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Determining The Ratio Of Pressure And Compressor Air Mass Flow Rate To Generate Thrust

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Abstract

Missiles are strategic defense equipment that have a high deterrent effect in the national defense system because they have high destructive power, high precision, and can be launched remotely. With the above characteristics, the missile is a high-tech product, and it still needs a lot of engineering effort to master the technology, especially the propulsion / propulsion system technology which is mostly in the form of turbojet engines. With the above background, this study designs and analyzes one of the main components of the missile propulsion system, namely the compressor impeller. This study analyzes the pressure ratio and mass flow rate of compressor air whose values are used to obtain the impeller design of a small turbojet engine compressor on a surface-to-surface cruise missile propulsion system. The method used is analytical method. The conclusion of the study is that the combination of a compressor pressure ratio of 4 and an air mass flow rate of 2.5 kg/s can produce a target thrust of 1,300 N, and the diameter of the turbojet engine (d_T) *is smaller than the maximum allowable space diameter of 270 mm.*

Keywords: Missiles, Turbojet Engines, Impeller Compressor

INTRODUCTION

Law of the Republic of Indonesia Number 6 of 1996 concerning Indonesian Waters states that in the territory of Indonesian waters there are 17,508 islands under the sovereignty of the Republic of Indonesia. With a very large area of jurisdiction of the sea as well as a very diverse population. It is vulnerable to a wide variety of threats. The threats faced by Indonesia can be in the form of military threats or non-military threats, so defense forces are needed to deal with these two types of threats In order to anticipate the threats that may arise, it is very necessary to carry out a reliable and high-deterrent state defense. Therefore, it is necessary to build defense forces and capabilities continuously and continuously (Buku Putih Pertahanan Indonesia, 2015).

In 2021, through Presidential Regulation number 8 of 2021 concerning the General Policy of State Defense, the Government has set priority programs from the previous 7 programs to 11 priority programs, are: (a) propellant; (b) rockets; (c) missiles; (d) medium tanks; (e) radar; (f) submarines; (g) fighter aircraft; (h) military satellites; (i) unmanned aircraft; (j) subsurface sensing of water and (k) information and communication technology. Of the eleven priority programs of the defense industry, missiles are one of the strategic defense equipment to be developed, because they have great destructive power, a high level of precision, and can be launched from a long distance against the enemy, causing the missiles to have a large deterrent effect. Missiles are necessary to defend sovereignty placed in the outer islands in particular from the threat of potential adversaries (BPPT, 2019).

Guided missile technology is abbreviated as missile, covering communication systems, control, structure, propulsion, target acquisition, warhead. Missile technology until now these components, almost entirely still depend on foreign countries. In fact, the very high dependence is very unfavorable, because at any time it can change according to the situation and will of the defense exporting country (Seminar Nasional Peluru Kendali, 2016).

The Missile Technology Innovation Program begins with the preparation of Design Requirements & Objectives (DR &O), mastery of the vehicle system (airframe), mastery of control and navigation technology, mastery of fuze system technology, mastery of booster propulsion technology, and mastery of sustainer propulsion / pusher technology is turbojet engines.

Surface-to-surface cruise missiles require a sustainer propulsion/thruster system using a small turbojet. Based on the DR&O and the initial design of the BPPT missile, which determines the geometry of the ride, the total weight, speed, and thrust requirements of the missile, the total weight of the missile is obtained, the geometry of the vehicle is 4,380 mm long outside diameter 280 mm, the wingspan is 1,600 mm, and the cruising speed is 0.8 mach with a thrust force of 1,300 N. Thrust force of 1,300 N is obtained from aerodynamic analysis of the flying vehicle in this case the missile (BPPT, 2019).

Aerodinmic analysis is intended to predict the thrust required by a missile based on the influence of the forces arising from the interaction between the airflow and the missile vehicle. The forces that arise are in the form of drag force, lifting force, and heavy force. The inhibitory force arises due to the presence of an airflow rate that interacts with the shape of the geometry of the missile vehicle. The faster the air flow in this case the cruise speed of the missile, the greater the drag force, as well as the less aerodynamic the geometry of the missile vehicle, the greater the drag force. The lifting force is intended to overcome the heavy force of the total weight of the missile vehicle due to the gravitational pull of the earth. The lifting force is influenced by the airflow in this case the cruise speed of the missile, the design of the missile wing in the form of wing area, the shape of the wing airfoil, and the angle of attack of the wing. The faster the cruise speed of the missile, the greater the lifting force. The more aerodynamic the wing design, the greater the lifting force. The targeted thrust force is able to overcome or counteract the inhibitory forces and heavy forces arising from the initial design of a predetermined missile. In other words, the amount of thrust required is directly proportional to the total weight and inhibition force but inversely proportional to the lifting force in order to fly and maintain its position in the air when heading towards the targeted target. (Arismunandar, 2002).

Based on the aerodinmic analysis, a thrust of 1,300 N is needed to deliver the missile to the intended target. If the thrust force is less than 1,300 N, the speed of the missile will decrease which results in a loss of lift force and can cause a fall, in aviation science it is called a stall. However, if the thrust is more than 1,300 N, there is an over-engineering where the speed will increase which results in the lifting force increasing and the flying altitude increasing as well, so that it can be detected by the enemy because it flies too high. In addition, fuel consumption increases so that waste occurs. Need additional space to store fuel. The dimensions of the turbojet engine become larger so that it is not accommodated by the space provided by the missile vehicle. (Arismunandar, 2002)

1,300 N thrust can be met with a wide variety of turbojet engine sizes, can be small in size and can be large in size. If it is small, in addition to requiring more fuel, it also requires a large turbojet engine rotation, and the rotation of a large turbojet engine will be limited by the strength of the material used. If the turbojet engine is large, the fuel needed is less, the turbojet engine speed is low, but it can cause the turbojet engine not to enter the room provided by the missile structure (El-Sayed, 2016).

