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Study of Aircraft Thrust-to-Weight Ratio

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Abstract: In order to ensure the best performance of aircraft, the aircraft designer may face challenges regarding the critical parameters where there were lack of references that they can refer to. The method used for this investigation is by doing analysis in terms of mathematical formula for their performance parameters and to calculate their respective thrust-to-weight ratio. Numbers of tables and graphs has been formed in order to show the result of this study. Hence, with the result of this research then the aircraft designers can increase their references to design an aircraft especially regarding with its thrust-to-weight ratio and can clearly see the comparison between different types of aircrafts. The relations between the thrust-to-weight ratios with aircraft performances can also be determined which will lead to the importance of the thrust-to-weight ratio in designing an aircraft to ensure the best aircraft performance that will be use in aviation industry in the future especially between various types of aircrafts such as military aircraft, commercial aircraft, wide body aircraft and narrow body aircraft. At the end of this study, a conclusion can be made that a thrust-to-weight ratio of an aircraft can never be only one while its value is actually depending on the situations, altitude, density, temperature and their aerodynamic hence the value is inconsistent.

Keywords: thrust-to-weight ratio, aircraft performance, thrust, weight, performance parameters, critical parameters, aircraft design.

1. Introduction

'Thrust is a mechanical force generated by the engines to move the aircraft through the air' [1]. The engines of an aircraft are responsible for generating the aircraft thrust through its propulsion system that consists in the engines itself. Thrust also can be named as the force that acts on the aircraft which it moves an aircraft throughout the entire air. This force also was used to overcome the drag of the airplane which comes due to the opposition forces act to counter the thrust force acted on it plus it is also can be related to overcoming the weight of an aircraft. From NASA website [1], it is stated that thrust is a mechanical force, which means the propulsion system have to physical in contact with working fluid in order for it to produce thrust and the generating of thrust is based on the opposite direction of the reaction of accelerating mass of gases throughout the rear of an aircraft engines. From this statement stated, we can conclude that thrust was generated throughout the combustion of fuel in aircraft engines that will be producing such accelerated gases to produce the thrust. The amount of thrust can be produced by the engines depends on the number of accelerated gases produced by the reaction of the combustion of fuel in the engines. The graphical explanation about these parameters of thrust can be explained graphically as in Fig. 1.

From NASA website [2], it is stated that weight is when the force was generated by the gravitational attraction towards the center of the earth. This type of force is quite different from the thrust force which is this is not a mechanical force which causes the motion of an aircraft otherwise weight force is the type of force that act based on the attraction towards the gravity or the generation act of pull on the object towards the center of the earth.

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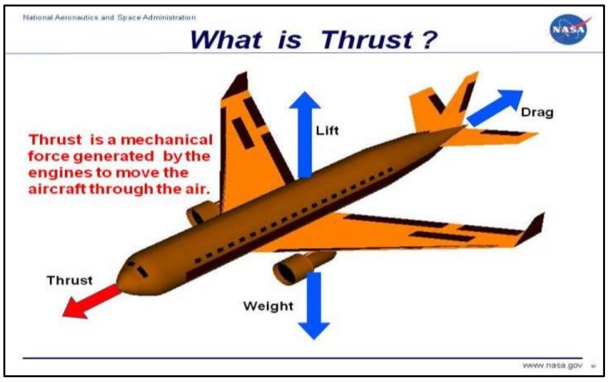

Fig 1 - The graphical represent the definition of weight force that act on an aircraft [1]

A weight force that acting on an aircraft basically depends on the amount of the aircraft mass and the inverse of the square of the distances between the aircraft. The larger the mass of an aircraft, the greater the weight forces created in conjunction also with the farther apart the aircraft are, the weaker the attraction towards the center of the earth. For weight force of an aircraft, it relies on the mass of all parts of the aircraft itself, including the amount of fuel contained in the aircraft and any payload such as people, luggage and any objects that placed in the aircraft. When an aircraft is flying on the air, it will burn fuel hence this will let to the reduction of the mass of the fuel that means that the aircraft will also reduce in its weight that will let to lesser weight force acting on the aircraft. Besides that, the weight of an aircraft also plays an important role which is in the determination of the center of gravity for the aircraft to be in balance during flying on the air. More detail about weight force of an aircraft are explained in graphically as in Fig 2.

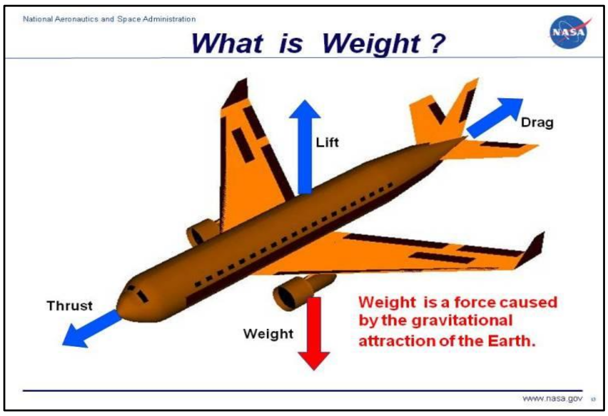

Fig 2 - The graphical represent the thrust-to-weight ratio equation and its relation with the acceleration of an aircraft [2]

