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THERMAL ANALYSIS OF ROCKET NOZZLE BY USING ABLATION MATERIALS IN THE PORTION OF DIVERGENT USING FEM

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Abstract:- The present analysis deals with the estimation of ablation of thermal protection system provided at the inner surface of rocket nozzle using finite element method. The temperature due to hot gases varies from point to point in convergent, throat and divergent portion of the nozzle. The previous studies on ablation of rocket nozzle liner, assumed uniform variation of heat across certain portion along the axial direction. In present study the solution is refined for actual distribution of thermal load at the inner surface of the liner in nozzle. It is observed that, in the present case, the predicated ablation is less when compared to the previous studies and hence recommended for optimum design of liner

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I INTRODUCTION

A spout might be characterized as an entry of changing cross area, through which heat vitality is changed over into dynamic vitality. Its significant capacity is to give pushed into aviation vehicle. Spout assumes a significant job in giving the fundamental push to the rocket. The gases extend through the spout, whose capacity is to change over this weight into supersonic fumes.

1.1 CONICAL NOZZLE

The conelike spout is utilized as often as possible in prior rocket applications in view of both the plan and assembling are basic. In this spout, the little difference in disparate edge which gives an enormous push, amplifies the hub factor of leave speed and creates an inordinate specific drive (a proportion of rocket proficiency). Notwithstanding, is an all-encompassing and heavier spout this is 2 progressively entangled to fabricate. At the option exorbitant, length and weight are limited through a gigantic spout divider edge. Too bad, huge edges lessen generally speaking execution at low elevation on the grounds that the unreasonable surrounding pressure causes overexpansion and stream partition.

1.2 ROCKET PERFORMANCE

The rocket performance depends upon the subsequent parameters that are given below.

- Thrust
- Specific impulse
- Mass ratio

1.2.1 Thrust (T)

It is a measure of power which is delivered by the rocket motor. The push relies on the mass of the rocket and worthy increasing speed. When the vehicle is in circle, the vehicle‟s energies parity to the gravitational power. So a littler push powers are commonly enough for any moving.

1.2.2 Specific Impulse (Isp)

It the proportion of push delivered by the vehicle to mass of the charge is known as a particular drive. It is an another method to communicate the charge proficiency and numerically is the pushed delivered isolated by the heaviness of force devoured every second. So the Isp is in actuality another proportion of a rocket‟s exhaust speed. Explicit motivation is the basic proportion of force and drive framework execution, and is really similar to the equal of the particular fuel utilization utilized with conventional vehicle or plane motors or airplane motors. For the high estimation of explicit drive, the general execution of the rocket is better. 4 A spout might be characterized as an entry of shifting cross area, through which heat vitality is changed over into motor vitality. Its significant capacity is to give pushed into aviation vehicle. Spout assumes a significant job in giving the essential push to the rocket. The gases extend through the spout, whose capacity is to change over this Particular motivation might be improved through introducing more prominent vitality to the forces (developing the fumes speed), this implies more push can be gotten for each pound of charge expended. This significance is one pound of fuel which offers one pound of push

1.2.3 Mass Proportion (MR)

It is the proportion of mass of force to without the mass of charge is known as a mass proportion. The rocket motor is ceaselessly devoured the charges with the flight time increments. The rocket is reached to the circle the push is staying stable and effectively balance speeding up of gravity of the rocket. On the off chance that the rocket is arriving at the greatest estimations of motor speed, when one piece of the motor is cut off. The separation transport has arrived at three Gs only sooner than the significant motor diminish off. The reason for a rocket is to region a payload at an uncommon capacity with a particular speed. It is relying upon both a position and speed of vehicle this area and speed relies upon the mission. Before to evaluate the vitality necessity to do this to the change in speed (or delta-v, Dv) the rocket gives to the satellite television for pc. For a rocket, the perfect Dv gain relies upon the ISP (exhaust pace, Ve) and the mass proportion.

The additional force the vehicle can convey with acknowledge to its "dry" weight, or weight without charge on board, the quicker it will be fit for pass.Mass proportion is an articulation relating the fuel hundreds to vehicle mass; the better the mass proportion, the higher the last speed of the rocket. Consequently, a rocket vehicle is made to weigh as low as reasonable in its "dry" state. Developing the heaviness of the vehicle payload results in bringing down the mass proportion and subsequently chopping down the most extreme elevation or assortment for instance, the expansion of one pound of payload to an exorbitant height sounding rocket may decrease its pinnacle height by utilizing as bounty as 10,000 ft.