In this study, the calculation of compressor performance parameters in the form of air mass flow rate and compressor pressure ratio will be carried out so that the turbojet engine produces the specified thrust force, then determine the geometric design of the turbojet centrifugal compressor impeller. The method to be applied is an analytical method using the laws of conservation of mass, conservation of momentum, and conservation of energy, with the requirements set, namely the thrust value of 1,300 N, and the maximum outer diameter of the turbojet engine of 270 mm. The results of the two stages mentioned above can be used as input in making trade offs in making small turbojet designs. However, further research is needed to validate the results of this study, namely by using CFD software and experiments.

RESEARCH METHODS

Research Methods of this research is Qualitative Analytic. With the steps are:

1. Determine the Specific Power, used $Y = \left({\pi_c}^{\frac{\gamma_c - 1}{\gamma_c}} - 1\right) c_{pc} T_{02}$
2. Determine the absolute velocity of the tangential component of the airflow $[C_{u3}]$, used $C_{u3} = \frac{Y}{U_3}$
3. Determine the absolute velocity radial outside of airflow, used $C_{m3} = \varphi_m U_3$
4. Determine of relative velocity of the tangential component of the airflow, used $W_{u3} = U_3 - C_{u3}$
5. Determine of relative velocity outside of airflow, used, $W_3 = \sqrt{W_{u3}^2 + C_{m3}^2}$
6. Determine of absolute velocity outside of airflow, used $C_3 = \sqrt{C_{u3}^2 + C_{m3}^2}$
7. Determine of blade angel outside of impeller, used $\beta_3 = tan^{-1}\left(\frac{C_{m3}}{W_{u3}}\right)$
8. Determine of outside diameter of impeller, used $d_3 = \frac{U_3}{3.14n}$
9. Determine of diffuser diameter, used $d_d = 1.6d_3$
10. Determine of Turbojet Engine outside diameter, used $d_T = d_d + 8\,mm$
11. Determine of outer airflow total temperature of impeller, used $T_{03} = T_{02}\left[(\pi_c)^{k-1/k}\right]$
12. Determine of outer airflow static temperature of impeller, used $T_3 = T_{03} - \left(\frac{C_3^2}{2c_p}\right)$
13. Determine of outer airflow pressure of impeller, used $p_{03} = \pi_c p_{02}$
14. Determine of outer airflow static pressure, used $p_3 = \frac{p_{03}}{\left(\frac{T_{03}}{T_3}\right)^{k/k-1}}$
15. Determine of outer static air mass of impeller, used $\rho_3 = \frac{p_3}{RT_3}$
16. Determine of outer width of impeller, used $b_3 = \frac{\dot{m}_a}{\pi d_3 \rho_3}$
17. Determine of outer statistical speed of sound, used $a_3 = \sqrt{kRT_3}$
18. Determine of Mach number at outer of impeller, used $M_3 = \frac{C_3}{a_3}$
19. Determine of inner axial speed of impeller, used $C_{m2} = C_{m3}$
20. Determine of inner static temperature of impeller, used $T_2 = T_{02} - \left(\frac{C_{m2}^2}{2c_p}\right)$
21. Determine of inner airflow pressure of impeller, used $p_2 = \frac{p_{02}}{\left(\frac{T_{02}}{T_2}\right)^{k/k-1}}$
22. Determine of inner static air mass of impeller, used $\rho_2 = \frac{p_2}{RT_2}$
23. Determine of inner wide of impeller, used $A_2 = \frac{\dot{m}_a}{C_{m2}\rho_2}$

24. Determine of inner diameter of impeller, used $r_H = ({}^{rH}/_{r2})r_2$, $r_2 = \sqrt{\frac{A_2}{3.14\left[1-\left(\frac{r_H}{r_2}\right)^2\right]}}$ and $d_2 = 2r_2$
25. Determine of inner diameter hub of impeller, used $r_H = ({}^{rH}/_{r2})r_2$
26. Determine of inner tangential velocity of impeller, used $U_2 = \pi d_2 n$
27. Determine of inner relative velocity of impeller, used $w_2 = \sqrt{U_2 + C_{m2}}$
28. Determine of inner angel of impeller, used $\beta_2 = tan^{-1}\left(\frac{C_{m2}}{U_2}\right)$

RESULT AND DISCUSSION

The following is a calculation of turbojet thrust with a compressor pressure ratio and an air mass flow rate of 1.8 kg/s

1. Calculations on the inlet (El-Sayed, 2017).

$$T_{02} = T_a + \frac{V^2}{2c_{pc}}$$
$$T_{02} = 288{,}15\,K + \frac{(0)^2}{2 \times 1.005{,}00\ {}^{J}/_{kg.K}}$$
$$T_{02} = 288{,}15\,K$$
$$P_{02} = P_a\left[1 + \eta_i\left(\frac{T_{02} - T_a}{T_a}\right)\right]^{\gamma_c/\gamma_c - 1}$$
$$P_{02} = 101{,}33\,kPa\left[1 + 0{,}90 \times \left(\frac{288{,}15\,K - 288{,}15\,K}{288{,}15\,K}\right)\right]^{1{,}40/1{,}40-1}$$
$$P_{02} = 101{,}33\,kPa$$

