Symposium on Ballistics

ber 22-26, 2008

Numerical Simulation of Muzzle Exit and Separation Process for Sabot-Guided Projectiles in Supersonic Flight

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- **Introduction / Motivation**
- **Physical Aspects of the Firing Process**
- **Strategies for the Numerical Simulation / Proposed Procedure for the Study**
- **Results for Sabot Separation Simulations**
- **Conclusions / Future Work**

vation

f Sabot Separation Processes

Sabot Separation: Coupled Problem of Aerodynamics and Structure Dynamics

Sabot Function:

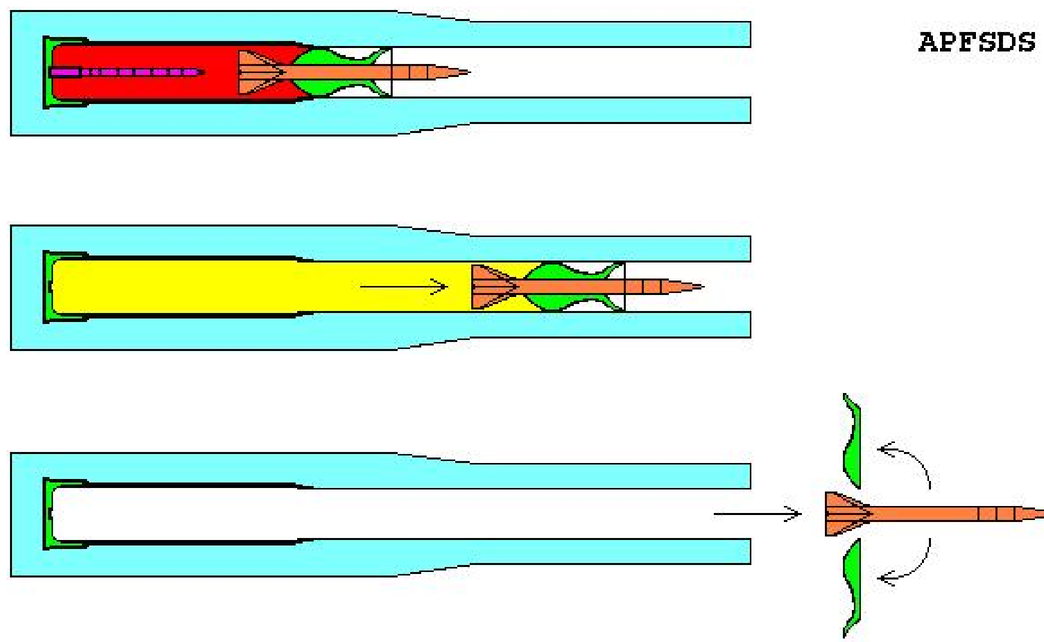
- Guidance of Sub-Caliber Munition

Design Tasks:

- Stability Against Mechanical Loading
- Undisturbed Separation Process
- **Minimum Weight**

Challenges for the Numerical Simulation:

- Highly Unsteady Problem
- Relatively Moving Bodies
- Material Failure Modelling



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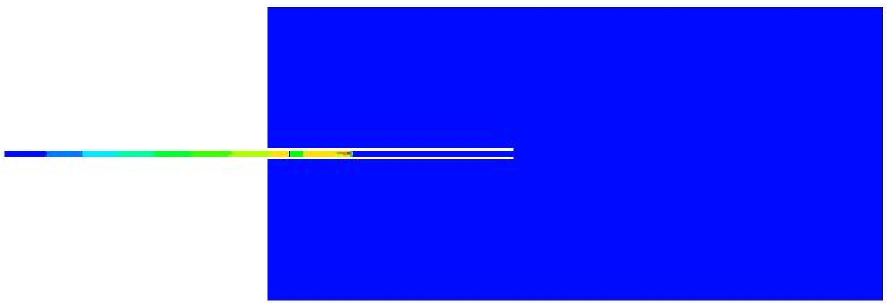
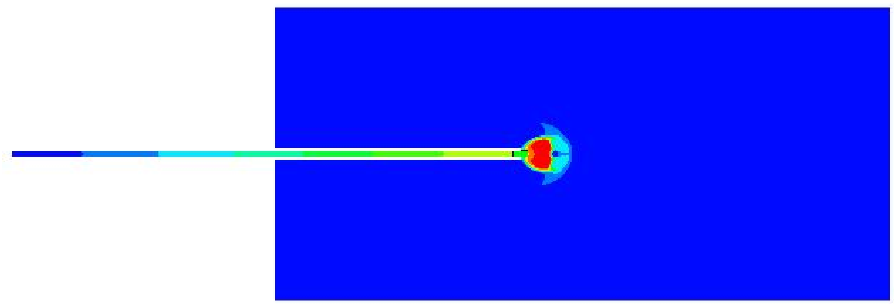
of the Firing Process

ndrical ĂProjectileñ(Autodyn)





Phase 1: Interior Ballistics

- $t_0 < t < t_1$
- Compressed Air Ahead of Projectile
- Interaction: Projectile-Gas-Barrel
- **Not Subject of the Presentation**

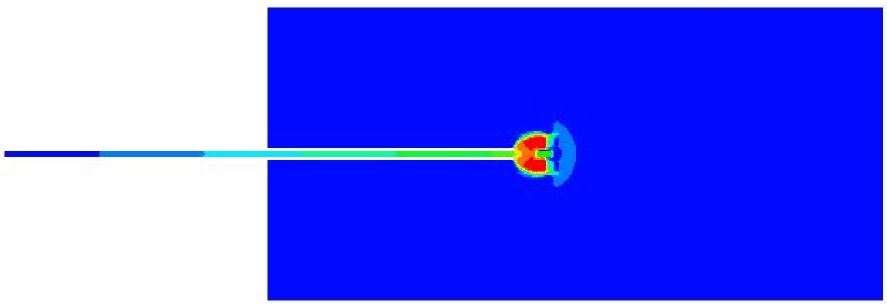
Phase 2: Muzzle Exit Ballistics

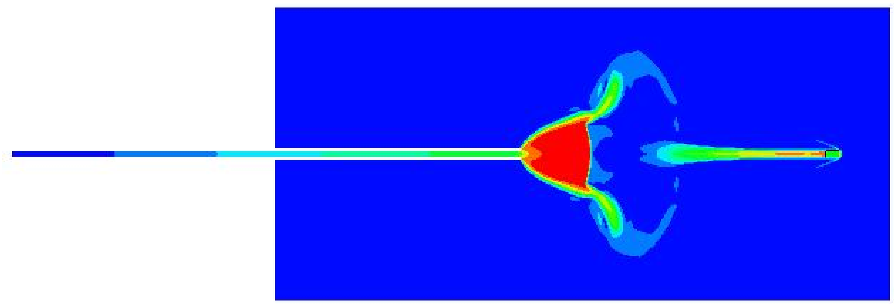
- $t_1 < t < t_2$
- Front of Projectile Outside the Muzzle
- Risk of Canting / Fracture

movie1.avi

…of the Firing Process

…ndrical ĂProjectileñ(Autodyn)





Phase 3: Muzzle Exit Ballistics

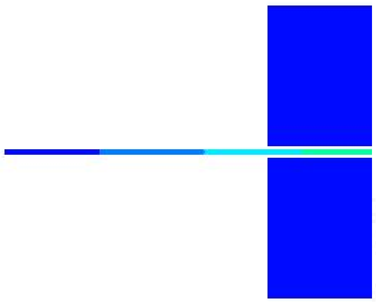
- $t_2 < t < t_3$
- Projectile Completely Outside the Muzzle
- Significant Incident Flow from Behind

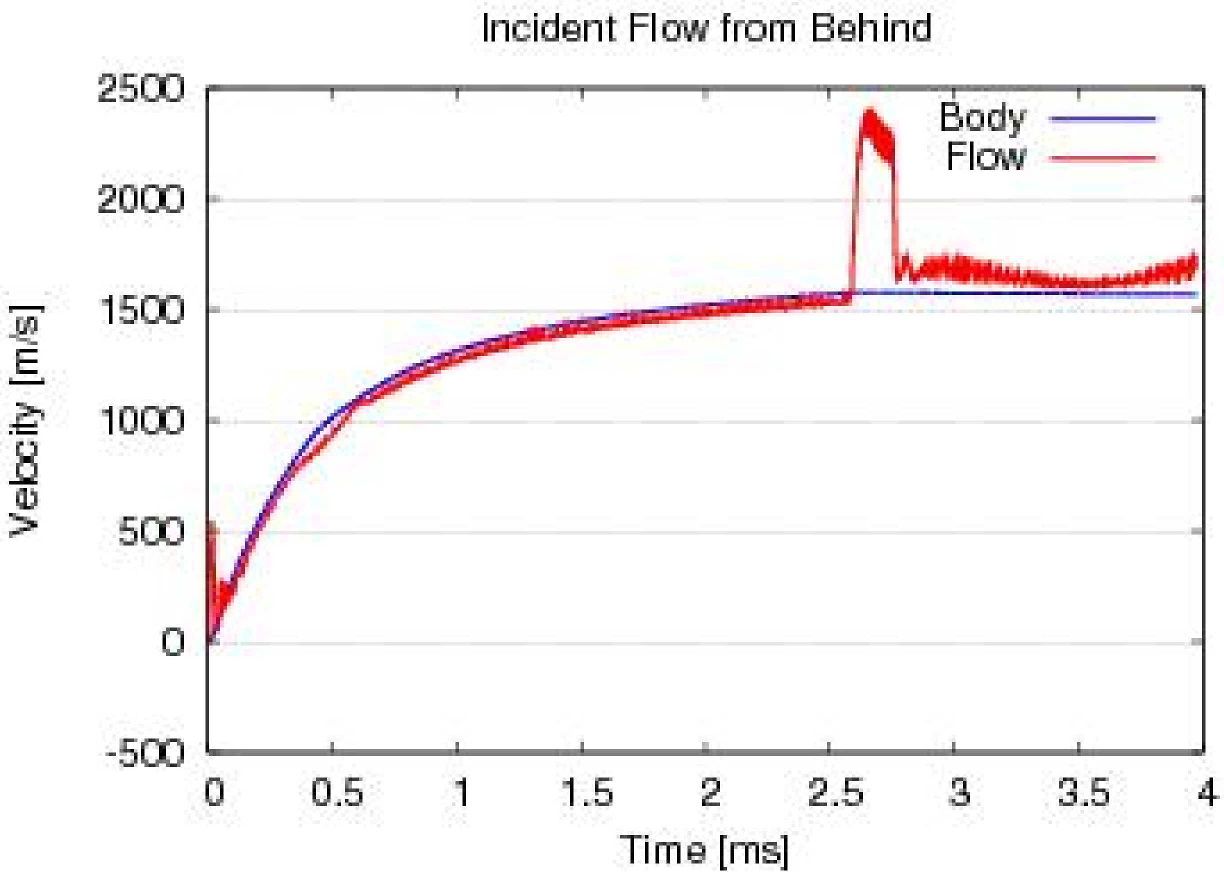
Phase 4: Exterior Ballistics

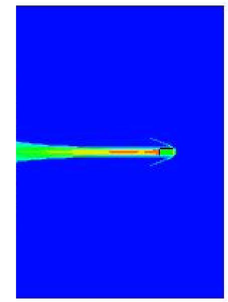
- $t_3 < t < t_4$
- No Interaction with Propellant Gas / Barrel
- Flight Through Undisturbed Atmosphere

of the Firing Process

ndrical ĂProjectileñ(Autodyn)



