Analysis of Boeing Aircraft's Fuel Consumption B737-800 NG for Yogyakarta-Singapore-Jakarta Route

Suar Ishak[1], Elisa Kusrini[2]
[1]Department of Master of Industrial Engineering, Faculty of Industrial Technology,
Islamic University of Indonesia
KM 14.5 Jl.Kaliurang KH Mas Mansyur Building, UII Integrated Campus,
Phone, (0274) 895287
[2]Department of Master of Industrial Engineering, Faculty of Industrial Technology,
Islamic University of Indonesia
KM 14.5 Jl.Kaliurang KH Mas Mansyur Building, UII Integrated Campus,
Phone, (0274) 895287
Email: suarishak@gmail.com, elisa_kusrini@yahoo.com

Abstract

In one trip, the flight route can be seen in terms of weight, cargo, and the price of fuel needed as a very important aspect. Fuel prices that are high enough can have an impact on operational costs that were incurred by an airline. The purpose of this study was to avoid re-fueling at the re-fueling stations that cost more than the original station. This study used the fuel tankering method, and also focused on the Garuda Indonesia flight B737-800 NG airline with Jogyakarta-Singapore-Jakarta route and alternative airports at Pekanbaru and Surabaya. From the results of the data that was obtained and the analysis the result of this study was by refueling using the fuel tankering method was more profitable than normal way of re-fueling. However, there were aspects that need to be considered in the route using this method including temperature, altitude, flight distance and fuel prices that were differrent at each airport.

Keywords: Route, Fuel price, Fuel tankering method.

Introduction
Background

The development of the aviation industry was marked by the increasing need for aircraft. The aerospace business people were racing to develop their business in choosing the aircraft that were going to be used. Besides, the development of flight routes that were built, would increase the frequency of flights.

Increasing number of aircraft and flight routes created competition for airline operators. Aviation operators were not only competing to get customers through the routes but also need to determine the capacity of the aircraft that were used and efficient fuel consumption. Besides that, flight operators were required to make good and timely flight schedules. Keep in mind that delays in flight time will incur significant costs and could lead to fuel waste.

Good and efficient flight could optimize the use of aviation turbine fuel properly and in the corridor to maintain safety of the flight. According to A Majka, (2007) the use of fuel at this time was one that must be considered, because aircraft that carry excessive fuel would increase costs and reduce the carrying capacity of the aircraft.

This situation certainly required effective and efficient fuel management. It was also important to know the price of aviation fuel at different airports. Therefore, airlines need to consider the routes that were chosen. Besides that, each aircraft has different aviation fuel specifications. Nur Feriyanto *et al*. (2016) conducted a study on the analysis of the used of aviation fuel based on flight routes by comparing Boeing 737-400 and Airbus A320-200 aircraft on the Jakarta-Bali route. The conclusion was that Airbus was more efficient in the use of aviation fuel compared to Boeing.

As was stated above, the price of aviation fuel at each airport was different. In Indonesia the price of aviation fuel was cheaper than in other countries such as Singapore. In terms of saving on aviation fuel costs, it is necessary to think about how technology with the aim of refueling was only done at a place where refueling stations were cheaper. Technologies that have been developed were included the *Fuel Tankering* method. *Fuel tankering* method is a method that was used to optimize fuel requirements based on flight routes and variations in fuel prices that vary at each airport DPPU station. The method that was used in addition to the *fuel tankering* method was the method of step climb and step cruise techniques. Step climb and step cruise techniques were flight techniques in order to save fuel by climbing-cruise-climb.

Purpose

1. Calculate the value of fuel requirements for a Boeing B737-800 NG flight when using a *fuel tankering* flight plan.
2. Knowing the variables that determine the *fuel tankering* method
3. Calculate the value of profit if the *fuel tankering* method would be applied.

Benefit

Build the treasury of science in connection with the science of industrial engineering in the field of aerospace.

Literature

The needs of airline's fuel consumption need to be calculated carefully. This is due to the effect that will be reflected to flight operations. Therefore, fuel consumption also affects the high and low profits of the company. According to Mohammad Mazraati, (2010) that fuel demand continues to increase from year to year and this was determined by the development of the country's economy.

An airline is a company that manages aviation services agents. This airline service agent has some kind of different types of aircraft manufacturing such as Boeing, Airbus, Bombardier, and ATR (Avions de Transport Regional). All these aircraft use the same fuel, Avtur (Aviation Turbine Fuel). From the various choices of aircraft that can be used, there are several types of aircraft that are similar in series, Airbus A320-200 and A320-300, Boieng 737 series, ATR 42 and 72 and Bombardier CRJ700 even though they have different manufacturers. Boieng 737-800 NG is similar with Airbus A320-200 in the seat sector with different aspect in manufacturing. Boeing was made in America while Airbus was in Europe. Whereas ATR 72-500 / 600 is similar with MA 60, ATR 42 is similar with DACH 7 and Bombardier CRJ700 is similar with F28 or F100.

The aircraft consumes very large amounts of fuel. The amount of fuel consumed during operation from one airport to the destination airport depends on several factors and parameters. Most of these factors such as take-off, climb, cruise, descent, and holding. According to a research study that was conducted by Jose` A.T.G.F *et al* (2011) the need for fuel consumption was the second highest in aviation operations, flight operations were estimated to represent 20% for aircraft fuel. Embraer (2005) research proved that 1% fuel savings could be done easily through operational practices that focus on fuel savings. One of the procedures that was used by airlines in saving fuel was "*Economic Fueling*" or "*Fuel Tankering*".

