PERSPECTIVES OF TURBOPROP AIRCRAFT: A STAKEHOLDER-ORIENTED EVALUATION USING SCENARIO PLANNING

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Abstract

Based on an extended analysis of the global air transport sector, this paper presents the conceptual design of a recently developed high-capacity turboprop transport aircraft destined for short- and mid-haul operations on highly frequented routes with entry into service estimated in 2025. In order to evaluate the sales potential of the aircraft concept, the focus of this paper is on portraying the methods and results of a stakeholder-oriented aircraft assessment study that combined scenario planning, stakeholder analysis, and technology assessment methods. Considering future stakeholder needs and operational constraints identified through the study, it was found that in spite of the favorable properties in terms of fuel consumption, noise emission properties and the layout of the passenger cabin do present the most critical aspects of the proposed design.

1. INTRODUCTION

The air transport industry is facing major challenges with regard to its future development. Sustainable growth and stable profit margins, especially those of commercial aircraft operators, are being more and more threatened by continuously rising energy costs. Challenging goals with regard to the mitigation of gaseous emission quantities produced by the global aircraft fleet require continuous efforts to improve the energy efficiency characteristics along the entire air transport chain.

In addition, capacity bottlenecks both on the ground and in the air gradually constrain the expansion of the air transport system, particularly on routes with high passenger demand. Air transport markets experiencing high rates of growth, such as those prevailing in Far East Asia, in the Middle East, and in India, have to cope with difficulties in expanding their infrastructure with the necessary speed, while more saturated markets especially in Europe and the U.S. are often affected by politically motivated restrictions regarding infrastructural expansion measures.

1.1. Market Overview and Motivation

In the face of the above mentioned challenges, the aviation industry has identified four major fields of action that are supposed to enable sustainable growth while reducing the environmental impact and avoiding capacity constraints: (1) the development and integration of new technologies, (2) advanced aircraft procedures and operations, (3) infrastructural measures, and (4) additional technologies and biofuels. [1] In this context, innovative aircraft concepts and their improved performance characteristics play a major role in shaping the future of aviation.

An analysis of the civil air transport system reveals that the vast majority of worldwide commercial flight connections is operated between city pairs below 2,000 km of great circle distance (Fig. 1). Furthermore, the air transport system produces approximately 90% of the globally available seat kilometers (ASK) with flights connecting city pairs at distances below 3,500 km. [2] In consequence, the short- and mid-haul air transport markets (i.e., air travel distances below 3,500 km) actually represent by far the most important market segment in the commercial air transport sector. This leads to the fact that technological progress will have its greatest impact on the overall performance of the air transport system if it can be achieved through the short- and mid-haul aircraft fleet.

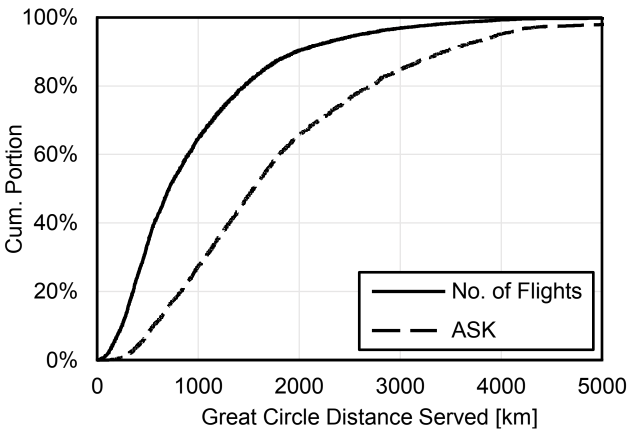


FIG 1. Cumulative flight frequency and ASK portions of air distances served at worldwide level. [2]

In the diagram provided in Fig. 2, currently operating types of aircraft are positioned according to how they are operated by airlines on average and at global level in terms of seat capacity offered and great circle distance served. The diagram reveals that there is almost a linear relationship between the distance served and the number of seats offered, with one exception being the Boeing 747-400 Domestic (Fig. 2: B74D).

When analyzing the global short- and mid-range aircraft fleet in more detail (Fig. 3), two major types of aircraft can be identified that strongly contribute to the worldwide production of ASK as well as to the overall number of flight events: the Boeing 737 and Airbus A320 aircraft families. Hence, the performance characteristics of the entire fleet greatly depend on these two types of aircraft.

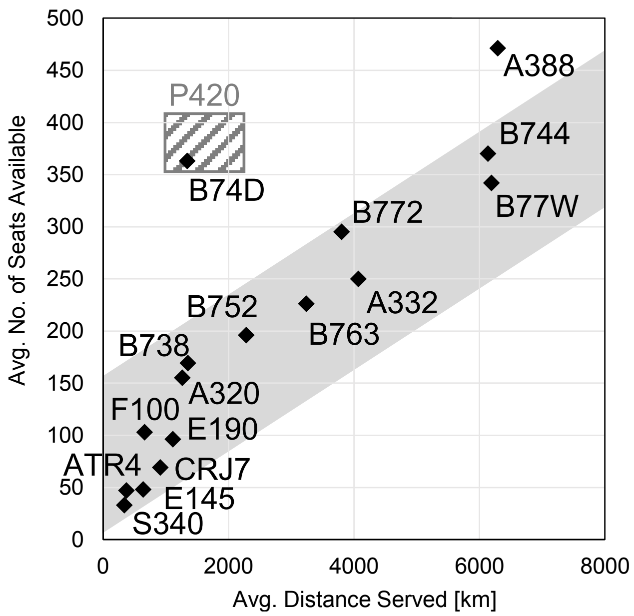


FIG 2. Typical operating characteristics of currently operated types of aircraft at global level. [2]

