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Data and design models for military turbo-propeller aircraft

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ABSTRACT

This article presents a comparative and analytic review of present fixed-wing military aircraft equipped with turboprops. The database includes several aircraft types ranging from the training/light attack role to strategic transport. Data concerning masses, wing and tail surfaces, propellers and engines, as well as aerodynamic data and performance figures of 43 military aircraft in current inventories is analysed. The data is compared to conceptual and preliminary design models that are commonly available in the literature for turbo-propeller aircraft. Models from different sources are used concurrently. Departures from those models reveal that purpose built design models for civilian aircraft are not applicable to military aircraft without amendment; while models specifically issued for military turbo-propellers often rely on outdated data. New model coefficients, or new model laws are proposed whenever necessary so that current trends are adequately translated into reliable design models for future military aircraft.

1. Introduction

The conceptual design phase ideally ends with a frozen set of requirements—though in practice some requirements evolve along the program, often for considerations of cost or sudden changes in the operational environment—as well as initial weight and cost estimates and an incipient configuration. At best, essential and/or critical technologies have been identified together with a first set of trade-offs and the necessary research and development measures can be initiated. In the end, the feasibility and viability of the program must be guaranteed. The ensuing preliminary design phase freezes the configuration so that the sizing and design of major items can be executed. This way, a more accurate cost estimate can be calculated and matched, or not, to the market. The next step sees a huge amount of resources and engineers being dedicated to the detailed design and testing of all actual parts and the required tooling along with the definition of the assembling process.

Even if the design process involves numerous iterations, it is good practice to get it right from the start. Therefore, having accurate design models is paramount to keeping the development cost down. Of course, this should not prevail innovative designs to break from the confinement of design models that tend to be rather conservative by essence. Moreover, the particular value of one aircraft's design characteristics may be used for benchmarking during an acquisition process that does not involve a full development program. Together with many other figures of merit, they allow to compare different aircraft among each other as well as to help identify and select the best design that will meet the acquisition requirements.

Since models and sizing laws are essential to a successful design process, the present paper focuses on those aircraft characteristics that need to be estimated as accurately as possible in the conceptual and preliminary design stages. Furthermore, because any aircraft design is the embodiment of the best answer from a multidisciplinary team of engineers and technicians to a complex set of requirements corresponding to a particular mission specification, we focus on military aircraft. Among those, aircraft featuring one or more turbo-propellers form the present subset of interest. Despite their importance in the multidisciplinary aircraft design framework, issues purely related to other fields than aerodynamics are not considered in this work. Nor are those aerodynamic parameters that do not relate to primary aerodynamic forces such as lift, thrust and drag or to basic stability and control issues.

The preliminary design models from unclassified literature [1,3,4,6,8,10,14–16,19–22,25] have been systematically searched for trends that apply to turboprop aircraft though in many cases no distinction is made between civil and military applications. Military turbo-propeller aircraft trends can be found in [3,6,10,15, 16,19–21]. These laws are then compared to a database of existing military turboprop aircraft of various types. The length of the present paper precludes from any rational development of a full step-by-step design method. Its purpose is therefore purely to

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Nomenclature

D_p	Propeller diameter (m)	V	Non-dimensional volume coefficient
D_i	Induced drag (N)	$-_e$	Empty mass/weight
n	Rotational velocity (revs per second—rps)	$-_{cr}$	Cruise value
M	Mach number	$-_{oew}$	Operating empty weight
v	Velocity (m/s)	$-_\infty$	Freestream value
c	Speed of sound (m/s), Chord (m)	$-_a$	All engines operating
$\bar{c}$	Mean aerodynamic chord (m)	$-_r$	Root value
P	Maximum engine shaft power (kW)	$-_t$	Tip value
ω	Rotational velocity (rad/s) .... $\omega = 2\pi n$	$-_f$	Fuselage value
η_p	Propulsive efficiency .... $\eta_p = T v_{cr}/P$	$-_h$	Horizontal tail value
λ	Taper ratio.................................. $\lambda = c_t/c_r$	$-_v$	Vertical tail value
Λ	Sweep angle (°)	$-_{MTOW}$	Maximum Take-Off Weight
B	Number of blades	SFC	Power specific fuel consumption (kg/kW/h)
$m_.$	Aircraft mass (kg)	AR	Aspect Ratio............................. $AR = (2s)^2/S$
S	Surface (m^2)	Trg	Training aircraft
T	Thrust force (N)	$LtAt$	Light Attack aircraft
t	Wing thickness (m)	Obn	Observation aircraft
$W_.$	Aircraft weight (N)......................... $W_. = m_. g$	$Spec\ Mis$	Special Mission aircraft
g	Gravitational acceleration (9.807 m/s^2)	Tpt	Transport aircraft
E	Number of engines	Lt	Light
e_0	Oswald efficiency factor	Med	Medium
R	Range (km)	Hy	Heavy
s	Wing half-span (m)	Note:	Aircraft are unambiguously identified by their usual military designation (e.g. C-130H, An-12, F-27, P-3C, PC-21, T-6A) and category (transport, trainer, etc.). Nicknames and company names are omitted for brevity.
h	Height (m)		
l	Length (m)		
b	Model parameter, Width (m)		
a	Model parameter		
ℓ	Moment arm between two quarter-chord positions (m)		

