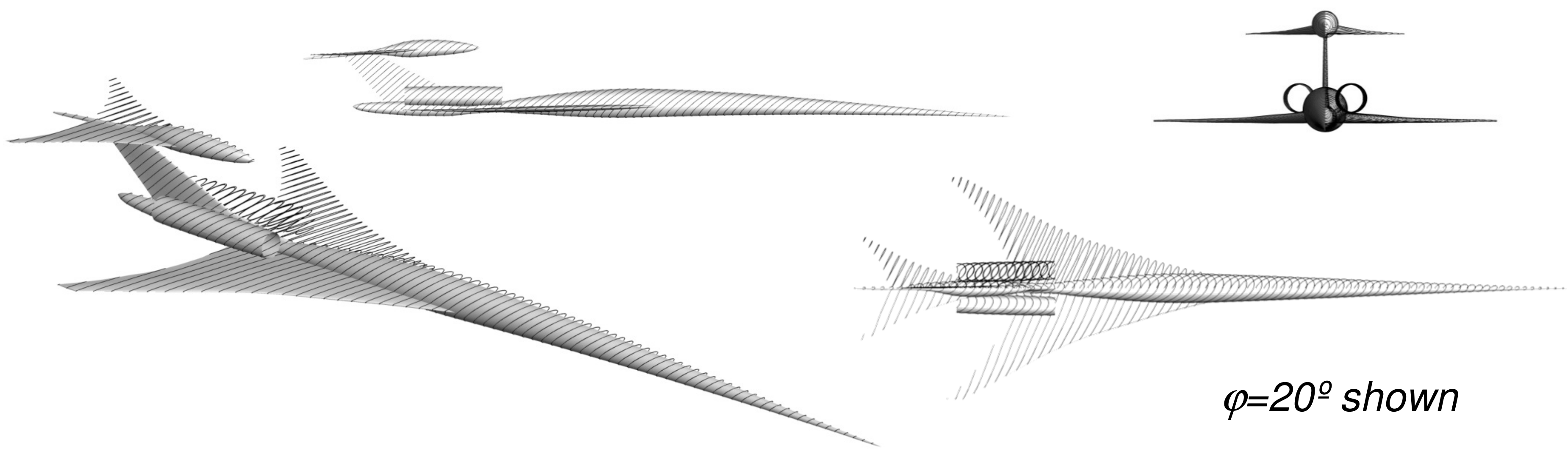
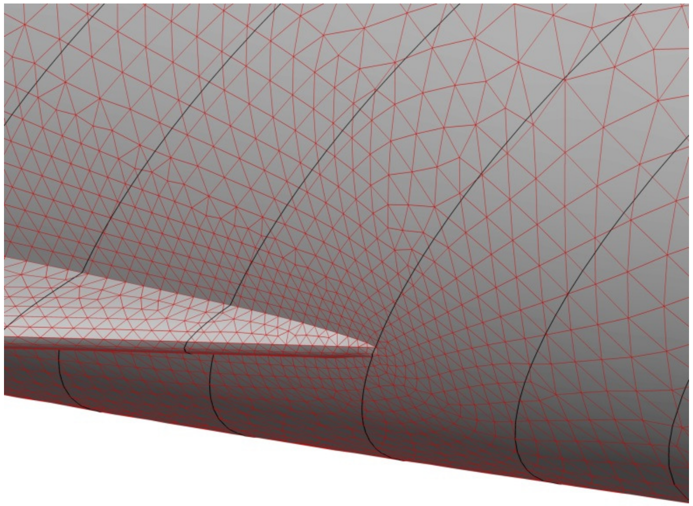
User Inputs