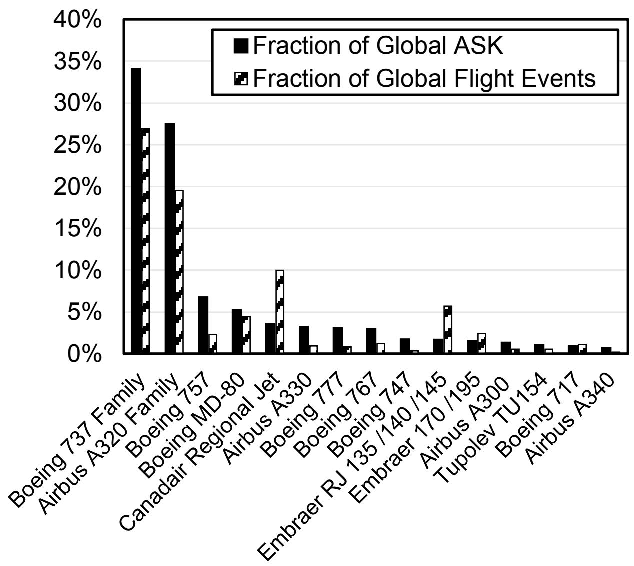


FIG 3. Top 15 types of aircraft of the global short- and mid-range market in terms of their contribution to global ASK and flight events. [2]

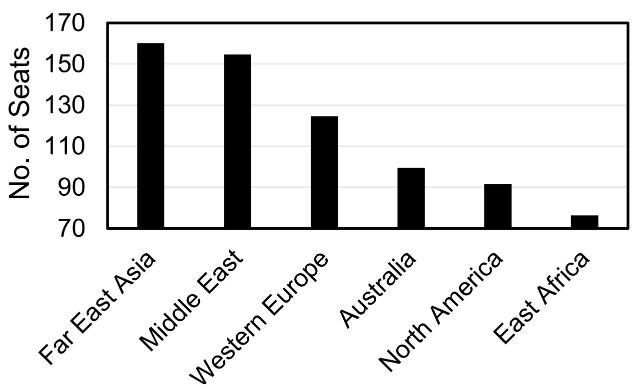


FIG 4. Average number of seats transported per flight on routes below 3,500 km in different regions. [2]

TAB 1. Top 5 international airports with lowest flights on-time performance. [3]

Airport Name (IATA Code)	Fraction of flights on time	Fraction of very late flights (30 – 44 min)	Fraction of excessively late flights (> 45 min)
Beijing (PEK)	38.25%	14.28%	12.86%
Shanghai (PVG)	39.20%	13.10%	16.27%
Istanbul (IST)	42.38%	11.79%	5.47%
Paris (CDG)	68.23%	6.27%	5.91%
Rome (FCO)	69.80%	5.93%	6.55%

Fig. 3 additionally reveals that a number of wide-body aircraft, such as the Airbus A330 and the Boeing 777 that were originally designed to serve the long-haul market, also operate on short- and mid-range routes. A further analysis of the operating characteristics of these types of aircraft shows that it is especially in the Asian markets (above all in China and Japan) where wide-body aircraft are employed on short- and mid-range routes. The average amount of seats transported per flight operation is correspondingly the highest in the Asian region compared to all other regions (Fig. 4).

A subsequent analysis with regard to the level of congestion on major international airports initially reveals that important airports in China are among those with the lowest fraction of flights on time (Tab. 1). Under the presumption that the fraction of flights on time is an indicator for the degree of congestion of an airport, it may be concluded from this data that major Chinese airports are highly congested. This consequently requires measures to adapt the airport infrastructure as well as the operating fleet mix in order to handle the high demand for air travel and ensure sustainable future development.

Taking into account the results of the statistical analysis of the air transport system described above, it is rather obvious to conclude that there is a distinct sales potential for a high-capacity aircraft designed to operate at short- and mid-range routes especially in the strongly growing Asian air transport market. This type of aircraft would be able to close the capacity gap between the large Boeing 747-400 Domestic with a typical seat capacity of 568 seats [4] (that is predominantly operated in Far East Asia) and smaller types of aircraft like the 737 and the A320 (Fig. 2: shaded area).

This type of aircraft would enable a further growth of passenger seats offered in the short- and mid-range market segment while not inducing an increase in the number of flights by the same factor. In addition, depending on the technologies integrated into the aircraft, it would be able to improve the ratio of fuel consumption to payload mass, hence raise the degree of fuel efficiency, and additionally benefit from an economy-of-scale effect. [5] If the aircraft was to replace parts of the current 737/A320-fleet, this effect would become more significant with more aircraft in operation. In conclusion, this type of aircraft owns the potential to make an important contribution to handle the challenges related to capacity constraints and environmental impact mitigation in aviation.

OEMs are heading into the same direction. Airbus has recently announced the development of a new version of its A330-300 aircraft with lower weight and improved performance characteristics for regional and domestic operations. “China will be one of the most important markets for this new version.” [6]

1.2. The Propcraft P-420/A Aircraft Concept

In order to address the sales potential for a high-capacity short-haul aircraft portrayed above, the conceptual design of an entirely new aircraft has been developed recently at the Institute of Aircraft Design of the Technical University of Munich (TUM). With an entry into service estimated in 2025, the *Propcraft P-420/A* represents the institute’s proposal to face the challenges of future aviation while simultaneously enabling further growth. Similar to the new Airbus A330 domestic version, it has been designed to operate in quickly emerging markets in Asia on stage lengths below 3,000 km. Typical city pairs served would be the routes between Shanghai and Beijing in China, and Tokyo and Osaka in Japan.

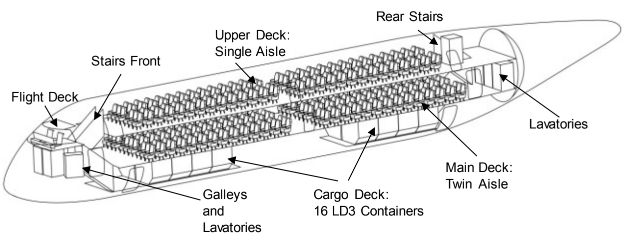


FIG 5. Interior view of the Propcraft P-420/A. [7]

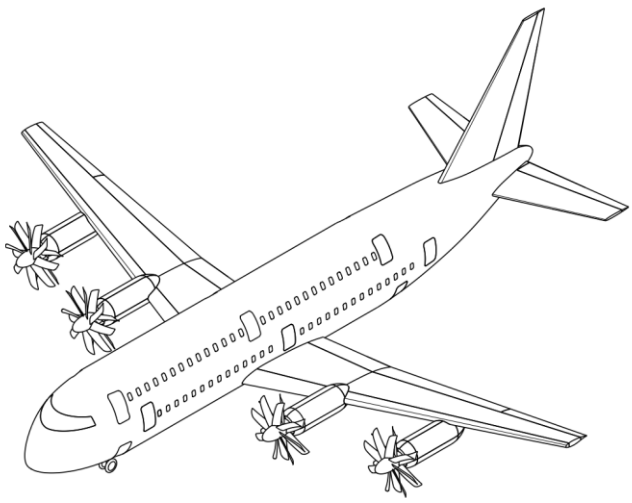


FIG 6. Outside view of the Propcraft P-420/A.