Thrust-to-weight ratio is an efficiency factor for total aircraft propulsion. This statement means that the performance of total aircraft propulsion can be rely on its thrust-to-weight ratio of an aircraft [3]. As an example, if the thrust-to-weight ratio is in good value, the performance of its aircraft propulsion also will be at its best. Hence, the aircraft performance will be at its best. In order to determine the performance of an aircraft based on their thrust-to-weight ratio, firstly have to relate the thrust and its weight and then calculate the value of both by dividing the amount of maximum thrust with the maximum take-off weight of an aircraft. There is a relation of thrust-to-weight ratio with the acceleration of an aircraft. This critical parameter can be seen more clearly as in the graphical analysis in Fig 3.

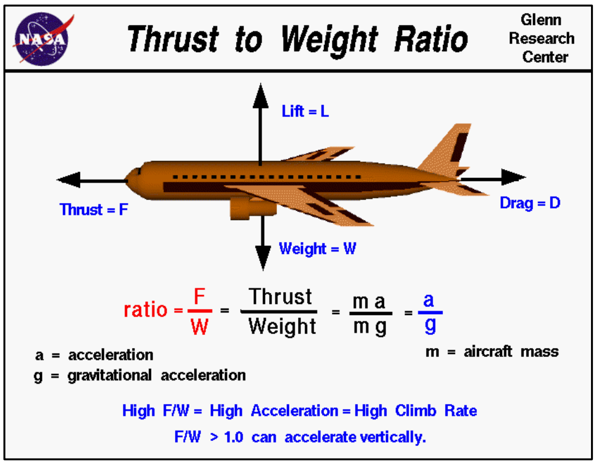

Fig 3 - The graphical represent the thrust-to-weight ratio equation and its relation with the acceleration of an aircraft [3]

As shown in Fig 3 that the thrust-to-weight ratio is directly proportional to the acceleration of the aircraft. In other words, the higher the thrust-to-weight ratio of an aircraft, the higher the acceleration of an aircraft during the flight operation especially on the air.

2. Determining the Importance of Thrust-to-Weight Ratio in Aircraft Performance

The importance of thrust-to-weight ratio in determining an aircraft performance are as follows:

$$V_{max} = \left\{\frac{[(T_A)_{max}/W](W/S)+(W/S)\sqrt{[(T_A)_{max}/W]^2-4C_{D,0}K}}{\rho_\infty C_{D,0}}\right\}^{1/2} \quad (2\text{-}1)$$

From the equation (2-1) the relationship between maximum velocity of an aircraft is directly proportional to the 3 parameters which is thrust-to-weight ratio, wing loading and the drag polar of the aircraft. The equation can be explain that if the value of thrust-to-weight ratio is increase, the maximum velocity is also increase, same goes to the wing loading and the drag polar of the aircraft [2]. This statement has strengthened the fact that thrust-to-weight ratio play an important role in determining the performance of maximum velocity of an aircraft.

After going through some derivation of some equations regarding the forces that act on the aircraft, finally the equation of rate of climb can be formed as shown in the equation (2-2) below:

$$Rate\ of\ climb = V_\infty \sin\theta \quad (2\text{-}2)$$

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Hence, the equation that relates the thrust-to-weight ratio and the rate of climb are as in the Equation (2-3) follows:

$$V_\infty sin\theta = V_\infty\left[\frac{T}{W} - \frac{1}{2}\rho_\infty V_\infty^2\left(\frac{W}{S}\right)^{-1} C_{D,0} - \frac{W}{S}\frac{2K\cos^2\theta}{\rho_\infty V_\infty^2}\right] \qquad (2\text{-}3)$$

As well as stated in equation (2-3) above, the relationship between the rate of climb of an aircraft also is directly proportional to its thrust-to-weight ratio. Therefore, can be concluded that the relationship between rate of climb and the thrust-to-weight ratio is directly proportional. If the thrust-to-weight ratio increases, the rate of climb will be also increase [4].

Next, the performance analysis of an aircraft that rely on the thrust-to-weight ratio is the take-off ground roll which leads to the take-off distance for an aircraft [4]. The relationship between take-off ground roll and thrust-to-weight ratio have been stated the form of equation (2-4) as follows:

$$s_g = \frac{1.21(W/S)}{g\rho_\infty (C_L)_{max}\left[\frac{T}{W} - \frac{D}{W} - \mu_r\left(1 - \frac{L}{W}\right)\right]_{0.7V_{LO}}} + 1.1N\sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{max}}} \qquad (2\text{-}4)$$

From equation (2-4), it can be concluded that the relationship between take-off ground roll and thrust-to-weight ratio of an aircraft is inversely proportional. From the relationship, it can be said that as the value of thrust-to-weight ratio increased, the value of ground roll will be decrease. Hence, this will make the aircraft to take shorter distance to take-off and this will lead to a great aircraft performance.

