A VALIDATED METHODOLOGY TO PREDICT REACTION OF COMPLEX WARHEAD TO FRAGMENT IMPACTS

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Agenda

Impact of the current geopolitical context

Importance of IM and availability

- Vulnerability of munitions to attacks, accidents or fire events is known since several years and is taken into account in warheads development as a design driver
- The war in Ukraine has underscored the devastating consequences of accidental explosions
- The development of IM remain essential priorities for defence agencies worldwide as they strive to address the challenges of modern warfare while safeguarding the well-being of both military personnel and civilian populations
- The current geopolitical context has also highlighted the need for the defence industry to be able to develop and deliver efficient weapons very rapidly

14 April 2022, Moskva, Black Sea (from MSIAC)

9 August 2022, Saki Air Base, Crimea (from MSIAC)

Introduction

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COMPLEX WARHEADS

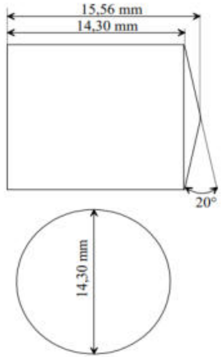
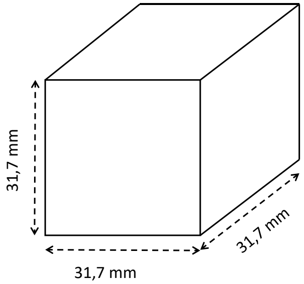
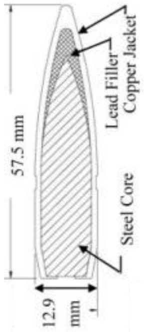
CENTRE D'EXCELLENCE

- MBDA France and the Centre of Excellence for Complex Warheads, as Design Authority, has to design new warheads taking into account these priorities driven by the current context:
  - Need of maintaining safety while enhancing performances
  - Reducing at the same time development delays and costs

- MBDA France with the support of EURENCO and ArianeGroup, has integrated an innovative methodology to predict as early as possible reaction of warheads to fragment impacts
- The methodology is based on the use of well-defined Ignition and Growth model for the explosive loading
- This way allows us to optimize design and avoid specific tests in future developments

Fragments description

- Three mechanical solicitations considered for our study:

Fragment type	Light	Heavy	Bullet
Material	Steel	Steel	Steel, lead, copper
Mass	18.6 g	250 g	42.5 g
Velocity	1830 m/s	1650 m/s	850 m/s
Shape			

First step: model construction

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Ignition and Growth model

- Objective: to build the reactive model for the explosive
- Use of model proposed by Taver et al. in its 1985 version
- Three equations: one EOS for unreacted phase, one EOS for the reacted phase and kinetics law

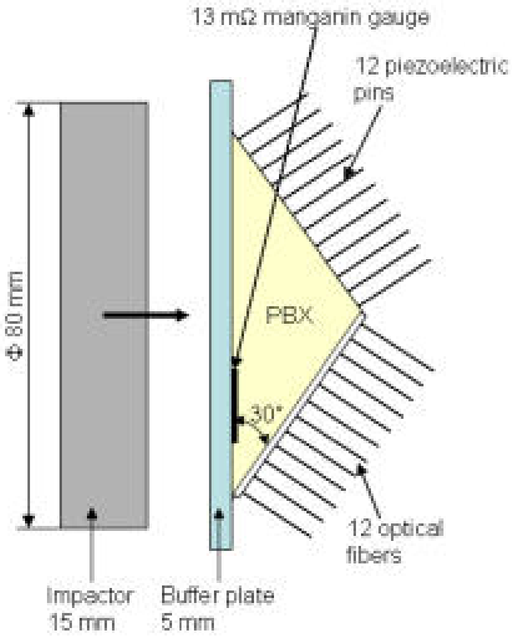
Kinetics law	$\frac{d\lambda}{dt} = I(1-\lambda)^b\left(\frac{v_0}{v} - 1 - a\right)^x + G_1(1-\lambda)^c\lambda^d P^y + G_2(1-\lambda)^e\lambda^g P^z$
JWL EOS for unreacted phase	$P(\mu,T) = A^r.e^{-\frac{R_1^r}{1+\mu}} + B^r.e^{-\frac{R_2^r}{1+\mu}} + R_3^r.\frac{T}{1+\mu}$
JWL EOS for reacted phase	$P(\mu,T) = A^p.e^{-\frac{R_1^p}{1+\mu}} + B^p.e^{-\frac{R_2^p}{1+\mu}} + R_3^p.\frac{T}{1+\mu}$

