Strength Design of Rx 450 Rocket Fin Due To Effect of Aerodynamic Load

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Abstract. The stability of the rocket is a very important parameter, therefore it is necessary to study the forces and moments that occur on the rocket due to air flow on the rocket's body. The force and moment that occurs must be able to be held by the rocket, especially by the fins without fail. The rocket fins are connected to the rocket body using a holder made of plates which are reinforced with bolt joints. Loads that occur during the duration of the rocket flight in this part include: aerodynamic forces in the form of lift and drag forces, as well as thrust which is the result of propellant combustion. This paper discusses the design of RX 450 rocket fin strength due to aerodynamic loads that occur. Analytical calculations are carried out to get an estimate of rocket velocity based on the results of static tests, lift, drag and stress that occur on the rocket fins. The stress calculation results are then analyzed based on the material properties of the rocket fins to get the conclusion that the rocket fin design is safe or not. From the calculation results obtained bending stress that occurs in the design of the fin design using 6061 aluminum alloy material with a thickness of 25 mm is σ_{max}= 58.09 MPa, with a safety factor of (SF) = 4.75.

Keywords: Bending stress, rocket fins, aerodynamic forces.

1. Introduction

With the increasing ability of the rocket motion such as velocity and maneuverability the rocket, the stability of the rocket direction becomes very important. This causes the need to study the force and moment caused by the air flow on the rocket which can affect the stability of the rocket direction. The force and moment that occurs must be able to be safely received by the rocket fins structure.

The rocket fins are mounted on the back of the rocket and connected to the rocket body using a plate holder which is reinforced with bolts. Rocket fins experience aerodynamic loads in the form of lift and drag during flight and thrust loads due to ignition of rocket motors during combustion. These loads cause stress on the rocket fins that are transferred by the fins to the bolt fastening and plate mounting fins [1,2,3]. Therefore, it is important to calculate the strength of the fins that receiving aerodynamic loads, the goal is fins designis able to accept the load that occurs during flight. The rocket technology program, especially the rocket control system, is indispensable for the development of aircraft. Changes in track, not only related to the used control system, but also related to the command system placed on the ground and the receiving system that will move the control actuator mounted on the rocket. Trying to find out and calculate according to plan, the results of these calculations are displayed so that it can be seen how far the success. This plan includes aerodynamic forces and moments to the fins stretch. Based on calculations of the force, moment and stress on the fins and the stand, the fins must be able to withstand the load given [4,9,11].

The theoretical approach used to determine the ability of the RX 450 rocket fins to accept the aerodynamic forces that occur is, first sought the moments that occur on the fins due to aerodynamic forces after that can be determined the amount of stress that occurs from the rocket fins. This paper discusses the design of the RX-450-LAPAN rocket fin strength due to aerodynamic loads that occur.

2. Methodology of Calculation Theoretical Basis

Air flow on the rocket fins can produce two kinds of forces namely: lift force and drag force, the lift force is perpendicular to the relative velocity of the air. whereas the drag is parallel to the relative velocity of the air.

The theoretical approach used to determine the ability of the RX 450 rocket fins to accept aerodynamic loads is first to look for the moment that occurs on the fins due to aerodynamic force after which the magnitude of the flexural stress of the rocket fins can be determined (see figure 1).

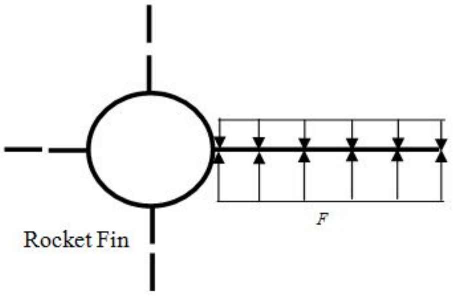


FIGURE 1. Lift force on a simplified RX 450 rocket fins structure

To know the phenomenon of lift and inhibition of fins at supersonic velocity can be seen in Figure 2 below, figure 2 shows a flat fin with length c and angle of attack α in supersonic flow. At the upper surface of this flow will reverse itself, then the wave of expansion occurs at the edge of the face and the pressure at the upper surface of the p_2 fin is less than the free flow pressure $p_2 < p_1$. On the back side, the flow must return to around the direction of free flow. Then the flow will return again and consequently a shock wave will occur at the back [2,11].

At the buttom of the surface, the flow changes by itself, tilted shock waves occur on the front side and the pressure at the buttom of the surface fin p_3 is greater than the free flow pressure $p_3 > p_1$. At the back of the flow changes back around the free flow through expansion waves.

