Simulation of Propulsion Effects

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Transonic CFD Peer Review

August 16-18, 1989
Outline

- Background
- Objectives
- Approach
- Results
- Summary
Schematic of Engine Model

Inlet

Nozzle

Engine

$\Delta p$, $\Delta T$

Engine Model
Background

- Survey of open literature

- Personal communications:
  - K. Y. Szema (Rockwell International Science Center)
  - K. Uenishi (General Electric)
  - Frank Marconi (Grumman)
  - Pradeep Raj (Lockheed, CA)
Objectives

• Assess propulsion effects in transonic Euler and Navier-Stokes computations of aircraft configurations
  
  o do not wish to model inlet and nozzle internal flows in detail
  
  o formulate appropriate b.c.'s along generally slanted and curved surface patches which are usually introduced to fair over inlets and nozzles
  
  o balance mass flux between inlet and nozzle

• Validate engine model using available transonic wind-tunnel data for a generic accelerator configuration
Approach

- Develop engine model to compute inlet and nozzle flow conditions based on 1-D flow assumptions and a balance of mass flux
  - general engine subroutine should be compatible with variety of codes

- Install model initially into CFL3D to update selected surface boundary conditions
  - define external slanted surface as inlet and nozzle boundaries, (can also be applied inside inlet and nozzle using blocked grid technique)
  - communication between grid blocks
Nozzle B.C.'s For Supersonic Jet

- prescribe \( p_o, T_o, v/u, w/u \), and \( p_{exit} \) for nozzle

\[
p = p_{exit}
\]

\[
\rho = \rho_o \left( \frac{p}{p_o} \right)^{(\frac{1}{\gamma})}
\]

\[
q = \sqrt{\left( \frac{2}{\gamma - 1} \right) (T_o - T)}, \quad \text{where } T = \frac{\gamma p}{\rho}
\]
Nozzle B.C.'s For Subsonic Jet

- prescribe $p_0, T_0, v/u, w/u$ for nozzle

\[
q = \frac{1}{A_e} \int \int \sqrt{u^2 + v^2 + w^2} \, dA \quad \text{(from flowfield)}
\]

\[
p = p_0 \left( \frac{T}{T_0} \right)^{\frac{\gamma}{\gamma - 1}} , \quad \text{where } T = T_0 - \frac{\gamma - 1}{2} q^2
\]

\[
\rho = \frac{\gamma p}{T}
\]
Inlet B.C.'s For Balanced Mass Flux

- Mass flux \( \dot{m} \) provided from nozzle

\[
T_{\infty} = T + \frac{\gamma - 1}{2} q^2
\]

\[
\dot{m} = \rho q A
\]

\[
p = \frac{\rho T}{\gamma}
\]

\[
\left( \frac{T}{T_{\infty}} \right)^{\frac{\gamma}{\gamma - 1}} = \frac{p}{p_{\infty}}
\]

\[
p = p_{\infty} \left\{ 1 - \frac{\gamma - 1}{2} \left( \frac{\dot{m}}{\gamma A} \right)^2 \frac{T_{\infty}}{(p_{\infty}^{\gamma - 1})^2} \right\}^{\frac{\gamma}{\gamma - 1}}
\]

- Extrapolate inflow parameters: \( u, v, w, s = p/\rho^\gamma \)
Characteristic B.C.’s For Inlet

• Treat inlet as a subsonic outflow boundary
• Compute local normal and tangential velocities
• Local 1-D Riemann invariants

\[ R_1 = \frac{2a}{\gamma - 1} - V_n = \frac{2}{\gamma - 1} \sqrt{\frac{\gamma p_{inlet}}{\rho_{inlet}}} - \left( \frac{\dot{m}}{\rho A} \right)_{inlet} \]

\[ R_2 = \frac{2a}{\gamma - 1} + V_n = \frac{2}{\gamma - 1} \sqrt{\frac{\gamma p_{in}}{\rho_{in}}} + (\zeta_x u_{in} + \zeta_y v_{in} + \zeta_z w_{in}) \]

• "Outflow" boundary:
  o Fix \( R_1 \) (engine)
  o Extrapolate \( R_2, V_{t1}, V_{t2}, \) and \( s = p/\rho^\gamma \) (flowfield)
Propulsion Simulation for a Generic Body

$M_\infty = 0.90$, $\text{Alpha}=0^\circ$, $\text{NPR}=3$

(Inviscid Flow)
Flow-Thru Inlet Simulation for a Generic Body

$M_\infty=0.6$, $\text{Alpha}=0^\circ$

(Inviscid Flow)
Propulsion Simulation for a Generic Body

$M_\infty = 0.85$, $\text{Alpha} = 0^\circ$, $\text{NPR} = 4$

(Inviscid Flow)
Summary

- Developed engine module
  - formulates appropriate b.c.'s along generally slanted and curved surface patches
  - balances mass flux between inlet and nozzle
  - installed in CFL3D

- Preliminary calculations look promising

- Proceeding with quantitative validation of code