FUTURE AIR GROUND INTEGRATION: A SCALABLE CONCEPT TO START WITH GREEN APPROACHES TODAY

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Abstract

Today, the usage of highly efficient flight procedures often lacks on the missing integration between air and ground based tools. Typically, modifications on both airborne and ground side are necessary to fully benefit from new technologies. Furthermore, modifications are usually expensive and therefore only implemented if the counterpart also invests in the corresponding work. This paper describes a scalable concept to allow green 4D-flight procedures in a mixed equipped traffic environment even in high traffic situations. Furthermore, the final results from the FAGI project (2007-2009) are introduced.

1 Introduction

The two major Air Traffic Management (ATM) programmes SESAR and NextGen initiated by Europe and the United States, respectively, foresee 4D-trajectory based operations as one of the key elements of the future ATM [1,2]. The expected benefits are

- Predictability of trajectories in advance allowing early planning of operations
- Safety benefiting from well known positions of aircraft for each moment in time
- Improved cost efficiency and less environmental impact by optimizing routing, vertical profiles, and fuel burn for single aircraft and the global traffic situation.

The big challenge of deployment is not delayed by nonexistent technology but today's missing integration of air and ground based tools. Furthermore, the lack of a transition process towards efficient trajectory based operations delays expensive upgrades of airborne and ground based tools.

In 2007, DLR launched the project "Future Air Ground Integration" (FAGI) introducing trajectory based TMA operations to combine aircraft optimized flight profiles with a high airport throughput. The FAGI concept distinguishes aircraft by their equipage:

- Aircraft equipped with a 4D-Flight Management System (FMS) are capable to predict and fulfill 4D trajectories board-autonomously.
- Conventional equipped aircraft without an onboard 4D-FMS are incapable of high precision board-autonomous 4D-guidance.

The achieved goal of FAGI was to let equipped aircraft make efficient usage of their equipage without penalizing conventional aircraft and airport's throughput.

2 FAGI Concept

FAGI tries to solve today's trade-off between capacity and environmental sustainability. A time based late merging allows aircraft to fly their preferred trajectories by staggering them laterally in an extended terminal manoeuvring area with a time constraint to be fulfilled at a late merging point (Fig. 1). According to a study performed by Eurocontrol [3] one out of nine aircraft is capable of reaching time constraints with an accuracy of +-6 seconds.

