Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD 2022)
December 15 -17, 2022, Hyderabad, India

Thermo-Fluid Structure Interaction of an Electric Bulb using MSC CoSim

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ABSTRACT

Thermal fluid-structure interaction (FSI) is the study of thermal effects in the exchange of fluids and structures. High-temperature conditions causing thermal stresses are encountered in many engineering structural analyses. The structural volume is coupled with the fluid which enables a real-time transfer of physical parameters between the fluid and structure. This paper investigates the Thermo-Fluid-Structural Interaction of an electric bulb. The temperature and velocity gradients of Argon gas, contained inside the bulb, heated by the filament are studied. This heating results in temperature-induced structural deformation and stress in the bulb enclosure. In this analysis, the deformations and stresses corresponding to the temperature distribution are investigated and the temperature at the top of the bulb is studied with respect to time. The Computational Fluid Dynamics software used is Cradle CFD and the structural analysis tool is MSC Nastran. These are coupled in real-time using the MSC CoSim Engine. This study shows the numerical means of performing a coupled Multiphysics problem involving the Thermo-Fluid-Structural -Interaction of an electric bulb.

Key Words: Thermo-Fluid Structure Interaction, Electric Bulb, Computational Fluid Dynamics, Finite Element Analysis, Multiphysics

1. INTRODUCTION

Development in computational technology is allowing simulation to be closer to reality. With the advancement of numerical methods like Computational Fluid Dynamics, Computational Structural Mechanics, and Multiphysics Co-simulation, the thermal simulation of designs has become more accurate and precise.[1] The thermal effects of an electric bulb by coupling the fluid flow, thermal transfer, and structural behavior are studied in this paper. MSC CoSim provides a platform for the coupling of fluid and flexible structures**.** [2]

2. MODEL MEASUREMENTS AND MATERIAL PROPERTIES

The model used for this study is that of an electric bulb as shown in Figure 1. It consists of a tungsten filament [3] and a glass globe. The bulb is filled with argon gas. The properties of tungsten, glass globe, and argon are specified in Table 1-3.

3. COMPUTATIONAL METHODOLOGY

3.1 Computational Fluid Dynamics

scFLOW is used for CFD Analysis which will be coupled with Finite Element Analysis[4] solver, MSC Nastran[5] using MSC CoSim. Radiation is considered for this analysis along with the SST k-omega turbulence model. This study is performed for transient analysis of 5 seconds with a time step of 0.01 seconds.

Argon fluid is recognized as a radiation field. The base of the bulb is considered fully fixed in 6 Degree of Freedom.

The outer boundary of the glass globe is considered as the convection boundary with convective heat transfer of value 5e-06 g/(ms^3-K). The ambient temperature is considered at 300 K. Radiation boundary condition is applied to the outer surface of the bulb glass globe having an emissivity of 0.9. The inner surface of the bulb glass globe receives heat from argon gas through conduction which in turn conducts heat to the outer surface.

The Argon gas is heated due to conduction and radiation from the tungsten filament. The Filament body is modeled as a volumetric heat source. The inner surface of the glass globe will be used for coupling where the transmission of temperature takes place and induces material expansion resulting in deformations and stresses.

Spatial hexahedral mesh is used for the fluid mesh as shown in Figure 2.

3.2 Computational Structural Mechanics

MSC Nastran uses solid Higher Order Tetrahedral elements for modeling the bulb structure in FEA. CTETRA[6] element as shown in Figure 3 is a four-sided solid element with 10 grid points. Structural mass is calculated for all solid elements. The nodes on these elements will receive temperature values from scFLOW through volumetric coupling via MSC CoSim. The magnitude of translational displacement and von mises stress is investigated from the structural model.

3.3 Multiphysics Co-simulation

MSC CoSim provides a platform for coupling thermal loads from scFLOW to be transferred to the bulb glass globe which undergoes deformation due to expansion and experiences stresses. The solid volume is coupled for temperature coupling.

4. ANALYSIS RESULTS

4.1 Temperature versus Time Graph

As shown in Figure 5, the temperature with respect to time at the top of the bulb is seen to reach a value of around 322 K in 5 seconds. The heat is transferred from the filament to the argon gas and in turn to the globe.

