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An Overview of Transonic Truss-Braced Wing Technology



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Overview

1. Introduction & Motivation
2. Aerodynamic Behavior
3. Structures, Aeroelasticity & MDO
4. Certification & Integration
5. Conclusion & Future Work

Introduction & Motivation



Background & Motivation

- The cantilever has plateaued
- Sustainability is forcing change
  - NASA's ARMD targets net-zero by 2050
- The TTBW is a promising candidate
  - High AR wings reduce induced drag



Background & Motivation

- Literature mostly NASA-funded
  - SUGAR has driven the program (Boeing/NASA)

- Extends synthesis into academic + international work

Aerodynamic Behavior



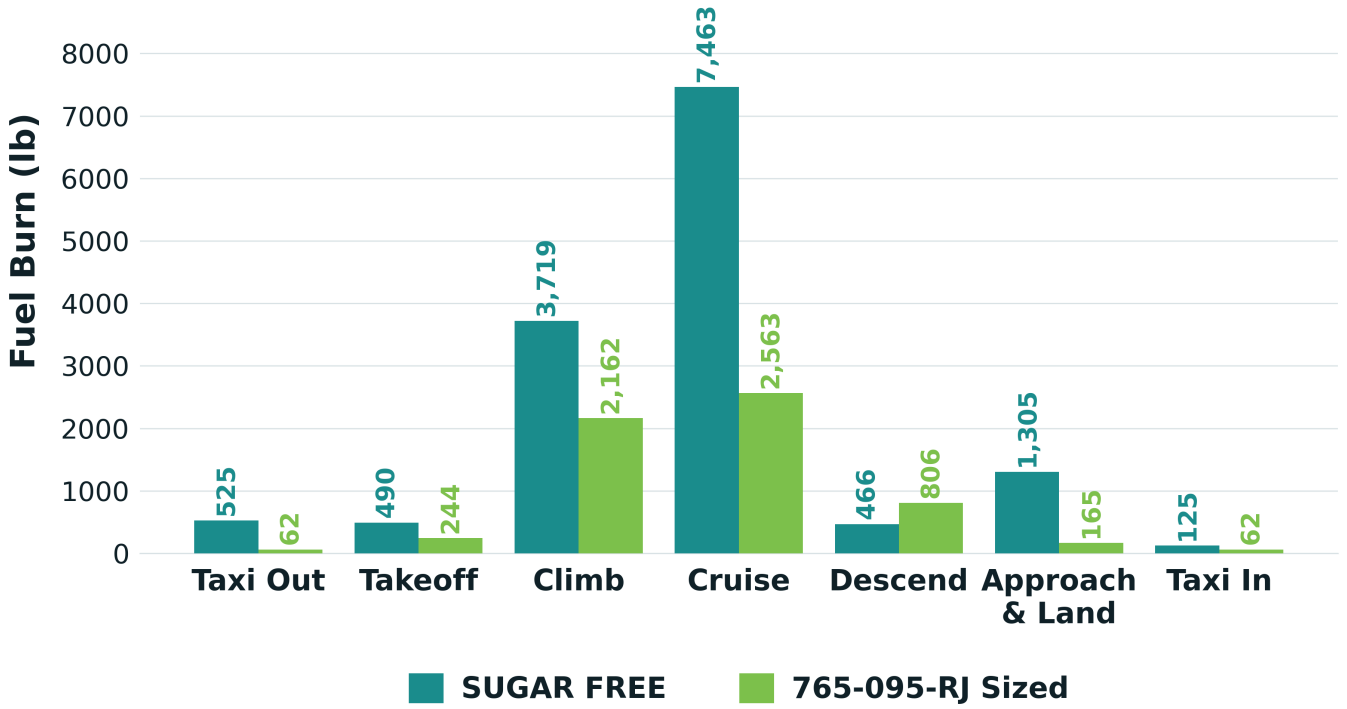
Multi-Mission Efficiency

- Short-range: 5.0–10.8% fuel benefit, 13.1% L/D gain
  - 500-1000 nmi
- Mid-range: 3.5–11.4% fuel benefit
  - ~3000 nmi
- Long-range: 6.0–9.5% fuel benefit
  - 7730 nmi
- **Lacks flight-test validation**