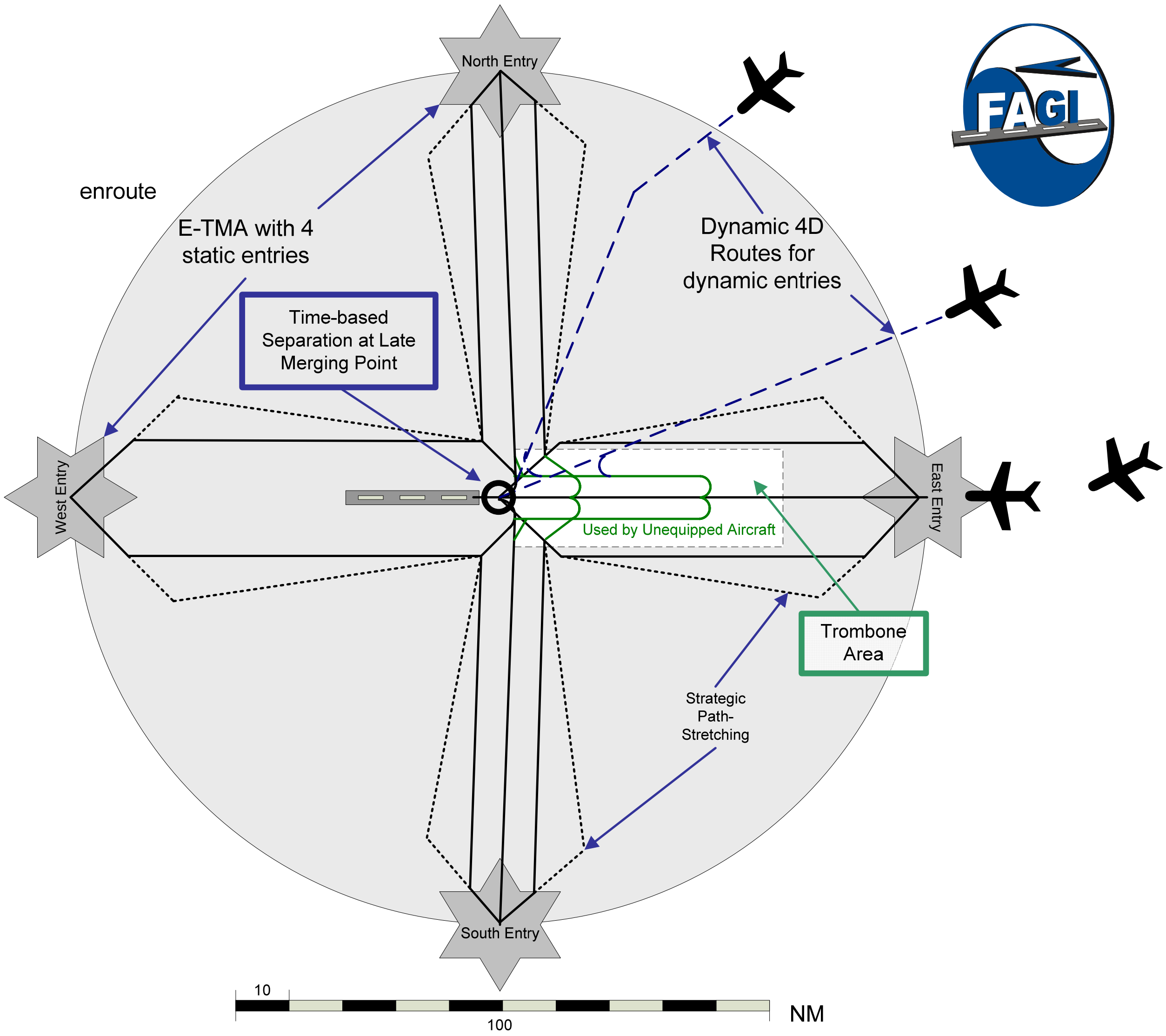

Fig. 1: A FAGI route structure with four entries

Due to their high navigational accuracy 4D-capable aircraft are able to follow their predicted flight path on their own. Unequipped aircraft are supposed to be integrated by means of a ground based 4D-guidance module [4]. The proposed concept integrates 4D-equipped aircraft in the normal traffic flow without losing aircraft throughput.

When entering the extended TMA, a time constraint for the merging point is assigned to each aircraft. Figure 1 depicts an example E-TMA route structure with four static entries aligned north, south, east and west. The late merging point is located in the center, just before the final approach. The early assignment of time constraints enables arriving aircraft to fulfill the requested time in an efficient way, i.e. speed adaptation. Therefore, the extended TMA is rather big (80-120NM radius). If speed variation is not enough to reach the constraint, strategic path stretching (the dotted lines) is supposed to delay the aircraft further. Parallel routes from every entry point to the late merging point enables fast aircraft to outrun slower ones until merging. Aircraft not entering near a static E-TMA entry are guided by means of dynamic routing.

Depending on the equipage, there are two different approaches possible:

- 4D-equipped aircraft are able to generate their own optimum 4D-trajectory board-autonomously. They fulfill a ground predicted time constraint at late merging with high precision, ideally without any interventions after the negotiation process with ground control. Equipped aircraft fly the direct routes to the late merging point. Aircraft violating their contract with ground control are supposed to be degraded to unequipped aircraft and thus follow the trombone routing

- Unequipped aircraft are not able to fulfill the given constraints on their own. Therefore, they are supposed to be guided by a ground based 4D guidance system. The ground-based guidance system generates speed vectors and, if necessary, also shortcuts to reach the target time. To get them precise in time at the merging point, they are guided along a trombone approach allowing very late correction of merging times.

Aircraft flying the trombone can be delayed to allow insertion of short term departures and simplify handling of emergency situations.

Fig. 2 depicts two aircraft approaching the late merging point. The aircraft at the top is conventionally equipped and flies the standard trombone route. The other aircraft is 4D-equipped flies the direct route to the late merging point. Both aircraft are separated in time when merging.