4.2 Temperature and Velocity Distribution at Different Times

As the filament begins to heat, the temperature distributions are seen to change. Due to the constant heat source applied, the temperature is seen to rise from 300 K to 2173.5 K in Figure 6(a-b) In a similar way, as the filament gets heated, the velocity distribution pattern is seen to change at 1 second and 5 seconds reflecting the convection of the argon gas which transfers heat along the inner surface of the glass globe. The velocity distribution pattern is clearly visible in Figure 7(a-b)

4.3 Displacement and Von Mises Stress Distribution

As the temperature on the surface of the glass globe begins to rise due to heat transfer, as seen in Figures 8-9(a-b) the deformation and stress distribution taking place on the bulb structure is evident. With increase in time, the deformation and stress distribution can be observed corresponding to the region where the hot gas contacts the bulb glass globe's inner wall due to convection. This location can be seen through the velocity distribution of the gas as well.

5. CONCLUSION

Multiphysics Co-simulation using MSC CoSim provides an engine for coupled TFSI. This paper has been successful in solving a common engineering problem to demonstrate the capabilities of coupling TFSI in real-time.

Parameter	Values	Units
Youngs Modulus	4.11E+05	MPa
Poisson's Ratio	0.28	
Coefficient of thermal expansion	4.30E-06	1/K
Density	0.0192	g/mm^3
Thermal Conductivity	0.173	$(g\text{-}mm)/(ms^3\text{-}K)$
Volumetric Power Source	1.2	W/mm^3
Specific Heat at constant pressure	132	$mm^2/(ms^2\text{-}K)$

Table 1 Properties of Tungsten (Filament)

Parameter	Values	Units
Viscosity	2.10E-08	g/mm-ms
Gravity	9.81	m/s^2
Coefficient of thermal expansion	3.33E-03	1/K
Density	1.65E-06	g/mm^3
Thermal Conductivity	1.60E-05	$(g\text{-}mm)/(ms^3\text{-}K)$
Ambient Temperature	300	K
Specific Heat at constant pressure	520	$mm^2/(ms^2\text{-}K)$
Specific Heat at constant volume	312	$mm^2/(ms^2\text{-}K)$

Table 2 Properties of Argon

Parameter	Values	Units
Young's Modulus	6.50E+05	MPa
Poisson's Ratio	0.22	
Coefficient of thermal expansion	4.00E-06	1/K
Density	0.002595	g/mm^3
Thermal Conductivity	0.0008	(g-mm)/(ms3-K)
Specific Heat at Constant Pressure	750	mm2/(ms2-K)

Table 3 Properties of Glass (Globe)

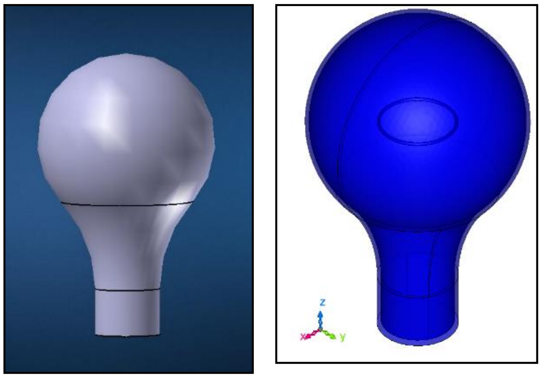

Figure 1 Structure and Fluid Model (left to right)