2. Calculation on Compressor (El-Sayed, 2017).

$$T_{03} = T_{02}\left[1 + \frac{\pi_c^{\gamma_c - 1/\gamma_c} - 1}{\eta_c}\right]$$
$$T_{03} = 288{,}15\,K \times \left[1 + \frac{2^{1{,}40-1/1{,}40} - 1}{0.90}\right]$$
$$T_{03} = 358{,}27\,K$$
$$P_{03} = \pi_c P_{02}$$
$$P_{03} = 2 \times 101{,}33\,kPa$$
$$P_{03} = 202{,}66\,kPa$$

3. Calculation on the afterlife space (El-Sayed, 2017).

$$P_{04} = (1 - \Delta P_{cc})P_{03}$$
$$P_{04} = (1 - 0.06) \times 202{,}66\,kPa$$
$$T_{04} = 1.003{,}15\,K$$
$$f = \frac{c_{ph}T_{04} - c_{pc}T_{03}}{\eta_b Q_R - c_{ph}T_{04}}$$

$$f = \frac{1.157{,}00\ {}^{J}/_{kg.K} \times 1.003{,}15\ K - 1.005{,}00\ {}^{J}/_{kg.K} \times 358{,}27\ K}{0{,}95 \times 43.500{,}00\ {}^{kJ}/_{kg} - 1.157{,}00\ {}^{J}/_{kg.K} \times 1.003{,}15\ K}$$

$$f = 0{,}0199$$

$$\dot{m}_e = \dot{m}_a(1+f)$$

$$\dot{m}_e = 1{,}80\ {}^{kg}/_{s}\,(1+0{,}0199)$$

$$\dot{m}_e = 1{,}84\ {}^{kg}/_{s}$$

$$\dot{m}_f = f\dot{m}_a$$

$$\dot{m}_f = 0{,}0199 \times 1{,}80\ {}^{kg}/_{s}$$

$$\dot{m}_f = 0{,}04\ {}^{kg}/_{s}$$

4. Calculations on the turbine (El-Sayed, 2017).

$$T_{05} = T_{06} = T_{04} - \frac{c_{pc}(T_{03} - T_{02})}{c_{ph}(1+f)}$$

$$T_{05} = 1.003{,}15\ K - \frac{1.005{,}00\,{}^{J}/_{kg.K} \times (358{,}27K - 288{,}15K)}{1.157{,}00\,{}^{J}/_{kg.K} \times (1+0{,}0199)}$$

$$T_{05} = 943{,}43\ K$$

$$P_{05} = P_{04}\left[1 - \frac{T_{04} - T_{05}}{\eta_t T_{04}}\right]^{\gamma_h/\gamma_h - 1}$$

$$P_{05} = 190{,}50\ K \times \left[1 - \frac{1003{,}15\ K - 943{,}43\ K}{0{,}9 \times 1003{,}15\ K}\right]^{1{,}33/1{,}33-1}$$

$$P_{05} = 144{,}58\ kPa$$

5. Calculations on the nozzle (El-Sayed, 2017).

$$P_e = P_a$$

$$P_e = 101{,}33\ kPa$$

$$T_e = T_{05}\left[1 - \eta_n\left\{1 - \left(\frac{P_e}{P_{05}}\right)^{\gamma_h - 1/\gamma_h}\right\}\right]$$

$$T_e = 943{,}43\ K \times \left[1 - 0{,}90 \times \left\{1 - \left(\frac{101{,}33k\ Pa}{144{,}58\ kPa}\right)^{1{,}33-1/1{,}33}\right\}\right]$$

$$T_e = 871{,}75\ K$$

$$u_e = \sqrt{2C_{ph}(T_{05} - T_e)}$$

$$u_e = \sqrt{2 \times 1.157{,}00\,{}^{J}/_{kg.K} \times (943{,}43\ K - 871{,}75\ K)}$$

$$u_e = 407{,}27\ {}^{m}/_{s}$$

$$\rho_e = \frac{P_e}{RT_e}$$

$$\rho_e = \frac{101{,}33\ kPa}{287{,}00\,{}^{J}/_{kg.K} \times 871{,}75\ K}$$

$$\rho_e = 0{,}41\, {}^{kg}/_{m^3}$$

$$A_e = \frac{\dot{m}_e}{\rho_e u_e}$$

$$A_e = \frac{1{,}84\, {}^{kg}/_{s}}{0{,}41\, {}^{kg}/_{m^3} \times 407{,}27\, {}^{m}/_{s}}$$

$$A_e = 0{,}011\, m^2$$

6. Calculations Thrust (El-Sayed, 2017).

$$T = \dot{m}_a[(1+f)V_e - V] + A_e(P_e - P_a)$$

$$T = 1{,}8\, {}^{kg}/_{s} \times [(1+0{,}0199) \times 407{,}27\, {}^{m}/_{s} - 0\, {}^{m}/_{s}] + 0{,}011 m^2 \times (101{,}33 kPa - 101{,}33 kPa)$$

$$T = 745{,}61\, N$$

7. Calculation TSFC (El-Sayed, 2017).

$$TSFC = \frac{\dot{m}_f}{T}$$

$$TSFC = \frac{0{,}04\, {}^{kg}/_{s}}{724{,}92\, N}$$

$$TSFC = 0{,}1732\, {}^{kg}/_{Nh}$$

Based on the results of the thermodynamic cycle calculation of the turbojet engine above, the compressor pressure ratio value of 2 and the air mass flow rate value of 1.8 kg/s only produce a thrust of 745.61 N and a thrust specific fuel consumption (TSFC) of 0.1732 kg/Nh. then a recalculation is carried out using the same formula by changing the value of the compressor pressure ratio and the value of the air mass flow rate. By changing the two paramater values, it will affect the value of the thrust, fuel mass flow rate, and the specific fuel consumption of the thrust as shown in table 1, table 2, table 3.

