Structural Analysis and Fabrication of a Scramjet Combustor for Future Space Transportation Systems

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Abstract. The scramjet is composed of three basic components: a converging inlet, where incoming air is compressed and decelerated a combustor, where gaseous fuel is burned with atmospheric oxygen to produce heat; and a diverging nozzle, where the heated air is accelerated to produce thrust. This paper explains and demonstrates the deformations and stresses developed in the scramjet combustor due to the simultaneous loading of thermal, pressure and centrifugal forces. Also, the fabrication of the combustor walls as per the design requirements is performed based on a well defined process plan with a focus on Inconel 718 super alloy machining complexities and the corresponding CNC part programs are generated using HYPERMILL cam software once the design safety is ensured.

Keywords: Scramjet, Inconel 718, combined stress, CNC programming, Hyper mill, process planning

I. Introduction

Generally a Scramjet Engine starts at a hypersonic free stream Mach no.4.The scramjet is composed of three basic components: a converging inlet, where incoming air is compressed and decelerated; a combustor, where gaseous fuel is burned with atmospheric oxygen to produce heat; and a diverging nozzle, where the heated air is accelerated to produce thrust.

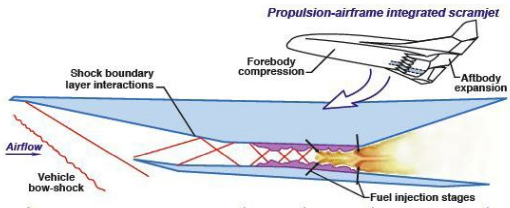


Fig.1 Schematic of scramjet

As they lack mechanical compressors, scramjets require the high kinetic energy of a hypersonic flow to compress the incoming air to operational conditions. One of the most critical parts in the scramjet engine is the scramjet combustor as it should handle thermal, pressure and centrifugal loading simultaneously. Hence, it is crucial to analyze the deformations and stress developed in the combustor because of this simultaneous loading. Since the combustor has to withstand high thermal loads, Inconel 718 material, a Nickel based super alloy is a suitable choice for the manufacturing of the combustor walls as it has got very high temperature strength. But, several machining complexities may arise while using Inconel 718 because of its work hardening effect.

II. Scramjet Combustor Design

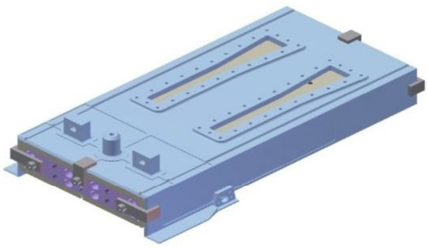


Fig. 2 Scramjet combustor model

The combustor is basically designed as a four- walled structure with provisions for fuel injectors on the top end. Two interface lugs are being provided on the top end for attaching the combustor to the engine frame. *Inconel 718* is the proposed material for manufacturing the combustor.

III. Finite Element Analysis of Scramjet Combustor

A thermo structural analysis is conducted on the combustor with *symmetry boundary conditions* applied on both the ends to analyze and demonstrate the extent of deformations occurring and the stresses developed in the combustor during combustion. Distributed temperatures obtained from the results of transient thermal analysis, maximum pressure load during combustion and *centrifugal force* developed because of the spinning effect of the rocket engine are used as the input loads for the static structural analysis of the combustor.

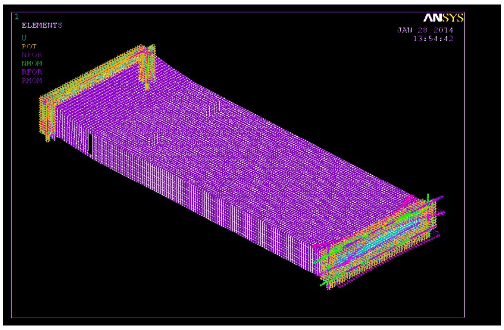
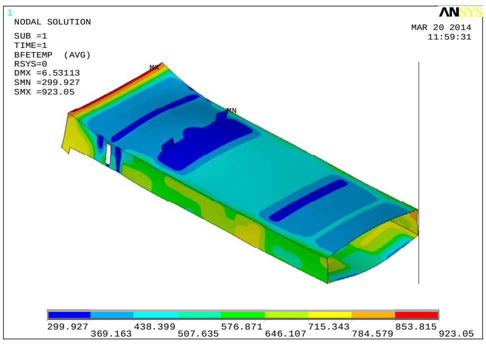


Fig. 3 2D quad mesh model

The maximum temperature developed in the combustor just after combustion is *923 K* as per the results from transient thermal analysis shown in Fig. 4. The maximum pressure developed is *2.9 bar (0.29 MPa)* as per Fig.5.



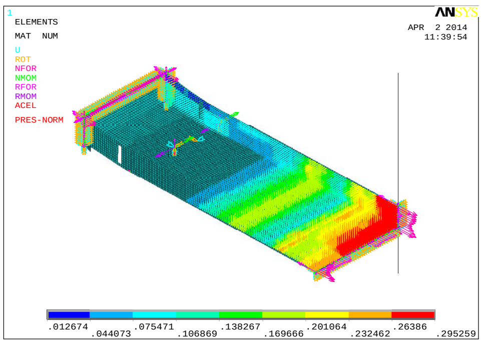


Fig. 4 Temperature distribution

Fig. 5 Pressure loading

Since the combustion happens in the rear end of the combustor, high pressure and temperature is formed in that particular region of the combustor as shown in Fig. 5.