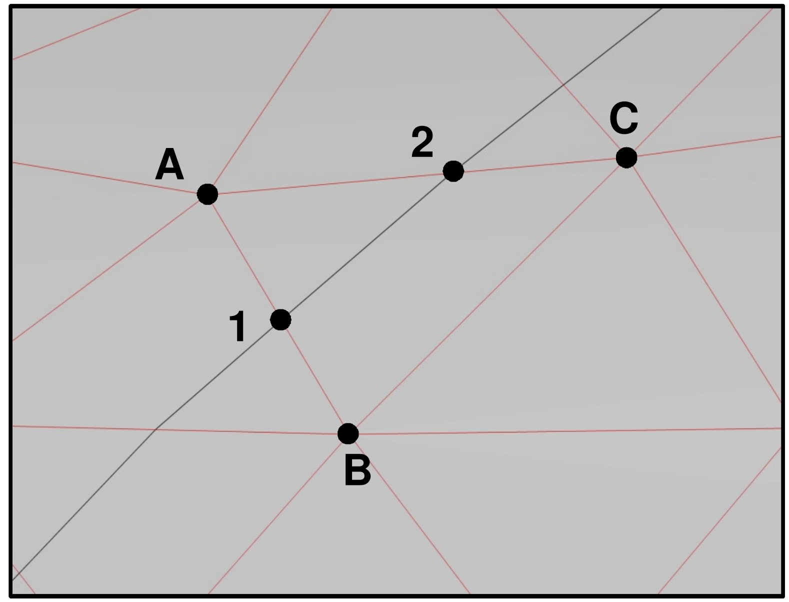


For as many user-specified Ae functions as desired, user supplies:

- *nplane* — Number of cutting planes along vehicle
- φ — Off-track angle in degrees
- G — Global scaling factor (optional, default=1.0)
- S — Lift scaling factor (optional, default=1.0)
- A_i — Target area distribution for plane (station) i (optional, default=0.0)
- ω_i — Weighting distribution for station i (optional, default=1.0)

Geometry/Solution Processing





- Using existing FUN3D visualization mechanics for slicing solutions, triangles/quads on all vehicle surfaces are processed for cutting plane intersections
- If symmetry plane is present, FUN3D will also locate virtual intersections to complete aircraft cross-sections
- Locations 1 and 2 along split edges are established
- Based on ratio of subareas within triangle ABC, element lift is distributed to streamwise stations i, $i+1$, etc as appropriate, forming L_i
    - Surface quads also handled appropriately
    - Special cases where cutting planes coincident with node(s) also handled
- Using Green's theorem, the area of the polygon formed by the closed cross-section at station i is computed and then projected onto the yz-plane, forming V_i

Target Distributions and Final Function Form

- Target distributions may be as fine/coarse as desired; FUN3D will linearly interpolate to each streamwise station
- A streamwise weighting distribution ω_i may also be supplied to locally weight the function as desired
- If no target distribution is supplied, FUN3D will set all A_i to zero (e.g. for baseline analysis)
- The final form of the scalar function for an azimuthal angle is