Based on table 1, the ratio of compressor air pressure (π_c) and air mass flow rate ($\dot{m}_a$) affects the thrust values of turbojet engines (T). At a fixed air mass flow rate ($\dot{m}_a$) an increase in the compressor air pressure ratio (π_c), will increase the thrust of the turbojet engine. At a fixed compressor air pressure ratio (π_c), an increase in the air mass flow rate also results in an increase in the thrust value of a turbojet engine (T).

Tablel 1 Effect of Compressor Pressure Ratio (π_c) and Air Mass Flow Rate ($\dot{m}_a$) Against Thrust (T)

No	**Air Mass Flow Rate ($\dot{m}_a$)**	**Compressor Pressure Ratio (π_c)**				
		2,00	2,50	3,00	3,50	4,00
1	1,80	745,61	843,51	904,12	944,55	972,61
2	1,90	787,04	890,38	954,34	997,02	1.026,64
3	2,00	828,46	937,24	1.004,57	1.049,50	1.080,68
4	2,10	869,88	984,10	1.054,80	1.101,97	1.134,71
5	2,20	911,30	1.030,96	1.105,03	1.154,45	1.188,74

6	2,30	952,73	1.077,82	1.155,26	1.206,92	1.242,78
7	2,40	994,15	1.124,68	1.205,49	1.259,39	1.296,81
8	2,50	1.035,57	1.171,55	1.255,72	1.311,87	1.350,85
9	2,60	1.077,00	1.218,41	1.305,95	1.364,34	1.404,88
10	2,70	1.118,42	1.265,27	1.356,17	1.416,82	1.458,91
11	2,80	1.159,84	1.312,13	1.406,40	1.469,29	1.512,95
12	2,90	1.201,27	1.358,99	1.456,63	1.521,77	1.566,98
13	3,00	1.242,69	1.405,86	1.506,86	1.574,24	1.621,01
14	3,10	1.284,11	1.452,72	1.557,09	1.626,72	1.675,05
15	3,20	1.325,53	1.499,58	1.607,32	1.679,19	1.729,08
16	3,30	1.366,96	1.546,44	1.657,55	1.731,67	1.783,12
17	3,40	1.408,38	1.593,30	1.707,77	1.784,14	1.837,15
18	3,50	1.449,80	1.640,17	1.758,00	1.836,62	1.891,18

Source. Made by researcher

When the ratio of compressor air pressure and air mass flow rate are simultaneously increased, it will result in a greater increase in turbojet engine thrust (T). The greatest thrust of a turbojet engine (T) is found in the combination of a compressor air pressure ratio of 4 and an air mass flow rate (m ̇_a) of 3.30 kg/s of 1,783.12 N.

In each combination between the ratio of compressor air pressure and air mass flow rate there is a turbojet engine thrust value (T) that is close to and greater than 1,300 N, namely in combination of 2 and of 3.2 kg/s produces (T) of 1,325.53N, combination of 2.5 and of 2.8 kg/s produces (T) of 1,312.13 N, a combination of 3 and of 2.6 kg/s yielding (T) of 1,305.95 N, a combination of 3.5 and of 2.5 kg/s yielding (T) of 1,311.87 N, and a combination of 4 and of 2.5 kg/s resulting in (T) of 1,350.85N.

Table 2 Effect of compressor pressure ratio and air mass flow rate on fuel mass flow rate

No	**Air Mass Flow Rate $(\dot{m}_a)$**	**Compressor Pressure Ratio (π_c)**				
		2,00	2,50	3,00	3,50	4,00
1	1,80	0,0359	0,0347	0,0337	0,0328	0,0320
2	1,90	0,0379	0,0367	0,0356	0,0347	0,0338
3	2,00	0,0399	0,0386	0,0375	0,0365	0,0356
4	2,10	0,0419	0,0405	0,0393	0,0383	0,0374
5	2,20	0,0439	0,0424	0,0412	0,0401	0.0391
6	2,30	0,0458	0,0444	0,0431	0,0420	0,0409
7	2,40	0,0478	0,0463	0,0450	0,0438	0,0427
8	2,50	0,0498	0,0482	0,0468	0,0456	0,0445
9	2,60	0,0518	0,0502	0,0487	0,0474	0,0463
10	2,70	0,0538	0,0521	0,0506	0,0492	0,0480
11	2,80	0,0558	0,0540	0,0525	0,0511	0,0498
12	2,90	0,0578	0,0559	0,0543	0,0529	0,0516
13	3,00	0,0598	0,0579	0,0562	0,0547	0,0534
14	3,10	0,0618	0,0598	0,0581	0,0565	0,0552
15	3,20	0,0638	0,0617	0,0599	0,0584	0,0569
16	3,30	0,0658	0,0637	0,0618	0,0602	0,0587
17	3,40	0,0678	0,0656	0,0637	0,0620	0,0605
18	3,50	0,0698	0,0675	0,0656	0,0638	0,0623

Source. Made by researcher

Based on table 2 the ratio of compressor air pressure and air mass flow rate also affects the fuel flow rate. At a fixed compressor air pressure ratio, with an increase in the value of the air mass flow rate, it will cause an increase in the value of the fuel flow rate. But on the contrary, with the increase in the value of the compressor air pressure ratio, at a fixed air mass flow rate , it causes a decrease in the value of the fuel mass flow rate. The increase in the air mass flow rate and followed by an increase in the compressor air pressure ratio together, will also increase the fuel mass flow rate, but the increase in the fuel flow rate is not as large as the fixed compressor air pressure ratio.

