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# BENEFIT ANALYSIS OF AIR REFUELING IN ULTRA LONG ROUTE AIRLINER OPERATION

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## Abstract

In order to illustrate the fuel benefit of applying air refueling on current airliners, this article designed two concepts of aircraft: ultra long range concept and medium long range concept. After building the direct model and refueling model of flight profile, the simulation results show that medium range airliner can save up to 16% of block fuel with air refueling than ultra long range airliner.

**Keywords:** air refueling, airliner, ultra long route, block fuel, conceptual design

## 1. The air route distribution analysis

With the progress of commercial airliners manufacturing industrial, airlines are capable of operating non-stop ultra long range air routes. The non-stop air routes have dramatic lower transition time, which means less flight duration and higher comfort for passengers. Those advantages make airlines become more competitive. The longest route operating currently is flight between Singapore and New York with great circle distance of 15329 km. However only 1% of wide body airliner make flight with GCD bigger than 12000 km, according to OAG[1] in table1, thus it is not economic to develop a specific airliner for ultra long range route. This article aims to investigate the feasibility to apply air refueling on general long range airliners, in order to satisfy the needs of ultra long range routes and reduce the fuel cost simultaneously.

Table 1 Air route distribution of wide body airliners in operation

| GCD km | ≤2000 | >2000 ≤5000 | >5000 ≤8000 | >8000 ≤10000 | >10000 ≤12000 | >12000 ≤16000 |
|---|---|---|---|---|---|---|
| Route number | 12195 | 11158 | 9345 | 4192 | 1242 | 356 |
| Route ratio | 32% | 29% | 24% | 11% | 3% | 1% |
| ASKs ratio | 7% | 18% | 35% | 22% | 12% | 5% |

Take an example of the global longest non-stop air route from Singapore to New York. Now this route is performed by A350-900LR, in order to make direct flight the passenger number is reduced to 161, while the typical cabin layout can hold around 320 passengers. The great circle distance between Singapore and New York is 15329 km, It is necessary to consider the margin from GCD to design range by about 10% because of airway and wind effect. As a result, Airliner needs a range of 17000 km to perform the non-stop flight between Singapore and New York, also the reserve fuel policy is included in this route. How to balance the fuel economic requirement and the ultra long route capability, air refueling in mid-way may be a comprehensive feasible solution.

## 2. The range impact to aircraft concept analysis

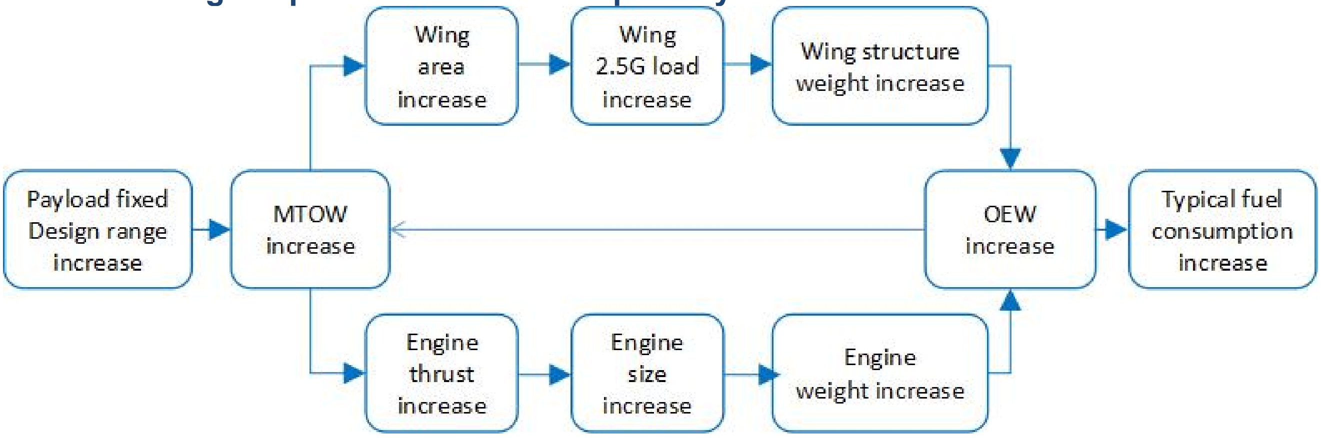


Figure 1 – Impact from design range to block fuel.

Design range is the top level requirement of the airliner aircraft design. As shown in Figure 1, with fixed standard payload, increase design range will increase MTOW, wing area, engine thrust and size, wing structure weight and engine propulsion system weight, OEW, and typical route fuel consumption as a result. Generally speaking, ultra long range needs a much heavier aircraft, which will increase the block fuel of typical route, also increase block fuel per seat per kilometer of design range.

