Summary/Agenda

• New Aero/Structural Model
  – Model formulation and new capabilities
  – Input simplifications

• New engine weight model

• Prioritization of TASOPT 3.0 applications (discussion)

• Fuselage layout tutorial/example
Collection of coupled low-order physical models . . .

- Primary structure
- Aero
- Engine
- Balance, trim, stability
- Flight trajectory

. . . wrapped with an optimizer
TASOPT 2.0 Calculation Loops

**Design Inputs**
- Range
- Nmax
- CMfuse
- Payload
- fstress
- IBFmax
- Mach
- Tmetal

**Design Parameters**
- (Sweep, CL, AR, Altitude, FPR, BPR, Tt4 ...)

**Optimization**
- Surface spans, areas
- Loads, Shears, Moments
- Structural gauges
- Volumes and Weights
- Drag, Engine size+weight
- Trajectory, Fuel Weight

**Design Closure**
- Total Weight converged?
- Fuel burn minimized?

**Design Outputs**
- Sweep
- FPR
- Weights
- Fuel burn
- CL
- BPR
- Dimensions
- Engine size
- AR
- Tt4
- Gauges
- T/O perf

Output = f(Input) results represent *closed, optimized* design
Changes for TASOPT 3.0

Collection of coupled medium-order physical models . . .

- Primary structure
- Aero
- Engine
- Balance, trim, stability
- Flight trajectory

. . . wrapped with an optimizer
TASOPT 3.0 Calculation Loops

Design Inputs

Design Parameters
- Range
- Nmax
- CMfus
- Payload
- fstress
- lBFmax
- Mach
- Tmetal ...

Optimization

Design Closure

- Surface spans, areas
- Loads, Shears, Moments
- Structural gauges
- Volumes and Weights
- Drag, Engine size+weight
- Trajectory, Fuel Weight
- Total Weight converged?
- Fuel burn minimized?

Design Outputs

- Sweep
- CL
- AR
- Altitude
- FPR
- BPR
- Tt4 ...
- Weights
- Dimensions
- Engine size
- Gauges
- T/O perf

Output = f(Input) results represent closed, optimized design
New Aero/Structural Model

- ASWING structural formulation
  - Full bending/torsion beam component representations
  - Strongly-coupled Panel/Vortex-Lattice potential flow model

- Accounts for load changes in critical sizing cases:
  - Spanwise aero load redistribution in $N_{\text{max}}$ wingbox-sizing case
  - Inertial relief in $V_{\text{NE}}$ max tail load cases

- Eliminates need for offline panel analysis for fuselage $C_L, C_M$ contributions

- Potential future extensions to dynamic load cases (gust encounter)
Wing Geometry/Loading Parameters

**TASOPT 2.0**

- Sweep: $\Lambda$
- Chord ratios: $\lambda_s, \lambda_t$
- $c_\ell$ ratios: $r_{c_\ell s}, r_{c_\ell t}$
- Loadings: $p = p_0 \lambda r_{c_\ell}$
- Root, tip rolloffs: $f_{Lo}, f_{Lt}$

- $\bullet$ Wing box sized by $N_{\text{max}}$ case
- $\bullet$ $p(\eta)$ shape assumed independent of $N$
  (conservative)

**TASOPT 3.0**

- Sweep angles: $\Lambda_i$
- Dihedral angles: $\gamma_i$
- Chord ratios: $\lambda_i$
- Twists: $\theta_i$
- Loadings: computed (VL)
- Root, tip rolloffs: computed (VL)

- $\bullet$ Wing box sized by $N_{\text{max}}$ case
- $\bullet$ $\Gamma(\eta)$ computed with aero/structural model
  (captures passive bend/twist load alleviation)
Body/Surface Panel Method

Surface $C_p$

Provides:

- Overall $C_L$, $C_M$, $C_{D_i}$
- Component load diagrams for structural loads
Eliminated Input Parameters

- fLo: fuselage lift carryover loss factor
- fLt: tip lift rolloff factor
- dCLh/dCL: HT lift-curve slope factor for NP calculation
- deps/da: downwash factor at tail
- CMVf1: fuselage moment derivative \( \frac{d(M_{\text{fuse}}/q)}{dC_L} \)
- CLMf1: \( C_L \) where \( M_{\text{fuse}} = 0 \)
- fduo: fuselage velocity overspeed at wing root
- fdus: fuselage velocity overspeed at wing break
- fdut: fuselage velocity overspeed at wing tip
- rcls: break/root ratio \( c_{\ell_s}/c_{\ell_o} \) at takeoff, landing
- rclt: tip/root ratio \( c_{\ell_t}/c_{\ell_o} \) at takeoff, landing
- cmpo: root \( c_m \) at takeoff, landing
- cmps: break \( c_m \) at takeoff, landing
- cmpt: tip \( c_m \) at takeoff, landing
Coupled Aero/Structural Model

