Interference Liability of a civil Air to Air refueling Traffic Network

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Abstract

The project REsearch on a CRuiser Enabled Air Transport Environment (RECREATE) is about the introduction and airworthiness of cruiser-feeder operations for civil aircraft. Cruiser-feeder operations are investigated as a promising pioneering idea for the air transport of the future.

The top level objective of the project is to demonstrate on a preliminary design level that cruiser-feeder operations (as a concept to reduce fuel burn and CO_2 emission levels) can be shown to comply with the airworthiness requirements for civil aircraft.

(The 42-month RECREATE project research receives funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 284741.

This publication reflects only the authors' views. The European Union is not liable for any use that may be made of the information contained therein.)

Air-to-air refuelling operations are an example of this concept. Currently Air-to-air refuelling operations are primary used to extend range of aircrafts in military operation. However some research has been done in the past to estimate fuel saving capabilities of air-to-air refuelling in both military and civil operations. Most of these estimations give highly positive results on the fuel saving capabilities. Nevertheless these results mainly based on a small number of optimised cases.

As part of the primary design in the RECREATE project this paper will discuss air-to-air refuelling operations in a traffic scenario based on Eurocontrol-Data containing one day of traffic over Europe. With this traffic two main scenarios have been created. The first contains traffic between Europe and America while the other one contains traffic between Europe and Asia.

The traffic scenarios used in the paper will exchange current flights due flight with air to air refuelling somewhere on the route. The aircrafts used on these routes will be exchanged to RECREATE specific aircrafts as aircrafts who use air to air refuelling have a much lower design range than the aircrafts they replace. As reference the same routes will be flown by aircrafts without air to air refuelling and a higher design range. These aircrafts have the same efficiency as the RECREATE Aircraft. Also the reference aircrafts will use direct routes while the aircrafts with air to air refuelling will use fuel optimized routes with one or more refuelling operations.

The third aircraft type used in the traffic simulation is the Feeder aircraft. The Feeder aircraft will take off from a specific Feeder base and refuel a number of cruiser aircrafts depending on the size of the feeder. The Feeder will then land on the same Feeder base. The main parameters for the Feeder are the Feeder size, the Feeder range and the Feeder efficiency.

The Scenario includes 2776 connections between Europe and North-America. In this Transatlantic Scenario 8 Feeder bases have been chosen to serve as take-off and landing airport for the feeder aircrafts. The location of these feeder bases orientates at the optimal refuelling position for these connections.

In the simulation the cruiser aircrafts will fly routes where the fuel spend by the cruiser and the fuel spend by the feeder spent on refuelling this cruiser aircraft is minimal. Furthermore the Cruiser will use the same take-off time as the original aircraft in the Eurocontrol data. The Feeder aircrafts then will be scheduled according to the cruisers flight plan.

With these fuel optimized routes the traffic is more centred towards the feeder bases. The whole system depends strongly on reliable services at the feeder bases. This paper will discuss the effect of discontinuances at the feeder bases.

NOMENCLATURE

$\dot{M}_{fuel}$	FUELFLOW
M_{fuel}	FUEL USED (OVERALL)
$M_{fuel\ cruise}$	CRUISER FUEL USED DURING CRUISE LEVEL FLIGHT AS A FUNCTION OF MASS, X-FACTOR AND THE FLOWN DISTANCE
$M_{fuel\ takeoff}$	FUEL USED IN THE TAKEOFF PHASE
$M_{fuel\ landing}$	FUEL USED IN THE LANDING PHASE
$M_{Cruiser}$	CRUISER MASS
M_{Feeder}	FEEDER MASS
X	EFFICIENCY FACTOR X (DEFINED IN FORMULA 2)
d_{1-2}	RANGE BETWEEN POINT 1 AND 2
v	CRUISE LEVEL AIRSTREAM VELOCITY
$\frac{L}{D}$	LIFT OVER DRAG RATIO
sfc	SPECIFIC FUEL CONSUMPTION
$n_{refuelingoperations}$	NUMBER OF REFUEL OPERATIONS PER TANKER

1. SCENARIO DESCRIPTION

The general idea in fuel saving through air to air refueling is to divide the flight range in two or more smaller ranges and refuel on air between them. Thus the aircraft need less fuel for each step. Less fuel then leads to weight reduction which results in less fuel burn over the whole distance.

On the other hand the feeder aircraft will burn fuel while refueling the cruiser. Earlier studies [1-3] have shown that the fuel saving with air to air refueling is quite low if the refueled aircraft is the same aircraft that could fly the complete distance without refueling.

