Impact Of Temperature and Pressure Loads Upon the Structure of the Combustion Cavity of a Fluid Oxygen/Methane Engine

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**Abstract:** A comprehensive thermo-structural evaluation plan, comprising fluid-thermal evaluation and fundamental finite element modelling, is created, after which it is confirmed to be appropriate in order to look into the impacts of heat pressure as well as a lot on the skeletal stretching of the combustion area of the gaseous oxygen or methane that radishes the engine. The comprehensive dispersion of both regulatory and pressure loads is acquired via the use of fluid-thermal modelling. These outcomes are applied to architectural finite element evaluations such as surface pressures and core pressures. Next, a thorough analysis was conducted on the furnace's strain-stress reactions as well as the deformation's accumulated processes brought on by high temperatures and pressure loading. The following are the primary findings: The nozzle of the diverging segment's downstream region experiences the most remaining mechanical stress when subjected to thermal stresses only. Mitigating the temperature differential that exists between the hot runs and the preheating stage may be a workable solution for this problem. The bottom of the cooling conduit curves in the opposite manner of the flame chamber's midline only when atmospheric forces are applied.

**Keywords:** Thermal loads; Pressure loads; Liquid oxygen; Combustion chamber; Nozzle.

# Introduction

Retractable Launching Vehicles (RLVs), which have drawn attention from several nations because of their outstanding performance and thorough architecture, are becoming an efficient way to address the need for reduced cost in corporate aviation missions. Since liquid-air (LOX) or methane-radishes engines possess multiple obvious benefits over conventional fuel arrangements, including a high level of particular impulses, non-toxicity, low cost, and ease of production, it is thought to represent the best option for the engines and propulsion of RLVs. Engineers and academics have been researching the use of methanol in launching rockets for the last 20 years [1]. The regenerated cooled combustion room, a vital part of the LOX/methane engines, is made up of a copper alloy liner with excellent thermal conductivity and nickel-based jackets. To ensure that the chamber for combustion is sufficiently strong, a nickel jacket is attached to the aluminium alloy liner that has machined coolant canals. To improve achievement, the regenerating and refreshing combustion room utilised in RLVs is designed to operate at extreme temperatures and pressures. It must also be capable of igniting and shutting down repeatedly without experiencing any problems in order to ensure excellent dependability in these demanding circumstances. The burning chamber's chilling duct bottom will acquire permanent inelastic distortion following a number of operating cycles [2].

The cooling fluid will immediately seep into the tip of the nozzle as a result of the malfunction, which will have disastrous results. Many studies were done on this topic between 1970 and the present day, analysing cooling channel distortion and estimating the extent of harm done and its life span. The elastoplastic study of the firebox neck sections was carried out using a finite element computational programme that was constructed under the premise of a bilinear strain and stress lationship. The short-cycle fatigue endurance of the burning chamber was assessed using the estimated strain ranges and low cycling failure data from experiments with OFHC components. A Freed-created viscoplastic approach was employed to forecast how the combustion chamber neck section will flex [3]. The refrigeration duct bottom's swelling and narrowing phenomena, which were discovered in a study designed to simulate the Shuttle Primary Engine's operating conditions, were substantially duplicated by the computerised findings. In order to compare the various impacts of generalised plane stress modelling and plane strain models on simulation outcomes, we presented a full set of life assessment processes and a structural modelling approach incorporating time-dependent impacts. In-depth discussion was held on the thermo-structural reaction of the combustion chamber with a combined closing that cools by regeneration means [4]. On the basis of several models and research investigations, some workable efforts have been made to lessen the plastic stress brought on by thermo-mechanical stresses and increase a combustion chamber's lifespan. A fundamentally compatible construction that allowed for heating and cooling on the circular axis was suggested by earlier research. Once the average temperature within the gas-side walls reached 1154.25K, the fatigue lifespan of the burning chamber rose by 297%, while when it was 1053.15K, it rose by 184%. Previous studies presented a cylindrical channel design, followed by a comparison of the steel climate, anxiety, and strain-ranging variations within the cylindrical tube and the usual milled round channels [5].

