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ESDU Technical Memorandum

Concept and preliminary design
Examples of applying rapid aerodynamic analysis tools to three classic historical configurations designed to similar requirements

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CONCEPT AND PRELIMINARY DESIGN
EXAMPLES OF APPLYING RAPID AERODYNAMIC ANALYSIS TOOLS TO THREE CLASSIC HISTORICAL CONFIGURATIONS DESIGNED TO SIMILAR REQUIREMENTS

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1. INTRODUCTION

Decisions made during the concept and preliminary stages of an aircraft design have a major impact on the life-cycle cost of the project. Typically, up to the end of the concept and preliminary design stages, the actual spend is about 20% of the total cost but decisions taken during these two phases lock in 70% of the total cost. Poor choices early in the design process not only result in changes and modifications that are expensive to implement but may also delay entry into market and impact sales. Because of this, it is important that these decisions are correct and based on information that can be obtained rapidly and cheaply but is also as reliable and complete a possible.

At the concept and preliminary design stages, several different configurations may be considered as possible candidates to meet a given design specification. As more information becomes available, the range of configurations are reduced to a single choice. This Data Item gives an example of the use of rapid aerodynamic analysis tools at the concept and preliminary design stages applied, retrospectively, to three, markedly different historical candidate designs to similar design specifications.

At the time these designs were developed such aerodynamic analysis tools were not available and the knowledge of high-subsonic wing aerodynamics was limited. Based on the state of knowledge at that time, the three proposed designs were all capable of meeting the requirements, but with risks, and all three were taken to the flight-testing stage, which revealed a number of problems. This Data Item shows how the application of the rapid aerodynamic analysis tools that are now available could have predicted these problems and provided information allowing better decisions earlier in the design cycle.

The rapid aerodynamic analysis tools used in this study represent a wing geometry with approximate corrections made for the presence of the fuselage but with no representation of items such as nacelles, pylons, engine intakes *etc*. However, this degree of simplification gives sufficient accuracy to predict potential problems, such as those identified in the flight tests of the aircraft that are the subject of this study, while considerably reducing the task of setting up the methods.

2. NOTATION

A	aspect ratio
A_v	aspect ratio of vane vortex generator (together with its reflection), *i.e.* $(4h_v^2)/S_v$
amc	aerodynamic mean chord
C_{D0}	zero lift drag coefficient based on wing reference area
C_L	lift coefficient based on wing reference area
C_M	pitching moment coefficient based on wing reference area and wing geometric mean chord about a moment reference point, positive nose up

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c	local chord
$c.g.$	centre of gravity position expressed as a percentage of reference chord which can be either aerodynamic mean chord or geometric mean chord
D	drag or lateral distance between neighboring vortex generators (for co-rotating arrays), or least distance between vortex generators of the same sense (for counter-rotating arrays)
d_V	lateral distance between trailing edges of a pair of counter-rotating vane vortex generator arrays
$dC_L/d\alpha$	lift slope
dC_M/dC_L	pitching moment slope
H	height of fuselage relative to the horizontal fuselage datum.
h	height of wing relative to horizontal fuselage datum
h_v	height of vane vortex generator
i_w	wing body setting angle
K	local vortex strength
k_D	vane vortex generator drag parameter $D_v/\frac{1}{2}\rho_v U_v^2 h_v^2$
k_v	vane vortex generator strength parameter $K/h_v U_v$
L	lift
l_p	streamwise distance over which full pressure rise downstream of shock occurs with vortex generators present
M	Mach number
$M_{N\ SHOCK}$	local Mach number normal to the shock
n	chord fraction
s	wing semispan
t	thickness
Re	Reynolds number
U_v	local speed at edge of boundary layer at vortex generator location
V_{MIN}	minimum speed
W	fuselage width

x	chordwise distance
y	spanwise distance
α_v	angle of incidence of vane vortex generator relative to local stream direction at edge of boundary layer, positive when vane is toed-out relative to this direction
Δ	increment
α	incidence
δ	boundary layer thickness
Λ_0	leading edge sweep
$\Lambda_{0.5}$	mid chord sweep
Λ_1	trailing edge sweep
λ	taper ratio
λ_v	vane vortex generator taper ratio
ρ_v	density at edge of boundary layer at vane vortex generator location
ξ_v	vane vortex generator setting angle
σ	angle between undisturbed local stream direction (*i.e.* in the absence of vane vortex generators) and free stream direction, positive when flow is directed inboard
η_p	spanwise peak loading location

Suffices

a/c	aircraft
max	maximum
n	normal
$SHOCK$	shock location
w/b	wing body
$\alpha 0$	zero incidence

3. THREE DESIGNS

3.1 Origins

Towards the end of the second world war the arrival of the jet engine, leading to the development of the jet fighter, raised interest in a jet powered bomber in the UK and USA. Initial design studies centered around unswept configurations with jet engines replacing propellers driven by reciprocating engines. Some designs were put into production, such as the North American B-45 Tornado, of which saw operational service between 1948 and 1958. These early designs produced an improvement in performance relative to their propeller engine counterparts but this improvement was not equivalent to that of current jet fighter aircraft and these bombers were regarded as stop gap solutions until the technology was developed to produce more advanced designs.

Information obtained from German research indicated that the concept of swept wings with reasonably thick sections flying at high subsonic speeds offered promise of a significant increase in performance and operational capability. Furnished with this new knowledge investigations into jet powered bombers were initiated by UK and USA aircraft companies, along with their respective government research establishments.

The UK Ministry of Supply and USAAF produced similar requirements for a medium range bomber and the main points of the two specifications are given in the following table.

Specification	Speed	Range	Alt	Payload
USAAF Request	390knts (cruise) 480knts (max)	3500nm 1750nm	45000ft	10000lb
B35/46	500knts (cruise)	3350nm 1500nm (radius)	35000ft to 5000ft	10000lb

US and UK aircraft companies produced several designs meet the specification, ranging from least risky options to more challenging designs incorporating the latest technology but with the associated risk of failure. The least risky options sacrificed speed by relying on 1940’s technology that incorporated zero sweep. These designs were considered as back stop solutions and included Short SA.4. Sperrin, for which the specification was rewritten as B14/46, the Convair XB-46, Martin XB-48 and the North American B-45 Tornado.

The riskier designs were the Boeing B-47 Stratojet, Vickers Valiant, Avro Vulcan and Handley Page Victor. UK contracts were awarded for the Vulcan and Victor. A contract for the Vickers Valiant was added later because it was available much sooner than the Vulcan and Victor.

Of the four designs, the three most challenging configurations were selected for investigation in this Technical Memorandum; namely the high aspect ratio wing Boeing B-47 Stratojet, the low aspect ratio delta wing Avro Vulcan and the moderate aspect ratio crescent wing Handley Page Victor. The main details of the three wings are given in the table below.

Aircraft	Area (sq. ft.)	Span (ft)	Aspect Ratio	Sweep LE	Sweep TE	Max t/c
Boeing -B47	1428	116	9.43	36.6	29.7	0.12
Avro Vulcan B1 (Straight wing)	3446	99	2.84	49.9	3.5	0.10 (root) 0.08 (tip)
Handley Page Victor B1	2406	110	5.03	52.4, 44.5, 35.2	25.5, 25.3, 21.1	0.16 (root) 0.10 (1st kink) 0.08 (2nd kink) 0.06 (tip)