D6.7: ATM AND AIRPORT CHALLENGES OF HYBRID ELECTRIC AIRCRAFT INTEGRATION

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TABLE OF CONTENT

LIST OF FIGURES

Glossary

Acronym	Signification
ATM	Air Traffic Management
BADA	Base of Aircraft Data
ECAC	European Civil Aviation Conference
FL	Flight Level
HEP	Hybrid Electric Propulsion
Nmi	Nautical Miles
REG-R	Radical Regional
SMR	Short-Medium Range

1. INTRODUCTION

The primary goal of the IMOTHEP EU-funded project was to achieve a key step in assessing the potential of hybrid thermal-electric propulsion (HEP) for reducing commercial aircraft fuel consumption beyond the performance of conventional propulsion technologies projected to 2035. Technical objectives included identifying propulsion architectures and associated aircraft configurations for which HEP brings a benefit and investigating the most promising technologies for components of a hybrid propulsion chain. The final objective was to propose a research and technology roadmap for the maturation of hybridization for commercial aircraft.

IMOTHEP investigated four aircraft configurations, their power train architecture, and associated components for regional and short-medium range (SMR) missions. Results indicated that hybridization is not viable for SMR aircraft in the short to medium term, with significant technical challenges pushing the emergence of operational aircraft beyond 2035-2040. However, for regional aircraft, a promising configuration was identified that exceeds the project's initial targets. The fully electric aircraft with a thermal range extender ("plug-in" hybrid) offers unrivaled energy efficiency over a 200 nautical mile (Nmi) typical mission and still achieves fuel burn reduction in extender mode over a 600 Nmi mission. Other configurations, such as turboelectric power trains and parallel hybrids, showed limited benefits.

IMOTHEP aimed to question regulatory and operational impacts of the different aircraft concepts elaborated in the previous investigations. The operational impacts concerned the integration of hybrid electric aircraft in air space, for which the objective was to identify air traffic management (ATM) and airport technical and operational challenges associated to the integration of hybrid electric aircraft in the European Network.

Performance characteristics of hybrid aircraft may differ significantly from those of aircraft populating today the European sky. The objective is to identify the new challenges introduced by HEP in terms of trajectory, connectivity, and ATM performances, and to assess their impact, also in terms of aviation’s environmental footprint, for different operations scenarios in the European Network, using and complementing notably EUROCONTROL’s BADA database. These initial results could then be fed into SESAR framework where appropriate ATM measures could be developed and validated.

For this purpose, EUROCONTROL initially intend to perform the following activities:

- Modelling of the performance of the different configurations of aircraft developed in IMOTHEP to ensure compatibility with the EUROCONTROL aircraft performance database (BADA).
- Development and performance of a fast-time simulation scenario for the operational integration of hybrid aircraft in a congested terminal area, for a given European airport.
- Development and performance of a fast-time simulation scenario for the operational integration of hybrid aircraft in en-route, for a specific European city-pair for which the trajectory crosses highly congested airspace.
- Assessment of the fast-time simulations results, from an environmental impact perspective but also from an ATM Network performance perspective.

The results from IMOTHEP investigations concluded that one hybrid concept was promising in terms of CO_2 reduction, but not the others.

In this context, EUROCONTROL investigated air traffic management (ATM) and airport challenges of hybrid electric aircraft integration focusing on the most promising configuration, the radical regional aircraft concept (REG-R).

The methodology aims to compare two different traffic forecasts in 2035: one based on traffic evolution trends from ATR aircraft operations in 2010 and 2022, and the other on the introduction of the REG-R, replacing two-thirds of ATR flights in 2022. The comparison focuses on the flights below 200 Nmi, flights below 600 Nmi, network coverage, societal challenges, and market opportunities. The analysis highlights potential benefits and identifies key challenges associated with this transition.

The paper exposes the impacts of introducing regional hybrid-electric aircraft on ECAC air traffic by 2035, assuming a replacement of ATR42 aircraft types only.

2. WORK PERFORMED

For the analysis, the consolidated results from the technical analysis about the hybrid aircraft concepts are necessary.
In the meantime, EUROCONTROL developed a strategy to identify the actual effort and studies that could be done after receiving the inputs about the hybrid aircraft concepts.

The strategy was to:

- Model hybrid aircraft concepts;
- Run an ATM simulation with the new hybrid concepts;
- Run an airport simulation with the new hybrid concepts;
- Make an analysis of the results.

2.1. INVESTIGATIONS AND RESULTS ON MODELLING OF THE PERFORMANCE OF THE DIFFERENT CONFIGURATIONS OF AIRCRAFT

According to the results from IMOTHEP's preliminary work, the REG-R concept is the only promising one of the four concepts, based on the reduction of CO_2 emissions. Consequently, the work focused on the REG-R concept only.

In collaboration with DLR, which provided the requested REG-R data for the aircraft modelling by EUROCONTROL, an aircraft performances profile for a typical mission over 200 Nmi could be established.

This performances profile focuses on the vertical flight profile and the aircraft speed profile.

Current limitations on our aircraft model led to a double model of the aircraft, a first one for the electric mode, represented as IMOE, and the second one for the thermal mode, called as IMOH.

The methodology was to establish a performance profile for different mass assumptions:

- LOW: a scenario in which the aircraft is initially 5% heavier than the lowest REG-R possible mass. This depicts a situation with at least some fuel embarked on for the thermal range extender.
- NOMINAL: a scenario in which the aircraft departure weight is equal to its nominal value.
- HIGH: a scenario in which the aircraft is fully loaded for the departure phase.

The results on modelling of the performance of the REG-R concept consider a comparison with ATR42 and ATR72 performances.
The typical ATR42 aircraft that was selected for the comparison is the ATR42-500, and the ATR72-500 was chosen for the ATR72 family.

The LOW scenario for the ATR aircraft considers a +20% mass for the take-off. This is different than the 5% assumption for the hybrid aircraft because of the higher volume of fuel to embark.

The main difference between the ATR42 and ATR72 family resides in the mass of the aircraft and the passenger capacity, physically represented with an extended airframe.