To save fuel the lower distance between the refueling points is used to fly the distance with a lower range aircraft. As such an aircraft is designed to carry less fuel with it the whole aircraft is less heavy then a long range aircraft for the same amount of passengers. Studies have shown that with this method fuel savings of up to 20% are possible [1-3].

As it is quite unlikely that cruiser will fly multiples of their range in day to day business the main task of a traffic simulation is to determine realistic fuel savings in an air traffic network. Furthermore the traffic simulation could show difficulties and aspects of an air to air refueling network which will not show up in single flight analysis.

To achieve these functions the Traffic Simulation needs to make some choices between optimal refueling condition and realistic compromises.

In the first step the prepared scenario data will be loaded including the connections, the take of time, the aircraft time and the available feeder bases. In this paper one day [5] of Eurocontrol traffic will be used as basis for the Scenario. The aircrafts from the scenario data will be replaced with RECREATE aircrafts. As the parameter of the RECREATE aircrafts could change between simulation runs the actual replacement could not be done within the scenario design.

In the next step a first fuel consumption for the reference aircraft will be estimated. The reference aircraft uses the same efficiency as the refueled aircraft and flies on great circle rout to the target airport. The calculated fuel consumption will be used to analyze the fuel savings from the air to air refueling maneuver in the following steps. Furthermore the maximal achievable fuel savings will be calculated in this step. For this calculation the cruiser will fly on great circle routes directly to their destination. They will be refueled at their optimal refueling position (in the middle of the route or at a third/quarter if more than one refueling operation is necessary). To calculate the fuel burned by the feeder aircraft a feeder base near the refueling position will be assumed.

In the following step the cruiser routes will be optimized to their fuel savings. Unlike to the maximal achievable fuel saving calculations the feeder bases of the scenario will be used in this calculation. The feeder base selection will be described in the feeder section of this paper [Chapter 3.1]. To find an optimal refueling position the meeting point between feeder and cruiser could be moved freely until the spent fuel for both aircrafts is minimal. The fuel consumption calculated in this step is the minimal achievable fuel consumption for this connection and the fixed feeder bases. The feeder situation is optimal but unrealistic.

To get more realistic feeder fuel consumptions is the intention of the next step. Thus the refuel requests on one feeder base are scheduled to feeder aircrafts. The scheduling routine balances between short feeder routes and occupied feeders. These calculations give not only more realistic feeder fuel consumption but also a number of necessary feeder aircraft at each feeder base. Furthermore these calculations result in full trajectories for the feeder and the cruiser. Thus numbers like the feeder workload over the day or the runway traffic on the feeder base could be analyzed.

1.1. Cruiser optimization

The following chapter will describe the Cruiser optimization routine. As the cruiser routes will be optimized on their full consumption the fuel calculations are the main part in the optimization routine. In the Calculation the cruiser will fly on great circle routes between start and end position as well as any refueling position calculated in the optimization routine. The fuel consumption with n refueling operations is calculated with the following formula.
The current fuel burn calculates as:

$$\dot{M}_{fuel} = \left[\frac{M_{aircraft}(s)}{\frac{L}{D}} + g\, M_{aircraft}(s)\sin(\gamma)\right] * sfc$$

With

$$M_{fuel} = \int_{s_0}^{s_1} \dot{M}_{fuel}(s)\, ds$$

and

$$X = \frac{v\,\frac{L}{D}}{sfc}$$

Follows

$$\begin{aligned} &M_{fuel} \\ &= M_{fuel\ takeoff}(M_{cruiser}, X_{cruiser}) \\ &+ \sum_{2}^{n_{max}-1} \Big[M_{fuel\ cruise}\big(M_{cruiser}, X_{cruiser}, d_{p(n-1)-pn}\big) \\ &+ \Big(M_{fuel\ takeoff}\big(M_{feeder}, X_{feeder}\big) \\ &+ M_{fuel\ cruise}\Big(M_{feeder}, X_{feeder}, \big(d_{base-pn} + d_{refuel} \\ &+ d_{p(n+1)-base}\big)\Big) + M_{landing}\big(M_{feeder}, X_{feeder}\big)\Big) \\ &/ n_{refueling\ operations} \\ &+ M_{fuel\ cruise}\big(M_{cruiser}, X_{cruiser}, d_{p(n+1)-p(n+2)}\big)\Big] \\ &+ M_{landing}(M_{cruiser}, X_{cruiser}) \end{aligned}$$

The optimization routine searches in the first step for one refueling position along the route which brings a reduction on the fuel consumption compared to the direct route. If the direct route is longer than two times the cruiser range two refueling positions will be used. The refueling position could be moved between the start position, the end position and the refueling base. Connection with only one refueling position will use the planed airports as start and end position. Longer connection will use an optimal refueling position on one side to search for a refueling position between this position and the end position. In the next step a refueling position between the already found position and the start position will be searched. The refueling position will be rotatory adjusted until both stay within a 5nm radius.