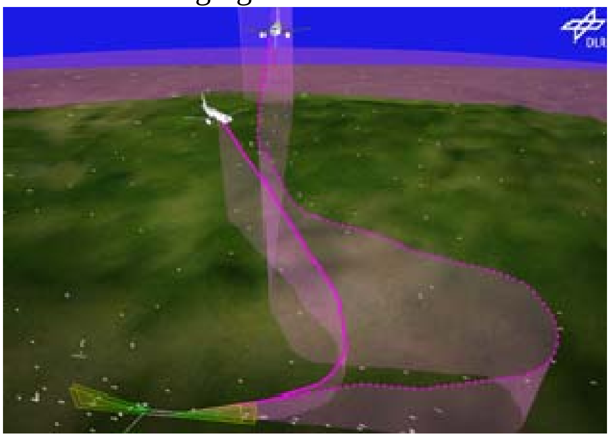

Fig. 2: Two aircraft – two approach routes

3 Simulation Setup

Human-in-the-loop simulations were performed using a generic airport layout with one runway to validate the concept's feasibility. The FAGI route structure had four static entries, with one of them being aligned to the landing direction. The simulated scenarios contain 33-36 aircraft with 10%-90% of them being FMS equipped; simulation time was one hour. To keep the number of variable parameter low, an equipage degree of 30% was selected for the human-in-the-loop real time simulations, 10%-90% were used for automatic runs only.

During the project's term, aviation stakeholders like air traffic controllers and pilots have been involved periodically by means of workshops and preliminary simulations. In the end of 2009, real time simulations (RTS) were conducted with four teams of international professional air traffic controllers.

The system hosting the RTS is depicted in Fig. 3. Core of the simulation is a powerful traffic simulation tool (right lower corner) performing a motion simulation for multiple aircraft. The tool incorporates support for more than thousand aircraft of mixed equipage flying interactively at the same time. FMS-equipped aircraft are simulated with onboard 4D-FMS that follow their predicted trajectory on their own.

The underlying FMS is DLR's generic advanced flight management system (AFMS). The AFMS is based on BADA [5] and therefore supports all 295 aircraft models listed in BADA version 3.6, an update to version 3.8 is in progress. In addition to the desired route containing altitude-, time- and speed-constraints a vertical flight profile can be chosen to generate an appropriate 4D trajectory.

