the increasing temperature shall be selected to be used as an insert.

In this work, a design modification is proposed and division is added to the original nozzle. Procedure is based on the division of the insert where high maximum principal stresses are obtained. Additionally, gap effect is investigated on the modified design. According to the analysis results, maximum and minimum stress levels decreased in modified design and failure risk is of the insert is reduced. Gap effect reduces the level minimum principle stress in the throat region. Gap effect will be investigated in more details as a future work about this nozzle design. It must be considered that the pyrolysis, erosion effects are not taken into consideration in this work. It is also assumed that temperature distribution does not change with the contact status on the insert.

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