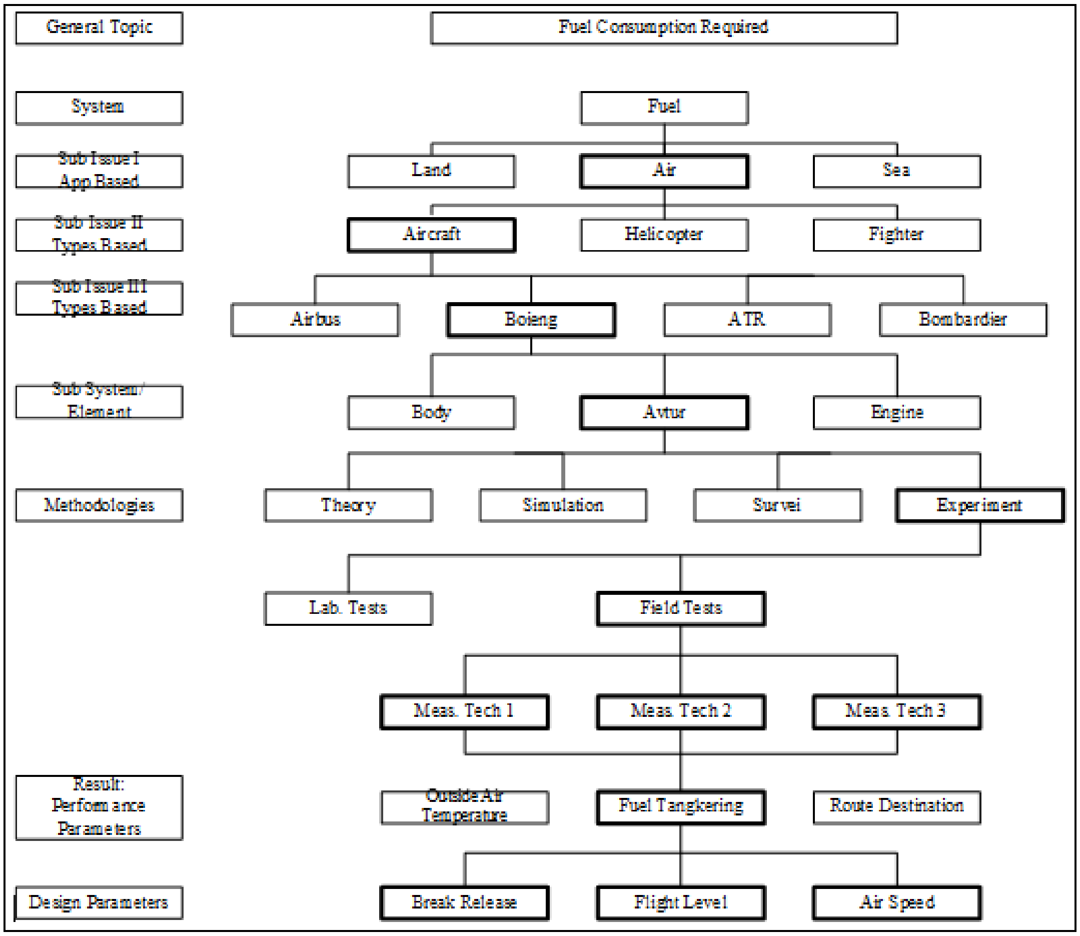
Flight planning, aircraft load, proper maintenance, flight procedures, and fuel have significant impact on aircraft fuel consumption during operations. During operation the aircraft has the main factors that was affecting fuel consumption in greater usage such as weight, aircraft speed, and wind speed and wind direction. David A. Pilati (1974) describes the use of energy and aircraft maintenance in evaluating fuel savings. John W. Drake (1974) suggests that cruising speeds for slower flight optimization could reduce fuel consumption. Meanwhile the research that was conducted by D. Wayne Darnell and Carolyn Loflin (1977), Barry Nash (1981), John S. Stroup and Richard D. Wollmer (1992), Zouein, *et al* (2002), Khaled Abdelghany (2005) developed a model fuel management, so that all models produce savings in fuel consumption. R. R. Covey (1979) describes the operational strategy of maintaining energy in commercial aviation, he explains that there were twelve fuel maintenance strategies and this strategy results in fuel savings.

Current technological developments went quickly and effectively utilize the latest technology to reduce fuel consumption on commercial aircraft. Improvements in aircraft fuel efficiency depend on the design of engine and airframe products. David L. Greene (1990) examines the potential for increasing the efficiency of commercial aircraft engines. The research shows some major improvements in the fields of engine efficiency, aerodynamic changes, and aircraft structural. Larger aircraft could carry more passengers thereby increasing fuel efficiency on the aircraft and reducing congestion at major airports and reducing holding time before landing or idling time before takeoff. Lee *et al*., 2001, Babikian *et al*., 2002. Joosung Lee (2010) and Raffi Babikian (2002) studied aircraft technology performance, fuel consumption, lift / drag, operation empty, and maximum take off weight were the main variables that were affecting aircraft fuel consumption and the effect of technology on energy use that was based on engine efficiency, structural technology, and aerodynamic efficiency.

Aviation infrastructure was also the most important thing in optimizing fuel consumption. Traffic congestion experienced at airports and improper air traffic management could increase fuel consumption. Senzig *et al*. (2009) modeled the use of fuel for the terminal area which resulted in a reduction in fuel consumption. David A. Van Cleave (2009) in his research suggested reducing the level-off of terminal airspace and using runways at airports to reduce fuel combustion. Whereas Anderson R. Correia (2005) suggests that airport design greatly influences fuel consumption in maneuvering between runways and terminals. Kazda and Robert Caves (2000) suggest an optimal taxiway design can reduce aircraft fuel consumption. While research that was conducted by Rapoza and Amanda (2010), studied the factors that influence fuel combustion and the flow rate of fuel on a plane at the time of departure and arrival. This study found several parameters that were affecting flight fuel consumption.