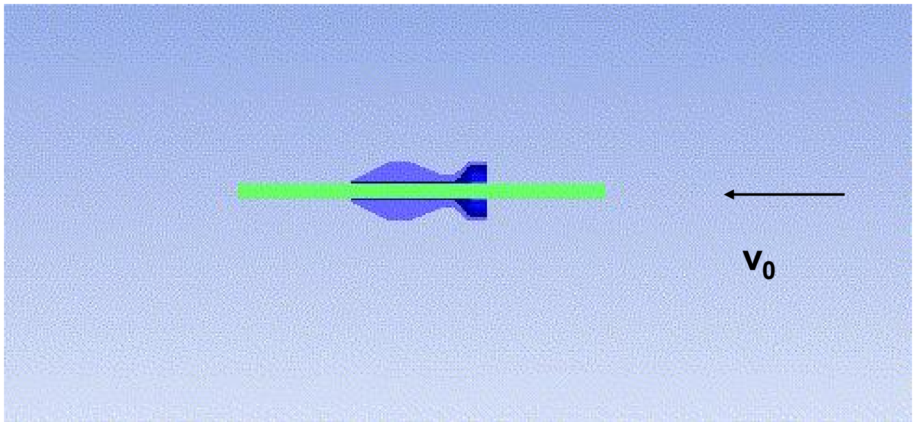


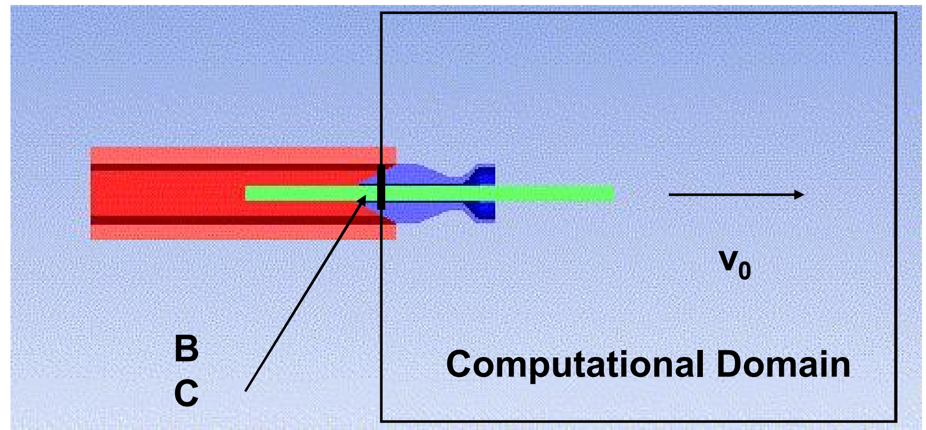


Phase 3: Muzz ... ics

- $t_2 < t < t_3$
- Projectile Comp ... ellant
- Significant Incic ... ed Atmosphere

Numerical Simulation





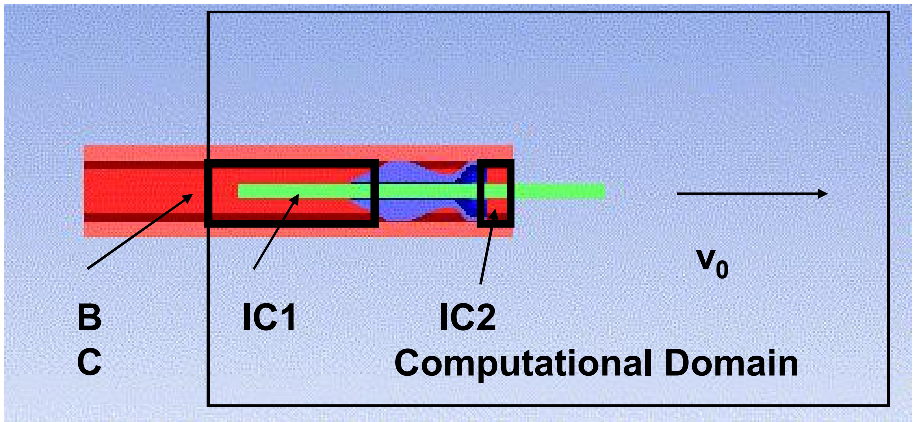
Concept A

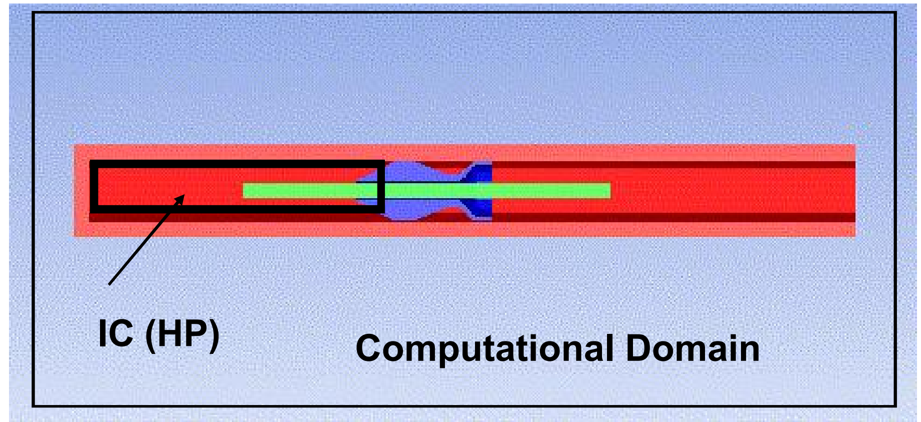
- Moving Observer
- Instantaneous Inflow

Concept B

- Earth-Fixed Observer
- Boundary Condition at Muzzle Exit

Numerical Simulation





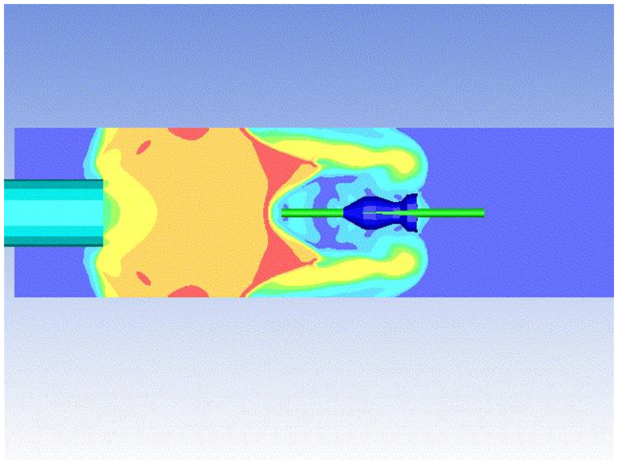
Concept C

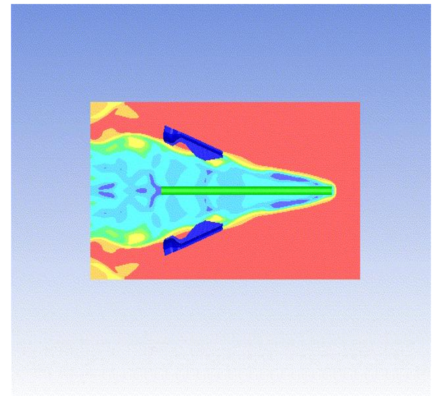
- Earth-Fixed Observer
- Initial and Boundary Conditions Inside the Barrel

Concept D

- Earth-Fixed Observer
- Initial Condition Inside the Barrel (**H**igh **P**ressure)
- **Estimation of Required Gridpoints ~ 90.000.000 → Very Expensive**

...ure for the Study
(...pts A und C)





Phase 1:

Earth-Fixed Observer (Concept C) →

Phase 2:

Moving Observer (Concept A)

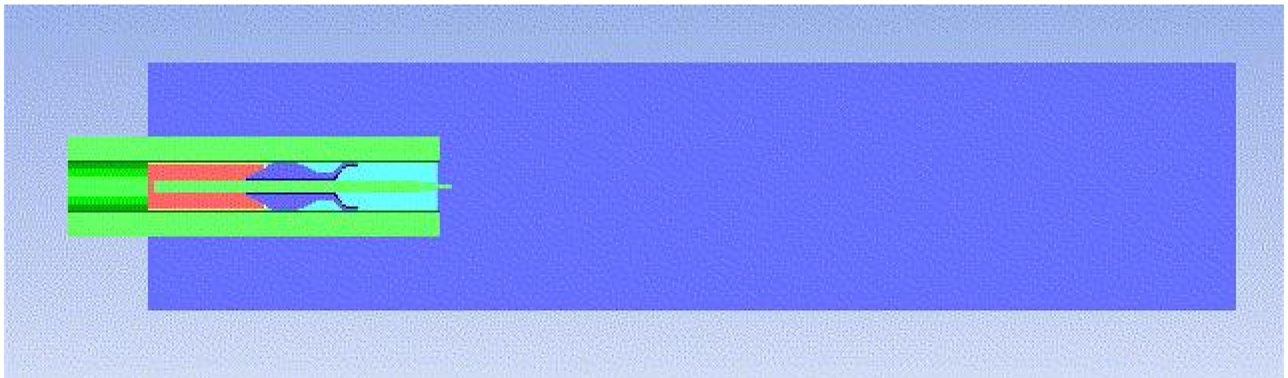
Switch of Coordinate System!