update and sometimes amend the existing and readily available models, in a synoptic way, with relevant information from recent military aircraft propelled by turbo-propellers. All alterations and revisions suggested along the course of this study are formulated in a constructive way and aim at refining the knowledge of this precise aircraft type.

After describing the methodology, mass estimate models are reviewed before surface sizing laws. Finally, engine and propeller related quantities are considered before drawing conclusions.

2. Database and methodology

The database consists of entries for 43 military aircraft that are currently encountered in air forces inventories across the globe. All of them are equipped with turbo-propeller propulsion. In total 3354 records have been collected for 78 aircraft characteristics covering aircraft name and type, entry into service date, dimensions and geometrical shape parameters of the fuselage, wing and tail surfaces as well as control surfaces, operating masses including maximum payload and fuel masses, number of engines, engine type and engine figures of merit (such as maximum power and power specific fuel consumption), propeller diameter and rotational velocity, together with operational characteristics (long range cruise speed and altitude, range at maximum payload and ferry range).

Aircraft types and categories. For pragmatic reasons, and according to common practice in the literature, the aircraft have been arranged by mission type. Military aircraft equipped with turbo-propellers have been arranged into four categories: aircraft conducting training, light attack or observation missions, light transport aircraft (with a maximum take-off mass lower than 30,000 kg), medium and heavy transport aircraft (maximum take-off mass superior to 30,000 kg) and finally special mission aircraft (such as airborne early warning or maritime patrol). For the sake of clarity, these categories are respectively abbreviated in: Trg-LtAt-Obn,[1] Tpt Lt,[2] Tpt Med-Hy,[3] and Spec Mis.[4] At this point, it is important to notice that both categories of transport aircraft differ from civilian aircraft in that the first are inherently hybrid transports: they can be rapidly configured to transport vehicles, bulk supplies, troops or even serve for medical evacuation duties. On top of translating the driving requirement behind each aircraft design—even though some designs are variants of regional transport aircraft—, this classification safeguards the value of statistical trends by having a significant number of samples in each aircraft category (14 Trg-LtAt-Obn, 11 Tpt Lt, 6 Tpt Med-Hy and 12 SpecMis) despite the relatively narrow population of military turbo-propeller aircraft.

Origin and reliability of the data. The original data has been collected from a variety of sources such as [2,9] and manufacturer leaflets or performance manuals. Whenever possible the data from the unclassified literature has been cross-checked with open source web-based data or data from reference textbooks [16,17,21] and papers [4,8]. The same check has been performed on derived quantities. Some geometrical data has been digitally computed through the use of technical drawings. Wherever needed, the data is accompanied by a label indicating the flight-phase to which the value refers (cruise, take-off/landing, climb, descent). Given its origin, the data presented in this paper should be considered as the best available record and not as a certificated value. SI units with the exception of kW, km/h and kg/kW/h are used throughout this paper.

1 Trg-LtAt-Obn for Training—Light Attack and Observation aircraft.
2 Tpt Lt for Light Transport aircraft.
3 Tpt Med-Hy for Medium and Heavy Transport aircraft.
4 Spec Mis for Special Mission aircraft.