IV. RESULTS AND DISCUSSION (ANALYSIS)

The ultimate tensile strength of an aged, annealed Inconel 718 at 1200^{0}F (921^{0}C) is 1103 MPa and the yield strength is 965 MPa. As per fig. 7, the maximum von Mises stress developed in the combustor is combustor is 899.25 MPa which is well within the acceptable limit of the ultimate tensile strength and yield strength of Inconel 718. The maximum temperature that the Inconel reaches is less than 1200K which falls within the requirements to maintain structural integrity. Since the von Mises stress is in the acceptable limits, the combustor design is found safe.

Table 1. Load data

Thermal load	Pressure load	Centrifugal load
295-923K	3 bar (maximum)	6 rps

Stress developed = 899 MPa (maximum)
X deformation = 1.5 mm (maximum) (Fig.6)
Y deformation = 1.6 mm (maximum)

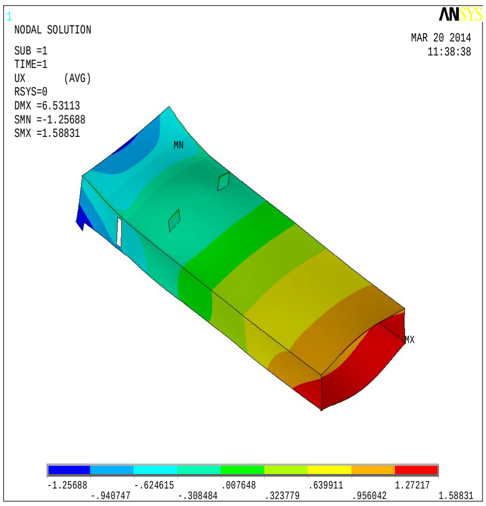


Fig.6 X deformation

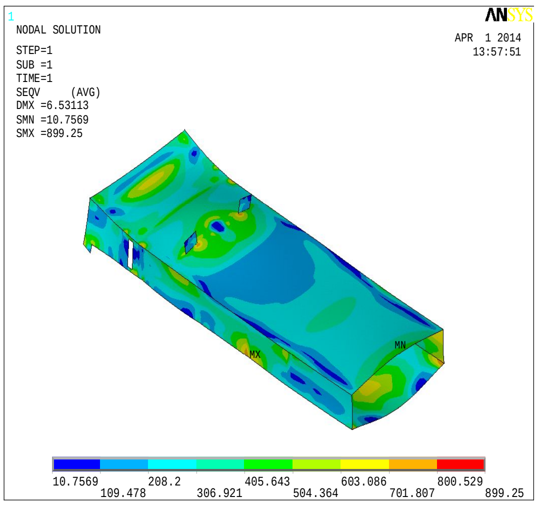


Fig.7 von Mises stress

Based on the analytical results, machining of the combustor walls are performed by choosing the appropriate tools, proper feed rate in accordance with the properties of Inconel 718.

A trial run of machining operations are performed on the HYPERMILL software with the help of heidenhain part programming. Simulations of machining operations are closely monitored to avoid any collisions and machining faults and there by flawless machining of the combustor walls are achieved and finally the scramjet combustor is manufactured based on a well defined process plan.

REFERENCES

[1] *Scramjet combustor development* Dr. Satish Kumar & Team* Head, Hypersonic Propulsion Division & Dy. Project Director, HSTDV,DRDL, Hyderabad

[2] *Design and Analysis on Scramjet Engine Inlet* , Aqheel Murtuza Siddiqui, G.M.Sayeed Ahmed, Senior Assistant professors, Muffakham Jah College of Engineering & Technology, Hyderabad

[3] *Scramjet Isolators*, Professor Michael K. Smart, Chair of Hypersonic Propulsion, Centre for Hypersonics, The University of Queensland

[4] *A Supersonic Combustion Model for Scramjet Vehicle Performance Studies* C.J. Doolan, School of Mechanical Engineering, The University of Adelaide

[5] *Ceramic Matrix Composite (CMC) Thermal Protection Systems (TPS) and Hot Structures,* A E Glass, NASA Lanley research center

[6] *Machining nickel base superalloys: Inconel 718,* A Choudhary, University of Malaya

[7] *Tech Bulletin for super alloys,* www.specialmetals.com

[8] *High speed milling of nickel based super alloys,* E.O Ezugwu, I.R Pashby, Journal of Materials processing technology, 33 (1992) p429-437.

[9] *The machinability of Inconel 718,* M. Rahman, W.K.H Seah, Journal of material processing technology, 63(1997) 199-204.

[10] "*Heat Flux Measurements in a Scramjet Combustor Using Direct Write Technology*", by Paul J. Kennedy and Jeffrey M. Donbar, AIAA paper, April 2011

[11] *Computation of losses in a scramjet combustor*" by Pradeep s.Kamath & Charles R. McClinton of NASA Langley Research Center, Virginia, Journal of American Institute of Aeronautics and Astronautics (AIAA -92-0629)

[12] *CAPP: From design to production*" by Joseph Tulkoff of Society of Manufacturing Engineers (SME)