Point of Time: t = t_3

Separation Simulations

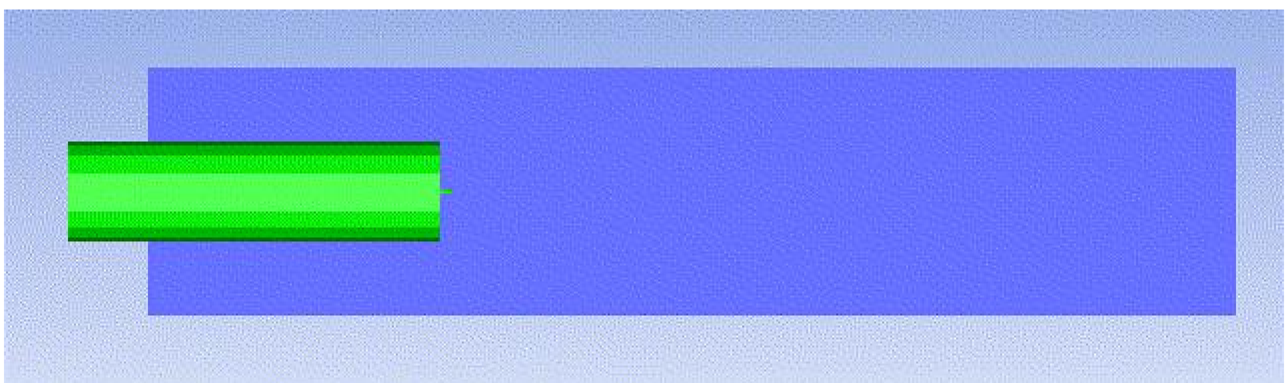
ordinate Switch (Sim. EMI, **Concept C+A**)

Discretization: Air (1.000.000 Points), Sabot (3.900 Points)



Pressure

t = 0.00 ms



Abs. Velocity

Separation Simulations

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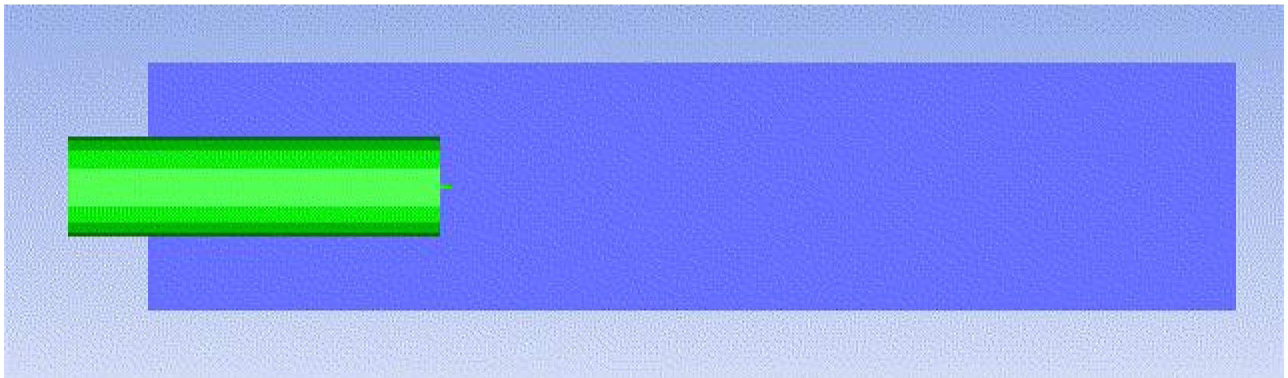
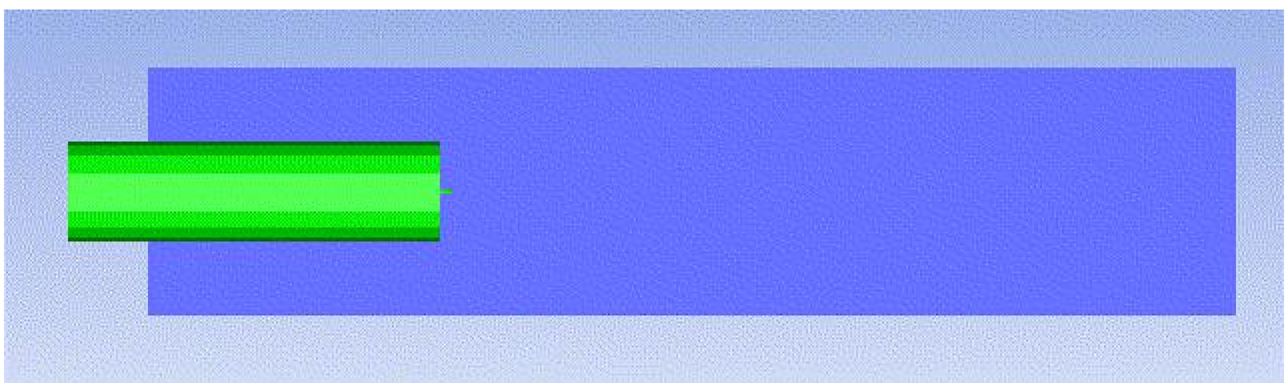
Discretization: Air (1.000.000 Points), Sabot (3.900 Points)



Pressure

t = 0.00 ms



Abs. Velocity

Separation Simulations

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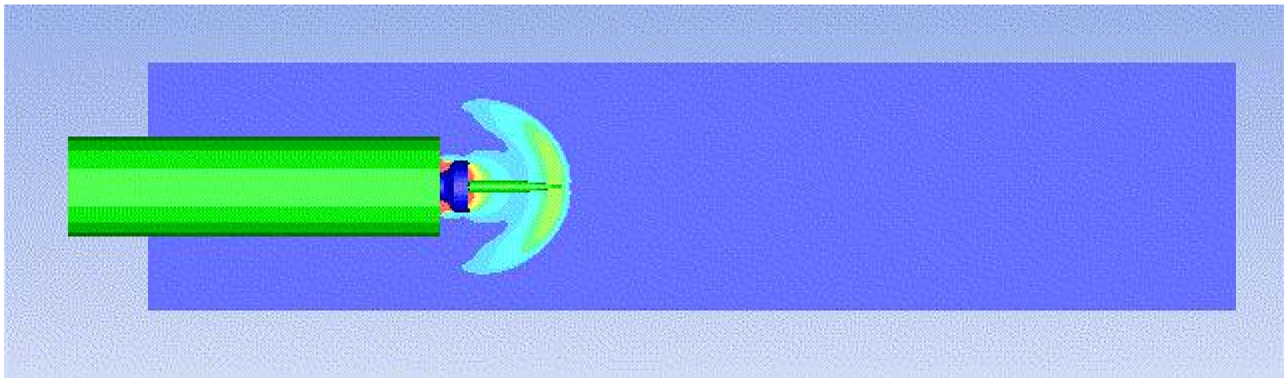
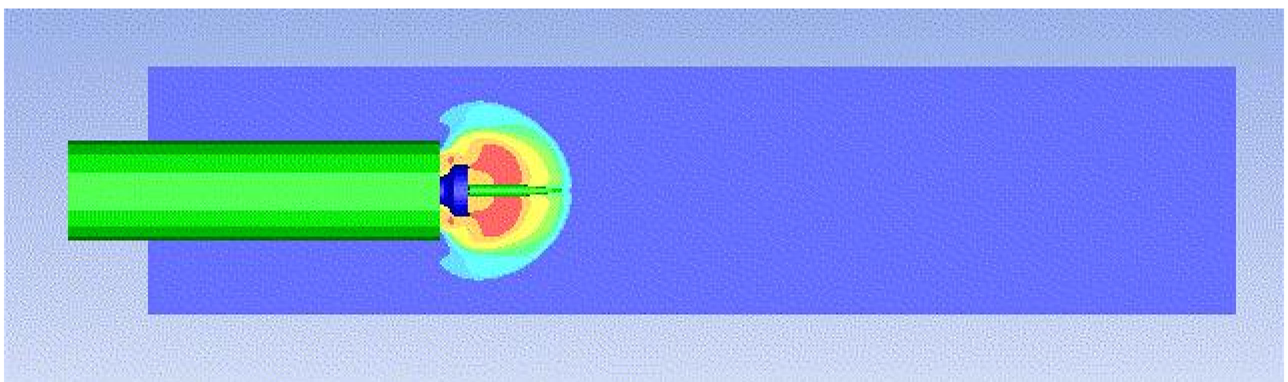


Pressure

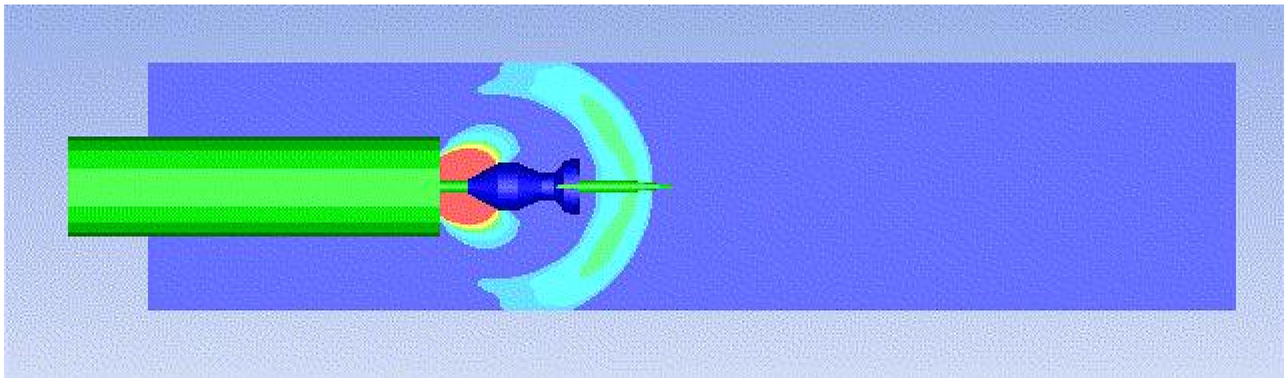
t = 0.06 ms



Abs. Velocity

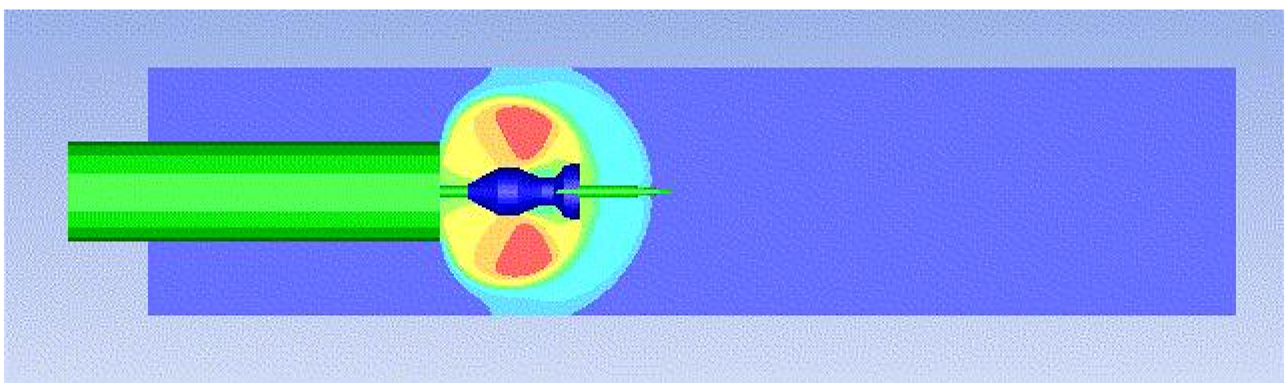
Separation Simulations

...rdinate Switch (Sim. EMI, **Concept C+A**)