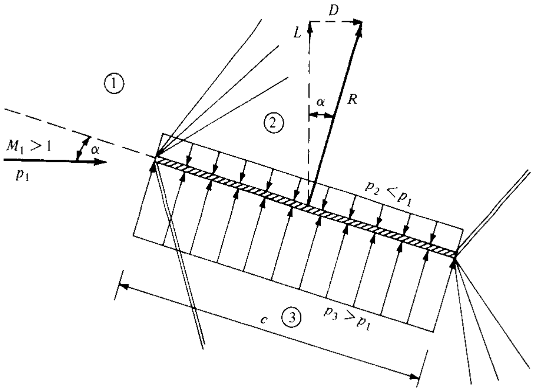


FIGURE 2. Flat fins on supersonic flow

- Lift Force

$$F_L = (p_3 - p_2)A.\cos\alpha \tag{1}$$

where: FL = Lift Force (N), p3 = pressure under the surface of the fin, p2 = pressure under the surface of the fin, A = fin area.

- Drag Force

$$F_D = (p_3 - p_2)A.\sin\alpha \tag{2}$$

where: FD = Drag Force (N), dan = angle of attack

- Resultant Force

$$R = (p_3 - p_2)A. \tag{3}$$

- Bending stress of fins (σ)
  Bending stress on rocket fins RX 450 can be determined by the following equation:

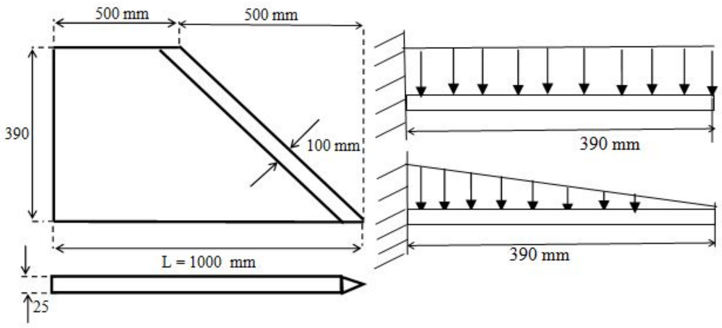


FIGURE 3. Shape and size of the RX 450 fin and support at L = 1000 m

From figure 3, the moment is taken towards the right end of the fin, then the moment equation is the moment on the pedestal due to wide load (50cm x 39cm = 1950 cm^2)

$$M_1 = 1/2\, qx^2 \text{ [5,6,8]} \tag{4}$$

moment on the pedestal due to wide load (50 cm x 39 cm x 1/2 = 975 cm^2) is

$$M_2 = 1/6\, qx^2 \text{[5,6,8]} \tag{5}$$

The maximum moment on the pedestal $M_{mak} = M_1 + M_2$

The maximum stress that occurs in the fins (holders) fins:

$$\sigma_{\max} = M_{\max}/W \text{[5,6,8]} \tag{6}$$

where: q = resultant aerodynamic force of fin length = R / L = (N / m), I = fin profile moment of inertia (m^4), W = moment of resistance (m^3), E= modulus of elasticity (N / m^2), L = length of fins.

3. Methodology

This research is to determine the strength of RX 450 rocket fins due to aerodynamic forces. What is done is to find complete data of the RX 450 Rocket fins including dimensions, thickness and fin material then static test results, then look for Mach numbers to calculate the aerodynamic forces on the fins such as lift, resistivity and thrust, then calculate the moment that occurs in the fin as a result of aerodynamic forces then calculate the magnitude of the flexural stress on the fins. Then calculate the safety factor of the RX 450 fin due to aerodynamic forces. The work scheme in this study is illustrated on figure 4.

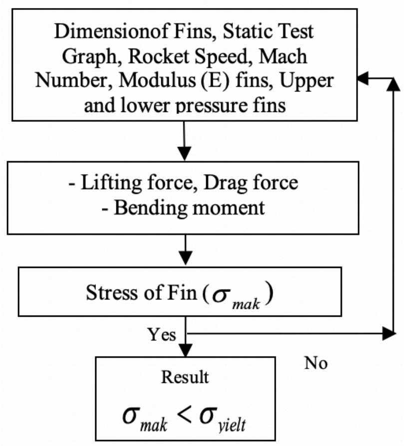


FIGURE 4. Flow chart of RX 450 rocket fins design

4. Data Processing

Static test results can be seen in Figure 5 below:

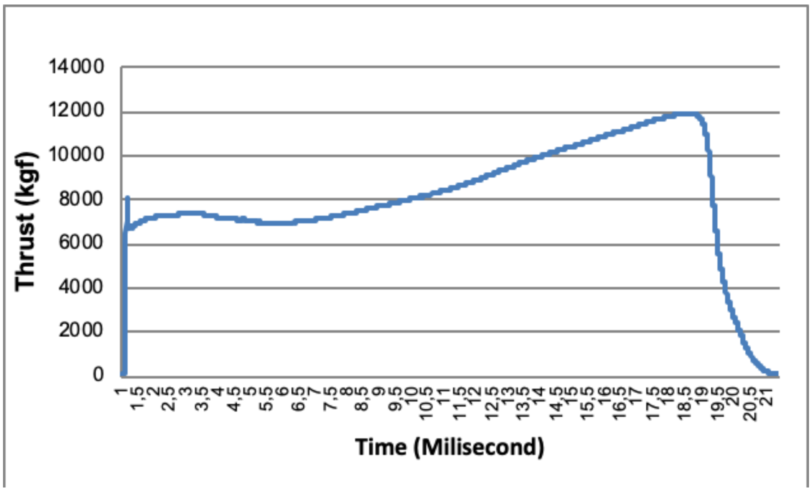


FIGURE 5. Static test results for the RX 450 rocket

RX 450 rocket fin data, as follows: Rocket fins using material from Al-Alloy 6061, E = 69.109 N / m^2, mass density 2.7 (103) kg / m^3.

4.1. Rocket Exit Velocity Determination Based on Test Static Data

From the test results of graph (figure 5) we get propellant weight Wp = 740 kg, combustion time tb = 21 seconds. Then the mass propellant rate $\dot{m} = W_p / t_b$ = 740/21 = 35.238 kg / sec [9], meaning that the weight of the propellant or rocket will be reduced during flight by 35.238 kg per second due to combustion. The amount of acceleration that occurs in a rocket during flight can be found by the equilibrium of the force on the rocket:

$$F - W\cos\alpha - D = F - m.g.\cos\alpha - 1/2\,\rho v^2 A = m \times a$$ [2,4]. (see figure 6)

where: F = rocket thrust / N (test) results, W = rocket weight (N), D = rocket / drag force (N).

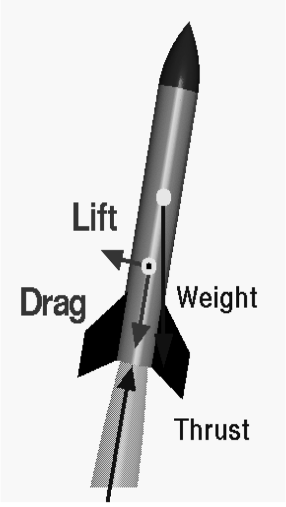


FIGURE 6. The forces on the rocket

where Cd = 0.33. The results of processing the test results of the RX 450 rocket for various combustion times (tb) are in table 1.

TABEL 1. Static test data processing results

t_b Second	W (kg)	$\dot{m}$ kg/sec	F (N)	A m/sec^2	Ue m/sec	M mach
0	17971.92	0	-1.80E+04	-9.81E+00	0.00E+00	0
1	17626.24	35.238	-1.76E+04	-9.76816	-9.77E+00	-0.0284
2	17280.55	35.238	5.34E+04	30.29003	60.58007	0.176105
3	16934.87	35.238	55247.2	32.00351	96.01052	0.2791
4	16589.18	35.238	53926.94	31.88966	127.5586	0.37081
5	16243.5	35.238	52286.61	31.57766	157.8883	0.458978
6	15897.81	35.238	52006.55	32.09148	192.5489	0.559735
7	15552.13	35.238	53536.36	33.76977	236.3884	0.687176
8	15206.44	35.238	56261.32	36.29538	290.363	0.844079
9	14860.76	35.238	59540.24	39.30417	353.7376	1.028307
10	14515.07	35.238	62618.55	42.3207	423.207	1.230253
11	14169.39	35.238	65812.16	45.56424	501.2066	1.456996
12	13823.7	35.238	69662.8	49.43625	593.235	1.72452
13	13478.02	35.238	7.39E+04	5.38E+01	6.99E+02	2.032048
14	13132.33	35.238	7.73E+04	57.7172	808.0408	2.348956
15	12786.65	35.238	79451.45	60.95567	914.3351	2.657951
16	12440.96	35.238	80912.35	63.80134	1020.821	2.967504
17	12095.28	35.238	81480.95	66.08596	1123.461	3.265876
18	11749.59	35.238	80584.66	67.28194	1211.075	3.520567
19	11403.91	35.238	76400.58	65.72217	1248.721	3.630004
20	11058.22	35.238	13832.67	12.27127	245.4254	0.713446
21	10712.54	35.238	-9.16E+03	-8.39E+00	-176.243	-0.51233

From the table 1. Obtained the highest velocity of output Ue design and static test Ue = 1248.72 m / sec, equivalent to Ue = 3.63 mach.