1.2. Feeder routing

After the refueling positions have been found the information will be used at the feeder bases to plan the feeder mission from this base. The feeder mission plan is designed to give each feeder aircrafts enough refueling targets to reach the maximal number of refueling operations for each feeder. Also plan tries to keep the number auf necessary feeder low as well as the flown distance of each feeder.

For the first refueling operation of the day the first feeder will be scheduled. In all subsequent refueling operations the distance and time to the rendezvous location from the last scheduled location of each feeder will be calculated. Thereafter the feeder will be scheduled on the refueling mission due the following criteria:

- The feeder with the closest distance in time and space will be chosen for the refueling mission. In the normal operation mode the cruiser time is fixed. The Feeder routing could include slight changes in the cruiser schedule if this would allow a better located feeder to execute the refueling mission.

- Feeder already airborne will be preferred. Thus Feeders who have already performed a refueling mission will more likely be scheduled a following refueling mission than a feeder from the feeder base.

- Airborne Feeder without a refueling mission for a defined timespan will be send back to the feeder base.

- After refueling the maximal number of Cruiser a Feeder will return to the Feeder base.

- Returned Feeders will be stay at the Feeder base for a defined timespan while they will be refueled and prepared for the next mission.

The calculation of the Feeder routes and schedules also defines the number auf necessary Cruiser at the Feeder base.

1.3. Input Parameters

The earlier described route calculation methods need some Parameters for their calculation. The following will describe those parameters that will be varied between the different simulations:

X-Factor:
The X-Factor determinates the aircrafts efficiency and is defined as the aircraft velocity multiplied with the lift over drag ratio divided by the specific fuel consumption (X = V L/D /sfc). In the basic configuration the cruiser will be calculated with an X-Factor of 18500 nm and the Feeder with an X-Factor of 14000 nm.

Design Range:
The Cruiser design range determinates the distance the

cruiser is allowed to fly until a refueling is necessary. The design range also determinates the cruisers weight as more fuel for longer distances will require more structure to hold this fuel. Apart from the basic cases of 2500nm and 3000 nm cruiser the cruiser masses are just rough estimations. The calculated weight is used to calculate the fuel consumption.

Duration of the refueling operation:
The duration of the refueling operation includes the entire phase when the feeder and the cruiser fly along the same track. The time spend in the refueling operation is a huge part in the flight plan of the feeder. With less time spend in the refueling operation less fuel will be burned by the feeder. Furthermore the feeder will stay closer to the feeder base with shorter refueling operations. The default duration of the refueling operation is 20 minutes.

Maximal Feeder-base distance
The maximal feeder base distance is not the same as the feeders design range. It has no effect on the feeder size and only limits the feeder to an area around the feeder base. This limitation keeps the refueling position in a fixed area. In this way feeder for more refueling operations could shorten their routes.

1.4 Feeder Base selection

As the number of feeder bases theses bases should be able to satisfy most of the connections in the scenario. Thus the feeder Bases will lie at position close to the cruiser routes and their optimal refueling position. Presuming the feeder stays close at the feeder base lines with the same fuel saving results could be drawn around the optimal fuel saving position and along the direct cruiser routes as shown in picture 1.

Fig. 1 direct routes in the Transatlantic Scenario

The optimal refueling position and with it possible areas for Feeder bases depend on the cruiser design range. Picture 2 shows the optimal refueling position for cruiser with 2500nm and 3000nm range.

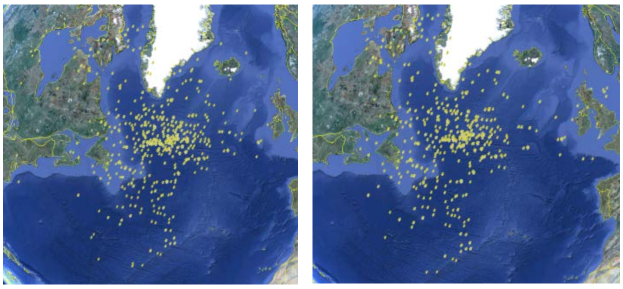

Fig. 2 optimal refueling position for 2500nm cruiser (left) and 3000nm cruiser (right)

In both cases most of the optimal refueling positions lie over the Atlantic in an area south of Greenland between Newfoundland and Ireland. The very small difference between the two cases makes it easier to select feeder bases. Unfortunately the best feeder base location lies on the ocean. Thus the first feeder bases in the transatlantic Scenario are placed around the north Atlantic. Figure 3 shows theses four basic feeder base at Shannon (Ireland), Keflavik (Island), Kangerlussuaq (Greenland) and Gander (Newfoundland).