Pressure

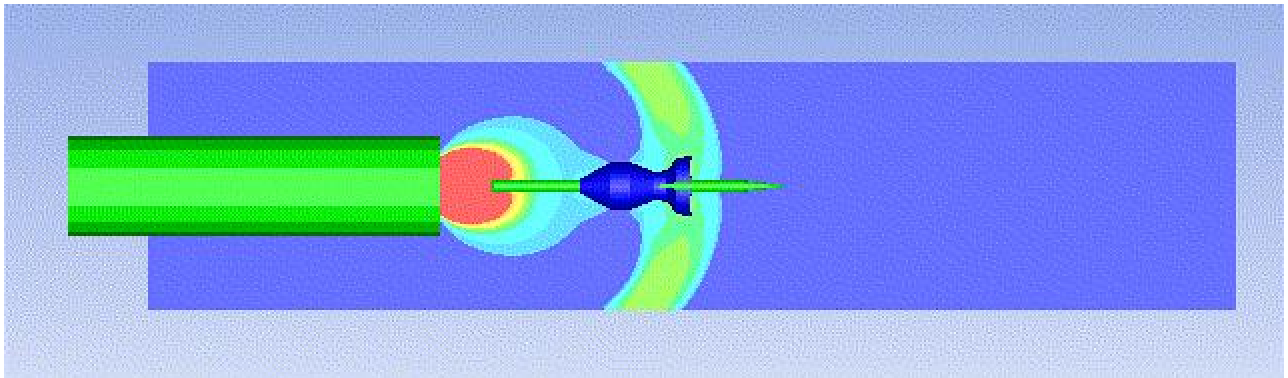
t = 0.12 ms



Abs. Velocity

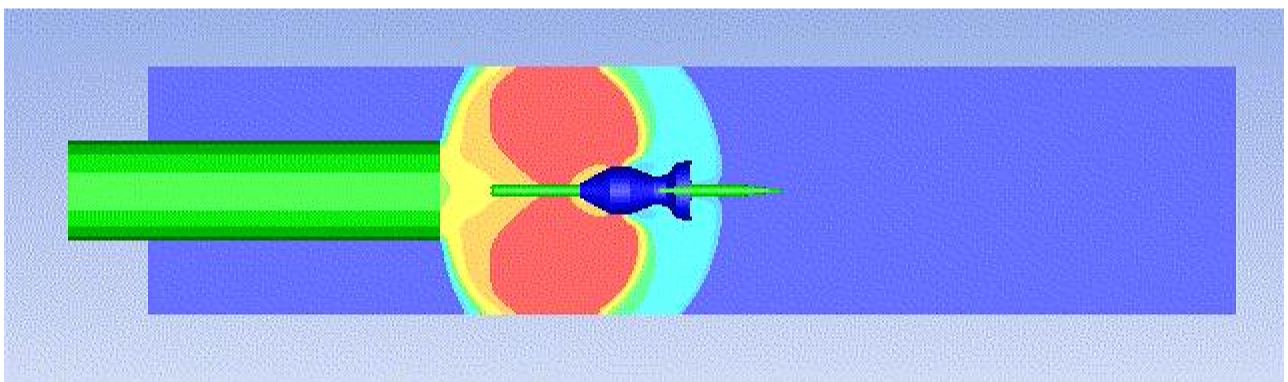
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

t = 0.18 ms



Abs. Velocity

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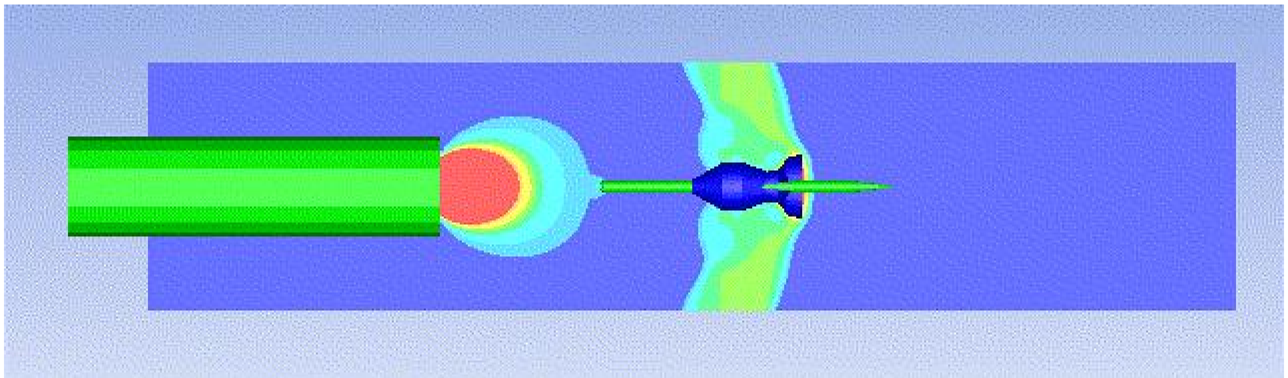
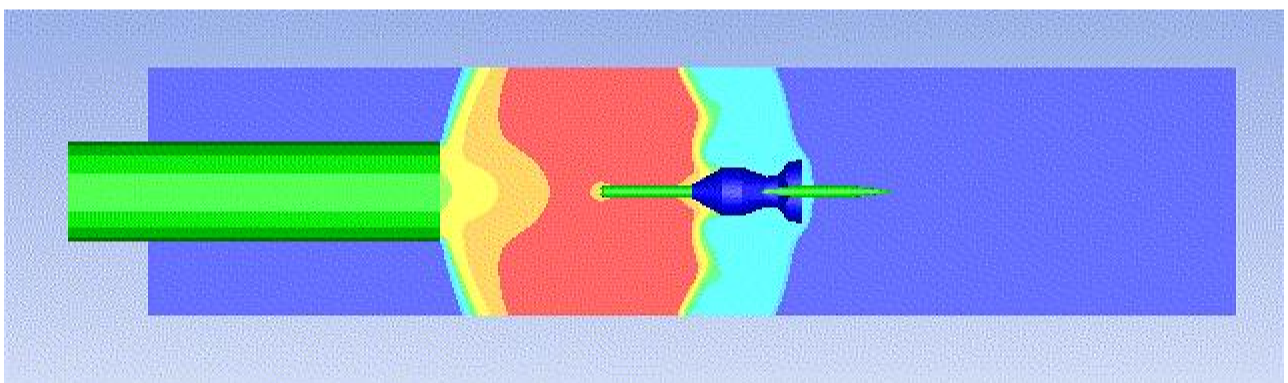
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

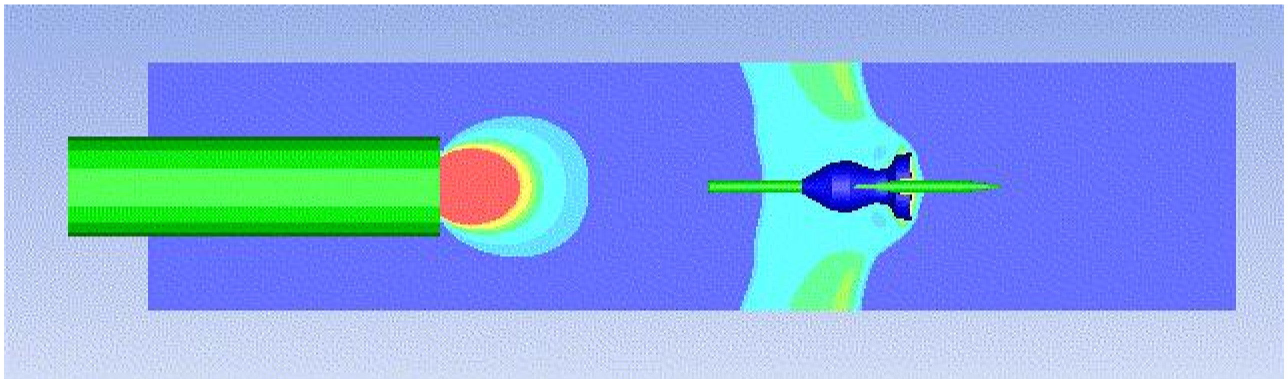
t = 0.23 ms



Abs. Velocity

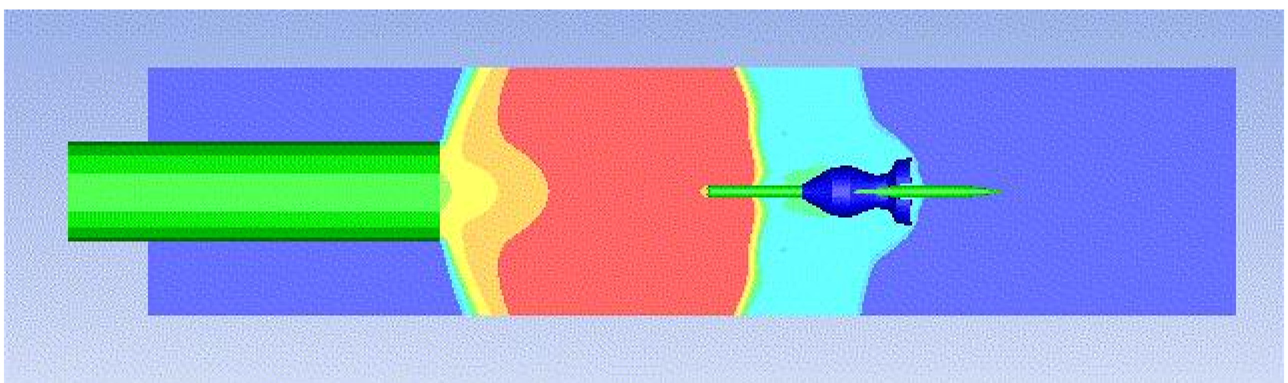
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