CK-Chart Planning and Tools

CK-chart planning tools was designed to present the results of systematic and structured studies in deductive and inductive way. In addition to directing the focus of research and explain research to be done to be understood. An important point of the CK-chart planning tools was that they can show the latest studies (novelty) based on previous research. Furthermore, the ck-chart also illustrates the flow of research that will be conducted.



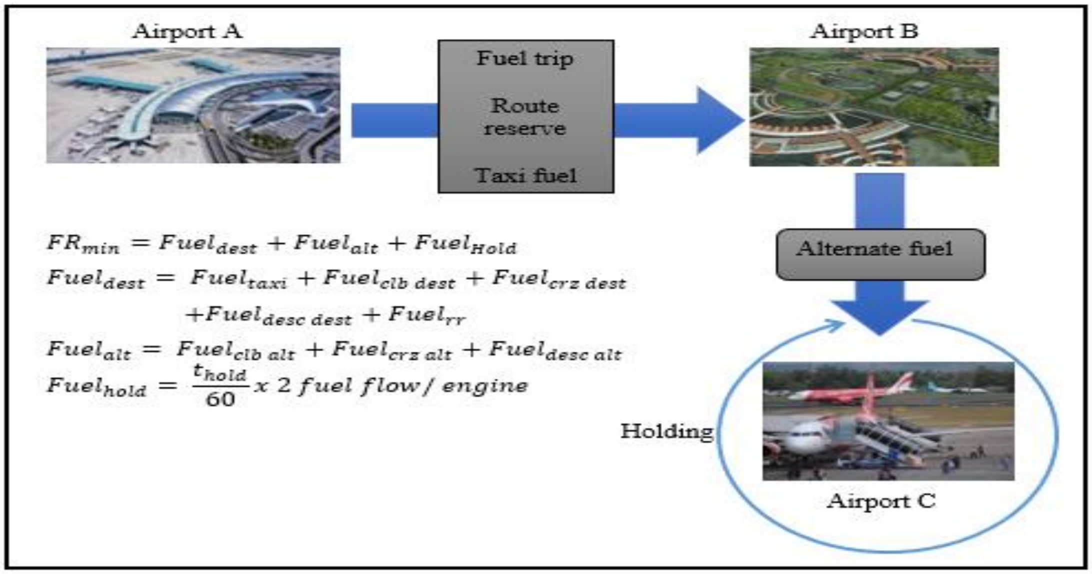
Picture 1. *CK-Chart Planning and Tools*

The focus of this research can be seen in Figure 1, which is this research takes the focus of fuel on Boieng flight. This aircraft uses avtur fuel (Aviatiaon Turbine Fuel). So this research uses a model in order to optimize the use of fuel namely fuel Tangkering with the aim of the Yogyakarta-Singapore-Jakarta route. Where this model is influenced by 3 specific aspects namely Break release, flight level and air speed.

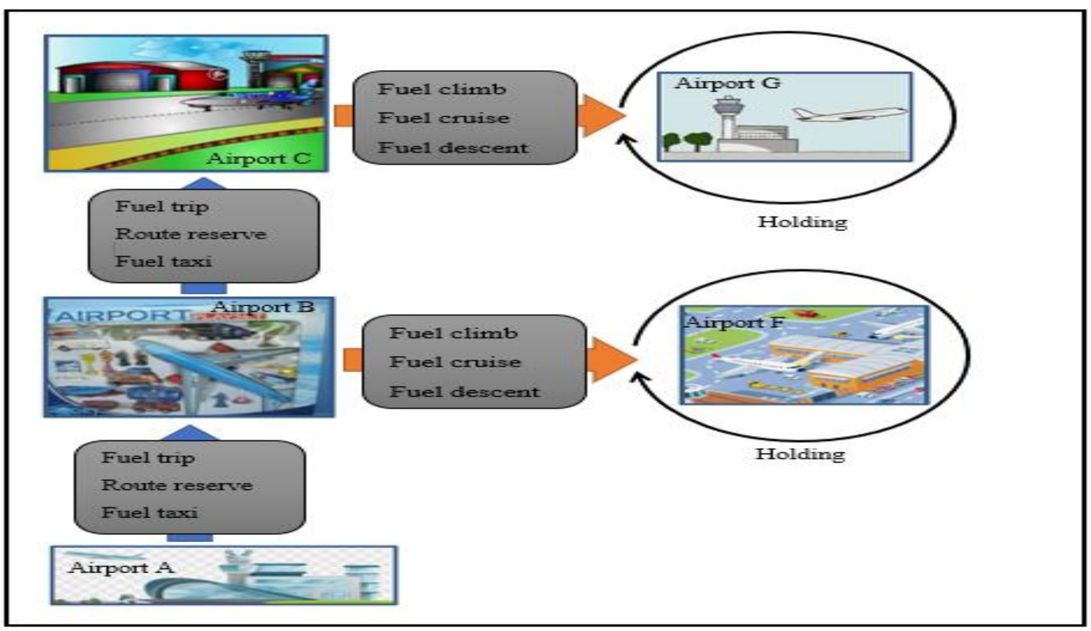
Model *Fuel Tankering*

According to Jose´ A.T.G.F *et al* (2011), he was presenting a design programming model that explains the optimization of aircraft refueling for one or two flight routes. Jose Alexander examines *fuel tankering* on airlines in Brazil. While assuming the refueling depot can meet refueling needs and there were no restrictions on every aircraft refueling station.

In general, airlines that carry out multi-route flying missions will refuel at each transit landing station, where the amount of fuel that was loaded into the aircraft for each flight route of the multi-flying it has was different. On the other hand, the price per unit of fuel for each airport station was different from one another.