$$J = \sum_i \left[L_i + V_i - A_i \right]^2$$

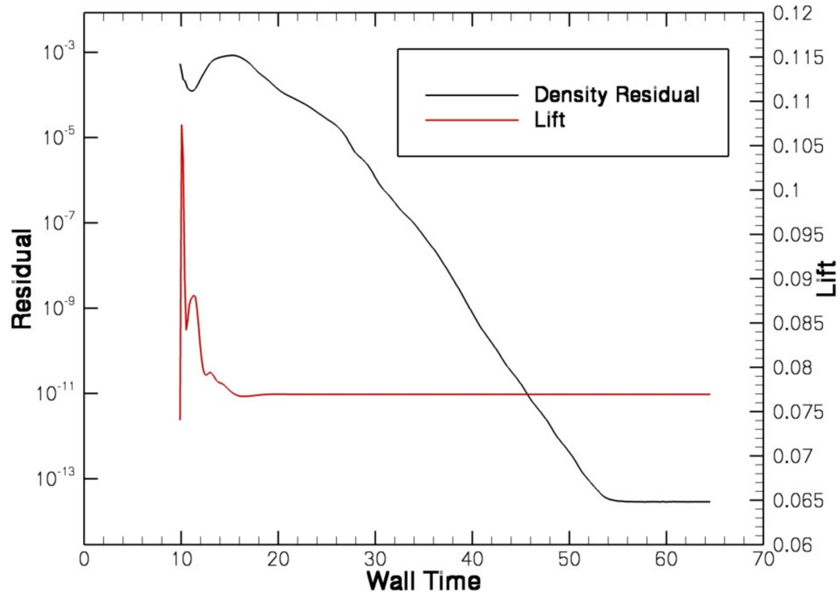
Adjoint-Based Sensitivity Analysis

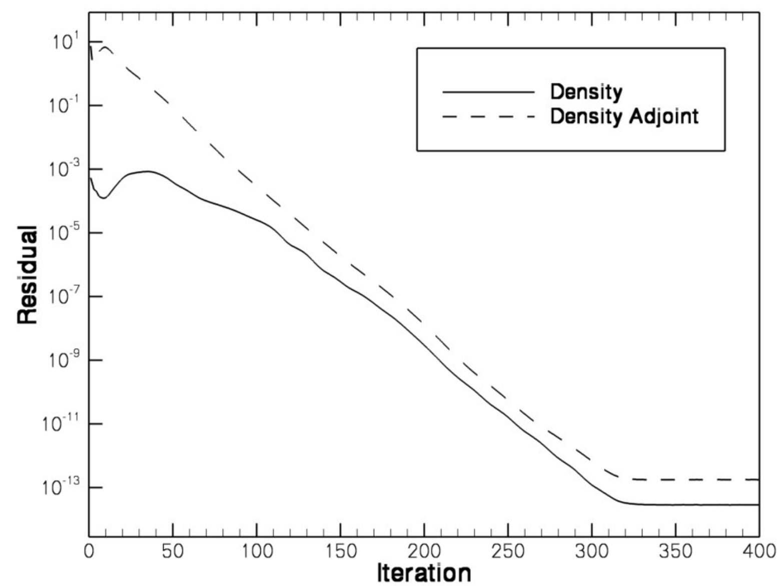
- A discretely consistent linearization has also been provided for this class of objective/constraint functions
- As demonstrated here, FUN3D's adjoint solver provides the exact sensitivities of the specified functions
- **Note:** An optimization process based on these functions may not be successful:
  - Functions relying on pointwise matching of target distributions such as those used here are known to produce noisy design spaces for which many local minima may exist; sensitivities may not indicate the desired direction of global descent.
  - The collection of surface elements cut by a specific slicing location may significantly change during the design; this can also introduce artificial noise in the design space.
  - *These potential problems are properties of the chosen functional form and have nothing to do with the adjoint-based sensitivity analysis, which simply provides the discrete sensitivities requested.*

Performance

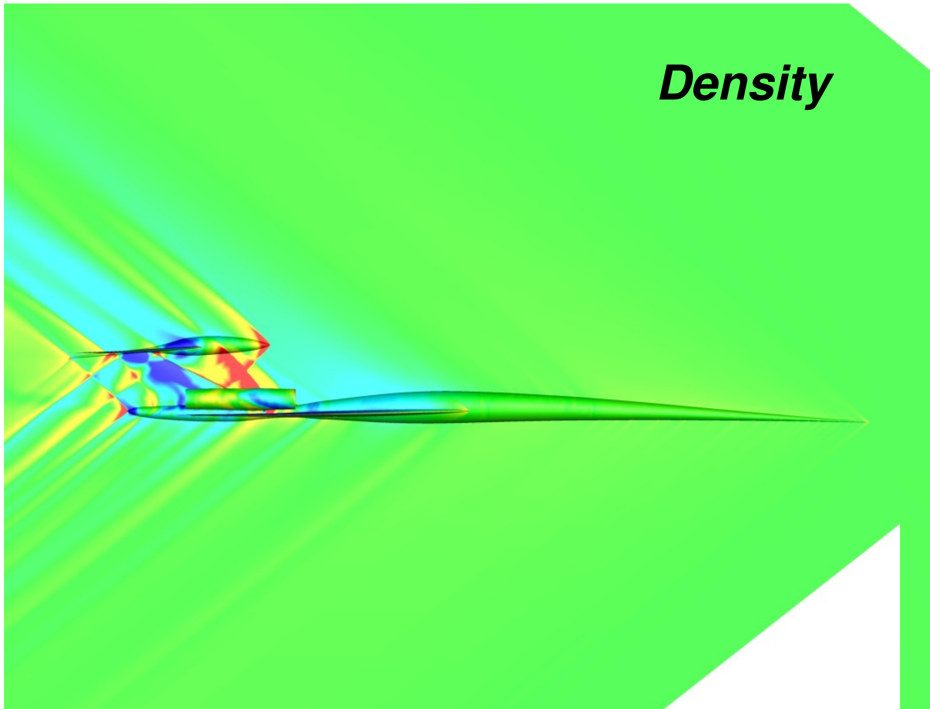
"In-House" Test Case with 2.2M Points / 12.5M Elements