Undeformed/Deformed Lattice
Coupled Aero/Structural Model

Sizing calculation at critical load case

- Wingbox gauges $t_{\text{cap}}$, $t_{\text{web}}$ additional unknowns
- Solved together with beam equations, via added strain/stress constraints

\[
\sigma_{\text{max}} = \frac{M h / 2}{I(h,t_{\text{cap}})} \quad \tau_{\text{max}} = \frac{T}{2A t_{\text{web}}}
\]
Coupled Aero/Structural Model

Analysis calculation at mission points

- Stiffness and mass properties fixed
- Aero/structural problem solved as usual
- Outputs are $C_{Dp}$, $C_{Di}$
Engine Model: HPC Efficiency Correction

- Decrease HPC polytropic efficiency as a function of compressor exit corrected mass flow, $\bar{m}$, to account for compressor size based on DiOrio (2012), figures below
- Accounts for effects of manufacturing tolerances and decreased Reynolds number in small core engines ($\bar{m} \leq 6$ lbm/s)
- Two correlations built for upper and lower bound cases A and B respectively
  - Pure Scale: modern compressor geometry scaled down (black dotted line)
  - Shaft Limited: scaling down of compressor constrained by LP shaft increasing mean radius and hub-to-tip ratio from pure scale case (solid line)
- HPC polytropic efficiency correction can be turned on with new flag in input file, $i_{hpc}$
- Worst-case correction for the D8.5 is about 12%, best-case is about 2%

![Figure 5-5: HPC efficiency versus core size for Case A (efficiency upper bound). Baseline efficiency at 6.0 lbm/s.](image)

![Figure 5-6: HPC efficiency versus core size for Case B (efficiency lower bound). Baseline efficiency at 6.0 lbm/s.](image)
Engine Model: Weight

• Current model based on a single correlation for bare engine weight as a function of overall pressure ratio ($\pi_o$), bypass ratio ($\alpha$), and core mass flow ($\dot{m}_{\text{core}}$), developed by Nate Fitzgerald at Aurora
  
  – Four bare engine weight correlations based on data from NPSS/WATE++
    * Direct-drive turbofan: current and advanced materials
    * Geared turbofan: current and advanced materials
  
  – Nacelle, pylon, and additional weights calculated as functions of bare engine weight and fan diameter, then summed to find total engine weight

$$W_{\text{eng}} = W_{\text{ebare}} + W_{\text{pylon}} + W_{\text{nacelle}} + W_{\text{add}}$$ (1)

• New model uses same NPSS/WATE++ data but features separate surrogate models for the core, fan, combustor, nozzle, and nacelle weights

$$W_{\text{eng}} = W_{\text{core}} + W_{\text{fan}} + W_{\text{comb}} + W_{\text{nozz}} + W_{\text{nace}} + W_{\text{pylon}}$$ (2)

  – Each component weight is a function of $\pi_o$, $\alpha$, and either $\dot{m}_{\text{core}}$ or $\dot{m}_{\text{inlet}}$
  
  – Four correlations for each component: direct-drive/geared, current/advanced materials
  
  – Pylon weight added as a function of the other component weights

• Input Gearf to specify geared or direct-drive configuration

• Input iengwgt to specify materials and model
Engine Model: Remaining Issues

- HPC efficiency correction iteration loop as currently implemented degrades convergence of overall engine state loop
  - Need to integrate modified efficiency into the engine cycle Newton solver
- Discrepancies between weight models
  - Total engine weight from new model is 14% less than current model (based on TASOpt model of 737-8)
  - Likely due to how added/accessory weight is accounted for in each model
Prioritization of TASOPT 3.0 Applications

- Aircraft design optimization
- Unsteady gust loading modeling
- Different critical loading cases
- …
Fuselage Geometry Definition for TASOPT

1/4. Design cross-section

2/4. Design floor plan
Fuselage Geometry Definition for TASOPT

3/4. Wrap with aero shape and pressure shell

4/4. Fit with parameterized shapes
Fuselage Aero Shape Parameters

Hyperellipse:

\[ R = R_{\text{fuse}} \left(1 - \xi^a \right)^{1/a} \]

Power law:

\[ R = R_{\text{fuse}} \left(1 - \xi^b \right) \]

Fuselage aero shape used for:

- Potential-flow aero
- Boundary layer development and profile drag
Pressure shell and tailcone shapes used for:

- Structural weight
- Volume and pressurization weight