1.3 ABLATION MATERIAL

Presentation Advances in Air transportation and Astronautics have been firmly connected with significant increments in working temperatures. In rocket burning frameworks, fire temperatures are moving toward 55000F and higher. Gas temperatures at any rate twice that high are being experienced in the limit layer of Hypersonic climatic section vehicles. These amazingly high temperature conditions may prompt warm devastation of an uncovered vehicle or a part, except if reasonable insurance is given. Insurance of a structure in an exceptionally high temperature condition might be cultivated effortlessly using another class of building materials. These materials are essentially known as ablative materials which are utilized to secure the structure of materials at raised temperatures. Ablative substances are specific in that they oblige just any temperature or warmth motion condition, naturally deal with the surface temperature, significantly confine any inward 6 progression of warmth, and grow a huge number of Btu"s of vitality for each pound of material. These abilities are simply the aftereffect of a control, precise and progressive evacuation of uncovered surface material, which happens during the collaboration of the high temperature condition with the material. 1.3.1 Removal Procedure Materials removal in high temperature condition is a subject of incredible unpredictability, and as an outcome isn't excessively surely known. Certain compound and physical parts of the procedure have been recognized, be that as it may, and they will be given for the instance of a removing vitreous fiber strengthened plastic. At first, heat episode to the surface is retained and afterward directed into the material substrate. Warmth entrance continues at a lower rate, because of the low warm conductivity of the ablator. The surface temperature in this way rises quickly, and warm corruption starts In some structure. Natural parts of the composite fume into various vaporous results of shifting atomic loads, frequently deserting a leftover singe layer. Thermo-compound and mechanical assault of this permeable carbonaceous structure bring about surface downturn, hence uncovering the strengthening filaments to the hot gas stream. Combination of the strands happens and the liquid material covers the surface either as a film or as beads. This liquefy is incompletely disintegrated, and the rest of indicted along the surface affected by the outside powers of gas weight and shear.

II.LITERATURE SURVEY

The writing review was recognizing the extent of the work. The current work is introduced in the further sections and the significant data are given beneath. John W. Schaefer, Thomas J. Dahm, David A. Rodriquez, John J. Reese, Jr. Mitchell R. Fleece

[1] Considered different systematic and exploratory strategies for ablative material execution for strong rocket spout applications. Enormous scope PC codes were used to compute the expulsion (removal), warm, and structure responses of the 260-SL-3 spout as a plan check and as an explanation behind post fire assessment (investigations). The determined exhibition included thought of surface compound responses, dissolve evacuation, molecule testimony, singe expanding, inside and out active deterioration, and anisotropic mechanical and warm properties. Research center tests were performed to decide and consider the properties and execution components of three silica phenolic materials - MX2600, MX2600-96, and MXS-113. In playing out these tests, a curve plasma generator was used to reenact the strong rocket spout condition and a two-dimensional spout was utilized to mimic a huge ablative part. The outcomes incorporated the meaning of the surface dissolve evacuation attributes and the warm conductivity of the burning material to 5,000°R for 00 and 900 layup points. Ablative 9 and warm execution estimations were likewise performed for the spout of an upper-stage restartable beryllium force engine.

R.D Carnahan decided the mechanical properties, tractable yield, extreme quality, and Youthful's modulus of versatility of a silica fortified phenolic composite at temperatures over the fix level. The proposed application for this class of material as an ablative liner of a rocket spout skirt extension requires such structure data for temperatures approaching 30000F. With the objective that arrangement prosperity edges can be established on a thermo auxiliary assessment. Testing was done on tests taken from the three focal direction of a tape-wrapped cone formed frustum, i.e., hover, corresponding to-deal with, and inverse touse headings, at temperatures stretching out from 750 to 30000F. For all of the three headings the quality exhibited a basic reduction up to -10000 F took after by a level loosening up to the conditioning motivation behind silica (22000F) past which the quality dropped further. A base in the modulus twist for the circle acquaintance is acknowledged with be connected with the advancement of virgin phenolic to sear and thinks about to dimensional changes noted in the warm augmentation lead.