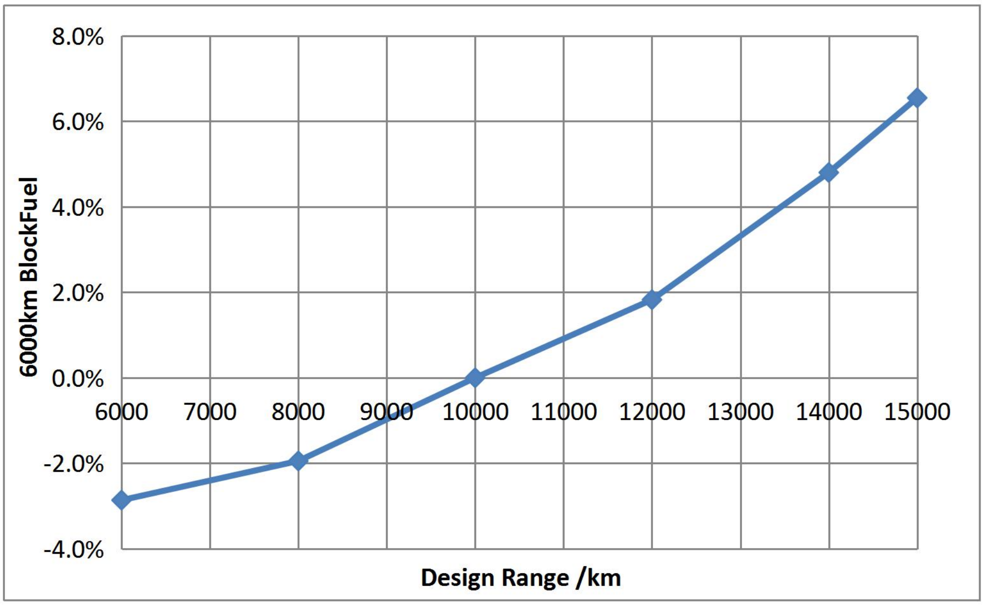


Figure 2 – 6000km block fuel for different design range concepts.

In order to illustrate the upper point of view, according to design range impact analysis of wide body airliner[2] performed, six 300 seats wide-body concepts were built and optimized, while the seats number and cabin layout keep constant. According to the modeling and estimation of the optimized concepts design, the decrease of design range can introduce an apparent reduction of maximum takeoff weight, thus a smaller requirement of wing reference area, which can decrease both the structural weight and the aerodynamic efficiency. A compromise of wing area has to be made to balance those two impacts. In general, according to the six optimized conceptual designs, the reduction of design range can increase the fuel efficiency to a certain level. As shown in Figure2, 6000km block fuel decreased by about 2%, while the benefit of longer range is higher, the shorter range is lower. On the other hand, the increase of design range from 10000km to 15000km will increase block fuel of typical route with 6000 km by around 7%, with design range increased further to 17000km, it is reasonable to deduce that the typical route block fuel will increase by around 10%. while this value should be checked by following study.

## 3. Two airliner conceptual solutions analysis

In order to illustrate the benefit of application of air refueling on long range airliner, there are two concepts of commercial wide body aircraft have been defined and investigated in Pacelab APD. Both concepts have the same fuselage and cabin layout with capacity of 300 passengers: Concept-17 has a range of 17000 km while Concept-10 has a range of 10000 km. Both concepts are designed deliberately based on current technique level assumption, the mass estimation[3] and aerodynamic estimation[4] is based on empirical formula method integrated in Pacelab APD and calibrated by certain aircraft validated data developed by COMAC.

Consequently the different range will have deep impact on wing geometry size and characteristic weights of the aircraft. With the same standard payload of 30 tons, Concept-17 has 328 tons of maximum take off weight, while Concept-10 has only 223 tons of MTOW. Figure 3 shows the general configuration of both concepts, Concept-17 has a bigger wing and six wheels bogie compared with smaller wing and four wheels bogie in Concept-10.