The main objective of this report is to examine how temperature and heat loads affect the LOX/methane burning chamber's thermo-structural responses. Flow-thermal assessment yields the heat field for the metal solids domains and the pressure distribution across the liquid domains; those CFD (Mathematical Flow Dynamical) findings are input as thermal stresses and pressure loads, accordingly, to the structural assessment programme. A finite element analysis (FEA) is performed to determine the framework's deflection pattern under the distinct action of each loading. This provides a detailed picture of how each load influences the structure's displacement, period by period. Finally, as a contrast, the combustion room's thermo-mechanical reaction to the combined movement of pressure and temperature also gets covered.

# Model and Methodology

## Structure of the combustion chamber

This research examines the regeneration conditioning chamber for combustion of a 25KN performance LOX/methane missile motor under development at Beihang University. The combustion engine depicted and has essentially finished its engineering work as of right now, and an initial hot running trial is scheduled for shortly. The combustible room, which is selected from the complete engine, is made up of a silver blazer and a Narloy-Z lining [6-12]. One possible substance for the rocket's engine's fuel tank lining is narloy-Z. It is an alloy with a metal basis that has 0.5% zirconia and 3% notional gold content. This particular type of zinc, copper, and argent alloy has moderate tensile preservation at extremes of temperature along with strong conductivity for both electricity and heat. Heat treatment strengthens the material [13-19].

The water intake funnel is ignored, and the metallic area that is examined in this study has been streamlined from the real combustion area taking into account the model's achievability. The modelled combustion area construction, coolant duct arrangement, and grid dispersion. The whole grid quantity in the computation area, which includes the warm gas area, silver jacket area, gas cooling area, and Narloy-Z liner area, is listed. In every zone, the hexahedral structural grid with excellent convergence is used. The research provides some essential details regarding the liquid area arrangement, as the near-wall grid's dimensions and workmanship have a significant impact on the CFD findings [20-25]. Previous research illustrates how the near-wall mesh's vertical height is adjusted to a suitable level in the fluid region in order to ensure the y+ values on the liquid-solid interfaces may satisfy the conventional wall functions and the k-ε turbulent algorithm's criteria. This may ensure a chaotic border layer's flow or heat transmission findings are sufficiently precise [26-30].

## Working process of the combustion chamber

The burning chamber's lifespan and thermo-mechanical distortion are significantly impacted by the operating circumstances and procedures used. Four stages make up a whole planned operating procedure for the combustion vessel under study in this work: preheating, hot operation, post-cooling, and rest. The model provides an exploded view of each of these phases, so the various pressures that the combustion area experiences throughout each phase may be better understood [31-36].

# Results and discussion

## Thermal loads distribution

A elastoplastic distortion of the framework is strongly impacted by the significant variations in both pressure and heat stresses that the combustion chamber experiences as it transitions from one operating phase to a different one, as covered in Sectio. The thermal profiles of the combustion space throughout its four operating stages are shown in the ninth figure. At 120K after the preheating stage, as seen in Fig. 1, methane fully cools the liner plus the outer jacket, resulting in a homogeneous distribution of temperatures throughout the whole structure [37-40]. As seen in Fig. 1, the concurrent warming of the hot gas and the ensuing cooling of the methane during the hot running period cause the inside temperature of the firebox to display a complex dimensional pattern. The liner's heat is much greater compared to the gold jackets in a circumferential orientation. In accordance with the flow of heat on the gas-side surface shown in Fig. 1, the place having the greatest temperatures in the direction of axial motion is found close to the throat area [6]. Further, there are also a few minor variations in the concentric temperatures on the gas side of the wall, which are influenced by the configuration of the injector components, conditioning pathways, and film conditioning pores. In the post-cooling period, the heat range of the chamber of combustion reverts to its normal condition, as seen in Fig. 1. because, similar to the cooling stage, gas alone cools the combustible cylinder. Despite using additional mechanical cooling techniques, the complete structure progressively returns from 120K to ambient temperatures [7, 41-45].