Picture 2. ***Single Leg Flight***



Picture 3. ***Multi Leg Flight***

The formula that was used to calculate minimum fuel requirements from airport B to destination airport C is as follows (Nur feriyanto, 2016)

$$FR_{minBC} = Fuel_{destBC} + Fuel_{altBC} + Fuel_{Hold} \quad \ldots (1)$$

$$Fuel_{destBC} = Fuel_{clb\ destBC} + Fuel_{crz\ destBC} + Fuel_{desc\ destBC} + Fuel_{rrBC} \quad \ldots (2)$$

$$Fuel_{altBC} = Fuel_{clb\ altBC} + Fuel_{crz\ altBC} + Fuel_{desc\ altBC} \quad \ldots (3)$$

$$fuel_{hold} = \frac{t_{hold}}{60} x\ 2\ fuel\ flow/eng \quad \ldots (4)$$

In order to avoid refueling at airport B, the formula to get the value of fuel tankering at airport A is as follows:

$$Fuel_{Tankering.A} = FR_{minBC} + Fuel_{destAB} + Fuel_{taxi} \quad \ldots (5)$$

Research Method

Research Object

The focus of the study in question is to analyze the fuel consumption needs of the Garuda Indonesia B737-800 NG airline by taking the Yogyakarta - Singapore - Jakarta route. Based on previous literature obtained, there are several factors that influence fuel consumption

The object of this research is the Garuda Indonesia B737-800 NG airline by taking the Yogyakarta - Singapore – Jakarta route. Whereas for the subject of this study the researcher was assisted by several operational staff in the section of fuel management as well as active pilots who flew during flights on this route.

Fuel Tankering Model Building

The right way of calculating aircraft fuel consumption, managing and handling traffic flow in an accurate method and the design of flight procedures which were very important and according to the rules could provide optimal efficiency in fuel consumption. One example of a method for reducing fuel consumption is designing optimal operational flight procedures such as Optimized Profile Descent (OPD) and often called Continuous Descent Operation (CDO). Additionally, the arrival route could be disabled based on navigation area (RNAV), such as the Point Marge System that also reduced fuel consumption, because this procedure allows the aircraft to descend from its optimal position with minimum engine thrust.

Result and Discussion

Determining the Maximum Takeoff Weight of Yogyakarta's Adisutjipto Airport and Changi-Singapore

By using FFPM Flaps 1 and Flaps 5 Dry Runway Graphs. In order to get the RTOW value that was limited by the field length, climb limit, obstacle limit and tire speed limit both in the afternoon and evening. By taking the smallest value of each flaps, which were: during the day with the smallest flaps was 59.000 and the afternoon with the smallest value was 59.000.

Tabel 1. *Restricted Takeoff Weight (RTOW) Limited by Field Length, Climb Limit, Obstacle Limit and Tire Speed* Adisutjipto - Yogyakarta.

Time Period	Everage Temp deg (C)	Everage Wind Knot	Flaps	Fielg Lenght	Climb Limit	Obstacle Limit	Tire Speed Limit	Lowest
Day	29	12	1	72000	83600	59000	>88000	60000
			5	75000	81000	60000	>88000	59000
Afternoon	28	11	1	72000	83600	59000	>88000	60000
			5	75000	81000	60000	>88000	59000

The flight destination to Singapore RTOW was limited by field length, climb limit, obstacle limit and tire speed limit both in the afternoon and evening. By taking the smallest value of each flaps which were: during the day with the smallest flaps was 81000 and the afternoon with the smallest value was 81000.

Tabel 2. *Restricted Takeoff Weight (RTOW) Limited by Field Length, Climb Limit, Obstacle Limit and Tire Speed* Changi – Singapura.

Time Period	Everage Temp deg (C)	Everage Wind Knot	Flaps	Fielg Lenght	Climb Limit	Obstacle Limit	Tire Speed Limit	Lowest
Day	28	11	1	>88000	84000	-	>88000	84000
			5	>88000	81000	-	>88000	81000
Afternoon	27	12	1	>88000	84000	-	>88000	84000
			5	>88000	81000	-	>88000	81000

On this flight requires data of total mileage that will be used on the Boieng 737-800 NG Garuda Indonesia flight. From the route chat analysis we get the total destinations of Yogyakarta - Singapore with alternate Pekanbaru and Singapore - Jakarta with Surabaya alterate as follows:

Tabel 3. Total destination Yogyakarta-Singapura alternate Pekanbaru and Singapura – Jakarta alternate Surabaya

No	To destination	Total destination	To alterntae	Total destination alt
1.	Yogyakarta - Singapura	755 Nautical miles	Singapura - Pekanbaru	182 Nuatical miles
2.	Singapura - Jakarta	500 Nautical miles	Jakarta - Surabaya	375 Nautical miles

The Calculation Trip Flight JOG-SIN (BRW 59000 kg Flaps 5)

JOG-SIN and SIN-PKU flights are influenced by several important factors specifically climb, cruise, descent and holding where the data can be seen in the table below:

Tabel 4. Climb, Cruise, Descent and Holding JOG-SING alt PKU

Route (Up limit and Low limit) / kg	Enroute Climb (time, fuel, distance and speed)		Cruise table (FF/ENG)		Descent (time)		Descent (fuel)		Descent (distance)		Holding	
	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit
To destination (60000 and 55000)	15/1400 88/389	14/1250 78/388	1282	1248	23	22	320	310	109 103	98 93	-	-
To alternate (60000 and 55000)	11/110 55/361	10/950 49/360	1550	1531	20	19	300	290	90 84	82 76	950 1030	970 1050

a. *Climb RTOW* 59000 kg

Analysis calculation already done is known that:

$$time_{clb} = 14 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (15 - 14) \right) = 14.8 \text{ minute}$$

$$fuel_{\boldsymbol{clb}} = 1250 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (1400 - 1250)\right) = 1370 \text{ kg}$$

$$descent_{clb} = 78 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (88 - 78)\right) = 78.8 \text{ NM}$$

$$speed_{clb} = 388 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (389 - 388)\right) = 388.8 \text{ kg/NM}$$

b. *Cruise height* 32000 feet
Top of Climb (TOC) is as follows:
Aircraft Weight in TOC = BRW – *fuel climb*
= 59000 – 1370 = 57630 kg

$$fuel_{flow} = 1248 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (1282 - 1248)\right)$$