The Propcraft P-420/A is a heavy transport aircraft that is able to carry a maximum of 420 passengers in a twin-deck passenger cabin and 5 tons of cargo payload in 16 LD3 containers over a distance of approximately 3,000 km (Figs. 5, 7). [7]

Like the Antonov An-70 military transporter [8], four turboprop engines drive the P-420/A with counter-rotating propellers (Fig. 6). Each gas turbine achieves a maximum shaft power of roughly 10 MW. Turboprop engines were selected due to the better characteristics in specific fuel consumption compared to conventional turbojet or turbofan engines. [9–11] Fig. 7 provides the payload-range diagram of the aircraft while Tab. 2 summarizes the key technical data.

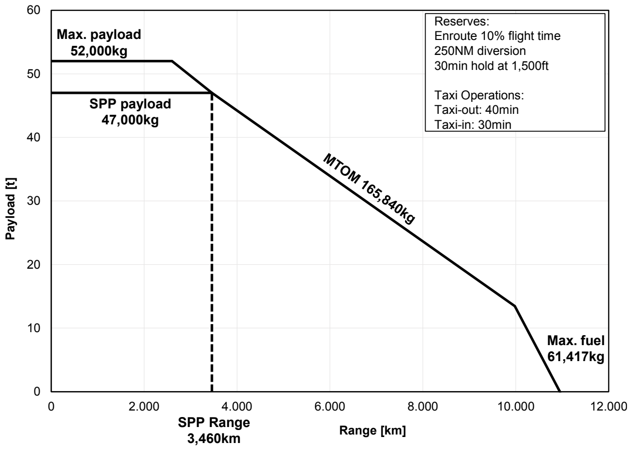


FIG 7. Payload-range diagram of the Propcraft P-420/A.

TAB 2. Key technical data of the Propcraft P-420/A (rounded values are shown).

Max. take-off mass	166 tons
Operating mass empty	92 tons
Max. fuel load incl. reserves	61 tons
Max. passenger load	420 Pax (100 kg per Pax)
Max. cargo load	10 tons
Wing area	250 m^2
Wing span	52 m
Length of fuselage	48 m
L/D ratio (at cruise, FL290)	17
Mach number (at cruise, FL290)	0.64
Total take-off power at MSL	4x 10 MW
Fuel efficiency (at max. payload range)	0.212 l / (ton-kilometer)

Despite its favorable fuel consumption, the P-420/A concept owns two major disadvantages, especially when comparing it to modern turbofan-powered aircraft.

Cruising speed: The turboprop propulsion system of the P-420/A only allows relatively low travel speeds (around -20% compared to conventional jet aircraft). However, considering the short distances that the aircraft is designed to operate on, the resulting effect on block time will probably be marginal.

Propulsion system/noise emissions: The required engine power of 10 MW per engine is massive. In fact, the most powerful Western-built turboprop engine currently available is the TP400-D6 of engine manufacturer Europrop International, delivering a maximum certified shaft power of 8.3 MW. [12] Besides the fact that a new engine system would have to be developed that could propel the P-420/A, the four engines and counter-rotating propellers are highly likely to cause very high levels of noise emissions.

In fact, the only existing aircraft with a comparable performance and design profile is the Tu-95 (strategic bomber version) / Tu-114 (civil transport version) of Russian aircraft manufacturer Tupolev [13] – an aircraft that is widely known to be one of the noisiest air vehicles ever built. [14]

Given the dynamic nature of ever-changing customer needs, environmental conditions, and rules and regulation prevailing in the civil air transport sector, it is difficult to estimate whether the P-420/A actually presents a realistic aircraft option in future aviation. Yet, from the viewpoint of an aircraft manufacturer, a comprehensive assessment of the concept would be vital before deciding whether to proceed with the development program or stop it.

2. METHODICAL APPROACH TO STAKEHOLDER-ORIENTED AIRCRAFT ASSESSMENT

2.1. Overview and Organizational Aspects

In spite of the drawbacks of the P-420/A portrayed in the previous section, would the aircraft still have a potential to be operated in commercial air transport in general and in the markets that it has been designed for in particular?

In order to evaluate the prospective market success of the P-420/A aircraft concept, a stakeholder-oriented assessment study was held at the TUM Institute of Aircraft Design in spring 2014. The study lasted over a period of two full weeks and was conducted in the form of daily workshop units. It combined scenario-planning techniques, market and stakeholder analyses, and technology assessment methods. As such, the goal of the study was to lay the foundations of an advanced aircraft design iteration loop by providing more profound quantified requirements and evaluation data based on the various needs of the stakeholders under scrutiny.

A team composed of 24 undergraduate and graduate students of mechanical and aeronautical engineering and business administration at TUM conducted the aircraft assessment study. Five aviation professionals (representatives of a major European aircraft manufacturer, a German hub airport, an aviation-related German research institution, and a research engineer of the TUM Institute of Aircraft Design) accompanied the team, giving introductory lectures on the perspectives of civil aviation, aircraft assessment practices, aircraft direct operating costs modeling, and aircraft noise emissions. These specialists also provided their feedback concerning the intermediate results elaborated by the student team in the course of the study. The author of this paper designed, organized, and ran the overall assessment study.

