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Sizing of a Turboprop Engine Powered High Altitude Unmanned Aerial Vehicle and It`s Propulsion System for an Assumed Mission Profile in Turkey

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Abstract

In this study, preliminary sizing of a turboprop engine powered high altitude unmanned aerial vehicle and it`s propulsion system for an assumed mission profile in Turkey was performed. Aircraft mission profile is one of the most important design inputs in aircraft design. While the aircraft is dimensioned according to the requirements in the specification (useful payload, range, target cost, etc.), parameters such as cruise altitude and speed within the mission profile affect the engine type, power level, fuel quantity, and therefore the overall dimensions and total weight of the aircraft. The unmanned aerial vehicle with turboprop engine investigated in this study, can stay in the air for at least 24 hours at high altitude (40000 ft) and can be used for border surveillance, coast control, forest fires and land exploration.

Keywords

Unmanned aerial vehicle sizing
Turboprop engine
Gas turbine engine
Cycle analysis

Time Scale of Article

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1. Introduction

The aviation industry has made great progress since the Wright brothers made their first controlled, propulsion and heavier than air human flight in 1903. Over the last century, many types of aircraft with complex systems have been designed and built as technology advanced. In parallel to this, unmanned aerial vehicles (UAVs) have been developed by using pioneering technologies in recent years and have increased their prevalence and effectiveness in civil and military applications. UAVs are generally referred to as aircrafts that are pre-programmed to fly autonomously without remote flight crew or which can be controlled from the ground by remote control and can be used multiple times. Today, there are many types of UAVs which are produced for different purposes. Within the scope of this study high altitude unmanned aerial vehicles with turboprop engines were investigated and the following examples can be given in this class: “Predator B” [1] developed by General Atomics (USA), on “Heron TP” [2] of IAI (Israel Aircraft Industries) and “Akıncı” [3] unmanned aerial vehicle which is being developed by Baykar Defense Company in recent years.

In Turkey, there exists many institutions and organizations which conduct studies in the areas of UAV airframe, engines, software, electronics, sensors for both domestic and foreign markets. This study was conducted to support UAV development activities in our country.

2. Sizing of Unmanned Aerial Vehicles

In order to size unmanned aerial vehicles, general aircraft equations can be used by removing the parts related to crew and passengers [4].

$$W_0 = W_e + W_{FL} + W_f + W_{misc} \quad (1)$$

W_0 : gross weight (kg); W_e : empty weight; W_{PL} : payload weight; W_f : fuel weight; W_{misc} : miscellaneous other components weight.

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$$W_e = W_{airframe} + W_{lg} + W_{eng} + W_{sys} \quad (2)$$

$W_{airframe}$: airframe weight; W_{lg} : landing gear weight; W_{eng}: engine weight; W_{sys} : systems weight

$$W_e = W_0 - + \left(W_0 \frac{W_f}{W_0}\right) + \left(W_0 \frac{W_{misc}}{W_0}\right) - W_{PL} \quad (3)$$

$$W_{eng.inst} = W_0 \left(\frac{T_0}{W_0}\right) \left(\frac{\left(\frac{W_{eng.inst}}{W_{eng.uninst}}\right)}{\left(\frac{T_0}{W_{eng.uninst}}\right)} \right) \quad (4)$$

$W_{eng,inst}$: installed engine weight;

$W_{eng,uninst}$: uninstalled engine weight;

T_0 : sea level engine power or thrust;

Fig. 1. Predator B turboprop UAV [1].

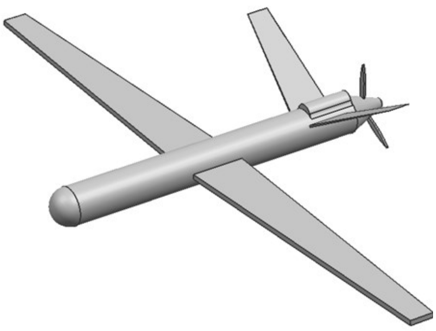

Fig. 2. Assumed UAV geometry [5].

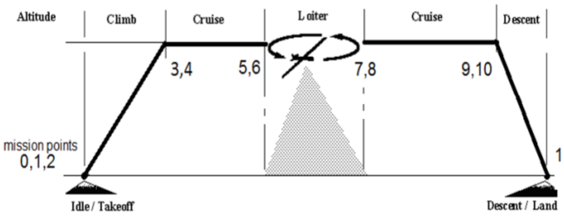

Fig. 3. Typical mission profile of a reconnaissance UAV [5].

The validation of the methodology used in this study was performed on "Predator B" UAV with turboprop engine in a previous study [5]. The deviation rate in the obtained results was determined as ± 1.5% for UAV dimensions and weights. The simplified unmanned aerial vehicle geometry used in the study is given in Figure 2. The mission profile of a typical reconnaissance unmanned aircraft is shown in Fig. 3.