- 12+5+5=22 parameters to identify for each explosive

Parameters identification (1/2)

- EOS of unreacted phase is based on data Hugoniot curves ($U = C_0 + Su$)
- EOS of reacted phase is based on either thermochemical codes or experimental data given by the cylinder test

- Parameters of the kinetics law are identified thanks to a macroscopic approach of SDT
  - Use of ”Wedge test” giving the pop-plot curve
  - Explosive machined into a wedge shape
  - Progression of shock wave is measured



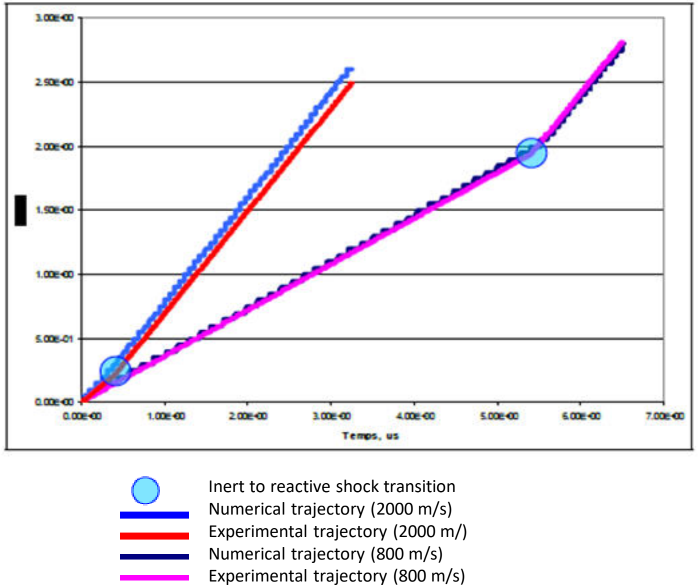
Wedge test illustration (from G. Baudin et al.)

Parameters identification (2/2)

- Flow diagram allows to determine the run distance to detonation = depth of the explosive from which the transmitted shock wave transits to a detonation)
- Run distance to detonation “X” can be linked to the solicitation “P”. A et B are specific coefficients for the tested explosive.

$$\log(X) = A + B \log(P)$$

- Several tests are carried out to build the flow diagram
- Numerical simulations of each test are performed until identification of the best set of parameters

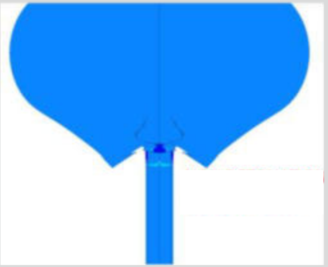
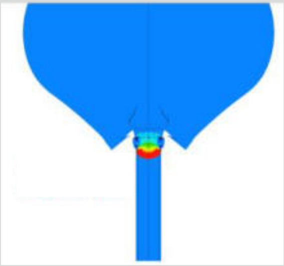


Flow diagram example (from ArianeGroup)