The entire workshop was held at a seminar room located at the Faculty of Mechanical Engineering of TUM. In this room, all study participants had access to computers with an internet connection. In addition, a shared network drive was made available where relevant statistical data and further sources of useful information could be stored, shared, and exchanged. This enabled the creation of a comprehensive knowledge base during the course of the project.

During the study, a time horizon starting from the present (i.e., 2014) to 2035 was considered. Thus, a ten-year period of operation of the P-420/A was taken into account (2025 – 2035), while potential paths of evolution of the domestic air transport markets within Europe (EU), North America (NA), the Middle East (ME), and Asia (AS) were exclusively examined. For reasons of simplification, other market segments were neglected. For all of the markets under scrutiny, special focus was on the analysis of the design-driving needs of commercial aircraft operators as well as their most important groups and types of passengers. In addition, the evolution of aviation-related regulations and infrastructural conditions was taken into account.

The aircraft assessment study was set to follow nine major methodical steps at three different levels of abstraction, as depicted in Tab. 3. The subsequent sections will describe each process step in more detail.

TAB 3. Overview of the methodical steps conducted in the aircraft assessment study.

Level of Abstraction	Methodical Steps
Environment level	Environmental analysis Alternative scenarios generation Scenario design
Aviation level	Market analysis Stakeholder analysis Concept of operations
Aircraft level	Requirements & constraints Aircraft analysis & assessment Sales potential & risk analysis

2.2. Environment Level: Scenario Building and Quantification

Given the broad time horizon considered in the aircraft assessment study, one can find it hard to anticipate the future development of the air transport sector in general, and of the considered market segments and stakeholder requirements in particular. While analyzing the status-quo situation constitutes a challenging but feasible task, uncertainty makes it very difficult, if not impossible, with regard to statements about the future.

Following the suggestions made by [15], the approach to handle future uncertainties used in the aircraft assessment study was scenario-based. Hence, alternative, discrete scenarios of the future were created, each describing a unique future state of the environment that affects the problem under consideration. Note the following definition of scenarios: *scenarios* are “focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion.” [16] As such, they should be made “accessible to and sharable by diverse stakeholders in a design project.” [17] Scenarios are neither “states of nature nor statistical predictions,” [16] but “multiple, but equally plausible” [18] descriptions of potential states of the environment used to better understand and treat future uncertainties.

The term ‘environment’ is defined here according to the definition of the IEEE: the environment comprises all “circumstances, objects, and conditions that will influence the completed system; they include political, market, cultural, organizational, and physical influences as well as standards and policies that govern what the system must do or how it must do it." [19] In the case here, it is the P-420/A aircraft concept that represents the 'system' being under the influence of the environment.

For reasons of simplification, the above-mentioned 'circumstances, objects, and conditions' building up the environment are all distilled in the term "environmental factors." [20] Now, depending on the respective scenario, each environmental factor may hold a certain future state, "outcome," [21] or "projection." [22] Therefore, the synopsis of several environmental factors, each owning an individual projection, will eventually constitute the framework of a scenario, sometimes also referred to as a "raw scenario." [23]

A scenario is derived from its raw scenario by working on a scenario "storyline" [24] that provides a clear narrative of the scenario-specific future. Scenarios should be created in a way to be both plausible and internally consistent (i.e., free of contradictions). [15] Furthermore, in order to cover a broad range of possible futures (and hence to address a wide spectrum of future uncertainties), each scenario should tell a different story, i.e., be unique among the set of created scenarios. [25]

TAB 4. Environmental factors building up the scenario environment.

Factor Area	Factor Title	Definition of Projection
General environment	GDP development	± % of change year-on-year
	Regional & international cooperation	Supranational vs. national
	Development of regulative costs	± % of change year-on-year
	Population growth	± % of change year-on-year
	Development of modal split	± % of change year-on-year in air transport share
Aviation-related environment	Development of the price for jet fuel	± % of change year-on-year
	Air transport network	Point-to-point vs. Hub-&-spoke
	Air space	Open vs. constrained
	Airport capacity	No adaptation to air traffic growth vs. Significantly constrained vs. Limited adaptation vs. Perfect adaptation

Environmental Analysis. Identifying the most important environmental factors and analyzing their impact on the development of the air transport market, the needs of the relevant stakeholders, and particularly on the sales potential of the P-420/A concept was the first part of the aircraft assessment study (Tab. 3). For that, prior to the actual beginning of the team-based workshop phase of the study, nine environmental factors had been identified (by the author of this paper) that were considered as highly relevant to the scope of the study. In addition, similar factors had been selected in preceding scenario studies held at the institute [26–29] and had proven themselves very effective. All factors were presented and provided to the study participants in the form of printed booklets that contained brief definitions of the factors as well as indications on additional sources of information freely available on the internet.

Tab. 4 provides an overview of the factors selected. Note that a distinction was made between factors belonging to the top-level environment (i.e., addressing the socio-economic environment) and factors that directly relate to aviation. In addition, Tab. 4 indicates the way the factor projections were to be defined.

After familiarizing with the environmental factors, the project team was split into four equally sized sub-teams, each being responsible for one regional market (i.e., EU, NA, ME, AS). The sub-teams then had to carry out an uncertainty-impact analysis during which they had to position firstly the general and secondly the aviation-related factors into a diagram (a "driving force ranking space" [18]) to identify those two "key factors" [23] with the highest degree of uncertainty in terms of their future development and highest strength of impact.

Alternative Scenarios Generation. Following the "alternative futures analysis" method to generate "multiple scenarios" proposed by [30], the sub-teams created four raw scenarios for their respective market, taking into account all nine environmental factors. By initially defining two different projections for each of the two previously identified key factors, the teams opened up a field of four fundamentally different 'base scenarios' (i.e., the four possible combinations of the 2x2 factor projections). The teams subsequently added all remaining factors to these base scenarios by defining corresponding projections in a way to make each scenario internally consistent. As a result, four raw scenarios for each one of the four considered regional markets were finally obtained.