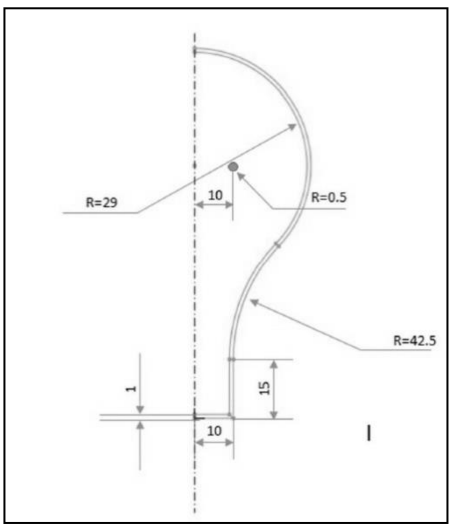

Figure 2 Bulb Section Dimensions

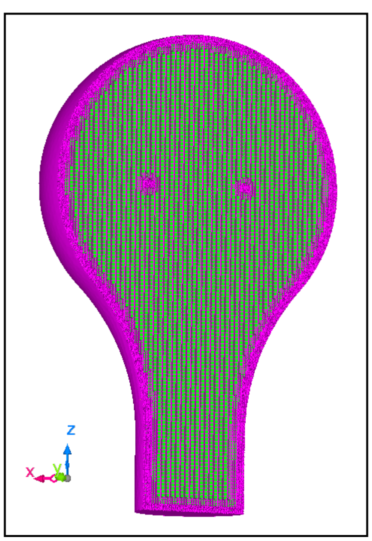

Figure 3 Spatial Hexahedral Mesh in Fluid Model

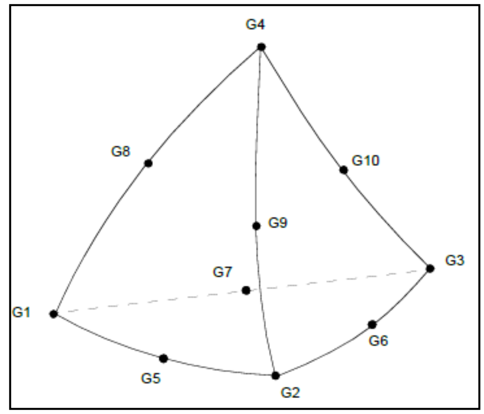

Figure 4 CTETRA Element

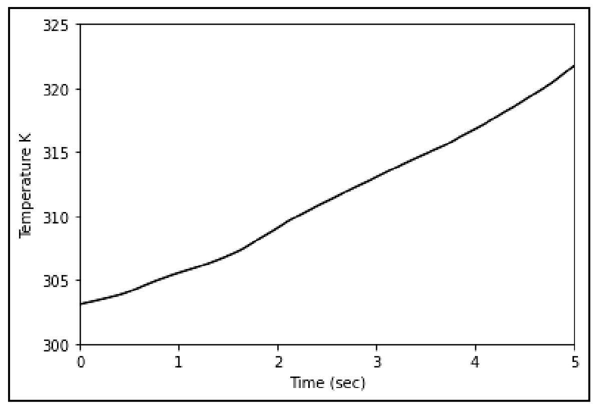

Figure 5 Temperature versus Time Graph at the top of the bulb

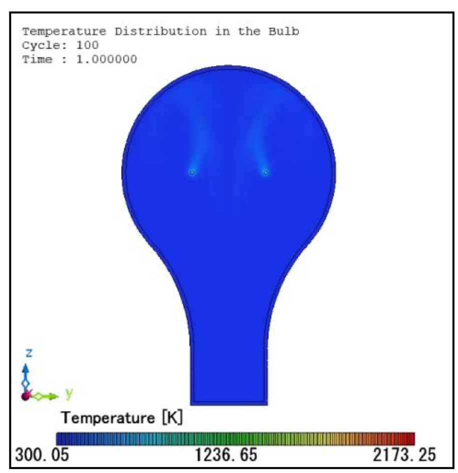

Figure 6(a) Temperature Distribution at 1 second

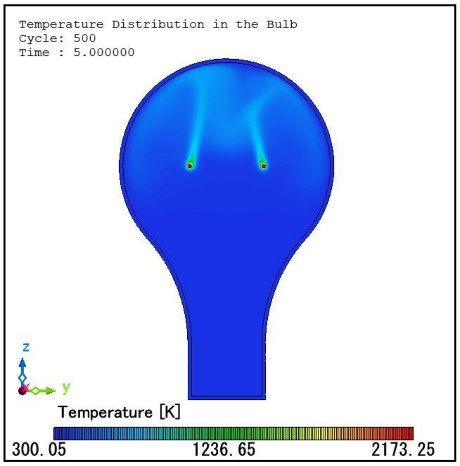

Figure 6(b) Temperature Distribution at 5 seconds

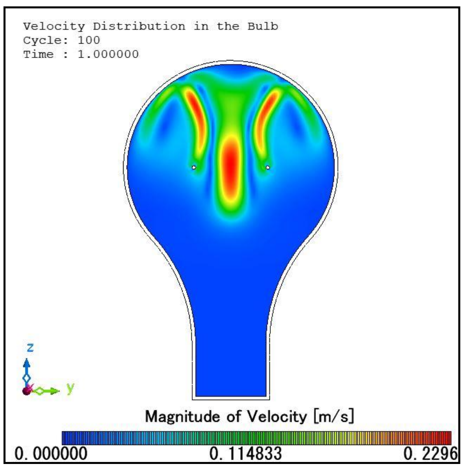

Figure 7(a) Velocity Distribution at 1 second

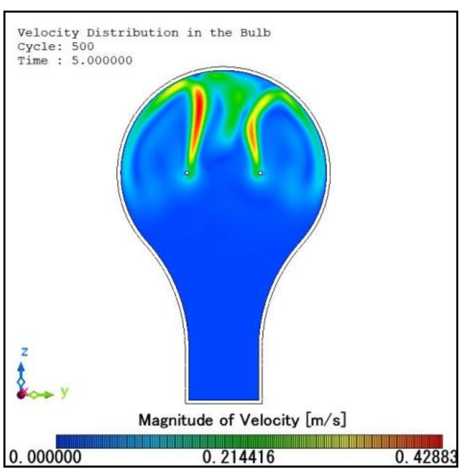

Figure 7(b) Velocity Distribution at 5 seconds

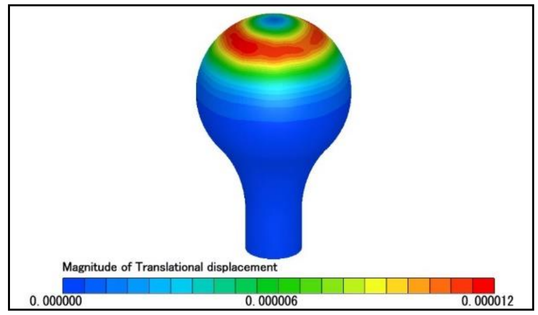

Figure 8(a) Translational Displacement at 1 second

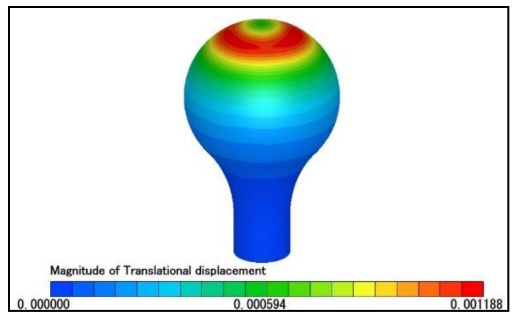

Figure 8(b) Translational Displacement at 5 seconds

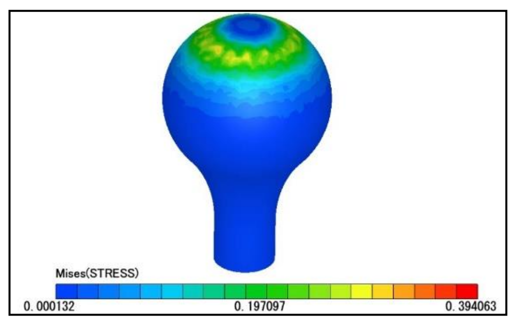

Figure 9(a) Von Mises Stress at 1 second

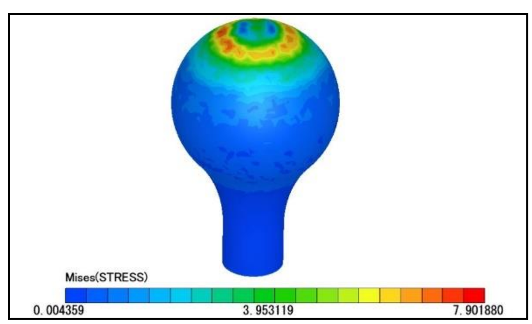

Figure 9(b) Von Mises Stress at 5 seconds

Acknowledgment

A token of gratitude to Dr. Karthik Sundarraj, Shripathi V., Sakujiro Hatazawa, and Sachin Pande for their constant support.

A special thanks to Hexagon Manufacturing Intelligence for providing this opportunity to conduct this study.