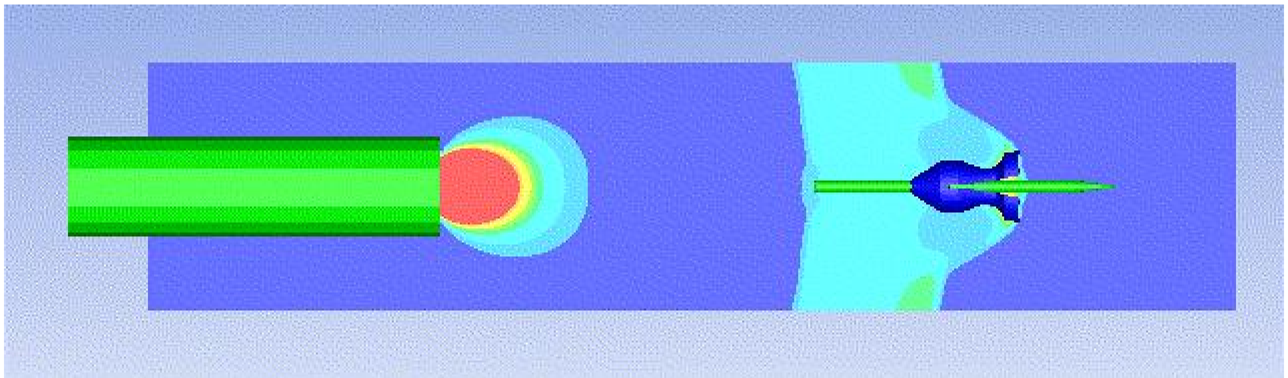
t = 0.29 ms



Abs. Velocity

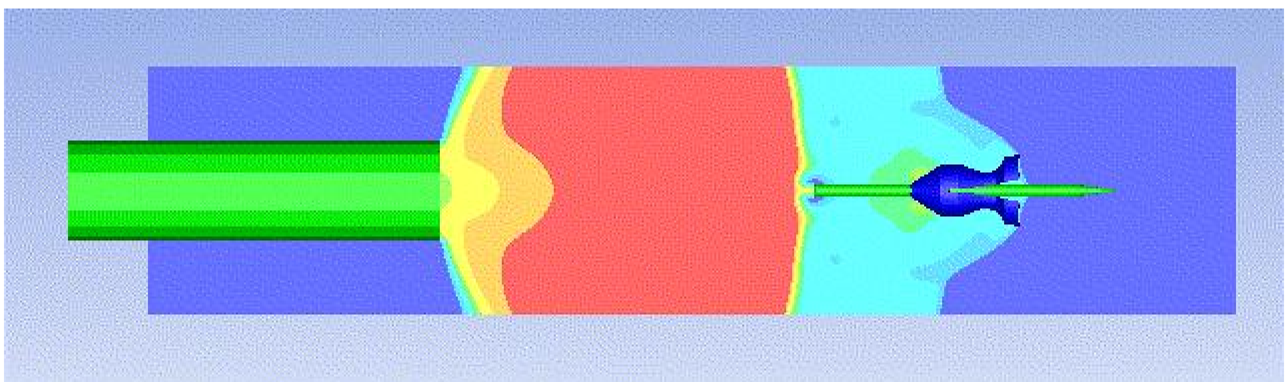
Separation Simulations

...rdinate Switch (Sim. EMI, **Concept C+A**)



Pressure

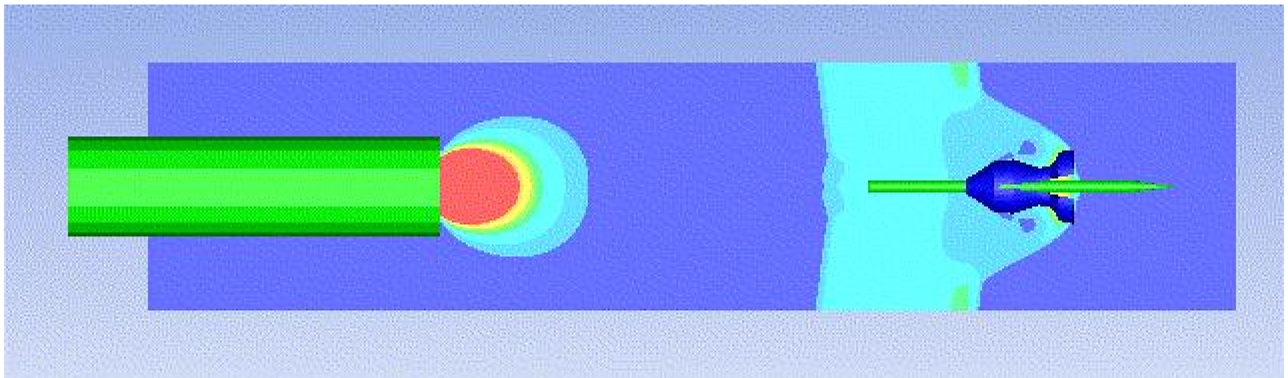
t = 0.35 ms



Abs. Velocity

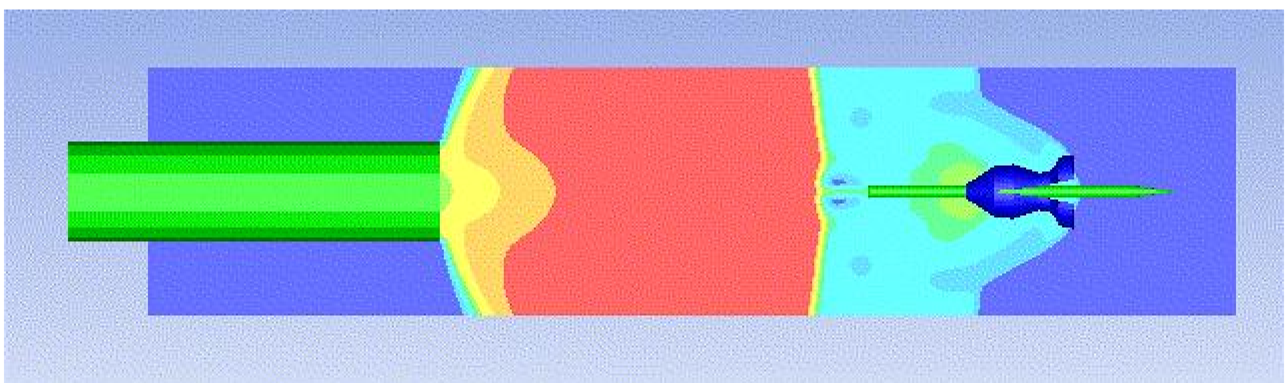
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

t = 0.38 ms

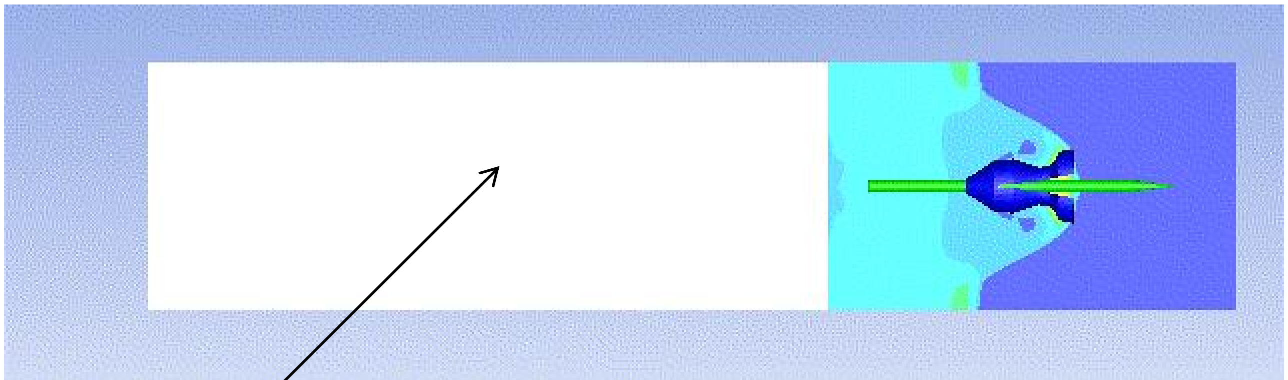


Abs. Velocity

Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)

