Single engine turboprop aeroplane class in small air transport

Abstract

Purpose – The paper presents the analysis of introduction of single engine turbo-prop aeroplane class in terms of certification specifications and flight crew licensing regulations.

Design/methodology/approach – Following the results of flight testing and additional performance and sizing calculations the proposed class was placed among the existing aeroplane taxonomy in terms of performance, flight loads, mass penalty, fuel economy and several other factors. Concerning small air transport initiative, the new class was tried to be placed as a starting point in commercial pilot career.

Findings – the paper points the potential market for single engine turbopropeller aeroplanes and lists today obstacles in wider introduction. Therefore remarks about required change of regulations and requirements for design process as well as for crew licensing are underlined.

Practical implications – the results of the study would be helpful in preliminary design of a new low power turboprop aeroplane as well as during tailoring the certification specifications.

Originality/value – The approach presented in this paper is detailed extension of an original idea presented by author for the first time during Clean Sky/Small Air Transport workshop.

Keywords Small Air Transport (SAT), turboprop aeroplane, flight training, aeroplane performance.

Paper type *Conceptual paper*.

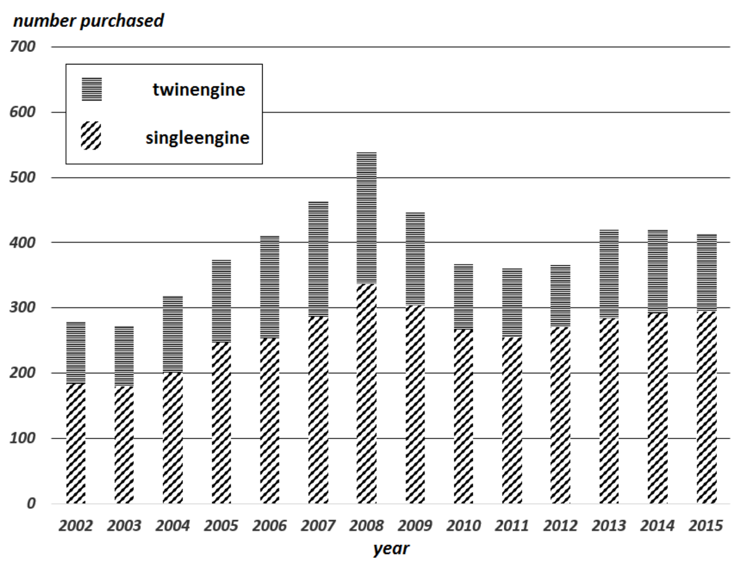
Introduction

Reliability of regular air transport, especially among the travellers from smaller communities, who appreciate the vicinity of airport of origin most, is the quite important factor when choosing the airline as a mean of transport in their journey. Ease of reaching the final destination, flights frequency and number of transfer connections become crucial whether the journey would take place (Zimon, 2016). Whereas type of propulsion, which determines the comfort to some extent with turbojet preferred, represents only 0.5% of all factors (Stone, 2016). Contemporary industrial societies show high mobility. Prosperity growth results in great number of travels up to 2'000 km, not only heading for employment or business trips, but also enjoyment and holidays. The European initiative of "door to door in four hours" from every corner of the continent could be an answer to these demands (European Commission, 2011). However, this model demands today making many types of air transport more popular and flexible, especially on the routes, that are shortest or have the lowest load factor. Unfortunately, the airlines follow totally different strategy, concentrating on medium jet aeroplane operations between hub airports, supplemented by feeder routes from smaller airports, as it has been going for last 25 years (Pai, 2010). The short haul services seem to be natural location for turbopropeller airliners, but it is not quite often. The manufacturers of regional turbopropeller aeroplanes optimize them for operations lasting up to 130 minutes at cruising level of 25'000 ft, but the most popular scenario goes at cruising levels up to 18'000 ft lasting not longer than 70 minutes (Cajani et al., 2011). What is more, local routes are serviced by narrow jet aeroplanes very frequent, due to the fact that jets give more flexibility in costs balancing between operation and passenger expenses. The analyses revealed (Ryerson and Hansen, 2010), the fuel consumption of turboprops is much lower than jets, contributing towards financial savings as well as reducing greenhouse gases pollution in the atmosphere (Peeters et al., 2005).

Model of widely spread of air transport between smaller cities had been realized in the United States of America since the World War II finished now (Stringer, 2013a), but it was highly limited and controlled by federal agencies. Deregulation of airline market in 1970s changed the transport structure entirely and contributed towards cancellation of hundreds connection irretrievably, as well as halted the development of aeroplanes designed for local flights (Stringer, 2013b). Introduction of a new aeroplane category concerning regional transport, called commuter, with simplified certification process was aimed at stride of local passenger services between small airports, as well as feeder routes to large hubs. Today, the commuter category remains as marginal, because lays out of interests of air carriers. It overlaps with limited capacity of airspace that may be provided by air traffic services. Nevertheless, the analyses suggest to fragment the connection networks and increase number of connections. It may have beneficial impact on the revenues of air carries (Majka, 2014a), and development of regions, as the regional passenger establishes still high percentage of the market (Gillen and Hazledine, 2015).