3. Turboprop Engine Cycle Analysis

In this study, cycle analysis of turboprop engine was done for all points during flight and results are given in the next sections. Engine design begins with parametric cycle analysis. The objective of parametric cycle analysis is to calculate performance characteristics (power, thrust, specific fuel consumption etc.) based on design constraints (maximum turbine inlet temperature and achievable component efficiencies etc.), flight conditions (ambient air temperature and pressure, flight Mach number), and design choices (compressor and fan pressure ratio, bypass ratio, etc.) [6].

Cycle analysis is the investigation of thermodynamic behavior of air flowing in the engine. Instead of dealing with components such as inlet, compressor, combustion chamber, turbine, exhaust nozzle, these components are characterized according to the results they produce. In other words, for example, the compressor is defined only by the total pressure ratio and efficiency. In fact, the behavior of a real engine depends on the geometry [7].

In general, the main components of the turboprop engine (Figure 4) can be listed as air intake (A), compressor (B), combustion chamber (C), high pressure turbine (D), low pressure or power turbine (E) followed by exhaust nozzle (F). In this study mathematical formulation of a turboprop engine was adopted from [8] in order to use in the cycle analysis.

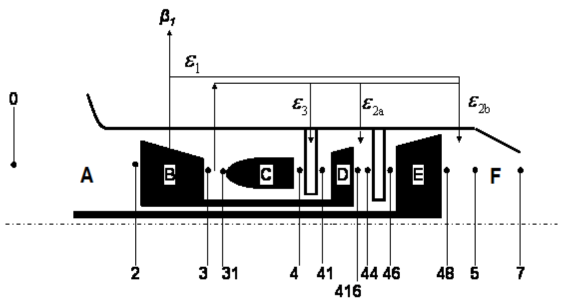

Fig. 4. Schematic representation of a two-shaft turboprop engine [8].

4. Sizing of a UAV for Surveillance Mission in Turkey

In this study, surveillance mission profile for a turboprop UAV was assumed be 24 hours at 40,000 ft altitude in Turkey. In addition, the amount of payload to be carried was assumed to be 1350 kg (450 kg internal and 900 kg external). In this category, Akıncı UAV is an example which is under development in our country [3] and is shown in Figure 5.

Fig. 5. Akıncı UAV [3].

In this study, the UAV for which the calculations were made was named as TURKUAV. The summary results of these calculations are compared with the literature values of Predator-B and Akıncı UAV in Table 1. The Predator-B UAV uses a 944 hp TPE331–10 turboprop engine [9]. The turboprop engine parametric model and computer program were developed in a previous study [5]. This computer code was also used for TURKUAV in this study.

When Table 1 is examined, it is seen that all three UAVs have similar technical characteristics. When the Predator B values are examined, it is understood that some of the values given by the manufacturer are given as maximum values and not all of them can be valid at the same time. For example, 27 hours flight time and 50000 ft flight altitude cannot be provided at the same time. Similarly, it will not be possible to load the payload and fuel weight at the same time as maximum. In this sense, there are 3 different configurations for Predator B [10]:

- Configuration 1: Internal payload (363 kg), internal and external fuel (862 + 907 = 1469 kg) and 1/3 external payload or ammunition (454 kg). Total take-off weight 4763 kg.
- Configuration 2: Clean configuration, internal payload (363 kg) and internal fuel (862 kg), (without external fuel and external ammunition). Total take-off weight is 3454 kg.
- Configuration 3: Internal payload (363 kg), full (100%) external payload or ammunition (1362 kg) (without external fuel). Total take-off weight 4763 kg.

The maximum flight time of 27 hours in Table 1 seems to be possible only with maximum fuel (Configuration 1). Similarly, a maximum altitude of 50000 ft would be possible without external fuel and external load, with reduced total take-off weight (Configuration 2). Operation altitude is specified as 30000 ft in fully loaded cases such as configuration 3 [10].

