NWTF

Adaptive Test Management – Moving on from OFAT and DOE

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Wind Tunnel Test Management – Moving on from OFAT and DOE

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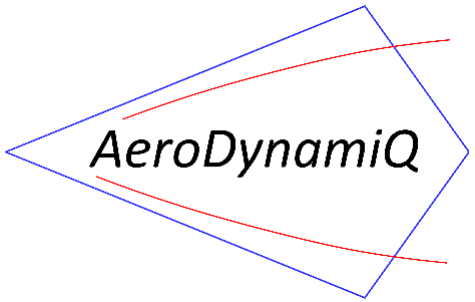


Dstl funded 3 year project (2023-2026)

Delivered though a prime contractor QinetiQ and a consortium of suppliers including OEMs, Tier 2, SMEs, and Academia

To address MODs future challenges in the air environment, there is a need for continued research and development of fixed wing aircraft concepts, technologies and knowledge within the Air Domain. The aim for the Fixed Wing Concepts & Technologies (FWCAT) project is to identify opportunities and deliver research and development activities that deliver high potential benefit to MOD's fixed wing aircraft programmes

Topic areas: Airframe Structures and Manufacturing, Aerodynamics and flight control, including propulsion integration and weapons integration, Vehicle Systems, Multidisciplinary and conceptual design

Platform priorities: Future combat aircraft, Unmanned air systems, Future tankers, Military transport, Reusable hypersonics

QINETIQ BAE SYSTEMS MORSON PROJECTS NATIONAL COMPOSITES CENTRE mtc University of Sheffield AMRC AeroDynamiQ MANCHESTER 1824 University of BRISTOL ARA Cranfield University

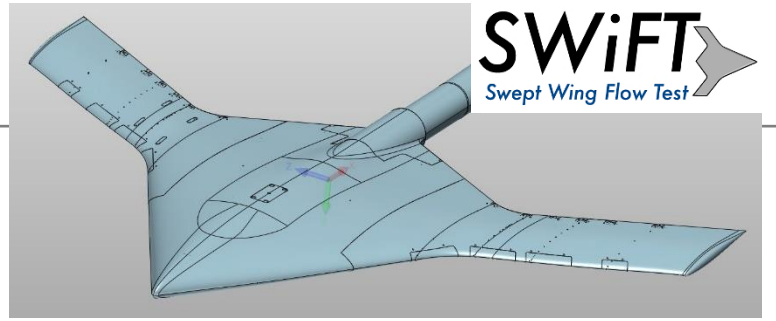
Wind Tunnel Test Management → *Background*

- **MoD/Dstl are completely dependent on other organisations for aerodynamic ground testing**
  - e.g. commercial facilities (ARA/BAe, ETW), overseas research organisations (NASA, AEDC, NRC, DSTG etc)
  - limited budgets, no preferential treatment → on access, on test capabilities, or on technical support
- **the UK needs to get the most it can out of the *available* test *capacity* and test *capability***
  - effectiveness → *will the test programme provide the information we need?*
  - cost → *can the test programme be undertaken within the budget we have?*
  - timeliness → *can the test programme be undertaken in time to make a difference?*
- **links to other 'Smart Testing' paradigms**
  - proposed ATI 'National Aerodynamics Challenge' programme → *a dual use civil/military capability*
  - BAe/ARA/MBDA collaborative activity on 'Smart Aerodynamic Testing' (SAT)
  - Airbus 'Feature Rich Testing' (FeRiT)

NATO STO AVT-369 Digital Twin Technology Development ←

- **these tend to emphasize advanced instrumentation systems and CFD/EFD fusion (digital twinning)**
- **the 'elephant in the room' → *the planning and management of the test itself***
  - covering both pre-test planning, and in-test execution
  - a major factor governing the effectiveness of the test → *under direct control of the test data customer*

