22nd International Symposium on Ballistics

Vancouver BC, Canada

14-18 November 2005

Agenda

Tuesday, 15 November 2005

Invited Presentation: by From Columbia To Discovery: Understanding the Impact Threat to the Space Shuttle, by James D. Walker, Southwest Research Institute

General Oral Session #1

- Plasma Ignition of a 30mm Cannon, Richard A. Beyer, Andrew L. Brant, Joseph J. Colburn, US Army Research Laboratories
- Numerical Computations of Subsonic and Supersonic Flow Choking Phenomeana in Grid Finned Projectiles, Nicolas Parise, SNC Technologies, Inc; Alain Dupuis, Precision Weapons Section, Defense Research and Development Canada
- The Use of Electric Power in Active Armour Applications, Martin van de Voorde, R. Boeschoten, TNO Defence, Security and Safety
- Prevention of Sympathetic Detonation Between Reactive Armor Sandwiches, Andreas Holzwarth, Fraunhofer-Institut Fur Kurzzeitdynamik

Terminal Ballistics Oral Session #1

- Bullet Impact on Steel and Kevlar®/Steel Armor - Experimental Data and Hydrocode Modeling with Eulerian and Lagrangian Methods, Dale S. Preece, Vanessa S. Berg, and Loyd R. Payne, Sandia National Laboratories
- Progress on the NDE Characterization of Impact Damage in Armor Materials, Joseph M. Wells, JMW Associates
- The influence of sabot threads on the performance of KE penetrators, Nick Lynch and John Stubberfield, QinetiQ
- The Use of Electric Power in Active Armour Applications, Martin van de Voorde, R. Boeschoten, TNO Defence, Security and Safety
- Prevention of Sympathetic Detonation Between Reactive Armor Sandwiches, Andreas Holzwarth, Fraunhofer-Institut Fur Kurzzeitdynamik

Exterior Ballistics Oral Session #1

- Micro-Adaptive Flow Control Applied to a Spinning Projectile, Dr. Jubaraj Sahu, U.S. Army Research Laboratory
- Micro-Adaptive Flow Control and Nonlinear Aerodynamics (Combustion Gas Generators), Dr. Jubaraj Sahu and Ms. Karen Heavey, U.S. Army Research Laboratory
- Aerodynamic Characteristics of a Grid Finned Projectile from Free-Flight Tests at Supersonic Velocities, Alain Dupuis, DRDC - Valcartier; Claude Berner, French-German Research Institute
- Recent Computations and Validations of Projectile Unsteady Aerodynamics, Roxan Cayaz, Eric Carette, Giat Industires; Remy Thepot, Patrick Champigny, Office National D'Etudes et de Recherches Aerospatiales
- Research of Flight Characteristics of Rod-Type Projectile with Triangular Cross-section, Dr. Wenjun Yi, Prof. Xiaobing Zhang, and Prof. Jianping Qian, Ballistic Research Laboratory of China

Wednesday, 16 November 2005

Exterior Ballistics Oral Session #2

- Impact of Nose-Mounted Micro-Structures on the Aerodynamics of a Generic Missile, Dr. Daniel Corriveau, Defence R&D Canada (DRDC - Valcatier)
- Analyses of Gliding Control for an Extended-Range Projectile, Prof. Zhongyuan Wang, Prof. Houqian Xu, Dr. Jinguang Shi, Dr. Wenjun Yi, Prof. Shaosong Chen, Ballistic Research Laboratory of China
- Theoretical Design for a Guided Supersonic Projectile, Pierre Wey, Claude Berner, Eckhart Sommer, Volker Fleck, Henry Moulard, French-German Research Institute of Saint-Louis (ISL)

Interior Ballistics/Launch Dynamics Oral Session #1

- Ceramic Gun Barrel Technologies, Larry Burton, Jeff Swab, Rob Carter, Ryan Emerson, U.S. Army Research Laboratory, Weapons & Materials Research Directorate
- M865 TID Improvement Study, Kerry Henry, Army Research Development & Engineering Center; Jason W. Gaines, General Dynamics-OTS
- Two-Dimensional Modeling of Mortar Interal Ballistics, Clive R. Woodley, David Finbow, QinetiQ; Vladimir Titarev, Eleuterio Toro, Umeritek Limited
- The Mechanism Analysis of Interior Ballistics of Serial Chamber Gun, Dr. Sanjiu Ying, Charge Design Laboratory of China; Prof. Xiaobing Zhang, Prof.

Yaxiong Yuan, and Dr.Yan Wang, Ballistic Research Laboratory of China

Terminal Ballistics Oral Session #2

- Behind Armor Debris Computations with Finite Elements and Meshless Particles, Gordon R. Johnson and Robert A. Stryk, Network Computing Services, Inc.
- Experimental and Numerical Study of the Penetration of Tungsten Carbide Into Steel Targets During High Rates of Strain, Eva K. Friis, Nammo Raufoss AS; Oyvind Froyland and John F. Moxnes, FFI (Norwegian Defence Research Establishment)
- Mine Neutralisation with Small Calibre Projetile Impact, Mark Dijkstra, J.H. Meulman, TNO Defence Safety and Security

Vulnerability, Lethality and Wound Ballistics Oral Session

- The Application of Critical Perforation Analysis (CPA) to Military Personal Armour Research and Evaluation, Catherine H. Crawford and Philip Gotts, Defence Clothing Research and Project Support
- Fragment Patterns Behind Concrete Structures Caused by KE Projectiles, S. Lampert, Fene Jeanquartier, D. Hoffmann, and B. Lehmann, Armasuisse
- Mine Neutralisation with Small Calibre Projetile Impact, Mark Dijkstra, J.H. Meulman, TNO Defence Safety and Security

Thursday, 17 November 2005

Warhead Mechanisms Oral Session #1:

- Soft-Recovery of Explosively Formed Penetrators, David Lambert and Matthew Pope, Air Force Research Laboratory, Munitions Directorate; Stanley E. Jones and Jonathan Muse, Aerospace Engineering and Mechanics, University of Alabama
- The Gurney Velocity: A “Constant” Affected by Previously Unrecognized Factors, Joseph E. Backofen, BRIGS Co.
- The Influence of Post Detonation Burning Process on Blast Wave Parameters in Air, Meir Mayseless and I. Belsky, IDF, Armor Branch; E. Muzychuk, IMI, Central Laboratory

Interior Ballistics/Launch Dynamics Oral Session #2

- 3-D Finite-Element Gun Launch Simulation of a Surrogate Excalibur 155-mm Guided Artillery Projectile - Modeling Capabilities and its Implications, M.R. Chowdhury and A. Frydman, US Army Research Laboratory; J. Cordes, L. Reinhardt and D. Carlucci, US Army ARDEC, Analysis and Evaluation Division
- Caseless Ammunition and Advances in the Characterization of High Ignition Temperature Propellant (HITP), Paul Shipley, AAI Corporation; Erin K. Hardmeyer, US Army ARDEC; and Ben Ashcroft, Alliant Technical Systems
- Ballistic Launch to Space, Ed Schmidt and Mark Bundy, Army Research Laboratory
- A Novel Launcher for Cavitating Weapons, Chris Weiland and Pavlos Vlachos, Mechanical Engineering Department, Virginia Polytechnic Institute and State University; and Jon Yagla, Engagement Systems Department, Naval Surface Warfare Center

Warhead Mechanisms Oral Session #2

- The Role of Rayleigh Taylor Instability in Shaped Charge Jets Formation and Stability, Dr. Simcha Miller, Mr. Gershon Kliminz, Rafael Ballistic Center,
- Simulation of Cylinder Expansion Tests Using an Eulerian Multiple-Material Approach, Laura Donahue, R.C. Ripley, Martec, Ltd
- Application of Powder Tantalum Material for Explosively Formed Penetrator (EFP) Warhead, Richard Fong, Mike Hespos, William Ng, and Steven Tang, US Army ARDEC
- Oilwell Perforators: Theoretical Considerations, Brenden Grove, Schlumberger Reservoir Completions Center
- The Study on Lethality Simulation Method for Fragmentation Warhead, Yang Yunbin, Qu Ming, and Qian Lixin, Institute of Structual Mechanics, China Academy of Engineering Physics

Friday, 18 November 2005

Terminal Ballistics Oral Session #3:

- Performance Evaluation of Multi-Threat Body Armour Systems, B. Anctil and M. Keown, Biokinetics and Associates Ltd.; G. Pageau, M. Bolduc, and D. Bourget, Defence R&D Candada - Valcartier
- The Residual Damage in CFRP Composite After Ballistic Impacts (Experiments & Simulations), Koen Herlaar, TNO Defence, Security and Safety
- The Effect of Boundary Conditions on the Ballistic Performance of Textile Fabrics, Colin R. Cork, University of Manchester, School of Materials

General Oral Session #2

- Wind Tunnel Verification of the Performance of a Smart Material Canard Actuator, Paul Weinacht, William F. Drysdale, Travis Bogetti, and Rod Don, US Army Research Laboratory; James T. Arters, Jack R. Vinson, Aaron R. Hickman, University of Delaware; Lamar Auman, US Army Aviation and Missile RD&E Center; Oded Rabinovitch, Technion Israel Institute of Technology
- The Fragmentation of Metal Cylinders Using Thermobaric Explosives, William Andrews, Royal Military College of Canada; Michael Dunning, Defence R&D Canada – Suffield; and Kevin Jaansalu, Montana Tech (University of Montana)
- A Novel Test Methodology to Assess the Performance of Ballistic Helmets, B. Anctil and M. Keown, Biokinetics and Associates Ltd.; G. Pageau and D. Bourget, Defence R&D Candada - Valcartier
- Ballistic Analysis of Bulgarian Electroslag Remelted Dual Hard Steel Armor Plate, William Gooch, Matthew Burkins, and David Mackenzie, US Army Research Laboratory Weapons and Materials Research Directorate; Stefan Vodenicharov, Institute of Metal Science, Bulgarian Academy of Sciences

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION

STRENGTH THROUGH INDUSTRY & TECHNOLOGY

22ND INTERNATIONAL SYMPOSIUM ON BALLISTICS

November 14-18, 2005

Vancouver
BC, Canada
Event #6210

IBC
International
Ballistics
Committee

International Symposium on Ballistics 2005

International Symposium on Ballistics 2005 is jointly organized and supported by the National Defense Industrial Association, USA in conjunction with the International Ballistics Committee

Symposium Co-Chairman: William Flis
Symposium Co-Chairman: Brian Scott

PREVIOUS INTERNATIONAL SYMPOSIA ON BALLISTICS

1st	Orlando, Florida, USA	1974
2nd	Daytona, Florida, USA	1976
3rd	Karlsruhe, Germany	1977
4th	Monterey, California, USA	1978
5th	Toulouse, France	1980
6th	Orlando, Florida, USA	1981
7th	The Hague, The Netherlands	1983
8th	Orlando, Florida, USA	1984
9th	Shrivenham, UK	1986
10th	San Diego, California, USA	1987
11th	Brussels, Belgium	1989
12th	San Antonio, Texas, USA	1990
13th	Stockholm, Sweden	1992
14th	Quebec City, Canada	1993
15th	Jerusalem, Israel	1995
16th	San Francisco, California, USA	1996
17th	Midrand, South Africa	1998
18th	San Antonio, Texas, USA	1999
19th	Interlaken, Switzerland	2001
20th	Orlando, Florida, USA	2002
21st	Adelaide, South Australia	2004
22nd	Vancouver, BC Canada	2005

SYMPOSIUM SCOPE AND OBJECTIVES

The objective of the 22nd International Symposium on Ballistics is to focus on potential technical advances and break-throughs in the 21st century in the general areas of:

- Interior Ballistics
- Launch Dynamics
- Exterior Ballistics
- Projectile and Warhead Design
- Terminal Ballistics
- Vulnerability
- Modeling and Simulation
- Wound Ballistics

Over 200 papers will be presented by authors from 26 countries.

SYMPOSIUM PROGRAM

Monday, November 14, 2005

2:00 pm - 5:00 pm Registration

5:00 pm - 6:30 pm Reception in Exhibit Area

Tuesday, November 15, 2005

7:00 am Continental Breakfast and Registration

7:00 am - 6:00 pm Exhibits Open

8:00 am Opening Remarks
C. Samuel Campagna, National Defense Industrial Association

8:10 am Welcome and Opening Remarks
William Flis, DE Technologies, Inc. & **Brian Scott,** US Army Research Laboratory

8:20 am **Keynote Address**
Dr. ***Robert Walker*****,** Director-General, Research and Development Programs (DGRDP), Defense Research and Development Canada

9:05 am **Invited Presentation**
From Columbia to Discovery: Understanding the Impact Threat to the Space Shuttle
James D. Walker**,** Southwest Research Institute

9:50 am Morning Break

General Oral Session #1
Chairpersons: *B. Janzon and J. Carleone*

10:20 am Plasma Ignition of a 30mm Cannon
Richard A. Beyer, Andrew L. Brant, Joseph J. Colburn, US Army Research Laboratories

10:40 am Numerical Computations of Subsonic and Supersonic Flow Choking Phenomena in Grid Finned Projectiles
Nicolas* Parisé,** SNC Technologies, Inc.; ***Alain Dupuis, Precision Weapons Section, Defense Research and Development Canada

11:00 am Multiple Explosively Formed Penetrator (MEFP) Warhead Technologies for Mine and Improvised Explosive Device (IED) Neutralization
Richard Fong, William Ng, Steve Tang, LaMar Thompson, U.S. Army Armament Research, Development and Engineering Center

11:20 am The Use of Electric Power in Active Armour Applications
Martin van de Voorde, ***R. Boeschoten***, TNO Defence, Security and Safety

11:40 am Prevention of Sympathetic Detonation between Reactive Armor Sandwiches
Andreas Holzwarth, Fraunhofer-Institut für Kurzzeitdynamik

12:00 pm Lunch

1:30 pm - 3:10 pm **Exterior Ballistics Poster Session**
Chairpersons: Z. Wang and P.A. Karsten

Terminal Ballistics Oral Session #1
Chairpersons: E. Lindén and C. Anderson

1:30 pm Bullet Impact on Steel and Kevlar®/Steel Armor – Experimental Data and Hydrocode Modeling with Eulerian and Lagrangian Methods*
Dale S. Preece, Vanessa S. Berg, Mathew A. Risenmay, Sandia National Laboratories

1:50 pm Progress on the NDE Characterization of Impact Damage in Armor Materials
Joseph M. Wells, JMW Associates

2:10 pm Design, Analysis, and Testing of an Unconfined Ceramic Target to Induce Dwell
Timothy J. Holmquist, Network Computing Services, Inc.; ***C. Anderson, Jr***., Southwest Research Institute; ***Thilo Behner***, Ernst-Mach-Institut

2:30 pm The Influence of Sabot Threads on the Performance of KE Penetrators against multiple plate targets
Nick J. Lynch, ***J. Stubberfield***, QinetiQ

2:50 pm Visualization of Wave Propagation and Impact Damage in a Polycrystalline Transparent Ceramic - AlON
Elmar Strassburger, Fraunhofer Institut für Kurzzeitdynamik; ***Parimal Patel, James W. McCauley,*** US Army Research Laboratory; ***Douglas W. Templeton,*** US Army TARDEC

3:10 pm Afternoon Break

3:40 pm - 5:20 pm **Terminal Ballistics Poster Session #1**
Chairpersons: A. Diederen

Exterior Ballistics Oral Session
Chairpersons: W. Reinecke and A. Dupuis

3:40 pm Advanced Time-Accurate CFD/RBD Simulations of Projectiles in Free Flight
Jubaraj Sahu, US Army Research Laboratory

4:00 pm Aerodynamic Characterstics of a Grid Finned Projectile from Free-Flight Tests at Supersonic Velocities
Alain Dupuis**,** DRDC - Valcartier; ***Claude Berner***, French-German Research Institute

4:20 pm Recent Computations and Validations of Projectile Unsteady Aerodynamics
Roxan Cayaz, ***Eric Carette***, Giat Industries; ***Rémy Thépot, Patrick Champigny***, Office National d'Études et de Recherches Aérospatiales

4:40 pm The Derivation of Spin Stabilised Projectile Yaw Rates and Ballistic Model Coefficients Using Conventional CW Doppler Radar Systems
John Tate, FLEET

5:00 pm Research of Flight Characteristics of Rod-Type Projectile with Triangular Cross-Section
Wenjun Yi, ***Xiaobing Zhang, Jianping Qian***, Ballistic Research Laboratory of China, Nanjing University of Science & Technology

5:20 pm Adjourn for the Day

Wednesday, November 16, 2005

7:00 am	Continental Breakfast and Registration
7:00 am - 5:00 pm	Exhibits Open
8:00 am	Administrative Remarks
8:10 am - 9:50 am	**Terminal Ballistics Poster Session #2** **Chairpersons: J. Riegel and E. Hirsch**
	Exterior Ballistics Oral Session #2 **Chairpersons: P. Nel and E. Schmidt**
8:10 am	Impact of Nose-Mounted Micro-Structures on the Aerodynamics of a Generic Missile ***Daniel Corriveau,*** Defence R&D Canada (DRDC - Valcatier)
8:30 am	Ballistic Simulations and Wind Tunnel Testing of 120 mm Mortar Bomb Tail Fin Geometries – In Search for Extra Range ***Jukka Tiainen, Ari Makkonen,*** Patria Weapon Systems Oy; ***Mikko Korhonen, Timo Sailaranta***, TKK/Laboratory of Aerodynamics
8:50 am	Bringing Solid Fuel Ramjet Projectiles Closer to Application – An Overview of the TNO/RWMS Technology Demonstration Programme ***Ronald G. Veraar***, TNO Defence, Security and Safety Research Group Rocket Technology; ***Guido Giusti***, Rheinmetall Waffe Munition Schweiz AG
9:10 am	Analysis of Gliding Control for an Extended-Range Projectile ***Zhongyuan Wang***, ***Houqian Xu, Jinguang Shi, Wenjun Yi, Shaosong Chen***, Ballistic Research Laboratory of China, Nanjing University of Science & Technology
9:30 am	Theoretical Design for a Guided Supersonic Projectile ***Pierre Wey***, ***Claude Berner, Eckhart Sommer, Volker Fleck, Henry Moulard***, French-German Research Institute of Saint-Louis (ISL)
9:50 am	Morning Break
10:20 am - 12:00 pm	**Warhead Mechanisms Poster Session** **Chairpersons: R. Fong and F. Mostert**
	Interior Ballistics/Launch Dynamics Oral Session #1 **Chairpersons: C. Candland and C. Woodley**
10:20 am	Ceramic Gun Barrel Technology ***Lawrence W. Burton, Jeffrey J. Swab, Ryan Emerson, Robert Carter***, US Army Research Laboratory, Weapons & Materials Research Directorate
10:40 am	M865E3 Cold Target Impact Dispersion Study ***Kerry Henry,*** Army Research Development & Engineering Center; ***Jason W. Gaines***, General Dynamics-OTS
11:00 am	An Alternative Technique to Evaluate and Characterize Pressure Waves in Large Calibre Guns ***Victor Schabort,*** Denel Land Systems Western Cape
11:20 am	Two-Dimensional Modelling of Mortar Internal Ballistics ***Clive R. Woodley, David Finbow***, QinetiQ; ***Vladimir Titarev, Eleuterio Toro***, Numeritek Limited

11:40 am — The Mechanism Analysis of Interior Ballistics of Serial Chamber Gun
Sanjiu Ying, Charge Design Laboratory of China, Nanjing University of Science & Technology; ***Xiaobing Zhang, Qaxiong Yuan, Yan Wang***, Ballistic Research Laboratory of China, Nanjing University of Science & Technology

12:00 pm — Lunch

Terminal Ballistics Oral Session #2
Chairpersons: M. Mayseless and T. Holmquist

1:30 pm — Behind Armor Debris Computations with Finite Elements and Meshless Particles
***Gordon R. Johnson*, Robert A. Stryk,** Network Computing Services, Inc.

1:50 pm — Expirmental and Numerical Study of the Penetration of Tungsten Carbide into Steel Targets During High Rates of Strain
Eva K. Friis, Nammo Raufoss AS, ***Oyvind Froyland, John F. Moxnes,*** FFI (Norwegian Defence Researdh Establishment

2:10 pm — Fragmentation Behavior of Tungsten Alloy Cubes on Normal Aluminum Plate Targets
***Karl Weber*,** Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach Institut

2:30 pm — The Failure Kinetics of High Density DEDF Glass Against Rod Impact at Velocities From 0.4 to 2.5 km/s
Thilo Behner, ***V. Hohler, M. Moll***, Fraunhofer Institut für Kurzzeitdynamik (Ernst-Mach Institut); ***Ch. E. Anderson Jr.***, Southwest Research Institute; ***D. L. Orphal***, International Research Associates, Inc.; ***D. W. Templeton***, US Army RDECOM-TACOM

2:50 pm — Mine Neutralisation with Small Calibre Projectile Impact
Mark Dijkstra, J.H. Meulman, TNO Defence, Safety and Security

3:10 pm — Afternoon Break

Vulnerability, Lethality and Wound Ballistics Oral Session
Chairpersons: R. Vaziri, A. Persson

3:40 pm — The Application of Critical Perforation Analysis (CPA) to Military Personal Armour Research and Evaluation
Catherine H. Crawford, Philip Gotts, Defence Clothing Research and Project Support

4:00 pm — An Efficient Mechanistic Approach to Modelling the Ballistic Response of Multi-Layer Fabrics
Ali Shahkarami, Reza Vaziri, Anounsh Poursartip, Composites Group, Departments of Civil Engineering and Materials Engineering The University of British Columbia; ***Navin Tajani***, DuPont Advanced Fibers Systems

4:20 pm — Pencilling – A Novel Behind Armour Blunt Trauma Injury
Eluned A. Lewis, Defence Clothing Research and Project Support; ***Ian Horsfall, Celia Watson***, Engineering Systems Department, Royal Military College of Science, Cranfield University

4:40 pm — Scaling the Dynamic Response of Armored Vehicle's Floor Subjected to a Large Buried Charge
Avidov Neuberger, MOD, Tank Program Management; ***S. Peles***, IMI, Central Laboratory Division; ***D. Rittel***, Technion, Israel Institute of Technology, Faculty of Mechanical Engineering

5:00 pm	Fragment Patterns Behind Concrete Structures Caused by KE Projectiles ***René Jeanquartier, D. Hoffmann, S. Lampert, B. Lehmann***, Armasuisse
5:20 pm	Adjourn for the Day

Thursday, November 17, 2005

7:00 am	Continental Breakfast and Registration
8:00 am - 11:00 am	Exhibits Open
8:00 am	Adminstrative Remarks
8:10 am - 9:50 am	**Interior Ballistics/Launch Dynamics Poster Session** ***Chairpersons: C. Woodley and C. Candlant***

Warhead Mechanisms Oral Session #1
Chairpersons: M. Murphy and P.Y. Chanteret

8:10 am	Soft-Recovery of Explosively Formed Penetrators ***David E. Lambert***, ***Matthew Pope***, Air Force Research Laboratory, Munitions Directorate; ***Stanley Jones, Jonathan Muse***, University of Alabama, Aerospace Engineering and Mechanics
8:30 am	The Gurney Velocity: A “Constant” Affected by Previously Unrecognized Factors ***Joseph E. Backofen,*** BRIGS Co.
8:50 am	Influence of Post Detonation Burning Process on Blast Wave Parameters in Air ***Meir Mayseless, E. Muzychuk,*** IDF, Mil.; ***M. Mayseless, I. Belsky, IMI,*** Central Laboratory
9:10 am	Steerable Fragment Masses ***Manfred Held***, TDW/EADS
9:30 am	Penetration Performances of Tungsten-Copper Shaped Charge Liner ***Seong Lee, Eun Pyo Kim, Youngmoo Kim, Sung Ho Lee, Moon-Hee Hong, Joon-Woong Noh***, Agency for Defense Development
9:50 am	Morning Break
10:20 am - 12:00 pm	**Vulnerability/Lethality/Wound Ballistics Poster Session** **Chairpersons: *W. Gooch***

Interior Ballistics/Launch Dynamics Oral Session #2
Chairpersons: ***B. Burns and R. Cayzac***

10:20 am	3-D Finite-Element Gun Launch Simulation of a Surrogate Excalibur 155-mm Guided Artillery Projectile - Modeling Capabilities and its Implications ***M.R. Chowdhury, A. Frydman,*** US Army Research Laboratory; ***J. Cordes, L. Reinhardt, D. Carlucci***, US Army ARDEC, Analysis and Evaluation Division
10:40 am	Method of Calculating Initial Firing Data of Artillery Laser Terminal-Guidance Weapon System ***Feipeng Zeng***, ***Liren Liu***, Faculty of Artillery Command, Nanjing Artillery Academy

11:00 am — Caseless Ammunition & Advances in the Characterization of High Ignition Temperature Propellant
Patricia M. O'Reilly, Erin Hardmeyer, Chad Sensenig, US Army ARDEC; ***Ben Ashcroft***, Alliant Techsystems; ***Dave Cleveland***, The Johns Hopkins University, 0Applied Physics Laboratory; ***Bo Engel, Paul Shipley***, AAI Corporation

11:20 am — Ballistic Launch to Space
Edward Schmidt, M. Bundy, US Army Research Laboratory

11:40 am — A Novel Launcher for Cavitating Weapons
Chris J. Weiland, Pavlos P Vlachos, Dept of Mechanical Engineering
Virginia Tech; Jon J Yagla, Mechanical Engineer Engagement Systems Department
Naval Surface Warfare Center

12:00 pm — Lunch

Warhead Mechanisms Oral Session #2
Chairpersons: **R. Brown and M. Held**

1:30 pm — The Role of Rayleigh Taylor Instability in Shaped Charge Jets Formation and Stability
Simcha Miller, Gershon Kliminz, Rafael Ballistic Center

1:50 pm — Simulation of Cylinder Expansion Tests Using an Eulerian Multiple-Material Approach
Laura K. Donahue, ***R.C. Ripley***, Martec, Ltd.

2:10 pm — Application of Powder Tantalum Material for Explosively Formed Penetrator Warhead
Richard Fong, ***William Ng, Steven Tang, Michael Hespos***, US Army Armament Research, Development and Engineering Center

2:30 pm — Oilwell Perforators: Theoretical Considerations
Brenden M. Grove, Schlumberger Reservoir Completions Center

2:50 pm — Planar Cutting Jets from Shaped Charges
Geoffery EB Tan, ***T.K. Lam, Y.K. Tham***, DSO National Laboratories

3:10 pm — The Study on Lethality Simulation Method for Fragment Warhead
Yang Yunbin, Qu Ming, Qian Lixin, Institute of Structural Mechanics, China Academy of Engineering Physics

3:30 pm — Adjourn for the Day

4:00 pm - 5:30 pm — Reception

Friday, November 18, 2005

7:00 am — Continental Breakfast and Registration

8:00 am — Adminstrative Remarks

Terminal Ballistics Oral Session #3
Chairpersons: I. Cullis and D. Nandlall

8:10 am — Performance Evaluation of Multi threat Body Armour Systems
B. Anctil, M. Keown, Biokinetics and Associates Ltd.; **G. Pageau, M. Bolduc D. Bourget**, Defence R&D Canada – Valcartier

8:30 am — Finite Element Simulations and Experiments to Determine the Residual Damage of a CFRP Composite Material After Ballistic Impacts
Koen Herlaar, M. Van der Jagt-Deutekom, TNO Defence, Security and Safety

8:50 am — The Effect of Boundary Conditions on the Ballistic Performance of Textile Fabrics
Colin R. Cork, University of Manchester, School of Materials

9:10 am — Terminal Ballistic Effects of Low Density Materials Used as Confinement Plates for Explosive Reactive Armours
Hanspeter Kaufmann, RUAG Land Systems; ***André Koch***, Armasuisse

9:30 am — Quantification of the Effect of Using the Johnson-Cook Damage Model in Numerical Simulations of Penetration and Perforation
Charles E. Anderson Jr., T. R. Sharron, Southwest Research Institute; ***Timothy J. Holmquist***, Network Computing Services, Inc.

9:50 am — Morning Break

General Oral Session #2
Chairpersons: V. Sanchez-Galvez and P. Cuniff

10:20 am — Comparisons of Internal Ballistics Simulations of the AGARD Gun
Clive R. Woodley, QinetiQ; ***Alain Carriere, Patrice Franco, Dieter Hensel, Julien Nussbaum***, Institut Franco-Allemand de Recherches de Saint-Louis (ISL); ***Tatjana Gröge***, Ernst-Mach-Institut (EMI); ***Stefan Kelzenberg***, Fraunhofer-Institut für Chemische Technologie (ICT), ***Baptiste Longuet***, DGA/DCE/ETBSr3

10:40 am — Wind Tunnel Verification of the Performance of a Smart Material Canard Actuator
Paul Weinacht, ***William F. Drysdale, Travis Bogetti, Rod Don***, US Army Research Laboratory; ***James T. Arters, Jack R. Vinson, Aaron R. Hickman***, University of Delaware; ***Lamar Auman***, US Army Aviation and Missile RD&E Center; ***Oded Rabinovitch***, Technion Israel Institute of Technology

11:00 am — Fragmentation of Metal Cylinders Using Thermobaric Explosives
M.R. Dunning, Defence Research and Development - Suffield, ***W.S. Andrews,*** Department of Chemistry and Chemical Engineering***,*** Royal Military College of Canada; ***K.M. Jaansalu***, Department of Metallurgical and Materials Engineering, The University of Montana

11:20 am — A Novel Test Methodology to Assess the Performance Ballistic Helmets
B. Anctil, M. Keown, Biokinetics and Associates Ltd.; ***D. Bourget, G. Pageau,*** Defence R&D

11:40 am — Ballistic Analysis of Bulgarian Electroslag Remelted Dual Hard Steel Armor Plate
William Gooch, Matthew Burkins and David Mackenzie, US Army Research Laboratory, Weapons and Materials Research Directorate; Stefan Vodenicharov, Institute of Metal Science, Bulgarian Academy of Sciences

12:00 pm — Presentation of Awards
The Rosalind and Pei Chi Chou Award for Young Authors
The Neil Griffiths Memorial Award
The Louis and Edith Zernow Award

12:15 pm — Invitation to the 23rd International Symposium on Ballistics, Tarragona, Spain, 2007

12:25 pm — Closing
William Flis, DE Technologies, Inc. & **Brian Scott,** US Army Research Laboratory

POSTER SESSIONS START HERE

Exterior Ballistics Poster Session
1:30 pm - 3:10 pm Tuesday, November 15

1913 Fractional Calculus for Design of Aerodynamic Missile's Autopilot and Digital Realization
Bangchu Zhang, ***Chenming Li, Zipeng Han, Zou Yun, Fuming Xu***, Ballistic Research Laboratory of China, Nanjing University of Science & Technology

1915 The Simulation of Rocket Trajectory in Simulink
Xin Changfan, Nanjing University of Science & Technology

1924 Establishing a Pitch Damping Test Capability at CSIR Defencetek
Fabrizio Dionisio, CSIR, Defencetek

1944 The Investigation About Using Different Guidance Laws on Improving Impact Point Deviation of a Rocket
Handong Zhao, ***Fang Wang, Qingshang Liu***, Key Laboratory of Instrumentation and Dynamic Measurement, North University of China

1951 Numerical Integration Method Based on 4th Largrange Polynomial of Strap-Down INS System
Guoguang Chen, ***Xiaoli Tian, Changfan Xin, Yaqi Bao***, North University of China

1952 Research on Real Time Trajectory Measure Device of Range
Changfan Xin, Guoguang Chen, Xiaoli Tian, North University of China

1953 Research on Attitude Control Strategy of Glide Range Extend Rocket
Xiaoli Tian, Guoguang Chen, Changfan Xin, North University of China

1954 Optimal Algorithm of Glide Range Extend Rocket's Trajectory
Guoguang Chen, Xiaoli Tian, Changfan Xin, North University of China

1978 Practical Propulsion by Directed Energetic Processes
Joseph P. Backofen, BRIGS Co.

2014 Investigating the Method of Obtaining Ammunition Roll Attitude by Detecting the Geomagnetic Vector
Hongsong Cao, ***Guoguang Chen***, Department of Mechatronics Engineering, North University of China

2065 External Ballistic Trajectory Computations for Direct/Indirect Fire Weapon Systems
David J. Norton, General Dynamics Canada

2087 The Influence of Laser Rangefinder Parameters on the Hit Probability in Direct Tank Fire
Vladimir Cech, OPROX, Inc., ***Jiri Jevicky***, Department of Mathematics, University of Defense

2123 Flight Dynamics Modeling and Experiment for Composite Concepts. Application to Ribbon Aerodynamic Stabilization
Christopher Grignon, S.Heddadj, Giat Industries

2128 Onboard Measurements with Magnetic Sensors: Determination of the Attitude and the trajectory Position
V. Fleck, E. Sommer, S. Changey, French-German Research Institute (ISL); ***D. Beauvois***, Ecole Superirure d'Electrecite (Supelec)

2133 Aerodynamic Characteristics of a Long Range Spinning Artillery Shell Obtained from 3D Magnetic Sensors
V. Fleck, E. Sommer, C. Berner, French-German Research Institute (ISL); ***A. Dupuis***, DRDC

2143 Experimental Testing and Numerical Simulation of Separation Disturbances for Two-Stage Kinetic Energy Missiles
Nicolas Parisé, SNC Technologies, Inc.; ***Richard Lestage, Francoise Lesage***, Precision Weapons Section, Defense Research and Development Canada Valcartier

2147 Numerical Study on the Base Drag Characteristics of a Base Bleed Projectile with a Central Propulsive Jet
Chang-Kee Kim, Agency for Defense Development; ***J.Y. Choi***, Pusan National University, Department Aerospace Engineering

2169 Solid Fuel Ramjet (SFRJ) Propulsion for Artillery Projectile Applications – Dynamic Testing Progress
Anton Stockenström, Dynax

3010 Pitch and Bending During In-Flight Extension
W. G. Reinecke, Institute for Advanced Technology; ***M. G. Miller,*** Physical Sciences, Inc.

4004 Improvements in Aerodynamic Design for KE Less-Lethal Projectiles
Jamie H. Cuadros, Arts & Engineering

Terminal Ballistics Poster Session #1
3:40 pm - 5:20 pm Tuesday, November 15

1001 Numerical Simulations of Silicon Carbide Tiles Impacted by Tungsten Carbide Spheres
Constantine G. Fountzoulas, Jerry C. LaSalvia, Bryan A. Cheeseman, Weapons and Materials Research Directorate; ***Michael J. Normandia***, Ceradyne, Inc.

1007 Shock Mitigation for Blast Protection Using Hertzian Tapered Chains
Robert Doney, US Army Research Laboratory; ***Surajit Sen***, Department of Physics, State University of New York at Buffalo

1011 A Predictive Model for the Dwell/Penetration Transition Phenomenon
Jerry C. LaSalvia, US Army Research Laboratory

1012 Effect of Ceramic Thickness on the Dwell/Penetration Transition Phenomenon
Jerry C. LaSalvia, US Army Research Laboratory

1014 The Development of Hybridized Thermoplastic-Based Structural Materials with Applications to Ballistic Helmets
Shawn Walsh, ***Brian R. Scott, David M. Spagnuolo***, AMSRD-ARL-WM-MB

1015 Time Resolved Observation of the Deformation and Surface Strain of a Textile Fabric Subject to Ballistic Impact
Brian Scott, ***Peter Dehmer***, US Army Research Laboratory; ***Timothy Schmidt***, Trilion Quality Systems

1016 Analytic Design Trends of Fabric Armor
Brian Scott, ***Chian-Fong Yen***, US Army Research Laboratory

1018 High-Speed Photographic Study of Wave and Fracture Propagation in Fused Silica
Elmar Strassburger, Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut (EMI); ***Parimal Patel, James W. McCauley,*** US Army Research Laboratory; ***Douglas W. Templeton***, US Army TARDEC

1022 Low Velocity Ballistic Properties of Shear Thickening Fluid (STF)–Fabric Composites
M. J. Decker, R. G. Egres, N. J. Wagner, University of Delaware, Dept. of Chemical Engineering and Center for Composite Materials; E. D. Wetzel, U.S. Army Research Laboratory

1023 An Approximate Solution of the Long-Rod Penetration Equations
William Walters, ***Cyril Williams,*** ARL, Terminal Effects Division

1901 Tubular Projectile Interaction with Stationary and Moving Oblique Plates
Olof Andersson, Swedish Defence Research Agency (FOI), Weapons and Protection Division

1911 A Study on the Moving Features of Double-Layer Explosive Reactive Armor with Definite Angle by Numerical Simulation and Experiments
Zhengxiang Huang, ***Xianfeng Zhang, Gang Li,*** School of Mechanical Engineering, Nanjing University of Science & Technology

1927 Mechanics of Structural Design of EPW Warhead
X.W. Chen, Institute of Structural Mechanics, China Academy of Engineering Physics

1928 Armour Qualification Utilizing Maximum Likelihood Ballistic Limit Calculation
Moshe Ravid, ***Shlomo Galperin***; Rimat Advanced Technologies, Ltd.

1934 Perforation of Concrete Targets by an Eroding Tungsten-Alloy Rod
Stephan Lampert, Rene Jeanquartier, Armasuisse

1955 Ballistic Properties of Single-Melt Titanium-6Aluminum-4Vanadium Alloy Plate
Brij J. Roopchand, US Army Tank-Automotive and Armament Command, Armament Research, Development, & Engineering Center

1987 Preliminary Investigations of Potential Light Weight Metallic Armour Applications
Martin van de Voorde, A.M. Dierderen, K. Herlaar, TNO Defence, Safety and Security

2001 Oblique Warhead Penetration and Perforation of Multi-Layered Metallic Targets
Yongxiang Dong, ***Feng Shunshan, Wang Fang***, State Key Laboratory of Explosion Science & Technology, Beijing Institute of Technology

2019 Influence of Projectile Material on Yawed Long Rod Projectiles Penetrating Oblique Plates
Ewa Lidén, Swedish Defence Research Agency (FOI), Weapons and Protection Division

2035 Advanced Aliphatic Polyurthane Resins for High Durability and Superior Ballistic Performance Laminated Glass
Francisco Folgar, INTER Materials, LLC

2037 Impact and Penetration of B4C Ceramic, Aluminum, and Berlyllium by Depleted Uranium Rods at 2.0 KM/S
Scott A. Mullin, ***James D. Walker, Carl E. Weiss***, Southwest Research Institute; ***Paul O. Leslie***, Los Alamos National Laboratories

2122 A Comparison of Some Analytical and Empirical Models for Kinetic Energy Penetration of Semi-Infinite and Finite Thickness Steel Targets
Nick J. Lynch, ***J T Mills***, QinetiQ

2181 Computed Tomography of High-Speed Events
Karsten Michael, Philip Helberg, Fraunfoher Institute for High Speed Dynamics, Ernst-Mach-Institut

2186 Characterization of Behind-Armor Debris Particles from Tungsten Penetrators
Brad A. Pedersen, ***S. Bless***, Institute for Advanced Technology

Terminal Ballistics Poster Session #2
8:10 am - 9:50 am Wednesday, November 16

2050 On the Critical Thickness of Ceramic to Shatter WC-Co Bullet Cores
Paul J. Hazell, Engineering Systems Department, Cranfield University, Royal Military College of Science; ***C. J. Roberson***, Advanced Defence Materials Limited

2060 The Effect of Spaced Armour on the Penetration of Shaped Charge Warheads
James D. Shattock, Cranfield University

2072 Modeling Impact and Penetration Using a Deterministic and Probabilistic Design Tool
David S. Riha, ***Jason B. Pleming, Ben H. Tucker, Scott A. Mullin, James D. Walker, Carl E. Weiss***, Southwest Research Institute; ***Edward A. Rodriguez, Paul O. Leslie***, Los Alamos National Laboratories

2106 On the Ballistic Efficiency of the Three Layered Metallic Targets
Stanislav Rolc, Military Technical Institute of Protection; ***Jaroslav Buchar***, Mendel University; ***Giovanni Cozzani***, OTO MELARA S.p.A ***Vojtech Hruby***, University of Defence

2107 Effect of the Temperature on the Ballistic Efficiency of Plates Made From Cast Iron
Stanislav Rolc, Military Technical Institute of Protection; ***Jaroslav Buchar***, Mendel University

2113 Displacement Device to Measure the Acceleration of the Bulge of RHA Plates Under Anti-Tank Mine Blast
Manfred Held, TDW/EADS; ***Peter Heeger***, WTD; ***Josef Kiermeir***, CONDAT

2116 Defeating Mechanisms of Explosive Reactive Armour Sandwiches
Manfred Held, TDW/LFK/EADS

2121 Comparisons of Unitary and Jacketed Rod Penetration into Semi-Infinite and Oblique Plate Targets at System Equivalent Velocities
John Stubberfield, N J Lynch, QinetiQ; ***I Wallis***, QinetiQ Farnborough

2126 Finite Element Simulations and Experiments of Ballistic Impacts on High Performance PE Composite Material
Koen Herlaar, M. Van der Jagt-Deutekom, TNO Defense, Security and Safety

2129 The Use of Foam Structures in Armoured Vehicle Protection Against Landmines
David A. Cendón, ***Vincente Sanchez-Galvez, Francisci Galvez, Alejandro Enfedaque***, Departamento de Ciencia de Materiales, E.T.S.I. Caminos, Canales y Puertos, Universidad Politecnica de Madrid, Spain

2136 The Numerical Simulation of the Impact of an Aluminum Cylinder into a Steel Cone
Izak M. Snyman, Defencetek Landwards Programme, CSIR

2139 Characterization of Al 6061-T6 using Split Hopkinson Bar Tests and Numerical Simulations
Amal Bouamoul, ***Manon Bolduc***, DRDC - Valcartier

2145 Finite Element Modeling of Light Armoured Vehicles (LAV) Welds Heat Affected Zones Sublected to an Anti-Vehicular (AV) Blast Landmine Loading: A Summary of the Numerical Model and Experiment
Patrice Gaudreault, Defence Research & Development Canada; ***Amal Bouamoul, Robert Durocher, Benoit St-Jean***, DRDC Valcartier

2151 Designer Projectiles by Density Variation: Towards the Nano-Projectile
John P. Curtis, QinetiQ

2160 Numerical Simulation for the Front Section Effect of Missile Warhead on the Target Perforation
Ho Soo Kim, ***Ki-Sun Yeom, Seong Shik Kim***, Agency for Defense Development (ADD); Larry Sotsky, US Army ARDEC

2180 The Penetration Process of Projectiles into Long Bars in the Axial Direction
Dan Yaziv, G. Gans, Y. Reifen, RAFAEL

2199 The Electromagnetic Launch Trends Utilization for Shaped Charge Jets Penetration Depth Decrease
S.V. Demidkov, Effective Soft Ltd.

3003 Simulation of the Perforation of Low Mass Long L/D Rods Against Finite RHA Plates
P. Church, ***I. Cullis, A Bowden, D Gibson***, QinetiQ, Ltd.

3011 Deflection and Fracture of Tungston Rods by Yawed Impact
S. Bless, R. Russell, Instutite for Advanced Technology; ***K. Tarcza***, US Army ARDEC; ***E. Taleff***, Department of Mechanical Engineering, The University of Texas at Austin; ***M. Huerta***, The University of Texas at El Paso

3012 Anomalies in the Strength of Alumina under Dynamic Compression
T. Beno, S. Bless, S.Nichols, Instituite for Advanced Technology

3014 On the 3D Visualization of Ballistic Damage in TI-6AL-4V Applique Armour with X-Ray Computed Tomography
J.M. Wells, JMW Associates; ***W.H. Green, N.L. Rupert***, US Army Research Laboratory, Weapons & Materials Research Division; J***ohn M. Winter, Jr.***, ORISE Contractor at WMRD; ***S.J. Cimpoeru***, DSTO Melbourne

4012 Analytical Models for Foam, Ice and Ablator Impacts into Space Shuttle Thermal Tiles
James D. Walker, Sidney Chocron, Walt Gray, Southwest Research Institute

4013 CTH Simulations of Foam and Ice Impacts into the Space Shuttle Thermal Protection System Tiles
Sidney Chocron, Walt Gray, James D. Walker, Southwest Research Institute

4016 Damage Created in Composite Sheet by Explosives – Effects of Fibre Type, Explosive Mass and Attenuating Material
M. R. Edwards, R. Unwin, Centre for Materials Science and Engineering, Cranfield University

Warhead Mechanisms Poster Session
10:20 am - 12:00 pm, November 16

1914 Experimental Investigation of Equivalent Blast Characteristics for Aluminiferous Explosive in Shallow Underwater
Wenbin Gu, ***Jianqing Liu, Qingli Su, Weiping Zhou***, Ballistic Research Laboratory of China, Nanjing University of Science & Technology

1935 Break-up of Copper Shaped – Charge Jets: A Combined Experimental/Numerical/Analytical Approach
Jacques Petit, Centre d'Etudes de Gramat; ***V. JeanClaude, C. Fressemgeas***, Laboratoire de Physique et Mecanique des Materiaux, Universite de Metz/CNRS

1949 A Theoretical Analysis for Initial Fragment Velocity and Peak Overpressure of a Blast Fragmentation Device
Jin Jianming, Institute of Structural Mechanics, China Academy of Engineering Physics

1963 Scaling the Dynamic Response of Armored Vehicle's Floor Subjected to a Large Buried Charges
Avidov Neuberger, IMOD, MANTAK, Tank Program Management; ***S. Peles***, IMI Central Laboratory Division; ***D. Rittel***, Technion, Israel Institute of Technology, Faculty of Mechanical Engineering

1984 High-Speed Flash X-Ray Computed Tomo-Cinematography
Philip Helberg, ***Karsten Michael***, Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut

2002 The Influence of Parameters Other Than Liner Velocity on Shaped Charge Jet Coherence
Frederik Mostert, CSIR Defencetek; ***C. J. Terblanche***, Denel Land Systems - Western Cape; ***M. F. Maritz***, Department of Applied Mathematics, University of Stellenbosch

2053 Comparison of Vulnerability and Performances of Insensitive Munitions (IM) and Non IM Directed Energy Warheads
Frederic Peugeot, MSIAC, NATO HQ

2059 Trumpet Shaped Liners' Influence on Slug Properties
Eitan Hirsch, Consultor***; Meir Mayseless***, IMI Central Laboratory

2077 A Study on the Structure of Small Caliber EFP
Chen Zhigang, Zhao Taiyong, Hou Xiucheng, Dong Surong, The Research Institute of Explosive Demolition & Defence Technology, North University of China; ***You Zheng***, Department of Precision Instruments and Mechanics, Tsinghua University

2078 A Framework for the Analyses and Visualization of X-Ray Computed Tomography Image Data using a Compute Cluster
Jeffrey R. Wheeler, US Army Research Laboratory; ***William H. Green***, US Army Research Laboratory, Weapons & Materials Research Division; ***Michael Schuresko***, Baskin School of Engineering, University of California; Michael Patrick ***Lowery***, Computational Mathematics Department, University of California

2137 An Artillery Shell for Anti-Bunker Applications (155 ABS)
Rémi Boulanger, Giat Industries; ***Anders Vangen Jordet, Dagfinn Hoff***, NAMMO Raufoss

2141 Development of a TMRP-6 Surrogate Mine
Yves Baillargeon, ***A. Sirois and G. McIntosh***; DRDC Valcartier

2148 Use of Foamed TNT Mixtures as a Dispersion Charge of Submunitions
Jun Sik Hwang, S.-K. Kwon, C.-K. Kim, S.-W. Kwon, S.-S. Kim, S.-H. Moon, Explosive Trains and Gun Propellant Team, Agency for Defense Development

2152 Wall Breaching Tandem Warhead
Andreas Helte, Torgny Carlsson, Håkan Hansson, Svante Karlsson, Jonas Lundgren, Lars Westerling, Håkan Örnhed, Swedish Defence Research Agency, FOI, Weapons and Protection Division

2156 An Analytical Penetration Model for Jets with Varying Mass Density Profiles
Milton F. Maritz, Stellenbosch University; ***Klaus D. Werneyer***, TTP Products; ***Frederik J. Mostert***, Defencetek

2168 Peripheral Initiation Technology Development
Arthur S. Daniels, ***Ernest L. Baker, William J. Poulos, Vladimir M. Gold, B. Fuchs***, US Army ARDEC

2175 Shaped-Charge Jet Stability Calculations: The Role of Initial and Boundary Conditions
James S. Stolken, ***S. Christian Simonson, Mukul Kumar***, Lawrence Livermore National Laboratory

3007 Enhanced Focused Fragmentation Warhead Study
Richard Fong, ***William Ng, Peter Rottinger, Steve Tang***, US Army Armaments Research, Development and Engineering Center

4015 Microstructure and Properties of the Explosively Formed Petals in Aluminium Alloys
M. R. Edwards, J. M. Cassar, Centre for Materials Science and Engineering, Cranfield University

Interior Ballistics/Launch Dynamics Poster Session
8:10 am - 9:50 am November 17

1017 In-Bore Mechanics Analysis of the M855 Projectile
Joseph T. South, James F. Newill, US Army Research Laboratory

1020 Dynamic Strain Measured in a 105-mm Composite Gun Barrel - A Fiction or Reality
Jerome T. Tzeng, US Army Research Laboratory

1916 A Vector Way for Calculating Propellant's Combustion Performance
Wei Zhifang, Department of Mechanical and Electronic Engineering, North University of China

1931 Interior Ballistics Code Applied to ETC Concept: Computations and Validations
Gilles Legeret, ***Dominique Boisson***, Giat Industries

2004 The FHIBS Internal Ballistics Code
Clive R. Woodley, Steve Billett, QinetiQ; ***Caroline Lowe***, Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Studies, University of Cambridge; ***William Speares***, The Cylinders; ***Eleuterio Toro*** Laboratory of Applied Mathematics, Faculty of Engineering, University of Trento

2005 Modelling the Ignition of 40mm Gun Charges
Clive R. Woodley, QinetiQ

2020 Thermo-Mechanical Erosion Study of the 120mm Chromium Coated Gun Barrel: Computation and Validation of the Heat Exchange Boundary Condition
Dominique Boisson, ***Gilles Légeret, Roxan Cayzac***, Giat Industries

2031 MOBIDIC-NG: A 1D/2D CFD Code Suitable for Interior Ballistics and Vulnerability Modelling
Baptiste Longuet, Pascal Millet, Eric Taiana, ETBS; ***Patrick Della, Pieta Christiane Reynaud***, SNPE Matériaux Energétiques CRB; ***Patrice Franco, Alain Carrère***, Institut Franco-Allemand de Recherches de Saint-Louis (ISL); ***Gilles Légeret***, ***Dominique Boisson***, Giat Industries; ***Alexandre Papy***, ERM ABAL 30

2070 Barrell Life Results of the 5.56 mm XC77A1 Cartridge
Etienne Munger, SNC Technologies, Inc.

2117 Further Investigation of the Effect Known as Electrothermal Pyrolysis
Steve R. Fuller, M.J. Taylor, QinetiQ

2150 Determination of Force and Temperature Impact on Missile's Fuel Charge in Process of Ignition
Dmitriy Orlov, GDT Software Group

2161 Unsteady Intermediate Ballistics: 2D and 3D CFD Modelling, Application to Sabot Separation
Roxan Cayzac, ***Eric Carette***, Giat Industries, Division Munitions; ***Thierry Alziary de Roquefort***, Université de Poitiers, Laboratoire d'Études Aérodynamiques; ***Philippe Bidorini, Emmanuel Bret, Pascal Delusier, Serge Secco***, DGA/ETBS, Direction de l'Expertise Technique

2166 Large Caliber Firing with Electro Thermal-Chemical Ignition (ETI)
Jonathan D. Shin, ***John J. O'Reilly, David T. Keyser***, US Army Research, Development and Engineering Center - TACOM; ***Jahn Dyvik***, United Defense L.P.

3006 Rail Gun Test Projectile for Improved Developmental Testing of Precision Munition Electronics
T. Myers, D. Carlucci, J.A. Cordes, US Army ARDEC, Analysis and Evaluation Division, Fuze and Precision Munitions Technology Directorate

4010 Improved Mortar Barrel Thermal Model
M. Pocock, C. Guyott, Frazer-Nash Consultancy Ltd; ***P. Locking***, BAE Systems, Land Systems

Vulnerability/Lethality/Wound Ballistics Poster Session
10:20 am - 12:00 pm November 17

1855 On Incorporating XCT into Predictive Ballistic Impact Damage Modeling
Joseph M. Wells, JMW Associates

1878 New Soft-Target Failure Criteria for System-Analytical Considerations
Markus J. Estermann, RUAG Defence, Warhead Division; ***Beat P. Kneubuhl,*** Aramasuisse

1941 Protecting Vehicles from Landmine Blasts
Sheri L. Hlady, Denis Bergeron, Defence R&D Canada – Suffield; ***Rene Gonzalez***, US Army, PM Light Tactical Vehicles

1957 Office of Naval Research Limb Protection Program
Graham K. Hubler, NRL

1980 Survivability and Lethality Assessment Software Based on Virtual Mode Technology
Lu Yonggang, Qian Lixin, Yang Yubin, Liu Tong, Institute of Structural Mechanics, CAEP

1981 "TBM-Xpert" - A New Endgame Code: Features and Validation
Werner Arnold, EADS-TDW Gesellschaft für verteidigungstechnische; ***E. Rottenkolber***, NUMERICS GmbH

1989 The Use of Ballistic Knowledge in Ammunition Safety Cases
Martin van de Voorde, TNO Defence, Safety and Security

2011 A Note on the Roecker-Ricchiazzi Model of Penetrator Trajectory Instability
William J. Flis, DE Technologies, Inc.

2022 Numerical Calculation and Simulation of Missile Jet-Airplane Interaction
Feipeng Zeng, Faculty of Artillery Command, Nanjing Artillery Academy

2111 Need for Enhanced Protection Against Blast Threats for Soldiers Exposed to Roadside Improvised Explosive Devices (IEDs)
François-Xavier Jetté, Jean-Philippe Dionne, Aris Makris, Med-Eng Systems, Inc.; ***Karl Masters***, PEO Soldier; ***Christine Perritt,*** PM Soldier Equipment

2119 WitnessMan: *The* Software Tool to Design, Analyse and Assess a Witness Pack with Respect to Military and Medical Effects on an (Un)protected (Dis)mounted Soldier.
Theo L.A. Verhagen, R. Kemper, H. Huisjes, S.G. Knijnenburg, A. Pronk, M.H. van Klink, TNO Defence, Security and Safety

2154 Injury Risks Resulting from Deminer Position
François-Xavier Jetté, Jean-Philippe Dionne, Ismail El Maach, Aris Makris, Matt Ceh, Med-Eng Systems, Inc.; ***Denis Bergeron***, Defence R&D Canada Suffield

2163 RPG Mitigation for Military Vehicles
Karl Pfister, Dipl. Ing (FH) Armatec Survivability Corporation

2164 Protection Against Closely-Spaced Impacts by Small Arms Bullets
Michael J. Iremonger, Cranfield University, Royal Military College of Science; ***Abdullah Alsalmi***

3013 Vulnerability Evaluations of 30mm Airburst Ammunition
Quoc Bao Diep, ***Eimund Smedstad***, Nammo Raufoss AS; ***Nick Rogers***, System Design Evaluation (SDE)

3018 Challenges and a Solution in Determining Land Mine or IED Neutralization Effectiveness
Robert Colbert, Mark Majerus, William Clark, DE Technologies, Inc.

4011 Numerical and Experimental Analysis of the Detonation of Sand-Buried Mines
N. Heider, A. Klomfass, Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut

The symposium registration fees are:

	Regular	Late/Onsite after 10/28/05
	$950 (US)	$1045 (US)
IBC Committee Appreciation Dinner	$75 (US)	
Guest at Both Receptions	$75 (US)	
Guest at One Reception	$50 (US)	

The symposium registration fee includes attendance at all sessions, bound symposium proceedings with CD, continental breakfasts, coffee breaks, lunches, receptions, and administrative costs. The registration fee will also include a compact disc (CD) which contains a cumulative database of titles, authors and abstracts of all of the 22 Ballistics Symposia.

To register online for this conference visit: http://register.ndia.org/interview/register.ndia?~Brochure~6210. You can also visit the NDIA website at www.ndia.org and select "Schedule of Events". Then select 2005 November and scroll down to the 22nd International Symposium on Ballistics. Once there, select the blue "Register" link in the lower left hand corner of your screen. Review your information and then select "submit" one time only and then select "confirm". On-line registration will close at 5:00 pm EST on October 28, 2005. You must register on-site after this date.
-or-
You may fax the completed registration form contained in this brochure to (703) 522-1885.
-or-
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Registrants who cannot attend the 22nd International Symposium on Ballistics must provide written notification via email to bbommelje@ndia.org or fax to (703) 522-1885 on or before September 16, 2005 to avoid a cancellation fee.

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You must have a government picture identification (drivers license, passport, military ID, etc.) to receive a symposium badge. Badges must be worn at all times during the symposium.

Special Needs
NDIA supports the Americans with Disabilities Act of 1990. Attendees with special needs should call (703) 522-1820 prior to October 3, 2005.

Hotel Accommodations
A limited block of rooms have been reserved at the Fairmont Waterfront Hotel. The industry room rate is $219 Canadian (approximately $180 US). The government symposium room rate is approximately $114 Canadian ($94 US). Please call (604) 691-1991 to make reservations.

In order to ensure the discounted NDIA rate, please make reservations early and ask for the NDIA room block. Rooms will not be held after Tuesday, October 11, 2005 and may sell out before than. Rates are also subject to increase after this date.

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GENERAL INFORMATION

Symposium Attire
Appropriate dress for this symposium is business for civilians (coat and tie) and class A uniform for military.

Inquiries
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IBC Committee Appreciation Dinner
The IBC Committee Appreciation Dinner will be held on Friday, November 18, 2005 in Vancouver. This dinner is open to IBC Committee members and their guests only. If you and your guest would like to attend, please make a note of it on the registration form. There is a $75 charge per person to attend.

"The Department of Defense finds this event meets the minimum regulatory standards for attendance by DoD employees. This finding does not constitute a blanket approval or endorsement for attendance. Individual DoD component commands or organizations are responsible for approving attendance of its DoD employees based on mission requirements and DoD regulations."

22nd International Symposium on Ballistics
Vancouver Convention Center ~ Vancouver, BC, CANADA
November 14-18, 2005
Event # 6210

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22nd International Symposium on Ballistics

Vancouver Convention Center
Vancouver, BC, CANADA
November 14-18, 2005

The objective of the 22nd International Symposium on Ballistics is to focus on potential technical advances and break-throughs in the 21st century in the general area of: interior ballistics, launch dynamics, exterior ballistics, projectile and warhead design, vulnerability, wound ballistics, and armored and personal protection. The symposium is an opportunity for ballistic scientists, engineers and others to report, share and discuss current research and advances in ballistics and visions of the future.

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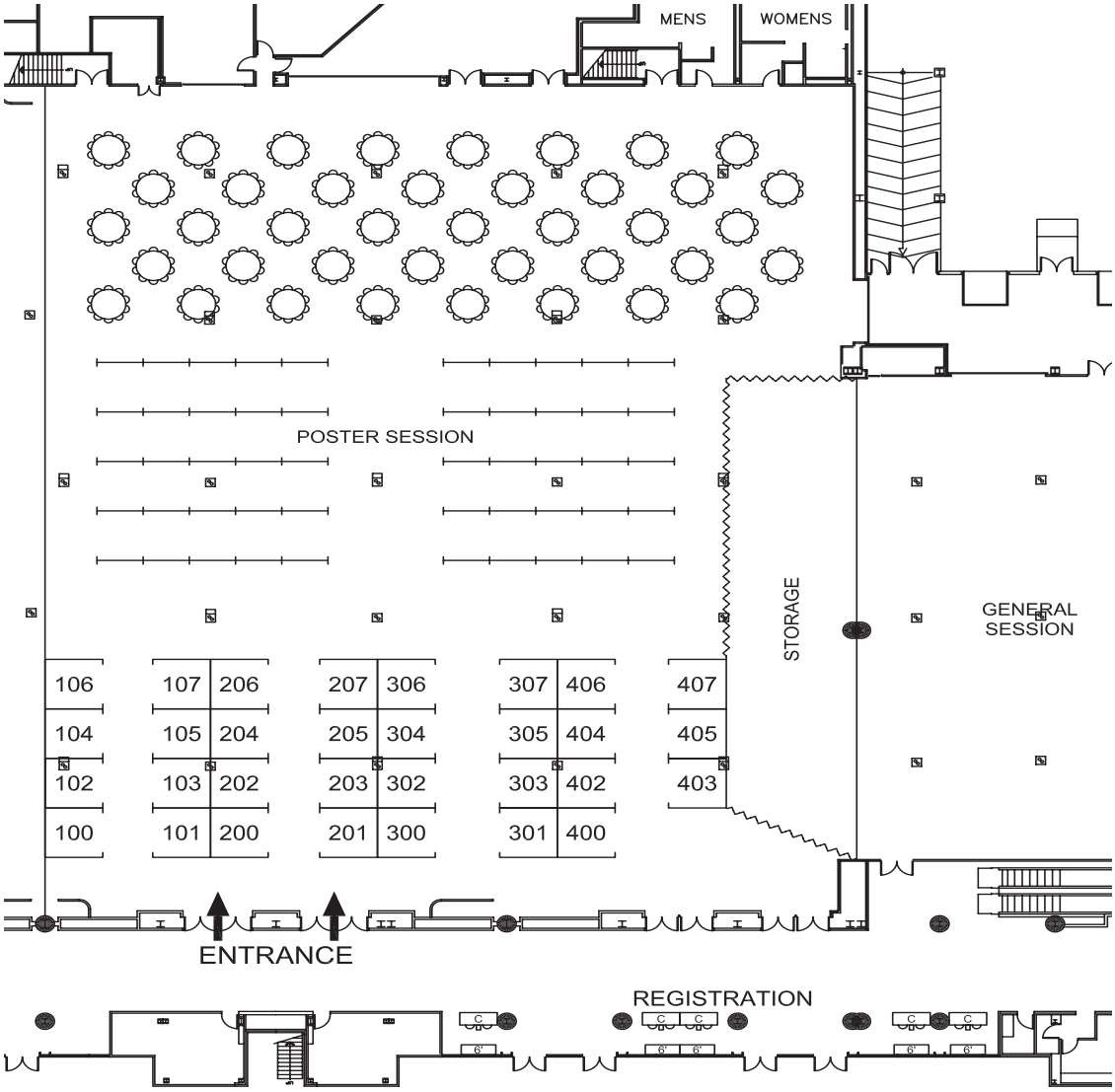

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Tentative Exhibit Schedule*:

Monday, November 14: 4:00pm - 7:30pm
Tuesday, November 15: 7:00am - 6:00pm
Wednesday, November 16: 7:00am - 5:00 pm
Thursday, November 17: 8:00am - 11:00am
Friday, November 18: 8:00am - 11:00am

**Show days only. Does not include move-in and move-out. For complete exhibit schedule go to http:exhibits.ndia.org.*

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Questions? Contact Tina Lynn Mercardo at TMercardo@ndia.org or 703-247-2582

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Vancouver Convention Center
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	Regular	Late *after 10/28/05*
All Attendees	$950	$1045
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Contact info

- Larry Burton
- 410-306-0767
- U.S. Army Research Laboratory
- coach@arl.army.mil

Ceramic Gun Barrel Technologies

Larry Burton

Jeff Swab

Rob Carter

Ryan Emerson

U.S. Army Research Laboratory

Weapons & Materials Research Directorate

Ceramic Materials

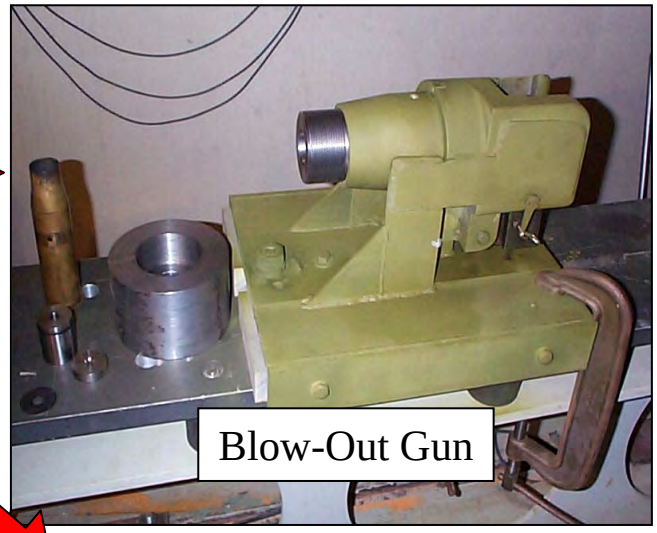
Material	Vendor	Vendor Code	ARL Code	Density (g/cm^3)
Al_2O_3	CoorsTek	AD995	ALOX	3.8
ZrO_2	CoorsTek	Ce-TZP	ZRO2	6.1
SiC	Saint-Gobain	Enhanced Hexoloy SA	SCEH	3.1
SiC	Saint-Gobain	LPS Hexoloy SA	SCLH	3.1
SiC	Ceradyne	146-5S	SC46	3.1
Si_3N_4	Ceradyne	147-31N	SN47	3.2
Si_3N_4	Kyocera	SN235P	SN5P	3.2
SiAlON	Kennametal	TK4	STK4	3.4

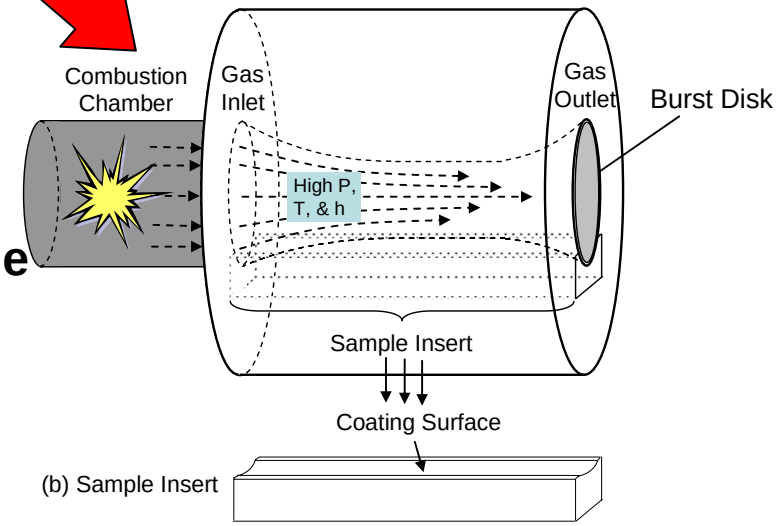
- **Eight candidate materials were chosen from commercial vendors**
  - **All materials are off-the-shelf technologies**
  - **No material development was planned for this ATO**
- **Extensive test matrix developed to characterize the mechanical and thermal properties of each material**

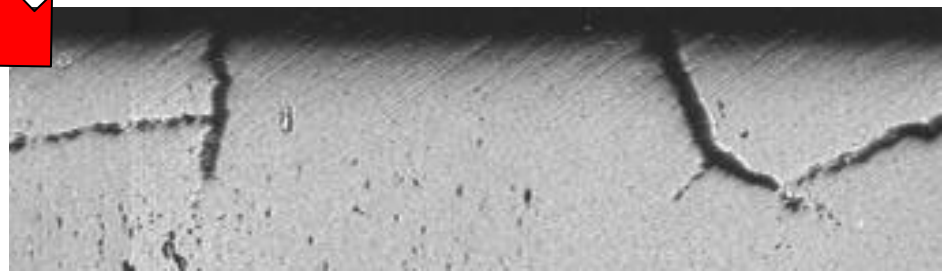
Erosion and Damage Tests

Different simulators used to test the erosion resistance of ceramics

- **Blow-out Gun – ARL**
  - **Extreme condition erosion test**
- **Closed Bomb Test – ARL**
  - **Examine propellant gas-ceramic chemical interactions**
- **Vented Erosion Simulator (VES) Test– Benet Laboratories**
  - **Simulates the IB conditions seen in a 120mm system**
- **Pulsed Laser Heating Test – Benet Laboratories**
  - **Capable of inducing thermal shock damage similar to that created during an IB event**



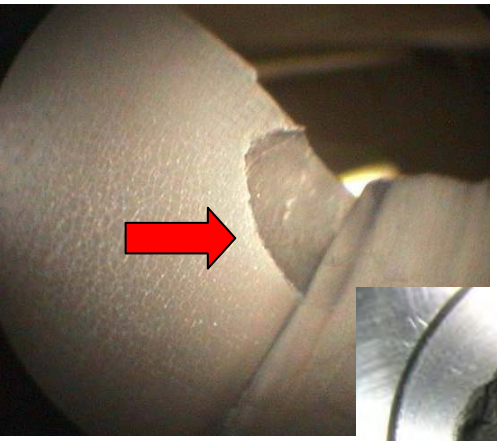


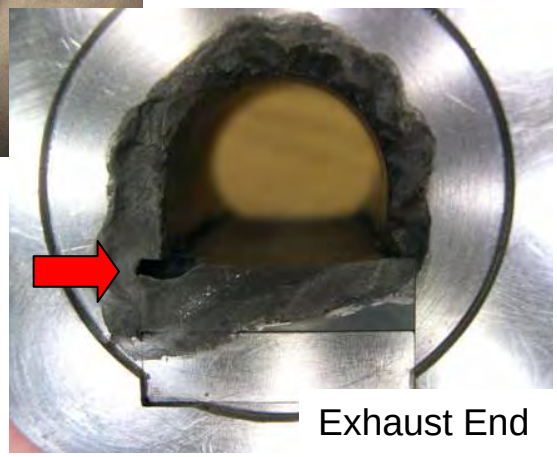


VENTED EROSION SIMULATOR

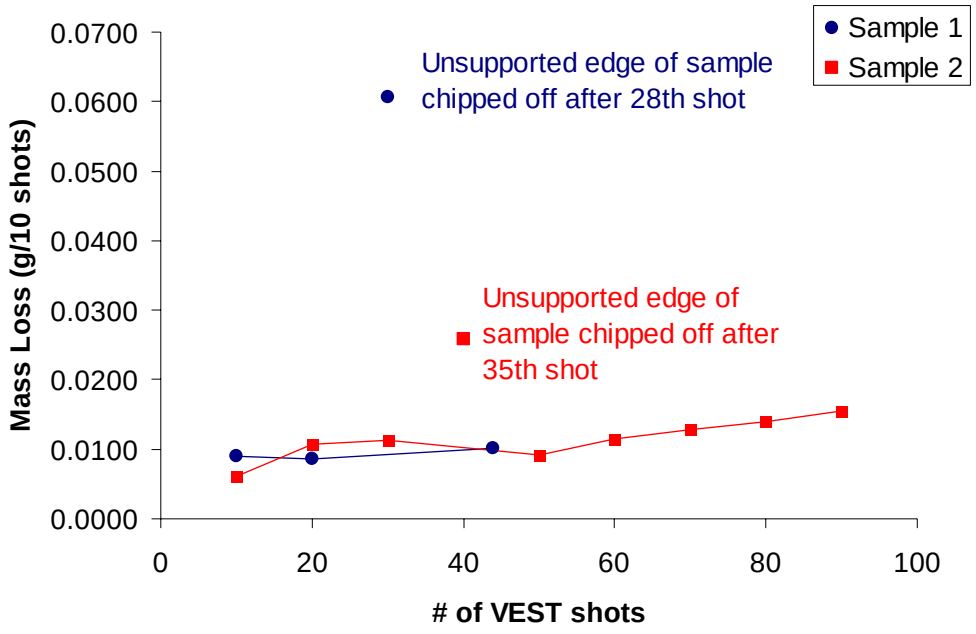
Simulates erosive environment of a Large Caliber tank gun

