The Modelling and Design of Advanced Wing tip devices

M-DAW
Advanced Wing Tips – The Strategic Challenge

• European Aeronautics Vision for 2020 → http://www.acare4europe.org
  › Quality and Affordability (continuous improvement)
    – Reduced drag
  › The Environment (reduced impact of increased traffic)
    – 50% cut in CO₂ (≡ 50% cut in fuel burn), 20-25% via airframe
    – 50% cut in perceived noise
  › Safety (reduced accidents with increased traffic)
  › Efficiency of the Air Transport System
  › Security
• The 2020 Vision represents a Step change in performance
  › Novel concepts required
• Winglets identified as key technology offering potential in short term
  › Benefits at all stages of flight
  › Retrofit onto existing products
• M-DAW covers the Novel end of a coordinated Winglet Research Activity
Advanced Wing Tips – The Technical Challenge

- Winglet design is a balance between Aerodynamic benefits and Structural penalties

\[ \Delta \text{WRBM due to aerodynamic forces} \]

Each Winglet curve represents an increasing load for constant winglet planform

Impact of Winglet retrofit on Rigid Wing

- Off Design Mach No. (Increasing Shock Strengths)
- WINGLET AERODYNAMIC OPTIMUM
- AIRCRAFT OPTIMUM

WRBM = “Wing Root Bending Moment”
Advanced Wing Tips – The M-DAW Objective

“To Deliver to the European Aerospace Industry a Novel Wing Tip Device to Improve Aircraft Efficiency and Environmental Impact together with a Capability to Accurately Predict the Effect of Wing Tip Device Design on Aircraft Performance”

• Develop a deeper understanding of the aerodynamics of wing tip devices
  ‣ Delivering a unique and extensive experimental database
• Assess the capabilities of advanced CFD to predict tip device effects
  ‣ Delivering validated flow simulation methods
• Explore novel wing tip device concepts
  ‣ Delivering an assessment of a range of advanced wing tip device concepts
• Demonstrate the most promising device by wind tunnel testing
  ‣ Delivering a demonstrated performance improvement by an advanced wing tip device

• M-DAW performance targets were stated as
  ‣ A further 1% reduction in aerodynamic drag at cruise
  ‣ A 2% increase in L/D at take-off
  ‣ Relative to a wing with a conventional tip device for a constant aerodynamic wing root bending moment in cruise
The M-DAW Project Plan

**WP1 Experimental Investigation**
Conventional Baseline Performance
Validation Data
Detailed Study of Flow Physics

2003 2004 2005 2006

**WP2 Application of CFD**
Validated CFD Design & Analysis Capability

**WP3 Novel Wing Tip Device Design**
Study of a Range of Concepts Combining to Deliver One Novel Device

**WP4 Assessment, Selection & Demonstration**
Selection & Demonstration of One Novel Device

Over 330 person months plus 1.8 Million € costs
M-DAW – CFD Validation and Wing Deformation

M = 0.2, Re = 7.2 \times 10^6

Küchemann (TAU)

\eta = 0.56

\alpha = 1.0^\circ

Küchemann Tip

\alpha = 1.5^\circ

Tip Fence

\alpha = 2.0^\circ

50\% Winglet

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50\% Winglet
M-DAW – CFD Validation and Wing Deformation

Kuchemann Tip
M = 0.85, Re = 54.2 × 10^6,
α = 1.5°

Improvement due to accurate simulation of half model effects
Improvement due to accurate simulation of deformation effects

• CFD has proved valuable in the development of a new tip concept
• A combination of CFD and WTT is required to assess performance

Stereo Pattern Tracking
Markers on M-DAW model

16mm
8μm thick

ETW SPT Method (±0.1°)
Design Deformation
ETW Pressure Method

"Virtual Twist" due to technique

Wing Span

Twist Deformation
M-DAW – Advanced Wing Tip Design Activities

• Design Studies Based on:
  ‣ Retrofit scenario
  ‣ “Equivalent Drag”

\[
\Delta C_{\text{Dequiv}} = \Delta C_{\text{Dest}} + \Delta C_{\text{Dtrim}} + \Delta C_{\text{D1gwrbm}} + \Delta C_{\text{Dweight + mech}}
\]