Concerning described obstacles, it may be worth to create friendly environment for the development of passenger transport on the lowest level, so General Aviation. However the definition of the latter includes hardly whole civil aviation, but passenger and freight transport, the typical General Aviation aeroplane is associated with the simplest single engine piston low-wing monoplane, carrying four persons on board (Turnbull, 1999). Today, this kind of aeroplane may be met in flight training schools mostly, because of two reasons. The light and very light aeroplanes, simpler and cheaper took over a group of private pilots flying for pleasure. While business travellers moved towards more reliable and efficient turbopropeller aeroplanes, as might be seen in the Figure 1. Lingering trend in the number of factory purchased single engine turboprop aeroplanes suggests, it would be worth to consider enhancement of the range of aeroplanes offered down to engines with lower power – equal to the power of contemporary piston engines.

Figure 1 Number of factory built turboprops purchased within last 13 years (GAMA, 2015).



The paper presents a study on a possible new class of aeroplanes in terms of flight crew licensing obligatory in member states of European Community and several other, recognized by European Aviation Safety Agency (EASA). The idea presented here intends to be one of the stimuli to popularize a turbopropeller aeroplanes among users, strongly attached to the piston ones so far.

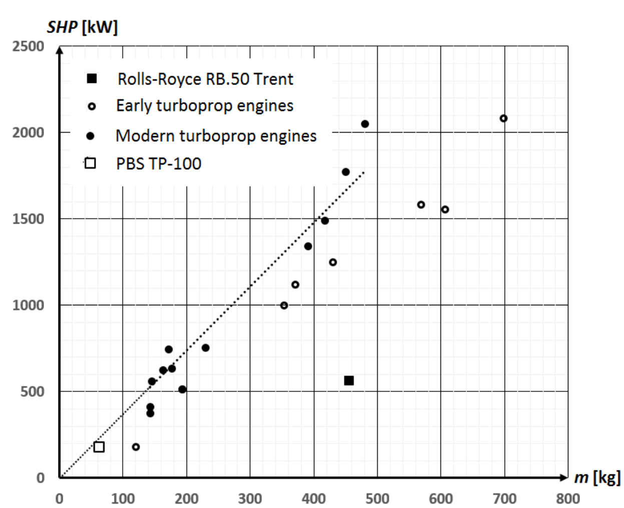
In the following chapters, short description of turbopropeller engines development was presented, focused especially on low power engines and their application to light single engine aeroplanes. Consecutively, author elaborates requirements of two potential customer's groups of a new aeroplane class – flight training organizations for future airline pilots and enterprises in the network of small aeroplanes transport system. On the grounds of these expectations filtered by requirements of European air law system, an attempt to define conditions for a new aeroplane class was performed. Then, the results of flight test program and supplementary calculations for an example aeroplane were compared to the boundary conditions. In aftermath, conclusions and issues for future work were formulated.

Aeroplane with single turbine engine propulsion

Since the advent of turbine propulsion in aviation, piston engines became obsolete for military and commercial transport purposes. The only one area, where piston engines rule even today is private and sport flying, and aerial works to some extent. Therefore, the most popular arrangement of reciprocating engine last in-line boxer, air-cooled, charged sometimes, having output power not more than 1’000 kW.

One of the criteria of propulsion selection is engine specific power related to the engine mass. Turbopropeller engine looks quite attractive compared to the piston engine, beating twice with number of kilowatts per kilogram of engine mass. Referring to data of turbopropeller engines produced today (Gudmundsson, 2014) and selected examples from the pioneering era (Smith, 1955), the Figure 2 presents shaft horse power (SHP) as a function of engine mass. At a first glance, one may notice, the first turbopropeller engine Rolls-Royce RB.50 Trent have a significant mass. From the very beginning the main purpose of turboprop engines was to replace reciprocating in every possible application in transport and military aviation. Therefore no one looked for propulsion weaker than 1’000 kW. The first attempt to apply turbopropeller engine for single engine aeroplane came as a bid in contest for replacement of North American Harvard training aeroplane for Royal Air Force. Prototypes of Boulton-Paul Baliol I and Avro Athena were equipped with Armstrong Siddeley Mamba. Finally however, the Baliol as a winner was powered by piston Rolls-Royce Merlins, due to the fact that large numbers were still in store after the war. The Boeing 502 belongs to the rare examples of low power turbopropeller engines from that period, but it was intended to drive light unmanned vehicles or flying targets. These engines were not in the field of interest of aeroplane designers due to several factors. Piston engines, despite less profitable (twice at least) rate of power available to the engine mass were favoured, concerning simplicity in maintenance, spare parts availability, number of fuel stations in remote places, and reliability. All these factors played crucial role to satisfy a client (Flying Businessman, 1953).

Figure 2 Trend in dry mass of the engine increment related to the output SHP.



Progress in material sciences and computer aided design allowed to increase rate of power available to the engine mass from one side and to increase reliability of this type of propulsion from the other. Thereby, turbopropeller engines became more popular as a power source for civil single engine aeroplanes designed from scratch as well as conversions from piston aeroplanes. Aircraft manufacturers, looking for advantages of turbopropellers, concentrated on a power range from 300 to 1’000 kW to a large extent. As a result, average product became a corporate passenger aeroplane flying up to speeds 250 kts and altitudes 25’000 ft. This set is complemented by multipurpose aeroplanes of specific performance and agriculture and firefighting aeroplanes. In contrast, aeroplanes similar to light training and leisure, so these defined earlier as typical General Aviation, belong to rarity (Turnbull, 1999).

