Theoretical Design for a Guided Supersonic Projectile

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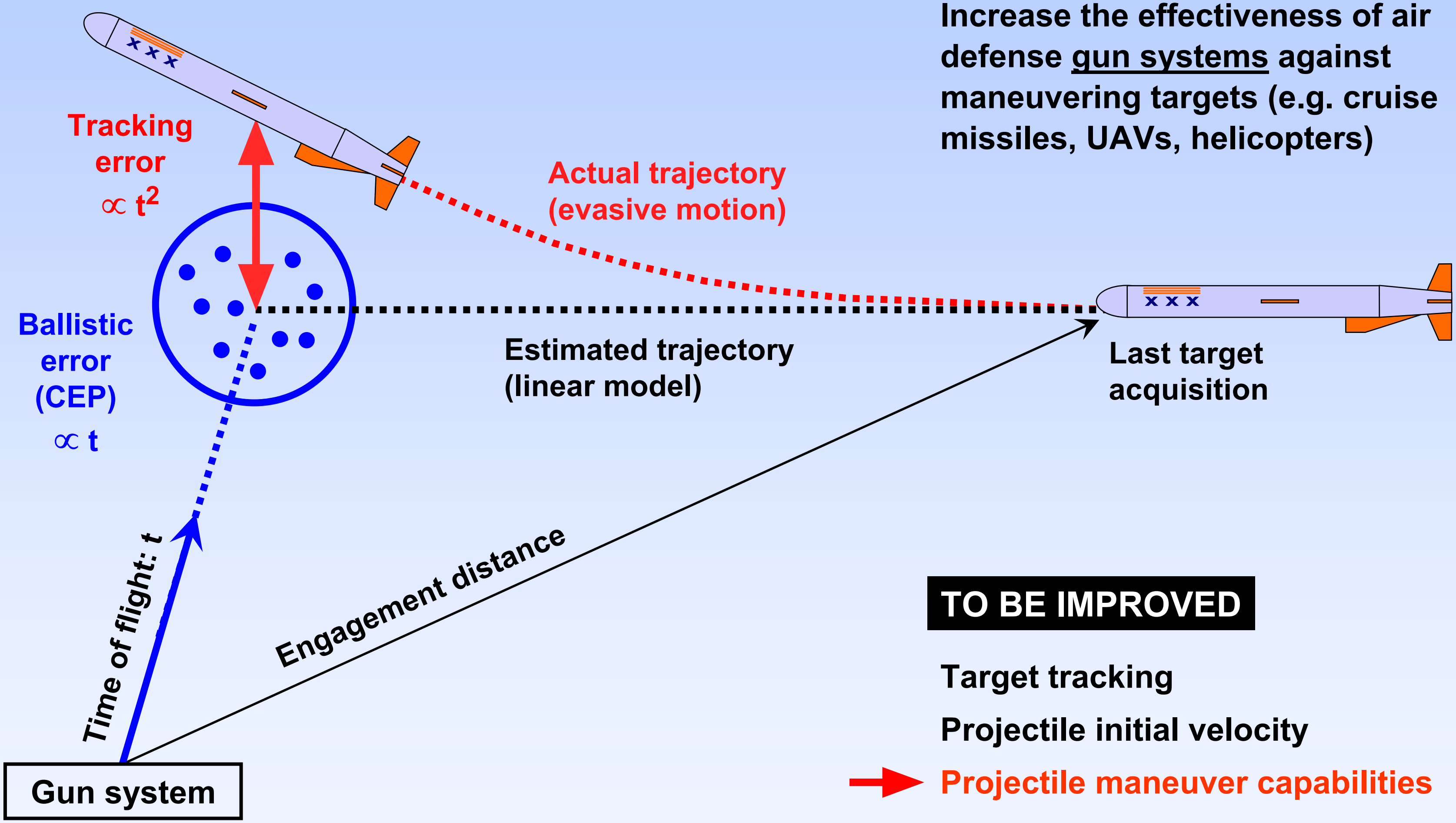
Context: Air Defense vs. Maneuvering Targets



GOAL

Increase the effectiveness of air defense <u>gun systems</u> against maneuvering targets (e.g. cruise missiles, UAVs, helicopters)