- SN5P scheduled to be exposed to 100 rounds
- Mass loss determined after every 10 rounds
- Terminated after 44 and 94 rounds due to potential damage to the VES fixtures *NOT because of damage to the ceramic*





Exhaust End



Erosion Summary

- Si_3N_4 and SiAlON performed well in all tests
  - Lower mass loss per shot than gun steels
  - Exhibited some fracturing
    - Not unexpected since all fixtures were originally designed for steel samples with no modifications made for the ceramic samples
    - Damaged VES samples did not exhibit an accelerating erosion rate
- SiC and Al_2O_3 showed significant mass loss due to fracture
- ZrO_2 exhibited extensive damage & accelerating mass loss

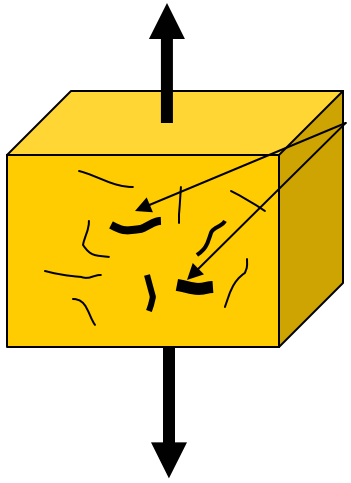
Low erosion rates make ceramics attractive as gun barrel materials

However, ceramics are hindered by brittle facture, low fracture toughness, and highly variable tensile strength

- Need new modeling and failure prediction approaches to design a ceramic lined barrel.
- Require methods for imparting high compressive prestress

Modeling Brittle Failure

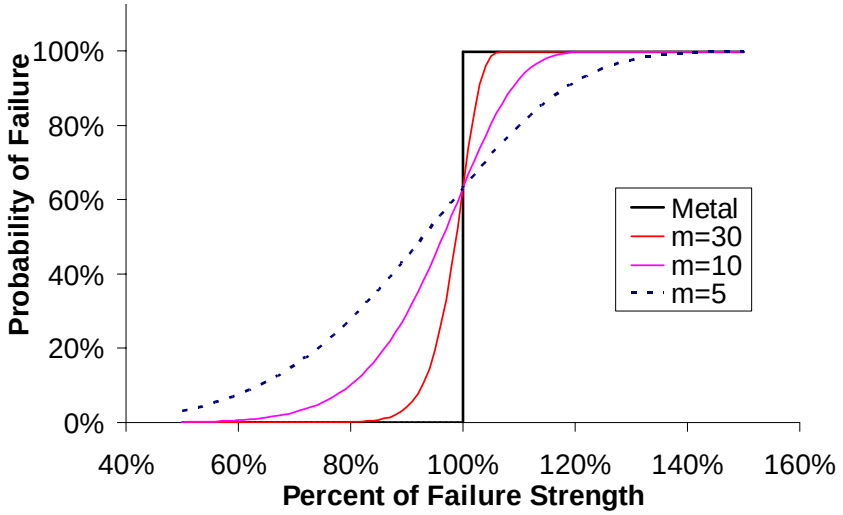
- **Ceramics can support tensile load, but are subject to large scatter in the observed strength**
- **Brittle material design requires a change from the *deterministic methods* used in metals to a *probabilistic approach*:**
  - **Failure initiated at random flaw sites scattered throughout the material**
  - **Failure strength for each sample determined by the stress exceeding the strength at a critical flaw**
- **Weibull statistics are used incorporate this information into design parameters**



Inherent flaws are undetectable and potential failure sites

$$P_f = 1 - e^{-\int \left(\frac{\sigma}{\sigma_o} \right)^m dV}$$

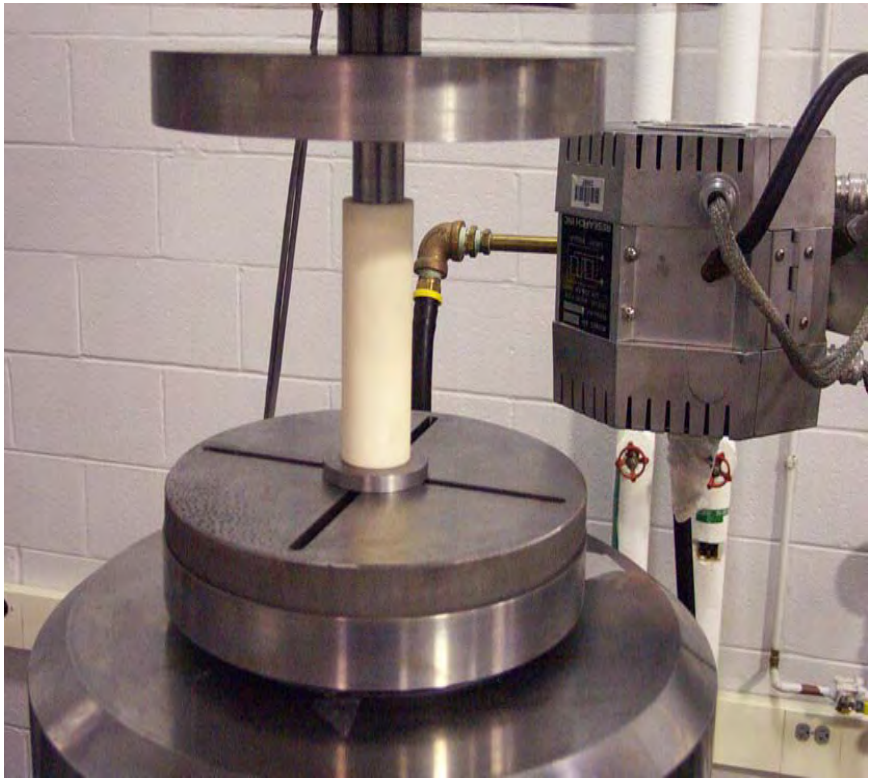
P_f = Weibull Probability of Failure
σ = Applied Stress
σ_o = Characteristic Strength
m = Weibull Modulus



Internal Pressure Testing

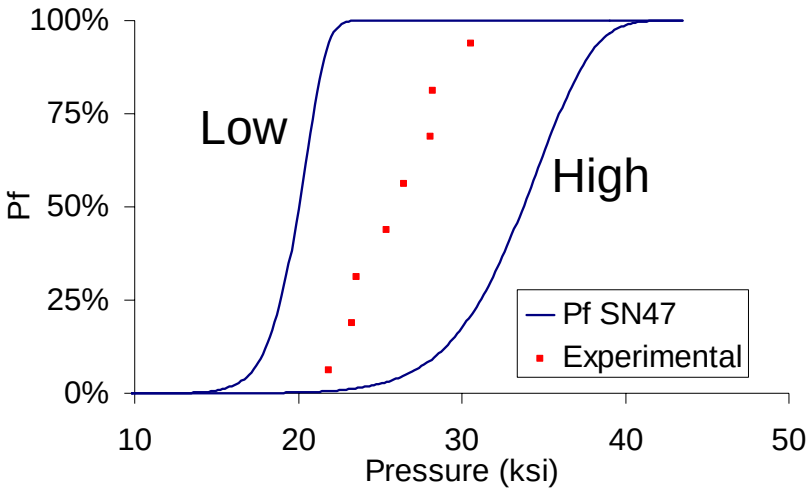
Experimental Data and Model Predictions

- Ceramic tubes tested by internal pressurization
- Model predictions based on measurements for the strength of different flaw populations
  - Uniaxial tension to determine the volumetric flaws
  - C-ring tests the outer surface flaws
- A lack of data on the inner surface flaws - *they are presumed to be identical to the outer surface flaws*
  - This leads to two different predictions for the following plots
    - High - the predicted strength for volumetric flaws only
    - Low - the predicted strength for volumetric and surface flaws

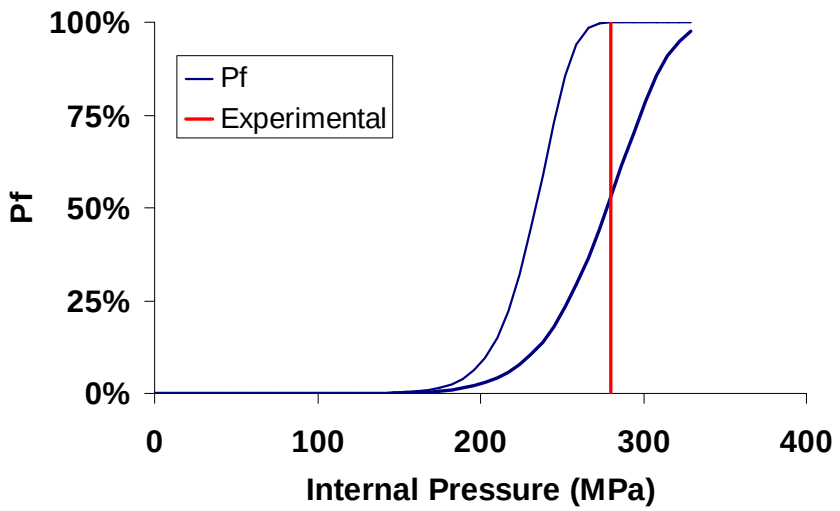


Model Predictions

SN47 Unsheathed



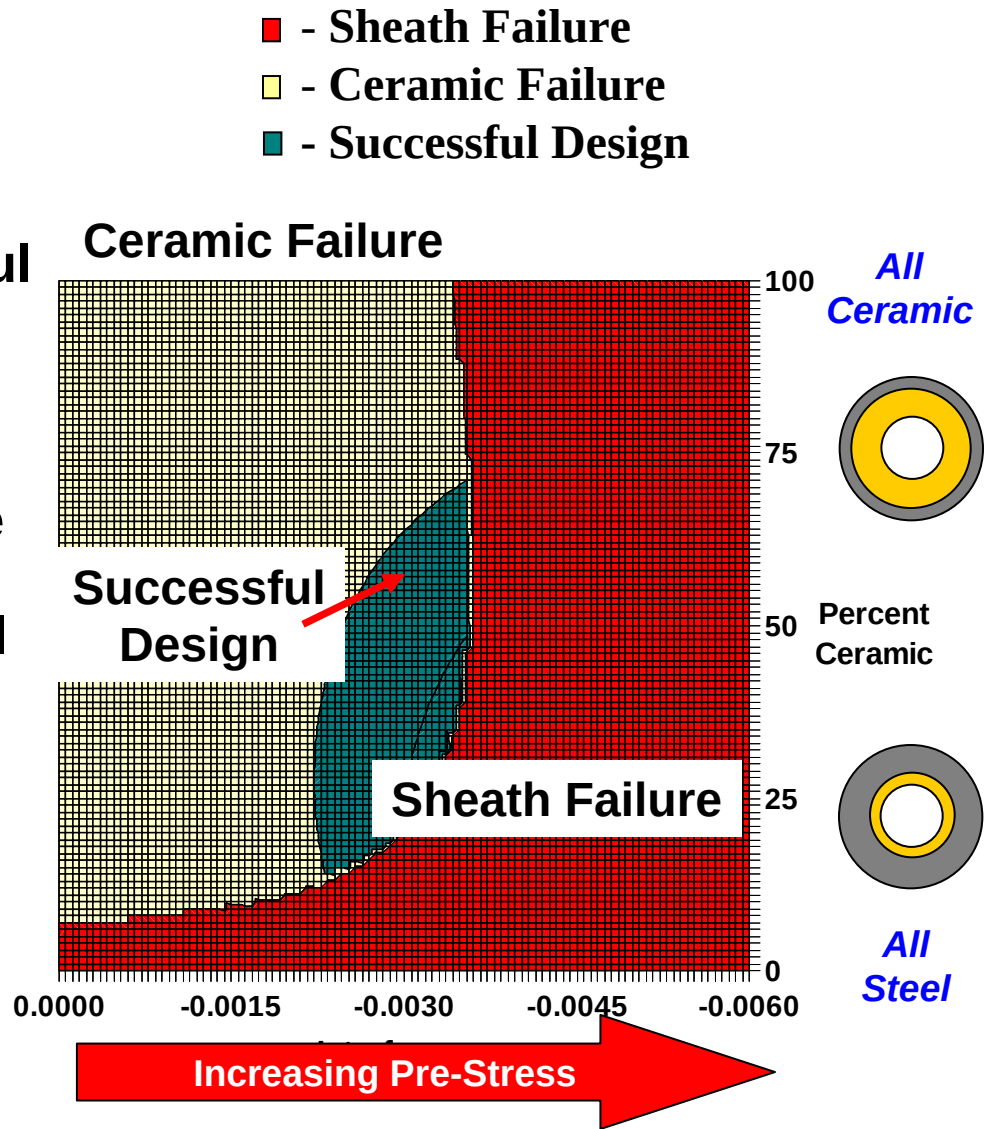
SN47 + Composite Sheath



- **Calculated failure pressure ranges bracket the experimental values**
- **The model predicts ranges for both unsheathed and sheathed tubes**

Failure Surface Plots

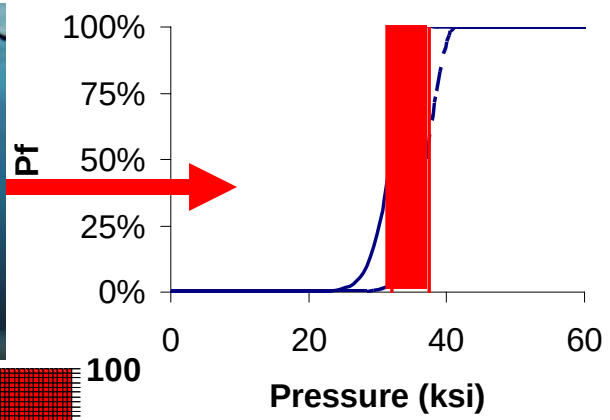
- Experimental data supports model predictions
- The next step is to apply the model to search for successful designs for different gun/cannon tubes
- Failure surface plots illustrate the effects of varying ceramic thickness and pre-stress level for a pressurized tube
- Provides quick approach for visualizing 10,000 different design concepts

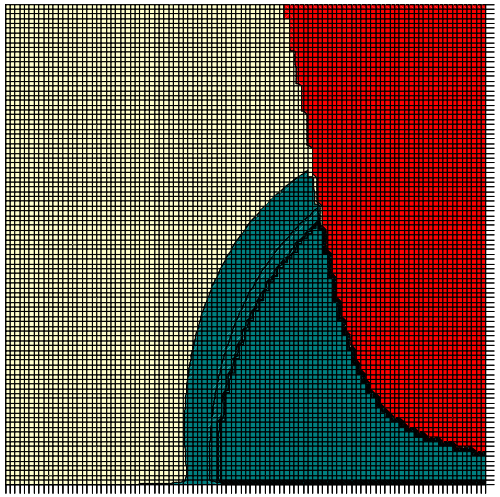


Probabilistic Modeling Summary

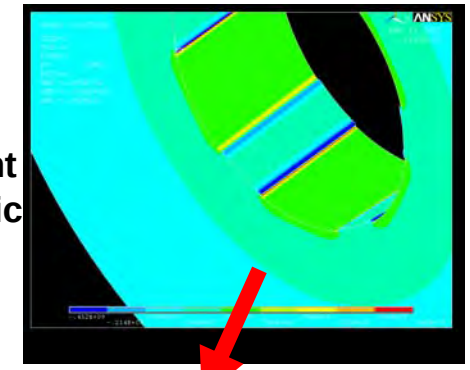
Validated probabilistic modeling capability for predicting the strength of ceramic lined gun tubes has been coupled with FEA models to assess:

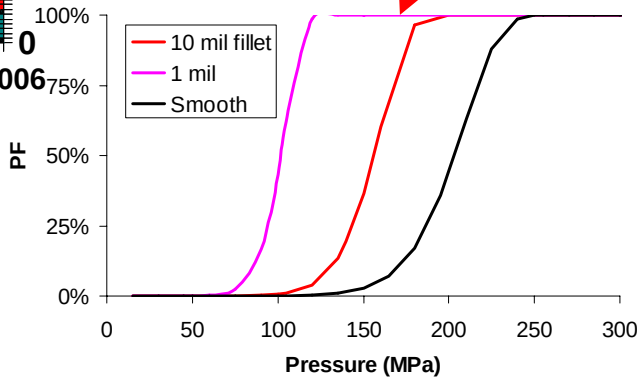
- Transient thermal behavior
- Thermal shock on the bore surface
- Dynamic thermo-mechanical loading
- Rifling/engraving
- Projectile/barrel interactions



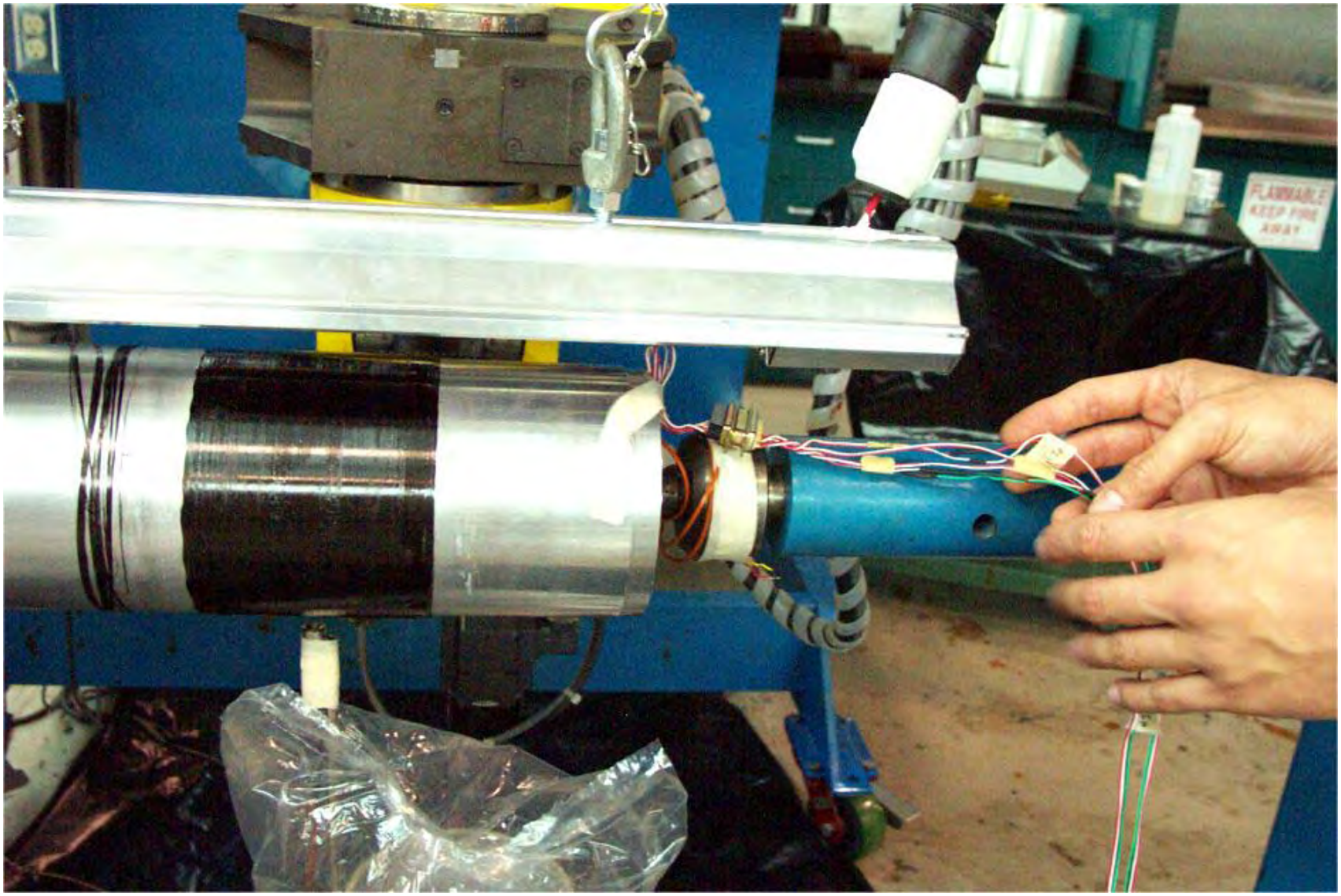


Percent Ceramic

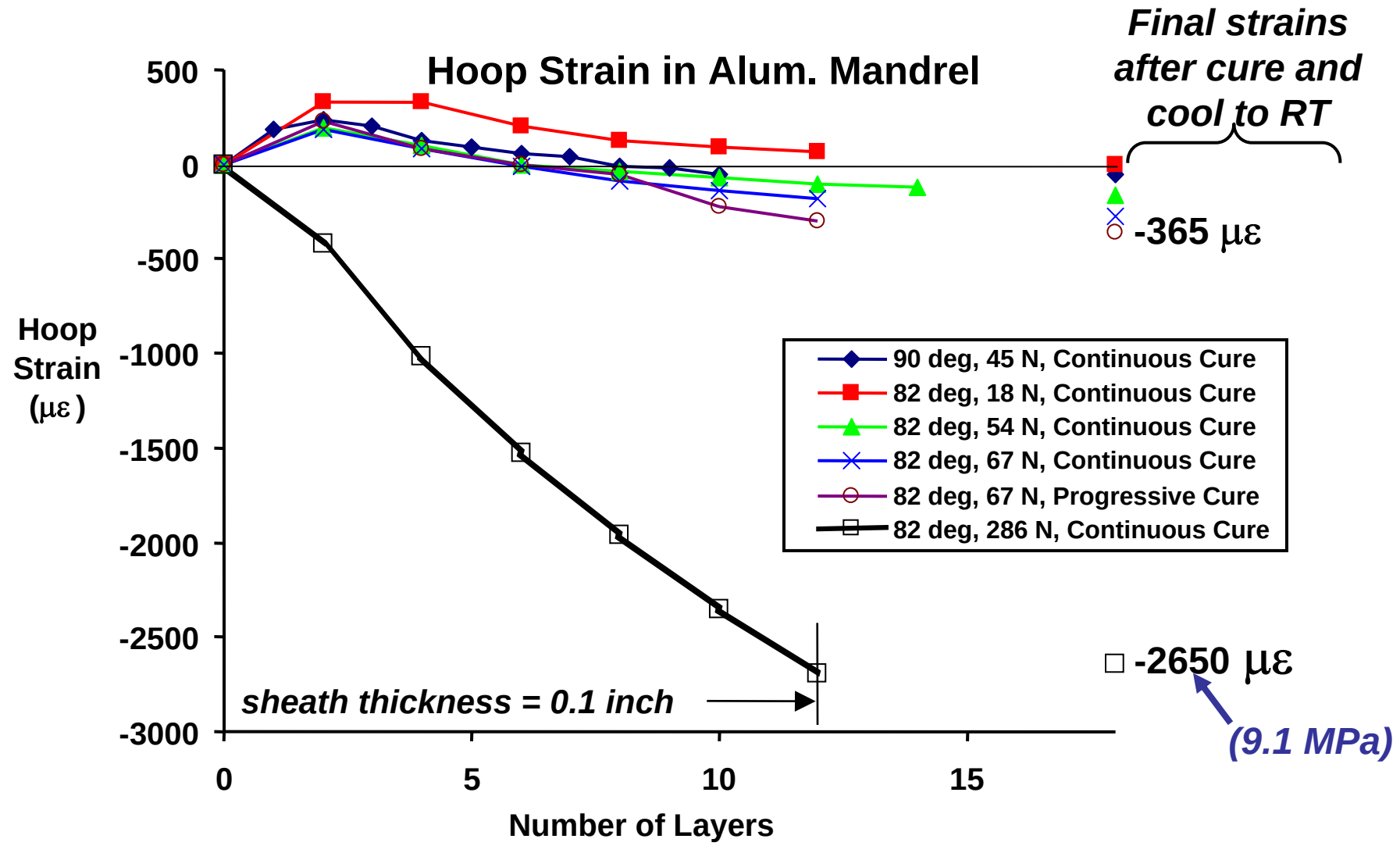




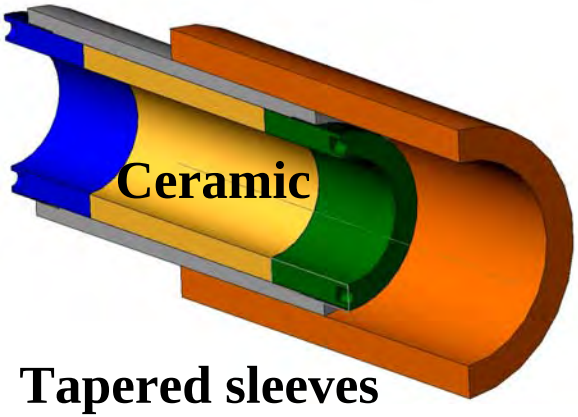
High-Tension Winding



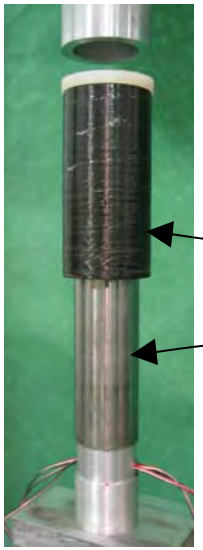
High-Tension Winding Results

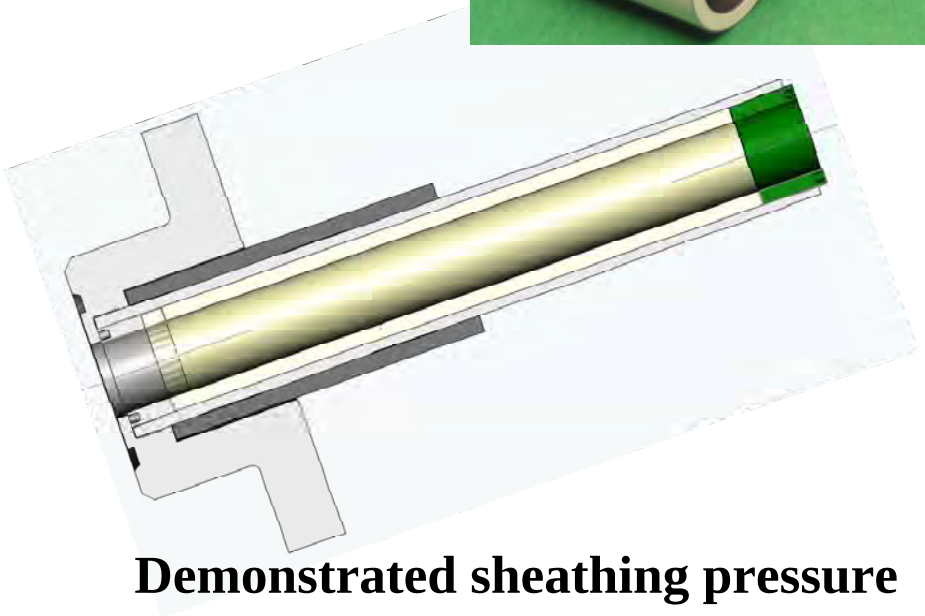


Multiaxial Sheathing

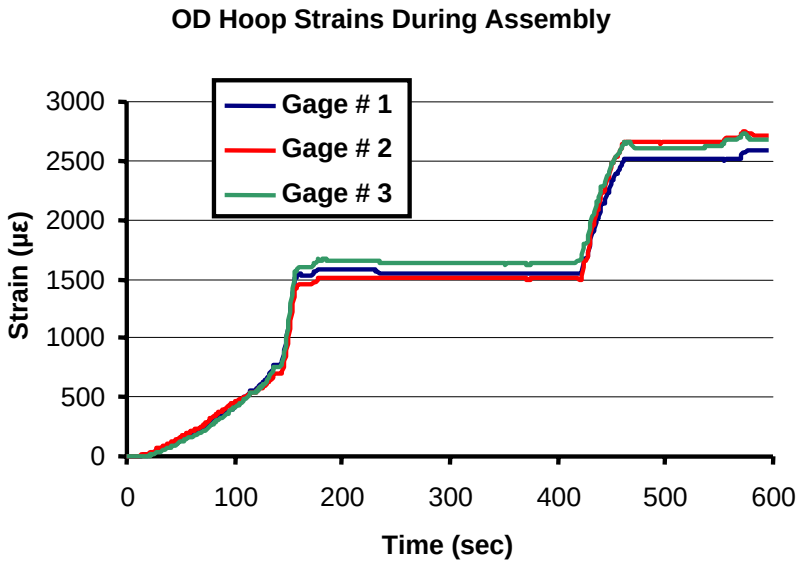


Tapered sleeves for press-fit

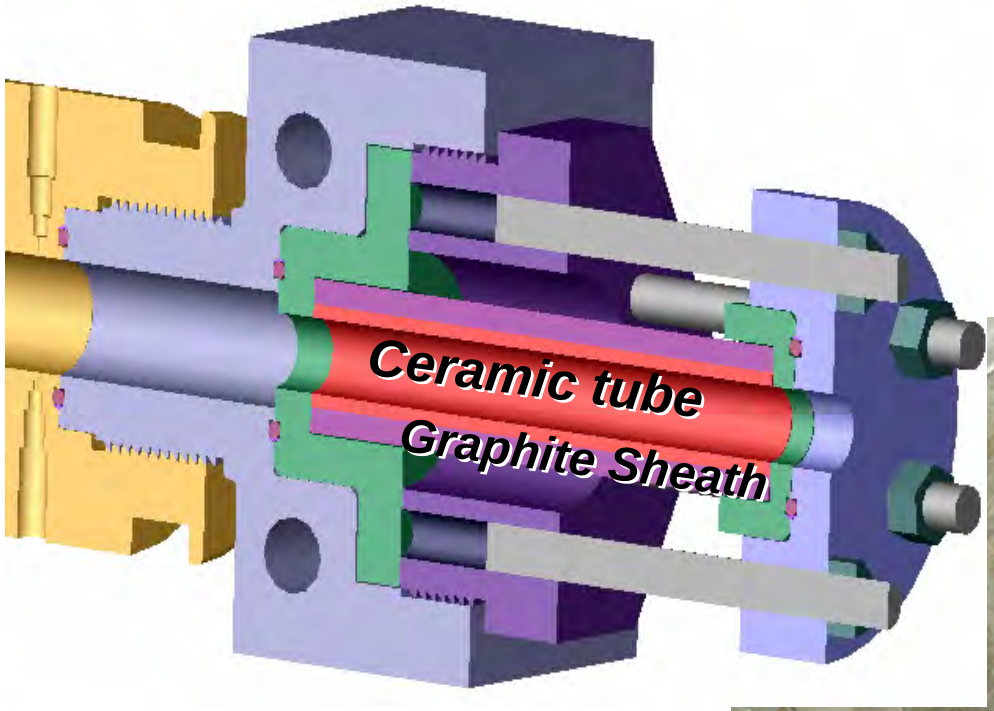




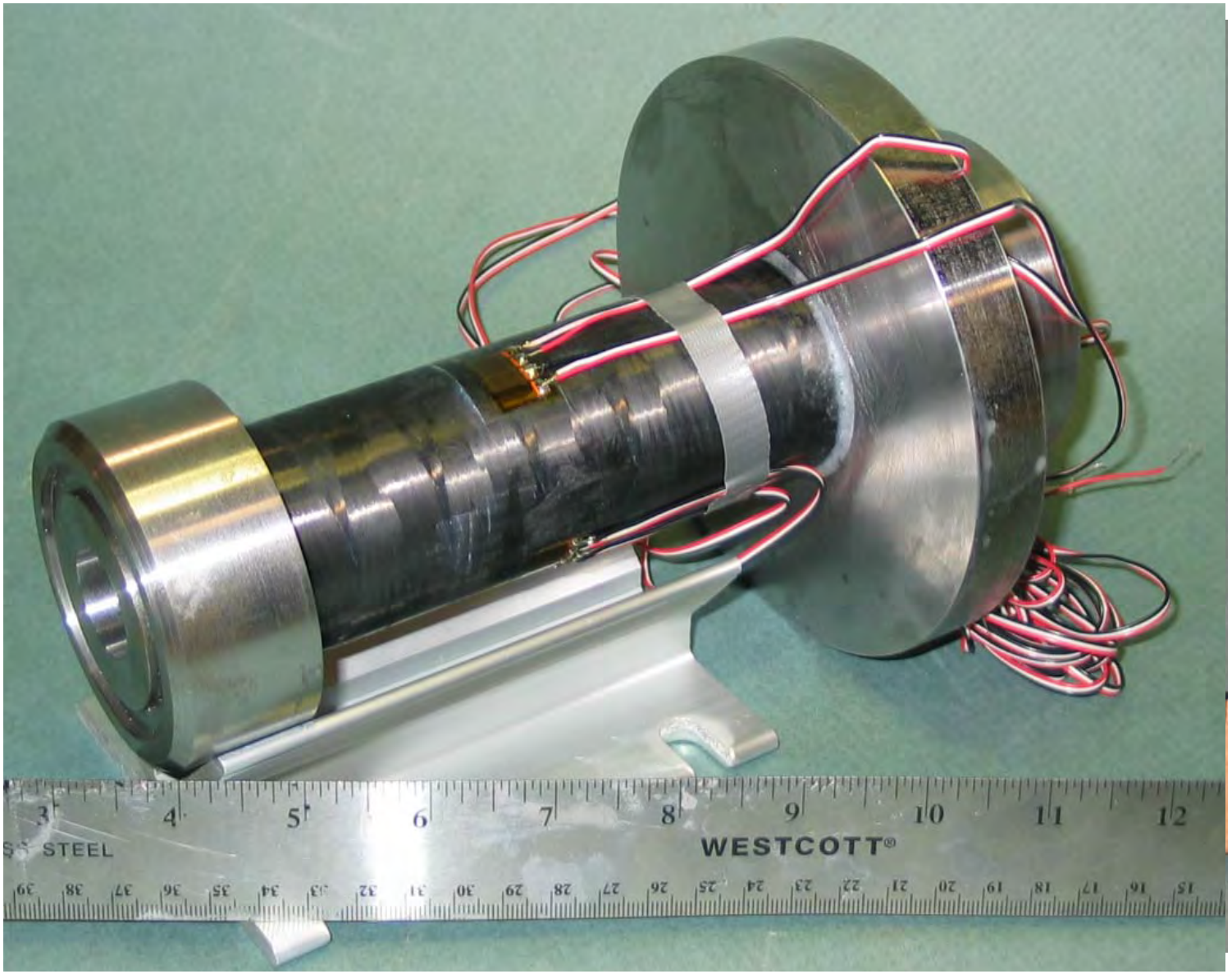
Demonstrated sheathing pressure in excess of 200MPa



Ballistic Test Fixture



Ballistic Specimens



Firing History & Plans

- Four Si_3N_4 tubes with high-tension wind
  - Maximum pressure achieved ~45 ksi
  - Ceramic tubes crack but failure is not catastrophic
- Two SiAlON tubes with high-tension wind
  - Maximum pressure achieved ~25ksi
  - Issues with tube concentricity and the firing fixture have limited the achievable pressure
- Test of multi-axial confinement schemes planned by year end

Conclusions

- Identified commercially available ceramics for ceramic-lined gun barrel application
- Developed a probabilistic design approach to account for ceramic failure behavior
- Investigated robust sheathing schemes to provide the required level of compressive pre-stress
- Have conducted preliminary firing tests with 25-mm tubes achieving 45 ksi (in line with predicted limits of sheathing)

Future Challenges

- **Imparting rifling without degrading the performance of the ceramic liner**
- **Manufacturing of longer, straighter, more concentric tubes held to tight tolerances**

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Impact of Nose-Mounted Micro-Structures on the Aerodynamics of a Generic Missile

Dr. Daniel Corriveau

Flight Mechanics Group / Precision Weapons Section

22nd International Symposium on Ballistics

November 14-18, 2005

Defence Research and Development Canada

Recherche et développement pour la défense Canada

Canada

Presentation Overview

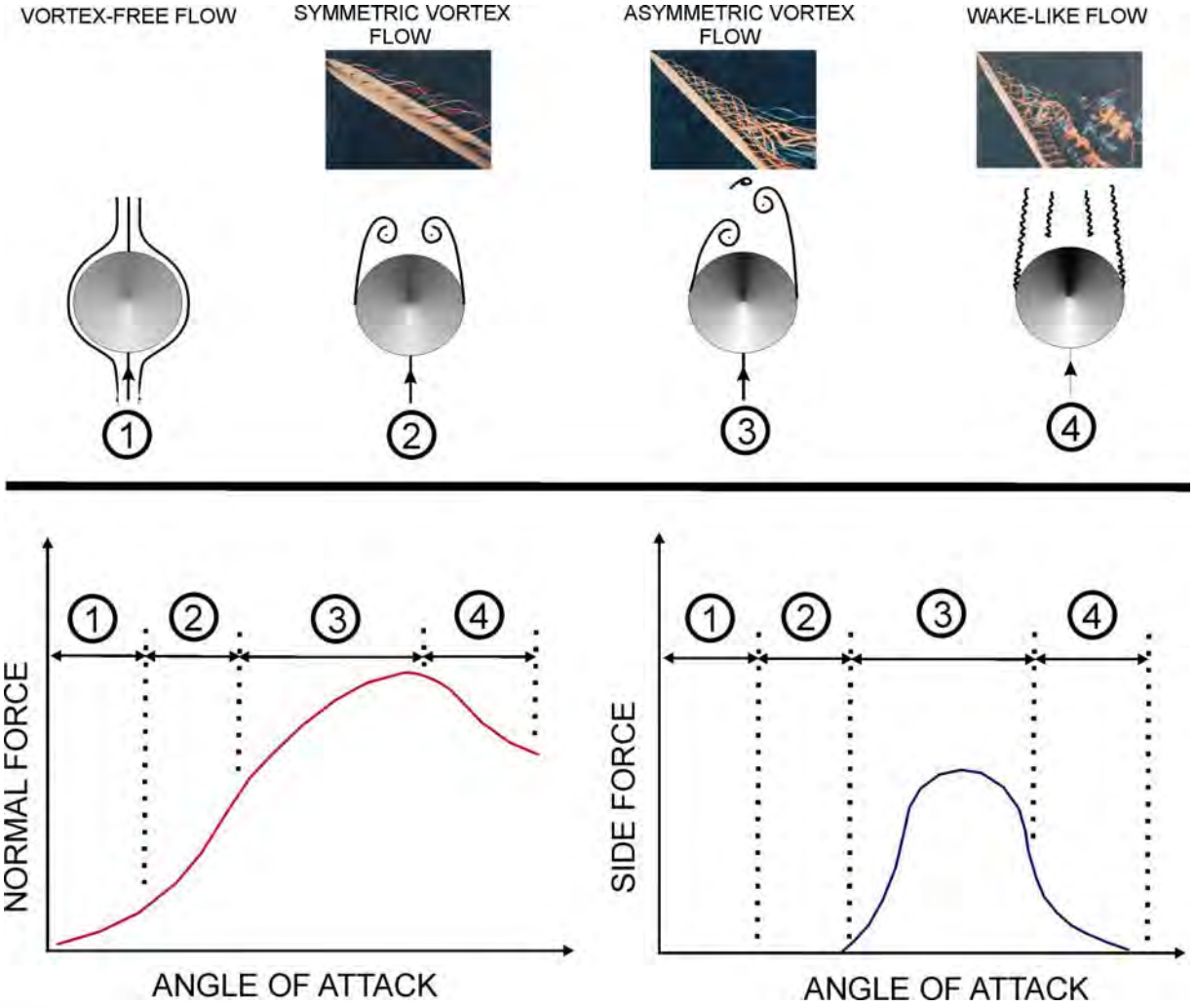
- Objectives
- Background
- Experimental apparatus
- Missile configuration
- Experimental results
- Conclusions

Objectives

- Determine: Optimum flow effector configurations
- Determine: Range of AOA for which a side force is generated
- Evaluate: Use of vortex-induced side force to achieve yaw control

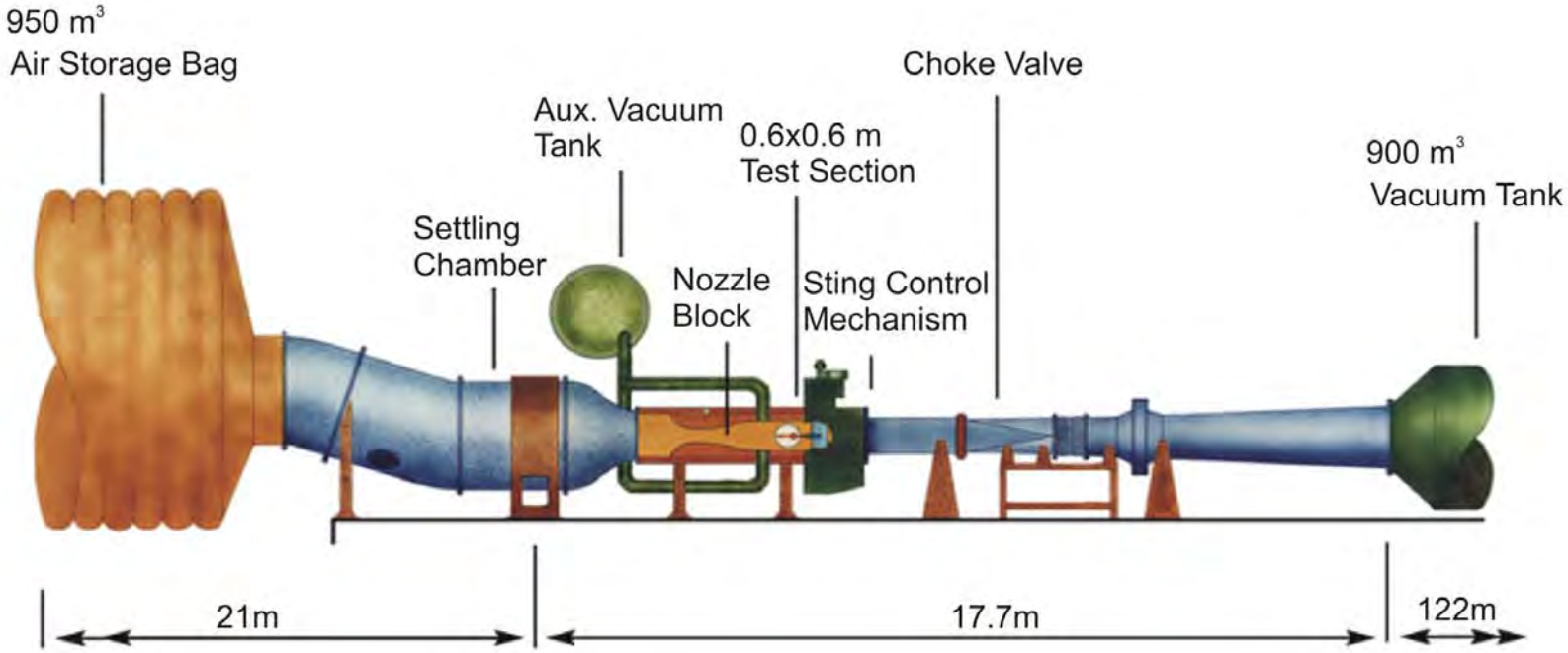
Background

Slender Body Vortex Shedding



Test Setup and Instrumentation

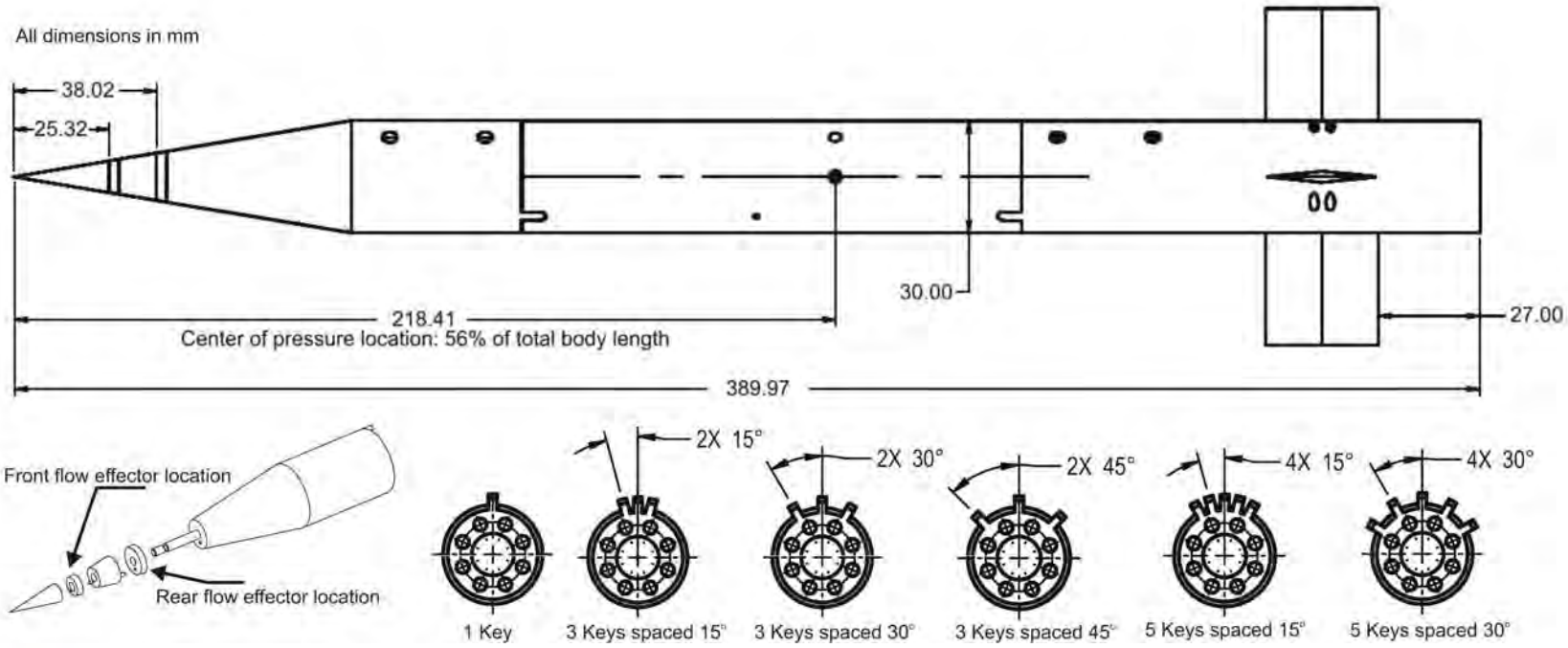
DRDC Trisonic Wind Tunnel



- Indraft wind tunnel
- Test section: 0.6m x 0.6m
- 0.2 < Ma < 4.0
- -20° < AOA < +20 °
- Test duration: 5 – 11 sec
- Turnaround time: 30 min.

Missile Configuration

Baseline Geometry With Conical Nose



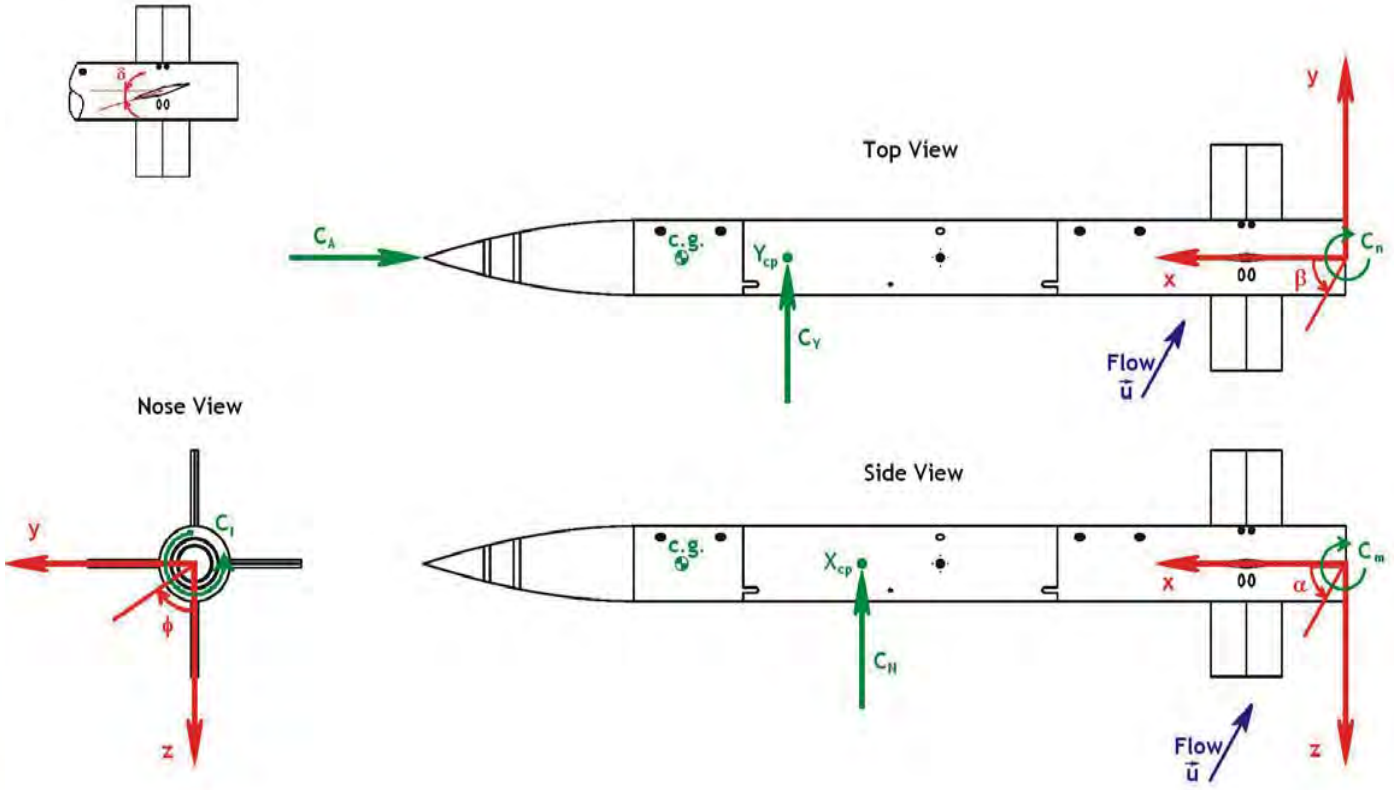
- Aspect Ratio L/D = 13.0
- Nose Aspect Ratio L_N/D = 3.0
- Conical Nose
- 4 Fins in + Configurations (Removable)

Missile Configuration

Baseline Geometry With Conical Nose

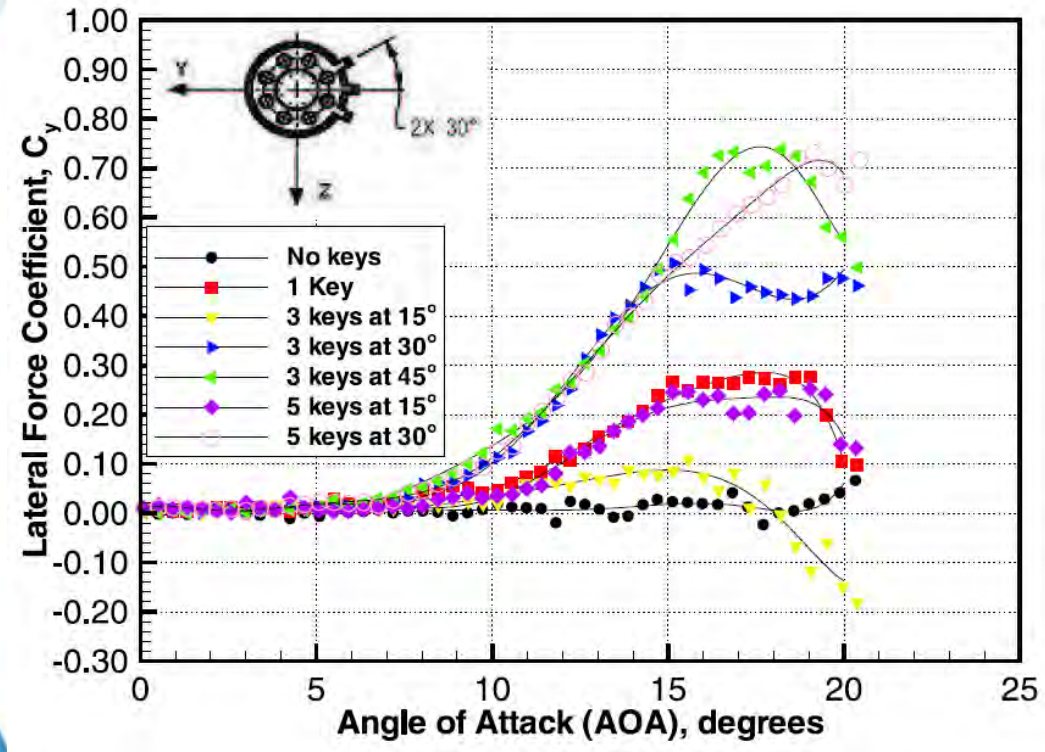
Missile Configuration

Nomenclature: North East Down Coordinate System



Experimental Results

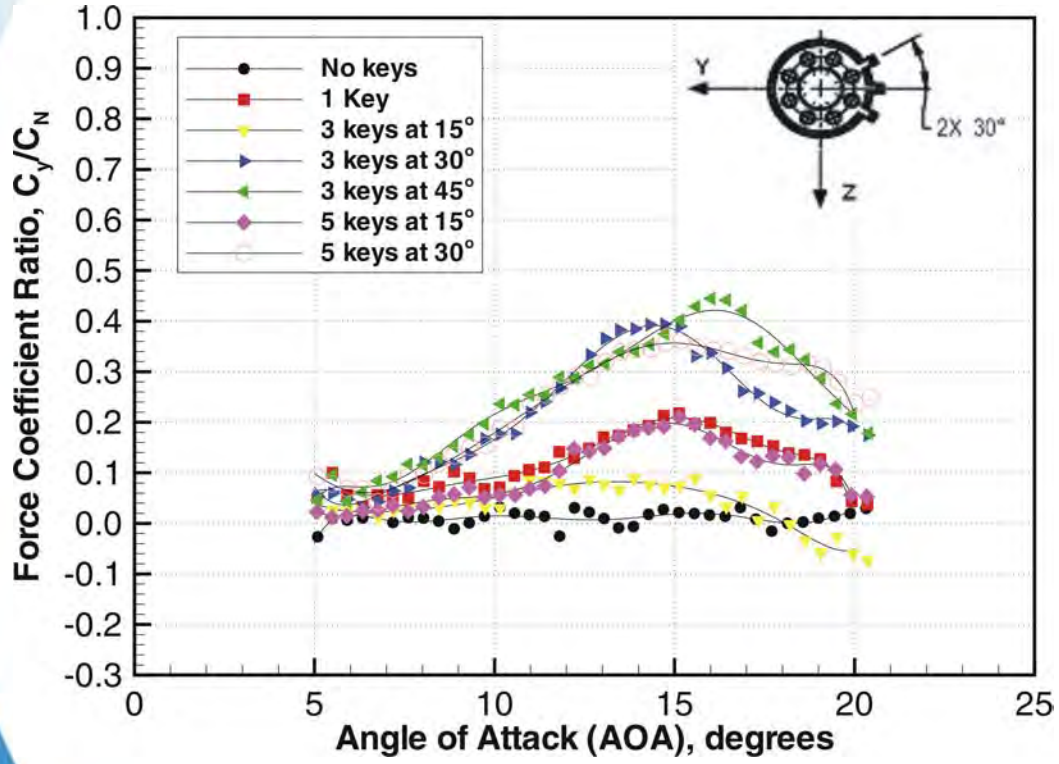
Lateral Force Coefficient vs AOA



- No fins
- Conical nose L_N/D= 3.0
- Flow effectors centered at 270°
- Front row
- Ma= 1.5
- Re/m= 15.2×10^6

Experimental Results

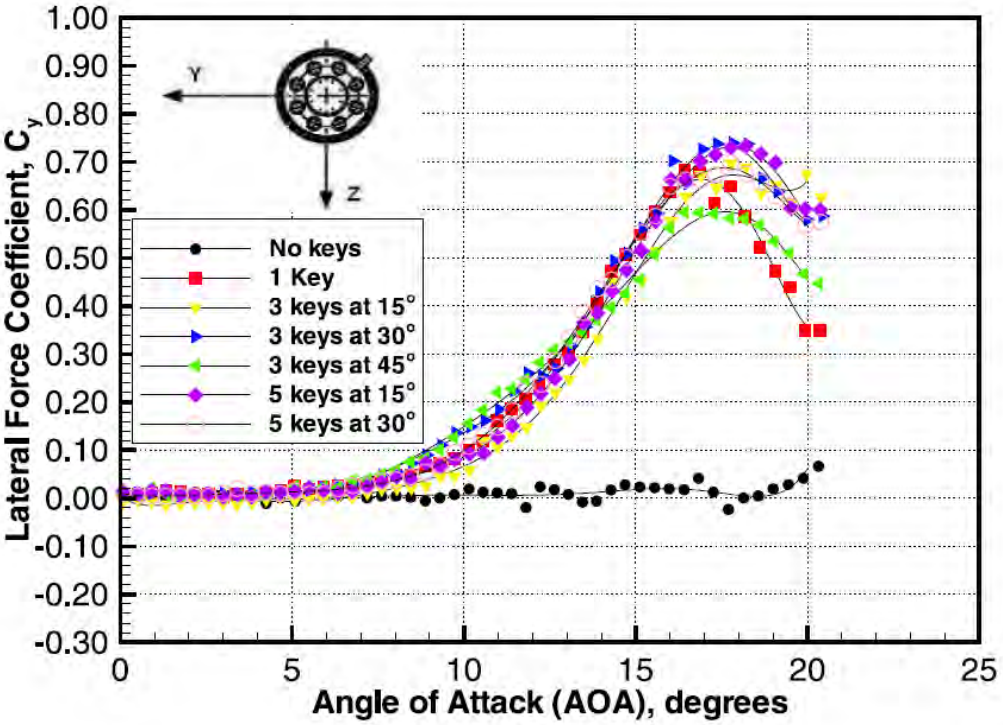
Lateral Force Coefficient vs AOA



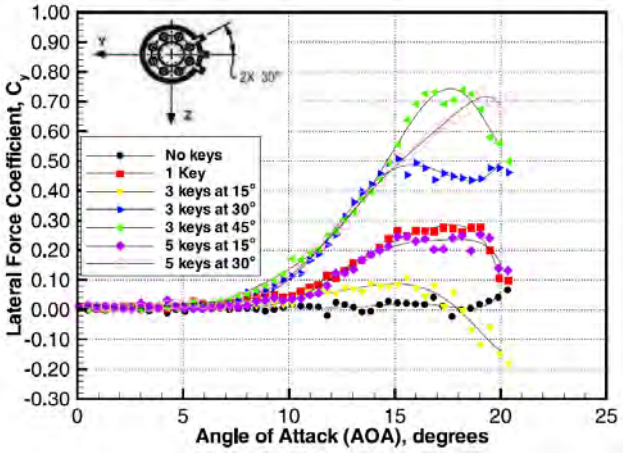
- **No fins**
- **Conical nose L_N/D= 3.0**
- **Flow effectors centered at 270°**
- **Front row**
- **Ma= 1.5**
- **Re/m= 15.2×10^6**

Experimental Results

Lateral Force Coefficient vs AOA

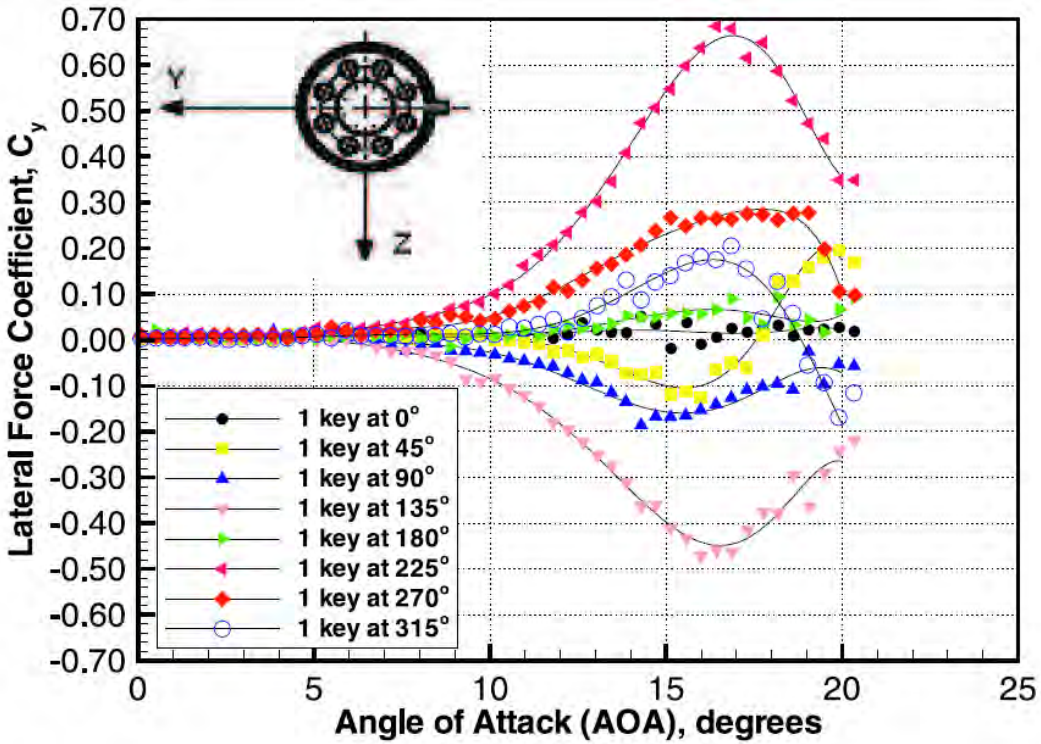


- No fins
- Conical nose L_N/D= 3.0
- Flow effectors centered at 225°
- Front row
- Ma= 1.5
- Re/m= 15.2×10^6



Experimental Results

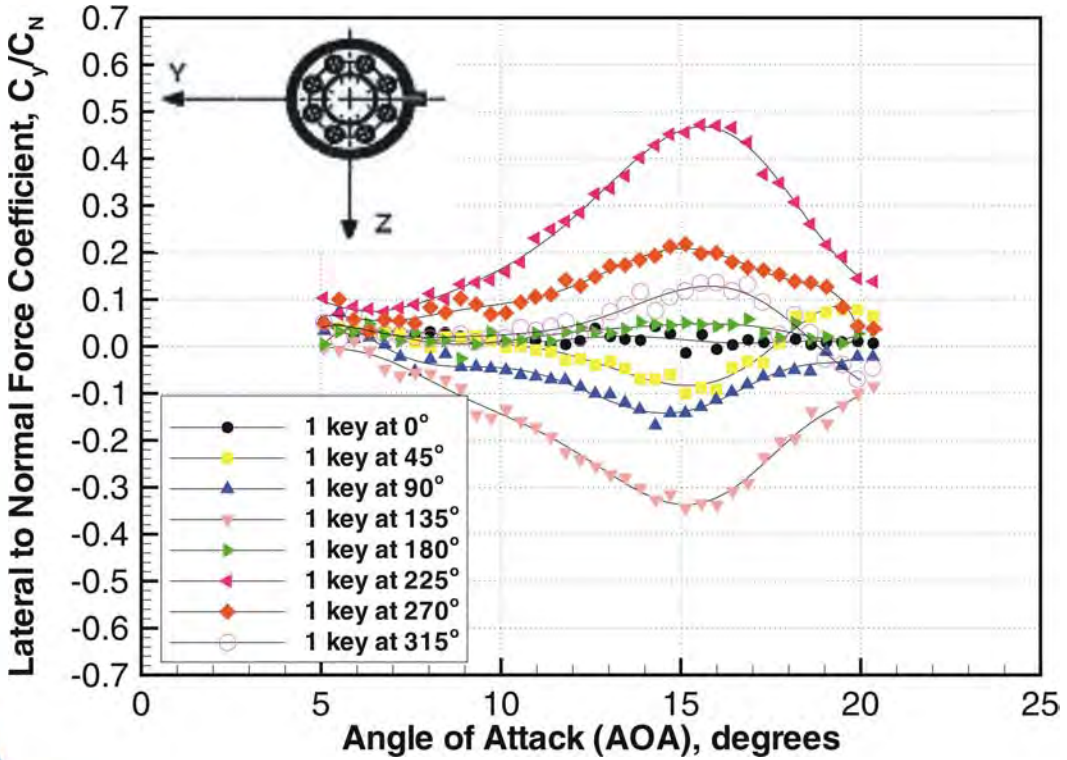
Lateral Force Coefficient vs AOA



- **No fins**
- **Conical nose L_N/D= 3.0**
- **Flow effector: 1 key**
- **Front row**
- **Angular position: 0° - 360°**
- **Ma= 1.5**
- **Re/m= 15.2×10^6**

Experimental Results

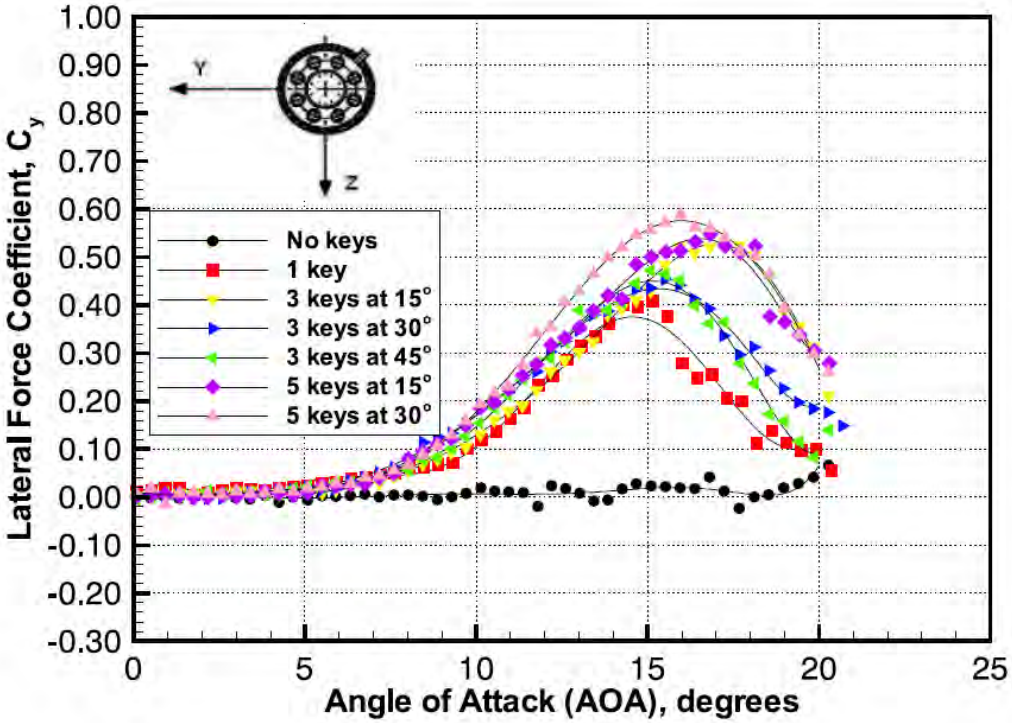
Lateral Force to Normal force Coefficient Ratio vs AOA



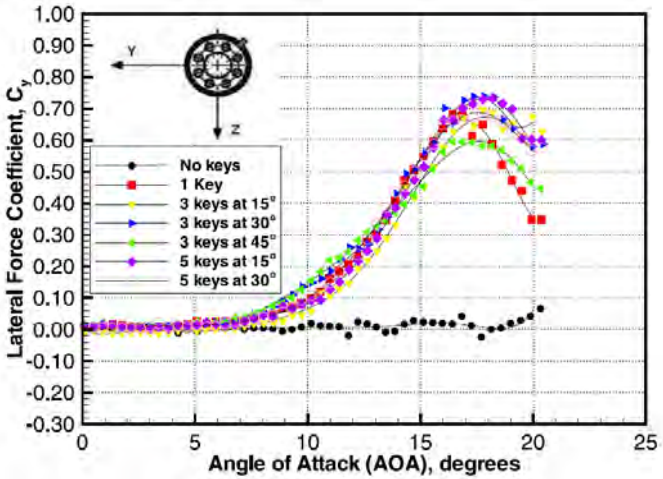
- **No fins**
- **Conical nose L_N/D= 3.0**
- **Flow effector: 1 key**
- **Front row**
- **Angular position: 0° - 360°**
- **Ma= 1.5**
- **Re/m= 15.2×10^6**

Experimental Results

Lateral Force Coefficient vs AOA

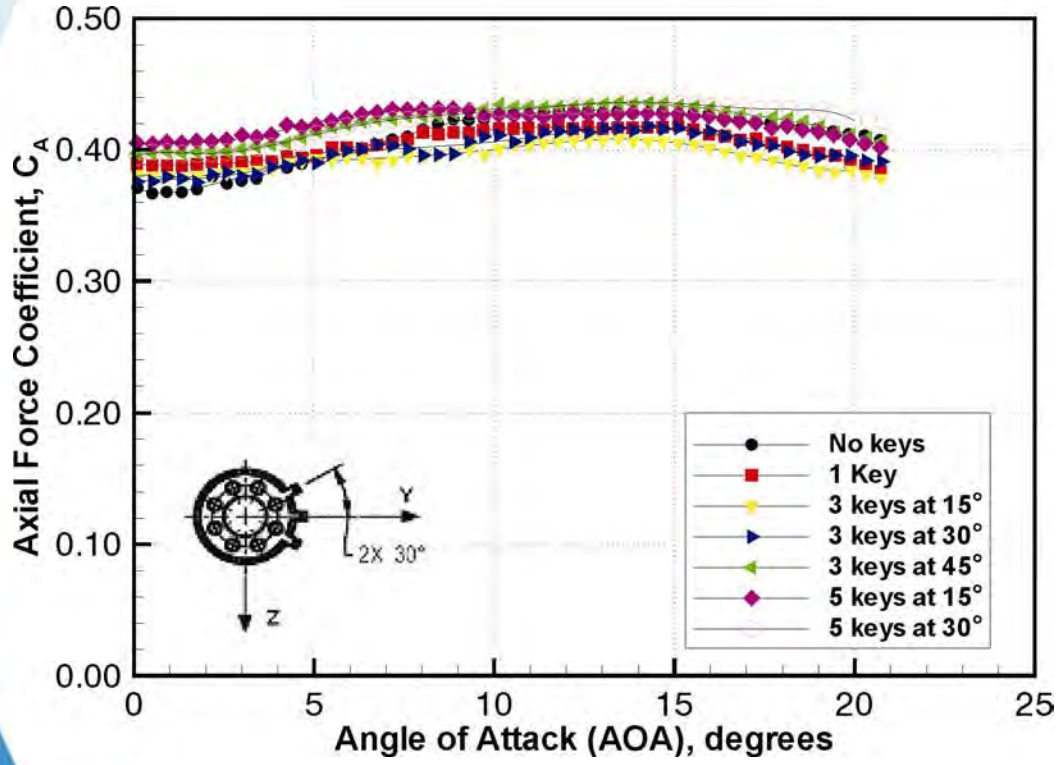


- No fins
- Conical nose L_N/D= 3.0
- Flow effectors centered at 225°
- Aft row
- Ma= 1.5
- Re/m= 15.2×10^6



Experimental Results

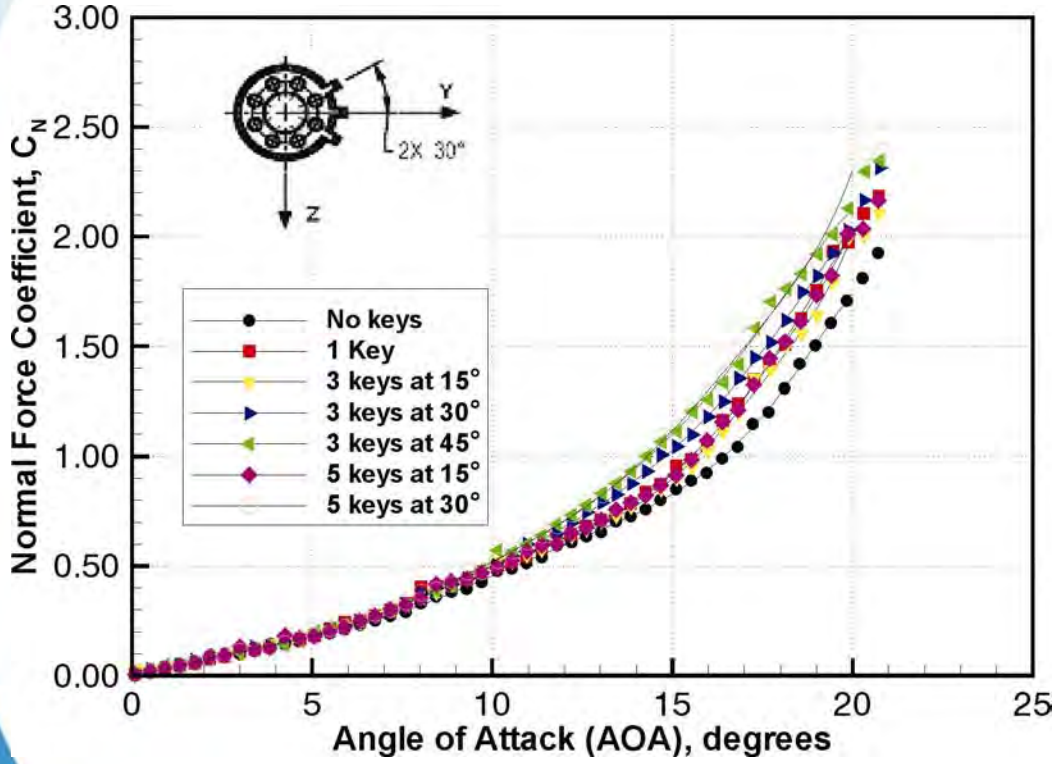
Axial Force Coefficient vs AOA



- No fins
- Conical nose L_N/D= 3.0
- Flow effectors centered at 270°
- Front row
- Ma= 1.5
- Re/m= 15.2×10^6

Experimental Results

Normal Force Coefficient vs AOA



- **No fins**
- **Conical nose L_N/D= 3.0**
- **Flow effectors centered at 270°**
- **Front row**
- **Ma= 1.5**
- **Re/m= 15.2×10^6**

Conclusions

- Peak Side force magnitude measured between AOA of 15.0° and 20.0°
- Locating the flow effectors closer to the nose tip results in higher side forces
- Maximum side forces measured at an angular position of 225°
- Side forces generated by the micro-structures are symmetric for complementary flow effectors angular position
- Apart from side force, the nose-mounted micro-structures have little impacts on the other aerodynamic coefficients

DEFENCE
R&D
DÉFENSE

The Application of Critical Perforation Analysis (CPA) to Military Personal Armour Research and Evaluation

Catherine Crawford
Personal Armour Team
DC R&PS

British Crown Copyright 2004/MOD

Background

CPA was developed by:

- RMCS – Royal Military College of Science
- MPS – Metropolitan Police Service
- DC R&PS

This presentation will:

- Outline the method
- Describe the current status of development
    - Focusing on shoot pack testing carried out at DC R&PS

Background

When testing with bullets (not fragments) the usual method of assessment is a pass/fail criteria

- No way of quantitatively assessing how close to failing the armour is (i.e. has it been over-engineered or will the next shot perforate?)
- Many test standards require only 6 shots on an armour assessment (although several armours will be tested for certification)

When testing with fragments the two values of interest are the V_{50} and V_0

- V_{50} - velocity at which the estimated probability of perforation is 0.5 for a given projectile and target. Three perforations and three non-perforations of the pack are used to calculate the arithmetic mean (V_{50}).
- V_0 - highest velocity at which the estimated probability of perforation is 0 for a given projectile and target.