$f_{flow} = 1275.2\ k$g / engine / hour
Fuel Flow both of engine = 2 x 1275.2 kg = 2550.4 kg/ hour
Aircraft speed on cruise = 462 knot
Total Distance JOG-SIN = 755 NM
In interpolation value is obtained
Dist Cruise = Dist Total – (Dist Climb + Dist Desc)

$$d_{dsnt1} = 93 + \left(\frac{59000 - 50000}{60000 - 50000}\ x\ (98 - 93)\right) = 97 \text{ NM}$$

$$d_{dsnt2} = 103 + \left(\frac{59000 - 50000}{60000 - 50000}\ x\ (109 - 103)\right) = 107.8 \text{ NM}$$

$$disc_{dsnt} = 97 + \left(\frac{59000 - 50000}{60000 - 50000}\ x\ (107.8 - 97)\right) = 105.64 \text{ NM}$$

Dist cruise = 755 – (78.8 + 105.64) = 570.56 NM
By using a formula:

$$t_{crz} = \frac{Dist_{crz}}{Speed\ crz}\ x\ 60 = \frac{570.56}{462}\ x\ 60 = 74.09 \text{ menit}$$

fuel cruise = (74.09/60) x 2550.4 kg = 3136.99 kg
The weight of the aircraft when starting descent (Top of Descent) so that the values of Top of Descent, time descent, and fuel descent are as follows:
TOD Weight = TOC weight – fuel cruise = 57630 – 3136.99 = 54493.01 kg

$$time_{dsnt} = 22 + \left(\frac{32000 - 31000}{33000 - 31000}\ x\ (23 - 22)\right) = 22.5 \text{ minute}$$

$$fuel_{dsnt} = 310 + \left(\frac{32000 - 31000}{33000 - 31000}\ x\ (320 - 310)\right) = 315 \text{ kg}$$

c. *Climb to alternate* pekanbaru (PKU) height 26000 feet
The weight of the aircraft when climbing to alternate is as follows:
Aircraft Weight to alt = TOD weight - Fuel descent
= 54493.01 – 315 kg = 54178.01 kg
By using FPPM and flight level of 26000 ft, the interpolation values are known as follows:

$$time_{clbalt} = 10 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (11 - 10)\right) = 10.8 \text{ minute}$$

$$fuel_{clbalt} = 950 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (1100 - 950)\right) = 1070 \text{ kg}$$

$$descent_{clbalt} = 49 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (55 - 49)\right) = 49.8 \text{ NM}$$

$$speed_{clbalt} = 360 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (361 - 360)\right) = 364.8 \text{ kg/NM}$$

d. *Cruise to alternate*
Top of climb (TOC) are as follows:
Aircraft weight in TOC = BRW – *fuel climb* (alt) = 59000 – 1070 = 57930 kg

$$fuel_{flow} = 1531 + \left(\frac{59000 - 55000}{60000 - 55000}\ x\ (1550 - 1531)\right)$$

$f_{flow} = 1546.2$ kg / engine / hour
Fuel Flow both of engine = 2 x 1546.2 = 3092.4 *kg/ hour*
Aircraft speed on cruise = 474 knot
Total distance SIN-PKU = 182 NM
In interpolation value is obtained
Dist cruise = Dist total – (Dist climb + Dist Descent)

$$d_{dsnt1} = 76 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (82 - 76)\right) = 79 \text{ NM}$$

$$d_{dsnt2} = 84 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (90 - 84)\right) = 87 \text{ NM}$$

$$disc_{dsnt} = 79 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (87 - 79)\right) = 83 \text{ NM}$$

Distance cruise for this flight are as follows:
Dist cruise = 182 – (49.8 + 83) = 49.2 NM

$$t_{crz} = \frac{Dist_{crz}}{Speed\ crz}\ x\ 60 = \frac{49.2}{474}\ x\ 60 = 6.22 \text{ minute}$$

fuel cruise = (6.22/60) x 3092.4 kg = 309.24 kg

e. *Descent to alternate*
The weight of the aircraft when starting descent (*Top of Descent*) are as follows:
TOD weight = TOC *weight* – *fuel cruise* = 57930 – 309.24 kg = 57620.76 kg

$$time_{dsnt} = 19 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (20 - 19)\right) = 19.5 \text{ minute}$$

$$fuel_{dsnt} = 290 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (300 - 290)\right) = 295 \text{ kg}$$

f. *Holding*
TOD (Top of Descent) weight 57620.76 kg holding data is obtained *FF/ENG* are as follows:

Reference lower data limit	: 1500 feet
Lower border value *fuel flow/engine*	: 1091.93 kg/eng/hr
Reference upper limit of data	: 5000 kg
Upper limit value *fuel flow/engine*	: 1071.93 kg/eng/hr
Air pressure	: 4500 feet

Then the interpolation calculation for the height value *Fuel flow/eng/hr* (FF/eng/hr):

$$\text{FF/eng/hr} = 1071.93 + \left(\frac{4500 - 1500}{5000 - 1500}\ x\ (1091.93 - 1071.93)\right)$$

$$\text{FF/eng/hr} = 1071.93 + \left(\frac{3000}{3500}\ x\ 20\right) = 1089.07 \text{ kg}$$

Fuel Flow both of engine = 2 x 1089.07 = 2178.14 kg
Time holding = 30 minute (certain conditions)

The Calculation Trip Flight SIN-CGK (BRW 81000 kg Flaps 5)

SIN-CGK and CGK-SUB flights are influenced by several important factors specifically climb, cruise, descent and holding where the data can be seen in the table below:

Tabel 5. Climb, Cruise Descent and Holding SIN-CGK alt SUB

Route (Up limit and Low limit) / kg	Enroute Climb (time, fuel, distance and speed)		Cruise table (FF/ENG)		Descent (time)		Descent (fuel)		Descent (distance)		Holding	
	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit	Up limit	Low limit
To destination (75000 and 70000)	22/1900 127/393	19/1750 112/391	1429	1373	23	22	320	310	- -	116 110	-	-
To alternate (75000 and 70000)	15/1450 75/363	13/1300 68/362	1643	1610	20	19	300	290	- -	96 90	1350 1370	1270 1290

a. *Climb RTOW* 73708 kg
Analysis calculation already done is known that:

$$time_{clb} = 19 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (22 - 19)\right) = 21.22 \text{ minute}$$

$$fuel_{clb} = 1750 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (1900 - 1750)\right) = 1861 \text{ kg}$$

$$descent_{clb} = 112 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (127 - 112)\right) = 123.1 \text{ NM}$$

$$speed_{clb} = 391 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (393 - 391)\right) = 392.48 \text{ kg/NM}$$

b. *Cruise height* 32000 feet
Top of Climb (TOC) is as follows:
Aircraft weight in TOC = BRW – *fuel climb* = 73708 – 1861 = 71847 kg

$$f_{flow} = 1373 + \left(\frac{73708-70000}{75000-70000}\ x\ (1429 - 1373)\right) = 1414.44 \text{ kg / engine / hour}$$

Fuel flow both of engine = 2 x 1414.44 = 2828.88 kg/ hour
aircraft speed on cruise = 462 knot
Total distance JOG-SIN = 500 NM
In interpolation value is obtained
Dist cruise = Dist total – (Dist climb + Dist Descent)

$$d_{dsnt} = 110 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (116 - 110)\right) = 114.44 \text{ NM}$$

Distance cruise for this flight are as follows:
Dist cruise = 500 – (123.1 + 114.44) = 262.46 NM
by using a formula:

$$time_{crz} = \frac{Dist_{crz}}{Speed\ crz}\ x\ 60$$

$$t_{crz} = \frac{262.46}{462}\ x\ 60 = 34.08 \text{ menit}$$

fuel cruise = (34.08/60) x 2828.88 kg = 1606.80 kg

c. *Desent height* 32000 feet
The weight of the aircraft when starting descent (Top of Descent) so that the values of Top of Descent, time descent, and fuel descent are as follows:
TOD weight = *TOC weight* – *fuel cruise* = 71847 – 1606.80 kg = 70240.2 kg

$$time_{dsnt} = 22 + \left(\frac{32000 - 31000}{33000 - 31000}\ x\ (23 - 22)\right) = 22.5\ menit$$

$$fuel_{dsnt} = 310 + \left(\frac{32000 - 31000}{33000 - 31000}\ x\ (320 - 310)\right) = 315 \text{ kg}$$

d. *Climb to alternate* Surabaya (SUB) 26000 feet
The weight of the aircraft when climbing to alternate is as follows:
Aircraft weight to alternate = *TOD weight* - *fuel descent* = 70240.2 – 315 kg = 69925.2 kg
By using FPPM and flight level of 26000 ft, the interpolation values are known as follows:

$$t_{clb} = 13 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (15 - 13)\right) = 14.48 \text{ menit}$$

$$f_{clb} = 1300 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (1450 - 1300)\right) = 1411 \text{ kg}$$

$$d_{clb} = 68 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (75 - 68)\right) = 73.18 \text{ NM}$$

$$speed_{clb} = 362 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (363 - 362)\right) = 362.74 \text{ kg/NM}$$

e. Cruise to alternate
Top of climb (TOC) are as follows:
Aircraft weight in TOC = *BRW* – *fuel climb* = 73708 – 1411 kg = 72297 kg

$$fuel_{flow} = 1610 + \left(\frac{73708-70000}{75000-70000}\ x\ (1643 - 1610)\right) = 1634.42 \text{ kg / engine / hour}$$

Fuel Flow both of engine = 2 x 1634.42 kg = 3268.84 kg/ hr
Aircraft speed on cruise = 474 knot
Total distance SIN-PKU = 375 NM
In interpolation value is obtained
Dist cruise = *Dist total* – *(Dist climb + Dist Descent)*

$$dist_{dsnt} = 90 + \left(\frac{73708 - 70000}{75000 - 70000}\ x\ (96 - 90)\right) = 94.44 \text{ NM}$$

Distance cruise for this flight are as follows:
Dist cruise = 375 – (73.18 + 94.44) = 207.38 NM
by using a formula:

$$t_{crz} = \frac{Dist_{crz}}{Speed\ crz}\ x\ 60 = \frac{207.38}{474}\ x\ 60 = 26.25 \text{ minute}$$

fuel cruise = (26.25/60) x 3268.84 kg = 1430.11 kg

f. Descent to alternate
The weight of the aircraft when starting descent (*Top of Descent*) are as follows:
TOD weight = *TOC weight – fuel cruise* = 72297 – 1430.11 kg = 70866.89 kg

$$\boldsymbol{t_{dsnt}} = 19 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (20 - 19)\right) = 19.5\ menit$$

$$\boldsymbol{f_{dsnt}} = 290 + \left(\frac{26000 - 25000}{27000 - 25000}\ x\ (300 - 290)\right) = 295 \text{ kg}$$

g. Holding
TOD (Top of Descent) weight 57620.76 kg holding data is obtained *FF/ENG* are as follows:
Reference lower data limit : 1500 feet
Lower border value *fuel flow/engine* : 1303.87 kg/eng/hr
Reference upper data limit : 5000 kg
Upper limit value *fuel flow/engine* : 1283.87 kg/eng/hr
Air pressure : 4500 feet
Then the interpolation calculation for the height value *Fuel flow/eng/hr* (FF/eng/hr):

$$\text{FF/eng/hr} = 1283.87 + \left(\frac{4500 - 1500}{5000 - 1500}\ x\ (1303.87 - 1283.87)\right)$$

$$\text{FF/eng/hr} = 1283.87 + \left(\frac{3000}{3500}\ x\ 20\right) = 1283.87 + 17.14 = 1301.01 \text{ kg / engine}$$