TO BE IMPROVED

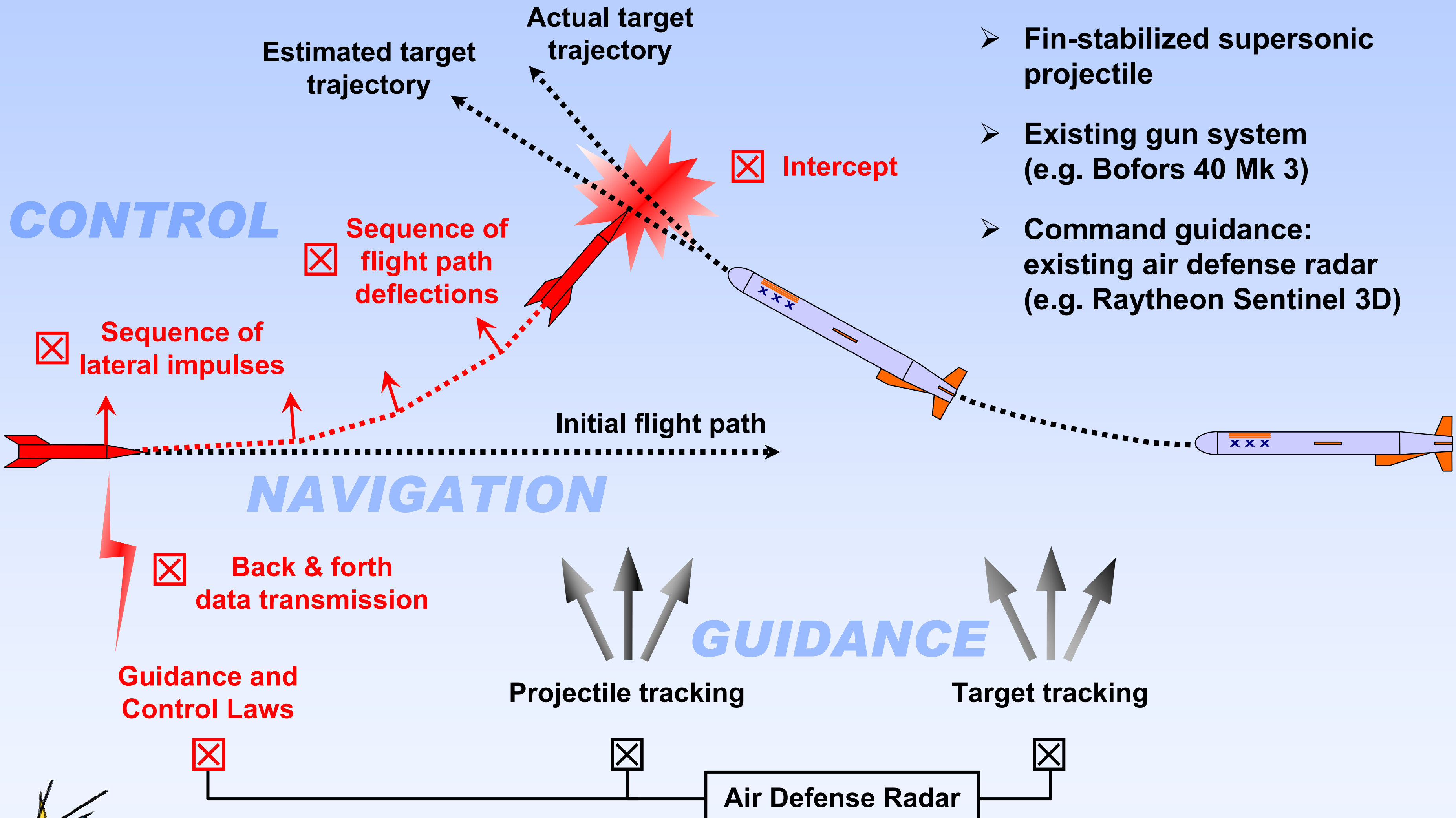
Target tracking

Projectile initial velocity

→ Projectile maneuver capabilities

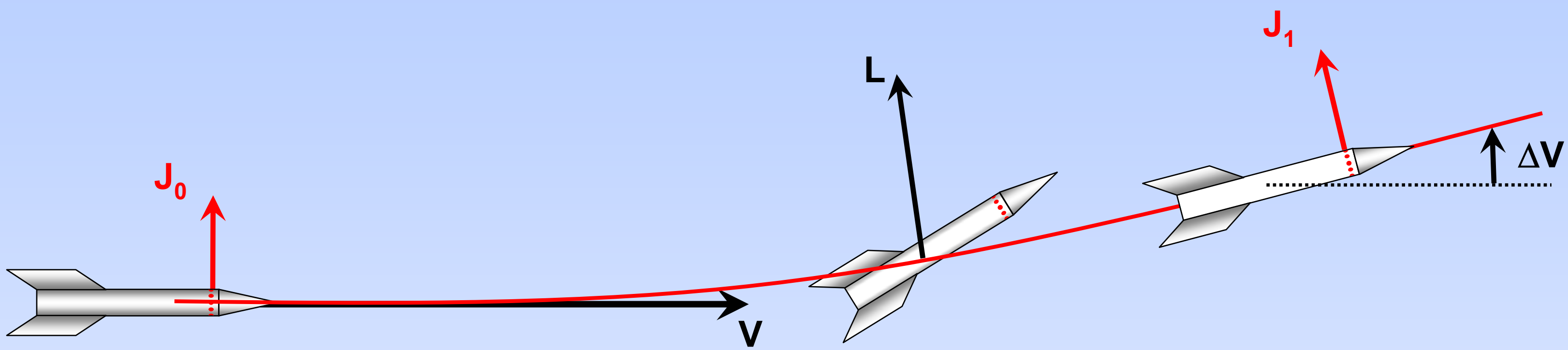
GSP: System Concept

- Very short range air defense (engagement distance < 5 km)
- Fin-stabilized supersonic projectile
- Existing gun system (e.g. Bofors 40 Mk 3)
- Command guidance: existing air defense radar (e.g. Raytheon Sentinel 3D)



Control Sequence

1. Singular impulse J_0 yields deviation speed and triggers the yaw motion