Tabel 3 Effect of compressor pressure ratio and air mass flow rate on thrust specific fuel consumption (TSFC)

No	**Air Mass Flow Rate $(\dot{m}_a)$**	**Compressor Pressure Ratio (π_c)**				
		2,00	2,50	3,00	3,50	4,00
1	1,80	0,17	0,15	0,13	0,13	0,12
2	1,90	0,17	0,15	0,13	0,13	0,12
3	2,00	0,17	0,15	0,13	0,13	0,12
4	2,10	0,17	0,15	0,13	0,13	0,12
5	2,20	0,17	0,15	0,13	0,13	0,12
6	2,30	0,17	0,15	0,13	0,13	0,12
7	2,40	0,17	0,15	0,13	0,13	0,12

8	2,50	0,17	0,15	0,13	0,13	0,12
9	2,60	0,17	0,15	0,13	0,13	0,12
10	2,70	0,17	0,15	0,13	0,13	0,12
11	2,80	0,17	0,15	0,13	0,13	0,12
12	2,90	0,17	0,15	0,13	0,13	0,12
13	3,00	0,17	0,15	0,13	0,13	0,12
14	3,10	0,17	0,15	0,13	0,13	0,12
15	3,20	0,17	0,15	0,13	0,13	0,12
16	3,30	0,17	0,15	0,13	0,13	0,12
17	3,40	0,17	0,15	0,13	0,13	0,12
18	3,50	0,17	0,15	0,13	0,13	0,12

Source. Made by researcher

Based on table 4.8 the ratio of compressor air pressure and air mass flow rate also affects thrust specific fuel consumption (TSFC). Increasing the value of the compressor air pressure ratio at a fixed rate of air mass flow will decrease the thrust specific fuel consumption value (TSFC). However, the air pressure ratio is fixed but the air mass flow rate value increases, not causing a change in the thrust specific fuel consumption value (TSFC) or its constant value.

Variations in the value of the flow rate of air masses and the ratio of pressure to obtain a thrust force of 1, 300 N. based on the calculation of the thermodynamic cycle of the thrust force of 1, 300 N is obtained from several combinations of the two parameters. Furthermore, some of these combinations are determined in combinations that have a thrust value close to 1,300 N with the most minimum fuel consumption. Based on this, it is found in the combination of the air mass flow rate of 2.5 and the compressor reaction ratio of 4 with a thrust force of 1,350.85 N. and the air mass flow rate and compressor pressure ratio will be used as input data to determine the impeller geometry of the centrifugal compressor.

The iteration carried out to obtain the value of the thrust and fuel consumption is by making variations in the value of the air mass flow rate from 1.8 kg/s to 3.5 kg/s and variations in the value of the air pressure ratio from 2 to 4.

The process of determining the geometry of a centrifugal compressor begins with the determination of the basic parameters as a design point. The value of this parameter comes from the results of the calculation of the thermodynamic cycle of a turbojet engine. This basic parameter will later become the input value for determining the impeller geometry of the centrifugal compressor.

1. Determine the Specific Power [Y]

   Specific power is the energy provided by the turbine through the shaft to the compressor to rotate the impeller so as to increase the pressure by 4 times the atmospheric pressure per 1 kg of air mass. there are four parameters that must be known to determine the specific power [Y] are specific heat ratio $[\gamma_c]$, the cold air specific heat $\left[c_{pc}\right]$, the total temperature of the compressor incoming air $[T_{02}]$, and the compressor pressure ratio $[\pi_c]$. For the value of $[\gamma_c]$, $\left[c_{pc}\right]$ obtained from table 3, while for the value of [π_c] is obtained from table 3 based on the anlysis that has been performed. Then the four parameters are calculated using the equation below (Venkanna, 2009).

$$Y = \left({\pi_c}^{\frac{\gamma_c - 1}{\gamma_c}} - 1\right) c_{pc} T_{02}$$

$$Y = \left(4^{\frac{1,4-1}{1,4}} - 1\right) \times 287,1 \ {}^{J}\!/_{kg.K} \times 288,15\ K$$

$$Y = 140.725{,}45\ {}^{J}/_{kg}$$

The specific power value is then used as a reference to determine the abslout speed of the tangential component of the air flow $[C_{u3}]$.

2. Determine the absolute velocity of the tangential component of the airflow $[C_{u3}]$.
To find out the value of is required the value of the parameters of the tangential speed of the impeller and the specific power [Y]. The value of [Y] is already known, but the value of [U_3] is not yet known. For this reason in this thesis the value is determined to be 505.13 m/s (Hill,1992).

o $[C_{u3}]$ calculated with the equation below (Venkanna, 2009).

$$C_{u3} = \frac{Y}{U_3}$$

$$C_{u3} = \frac{140.725{,}45\ {}^{J}/_{kg}}{505{,}13\ {}^{m}/_{s}}$$

$$C_{u3} = 278{,}59\ {}^{m}/_{s}$$

3. Determine the absolute velocity radial outside of airflow $[C_{m3}]$
To determine the value of $[C_{m3}]$ requires two parameter values that must be known namely and the coefficient of airflow. For the value is already known but for the value is not yet known. For that in this thesis the value is determined based on a reference of 0.5 (Venkanna, 2009).

$$C_{m3} = \varphi_m U_3$$

$$C_{m3} = 0{,}5 \times 505{,}13\ {}^{m}/_{s}$$

$$C_{m3} = 252{,}56\ {}^{m}/_{s}$$

The calculation results show that the value of $[C_{m3}]$ is half the value $[U_3)]$.