Scenario Design. In this step, three new sub-teams were formed out of the overall project team, each sub-team including at least one 'market specialist' for every considered regional market. The three teams were then tasked with generating one global scenario each by selecting and combining four market scenarios (one for every market examined) while ensuring that the selected market scenarios would fit together (i.e., ensure the internal consistency of the global scenario). Afterwards, the sub-teams had to formulate short key statements to describe their individual global scenario in brief. This is how three different global scenarios, each addressing the future projections of the nine environmental factors considered, were obtained at the end of this process step.

2.3. Aviation Level: Market and Stakeholder analyses, and ConOps

The three subsequent project steps focusing on the aviation level were aimed at identifying the key market in each global scenarios (i.e., the regional market with the highest potential growth in revenue passenger kilometers (RPK) on average within the time frame considered), and at analyzing the stakeholders as well as their travel preferences in each market.

Market analysis. The three teams, each one being responsible for one global scenario, were given the task of analyzing what impact the market-specific projections of the environmental factors would have on the average market-specific change in RPK per annum from the present to 2035. This approach followed a practice from Eurocontrol that derives the average annual growth of air traffic from a “mix of factors pushing the passenger demand and growth in traffic.” [31] Going from factor to factor, the teams stipulated the degree of impact on RPK change with the help of an in-depth analysis of statistical data and by consulting the expertise of the aviation professionals partaking in the project. They ended up with an overall value for each market and were thus able to identify the scenario-specific primary and secondary key market.

Besides quantifying the average RPK change for each market in their scenario, the teams also had to estimate the importance of air transport relative to the other (ground-based) modes of transport, an average load factor, and the relevance of different airline business models among each other (full-service carrier vs. low-cost carrier vs. charter airline). In addition, they had to name the three real-life airlines with the highest shares in each regional market. They accomplished all tasks by accessing their previously gained knowledge and doing a further research and analysis of publicly available data and reports. All results were then presented and intensely discussed among the entire project team.

Stakeholder analysis. Two stakeholder types were addressed in the project: airlines and air travelers. (Other stakeholders were not taken into account for the sake of limiting the overall workload of the project.) Considering the primary and secondary key market in each scenario, the teams had to conduct a profound analysis of these two stakeholder groups.

With regard to airlines, the teams had to select one of the three previously determined real-life airlines (i.e., a potential operator and buyer of the P-420/A aircraft concept), and precisely analyze its current and estimate its future business model. Furthermore, they had to examine its current aircraft fleet structure and route network in order to explain the path of development of these in the scenarios. The teams also had to explain the airline’s role within an airline alliance (if applicable). With regard to air travelers, their main travel motive had to be explained, physical characteristics stipulated, the financial situation analyzed, and travel habits and preferences derived. In addition, special needs (e.g., access to the internet during the entire trip) had to be detected.

Concept of Operations. A concept of operations (ConOps) “focuses on the goals, objectives, and general desired capabilities of the potential system without indicating how the system will be implemented to actually achieve goals.” [19] It is “a user-oriented document that describes a system’s operational characteristics from the end-user’s viewpoint.” [32] As such, it can be used to support eliciting operational requirements. [33]

In the case of the project presented here, ConOps from the air traveler’s perspective were elaborated for the primary and secondary key market of each scenario. Treating the air traveler described in the previous step as the ‘end-user’ mentioned in the ConOps definition above, the teams defined a representative trip from door to door (thus including means of transport other than airplanes) that he would be likely to undertake in the respective scenario and market, using the airline company previously examined through the stakeholder analysis. Statements about the departure and arrival time, the number of transfers from one transport vessel to another, and estimated ticket costs had to be made. Each ConOps was eventually defined by describing in chronological order all activities that the air traveler would undertake along this trip, considering both formal (e.g., passport controls) and personal activities (e.g., reading a book for personal pleasure).

2.4. Aircraft Level: Requirements Analysis and Aircraft Assessment

At the aircraft-related level of abstraction, requirements from the stakeholders’ perspectives were formulated based on the previously generated information about their characteristics, needs, and preferences. These requirements then formed the basis for the stakeholder-oriented assessment of the P-420/A aircraft concept as well as a final estimation of the overall sales potential specific to each scenario.

Requirements and constraints. Requirements were directly derived from the ConOps and the examined scenario- and market-specific characteristics of the stakeholders considered. Again, only the primary and secondary market were considered.

In this respect, the requirements were elicited taking into account the fields shown in Tab. 5. These fields had been predefined in the course of preparing the aircraft assessment study in order to ensure that the three teams would produce mutually comparable assessment results. Note that in addition to the stakeholder requirements, constraints addressing the scenario-specific rules, regulations, and infrastructural restrictions, and thus stipulating the operational environment of the P-420/A concept, were determined.

TAB 5. Fields of requirements from the stakeholders’ perspectives and operational constraints.

Airline	**Air Traveler**	**Constraints**
Payload to carry	Desired trip length	Noise regulations
Design mission range	Desired trip time	Emissions regulations
Block time	Trip costs	ATC restrictions
Fuel consumption	Baggage	Airports served (runway)
Airports served	Airports served	Airports served (taxi and boarding)
Interior and cabin design	Interior and cabin design	Others
Passenger comfort	Passenger comfort	
Crew	Others	
Entry into service		

Aircraft analysis and assessment. In this step, the three scenario teams directly compared the technical features and operational performance characteristics of the P-420/A concept with the entire set of requirements identified in the previous step. For this task, the teams were provided with a comprehensive fact sheet addressing all major design aspects of the aircraft concept, e.g., geometry, masses, aerodynamics, propulsion system, and mission performance.

In order to assess the degree of fulfillment of each requirement, a three-stage evaluation scheme was applied: (1) requirement unsatisfied, (2) requirement partially satisfied, and (3) requirement fully satisfied by the P-420/A. In case the fact sheet did not provide sufficient information in order to properly assess the degree of fulfillment of the respective requirement (or the required information could not be made available otherwise), the requirement was treated as unsatisfied, leading to a worst-case assumption.

Furthermore, in order to distinguish highly important requirements from those being of minor relevance, a weighting scheme was applied. E.g., the requirements field ‘desired trip length’ was given a higher weighting than the field ‘passenger comfort’ (Tab. 5), as it was considered to be a stronger driver for the conceptual design of the aircraft. Again, the weighting scheme had been defined already while preparing the overall study in order to ensure comparability across all scenarios.

