Optimate CFD Evaluation

Optimate Glider Optimization Case

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Purpose

• For design optimization, the gold standard would be to put in requirements and have algorithm spit out an optimal design
  • Requires multiple objective optimization technique
  • Very complicated and robust objective functions
  • Many variables to be tweaked
  • Many evaluations performed
• Our desire was to evaluate Optimate in a case as closely to this gold standard as possible
  • Very complicated Objective function
  • Complicated Geometry
  • Large set of Evaluations
  • Multiple objective functions
• Optimization of a basic glider shape
Geometry Generation

• Glider Geometry was generated in STAR-CCM+ CAD.
  • Desire to have the model be highly parameterized
    • 140 Parameters for Define Geometry, significantly more used for interim calculations
    • Due to CAD bug, held airfoil Parameters constant, leaving 53 parameters to act on
  • Due to complexity, Macro was written to generate CAD model
    • Several restarts necessary as a part of learning process
    • Each step was broken into a separate function to reuse as much code as possible, and minimize time when forced to restart
      • Generate Airfoil for lifting surfaces
      • Generate Airfoils at Control Surface
      • Generate lifting surfaces from Airfoils
      • Generate Fuselage X Section
      • Generate Fuselage
      • Name and set/define all of the parameters according to consistent naming convention
  • Generate CAD model Macro is over 1000 lines of code
Airfoil Generator

• Every Airfoil in the model is designed by one of two Macros.
  • One Macro generates a clean airfoil for areas such as the root and wing tips
  • A second Macro generates a similar airfoil, but contains a break at the second airfoil definition point for a control surface.
  • Neither is an ideal airfoil in order to make modifications through Design Parameters simpler
Wing Generator

- The Wing Generator creates a half span lifting surface, used for all lifting surfaces in the body (Wing, Horizontal Tail, Vertical Tail)
  - First defines all planes for the Airfoils
    - Defined so that origin is at nose of each airfoil
    - Each can be rotated for twist individually
    - Each is translated for sweep, dihedral, wing control surfaces, and surface placement
  - Generate all of the Airfoils
    - Wing Root
    - Wing inboard control surface
    - Wing outboard control surface
    - Wing Tip
  - Creates a control surface rotation axis
  - Last step is to generate lofts between all cross sections
Fuselage Generator

- Fuselage Generator creates the fuselage
  - First creates the planes for each of the fuselage x sections (6 in all)
  - Then generates a cross sectional shape
    - Shape is two half circles with a gap between them
    - Defined by a radius of the circles and an Aspect ratio of the final shape
  - Next define design parameters for all cross sections
  - Last step generates the loft to create the fuselage
Geometry Generation

• Last step merges the lofts together and mirrors them for left/right symmetry
Gridding – Mesh

Grid Generated in: STAR-CCM+
Mesh Type: Trimmer
Number of Cells: 5 – 11 Million
Number of Prism Layers: 8
Prism Layer Height: 1”
Special Features: None
Evaluation Code

• Optimate’s StarDriver.java routine was modified to allow a java Macro to be used for the evaluation instead of simply solving the existing problem

• The Java Macro basic functionality
  – Calculate the new designs Mass properties
    • Uses a function based on 0th order estimations detailed in Daniel Raymer’s Aircraft Design: A Conceptual Approach
  – Performs a basic angle of attack sweep
  – Performs a sideslip point at peak untrimmed L/D
  – Deflects the elevator and performs a second angle of attack sweep
  – Trims in pitch at all conditions and calculates all stability derivatives
  – Calculates Objective values
    • Peak trimmed L/D
      – Penalized for instability in roll pitch and yaw
    • Maximum wing bending
Input Case Values and Remesh

Calculate Mass Properties

Set all Moment References to CG

Perform Angle of Attack Sweep

Perform single sideslip Condition

Calculate Lateral Stability Terms

Deflect Elevator and Remesh

Perform Angle of Attack Sweep

Calculate Trimmed L/D at all conditions

Calculate Objective Values (Max trimmable L/D and Wing Bending Moment)

Begin Iterating

Output Results
## Run Conditions – Optimate

- Set up Optimate to modify 54 variables
- Run 200 Evaluations

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Results – Configurations Explored
Results – Configurations Explored

- After 200 runs, evaluated Results
- Due to an weak weighting on the trim requirement, several cases involving large trim deflections were given falsely high L/D values

![Graph of Wing Bending Moment vs. Peak Trimmed L/D](image)
Results – Distribution of Results

• Also found a majority of results focused in the smaller wing span region, this was counter to maximizing L/D
• Also small spans on all control surfaces due to lack of emphasis on trim requirements
Results – Configurations Explored

- Looking at wing span alone
  - Find an increase in span increases wing bending moment
  - Much weaker correlation between span and peak trimmed L/D

- Appears that this case led Optimate to minimize Wing Span before it could find the high L/D cases due to higher AR
Preliminary Runs Conclusion

- It appears that several things prevented Optimate from finding a good final solution
  - The L/D objective function had several holes that Optimate found
    - Stability requirement was too weak of a forcing function
    - Trim requirement calculation could lead to very large and unrealistic L/D cases
  - The wing bending requirement is also looking at peak wing bending, some of which are for unrealistic conditions
  - The competing nature of the two objectives led to Optimate not fully exploring the design space
  - Significant amount of time spent exploring less ideal design space, i.e. highly swept wings.
Fix issues and re-run

- Several of the issues Optimate had could be fixed from our end
  - Fix the L/D objective
    - Trim function can increase L/D no more than 10%.
    - Only angles of attack that trim with less than 20 degress deflection used
    - Increased deflection runs to ensure outside of any dead bands
  - Modified the Wing Bending objective
    - Only considers wing bending at peak L/D angle of attack
    - Scales the wing bending by weight/Lift to ensure fair comparison
  - Modified the base configuration to be more representative of a desirable solution
    - Limited wing sweep to ignore very forward swept wings
- Re-submitted runs and have completed 90 out of 200 evaluations
  - Behavior is greatly improved
Re-Run Results – Configurations Explored
Re-Run Results: Pareto Behavior

Wing Bending Moment vs. Peak Trimmed L/D

Appears to have a more classical Pareto front behavior
Re-Run Results: Span Distributions

- More even distribution in span for lifting surfaces
- Likely due to trim requirement being enforced
Re-Run Results: Twist Behavior

- Wing is showing dominance of a washout behavior on wing
  - Large positive pitch at root
  - Large negative pitch at tips
Conclusions

• Second run has shown promising results of Optimate evaluating a complex objective function
  – Distribution trends are behaving as expected
  – Pareto front appears to be defining
  – Some concerns about driving to higher aspect ratio

• Overall evaluation has revealed several lessons in using Optimate
  – Evaluate the objective functions very carefully
    • Optimization routines are good at exploiting holes in objective functions, usually in the worst possible way
  – Initialize the case study with a base design that makes sense, using the minimum values is not the best case
  – For complicated cases, still need large numbers of evaluations