REG-R LOW Mass Performance Profile

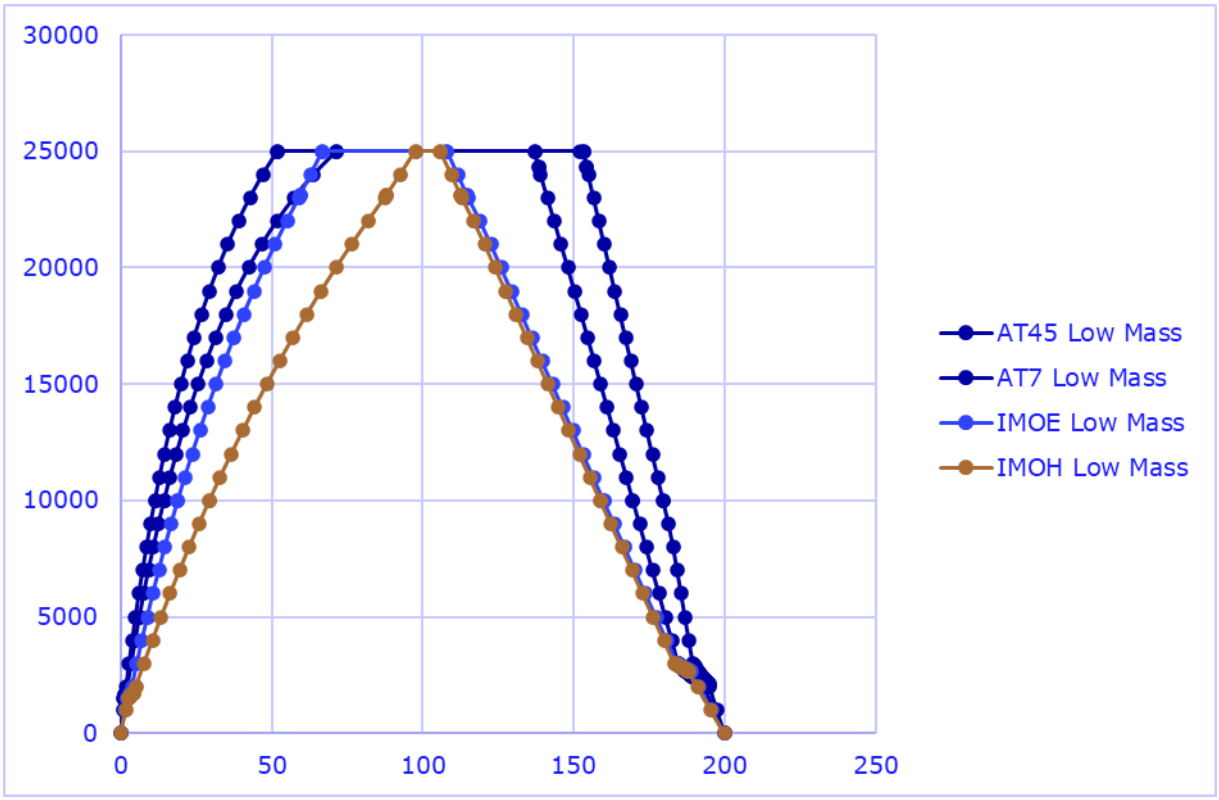


Figure 1: REG-R low mass vertical profile for a 200 Nmi mission.

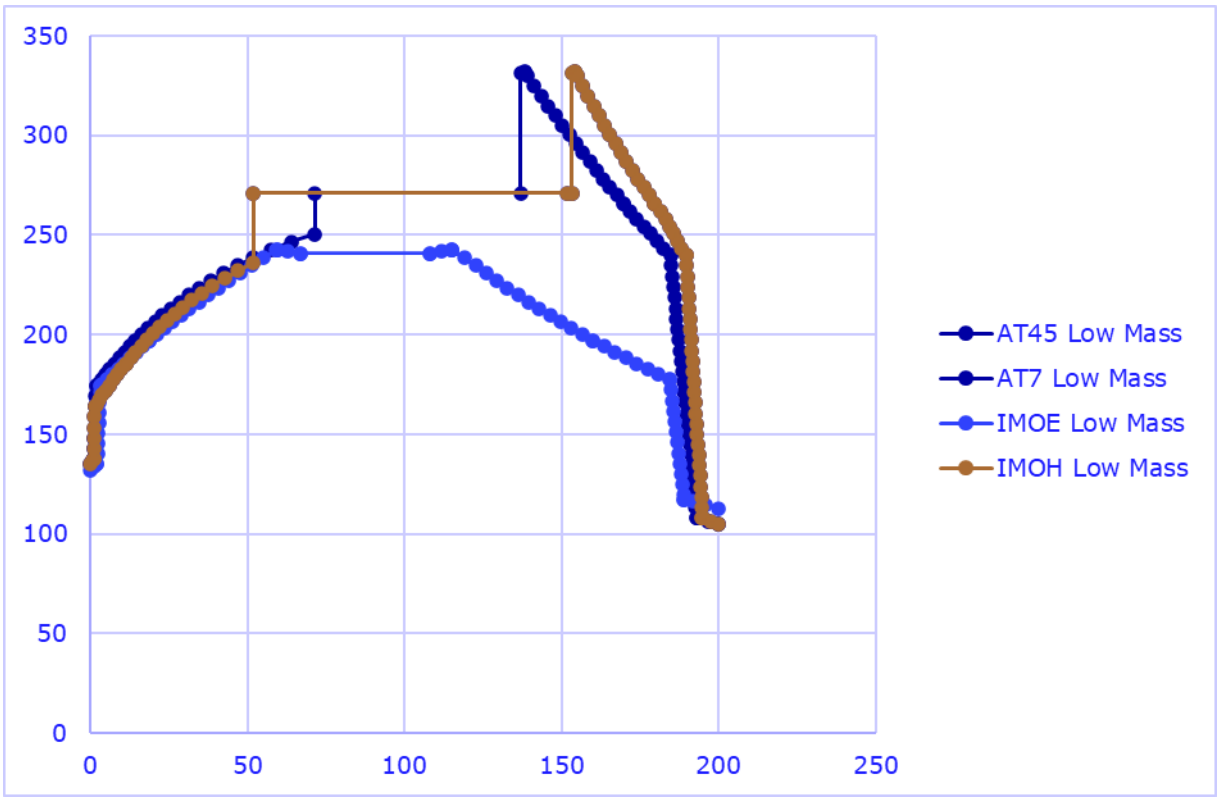


Figure 2: REG-R low mass speed profile for a 200 Nmi mission.

The IMOH and AT45 speed profiles are exactly the same.