• Design Studies Included:
  ‣ Novel shapes
  ‣ Optimised shapes
  ‣ Movable elements
  ‣ Aeroelastic and Structural effects
M-DAW – Advanced Downward Tip Design

• Approach
  ‣ Vortex Lattice Method study
  ‣ Euler optimisation
  ‣ N-S analysis

• Small Downward Device
  ‣ Modest drag reduction
  ‣ Good WRBM behaviour

• Analysis
  ‣ High and low speed
  ‣ Lateral stability
  ‣ High-g structural impact

Additional lift due to tip device
M-DAW – Advanced Downward Tip Assessment

**Dihedral winglet:** Favorable trend

**Anhedral winglet:** Detrimental trend

**Vertical Downward Device:**
Structural impact remains negligible even at high-g
• Demonstrated in high and low speed tests at ETW
• The performance of the M-DAW novel concept has been broadly confirmed
• Good agreement with drag predictions for attached flow devices
• The SPT wing deformation method confirmed the expected negligible high speed penalty of the novel device
Test Results Summary

- Large winglet offers best drag reduction
- Fence is insensitive to Reynolds Number
- Attached flow Downward Device behaves as Winglet

Design Conditions

\[ M = 0.85, \ Re = 35.4 \times 10^6 \]
M-DAW – WTT High Speed $C_{Roll}$ Increments

Test Results Summary

Design Conditions

$M = 0.85$, $Re = 35.4 \times 10^6$

- Large winglet has a significant impact on Rolling Moment and thus structural sizing
- Fence and Downward Device both display low Bending Moment penalties
M-DAW – WTT Low Speed $C_D$ Increments

Test Results Summary

- Large winglet offers the largest span and largest low speed performance benefit
- Fence is not primarily a low speed device
- Attached flow Downward Device offers an improvement over the Fence

$\Delta C_D$

$M = 0.2, \ Re = 7.2 \times 10^6$
M-DAW – Generic Design Conclusions

- The optimum wing tip device will change depending on the aircraft and project context
- The multi-disciplinary trades, and especially the impact on the wing bending moments, can dominate the high speed design process
- Structural and aeroelastic studies, including high-g loads, are an integral part of the design and analysis process
  - The focus of advanced cryogenic wind tunnel test techniques in M-DAW changed from measuring the wake to measuring the geometry
  - Some aero/structural coupling approaches developed in M-DAW
- Span and attached flow are the key drivers for low speed performance
  - Nothing matched the large winglet at low speed
- Whilst the practical multi-disciplinary constraints make dramatic drag reductions unlikely, improvements are possible through careful optimisation
M-DAW – Specific Design Conclusions

• M-DAW achievements relative to the original targets
  ‣ A further 1% reduction in aerodynamic drag at cruise
    – Achieved by the anhedral winglet relative to the large winglet though low speed performance was impacted
  ‣ A 2% increase in L/D at take-off
    – Achieved by the downward pointing winglet relative to the wing tip fence with similar high speed performance

• M-DAW has developed a novel downward pointing winglet that achieves a similarly low drag and bending moment to a wing tip fence due to the changed lift vector, whilst also offering an attractive low speed benefit due to its attached flow design

• Final M-DAW devices, whilst not exploiting revolutionary flow physics, do demonstrate a useful expansion of design space
  ‣ Practical multi-disciplinary issues dominated giving results that are immediately available for industrial consideration

• Downward pointing winglets can be added to the catalogue of useful wing tip devices.
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M-DAW – Practicalities of Downward Devices

• Considerations
  ‣ Gear collapse crash load philosophy
  ‣ Allowance for cross wind speeds (landing & take-off)
    – JAR 25.445, JAR 25.237, (JAR 25.149)
  ‣ Ground handling philosophy (e.g. support vehicle incident avoidance)
  ‣ Dynamic calculation and margin definition required for any component considered critical

• Constraints but not showstoppers

Designed sacrificial, but still needs to meet standard operational requirements