R.W. Rancheris examine the exhibition of ablative materials in both an Exploratory and diagnostic methodology on specific ablative materials like silica phenolic, carbon phenolic. These composites under expanded warming conditions. Examples of up to 8.75 sq.in. In territory and instrumented with top to bottom thermocouples have been described underneath stepwise beats of both 5 minutes (2 stages) or up to 1.4 minutes (to five stages) in period the utilization of air bend radiators. The ostensible burden is 35,000 Btu/square feet. Inner and surface temperatures, downturn rates, and 10 downturn designs inside the lingering singe were not bizarre for the 2 stages, low shear (to 2.5 lb/square feet) runs. Scorching ablator hypothesis top to bottom and surface temperature reactions concurred appropriately with exploratory results for a carbon phenolic. For the 5 stage condition with a moderate shear (30 lb/square feet) there was film verification of micromechanical surface expulsion finally times. Micromechanical results, with the guide of differentiation, were likewise steady with idea solid composite properties were seen as important to precisely show broadened warming removal.

Borie, V. broke down on ablator of carbon-carbon material and their arrangement. These mixes of the building materials are progressively useful in Flight division and flying office. It is basic for high temperatures of the rocket spout and burning office of the rocket. It is utilized as a liner material for ensuring the structure of the rocket spout. The thermo compound examination was led on ablative material which is set at high temperaturezones like large motor casing in rocket and the nozzle portion. This evaluation consists of the calculation of the equilibrium traits of the combustion products within the chamber, the calculation of the characteristics inside the inviscid part of the flow within the nozzle, the dedication of the convective load on wall of the nozzle, the achievement of experimental data concerning the ablation rates and the surface roughness of the carbon-carbon materials constituting the nozzle throats, an explanation of the chemical attack of these substances with the aid of the aggressive species present in the combustion products of the solid propellants, and the computer elevation of the heat transfer and ablation of large rocket motor nozzle throats. The experimental results obtained are compared with the experimental information of the same type provided in the literature concerning the ablation of carbon materials. The comprised results are in good agreement with the measured ablations on large scale rocket motors when the hypothesis of a transition between a laminar boundary layer flow existing on a virgin material and a turbulent boundary layer flow existing on 11 very rough material during ablation are made in the modelling.

III PROBLEM MODELING

In the chapter 2, the relevant literature available has been reviewed and the scope of the present work has been identified. In this chapter the problem statement, problem modelling and validation of the finite element results are explained.

3.1 PROBLEM STATEMENT

The present work is to estimate the required ablative material thickness of the liner at the divergent portion of a rocket nozzle using finite element analysis.

3.2 METHODOLOGY

The task is achieved by eliminating the portion of the ablating liner which undergo beyond melting point temperature due to the convective load liberated in the rocket during combustion. 17 Thermal load on the nozzle is evaluated from Bartz equations. Nozzle is modelled as a 2D axi-symmetric problem and heat transfer analysis are carried out over the time. A two dimensional axi-symmetric geometric model has been considered since this rocket nozzle is axi-symmetric. The model is meshed with a linear quadrilateral element named SOLID plane 55 with an element edge length of 0.1 mm. The transient heat transfer analysis is carried out during the period equal to flight time (t=80s) and the portion which is subjected to the temperature beyond the melting point is removed.

3.3 GEOMETRIC MODELING

The details of the geometry, consider in the present analysis are given below

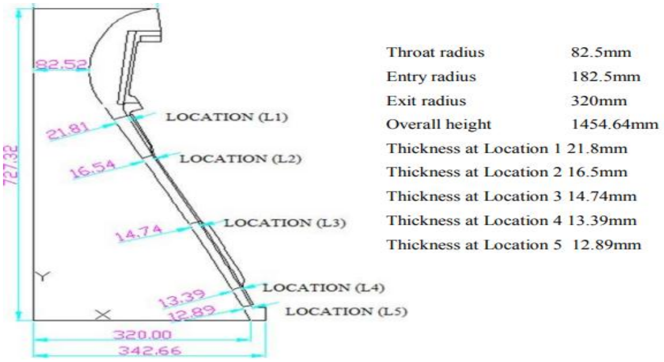

FIGURE 1 Geometry of flex nozzle.

3.4 FINITE ELEMENT MODELING

The geometry created in Auto cad that 2D files are saved in IGES format (.Iges). The file imported into the ANSYS is edited as per requirement for finite element of model

3.5 FINITE ELEMENT MESHING

This is the important phase in which it is required to assign element type, attributes to areas. Thereafter, necessary line divisions are given in the mesh tool and mesh the areas by using „Mapped" option.