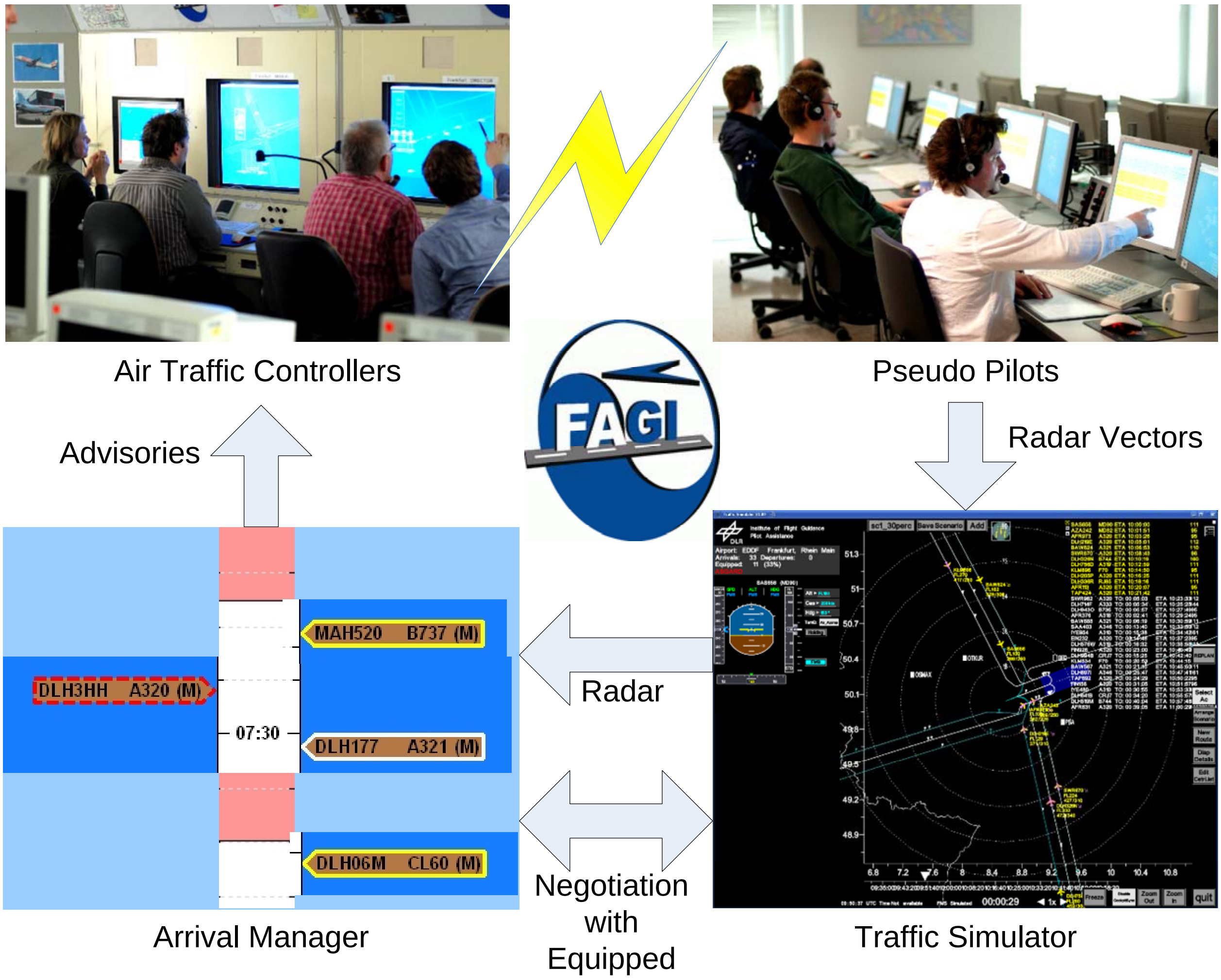

Fig. 3: Setup for the FAGI Real Time Simulations

Supported profiles are

- Low drag low power (LDLP) approach with an intercept level,
- Continuous descent approach (CDA) without intermediate level on descent, see Figure 3.
- and Segmented continuous descent approaches (SCDA) with a steep descent segment achieved by early gear and flaps extraction. This results in higher altitudes and therefore higher damping of noise but increases airframe noise. SCDA profiles were not used in the FAGI trials.

All three implemented descent procedures can be adjusted by a set of parameter (altitudes and lengths of levels). The profiles have in common that

- Descents are performed with engines idle. Thus, sink rate and flight path angle are not necessarily constant while descending. Idle thrust does not only reduce noise emissions of the engines but also reduces noise immissions on the ground and fuel consumption due to higher and therefore more economical flight profiles.
- The vertical profile can be specified independently of the lateral path. This enables the implementation of special procedures like curved approaches.

The AFMS proved high realism and accuracy during runs on a level D certified A330 full flight simulator and real flight trials with DLR's ATTAS (a modified VFW614) and ATRA (a modified A320), that is the newest member of DLR's research fleet, see Fig. 4 and Fig. 5.

Fig. 4: DLR's new Airbus A320 called ATRA

Fig. 5: First flight trials with AFMS in ATRA

In order to cope with the new demands, the question how human operators can be supported in performing the described tasks in the best way is crucial. New automation in terms of advanced 4D-arrival managers (AMAN) is necessary to help the controller with appropriate time-based planning functions for all aircraft. Therefore, another key module besides the traffic simulator in the RTS is the arrival manager called 4D-CARMA depicted in the left lower corner of Fig. 3.

4D-CARMA permanently analyses the traffic situation and produces advisories for highly efficient guidance of all aircraft. It is also responsible for putting the arriving aircraft onto the FAGI route structure and building an arrival sequence. The AMAN is supposed to assist the controller to achieve an efficient flow of traffic. Once successfully negotiated a requested time of arrival with an equipped aircraft the AMAN avoids touching the aircraft again in order to ensure high efficiency. Unequipped aircraft are handled much more flexible. They are rescheduled when necessary, e.g., when the AMAN needs to adapt to a controller's decision. The air traffic controllers are supported by means of

- Ghosting (i.e. projection) of equipped aircraft to the centerline assists the controller in filling the gaps between the equipped aircraft (see also [6]).
- The optimal position for unequipped aircraft on the centerline is provided using targets.
- An advisory stack assists the controller especially with speed control and turn advisories on the trombone.