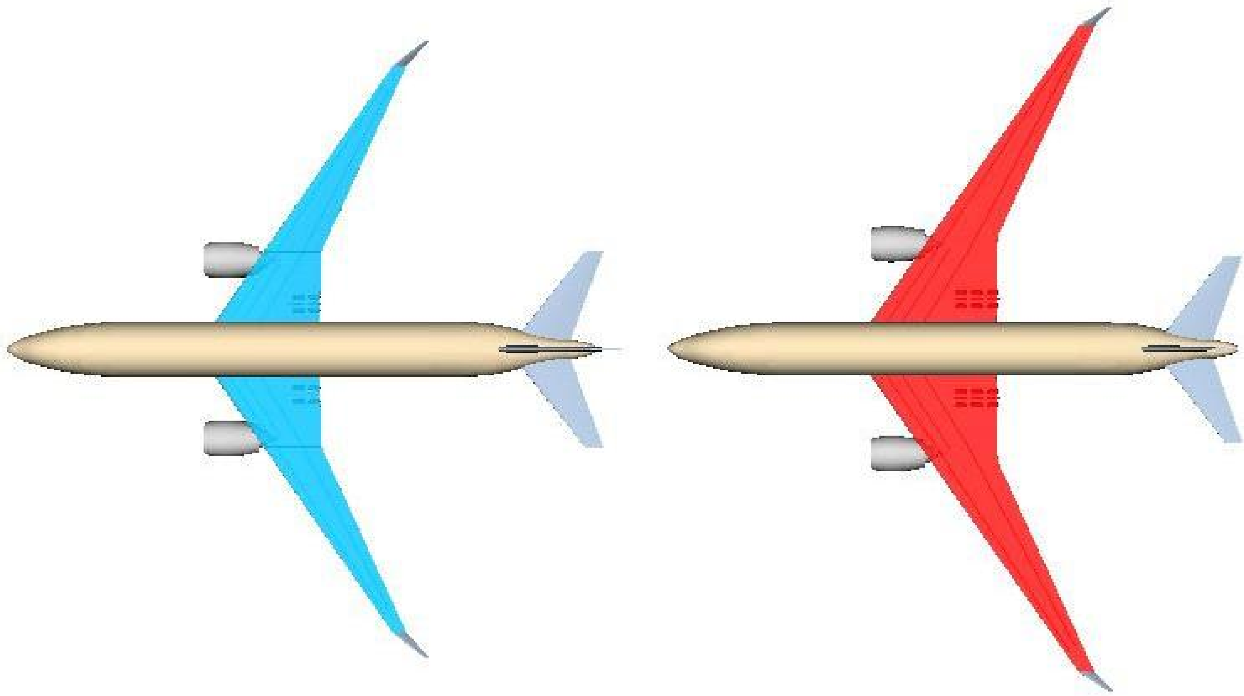

Figure 3 – Configuration of Concept-10 (left) and Concept-17 (right)

Table 2 General parameters of Concept-17 and Concept-10

| | Standard Payload | Design Range | Cruising Mach | MTOW | OEW | Wing reference area | Wing span |
|---|---|---|---|---|---|---|---|
| Concept -10 | 30 tons | 10000 km | 0.85 | 223 ton | 125 ton | 350 $m^2$ | 60 m |
| Concept -17 | 30 tons | 17000 km | 0.85 | 328 ton | 150 ton | 500 $m^2$ | 72 m |

Table 2 shows the general parameters of both concepts, the main difference is focused on MTOW OEW and wing geometry parameters. Fuselage is almost the same, landing gear and engines are modified to fulfil the different requirements. Figure 4 shows the payload range diagram of both concepts. The applied reserve fuel policy of ICAO includes 5% trip fuel and 200nm division fuel and 30mins holding fuel. The standard payload and maximum payload is the same, while the key difference is the range.