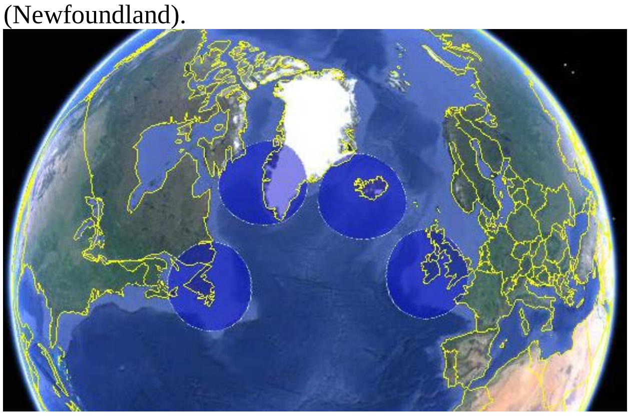

Fig. 3 500 nm radius around the feeder bases at Shannon (Ireland), Keflavik (Island), Kangerlussuaq (Greenland) and Gander (Newfoundland)

In the first test simulation the feeder base at Gander was the most used feeder base. Thus it was reasonable to at a second feeder base in the same area at goose bay. As this feeder base lies more in the north it also serves routes between Europe at the great lake area better than the one at Gander. A sixth feeder base has also been added on the Azores (Lajes) to serve more southern routes from south Europe or the Caribbean area. The last two feeder bases have been added to increase the fuel savings on the routes to east Europe and the American west coast. These feeder bases lie at Churchill Airport in Canada and in Chisinau in the Republic Moldavia.

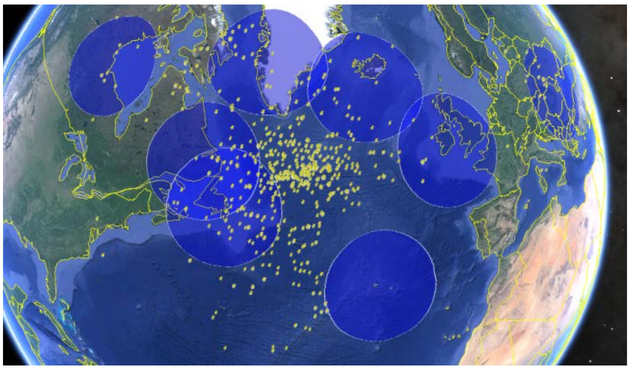

Fig. 4 500 nm radius around the feeder bases at Shannon (Ireland), Keflavik (Island), Kangerlussuaq (Greenland) ,Gander (Newfoundland), Goose Bay (Canada), Lajes (Azores), Churchill Airport (Canada) and Chisinau (Republic Moldavia)

2 Interferences

In the complete scenario cruiser and feeder have full matched trajectories. Furthermore the cruiser trajectories have been optimized to save fuel and ,even if the feeder trajectories are not complete optimal for feeder designed for more than one refueling operation (for scheduling reasons), the feeders trajectories are also designed to use little fuel while serving the cruisers demands. It is likely to expect a system with a lot of aircrafts depending on each other to be at a specific point in a specific time is quite interference-prone. In the following this paper will discuss the impact of different interferences like delays of cruiser and feeder, missing feeders, expected shutdowns of entire feeder bases and sudden shutdowns of entire feeder bases.

2.1 Delays

Delays of cruiser and feeder will be likely the most common interference in the system. Also it is the easiest one to deal with. In case of a one refuel operation feeder the feeder will takeoff while the cruiser is already closing on the feeder base. If the cruiser is delayed the feeder takeoff time could be delayed so the feeder does not need to uses its reserve fuel to wait for the cruiser. On feeder bases with very high workload the runway capacity could cause some problems for the feeder to delay the takeoff and landing time.

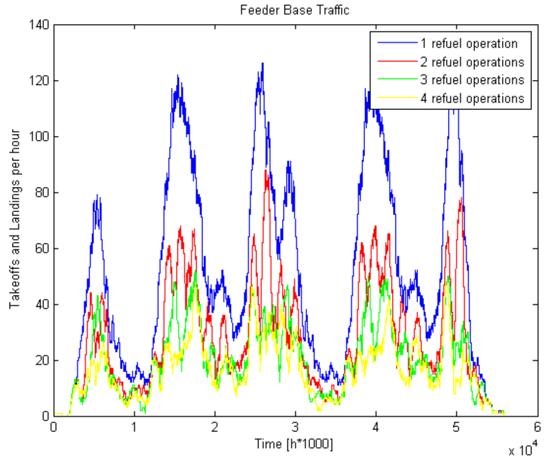

Fig. 5 Takeoffs and Landings per hour at the Feeder base Gander in a Transatlantic Scenario

Figure 5 shows the Takeoffs and Landings per hour of a high traffic Feeder base (Gander). During the peak times it could be seen that the airport would need a lot of runways. Thus a delayed takeoff and landing of one feeder would case more delays for other feeder. As the scenario has already planned a time reserve for the feeder it could be used together with the fuel reserve of the feeder to deal with delayed cruiser. The loss in fuel savings in this situation is noticeable for the single aircraft and very low in the complete. Also the delay will not affect the efficiency and functionality of the overall air to air refueling system.