**Figure 1.** Thermophysical properties of the methane

## Effect of thermal loads

Unlike conventional rocket engines, which are meant to be used just once, the LOX/methane missile motor covered in this piece is intended to be reused [8]. One point that has to be addressed is whether the furnace is capable of finishing one operating cycle before beginning another. The remaining mechanical stress at the conclusion of the work session is useful in determining the building's present level of safety and precisely identifying the place that requires further quantitative investigation [9]. It is a tangible amount; hence, this essay will mention it often [10. 46-50]. The thermal stresses discussed are used as body loads and incorporated into the structure's analysis using finite elements in order to demonstrate the effects of the heat loads on the deformed behaviour of the combustion area. To investigate the reaction between stress and strain caused by motion, temperatures are filled sequentially in the preheating, hot operating, post-cooling, and rest periods [11]. The breakdown of the mechanical stress and remaining stress brought on by thermal stresses after the conclusion of the time of rest is shown in Figure 2. As can be seen in Fig. 2, the gas-side wall of the chamber's neck has a significant remaining circular tension. Furthermore, in the divergence part of the furnace, the remaining stress concentration takes the form of stripes. Compared to the gas-side walls on the rib bottom, the remaining stress on the channel bottom's gas-side walls is noticeably greater [12].

The final mechanical strain pattern across the gas-side exterior resembles the streak influence, identical to the tension shipping. As demonstrated in Fig. 2 the spread of leftover mechanical pressure in the coolant-side exterior is fairly homogeneous, so there is no discernible position of significant mechanical strains [13]. Additionally, the diverging area of the combustion chamber is the location where the torsional force becomes most noticeable. The traditional study plan in the area of thermo-structural evaluation for chambers of combustion may be split into two stages [14]. First, using the mechanical stress dispersion as a guide, precisely determine which place is the most badly distorted. Second, pinpoint strain and stress reactions at critical points. Plot the information as arcs and look at the patterns of strain and stress. To identify the causes of strain buildup, these numbers require additional investigation. Node 1 is the place that is most visibly distorted according to the strain shipping, as seen by the data displayed [15].



**Figure 2.** Temperature distribution based on the transverse length

# Conclusion

In the conclusion It delves deeply into the effects of heat and pressure loads on the deformation of the structure of the combustion area of a LOX/Methane engine. The LOX/methane rocket engine development method served as the foundation for the findings. Certain patterns deviate from the phenomena seen in the combustible chambers when using hydrogen or LOX. As a result, although some of the manuscript's findings may not apply to every kind of new rocket engine, they could nonetheless offer insightful guidance for the development of LOX/methane motor designs. The following is a summary of the findings drawn from this work: In the preheating, post-cooling, and rest phases, thermal stresses are equal; during the hot running stage, they are different. In the hot run phase, there is a noticeable asymmetry in temperature concentration in the oriented, axially circumferential, and radial directions. One significant problem in the fire chamber design procedure is the uneven dispersion of thermal stresses throughout the hottest run stage, which is brought on by the configuration of the injector components and cooled channels.