Table 1. UAV specifications

Technical Specifications	Predator B	Akıncı [3]	TURKUAV
Payload (kg)	1747 [1]	1350	1350
UAV gross weight (kg)	4763 [1]	5500	6304
Fuel weight (kg)	1769 [1]		1110 internal/1110 external
Endurance (h)	27 max [1]	24	26.5
Surveillance time (h)			24
Engine power (hp)	944 [5]	2x750	1572
Surveillance altitude (ft)		40000	40000
Maximum altitude (ft)	50000 [1]		

Table 2. TURKUAV size/performance and engine cycle analysis results

UAV size/performance			
W_0	UAV gross weight	6304	kg
t_{loi}	Loiter (surveillance) time (constant 40000 ft altitude)	24	h
t_{tot}	Total mission time (taxi, takeoff, climb, loiter, descent, landing)	26.5	h

Mission points		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
H (altitude)	km	0	0	12.19	12.19	12.19	12.19	12.19	12.19	12.19	0
M_0 (speed)	mach	0.151	0.188	0.400	0.349	0.349	0.400	0.357	0.349	0.349	0.152
C_L (lift coefficient)		1.354	0.868	1.021	1.337	1.337	1.016	0.868	0.909	0.901	0.868
V_0 (speed)	km/h	185.2	230.6	464.8	370.4	370.4	424.9	379.0	370.4	370.4	186.3
Lift/Drag		22.10	24.31	24.00	22.21	22.21	24.01	24.31	24.28	24.29	24.31
W (weight)	kg	6291	6259	6118	6118	6118	6118	4161	4161	4121	4121
D (drag)	kN	2791	2524	2512	2700	2700	2497	1678	1680	1663	1647
Engine cycle analysis (turboprop)											
PW	kW	1189	1203	418	404	404	418	406	404	404	1189
PWeq	kW	1234	1259	441	425	425	441	427	425	425	1234
PSFC (fuel consumption)	kg/(kW.h)	0.324	0.322	0.254	0.258	0.258	0.254	0.258	0.258	0.258	0.324
PSFC equivalent	kg/(kW.h)	0.312	0.308	0.241	0.246	0.246	0.241	0.245	0.246	0.246	0.312
Total thrust (prop+nozzle)	kN	18.88	15.34	2.83	3.16	3.16	2.83	3.10	3.16	3.16	18.77
TSFC (fuel consumption)	g/(kN.s)	5.67	7.02	10.44	9.17	9.17	10.44	9.37	9.17	9.17	5.71

In this study, the values are given for the TURKUAV calculated by analytical method are valid as full load (450 kg internal and 900 kg external useful load). It is also assumed to be fully loaded at 40000 ft altitude. In addition, a 24-hour net reconnaissance (at 40000 ft) time was provided. A total flight time of more than 26 hours was calculated, including take-off, climb, descent and 1-hour reserve fuel for landing loiter. For these reasons, it was calculated that it would be larger and heavier than the others. Unlike Predator B, the TURKUAV will be able to meet all the maximum values specified for at the same time. In other words, it will be able to operate with full payload (1350 kg), continuously at altitude of 40000 ft and a net of 24-hour surveillance or loiter. The required engine power will be around 1572 hp (single engine). In terms of engine power level, it is similar to Akıncı UAV (750 hp x 2 engine).
Some of the possible uses of such a UAV can be listed as follows:

- Security operations in and out of country.
- Border patrolling (smuggling, illegal trespassing etc.)
- Coastal surveillance (detection of waste from ships etc.).
- Search and rescue operations after accidents and natural disasters etc.
- Monitoring of energy and oil pipelines for security purposes.
- Detection and extinguishing of forest fires, which intensify especially in summer and cause big losses.
- Examination of climate change and its impacts on the vegetation and forests.
- Occupancy rates of agricultural areas, crop yields, planning and monitoring of forests.

Such a UAV with 24 hours of surveillance time can be used for those missions. For example, with an average speed of 400 km/h, UAV can travel al Turkish sea and land borders 10765 km in 27 hours. Similarly, it can scan all the eastern and southern borders (2477 km) from Batum to Antakya in 6.2 hours or all Iraq and Iranian (944 km) borders in 2.4 hours.

5. Conclusion

In the world of today, where unmanned aerial vehicles are becoming more and more important, the development of these vehicles and engines are within the objectives of our country. For this reason, it is of strategic importance that the studies by domestic companies, institutions, and organizations to be carried out. It has been evaluated that studies like this paper will support the development of long endurance and high-altitude turboprop engine powered UAVs which can be used for civilian and military purposes. The domestic computer code which was developed within the scope of this study can be used for preliminary sizing-dimensioning of aircraft and its engine.

Nomenclature

W_0	:	Gross weight (kg)
t_{loi}	:	Loiter time (h)
t_{tot}	:	Total mission time (h)
H	:	Altitude (km)
M_0	:	Speed (Mach)
C_L	:	Lift coefficient
V_0	:	Speed (km/h)
W	:	Weight (kg)
D	:	Drag (kN)
PW	:	Engine power (kW)
PWeq	:	Equivalent engine power (kW)
PSFC	:	Fuel consumption (kg/kW.h)
PSFC	:	Equivalent fuel consumption (kg/kW.h)
TSFC	:	Thrust specific fuel consumption (g/kN.s)

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