Paris – Washington with refueling at Gander
(Optimal feeder)

Cruiser step 1 = 2085.24 nm
Cruiser step 2 = 1279.69 nm

Fuel spend = 43,699.4 lb
Fuel spend with 15 minutes delay = 45,227.9 lb

Reference aircraft fuel spend = 47,774.4 lb

Feeder with more than one refueling operation will have to use their reserve fuel to cover the time until the delayed cruiser is arriving. Also the delayed refueling operation off one cruiser will cause a delay for another cruiser. Even if the overall loss in fuel is minor delayed cruisers have a greater effect on Feeders for more refueling operations then on one refueling operation Feeder.
Traffic Systems with feeders for more than one refueling operations on the other hand lead to unoccupied feeders during most times of the day
Thus a feeder free feeder capacity could be used to serve cruisers after the delayed cruiser to cover the regular feeder for these cruisers.
Furthermore are feeders for more than three refueling operations inefficient even in with optimal feeder scheduling (Fig 6). And feeder for three refueling operations will cause delays for a maximum of two following cruiser.

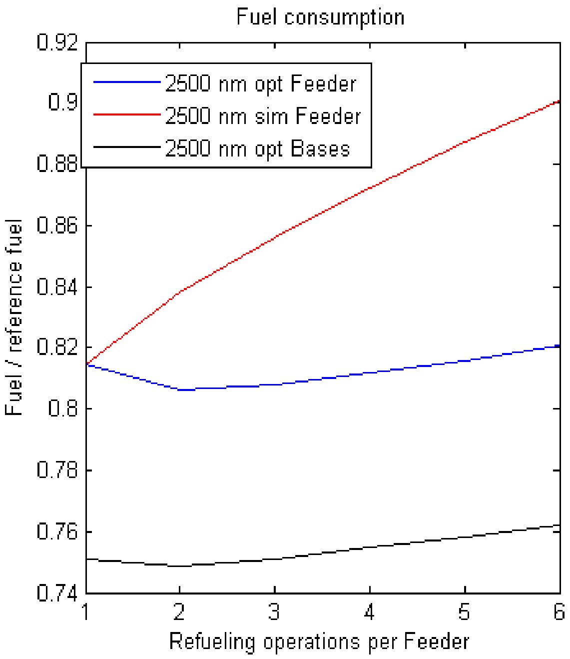

Figure 6 Fuel savings with different Feeder sizes in the Transatlantic Scenario

A delayed Feeder then will always cause a delay for the cruiser and the uses of the cruisers fuel reserve. The effects of delayed multi refueling feeders are the same as described above for delayed cruisers in these cases.

Very high delays on cruiser or an feeder side could result in a situation where the planed feeder could not serve the cruiser. In this case the results will the same as if there is a general failure of one feeder. The following chapter will analyze this situation.

2.2 Feeder Failure

If a feeder cannot serve the schedule cruiser for any reason another feeder has to take over the mission. It is likely that for many reasons every feeder base has to keep some spare feeder for the case of a feeder failure. If the failure is known before the cruiser is approaching the situation could be easily solved by one of the spare feeder or by rerouting the flight over another feeder base (the rerouting option will be discussed in the next chapter).

If the feeder failure appears while the cruiser is already approaching the feeder base it will take some time for a spare feeder to reach the cruiser(17 minutes pure flight time at the Washington – Paris flight).
If the time it takes to get a feeder from a parking position flight ready is added to the time it takes the feeder to takeoff and reaches the cruiser the cruiser will have to land before the feeder will reach it. Thus the cruiser will be served by a feeder planned for another cruiser and so on until a spare feeder is in the position to take over and brakes the cycle. Another option is the rerouting of later cruiser over other feeder bases. This might be useful if a feeder base is already at its limit and an alternative feeder base has some spare feeder left.

The decision if a spare feeder is used or if a cruiser could use an alternative route depends on the time that it would take for either of them to get the system back to its original schedules.