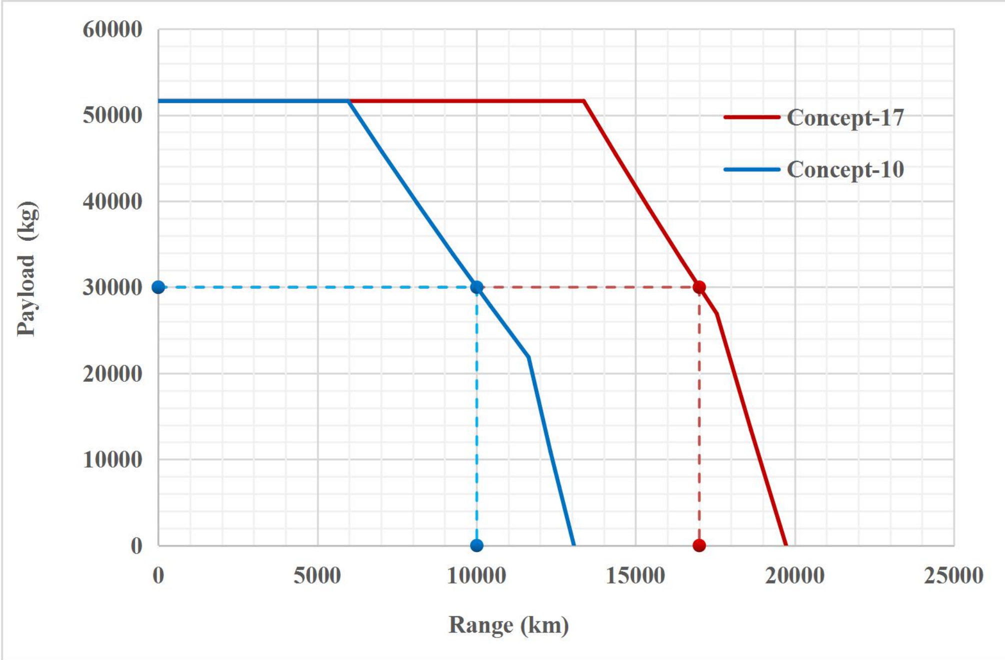


Figure 4 – Payload range of Concept-17 and Concept-10

According to the calibrated APD performance model calculation, Figure 5 shows block fuel per km variation with flight distance. As shown in those curves, the lowest fuel consumption per km is located at distance around 4000~6000 km. The block fuel per km increases dramatically before this distance range while it increases gradually after this scope. When flight distance smaller than 4000km, the ratio of cruise distance to total distance become rapid smaller with distance decrease, thus block fuel per km increase dramatically with decreased distance. When distance bigger than 6000km, the rear part of flight fuel equivalents to the payload of forward part, the forward flight segment has to take extra tons of fuel for rear flight consumption. According to Figure 5, the block fuel per km at 17000 km will increase by approximately 15% than the bottom part of red curve.

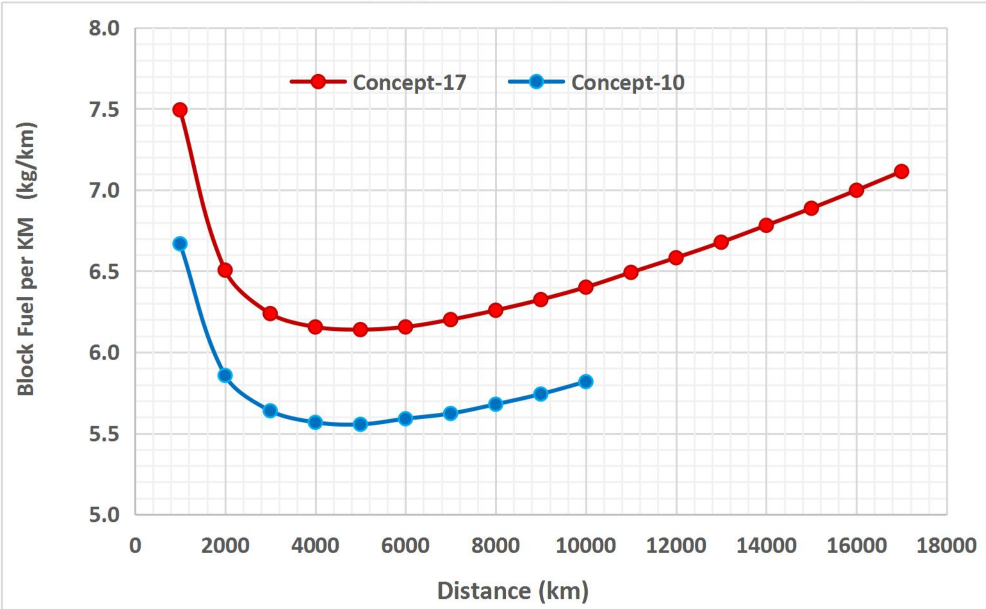


Figure 5 – Block fuel per KM of Concept-17 and Concept-10

## 4. Two types of flight profile with/without air refueling analysis

For ultra long range air route bigger than 15000km, there are two potential different solutions. One solution is to develop a specific aircraft with range of 17000km i.e. Concept-17, which can fly directly by 17000km with 30tons payload. The typical flight profile is defined and shown in Figure 6 below:

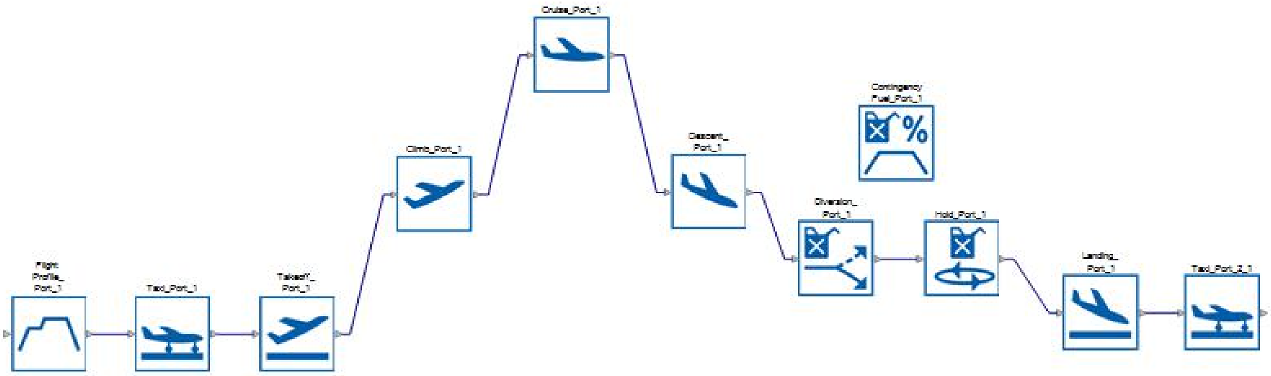

Figure 6 – Typical flight profile definition of airliner

The other solution is to develop an aircraft with range of 10000km with refueling installed. i.e. Concept-10, which has to be refueled in midway from a tanker such as A330MRTT. The correspondent flight profile is shown in Figure 7, the cruise segment separated into 3 segments, first cruise segment, refuel segment and the second cruise segment.

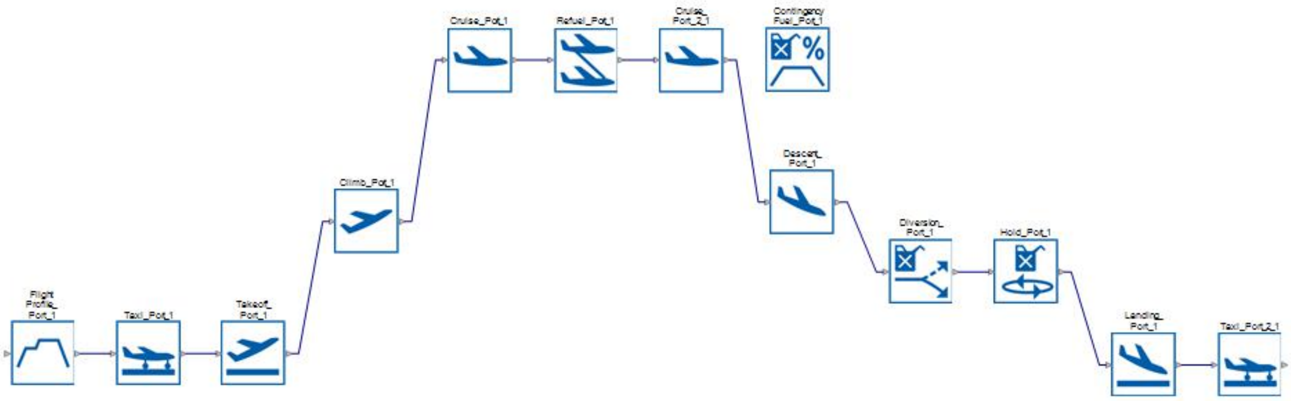

Figure 7 – Refueling flight profile definition of airliner

It is easy to acknowledge that air refueling operation could extended even double the flight range of a developed aircraft. Take Concept-10 as example, with once refueling operation as flight profile in Figure 7, Concept-10 can easily double the range as shown in Figure 8, the red curve shows flight distance with block fuel on board when take off. The red curve shows that Concept-10 can fly up to 10000 km with about 60tons of block fuel. The blue curve shows that the flight distance could reach about 21000 km with once air refueling operation.