Contemporary application of turbopropeller engines covers areas, distinguished by author as follows:

- Four engine, heavy and medium military transport aeroplanes (Lockheed L-100 Hercules, Antonov An-12, An-70, Airbus A400); Heavy Lift Transport – HLT,
- Fourengine passenger aeroplanes of the special purpose (DHC-7); Regional Aircraft – REG,
- Twin-engine passenger aeroplanes of regional transport (ATR.72/42, DHC-8, Antonov An-140); REG,
- Light twin-engine passenger and transport aeroplanes - commuters (PZL M.28, DHC-6, Hawker Beechcraft 1900); Commuter – COM and Multi Engine Turbine – MET,
- Single engine corporate aeroplanes (PC-12, TBM-900); Single Engine Turbine – SET,
- Single engine military trainers (PZL.130, PC-21, TB-31); Trainer – TRN,
- Single and twin-engine upgrades of piston driver aeroplanes (Piper PA-46); Upgraded – UPGR.

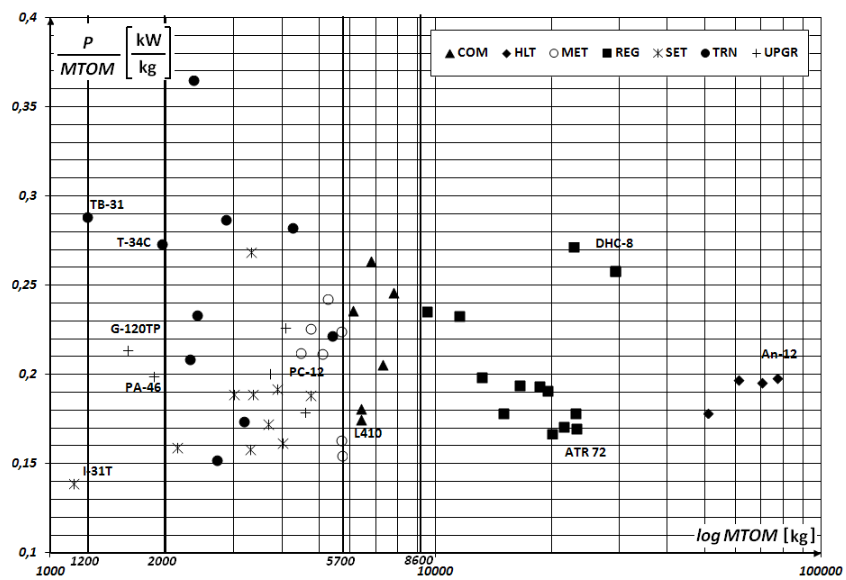
The Figure 3 presents, for above groups of aeroplanes, relation of power loading and maximum take-off mass. The power loading belongs to the most important parameters responsible for performance of the aeroplane (Loftin, 1980), henceforth it may describe capabilities and purpose of the aeroplane to some extent.

Additionally, there are distinctive intervals of aeroplane maximum take-off mass, important in terms of certification and airworthiness regulations:

- 12’500 lbs (converted to 5’700 kg) sets the lower limit for large aeroplanes, but does not include commuters (CS Definitions), additionally all aeroplanes above this margin belong to complex motor powered aircrafts (REG 216/2008).
- 12’500 lbs (converted to 5’670 kg) sets the upper limit for normal, utility and aerobatic aeroplanes, certified according to CS-23 (CS-23, 2015).
- 19’000 lbs (converted to 8’618 kg) sets the upper limit for commuter aeroplanes, certified according to CS-23.

- 2’000 kg is a limit mass for aeroplanes belonging to ELA2 (ELA – European Light Aircraft) (COM REG 1321/2014), additionally aeroplanes below 2’000 kg make use of many privileges and facilitations regarding certification process, flight testing, maintenance, operations and navigation charges.
- 1’200 kg is a limit mas for aeroplanes belonging to ELA1 (COM REG 1321/2014).

Figure 3 Power loading versus maximum take-off mass for different turboprop aeroplanes.



Regardless the maximum take-off mass, the aeroplanes having power loading 0.2 or less, are designed for normal cruise operations without any special manoeuvring performance or particular take-off characteristics. It refers to heavy lift transport aeroplanes, regional passenger aeroplanes as well as light single engine aeroplanes designed from scratch. The highest values of power loading are fitting to manoeuvring military trainers (0.25 – 0.37). Somewhere in-between are located twin-engine and commuter aeroplanes, characterized by extraordinary short airfield take-off performance, including one engine inoperative operations.

Analysing the chart, one may draw attention to a significant gap in group of light aeroplanes below 2’000 kg MTOM that power loading does not exceed 0.2. Author may point following factors:

- Leading role of reciprocating engines in propulsion of light aeroplanes for seventy years, followed by worldwide service and spare parts availability;
- Deficiency in serial low power turbopropeller engines – contemporary turbine engines are still more powerful than most powerful serial piston engines (sometimes the power is flat rated artificially);
- Harmonization of training requirements for different licenses and ratings based on piston aeroplanes and additional, expensive entry requirements for turbine aeroplane ratings;
- Lack of unified regulations for passenger transport with small single engine aeroplanes.

In favour of wider turbopropeller engine introduction in General Aviation author would argue:

- Simplicity in maintenance and operation of turbopropeller engines, proved in remote and adverse locations;
- Introduction of new aeroplane categories driven by car fuels, which became popular among private pilots, as well as continuous demand on brand new single engine turboprops;
- Tendencies in professional pilot training, emphasizing the fact that the first contact with turbine engine should take place much earlier;
- Requirement for flexible transport systems based on “door to door in four hours” formula.