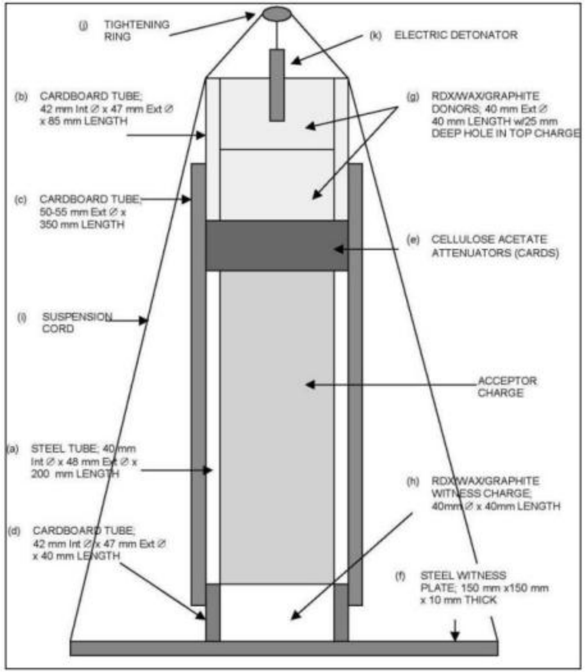
Second step: model validation

Intermediate Scale Gap-Test

- Simulation of ISGT with reactive model carried out in 2D-axisymmetric representation with 0.5 mm elements
- Several simulations have been performed to determine the “numerical” ignition threshold

	
165 cards	160 cards
No transition	Transition to detonation

- Experimental threshold = 175 cards → good agreement

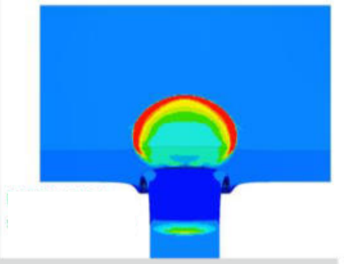


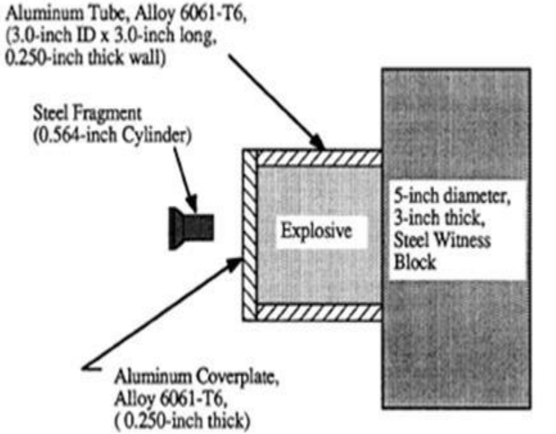
ISGT illustration
(from STANAG 4488)

Second step: model validation

Impact tests from the studies of Collignon et al.

- Experimental set-up:
  - Cylinder of explosive placed behind an aluminum barrier
  - Projectile is a steel cylinder
- Simulation of these tests with reactive model carried out in 2D-axisymmetric representation with 0.25 mm elements

	
1357 m/s	1417 m/s
No transition	Transition to detonation



Impact tests illustration (from Collignon et al.)

- Perfect agreement with the experimental threshold which showed no detonation @1357 m/s and detonation @1417 m/s

Third step: model application

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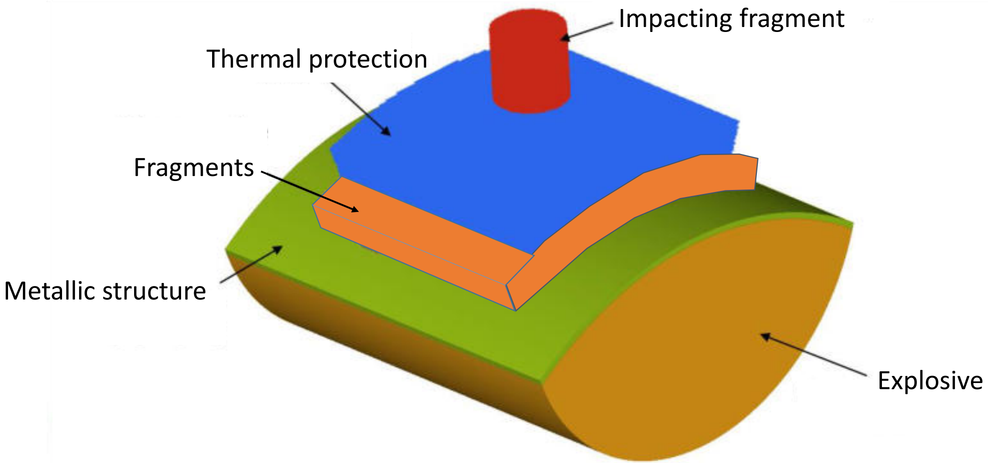
Warhead presentation