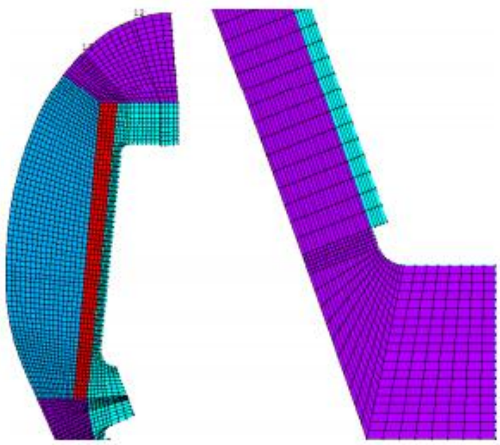

FIGURE 4 Meshing portion of the convergent and divergent portion of flex nozzle.

3.6 MATERIALS

In the present problem, the model consists of 5 different materials for different portions of the nozzle. Carbon Phenolic, Silica Phenolic, Graphite, Steel and GFRP. These insulation materials have been successfully used in aerospace applications. In place of Carbon Phenolic some of the designers use Silica Phenolic as the liner material. In the present study the analysis is carried out for both the materials and also combination of these two as explained below. The liner materials 20 used here are named Carbon Phenolic, Silica Phenolic and Half Carbon Phenolic and remaining half Silica Phenolic. The material properties which are used in the Finite Element Analysis are assumed values due to the inadequate definition of material properties provided by NASA. The melting temperature of Carbon Phenolic and Silica Phenolic are 2300K and 1800K respectively. So the first half of liner material is given Carbon Phenolic properties and below half is given Silica Phenolic properties. The below table 3.1 shows the material properties of the materials used, where Kxx represents through thickness thermal conductivity and Kyy and Kzz represents the inplane thermal conductivity material.

Carbon Phenolic				
Temp	Kxx	Kyy=Kzz	Specific Heat	Density
	(W/mm-K)	(W/mm-K)	(J/Kg-K)	(Kg/mm3)
300K	0.0009	0.00134	921.1	1.44E-06
395K	0.0009	0.00141	1549.1	1.44E-06
533K	0.0009	0.00157	1785.5	1.44E-06
811K	0.00105	0.00202	1967.8	1.44E-06
1366K	0.00194	0.00388	2051.5	1.44E-06
1922K	0.00492	0.00709	2072.5	1.44E-06
2478K	0.00843	0.01093	2093.4	1.44E-06
Silica Phenolic				
Temp	Kxx	Kyy=Kzz	Specific Heat	Density
	(W/mm-K)	(W/mm-K)	(J/Kg-K)	(Kg/mm3)
300K	0.00036	0.00079	837.4	1.65E-06
1366K	0.00099	0.00152	1395.6	1.65E-06
1922K	0.00128	0.00291	2051.5	1.65E-06
2478K	0.00152	0.00326	2051.5	1.65E-06

Table1 Material Properties for composites

Graphite			
Temp	Kxx	Specific Heat	Density
	(W/mm-K)	(J/Kg-K)	(Kg/mm3)
300K	0.10932	586.15	1.78E-06
533K	0.08141	1339.7	1.78E-06
811K	0.0628	1632.85	1.78E-06
1366K	0.04094	1925.93	1.78E-06
1922K	0.0284	2051	1.78E-06
2478K	0.02382	2093	1.78E-06
Steel			
Temp	Kxx	Specific Heat	Density
	(W/mm-K)	(J/Kg-K)	(Kg/mm3)
300K	0.0146	495	7.90E-06
400K	0.0166	515	7.90E-06
600K	0.0198	557	7.90E-06
800K	0.0226	582	7.90E-06
1000K	0.0254	611	7.90E-06
1200K	0.028	640	7.90E-06
1500K	0.317	682	7.90E-06
GFRP			
Temp	Kxx	Specific Heat	Density
	(W/mm-K)	(J/Kg-K)	(Kg/mm3)
	960	960	1.85E-06

Table 2 Other Material Properties.

IV RESULTS AND DISCUSSIONS

This section provides the results that are obtained from the finite element models developed. 2-D Axi-symmetric analysis is performed on flex nozzle system model subjected to varying convective load in order to find ablation in liner material. The influence of operating time of liner on ablation is discussed. Finally some material specific studies are carried out. The results obtained from finite element analysis are discussed in following sections.