Moreover, the landing distance of an aircraft which is also the performance analysis of an aircraft that also may rely on the thrust-to-weight ratio [4]. The relationship of the landing ground roll or the landing distance with the thrust-to-weight ratio can be interpret as in equation (2-5) below:

$$s_g = jN\sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{max}}} + \frac{j^2(W/S)}{g\rho_\infty (C_L)_{max}\left[\frac{T_{rev}}{W} + \frac{D}{W} + \mu_r\left(1 - \frac{L}{W}\right)\right]_{0.7V_{LO}}} \qquad (2\text{-}5)$$

From the equation (2-5), it is shown that the relationship of landing ground roll with the thrust-to-weight ratio of the aircraft is inversely proportional. From the relationship of both, generally can conclude that as the thrust-to-weight ratio (in this case the thrust is reversed thrust due to the aircraft is slowing down in order to stop) increase, the landing ground roll will be decrease hence will make the aircraft to have a short distance of landing on the runaway.

The optimization of any system in the aircraft engine can lead to the improvement of the engines performance parameters hence can increase the value of thrust produced for an aircraft [5]. The optimization can be done by changing the defect that may appear in the system which cause the efficiency of the system cannot be perfectly hundred percent. However, nothing perfect in this world but at least the deficiency of the engines system of an aircraft perhaps can be decrease in order for the thrust to be produced to its maximum value hence can increase the thrust-to-weight ratio.

The weight reduction of the aircraft is one of the ways for the aircraft to having the high value of thrust-to-weight ratio in determining the best performance of the aircraft and the capability for the aircraft to have short take-off vertical landing (STOVL) [6]

However, if the aircraft weight is increased it definitely will give an impact to the aircraft performance which it will lead to the longer take-off or landing distances, degraded the climb gradients and airframe failure may occur in turbulence [7]. Hence, the value of the aircraft weight must be suitable for the thrust or power produced by the engines to ensure that thrust-to-weight ratio of the aircraft in a high value to provide the best performance of the aircraft.

3. Methodology

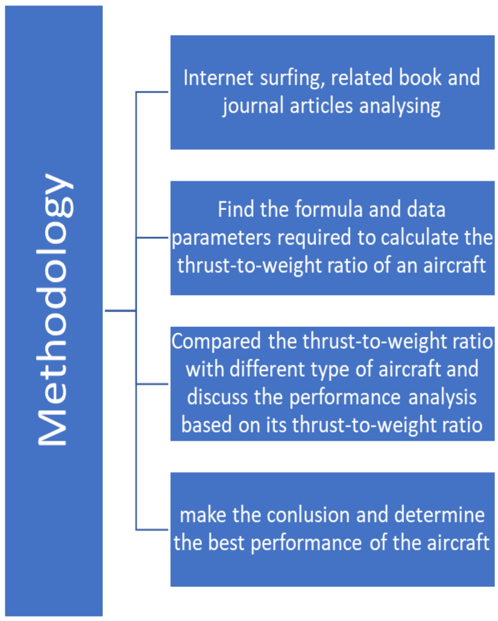

Fig 4 - The overview of the methodology used in this study [3]

As shown in Fig.4, the methodology used for this study is internet surfing, relate book and journal articles analysing. Hence, the formula and data parameters that needed to calculate the thrust-to-weight ratio were used. The comparison of the thrust-to-weight ratio of an aircraft and the performance analysis based on thrust-to-weight ratio have been discussed.

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3.1 Thrust-to-weight Ratio Calculation

$$\frac{T}{W} = \frac{Maximum\ thrust\ of\ the\ aircraft}{Maximum\ take\ off\ weight\ of\ the\ aircraft} \quad (3\text{-}1)$$

This can be shown in more details like the equation stated below:

$$\frac{T}{W} = \frac{Thrust_{maximum}(in\ N)}{MTOW\ (in\ kg)\ x\ Gravitational\ field\ strength\ (in\ m/s^2)} \quad (3\text{-}2)$$

This equation (3-2) been used in order to calculate the thrust-to-weight ratio of an aircraft.

3.2 Military Aircraft

Table 1: The maximum thrust and maximum take-off weight of the 10 military aircraft chosen

No	Name of the aircraft	Maximum thrust (kN)	Maximum take-off weight (kg)
1	F-16 Fighting Falcon	129.00	21,772
2	F-15 Eagle	258.00	36,700
3	Saab JAS 39 Gripen	98.00	16,500
4	MiG 35	176.60	29,700
5	J-10	123.00	18,400
6	Sukhoi-Su-35	283.80	35,000
7	Dassault Rafale	147.10	24,500
8	F-35 Ligthning II	177.93	31,751
9	Eurofighter Typhoon	180.00	23,500
10	F-22 Raptor	311.38	38,000

Table 1 shows that the required data to calculate the thrust-to-weight ratio of the military aircraft which is the maximum thrust produced by the engines of the aircraft and its maximum take-off weight.