REFERENCES

[1] H. A. Mrope, Y. Abeid, C. Jande, and T. T. Kivevele, "A Review on Computational Fluid Dynamics Applications in the Design and Optimization of Crossflow Hydro Turbines," Journal of Renewable Energy, vol. 2021, pp. 1–13, Oct. 2021, doi: 10.1155/2021/5570848.

[2] "CoSim 2021 - Online Help (HTML)." https://help.hexagonmi.com/bundle/cosim_2021/page/cosim_main.htm (accessed Aug. 15, 2022).

[3] N. Yampolsky, L. Rybarcyk, E. Henestroza, and I. Draganic, "Modeling of tungsten filament in gas discharge in H-ion source," Review of Scientific Instruments, vol. 92, no. 11, Nov. 2021, doi: 10.1063/5.0056123/REFERENCES.

[4] N. S. Gokhale, "Practical finite element analysis," p. 416, 2008, Accessed: Aug. 15, 2022. [Online]. Available: https://books.google.com/books/about/Practical_Finite_Element_Analysis.html?id=yKTObdhQ66YC

[5] "Hexagon MI Documentation Center." https://help.hexagonmi.com/bundle/MSC_Nastran_2021.3/page/Nastran_Combined_Book/non_linear/ch01/TOC.MSC.Nastran.Documentation1.xhtml (accessed Aug. 15, 2022).

[6] "Four-Sided Solid Element (CTETRA)." https://help.hexagonmi.com/bundle/MSC_Nastran_2021.1/page/Nastran_Combined_Book/getstart/GS-ElementLibrary/TOC.Four.Sided.Solid.Element.xhtml (accessed Aug. 15, 2022).