Fuel Flow both of engine = 2 x 1301.01 = 2602.02 kg
Time holding = 30 minute (certain conditions)

Minimum fuel required
Minimum fuel required on flight Yogyakarta (JOG) – Singapura (SIN) alt Pekanbaru (PKU) as follows:

a. $fuel_{destAB} = fclimb_{destAB} + fcruise_{destAB} + fdescent_{destAB}$
$fuel_{dest} = 1370 + 3136.99 + 315 = 4821.99$ kg
b. $fuel_{route\ reserveAB} = 2.5\ \%\ x\ fuel_{dest}$
$fuel_{route\ reserveAB} = 2.5\ \%\ x\ 4821.99 = 120.54$ kg
c. $fuel_{altBF} = fclimb_{altBF} + fcruise_{altBF} + fdescent_{altBF}$
$fuel_{altBF} = 1070 + 309.24 + 295 = 1674.24$ kg
d. $fuel_{holdAB} = \frac{t_{hold}}{60} x\ 2\ fuel\ flow/eng$
$fuel_{holdAB} = \frac{30}{60} x\ 2\ x\ 1089.07 = 1089.07$ kg
e. $fuel_{taxiAB} = 250$ kg
f. $time_{destAB} = tclimb_{destAB} + tcruise_{destAB} + tdescent_{destAB}$
$time_{destAB} = 14.8 + 74.09 + 22.5 = 111.39$ menit
g. $time_{altBF} = tclimb_{altBF} + tcruise_{altBF} + tdescent_{altBF}$
$time_{altBF} = 10.8 + 6.22 + 19.5 = 36.52$ menit
h. $time_{holdAB} = 30$ menit
i. $time_{taxiAB} = 10$ menit

Minimum fuel required on flight Singapura (SIN) – Jakarta (CGK) alt Surabaya (SUB) as follows:

a. $fuel_{destBC} = fclimb_{destBC} + fcruise_{destBC} + fdescent_{destBC}$
$fuel_{destBC} = 1861 + 1606.80 + 315 = 3782.8$ kg
b. $fuel_{route\ reserveBC} = 2.5\ \%\ x\ fuel_{dest}$
$fuel_{route\ reserveBC} = 2.5\ \%\ x\ 3782.8$ kg $= 94.57$ kg
c. $fuel_{altCG} = fclimb_{altCG} + fcruise_{altCG} + fdescent_{altCG}$
$fuel_{altCG} = 1411 + 1430.11 + 295 = 3136.11$ kg

d. $fuel_{holdCG} = \frac{t_{hold}}{60} x\ 2\ fuel\ flow/eng$
$fuel_{holdCG} = \frac{30}{60} x\ 2\ x\ 1301.01 = 1301.01$
e. $fuel_{taxiCG} = 250$ kg
f. $time_{destBC} = tclimb_{destBC} + tcruise_{destBC} + tdescent_{destBC}$
$time_{destBC} = 21.22 + 34.08 + 22.5 = 78.79$ menit
g. $time_{altCG} = tclimb_{altCG} + tcruise_{altCG} + tdescent_{altCG}$
$time_{altCG} = 14.48 + 26.25 + 19.5 = 60.23$ menit
h. $time_{holdBC} = 30$ menit
i. $time_{taxiBC} = 10$ menit

Fuel Required Full Tankering

Fuel required full tankering on this flight are as follows:
$Fuelrequired_{min\ BC} = fuel_{destinationBC} + fuel_{altBC} + fuel\ taxi$
$fuelreq_{minBC} = 3782.8 + 3136.11 + 250 = 7168.91$ kg
$Fuel_{destinationAB} = 4821.99$ kg
$Fuel_{taxi} = 250$ kg
$\boldsymbol{F_{tankeringA}} = 7168.91 + 4821.99$ kg $+ 250$ kg $= 12240.9$ kg

Conclusion and Suggestion

Conclusion

1. From the analysis results that was calculated, there were some differences between filling in general by filling using the fuel tankering method, where filling is generally only refueling at each station to go to the destination airport with fuel required at each airport. Filling in general can be interpreted as filling as needed from the origin airport to the destination airport, with normal filling not counting the fare value or price of fuel at each airport, the value of this refueling destination for the Yogyakarta-Singapore-Jakarta route was 13884.95 kg, while filling using the fuel tankering method, which was fuel filling by looking at the different fuel rates or prices at each airport, thereby reducing operating costs in the fuel section. It can be drawn from the results of the analysis in the previous chapter that the value of fuel requirements for filling using the B737-800 NG fuel tankering method for JOG (Yogyakarta) - SIN (Singapore) - CGK (Jakarta) flights with alternative PKU routes (Pekanbaru) and SUB (Surabaya) was 12240.9 kg.
2. Variable yang menjadi penentu dalam *fuel tankering* tidak hanya *fuel required* tetapi ada beberapa variable yang berpengaruh terhadap *fuel tankering*. Variable tertentu bisa berupa suhu atau temperature, ketinggian terbang, jarak terbang dan harga fuel yang berbeda disetiap bandara yang perlu di hindari untuk mengurangi biaya operasional. Variabel lain yang menjadi penentu berupa antara lain:
   Variables that determined the fuel tankering were not only the required fuel but there were several variables that were affectin fuel tankering method. Certain variables could be temperature, altitude, flight distance and different fuel prices at each airport that need to be avoided to reduce operational costs. Other determinant variables were:
   a. Fuel required BC (Singapura-Jakarta) in which this required fuel was including fuel destination BC (Singapura-Jakarta), fuel alternative BC (Jakarta-Surabaya) and fuel holding.
   b. Fuel destination AB (Yogyakarta-Singapura), In which the amount of fuel that was brought from the original airport (Yogyakarta) to the destination airport (Singapore) with an alternative airport (Pekanbaru).
   c. Fuel taxi, the amount of fuel used at the airport from the apron (parking stand) to the end of the runway (runway).
3. The value of the benefit that was obtained when using fuel tankering method with the JOG-SIN-CGK route was to look at filling fuel requirements normally at 13884.95 kg by filling fuel