What is CPA

CPA is a ballistic test method tool giving a quantitative value of performance

- Determines V_{50} using all projectiles
- Determines Standard Deviation (SD)
- Using the V_{50} and SD to estimate the $V_{0.1}$ (estimated as an approximation to V_0)
- Determines F_{perf} – frequency of perforation (between 40 to 60% is acceptable)

Theory of CPA

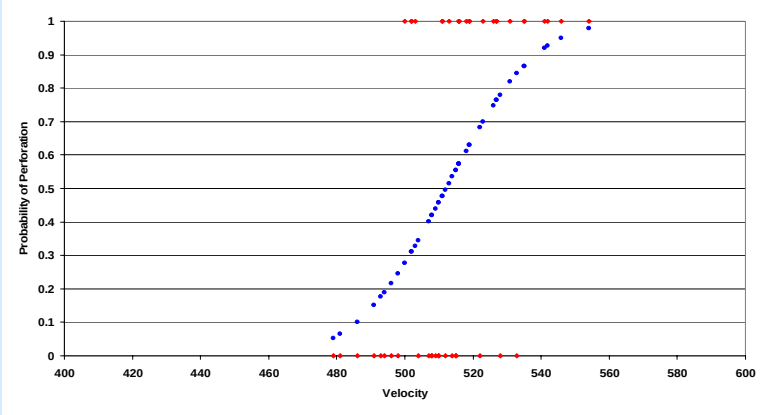
Projectile either will or will not perforate the target

Probability of perforation can be plotted as:

- 0 = non-perforation or
- 1 = perforation
- Can be plotted against velocity

If ‘least squares’ method is applied:

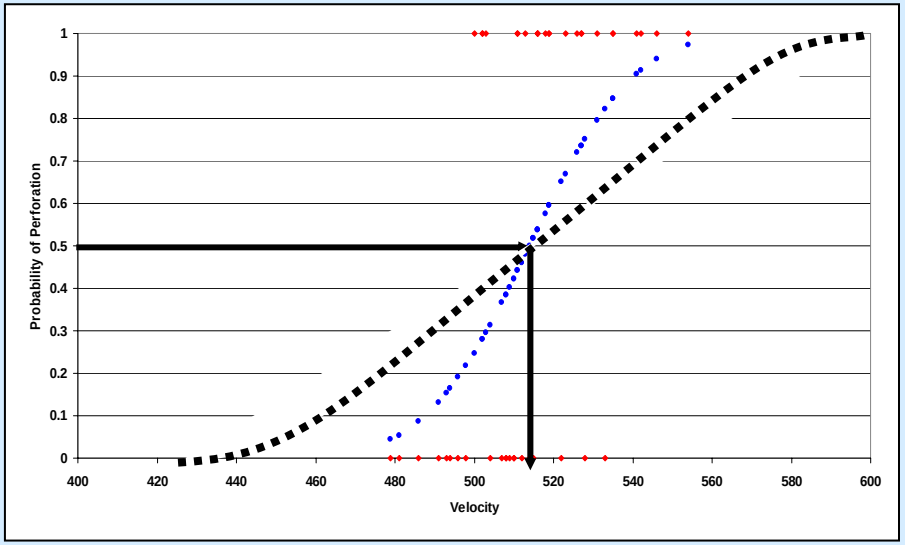
- produce a Cumulative Normal Distribution Curve (CND)



Theory of CPA

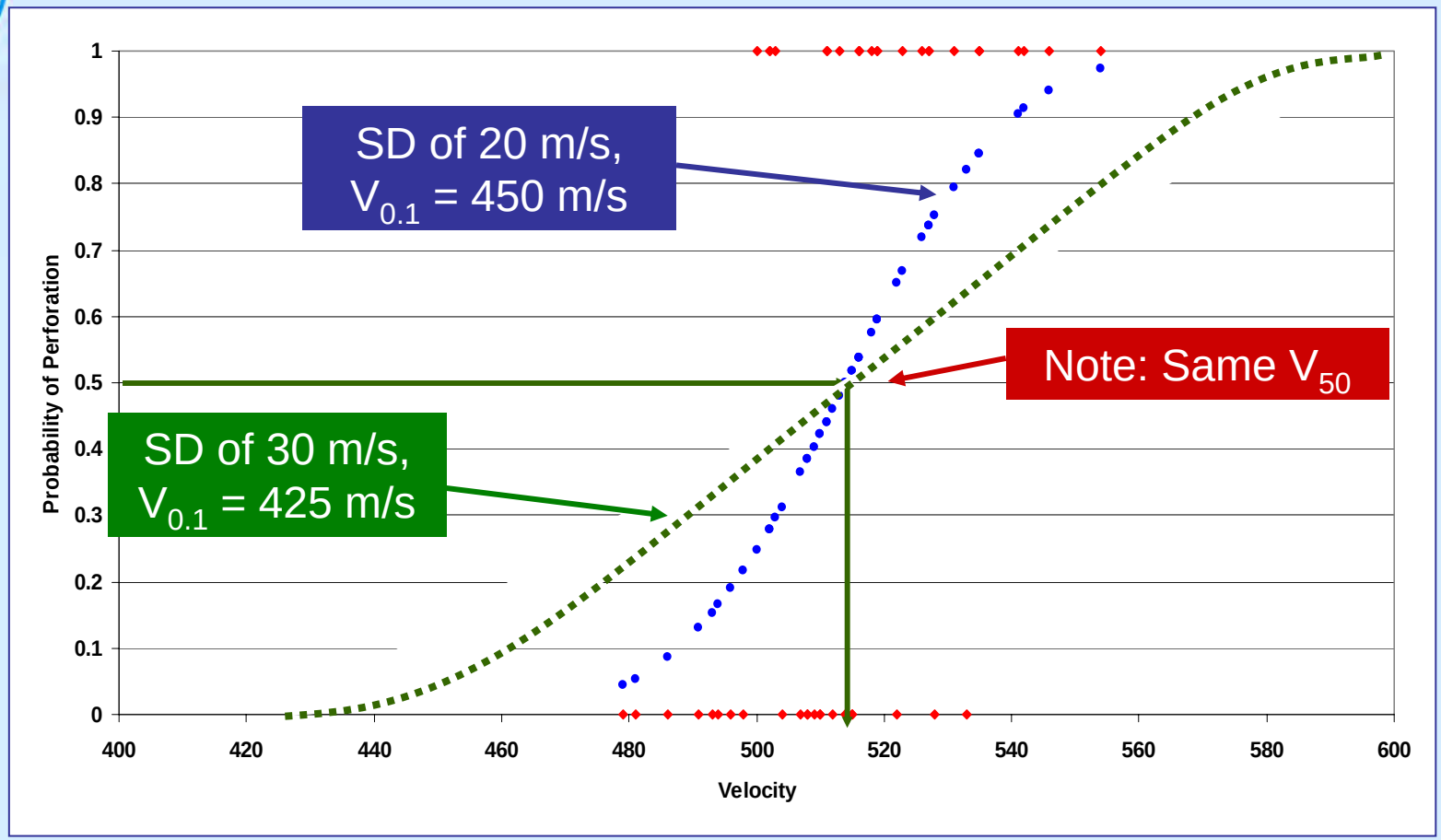
Using the CND curve we can assume that:

- Probability of 0.5 equates to the V_{50}
- There is an associated standard deviation (SD)
- The V_0 can be estimated, more accurately the $V_{0.1}$ can be estimated as an approximation to V_0
  - It is assumed to be 3x SD below the V_{50}

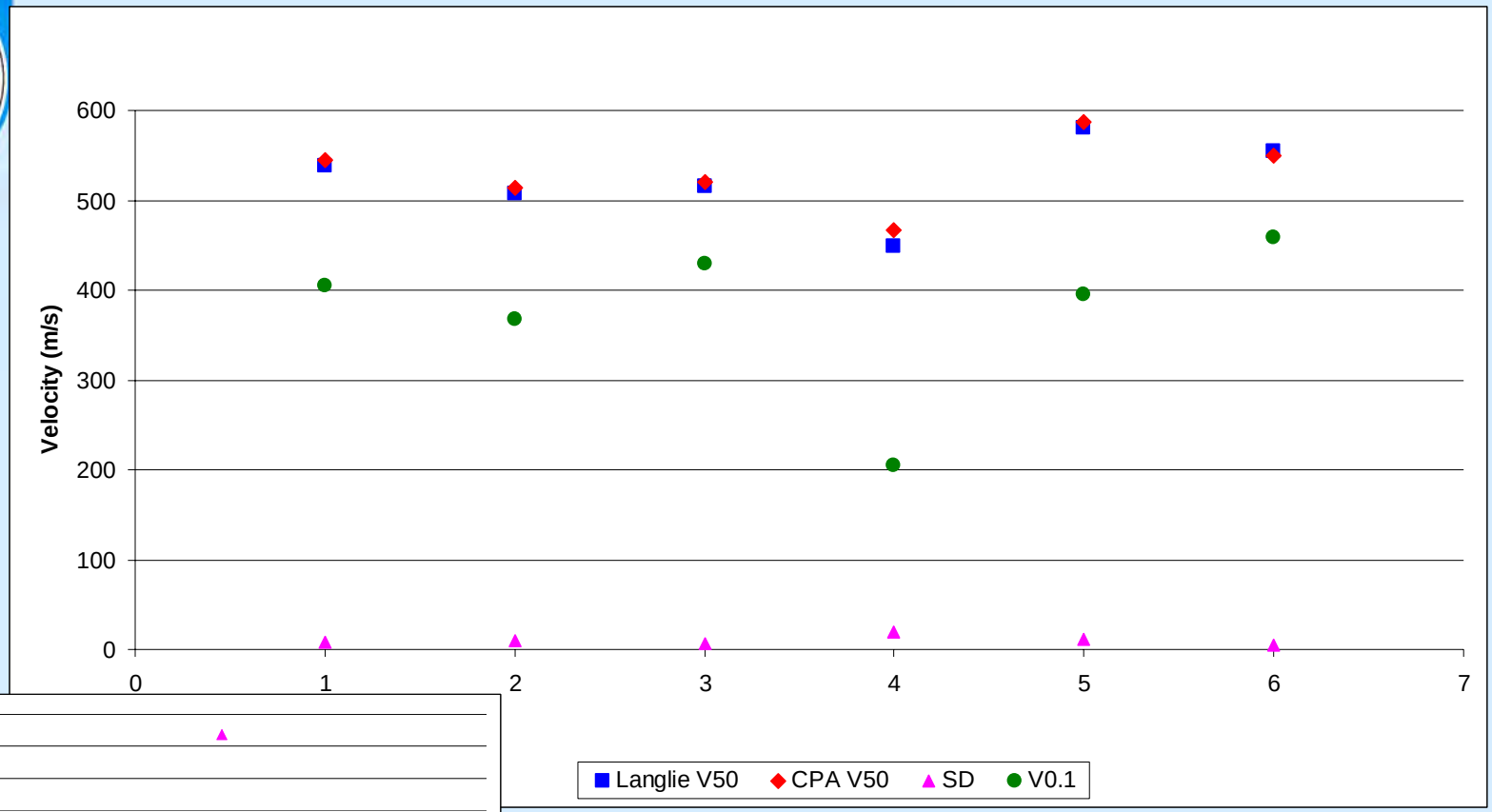


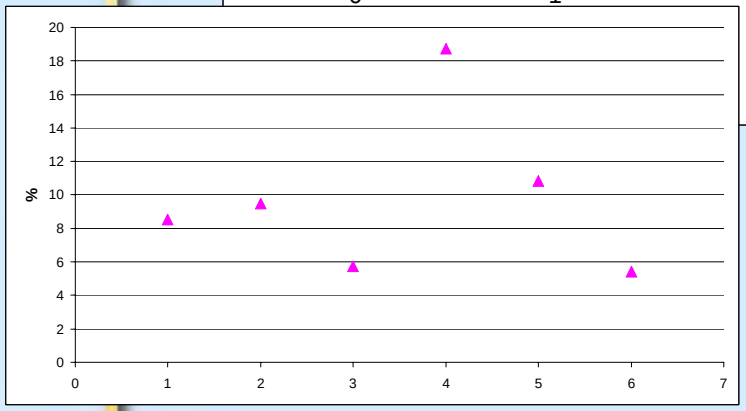
Theory of CPA

V_{50} in isolation does not give all the information



Comparison of Results

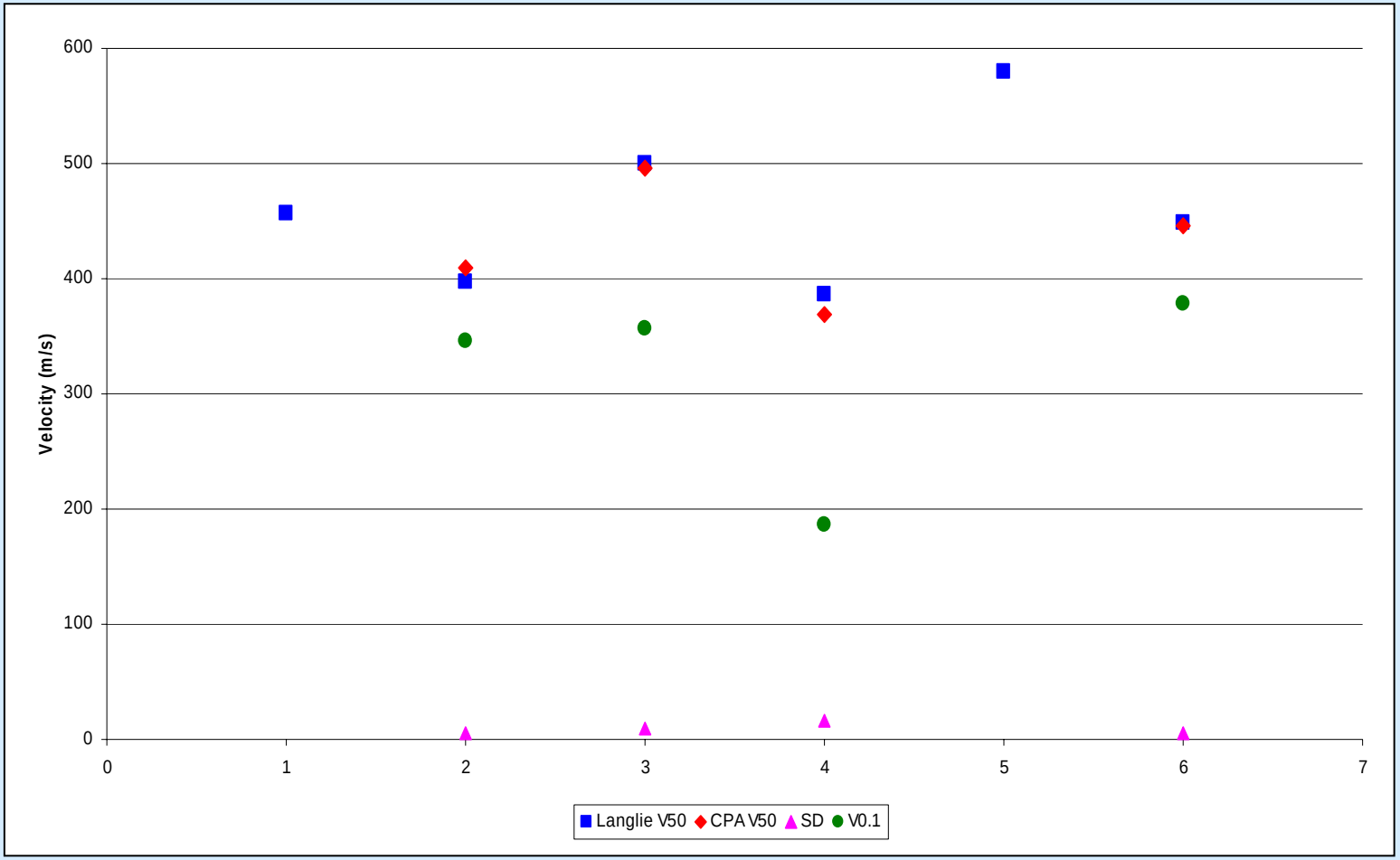




Comparison of Results

Textile	No of Shots	V_{50} (m/s)		CPA		
		STANAG 2920	CPA	SD (%)	Est $V_{0.1}$ (m/s)	F_{perf} (%)
1	50	538	544	8.52	405	46
2	49	508	514	9.50	368	45
3	61	515	520	5.75	430	49
4	52	448	467	18.72	205	37
5	42	580	586	10.84	396	43
6	41	554	549	5.44	459	59

Comparison of Results



Comparison of Results

Textile	No of Shots	V_{50} (m/s)		CPA		
		STANAG 2920	CPA	SD (%)	Est $V_{0.1}$ (m/s)	F_{perf} (%)
1	44	457	No Solution			
2	35	397	409	5.14	346	51
3	37	500	496	9.39	356	54
4	44	387	369	16.50	186	64
5	41		No Solution			
6	39	448	446	5.08	378	54

Further Work

- Validation of estimated $V_{0.1}$ predictions
- Improve user-friendliness
- Define testing procedures
- Validation for hard armour targets
  - Taking into account possible bi-modal distribution
- Confidence levels

Contact Details

For further information please contact

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Catherine Crawford
Personal Armour Team
DC R&PS

Mine neutralization with small caliber projectile impact

TNO | Knowledge for business

Mark.Dijkstra@tno.nl

Contents

- Introduction
- Experiment set-up
- Results and Conclusions
  - Mine without detonator
- Results and Conclusions
  - Mine with detonator
- Latest results

Introduction

- Method will not demand close approach of the mine
- Possible mine responses due to impact
  - Mechanical break-up or disintegration
  - Burning
  - Deflagration
  - Detonation
- Humanitarian demining requires low order reaction
- Military demining a detonation can be preferred

Experiment set-up (1)

AP 22C1 Mine

- Mass explosives
  - Main charge: 84 g
  - Detonator: 3 g

Experiment set-up (2)

.338” (8.6 mm) ← **Projectiles** → .50” (12.7 mm)

Ball

AP

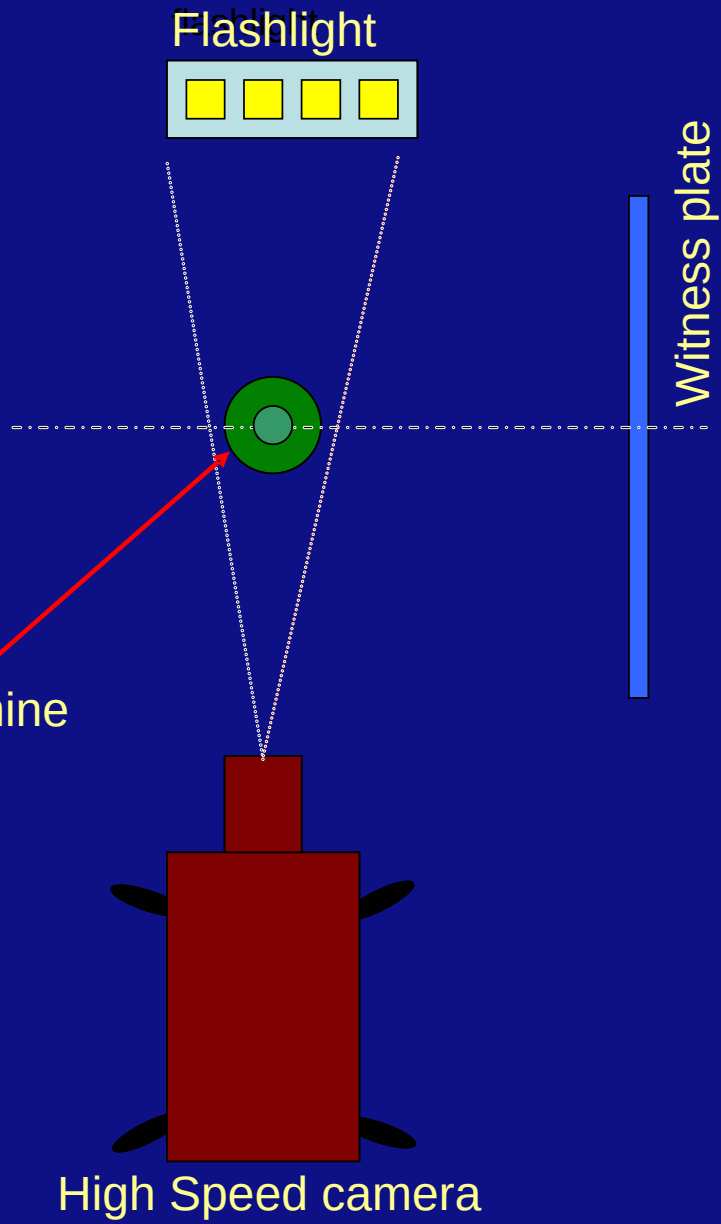
Ball

AP(I HC)

Experiment set-up (3)

Weapon

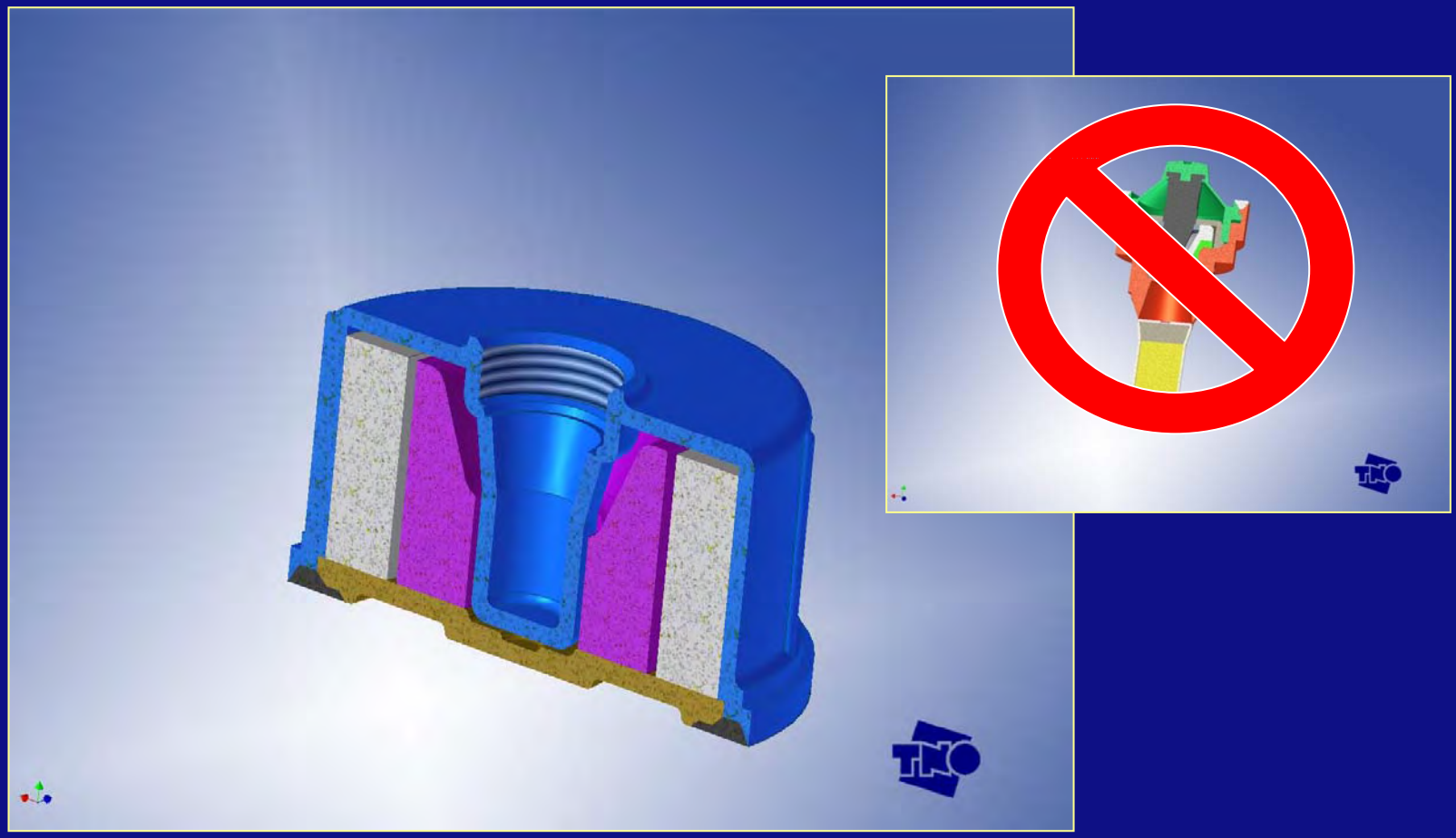
Projectile



Registration of events by use of
- High speed camera
- Normal speed video camera (25 fps)
- Witness plate

Experiment set-up (4)

RESULTS (1)
Unarmed AP 22C1 Mine (NO detonator)

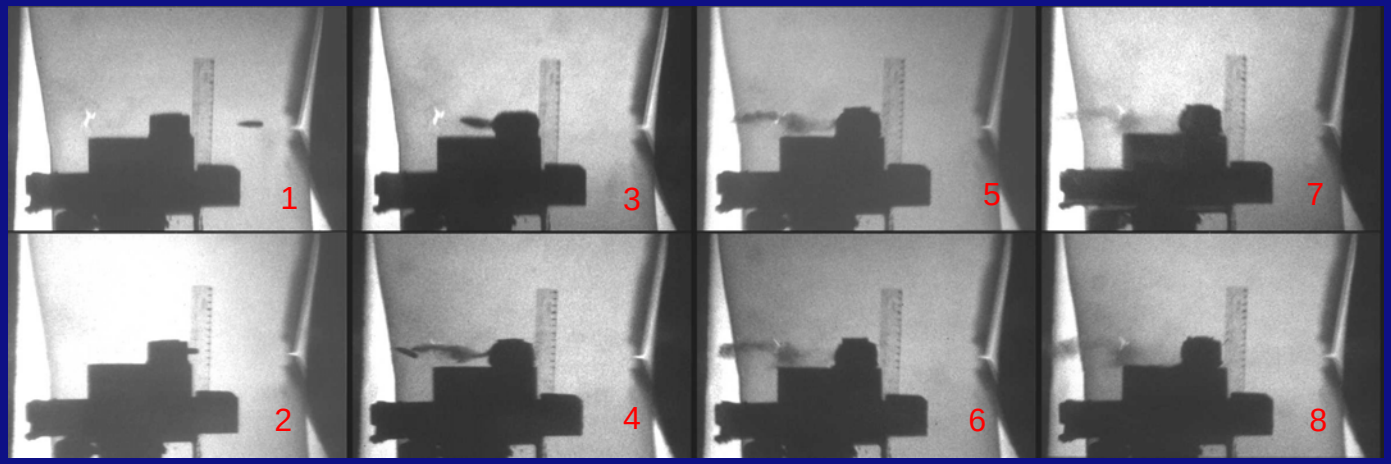


Some illustrating pictures (1)

mine remnants after impact .338 Ball

Impact hole

Exit hole



Some illustrating pictures (2)

mine remnants after impact .338” AP and .50” ball

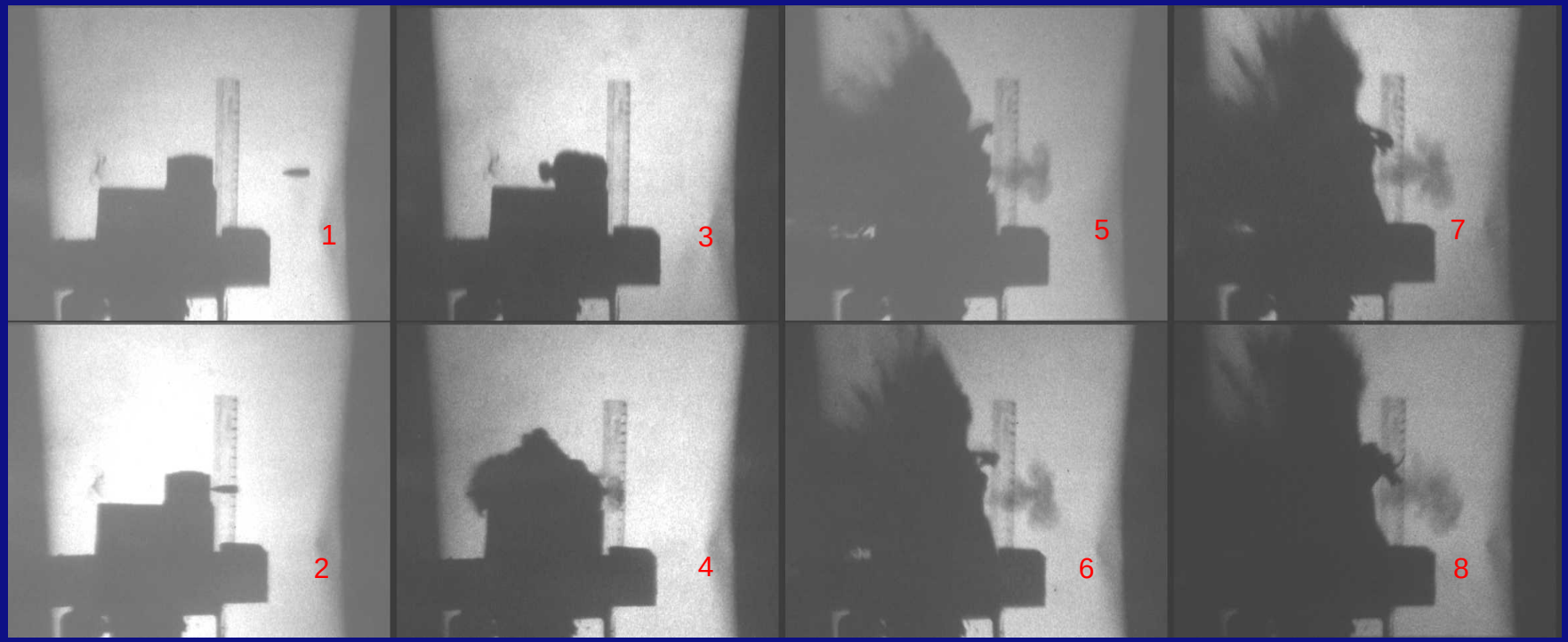
.338” AP

.50” Ball

Some illustrating pictures (3)

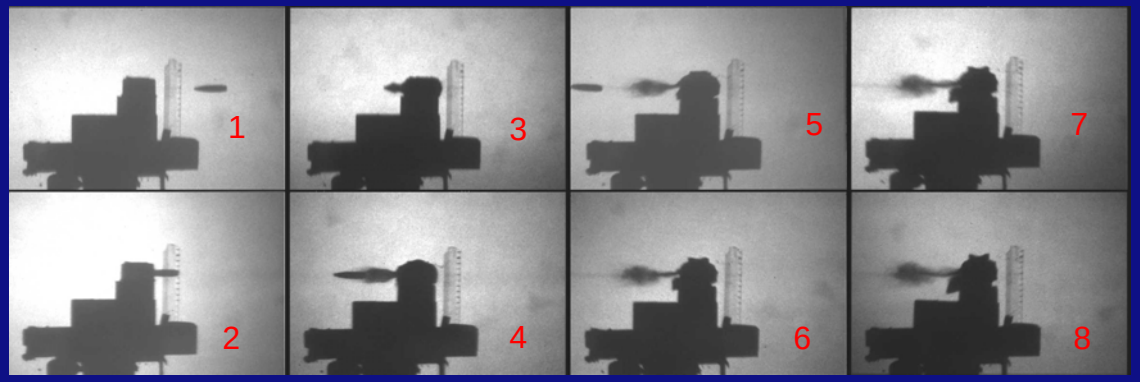
mine response on impact .338” AP and .50” ball

Typical result of .338” AP and .50” Ball
Mechanical break-up



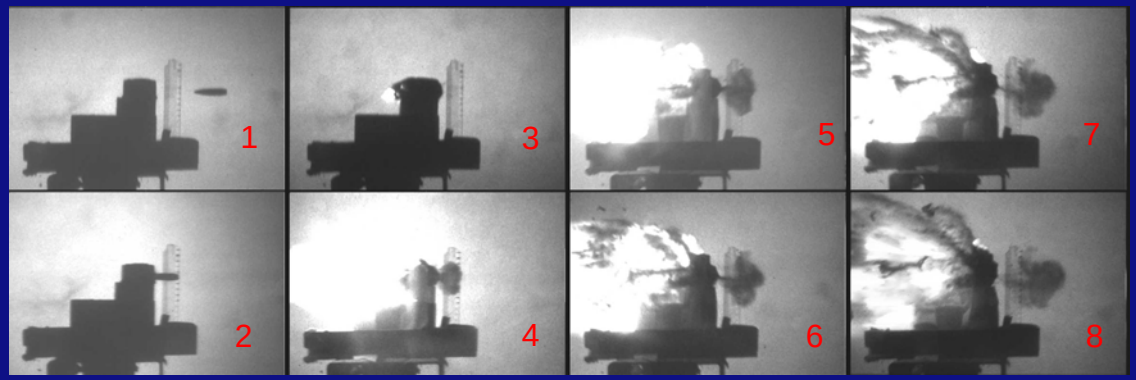
Some illustrating pictures (4)

mine response after impact .50 AP I HC



3 shots mechanical break-up only

.50” AP I HC



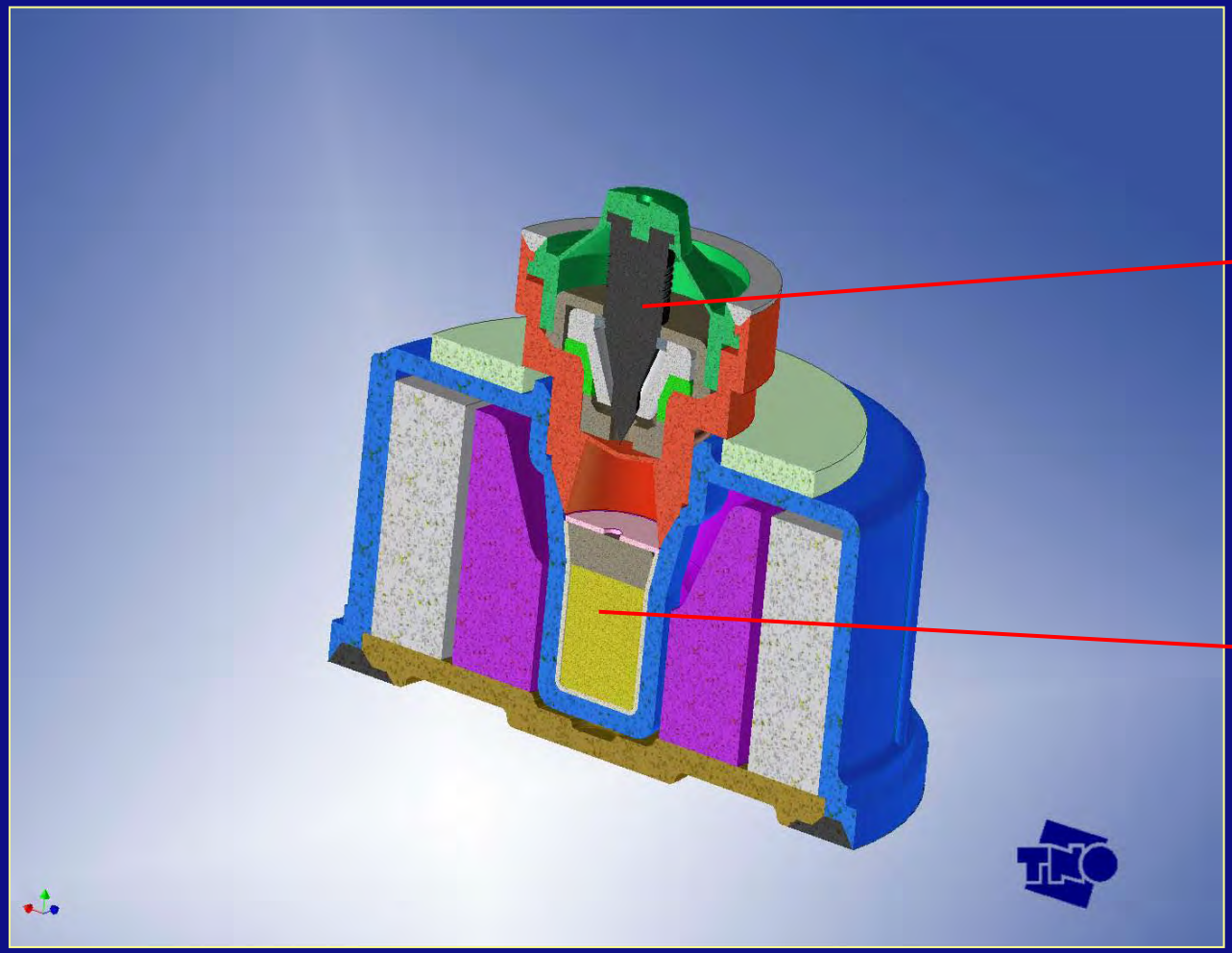
3 shots mechanical break-up and reaction of incendiary tip **(No deflagration!)**

Conclusions

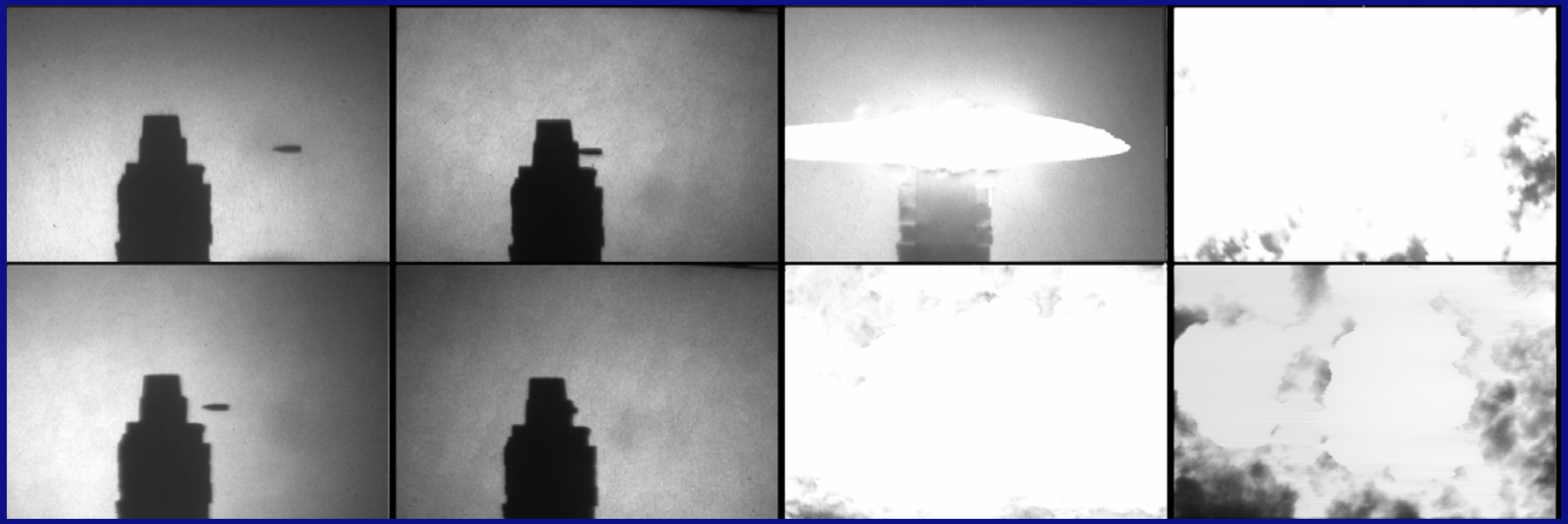
AP 22C1 mine without detonator (fuse)

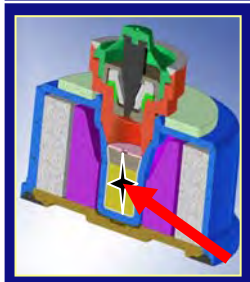
- No detonation or deflagration recorded
- .338” Ball unsuitable to neutralize mine
- All other munitions tear open mine body and pulverize explosive material
- I-tip melts TNT, no evidence of burned TNT found
- Impossible to draw conclusions on response of mine with detonator

RESULTS (2)
Armed AP 22C1 Mine (with detonator)



Illustrating picture of a detonation



Aiming point	.338 Ball	.338 AP	.50 Ball	.50 AP I HC
	No reaction 2x	**No reaction 1x** **Partly burned 1x**	**No experiment**	**No reaction 1x** **I-tip reacts 1x**
	**No reaction 1x**	**Partly burned 1x**	**Detonation residual explosives 1x**	**No reaction** **I-tip reacts 1x**
	Detonation 1x **No reaction 1x (graze)**	**Detonation 2x**	**Detonation 2x** **No reaction 1x**	**No detonation 2x** **Fire witnessed on video (I-tip)**
	No experiment	**Detonation1x**	**No reaction 2x** **1x(graze)**	**No experiment**

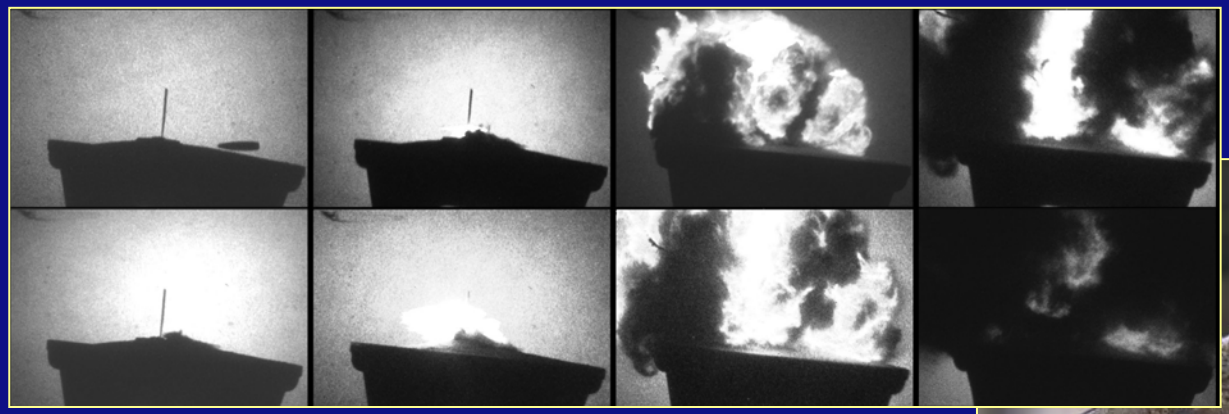
Conclusion from experiments

AP mine with detonator

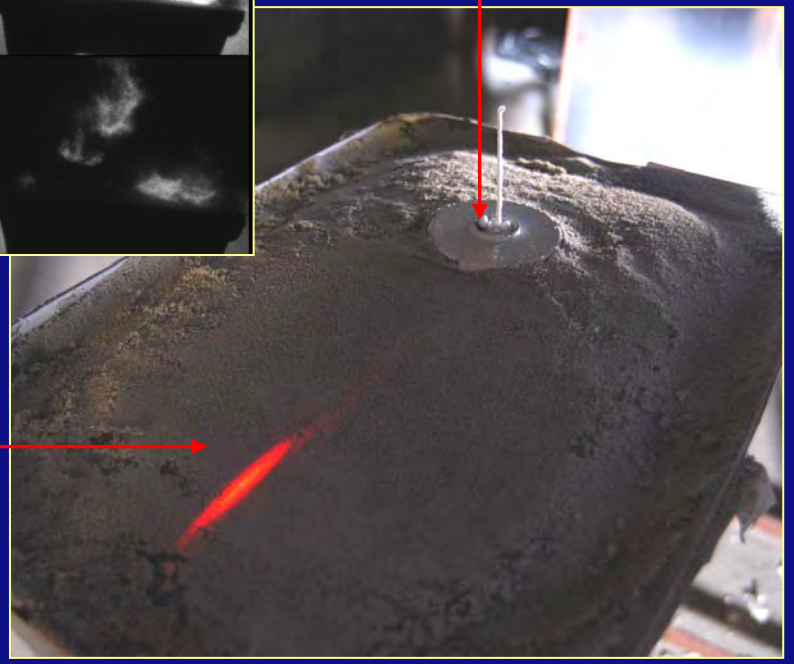
- only an armed AP-22C1 mine shows a chemical reaction (burning, deflagration or detonation) when it is impacted by a small calibre projectile.
- AP22 mine can only be detonated by an impact on the primary explosives
- These preliminary results show that mine neutralization with small caliber projectiles impact seems a promising technique

Latest results

- Experiments conducted on the mine without detonator with two other .50” projectiles
  - .50 PELE (mechanical break-up only)
  - .50 MP (4 out 4 deflagration)



AP mine buried in sand



Impact position

HIGH SPEED VIDEO

Experimental and Numerical Study of the Penetration of Tungsten Carbide Into Steel Targets During High Rates of Strain

John F. Moxnes (FFI, Norway)
Eva K. Friis (Nammo Raufoss, Norway)
Oyvind Froyland (FFI, Norway)

MEDIUM CALIBER DIVISION
Nammo Raufoss Proprietary Information

Introduction

- Overall purpose of our research programme: Establishment of a constitutive model with corresponding material data of a given Tungsten Carbide material, containing Cobalt
  - Obtain insight and understanding
  - Enable numerical modeling

- Focus in this work: Strain rate dependency of the plastic yield stress and/or the fracture stress

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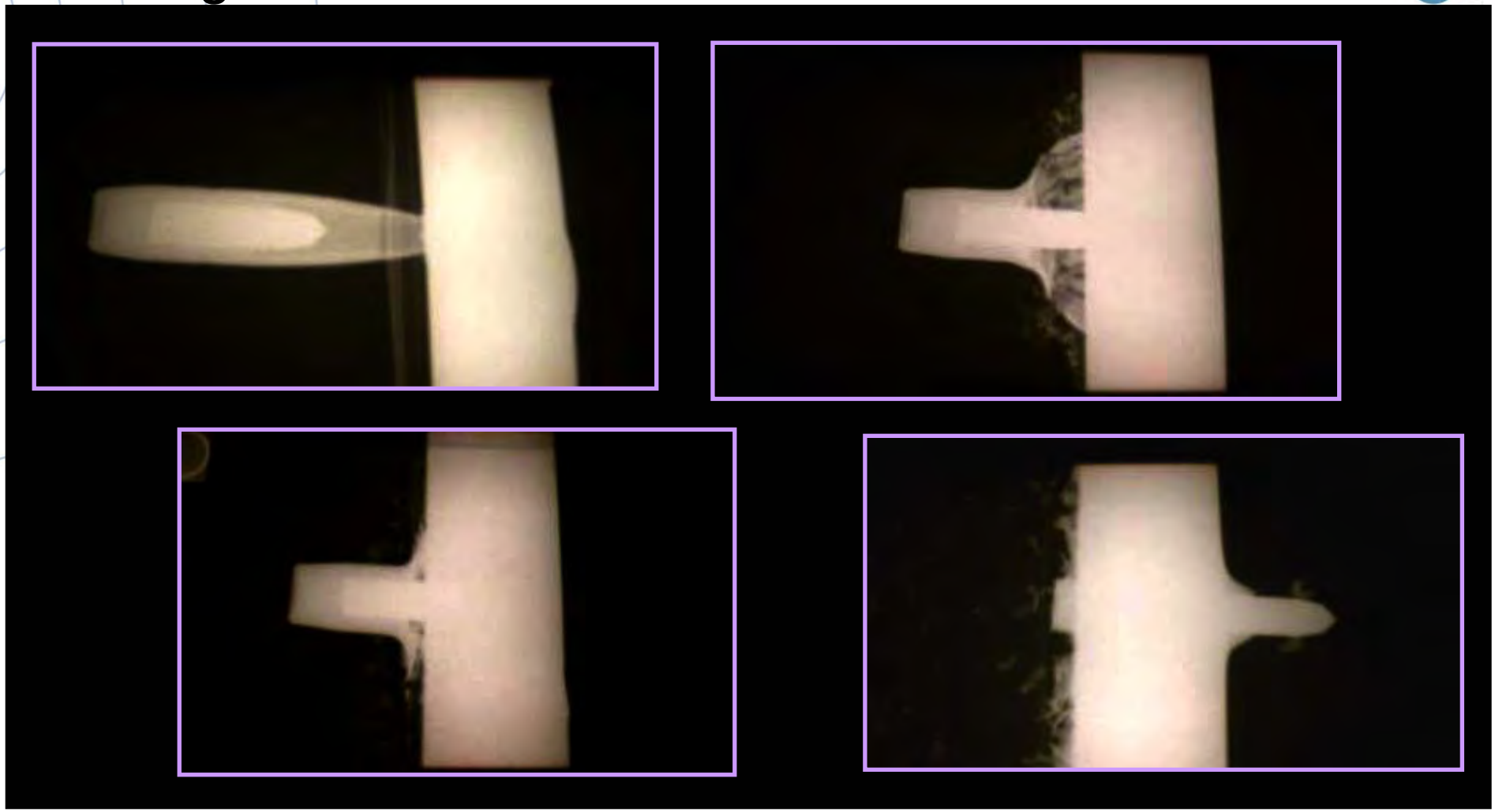
Flash X-Ray Picture of Nammo Raufoss 12.7 mm MP ammunition with Tungsten Carbide Cobalt Penetrator



Introduction

- Tungsten Carbide is in general a superb penetrator material
- The penetration capability will be reduced if the penetrator fractures in an early stage of the penetration or if the penetrator undergoes large plastic deformation
  - for harder targets the penetrator could fracture
  - for higher impact velocity the penetrator could fracture

- Increased fracture stress and reduced plastic flow due to strain rate dependency of intact material could potentially increase the strength of the penetrator

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Topics

- Material data established by quasi-static experiments
- Comments on the feasibility of the Johnson-Holmquist constitutive model for Tungsten Carbide containing Cobalt
- Experimental results of firing experiments
- Numerical modeling of the firing experiments

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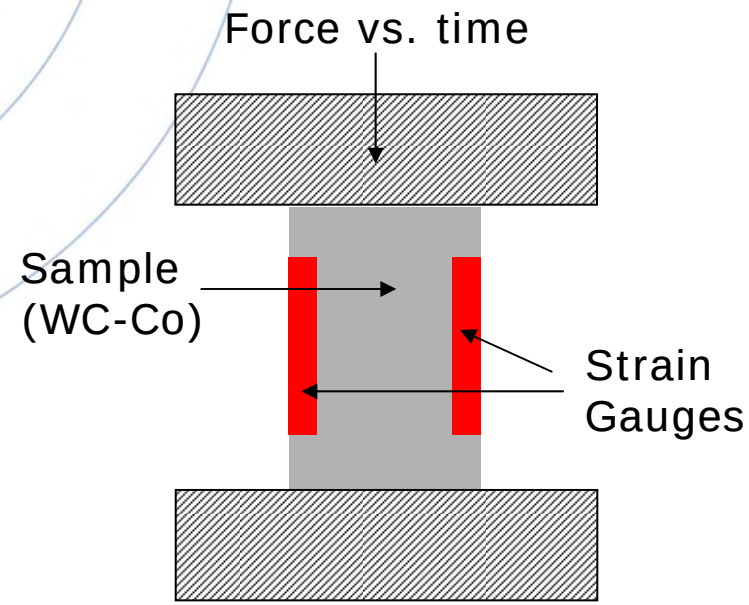
Constitutive Model for WC-Co Penetrator

- The elastic moduli of the intact material
- Plastic yield stress as a function of strain for the intact material
- Fracture stress as a function of pressure for the intact material

- Constitutive relations not presented in this work
  - The fracture development from intact to completely damaged material
  - The constitutive model for the partly of fully damaged material

Quasi-Static Experiments

Simple compression



⇒ Elastic moduli (K, E)

⇒ Yield stress (stress vs. strain)

⇒ A fracture point on the intact fracture surface

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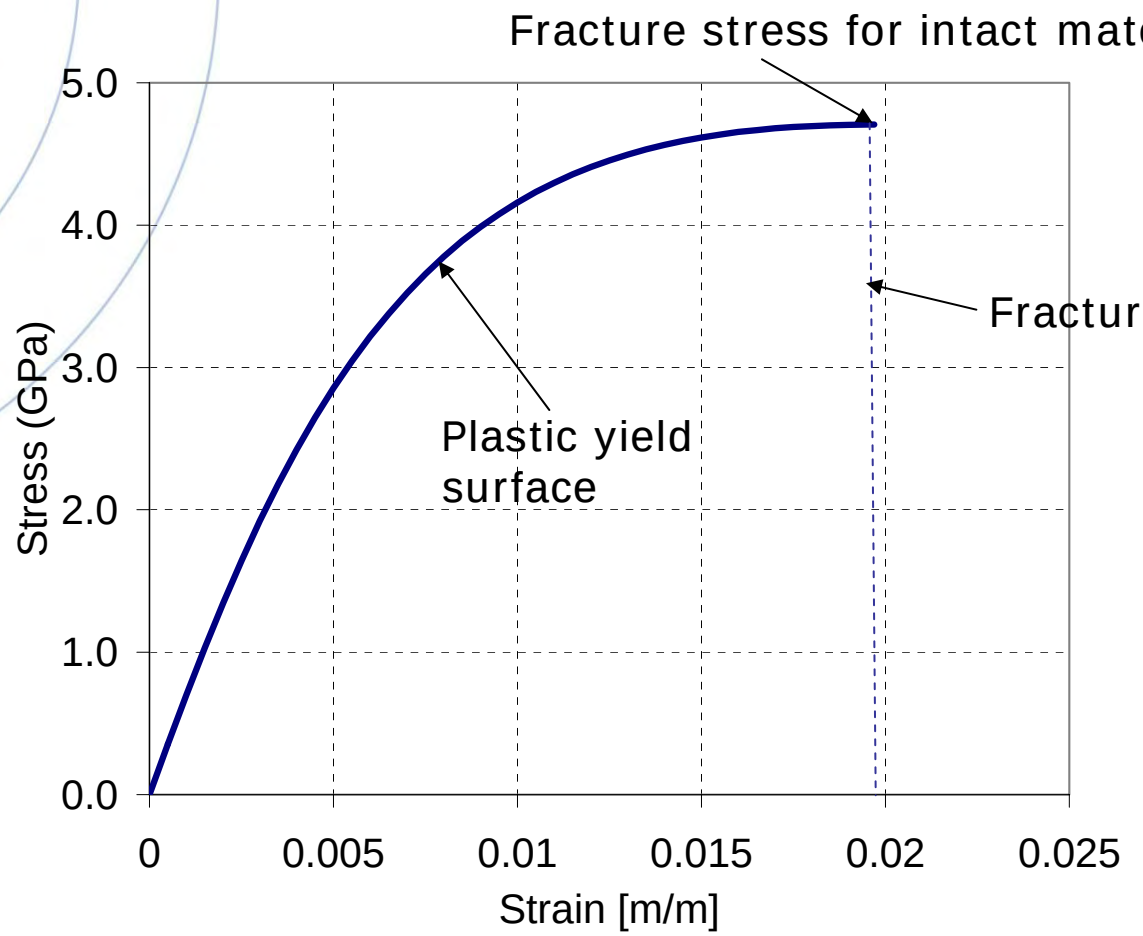
Quasi-Static material data

From simple compression experiment:

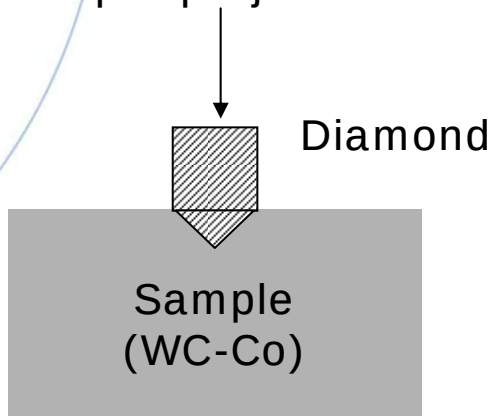


The yield stress shows a clear strain hardening effect

Quasi-Static Experiments

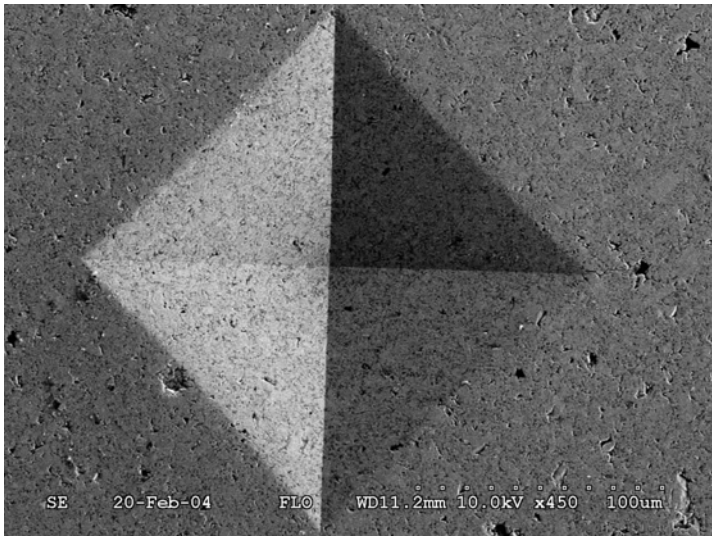
Hardness Measurement

Force per projected area



Loads of 10, 100 and 300 N

Picture of sample after indentation



⇒ The hardness of intact and damaged material after penetration is measured

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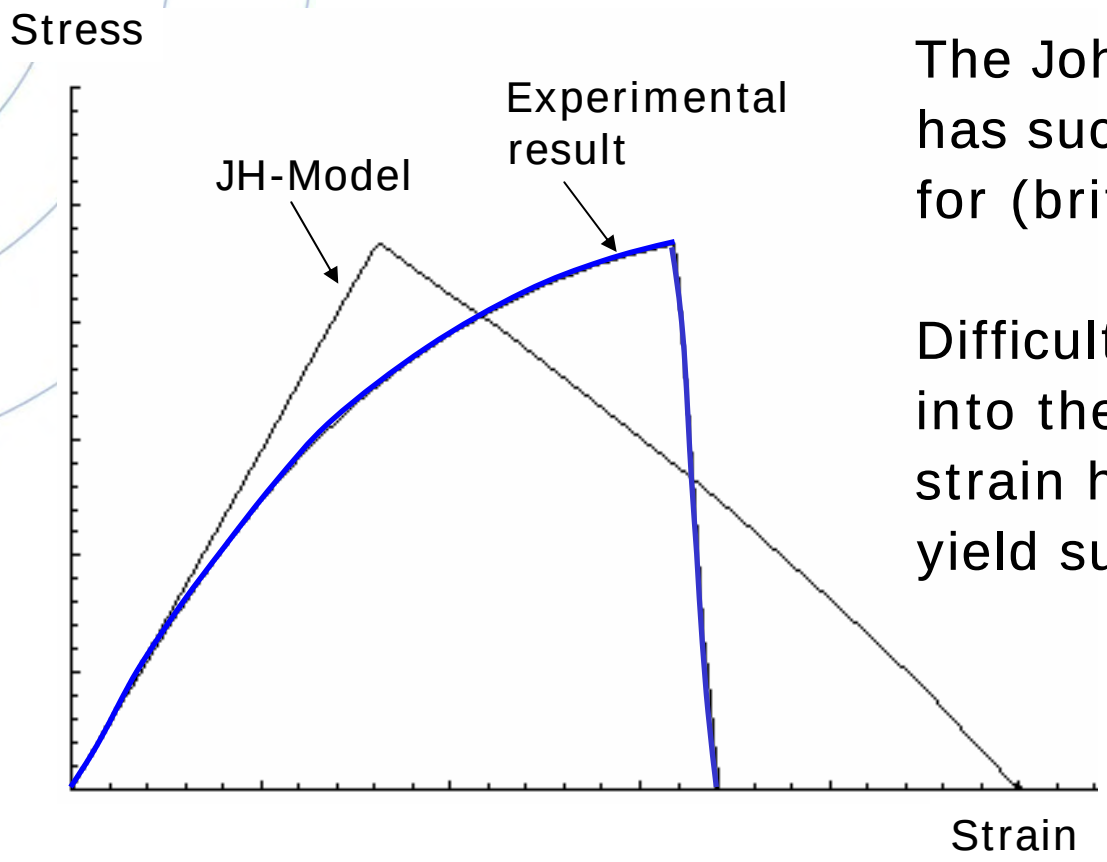
Material Model for WC-Co Penetrator

The curves apply in the case of simple compression



The Johnson-Holmquist model has successfully been used for (brittle) ceramic material

Difficult to fit the WC-Co results into the JH models due to the strain hardening of the plastic yield surface

Firing Experiments

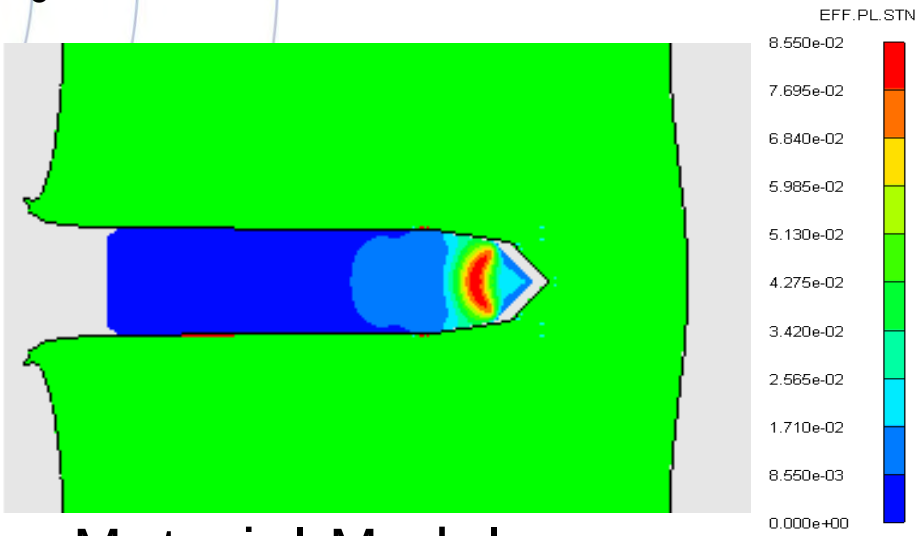
v_0=890 m/s (strain rate of 10^4 -10^5 /s), 40 mm armor steel

Penetration depth
= 30 – 31 mm

- No sign of plastic flow or fracturing
- Hardness after firing = 14.6 GPa = hardness of intact material before firing

Modeling of Firing Experiments

v_0=890 m/s, 40 mm armor steel



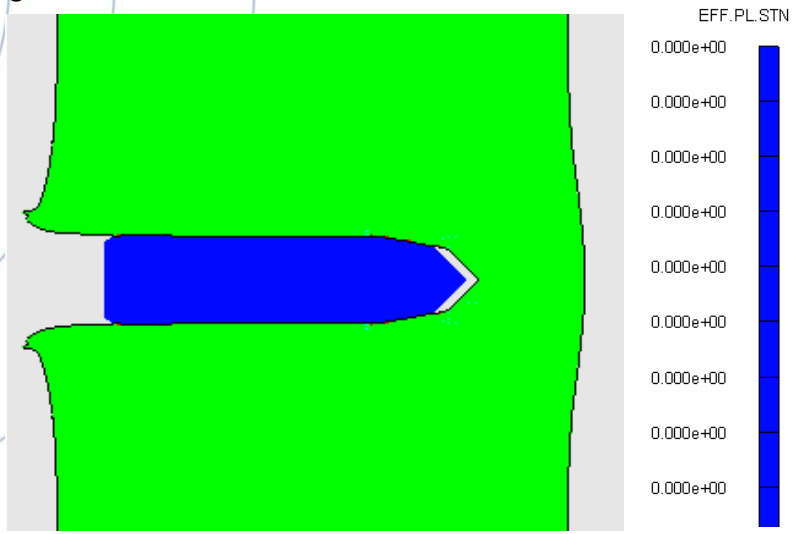
Penetration depth
= 32.4 mm
(30-31 mm in exp.)

Deviation from experiment assumed due to use of no friction

- Material Model:
  - the quasi-static yield surface fitted into the Johnson-Cook model
  - no strain rate hardening
  - no fracture model
  - no friction was used (Euler target)

Modeling of Firing Experiments

v_0=890 m/s, 40 mm armor steel



Penetration depth = 33.3 mm

Larger deviation from experiment than with the elastic-plastic model

- Material Model:
  - highest possible strain rate hardening (elastic model)
  - no fracture model
  - no friction

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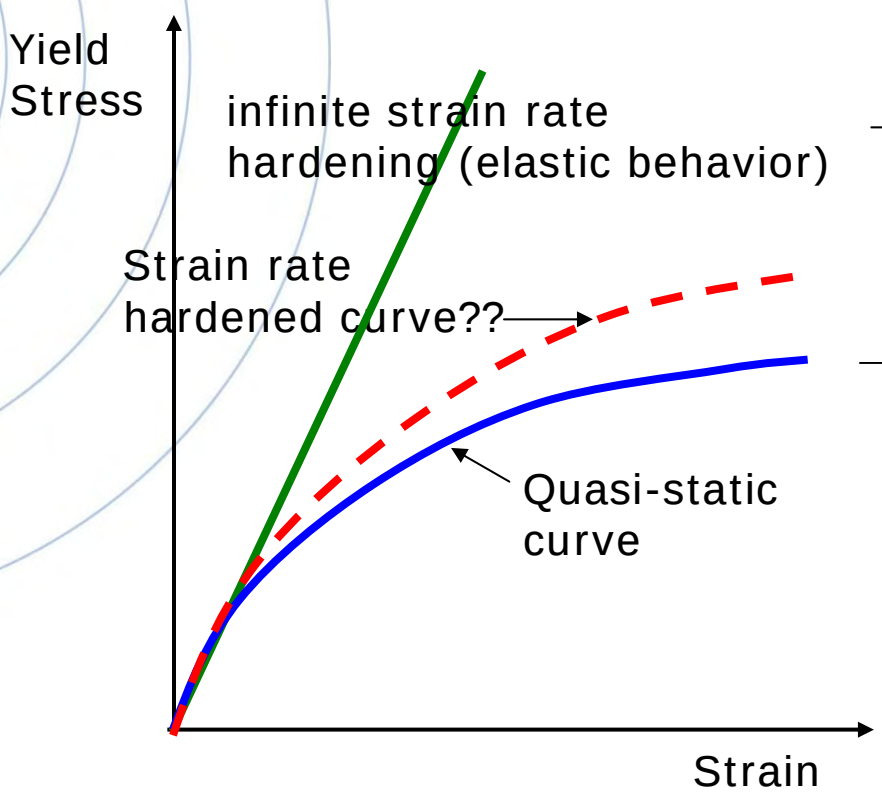
Interpretation



→ 33.3 mm

→ 32.4 mm

Experiments = 30-31 mm :

Is there any strain rate dependence?