- Study on a simplified warhead with explosive filling, metallic structure, fragments and potentially thermal protection
- 3D model with 0.5 mm size elements to limit calculation times
- Impacting fragment and thermal protection are meshed in SPH (cubic model of 0.03 cm) with RADIOSS code
- Radial size of elements in the fragments is increased to 0.05 cm to ensure good interaction with SPH particles

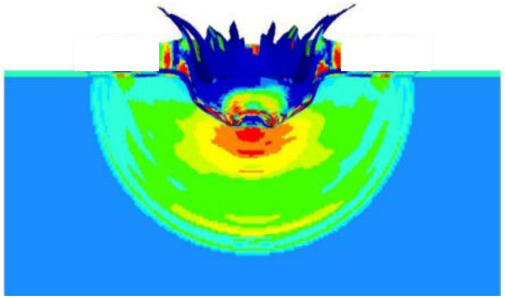


Third step: model application

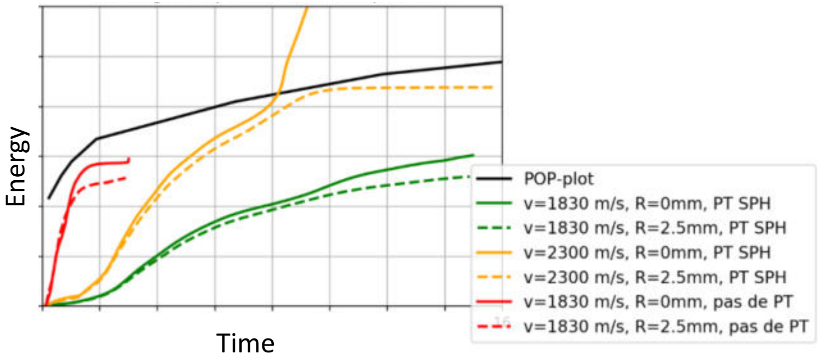
Light fragment impact

- Simulation of light fragment impact @1830 m/s
- <u>No transition to detonation has been observed</u>

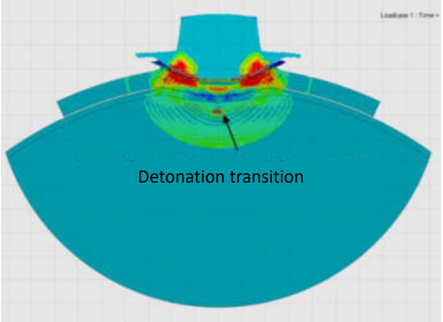
- Higher impact velocities have been simulated to identify numerical ignition threshold → transition to detonation is observed for impact velocities between 2000 and 2300 m/s



Pressure contours in the warhead @1830 m/s (thermal protection and fragments not represented)



Evolution of energy in the explosive vs. time for different cases in comparison with the initiation threshold given by the pop-plot curve

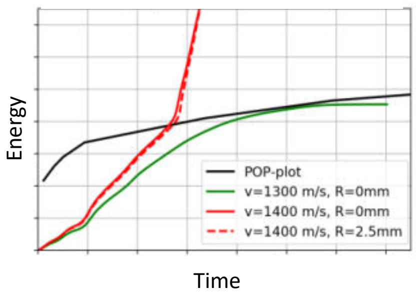


Pressure contours in the warhead @2300 m/s (thermal protection not represented)