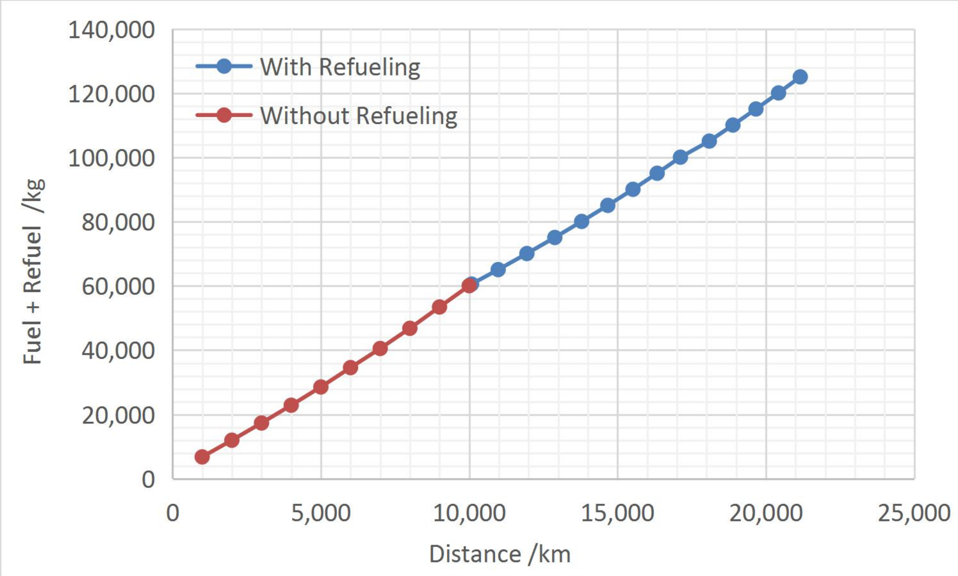


Figure 8 – Concept-10 flight distance with/without air refueling

## 5. Fuel consumption benefit analysis

In order to perform the air refueling operation, there are two types of aircraft involved, the fuel receiver as airliner and the fuel provider as air tanker. There is a list of air tanker developed by Boeing and Airbus company, such as Boeing KC-135 and KC-767, Airbus A310MRTT and A330MRTT. Based on current technical level assumption, this article built a conceptual model of air tanker aircraft, with MTOW of 250 tons and OEW of 129 tons. The air tanker can provide up to 100 tons fuel transferred with refueling rate of 45 kg/s. Figures 9 shows the typical air refueling flight profile of air tanker, the cruising segment consists of a loiter segment and a refueling segment. Based on the preliminary calibrated model of air tanker concept, the refueling performance is calculated and shown in Table 3 below.

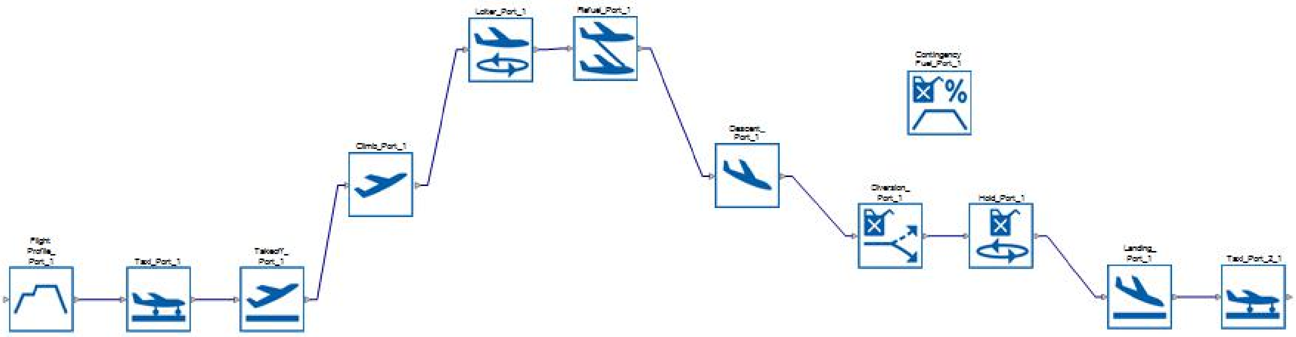

Figure 9 – Typical air refueling flight profile of air tanker

Table 3 Refueling performance of air tanker concept

| Name | Fuel Transferred | OEW | TOW | Fuel Burning |
|---|---|---|---|---|
| Air Tanker | 15,000 | 129000 | 155,050 | 5,382 |
| Air Tanker | 25,000 | 129000 | 165,664 | 5,996 |
| Air Tanker | 35,000 | 129000 | 176,309 | 6,641 |
| Air Tanker | 45,000 | 129000 | 187,014 | 7,346 |
| Air Tanker | 55,000 | 129000 | 197,803 | 8,135 |
| Air Tanker | 65,000 | 129000 | 208,675 | 9,006 |
| Air Tanker | 75,000 | 129000 | 219,659 | 9,991 |
| Air Tanker | 85,000 | 129000 | 230,788 | 11,120 |
| Air Tanker | 95,000 | 129000 | 242,135 | 12,466 |

Based on the airliner refueling flight profile in Figure 7, the block fuel of airliner could be divided into three parts:first segment which is before refueling , second segment which is after refueling and middle segment which is during refueling. The air tanker block fuel consumed to perform refueling operation is also considered in the total fuel.