# References

1. Gargiulo, G., P. P. Ciottoli, E. Martelli, R. Malpica Galassi, and M. Valorani. "Numerical analysis of laser-pulse transient ignition of oxygen/methane mixtures in rocket-like combustion chamber." *Acta Astronautica* 159 (2019): 136-155.
2. Grosious et al., (2024). Advancements in automotive production: exploring the role of 3D printing and selective laser sintering. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 403-415). SPIE. <https://doi.org/10.1117/12.3030833>
3. Herrera, Manuel, Mariana Chaidez, Zachary Welsh, Jason Adams, Luz I. Bugarin, Jack Chessa, and Ahsan R. Choudhuri. "Design and Testing of a 500 lbf Liquid Oxygen/Liquid Methane Engine." In *AIAA Propulsion and Energy 2019 Forum*, p. 3937. 2019.
4. Boulal, Stéphane, Nicolas Fdida, Lionel Matuszewski, Lucien Vingert, and Miguel Martin-Benito. "Flame dynamics of a subscale rocket combustor operating with gaseous methane and gaseous, subcritical or transcritical oxygen." *Combustion and Flame* 242 (2022): 112179.
5. Kaushal et al,. (2024). Navigating Independence: The Smart Walking Stick for the Visually Impaired. In 2024 5th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI) (pp. 103-108). IEEE. <https://doi.org/10.1109/ICMCSI61536.2024.00022>
6. Garcia, Marissa. "Thermal/Mechanical Analysis and Development of a 2000 lbf Liquid Oxygen/Liquid Methane Rocket Engine." (2019).
7. Remiddi, Arianna, Pasquale E. Lapenna, Giuseppe Indelicato, Mauro Valorani, Marco Pizzarelli, and Francesco Creta. "Heat Transfer in Rocket Combustion Chambers Firing Plates: Role of Injector Confinement." *Journal of Propulsion and Power* 39, no. 2 (2023): 176-189.
8. Anand et al., (2024). A comprehensive analysis of small-scale building integrated photovoltaic system for residential buildings: Techno-economic benefits and greenhouse gas mitigation potential. *Journal of Building Engineering*, *82*, 108232. <https://doi.org/10.1016/j.jobe.2023.108232>
9. Leccese, Giuseppe, Daniele Bianchi, Barbara Betti, Diego Lentini, and Francesco Nasuti. "Convective and radiative wall heat transfer in liquid rocket thrust chambers." *Journal of Propulsion and Power* 34, no. 2 (2018): 318-326.
10. Concio, Pierluigi. "Heat transfer modelling and analysis of Oxygen/Methane uncooled and film-cooled liquid rocket engines." (2023).
11. Almatrafi et al., (2024). Reducing metastasis ability of gastric cancer cell line by targeting MMP16 using miR-193a-5p and 5-FU. Advances in Medical Sciences, 69(2), 463-473. https://doi.org/10.1016/j.advms.2024.09.008
12. Kumar et al., (2024). Cognitive Digital Twin Systems for Predictive Security in AI-Enhanced IoT Environments. In 2024 First International Conference on Software, Systems and Information Technology (SSITCON) (pp. 1-6). IEEE. https://doi.org/10.1109/SSITCON62437.2024.10796449
13. Vinodh et al., (2024). Experimental analysis on surface hardness of AA5083 with SiC/eggshell powder reinforced novel metal matrix composite. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 368-377). SPIE. https://doi.org/10.1117/12.3030842
14. Baruah et al., (2024). Artificial Intelligence Influence on Leadership Styles in Human Resource Management for Employee Engagement. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568819
15. Aslam et al., (2024). Smart Multiphase Power Converter in the Fault-Tolerant Machine Development for Aerospace Applications. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568598
16. Selvi et al., (2024). Transfer Learning Approaches for Improved Thyroid Detection. In 2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC) (pp. 1311-1317). IEEE. <https://doi.org/10.1109/ICESC60852.2024.10689771>
17. Melvin Victor De Poures et al. Influences of Zinc Oxide Doping on Functional Characteristics Study of Thin Film Solar Cell for Hybrid Solar Electric Vehicle Utilization" SAE Technical Paper 2024-01-5256, 2024, <https://doi.org/10.4271/2024-01-5256>