Potential areas of application of single engine turboprop aeroplane

Small Air Transport

Intentions of European Commission state, that before the year 2050 almost every traveller (90%) in Europe will be capable to accomplish trip within time span not longer than four hours. The passengers, as well as freight will travel by different means of transport including aviation, in order to have the trip performed in predictable way and on time (Flightpath 2050). One of the new means of transport, that may contribute significantly to proposed intention, would be Small Air Transport (SAT), as an alternative for car travel longer than 200 kilometres (Piwek, 2012). In its structure, SAT includes three aeroplane classes differed by engine type – reciprocating (ACP), with hybrid option, turbopropeller (ACT), and jet (ACJ) (Piwek & Wisniowski, 2016). This classification is based on contemporary structure of the General Aviation market. The aeroplanes belonging to SAT should be certified according to CS-23 categories. Limitation in number of places and maximum take-off mass imposes single pilot crew. The basic SAT requirement of “door to door in four hours”, depending on the engine type, creates boundary conditions for cruising speed from 300 to 700 kph and altitudes from 12’000 to 30’000 ft.

Among three classes listed above, single engine aeroplanes with number of places 1+3 (ACP-1) were put in to segment of on-demand private or business trip. The majority of such operations may be accomplished within 300 km and lasting 1.5 h. The maximum range would not exceed 900 km and endurance 3.5 h. Today, only piston driven aeroplanes fit into this class.

Professional flight training

The basic requirement in order to begin career as an airline pilot is commercial pilot license CPL(A) with instrument flight rating IR and multiengine aeroplanes rating ME. This system lasts since decades and has its grounds in European and American regulations, which are implemented by many countries worldwide (Bakunowicz and Miąskowski, 2010).

Concerning many issues, among them: economical, historical and cultural including these mentioned in chapter 2, the training of candidates for commercial pilots from the first flight till the very end relies on the piston aeroplanes only. On the other hand, military pilot training introduces turbopropeller aeroplane as an obligatory step in career, no matter where the officer will find his future assignment. In civil training this aeroplane class has not found permanent place. It does not mean, there had not been initiatives earlier. Lufthansa Flight Training and several other airline flight schools operated twin-engine turboprop aeroplane Piper PA-42 Cheyenne III as a platform to simulate an aeroplane with certain performance. Following this trace, Piper Aircraft tried to attract attention with modified Piper PA-46 Malibu, naming the craft Turbine Transition Training Platform (Cornak, 2010). However, the law regulations did not demand such training resulting in zero response from training schools. The application of flying platforms in performance simulation remains still domain of research activities of scientific institutes and universities (Tomczyk et al., 2016). This approach results in fact that the candidate for airline pilot demonstrates fluency in operations of reciprocating engines, having no experience with engines he is supposed to work with.

The new class of aeroplane

Proper placement of a new aeroplane class – low power singleengine turbopropeller land or water LSET among other existing contemporary classes and types demands a review of regulations, requirements and definitions. Multitude of possible descriptions related to the only one and still the same aeroplane, concerning classes, categories, types and other taxonomies suggests to concentrate on a certain group of features of the aeroplane. This should be preceded by analysis of regulations in the following areas:

- → Design and certification;
- → Continue airworthiness;
- → Type of operations;
- → Flying personnel skills,

in order to introduce a new class in the least invasive manner.

Two first areas mentioned above should be considered as subordinated to two next. The kind of operation, so mission profile determines the masses and performance of the aeroplane. Consequently, in a simple way indispensable skills of the pilot – commander of the ship may be assessed. The user requirements described in previous chapter, or basically expectations of potential clients of new aeroplane class established an envelope of performance and mass. Concerning the travellers inclined toward flying an aeroplane instead driving a car as well as flight schools focused on training of future airline pilots, these envelopes should be fitted into frames of regulations in a way which would not jeopardize the initiative as a whole.

The aeroplane should be recognized by EASA having type certificate (TC) for air transport and training. The initial airworthiness is required in accordance with COM REG 748/2012, and following continuous airworthiness according to COM REG 1321/2014. It seems naturally, the most suitable certification specifications are CS-23 in normal, utility and aerobatic category with maximum take-off mass not greater than 5670kg. The normal category would be sufficient for transport flights from A to B, but including flight training suggests to enhance the certification to utility with spinning approved. The latter demand results from increasing importance of training in abnormal attitudes, so called up-set recovery including spinning. In order to facilitate operations, maintenance and airworthiness management it would be recommended to keep maximum take-off mass within limits of ELA2, or better ELA1, and avoid, for sure, complex aircraft classification. Particular attention should be paid for designed fuel capacity, which may include between 47% and 83% of Operating Empty Mass - OEM (Marinus and Mason, 2016).

Application of this aeroplane class in the passenger air transport, similarly to present single engine piston and single engine turbopropeller aeroplanes, will be strictly limited in order to satisfy operational regulations (COM REG 965/2012). Due to the fact that the commercial air transport is widely spread to all operations involving carrying passengers or freight for remuneration, not only in pure cash, would be quite difficult to place these SAT operations into a different category.

Single-engine aeroplanes in air transport got limited to flights in daytime and according to visual flight conditions. It is related to emergency capabilities after engine malfunction. The operator, when planning passenger flight in single-engine aeroplane is committed to plot a route along all potential places for emergency landing, concerning glide performance of the aeroplane. Therefore, the operators in Europe do not use singleengine aeroplanes, due to the fact that all problems related to them disappear along the twin-engine configuration. We may presume only, the passenger transport on-demand in private or business journey postulated by SAT remained marginal, suffocated by operational requirements to large extent, concerning the weather and time of the day. Therefore, the basic customer branch for the new aeroplane class would consist of flight schools and private owners, these who cannot afford for today single engine turbopropeller aeroplanes.