Recent Experience



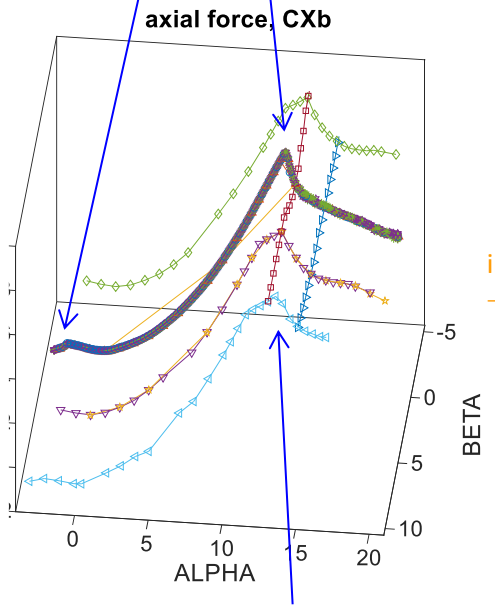
AeroDynamiQ

FWCAT
Fixed Wing Concepts and Technologies

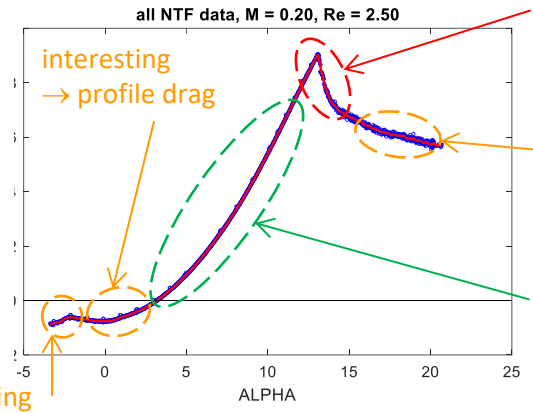
AIAA-2025-1839,40,41,42
AIAA-2025-2018, 19,20,21,22

- **NATO AVT-298 'SWiFT' blended wing body UCAV**
  - Dstl/AFRL/NAVAIR/NASA collaboration 2018-25
- **Reynolds Number effects on swept wings**
  - Dstl test at ARA, NASA test in NTF (cryogenic)
  - to be tested at ETW in 2025, with ATI support
  - very complex flow topology, dominated by leading-edge separation
- **NTF data illustrates common issues with conventional wind tunnel test planning**
  - pre-determined sideslip sweeps missed the critical breaks at higher M/Re
    → *test matrix needs to adapt to events*
  - nothing much of interest happens over large regions of the test envelope
    → *high data density not always needed*
- **implications for test <u>effectiveness</u> and <u>cost</u>**

CZ, CX, Cm breaks due to LE separation
- onset α and severity depends on M, Re, β
- static hysteresis, buffet, lateral transients



sideslip sweeps at 13° and 15°, based on low Re data from the ARA TWT
- intended to bracket the break …



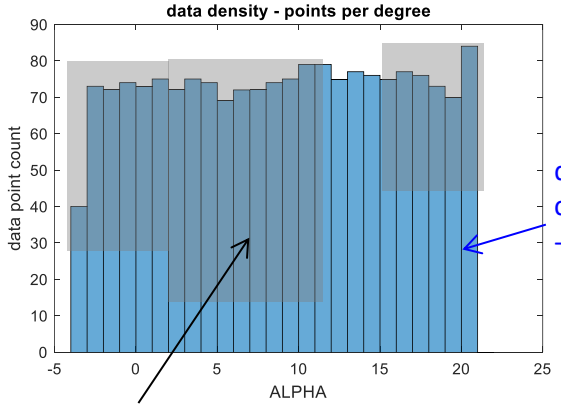
interesting
→ profile drag

critical
→ large-scale separations, loss of control

interesting
→ buffeting

uninteresting
→ linear attached flow (= predictable)

interesting
→ lower surface separation



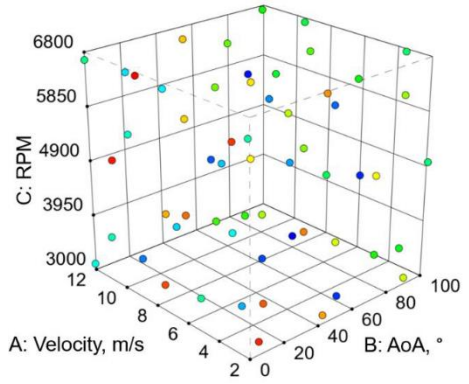
data density almost constant
- continuous + 'move & pause' traverses

redundant data?