REG-R NOMINAL Mass Performance Profile

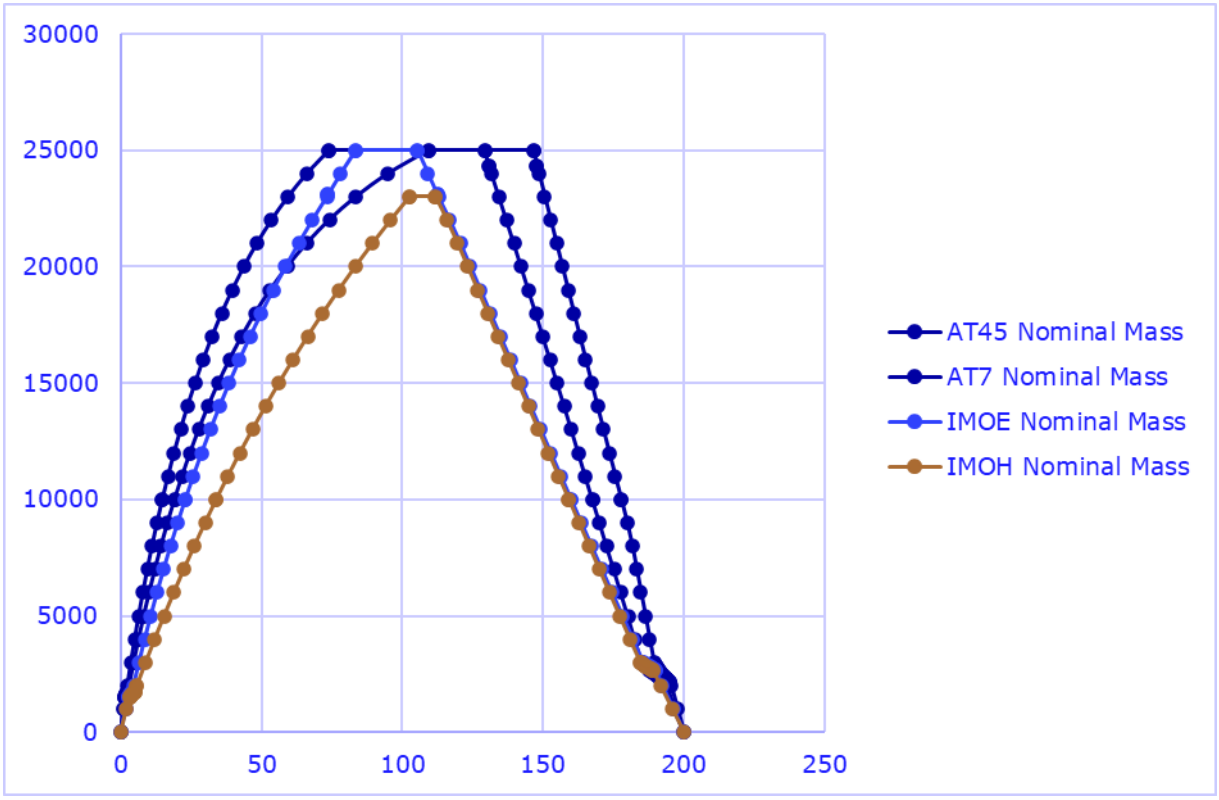


Figure 3: REG-R nominal mass vertical profile for a 200 Nmi mission.

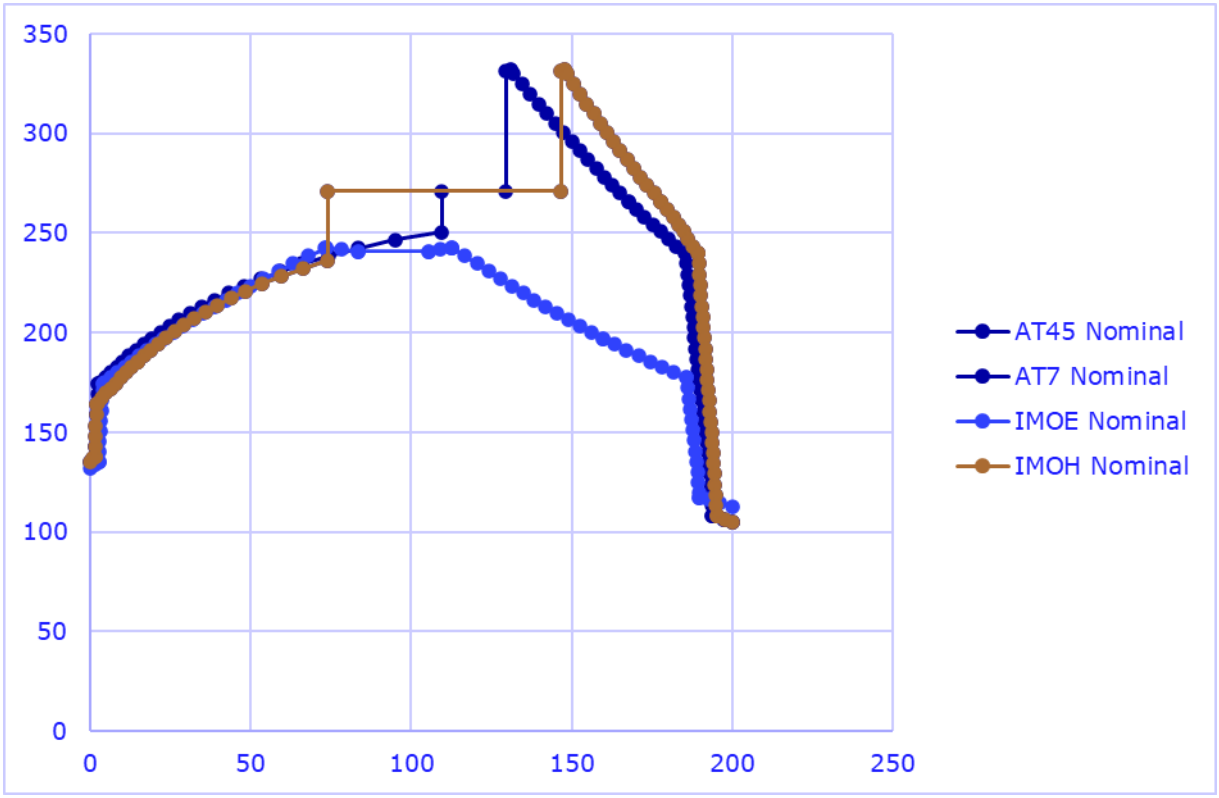


Figure 4: REG-R nominal mass speed profile for a 200 Nmi mission.

The IMOH and AT45 speed profiles are exactly the same.