The flight crew licensing regulation obligatory today (COM REG 1178/2012) among other aeroplane classes, distinguish single engine turbopropeller aeroplanes class SET, as well. These are aeroplanes for single pilot operations, but in contrast to classes of piston driven aeroplanes, single and multiengine – SEP and MEP, the SET class is not intended for all aeroplanes and depends on requirements in operational suitability data (OSD) prepared by the aeroplane's manufacturer. SET class aeroplanes are limited only to one manufacturer (e.g. Cessna SET) or group of types (Socata TBM SET) or types only or variants, depending on OSD. Therefore, for every EASA SET aeroplane class there is an individual training in recognized training school required acknowledged by national exam, and then consecutive exams for revalidation taken each year. The current Type Rating & License Endorsement List recognized by EASA (2016) mentions (the agriculture and firefighting aeroplanes are excluded in this paper, as aeroplanes of special purpose) 16 SET classes for 27 types with variants, including 5 classes presumed as high performance aircraft (HPA). Available sources of European regulations do not excerpt definition of HPA aeroplane. Generally, it may be presumed, HPA concerns single pilot aeroplanes of high normal operation speeds and high cruising levels. It stands in contrast to American regulations, which define HPA clearly, but according to totally different assumptions (CFR.PART.61.31.(f)). The "American" HPA includes every aeroplane regardless the propulsion, whether piston or turbine, but having power of 200 hp or more. Whereas, there is a separate rating for flying aeroplanes having pressurized cabin (CFR.PART.61.31.(g)).

In the Figure 4 the relation of maximum operational speed V_{MO} as a function of power index I_p is presented. The latter parameter is calculated as (Loftin, 1980):

$$I_p = \sqrt[3]{\left(\frac{W/_S}{W/_P}\right) \cdot \frac{1}{\sigma}}, \quad (1)$$

where:

W - aeroplane take-off weight (lbf);

S - lifting area (sqft);

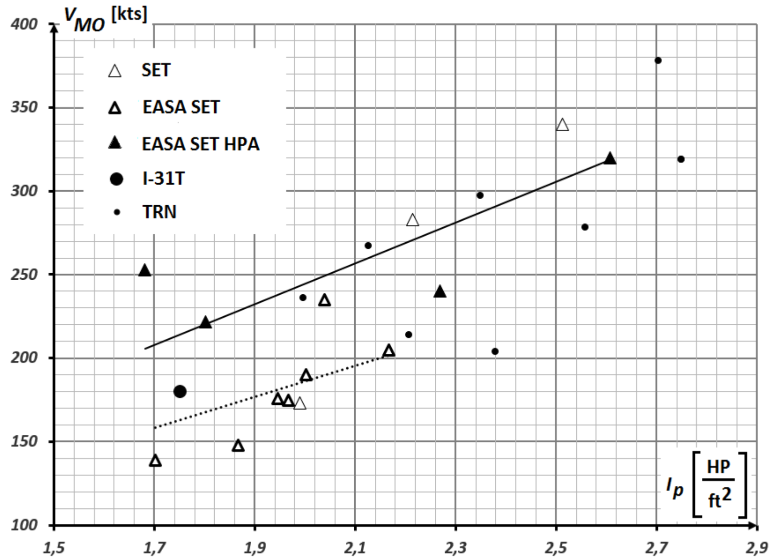
P - propulsion take-off power (HP);

σ - specific air density (1),

and shows linear relations with the speed. Referring to Loftin, power index indicates the efficiency of the propulsion and its value remains almost constant for certain performance groups of aeroplanes. The data presented in the chart were all for single engine turbopropeller aeroplanes, but were divided into several groups: aeroplanes endorsed by EASA as a SET class in the type rating (defined in OSD), EASA SET aeroplanes categorized as HPA, all other remaining SET aeroplanes of contemporary market and military training aeroplanes. Analysis of the chart would allow to point that:

- HPA aeroplanes are characterised by maximum operational speed greater than 200 kts;
- SET aeroplanes, which are not dedicated for special purposes, have power index not greater than 2.3;

Figure 4 Maximum operating speed of the aeroplane versus power index for different groups of single engine turbopropeller aeroplanes. The lines represent trends for EASA SET – dotted and EASA SET HPA – continuous.



The consideration above may suggest, that principal determinants for the new aeroplane class, besides the propulsion type, should comprise performance characteristics, consistent with demand from the potential customers. Contrarily, to be in line with licensing authorities, this performance cannot trigger extraordinary skills from the pilot. Therefore, to summarise all requirements and limitations presented in previous chapters, the new aeroplane class could be defined by following features:

- Propulsion consisting of the one turbopropeller engine, maximum continuous power of 250 kW and constant speed propeller with feather feature;
- Maximum take-off mass limited to 2'000 kg, the number of seats not more than 4;
- Endurance up to 3.5 h and range of 900 km;
- Flight endurance with MTOM above 2 h15 min and range not less than 300 km;
- Unpressurized cabin, operational altitude of 3-3.5 km;
- Retractable undercarriage;
- EASA performance class B (COM REG 965/2012) and ICAO performance category A (Doc. 8168).

These features do not describe just only an aeroplane class in terms of European flight crew licensing regulations. They make ground to define a certain group of aeroplanes, as a one of modern development trends in aviation. Nowadays, this direction encounters lot of restrictions and disadvantages listed above. The future of turbopropeller engine and SAT introduction act as a stimulus to follow.