- Question can not be clearly answered from these experiments

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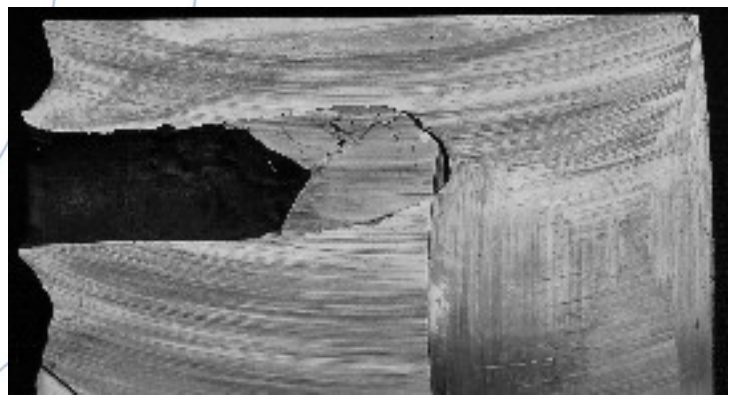
Firing Experiments

v_0=950 m/s, 40 mm armor steel



- The penetrator has fractured

- Hardness of penetrator pieces = 13.1 GPa
  (compared to 14.6 GPa for intact material)
  => Micro cracks have developed

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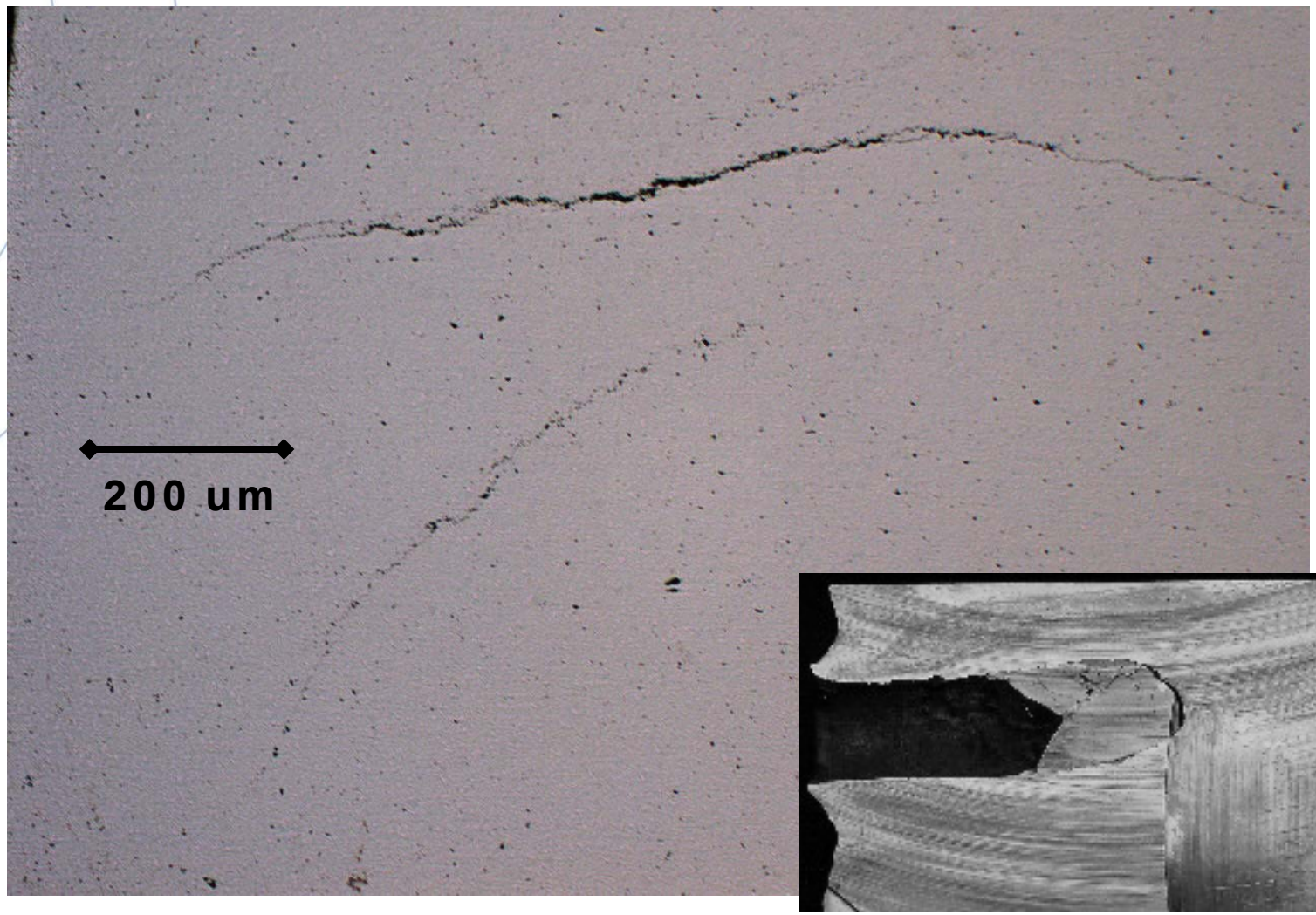
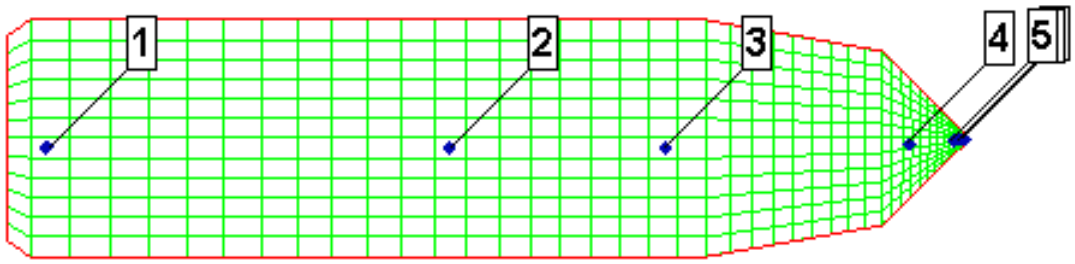
Microscopy Picture of Micro Cracks



Simulation of Stresses in the Penetrator

Study of the stresses
in different gauge points



Penetrator modeled with the yield surface established in quasi-static experiments, with no strain rate hardening

- The target is modeled using a cavity expansion theory boundary condition for the stresses on the penetrator
- This was done to ensure no unphysical spikes

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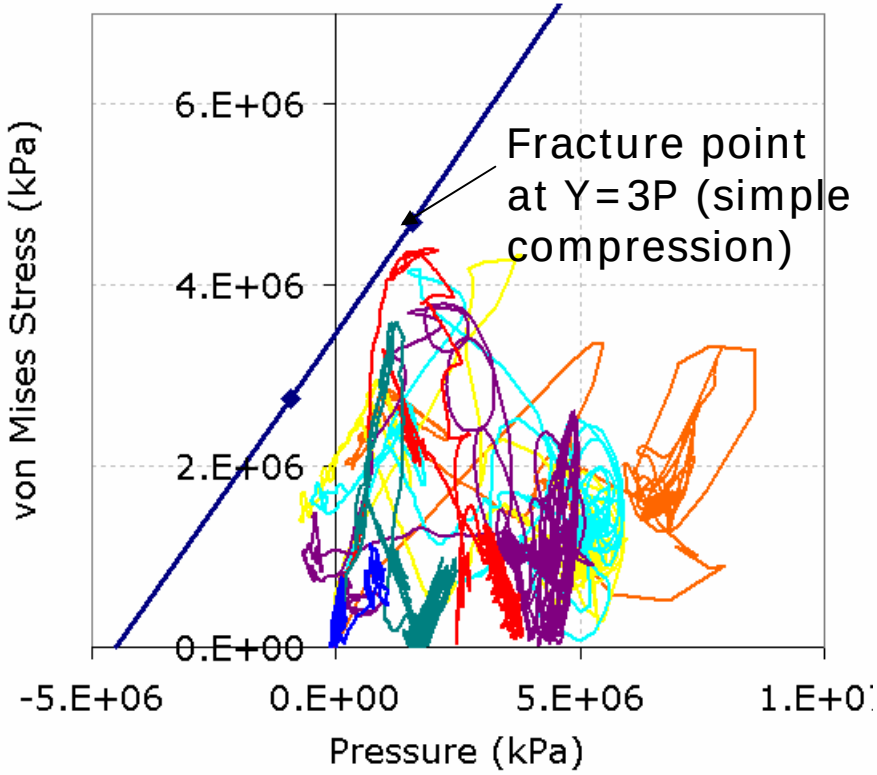
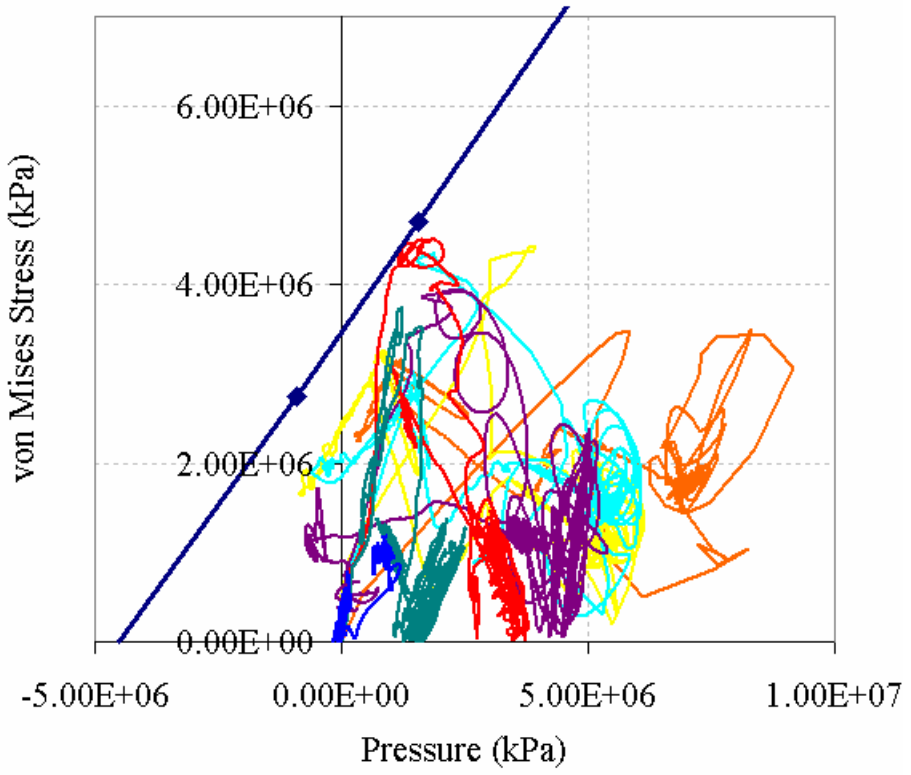
von Mises Stress vs. Pressure

- Also shown in the figures are two fracture points found from quasi-static experiments (not applied in the simulation)

890 m/s



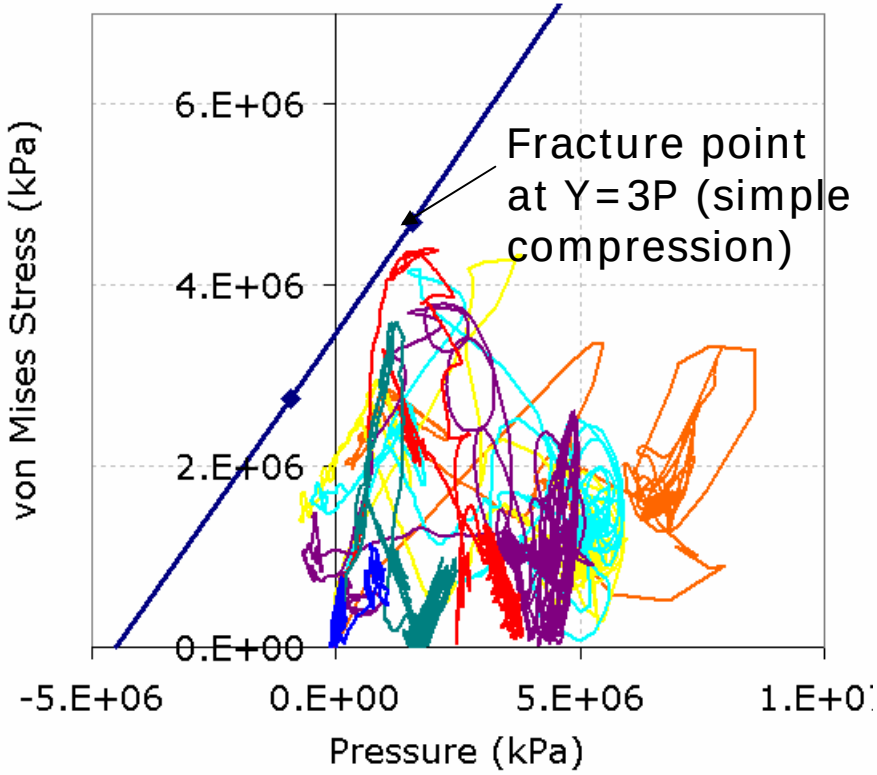
950 m/s



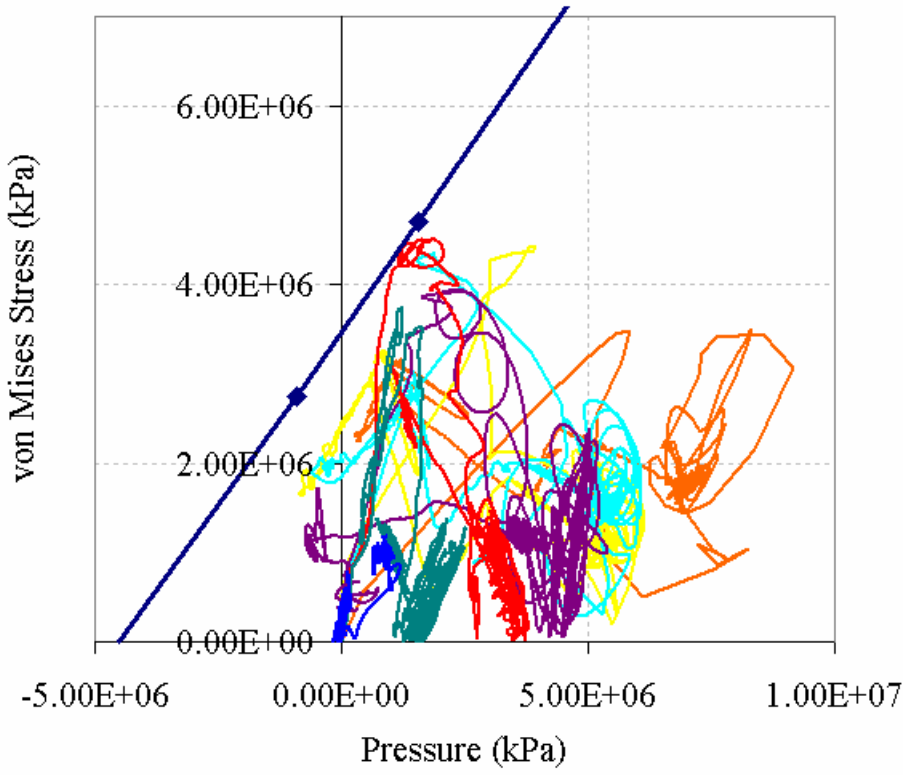
von Mises Stress vs. Pressure

Good agreement with experiments with no strain rate hardening of the fracture and the yield surfaces

890 m/s

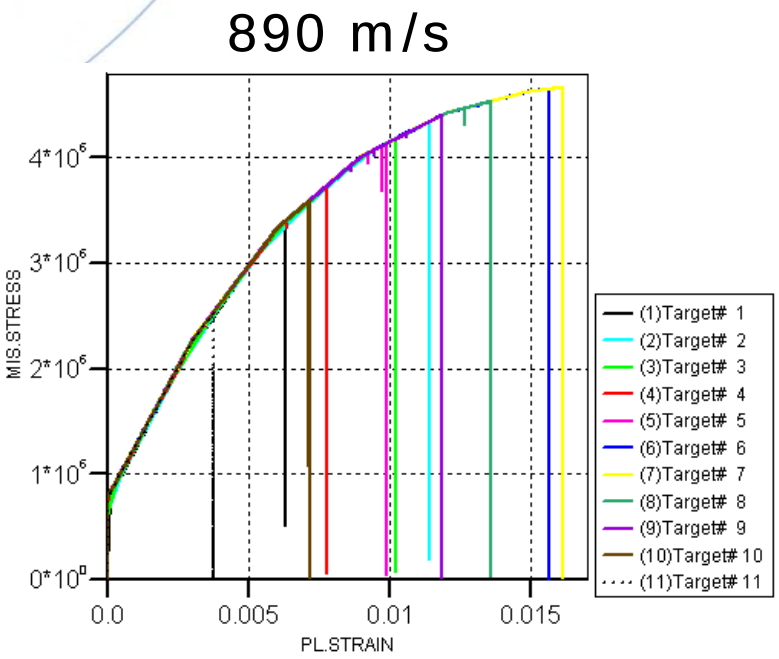


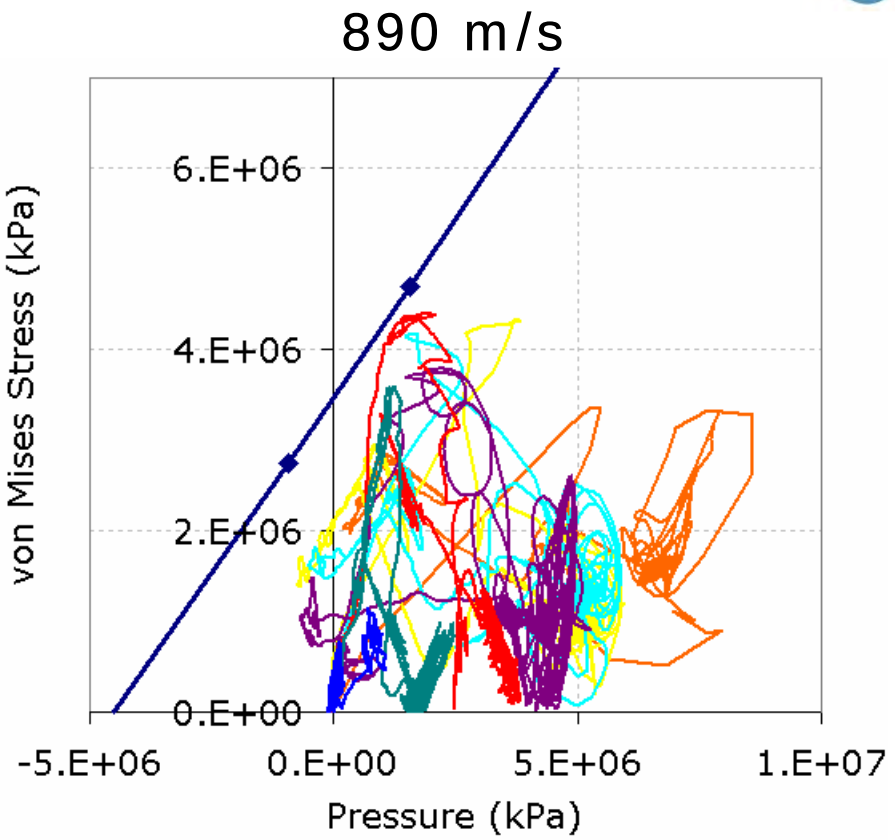
950 m/s



Interpretation

- The yield surface can not strain rate harden if the fracture surface does not strain rate harden at the same time





Interpretation

- If the fracture surface strain rate hardens, the yield surface must also strain rate harden at the same time

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Conclusions, strain hardening

- The WC-Co material shows a strain hardening effect, and is more ductile than most ceramics
  - The fracture strain was 2% during a simple compression test

- If a Johnson-Holmquist damage model is used, it should be combined with a strain hardening model of the plastic yield surface as a function of strain

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Conclusions, strain rate hardening

- The constitutive model with no strain rate dependency gave good agreement with experiments for strain rates below 10^4 -10^5 /s
- Strain rate hardening of the fracture surface is possible if and only if there is a strain rate hardening of the plastic yield surface
- Further studies on strain rate dependency will be performed in a Split Hopkinson Bar equipment

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M865 TID Improvement Study

Presented by: Kerry Henry, M865 Program Lead, US ARMY ARDEC

Jason Gaines, Systems Engineer, General Dynamics-OTS

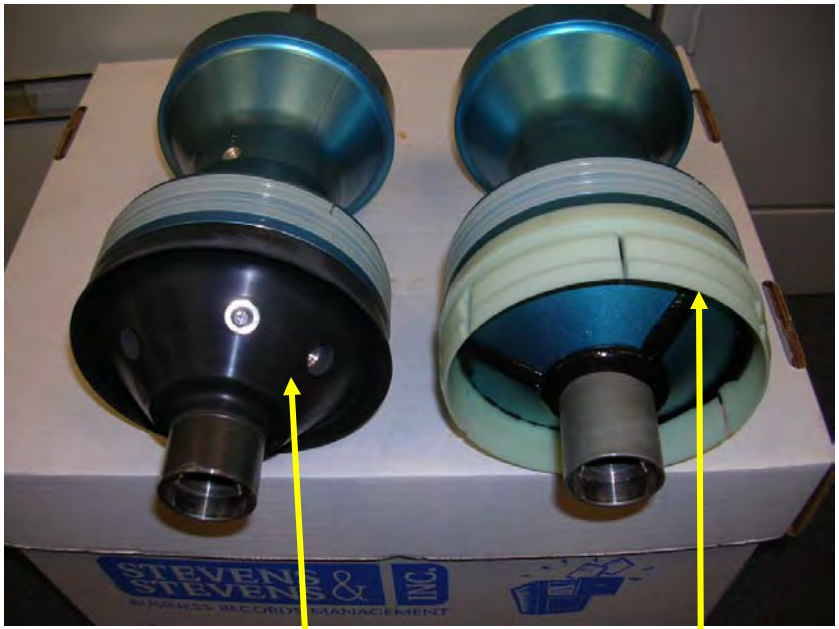
Introduction to the 120mm M865

- The M865 Kinetic Energy (KE) training round, in service with the United States Army's main battle tank fleet, provides a realistic training device displaying the accuracy and time-of-flight of the M829 series service rounds.

- The fin stabilizer provides a safety feature limiting the overall flight range to under 8 km.

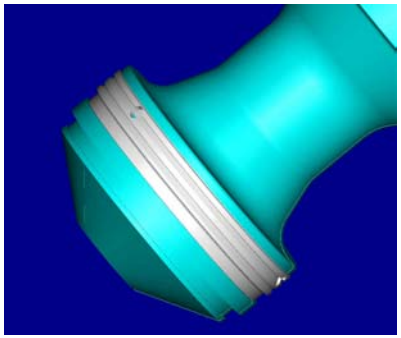
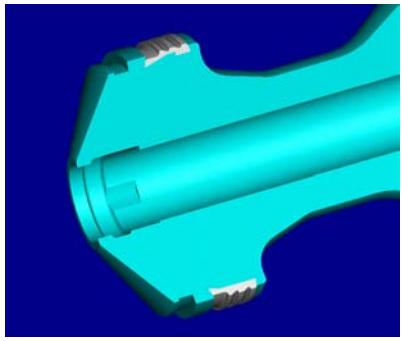
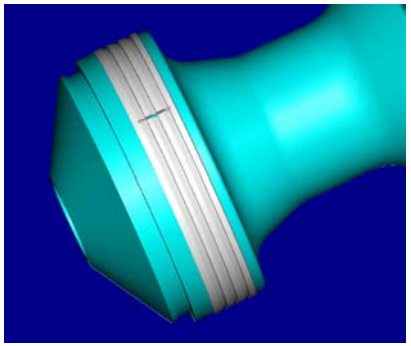
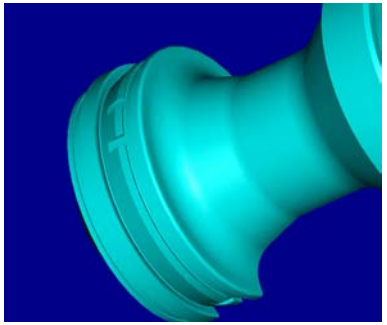
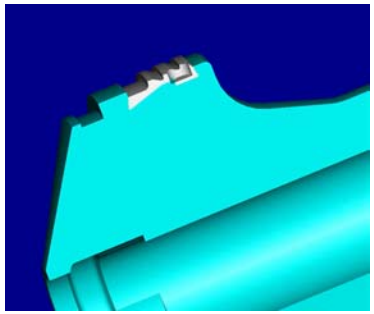
TID Background

- Target Impact Dispersion (TID) of the M865 at cold temperature (-32°C) has seen a consistent increase since the inception of the new design in FY99.
- This increase is largely due to the large number of fliers at cold temperature.
- The new design utilizes a plastic snap on insert cover which connects the projectile to the cartridge case adapter. The previous design utilized a rubber cuff which was bolted to the cartridge case adapter.



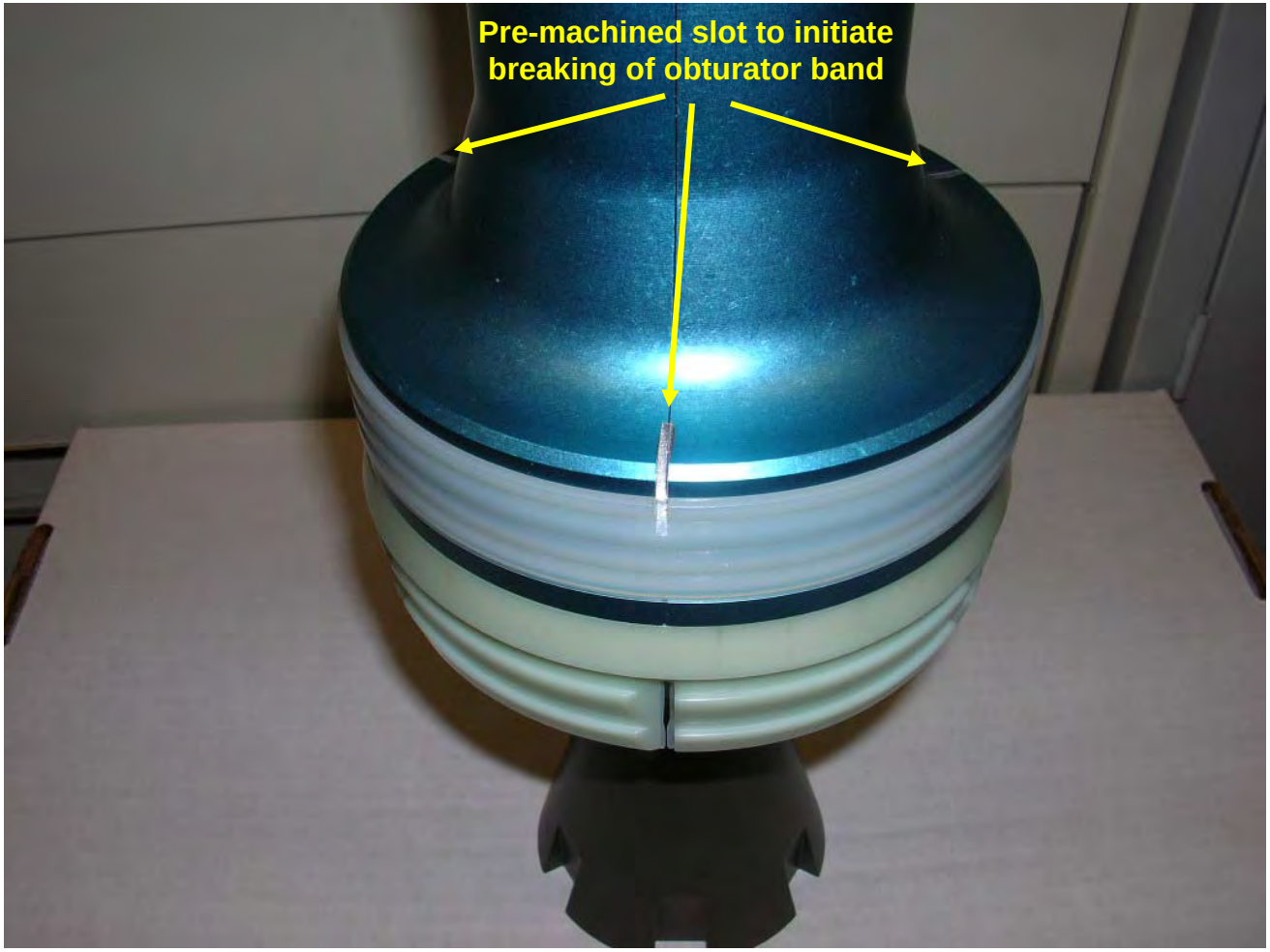
Project Objective

- To Improve the M865 KE Training Round's cold TID by reducing the number of "fliers" through redesigning the nylon obturator band and aluminum sabot.

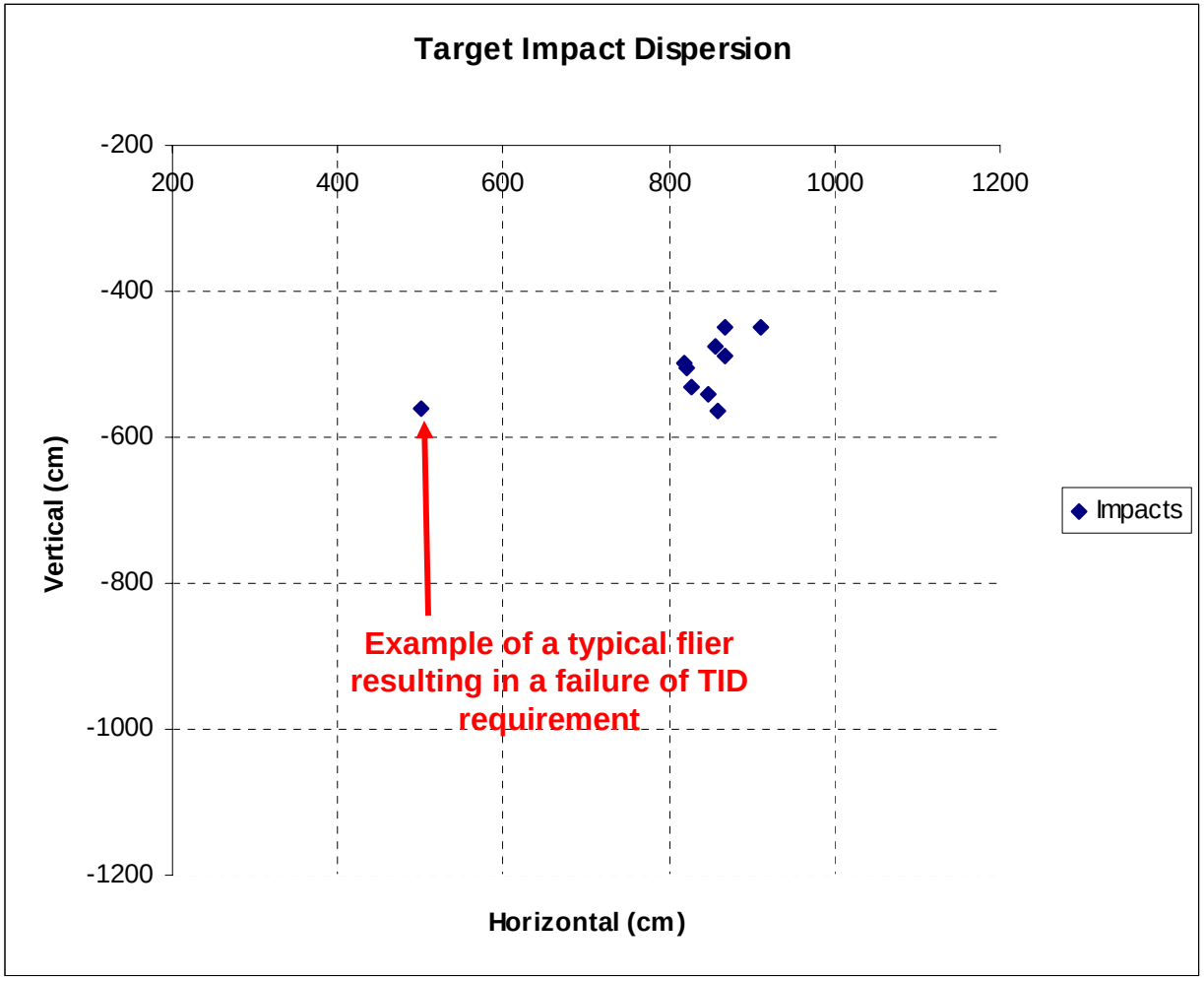






High Speed Flight Follower

Current M865 Projectile Design



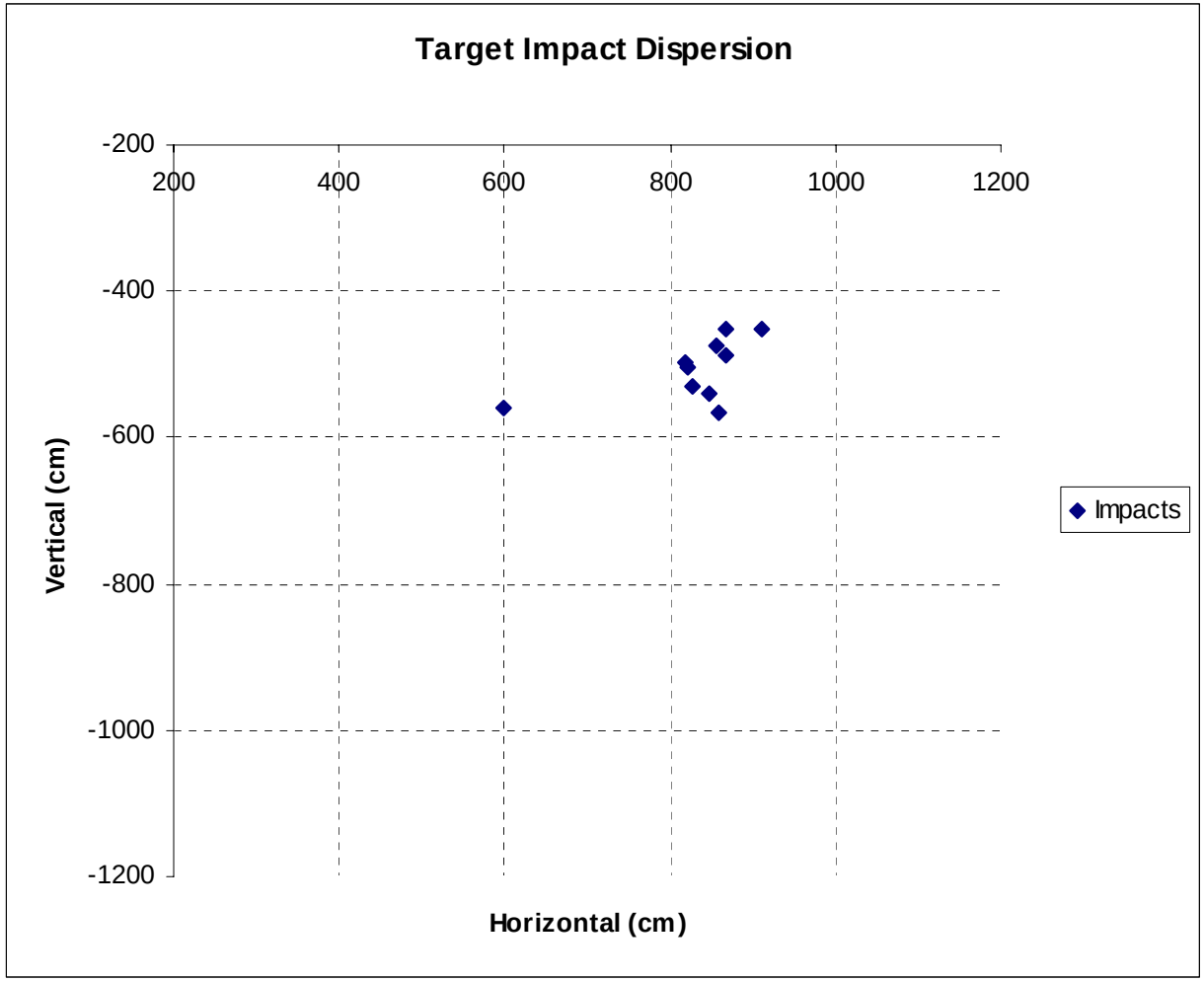
Impact Result at -32°C



TID (mils)		
	X	Y
First 5	**0.61**	**0.12**
Second 5	**0.12**	**0.13**
Pooled	**0.44**	**0.13**

The M865 Performance Specification requires a TID of .30 x .30 or lower to accept a cartridge lot.

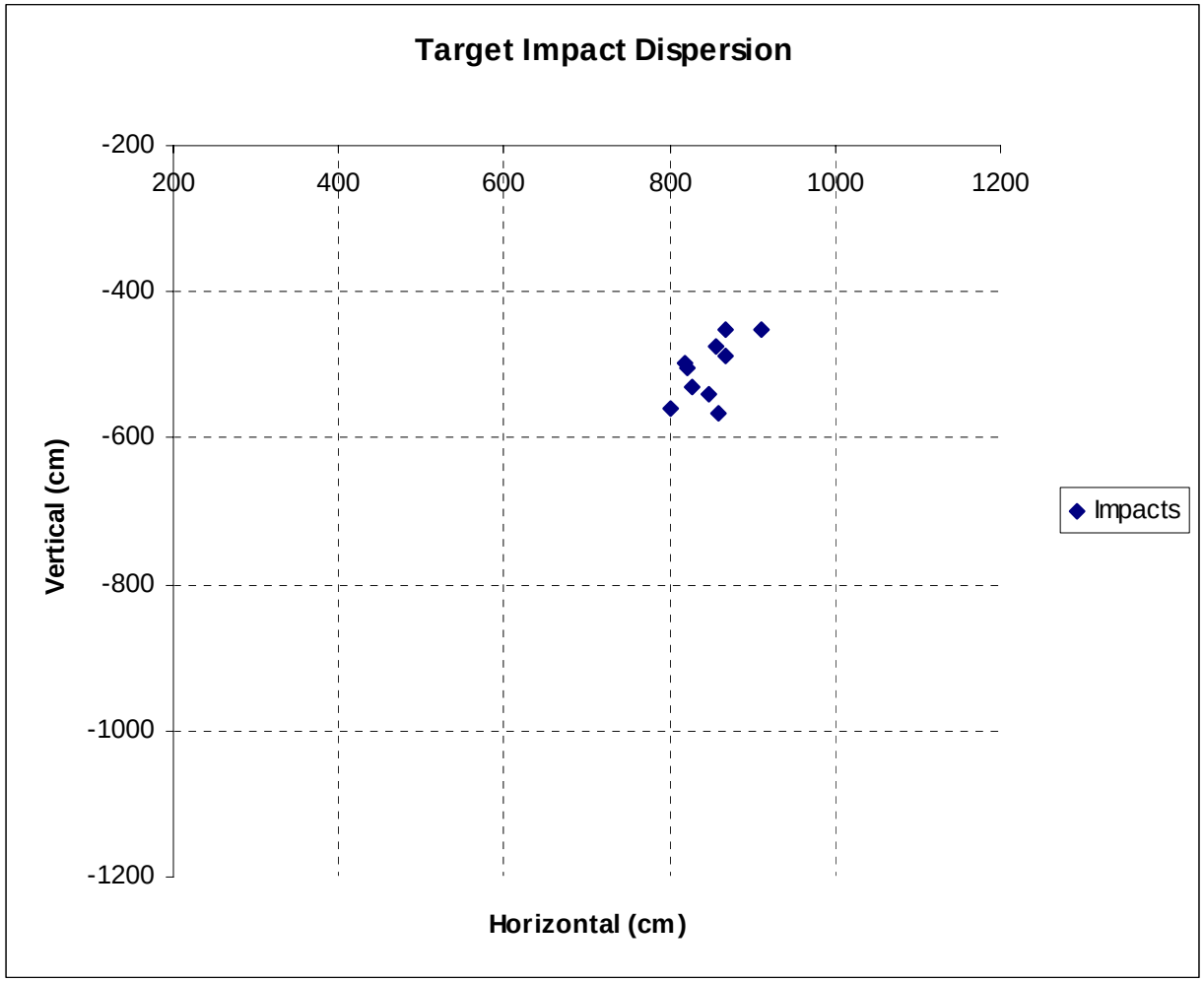
Improved Impact Result at -32 °C



TID (mils)		
	X	Y
First 5	**0.43**	**0.12**
Second 5	**0.12**	**0.13**
Pooled	**0.32**	**0.13**

The M865 Performance Specification requires a TID of .30 x .30 or lower to accept a cartridge lot.

Desired Impact Result at -32 °C



TID (mils)		
	X	Y
First 5	**0.10**	**0.12**
Second 5	**0.12**	**0.13**
Pooled	**0.11**	**0.13**

The M865 Performance Specification requires a TID of .30 x .30 or lower to accept a cartridge lot.

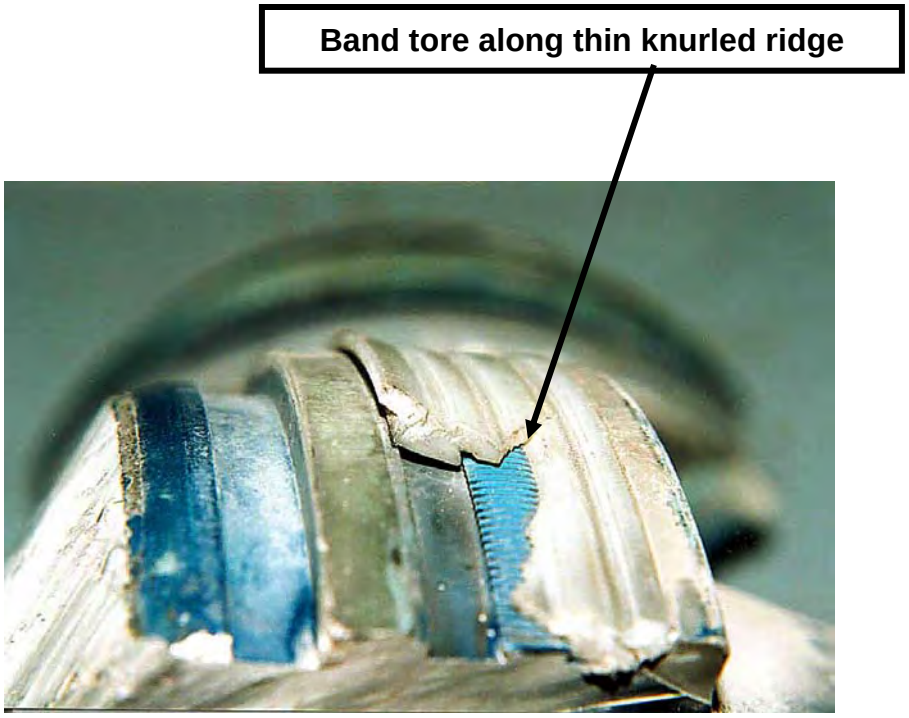
M865 Sabot Recovery History

- General Dynamics – OTS Red Lion Operations has been evaluating recovered sabot segments for the past 10 years.
- After the design change in 1999, the focus was primarily on the function of the nylon obturator band.
- Three major phenomena where discovered which raised concern that an asymmetrical discard of the sabot could be contributing to the sometimes, erratic flight of the M865 Projectile at cold temperatures.
    1. Circumferential tearing of obturator band
    2. Gas intrusion beneath aft end of obturator band
    3. In-bore obturator band rotation

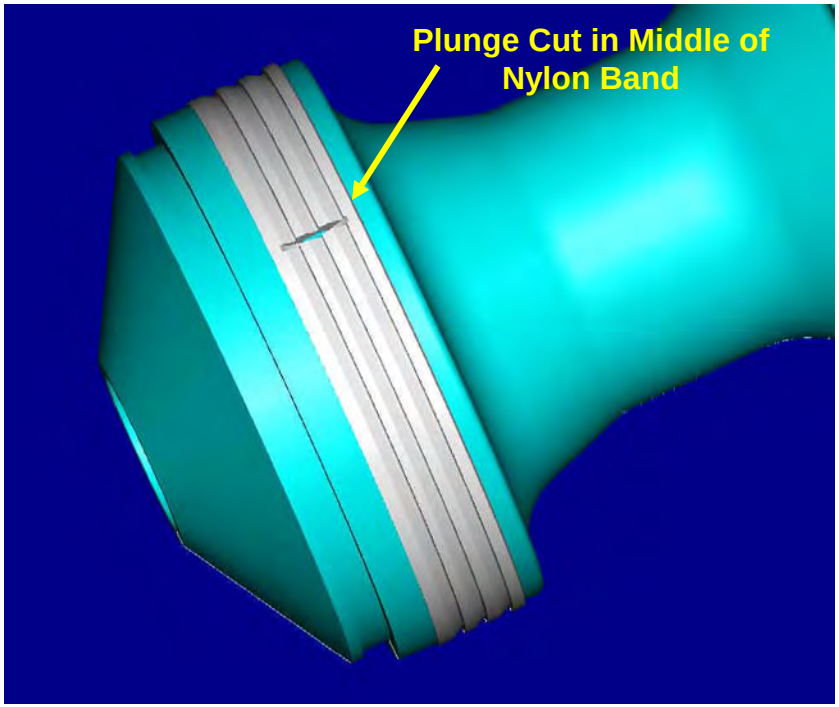
Circumferential Tearing

- Sabot recovery analysis revealed evidence that the nylon obturator band did not always break along the pre machined slot.

- In many instances, the fracture reaches the area of thinner nylon over the knurled area between the dovetails and the fracture will on occasion, especially at cold temperatures, propagate circumferentially rather than directly aft.

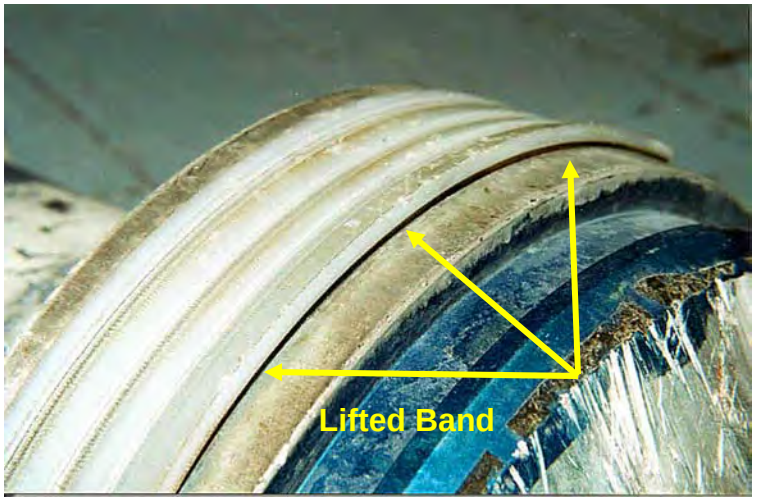


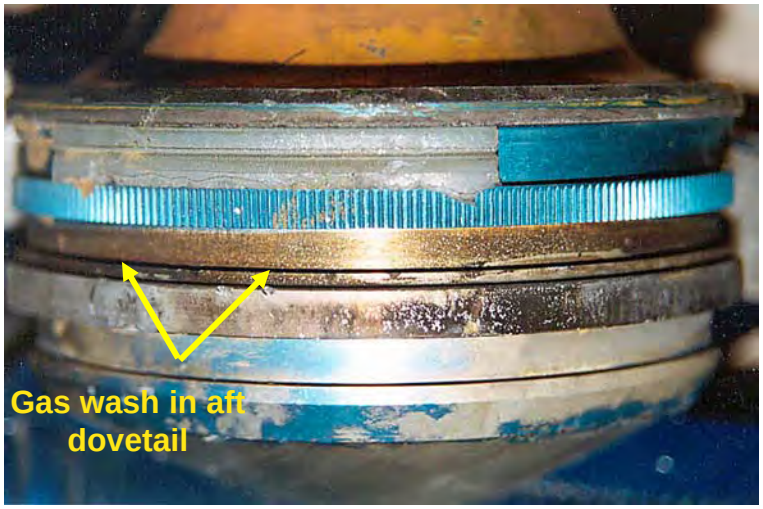
Design Feature One – Plunge Cut



- The plunge cut is designed to prevent circumferential tearing of the obturator band.
- The plunge cut is located directly in the center of the band so that each shoulder, forward and aft, of the cut have an identical thickness. This will promote an even, symmetrical break.

Gas Intrusion Beneath Nylon Band

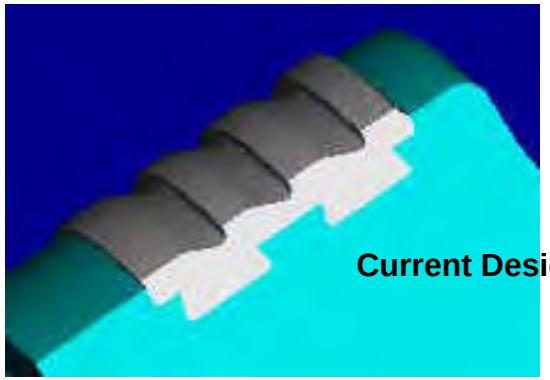


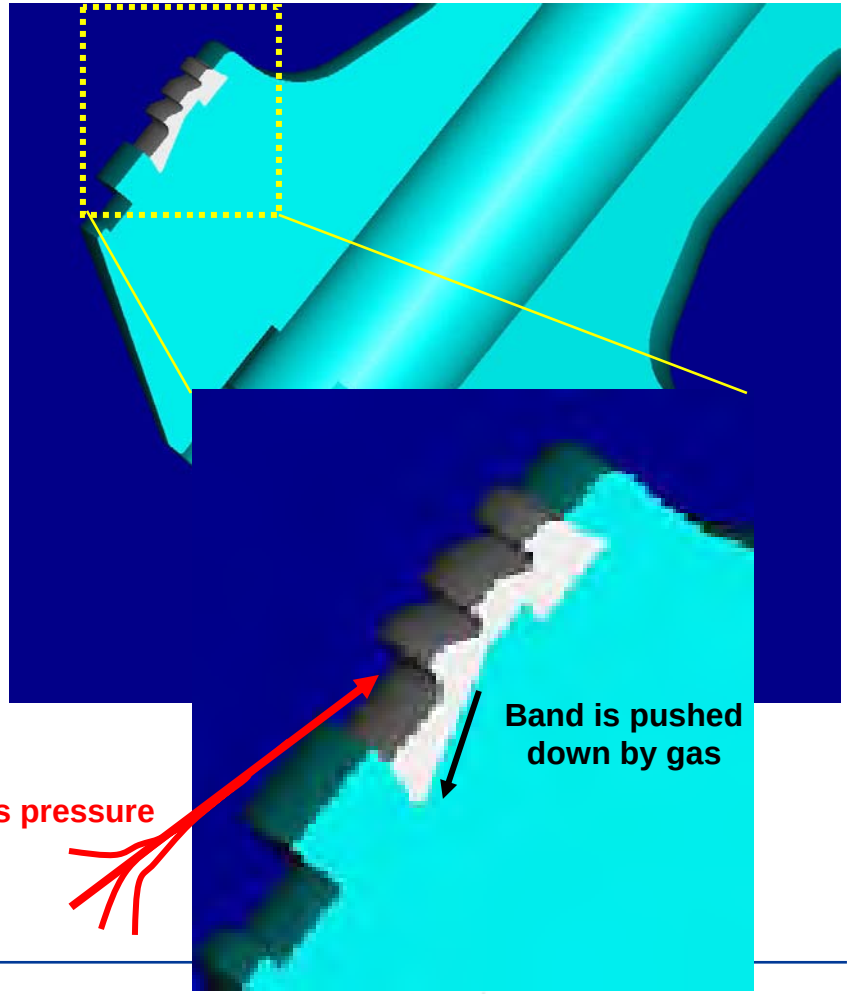


- It was noticed during the sabot recovery evaluation that there was evidence of gas intruding under the aft dovetail of the nylon band.
- The evidence of this lifting was shared with the technical community and the modified dovetail design was created and became known as the ARL design.

Design Feature Two – ARL Groove

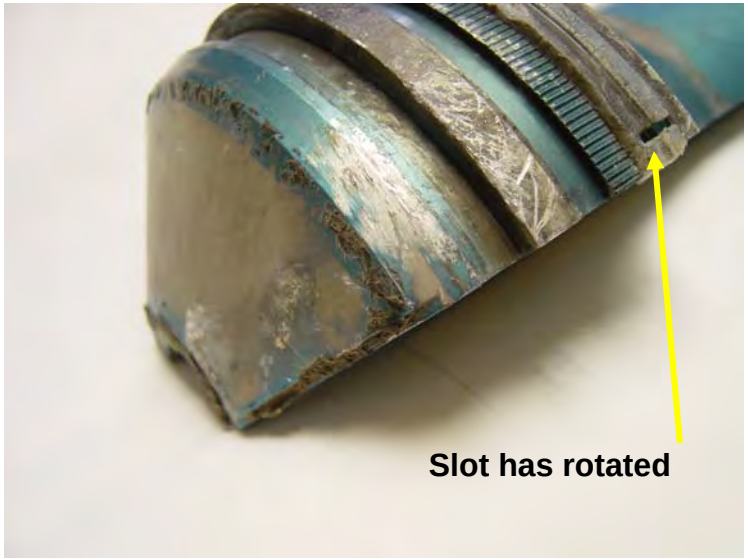
- Designed to prevent gas intrusion underneath the obturator band causing the band to lift prior to exiting the gun tube.
- In theory the gas should force the obturator band into the extended dovetail.

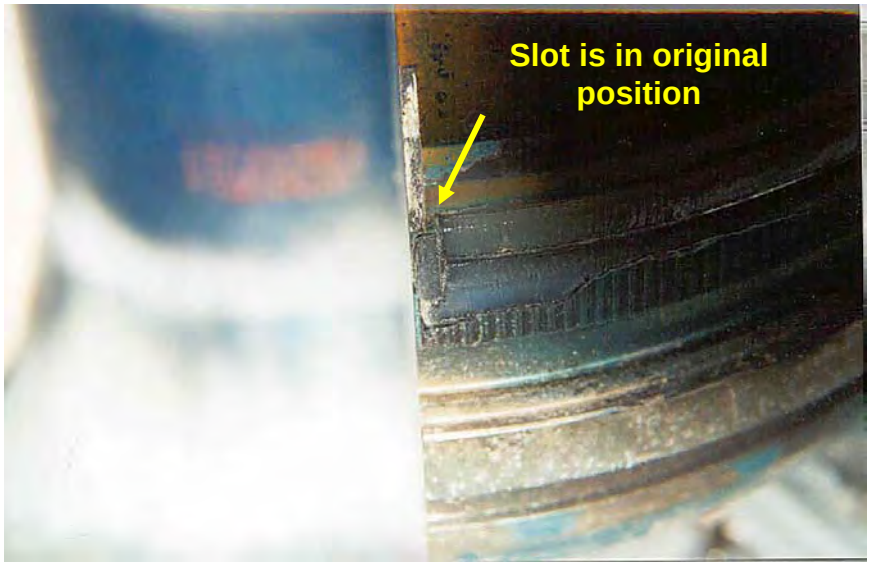




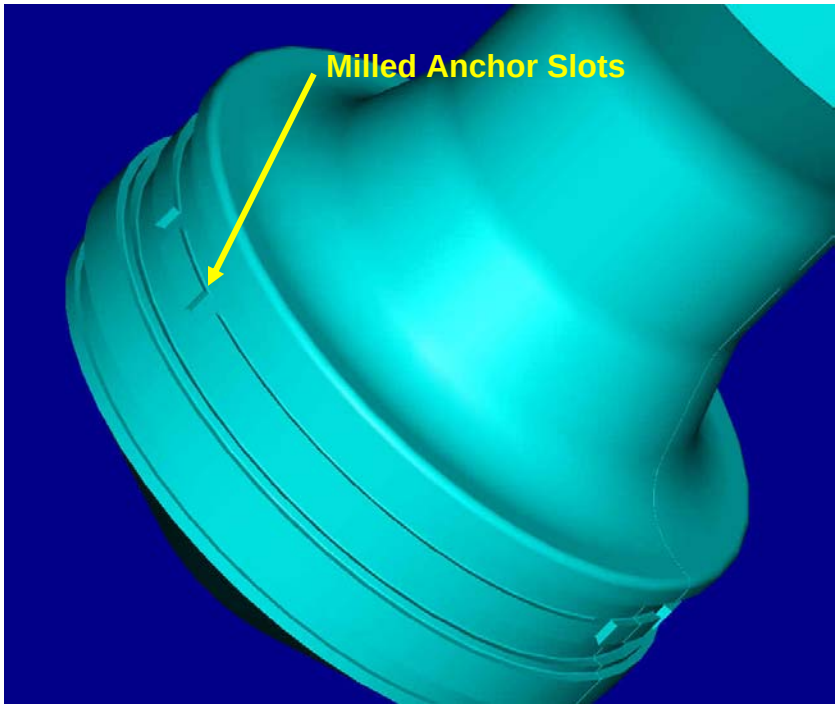
Band Rotation

- It was noticed that on some recovered sabots there was evidence of in-bore band rotation.
- Some recovered sabot segments showed evidence of the slot being intact and shifted circumferentially up to ten or twenty degrees.
- This rotation would not stop the discarding of the sabot, but it would certainly create a different discarding process than what is normally seen.





Design Feature Three – Anchor Slots



- Anchor slots are designed to prevent the obturator band from rotating while in bore.
- Rotation of the band in-bore causes the band to break in a location other than the precut slots resulting in a negative affect on final TID results.

Design Combinations

- 5 test groups were developed from the three design features

	ARL Groove	Plunge Cut	Anchor Slots	Ballistic Test Qty.
Design 1 (T_1)		**X**		**30**
Design 2 (T_2)	**X**	**X***		**30**
Design 3 (T_3)			**X**	**30**
Design 4 (T_4)		**X**	**X**	**30**
Design 5 (T_5)	**X**		**X**	**30**
Control Rounds				**60**

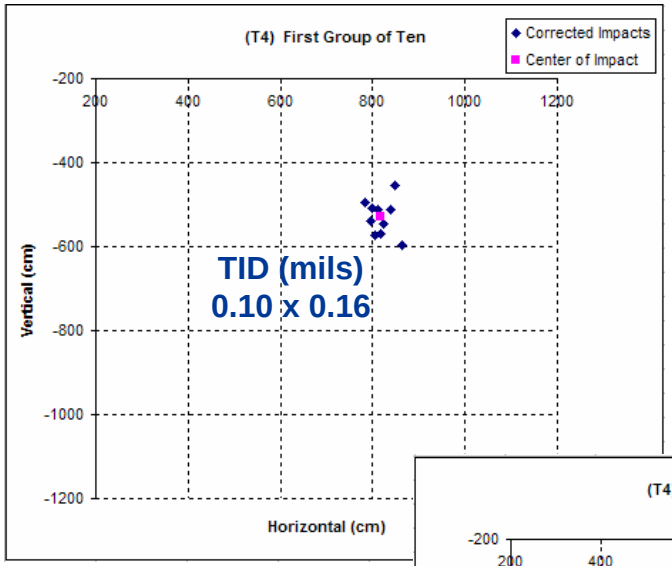
*** Plunge cut had to be modified from a slot to a drill cut due to modified obturator band**

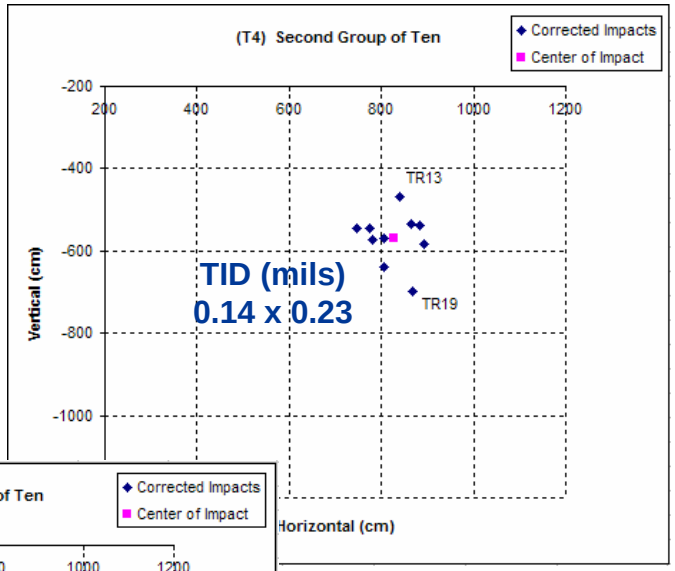
Summary of Results

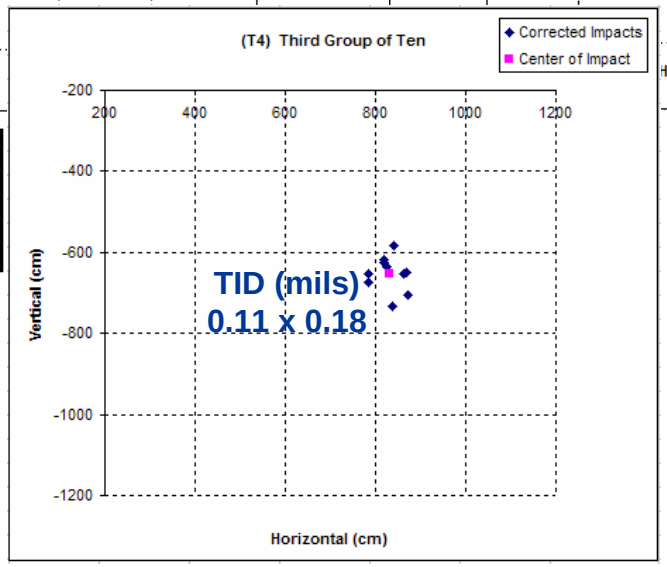
	No of Rounds Fired	Fliers[1]	Percent Fliers	Improvement over Control Rounds	Total Average TID
Design 1	30	7	23.3%	8.3%	.20 x .27
Design 2	30	6	20%	11.6%	.25 x .25
Design 3	30	6	20%	11.6%	.27 x .26
Design 4	**30**	**2**	**6.6%**	**25%**	**.12 x .19**
Design 5	30	4	13.3%	18.3%	.21 x .23
Controls	60	19	31.6%	-	.26 x .26

[1]Any single round which resulted in an impact greater than 100 cm from the center of impact was considered a flier during test evaluation.

Design 4 Resultant Impacts



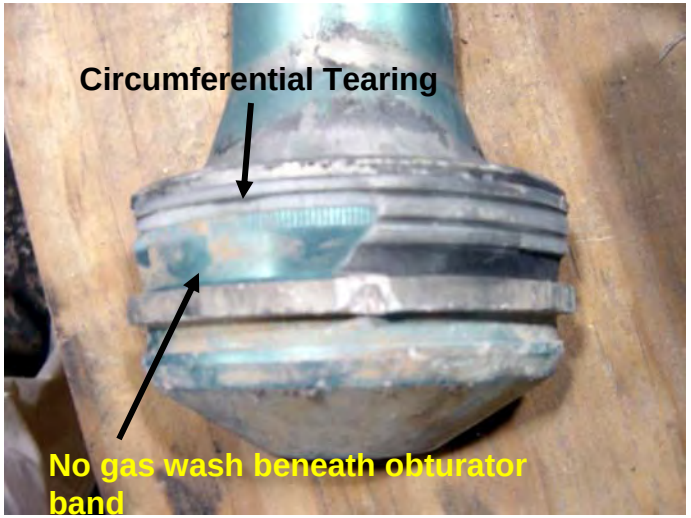




3 out of 40 test since the design change have had a TID result below a 0.20 x 0.20.

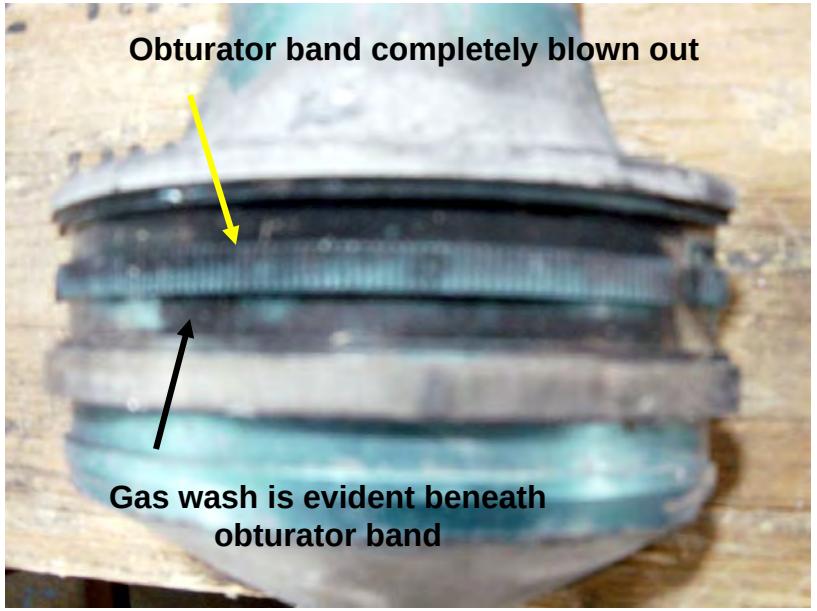
Recovered Sabots – General results

1. ARL Groove
   - Gas did not intrude underneath nylon obturator band.
   - There were many recovered sabots that exhibited circumferential tearing.
   - In most instances large portions of the obturator band remained in tact.



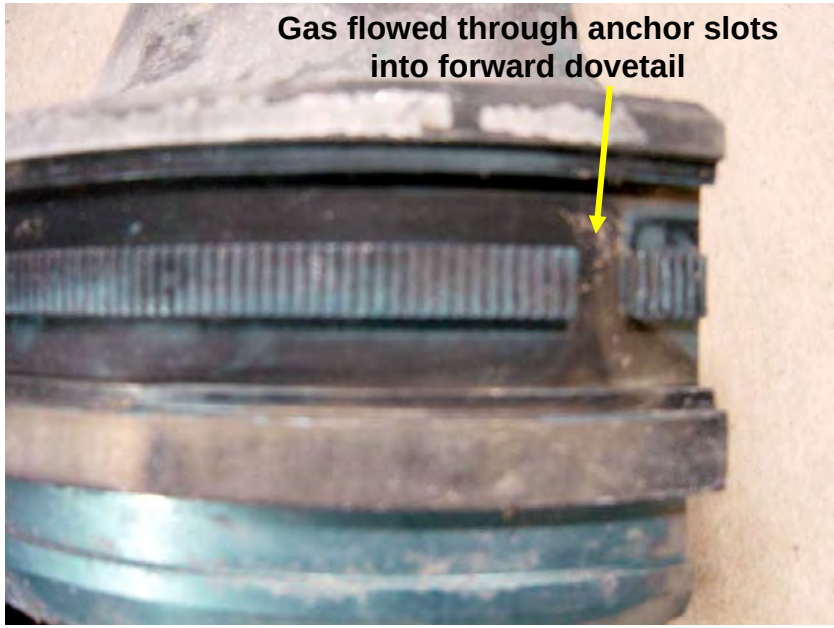
Recovered Sabots – General results

2. Plunge Cut
   - The nylon obturator bands showed very little signs of circumferential tearing.
   - 90% of the bands were completely blown out of the sabot segments. This is typical to what is seen during +52°C and +21 °C.
   - Gas was able to intrude under the obturator bands.



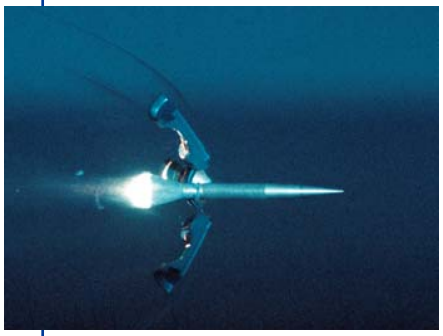
Recovered Sabots – General results

3. Anchor Slots
   - Gas wash intruded into forward and aft dovetail on 95% of the sabot segments. Gas wash flowed through the anchor slots.
   - There was no evidence of band rotation.
   - Designs with this feature on average exhibited an increase in muzzle velocity of 20 m/s.



Conclusions and Path Forward

Design 4 (Plunge cut and Anchor slots) performed significantly better than the current M865 design.



- Significant improvement in TID
- 25% lower rate of fliers than current design
- Increased muzzle velocity by an average of 20 m/s
- Recovered sabot segments exhibited characteristics similar to what is seen after +52°C and +21 °C tests.

Verification testing of Design 4 to took place in October 2005 at YPG.

- GD-OTS and ATK to participate in verification test
- 180 test rounds with 60 control rounds.