Finally, an ‘assessment triangle’ was created for each scenario that presents the overall assessment result in a three-dimensional, quickly understandable manner (see Figs. 10 – 12). The two considered stakeholder groups and the operational constraints built up the three axes of the triangle, while the assessment results were normalized using a 100%-scale (quotient of actually achieved result and maximum achievable result) before writing them on the respective axes of the triangle.

Sales potential and risk analysis. This final step of the project consisted of estimating the P-420/A-related sales potential in the time frame from 2025 to 2035 in each scenario as well as analyzing the major sales risks according to the preceding aircraft assessment. Here, two major aspects determined the sales potential: (1) the development, size, and structure of the overall aircraft fleet in operation as stipulated by the scenario, (2) the results of the aircraft assessment and analysis. This second point gave an indication of how well the P-420/A may be able to compete with other types of aircraft designed to operate in the short- and mid-range market segments (e.g., Airbus A320neo, Airbus A330 domestic, Boeing 737MAX)

In order to determine the scenario-specific development of the aircraft fleet, the “Fleet System Dynamics Model” developed at the Institute of Aircraft Design of TUM was utilized, [34] taking the quantified scenario data as input parameters (annual changes in RPK, load factors, etc.). With this tool, the overall market size of aircraft sales from 2025 to 2035 could be quantified for the short- and mid-range market segments of the considered regions.

The entire project finally resulted in obtaining merely one figure, i.e., the overall sales potential of the P-420/A concept corresponding to each scenario.

3. RESULTS OBTAINED

In this chapter, the main findings obtained in the course of the aircraft assessment process are presented. Prior to that, however, the three scenarios are briefly depicted in order to enable a better understanding of the derived stakeholder requirements and assessment results.

3.1. Future Scenarios

Due to the huge amount of data and contents produced for each scenario, only the projections of the considered nine environmental factors corresponding to each scenario and market are presented here (see Tab. 4 for an overview of the environmental factors). The following tables summarize the data for each scenario. Note that the data refer to the average values within the period addressed in the scenarios (i.e., 2014 – 2035). Thus, they do not account for fluctuations.

TAB 6. Scenario A – key data.

Title: “Slacking global economy”				
Factor	**EU**	**NA**	**AS**	**ME**
GDP development	-0.5% p.a.	±0% p.a.	+3.0% p.a.	+2.0% p.a.
Regional & international cooperation	National	National	Supra-national	Supra-national
Development of regulative costs	+0.5% p.a.	±0% p.a.	+1.0% p.a.	+1.0% p.a.
Population growth	+1.0% p.a.	1.5% p.a.	+1.5% p.a.	+2.5% p.a.
Development of Modal Split	-0.5% p.a.	-0.5% p.a.	+1.0% p.a.	+1.5% p.a.
Development of the price for jet fuel	+5.0% p.a.	+3.5% p.a.	+5.0% p.a.	+5.0% p.a.
Air transport network	Hub-&-spoke	Hub-&-spoke	Point-to-point	Hub-&-spoke
Air space	No change	No change	Constrained	No change
Airport capacity	Limited adaptation	Limited adaptation	Limited adaptation	Perfect adaptation

TAB 7. Scenario B – key data.

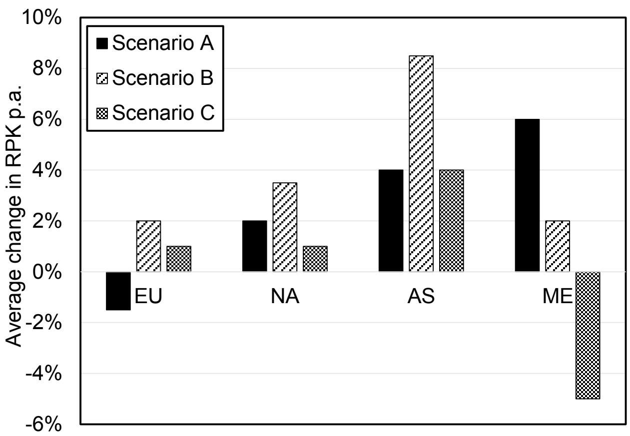
Title: “Growth and stability”				
Factor	**EU**	**NA**	**AS**	**ME**
GDP development	+2.0% p.a.	+4.0% p.a.	+6.5% p.a.	-0.5% p.a.
Regional & international cooperation	Supra-national	Supra-national	Supra-national	Supra-national
Development of regulative costs	+3.0% p.a.	±0% p.a.	+1.0% p.a.	±0% p.a.
Population growth	+0.5% p.a.	+1.0% p.a.	+1.0% p.a.	+2.0% p.a.
Development of Modal Split	±0% p.a.	+1.0% p.a.	+0.5% p.a.	-0.5% p.a.
Development of the price for jet fuel	+4.0% p.a.	+3.0% p.a.	+3.0% p.a.	+6.0% p.a.
Air transport network	Point-to-point	Point-to-point	No change	Hub-&-spoke
Air space	Constrained	No change	Open	Open
Airport capacity	Significantly constrained	Significantly constrained	Limited adaptation	Perfect adaptation

TAB 8. Scenario C – key data.

Title: "Arabian summer"				
Factor	**EU**	**NA**	**AS**	**ME**
GDP development	-1.0% p.a.	+1.0% p.a.	+3.0% p.a.	-1.0% p.a.
Regional & international cooperation	Supranational	National	National	National
Development of regulative costs	-3.0% p.a.	+1.0% p.a.	±0% p.a.	±0% p.a.
Population growth	±0% p.a.	+1.0% p.a.	+1.0% p.a.	+1.0% p.a.
Development of Modal Split	±0% p.a.	±0% p.a.	+1.0% p.a.	-3.0% p.a.
Development of the price for jet fuel	+5.0% p.a.	+2.0% p.a.	+4.0% p.a.	+3.0% p.a.
Air transport network	Hub-&-spoke	Hub-&-spoke	Hub-&-spoke	Hub-&-spoke
Air space	Open	Open	Constrained	Constrained
Airport capacity	No adaptation	Significantly constrained	Perfect adaptation	Perfect adaptation

A major quantitative indicator of the three scenarios is represented by the annual change in RPK, averaged over the entire period considered. Fig. 8 depicts the market-specific RPK growth rates for each scenario.