3.3 Commercial Aircraft

Table 2: The maximum thrust and maximum take-off weight of the 10 commercial aircraft chosen

No	Name of the aircraft	Maximum thrust (kN)	Maximum take-off weight (kg)
1	Boeing 737-900	2 x 117.30	74,389
2	Boeing 777-300ER	2 x 512.87	351,534
3	Boeing 787-10	2 x 340.00	254,011
4	Airbus A320	2 x 120.00	78,000
5	Airbus A330-300	2 x 320.00	242,000
6	Airbus A350-1000	2 x 432.00	311,000
7	Airbus A380-800	4 x 374.00	569,000
8	Concorde	4 x 170.00	185,000
9	Bombardier C Series	2 x 103.60	67,585
10	Tupolev Tu-114	4 x 171.60	180,000

Table 2 shows the required data for commercial aircraft to calculate the thrust-to-weight ratio which is the maximum thrust produced by the aircraft engines and the maximum take-off weight of the aircraft.

3.4 Wide Body Aircraft

Table 3: The maximum thrust and maximum take-off weight of the 10 wide body aircraft chosen

No	Name of the aircraft	Maximum thrust (kN)	Maximum take-off weight (kg)
1	Boeing 747-8	4 x 295.80	447,696
2	Boeing 767-400ER	2 x 269.60	204,116
3	Ilyushin Il-86	4 x 127.50	208,000
4	Ilyushin Il-96	4x 156.90	226,796
5	Lockheed L-1011 Tristar	3 x 222.40	211,375
6	McDonnell Douglas DC-10	3 x 235.80	259,450
7	McDonnell Douglas MD-11	3 x 276.00	273,314
8	McDonnell Douglas MD-12	4 x 273.57	430,459
9	Airbus A300-600	2 x 273.60	170,500
10	Airbus A340	4 x 145.00	275,000

Table 3 shows the data that were gathered such as the maximum thrust and the maximum take-off weight of the wide body aircraft in order to calculate their thrust-to-weight ratio.

3.5 Narrow Body Aircraft

Table 4: The maximum thrust and maximum take-off weight of the 10 narrow body aircraft chosen

No	Name of the aircraft	Maximum thrust (kN)	Maximum take-off weight (kg)
1	Hawker Siddeley Trident	3 x 53.40	65,318
2	Boeing 707	4 x 84.40	151,315
3	Boeing 727-200	3 x 71.20	95,100
4	Boeing 757-200	2 x 178.37	115,666
5	Ilyushin Il-62M	4 x 107.90	165,500
6	Tupolev Tu-154M	3 x 103.60	100,000
7	Tupolev Tu-134A	2 x 66.70	47,000
8	McDonnell Douglas MD-88	2 x 93.40	67,810
9	McDonnell Douglas MD-90-55	2 x 124.50	78,245
10	Vickers VC10	4 x 100.10	151,956

Table 4 shows the data that were required which is the maximum thrust that were produced by aircraft's engines and the maximum take-off weight in order to calculate the thrust-to-weight ratio.

4. Results and Discussion

The result of this study is represented by the statement from the analysis about the aircraft performance and design that were done through some books and article [4]. Furthermore, several graphs and tables were formed in order to shows the comparison of thrust-to-weight ratios and the trends of them with four different types of aircraft.

From the formulas in finding the aircraft performance analysis such as the maximum velocity, the rate of climb, the take-off distance and landing distance of the aircraft. For all of the performance parameter analysis formulas shows that the higher the value of thrust-to-weight ratio, the better the performance of the aircraft would be.

From the graph plotted, an regression line can be made which lead to the form of the trend line equation which can be used in order to make an estimation about the maximum thrust required when the maximum take-off weight is known. However, the estimation may not be accurate as it consist of only 10 number of aircraft for each type compared to millions others in the world.

4.1 Military Aircraft

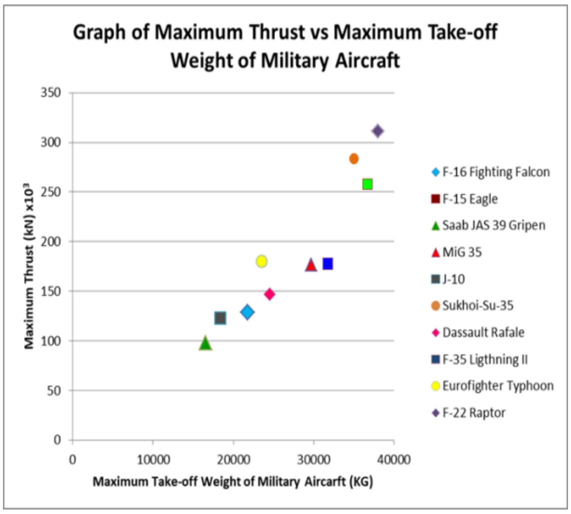

Fig 5: The graph of Maximum Thrust against the Maximum Take-off Weight of the Military Aircraft

Fig. 5 shows that the trend form from the graph is increasing positively which means the value of maximum thrust will increase accordingly to the maximum take-off weight of the aircraft.