Representative example

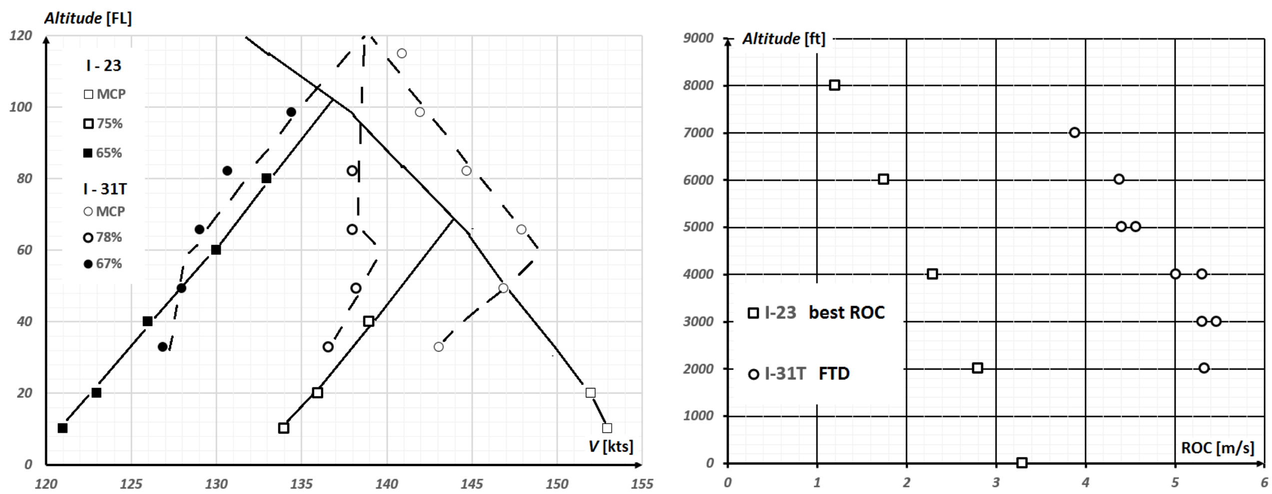
The aeroplane that could pretend to be included in the new class, as proposed by the author, is the I-31T prototype (Figure 5), designed in the Institute of Aviation in Warsaw, Poland - IoA (Iwaniuk et al., 2016). It is four-seat, low-wing monoplane with retractable undercarriage, driven by PBS TP-100 turbopropeller engine, manufactured by PBS Velka Bites, Czech. The presented aeroplane is upgraded version of I-23 Manager airframe (Baron, 2012) and aimed as a research flying platform and propulsion demonstrator in Efficient Systems and Propulsion for a Small Aeroplane (ESPOSA) research project co-funded by European Commission within 7th Framework Program.

Figure 5 I-31T aeroplane during one of the test flights.

The aeroplane underwent a series of test flights, inter alia, determination of performance and operational characteristics. In the present chapter, the most significant performance data were compared, regarding the turbopropeller aeroplane and her piston predecessor. It should be pointed, at the beginning, the modification presented did not attempt to be finalised by market product, and therefore a couple of limitations were accepted during the design phase.

The Figure 6 presents the flight envelopes and climb profiles of both variants. These characteristics may demonstrate many capabilities of the new aeroplane, at a first glance. Due to the fact that the output power of both engines - piston and turbine – are quite comparable, therefore range of operational speeds did not differ much. However, climb performance improved significantly in favour to the turbopropeller propulsion. The results of stability and control test flights as well as subjective handling assessment revealed no significant difference in flying characteristics. There is noticeable change in gyroscopic effects from the propulsion. The large, five blade propeller and fast rotating engine produces significant torque during the each change of power. This feature is rather negligible in modern low power boxer piston engines. On the ground of presented results and making use of pilots' opinions it could be pointed that performance and handling of the aeroplane, which could be selected as a LSET representative, do not require any particular skills from the average pilot.

Figure 6 Flight envelopes (L) and climb profiles (R) of turbopropeller I-31T LSET aeroplane and her predecessor – piston driven I-23 SEP (data source: I-31T flight test, I-23 Flight Operation Manual).



The results of range and endurance tests present a rather different outcome. The range of the aeroplane equipped with a turbopropeller engine decreases much. The piston driven aeroplane was able to fly more than 10 nautical miles per U.S. gallon (NMPG) of aviation gasoline (AVGAS) with maximum continuous power available (MCP). Having the power lowered to best economy setting increased the range significantly to 16 NMPG. The turbine propulsion avails only 5 to 7 NMPG of kerosene (JET A-1). Moreover, the fuel consumption of turbopropeller engine does not change much with the cruising flight level, comparing to the piston one. Unfortunately, this analysis disposes to the conclusion that the presented modification became less economical, bearing in mind that the main goals of proposed mission profile are endurance and range. The unchanged spectrum of operational speeds makes the aeroplane more wasteful.