FIG 8. Overview of the average RPK growth rates in each market for all scenarios from 2014 to 2035.



Finally, Tab. 9 presents the market size from 2025 to 2035 of the short- and mid-range aircraft fleet ("cluster 9 short/mid-range passenger aircraft," [34]) in the respective markets, as determined by the 'Fleet System Dynamics Model' for each scenario.

TAB 9. Short-/mid-range aircraft market sizes from 2025 to 2035 [no. of aircraft units new to fleet].

Scenario	EU	NA	AS	ME
A	776	2,126	2,788	225
B	1,936	3,317	14,070	11
C	1,417	1,562	5,654	0

Considering the estimated market sizes shown in Tab. 9, it is obvious that in spite of the clear differences between the three scenarios, all of them state that especially the Asian domestic market will grow with the highest absolute values and thus constitutes the most attractive market to aircraft manufacturers in the short-/mid-range segment. Furthermore, the North American domestic market appears to face an interesting future perspective according to the scenarios as well.

3.2. Stakeholder Requirements and Constraints

As specified in Tab. 5, various fields of requirements were considered in the project. Hence, a huge amount of requirements was actually produced. Presenting all of them would clearly exceed the limits of this paper. Still, in order to provide a brief insight into what requirements were defined and how they were formulated, the following tables summarize the most important ones and indicate the ranges of the target values through all scenarios (if applicable). Note that for reasons of simplification, a distinction between the three scenarios is not made here and that the requirements were only elicited for the primary and secondary key markets (i.e., AS and NA for all scenarios).

TAB 10. Airline Requirements.

Requirement	AS	NA
Payload capacity	400 – 450 pax	280 – 355 pax
Design mission range	1,000 – 1,700 km	900 – 3,000 km
Interior & Cabin Design	Robust, easy to keep clean, internet, flexible seating configs.	Space for advertisements, food dispensers, reduce cabin noise
Desired Entry-into-Service	2016 - 2021	2025 - 2029

TAB 11. Air Traveler Requirements.

Requirement	AS	NA
Desired trip length	600 – 2,000 km	800 – 1,800 km
Baggage	7 – 25 kg	10 – 23 kg
Interior & Cabin Design	Big overhead compartments, in-flight entertainment, internet, smooth lighting	Spacious feeling, big overhead compartments, comfortable seats
Misc.	Express boarding, on-board shopping, various meals offered	Silent cabin, express boarding, personal TV available

TAB 12. Operational Constraints.

Constraint	AS	NA
Noise regulations	ICAO chapter 3	unknown
Emission regulations	unknown	unknown
Runway	Length > 2,000 m	Length > 2,000 m
Taxi operations	Ensure operability for large aircraft	Ensure operability for large aircraft
Boarding	Quick de-/boarding must be possible	Quick de-/boarding must be possible

3.3. Assessment Results

In order to provide an overview of the overall assessment results concerning the P-420/A aircraft concept, the above-mentioned assessment triangles are shown in the following three figures for each scenario.

FIG 9. Scenario A – assessment triangle.

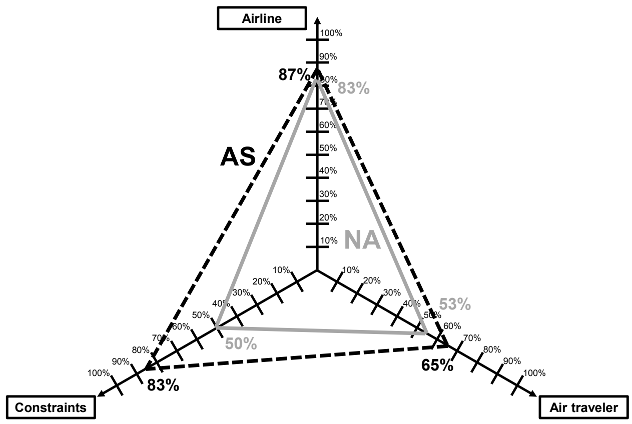


FIG 10. Scenario B – assessment triangle.

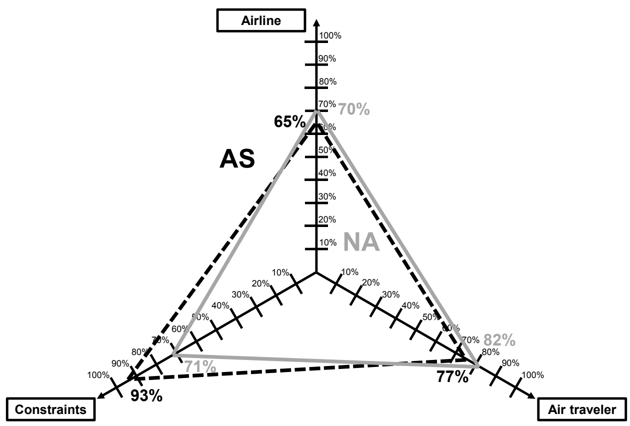
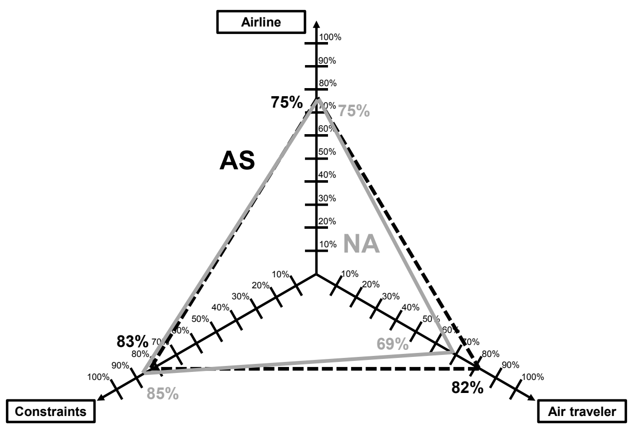


FIG 11. Scenario C – assessment triangle.