4.2. Lift Force and Drag Force Calculation

First calculate on the upper surface of the fin (see figure 2) using the Deflection angle equation: $\theta = v(M_2) - v(M_1)$

$v_2 = v_1 + \theta$, where $\theta = \alpha$ was taken θ = 5^0 from appendix C (John D Anderson, Jr " Fundamentals of Aerodynamics",page:547). Obtained $M_1 = 3{,}63$ *machand* $v_1 = 60{,}55^0$, *then* $v_2 = 60.55 + 5 = 65.55$ $v_2 = 60{,}09 + 5 = 65.55^0$ and obtained $M_2 = 3.97$.

from appendix Afor , $M_1 = 3.63$ obtained $p_{01}/p_1 = 91.656$ *for* $M_2 = 3.97$ obtained $p_{02}/p_2 = 145.92$, where $p_{01} = p_{02}$

$$\frac{P_2}{P_1} = \frac{P_{01}/P_1}{P_{02}/P_2} = \frac{91{,}656}{145{,}92} = 0.628 \text{ and}$$

$$P_2 = \frac{P_2}{P_1}(P_1) = 0.628 \text{ atm}$$

*) Calculate p_3 / p_1 on the underside of the fin, from the diagram $(\theta - \beta - M)$(Figure 9.7 John D Anderson, Jr" Fundamentals of Aerodynamics), for M_1 =3.63 and $\theta = 5^0$ obtained β= 19.5 then , $M_{n,1} = M_1 \sin\beta$= 3.63 sin 19.5 =1.212

From Appendix B untuk $M_{n,1}$ = 1.212 obtained p_3 / p_1= 1.547 then $\rho_3 = {}^{\rho_3}/_{\rho_1}\,(\rho_1) = (1{,}547)(1) = 1{,}547$= 1.547 atm. (1 atm =1.013 kg/cm^2)

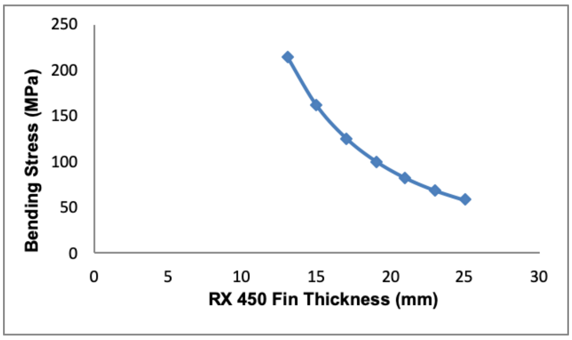
*) calculate lift, drag and resultant forces: for the fin areaA_1 = 1950 cm^2
Lift Force =$F_L = (P_3 - P_2)A_1.\cos\alpha$=(1.547-0.628) x 1950 x cos 5^0= 1551.97 kg
Drag Fore = $F_D = (P_3 - P_2)A_1.\sin\alpha$ = (1.547-0.628) x 1950 x sin 5^0= 156.19 kg
Resultant Force = $R_1 = (P_3 - P_2)A_1$= (1.547- 0.628) x 1.013 x 1950 = 1792.05 kg = 18152.96 N

And for the fin areaA_2 = 975 cm^{2}got :
F_L = 775.985 kg , F_D =78.1 kg , R_2 = 896.025 kg, q = 18152.96 /0.5 =36305.92 N/m

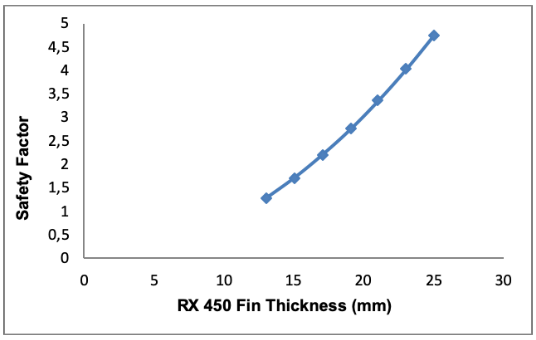
*) The moment that occurs in the fins:
by using the terms 4 and 5 above,
$M_1 = 1/2\,qx^2$= ½ (36305.92)(0.5)^2 = 4538.24 Nm, $M_2 = \frac{1}{6}qx^2$ = 1/6 (36305.92)(0.5)^2 = 1512.747 Nm, thenM_{tot} = $M_1 + M_2$ =4538.24 + 1512.747 = 6050.987 Nm.

