Body Aerodynamic Optimization in Wing-Body Configuration at Supersonic Speeds

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Overview

- Introduction
- Problem formulation
- Solution technique
- Analysis of the results
- Brief summary
Background

- **Supersonic area rule [1]**
- **Practical supersonic area rule use [2],[3],[4] etc.**


Motivation

Supersonic area rule has some inaccuracies:

- Supersonic area rule is based on linearized slender body theory
- Problems of taking into account the effect of disturbances reflection from wing, especially in case of “integrated” aerodynamic layout
- Lift is not considered
- Longitudinal aerodynamic torque balance is not considered
- Viscous effects are neglected
- Optimal equivalent body of revolution is usually based on linearized slender body theory

Rapid development of the modern numerical methods of RANS equations solving makes optimization in the framework of RANS realizable.
Main goals

- Developing and testing the optimization procedure
- Improvement of the results achieved by supersonic area rule
- Data mining for further optimization problems formulation and solution
General problem formulation

- Configuration with fixed length $l_B$ and volume
  \[ l_B = l_{B0} \]
  \[ V \geq V_0 \]

- Wing is fixed

- Pointed front and fixed radius base

- Flow of a compressible viscous heat-conducting gas
  - International Standard Atmosphere at altitude of 11 km

- Zero Angle of Attack

- Mach number $M=1.8$ ($Re=122 \cdot 10^6$)

- 9 uniformly distributed along the length variable body cross sections:
  - Circular (9 parameters)
  - Elliptical (18 parameters)

- Minimum drag configuration search
Mesh generator: ANSYS ICEM CFD (scripted)
Solver: ANSYS CFX
Optimizer: IOSO (Indirect Optimization based on Self-Organization)[5]

Baseline configuration

Wing:
- Wingspan \( L \)
- Area \( 0.37L^2 \)
- AR 2.67
- TR 0.092
- L.E. sweep 50°
- T.E. sweep -3°
- Relative thickness 5%

Body:
- Length \( L_b = 1.37L \)
- Base radius 0.054L
- Pointed front (small radius of 0.001L for mesh simplification)
- Circular cross section

Configuration
- Volume \( 0.026L^3 \)
- Wing central chord L.E. position \( X = 0.45L \)
Computational domain

- Length 4.8 L
- Radius 6.7 L
- Geometry modifications: cylinders, wing tip

Shockwave at M=1.8 falls here

Cylinders

Wing tip
Optimization mesh

- 1.8 millions nodes total
- Average Y+ ~ 2
- Lateral H-topology; radial O-topology
Boundary conditions and solver

- **Boundary conditions**
  - Front boundary – inlet
    - Reference pressure of 22700 Pa
    - Static temperature of 216.8 K
    - Mach number 1.8
    - Re=122 millions (for the wingspan L)
  - Back – supersonic outlet
  - Cylinders – free slip walls
  - Model – no slip wall
  - Symmetry planes

- **Solver**
  - RANS with SST (ANSYS CFX)
  - 2\textsuperscript{nd} order approximation scheme
  - Approximately 200 iterations (variable timescale)
Approximately 1000 configurations

Optimized in the framework of elliptic cross sections bodies provide significantly smaller drag coefficient
Convergence takes much more time in case of elliptic cross sections formulation (18 parameters) than in case of circular cross sections formulation (9 parameters).

The result in case of elliptic cross sections is significantly better.
Optimization results

Optimal bodies generatrices

Baseline configuration

Optimized configuration (circular cross sections)

Variation limits

Optimized configuration (horizontal semi-axes)

Optimized configuration (vertical semi-axes)
- More detailed mesh (12 mln nodes for half-model)
- No geometry simplifications
- Y+<1.4 at M=1.8
- Verification confirms drag coefficient decrease of about 10%}
- Extended domain for subsonic calculations

Optimization

Verification and M/AoA effect calculation
Drag reduction sources

- Pressure drag is significantly decreased as for wing as for the body (favorable aerodynamic interference)
- Tangential drag is practically the same
Pressure coefficient distributions

M=1.8  AoA=0

Body

Wing

Weaker suction

Suction

Optimized
Baseline

Optimized
Baseline
Mach number effect

- $C_D_0$ reduction remains approximately constant (in percent) for different Mach numbers at least for $M=0.6-2.1$
Angle of attack effect

- $C_D$ reduction remains approximately constant (in absolute value) for different AoA at least for $CL=0-0.5$
- Lift-to-drag ratio of the optimized (elliptic cross sections body) configuration is approx. 6.7% higher than baseline
Body optimization for configuration drag reduction at AoA=0 M=1.8 under volume constraint with fixed wing is carried out.

Significant drag decrease (up to 10%) is obtained in comparison with traditionally designed baseline configuration. Drag decrease is realized at least M=0.6-2.1 and CL =0-0.5.

Better result can be achieved in case of variation semi-axes of the elliptic cross sections than in case of circular cross sections radius variation (by approx. 6% of CD₀; this result cannot be obtained by supersonic area rule).

Optimized body has horizontal extension and vertical constriction in the vicinity of the wing root leading edge with downstream horizontal constriction and height growth rate recovery. The rear part of the optimized fuselage has tiny height descent rate.
Thank you for your attention!

- You can ask your questions or send them to n.d.ageev@gmail.com