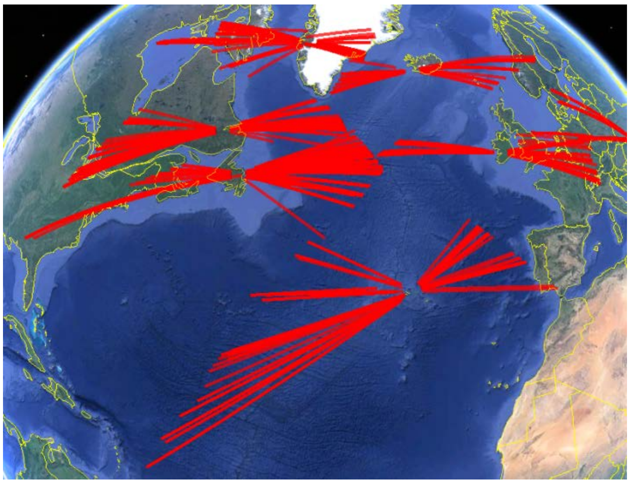

Figure 7 parts of flight where rerouting to another feeder base is impossible

Figure 7 shows the flight parts were a rerouting of the flight is impossible. During this time it is impossible for the cruiser to reach an alternative feeder base. For the calculation the cruiser is not allowed to use reserve fuel and the feeders are not allowed to fly towards the cruiser. A lot rerouting options in these cases will include a return to the last refueling base. From here the cruiser can find an alternative route to its target airport in nearly all cases.

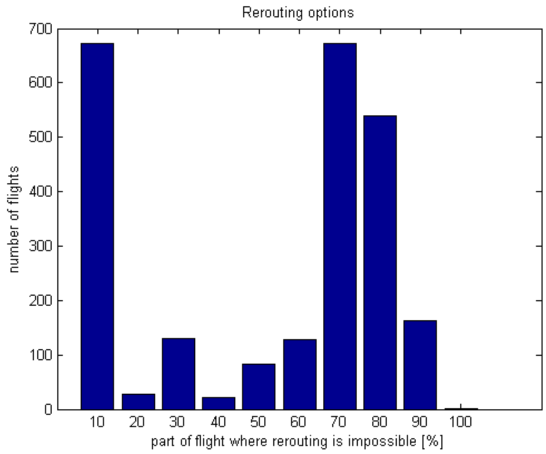

Figure 8 parts of flight where rerouting to another feeder base is impossible (distribution)

As Figure 8 shows that still a lot of flight have the chance to be rerouted during their flight even if that means to return to the last refueling position. The rerouted cruiser will then cause additional refueling operations at the alternative bases with the above discussed effects.

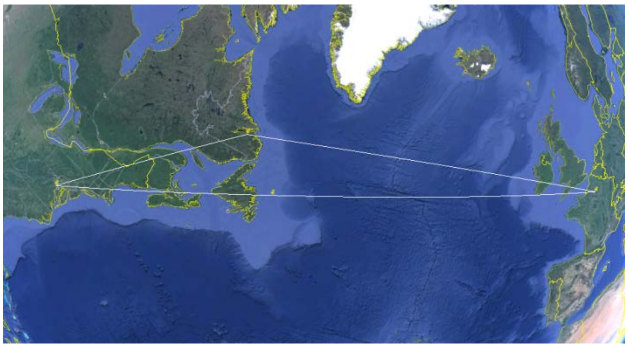

Figure 9 Paris - Washington with refueling at gander with their original route and their alternative route

Most of the alternative routes have only slightly higher fuel cost than the original route. As long as the connection line lies close to the majority of connection enough alternative feeder bases could be used without losing to much fuel. For example the connection

Paris – Washington with refueling at Gander
(Optimal feeder with 2 refueling operations)

Fuel spend = 43,480.9 lb
Fuel spend with refueling at Goose Bay= 44,442.0 lb

Reference aircraft fuel spend = 47,774.4 lb

These fuel efficient alternatives could only be used if the rout has been rerouted before the cruiser has taken off. If a cruiser could be rerouted during the flight the alternative route will lead to a much higher detour and in the end much higher fuel consumption then the direct route.

Paris –notification of missing feeder = 1,000 nm
(Goose Bay is not reachable with the cruisers fuel)
Notification of missing feeder – Shannon = 529.70 nm
(Washington out reach for a 2500nm Cruiser)
Shannon – Goose Bay = 1,826.61 nm
Goose Bay – Washington = 1,110.88 nm

Fuel spend = 60,446.5 lb

Reference aircraft fuel spend = 47,774.4 lb

Some rerouting options make an additional feeder at the alternate base necessary if the cruiser arrives during the peak hours of the feeder base. During other times the normal feeder base capacity will be enough to serve an additional cruiser. Short term rerouting will nearly always make additional feeder or delays for the following cruiser necessary.

