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Technical Notes

Optimum Design of Turboprop Engines Using Genetic Algorithm

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Nomenclature

C = work output coefficient
Cp = specific heat
F = thrust
f = fuel-to-air ratio
k_1 to k_9 = constants in offdesign equations
Lcv = fuel heating value
M = Mach number
MFP_9 = mass flow parameter at nozzle exit
$\dot{m}$ = mass flow
P = pressure
T = temperature
V = velocity
Ws = specific power
η = efficiency
π = pressure ratio
τ = temperature ratio

Subscripts

b = burner
C = compressor, core
g = gear
H = high pressure
L = low pressure
m = mechanical, mixing losses due to cooling
prop = propeller
r = ram
T = turbine
t, tot = total

I. Introduction

TURBOPROP engines came into wide use with a need for higher thrust levels and reduced fuel consumption at relatively low flight speeds. However, their development has to be reconsidered because they were quite modest. Higher compressor pressure ratios (CPRs) and turbine inlet temperatures (TITs) are still difficult to achieve, owing to small blades in the rear stages of the compressor and the turbine which do not allow using sophisticated cooling techniques. Morris [1] showed that if size effects were ignored, a CPR in excess of 30 and a TIT of 1700 K could be reached. Brooks and Hirschkron [2] arrived at a CPR of 17–20 and a TIT of 1535–1590 K, based on turboprops for commuter aircraft.

In constrained optimization problems, direct methods start with a single design point and use the local gradient of the objective function to determine a search direction. Such methods are efficient as long as the objective functions are differentiable and convex [3]. These limits have led to other heuristic optimization methods, particularly the genetic algorithms (GAs) [4], because they are capable of searching the entire solution space with an increased likelihood of finding the global optimum. These algorithms are very well suited to deal with multi-objective real design problems (MOPs) because they make use of an evolving population of solutions that is driven toward the set of the true tradeoff. Since the original nondominated sorting procedure given by Goldberg [4] (considered as the catalyst for several different versions of multi-objective optimization algorithms), there has been a growing interest in devising GAs for MOPs, such as the vector evaluated GA (VEGA) proposed by Schaffer [5] and the nondominated sorting GA (NSGA) by Srinivas and Deb [6].

The present paper describes an approach that gives the freedom to select or optimize the design of new turboprops to match the power requirements of a propeller-driven L100-30 aircraft powered by four turboprops, for which flight performance and a diagram of constraints were established. In such thermal systems, the Pareto solutions provide more insights into the competing objectives: the minimum power specific fuel consumption (PSFC) can be directly translated into increased range and payload, whereas, the high specific power leads to reducing engine size, weight, and installation losses. Three configurations of turboprops included a single-spool fixed turbine, a single-spool free turbine, and a twin-spool fixed turbine that were modeled within the developed engine performance analyzer. The obtained results based on the model of aircraft have indicated that, by adopting the GA PIKAIA for this two-objective optimization problem, we could preserve the diversity of nondominated individuals and the quality of the Pareto front, and the decision variables related to the propulsion cycle could be determined easily.

II. Flight Performance Analysis

Propeller-driven aircraft are designed to meet short takeoff and landing (STOL) requirements and performance during climb and cruising to conform to the Federal Air Regulation standards in FAR 25 [7]. For this studied aircraft, the optimum cruise is at Mach = 0.475 and an altitude of 28,000 ft (8535.4 m) [8], whereas the takeoff is at Mach = 0.1 at sea level on a hot day. Analysis of performance in different flight mission segments have led to the constraints diagram in terms of wing loading and power loading (not shown here), based on available drag polar [9]. The envelope function used to plot the constraints' boundaries [10] allowed the determination of the matching point close to maximum power loading and wing loading. By considering a value of wing loading of $4251.76\ \mathrm{N/m^2}$, the power loading had a value of $0.04823\ \mathrm{N/W}$, and subsequently had a takeoff power of 4795 hp per engine.

III. Propulsion Cycle Analysis

Three configurations of turboprop engines are considered: single-spool, free power turbine, and twin-spool fixed power turbine, shown with stations numbered in Fig. 1.

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