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Outline

• Basic Muzzle Brake Design Principles
• Impulse Reduction Modeling
• CFD Based Blast Modeling
• Empirical Blast Modeling
• One-Way Structural-Thermal Modeling
• Two-Way Fluid-Structure Modeling
Muzzle Brake Design Principles

- Reduced gun impulse
- Minimize blast effects
- Minimize gun weight
- Minimize flash
CFD Based Blast Modeling

- **Blast - Moving Shock Wave**
  - Propagates at Faster than Speed of Sound
  - Very Fine Structures (0.5 mm thick)
  - Very High Pressures (7,000 – 15,000 psi at muzzle)

- **CFD Requirements**
  - Shock Wave is a Discontinuity in Flow Field
  - Requires
    - Very Fine Grid
    - High-Order Spatial Resolution
    - Very Large 3-D Flow Domains
  - Fixed Grids are Not Feasible for 3-D Gun Simulation
  - Higher Order Solvers Typically Not Stable at Gun Pressures
  - Dynamic Grid Adaption is Only Realistic Option
  - Highly Specialized Codes is a Second Option

- **Dynamic Grid Adaption**
  - Refine and Coarsen Mesh as Blast Wave Propagates Through Flow Domain
  - Based on Flow Field Gradients and Properties
  - Solution Based Automatic Adaption
CFD Blast Analysis – Fluent
7.62 NATO G3 with DM41 Round

Pressure outlet

1st Pre-Cursor

2nd Pre-Cursor

Main blast wave

Pressure-inlet

FLUENT: \( t = -350 \ \mu\text{sec} \)

Experiment

Ref: Gun Muzzle Blast and Flash, Progress in Astronautics and Aeronautics, Vol. 139; Klingenberg, Gunter, Heimerl, Joseph M., Seebass, A. Richard Editor-in-Chief, AIAA

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Solution-based Blast Wave Identification Parameter (BWIP)

- ANSYS-Fluent CFD Solver
- Add-on to Improve Adaption
- Find Shock Location
  - Mach Number Near 1
  - Large Pressure Gradient
- Control Adaption
  - Better Coarsening
  - Better Refinement
- Reduce Total Cell Count
- Reduce Solution Time
- Improve Quality With Finer Resolution

XM-360 Gun on FCS MCS Chassis
BWIP Validation
Overpressure for XM-360 on FCS MCS Chassis
BWIP Validation
Peak Overpressure Contour Plot – XM360
BWIP Validation
Dynamic Grid Adaption – XM360
2-D simulation of Fixed Mesh, BWIP and Advanced BWIP.
Advanced BWIP is one order of magnitude faster than a fixed mesh.
Extrapolating to 3-D, we can see BWIP would be two or more orders of magnitude computationally faster than fixed mesh.
Empirical Blast Wave Modeling  
3-D Fansler Blast Code

- Simplified Empirically Based Scaling Based On Fansler Blast Code
- Mat-Lab Based GUI Front End
- Input Parameters
  - Gun Geometry, Elevation and Azimuth
  - Vehicle and Ground Reflection Planes
  - Interior Ballistics
  - Muzzle Brake Efficiency

M256 Gun With M1 Abrams Turret Plane 
Gun at 20 Degrees Elevation

Turret Peak Incident Pressure (psi)
XM-324 NLOS-C Muzzle Brake
Thermal-Structural Analysis

• 3.5 Caliber Optimized Muzzle Brake
  • Maximum Efficiency
  • Short Length
  • Minimum Weight
XM-324 NLOS-C Muzzle Brake
Thermal-Structural Analysis

- High rate of fire cannon
  - 6 rounds/minute
  - Standard magazine
  - Standard reload
- Determine Temperature Field Prior to Last Shot
- Reduced Structural Properties
- Unsteady Structural Model For Last Shot
- Determine Peak Stresses and Structural Integrity
- Reduce Muzzle Brake Material In Low Stress Regions
Step 1: Fluent CFD Steady-State Convective Heat Transfer Analysis

- Steady-State Fluent Analysis
  - Vary Muzzle Pressure
  - Vary Wall Temperature
- Output
  - Surface Average Heat Transfer
  - 33 Separate Model Surfaces
- Utilizes Designed Experiments to Make Polynomial Models

Contour Plot of Surface Total Temperature
Step 2: Develop Polynomial Models from Fluent Heat Transfer Data

- Develop a single cubic polynomial model of surface heat transfer for each of the 33 sub-surfaces.
  - Based on Muzzle Static Pressure
  - Based on Surface Wall Temperature
- Example polynomial model shown below for one surface.
Goal – Determine Peak Temperature after Round 95

**Boundary Conditions**

- **Firing Conditions**
  - Forced convection heat transfer
  - Driven by polynomial pressure curve
  - Heat transfer boundary condition from Fluent polynomial model

- **Between Shot Conditions**
  - Natural Convection Heat Transfer
  - Temperature dependent natural convection (no wind)
  - Solar radiation heat flux
  - Radiation to ambient
  - Ambient air temperature ≈ 54°C
Step 3: ABAQUS Unsteady Thermal
Surface Temperature vs Time
Step 4: Fluent Unsteady Loading Model

- Temperature and pressure patched into gun barrel based on projectile ready to enter muzzle brake.
- Flow allowed to expand using unsteady, coupled-explicit inviscid solver.
- Surface average pressure vs. time recorded during run for multiple surfaces.
- Used as input for unsteady ABAQUS structural model.
Step 5: ABAQUS Unsteady Structural Input Temperature Conditions
Step 5: ABAQUS Structural FEA

Peak Stress Results

Results: Von Mises Stress

Results: Factor of Safety
Fully Coupled Fluid-Structural Analysis
Generic Barrel and Muzzle Brake

- Fluid Domain Simulated with ANSYS CFX
- Solid Domain Simulated with ANSYS Mechanical
- Full Two-way Coupling with ANSYS Multi-Physics
ANSYS Mechanical Multi-field Solver to CFX Coupling

- CFX
  - External Solver Coupling
    - Hydrodynamics
    - Turbulence
    - Heat Transfer

- ANSYS
  - Multi-field Solver
    - MFX
    - MFS
      - Structural Element
      - Thermal Element
Mesh and Setup

• Solid mesh developed in ANSYS Workbench.
• Fluid mesh developed in ICEM CFD.
• Coupling and interfaces of two meshes done in ANSYS Workbench.
• Pulse source term used in CFX to simulate gun firing.
• Structural deformation passed between to solvers.
• Multi-round mission simulated.
Workflow Snapshots
Mechanical Simulation Setup

Flexible Dynamic
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- Boundary Conditions Shown
- Analysis Type: Flexible Dynamics
- Coupled Field Element
  - Solve for thermal and structural stresses
Conclusions

• Advanced Design Tools:
  • Impulse modeling:
    ■ Full 3-D CFD analysis capable of predicting impulse with high degree of accuracy.
  • Blast modeling:
    ■ Low fidelity, quick estimates of 3-D blast fields with empirical models.
    ■ High fidelity models of complex 3-D blast fields with BWIP Based CFD models.
  • FSI:
    ■ Complex thermal-structure forced and natural convection modeling.
    ■ Full two-coupled structural response modeling of gun and muzzle brake structures.

• Results:
  • Higher efficiency, lower blast, lighter weight muzzle brakes.