Questions

Behind Armor Debris computations with finite elements and meshless particles

Gordon R. Johnson and Robert A. Stryk
also
Stephen R. Beissel and Charles A. Gerlach

Army High-Performance Computing Research Center
Network Computing Services, Inc; Minneapolis, MN

22nd International Symposium on Ballistics
Vancouver, BC, Canada

November 14-18, 2005

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The views and conclusions contained in this presentation are those of the authors and should not be interpreted as presenting the official policies or positions, either expressed or implied, of the U.S. Army Research Laboratory or the U. S. Government unless so designated by other authorized documents. Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

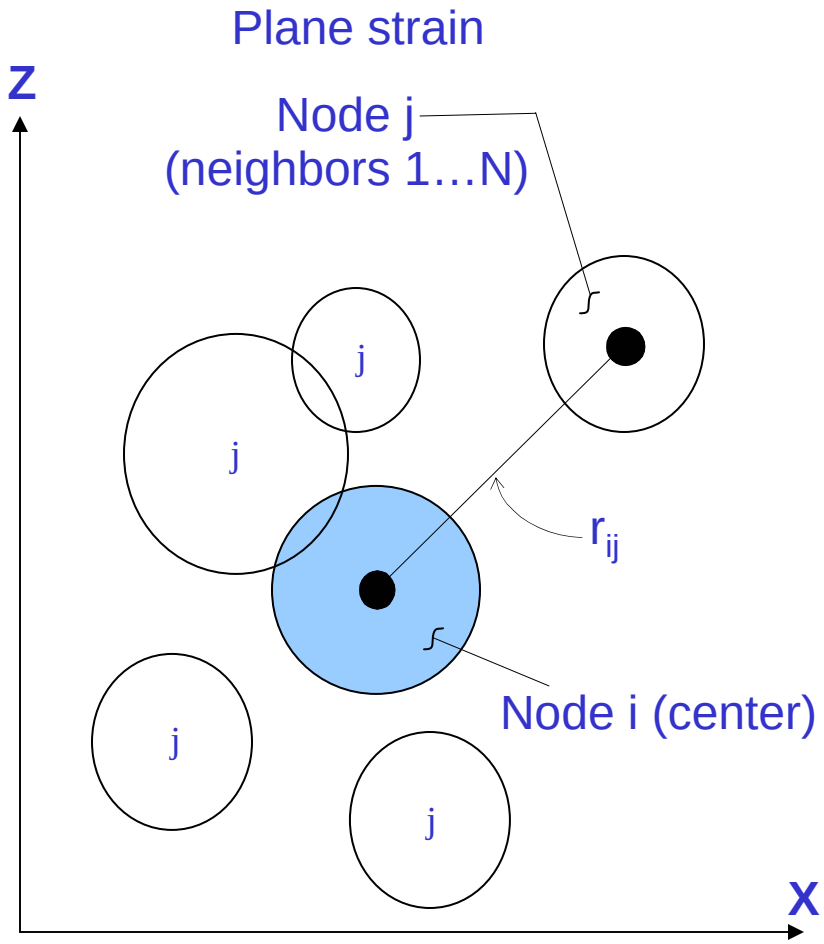
Outline

- Comments regarding Behind Armor Debris (BAD)
- Generalized Particle Algorithm (GPA)
- Conversion of finite elements to particles
- Description of computed fragments
- Computations of Behind Armor Debris
  - EPIC code
  - Ballistic velocities and hypervelocities
  - Computations compared to experiments
- Summary
- Movie (if time permits)

Comments regarding Behind Armor Debris

- Determination of BAD from testing is difficult
  - Requires fragment material, size, velocity, position
  - Another approach is to collect fragments in witness pack
- Determination of BAD from computations is difficult
  - Eulerian algorithms have trouble with large air gaps
  - Finite element algorithms have trouble with large distortions
  - Meshless particle algorithms may have trouble with accuracy
- Combination of finite elements and meshless particles is well suited for BAD computations

Generalized Particle Algorithm



Data from neighbors is required for gradients

strain rates

$$\dot{\varepsilon}_{xx}^{i} = \sum_{j=1}^{N} \frac{-R_{ij}A_iA_j}{r_{ij}} \left[\alpha_x^i \left(v_x^j - v_x^i \right) l_x^{ij} \right]$$

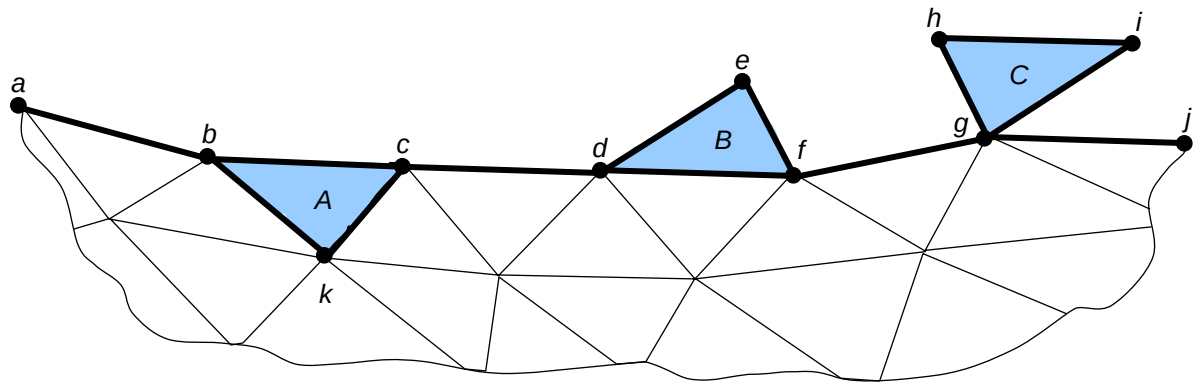
forces

$$P_x^i = \sum_{j=1}^{N} \frac{-R_{ij}A_iA_j}{r_{ij}} \left[\alpha_x^i \left(\sigma_{xx}^i - Q_{ij} \right) l_x^{ij} + \alpha_z^i \sigma_{xz}^i l_z^{ij} \right]$$

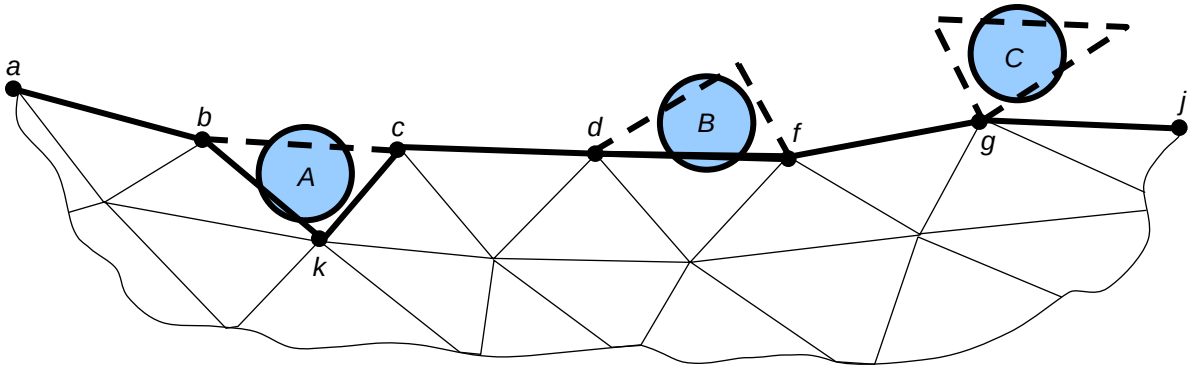
where $$\alpha_x^i = \frac{1}{\sum_{j=1}^{N} R_{ij}A_j \left(l_x^{ij} \right)^2}$$

Conversion of finite elements to particles

Interface nodes and elements before conversion



Interface after conversion of elements



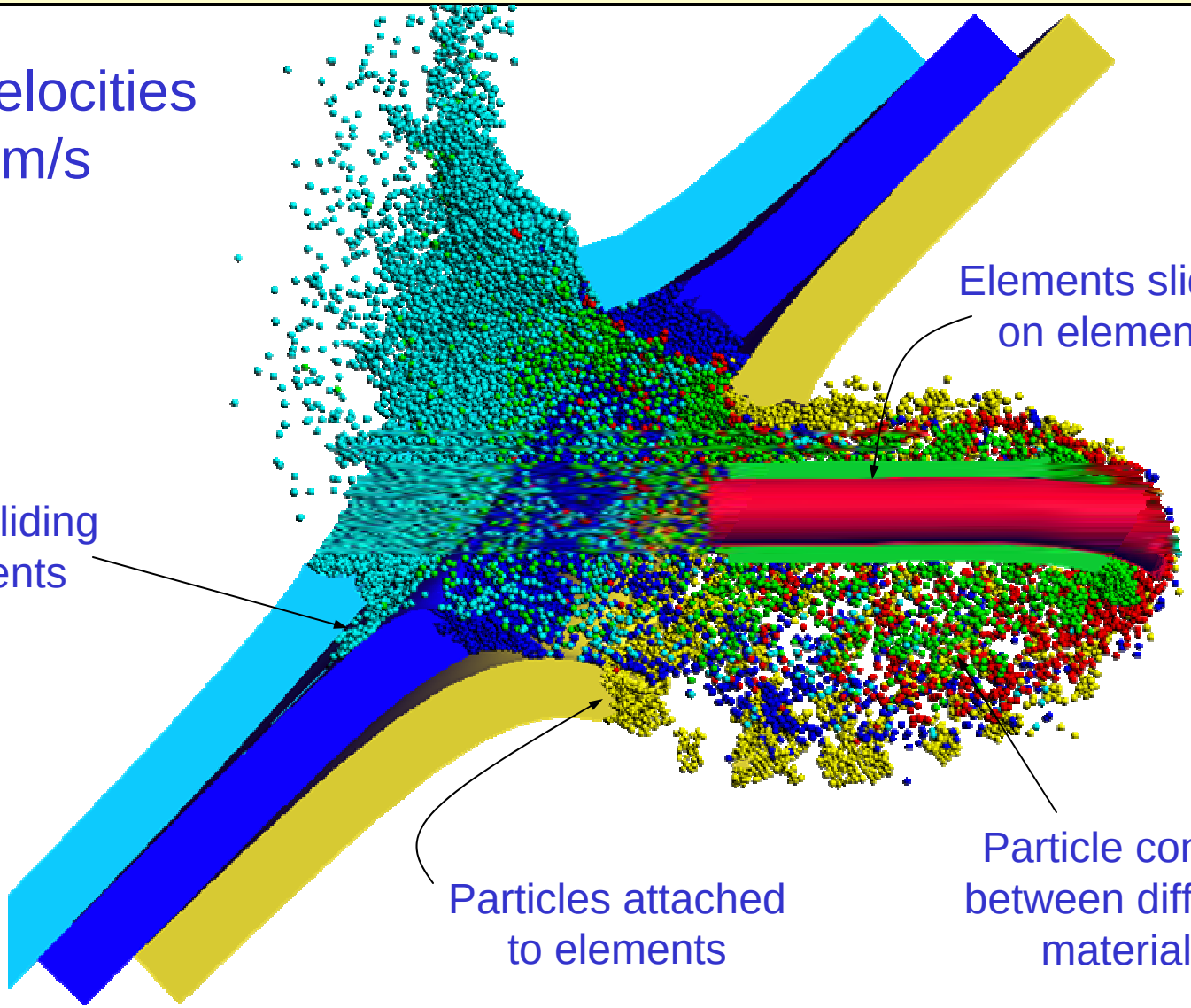
Capabilities of Lagrangian conversion algorithm

- Penetration and perforation of target
- Failure and fragmentation of material
- Highly distorted flow and structural deformations
- Accurate contact and sliding between materials
- Travel through large air gaps
  - no numerical diffusion of geometry or materials
  - no element or particle representation of air gaps
- Interaction with subsequent target components

Conversion of finite elements to particles

Ballistic velocities
V = 2000 m/s

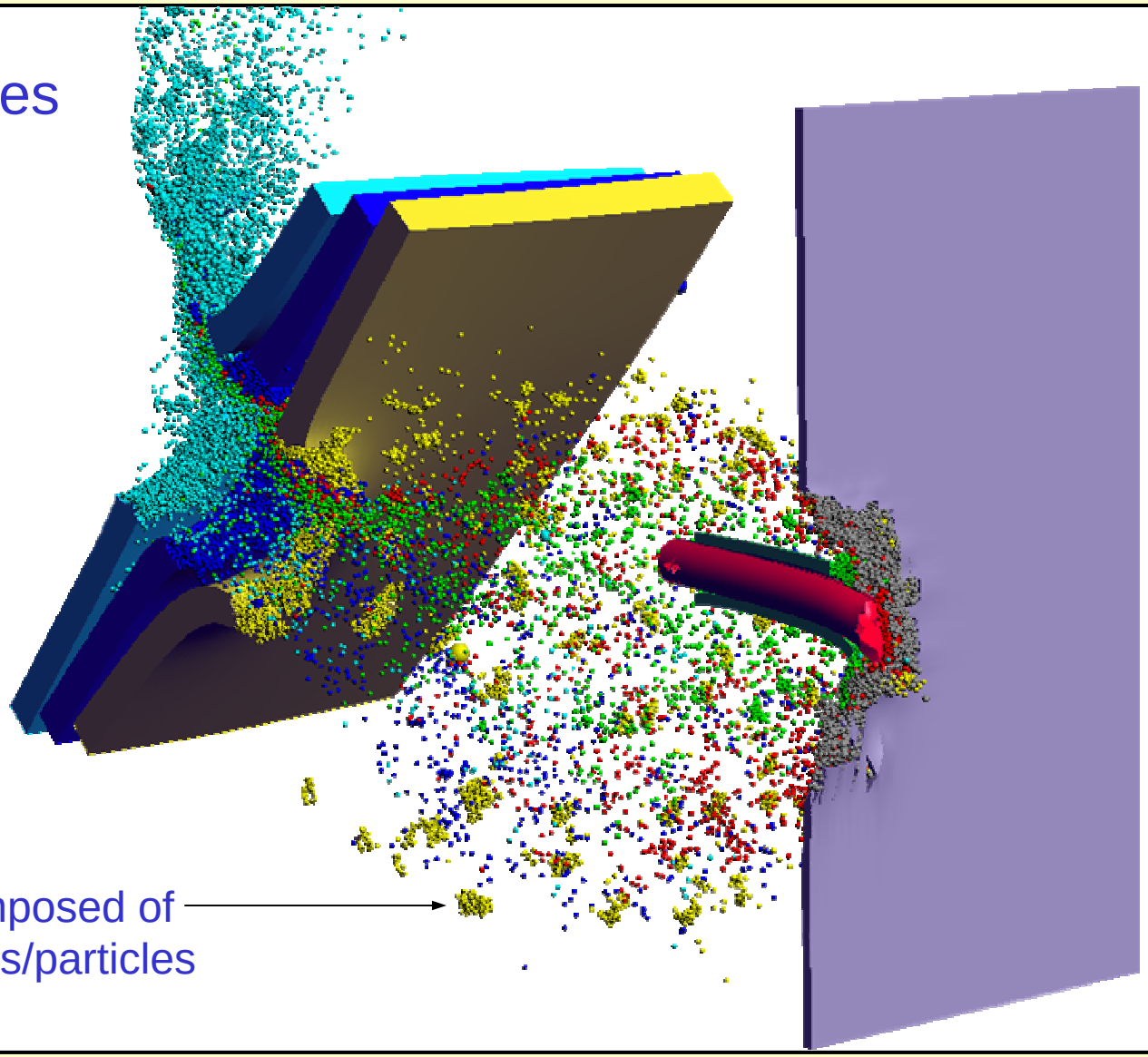
t = 100 μs



Conversion of finite elements to particles

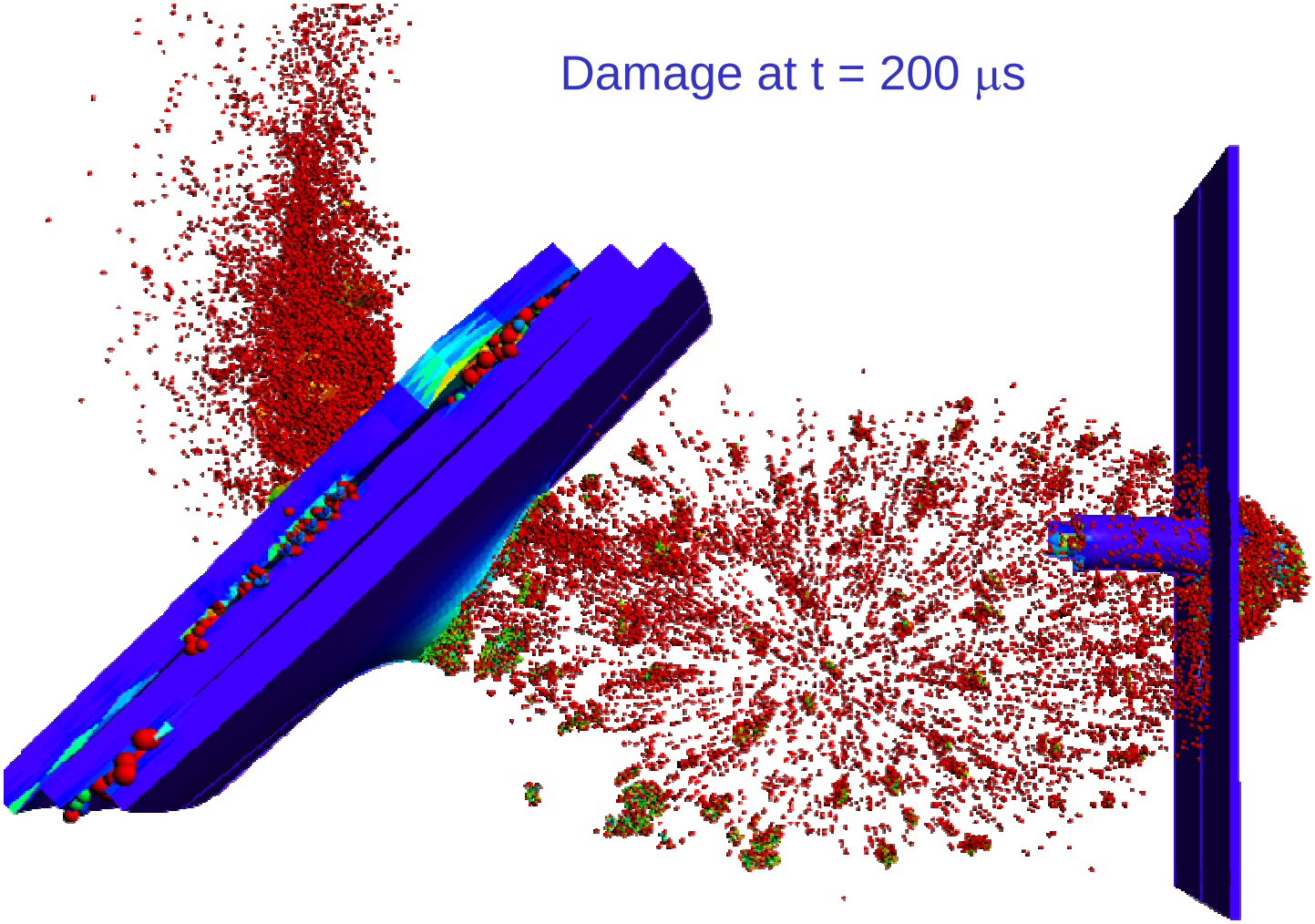
Ballistic velocities
V = 2000 m/s

t = 200 μs



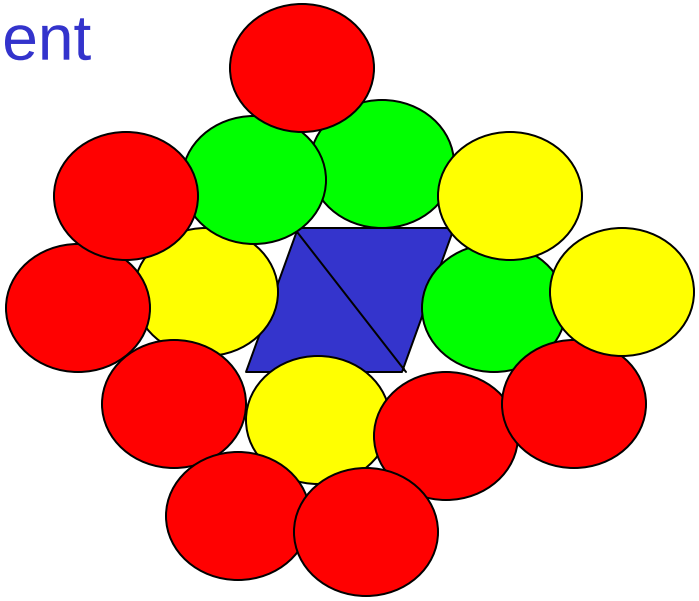
Fragments composed of multiple elements/particles

Conversion of finite elements to particles

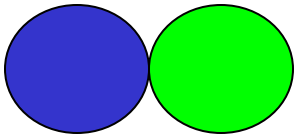


Description of computed fragments

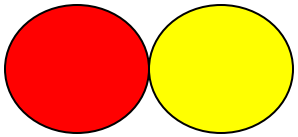
Fragment



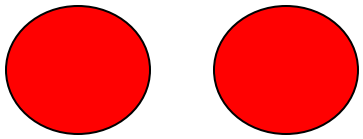
full bond



half bond



no bond



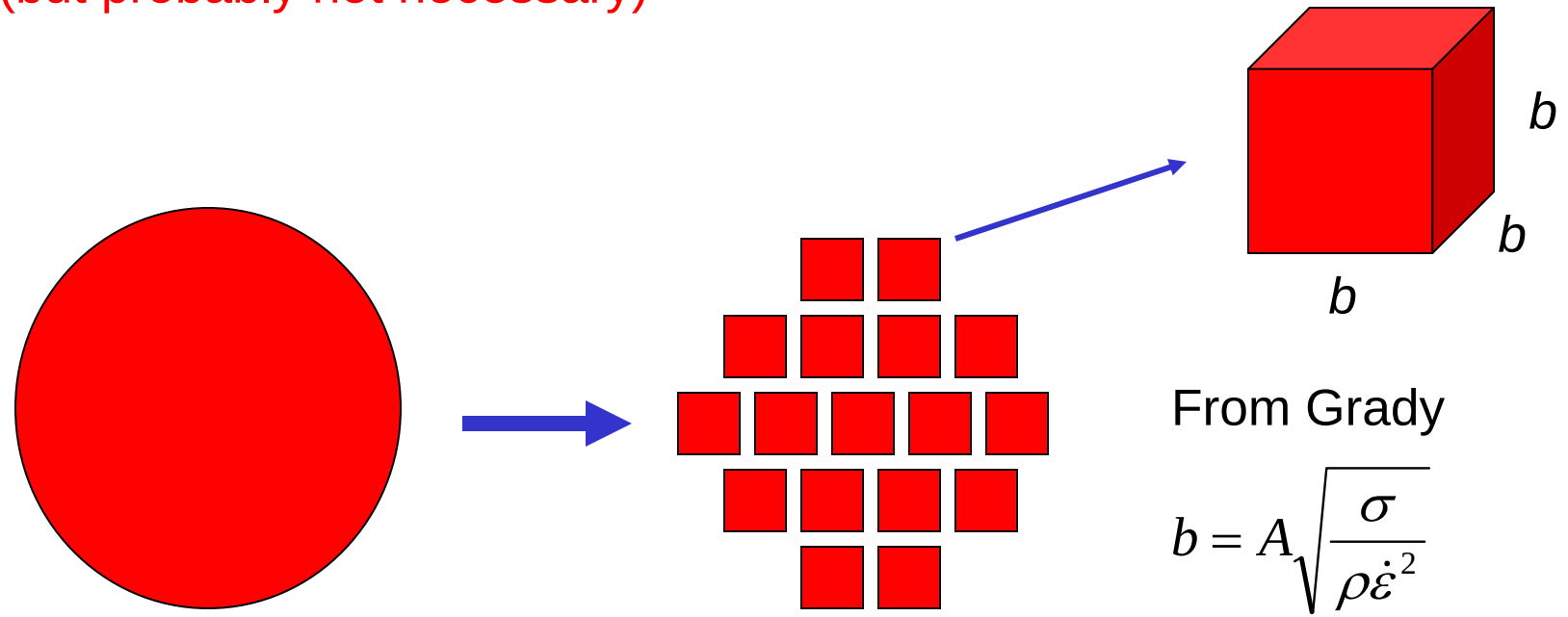
(compression only)

Red particles are failed (D = 1.0)

Estimate of small fragment sizes

It is possible to estimate the sizes of fragments smaller than the particles

(but probably not necessary)



From Grady

$$b = A\sqrt{\frac{\sigma}{\rho\dot{\varepsilon}^2}}$$

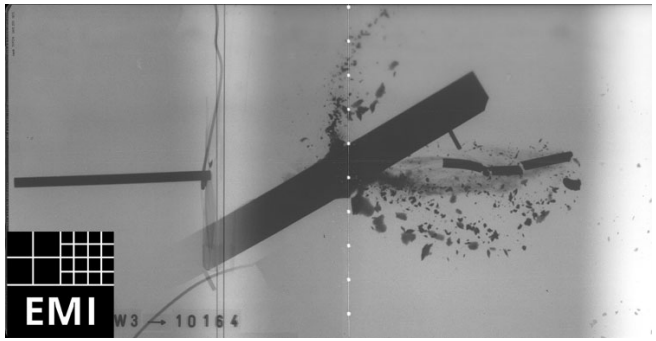
Failed particle

Number of fragments per particle

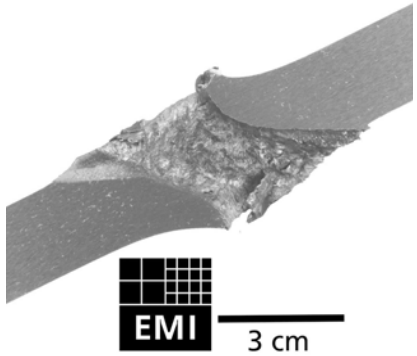
N = Volume of particle / b^3

Behind Armor Debris at ballistic velocities

N. Heider, K. Weber and P. Weidemaier, “Experimental and numerical simulation analysis of the impact process of structured KE penetrators onto semi-infinite and oblique plate targets,” presented at 21st International Ballistics Symposium, 2004.



Radiograph during test



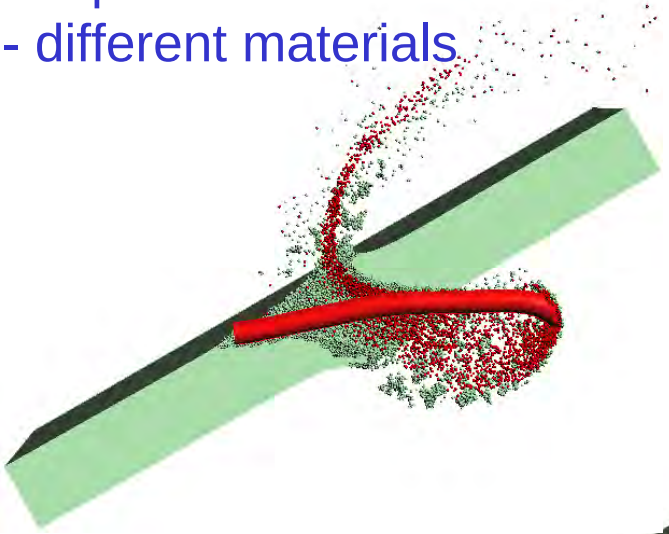
Section of recovered plate

- Tungsten rod (L/D = 20) impacting steel plate
- Impact velocity = 1615 m/s
- Impact obliquity = 60 degrees
- Angle of attack = 2.4 degrees (nose up)

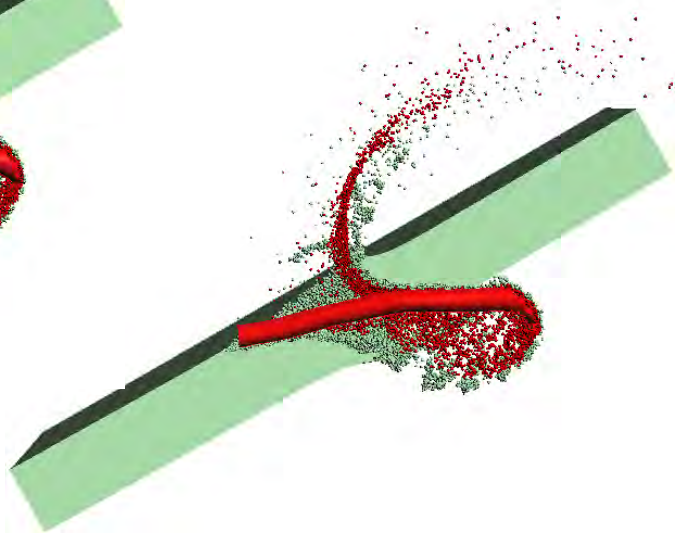
Computed results at ballistic velocities

Computed responses at 80 µs

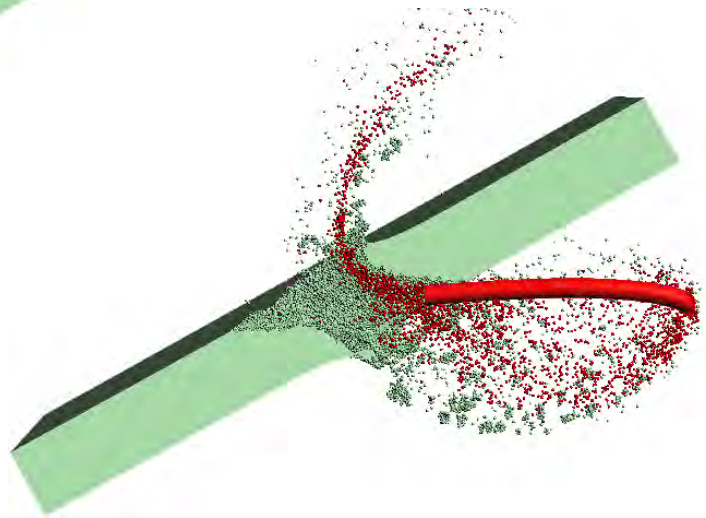
Baseline (V = 1615 m/s)
- impact conditions from test
- different materials



High-strength target
- 50 % stronger



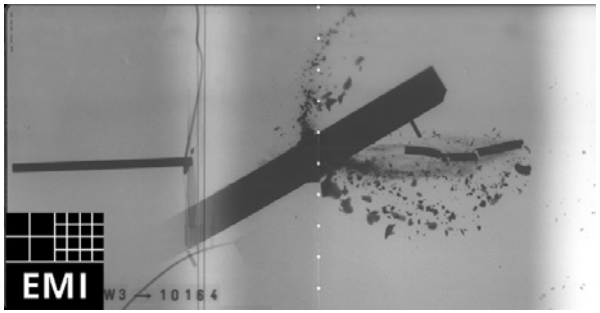
Constant kinetic energy
- higher velocity (25%)
- lower mass



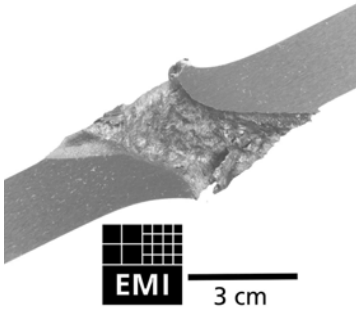
Computational and experimental results

Computed damage at 168 μs

Baseline
- impact conditions from test
- different materials



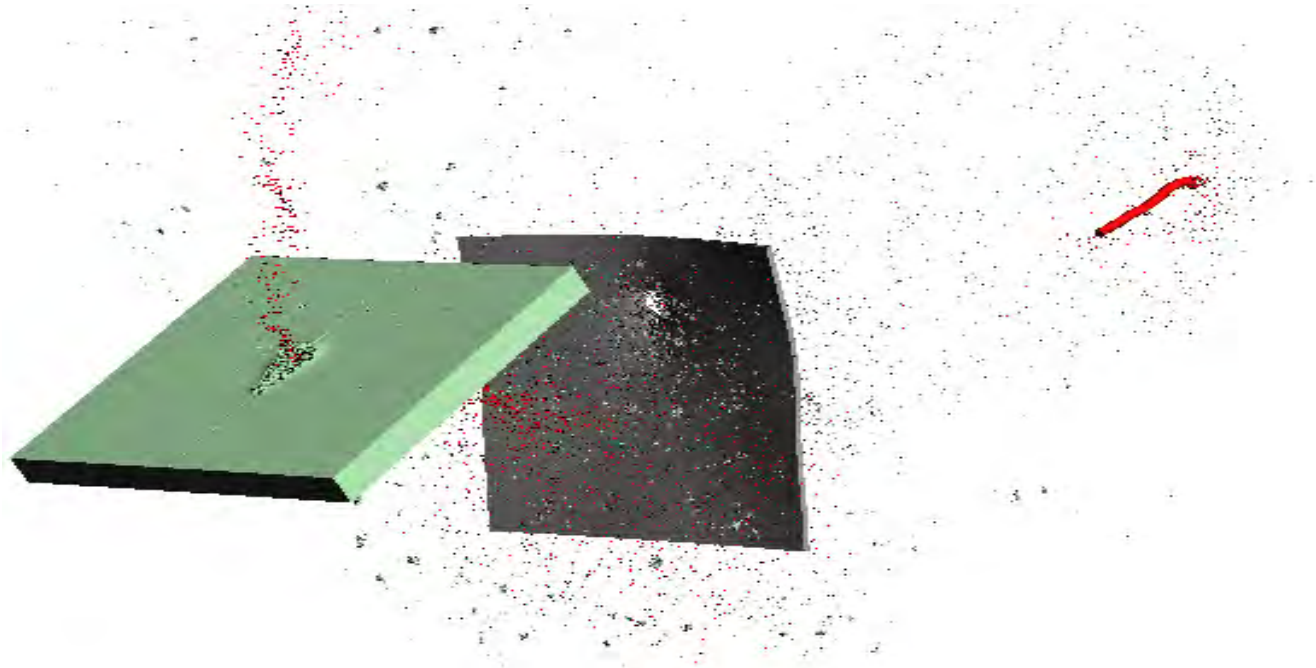
High-strength target



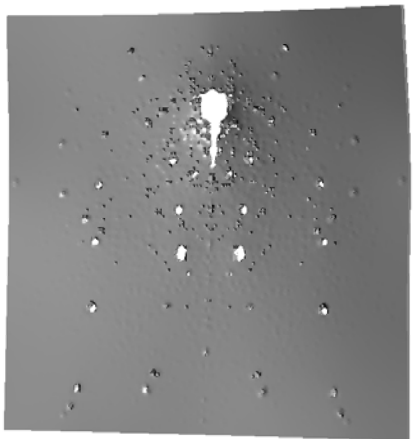
Constant kinetic energy
- higher velocity (25%)
- lower mass

Baseline computation with witness plate

Computed response at 500 μs

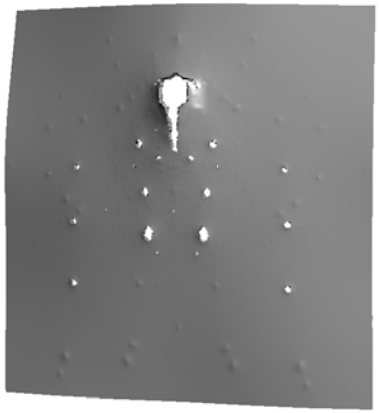


witness plate



front

back

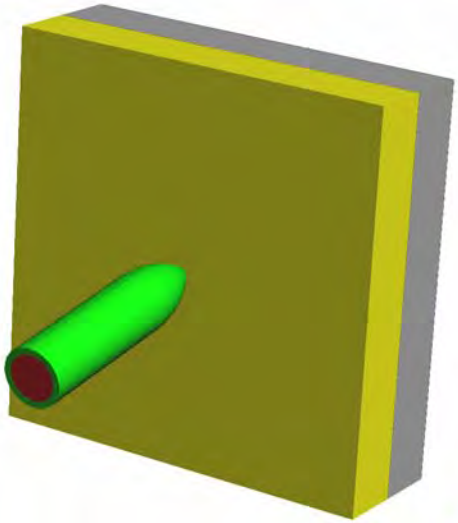


Thin aluminum witness plate placed behind target

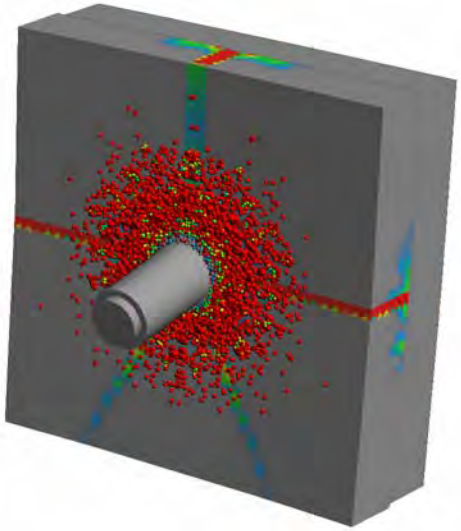
- projectile and target fragments damage witness plate
- used to quantify behind armor debris

Layered ceramic/aluminum target

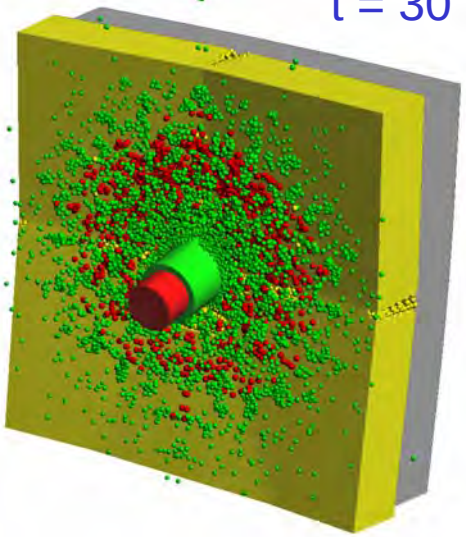
Projectile
- steel core
- copper jacket
- V = 900 m/s
- Ø = 10 deg

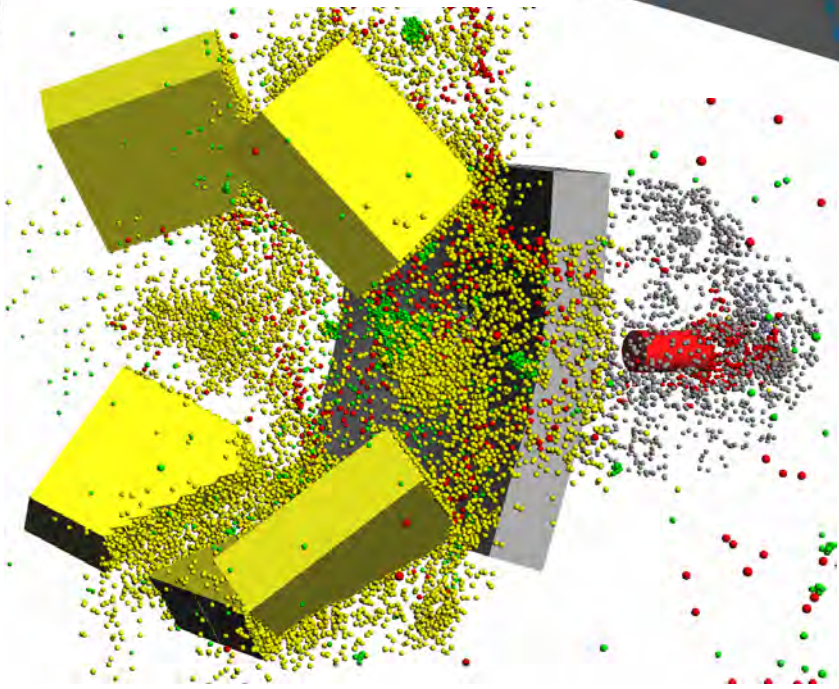


Damage
- t = 20 µs
- cracks form before conversion



t = 30 µs



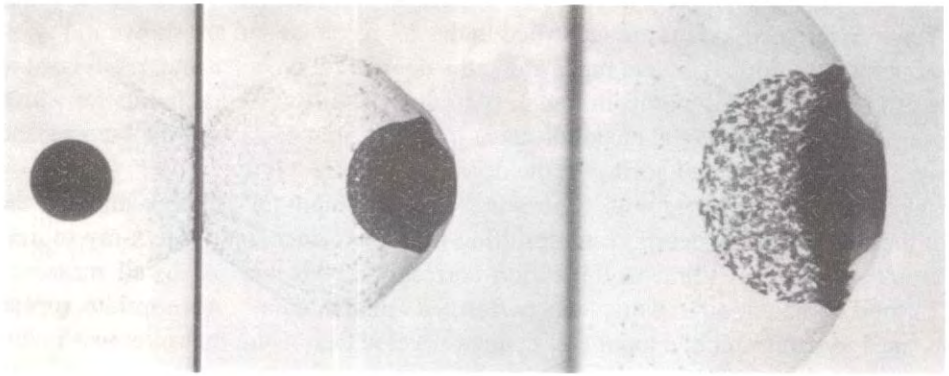


t = 300 µs

Computations of hypervelocity impact

Aluminum sphere impacting thin aluminum plate at 6.15 km/s

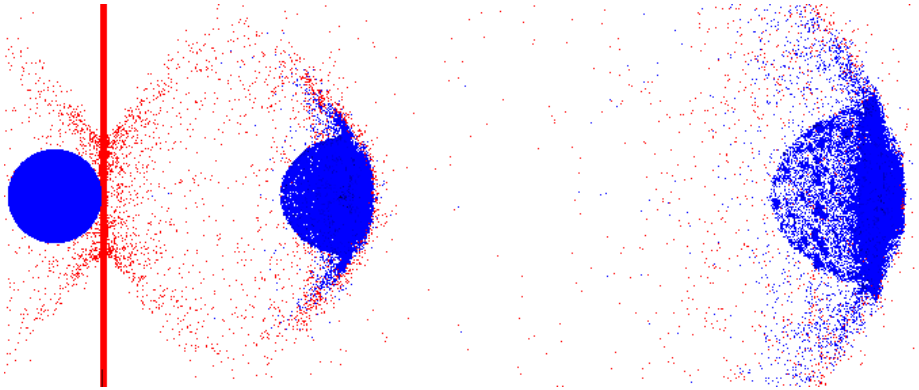
A. Piekutowski, “Effects of scale on debris cloud properties.” Int. J. Impact Engng **20** (1997).



Computation using conversion:

- Shows same debris-cloud characteristics
- Position/scale of radiographs distorted by x-ray projection

Beissel, Gerlach, Johnson (HVIS 2005)



8.1 μs

23.2 μs

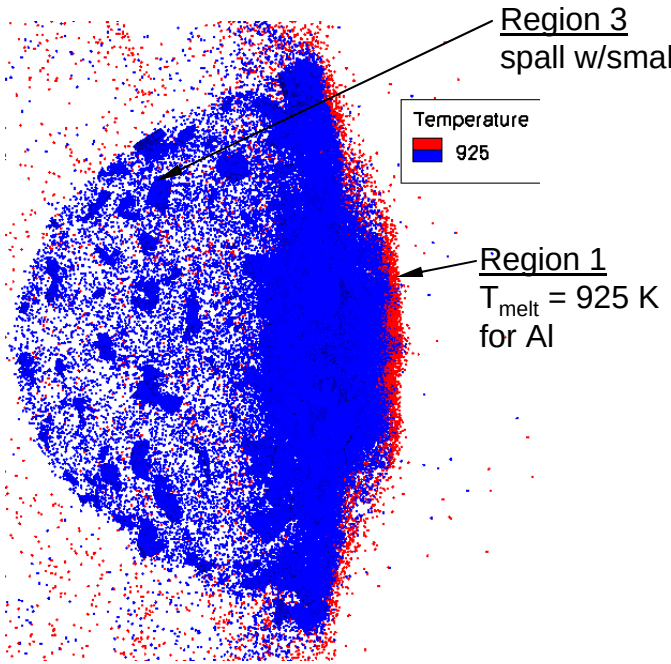
Computations of hypervelocity impact

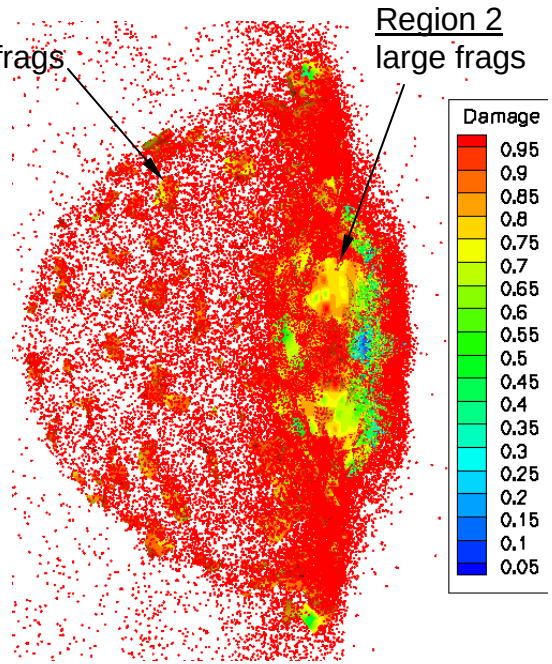
Aluminum sphere impacting thin aluminum plate at 6.15 km/s

Three regions identified by Piekutowski in test:

1. Melted target and projectile at front
2. Large projectile fragments in middle
3. Small projectile fragments in spall

Temperature at 23.2 μs



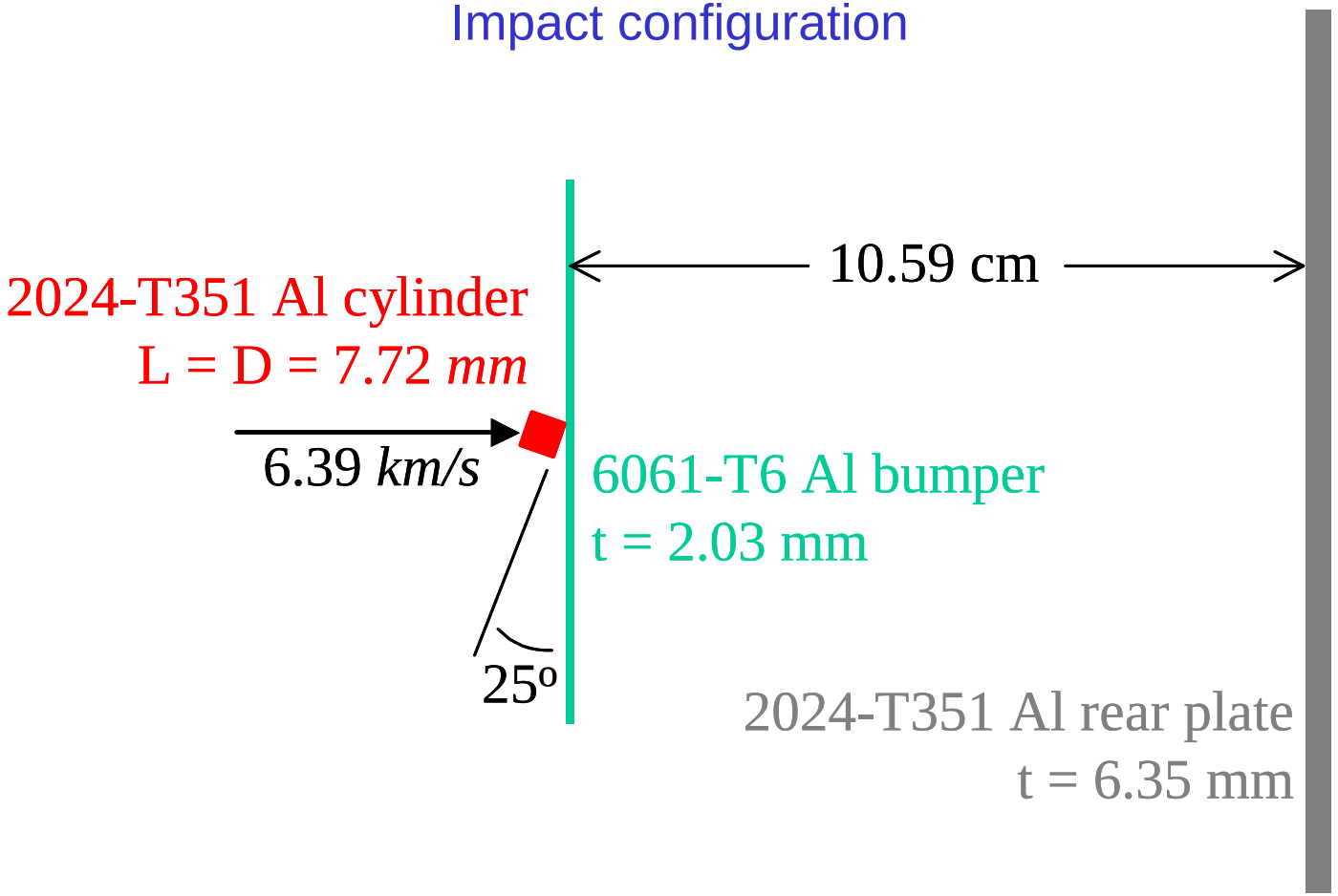


Damage at 23.2 μs

Computations of hypervelocity impact

Oblique cylinder impacting a Whipple shield

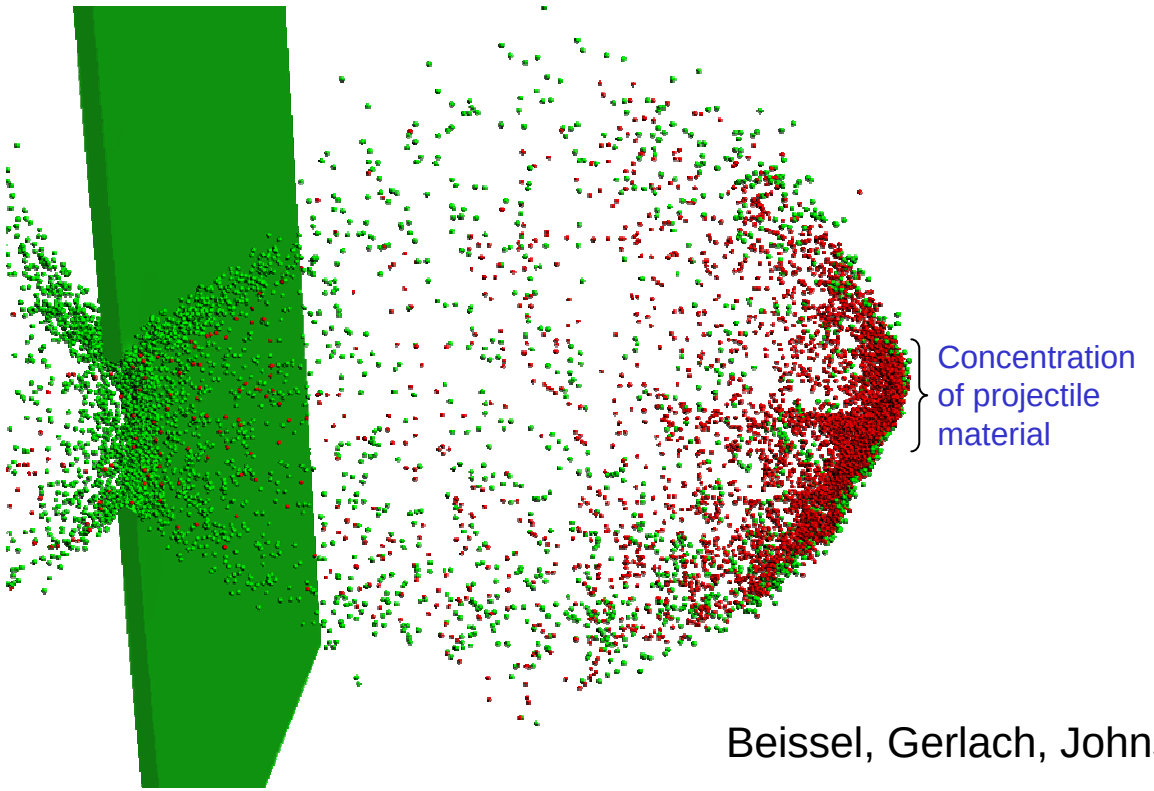
Impact configuration



Computations of hypervelocity impact

Oblique cylinder impacting a Whipple shield

Computed cross-section 15 μs after impact
(before debris cloud has reached rear plate)

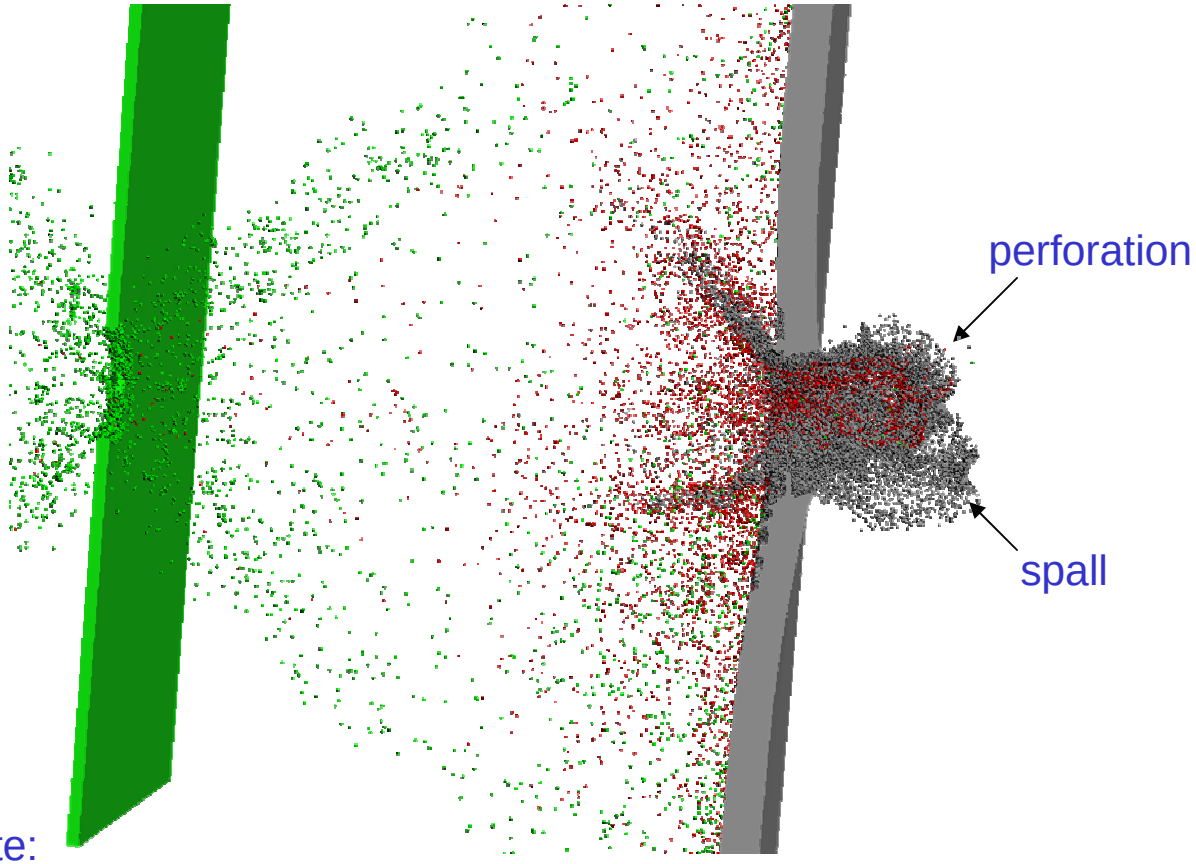


Beissel, Gerlach, Johnson (HVIS 2005)

Computations of hypervelocity impact

Oblique cylinder impacting a Whipple shield

Computed cross-section
50 μs after impact



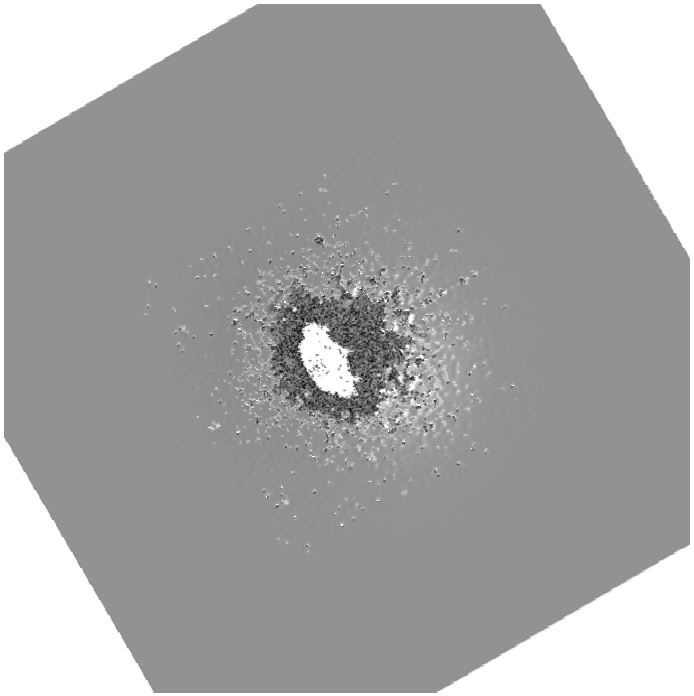
Two modes of failure in rear plate:

1. Perforation due to impact by concentration of projectile material in primary debris cloud
2. Spall due to impact by remaining projectile material in primary debris cloud

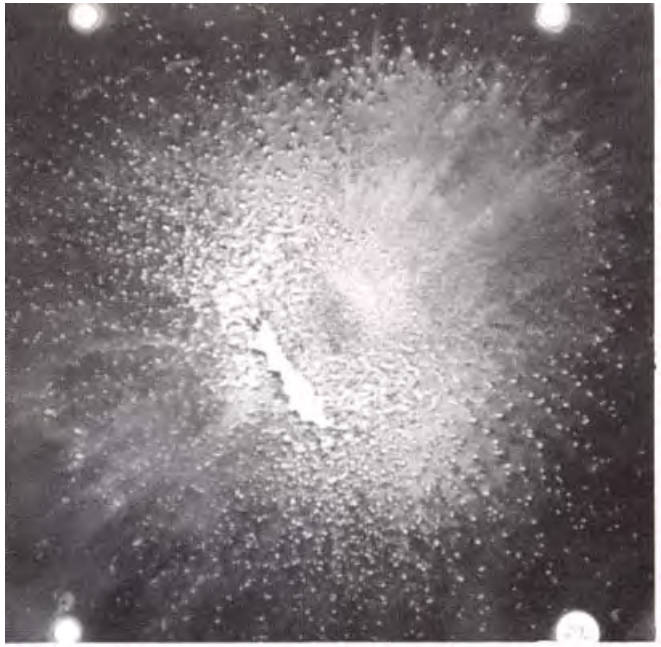
Computations of hypervelocity impact

Oblique cylinder impacting a Whipple shield

Computed rear plate 50 μs after impact



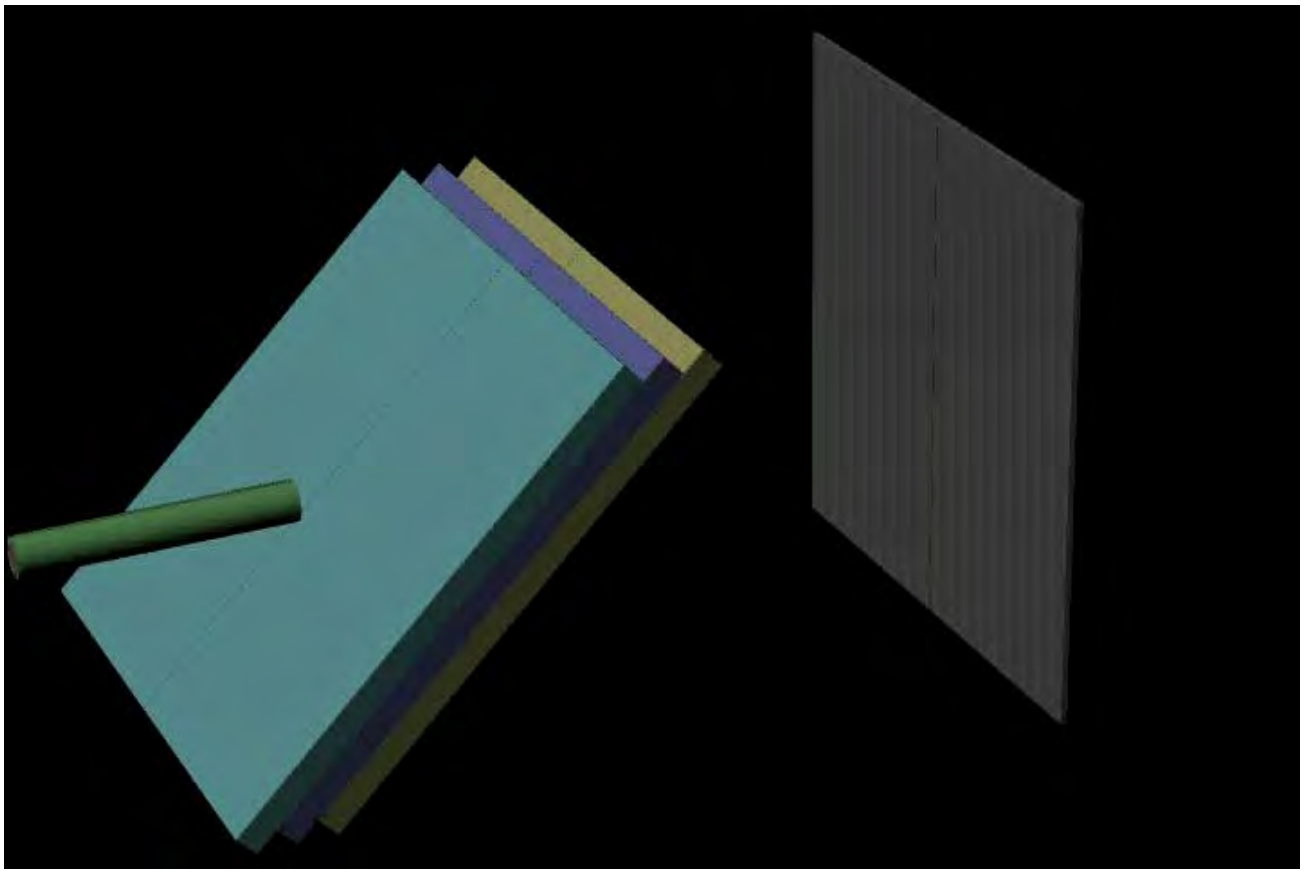
A. Piekutowski, “Debris clouds generated by hypervelocity impact of cylindrical projectiles with thin aluminum plates.” Int. J. Impact Engng **5** (1987).