4. Determine of relative velocity of the tangential component of the airflow $[W_{u3}]$
Value of $[W_{u3}]$ is the difference from the value U_3 and C_{u3} (Venkanna, 2009).

$$W_{u3} = U_3 - C_{u3}$$

$$W_{u3} = 505{,}13\ {}^{m}/_{s} - 278{,}59\ {}^{m}/_{s}$$

$$W_{u3} = 226{,}54\ {}^{m}/_{s}$$

5. Determine of relative velocity outside of airflow $[W_3]$
Value of $[W_{u3}]$ and $[C_{m3}]$ It is well known so that by the trigonometric equation of velocity, the value $[W_3]$ can be determined by the equation below (Venkanna, 2009).

$$W_3 = \sqrt{W_{u3}^2 + C_{m3}^2}$$

$$W_3 = \sqrt{(226{,}54\ {}^{m}/_{s})^2 + (252{,}56\ {}^{m}/_{s})^2}$$

$$W_3 = 339{,}28\ {}^{m}/_{s}$$

6. Determine of absolute velocity outside of airflow $[C_3]$
Value of $[C_{u3}]$ and $[C_{m3})]$ It is well known so that by the trigonometric equation of velocity, the value $[C_3]$ can be determined by the equation below (Venkanna, 2009).

$$C_3 = \sqrt{C_{u3}^2 + C_{m3}^2}$$

$$C_3 = \sqrt{(278{,}59\ {}^{m}/_{s})^2 + (252{,}56\ {}^{m}/_{s})^2}$$
$$C_3 = 376{,}04\,{}^{m}/_{s}$$

7. Determine of blade angel outside of impeller $[\beta_3]$

   Value $[W_{u3}]$ and (C_{m3}) It is well known so that by the trigonometric equation of velocity, the value $[\beta_3]$ can be determined by the equation below (Venkanna, 2009).

$$\beta_3 = tan^{-1}\left(\frac{C_{m3}}{W_{u3}}\right)$$
$$\beta_3 = tan^{-1}\left(\frac{252{,}56\ {}^{m}/_{s}}{226{,}54\ {}^{m}/_{s}}\right)$$
$$\beta_3 = 48{,}11\,°$$

8. Determine of outside diameter of impeller $[d_3]$

   Impeller rotation $[n]$ obtained from table 3, whereas $[(U_3)]$ s It is already known from previous calculations. So that of the two paramters, (d_3) can be determined by the equation below (Venkanna, 2009).

$$d_3 = \frac{U_3}{3{,}14n}$$
$$d_3 = \frac{505{,}13\ {}^{m}/_{s}}{3{,}14 \times 60.000\ {}^{1}/_{60\ s}}$$
$$d_3 = 0{,}16087\,m = 160{,}87\,mm$$

9. Determine of diffuser diameter $[d_d]$

   According to the reference mentions that $[d_d]$ 1,6 times greater than $[d_3]$ (Kamps, 2005).

$$d_d = 1{,}6d_3 = 1{,}6 \times 160{,}87\,mm = 257{,}39\,mm$$

10. Determine of Turbojet Engine outside diameter $[d_T]$

    Assuming a turbojet engine casing thickness of 4 mm, then from the thickness of the casing multiplied by 2. Then the diameter of the turbojet engine $[d_T)]$ can be determined by adding twice the thickness of the turbojet engine casing as in the equation below.

$$d_T = d_d + 8\,mm = 257{,}39\,mm + 8\,mm = 265{,}39$$

11. Determine of outer airflow total temperature of impeller $[T_{03}]$

    The total temperature of the impeller outflow of air $[T_{03}]$ determined on the ability of the impeller when performing air compression from the pressure of the air entering the impeller. the larger the compressed air, the greater the temperature. $[T_{03}]$ can be determined by the equation below (Venkanna, 2009).

$$T_{03} = T_{02}\left[(\pi_c)^{k-1/_k}\right]$$
$$T_{03} = 288{,}15\,K \times \left[(4)^{1{,}4-1/_{1{,}4}}\right]$$
$$T_{03} = 428{,}19K$$

12. Determine of outer airflow static temperature of impeller $[T_3]$ (Venkanna, 2009).

$$T_3 = T_{03} - \left(\frac{C_3^2}{2c_p}\right)$$

$$T_3 = 428{,}19K - \left[\frac{(376{,}04\, {}^{m}/_{s})^2}{2 \times 1.004{,}90\, {}^{J}/_{kg.K}}\right]$$

$$T_3 = 357{,}83\ K$$

13. Determine of outer airflow pressure of impeller $[p_{03}]$ (Venkanna, 2009).

$$p_{03} = \pi_c p_{02}$$
$$p_{03} = 4 \times 101{,}24\ \text{kPa}$$
$$p_{03} = 404{,}94\ \text{kPa}$$