2.3 Temporary unavailable Feeder Base

In some cases (e.g. Thunderstorm) a feeder base will be completely unavailable for a period of time. In general an unavailable feeder base will affect the refueling network as a high number of missing feeder without the option of a reserve feeder from the same feeder base. Thus rerouting is the only option the serve cruiser originally planned for this feeder base. Furthermore a high number of rerouted cruisers will affect the other feeder bases much higher than a single rerouted cruiser.

As in the previous cases the effects depend on the time left for the rerouting. Thus the following will describe two different cases. In the first case it is long known that the feeder base will be unavailable at the specific time. In the second case the feeder base is suddenly unavailable and all flights get informed at the time the feeder base gets unavailable.

2.3.1 Planned unavailable Feeder Base

In this case the cruisers will use an alternative rout without the unavailable feeder base. While the rerouting will have only low effects on the fuel savings (table 1) it will make a huger number of feeders necessary at the alternative feeder bases.

3 hours Block at	Rel. Fuel spend
Gander	100,01 %
Goose Bay	100,05%
Lajes	100,03%
Keflavik	100,00%

Table 1

The following Figures (Fig 10-13) shows the number of necessary feeder at all feeder bases in a scenario with a 3 hours block at different feeder bases. In each feeder base only one feeder base is block for 3 hours.

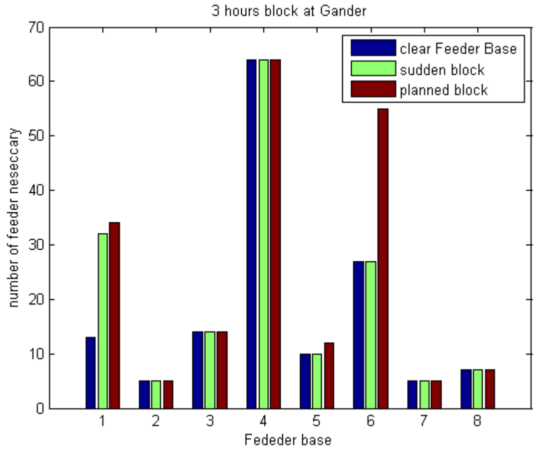

Figure 10 Number of necessary feeders at Feeder Bases (1 Shannon, 2 Keflavik, 3 Kangerlussuaq, 4 Gander, 5 Lajes, 6 Goose Bay, 7 Chisinau and 8 Churchill) with a 3 hours block at Gander

Gander is the feeder base with the highest traffic in the scenario. Thus a three hours block effects a lot of other feeder bases. In case of a planned unavailable feeder base the number of necessary feeder at Goose Bay nearly doubles (from 27 to 55). While Shannon needs only 13 feeders during a normal simulation run the number rises to 34. Even the small feeder base at Lajes needs 2 additional feeders (from 10 to 12). 51 additional feeders will be needed at other feeder base to cover 3 hours traffic from gander. It might be necessary to delay the takeoff of some cruiser for a better distribution of the additional cruisers at the other feeder bases and reduce the number of additional feeders.

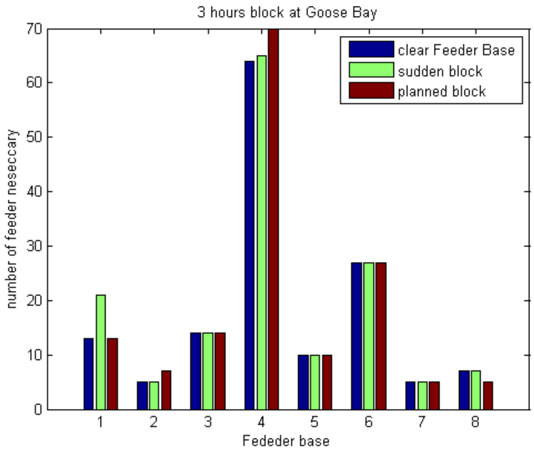

Figure 11 Number of necessary feeders at Feeder Bases (1 Shannon, 2 Keflavik, 3 Kangerlussuaq, 4 Gander, 5 Lajes, 6 Goose Bay, 7 Chisinau and 8 Churchill) with a 3 hours block at Goose Bay

Goose Bay is the second largest feeder base in the scenario. Still the effects are much lower than with the 3 hours block at Gander. Most of the rerouted traffic will be served at Gander where 6 additional feeders are needed. Keflavik will also need an additional feeder while Churchill saves one feeder in the rerouted system.