4.1 MATERIAL SPECIFIC STUDIES

4.1.1 Effect of operating time on ablation with Carbon phenolic as a liner material. The convective heat load is applied on axi-symmetric flex nozzle model. This load is calculated from Bartz equation as explained in section [3.8]. 34 At 1st second the maximum temperature is observed to be 2340K which is occurred at throat point. The maximum temperature exists at each and every case near throat portion of flex nozzle, because of high convective heat transfer coefficient and minimum area. Fig.4.1 shows the temperature distribution in nozzle at t=2s.The maximum temperature is 2570K at throat which is less than the melting temperature of graphite. The melting point of graphite is around 4000K at 100bar. Therefore ablation is not seen in throat portion. In the convergent portion, the ablation thickness is very small and it is neglected. At divergent portion the temperature reaches the melting point of Carbon phenolic material which is 2300K.

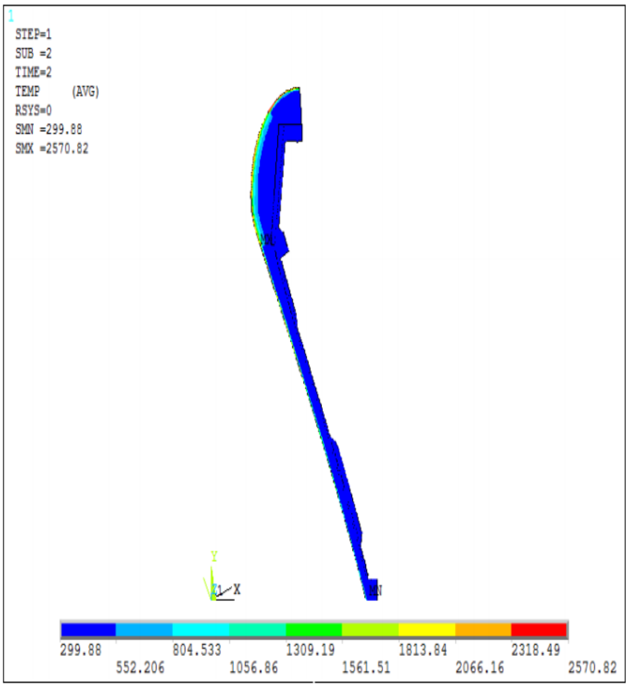

FIGURE 5 Temperature distribution in axi-symmetric model of flex nozzle at t=2s.

The thickness of ablation is measured in divergent portion that is less than 1mm up to 6s of time interval. During the next time interval i.e at t = 7s the ablation thickness is 1mm at L1 location. L1 is the first part of divergent portion.

Ablating thicknesses for remaining locations like L2, L3, L4 and L5 were also identified. These thicknesses are very small when compared to ablation thickness in L1 location, so those values are neglected. Table 4.1 shows the temperature of particular nodes along the thickness direction of the liner in L1 and L2 locations up to 20s. The numbers of nodes are taken up to a location where the maximum temperature reached in each time interval.

Operating time (s)	L1 portion in divergent			L2 portion in divergent		
	Temperatures in Kelvin			Temperatures in Kelvin		
	Node no	Node no	Node no	Node no	Node no	Node no
	3159	3161	3162	3789	3791	3792
1	2200.07	1216.63	538.94	1943.17	1184.91	615.749
2	2481.84	1805.07	968.587	2224.59	1730.55	1108.7
3	2572.57	2038.85	1406.18	2344.06	1954.2	1506.59
4	2622.88	2178.16	1700.17	2413.22	2083.29	1731.86
5	2657.04	2270.02	1850.98	2463.51	2175.1	1869.09
6	2682.77	2333.23	1957.51	2500.99	2241.94	1966.62
7	2702.9	2380.69	2039.94	2529.82	2292.51	2040.05
8	2718.17	2416.54	2103.11	2553.13	2334	2102
9	2730.94	2446.93	2155.35	2572.95	2368.02	2151.54
10	2741.87	2472.98	2199.99	2590.49	2395.99	2192.59

Table 2 Temperature of particular nodes along the thickness direction of the liner in L1 and L2 locations up to 20s.

The ablation thickness is 1.09mm at t=7s, for time intervals from 7 to 19s it is varying up to 2.18mm and finally at the time of 20th second it is reached 2.18mm of ablation thickness in L1 location. In the L1 location an ablation thickness changes from point to point. The minimum thickness (2.18mm) is provided to protect the L1 location. Similarly to the L2 location the thickness is 0.826mm at t=7s. Finally at the time of 20th second the thickness is reached to 1.65mm. Table 4.2 shows the temperature of particular nodes in L3, L4 and L5 location of divergent portion. As we go on the time increases up to 20s, the temperatures are measured at various nodes. Those nodes are taken along the normal direction of the heat flow.