The main task of the participating air traffic controllers (upper left on Fig. 3) was to separate the more flexible unequipped aircraft from the 4D-capable aircraft that had a rather fixed trajectory from top of descent at latest. They were assisted by means of a timeline providing the arrival sequence and times, an advisory stack providing advises on how to guide the unequipped aircraft, and ghosting/targeting of traffic onto the centerline.

Closing the loop, several pseudo pilots simulated the pilots and entered the given controller instructions back into the system.

Implementation of the proposed concept promises

- Improved flight efficiency due to more efficient (direct) routes
- Less fuel burn and less noise for equipped aircraft flying aircraft optimized profiles
- Less delays due to high mid-term predictability
- Increased usage of user preferred trajectories
- Less workload for controllers and pilots

4 Scenario Setup

Using the simulation setup above, several real time simulations have been carried out. Four teams of controllers were asked to operate the FAGI concept each for 3-4 days. Objective data was collected during the simulations by recording all aircraft movements, predicted trajectories, given vectors, on-screen inputs and in-trial measurement of situation awareness. Furthermore, subjective data was collected by means of questionnaires and debriefings.

To allow quantifiable analysis of data, all controller teams also handled a baseline scenario. All aircraft in the baseline scenario were set to 4D-incapable equipment. Therefore, all aircraft were guided along the trombone approach, just like today's operations at many international airports during high traffic hours.

The FAGI concept itself was operated in two different ways: with ghosting only and a combination of ghosting and targeting. Since there is a considerable difference between aircraft's arrival speeds, ghosting was an often discussed issue with controllers. A distance based mapping of the real aircraft is of no help for the controller because the 4D-equipped aircraft fly higher speeds and the ghosts would overtake the unequipped aircraft on the final to achieve proper separation.

To profit from the ghost's position when merging the traffic, the speeds on the finals should be the same for equipped ghosts and unequipped aircraft. Therefore, all ghosts are calculated to fly a speed profile averaged from unequipped aircraft on the final. A good choice is 240kts on the final with a deceleration of 0,75kts/second down to 180kts at the late merging point, all speeds being ground speeds. See Fig. 6 for a zoom of two equipped aircraft and their ghosts on the final. All controllers affirmed a proper mapping of equipped aircraft to the final and did a convincing job filling the gaps between the ghosts with unequipped aircraft.

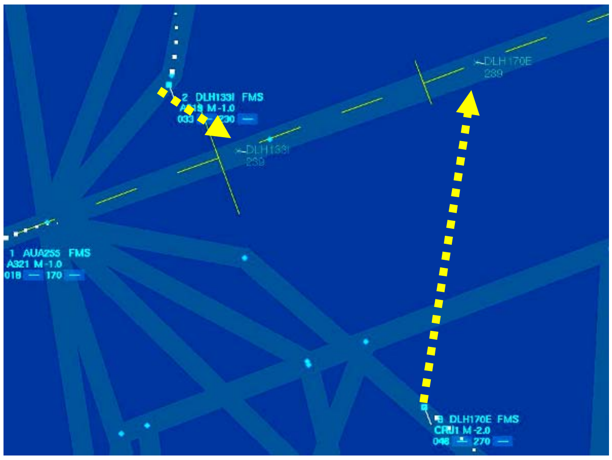

Fig. 6: Ghosting of two Lufthansa

Since the arrival manager calculates 4D trajectories for every participating aircraft, also targeting seems to be a feasible technique to improve situational awareness. In contrast to ghosting, targeting does not map equipped but unequipped aircraft to the centerline. Instead of filling the gaps between ghosts controller's job would be to guide aircraft to meet their own target. This procedure would especially be robust against heterogeneous airspeeds but puts greater demands on a stable trajectory prediction.

5 Results from Real Time Simulations

The first and most important result from the RTS debriefings was that all participating controllers confirmed a general feasibility of the FAGI concept even with the higher traffic setting of 36 aircraft an hour.

Both measurements during the trials (Fig. 7) and evaluation of the post-trial questionnaires (Fig. 8) indicated a reduction of controllers' workload using the FAGI concept compared to the baseline scenario. In particular, the workload was reduced for high traffic conditions.