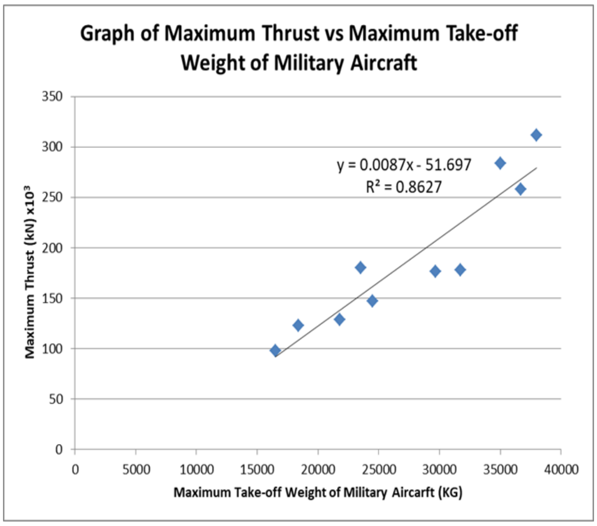

Fig 6: The graph of Maximum Thrust against the Maximum Take-off Weight of the Military Aircraft with its Linear Progression Line and Equation

Fig. 6 shows the correlation between the maximum thrust and maximum take-off weight from variety of military aircraft. It is helpful for the designer when estimating the maximum thrust of a new aircraft engine plus the maximum take-off weight of the military aircraft, for instance, during the weight and thrust estimation phase or for multi-disciplinary optimization. The maximum thrust can be estimated from:

$$y = 0.0087x - 51.697 \quad (4\text{-}1)$$

The value of the estimation from equation (4-1) may be not accurate but it is useful in estimation the maximum thrust of the aircraft in initial phase of designing an aircraft.

Table 5: Table of name of military aircraft with their respected thrust-to-weight ratio

No	Name of aircraft	Thrust-to-weight ratio
1	F-16 Fighting Falcon	0.603980
2	F-15 Eagle	0.716613
3	Saab JAS 39 Gripen	0.605443
4	MiG 35	0.606816
5	J-10	0.681425
6	Sukhoi-Su-35	0.826562
7	Dassault Rafale	0.612037
8	F-35 Ligthning II	0.571237
9	Eurofighter Typhoon	0.780793
10	F-22 Raptor	0.835292

Based on Table 5, a conclusion can be made that the highest thrust-to-weight ratio among those 10 aircraft chosen is absolutely 0.835292 which is the powerful Lockheed Martin F-22 Raptor. Furthermore, the lowest thrust-to-weight ratio among the 10 chosen military aircraft is F-35 Lightning II which the value is 0.571237 compared to others.

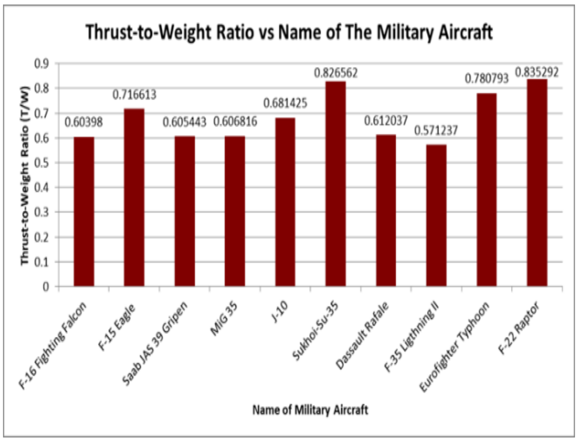

Fig 7: Graph of Thrust-to-weight Ratio of the aircraft against the Name of Military Aircraft

From Fig. 7, all of the 10 aircraft chosen have their thrust-to-weight ratio in the range of 0.571237 to 0.835292 which its shows that the value of thrust-to-weight ratio can be acceptable due to its high performance in defense of the nation and to patrol the air from any outside possible danger.

4.2 Commercial Aircraft

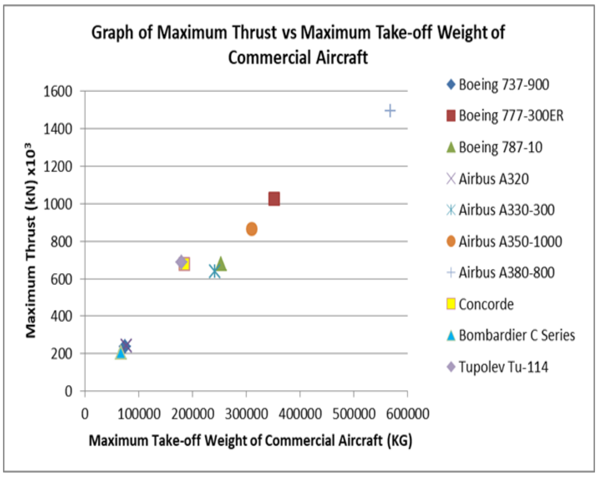

Fig 8: Graph of Maximum Thrust against the Maximum Take-off Weight of Commercial Aircraft

Based on Fig. 8, a conclusion can be made that the graph formed is increase or in other words positively increasing from its two different variables which is the maximum thrust and their maximum take-off weight of the different type of commercial aircraft.