requirements with the fuel tankering method of 12240.9 kg. Then the difference in profits earned by the airline was amounted to 1644.05 kg, so the company can reduce operating costs in the part of fuel needs.

Suggestion

1. For further research, the researchers must be able to master Industrial Engineering specifically Aerospace Engineering in order to create research that can be applied to the company or airline department.
2. For airlines, they have to really consider the policy on fuel if the price of fuel at each airport is different, so as not to incur greater operational costs.

References

Abdelghany K, Abdelghany A, Raina S 2005 A model for airline fuel management strategies. J Air Transp Manag 11: 199–206.

Babikian R, Lukachko SP, Waitz IA 2002 The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives. J Air Transp Manag 8:389–400.

Basic Operations Manual (BOM), 2011, Flight Operations.

Civil Aviation Safety Regulation (CASR) part 121 2009 Certification and Operating Requirement: Domestic, Flag, and Supplemental Air Carrier.

Civil Aviation Safety Regulation (CASR) part 91 amendment 4 2015 General Operating and Flight Rules.

Collins BP 1982 Estimation of aircraft fuel consumption. J Aircraft 19(11):969–975. DOI:10.2514/3.44799.

Correia AR, Alves CJ 2005 Optimal configuration of airport passenger terminals. 9th Annual World Conference Air Transport Research Society, Issue 31, 1–5.

Covey RR, Mascetti GJ, Rooesler WU, Bowles RL 1979 Operational energy conservation strategies in commercial aviation. Decision and Control Including the Symposium on Processes, 18th IEEE Conference, vol. 18, 408–414.

Darnell DW, Loflin C 1977 National airline fuel management and allocation model. Interfaces 7(2):1–16.

David A. Senzig and Gregg G. Fleming 2009 Modeling of Terminal-Area Airplane Fuel Consumption.

Drake JW 1974 Social, political and economic constraints on airline fuel optimization. Transp Res 8:443–449.

Embraer. Embraer 170/190 fuel conservation, Sa˜o Jose´ dos Campos, 2005.

Greene DL 1990 Commercial aircraft fuel efficiency potential through 2010. Proceedings of the 25th Intersociety Energy Conservation Engineering Conference- IECEC 90, vol. 4:106–111.

Jose` A.T.G.F et al 2011 A Fuel Tankering Model Applied to a Domestic Airline Network.

Harshad Khadilkar and Hamsa Balakrishnan 2011, Estimation of Aircraft Taxi-out Fuel Burn using Flight Data Recorder Archives.

Kazda A, Caves RE 2000 Airport design and operation. Elsevier Sciences Ltd, Oxford.

Lee JJ, Lukachko SP, Waitz IA, Schafer A 2001 Historical and future trends in aircraft performance cost and emission. Annu Rev Energy Environ 26:167–200

Lee JJ 2010 Can we accelerate the improvement of energy efficiency in aircraft systems? Energy Conserv Manag 51:189–196.

Majka A, Brusow V, Klepack Z 2007 Fuel Consumption and transportation energy effective analysis. European Personal Air Transportation System Study, EP- D4.3, SFC-V0, pp. 1–23.

Mazraati M, Alyousif OM 2009 Aviation fuel demand modeling in OECD and developing countries: impacts of fuel efficiency. OPEC Energy Rev 33(1):23–46.

Mazraati M 2010 World aviation fuel demand outlook. OPEC Energy Rev 34:42–71.

Nash B 1981 A simplified alternative to current airline fuel allocation models. Interfaces 11(1):1–9.

Nur feriyanto et al 2016 The Route Analysis Based on Flight Plan.

Pilati DA 1974 Energy use and conservation alternatives for airplanes. Transp Res 8:433–441.

Senzig DA, Fleming GG, Iovinelli RJ 2009 Modeling of terminal- area airplane fuel consumption. J Aircraft 46(4):1089–1093.

Singh V, Sharma SK, Vaibhav S 2012 Identification of dimensions of the optimization of fuel consumption in air transport industry: a literature review. J Energy Technology Policy 2(7):24–33.

Stroup JS, Wollmer RD 1992 A fuel management model for airline industry. Informs 40(2):229–237.

Trani, A., Wing-Ho, F, Schilling, G, Baik, H, and Seshadri, A, A Neural network model to estimate aircraft fuel consumption, in *4th* AIAA Aviation Technology, Integration and Operations (ATIO) Forum, AIAA, Chicago, USA, 2004.

Tyas E.R.P et al 2017 Optimalisasi Fuel Tankering Untuk Seluruh Rute Penerbangan PT. Sriwijaya Air dari Bandar Udara Soekarno Hatta.

Van Cleave DA 2009 Green air space: reducing fuel burn. The MITRE Digest.

Vedant Singh et al 2014 Evolving Base for the Fuel Consumption Optimization in Indian Air Transport: Application of Structural Equation Modeling.

Zouein PP, Abillama WR, Tohme E 2002 A multiple period capacitated inventory model for airline fuel management: a case study. J Oper Res Soc 53(4):379–386.