Application of one of several criteria of quality assessment, regarding an aeronautical vehicle, underlines rather disadvantages of presented modification. As an example, the Bartini criterion was applied (Fortinov, 2005) as below in Eqn (2):

$$\bar{P} = \frac{UL}{MTOM} \cdot V_{NO} \cdot L_{UL}, \quad (2)$$

where:

UL - useful load (kg);

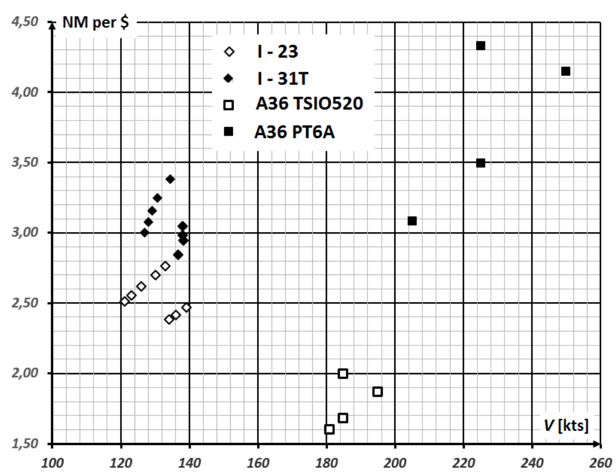
$MTOM$ - maximum take-off mass (kg);

V_{NO} - normal operational speed (km/h);

L_{UL} - range with a given load (km), which enables to asses transport efficiency of the aeroplane. Having relations between useful load and maximum take-off mass unchanged for both aeroplanes and the range decreased (bearing in mind increased fuel consumption and fuel capacity remaining), the only one solution to keep the efficiency is to speed up at the cruising level. In the presented case the speed also remained the same.

One of the factors, taken into account, when decision about the propulsion shift from piston to turbine has place is much lower cost of kerosene, compared to gasoline. This implies the total cost of the fuel for a given distance becomes lower. More often than not, it is also tantamount to cruise speed increasing caused by higher power of the propulsion. The Figure 7 presents fuel cost analysis, based on data acquired in 10 main airports in Poland in the end of August 2016 (it should be noticed that price relations presented are worldwide). Indeed, one may point, the application of turbopropeller engine gives for I-31T aeroplane half a nautical mile more per proverbial one U.S. dollar, than for piston I-23. But, throwing in, the remaining cruise speed range and specific range of the turbine version only a half of the piston, downgrades any profits in fuel price. In the same Figure, similar data for Beechcraft A36 Bonanza are presented. This example, having more powerful propulsion and flying faster justifies the modification, despite decreased range and increased fuel consumption as well. However, concerning other types of fuel would be a solution for this class (Jakubowski, 2016).

Figure 7 Distance in nautical miles flown per one US dollar by LSET aeroplane and her SEP predecessor.



The performance analysis of representative aeroplane that could be considered as LSET class showed they are characterised by similar cruise performance but much better climb profile compared to analogous SEP class aeroplanes. Disadvantageous data are related to increased fuel consumption of turbine engine. Additionally, unchanged capacity of fuel tanks and low operational density altitudes decrease range and endurance significantly. This last remark suggests emphatically, that LSET aeroplanes powered by low power turbopropeller engines should not be a simple modifications of existing piston driven aeroplanes. The success of these aeroplanes lays in quite new designs, which will come to existence from distinct sizing algorithms, as it is always, concerning new class of aeroplanes (Marinus and Poppe, 2015).

Conclusion

The proposal of introduction of a new aeroplane class introduction – LSET, Low Power Single Engine Turboprop – has been presented in this paper. The main goal of this action would be a replacement of existing classes within type ratings described in flight crew licensing regulations. The fundamental justification of this proposal is promulgation of turbine propulsion among these General Aviation stakeholders, who operated with piston driven aeroplanes only, thus far. The introduction of an additional aeroplane class, defined by size, arrangement, propulsion, masses and performance limited in a way, that do not demand any extraordinary skills and experience, would establish room for light aeroplanes driven by low powered turbopropeller engines. The main application, firstly would take place in flight training organizations. The candidates for airline pilots, from the very beginning should have connection with turbine propulsion. However it may be introduced only after change of regulations concerning flight training syllabi, in order to legitimize such application. Additionally, not only new operational requirements, but significant improvement in fuel economy would only allow to initiate passenger transport with these aeroplanes.

Initially however, the definition for a new aeroplane class was intended only in terms of flight crew licensing regulations, but it may concern a certain group of aeroplanes characterized by performance, dimensions and masses. One of the main findings in this study is these LSET aeroplanes cannot be designed as modifications of existing platforms, due to the fact that the restrictions in maximum take-off mass and minimum amount of fuel required for the mission coupled with different character of turbopropeller engine operation lead to wasteful vehicles. This has been proven during testing of presented LSET class demonstrator, designed as a modification of piston aeroplane.

The choice of total fuel mass as a function of required range and endurance on one hand, and the useful load on the other requires different design procedures, as the contemporary ones related to light piston aeroplanes (Stinton, 1983) or heavier turboprops. It is particularly important, due to the fact that for turbopropeller aeroplanes specific range changes the more nonlinear the lower maximum take-off mass is. (Marinus and Maison, 2016).

Further Work

The author intends in the future works, concerning data from test flights of presented I-31T aeroplane and additional analyses, to define more accurate and detailed algorithms, which would enable the better sizing of design variables of light aeroplane with low power turbopropeller engine.

It is not out of a question, in the not distant future the necessity for subsequent aeroplane class definition will arise. The development of low power turbopropeller engines is accompanied by the development of small turbojet engines. Within last decade several new designs of single turbojet engine passenger aeroplanes up to 6 seats appeared (Majka, 2014b).

In contrast to the presented LSET class, performance of light jets is closer to the turbojet aeroplanes in general and one cannot consider them as a large group of low performance aeroplanes.

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References

Aviation Information Film (1953). Flying Businessman.

Bakunowicz, J., Miąskowski, M. (2010). University integrated pilot training course versus Bologna Process. From Zero to ATPL, 14-15 Sep. 2010. Zilina Slovakia.