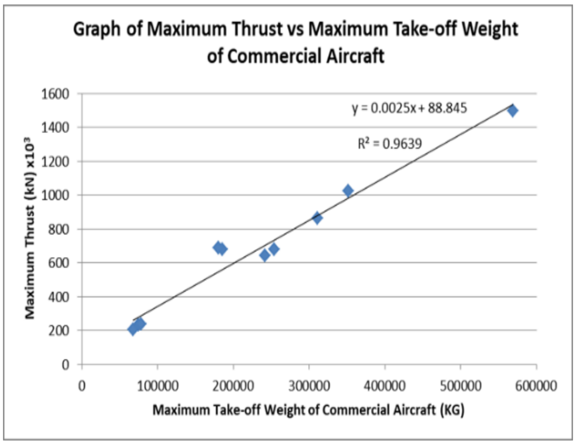

Fig 9: Graph of Maximum Thrust against The Maximum Take-off Weight of The Commercial Aircraft

From Fig. 9 shows the correlation between the maximum thrust and maximum take-off weight from variety of commercial aircraft.

From the equation that was formed from the graph we can make estimation for the maximum thrust as equation (4-2) as follows:

$$y = 0.0025x + 88.845 \qquad (4\text{-}2)$$

Table 6: Table of Name of Commercial Aircraft with its respective calculated Thrust-to-weight Ratio

No	Name of aircraft	Thrust-to-weight ratio
1	Boeing 737-900	0.321477
2	Boeing 777-300ER	0.297441
3	Boeing 787-10	0.272890
4	Airbus A320	0.313652
5	Airbus A330-300	0.269585
6	Airbus A350-1000	0.283194
7	Airbus A380-800	0.268010
8	Concorde	0.374687
9	Bombardier C Series	0.312515
10	Tupolev Tu-114	0.388719

From Table 6, a conclusion can be made that the highest thrust-to-weight ratio among those 10 aircraft chosen is absolutely 0.388719 which is the Russian Tupolev Tu-114 while the lowest among them is Airbus A380-800 which the value is 0.268010 compared to others.

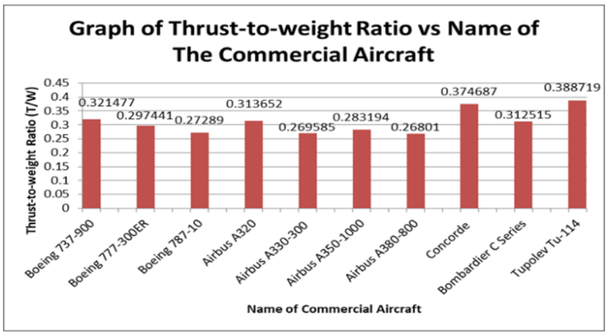

Fig 10: The Graph of Thrust-to-weight Ratio against The Name of Commercial Aircraft

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Based on Fig. 10, all of the 10 aircraft chosen have their thrust-to-weight ratio in the range of 0.268010 to 0.388719 which its shows that the value of thrust-to-weight ratio can be is not too high as commercial aircraft did not take the performance of aircraft as their first priority while to fulfil their passenger comfortability is their main concern.

4.3 Wide Body Aircraft

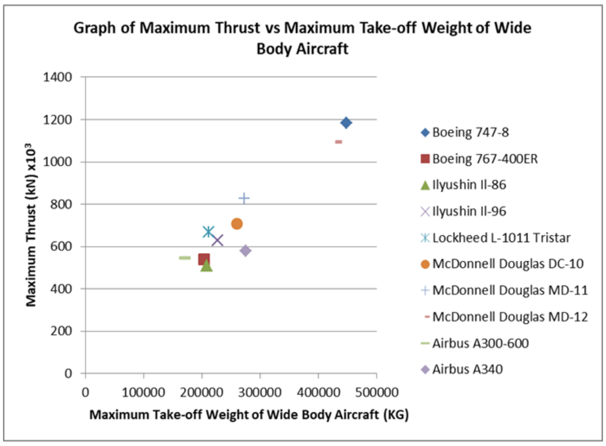

Fig 11: The Graph of Maximum Thrust against Maximum Take-off Weight of Wide Body Aircraft

Fig. 11 shows that the trend form from the graph is increasing positively which means the value of maximum thrust will increase accordingly to the maximum take-off weight of the aircraft.

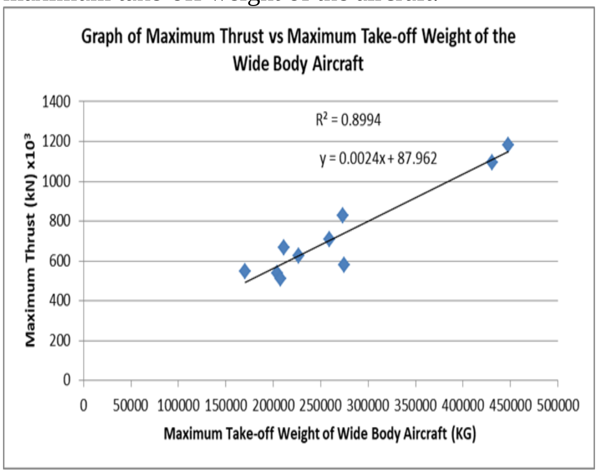

Fig 12: The Graph of Maximum Thrust against The Maximum Take-off Weight of The Wide Body Aircraft with The Regression Line

