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Challenges of future aircraft propulsion: A review of distributed propulsion technology and its potential application for the all electric commercial aircraft

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ABSTRACT

This paper highlights the role of distributed propulsion technology for future commercial aircraft. After an initial historical perspective on the conceptual aspects of distributed propulsion technology and a glimpse at numerous aircraft that have taken distributed propulsion technology to flight, the focal point of the review is shifted towards a potential role this technology may entail for future commercial aircraft. Technological limitations and challenges of this specific technology are also considered in combination with an all electric aircraft concept, as means of predicting the challenges associated with the design process of a next generation commercial aircraft.

Contents

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Nomenclature

E	maximum cargo range (km)
P	power output for each individual engine unit (kW)
R	aircraft range (km)
T	engine thrust (kN)
V	aircraft speed (km/h)
OWE	operating empty weight (kg)
PAY	payload (kg)
$MTOW$	maximum take-off weight (kg)
NoE	number of engines
ϕ	piston/propeller unit engine power (kW)
ξ	number of engine units
AC	alternating current
AEA	all electric aircraft
AEE	all electric engine
APU	auxiliary power unit
BLI	boundary layer ingestion
BWB	blended wing body
CESTOL	cruise efficient short take-off and landing
CMF	common-core multi-fans
CMP	common-core multi-propulsors
dB	decibel
DC	direct current
DEN	distributed engines
DEX	distributed exhaust
DFRC	NASA Dryden Flight Research Center
ECS	environmental control system
ERAST	environmental research aircraft and sensor technology
ESTOL	extreme short take-off and landing
ETOPS	extended range operation with two-engine airplanes
FAA	Federal Aviation Administration
HALE	high altitude long endurance
HP	horse power
HTS	high temperature superconductive
HALSOL	high-altitude solar energy
HWB	hybrid wing body
IDG	integrated drive generator
LP	low pressure
MDO	multi-disciplinary optimization
MEA	more electric aircraft
MEE	more electric engine
NASA	National Aeronautics and Space Administration
PAI	propulsion-airframe-integration
PFCC	power factor correction number
PM	permanent magnet
PPS	primary power systems
PWM	pulse width modulator
RAT	ram air turbine
RPM	revolutions per minute
SFC	specific fuel consumption
SPS	secondary power systems
SR	switched reluctance
STOL	short take-off and landing
TRU	transformer rectifier unit
TV	thrust vectoring
UHBR	ultra high bypass ratio
VF	variable frequency
VTOL	vertical take-off and landing
VSCF	variable speed constant frequency

1. Introduction

The intricate challenges of meeting future environmental goals in commercial aviation require a cross-disciplinary effort that focuses on: feasible propulsion systems, reduced fuel consumption, aviation safety and reliability, noise reduction, and optimized aircraft design to achieve desirable flight attributes. With a constant increase of air passengers, and the demands for technological innovation to reduce harmful emissions and jet noise, the impact of commercial propulsion systems becomes even more pronounced. Contemporary trends of intelligent engines raise a fundamental question that addresses the most promising propulsion system for commercial aviation and in retrospect, conceptual inventive engine systems are systematically investigated. The technical lessons learned from aviation history are important venues for future technical progress. One of the many intriguing subjects regarding future aircraft is the visions aviation enthusiasts anticipate for the future. Kuchemann's early approach to recognize the need for additional efforts in the aerodynamics of propulsion is noteworthy as prior advances in propulsion technology were indeed extended far beyond the realm of airfoil theory [1]. Kuchemann and Weber's comprehensive aircraft performance study at subsonic, supersonic and hypersonic speeds has further served as a gateway for improved understanding of aerodynamic shape and its evolution [2]. Challenges within the hypersonic flight regime are, however, particularly difficult to overcome, as strong shockwaves or disturbances are caused in response to lift generation and other means to provide volume and propulsion [3]. From a general perspective, it is possible to draw parallels between Kuchemann's envisioned differences in the design procedures for various aircraft [4] and this study, as both seek to examine at least one particular mode of propulsion in further detail. Air transport of the 21st century is no longer limited to technological constraints, but also to environmental restraints that in combination with increased flight safety, dictate the nature of future flight regimes and flight missions. Aircraft distributed propulsion is one of the promising propulsion systems currently considered for integration into a wide number of future air transport models. As with any promising system, the limitations and weak points of this technology are identified in light of its strengths and advantages. The aim of this paper is to make an assessment of aircraft distributed propulsion, with a mindset of environmental awareness. Throughout the scope of this study, an All Electric Aircraft concept is also considered in combination with the distributed propulsion technology, as the electric aircraft trend displays one of the environmental friendly propulsion options for future commercial aircraft.

Distributed propulsion is based on dividing up the thrust for the beneficiary gain of noise reduction, shorter take-off and landing, enhanced specific fuel consumption and flight range. This is particularly true if the complete aircraft history is to be included in this definition, dating back to the early days of flight, where the means of propulsion were different from those of the jet engine era. Fig. 1 depicts a few historical milestones of aircraft distributed propulsion. The planes above and below the time axis categorize aircraft distributed propulsion into a conceptual domain and a manufactured domain, respectively. The conceptual domain revisits a few hypothetical ideas that have contributed to the implementation of aircraft distributed propulsion arrangements. Variation among these different configurations covers, however, a substantial portion of different propulsion system designs that have made it to the manufacturing phase. Many of the known aircraft incorporating distributed propulsion systems