Baron, A. (2012). Samolot Osobowy I-23 "Manager". Wybrane problemy badawcze. Instytut Lotnictwa, Warszawa. ISBN 978-83-63539-01-6.

Cajani, M., Ciotola, R., David, J., Salvi, J. (2011). ATR Life Extension Project. 26th ICAF Symposium, Montreal, 1-3 June 2011:585-600.

Code of Federal Regulations. Part 61 CERTIFICATION: PILOTS, FLIGHT INSTRUCTORS, AND GROUND INSTRUCTORS

COMMISSION REGULATION (EU) No 748/2012 of 3 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations

COMMISSION REGULATION (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council

COMMISSION REGULATION (EU) No 1178/2011 of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council

COMMISSION REGULATION (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.

Cornak, L. (2010). Turbine transition training platform. From Zero to ATPL, 14-15 Sep. 2010. Zilina Slovakia.

European Aviation Safety Agency (2015). Certification Specifications for Normal, Utility, Aerobatic and Commuter Category Aeroplanes CS-23. Amendment 4.

European Aviation Safety Agency (2010). Definitions and abbreviations used in Certification Specifications for products, parts and appliances. CS-Definitions. Amendment 2.

European Aviation Safety Agency (2016). EASA Type Rating & License Endorsement List Flight Crew – All Aircraft excluding Helicopters 11 Jul 2016

European Commission (2011). Flightpath 2050 Europe's Vision for Aviation.

*Fortinov, L.G. (2005). Kriteryi otsenki sovershentva dozvukovyh letatelnyh apparatov (rus.). Aviatsyonno-kosmicheskaya technika i technologya, **23**:208-218.*

General Aviation Manufacturers Association – GAMA (2015). 2015 General Aviation statistical data book and 2016 industry outlook.

*Gillen, D., Hazledine, T. (2015) The economics and geography of regional airline services in six countries. Journal of Transport Geography, **46**: 129-136.*

Gudmundsson, S. (2014). General Aviation aircraft design: Applied methods and procedures. Elsevier.

International Civil Aviation Organisation. PANS-OPS, (Doc 8168), Procedures for Air Navigation Services — Aircraft Operations Volume I — Flight Procedures.

*Iwaniuk, A., Wiśniowski, W., Żółtak, J. (2016). Multi-disciplinary optimisation approach for a light turboprop aircraft-engine integration and improvement. Aircraft Engineering and Aerospace Technology, **88**: 348-355.*

*Jakubowski, R. (2016) Analysis of chosen fuels influence on turboprop engine work performance. Journal of KONES Powertrain and Transport, **23**: 163-170.*

Loftin Jr., L.K. (1980). Subsonic Aircraft: Evolution and the Matching of Size to Performance. NASA RP-1060. Langley Research Center, Hampton.

*Majka, A. (2014a). Multi objective optimization applied for planning of regional European airline. The Archives of Transport, **29**: 37-46.*

*Majka, A. (2014b). Multiple objective optimization of the power unit for a very light jet. Aircraft Engineering and Aerospace Technology, **86**: 234-241.*
*Marinus, B.G., Poppe, J. (2015). Data and design models for military turbo-propeller aircraft. Aerospace Science and Technology, **41**: 63-80.*
*Marinus, B.G., Maison, J. (2016). Fuel weight estimates of military turbo-propeller transport aircraft. Aerospace Science and Technology, **55**: 458-464.*
*Pai, V. (2010) On the factors that affect airline flight frequency and aircraft size. Journal of Air Transport Management, **16**: 169-177.*
Peeters, P.M., Middel, J., Hoolhorst, A. (2005) Fuel efficiency of commercial aircraft. An overview of historical and future trends. NLR-CR-2005-669.
Piwek, K. (2012) Small Aircraft Transport as a new component of the European air transport system. In: Knorzer D., Szodruch, J. (Eds.) Innovation for Sustainable Aviation in a Global Environment. IOS Press, doi:10.3233/978-1-61499-063-5-376.
*Piwek, K., Wiśniowski, W. (2015). Small air transport aircraft entry requirements evoked by FlightPath 2050. Aircraft Engineering and Aerospace Technology, **88**: 341-347.*
REGULATION (EC) No 216/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC.
*Ryerson, M.S., Hansen, M. (2010). The potential of turboprops for reducing aviation fuel consumption. Transportation Research Part D, **15**: 305-314.*
Smith, G. (1955). Gas Turbines and Jet Propulsion. Illife & Sons Limited, London.
Stinton, D. (1983). The Design of the Aeroplane. BSP Professional Books. Oxford.
*Stone, M.J. (2016). Reliability as a factor in small community air passenger choice. Journal of Air Transport Management, **53**: 161-164.*
*Stringer, D.H. (2013a). How America's local airlines put main street on the map. The Aviation Historian, **3**: 54-63.*
*Stringer, D.H. (2013b). Fly America! The Aviation Historian, **4**: 92-105.*
Tomczyk, A., Bakunowicz, J., Wałek, Ł. (2016). Simplified Total in Flight Simulator as a Tool in the Aeronautics Students' Education. 8th World Conference on Educational Sciences (WCES-2016), University of Alcala, Madrid, Spain.
Turnbull, A. (1999). The Typical General Aviation Aircraft. NASA CR-1999-209550. Langley Research Center, Hampton.
Zimon, D. (2016) An Attitude of Subcarpathian's Residents to Sustainable Solutions for Urban Transport, International Letters of Natural Sciences, Vol. 50, pp. 41-52.