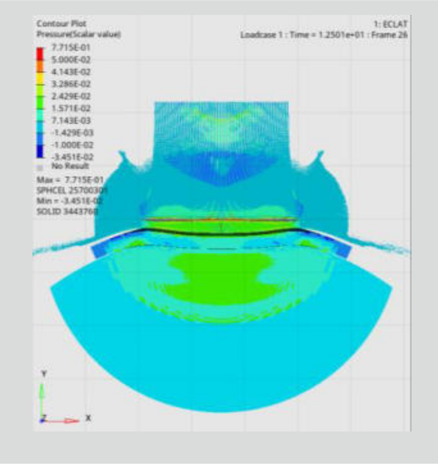
Heavy fragment impact

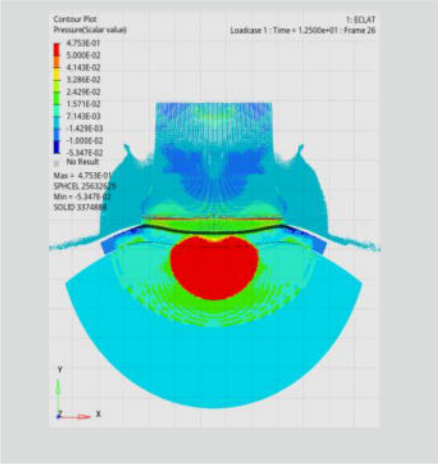
- Simulation of heavy fragment impact @1650 m/s
- **Transition to detonation has been observed**

- Lower impact velocities have been simulated to identify numerical ignition threshold → transition to detonation is observed for impact velocities between 1300 and 1400 m/s



Evolution of energy in the explosive vs. time for different cases in comparison with the initiation threshold given by the pop-plot curve



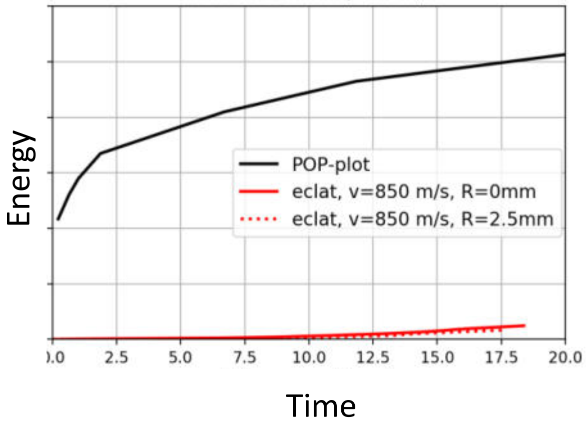


1300 m/s	1400 m/s
No transition	Transition to detonation

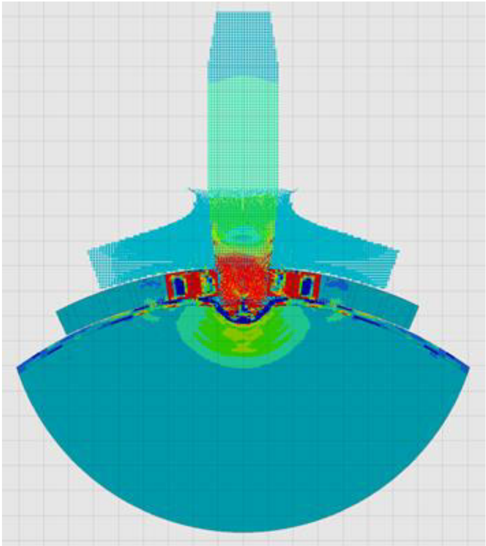
Third step: model application

Bullet impact

- Simulation of bullet impact @850 m/s
- Only SDT is determined
- No transition to detonation has been observed



Evolution of energy in the explosive vs. time for different cases in comparison with the initiation threshold given by the pop-plot curve



Pressure contours in the warhead @850 m/s

Conclusion & acknowledgments

Conclusion

- The methodology based on the use of a well-defined and validated reactive model for the explosive loading
- Application to complex warheads has been also verified thanks to a consistent comparison between numerical and experimental data
- MBDA France now considers this methodology validated and usable for future applications
- It is first necessary to determine the parameters of the reactive model for the considered explosive, to validate it on available and relevant data and to apply it to the definition of the warhead
- Considering the IM aspect from the beginning of development makes it possible to reduce development delays and costs by reducing the number of tests, and meet the needs driven by the current geopolitical context

MBDA

Acknowledgments

- MBDA France wants to acknowledge DGA for its support

DGA

DIRECTION GÉNÉRALE DE L'ARMEMENT

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