Table 4 shows the block fuel of Concept-17 with refueling in mid way. There are different distance inputted for first segment. Figure 10 shows total block fuel variation with first distance, it is easy to conclude that it is almost half the total distance to make refueling that could save maximum block fuel. Even Concept-17 can fly directly by 17000km, with the help of refueling, it can save about 8% of total fuel, about 10 tons of fuel, which cost 8000~10000 us dollars in one trip. According to performance calculation results in table 4, Concept-10 with refueling model could save up to 16% fuel compared with Concept-17 without refueling, about 20 tons of fuel, which cost 16000~20000 us dollars in just one trip.

Besides, the primary benefit of air refueling is the extended range ability for main stream airliners with range scope of 12000~14000 km, the doubled range ability of more than 25000 km can cover the whole world cities pairs; Second benefit is to save tens of hours of stop time, which makes non-stop flight of ultra long range routes become more and more convenient and frequent; The final apparent benefit is up to 16% reduction of fuel consumption and the decreased operation cost consequently.

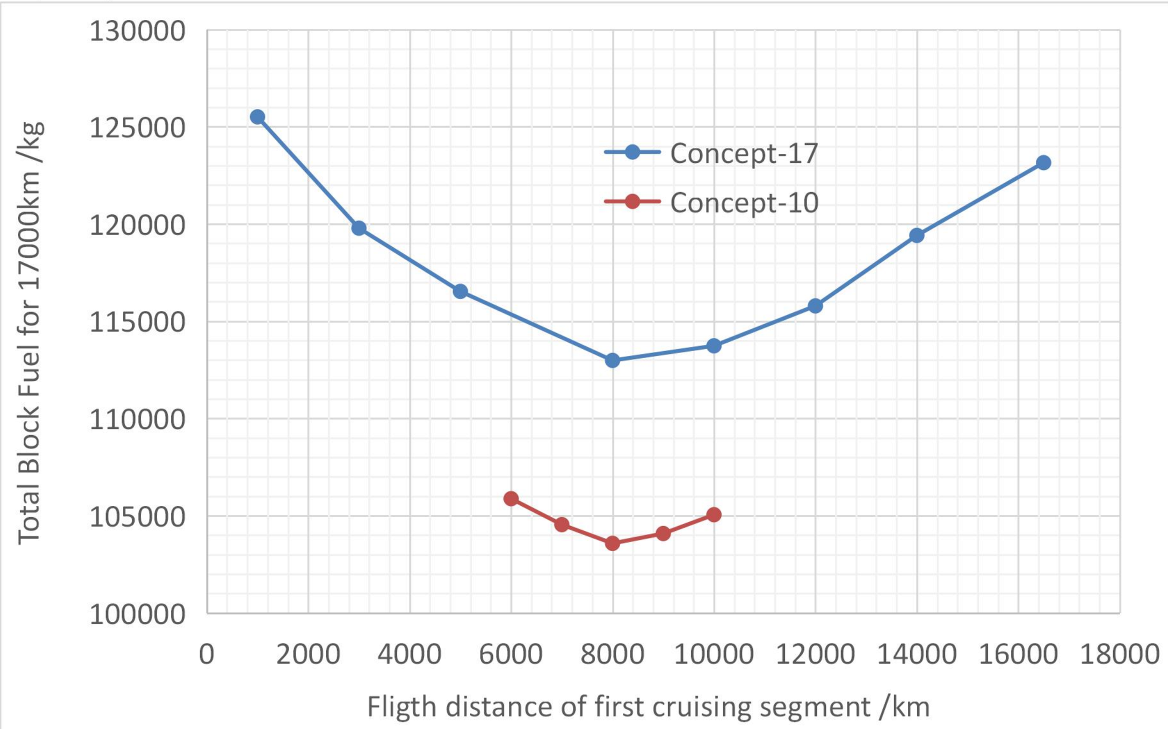


Figure 10 – Total block fuel for 17000km with air refueling of Concept-10 and Concept-17

Table 4 Block fuel comparison with refueling of Concept-17

| | Payload | Total Distance | 1st Distance | 1st Fuel | 2nd Distance | 2nd Fuel | Fuel Added | Tanker Fuel | Total Fuel Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|
| Concept-17 | 30000 | 17000 | 1000 | 5969 | 15098 | 99773 | 103000 | 12566 | 2355 | 1.9% |
| Concept-17 | 30000 | 17000 | 3000 | 17302 | 13144 | 84524 | 87000 | 11369 | -3368 | -2.7% |
| Concept-17 | 30000 | 17000 | 5000 | 29321 | 11309 | 71005 | 73000 | 9784 | -6619 | -5.4% |
| Concept-17 | 30000 | 17000 | 8000 | 48942 | 8263 | 49836 | 51400 | 7838 | -10168 | -8.3% |
| Concept-17 | 30000 | 17000 | 10000 | 63212 | 6395 | 37728 | 38500 | 6879 | -9417 | -7.6% |
| Concept-17 | 30000 | 17000 | 12000 | 78578 | 4471 | 25755 | 26000 | 6060 | -7365 | -6.0% |
| Concept-17 | 30000 | 17000 | 14000 | 94966 | 2563 | 14414 | 14200 | 5335 | -3741 | -3.0% |
| Concept-17 | 30000 | 17000 | 16500 | 117684 | 144 | 864 | 0 | 0 | 0 | 0.0% |