Summary

- Combination of elements and particles is well suited for BAD computations
- Conversion algorithm enhances accuracy and efficiency of computations
- Demonstrated capability to compute BAD
  - includes travel through large air gaps
  - includes interaction with subsequent target plates/structures
- Demonstrated general agreement with test data

Behind Armor Debris movie



Fragment Patterns behind Concrete Structures caused by KE Projectiles

R. Jeanquartier, D. Hoffmann*, S. Lampert and B. Lehmann
armasuisse, Science & Technology Departement, Thun, Switzerland
*IBH Consulting Services, Schramberg, Germany

Overview

- **Interest of Swiss Army: to know more about …**

  effectiveness of ammunition against urban targets (concrete, brick wall)

- **especially medium caliber ammunition (APDSFS and FAPDS)**

- **Computer Model (PANZKI3) for vulnerability assessments**

- **Modul of ammunition effectiveness against urban targets:**

  Effects of concrete fragments are not yet taken into consideration

- **Aim of present study**

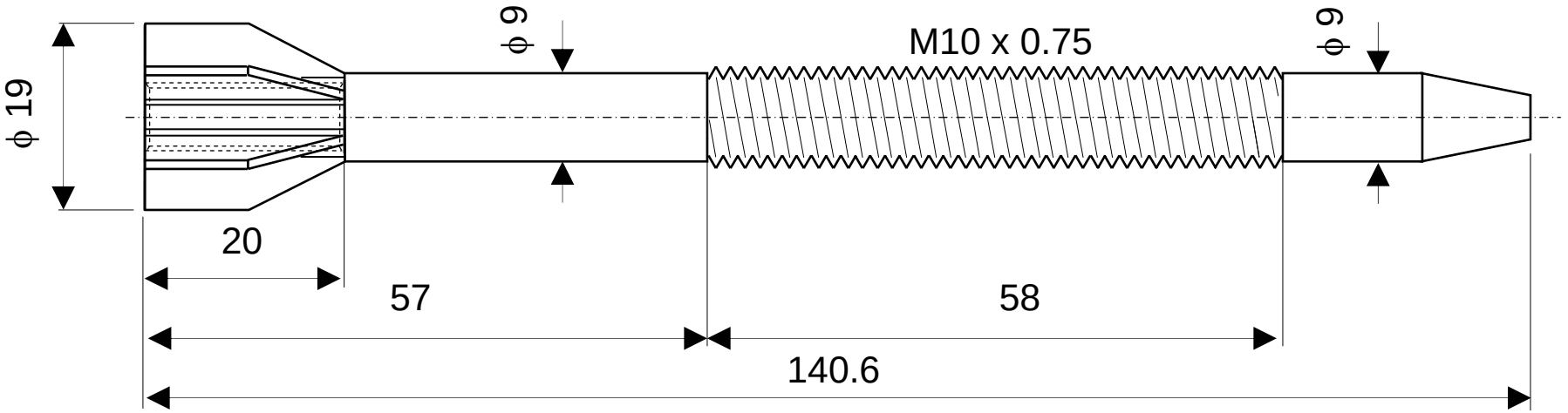
  - learn more about risk for people exposed to concrete fragments

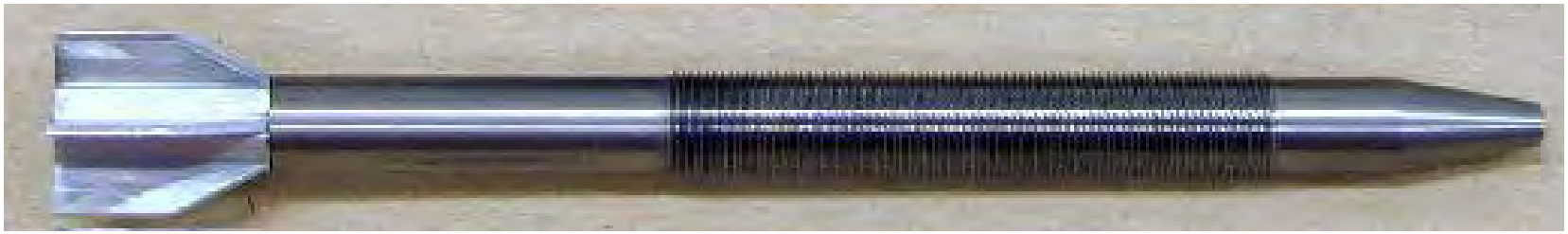
  - describe the dynamics of concrete fragments in a realistic model

  - Focus on perforation of concrete walls by KE projectile (APFSDS)

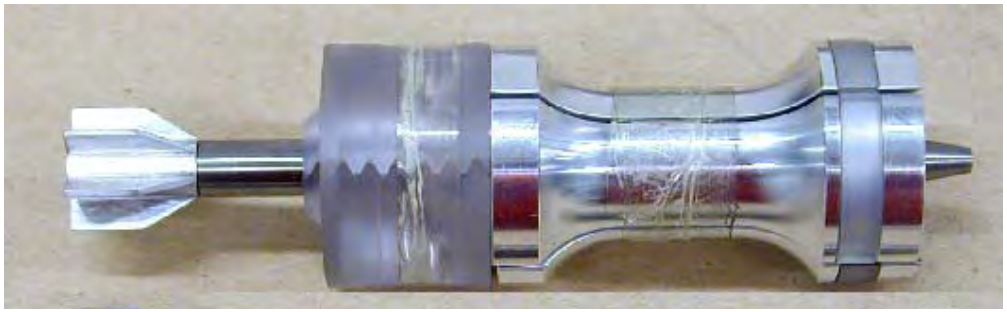
Model projectile

mass 152 g
Rod material: Tungsten-alloy Y 925
Fin material: Aluminum





Laboratory gun



Acceleration of model projectile

smooth barrel powder gun

Caliber 38 mm

Specifications of concrete

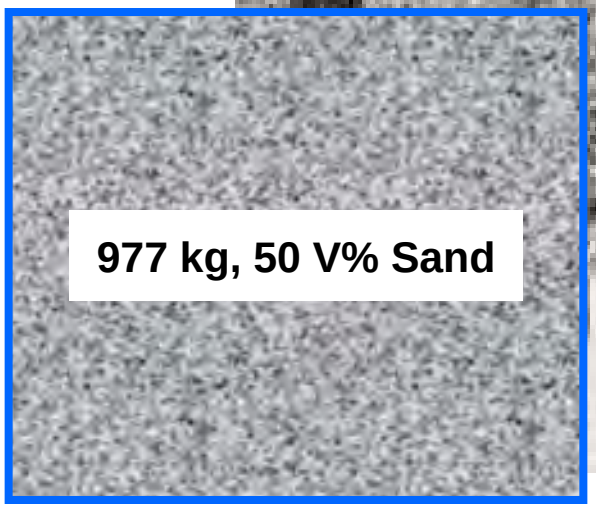
391 kg, 20 V%
Bebbles Ø 4 – 8 mm

1 m3

ρ = 2432 kg/m³

Compressive Strength ≈ 40 MPa

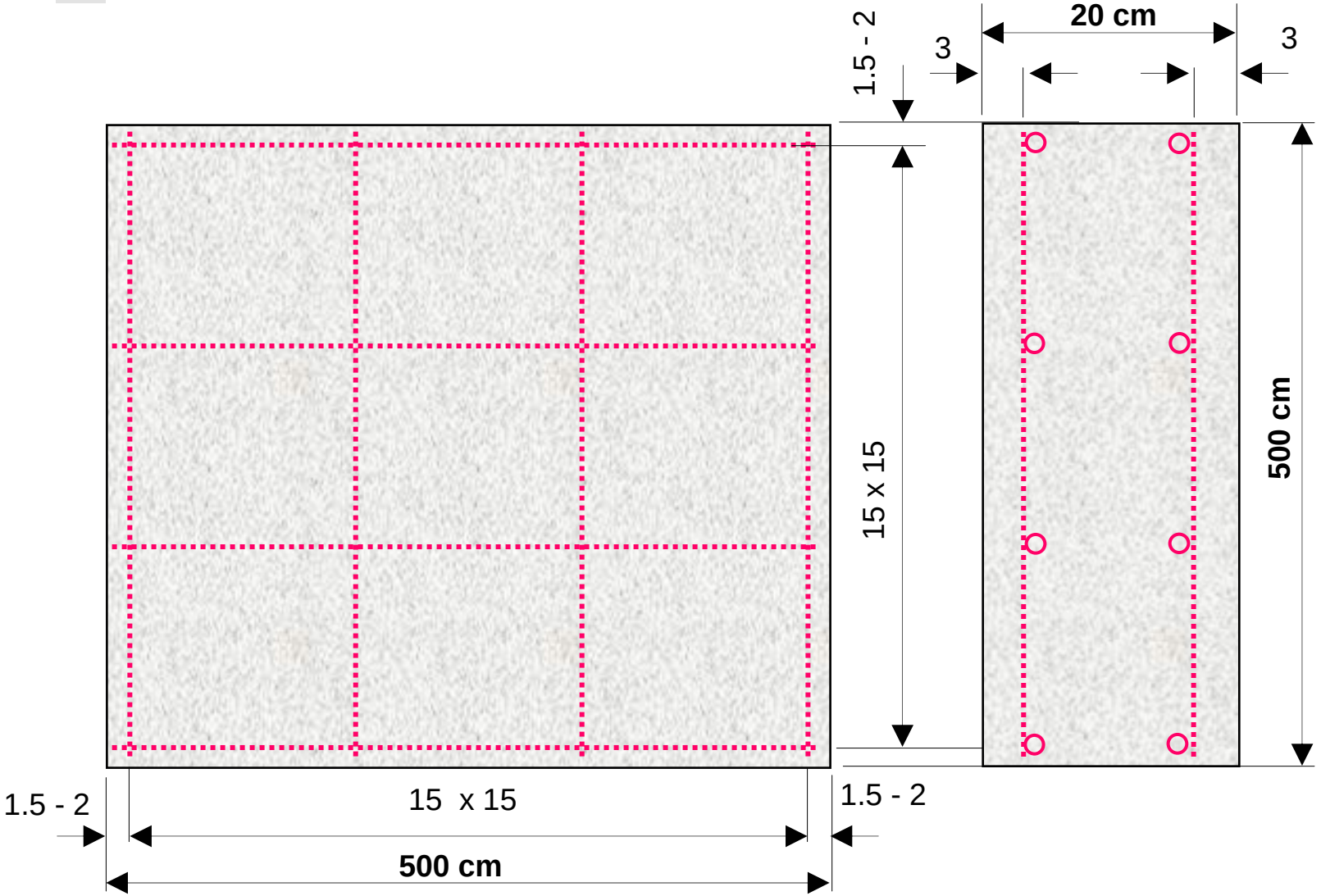
586 kg, 30 V%
Bebbles Ø 8 – 16 mm



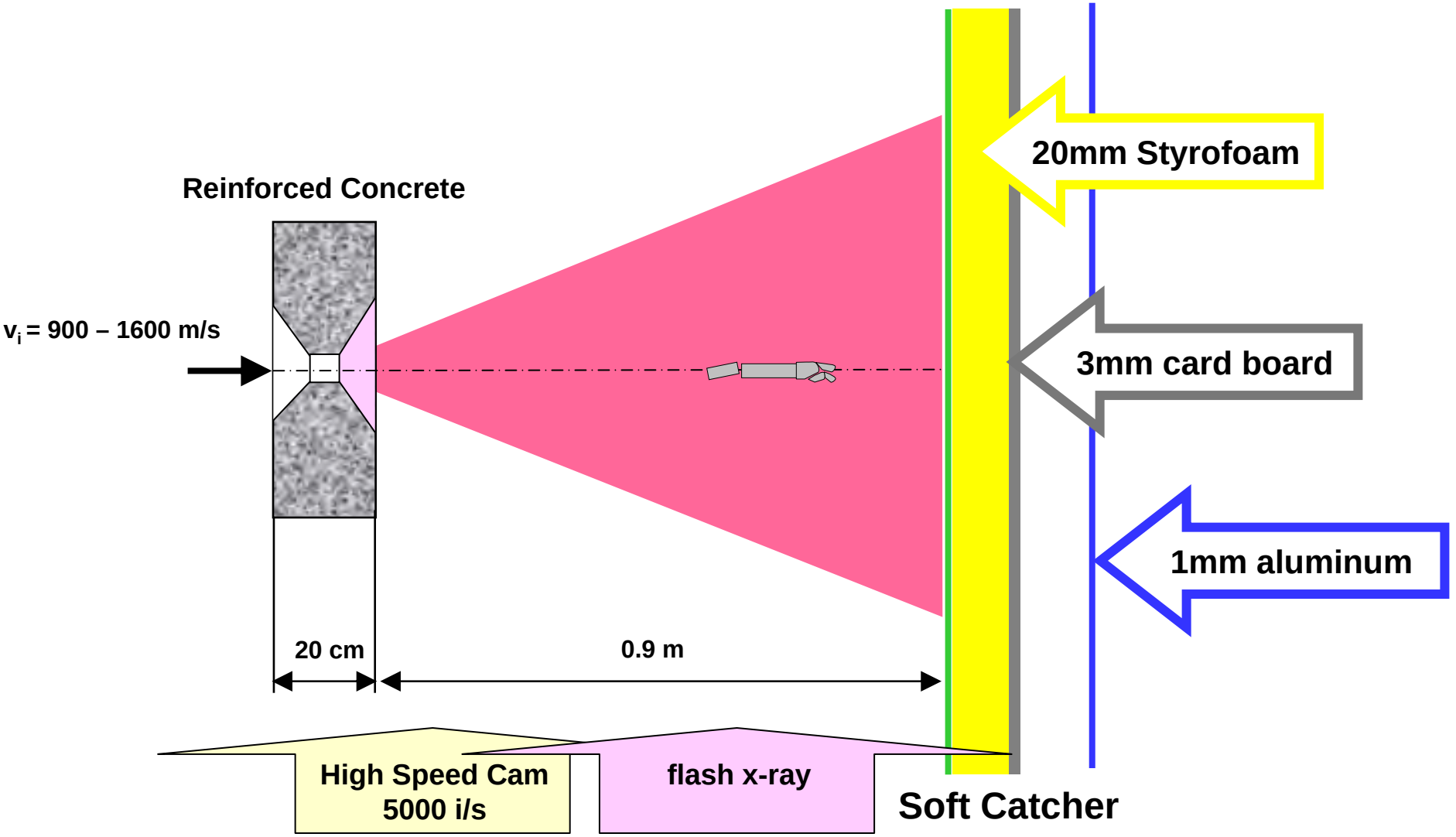
977 kg, 50 V% Sand

325 kg Cement +
153 kg Water

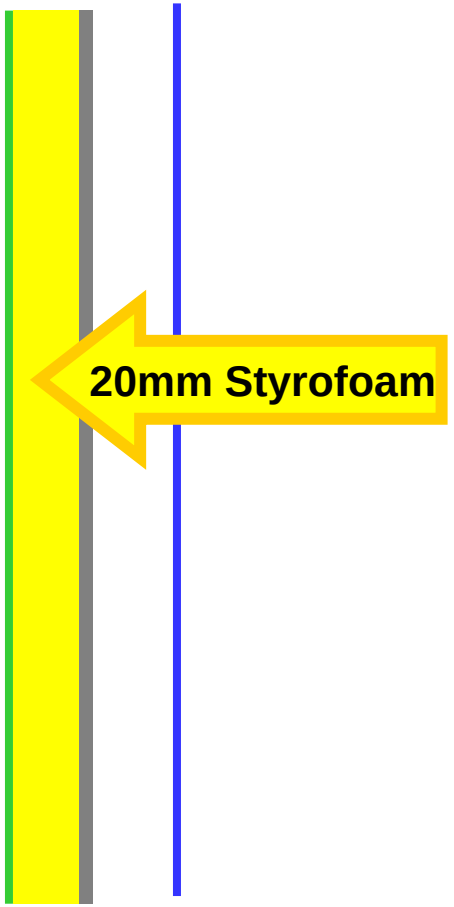
Concrete wall (dim)



Experimental set-up

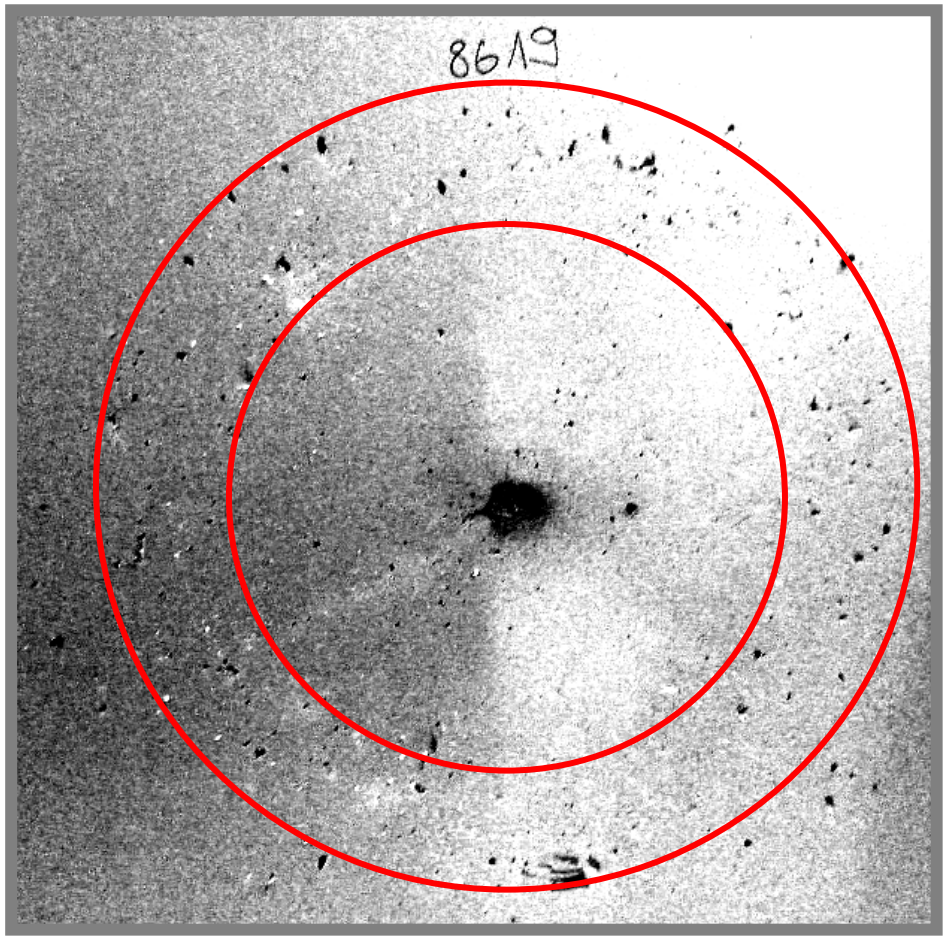


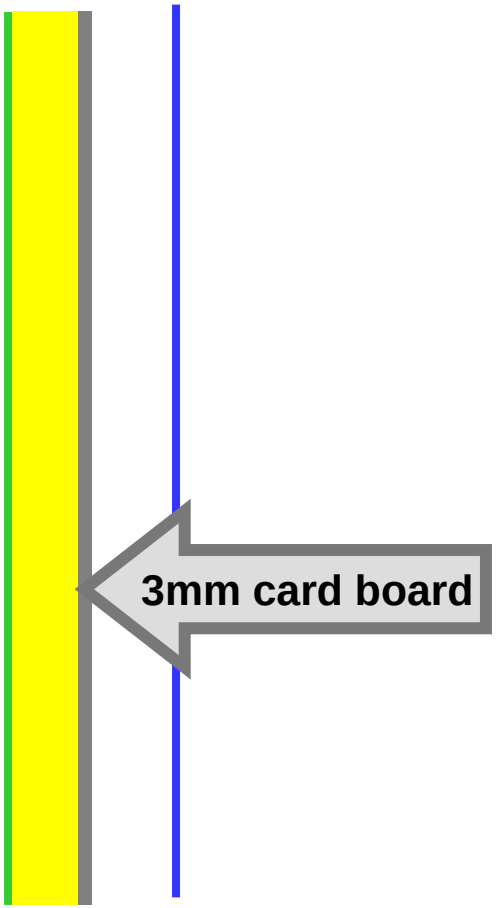
Soft catcher (1)



- **Small pebbles and concrete lumps were stopped**
- **Mass of stopped fragments is only 5 % of the total crater mass**

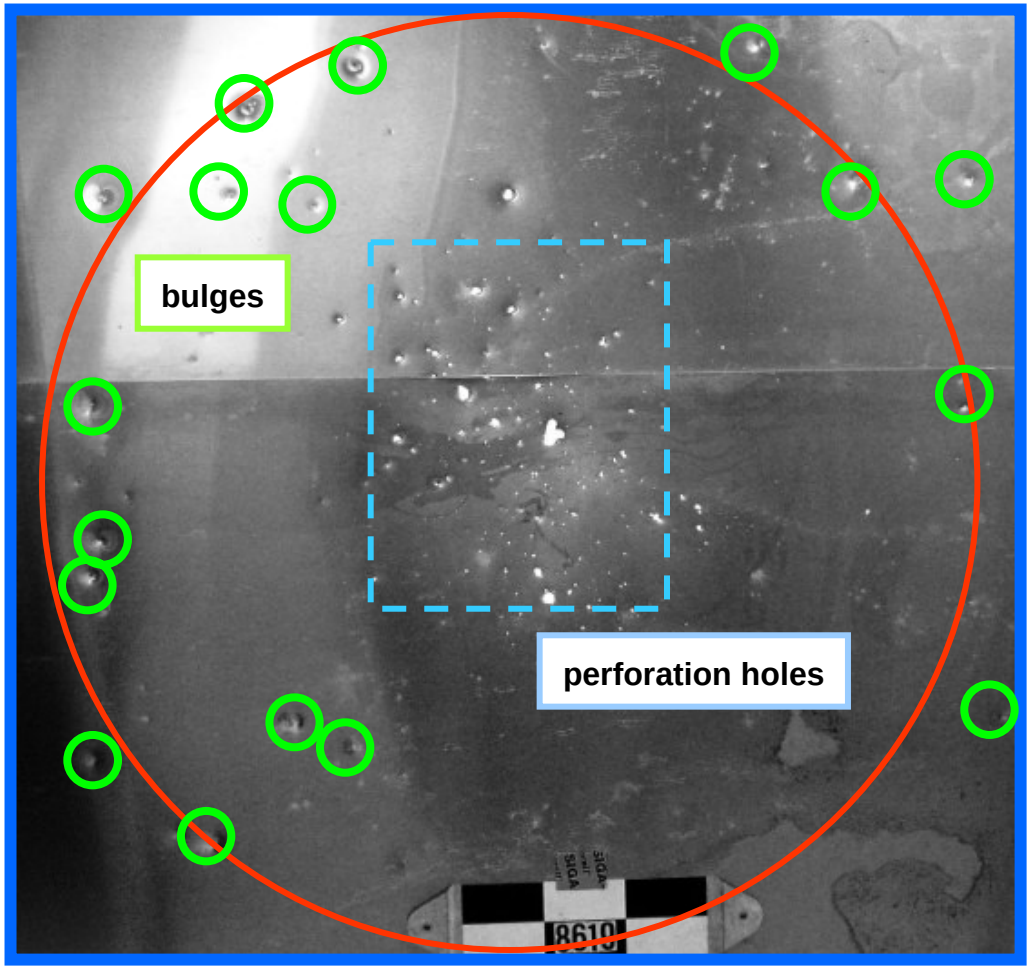
Soft catcher (2)

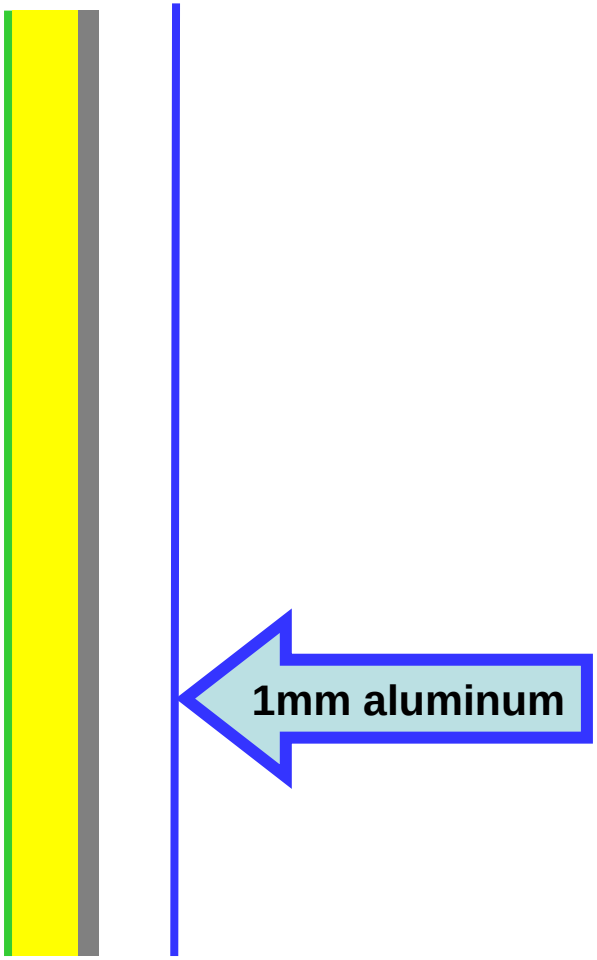




Perforations were registered, mainly caused by pebbles (in the ring)

Soft catcher (3)

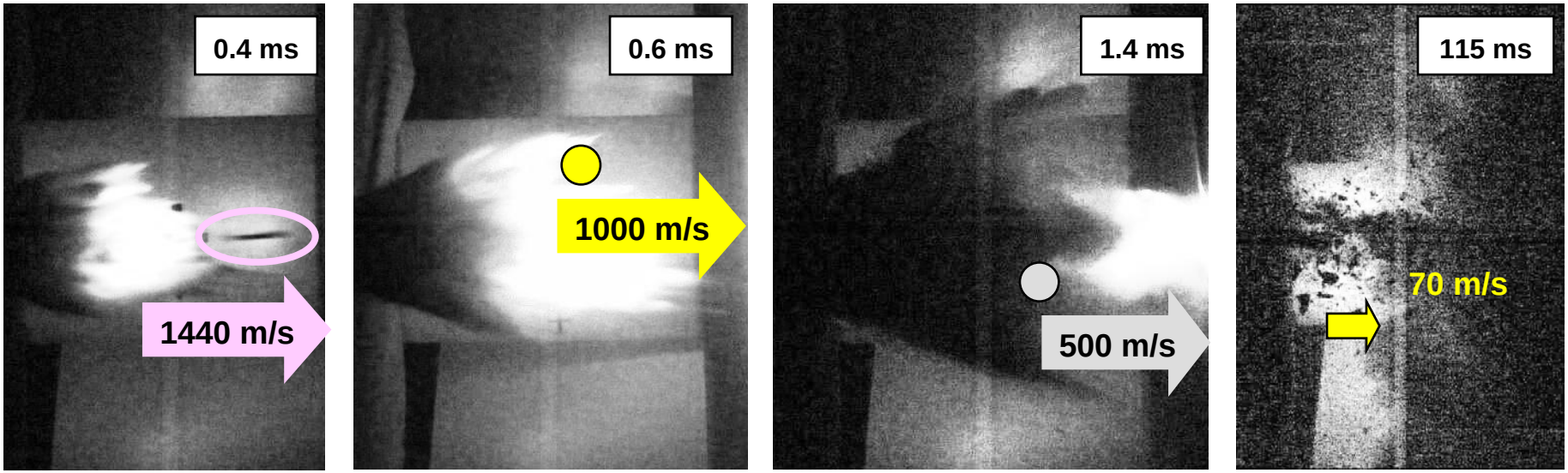




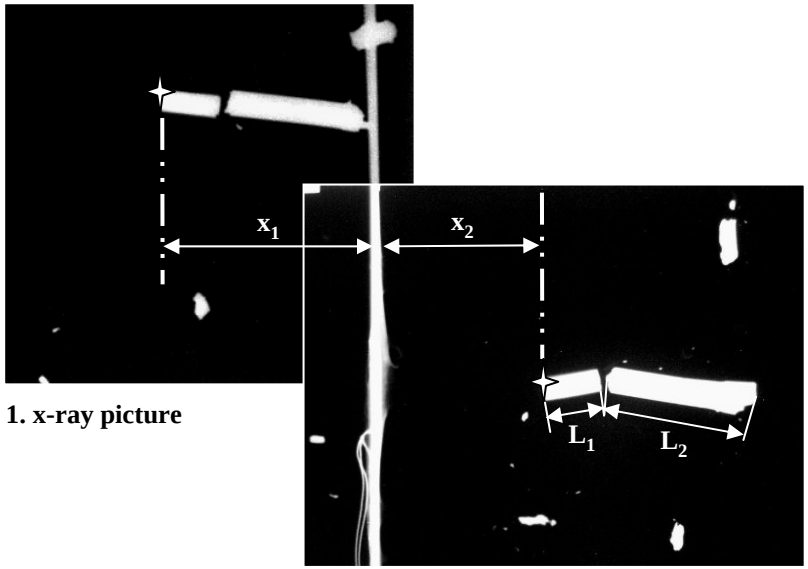
- No perforations of concrete fragments could be observed
- only perforations of projectile fragments

High speed recordings

Impact velocity of model projectile: v_i = 1600 m/s



x-ray pictures



1. x-ray picture

2. x-ray picture

Residual velocity of projectile

$$v_r = \frac{x_1 + x_2}{\Delta t}$$

Residual length of projectile

$$L_r = L_1 + L_2$$

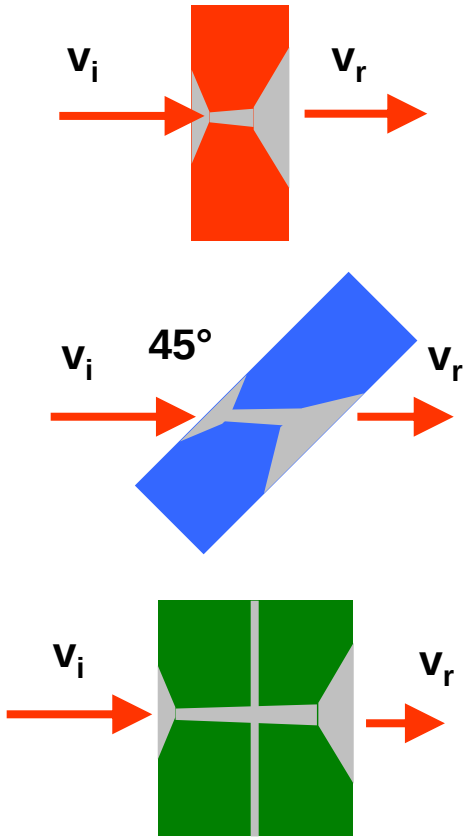
Empirical Formulas

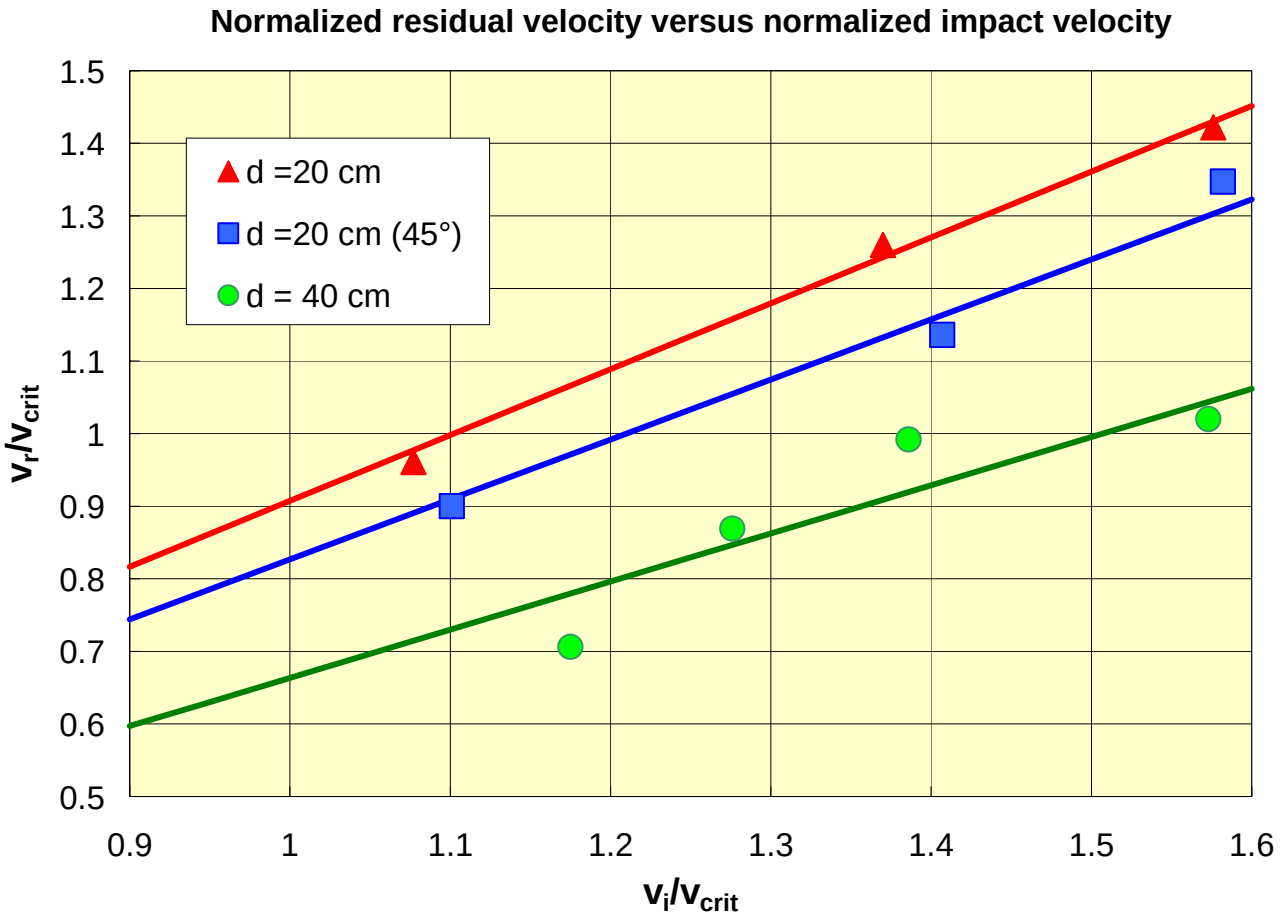
"Perforation of Concrete Targets by an eroding Tungsten-alloy Rod"
by Lampert and Jeanquartier

$$v_r = \left(1 - k_1 \cdot d^{k_2}\right) \cdot v_i$$

$$L_r = L_0 \cdot \left(1 - k_3 \cdot d \cdot \exp\left\{-\left(\frac{1 + \frac{k_4}{d}}{\frac{v_i}{v_{crit}}}\right)^{d \cdot k_5}\right\}\right)$$

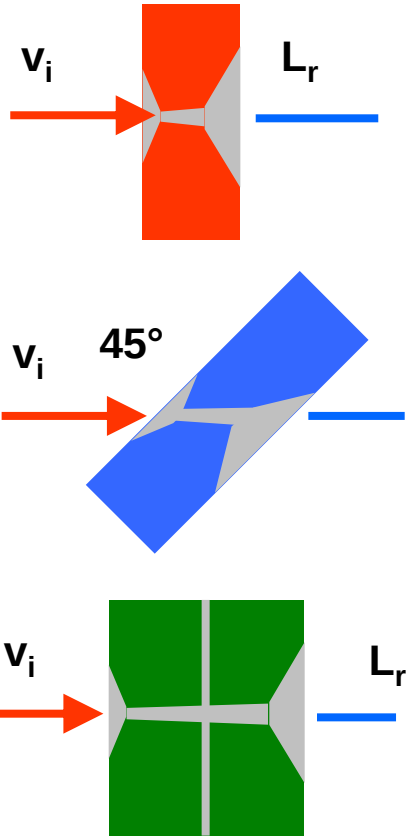
Residual velocity of projectile

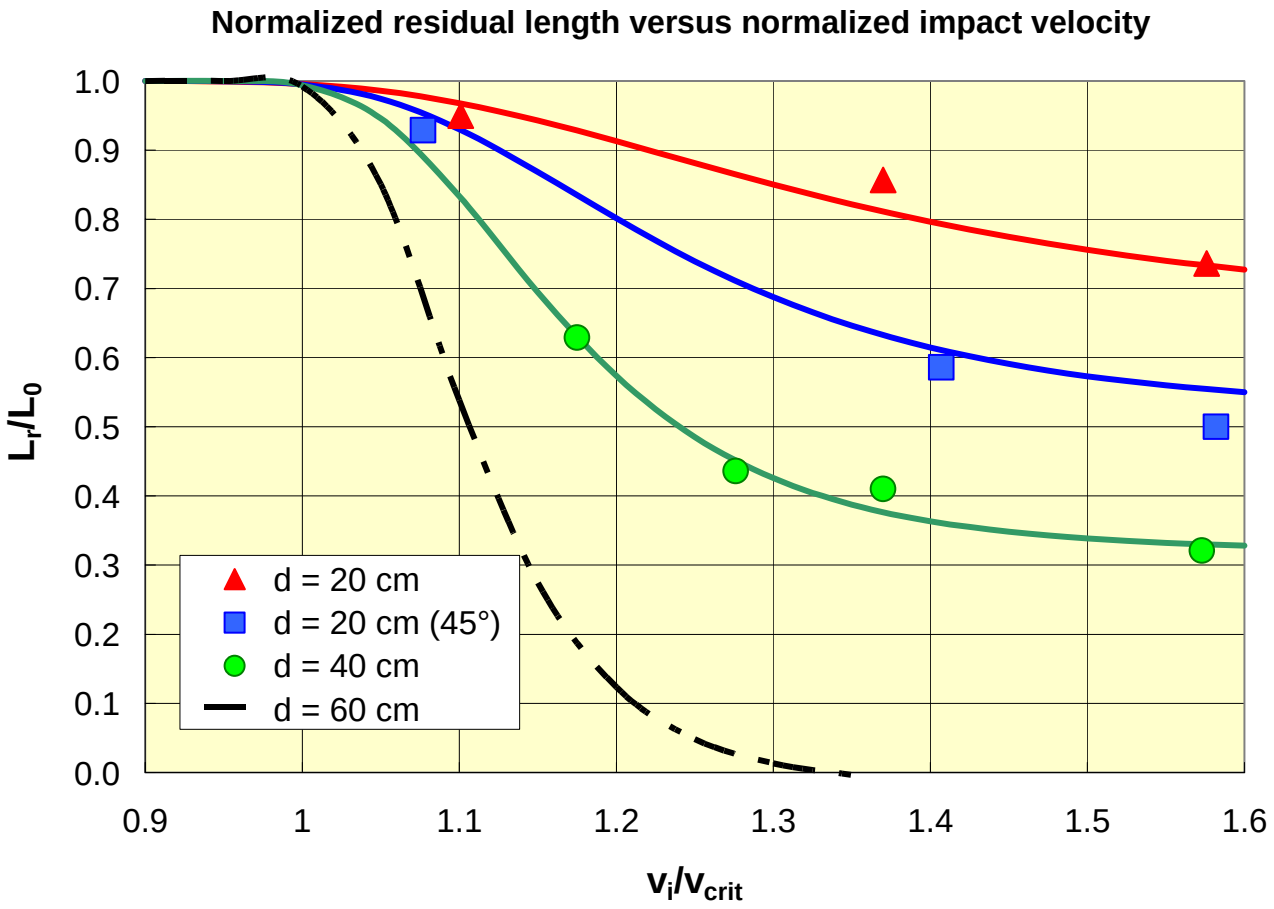




v_{crit} = 1000 m/s (determined by experiments)

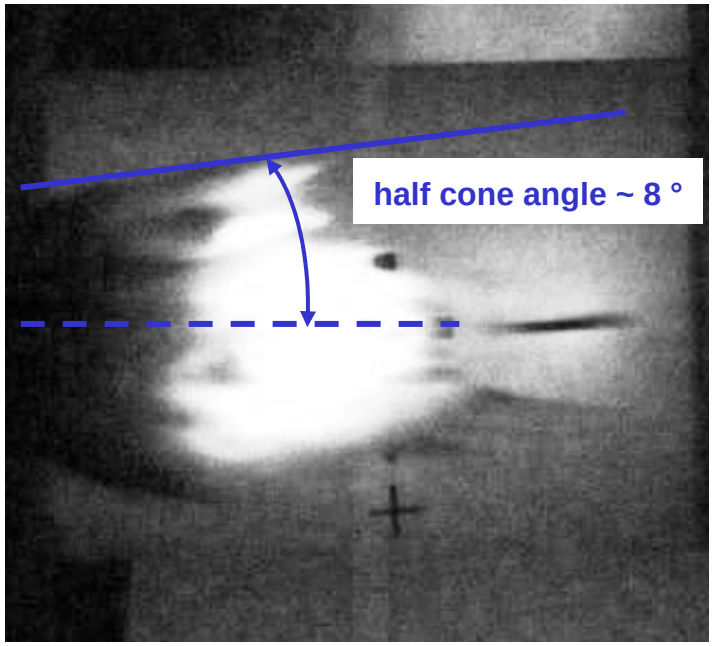
Residual length of projectile

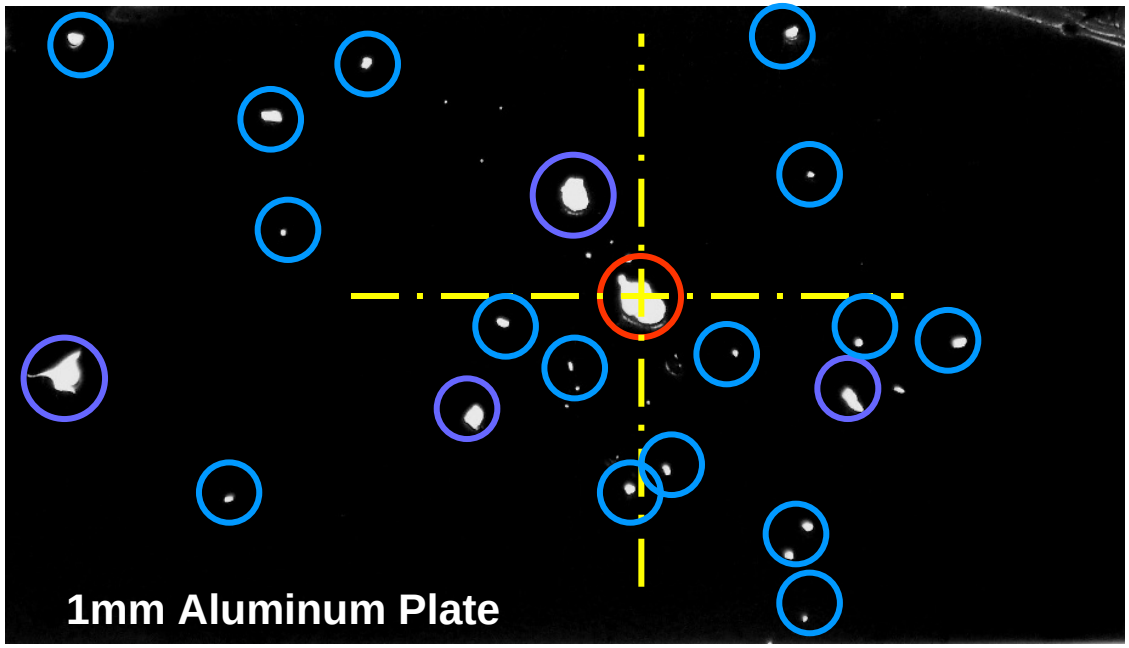




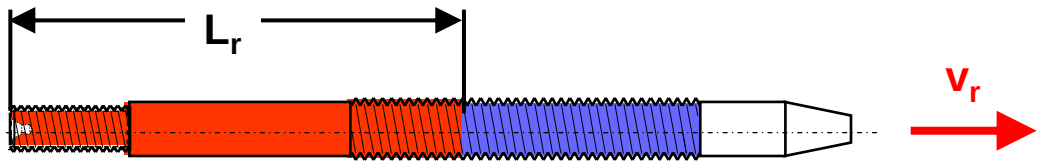
v_{crit} = 1000 m/s (determined by experiments)

Fragments of projectile

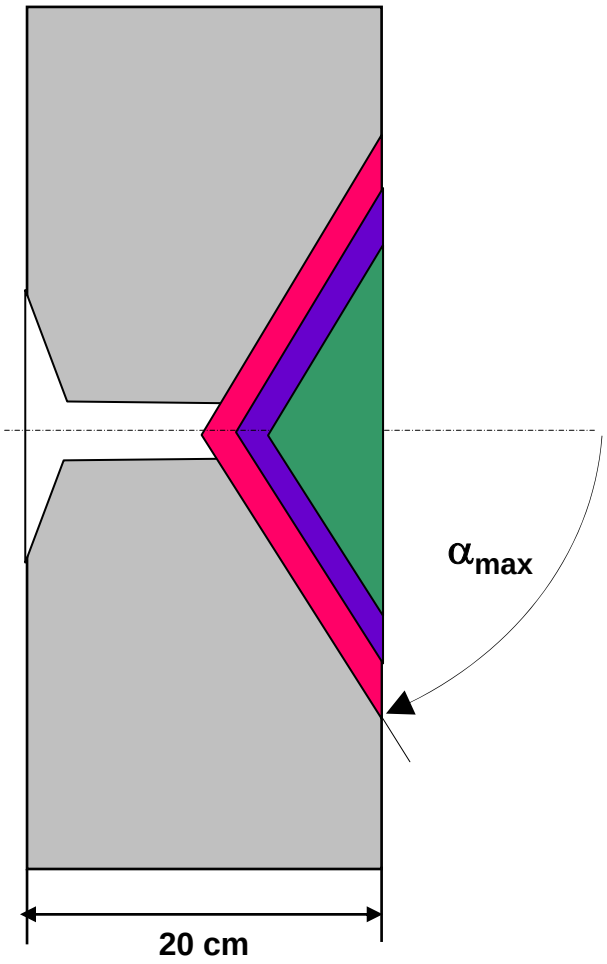


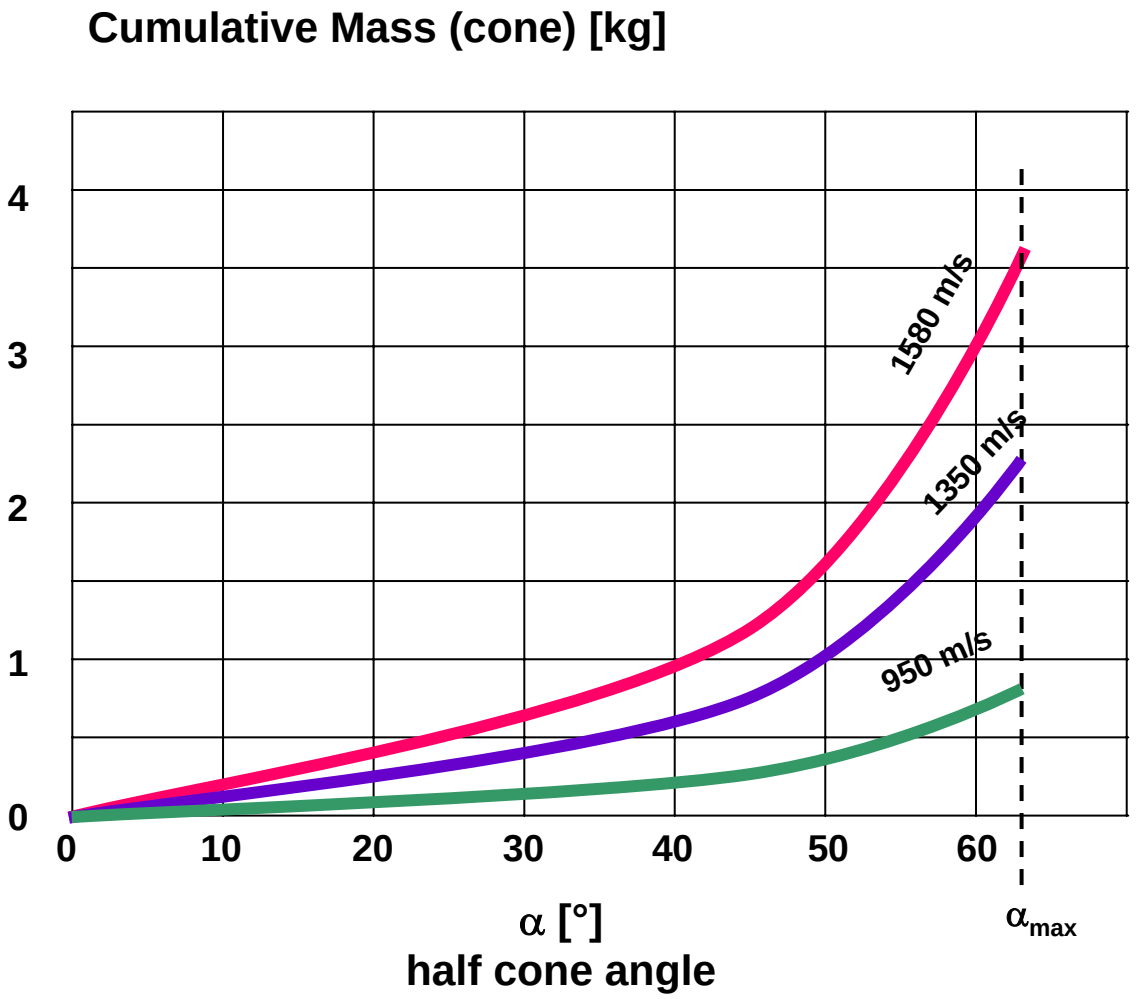


Residual Projectile | Projetile Fragments

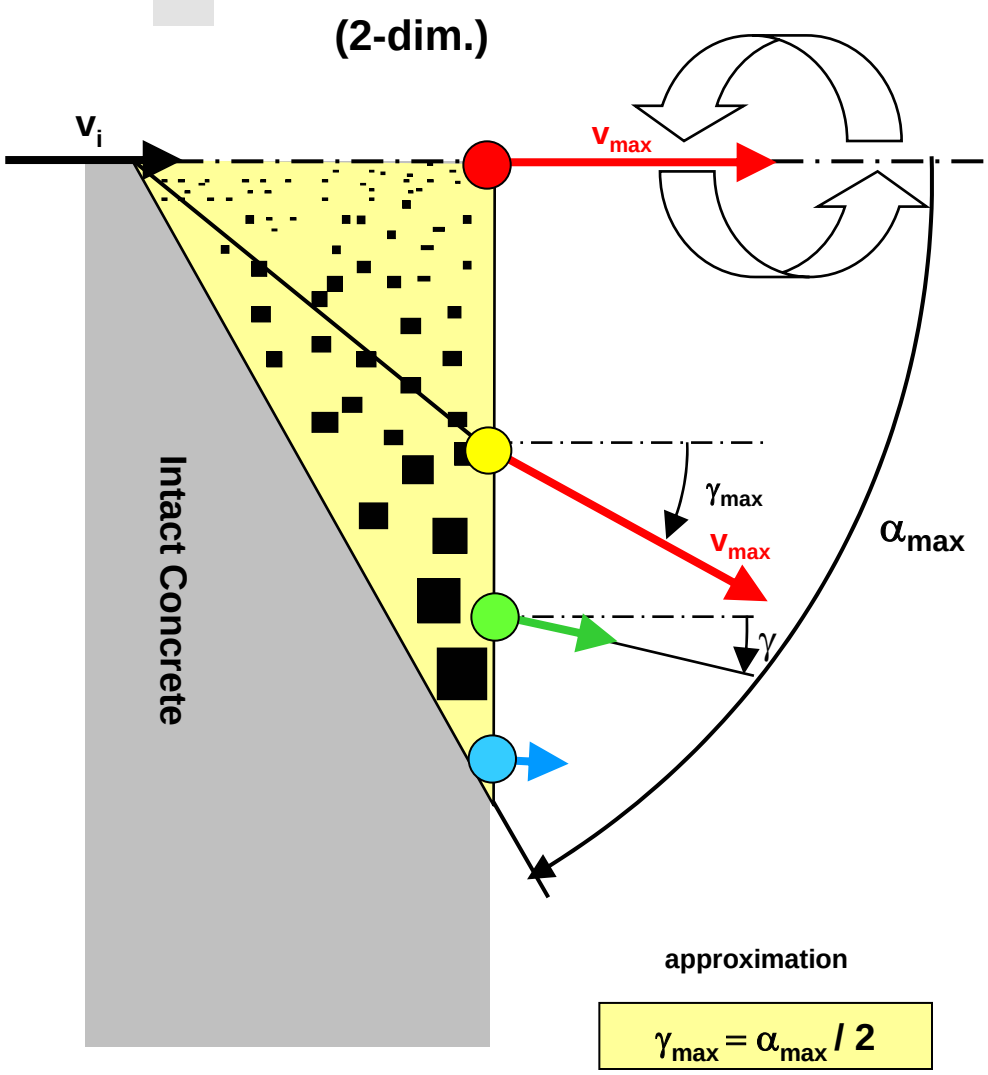


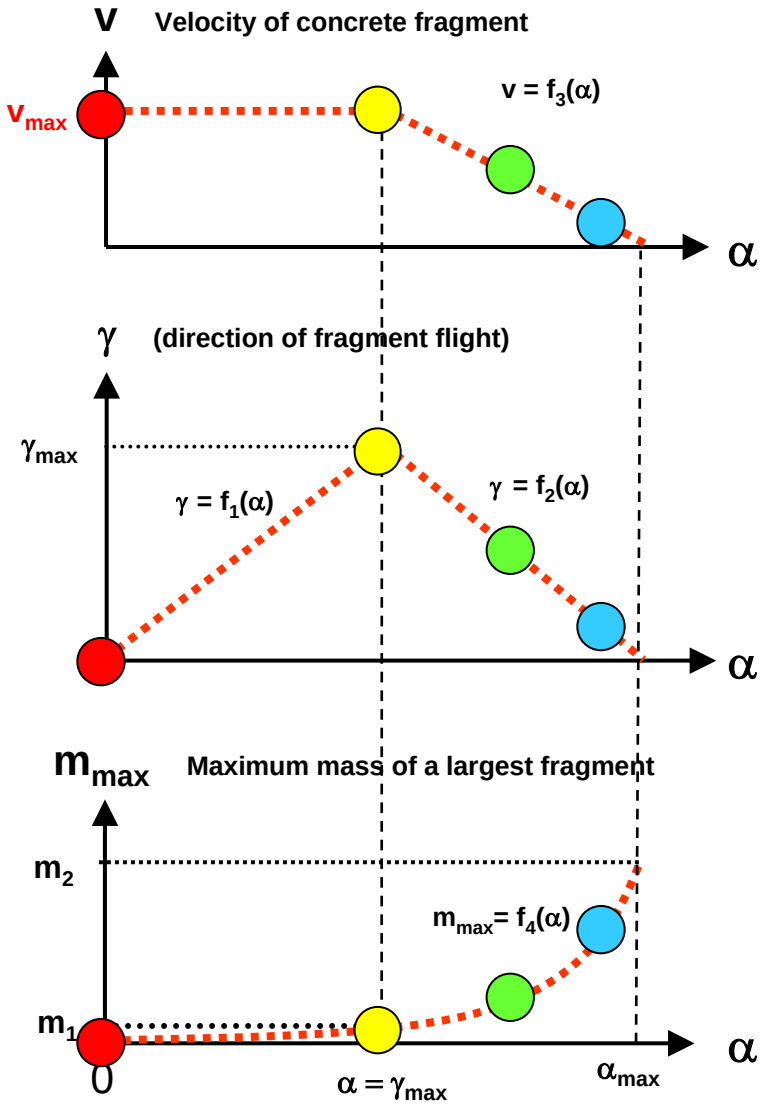
Excavation crater





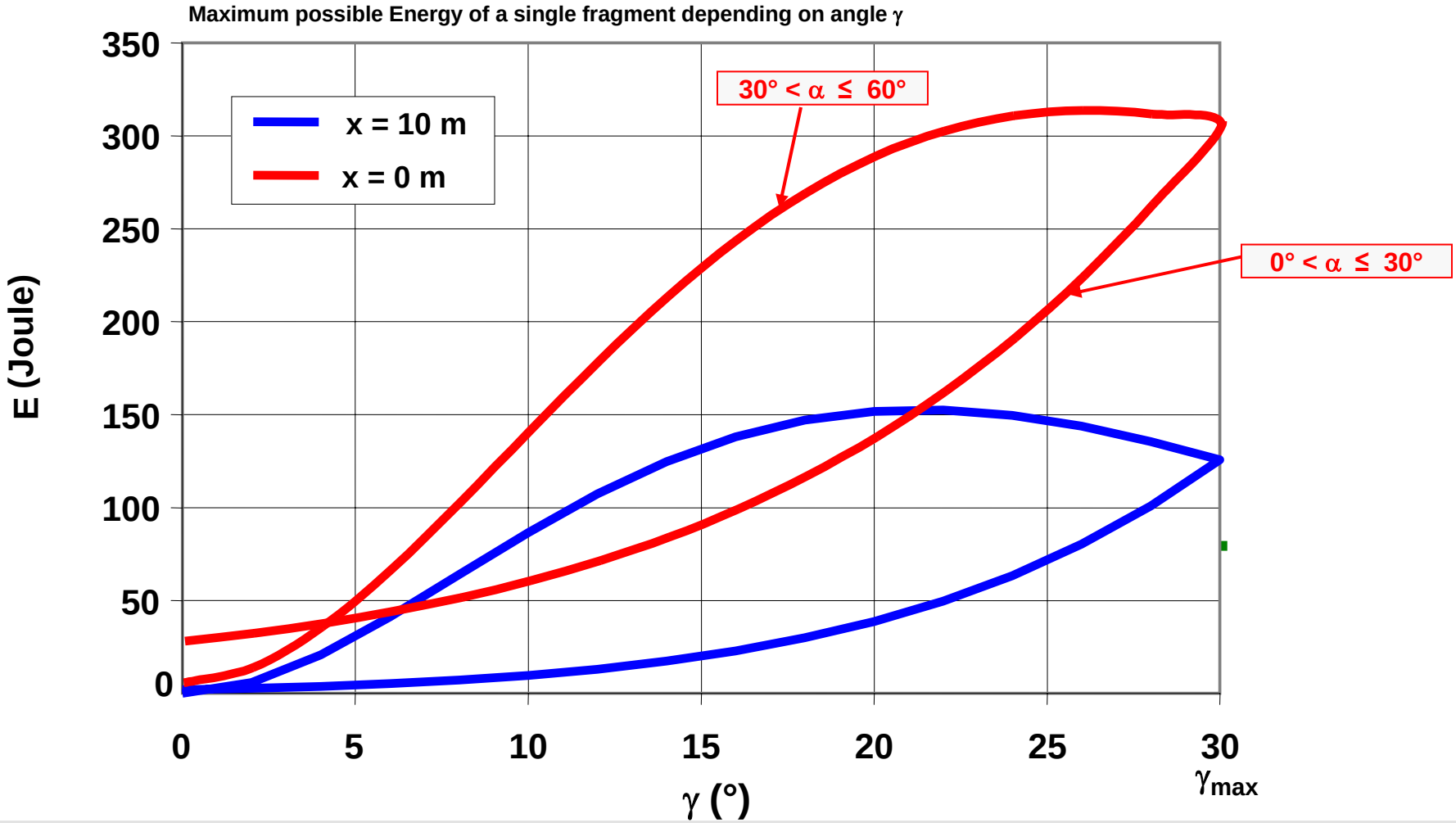
Concrete fragment model



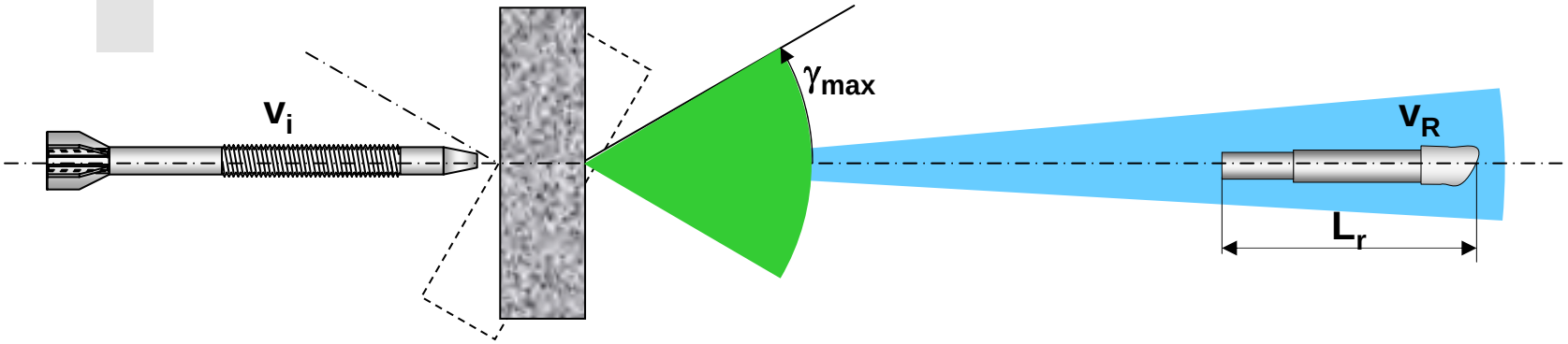


Example

Impact velocity: v_i = 1350 m/s
→ v_r = 1230 m/s
→ $L_r = 0.83 \cdot L_0$
→ $v_{max} = {}^1/_3 \cdot v_r$ = 410 m/s



Summary



Residual Projectile with enormous perforation potential …..

and the remaining fragments of projectile (half cone angle ~ 8°) represent the major threat

The fastest concrete fragments are small and the biggest fragments are very slow (half cone angle ~ 30°)

From energetic point of view the concrete fragment cloud does not represent a dramatic threat for people

But low-energy concrete fragments (unfractured pebbles) are dangerous for an unprotected person and also dust can affect eyes and respiratory organs

Thank you

Bringing Solid Fuel Ramjet Projectiles Closer to Application

An overview of the TNO/RWMS Technology Demonstration Programme

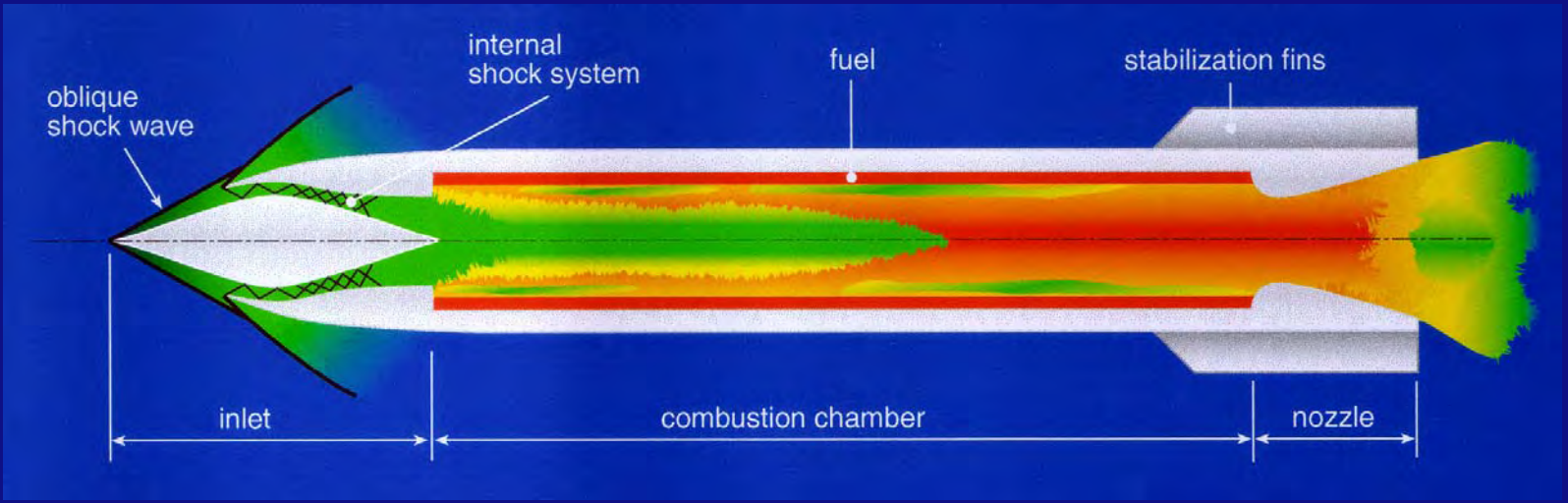
TNO | Knowledge for business

Ronald Veraar (TNO) and Dr. Guido Giusti (RWMS)

Contents

- Solid Fuel RamJet (SFRJ) projectile concept
- SFRJ projectile technology development
- TNO/RWMS technology demonstration programme
  - Programme definition
  - Design requirements and strategy
  - Projectile design
  - Free jet test facility and test results
  - Flight demonstration tests
  - Conclusions

Solid Fuel RamJet (SFRJ) projectile concept

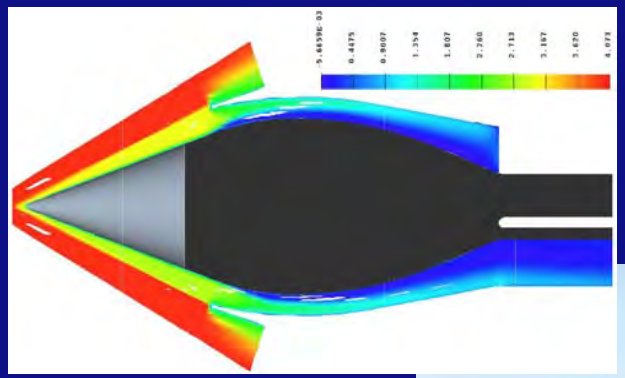


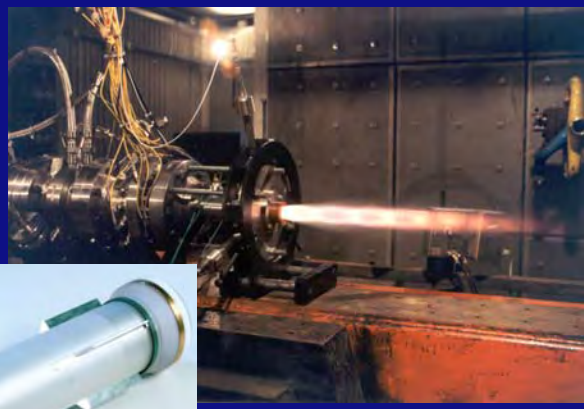
- No on-board oxidizer ⇒ superior propulsive performance
- Applications
  - Naval Fire Support, artillery (extended range & reduced time-to-target)
  - Direct-hit ammunition (reduced time-to-target & increased kinetic energy)
- Technology development at TNO since 1980

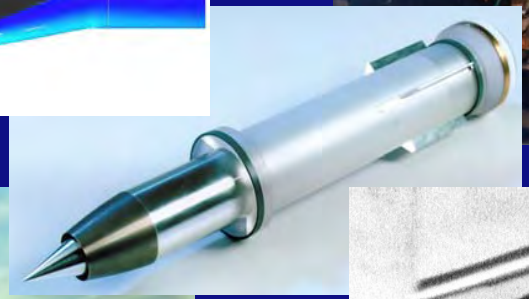
SFRJ projectile technology development Co-operation with FOI (1995-2000)

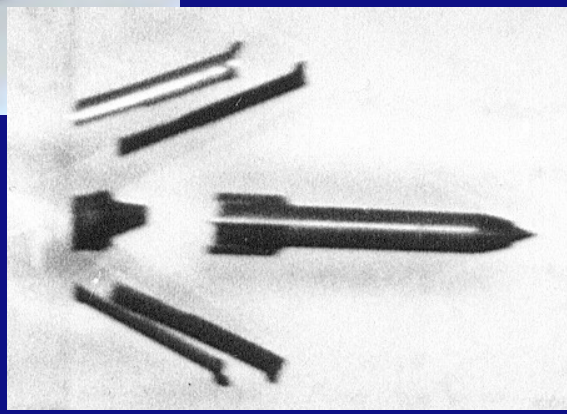
Demonstration SFRJ propulsion for generic projectile through

- design
- manufacturing
- development
- flight testing









Thrust equal to drag capability demonstrated in flight tests

TNO/RWMS technology demonstration programme Programme definition

Goal
- Demonstrate SFRJ technology for a specific application

Application
- Medium calibre spin-stabilised air defence projectile
- Fired from a standard gun

Approach
- Design
- Manufacturing
- Flight testing of a technology demonstrator

TNO/RWMS technology demonstration programme
Projectile design requirements & strategy

- Requirements
  - Total projectile length ≤ 179 mm
  - Projectile launch mass ≤ 0.375 kg
  - Acceleration load ~70000 g
  - Spin rate at launch ~80000 rpm
  - Propelled flight range ~3 km (~constant flight velocity)

- Design strategy
  - Geometric projectile design based on aero-thermodynamics
  - Mechanical design using geometric design as input
  - Perform experiments to verify different aspects of projectile design
  - Iterate projectile design until requirements are satisfied

- Challenges
  - Extreme interaction between aerodynamic & mechanical design
  - Aero-heating of intake and gas dynamic heating of nozzle

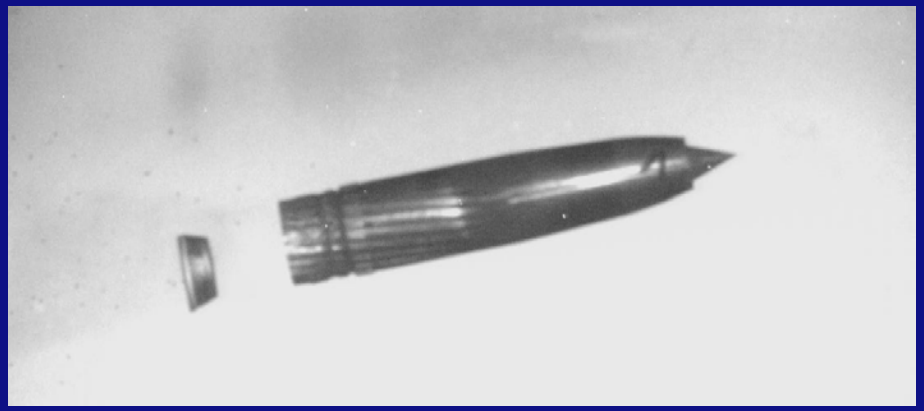
TNO/RWMS technology demonstration programme Aero-thermodynamic projectile design

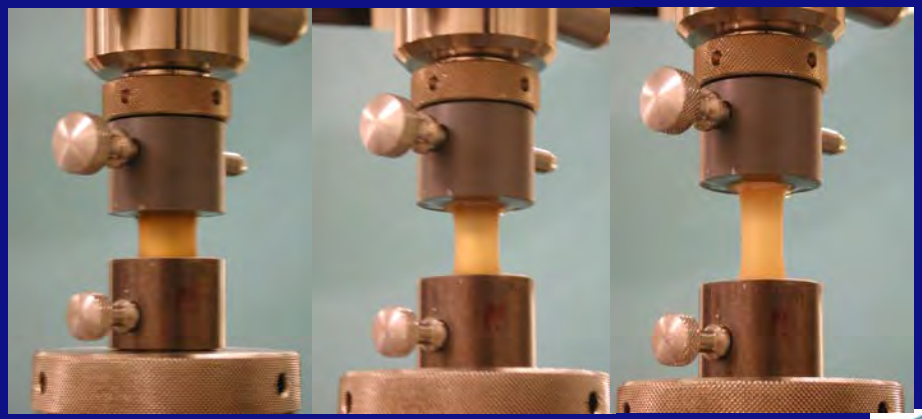
- Air intake design based on engineering design rules
- CFD calculations by CFS Engineering SA using NSMB code
  - Calculation of complete internal flow field of projectile

- Projectile flight performance prediction
  - RP[5] = Engineering code modelling subsystem performance and their interaction
  - Optimize projectile configuration

TNO/RWMS technology demonstration programme Mechanical projectile design

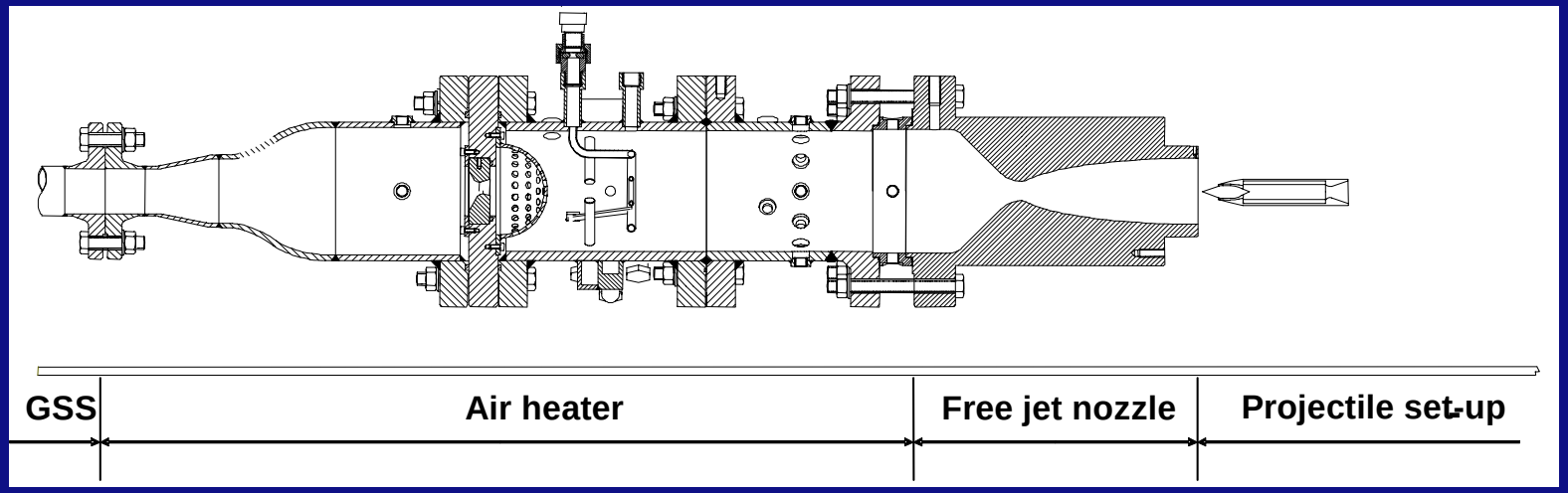
- Mechanical design based on engineering design rules
- Verification of structural integrity
  - Projectile structure by gun firings
  - Fuel by tensile tests and bonding tests
  - Fuel grain by gun firings





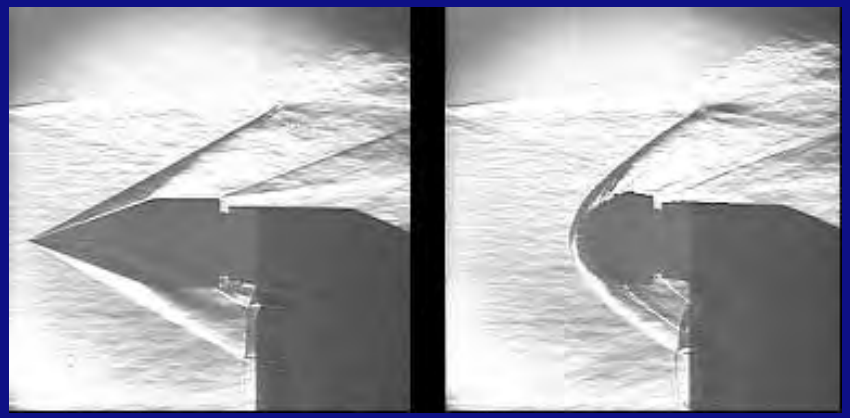
TNO/RWMS technology demonstration programme
Free jet test facility

- Following ignition problems encountered in TNO/FOI flight tests
- To enable on-ground verification of intake performance and projectile functioning
- Free jet Mach numbers: 3.25 and 4.0
- Simple fixed projectile set-up (spin not accounted for)



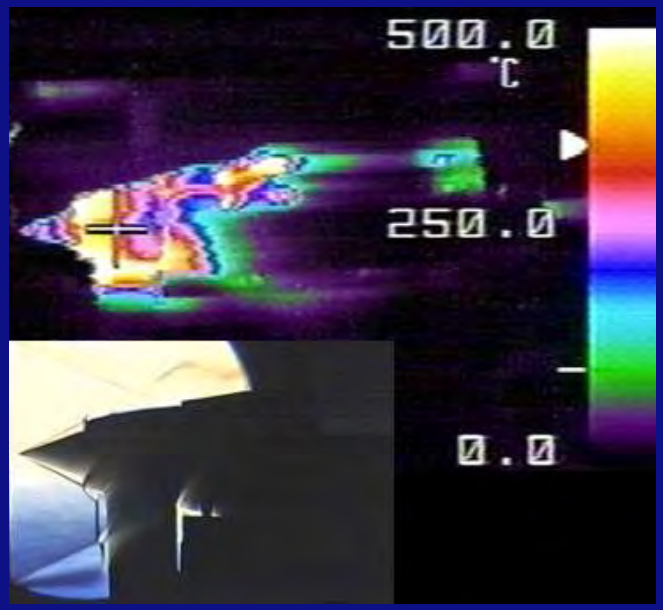
TNO/RWMS technology demonstration programme
Free jet aerodynamic heating tests

- Aluminium nose cone
- Schlieren images



t = 0 s t = 5 s

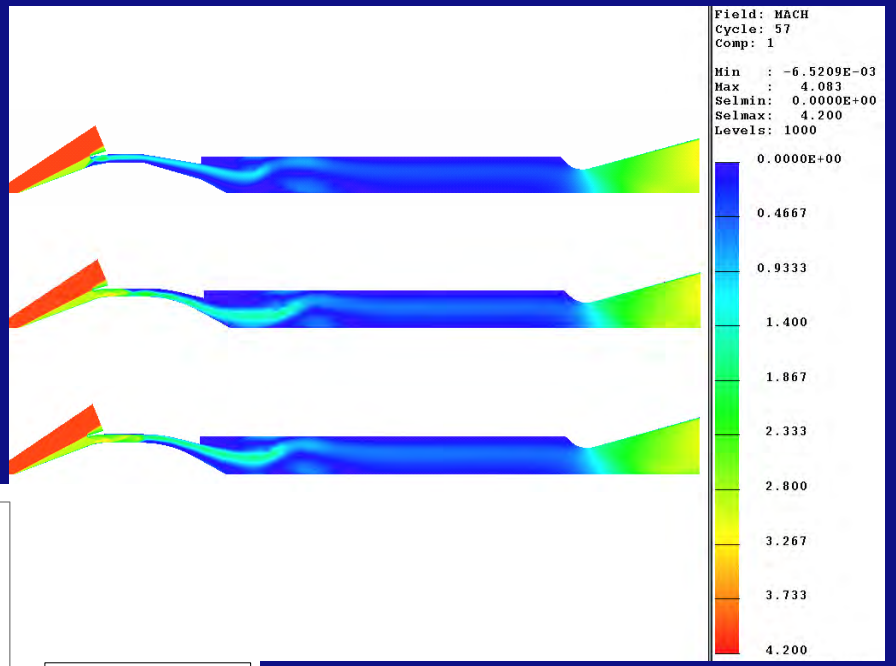
- Projectile intake
- Thermo-graphic image (top)
- Schlieren image (bottom)

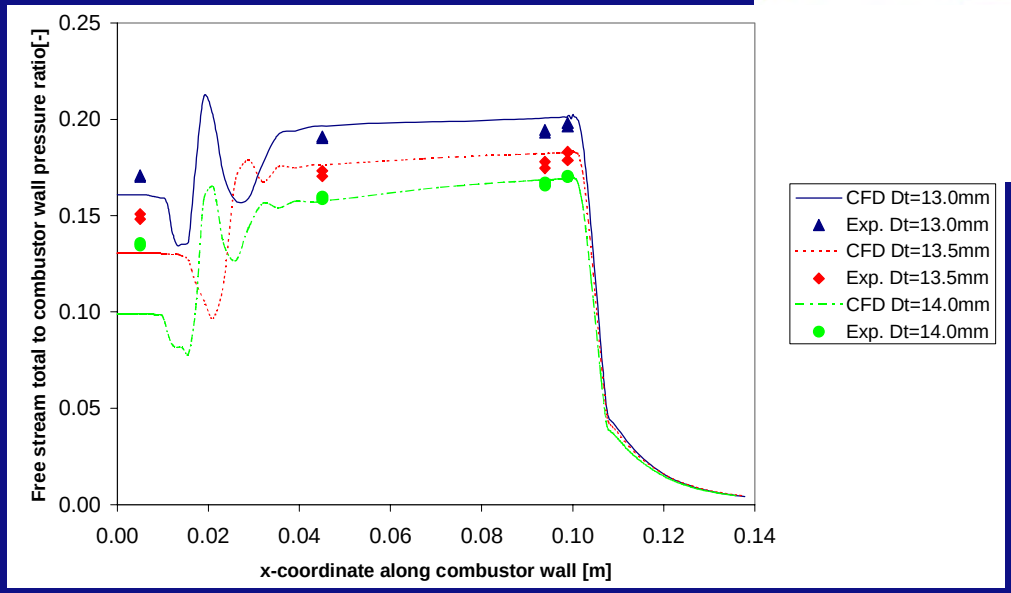


Material other than Aluminium is required for Mach 4 SL flight

TNO/RWMS technology demonstration programme
Free jet intake performance verification tests (1)

- Fixed nozzle throat areas
- Pressure measured at 4 locations along combustor wall
- CFD predictions performed by CFS Engineering SA

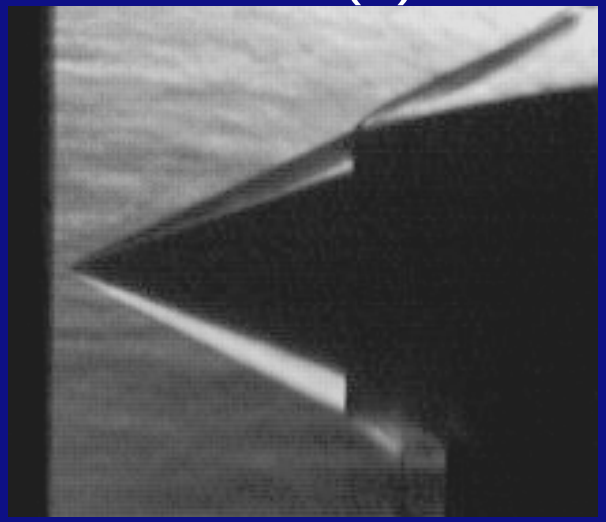




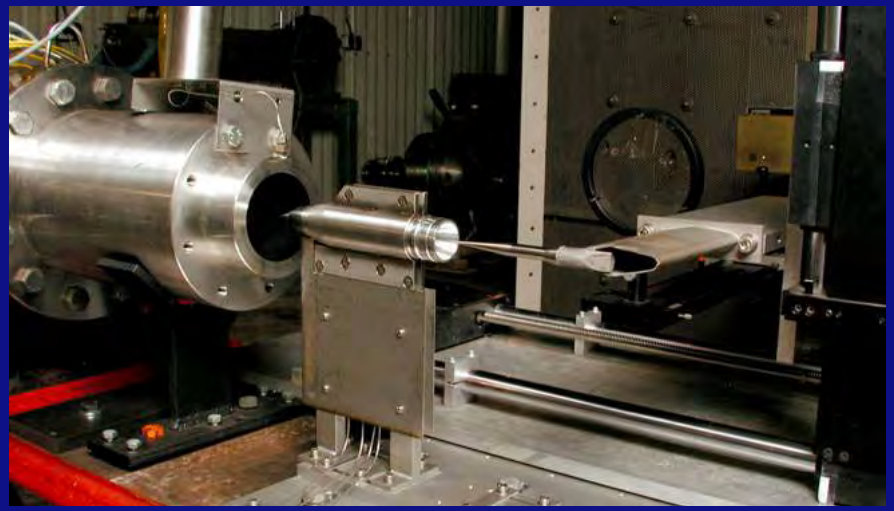
Good agreement with CFD predictions

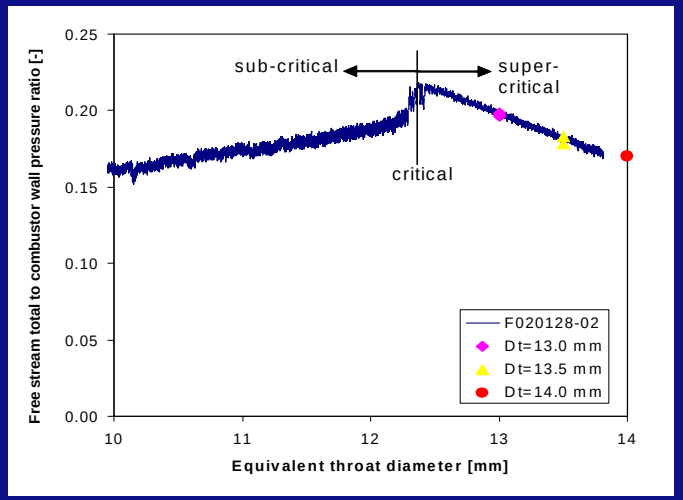
TNO/RWMS technology demonstration programme
Free jet intake performance verification tests (2)

- Variable nozzle throat area
- Good agreement with fixed nozzle results



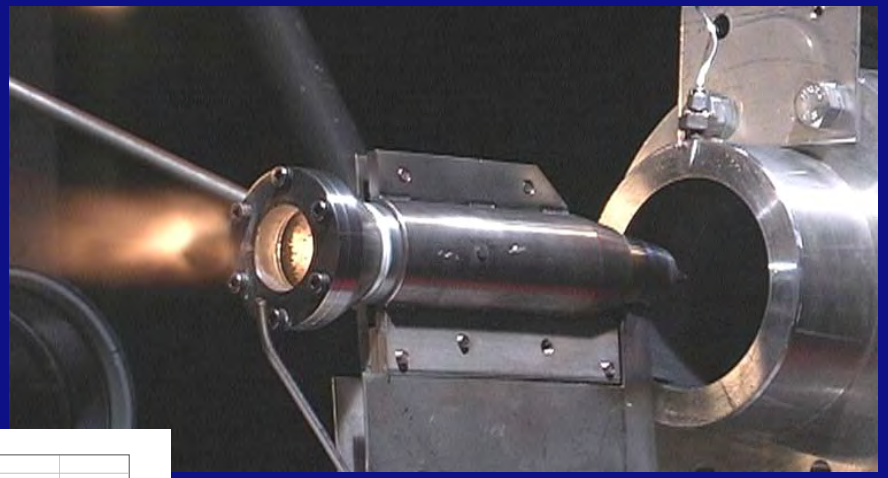
Intake performance verification in one experiment

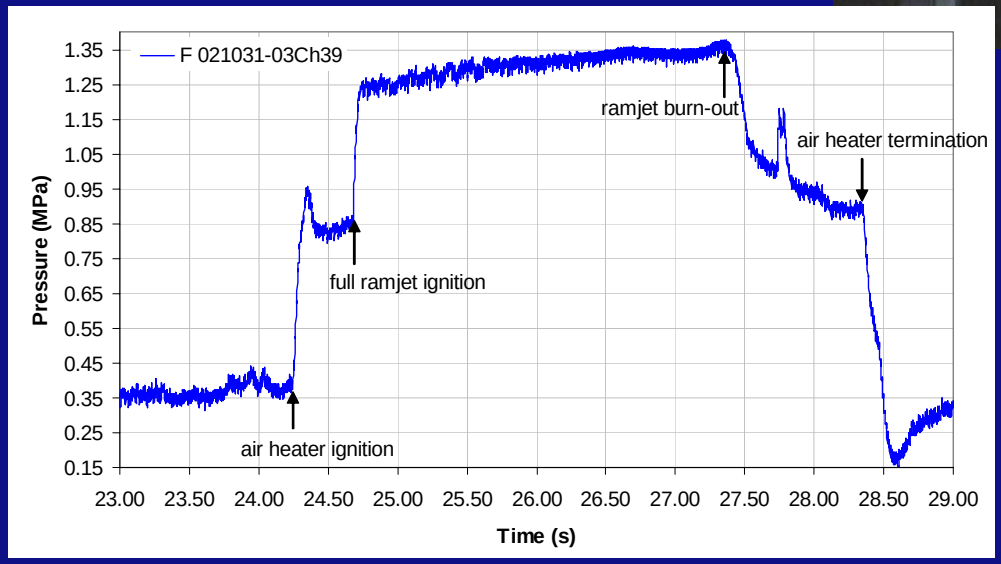




TNO/RWMS technology demonstration programme
Free jet projectile performance verification tests

- Pressure measured at 1 location
- Fast auto-ignition
- Stable and efficient combustion until fuel burn-out



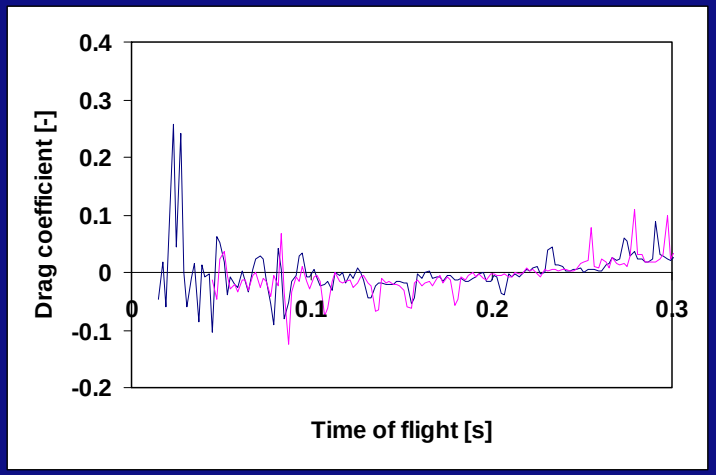


Proper functioning of complete projectile is demonstrated

TNO/RWMS technology demonstration programme
Flight demonstration tests

- Fast ignition
- Constant flight velocity
- Good reproducibility of flight performance

T = D @ 1400 m/s = world record !