[Chau 2023; Wells 2024; Mallik 2015]

Optimized Performance

- **57% block fuel reduction**
  - vs SUGAR Free baseline at 900nmi
- +38.7% peak L/D
- Tradeoffs:
  - Cruise Mach: 0.79 → 0.745
  - MTOW: 182,600 → 132,200



[Droney 2020]

Layout & Mechanism

- Staggered wing-strut layout
  - **Strut contributes lift**
    - ↓ inboard wing loading
    - Flattens spanwise lift distribution
    - ↓ compressibility drag
  - Wing acts as a flow straightener
    - ↓ stall risk



[Harrison 2020]

Drag & Interference

Drag Drivers:

- **Wing sweep is dominant**
  - ↑ sweep cuts shocks, ↓ sweep helps laminar flow
- Root chord & higher strut-wing clearance ↓ interference
- Higher AR reduces induced drag
  - Up to ~170 ft of span

[Jones 2023; Mallik 2015; Chakraborty 2015]

Interference & Alleviation:

- Sharp jumps in C_L, C_D, C_M at the wing-strut junction
- Interference worsens with Mach
- **Active drag alleviation feasible**
  - VCCTEF + jig twist: ~1–3% reduction
- Geometry optimized for drag alleviation

[Xiong 2021, 2022, 2023; Li 2022; Nguyen 2021]

Low-Speed Behavior

- **High-lift system meets target lift**
  - Leading-edge Krueger & trailing-edge Fowler + flaperon
  - $C_{L,max} = 3.1$ at max deflection
- No global stall (AoA <19°)
- Wing stalls earlier: $\alpha_{wing} = 15.3°$ vs $\alpha_{strut} = 23.4°$

[Droney 2020; Harrison 2021]

Structures, Aeroelasticity & MDO



Structural Behavior

Structural Necessity:

- Unbraced wing weighs 3–4x heavier
  - Aerodynamic gains evaporate
- Strut reduces bending moment by 6x
- **Strut enables ultra-high AR wings**

[Pelykh 2024]

Design Considerations:

- Outboard wing-strut junction
  - ↓ reinforcement needed
- Wing-mounted engines
  - ↓ wing bending stress
- High-wing configuration
  - Strut in tension (no buckling)
- Carbon fiber over aluminum
  - 30% mass reduction, no flutter penalty

[Solano 2023; Pelykh 2024; Roncolini 2024; Meadows 2012]

Aeroelastic Behavior

Flutter:

- **Healthy across flight envelope**
  - Validated to Mach 0.85; dive Mach 0.89 cleared
- Geometry trades weight vs flutter
  - 55%–70% span; true optimum unresolved
- Active suppression feasible
  - VCCTEF (wind tunnel validated)

[Wells 2024; Harrison 2020; Roncolini 2024; Bhatia 2012; Scott 2016; Bartels 2019]

Buffet:

- Improved buffet onset ceiling
  - +11.6% vs SUGAR FREE
- **No novel buffet concerns**
  - Strut, channel, & onset mechanisms are all conventional
- CFD: wind tunnel validated
- Flexibility delays buffet onset
  - Aeroelastic load relief

[Droney 2020; Wells 2024; Harrison 2025; Browne 2025; Xiong 2024]

MDO Frameworks

Optimization Necessity:

- **Couplings present from day 1**
  - Aerodynamic, structural, & aeroelastic constraints inseparable
- Advantage survives flutter
  - TTBW still outperforms cantilever
- Multipoint optimization→off-design gains
  - Minimal on-design cost

[Mallik 2015; Chau 2023; Li 2022]