18. Ravindra Pratap Singh et al. Enhancement and thermal performance evaluation of parabolic trough solar collector with the integration of innovative snail porous material. ASME. J. Thermal Sci. Eng. Appl. (2025) 1-23. <https://doi.org/10.1115/1.4067588>
19. V. Mohanavel et al. Investigation of Al/Mg composite behaviour by the adaptation of SiC and Al2O3 nanoparticle via electromagnetic stir cast route. Materials Science and Technology. 2025;0(0). doi:10.1177/02670836241306686
20. V. Mohanvel et al. Ferric oxide nanofluid on functional properties of parabolic trough solar collector under different flow rate, Applied Thermal Engineering (2025). Volume 265, 2025,125608, <https://doi.org/10.1016/j.applthermaleng.2025.125608R>
21. Melvin Victor De Poures et al., Processing and Characteristics Study of Hydrogen from Sewage and Waste Municipal Water via Gasification Process" SAE Technical Paper 2024-01-5257, 2024, <https://doi.org/10.4271/2024-01-5257>
22. R.P. Singh et al. Alumina-silicon dioxide hybrid nanofluid action on functional characteristics of photovoltaic thermal collector featured with spiral coil. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-024-13973-0>
23. Melvin Victor De Poures et al. Effect of Gasification Temperature on Biohydrogen Derived from Waste Agro Products for Alternative Fuel Application " SAE Technical Paper 2024-01-5260, 2024, <https://doi.org/10.4271/2024-01-5260>
24. Udhayakumar et al., (2025). Multi-functional natural fiber composites using flaxseed and cotton: tailoring acoustic, mechanical, and thermal properties for eco-friendly applications. Discover Applied Sciences, 7(8), 906.
25. Neelakandan Aagashram et al., Computational design exploration of rocket nozzle using deep reinforcement learning. Results in Engineering 25 (2025): 104439.
26. Jain, Akshay, et al. Conversion of water hyacinth biomass to biofuel with TiO2 nanoparticle blending: Exergy and statistical analysis. Case Studies in Thermal Engineering 67 (2025): 105771.
27. Logesh, K., Vinayagam, M., Kumar, A., Chaturvedi, R., Prabagaran, S., Soudagar, M. E. M., Salmen, S. H., and Al Obaid, S. (2025). "Solar collector featured dryer performance enriched by the adaptations of phase change material embedded with fin collector absorber." ASME. J. Thermal Sci. Eng. Appl. doi: <https://doi.org/10.1115/1.4067631>
28. M.E.M. Soudagar et al. Integration and heat performance evaluation of NaNO3–KNO3 PCM and hybrid nanofluid configured solar thermal heat exchanger. J Therm Anal Calorim (2025). <https://doi.org/10.1007/s10973-024-13970-3>
29. K. Logesh et al. Injection mould processing and characteristics measures of hybrid epoxy composites with jute fiber/boron nitride. J Mech Sci Technol. 39(1), 2025. <https://doi.org/10.1007/s12206-024-1219-1>
30. R. Venkatesh Effects of ramie fiber/boron nitride exposure on the mechanical characteristics of injection-moulded polypropylene composites for automated structural applications. International Journal of Automotive Science and Technology. 2024; 8 (4): 451-456. <http://dx.doi.org/10.29228/ijastech..1528281>
31. Umamaheswari, D. et al. Featuring of Fiber-Ceramic Combination on Behavior Studies of High Density Polyethylene Composite: Hot Compression Mould. Mech Compos Mater (2025). <https://doi.org/10.1007/s11029-025-10305-7>
32. R. Venkatasubramanian et al. Thermal characteristics and dryer performance analysis of double pass solar collector powered by copper and iron oxide. J. Thermal Sci. Eng. Appl. (2025) 1-20. https://doi.org/10.1115/1.4067258
33. R.P. Singh et al. Influence of a Copper Layer on the Functional Behaviour of a Cadmium Telluride Solar Cell Processed via Thermal Evaporation. J. Electron. Mater. (2024). <https://doi.org/10.1007/s11664-024-11669-7>
34. Saadh et al., (2024). Natural killer cell-mediated immune surveillance in cancer: Role of tumor microenvironment. Pathology-Research and Practice, 254, 155120. <https://doi.org/10.1016/j.prp.2024.155120>
