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Objectives, approach, and scope for the AVT-183 diamond-wing investigations

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ABSTRACT

A roughly six-year investigation of blunt-leading-edge vortical separation has recently been completed. Principles from a hierarchical complexity approach were used to develop a simple diamond wing configuration with vortex flow properties that were relevant to those of a complex Uninhabited Combat Air Vehicle concept, known as SACCON. The focus of this paper is to present an overview of the project including the basic flow of interest, the approach used to develop the specific research investigation, and the scope of the results. Subsequent papers address specific experimental and numerical findings. This work was conducted under the NATO Science and Technology Organization, Applied Vehicle Technology panel.

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1. Introduction

A fundamental study of blunt-leading-edge vortex separation from a diamond wing with a moderate leading-edge sweep of 53° has recently been performed. Both the moderate leading-edge sweep angle and the blunt leading edge introduce additional complexities for a leading-edge vortex as compared to the leading-edge vortices that form on slender, sharp-edged wings. For example, the moderate sweep results in vortices that are more unsteady and that breakdown at much lower angles of attack than for the highly-swept slender wing. The moderately-swept wings have also be referred to as nonslender wings, and a useful review of unsteady leading-edge vortices for nonslender wings has been given by Gursul et al. [1]. The blunt leading edge introduces an onset and progression of leading-edge vortex separation with angle of attack. The origin of the leading-edge vortex is decoupled from the apex of the wing, and new Mach and Reynolds number effects occur for the blunt-edge vortex flows as compared to the sharp-edge vortex flows. The Mach and Reynolds number sensitivities have been discussed by Luckring [2] for a blunt-edged 65° delta wing, and the onset and progression of leading-edge vortex separation for this same wing was studied in Vortex Flow Experiment 2 (VFE-2) [3]. The leading-edge vortices of the present work have both the moderate-sweep effects and blunt-leading-edge effects coupled together.

The present work was facilitated through the NATO Science and Technology Organization (STO), and the context for the present work was another project that was studying the configuration aerodynamics of an Uninhabited Combat Air Vehicle (UCAV) concept known as the Stability And Control CONfiguration (SACCON). This configuration incorporated some representative design fea-

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Nomenclature

AR	aspect ratio, b^2/S_{ref}
$b/2$	wing semispan
C_p	static pressure coefficient
$C_{p,\text{rms}}$	rms fluctuating pressure coefficient
c	wing chord
c_r	root chord
c_{ref}	reference chord
f	frequency, Hertz
M	Mach number
mac	mean aerodynamic chord
q_∞	free stream dynamic pressure, $1/2\rho_\infty U^2$
R_{cref}	Reynolds number based on c_{ref}, Uc_{ref}/ν
R_{mac}	Reynolds number based on mac, $U\text{mac}/\nu$
R_{ts}	Unit Reynolds number, per meter, U/ν
r_{le}	streamwise leading-edge radius
r_{ts}	radius from test section centerline, Table 1
S_{ref}	wing reference area
St_c	Strouhal number based on c, fc/U
s	wing local semispan
t	airfoil maximum thickness
U	free stream reference velocity
x, y, z	body-axis Cartesian coordinates
α	angle of attack, deg
β	angle of sideslip, deg
η	fraction of wing semispan
Λ	wing sweep, deg
μ	viscosity
ν	kinematic viscosity, μ/ρ
ρ	density
ω_x	longitudinal vorticity

Subscripts

le	leading edge
max	maximum
te	trailing edge
∞, o	free-stream reference conditions

Abbreviations

AEDC	Arnold Engineering Development Complex, *USA*
AER	Institute of Aerodynamics and Fluid Mechanics
AVT	Applied Vehicle Technology
DLR	German Aerospace Company, *Germany*
EADS	European Aeronautic Defence & Space Company
NATO	North Atlantic Treaty Organization
NLR	National Aerospace Laboratory, *Netherlands*
ONERA	French Aerospace Laboratory, *France*
PAI	Propulsion Airframe Integration
RANS	Reynolds Averaged Navier–Stokes
RTO	Research and Technology Organization
SA	Spalart–Allmaras turbulence model
SACCON	Stability And Control CONfiguration
SST	Shear Stress Transport turbulence model
STO	Science and Technology Organization
TUM	Technische Universität München, *Germany*
UAV	Uninhabited Air Vehicle
UCAV	Uninhabited Combat Air Vehicle
ZDES	Zonal Detached Eddy Simulation

tures from industry and developed a very complex suite of vortex flows. An overview of this SACCON project has been given by Cummings and Schütte [4]. The present work was conceived to isolate and study one of the vortical phenomena from this complex suite, blunt leading-edge vortex separation, and to do so in such a way that the results would relate to the more complex SACCON aerodynamics. Here the concepts for a complexity hierarchy from Oberkampf and Trucano [5] (system, subsystem, benchmark, and unit problems) provided a framework to design the specific diamond wing for this study. Thus, the diamond wing was intended to serve as a fundamental investigation that would be relevant to the more complex investigations of SACCON. These particular diamond wing and SACCON research projects were performed by STO task groups identified as AVT-183 and AVT-161, respectively.

This article provides an overview of the diamond wing research project. First, the basic flow that became the focus of this research is briefly reviewed. Next, the context is presented that was used to connect the more fundamental diamond-wing work to the more complex configuration research with the SACCON model. The design the basic research project with what became the AVT-183 diamond wing is presented next, followed by the scope of the overall research activity. Only limited examples of experimental and numerical results are included in this paper. Detailed analysis of results can be found in subsequent experimental [6,7] and numerical [8–12] papers of this special edition.

2. Basic flow of interest

A sketch of the basic flow of interest is shown in Fig. 1. This notional flow would be for a blunt-leading-edge wing of moderate leading-edge sweep (i.e., $50° < \Lambda_{\text{le}} < 65°$). The sketch is intended to represent a simplest possible vortical flow field with an isolated blunt-leading-edge vortex separation. The origin of this leading-edge vortex is shown at about half way in between the apex and tip of the wing and would vary with angle of attack. At low angles of attack the origin would be further aft on the leading edge, or possibly absent, and at higher angles of attack the origin would be further forward on the leading edge. The sketch also identifies five flow phenomena of interest. All these phenomena differ for a blunt-leading-edge wing from those of the sharp-leading-edge wing.

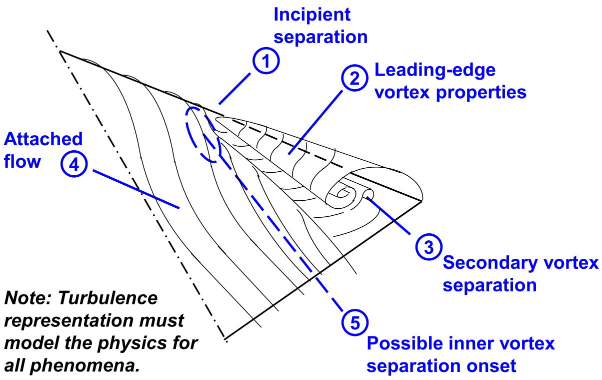

Fig. 1. Sketch of flow features.

The first phenomenon is incipient separation, where smooth surface vortical separation first emerges from the boundary layers near the leading edge to initiate a leading-edge vortex. The second phenomenon is the blunt-leading-edge vortex itself. Because of the blunt edge and low sweep, the properties of this vortex will be different from those known in association with the slender, sharp-edged delta wing. The third phenomenon is the secondary vortex which affects primary vortex attributes. The fourth phenomenon is the attached flow on the inboard portion of the wing.