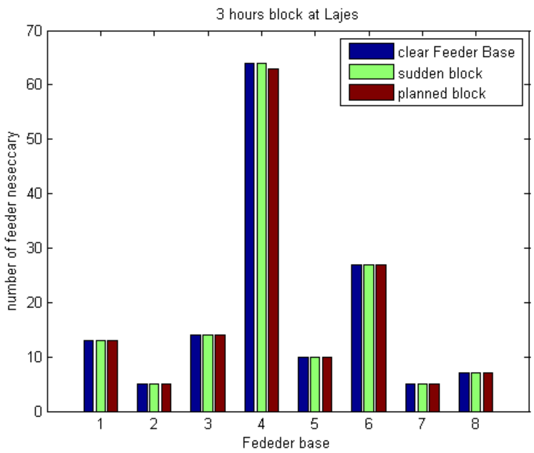

Figure 12 Number of necessary feeders at Feeder Bases (1 Shannon, 2 Keflavik, 3 Kangerlussuaq, 4 Gander, 5 Lajes, 6 Goose Bay, 7 Chisinau and 8 Churchill) with a 3 hours block at Lajes

Lajes is a very small feeder base. Thus the rerouting does not male additional feeders at other bases necessary. Furthermore Gander saves one feeder with the new schedule in the rerouted system.

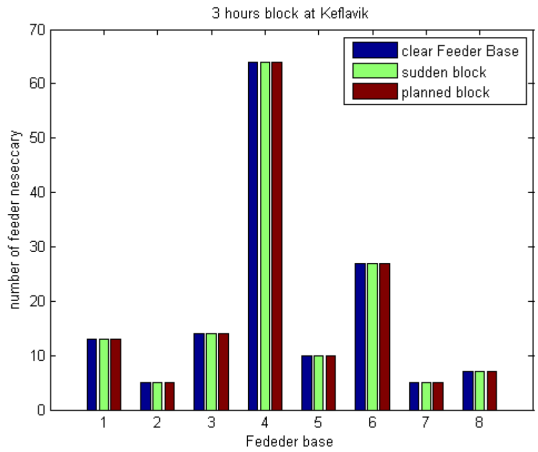

Figure 13 Number of necessary feeders at Feeder Bases (1 Shannon, 2 Keflavik, 3 Kangerlussuaq, 4 Gander, 5 Lajes, 6 Goose Bay, 7 Chisinau and 8 Churchill) with a 3 hours block at Keflavik

Keflavik is again a very small airport and the rerouted system could be solved without additional feeders.

2.3.1 Suddenly unavailable Feeder Base

In the second case some cruiser will not have the time to reroute over another feeder base or will have to fly back to their last feeder base and reroute from there. The feeders without the chance to reroute will land at an alternate airport. The rerouting the other flights will be highly inefficient as they will not be able to use a fuel efficient alternate route. Only if the feeder base is unavailable for some hours some cruiser will be able to reroute before the takeoff

Sudden 3 hours Block at	Aborted flights
Gander	44
Goose Bay	12
Lajes	11
Keflavik	0

Table 2

Tablle 2 shows the number of aborted flights in the different scenarios. As Gander is the feeder base with the highest traffic it also lead to the most aborted flight in the moment it becomes unavailable. Goose Bay and Lajes lead to a similar number of aborted flights. During the 3 hours where Keflavik is unavailable no flight needs to be aborted. In the first hours of the blocking event no flights have been scheduled to be refueled at Keflavik. Thus all flights could be rerouted.

Figure 10-13 also show that a sudden block at a feeder base leads to a different rerouting system. Most Reroutes flight from Gander uses Shannon as alternative feeder base while Goose Bay is not used as it is not reachable for the cruiser in this situation. Cruisers for Goose Bay also use Shannon in the sudden block scenario while they prefer Gander in the planned scenario.

3 Summary and conclusions

The simulations have shown that the system has problems solving sudden events on the feeder side. While it is possible to balance a single missing feeder with the use of other feeder and delays on several cruisers a higher number of missing feeder or a suddenly unavailable feeder base will nearly always lead to alternate landing for the cruiser.

With some lead-time to the event nearly all flights could be rerouted. Short time rerouting will result in much higher fuel consumption and a high delay on the cruiser side but the cruiser could reach the target airport. Rerouting before the cruisers take off will use only slightly less efficient route without more disadvantages for the cruiser.

On the other side will rerouting lead to a much higher number of necessary feeders at some feeder bases especially when a main feeder base is not available for several hours. To solve this situation some feeder bases would need more standby feeder than the number of feeder the use during normal operations. The simulations have also shown that the main feeder base could cover traffic from other feeder bases with only some additional feeders.

To solve this situation it could be reasonable to choose a feeder base with lower traffic during the optimization phase even if the results in fuel saving is slightly worse. Thus the cruisers distribution over the feeder bases could be more even without a single outstanding feeder bases as in the current transatlantic scenario with completely fuel optimized routing.

4 References

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