Table 5 Block fuel comparison with refueling of Concept-10

| | Payload | Total Distance | 1st Distance | 1st Fuel | 2nd Distance | 2nd Fuel | Fuel Added | Tanker Fuel | Total Fuel Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|
| Concept-10 | 30000 | 17000 | 10000 | 54348 | 6828 | 38209 | 39150 | 6925 | -18099 | -14.7% |
| Concept-10 | 30000 | 17000 | 9000 | 47885 | 7814 | 43336 | 44500 | 7309 | -19067 | -15.5% |
| Concept-10 | 30000 | 17000 | 8000 | 44048 | 8250 | 46050 | 49800 | 7712 | -19573 | -15.9% |
| Concept-10 | 30000 | 17000 | 7000 | 37992 | 9254 | 52487 | 56400 | 8257 | -18609 | -15.1% |
| Concept-10 | 30000 | 17000 | 6000 | 32553 | 10215 | 58816 | 60500 | 8627 | -17275 | -14.0% |

## 6. Technical feasibility and constraint analysis

Nowadays air refueling is widely used in military operation. There are a lot of military transport and fighter aircraft installing air refueling system to provide or receive fuel in air. Some main tanker aircraft operational currently is listed in Table 6 . Thus the air refueling technique is mature and popular. There are two main different ways of air refueling: Probe and drogue refueling and Flying boom refueling. Either ways of refueling could be installed on the same tanker aircraft, as shown in Figure 11 below.

Table 6 Mainstream operational tanker aircraft[6]

| Tanker aircraft | Developer and Country | Fuel Supply Method |
|---|---|---|
| A310 MRTT | Airbus, Europe | Probe and drogue |
| A330 MRTT | Airbus, Europe | Probe and drogue /Flying boom |
| A400M | Airbus, Europe | Probe and drogue |
| KC-135 | Boeing, USA | Flying boom /Probe and drogue |
| B767 MRTT | Boeing, USA | Probe and drogue /Flying boom |
| KC-10 | MD, USA | Flying boom |
| IL-78 | Ilyushin, Russia | Probe and drogue |
| H6-U | AVIC, China | Probe and drogue |

a) A330 MRTT with probe and drogue refueling b) A330MRTT with flying boom refueling

Figure 11 – A330 MRTT with different refueling method

Generally, the air refueling receiver are mostly small aircraft as fighter and helicopter, however the transport aircraft could also act as receiver as shown in Figure 12 blow.

b) A B737 variant refueled by A330MRTT    b) A B747 variant refueled by KC-135

Figure 12 – Transport aircraft be air refueled

For airliner, it is quite convenient to apply the flying boom refueling method, because the fuel receiver aircraft can just maintain its flat flight, let the tanker aircraft to do the fuel transfer operation. And the refueling device is smaller and light, easy to be installed on big airliner.

However, although the paper simply illustrated the economic and technical feasibility of air refueling for airliner, there are still some potential risk or constraints to limit the refueling application on airliner. First point is to answer the safety concern and verify that airliner refueling is safe enough between tanker and airliner. If it is safe enough to persuade the airliner and passenger to accept this new manner of air transportation. Then the air worthiness regulation and certification should be modified and approved. Second, the logistics and infrastructure such as airport and route of both airliner and tanker should be built accordingly, the refueling point and the procedure should be prepared and arranged in flight plan. In the early stage, the airliner refueling operation could follow the example of ETOPS, airliner air refueling operation could be classified as an specific requirement for ultra long route airliner.

## 7. Conclusion

Based on the flight profile simulation and analysis above , a medium range airliner with air refueling could save up to 16% of block fuel than a ultra long range airliner on the same ultra long route. Even the ultra long range airliner could save up to 8% of block fuel with air refueling installed. This phenomenon is due to the decreased gross weight before the air refueling segment, while the fuel consumption of air tanker is also considered. Including the fuel burning reduction, the primary benefit of applying air refueling is the extended or doubled non-stop range capability of current airliners. Besides the technical feasibility validated by military airliner variant refueled by air tanker, the public safety concern, the airworthiness regulation, the logistics and infrastructure will still limit the potential application of air refueling on current airliners in the predictable future.

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