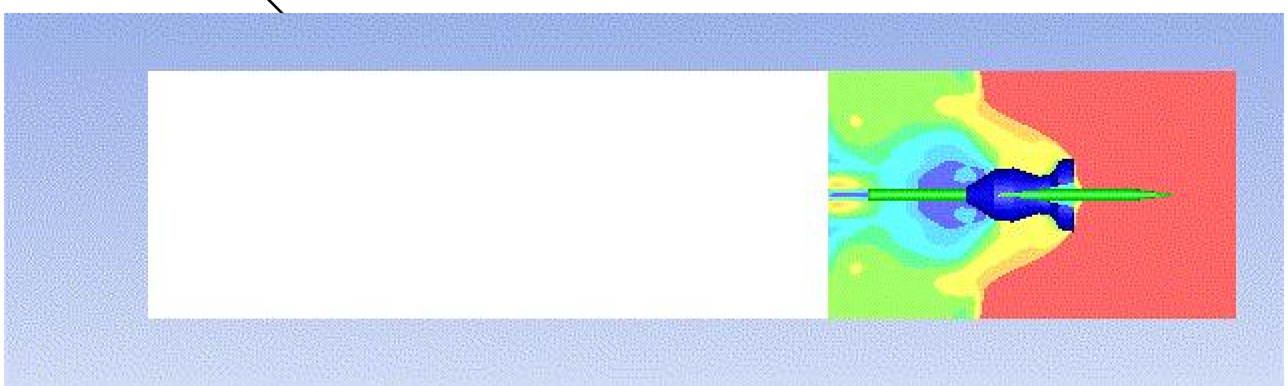
SWITCH



Pressure

UNUSED

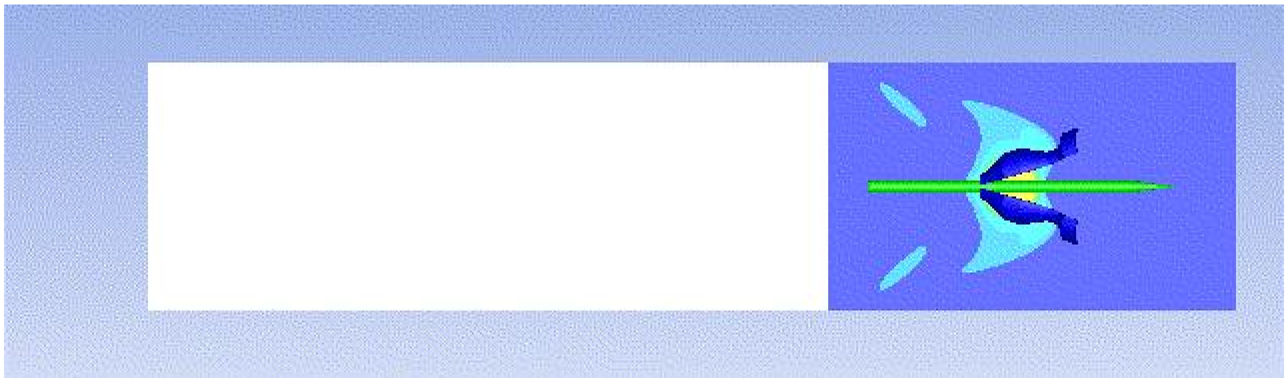
t = 0.38 ms



Abs. Velocity

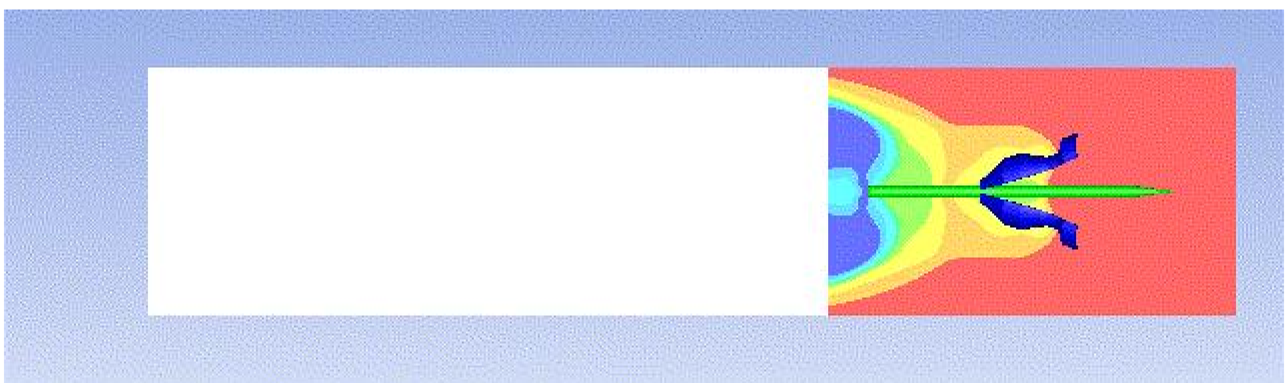
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

t = 0.71 ms



Abs. Velocity

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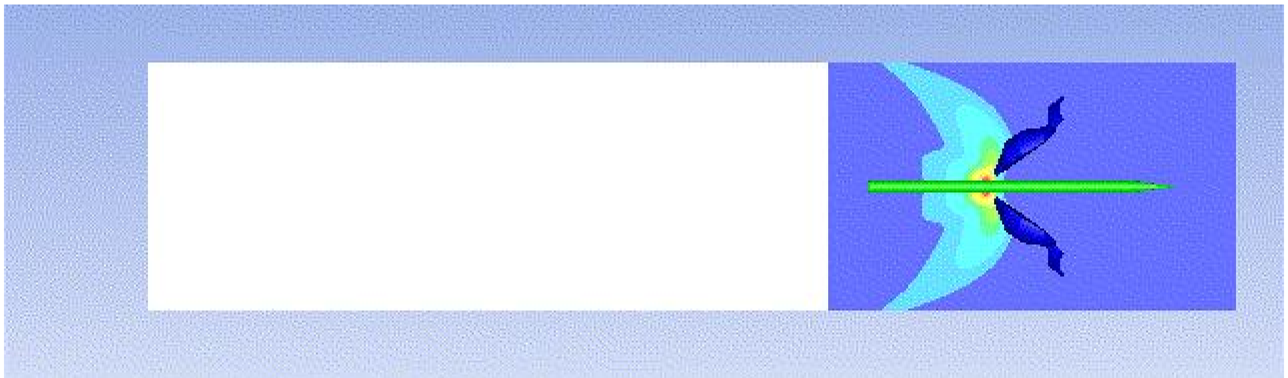
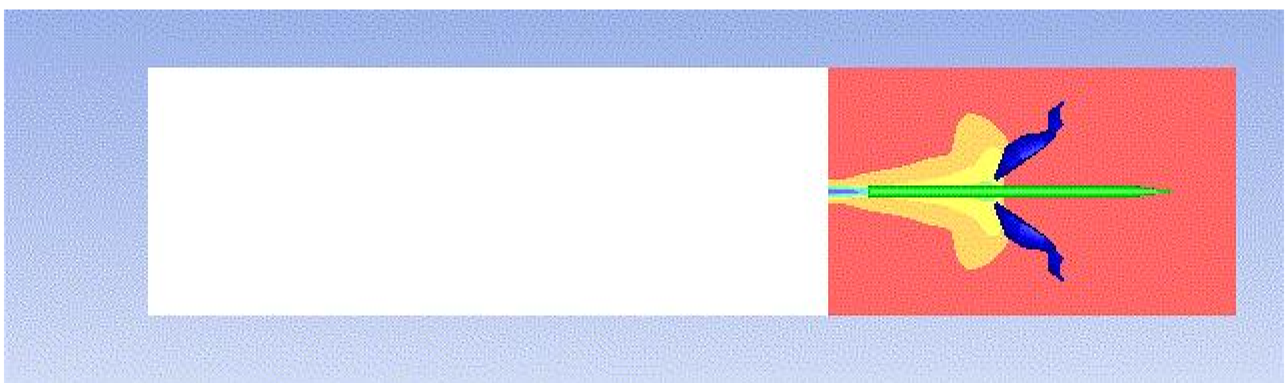
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

t = 1.05 ms



Abs. Velocity

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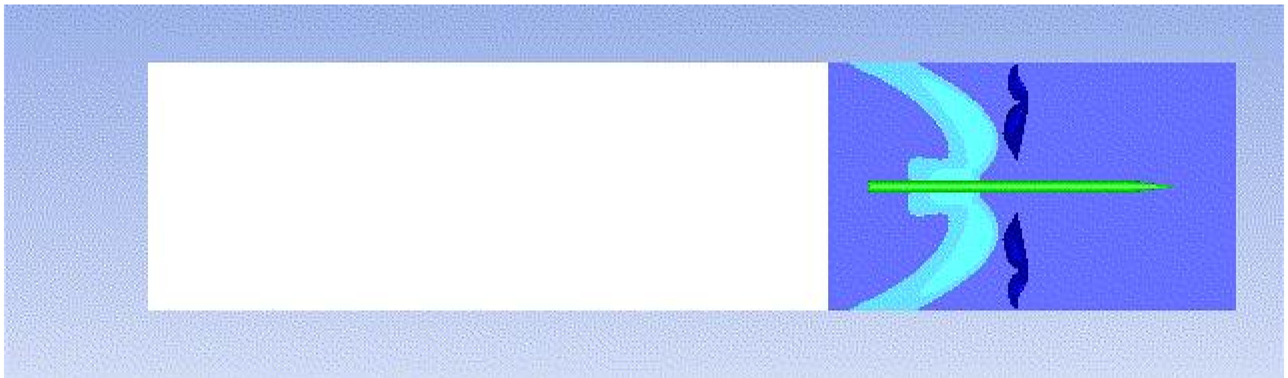
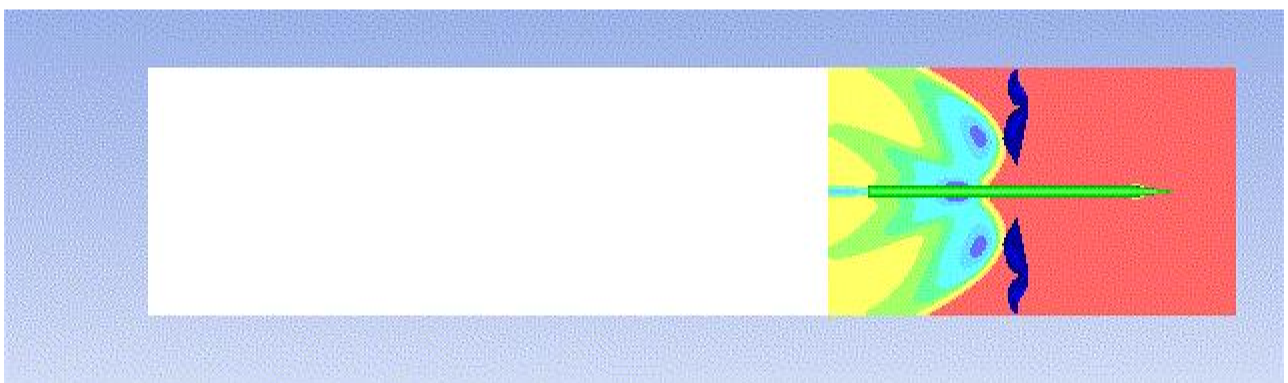
Separation Simulations

ordinate Switch (Sim. EMI, **Concept C+A**)



Pressure

t = 1.39 ms



Abs. Velocity

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C… xperimental Results (ISL)