14. Determine of outer airflow static pressure $[p_3]$ (Venkanna, 2009).

$$p_3 = \frac{p_{03}}{\left(\frac{T_{03}}{T_3}\right)^{k/_{k-1}}}$$

$$p_3 = \frac{404{,}94\ \text{kPa}}{\left(\frac{428{,}19K}{357{,}83\ K}\right)^{1{,}4/_{1{,}4-1}}}$$

$$p_3 = 216{,}05\ kPa$$

15. Determine of outer static air mass of impeller $[\rho_3]$ (Venkanna, 2009).

$$\rho_3 = \frac{p_3}{RT_3}$$

$$\rho_3 = \frac{216{,}05 \times 1.000Pa}{287{,}10\, {}^{J}/_{kg.K} \times 357{,}83\ K}$$

$$\rho_3 = 2{,}10\, {}^{kg}/_{m^3}$$

16. Determine of outer width of impeller $[b_3]$ (Venkanna, 2009).

$$b_3 = \frac{\dot{m}_a}{\pi d_3 \rho_3}$$

$$b_3 = \frac{2{,}50\ \dot{}\, {}^{kg}/_{s}}{3{,}14 \times 0{,}16087\ m \times 2{,}10\, {}^{kg}/_{m^3}}$$

$$b_3 = 0{,}00932\ m = 9{,}32\ mm$$

17. Determine of outer statistical speed of sound $[a_3]$ (Venkanna, 2009).

$$a_3 = \sqrt{kRT_3}$$

$$a_3 = \sqrt{1{,}4 \times 287{,}1\, {}^{J}/_{kg.K} \times 357{,}83\ K}$$

$$a_3 = 379{,}25\, {}^{m}/_{s}$$

18. Determine of Mach number at outer of impeller $[M_3]$ (Venkanna, 2009).

$$M_3 = \frac{C_3}{a_3}$$
$$M_3 = \frac{376{,}04\ m\ /\ s}{379{,}25\ m\ /\ s}$$
$$M_3 = 0{,}99$$

19. Determine of inner axial speed of impeller $[C_{m2}]$ (Venkanna, 2009).

$$C_{m2} = C_{m3}$$
$$C_{m2} = 252{,}57\ {}^{m}/_{s}$$

20. Determine of inner static temperature of impeller $[T_2]$ (Venkanna, 2009).

$$T_2 = T_{02} - \left(\frac{C_{m2}^2}{2c_p}\right)$$
$$T_2 = 288{,}15K - \left[\frac{(252{,}57\,{}^{m}/_{s})^2}{2 \times\ 1.004{,}90\ {}^{J}/_{kg.K}}\right]$$
$$T_2 = 256{,}41\ \ K$$

21. Determine of inner airflow pressure of impeller $[p_2]$ (Venkanna, 2009).

$$p_2 = \frac{p_{02}}{\left(\frac{T_{02}}{T_2}\right)^{k/_{k-1}}}$$
$$p_2 = \frac{101.24\ \text{kPa}}{\left(\frac{288{,}15K}{256{,}41\ \ K}\right)^{1{,}4/_{1{,}4-1}}}$$
$$p_2 = \ 67{,}29\ kPa$$

22. Determine of inner static air mass of impeller $[\rho_2]$ (Venkanna, 2009).

$$\rho_2 = \frac{p_2}{RT_2}$$
$$\rho_2 = \frac{67{,}29\ \times 1.000Pa}{287{,}10\ {}^{J}/_{kg.K} \times\ 256{,}41\ \ K}$$
$$\rho_2 = 0{,}91\ {}^{kg}/_{m^3}$$

23. Determine of inner wide of impeller$[A_2]$ (Venkanna, 2009).

$$A_2 = \frac{\dot{m}_a}{C_{m2}\rho_2}$$
$$A_2 = \frac{2{,}5\ {}^{kg}/_{s}}{252{,}57\ {}^{m}/_{s} \times 0{,}91\ {}^{kg}/_{m^3}}$$
$$A_2 = \ 0{,}0108\ m^2$$

24. Determine of inner diameter of impeller $[d_2]$ (Venkanna, 2009).

$$r_2 = \sqrt{\frac{A_2}{3{,}14\left[1-\left(\frac{r_H}{r_2}\right)^2\right]}}$$

$$r_2 = \sqrt{\frac{0{,}0108\, m^2}{3{,}14 \times [1-(0{,}4)^2]}}$$

$$r_2 = 0{,}06408\, m = 64{,}08\, mm$$

$$d_2 = 2r_2 = 128{,}15\, mm$$

25. Determine of inner diameter hub of impeller$[d_H]$

Based on the reference that the ratio of hub radius and outer impeller radius is ${}^{rH}/_{r2} = 0{,}4$ (Venkanna, 2009).

$$r_H = \left({}^{rH}/_{r2}\right) r_2$$

$$r_H = 0{,}4 \times 64{,}08\, mm$$

$$r_H = 25{,}63\, mm$$

$$d_H = 2r_H = 2 \times 25{,}63\, mm = 51{,}26 mm$$

26. Determine of inner tangential velocity of impeller$[U_2]$ (Venkanna, 2009).

$$U_2 = \pi d_2 n$$

$$U_2 = 3{,}14 \times 128{,}15\, mm \times \frac{60{,}000}{60\ s}$$

$$U_2 = 0{,}40239\ {}^{m}/_{s} = 402{,}39\, {}^{m}/_{s}$$

27. Determine of inner relative velocity of impeller$[w_2]$ (Venkanna, 2009).

$$w_2 = \sqrt{U_2 + C_{m2}}$$

$$w_2 = \sqrt{402{,}39\ {}^{m}/_{s} + 252{,}57\ \ {}^{m}/_{s}}$$

$$w_2 = 475{,}09\, {}^{m}/_{s}$$

28. Determine of inner angel of impeller$[\beta_2]$ (Venkanna, 2009).

$$\beta_2 = tan^{-1}\left(\frac{C_{m2}}{U_2}\right)$$

$$\beta_2 = tan^{-1}\left(\frac{252{,}57\ {}^{m}/_{s}}{402{,}39\ {}^{m}/_{s}}\right)$$