TNO/RWMS technology demonstration programme Conclusions

- Projectile design satisfies mass & length requirements
- Structural integrity verified successfully in gun firings
- On-ground free jet tests verified
  - Aerodynamic heating
  - Intake performance
  - Projectile functioning
- Flight demonstration tests demonstrated
  - Very short ignition delay
  - Clear capability to maintain initial flight speed of 1400 m/s

SFRJ projectile technology = ready for application

Analyses of Gliding Control for an Extended-Range Projectile

Prof. Zhongyuan Wang,

Prof. Houqian Xu, Dr. Jinguang Shi,

Dr. Wenjun Yi, Prof. Shaosong Chen

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Nanjing University of Science & Technology ,

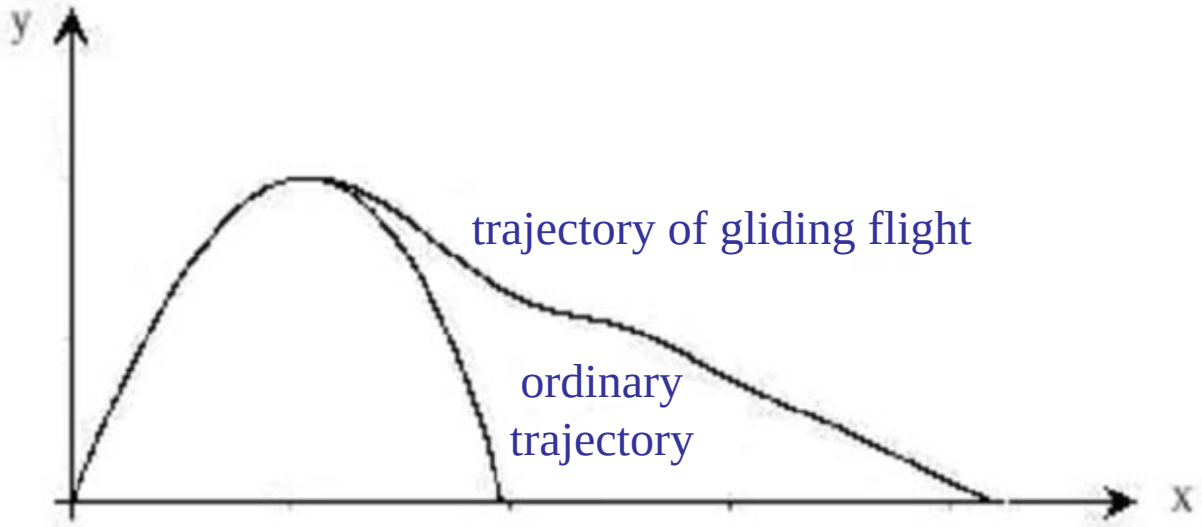
P.O.Box,210094,Nanjing,P.R.Chin

More Points

1. Introduction
2. Design of aerodynamic configuration for an extended-range projectile
3. Wind Tunnel Tests of extended-range projectiles
4. Analyses of favorite rotation of lift-canards during gliding flight

1. Introduction

Increasing range of a projectile with gliding flight is a quite efficient technique.



During gliding flight, the range and process of gliding control are strongly affected by following factors:

- **Fine design of aerodynamic configuration**
- **To match well change for the rotation of lift-canards and the angle of attack**

2. Design of aerodynamic configuration for an extended-range projectile

Aerodynamic Simulation and Code

The equations of CFD for a projectile can be described

$$\frac{\partial \boldsymbol{U}}{\partial t}+\frac{\partial \boldsymbol{F}(\boldsymbol{U})}{\partial x}+\frac{\partial \boldsymbol{G}(\boldsymbol{U})}{\partial y}+\frac{\partial \boldsymbol{M}(\boldsymbol{U})}{\partial z}=0$$

$$\boldsymbol{U}=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho w\\ E\end{bmatrix}\quad \boldsymbol{F}(\boldsymbol{U})=\begin{bmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ \rho uw\\ (E+p)u\end{bmatrix}\quad \boldsymbol{G}(\boldsymbol{U})=\begin{bmatrix}\rho v\\ \rho vu\\ \rho v^2+p\\ \rho vw\\ (E+p)v\end{bmatrix}\quad \boldsymbol{M}(\boldsymbol{U})=\begin{bmatrix}\rho w\\ \rho wu\\ \rho wv\\ \rho w^2+p\\ (E+p)w\end{bmatrix}$$

here, ρ—air density, u v w—three components of velocity,

E—total energy, p—pressure.

CFD Technique

We use a special method of finite volume as numerical simulation of the flow field for previous equations .

Fig.1 to Fig.3 are sketches of grids on surface of a projectile.

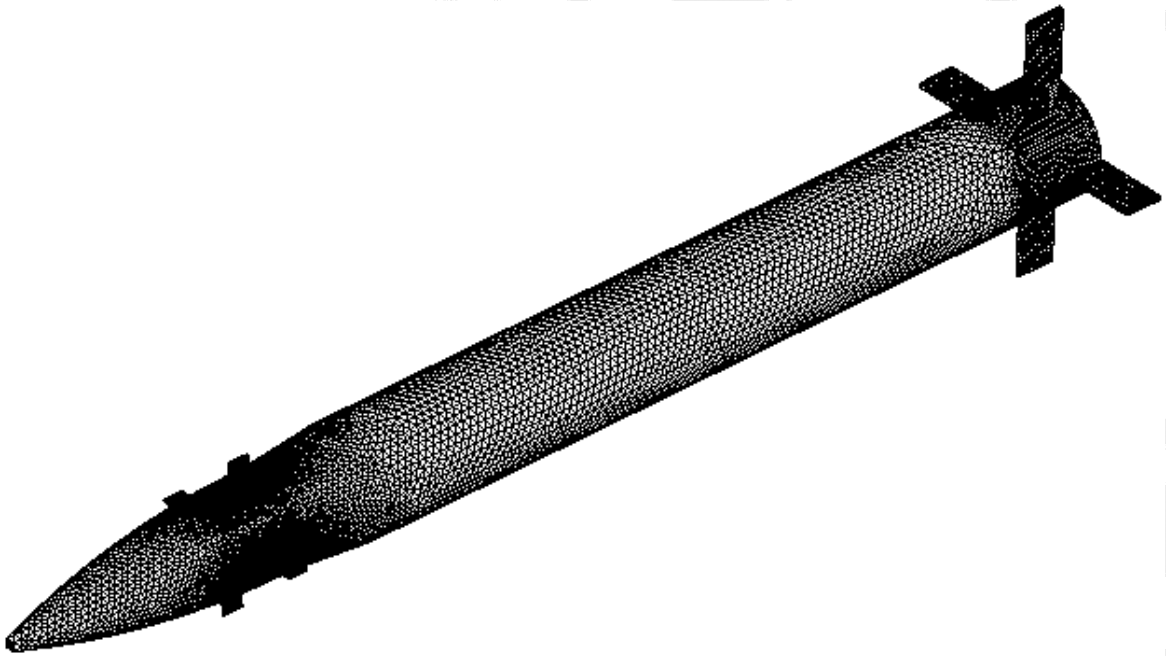


Fig .1 The sketch of grids on whole surface

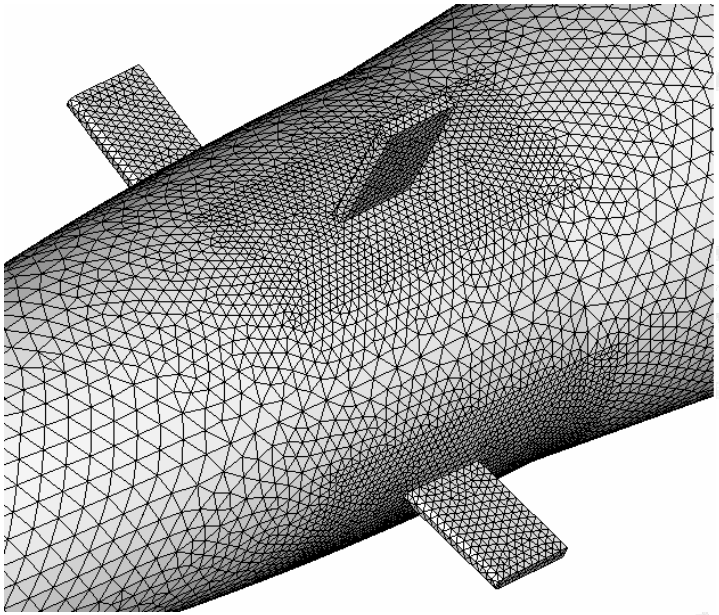


Fig .2 The sketch of grids on front projectile with lift-canards

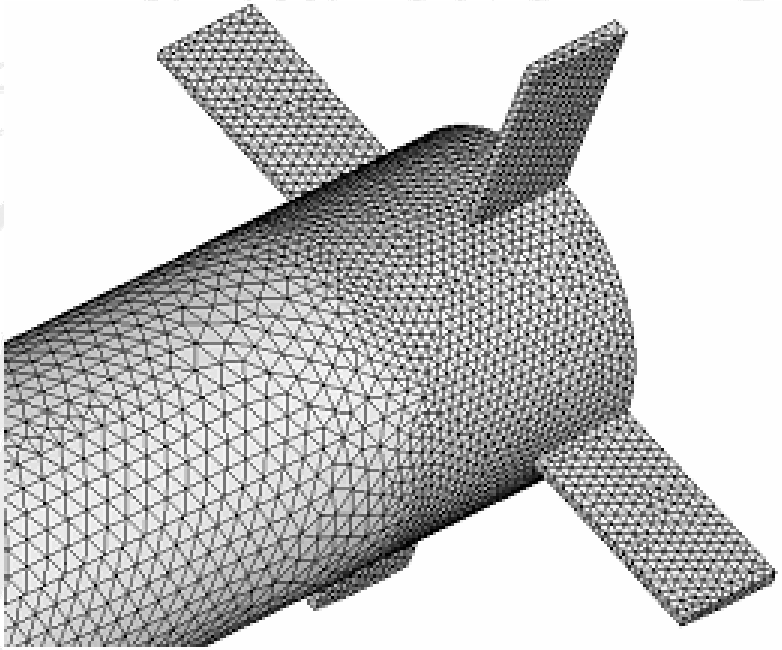


Fig .3 The sketch of grids on rear projectile with wings

Function of Code

Based on above basic equations and numerical simulation, we develop a code of aerodynamic computations .

Design of aerodynamic configuration

- Purpose of design
- Analyses of Aerodynamic Design

Fig.4 to Fig.7 are CFD numerical simulations for different lift-canards and wings.

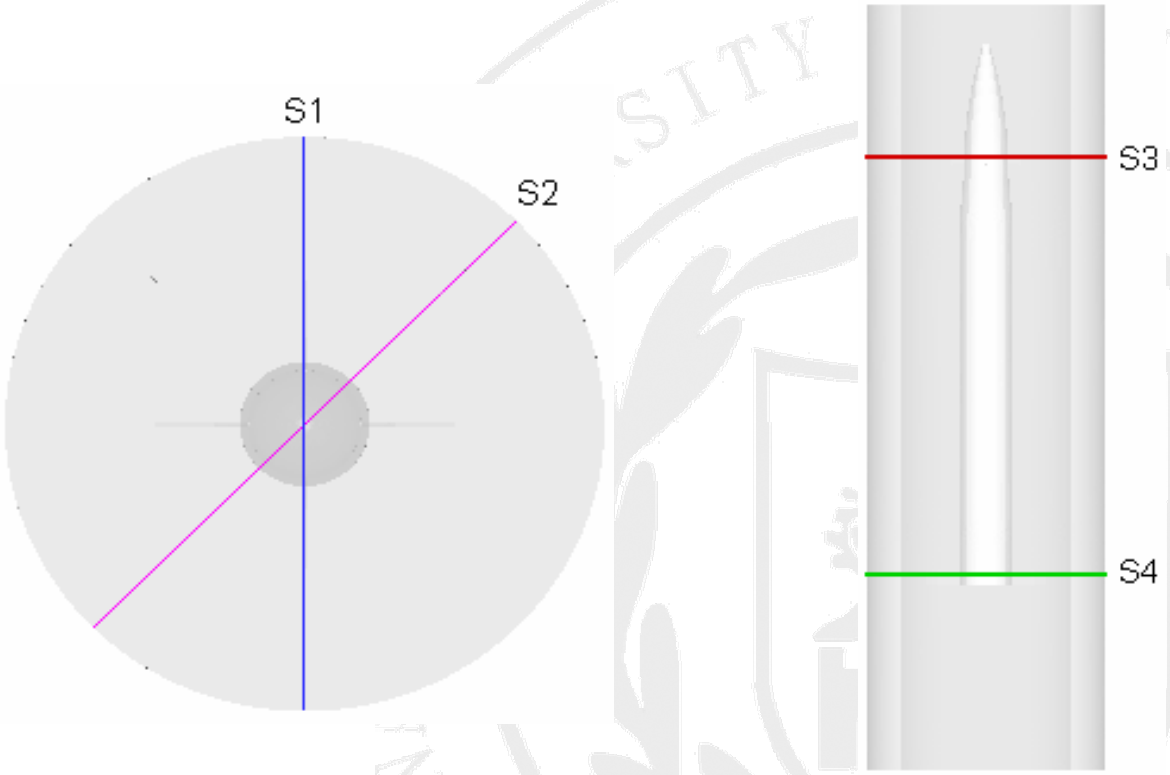


Fig .4 The sketch of different cross sections S1, S2, S3, S4 on a projectile

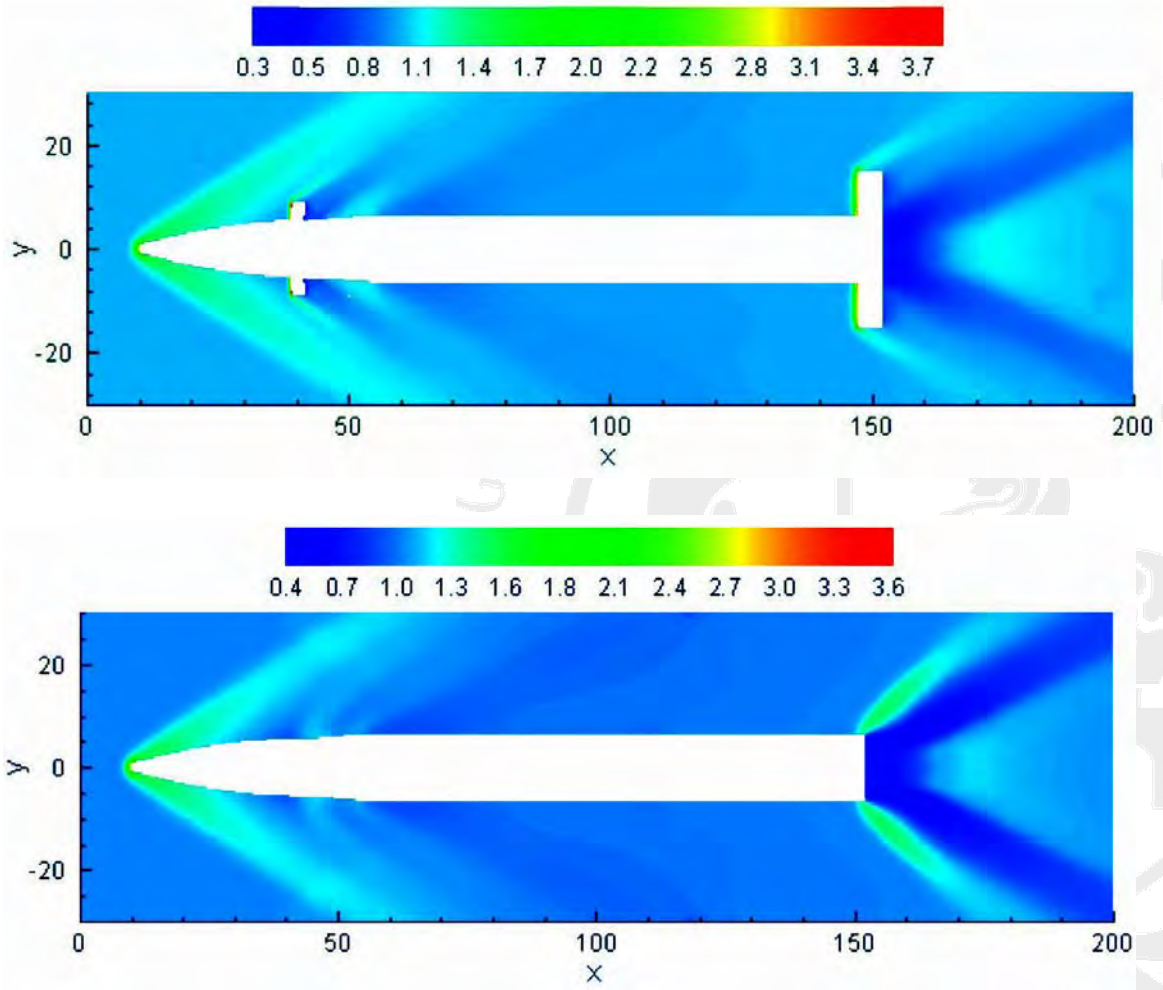
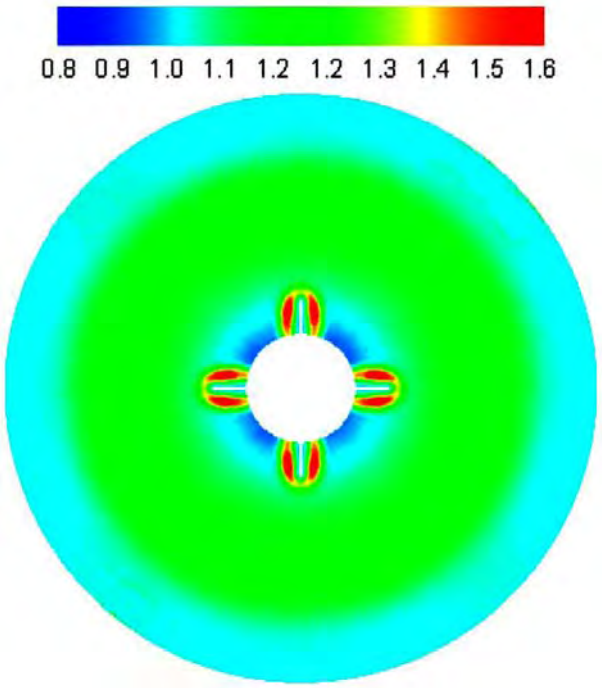
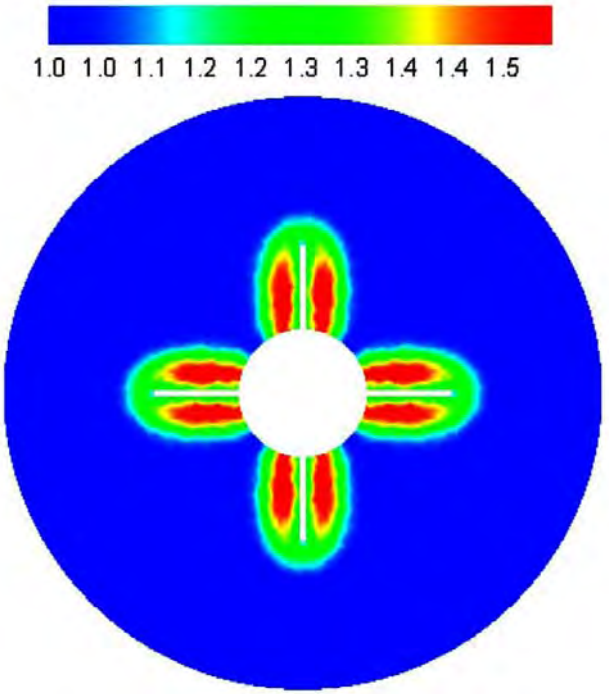


Fig .5 The pressure distribution on cross section S1, S2



(a)



(b)

Fig .6 The pressure distribution on cross section S3, S4

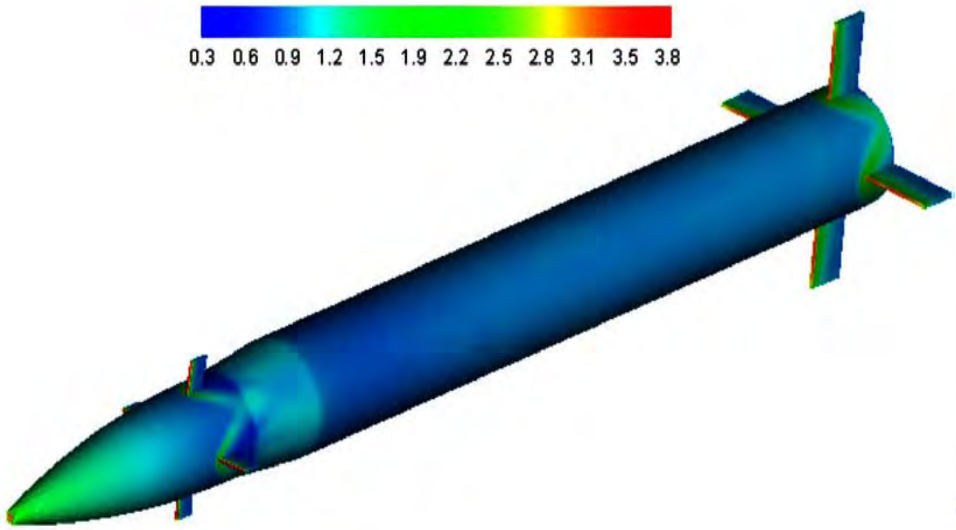


Fig .7 (a) The pressure distribution on whole surface of a projectile

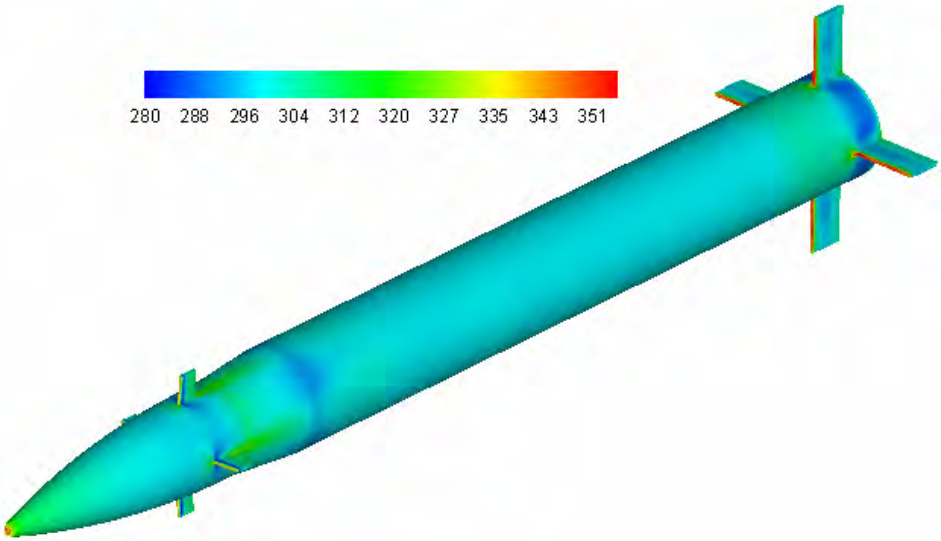


Fig .7 (b) The temperature distribution on whole surface of a projectile

From numerical results we know that these factors (including shapes, pairs and position) of lift-canards and wings strongly affect aerodynamic characteristics. So for any extended-range projectile, the aerodynamic design with CFD code should be done first in order to get good relation between flight stability and maneuverability.

3. Wind tunnel tests of extended-range projectiles

3.1 Models of wind tunnel tests

Some geometrical models with different shapes or pairs of lift-canards and wings are selected for wind tunnel tests.

Fig.8 to Fig.11 show the geometries of some these models.

Fig.8 The geometry of model No.1 (with one pair of lift-canards and three pairs of wings)

Fig.9 The geometry of model No.2 (with two pairs of lift-canards and three pairs of wings)

Fig.10 The geometry of model No.3 (with two pairs of lift-canards and two pairs of wings)

Fig.11 The geometry of model No.4 (with two pairs of lift-canards and four pairs of wings)

3.2 Description of Wind Tunnel

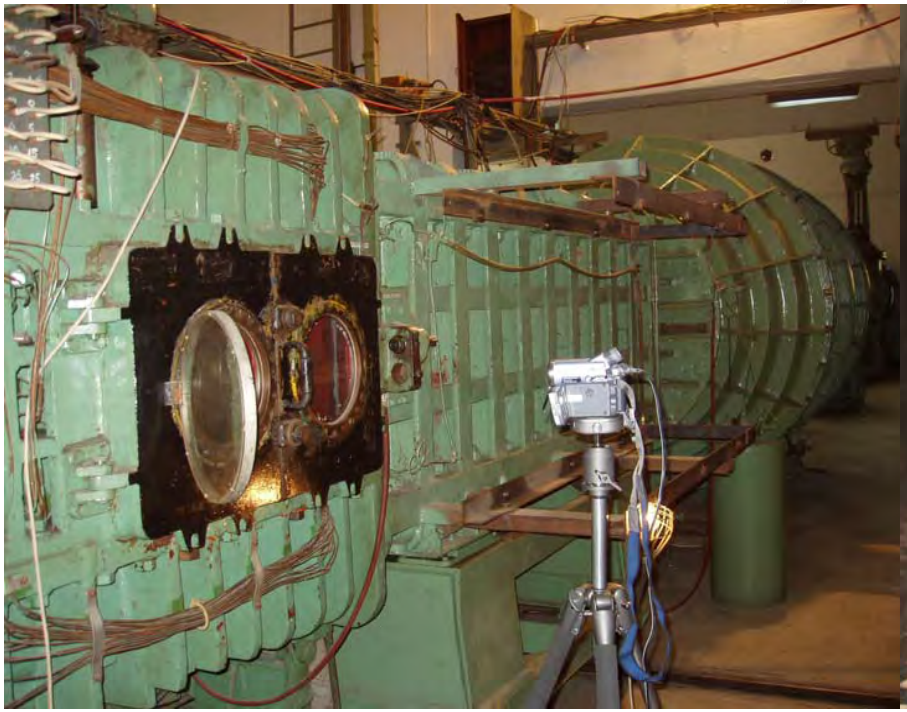


Fig.12 A blow-down wind tunnel

3.3 Results of Wind Tunnel

Fig.13 to Fig.18 show some results of wind tunnel tests.

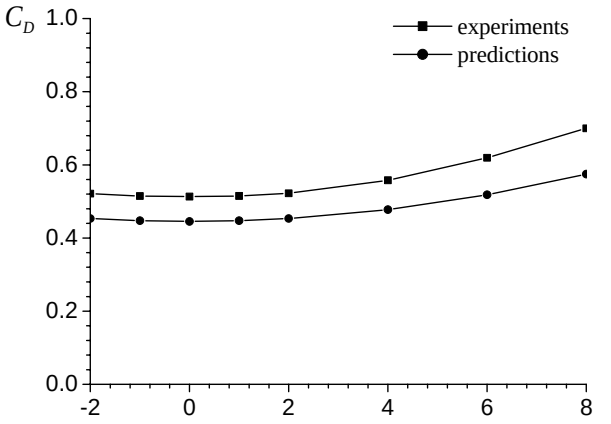


Fig.13 Axial force coefficient vs incidence (Model No.1, M=1.79)

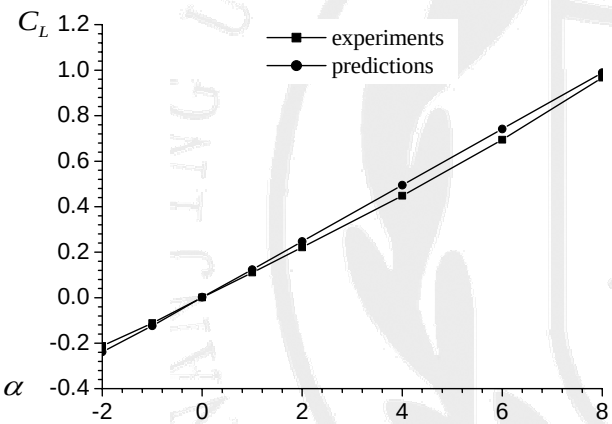


Fig.14 Normal force coefficient vs incidence (Model No.1, M=1.79)

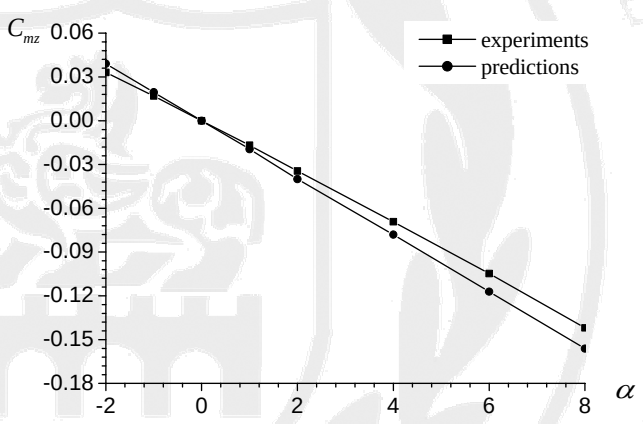


Fig.15 Pitching moment coefficient vs incidence (Model No.1, M=1.79)

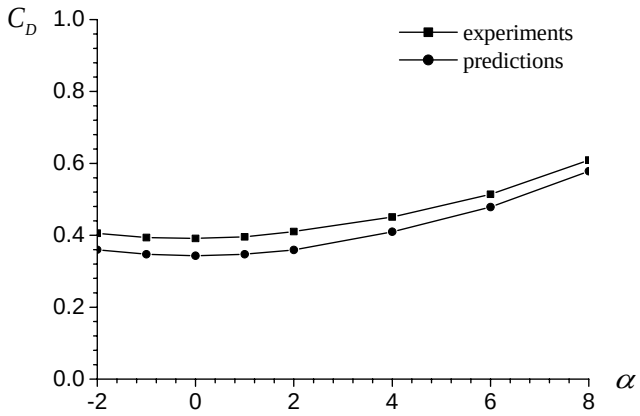


Fig.16 Axial force coefficient vs incidence (Model No.2, M=0.8)

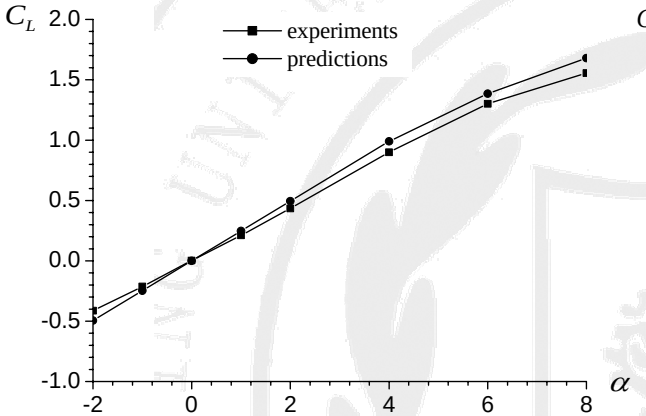


Fig.17 Normal force coefficient vs incidence (Model No.2, M=0.8)

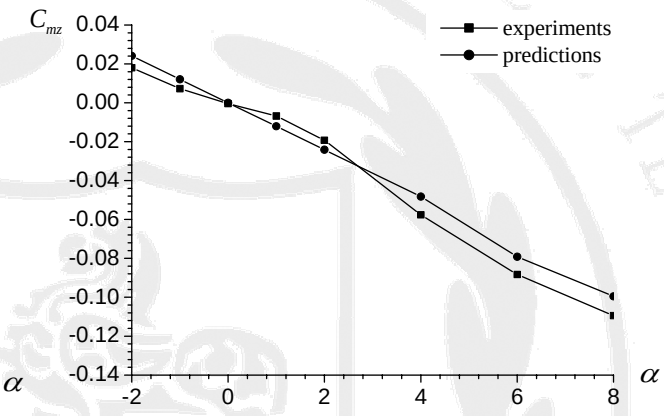


Fig.18 Pitching moment coefficient vs incidence (Model No.2, M=0.8)

Based on analyses of wind tunnel tests for different configurations we can see following results:

- **The predictions of CFD code are agreement well with wind tunnel tests.**
- **Those factors strongly affect flight stability, maneuverability and down-wash phenomenon.**
- **To design aerodynamic configuration for an extended-range projectile combined the predictions with CFD code and wind tunnel tests should be used.**

4. Analyses of favorite rotation of lift-canards during gliding flight

During gliding flight the angle of attack is changed by control of lift-canards. If the rotating angle of canards is too large, it will cause some problems such as flight stability or increasing drag fast and it is not suitable for gliding flight. If the rotating angle of canards is too small, it will cause other problems such as small angle of attack and it is not efficient to increase range with gliding flight.

At any time during gliding flight, there is an equilibrium relation between rotation of canards and angle of attack:

$$\alpha(t)=\left(\frac{C_y' x_1}{C_{y\alpha}' x_2}-1\right)\delta^*(t)$$

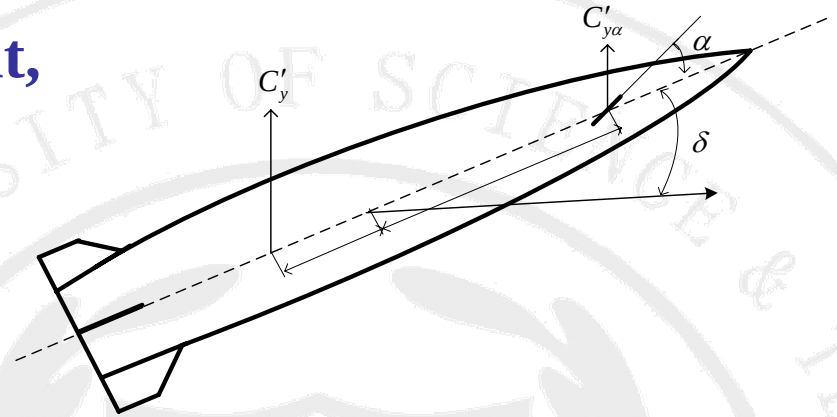


Fig.19 Angle of attack vs angle of rotating canards

$\alpha(t)$ —angle of rotating canards,

$\delta^*(t)$ —instantaneous balance angle of attack.

Of cause different $\alpha(t)$ causes different $\delta^*(t)$ and range of gliding flight.

To analyses the effect of rotating canards to range of gliding flight. We can use a 6D model of trajectory and some optimum method to find the favorite angle of rotating canards.

Sequence Quadric Programming (SQP)

Sequence Quadric Programming is a special method in optimum theory. We can use it to make optimization of the farthest range with different angles of rotating canards.

Main Idea or Process

To find a favorite angle of rotating canards, we can use following methods:

- CFD code and other empirical method to predict aerodynamic coefficients.
- 6D model of trajectory to calculate the range of gliding flight.
- SQP method to find the result of optimization for angle of rotating canards with the farthest range.

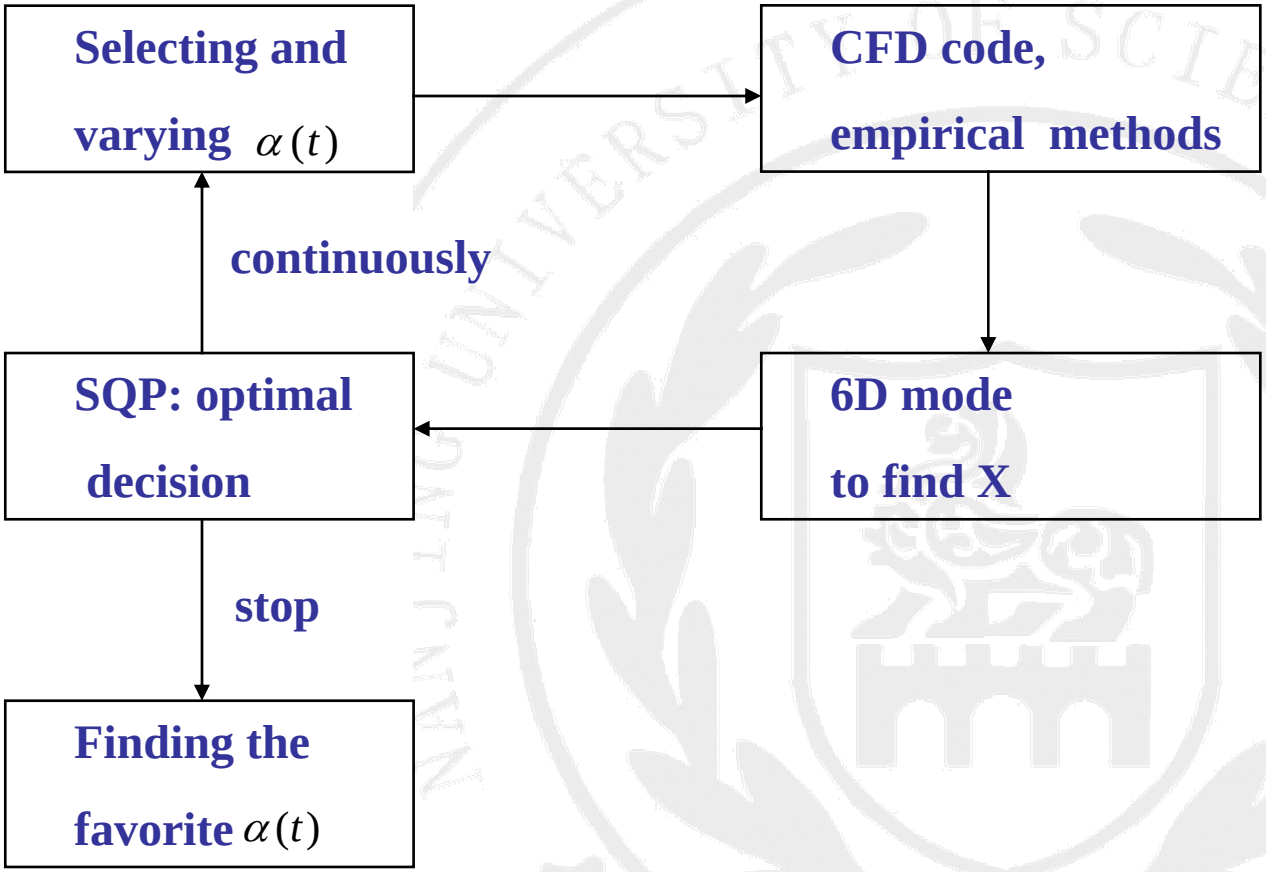


Fig.20 General process to find favorite $\alpha(t)$

For a special extended range projectile, the favorite angle of rotating canards and corresponding angle of attack have been calculated in Fig.21 and Fig.22

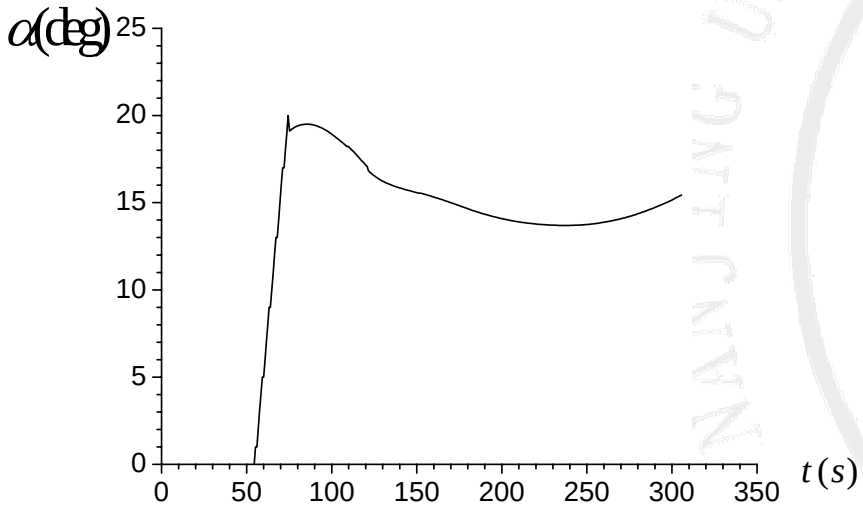


Fig.21 the curve of favorite angle of rotating canards

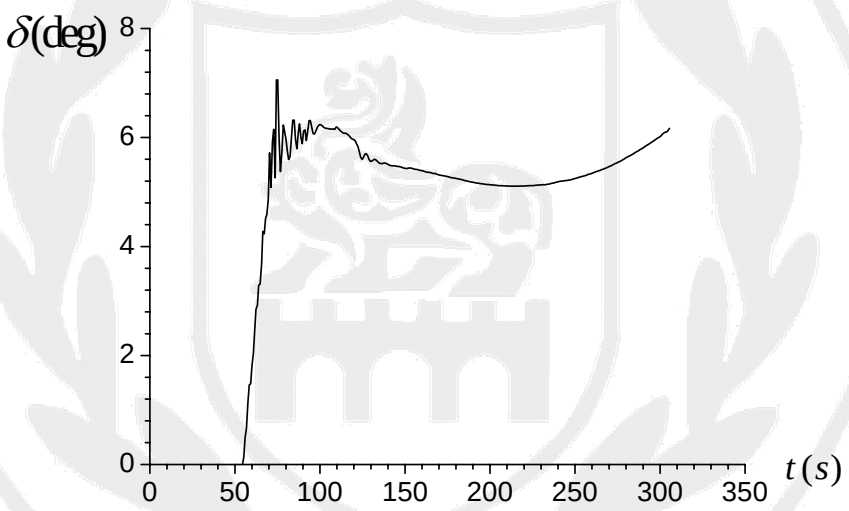


Fig.22 the curve of corresponding angle of attack

Conclusions

- For an extended-range projectile, the CFD code introduced here can be used.
- The results from predictions and experiments show that the factors strongly affect aerodynamic characteristics.
- Based on the 6D model of trajectory and SQP method, the favorite angle of rotating canards can be found.

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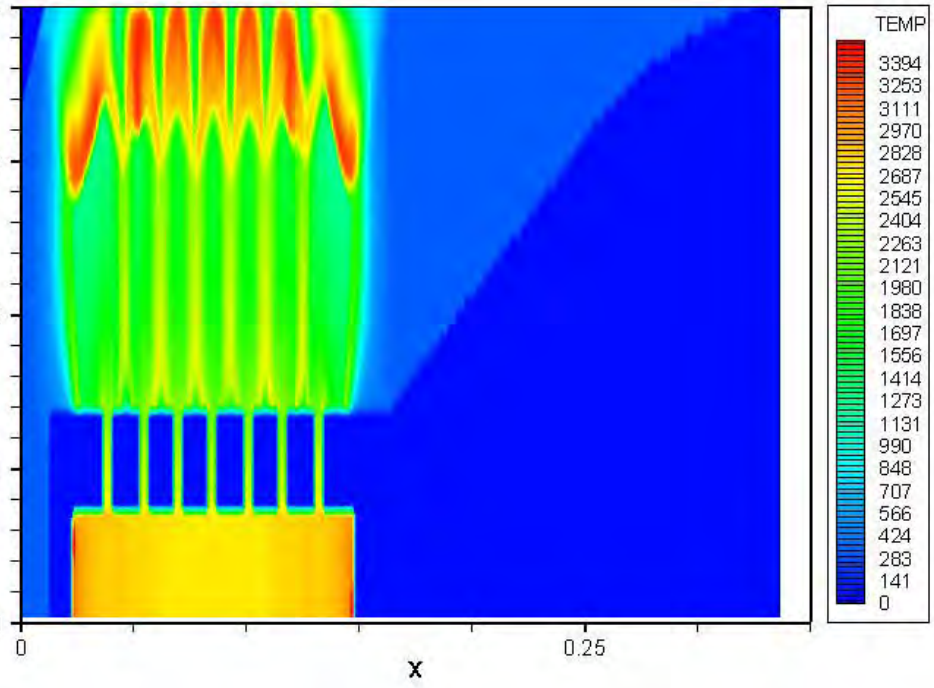

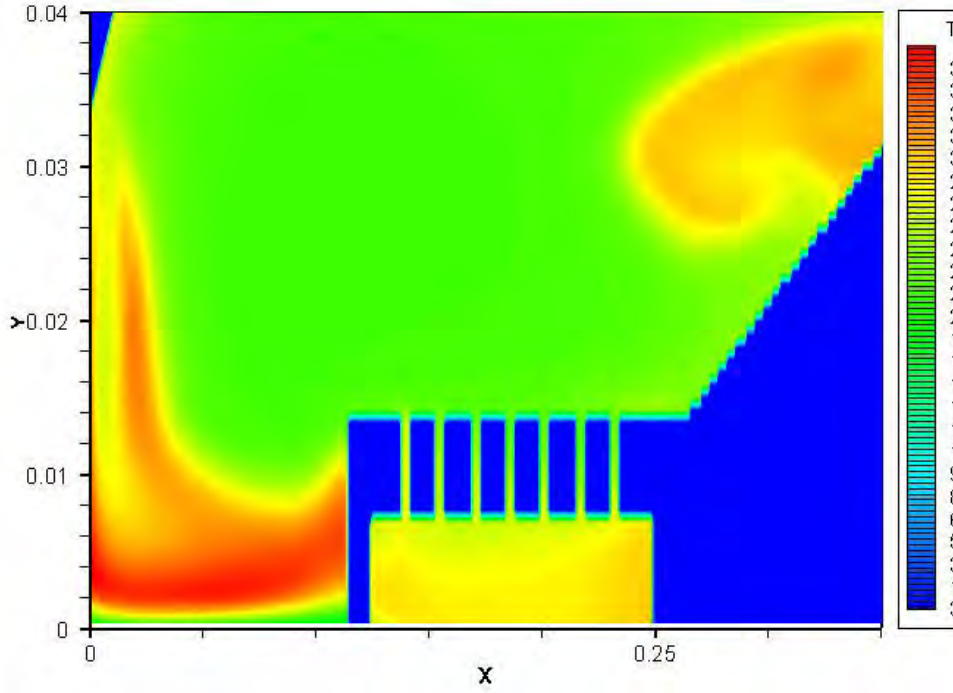

Two-dimensional Modelling of Mortar Internal Ballistics

Clive Woodley, David Finbow, Vladimir Titarev & Eleuterio Toro

International Symposium on Ballistics, November 2005

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QinetiQ

Contents

1 Introduction

2 Equations & numerics

3 Testing & results

4 Conclusions & furtherwork

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Section 1

Introduction

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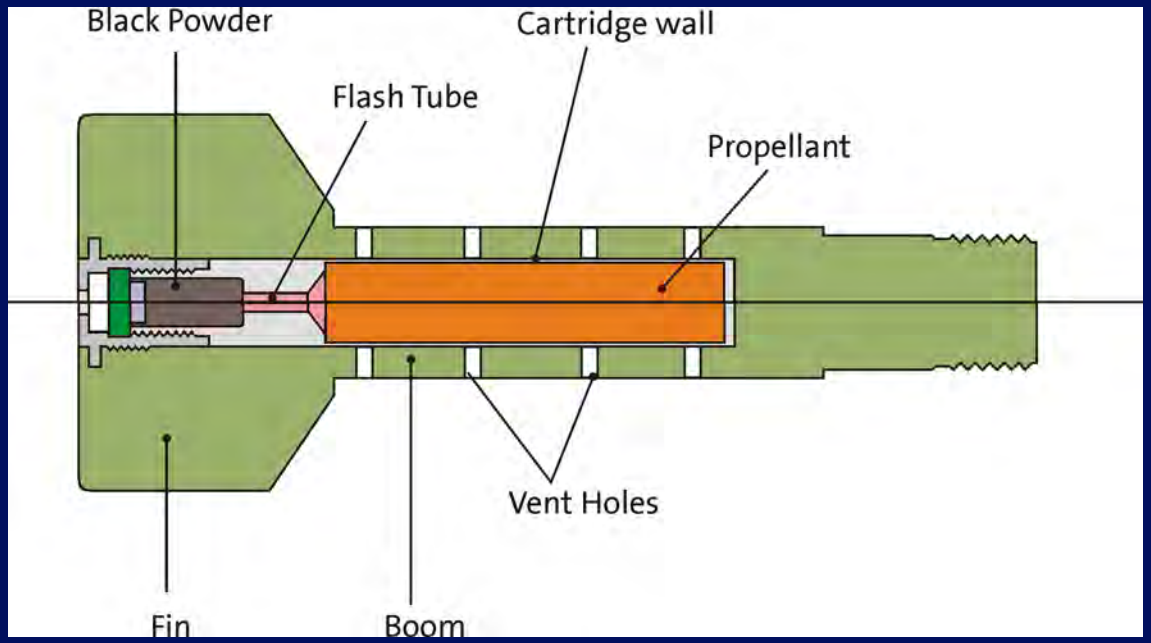
Background

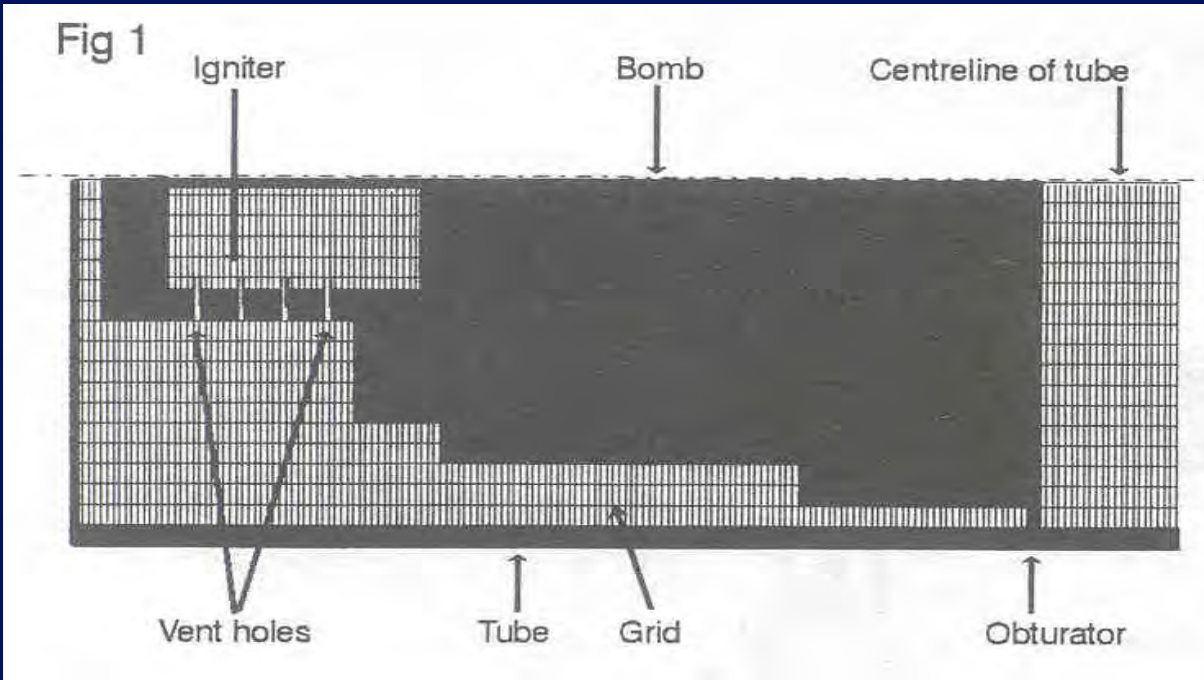
- 51mm & 81mm mortars exhibited pressure oscillations
- Bent fins
- Split/broken tail units



1 Introduction

Previous UK work

- Mostly 0D and 1D
- 2D work in mid 90s
  - Code not robust
  - Data hardwired
- New code needed



Section 2

Equations & numerics

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Equations – gas phase

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial z}(\rho\varepsilon u)+\frac{\partial}{\partial r}(\rho\varepsilon v)=-\frac{\varepsilon\rho v}{r}+\dot{m}_{ig}+\sum_{k=1}^{n}\dot{m}^{k}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon u)+\frac{\partial}{\partial z}[\varepsilon(\rho u^{2}+p)]+\frac{\partial}{\partial r}(\rho\varepsilon uv)=-\frac{\varepsilon\rho uv}{r}+p\frac{\partial\varepsilon}{\partial z}+\sum_{k=1}^{n}(\dot{m}^{k}u^{k})$$

$$\frac{\partial}{\partial t}(\rho\varepsilon v)+\frac{\partial}{\partial z}(\varepsilon\rho uv)+\frac{\partial}{\partial r}[\varepsilon(\rho v^{2}+p)]=-\frac{\varepsilon\rho v^{2}}{r}+p\frac{\partial\varepsilon}{\partial r}+\sum_{k=1}^{n}(\dot{m}^{k}v^{k})$$

$$\frac{\partial}{\partial t}(\rho\varepsilon E)+\frac{\partial}{\partial z}[\varepsilon\rho u(E+p/\rho)]+\frac{\partial}{\partial r}[\rho\varepsilon v(E+p/\rho)]=-\frac{\varepsilon\rho v}{r}(E+p/\rho)+\dot{m}_{ig}Q_{ig}+$$

$$\sum_{k=1}^{n}[\dot{m}^{k}(Q_{p}^{k}+\kappa^{k})-p\left(\frac{\partial(\varepsilon^{k}u^{k})}{\partial z}+\frac{\partial(\varepsilon^{k}v^{k})}{\partial r}\right)]$$

Equations – solid phase

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k) + \frac{\partial}{\partial z}(\rho^k \varepsilon^k u^k) + \frac{\partial}{\partial r}(\rho^k \varepsilon^k v^k) = -\dot{m}^k - \frac{\varepsilon^k \rho^k u^k}{r}$$

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k u^k) + \frac{\partial}{\partial z}[\varepsilon^k(\rho^k (u^k)^2 + p + p_{is}^k)] + \frac{\partial}{\partial r}(\rho^k \varepsilon^k u^k v^k) = p\frac{\partial \varepsilon^k}{\partial z}$$

$$-\frac{\varepsilon^k \rho^k u^k v^k}{r} - \dot{m}^k u^k$$

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k v^k) + \frac{\partial}{\partial z}(\varepsilon^k \rho^k u^k v^k) + \frac{\partial}{\partial r}[\varepsilon^k(\rho^k (v^k)^2 + p + p_{is}^k) = p\frac{\partial \varepsilon^k}{\partial r} - \frac{\varepsilon^k \rho^k (v^k)^2}{r} - \dot{m}^k v^k$$

$$\frac{\partial}{\partial t}(N^k) + \frac{\partial}{\partial z}(N^k u^k) + \frac{\partial}{\partial r}(N^k v^k) = -\frac{v^k N^k}{r}$$

Equations – closure & conservative form

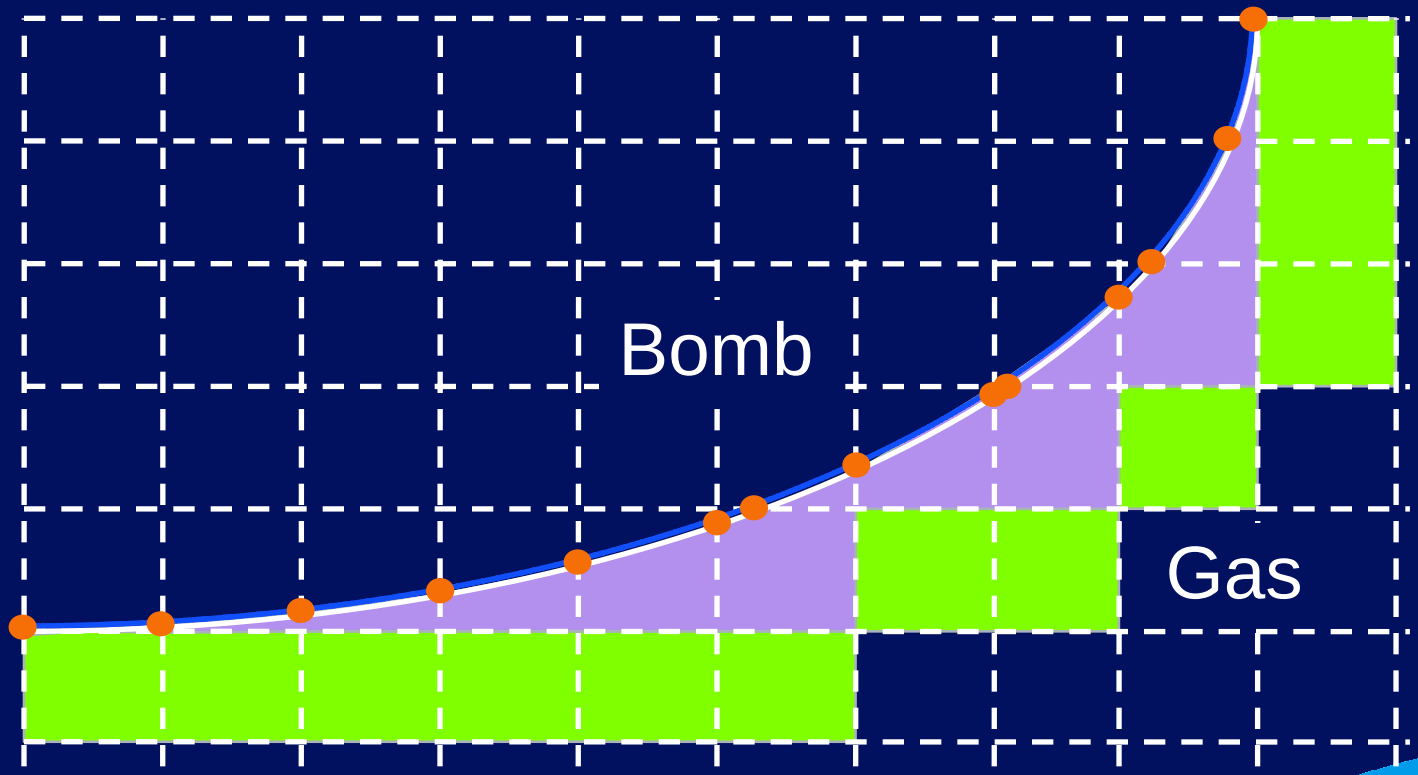
$$\varepsilon + \sum_{k=1}^{n} \varepsilon^{k} = 1$$

$$p(1/\rho - \eta) = RT / W$$

$$\partial_t Q + \partial_z F(Q) + \partial_r G(Q) = S(Q)$$

Numerical algorithm

- Cartesian cut cell mesh generator
- Numerical solver



Numerical solver

- Two step time splitting procedure

$$Q_{ij}^{*} = Q_{ij}^{n} - \frac{\Delta t}{V_{ij}} \sum_{s=1}^{N} A_s T_s^{-1} F^{HLLC}\left(T_s Q_L, T_s Q_R\right)$$

Step 1

Phase splitting

Gas phase Solid phases

$$Q_{ij}^{n+1} = Q_{ij}^{*} + \Delta t \sum_{k=1}^{3} S_k\left(Q_{ij}^{*}\right)$$