4.3. Calculating Stress on Rocket Fins

$\sigma_{max} = M_{tot}/W$, where, obtain M_{tot} = maximum total moment on the fins= 6050.987 (Nm) , W = section modulus of fin $W = I/y$ = 10.42e-5 (m^3). The design results obtained maximum bending stress on the fins is :$\sigma_{max} = \frac{M_{tot}}{W} = \frac{6050{,}987}{10.42e-5}$= 58.09 MPa. RX 450 fin material uses material fromAl- Alloy 6061, with σ_{yielt}= *276 Mpa*then the fin safety factorRX 450 is : **SF is 4.75**



GRAPH 1. Graph of bending stress vs fin thickness



GRAPH 2. Graph of Safety Factor vs. fins thickness

TABLE 2. Results of data processing from the RX 450 LAPAN rocket.

No	Specification	Notation	Result	Unit
1	Rocket maximum thrust force	F	80584.66	N
2	Maximum Rocket velocity	Ue	1248.72	m/sec
3	The resultant force on the fin	R	18152.96	kg
4	Maximum moment on the fins	M_{tot}	6050.987	Nm
5	Stress that occurs in the fins	σ_{max}	58.09	MPa
6	Safety Factor	SF	4.75	-

5. Discussion

From table 1, from the results of data processing on the static test results of the RX 450 LAPAN rocket, the rocket thrust force is obtained, with the equilibrium force that occurs in the rocket can be determined the acceleration that occurs in the rocket during flight, then the maximum velocity of the rocket is found, the results the calculation is obtained the maximum velocity Ue = 1248.72 m / sec is equivalent to 3.63 Mach of this velocity data then the pressure on the top and bottom of the RX 450 flat fin with the fin dimensions has been determined and the maximum angle of attack = 5^0 is ρ_3=1.547atm and ρ_2=0.628 atm, with a fin area A_1 = 1950 cm2, the magnitude of lift force F_L = 1551.97 kg, drag force F_D = 156.19 kg and the resultant force R_1 = 18152.96 kg. While for the fin area A_2 = 975 cm^2, it is obtained F_L = 775.985 kg , F_D= 78.1 kg , R_2 = 896.025 kg, the long unity load on RX450 fins is q = 18152.96 /0.5 = 36305.92 N/ m.

From graph 1: the graph explains the relationship between bending stresses to the thickness of the fins, the thicker the fins the smaller the bending stresses that occur. Lift and retardation forces that occur in the fins can cause bending moments where the results obtained from the design of the maximum bending moment that occurs in the fins binder is M_{tot} = 6050.987 Nm and then calculated the amount of stress that occurs in the rocket fins σ_{max}= 58.09 Mpa.From the material of rocket fins, it is known to use material from Al-Alloy 6061, with σ_{yield}= 276 MPa and it can be said that the RX 450 LAPAN rocket fins are quite safe and able to accept the burden due to aerodynamic forces during flight, because$\sigma_{max} < \sigma_{yield}$.

Can be seen from this graph for various thickness of fins in various calculations, in this design the thickness of fins taken 25 mm and can be said that the design of the RX 450 rocket fin structure is very safe because it has a high enough safety factor that is SF = 4.75. From Graph 2: this graph explains the relationship between the thickness of the fins and the safety factor, the thicker the rocket fins the greater the safety factor in this design is taken 25 mm thick fins with SF = 4.75 by considering the existence of vibrations in the RX 450 fins, so that the fins able to accept the dynamic load that occurs.

6. Conclusions

From the results of the design of the strength of the RX 450 LAPAN rocket fins can be concluded as follows:

1. In designing the strength of the rocket fins, it is necessary to calculate the maximum rocket velocity from the static test results that is equal to Ue = 1248.72 m / sec equivalent to Ue = 3.63 mach, the goal is to find out the pressure state on the RX 450 flat fin with the angle of attack α = 5^0, the calculation results obtained pressure above the fin P_2 = 0.628 atm and pressure below the fin P_3 = 1.547 atm and the resultant amount of aerodynamic force R = 18152.96kg.
2. The design results obtained for the RX 450 LAPAN rocket fins are as follows: the stress that occurs in the RX 450 rocket fin structure with a thickness of 25 mm, is σ = 58.09 MPa, while the material for the rocket fin structure is made of aluminum Alloy 6061 with a yield stress σ_{yield}= 276 Mpa, with the safety factor SF = 276 / 58.09 = 4.75. Or it can be said that the RX 450 rocket fins are very safe and capable of receiving aerodynamic loads that occur during flight.

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