REG-R HIGH Mass Performance Profile

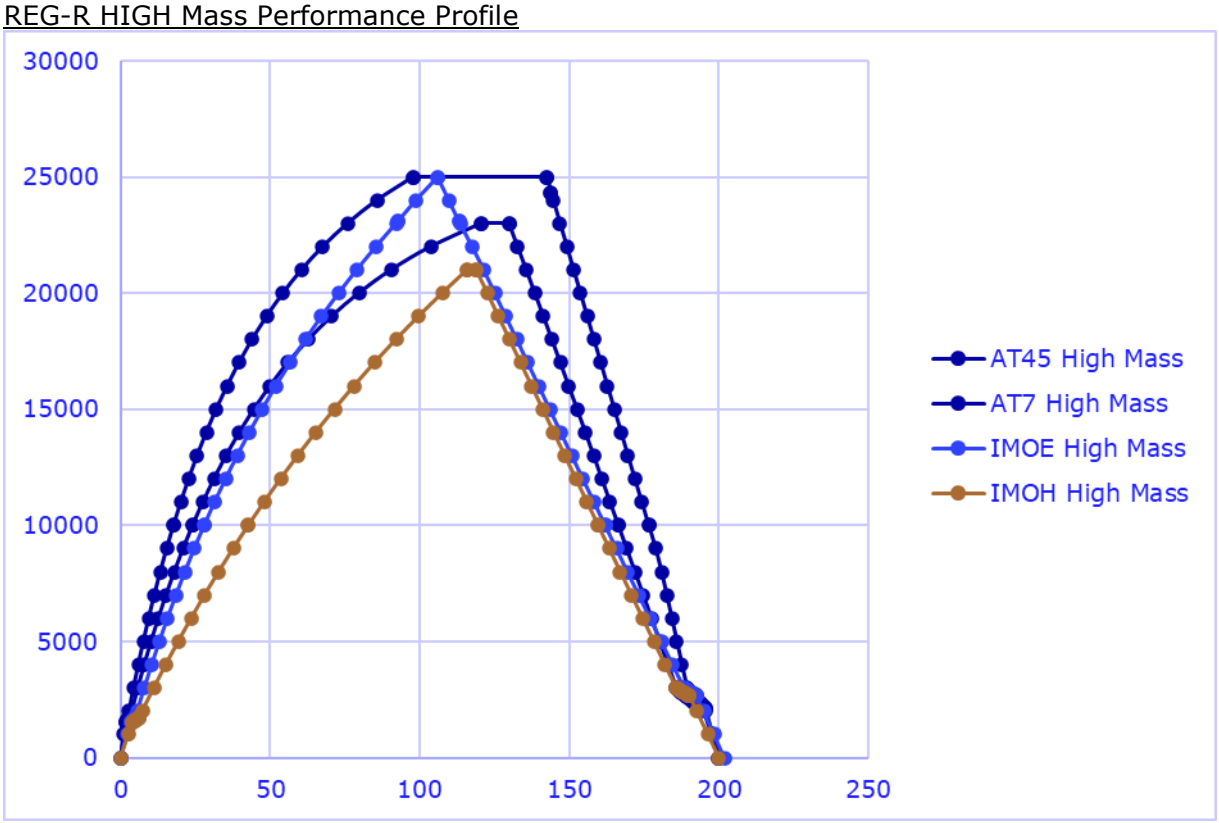


Figure 5: REG-R high mass vertical profile for a 200 Nmi mission.

The REG-R concept cannot reach FL250 over a 200 Nmi mission, as well as the AT7.

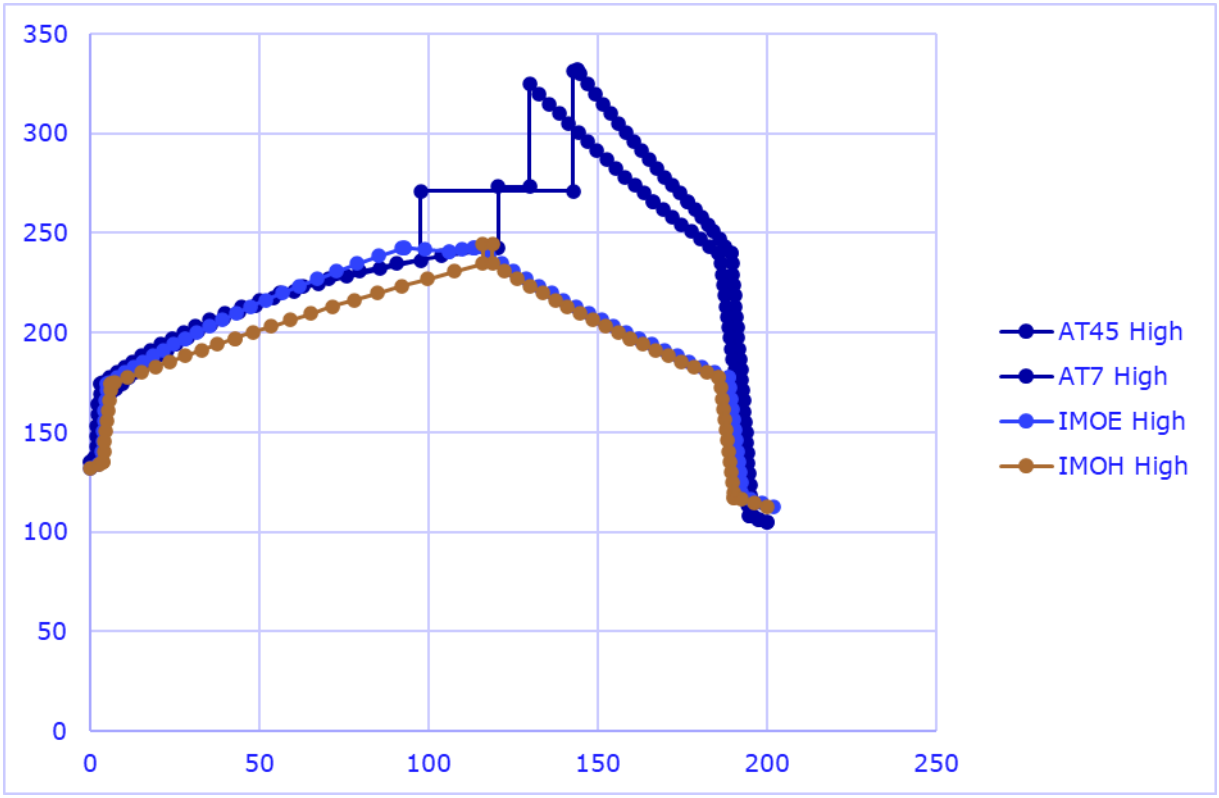


Figure 6: REG-R high mass speed profile for a 200 Nmi mission.