35. Venkatesh, R., "Synthesis and Machining Characteristics Evaluation of Silicon Nitride Made Magnesium Alloy Composites," SAE Int. J. Mater. Manf. 18(3), 2025, <https://doi.org/10.4271/05-18-03-0017>.
36. Munirathnam, Rajesh, Rohit P. Jadhav, Nilesh M. Mahajan, Amit Barve, and ME Shashi Kumar. Electric Vehicle Charging Demand Prediction using Multiresolution Sinusoidal Neural Network Optimized with Addax Optimization. In 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), pp. 604-609. IEEE, 2025.
37. Lakshmaiya, N. (2024). Short review of partial flow dilution systems for very low PM mass measurements. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 359-367). SPIE. https://doi.org/10.1117/12.3030836
38. Alamanda et al., (2024). Machine Learning-Based Fault Diagnosis for Rotating Machinery in Industrial Settings. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-5). IEEE. https://doi.org/10.1109/ICONSTEM60960.2024.10568891
39. Supriya et al., (2024). Securing loT Systems with AI-Infused Software and Virtual Replica Models. In 2024 International Conference on Integrated Intelligence and Communication Systems (ICIICS) (pp. 1-6). IEEE. https://doi.org/10.1109/ICIICS63763.2024.10860178
40. Chaudhary et al., (2024). AI-Driven Digital Mirror Technology for Securing IoT-Enabled Smart Infrastructures. In 2024 International Conference on Integrated Intelligence and Communication Systems (ICIICS) (pp. 01-08). IEEE. https://doi.org/10.1109/ICIICS63763.2024.10859436
41. Nikalje et al., (2024). Detecting Cancer through Analysis of Histopathological Images. In 2024 International Conference on Expert Clouds and Applications (ICOECA) (pp. 579-585). IEEE. https://doi.org/10.1109/ICOECA62351.2024.00107
42. Prasad et al., (2024). Deep Learning based Channel Assignment with Load Balancing in MANET for Improved Performance. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1172-1177). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544447
43. Mohan et al., (2024). Image Quality Enhancement using Deep Convolutional Network. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1272-1277). IEEE. https://doi.org/10.1109/ICICT60155.2024.10544980
44. Lakshmaiya, N. (2024). Perovskite photovoltaic cells with freezone zone carbon-based instruments: state of review. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 351-358). SPIE. <https://doi.org/10.1117/12.3030837>
45. Meshram et al., (2024). Investigation of Mechanical and Thermal Properties of Bamboo Fiber Reinforced with Epoxidized Soybean Oil for Automotive Seat Bases (No. 2024-01-5009). SAE Technical Paper. https://doi.org/10.4271/2024-01-5009
46. Singh et al. Natural fiber-ceramic filler configured polypropylene hybrid composite made via hot compression technique: Characteristics evaluation. J Mech Sci Technol. 39(1), 2025. <https://doi.org/10.1007/s12206-024-1216-4>
47. R. Venkatesh Fabrication and Functional Behavior Studies of Polypropylene Composite Containing Hybrid Reinforcements, SAE Int. J. Mater. Manf. 18(2), 2025, <https://doi.org/10.4271/05-18-02-0015>
48. R.K. Singh et al. Exposure of Cu on microstructural and functional performance of Cadmium telluride solar cell. Opt Quant Electron 57, 112 (2025). <https://doi.org/10.1007/s11082-024-08027-6>
49. G. Deepana et al. (2025). Synthesis and machining characteristics study of agro-waste coconut shell powder incorporated aluminium alloy composite via the squeeze cast technique. International Journal of Cast Metals Research, 1–11. <https://doi.org/10.1080/13640461.2024.2447101>
50. S. Prabagaran et al. Texturing of silicon nitride passivation layers on functional behaviour study of polycrystalline silicon (p-Si) made with plasma enhanced chemical vapour deposition. J Mater Sci: Mater Electron 36, 73 (2025). <https://doi.org/10.1007/s10854-024-14135-6>