"Development of Methodologies for the Aerodynamic Design and Optimization of New Regional Turboprop Aircraft"

3D TECH SRLS Via San Vito, 65, 80014, Giugliano in Campania, Naples, Italy.

Logo designed by Lamberto Maglione

Text printed in Italy at Universal Book SRL, Via S. Botticelli, 22, 87036 Rende, Cosenza.

ISBN 978-88-98382-02-6

9 788898 382026

UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

DOCTORAL THESIS

Development of Methodologies for the Aerodynamic Design and Optimization of New Regional Turboprop Aircraft

Author:
Pierluigi DELLA VECCHIA

Supervisor:
Prof. Luigi DE LUCA

Co-Supervisor:
Prof. Fabrizio NICOLOSI

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

in the

Doctor of Philosophy School in Aerospace, Naval and Quality Engineering

April 2, 2013

Declaration of Authorship

I, Pierluigi Della Vecchia, declare that this thesis titled, 'Development of Methodologies for the Aerodynamic Design and Optimization of New Regional Turboprop Aircraft' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This PhD thesis has been defended in a public dissertation on May, 3rd 2013 under the judgment of a specialized commission composed by:

- Prof. Giorgio Guglieri, Department of Mechanical and Aerospace Engineering, Politecnico di Torino;
- Prof. Giulio Avanzini, Department of Innovation Engineering, Università del Salento;
- Prof. Salvatore Miranda, Department of Industrial Engineering, Università degli Studi di Napoli "Federico II".

Signed: ______________________________

Date: ______________________________

"Rem tene, verba sequentur..."

Marcus Porcius Cato (Tusculum, 234 a.C. - 149 a.C.), *Orationes*

UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

University of Naples FEDERICO II

Abstract

Faculty of Aerospace Engineering
Doctor of Philosophy School in Aerospace, Naval and Quality Engineering

Doctor of Philosophy

Development of Methodologies for the Aerodynamic Design and Optimization of New Regional Turboprop Aircraft

by Pierluigi DELLA VECCHIA

The Development of Methodologies for the Aerodynamic Design and Optimization of New Regional Turboprop Aircraft is presented proposing innovative procedures and tools to improve the aerodynamic of this aircraft category. Nowadays the increase in oil price, the huge growth of air transport traffic and the increasing attention to the aircraft environmental footprint led to considerable interest of specialists in new configurations of regional transport aircraft. Airlines and aircraft industries forecast in the next twenty years about 12000 turboprop aircraft will be delivered. Of these aircraft about 7000 will replace the older turboprop which reach their product life-cycle, while the remaining amount of about 6000 aircraft will be new turboprop aircrafts to satisfy market needs. The 61% of new turboprop delivered expected to be under 70 seats category (20% under 50 seats and 41% of 70 seats), while the new 90+ seat segment is a strong percentage of the total, i.e. the 39%. For these reasons this work aims to provide some guidelines in the aerodynamic design of future regional turboprop aircraft with about 90 or more passengers. Currently there are no configurations on the market of this type, so a typical 70 passengers turboprop aircraft is taken as reference starting point to put in evidence those aircraft components which particularly affects the "aerodynamic", especially in terms of aerodynamic drag. Particular emphasis is posed on aircraft performance, to highlight how a more accurate aerodynamic design can improve aircraft performance and so give aerodynamic guidelines in the design of new turboprop aircraft configurations. Research work can be divided into three main topics: *i)* airfoil design and optimization,