The overall performance analysis shows that hybrid aircraft will have to fly at lower flight levels than ATR aircraft for a typical mission over 200 Nmi. However, for an extended range to 600 Nmi, the performance of hybrid aircraft does not prevent to reach FL250.

In the departure phase, the hybrid aircraft in its thermal configuration has a shift of 25 Nmi at 10000 ft and 50 Nmi at 20000 ft (scenario high) compared to ATR42 standard vertical profile.

This shift is reduced to 14 Nmi at 10000 ft and 27 Nmi at 20000 ft when making the comparison with ATR72 standard vertical profile.

The difference in the departure phase between hybrid and ATR72 is similar to the difference between the departure profiles of the ATR72 and the ATR42.

In conclusion, the departure phase of hybrid REG-R concept takes longer than that of a conventional flight in the ATR family, while the arrival phase is also longer. As a result, the cruise phase is shorter. Such vertical profiles are better suited to a distance greater than 200 Nmi (depending on the take-off weight) or to a lower cruise flight altitude.

2.2. INVESTIGATIONS AND RESULTS ON A SCENARIO OF HYBRID AIRCRAFT IN A CONGESTED TERMINAL AREA

Airport infrastructure needs to be adapted to the aircraft technology evolution. In the context of IMOTHEP, this adaptation means that charging stations shall be implemented at airport level.

We changed the initial approach to simplify it and only take into account the trend of airport involved in ATR flight routes below 600 Nmi.

The ATR flights accounts for ATR42 and ATR72.

Airports Frequentation of ATR42 Flights

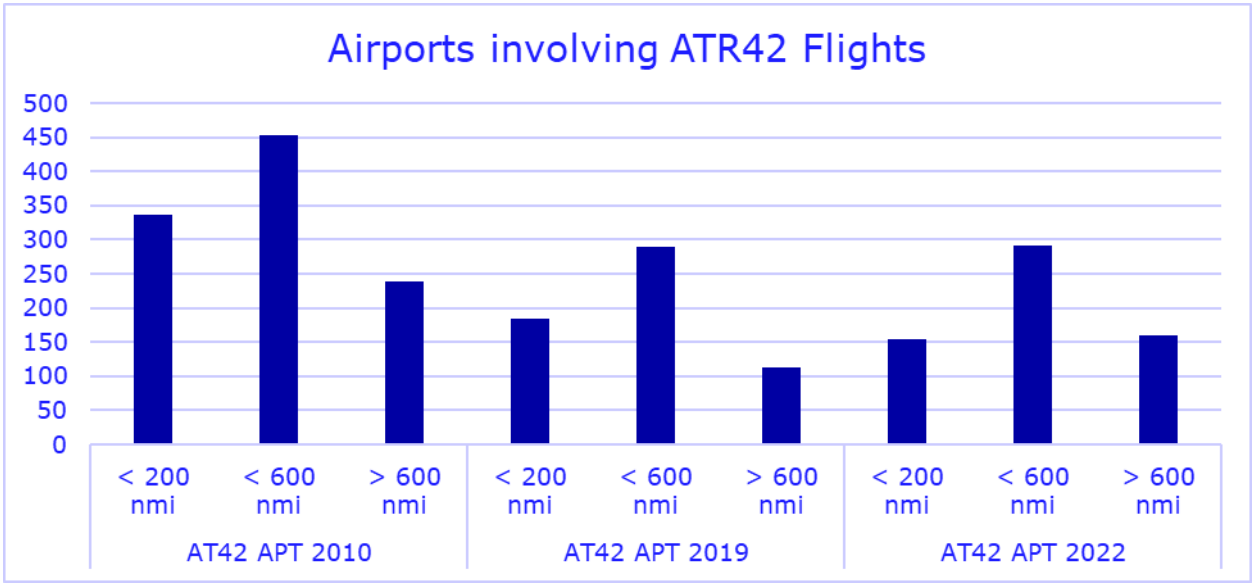


Figure 7: Number of airports involving ATR42 flights.

Considering the list of airports from the 2022 traffic of ATR42 below 200 Nmi, it has been reduced by more than 50% in comparison with 2010 traffic, for a total of 154 airports.

Airports Frequentation of ATR Flights (ATR72 included)

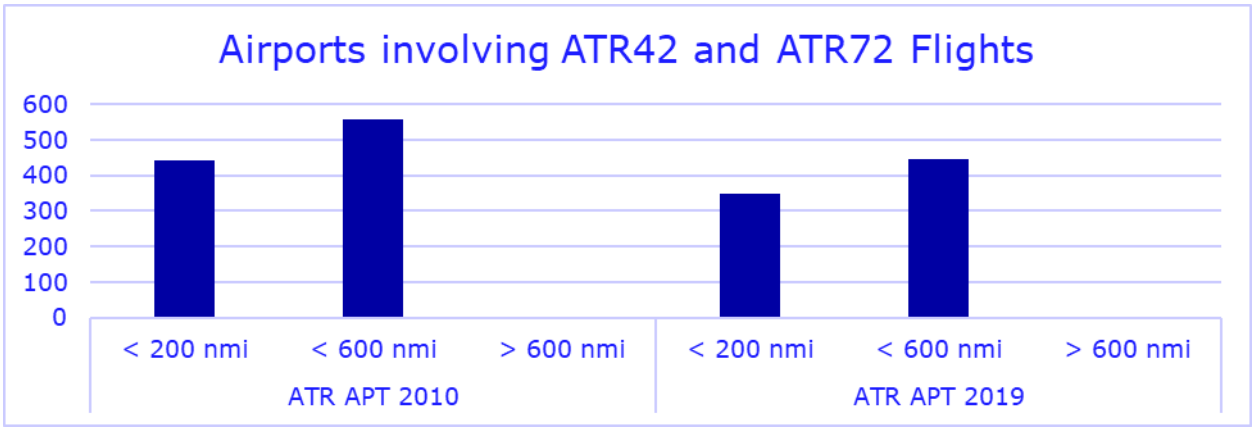


Figure 8: Number of airports involving ATR42 and ATR 72 flights.

ATR flights below 200 Nmi have reduced by 20 % between 2010 and 2019 (the year which reached the peak of traffic).
ATR flights below 600 Nmi have also reduced by 20%. 446 airports were used by ATR flights in 2019.

The deployment of charging stations at airport level is very unlikely to cover that number of airports. Further investigations on the deployment of charging stations at airport level should be undertaken to complement the paper.