$$\beta_2 = 32{,}11°$$

The calculation results produce a compressor impeller that is designed to have a diameter 160.87 mm. The diameter of the impeller was then added with the diameter of the diffuser and the outermost diameter of the turbojet so that the diameter became 265.39 mm. The outermost diameter of this turbojet will be compared with the diameter of the space provided by the missile vehicle for turbojet engines of a maximum of 270 mm. If the outermost diameter of the turbojet is greater than the diameter provided, then an iteration is carried out, namely recalculation by changing the value of the compression ratio and or the flow rate of the air masses entering the compressor until it reaches the indigo of the outermost diameter of the turbojet smaller than the diameter provided by the missile vehicle for turbojet engines.

CONCLUSION

Based on thermodynamic analysis counting result and centrifugal compressor impeller geometry of Turbojet Engines counting result, the conclusion is to get the target of the thrust:

To achieve the turbojet engine thrust target of 1,300 N can be achieved with different air mass flow rates and compressor pressure ratios. Based on the consideration of fuel consumption consumed by the lowest turbojet engine combustion chamber, the air mass flow rate is set at 2.5 kg/s and the compressor pressure ratio is 4.

From the air mass flow rate of 2.5 kg/s and the compressor pressure ratio of 4, the compressor impeller geometry is obtained as below.

Table 4 Result of Research

NO	PARAMETER	NILAI	
1	Diameter sisi masuk impeller (d_2)	121,49	mm
2	Diameter hub sisi masuk *impeller* (d_H)	65,00	mm
3	Sudut sudu sisi masuk *impeller* (β_2)	23,18	°
5	Diameter sisi luar *impeller* (d_3)	160,87	mm
6	Lebar *impeller* sisi luar (b_3)	9,23	mm
7	Sudut sudu sisi luar *impeller* (β_3)	48,11	°
8	Diameter *diffuser* (d_d)	257,39	mm
9	Diameter mesin turbojet (d_T)	265,39	mm

Source. Made by researcher

The diameter of the turbojet engine the result of the analytical calculation is smaller than the maximum space diameter allowed by the missile vehicle for the turbojet engine, which is 270 mm

REFERENCES

Arismunandar, W. (2002). Pengantar Turbin Gas dan Motor Propulsi. Bandung: ITB.

Buku Putih Pertahanan. (2016). Kementerian Pertahanan. Jakarta

Badan Pengkajian dan Penerapan Teknologi [BPPT]. (2019). Laporan Akhir Program Inovasi Teknologi Drone & Rudal. Tangerang Selatan.

El-Sayed, Ahmed F. (2016). Fundamentals of Aircraft and Rocket Propulsion. London : Springer.

El-Sayed, Ahmed F. (2017). Aircraft Propulsion and Gas Turbine Engines. Boca Raton:Taylor & Francies Group.

Venkanna, B.K. (2009). Fundamental of Turbomachinery. New Delhi: PHI Learning Private Limited.

Bakalis, D.P and A.G. Stamatis. (2011). “Data Analysis and Performance Model Calibration of a Small Turbojet Engine”. Journal of Aerospace Engineering, vol. 226(12), hh.1523-1533.

Dudave, Roshan et al. (2016). “Study of Cruise Missile Technology”. International Conference on Emerging Trends in Engineering and Management Research, vol. 23, hh. 1049-1056.

Ebaid, Munzer Shehadeh Yousef and Quasai Zuhair Mohammad Al-Hamdan. (2017). “Design of a Single Stage Centrifugal Compressor as Part of a Microturbine Running at 60000 rpm, Developing a Maximum of 60 kW Electrical Power Output”. American Journal of Aerospace Engineering, vol. 4, hh. 6-21.

Fathy, Tamer S., Aly M.E., and Mohamed K.Khalil. (2018). “Reverse Engineering of Micro Turbojet Centrifugal Compressor Design Based on Parametric CAD Data”. International Journal of Scientific & Engineering Research, vol. 9, hh. 672-683.

Paparan Seminar Nasional Peluru Kendali. (2016)

Tun, Khin Nwe Zin. (2014). ”Design of Centrifugal Compressor Impeller for Power Station”. International Journal of Scientific Engineering and Technology, vol.03, hh.1168-1171.

Undang-Undang RI Nomor 6 Tahun 1996 Tentang Perairan Indonesia.

Virdi, Prabjot Singh et al. (2017).”Design and Fabricationof Major Components of Turbojet Engine”. Energy and Power, vol. 7(5), hh. 130-135.

Wessley, G. Jims John. (2019). “Design and Modeling of a Micro Turbojet Engine for UAV propulsion”. International Journal of Engineering and Advanced Technology (IJEAT), vol. 8, hh. 722-726.

Xiang, J., Jorg Uwe Schluter and Fei Duan (2016). “Study of KJ-66 Micro Gas Turbine Compressor: Steady and Unsteady Reynolds-Averaged Navier-Stokes Approach”. SAGE Journals, vol. 231(5), hh. 904-917.

Yogaswara, Y.H. (2017). “Rekonstruksi Hukum Pemandu Peluru Kendali untuk Kendali Waktu dan Sudut Perkenaan”. Angkasa Cendekia. hh. 59-67.