Fig. 12 shows the correlation between the maximum thrust and maximum take-off weight from variety of wide body aircraft. It is helpful for the designer when estimating the maximum thrust of a new aircraft engine plus the maximum take-off weight of the wide body aircraft, for instance, during the weight and thrust estimation phase or for multi-disciplinary optimization. The maximum thrust can be estimated from:

$$y = 0.0024x + 87.962 \qquad (4\text{-}3)$$

The value of the estimation from equation (4-3) may be not accurate but it is useful in estimation the maximum thrust of the wide body aircraft in initial phase of designing future wide body aircraft.

Table 7: Table of Name of Wide Body Aircraft with its respective calculated Thrust-to-weight Ratio

No	Name of aircraft	Thrust-to-weight ratio
1	Boeing 747-8	0.269405
2	Boeing 767-400ER	0.26928
3	Ilyushin Il-86	0.249941
4	Ilyushin Il-96	0.282084
5	Lockheed L-1011 Tristar	0.321761
6	McDonnell Douglas DC-10	0.277934
7	McDonnell Douglas MD-11	0.308816
8	McDonnell Douglas MD-12	0.259136
9	Airbus A300-600	0.327154
10	Airbus A340	0.214994

Based on the Table 7, a conclusion can be made that the highest thrust-to-weight ratio among those 10 wide body aircraft chosen is absolutely 0.327154 which is the French manufactured Airbus A300-600 while the lowest is Airbus A340 which the value is 0.214994.

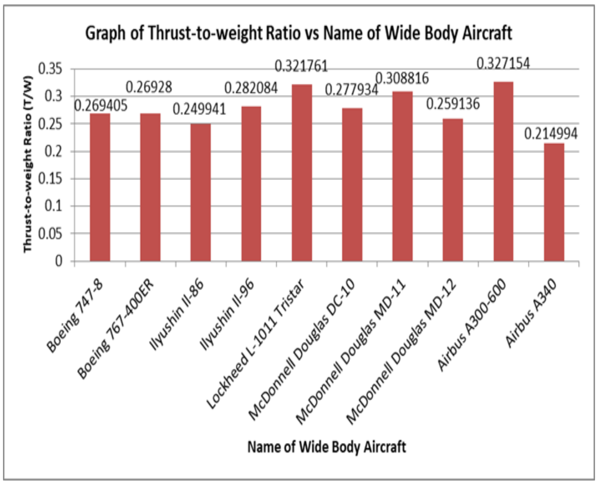

Fig 13: The Graph of Thrust-to-weight Ratio against their Name of Wide Body Aircraft

From Fig. 13, all of the 10 aircraft chosen have their thrust-to-weight ratio in the range of 0.214994 to 0.327154 which its shows that the value of thrust-to-weight ratio quite low based on their wide and big size of the aircraft which lead to heavier weight of the aircraft compared to other type of aircraft.

4.4 Narrow Body Aircraft

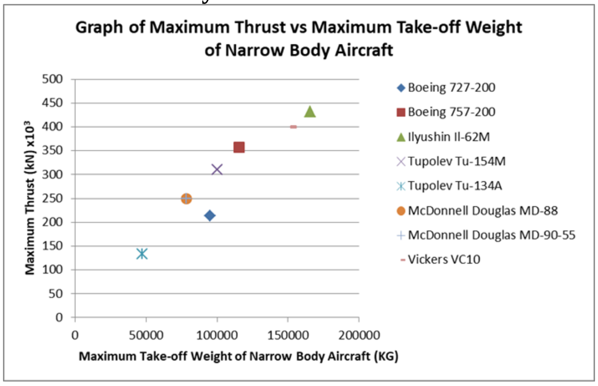

Fig 14: The Graph of Maximum Thrust against The Maximum Take-off Weight of The Narrow Body Aircraft

Based on Fig. 14, a conclusion can be made that the graph formed is increase or in other words positively increasing from its two different variables which is the maximum thrust and their maximum take-off weight of the different type of narrow body aircraft.

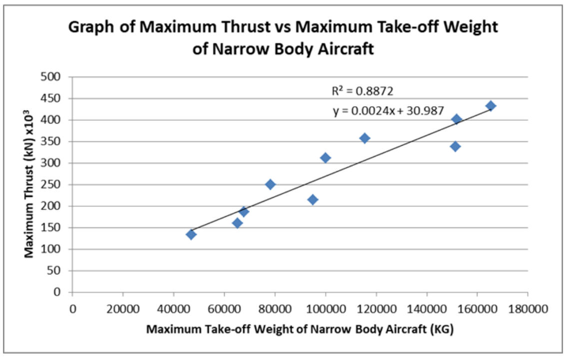

Fig 15: The Graph of Maximum Thrust against The Maximum Take-off Weight of the Narrow Body Aircraft with Regression Line

From Fig. 15 shows the correlation between the maximum thrust and maximum take-off weight from variety of narrow body aircraft.