We assume 3 scenarios for the ability of airports to handle hybrid electric aircraft:

- LOW: a scenario in which the airports' readiness is 50% of the total number of airports in 2019. Based on the traffic forecast*, the traffic in 2035 is likely to be like

2019, but the deployment of charging stations at each airport might differ significantly.
- BASE: a scenario in which the airports' readiness is 75% of the total number of airports in 2019, assuming a slight increase of the traffic in 2035.
- HIGH: a scenario in which the airports' readiness covers 100% of the total number of airports in 2019.

Scenarios of Airports Frequentation of ATR Flights in 2035

Figure 9: Scenarios of airports ready to hybrid in 2035.

In the figure above, the most optimistic scenario in 2035 reaches the same level as 2010 in terms of airports for ATR flights.

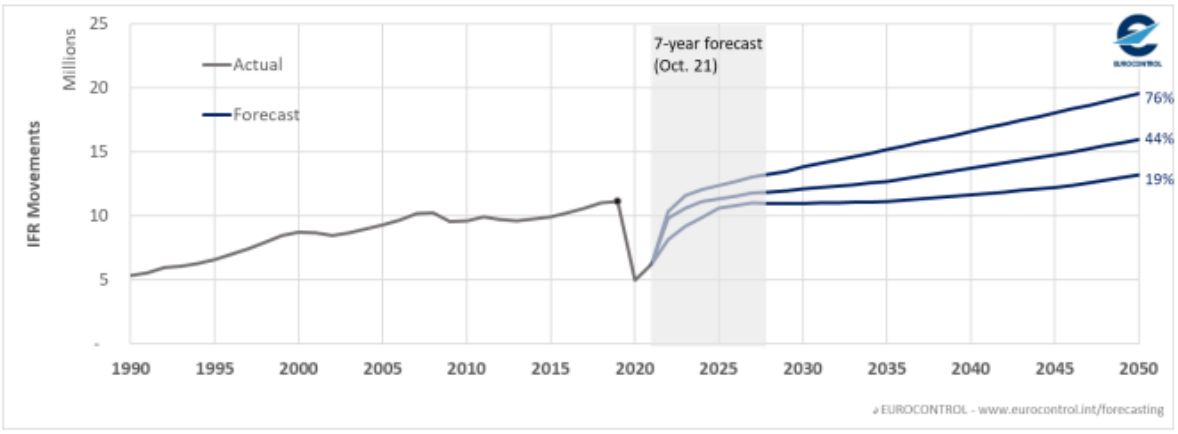
This roughly means that all the airports would be ready for hybrid electric aircraft by 2035. In terms of air traffic management, this scenario is considered the same as in 2010, which gets to the conclusion that this situation would be affordable.

In the other scenarios, less airports would be available for more traffic (or similar traffic), which has a significant impact on air traffic management.

The impact of a reduced number of airports to handle hybrid flights might be investigated to go further.

2.3. INVESTIGATIONS AND RESULTS ON A SCENARIO OF HYBRID AIRCRAFT IN A CONGESTED AIRSPACE

During the investigations, it appeared that the ATM simulation platform would need to be developed with new adaptations to be able to replicate the initial intended scenario. These developments could not be done on time, and the analysis was reduced to statistical analysis based on EUROCONTROL forecasts by 2050.



ECAC	IFR Flights						
	2019		2050			2050/2019	
	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Extra flights/day (thousands)	Total growth	AAGR
High scenario	11.1	30.4	19.6	53.6	23.2	+76%	+1.8%
Base scenario			16.0	43.7	13.4	+44%	+1.2%
Low scenario			13.2	36.2	5.8	+19%	+0.6%

Figure 10: EUROCONTROL Flight Forecast for Europe between 2019 and 2050.

2 scenarios were investigated:

- An introduction of hybrid flights covering 2/3 of ATR flights below 200 Nmi;
- An introduction of hybrid flights covering 2/3 of ATR flights below 600 Nmi.

Scenario of Hybrid Flights Covering 2/3 of ATR Flights Below 200 Nmi

For the purpose of this analysis, a scenario of introduction of hybrid aircraft accounting for 2/3 of the ATR flights below 200 Nmi was considered.

The three scenarios of the traffic forecast were investigated, the low, base and high scenario.

The methodology for the ATR traffic estimation in 2035 considers an average distribution of ATR flights with regards to the total traffic between 2010 and 2019. ATR flights accounts for 1.65% of the total traffic on average.
The ATR traffic forecast is then calculated by retrieving the 2035 forecast from the figure above with the application of the average distribution.

The number of hybrid aircraft flights is then calculated by applying a 2/3 factor to the ATR traffic forecast.

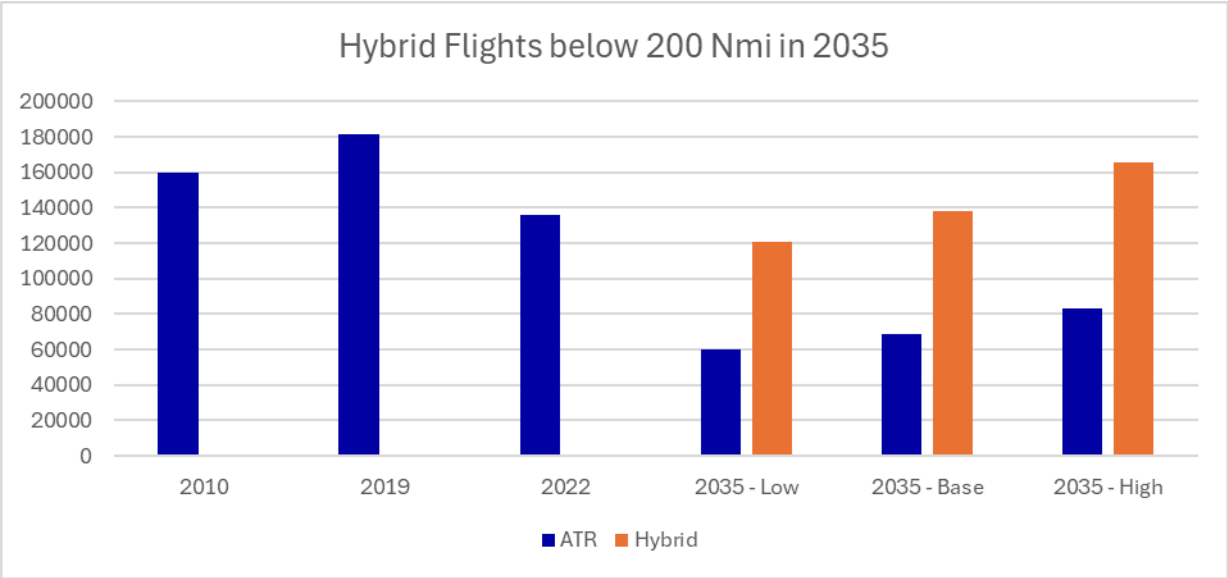


Figure 11: Scenarios of Hybrid Flights in 2035.