Step 2

Remesh

Section 3

Testing & results

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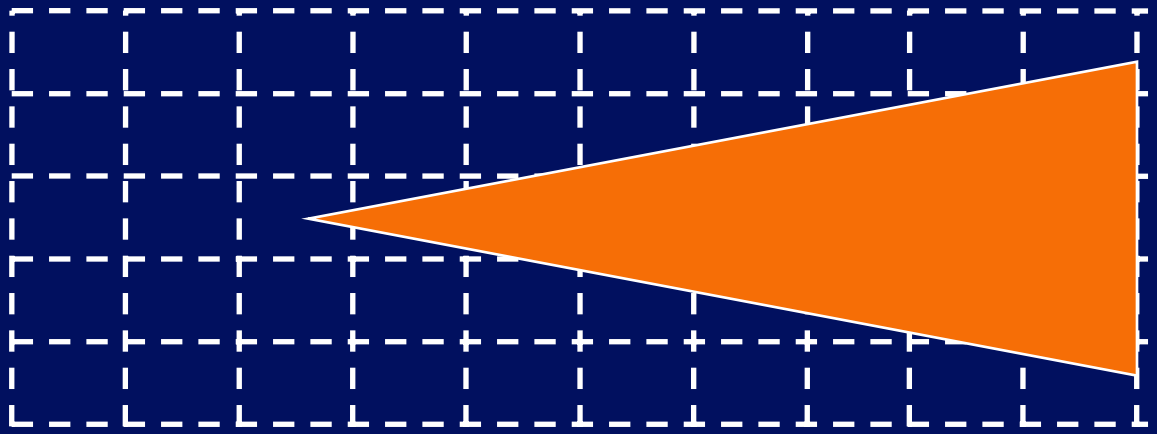
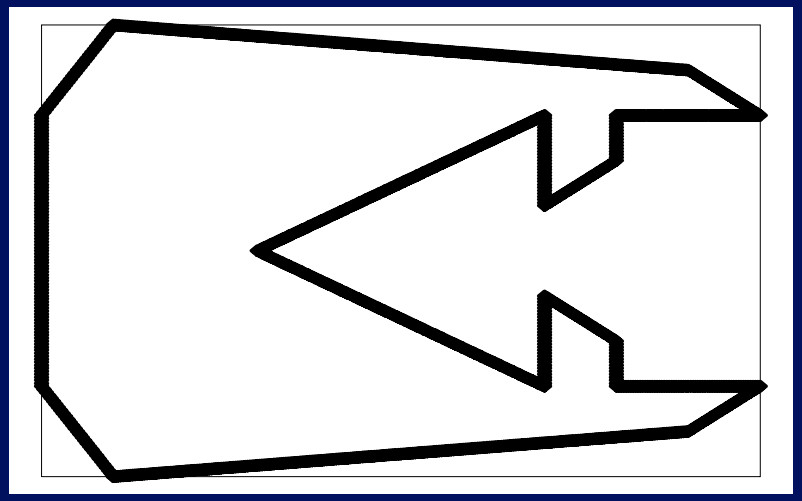
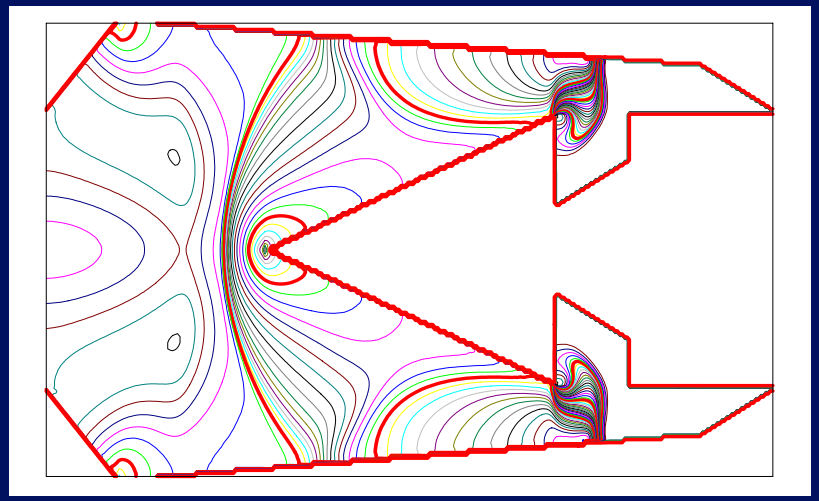
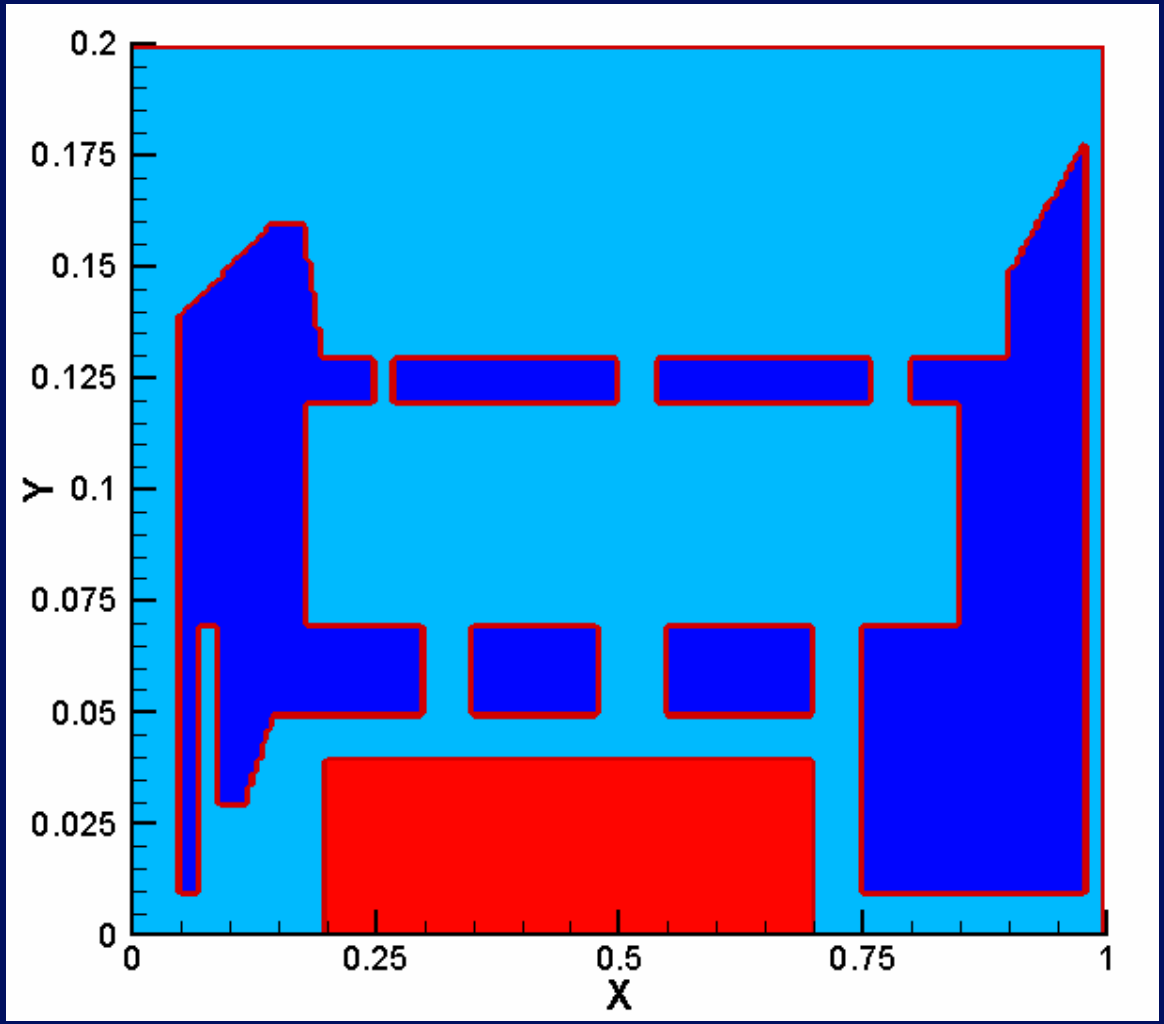
Testing on complex geometries



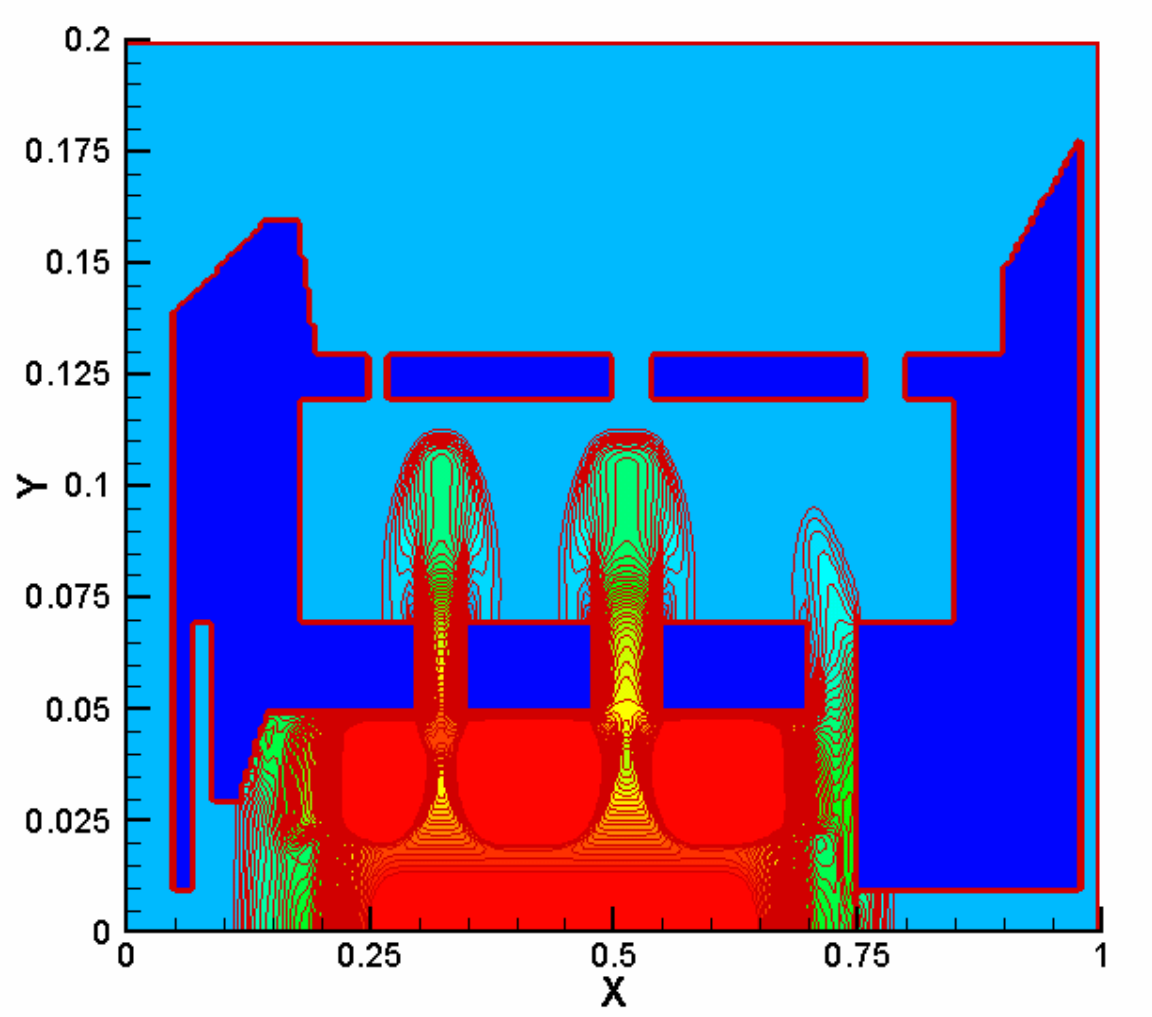




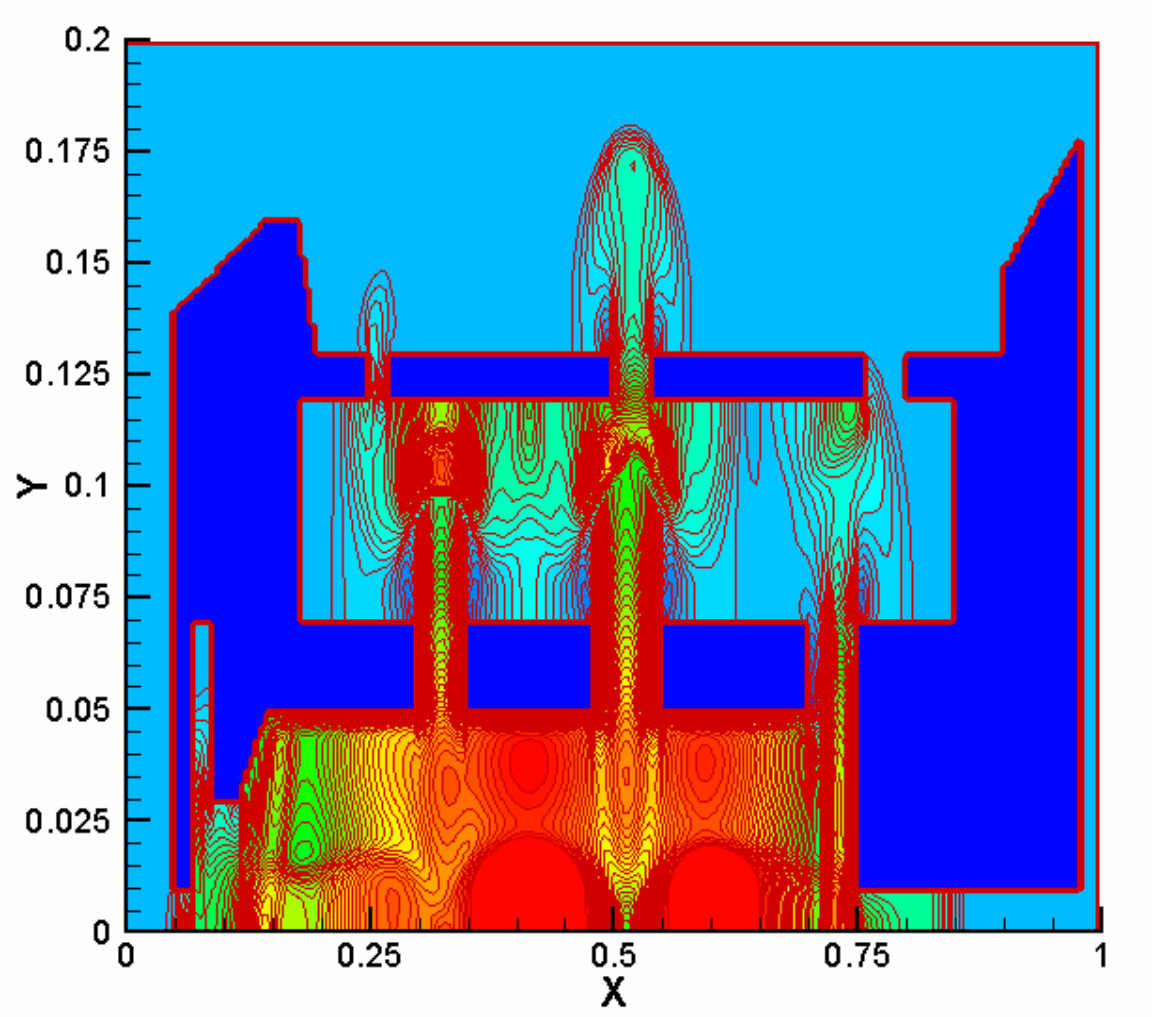
Testing on Mortar-like configuration



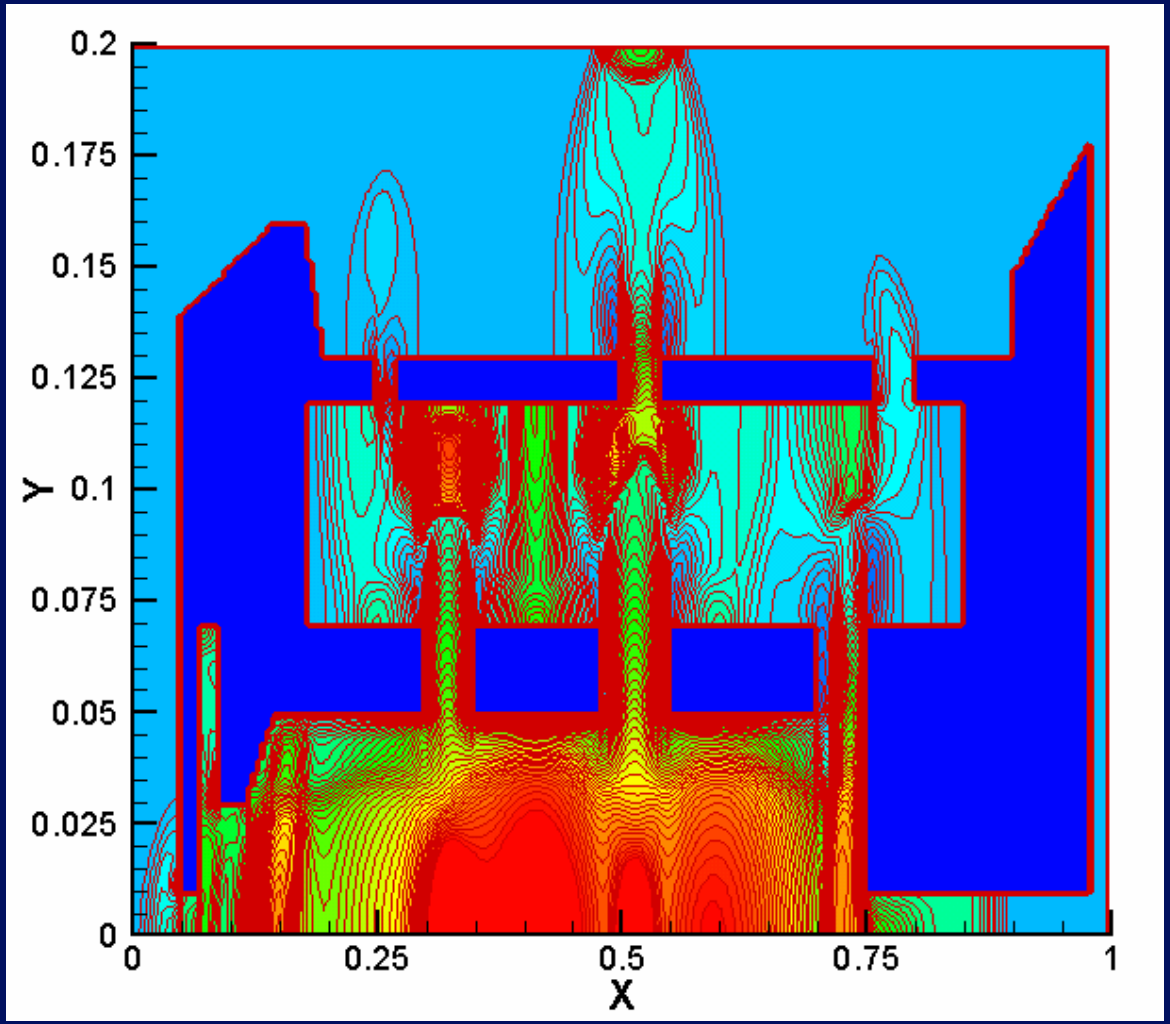
Testing on Mortar-like configuration



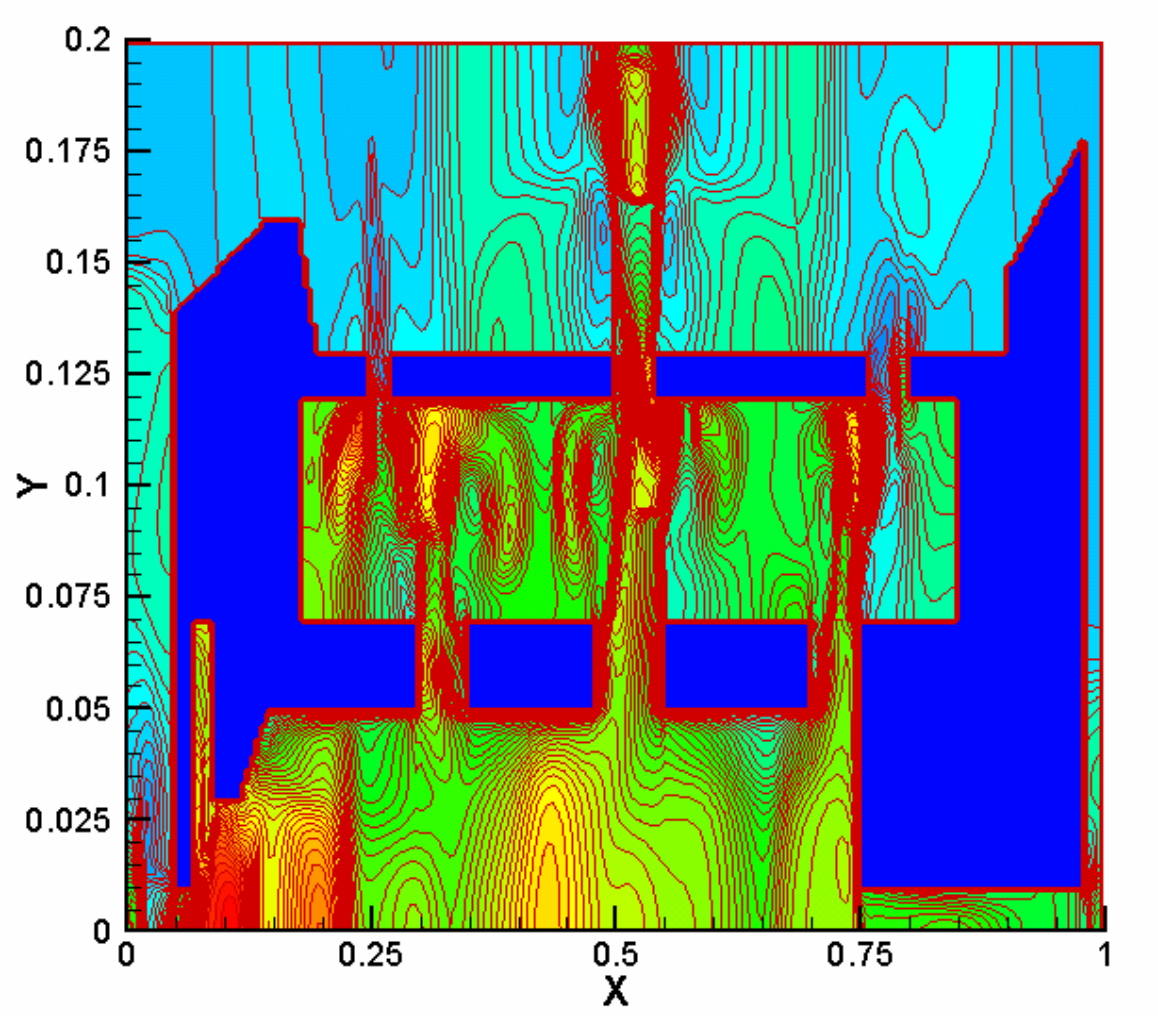
Testing on Mortar-like configuration



Testing on Mortar-like configuration

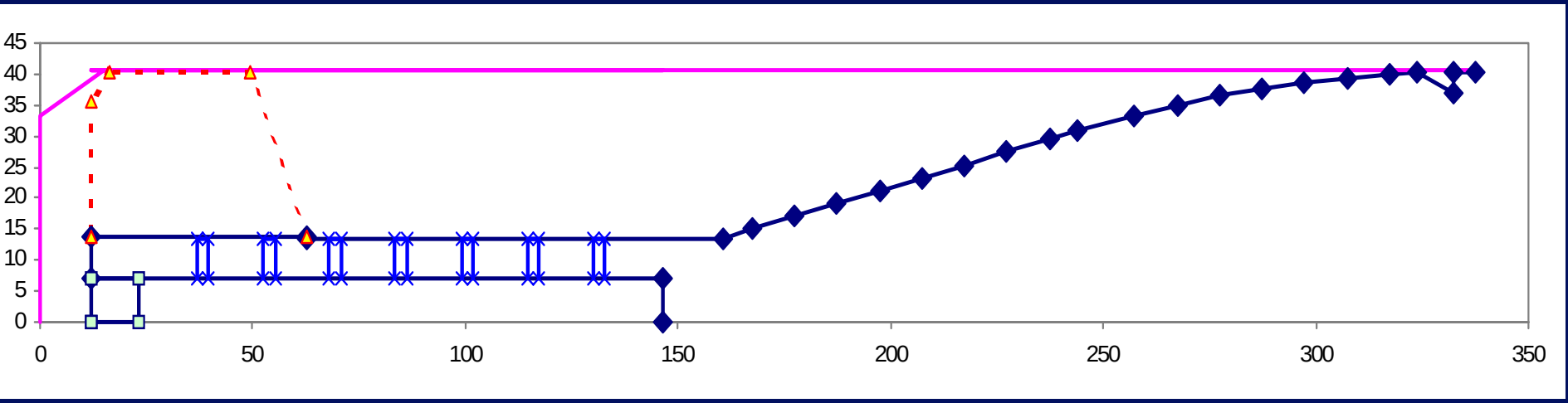


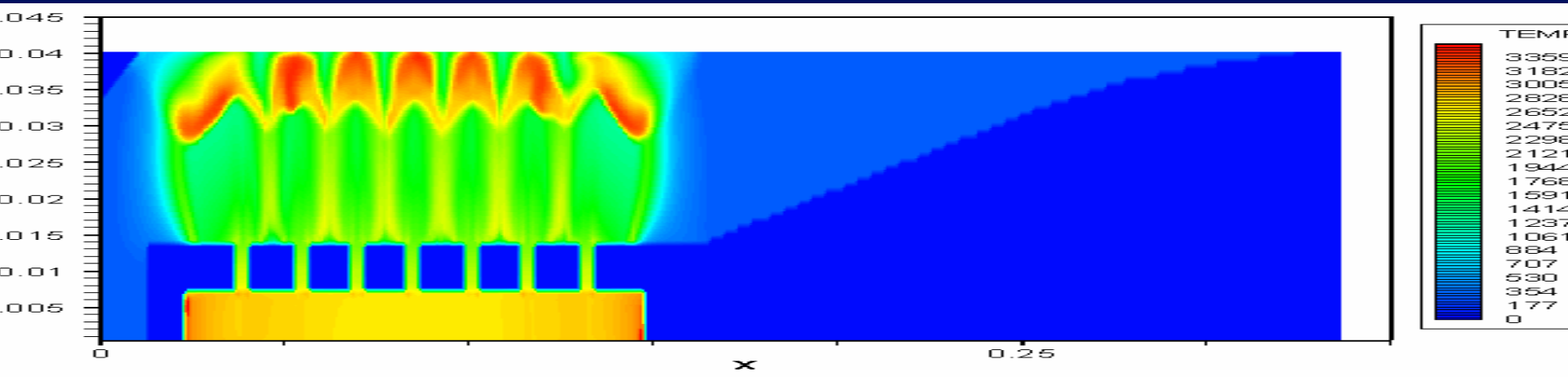
Testing on Mortar-like configuration



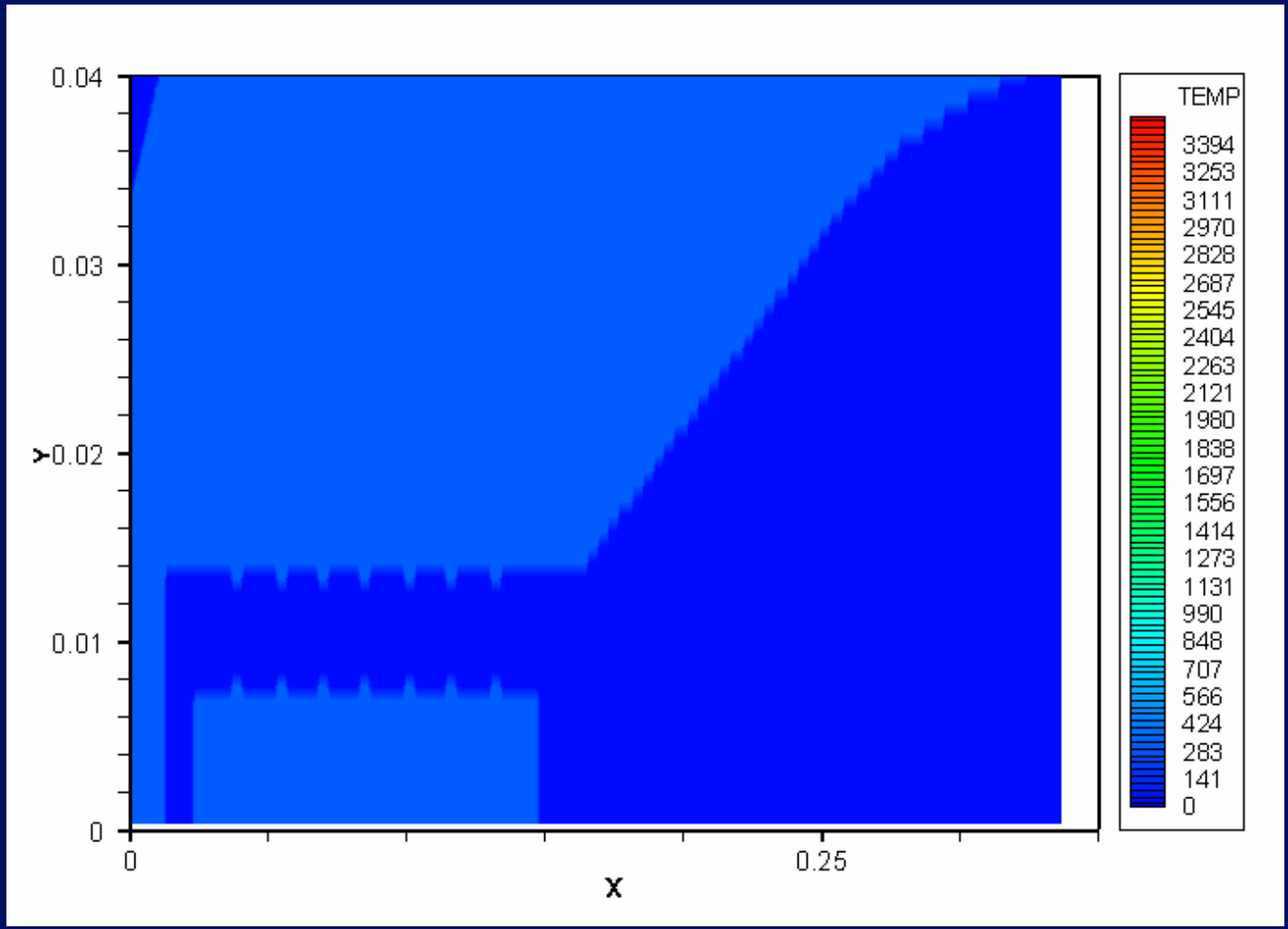
3 Testing & results

81mm mortar

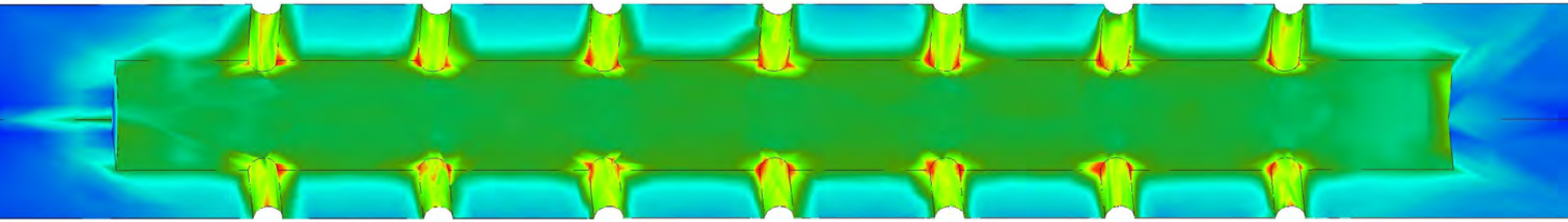




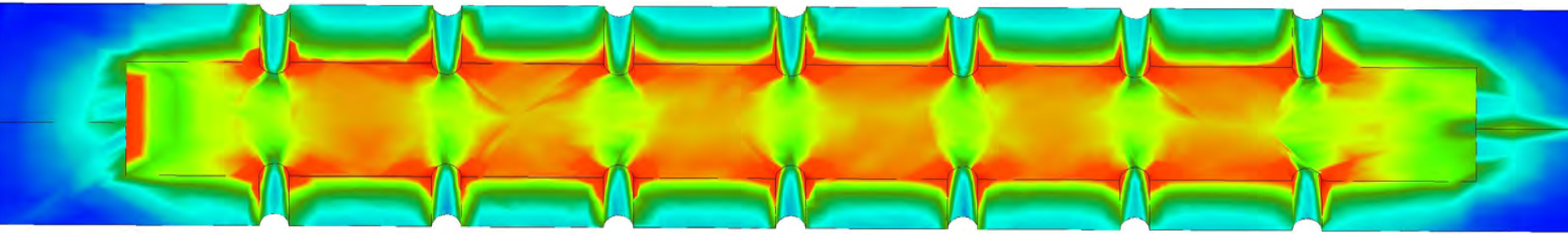
81mm mortar animation



FE analysis on tailunit



Stress distribution at 1ms



Stress distribution for 80MPa internal pressure

Section 4

Conclusions & further work

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Conclusions & furtherwork

- 2D mortar code developed & capable of modelling representative mortar geometries
  - Rigorously tested for complex geometries
- Output linked to FE analysis software to allow the calculation of stress distributions
- Software can also be used for any gun/projectile system in which the projectile intrudes significantly into the combustion chamber

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THE MECHANISM ANALYSIS OF INTERIOR BALLISTICS OF SERIAL CHAMBER GUN

Dr. Sanjiu Ying, Prof. Xiaobing Zhang,
Prof. Yaxiong Yuan, Dr.Yan Wang

Ballistic Research Laboratory of China

OUTLINE

- INTRODUCTION
- LAUNCH MECHANISM OF SERIAL CHAMBER GUN
- LUMPED PARAMETER MODEL
- TWO PHASE FLOW MODEL
- ANALYSIS OF CALCULATION RESULTS
- CONCLUSIONS

INTRODUCTION

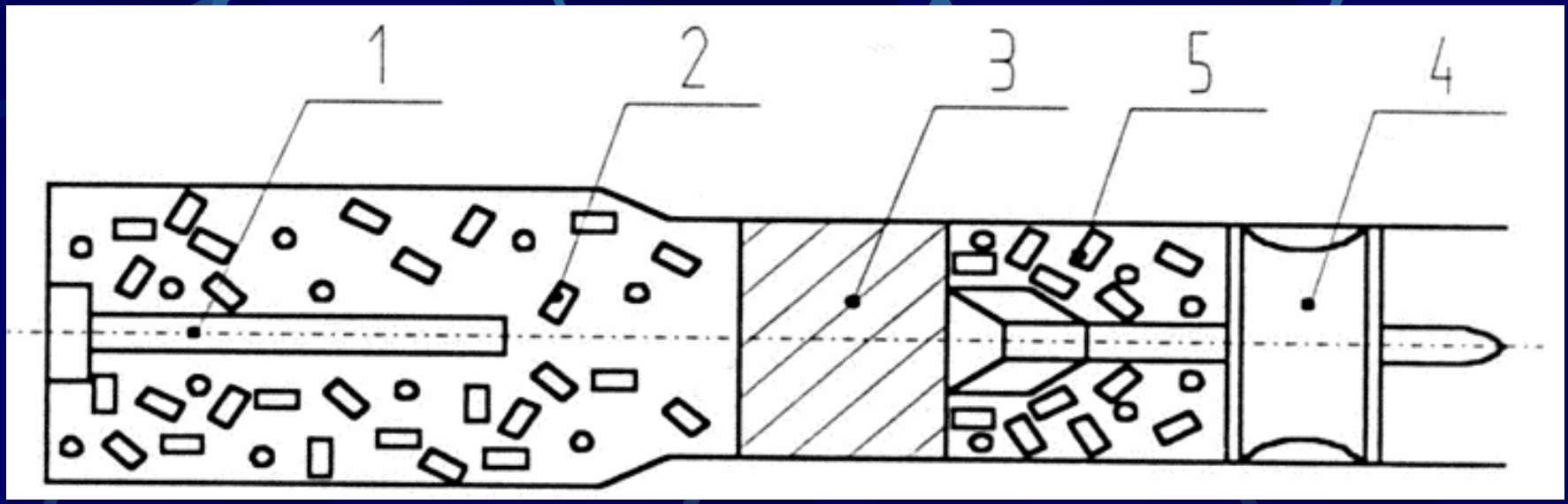
- The requirements for increasing muzzle kinetic energy and muzzle velocity
- Many new launch principles : electrothermal launcher, electromagnetic launcher, regenerative liquid propellant gun, ram accelerator, explosively-driven launcher, and travelling charge gun, and so on
- Serial double chamber gun

INTRODUCTION

Advantages:

- The peak pressure in the main chamber and the subsidiary chamber are lower
- The subsidiary chamber plays an important role in pressure plateau
- When the caliber is enlarged, the breech structure does not need to be changed, only the charge chamber is extended.

LAUNCH MECHANISM



1.center-core igniter 2.main chamber 3.piston
4.projectile and sabot 5.subsidiary chamber
Figure 1. Schematic diagram of serial chamber gun

LAUNCH MECHANISM

Key Problems:

- Propellant web thickness in the subsidiary chamber must be thinner than that of the main chamber.
- Reliable ignition of the subsidiary propellants by a device in the piston
- Ignition and flame-spreading of the propellant in the subsidiary chamber should be very fast and strong

LAUNCH MECHANISM

- Prevent the propellant gases in the main chamber from leaking into the subsidiary chamber, resulting in premature ignition of the propellant in the subsidiary chamber
- The projectile and piston must remain together until sufficient pressure is developed in the subsidiary chamber to promote burning of the propellant.
- How to design the piston, the subsidiary chamber and the projectile is also a key problem

LAUNCH MECHANISM

The whole firing process is divided into three stages.

(1) The main chamber is same as that of common solid propellant gun. When the chamber pressure is larger than the starting pressure, the piston, subsidiary propellant beds and projectile move forward.

(2) The subsidiary propellant beds are ignited by the ignition equipment in the piston. At this moment, the piston, subsidiary propellant beds and projectile move forward together.

(3) When the subsidiary chamber pressure reaches a certain value, the projectile and sabot are separated from the piston and driven forward.

LUMPED PARAMETER MODEL

Stage One

The mathematical model of the main chamber:

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

$$sp_1=\varphi\ (m_H+m_D+\omega_2)\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$l_{10}=W_{10}/s$$

$$l_{1\psi}=l_{10}[1-\frac{\Delta_1}{\delta}-(\alpha-\frac{1}{\delta})\Delta_1\psi_1]$$

LUMPED PARAMETER MODEL

Because the propellant in the subsidiary chamber has not burnt, the piston, subsidiary chamber and projectile move forward together

$$v_D = v_H$$

where v_D and vH is the projectile and the piston velocity.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

Stage Two

In this stage, the mathematical model of the main chamber is same as that of stage One.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

$$sp_1=\varphi\ (m_H+m_D+\omega_2)\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta} = \frac{f\omega_1\psi_1}{\theta} - \frac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

In stage two, the propellant of the subsidiary chamber is ignited and burns at isovolumetric state.

$$v_D = v_H$$

$$sp_2 l_{20} = \frac{f\omega_2\psi_2}{\theta}$$

LUMPED PARAMETER MODEL

Stage Three

In stage three, the projectile is separated from the piston and each part continues to move forward but at different velocities. The fundamental equations of the main chamber are as following.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi\, m_H v_H^2-\int sp\mathrm{d}l-W$$

$$s(p_1-p_2)=\varphi\, m_H\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

The conservation equations of the subsidiary chamber are as following.

$$\frac{sp_2(l_{20}+l_{2\psi})}{\theta}=\frac{f\omega_2\psi_2}{\theta}-\tfrac{1}{2}\varphi\, m_D v_D^2+\int sp\mathrm{d}l+W$$

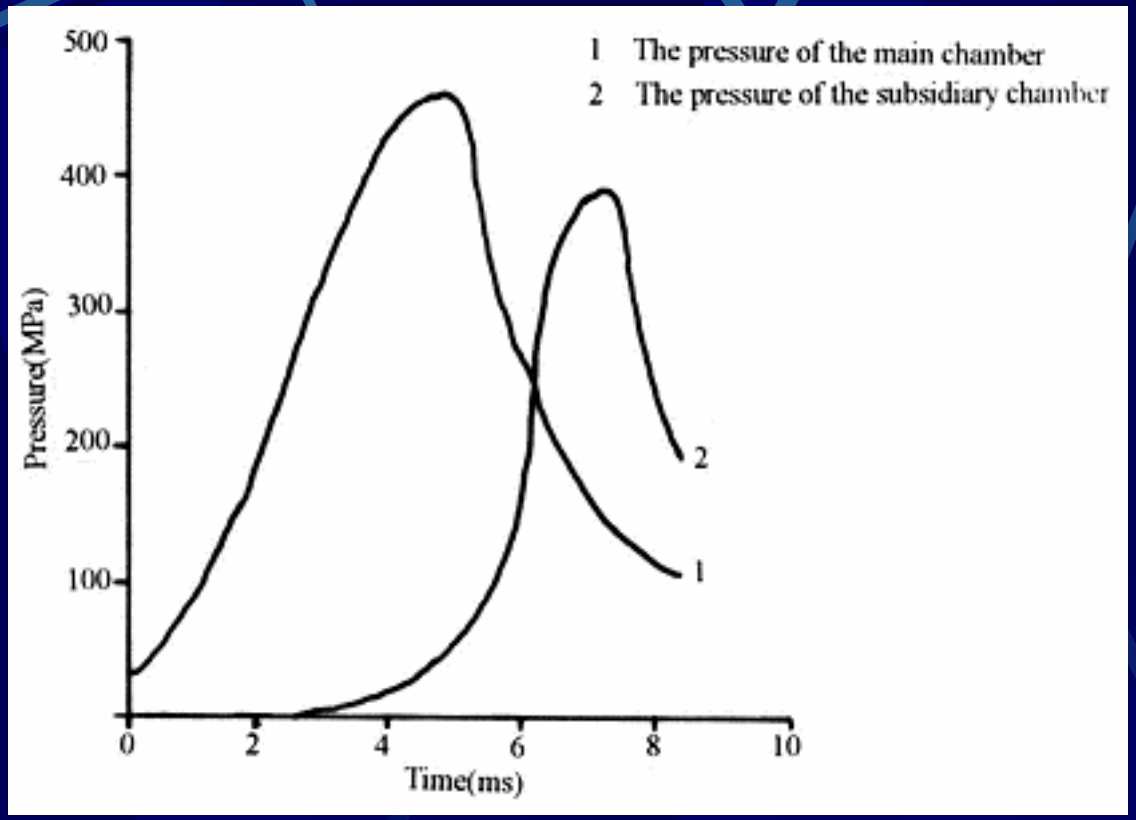
$$sp_2=\varphi\, m_D\frac{\mathrm{d}v_D}{\mathrm{d}t}$$

LUMPED PARAMETER MODEL

TABLE I CALCULATION INPUT DATA

ballistic chamber volume(m^3)	0.0235
loading weight of the main chamber(kg)	10.9
loading weight of the subsidiary chamber(kg)	4.88
projectile weight(kg)	11.12
projectile travel(m)	6.0
ignition delay of subsidiary chamber(ms)	1.5
specific heat ratio	1.23
propellant force(J/kg)	1050000
piston weight(kg)	12.5

LUMPED PARAMETER MODEL



dm³

Figure The pressure curves of main and subsidiary chamber

LUMPED PARAMETER MODEL

dm^3

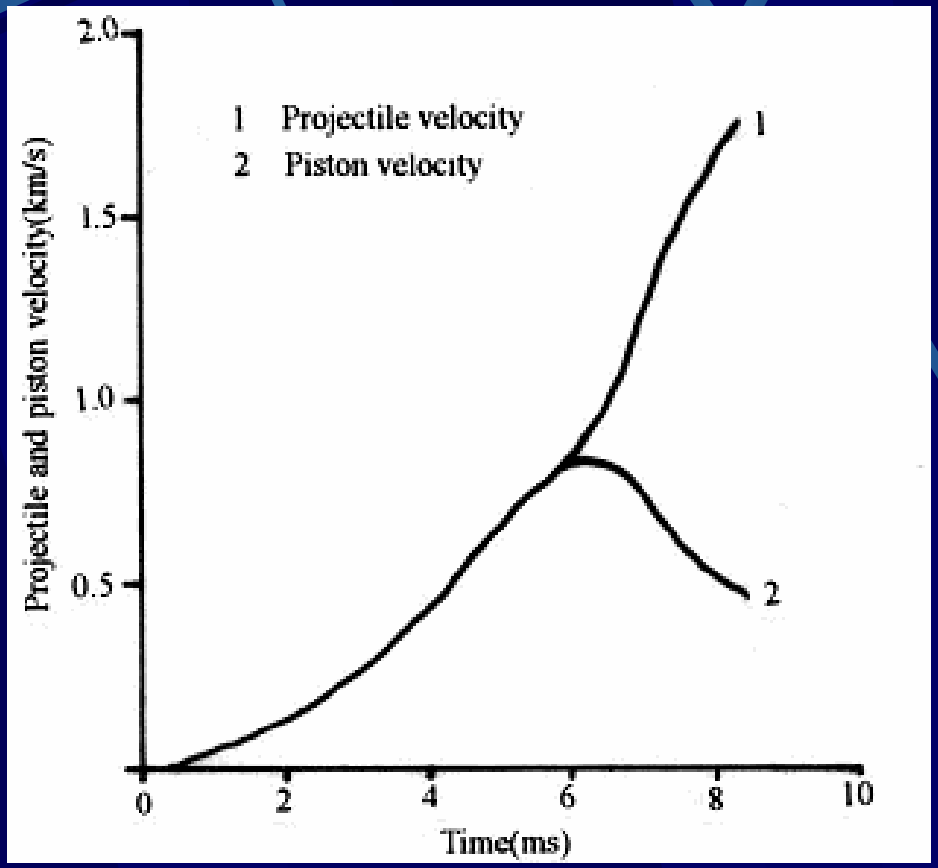


Figure The velocity curves of projectile and piston

TWO PHASE FLOW MODEL

A two phase flow model of the main chamber is also established.

$$\frac{\partial(\varphi_z \hat{\rho}_{gz} A_z)}{\partial t} + \frac{\partial(\varphi_z \hat{\rho}_{gz} u_{gz} A_z)}{\partial x} = \dot{m}_{cz} A_z + \dot{m}_{ignz} A_z$$

$$\frac{\partial(\varphi_z \hat{\rho}_{gz} u_{gz} A_z)}{\partial t} + \frac{\partial(\varphi_z \hat{\rho}_{zg} u_{gz}^{\ 2} A_z)}{\partial x} + (A_z \varphi_z)\frac{\partial p_z}{\partial x} = -f_{sz} A_z + \dot{m}_{cz} u_{pz} A_z + \dot{m}_{ignz} u_{ignz} A_z$$

$$\frac{\partial[\varphi_z \hat{\rho}_{zg} A_z (e_{gz} + \frac{u_{gz}^{\ 2}}{2})]}{\partial t} + \frac{\partial[\varphi_z \hat{\rho}_{zg} u_{gz} A_z (e_{gz} + \frac{p_z}{\hat{\rho}_{zg}} + \frac{u_{gz}^{\ 2}}{2})]}{\partial x} + p_z \frac{\partial(A_z \varphi_z)}{\partial t} = -Q_{pz} A_z - f_{sz} u_{pz} A_z + \dot{m}_{cz} A_z (E_{pz} + p_z / \hat{\rho}_{pz} + \frac{u_{pz}^{\ 2}}{2}) + \dot{m}_{ignz} H_{ignz} A_z$$

$$\frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} A_z]}{\partial t} + \frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz} A_z]}{\partial x} = -A_z \dot{m}_{cz}$$

$$\frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz} A_z]}{\partial t} + \frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz}^{\ 2} A_z]}{\partial x} + A_z(1-\varphi_z)\frac{\partial p_z}{\partial x} + \frac{\partial[(1-\varphi_z) R_z A_z]}{\partial x} = f_{sz} A_z - \dot{m}_{cz} u_{pz} A_z$$

TWO PHASE FLOW MODEL

A two phase flow model of the subsidiary chamber is established.

$$\frac{\partial(\varphi_f \hat{\rho}_{fg} A_f)}{\partial t} + \frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf} A_f)}{\partial x} = \dot{m}_{cf} A_f$$

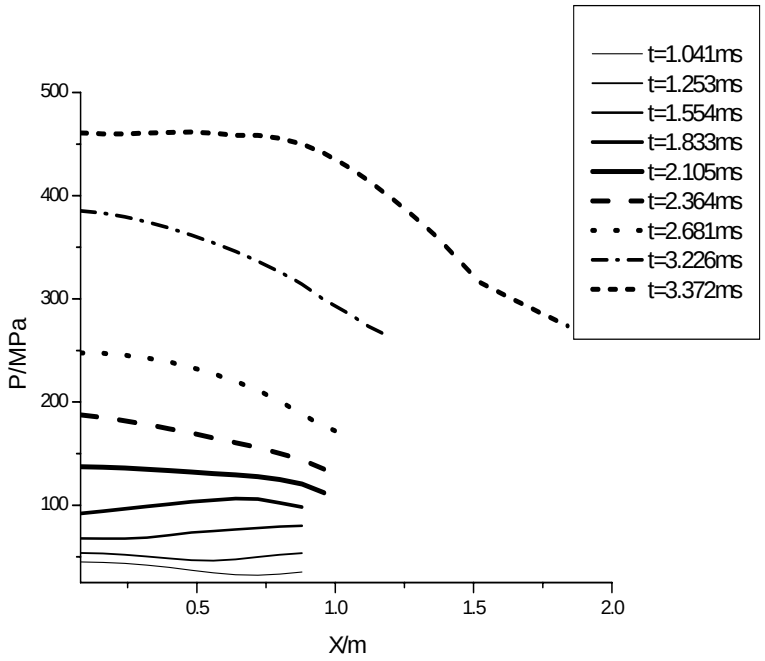
$$\frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf} A_f)}{\partial t} + \frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf}^{\ 2} A_f)}{\partial x} + (A_f \varphi_f)\frac{\partial p_f}{\partial x} = -f_{sf} A_f + \dot{m}_{cf} u_{pf} A_f$$

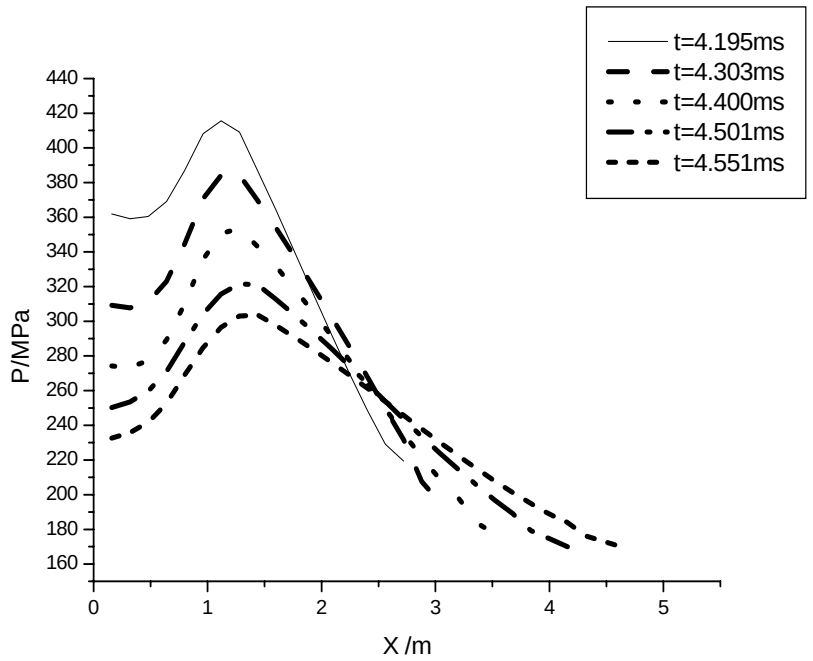
$$\frac{\partial[\varphi_f \hat{\rho}_{fg} A_f (e_{gf} + \frac{u_{gf}^{\ 2}}{2})]}{\partial t} + \frac{\partial[\varphi_f \hat{\rho}_{fg} u_{gf} A_f (e_{gf} + \frac{p_f}{\hat{\rho}_{fg}} + \frac{u_{gf}^{\ 2}}{2})]}{\partial x} + p_f \frac{\partial(A_f \varphi_f)}{\partial t} = -Q_{pf} A_f - f_{sf} u_{pf} A_f + \dot{m}_{cf} A_f (E_{pf} + p_f / \hat{\rho}_{pf} + \frac{u_{pf}^{\ 2}}{2})$$

$$\frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} A_f]}{\partial t} + \frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf} A_f]}{\partial x} = -A_f \dot{m}_{cf}$$

$$\frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf} A_f]}{\partial t} + \frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf}^{\ 2} A_f]}{\partial x} + A_f(1-\varphi_f)\frac{\partial p_f}{\partial x} + \frac{\partial[(1-\varphi_f)R_f A_f]}{\partial x} = f_{sf} A_f - \dot{m}_{cf} u_{pf} A_f$$

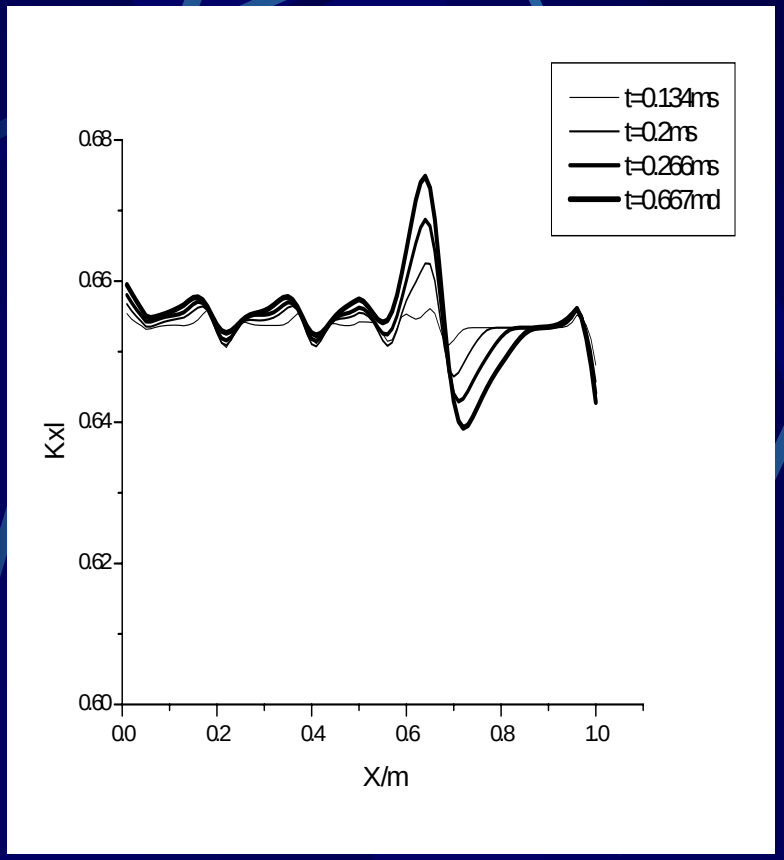
TWO PHASE FLOW MODEL

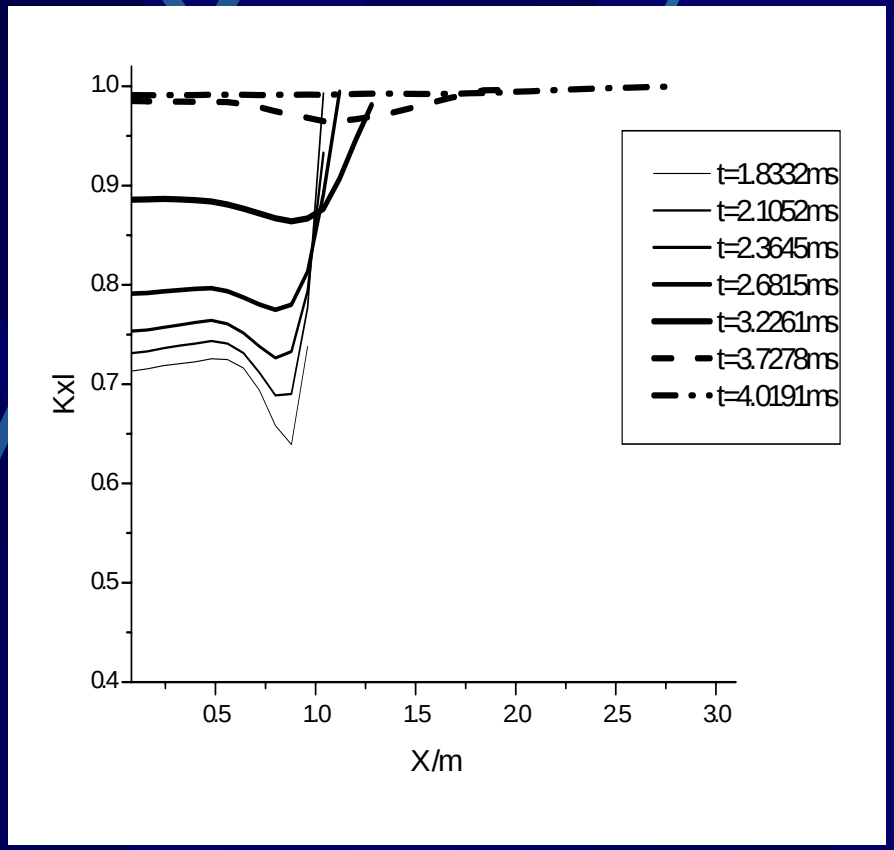




The pressure distribution of the main chamber.

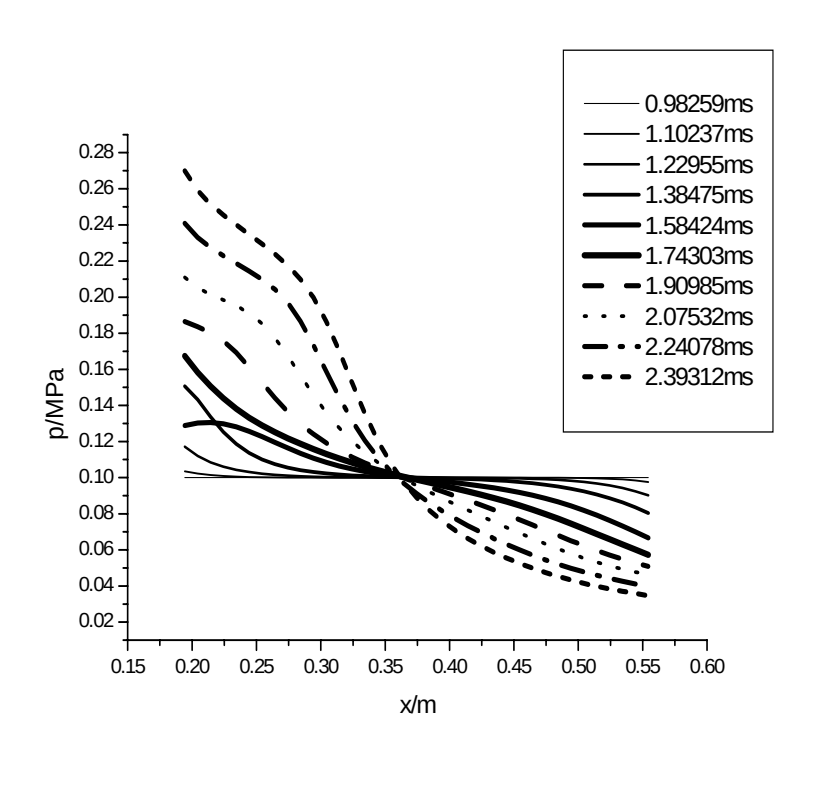
TWO PHASE FLOW MODEL

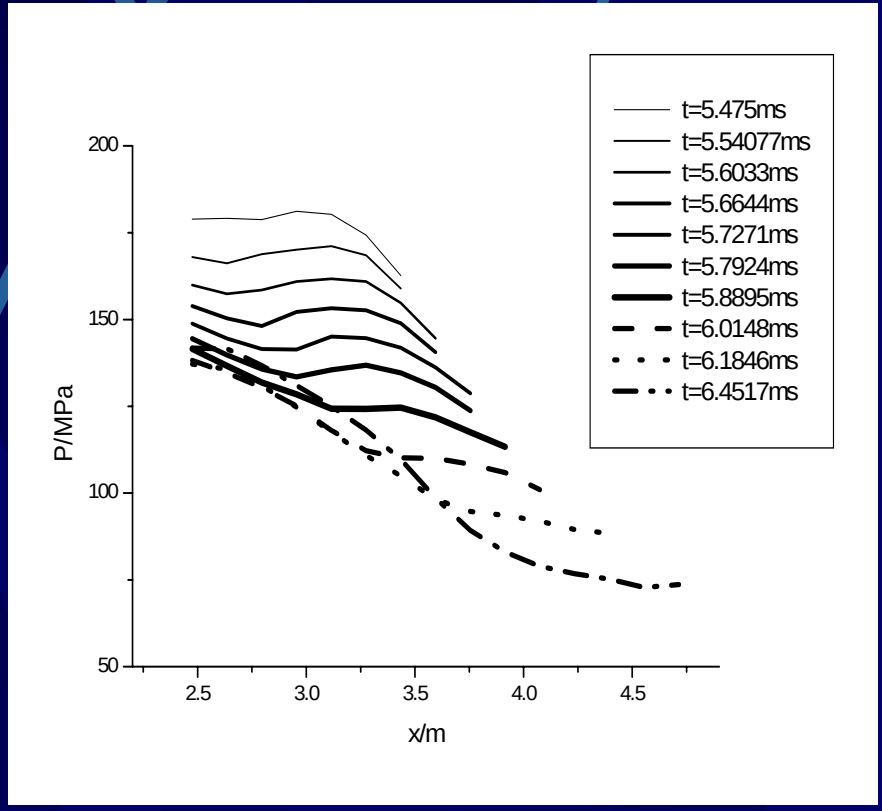




The porosity distribution of the main chamber.

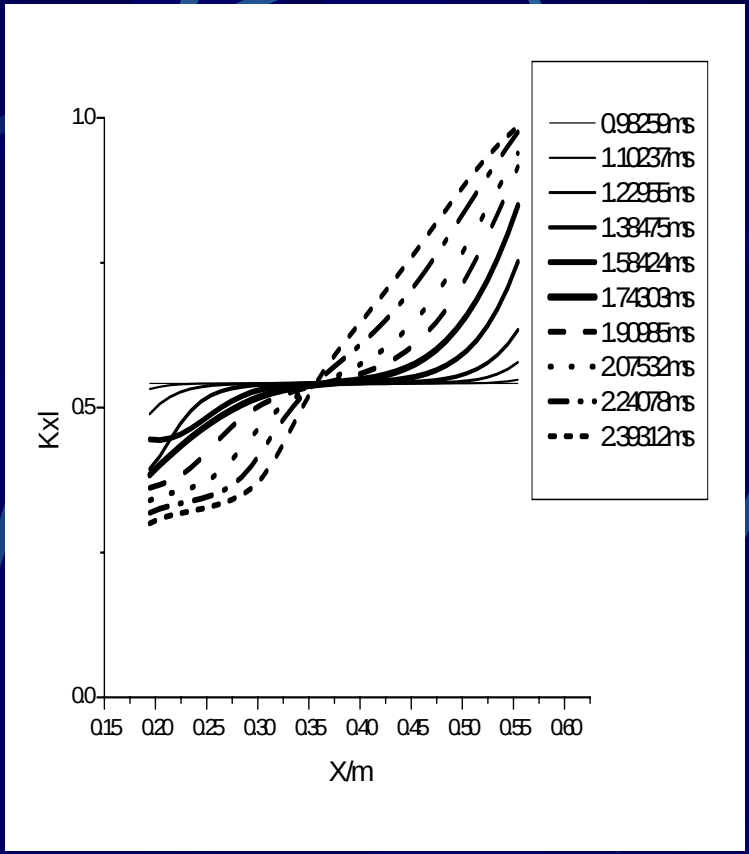
TWO PHASE FLOW MODEL

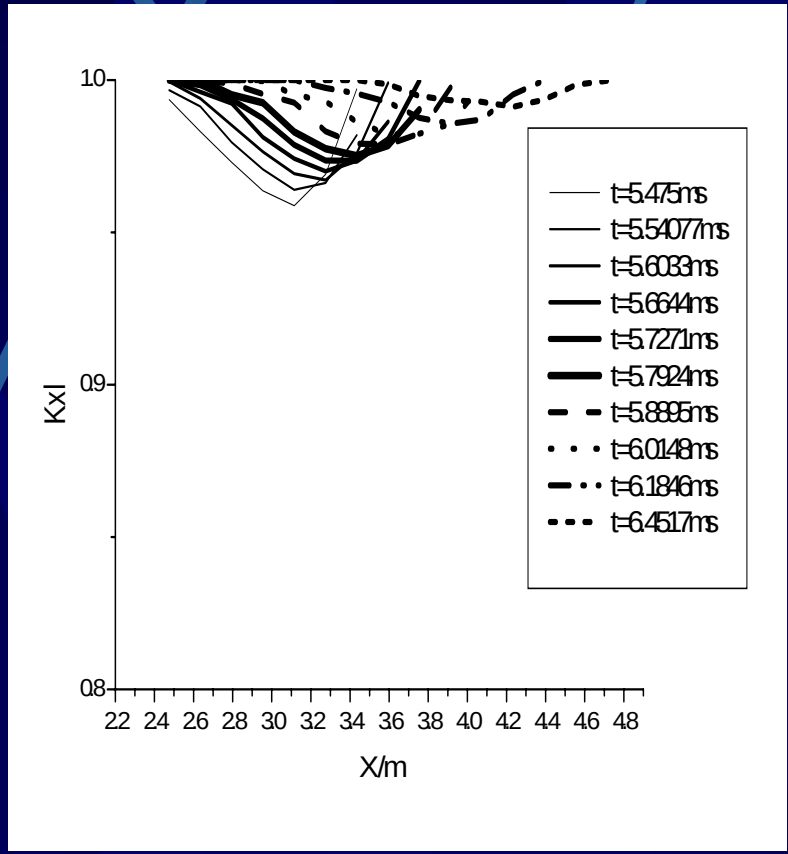




The pressure distribution of the subsidiary chamber.

TWO PHASE FLOW MODEL

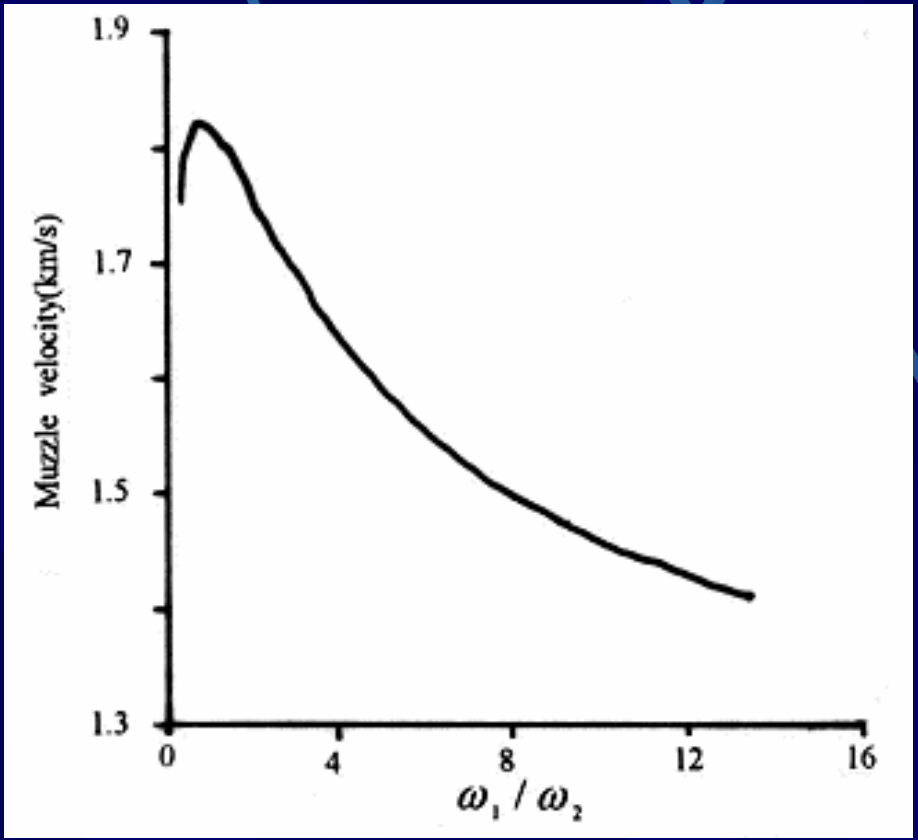




The porosity distribution of the subsidiary chamber.

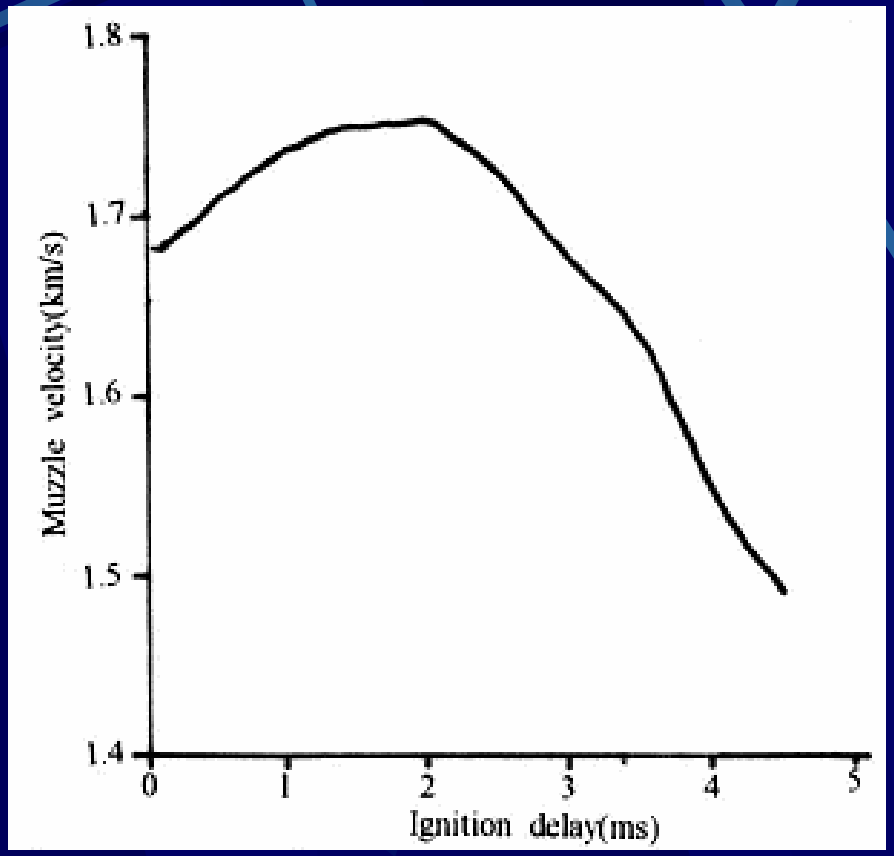
ANALYSIS OF CALCULATION RESULTS

dm^3



Effects of Loading Weight Ratio of Two Charge Chambers on Muzzle Velocity

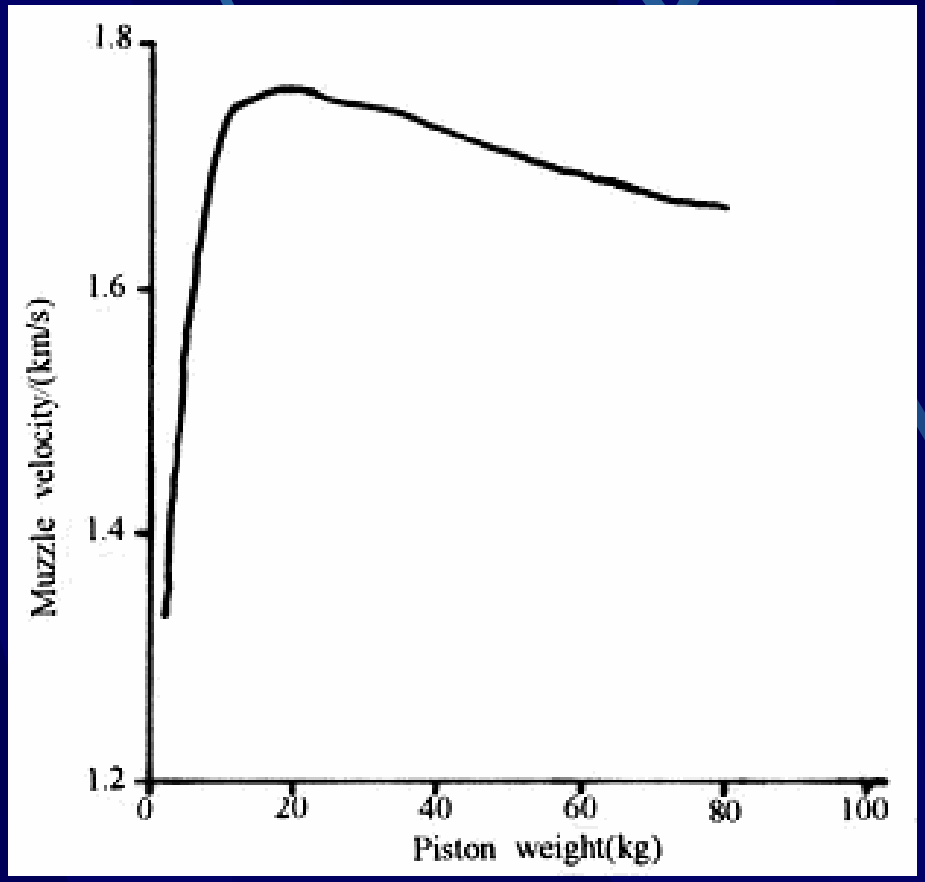
ANALYSIS OF CALCULATION RESULTS



The effects of ignition delay on muzzle velocity

ANALYSIS OF CALCULATION RESULTS

dm^3



The effects of piston weight on muzzle velocity

CONCLUSIONS

- The mechanism of serial double chamber is presented and some key problems are discussed.
- By theoretical analysis, it can be found that the loading weight ratio, the piston weight, the ignition delay and the propellant web thickness are main factors influencing the ballistic performance of the serial chamber gun.
- Only when these factors are reasonably matched, can the optimum performances be obtained.