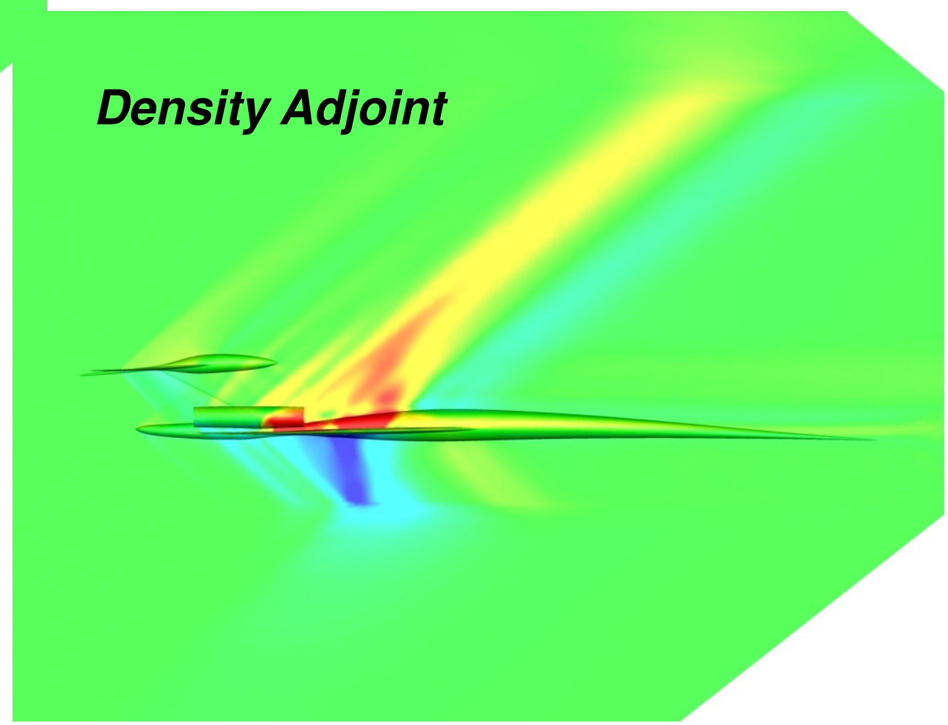
- Flow solution converges to machine precision in ~50 seconds using 15 fully-dense Sandybridge nodes on pleiades
- Adjoint solution converges asymptotically at the same rate (as expected) to machine precision in ~70 seconds for a single off-track objective function, or ~150 seconds for 3 separate off-track objective functions (3 adjoints computed simultaneously)
  - Practical use does not require nearly this level of convergence; these times could be reduced considerably using less stringent tolerances
  - Runtime could be further reduced using prisms rather than tetrahedra in the off-body region, as the cost of an Euler solution scales directly with number of edges in the mesh
    - Presumably this would also improve accuracy due to reduced dissipation