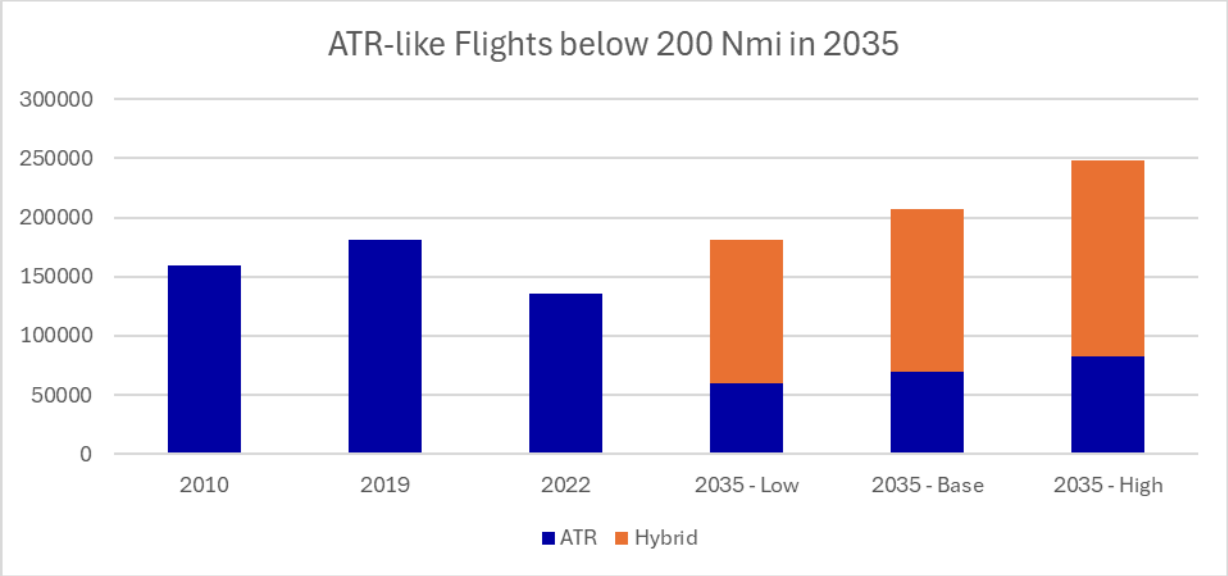


Figure 12: Scenarios of ATR-like Flights in 2035.

Figure 11 and Figure 12 show that the 2035 traffic remains at the same level as in 2019 in the low scenario. This scenario covers the new ATM challenges of the introduction of hybrid aircraft in Europe in terms of number of flights.

However, the performance data of the hybrid aircraft shown that the vertical profiles of hybrid aircraft are made of longer departure and arrival phases than the one of the conventional ATR aircraft.

Regarding the other scenarios, there will be more flights below 200 Nmi than in 2019. Focusing on the high scenario, the hybrid flights represent approximately the same volume as in 2010, which suggests that hybrid flights could be integrated to the European network without significant changes.

In a scenario in which the airspace is assumed congested, hybrid and conventional flights could be differentiated by their reference flight level. A simulation of the high scenario in an ATM simulation tool might be realized to go further in the study.

Scenario of Hybrid Flights Covering 2/3 of ATR Flights Below 600 Nmi

For the purpose of this analysis, a scenario of introduction of hybrid aircraft accounting for 2/3 of the ATR flights below 600 Nmi was considered.

The three scenarios of the traffic forecast were investigated, the low, base and high scenario.

The methodology for the ATR traffic estimation in 2035 considers an average distribution of ATR flights with regards to the total traffic between 2010 and 2019. ATR flights accounts for 4% of the total traffic on average.
The ATR traffic forecast is then calculated by retrieving the 2035 forecast from the figure above with the application of the average distribution.

The number of hybrid aircraft flights is then calculated by applying a 2/3 factor to the ATR traffic forecast.

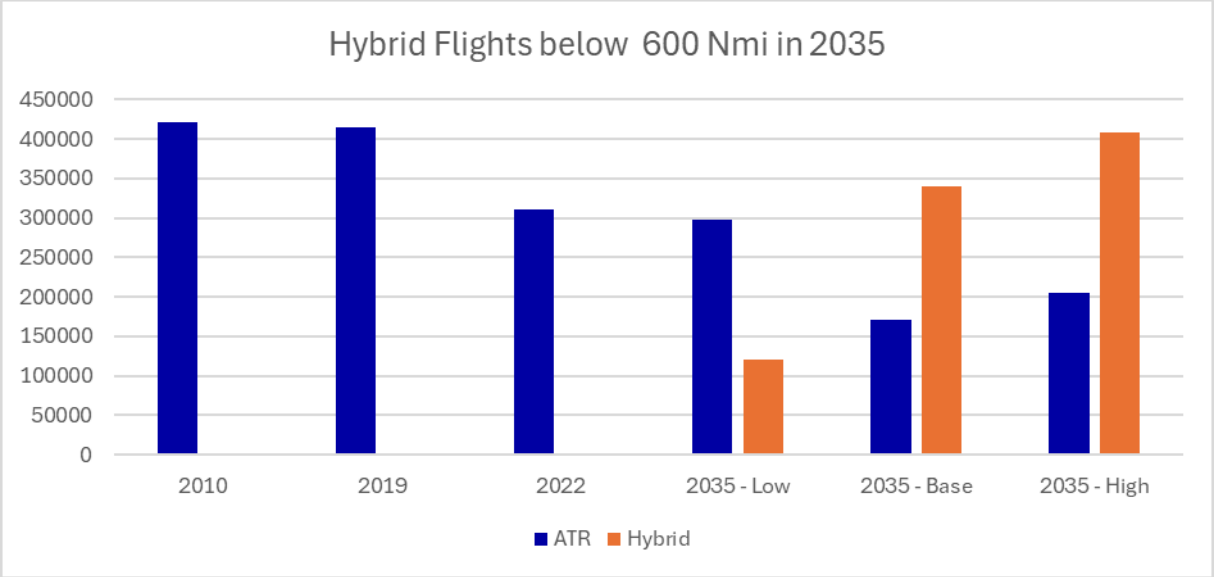


Figure 13: Scenarios of Hybrid Flights in 2035 (based on a 600 Nmi flight distance).