Tabs. 13 and 14 depict the major strengths and weaknesses of the P-420/A aircraft concept identified across all three scenarios for the Asian and North American domestic market, respectively, and additionally indicate important risks that the concept inheres.

TAB 13. Major strengths, weaknesses, and risks of the P-420/A concept in the Asian domestic market.

Strengths	Weaknesses	Risks
High payload capacity	Low cruising speed	Noise emissions may reach critical levels
Large cargo volume	Complex de-/boarding procedures expected	Cabin noise may reach inacceptable levels
Flexible to operate at various airports	Block time too long	Maintenance may be expensive
Short take-off and landing capabilities	Date of entry-into-service too late	
Appropriate range capabilities	Seat pitch (420 pax-config.) too small	
High fuel efficiency		

TAB 14. Major strengths, weaknesses, and risks of the P-420/A concept in the North American domestic market.

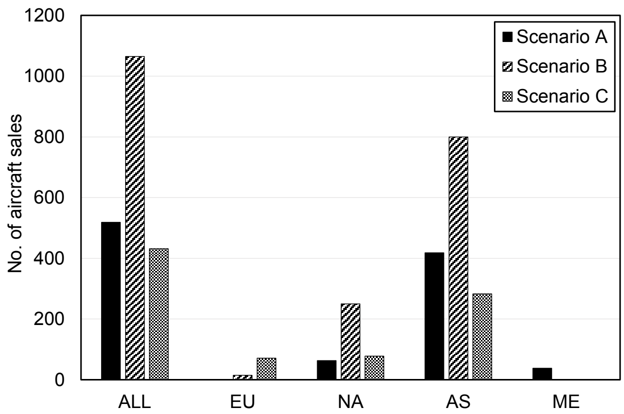
Strengths	Weaknesses	Risks
High payload capacity	Low cruising speed, thus increased block time	Noise emissions may reach critical levels
High fuel efficiency	East-West-coast connection not feasible with design payload	Cabin noise may reach inacceptable levels
All relevant airports can be served	Complex de-/boarding procedures expected	Overhead compartments in the upper deck may be too small
	Cabin of upper deck too narrow/small	Boarding process may require special airport infrastructure
	Seat density (420 pax-config.) too high	

Based on these assessment results and the scenario-based fleet development predictions determined by the Fleet Systems Dynamics Model, the overall sales potentials of the P-420/A concept were eventually determined. Fig. 12 illustrates the figures obtained for each scenario.

Referring to Fig. 12, the clear relevance and potential of the Asian market is confirmed. It constitutes by far the most important region in which the P-420/A may potentially be operated. While the North American market is still relevant to a certain extent, the European and Middle Eastern markets do not actually play a role and thus can almost be neglected.

Furthermore, a strong variation of more than 50% of predicted sales in scenarios A and C on the one hand and scenario B on the other hand is well apparent. This is due to the dependence of P-420/A sales on the Asian market.

FIG 12. Overall sales potential in each scenario.



4. SUMMARY POINTS AND CONCLUSIONS

A status-quo market analysis of the short- and mid-range air transport markets in Europe, North America, Asia, and the Middle East revealed a great potential for high-capacity aircraft to be operated on short routes, especially in the Asian domestic market segment. It was found that fuel-efficient wide-body turboprop concepts might enable further growth in RPK without equally inducing an increase in flight frequencies on the one hand, and still mitigate fuel consumption per transported passenger (and thus the environmental impact of these aircraft) on the other hand.

With this in mind, the Propcraft P-420/A aircraft concept was designed – a large transport aircraft powered by four high-performance turboprop engines with counter-rotating propellers. By means of the above presented aircraft assessment study, it was found, however, that the P-420/A concept is not able to fully meet the stakeholder requirements and operational constraints, and hence does not present the single best product solution in the market segments under scrutiny. Therefore, the aircraft is unlikely to become a major future competitor of well-established types of aircraft like the Airbus A320 and Boeing 737 aircraft families.

Considering the high variations of predicted aircraft sales from one scenario to another (Fig. 12), it must be concluded that the P-420/A concept does not constitute a "robust" product concept [35], i.e., its sales potential strongly depends on the environmental conditions. Summing up the assessment results found through the study, four major aspects related to the design of the aircraft must be considered critical:

- Due to its four turboprop engines, the P-420/A concept is likely to have disadvantageous noise emission properties, regarding both the external and cabin noise levels. Taking into account the increasingly stringent requirements related to aircraft noise [36], this aspect will become even more significant in the long-term future.

- Another critical subject directly related to the turboprop propulsion system of the aircraft is the lower cruising speed capability of the P-420/A in contrast to common turbofan-driven aircraft, which leads to increased block hours and thus a reduced degree of utilization for airlines. Still, this aspect becomes less critical with shorter flight routes served, as the cruise segment of the overall flight mission then gets shorter accordingly.

- A further critical design-related item of the aircraft concept is its twin-deck passenger cabin, leading to more complicated (and hence long-lasting) boarding procedures, which again have a negative effect on the degree of utilization of the aircraft. In addition, boarding gates and parking positions at the airports need to be adapted accordingly, which reduces the operational flexibility of the aircraft.

- An aspect that was being discussed frequently among the project team members is the 'old-fashioned look' of the P-420/A concept because of its four propellers. Apparently, some individuals tend to associate turbofan engines with a modern way of engineering while they consider propeller engines outdated. Hence, propeller engines may have a negative impact on passenger acceptance.

Three of the four above-mentioned critical aspects are directly related to the turboprop propulsion system of the P-420/A concept. It may be concluded that these aspects are likely to concern all future turboprop-driven transport aircraft, regardless of their actual size and design.

In spite of their highly favorable properties in terms of fuel efficiency, turboprop aircraft will definitely need to operate at much reduced noise levels relative to today. The success and speed of technological progress in this matter will certainly play a major role in shaping the future success (or failure) of turboprop aircraft.

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