One reason for the reduction was the 4D-contract with 4D-capable aircraft. Cleared for their green approach, there was no need to give further vectors. This also reduced the load on the voice channel.

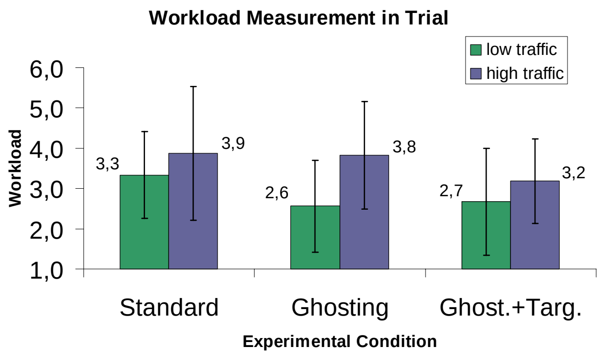

Fig. 7: Workload measurement in trial

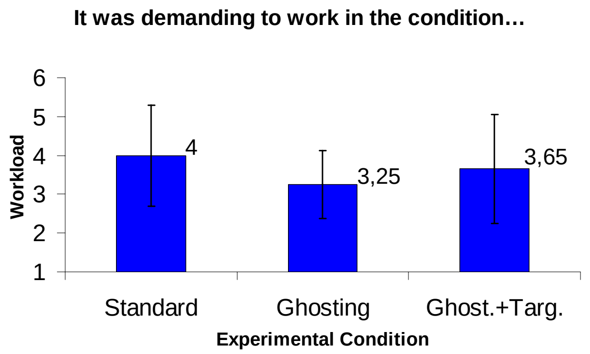

Fig. 8: Workload according to questionnaire

Having a look at the approaches carried out, a significant higher altitude profile was flown by 4D-capable aircraft (Fig. 9). This results in more efficient flying due to leaving aircraft's cruise flight level later. Consequently, the aircraft is further away from ground and the noise generated by the aircraft is damped down.

In addition, since equipped aircraft fly their descents with engines idle, aircraft also produce less noise (Fig. 10). While unequipped aircraft need thrust for flying intermediate level segments, equipped aircraft still fly an idle descent. Of course, idle descents also save fuel and thus burn less CO_2.

After reaching the late merging point (LMP, the red line in Fig. 10) the engine usage is quite similar for equipped and unequipped aircraft. Thus, the position of the LMP is essential. The trade-off for late merging is having all aircraft stabilized later on the centerline. The FAGI concept's 6 nautical miles to touchdown position (i.e., 2300 feet above ground assuming a glideslope angle of 3°) were judged as uncritical.

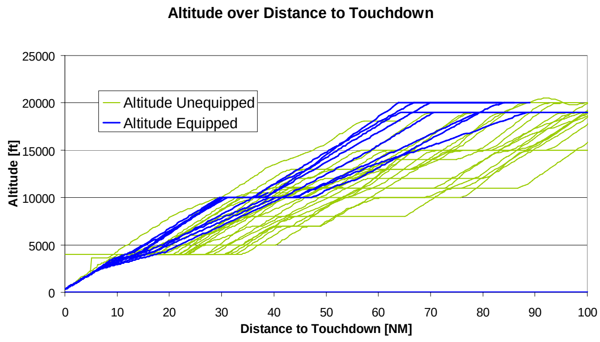

Fig. 9: Equipped aircraft fly higher altitudes

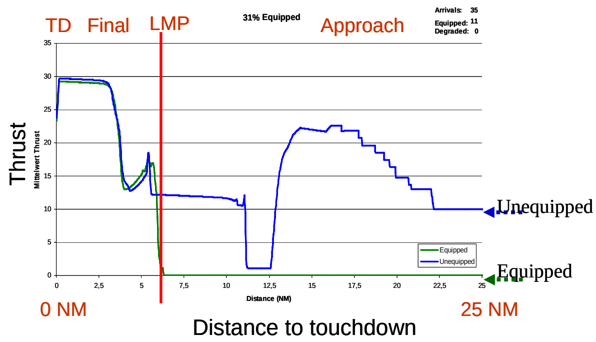

Fig. 10: Lower engine usage for equipped

As described above, the number of variable parameter was limited to avoid overloading of the simulation trials. Nevertheless, especially the number of equipped aircraft is a very important parameter:

- How many equipped aircraft are needed to get benefit?
- How does benefit improve with more equipped aircraft?
- How can unequipped aircraft be handled with more and more equipped?