Aviary:

- Open-source MDO framework
  - Concept → physics-based in 2 years
- Subsystem fidelity continues to improve
  - Higher-fidelity modules feasible
- **Adoption beyond Boeing/NASA**
  - Academic & international enabled

[Aretskin-Hariton 2024; Leader 2024; Brooks 2025; Carillo 2025]

Certification & Integration



Certification & Integration

Findings:

- Quieter than cantilever
  - 4.7 EPNdB cumulative margin advantage
- Substantial environmental gains
- Strut icing minimal
  - Wing leading edge needs IPS

[June 2022; Wells 2024; Harrison 2022]

Limitations:

- Noise margins below NASA target
  - Fan noise dominates
- **Simulation tools require validation**
- X-66A flight demonstrator paused
  - Ground-based redirect (April 2025)
- Powerplant placement sensitive
  - Spanwise CoM → structural/aeroelastic response

[Struk 2025; Quinn 2025; Wells 2024; June 2022; Naik 2024]

Conclusion & Future Work



Conclusions & Future Work

Established Findings:

- Efficiency translates across studies
  - 3.5–11.5% fuel benefit; multiple groups & multiple missions
- Aeroelastic envelope is healthy
  - Cruise & dive cleared
- Configuration survives engineering constraints
  - Flutter, novel structural couplings, MDO tradeoffs

[Mallik 2015; Wells 2024; Pelykh 2024]

Future Work:

- Modelling tools are catching up
  - ML surrogates, nonlinear flutter, multi-fidelity ROMs
- Aviary expands participation
  - Academic & international growing
- **Biggest gap: flight-data validation**
  - X-66A pause delays certification

[Khan 2023; Sohst 2022; Aretskin-Hariton 2024; Brooks 2025]

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Extension: Icing

- Strut/jury icing: minimal impact
- Leading edge icing: ↓ $C_{L,max}$ in cruise & high-lift
  - High-lift impact: ↑ approach speeds & ↓ maneuverability
- IPS integration: Thin wing constrains integration & may compromise aerodynamic gains
- Certification path blocked: Comparative analysis doesn't apply
- Struk et al. 2025: IRT tests & GlennICE validation
- SUGAR Phase VI: VCK icing in wing-strut junction

[Wells 2024; Harrison 2022; Struk 2022; Struk 2025]

Extension: Aviary (MDO)

- Aretskin-Hariton et al. (2024): Proof of concept
  - Hybrid-electric TTBW, low-fidelity systems
- Leader et al. (2024): Subsystem fidelity
  - Cell-level battery & motor modules
- Brooks et al. (2025): Physics-based integration
  - OpenAeroStruct + TACS
- Open-source MDO beyond NASA/Boeing

[Aretskin-Hariton 2024; Leader 2024; Brooks 2025]

Extension: Fuel & Propulsion Integration

- Wing tanks impractical (thin wings)
- Strut + fuselage tanks
  - ↓ TOGW, ↓ wing bending stress
  - Penalty: ↓ L/D, ↑ cruise C_D
- Wing-mounted engines: ↓ wing weight
- TTBW more sensitive to powerplant CoM than cantilever

[Pelykh 2024; Meadows 2012; Quinn 2025]

Extension: Contrails (Environmental)

- TTBW has a 10pp reduction on 3/4 test days
  - TTBW: ~3.75% flight miles in persistent contrail regions
  - Boeing 737-800 baseline: ~10.5% flight miles
- Higher cruise altitude

[Lauderdale 2023]

Extension: Noise Roadmap (Aeroacoustics)

- Baseline TTBW: -23.1 EPNdB
  - FTTP TTBW: -34.9 EPNdB
- NASA goal: 32-42 dB below ICAO Ch. 4
- Fan noise: Highest-leverage reduction source
- Sideline margin to FAA Stage 5: Only 2.9 EPNdB

[Naik 2024; June 2022]