E…

Penetrator: 10 mm Caliber, 240 mm Length

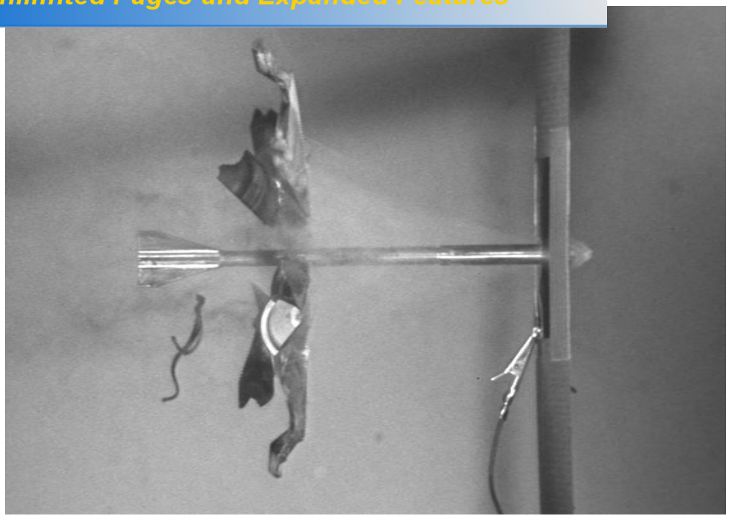
Sabot: 40 mm Caliber, Magnesium (Magnesium Alloys)

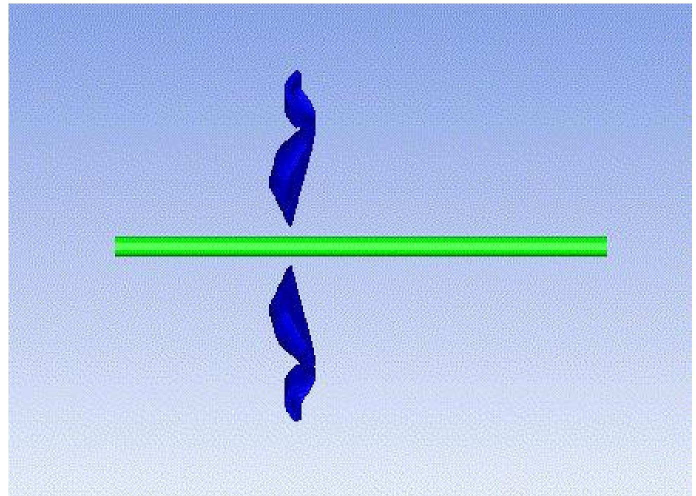
4 Parts → Two-Plane Symmetry

Parameter	Condition A [Schirm, ISL, 2005]	Condition B [Schirm, ISL, 2008]
Material Density Sabot	1.78 g/cm^3 (Mg)	1.52 g/cm^3 (Mg Al3 Li9)
Propellant Mass	0.38 kg	0.40 kg
Maximum Gas Pressure	341.2 MPa	380.3 MPa
Muzzle Velocity	1510 m/s	1633 m/s
Acceleration	794008 m/s^2	897000 m/s^2

R[illegible]eparation Simulations

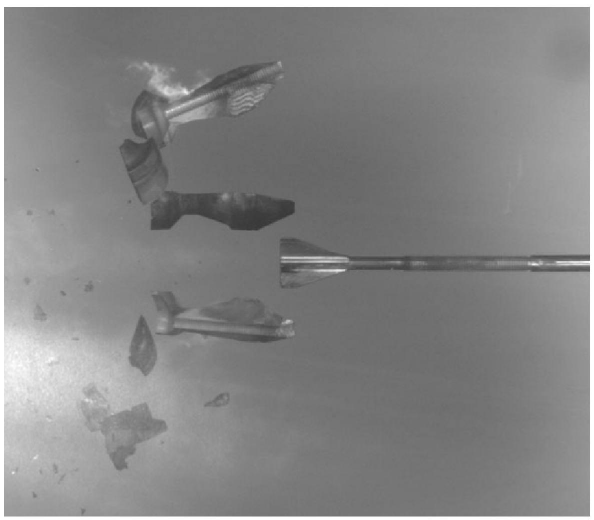
K[illegible]n: Exp. (ISL) / Sim. (EMI, Condition B)

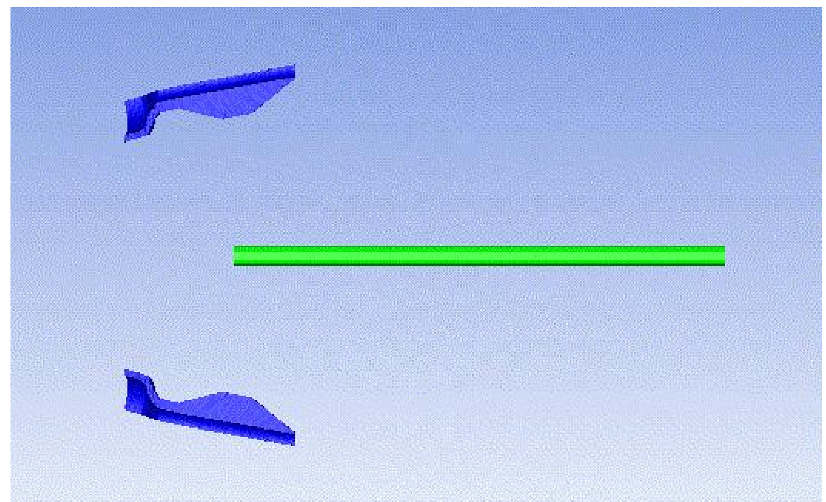




2.0m Behind Muzzle Exit

3.25m Behind Muzzle Exit

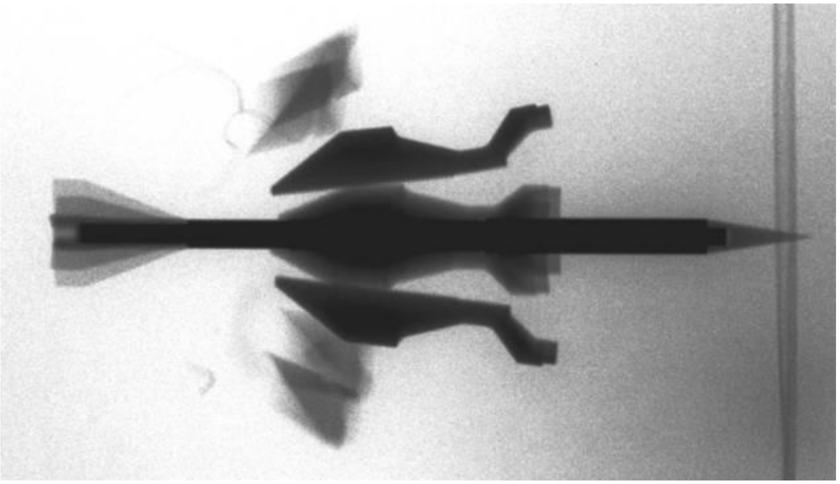


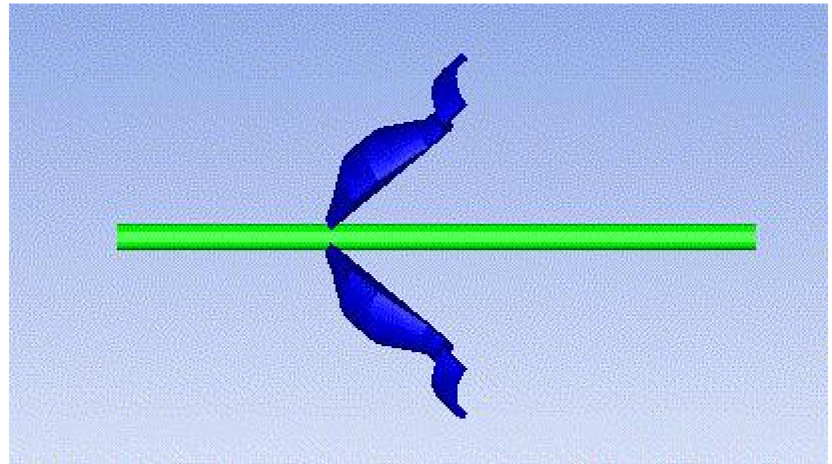


Experiment (ISL)

R eparation Simulations

Ki n: Exp. (ISL) / Sim. (EMI, Condition A)