To answer these questions, further simulation runs were performed in an automatic mode. The automatic mode trials used exactly the same simulation platform as the RTS, but without human actors. Instead, the advisories from the AMAN were fed directly into the traffic simulation, as depicted in Fig. 11.

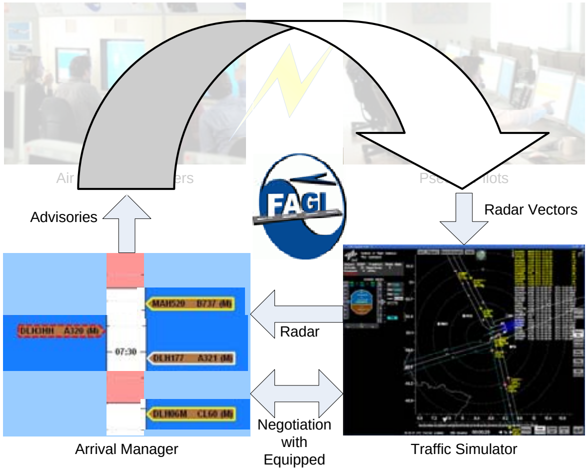

Fig. 11: Automatic mode with direct feed of advisories

The results from the automatic runs with different degrees of equipage are depicted in Fig. 12 and Fig. 13. Both pictures show the general trend of improving the situation not only for the equipped but for all aircraft. The cyan bars represent the equipped aircraft, the grey bars the unequipped, and the blue bars the whole traffic mixture. The plain-colored bars represent the (best) nominal profile without surrounding traffic; the shaded areas on top of the plain bars depict the overhead generated from ATC instructions.

Obviously, the gain (of time and fuel) is higher for 4D-capable aircraft, but it is remarkable that the unequipped aircraft are not penalized by shortcutting the equipped.

As expected, the gain increases with an increasing number of equipped aircraft. A little surprising is the gradient of the blue average line getting flatter. It means that high overall benefits can be reached with few equipped aircraft already; on the other hand equipage of the last remaining unequipped aircraft does not improve efficiency that much.

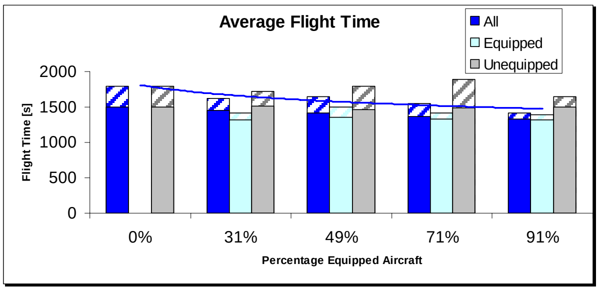

Fig. 12: Average Flight Time

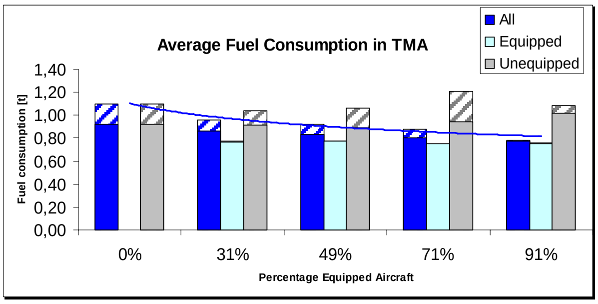

Fig. 13: Average Fuel Consumption

6 Summary

This paper presents the FAGI concept and its promising results. The generic concept is fully scalable based on the equipage degree. Since the concept does not penalize FMS-unequipped aircraft (compared to today's operation) the overall system performance benefits from every single aircraft flying advanced approach procedures. Thus, even with a small percentage of 4D-capable aircraft traffic is handled more efficiently and environmentally friendly.

The real time simulations and several fast time simulations proved the high potential and feasibility of the FAGI concept.

Next steps in a follow-up project will be to include departures and overflights as well as satellite airports in the simulation. Furthermore, simulation of real traffic and adaptation of the FAGI route structure for a real airport are envisaged. The promising results from the FAGI project encourage establishing the concept in the real world.

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