Progress in Aerospace Sciences 47 (2011) 573–588

Contents lists available at SciVerse ScienceDirect

Progress in Aerospace Sciences

journal homepage: www.elsevier.com/locate/paerosci

Modeling and simulating aircraft stability and control—The SimSAC project

Arthur Rizzi

Dept. of Aeronautical and Vehicle Engineering, Royal Institute of Technology (KTH), Stockholm 10044, Sweden

ARTICLE INFO

Available online 26 October 2011

Keywords:
Aircraft design
Aerodynamics
Flight dynamics
Flight control
CFD
Simulation

ABSTRACT

This paper overviews the SimSAC Project, Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design. It reports on the three major tasks: development of design software, validating the software on benchmark tests and applying the software to design exercises. CEASIOM, the Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods, is a framework tool that integrates discipline-specific tools for conceptual design. At this early stage of the design it is very useful to be able to predict the flying and handling qualities of this design. In order to do this, the aerodynamic database needs to be computed for the configuration being studied, which then has to be coupled to the stability and control tools to carry out the analysis. The benchmarks for validation are the F12 windtunnel model of a generic long-range airliner and the TCR windtunnel model of a sonic-cruise passenger transport concept. The design, simulate and evaluate (DSE) exercise demonstrates how the software works as a design tool. The exercise begins with a design specification and uses conventional design methods to prescribe a baseline configuration. Then CEASIOM improves upon this baseline by analyzing its flying and handling qualities. Six such exercises are presented.

Contents

E-mail address: rizzi@kth.se

0376-0421/$ - see front matter
doi:10.1016/j.paerosci.2011.08.004

Nomenclature

Symbols

C_L	lift coefficient
C_m	pitching moment coefficient
$\mathbf{F}$	forces acting on aircraft
$\mathbf{I}$	moments of inertia
K_n	static margin
$\mathbf{L}$	Euler angle rates
M_∞	Mach number
m	mass
$\mathbf{M}$	aerodynamic moments
q	pitch rate (rad/s)
S	surface Area
u_e	elevator control signal
x_{cg}	X-location of center of gravity
U	horizontal velocity
$\mathbf{V}$	velocity of aircraft

Greek letters

α	angle of attack
β	side slip angle
δ	control surface deflection
τ_e	elevator actuator lag time
$\boldsymbol{\Theta}$	aircraft orientation angle
$\boldsymbol{\omega}$	rotation rate of aircraft

Subscripts

c	chord length
c	canard
c	cruise
e	elevator
w	wing

Abbreviations

AC	aerodynamic center
ACBulder	aircraft builder
AMB	aerodynamic model builder
B-747	Boeing wide-body airliner
CAD	computer aided design
CG	center of gravity
CEASIOM	computerized environment for aircraft synthesis and integrated optimization methods
CFD	computational fluid dynamics
DSE	design simulate evaluate
FCS	flight control system
FHQ	flying handling qualities
GAV	general aviation vehicle
MAC	mean aerodynamic chord
MTOW	mean take-off weight
NeoCASS	next generation conceptual aero-structural sizing suite
Ranger 2000	EADS military trainer aircraft
SAS	stability augmented system
SDSA	simulation and dynamic stability analysis
SMJ	Alenia 70-seat regional commuter jet concept
SEJ	supersonic executive jet
SimSAC	simulating aircraft stability and control characteristics
S&C	stability and control
TCR	Transonic Cruiser
VLM	vortex lattice method
WB	weights and balances
WT	wind tunnel
Z-wing	asymmetric wing planform

1. Introduction

1.1. The aircraft design process

The design of aircraft is an extremely interdisciplinary activity produced by simultaneous consideration of complex, tightly coupled systems, functions and requirements. The design task is to achieve an optimal integration of all components into an efficient, robust and reliable aircraft with high performance that can be manufactured with low technical and financial risks, and has an affordable cost taking in consideration the whole lifetime of the aircraft. The aircraft design process (see Fig. 1(a)) is in general divided into three phases, which tend to overlap in a staggered fashion. In the conceptual design phase the aircraft is defined at a system level. Many variants are studied, and the design selected is the one that best fulfils the specifications of the market or a customer. This design then becomes a project and is studied further. In the preliminary design phase, the tentatively selected concept is refined until feasibility is established, i.e. extensive array of design sensitivities are generated, design margins, etc. About two-thirds of the way through this phase, the concept is frozen and no major changes are expected thereafter unless serious problems arise. The final phase is the detailed design phase in which details of the product are elaborated, optimizations are made and data sets are generated. A large variety of tools are used in each phase of the design process, including empirical/handbook methods, wind tunnel testing, flight-testing and numerical simulation and optimization tools including Navier–Stokes solution methods. In general, low-fidelity tools are supposed to be used in the conceptual design phase where many alternatives need to be analyzed in a short period, while high-fidelity tools are used in the other design phases since the concept evolves to an acceptable level of maturity. The term fidelity refers here to the representation of the aircraft geometry (and/or structure, where applicable) and of the physical modeling that determines the aircraft behavior and performance (aerodynamic stability and control and loads data bases). Today this is the existing practice for developing a new aircraft. SimSAC focuses on the modeling and simulation aspects in the design stages in the circle in Fig. 1(a), namely in conceptual design and the down-selecting of configurations for project studies in preliminary design. The reason that SimSAC focuses mainly on the conceptual design process is that 80% of the life-cycle cost of an aircraft is incurred by decisions taken during the conceptual design phase, see Fig. 1(b). Mistakes here must be avoided because they are very costly to remedy later and delay acceptance. Matters involving the interaction of aerodynamics with structures and controls are particularly prone to errors due to the low fidelity of the analysis methods traditionally used.

1.2. Conceptual design for stability and control

Present trends in aircraft design toward augmented-stability and expanded flight envelopes call for an accurate description of