Time (s)	Temperature in Kelvin			
	L3 location		L4 location	L5 location
	Node no	Node no	Node no	Node no
	5509	5540	7210	7336
1	1621.11	929.702	1383.09	1336.58
2	1885.68	1422.84	1666.46	1624.14
3	2013.48	1677.5	1786.92	1739.2
4	2095.96	1817.56	1869.66	1822.82
5	2159.11	1913.31	1932.09	1884.22
6	2207.37	1984.48	1982.45	1935.27
7	2246.83	2041.94	2023.97	1976.41
8	2278.59	2088.96	2059.16	2010.58
9	2307.25	2129.38	2089.8	2041.9
10	2331.68	2163.46	2117.32	2069.67

Table 3 The temperature of particular nodes along the thickness direction of the liner in L3, L4 and L5 locations up to 20seconds.

The above process is continued for every 5s, within the time range of 20s to 40s. Above the range from 40s to 80s, the time interval is changed from 5s to 10s and the same process will be repeated.

Operating time	Carbon phenolic Material				
	Ablation thicknesses are measured in mm				
	Various location in divergent portion				
	L1	L2	L3	L4	L5
25s	3.27317	2.66444	1.4748	0.36578	0
30s	3.31023	2.97494	2.06567	0.53204	0.38754
35s	3.8187	3.38812	2.21322	0.95765	0.62006
40s	4.36442	3.6443	2.8403	1.25486	0.77508
50s	4.47333	4.2145	3.48213	1.71718	1.58633
60s	5.45529	4.99955	3.67394	2.13656	1.92478
70s	6.32813	5.57801	4.36742	2.70785	2.32524
80s	6.54634	5.86754	4.46333	3.03807	2.84196

Table 4 The ablation thicknesses are identified in various operating time intervals in divergent portion.

The ablation thicknesses are changing from starting point of location to ending point of same location and also changes from one location to another location.

The thicknesses are measured in various locations and taken from maximum ablation thickness in each location those values are mentioned in the table 4.3. These values are used to protect the locations in the various operating time intervals of 25, 30, 35, 40, 50, 60, 70 and 80s. The fig 4.2 shows the temperature distribution in axi-symmetric at t=80s

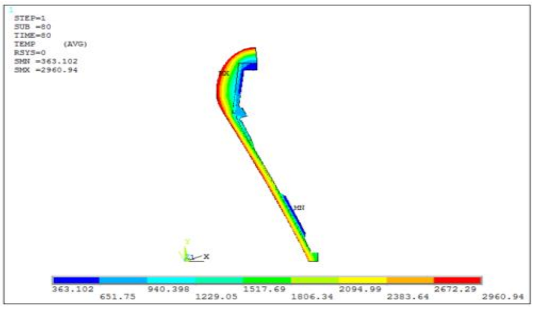

FIGURE 6 Temperature distribution in axi-symmetric nozzle at t=80s

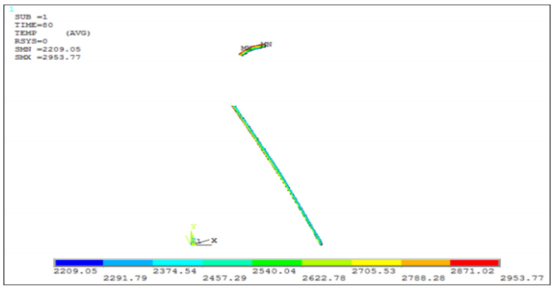

FIGURE 7 The ablated portion of inner liner of flex nozzle at t=80s.

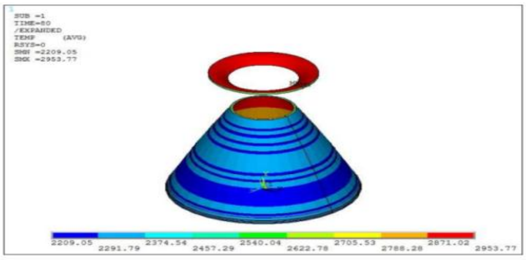

FIGURE 8 The full model of ablated portion is varying along the thickness direction of liner at t=80s

The liner material of the flex nozzle system is provided minimum thickness at operating times of 40, 50, 60, 70 and 80 s for the given layer thickness. Fig 9 shows the effect of time on ablation.