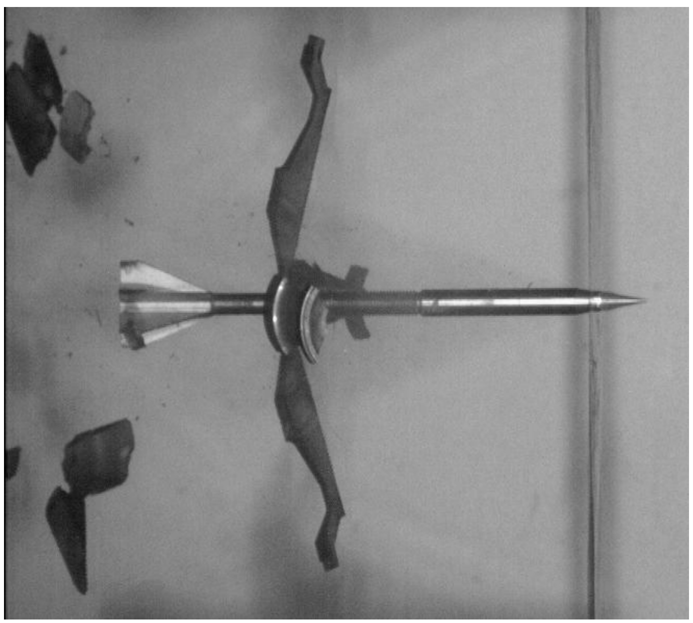


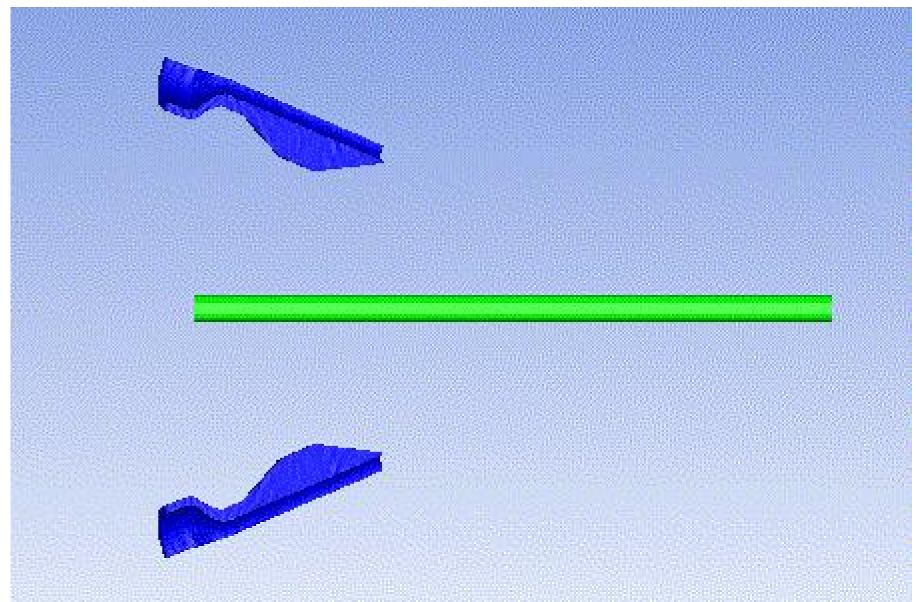


1.8m Behind
Muzzle Exit

3.0m Behind
Muzzle Exit

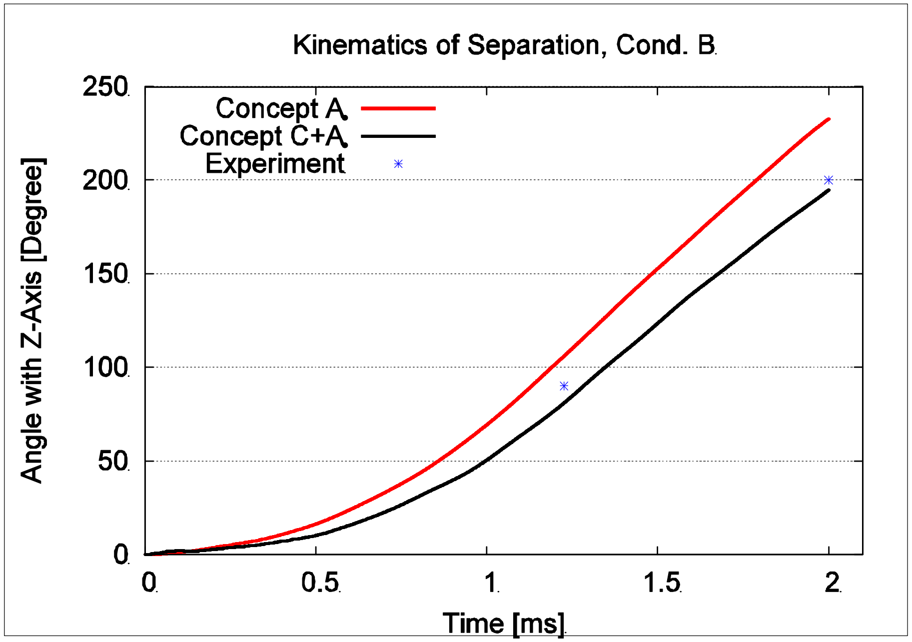
Experiment (ISL)

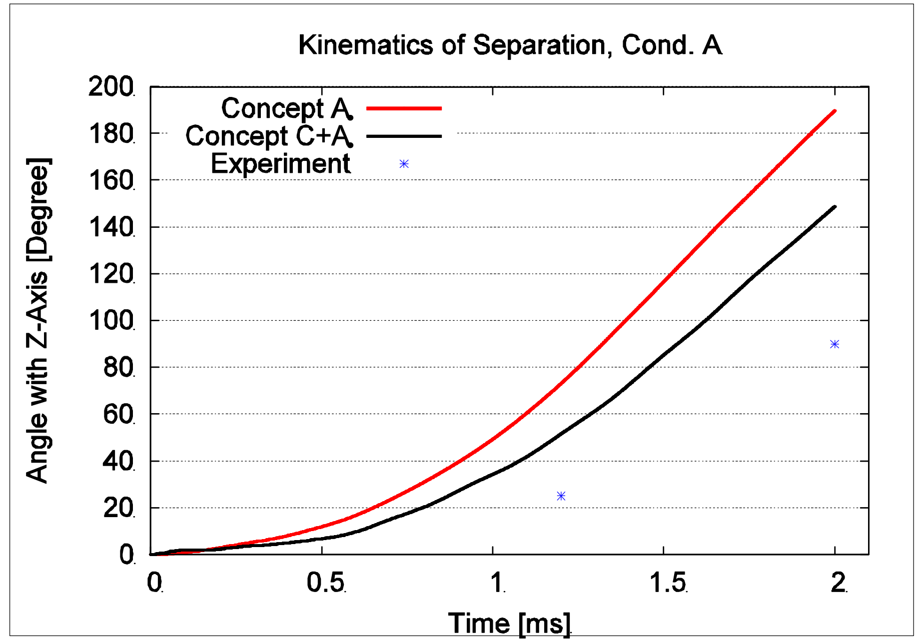




Separation Simulations

tics of Separation (Different Strategies)





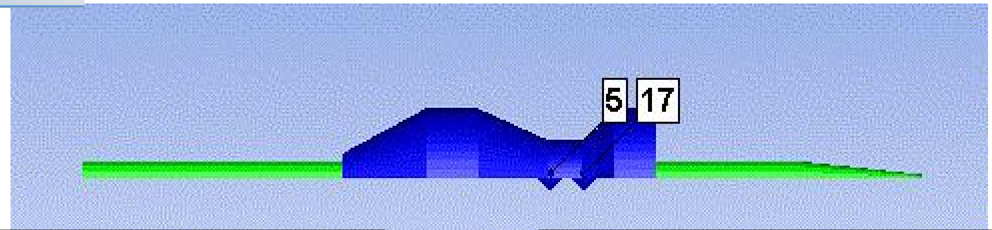
Effects of Muzzle Exit have to be Considered (Both Conditions)

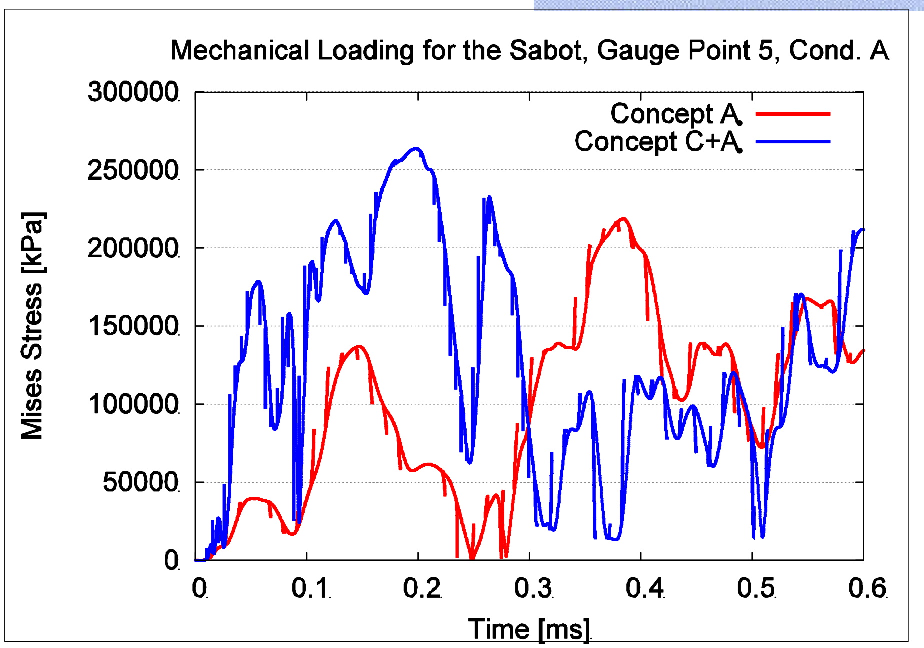
Problem of Numerical Capturing (Tracking) of the Penetrator Nose (Geom. Singularity)

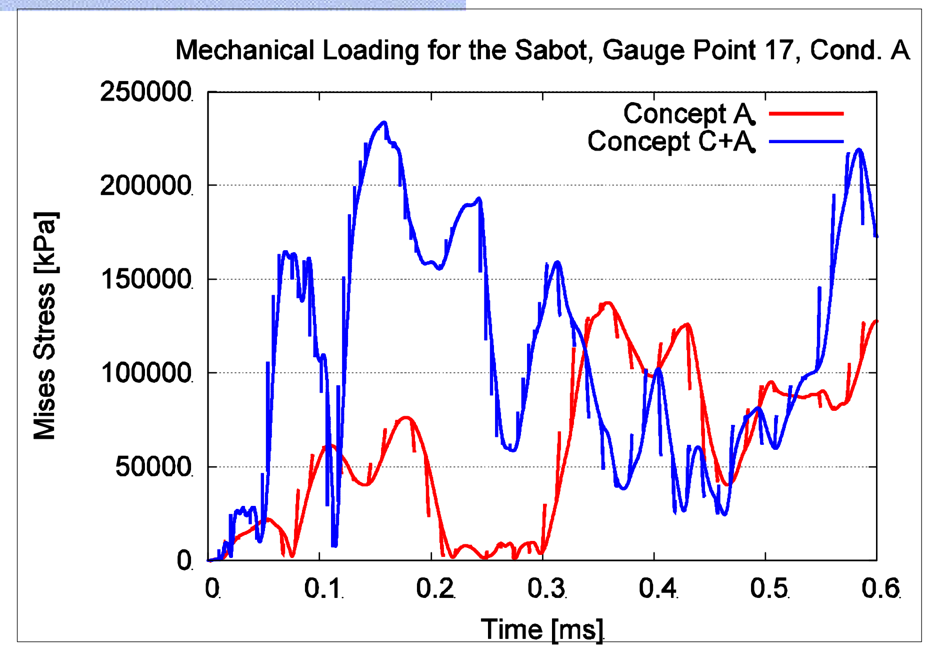
Additional Uncertainties in the Experiments

Separation Simulations

r the Structure (Different Strategies)







Effects of Muzzle Exit Result in Significantly Higher Structure Loads

movie2.avi

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ure Work

- Numerical Simulations for Sabot Separation Processes with Different Approaches
- Ability for Simulation of Muzzle Exit- and Exterior Ballistics by Coordinate Switching
- Future Work:
  - Numerical Investigation of Effects of Experimental Uncertainties (Mass, Geometry, Muzzle Exit Velocity / Angle of Attack)
  - Influence of the Penetrator Nose / Fins
  - Sabot Design Optimization
  - „Loading History“ for Separated Structural Calculations

Funded by: Bundeswehr Research Institute for Materials, Explosives, Fuels and Lubricants

(WIWEB, Erding, Germany)