ii) aircraft components design and optimization and *iii)* vertical tail design. Airfoil design and optimization is a typical aeronautic topic, which involves several aspects such as parameterization techniques, optimization algorithms and aerodynamic solvers. These aspects have been analyzed and put together into a user friendly code which allows to design and optimize a generic airfoil geometry choosing *i)* the parameterization technique, *ii)* the optimization algorithm and *iii)* the aerodynamic solver. Constraints and multi-objective optimization have been performed, highlighting the crucial features in the design and optimization of a regional turboprop airfoil. The second topic aims to provide an optimization procedure for several aircraft components, fast to use also in a preliminary design phase. By coupling non uniform rational b-spline (NURBS) and a panel code aerodynamic solver, the geometry of a regional turboprop nose, wing-fuselage junction and undercarriage vane have been optimized to reduce aircraft aerodynamic drag. Particular emphasis has been also posed on the winglet design, highlighting how an accurate design can give an improvement in the whole regional aircraft flight envelope. The last topic involves the design of vertical tail plane for turboprop aircraft. This is a crucial topic for all twin-engine commuter aircraft because of all the ground performance are strictly related to the minimum control speed (V_{MC}) which mainly depends from the engine failure speed (V_{EF}), clearly related to vertical tail design. As a matter of fact both Part 23 and Part 25 of the aircraft regulations relates the certification speeds (especially for ground performance) to the V_{MC}; the lower will be the last, the better will be the performance. Moreover a performance improvement also means the commercial success of an aircraft, given the capability to be more competitive in several scenarios respect to competitors. In this research work, using a Navier-Stokes aerodynamic solver, a new method named VeDSC (Vertical tail Design Stability and Control) to design a vertical tail and a rudder has been carried out. More than 300 Navier-Stokes runs have been performed to accomplish with the objective. Particular care has been posed to the software set-up and several test-cases have been performed to validate the methodology. Finally the new method has been applied to several turboprop and twin-engine commuter aircraft and compared to typical semi-empirical methodologies to highlight the capabilities and reliability.

Contents

List of Figures

List of Tables

Abbreviations

AEO	**A**ll **E**ngine **O**perative
AOT	**A**irfoil **O**ptimization **T**ool
CAD	**C**omputer **A**ided **D**esign
CFD	**C**omputetional **F**luid **D**ynamic
CPU	**C**entral **P**rocessing **U**nit
DII	**D**ipartimento di **I**ngegneria **I**ndustriale
DNO	**D**irect **N**umerical **O**ptimization
EASA	**E**uropean **A**viation **S**afety **A**gency
ESDU	**E**ngineering **S**cience **D**ata **U**nit
FAR	**F**ederal **A**viation **R**egulations
FEM	**F**inite **E**lement **M**ethod
GB	**G**radient **B**ased
GA	**G**enetic **A**lgorithm
ID	**I**nverse **D**esign
MATLab	**Ma**trix **L**aboratory (a MathWorks software)
N-S	**N**avier **S**tokes
NACA	**N**ational **A**dvisory **C**ommittee for **A**eronautics
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NURBS	**N**on **U**niform **R**ational **B**-**S**pline
OEI	**O**ne **E**ngine **I**noperative
SCoPE	**S**istema **Co**perativo
	Per **E**laborazioni Scientifiche Multidisciplinari
USAF DATCOM	**U**nited **S**tates **A**ir **F**orce **Da**ta **Com**pendium
VeDSC	**Ve**rtical tail **D**esign **S**tability and **C**ontrol

Symbols

A	aspect ratio
AR	aspect ratio
C_D	3-D Drag coefficient
C_L	3-D Lift coefficient
$C_{\mathcal{L}}$	3-D Rolling moment coefficient
C_M	3-D Pitching moment coefficient
C_N	3-D Yawing moment coefficient
C_Y	3-D Sideforce coefficient
C_d	2-d Drag coefficient
C_f	friction coefficient
C_l	2-d Lift coefficient
C_m	2-d Pitching moment coefficient
C_p	pressure coefficient
P_0	maximum shaft horsepower
R/C	rate of climb
S	wing surface
S_H	horizontal tailplane surface
S_V	vertical tailplane surface
S_{TO}	take-off distance
S_{LAN}	landing distance
SHP	shaft horsepower
V_{EF}	engine failure speed
V_{MC}	minimum control speed
V_{TAS}	true airspeed

$2r$	fuselage diameter at vertical tail aerodynamic center
b	wing span
b_H	horizontal tailplane span
b_V	vertical tailplane span
b_{v1}	vertical tailplane span extended on fuselage centerline
c	wing chord
$cant_w$	winglet cant angle
c_{mac}	mean aerodynamic chord
c_v	vertical tailplane chord
d_f	fuselage diameter
e	oswald factor
e_w	wing induced drag factor
h_w	winglet height
r_w	winglet radius
r_f	fuselage half equivalent diameter
toe_w	winglet toe angle
z_w	wing position
Δ_w	winglet sweep angle
Λ	wing and tailplane sweep angle
α	angle of attack
β	angle of sideslip
ϵ_w	winglet twist angle
η_p	propeller efficiency
θ	fuselage upsweep angle
λ	taper ratio
λ_w	winglet taper ratio