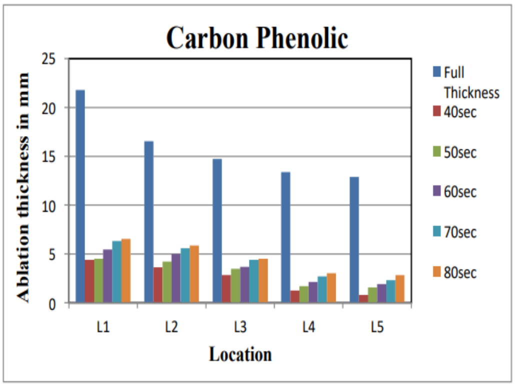

FIGURE 9 Effect of time on ablation.

4.1.2 Uniform vs Non-uniform load

The results of present work are compared with result obtained from the uniform convection load at different locations as done by the previous reference work [1]. It shows the ablation thicknesses are identified in various operating time intervals at the divergent portion. The variation in the two analyses. The Ablation thicknesses are measured in various operating time intervals. The liner material of the flex nozzle system is safe for the given layer thickness at operating times of 40, 50, 60, 70and 80 s..

Carbon Phenolic Material						
Ablation thicknesses are measured in mm						
Portion	Full Thickness	40s	50s	60s	70s	80s
L1	21.8	4.52789	4.65370	5.78621	6.73724	7.49135
L2	16.54	3.78735	4.45550	5.36153	6.29864	6.98924
L3	14.74	2.98688	3.77214	4.02568	4.96264	5.42654
L4	13.39	1.32095	1.91624	2.40455	3.15928	3.82523
L5	12.89	0.84043	1.78793	2.20659	2.78920	3.92295

Table 5 The ablation thicknesses are identified in various operating time intervals at the divergent portion

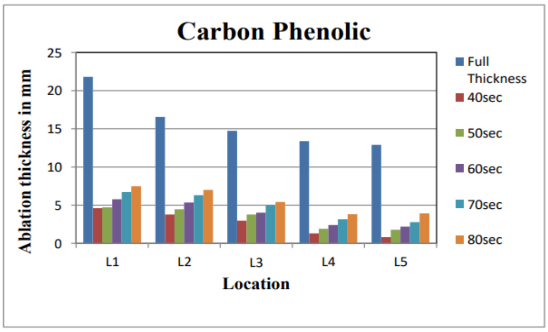

FIGURE 10 Effect of time on ablation.

TABLE 6 Comparison of the ablation thickness between the uniform load and varying load with an operating time at t=40s.

Carbon Phenolic Material					
Ablation thicknesses are measured in mm					
Operating time at t = 40s					
Location	Full thickness	Uniform	Varying	Difference	% of deviation
L1	21.8	4.52789	4.36442	0.16347	3.61023
L2	16.54	3.78735	3.64430	0.14305	3.77710
L3	14.74	2.98688	2.84030	0.14658	4.90755
L4	13.39	1.32095	1.25486	0.06609	5.00302
L5	12.89	0.84043	0.77508	0.06535	7.77533

The scarifying layer thickness is changes from location to location of divergent portion of nozzle. The maximum thickness provided is 4.5mm at L1 and remaining locations of the thicknesses are given..

Table 7 Comparison of the thickness between the uniform load and varying load with operating time at t=50s.

Carbon Phenolic Material					
Ablation thicknesses are measured in mm					
Operating time at t = 50s					
Location	Full thickness	Uniform	Varying	Difference	% of deviation
L1	21.8	4.65370	4.47333	0.18037	3.87582
L2	16.54	4.45550	4.21450	0.24100	5.40900
L3	14.74	3.77214	3.48213	0.29001	7.68811
L4	13.39	1.91624	1.71718	0.19906	10.38796
L5	12.89	1.78793	1.58633	0.20160	11.27580

When the flight time increases the scarifying layer of liner also increases. In those cases the design of ablation thickness plays a vital role without distribution of solid metal. When there is an increase in the liner thickness both cost and weight factors influence the entire nozzle. That situation more realist approach is the best method than compared to remaining theoretical methods, so method of varying load is the best than uniform load. The ablation thickness is optimum in case of varying load and the thickness difference in both cases is around one mm. That value is considered for safe design. Then the operating time of flight is beyond the 60s the method of varying load is the best.