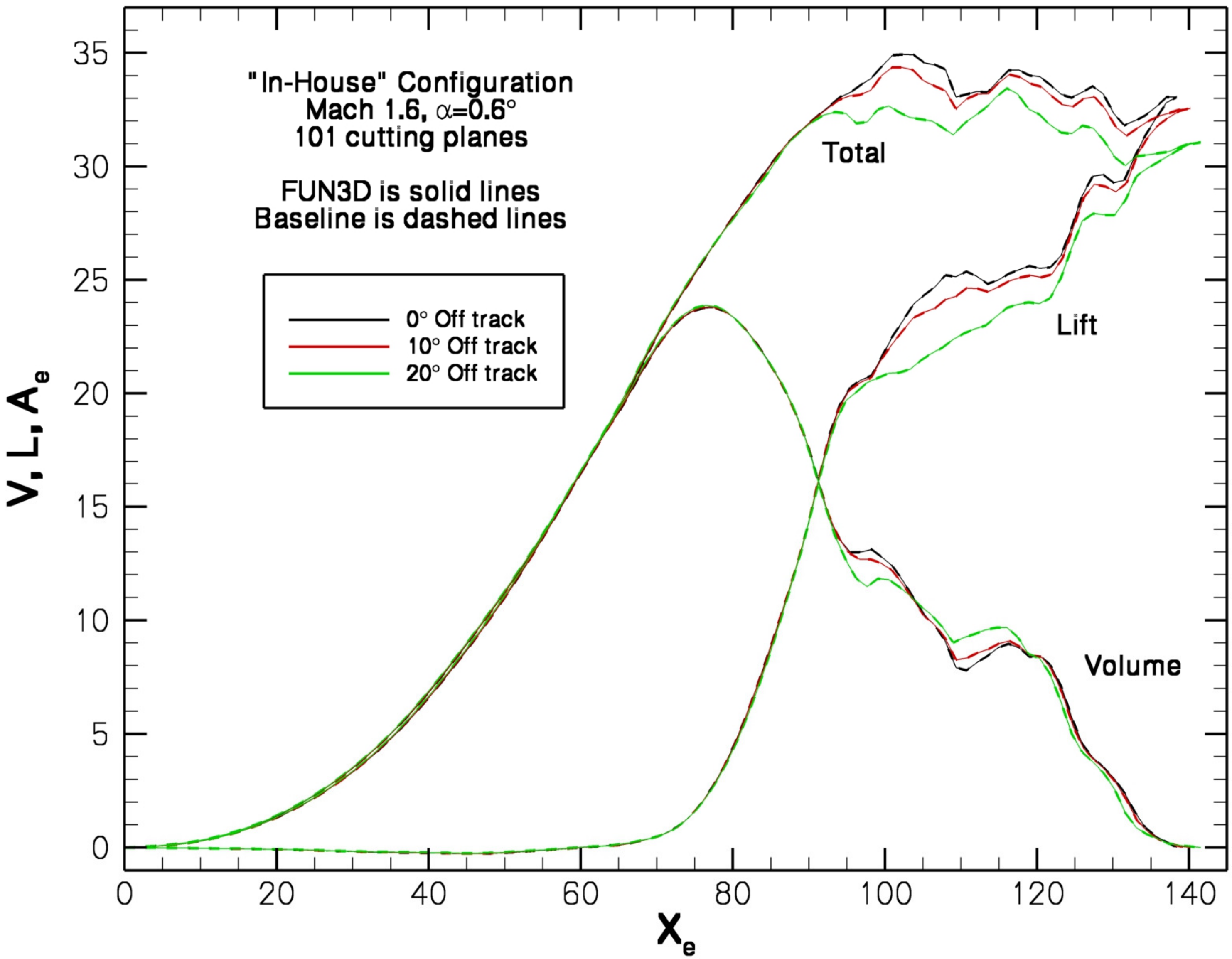
Solution Visualization





Ae Verification

Comparison to Existing ASAB Toolset



Consistency of Linearization

Design Variable (Off-track Angle)	Complex Variable Sensitivity ($\mathcal{E}=1\times10^{-50}$)	Adjoint Sensitivity
Alpha (0º)	3.5939379592**4730**	3.5939379592**9532**
Alpha (10º)	3.393895810**39875**	3.393895810**44947**
Alpha (20º)	3.21951017**888487**	3.21951017**901405**
Shape (0º)	-0.0034364513836**14**	-0.0034364513836**01**
Shape (10º)	-0.0027142092414**48**	-0.0027142092414**65**
Shape (20º)	-0.002467764267**585**	-0.002467764267**626**

- Here, the shape design variable consists of a combination of the x, y, and z coordinates of a single point on the wing surface
  - In practice, this would be a parameter associated with MASSOUD, bandaids, etc

Notes

- Any Ae functions posed by the user may be used as
  - Stand-alone objective functions
  - Combined with other Ae or other FUN3D functions (lift, drag, boom, inlet distortion, etc) as part of more general multiobjective functions
  - Implicit penalty functions
  - Explicit constraints
  - Objectives/constraints for multipoint optimizations
- Available for inviscid, laminar, and turbulent flows using any combination of element types/surface discretization
- All computations are performed in parallel domain-decomposed environment and scale with the surface grid decomposition
- FUN3D provides the user with output plot files `{project}_ae.dat` containing the current V_i, L_i, A_i distributions for all specified objective/constraint functions
- FUN3D also provides the user with output plot files `{project}_ae_cuts_i.dat` containing the slice geometries for i^{th} Ae objective/constraint
- Complete implementation of new FUN3D Ae module required ~7,950 LOC:
  - Infrastructure and baseline function evaluation (2,850)
  - Flow jacobians (1,000)
  - Alpha jacobians (1,100)
  - Grid jacobians (3,000)
- Capability will be available in FUN3D v12.4