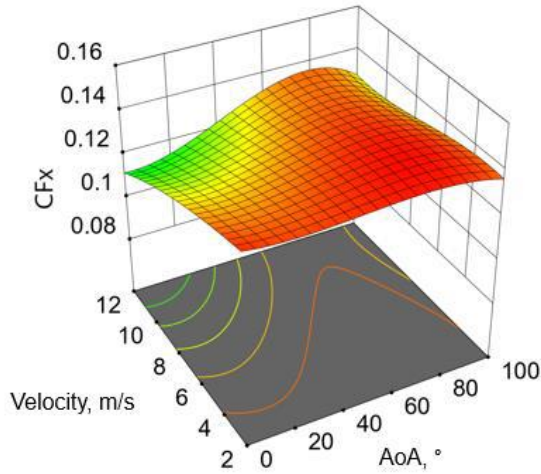
Test Management Methodologies → *Test Matrices*

AIAA-2021-834

- **current approaches to test matrix planning can be categorised as:**
  - *ad-hoc* → 'One Factor at a Time' (OFAT)
  - *formal* → 'Design of Experiments' (DOE)
- **OFAT experimental design is the default methodology for most wind tunnels**
  - simple, intuitive, easy to implement … but can be inflexible and inefficient
  - heavily influenced by the data customer's and the facility test engineer's prior knowledge, experience, prejudices, and expectations …
  - planning focuses on sequencing traverses to minimise model and tunnel condition changes
  - 'in-test' matrix reconfiguration done under pressure, and in a rather ad-hoc manner

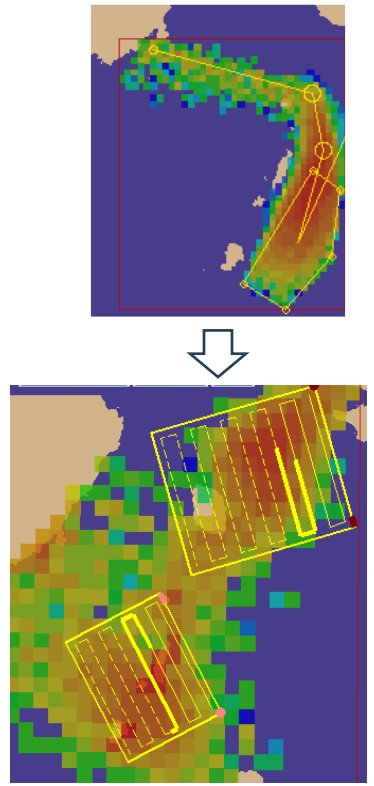


- **DOE covers a range of statistically-based methodologies for experiment design**
  - complex, training needed, difficult to implement … but (in principle) more efficient
  - factorial design makes minimal use of prior knowledge of expected aero behaviour
  - best suited to 'handle-turning' S&C or performance database generation, and to calibration → *when the data is well-behaved*, i.e. representable by smooth(ish) response surfaces
  - *data sequence must be 'randomised'* → makes it very unpopular with tunnel managers
  - inflexible → optimal factorial design requires the entire test programme to be completed …



Test Management Methodologies → *An Alternative*

- **OFAT and DOE are both 'grid' or 'mapping' methods**
  - an n-dimensional lattice encompassing the full range of relevant factors is defined *before* the test
  - adjustments to the grid in response to data surprises or test constraints are not easy
  - much of the data acquired is not actually needed
- **but objectives for wind tunnel testing of (military ?) flight vehicles have changed**
  - database generation no longer a priority
    → but we do need to know where the edges of the envelope are, and what causes them
  - we usually have a reasonable idea upfront of the behaviour to be expected
    → CFD, exploratory testing, prior experience/knowledge
- **a wind tunnel test can therefore be thought of as more akin to a maritime search …**
  - move quickly through 'boring' or 'empty' regions, focus on 'interesting' or 'worrying' regions
  - define an initial search pattern based on *prior knowledge*,
  - continuously adjust the search pattern as new knowledge is acquired,
  - stop when you've found what you need to find
- **ADQ and CU will be looking at existing theories and tools for optimal searches**
  - based on a 'Bayesian' rather than 'frequentist' approach to probability



US Coast Guard
'Search and Rescue Optimal Planning System'