Design for Air-to-Air Refuelling Operations

New passenger and tanker aircraft design for AAR scenarios

Air-to-air refuelling is a way to improve fuel efficiency of the overall transport system without waiting for the improvement of basic aviation technology. To take full advantage of such an operation, both passenger aircraft and tanker aircraft (which deliver required fuel to the passenger aircraft in halfway) must be designed accordingly. Moreover, the issues of safety and reliability must also be considered besides fuel economy.

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rrial and propulsion improve the overall airplane efficiency in the order of 1-5%.

But long range requirements do have a reason if the aircraft is designed with relatively short range, even though it can be very efficient, the airliners are less likely to buy it. This is mainly because it lacks the flexibility to be operated in long-range routes. To overcome this dilemma, air-to-air refuelling is a possible solution, which provides airliners with the required range flexibility. This scenario is studied in a European project called RECREATE (Research on a Cruiser Enabled Air Transport Environment). In this project, a passenger aircraft specially designed for AAR operations is the "cruiser", which is refueled by another special designed tanker aircraft.

REFUELING CONFIGURATION

The first attempts at AAR operations were not feats of engineering prowess, but of aerobatic and acrobatic skill. There were numerous styles of connecting two aircraft in the sky. When the fancy stunt became a serious military operation, aviation engineers put a lot of effort in designing and testing many potential configurations. New series of technologies have been developed, including communication, navigation, fuel-transferring and flight control. Besides, also the standard for operation has been established and enriched. Nowadays, the AAR approach features staggered formation, with the tanker positioned above and in front of the receiving aircraft, which in turn performs the entire manoeuvre. To reduce the risk of civil AAR operations, it is reasonable to use the mature military experience and equipment as much as possible. But if the differences of two operations are overlooked, the effectiveness of civil AAR operations could be compromised.

In order to have a proper understanding, all the possible fuel transfer systems were listed in a design option tree for the preliminary assessment and selection. The flying boom system was chosen because a high fuel transfer mass rate is required for such large aircraft. The tanker aircraft should carry the boom and most of the associated systems, since the cruiser's fuel consumption is more sensitive to weight increments because of their longer range. After that, all the possible relative cruiser and tanker positions were considered. Some infeasible options were discarded first, while the remaining ones were graded in a trade-off matrix, which includes twelve independent criteria covering important aspects. Surprisingly, it turned out that the current military approach got the lowest total score and the reversed approach (receiving aircraft flies above and ahead, while tanker performs approach manoeuvre) received the highest score. This innovative approach has great advantages in safety, the lowest requirements for the pilot training level, a good passenger comfort level and low costs for deploying the whole system, which are all crucial aspects in civil aviation.

The main challenge comes from the fuel transfer system. Because the tanker should carry the major part of the fuel transfer system and the tanker stays below and behind the cruiser, the refuelling boom should be deployed against the incoming flow, which is not a mature technology and may encounter aeroelastic issues. As a spin-off, the forward extending boom had become an interesting and challenging research topic.

A preliminary study has already provided several solutions to fight the static aeroelasticity. No evidence indicates the infeasibility of the forward extending boom. In next step, dynamic aeroelasticity like flutter will be analysed.

IMPACT ON PASSENGER AIRCRAFT DESIGN

When selecting the refuelling configuration, it is beneficial for the overall air transport system to put the most part of the refuelling system on the tanker aircraft. Besides, the tankers, rather than the cruisers, should also carry out the formation manoeuvre. It results in minor modifications in terms of the cruiser's refuelling system. The major changes to the cruiser are the design parameters. To design the aircraft, a series of aircraft design tools have been developed and adapted to the scenario. Generally speaking, AAR operations allow a cruiser aircraft to be designed with much less fuel capacity, thus less structure weight and less engine thrust, which would reduce the required wing area. Again, a smaller wing area would reduce the structure weight and engine thrust as well. For a mission length of 5,000nm with one refuelling operation in the middle, the snowball effect would result in about 25% reduction in the operative empty weight. Weight reduction is a main reason why AAR could result in fuel savings. Actually, the smaller wing-area will cause some decrease in aerodynamic efficiency because of size effects but the overall gaining is dominant.

Besides the weight reduction, AAR also allows to reduce fuel reservations. Nowadays, the passenger aircraft flies over ocean with relatively straightened paths, which is achieved by extending diversion time in the ETOPS regulations. Because of these regulations, these aircraft carry more reserved fuel for a potential diversion flight, as they are further away from backup airports. To achieve a good overall efficiency in AAR operations, it is beneficial to put the refuelling rendezvous close to the tanker base. So the flight paths of cruisers are close to the tanker base already, which can be used as backup airports, allowing the cruiser to carry a much lower amount of reserve fuel, from 16% down to 9% of the total mission fuel.

In general, refuelling once in a 5,000nm mission range will guarantee a cruiser to burn about 15% less fuel than a comparison direct flight aircraft with the same payload. If a tanker can refuel the cruisers with its fuel consumption less than the fuel saved by the cruisers, then the overall AAR operation is beneficial in terms of fuel consumption compared to the direct flight.
TANKER AIRCRAFT DESIGN

The winning or losing margin of AAR operations relies on the tanker efficiency, which is measured as fuel transferred to the cruiser divided by fuel consumed by the tanker itself. Like the cruiser aircraft, tankers are also designed with the same design tools. To make a comparison, current military tankers are also analyzed in the typical tanker mission of 250nm refuelling radius with the capability of refuelling three cruisers in one-flight. Each refuelling process takes about 20min and there are also 20min loiters between two refuelling operations.

Current military tankers are conversions from existing transport aircraft. They are versatile in terms of the capability to carry some cargo, but they consume too much fuel since they are too heavy and have too much empty volume, which produces extra form drag. In this mission profile, the KC-135 and A310-MRT have tanker-efficiency of only 3 to 3.5. If they are used for a civil AAR operations, almost all the benefits gained by the cruisers will be lost. It would be more reasonable to convert smaller aircraft like the A320 to be a specialized tanker. The maximum take-off weight should be increased by more than twenty tons to accommodate the required fuel capacity. Landing gear, maybe even wings should be strengthened; engine thrust should be increased too. After a large amount of modifications, it could achieve a tanker efficiency of 5.5. With this A320-ST tanker in place, the overall fuel savings of AAR operations could be around 7%. Completely new tankers are also to be designed. By doing this, the tanker efficiency could be increased at least to 7.5, making the overall AAR fuel savings go up to 10%.

SYSTEM OF SYSTEM LEVEL

The tanker efficiency also varies with the design refuelling radius and the number of refuelling counts per flight. Increasing the refuelling radius would allow for less devious cruiser paths, and thus shorter travel distances for the cruiser, but more fuel is consumed by the tanker. This is a trade-off on the system of system level. When a tanker is designed to refuel more cruisers per flight, the tanker efficiency tends to go down. But this also means fewer tankers should be deployed and operated to feed a certain fleet of cruisers, relieving the burden of flight management.

According to the real geologic map, the tanker bases do not always sit in the middle of all the cruiser routes. The off-design AAR scenarios should be studied. The results could also change the inputs for aircraft design. In general, the RECREATE project opens more design topics than it closes.

References