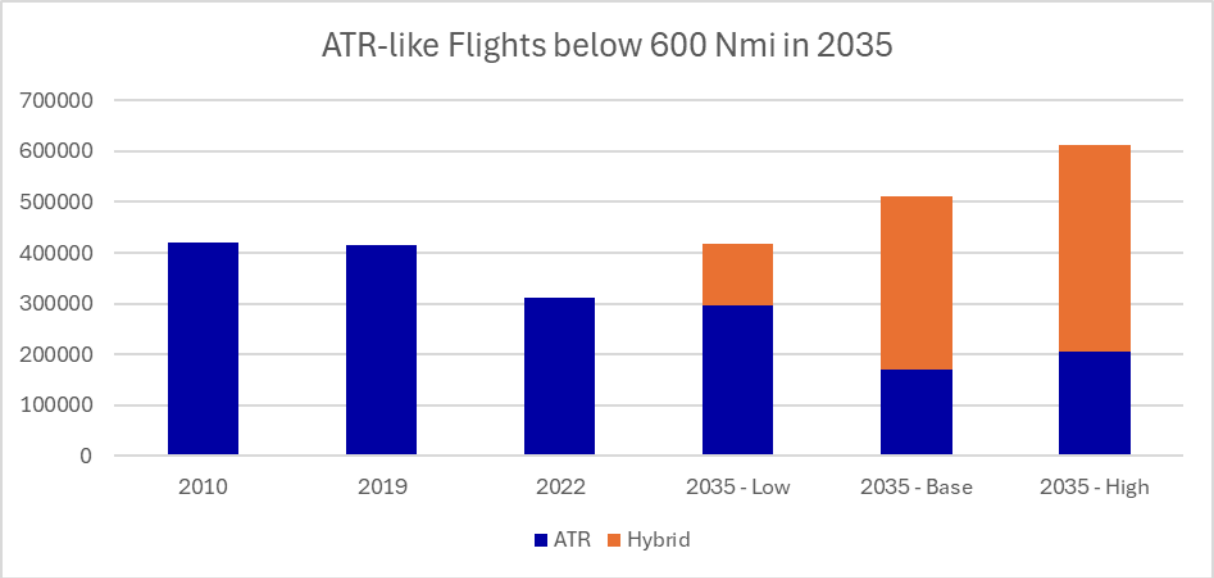


Figure 14: Scenarios of ATR-like Flights in 2035 (based on a 600 Nmi flight distance).

In the low scenario, the volume of flights (below 600 Nmi) in 2035 does not exceed the levels of 2010 and 2019. The introduction of hybrid aircraft is very unlikely to have a significant impact on ATM in Europe.

For the other scenarios, it would be more affordable to consider an introduction of hybrid aircraft in a more reduced proportion than the 2/3 assumption. The volume of hybrid flights is already greater than the volume of conventional ATR aircraft flights in 2022 in the base scenario. Given that the thermal range extender should also be a response to re-routing, and considering safety issues, the 600 Nmi flights might reflect this consideration in the aircraft distribution.

Keeping the initial assumption, the challenge in ATM for the introduction of hybrid aircraft is at its utmost in the high scenario because of the highest risk to fall in extreme situations such as re-routing, holding approach, and introducing additional stops. Additionally, the airport's upgrade to hybrid electric aircraft might not be ready for a full coverage of all the involved airports in 600 Nmi flights.

2.4. INITIAL PLANNED ACTIVITIES

Performance characteristics of hybrid aircraft may differ significantly from those of aircraft populating today the European sky. The objective is to identify the new challenges introduced by HEP in terms of trajectory, connectivity, and ATM performances, and to assess their impact, also in terms of aviation's environmental footprint, for different operations scenarios in the European Network, using and complementing notably EUROCONTROL's BADA database. These initial results could then be fed into SESAR framework where appropriate ATM measures could be developed and validated. Moreover, airport infrastructure constraints and operational impacts were to be assessed at several European airports.

For this purpose, EUROCONTROL intend to perform the following activities:

- Modelling of the performance of the different configurations of aircraft developed in IMOTHEP to ensure compatibility with the EUROCONTROL aircraft performance database (BADA).
- Development and performance of a fast-time simulation scenario for the operational integration of hybrid aircraft in a congested terminal area, for a given European airport.
- Development and performance of a fast-time simulation scenario for the operational integration of hybrid aircraft in en-route, for a specific European city-pair for which the trajectory crosses highly congested airspace.
- Assessment of the fast-time simulations results, from an environmental impact perspective but also from an ATM Network performance perspective.

2.5. DEVIATIONS AND CORRECTIVE ACTIONS

2.5.1. DESCRIPTION OF THE DEVIATION

The scope of activity was reduced to the most promising hybrid aircraft concept, the REG-R aircraft.

During the investigations, it appeared that EUROCONTROL ATM simulation platform would need to be developed with new adaptations to be able to replicate the initial intended scenario on air traffic management. These developments could not be done on time, and the analysis was reduced to statistical analysis based on EUROCONTROL forecasts by 2050.

The initial approach concerning airport investigations was switched by an analysis of the trend of airports involved in ATR flight routes below 600 Nmi, where ATR flights accounts for ATR42 and ATR72 flights.

2.5.2. CORRECTIVE MEASURES IMPLEMENTED

The corrective measures implemented to perform an analysis of the introduction of hybrid electric aircraft in the European network consisted in getting traffic data from several years and make a statistical analysis.

The traffic data represented the year 2010, 2015, 2019 and 2022 in the ECAC area for ATR flights.

Additionally, the EUROCONTROL air traffic forecast was part of the input to have a realistic view of the 2035 traffic.

3. CONCLUSIONS AND PROSPECTS

- The introduction of hybrid aircraft on ATM will not bring significant challenges regarding routing and network capacity for short flights:
  - The vertical profile of the REG-R concept suggests that a lower reference flight level might be more appropriate. As a result, hybrid aircraft would fly lower than conventional ones for a typical mission over 200 Nmi.
  - The total replacement of ATR flights below 200 Nmi by hybrid electric aircraft covers a 40% replacement.
    - The current coverage of ATR flights below 200 Nmi represents 40% of the ATR flight traffic.
- The impact on airports is more significant with the need of installation of charging stations, and the operational management induced.
- 26% of ATR flights up to 600 Nmi would be covered by hybrid flights in 2035. This longer flight range brings new challenges in the case of re-routing situation. The strategy of introducing additional stops might also rise from the ATM point of view.

4. REFERENCES

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