Table 8 Comparison of the thickness between the uniform load and varying load with operating time at t=60s

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Carbon Phenolic Material					
Ablation thicknesses are measured in mm					
Operating time at t = 60s					
Location	Full thickness	Uniform	Varying	Difference	% of deviation
L1	21.8	5.78621	5.45529	0.33092	5.71915
L2	16.54	5.36153	4.99955	0.36198	6.75136
L3	14.74	4.02568	3.67394	0.35174	8.73734
L4	13.39	2.40455	2.13656	0.26799	11.14523
L5	12.89	2.20659	1.92478	0.28181	12.77129

Table 9 Comparison of the thickness between the uniform load and varying load with operating time at t=70s

Carbon Phenolic Material					
Ablation thicknesses are measured in mm					
Operating time at t = 70s					
Location	Full thickness	Uniform	Varying	Difference	% of deviation
L1	21.8	6.73724	6.32813	0.40911	6.07231
L2	16.54	6.29864	5.57801	0.72063	11.44098
L3	14.74	4.96264	4.36742	0.59522	11.99409
L4	13.39	3.15928	2.70785	0.45143	14.28909
L5	12.89	2.78920	2.32524	0.46396	16.63428

In this case the ablation thickness is more when compared to carbon phenolic material used as a liner material. The scarifying layer of liner which depends upon material properties like thermal conductivity and specific heat are along with temperature and density of material.

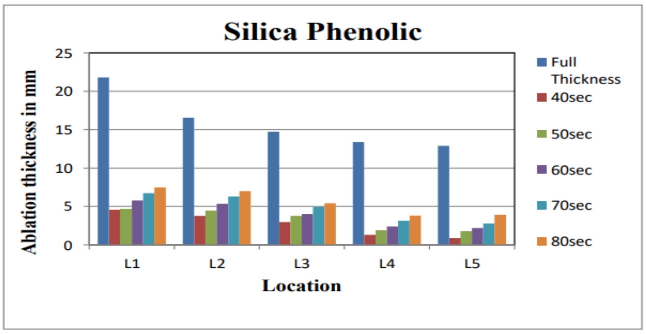

FIGURE 11 Effect of time on ablation.

In this case the ablation thickness is more when compared to carbon phenolic material used as a liner material. The scarifying layer of liner which depends upon material properties like thermal conductivity and specific heat are along with temperature and density of material.

In the both cases a carbon phenolic material used as liner and a silica phenolic material used as liner there is ablation difference changes from location to location. The maximum difference is 2.2mm at time 80s.

Difference of ablation thickness						
Ablation thicknesses are measured in mm						
portion	Full Thickness	40s	50s	60s	70s	80s
L1	21.8	0.45536	0.98196	0.46974	0.17003	0.20136
L2	16.54	0.78828	0.74373	0.42459	0.34045	0.54856
L3	14.74	0.84669	0.79477	0.78731	0.97871	1.21463
L4	13.39	2.07037	2.14008	2.18623	2.21348	2.14928
L5	12.89	2.45437	2.15983	2.33809	2.42851	2.26057

Table 10 Difference of ablation thickness in both cases.

V CONCLUSIONS AND SCOPEFOR FUTURE WORK

Analysis of Flex Nozzle System (FNS) of a solid rocket motor (SRM) has been studied in the present work. 2-D Axi-symmetric analysis is performed on Flex Nozzle System model subjected to convection load. The effect of time is considered in Carbon phenolic material, Silica phenolic material and combination of Silica Phenolic and Carbon Phenolic material. The following conclusions are drawn.

- It is observed that as the operating time increases the ablation of the liner material also increases in these three cases. The liner material of the flex nozzle system is safe at operating times of 40, 50, 60, 70 and 80 s.
- From the present study the Carbon phenolic material is recommended as a material of liner. 53
- From the present study the desired thickness of the liner at various locations for the combination of materials considered is provided in the following table for an operating time of 80s.

5.2 SCOPE FOR FUTURE WORK

The current examination can be stretched out in the accompanying manners.

- The present investigation should be possible for non Axi-symmetric material course of action
- Analysis for various ablative materials.
- To study the impact of outer cooling.
- Fluid examination is to be done to determine convective limit condition.
- Extension of the examination to various sorts of spout geometry.
- The investigation of spout with variable warmth load over the time on the liner.

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