From the equation that was formed from the graph we can make estimation for the maximum thrust as equation (4-4) as follows:

$$y = 0.0024x + 87.962 \quad (4\text{-}4)$$

Table 8: Table of Name of the Narrow Body Aircraft with its respective calculated Thrust-to-weight Ratio

No	Name of aircraft	Thrust-to-weight ratio
1	Hawker Siddeley Trident	0.250012
2	Boeing 707	0.227432
3	Boeing 727-200	0.228956
4	Boeing 757-200	0.314396
5	Ilyushin Il-62M	0.265836
6	Tupolev Tu-154M	0.316820
7	Tupolev Tu-134A	0.289327
8	McDonnell Douglas MD-88	0.280811
9	McDonnell Douglas MD-90-55	0.324395
10	Vickers VC10	0.268601

Based on Table 8 above, a conclusion can be made that the highest thrust-to-weight ratio among those 10 aircraft chosen is absolutely 0.324395 which is the Mcdonnell Douglas MD-90-55 while the lowest thrust-to-weight ratio among the 10 chosen narrow body aircraft is American manufactured Boeing 707 which the value is 0.227432 compared to others.

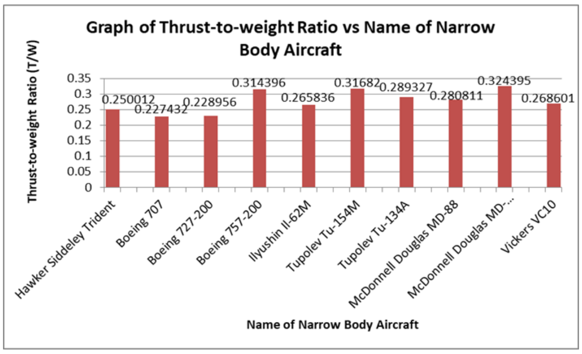

Fig 16: The Graph of Thrust-to-weight Ratio against The Name of Narrow Body Aircraft

All of the 10 aircraft chosen have their thrust-to-weight ratio in the range of 0.227432 to 0.324395 which its shows that the value of thrust-to-weight ratio quite low based on their mostly function which is used for commercial aircrafts as it is not too big to handle.

5. Conclusion and Recommendations

From this study, a conclusion can be made that the importance of thrust-to-weight ratio of an aircraft is critical as it is also one of the critical parameters that was taken more serious in the process of designing an aircraft. In designing an aircraft, mathematical equations that shows the relations between thrust-to-weight ratio and the aircraft performance such as take-off distance, landing distance, rate of climb and maximum velocity of the aircraft. This shows that the thrust-to-weight ratio of an aircraft gives a big impact in determining the aircraft performance analysis.

The difference of thrust-to-weight ratio of different types of aircrafts also can be made as shown from the calculated thrust-to-weight ratio and the graph that have been plotted respectively for military aircraft, commercial aircraft, wide body aircraft and narrow body aircraft. As presented from the graph of respected various types of aircrafts, it can be concluded that military aircraft have the highest range of thrust-to-weight ratio with in between 0.571237 to 0.835292. The lowest range of thrust-to-weight ratio from the four types of aircraft chosen is narrow body aircraft with the range in between 0.227432 to 0.324395. The factor of the difference in thrust-to-weight ratio of those types of aircrafts is can be said due to the requirement and usage of the aircraft performance as their main priority in designing the aircraft.

As the performance of those aircraft, it shown that the military aircraft is at their best performance

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due to the high thrust-to-weight ratio range while narrow body aircraft is vice versa. This is logically can be said that the usage of narrow body aircraft is mostly for commercial and cargo which the performance of the aircraft is not their best priority during the designation while the military is really set the performance of the aircraft as their number one reason to be fulfil.

Furthermore, from this study also the aircraft designer can get the general review of the thrust-to-weight ratio from different types of aircrafts. From the numbers of 10 aircrafts that have been chosen for each type of aircrafts that is military, commercial, wide body and narrow body. Aircraft designer can get the initial review of how the thrust to weight ratio of that particular types of aircraft works in order to ensure the great performance of the aircraft. This statement can be done by analysing the graph that has been plotted for those types of aircrafts. Moreover, aircraft designer can make an initial estimation of the maximum thrust needed for a given maximum take-off weight during the process of designing an aircraft. Based on the graph of Maximum Thrust against Maximum Take-off Weight of the Aircraft and the linear equations of the scatter plotted graph, a maximum thrust estimation when given the maximum take-off weight of the aircraft that want to be design can be made.

Hence for the recommendations and future works, the study of the aircraft performance based on thrust-to-weight ratio should be more detail since the thrust-to-weight ratio of an aircraft getting various depends on their situations and conditions which some of it may causes from the altitude, speed, pressure, their aerodynamic itself and many more. The mathematical formulas for the process of designing an aircraft need to be improving in order for them to be friendly user for the aircraft designer to design an aircraft.

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