2. Deviation speed due to the action of the lift force L
3. Singular impulse J_1 yields deviation speed and stops the yaw motion



t_0 , s_0 → one cycle of the angular motion → $t_0 + T$, $s_0 + \Lambda$

HYPOTHESES

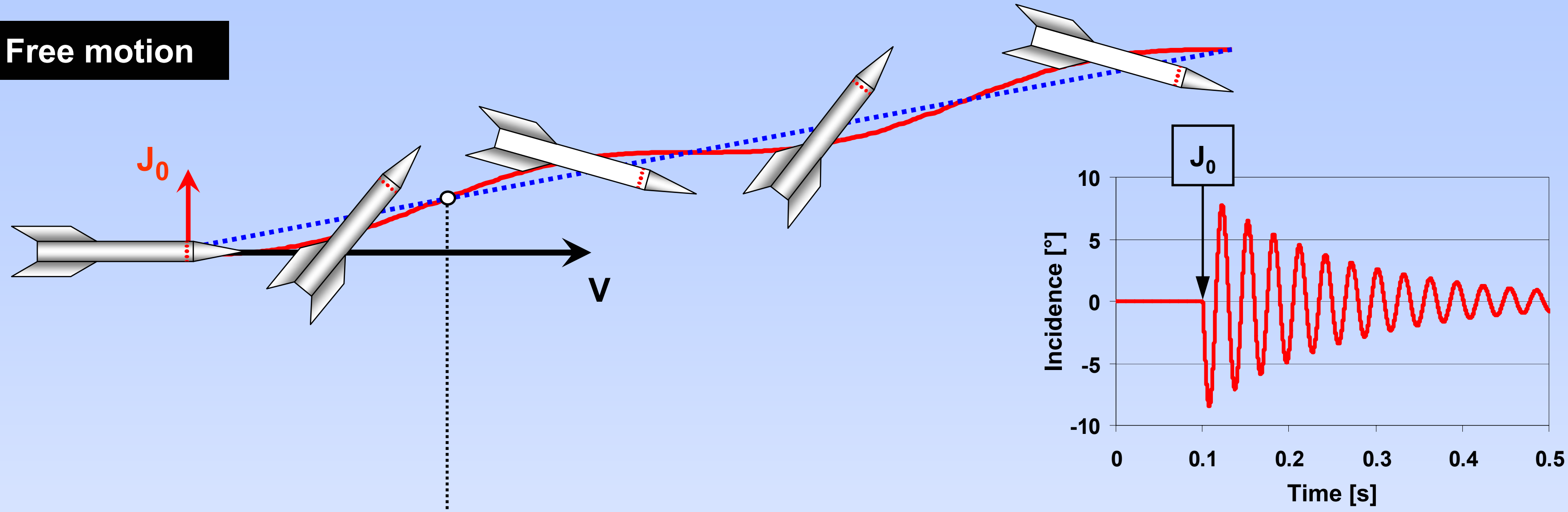
- Small deviation speed : $\Delta V << V$
- Lift force = prevalent force
- Overturning moment = prevalent moment
- Undamped angular motion
- Quasi-planar angular motion

→ **EQUATION OF THE DEVIATION SPEED**

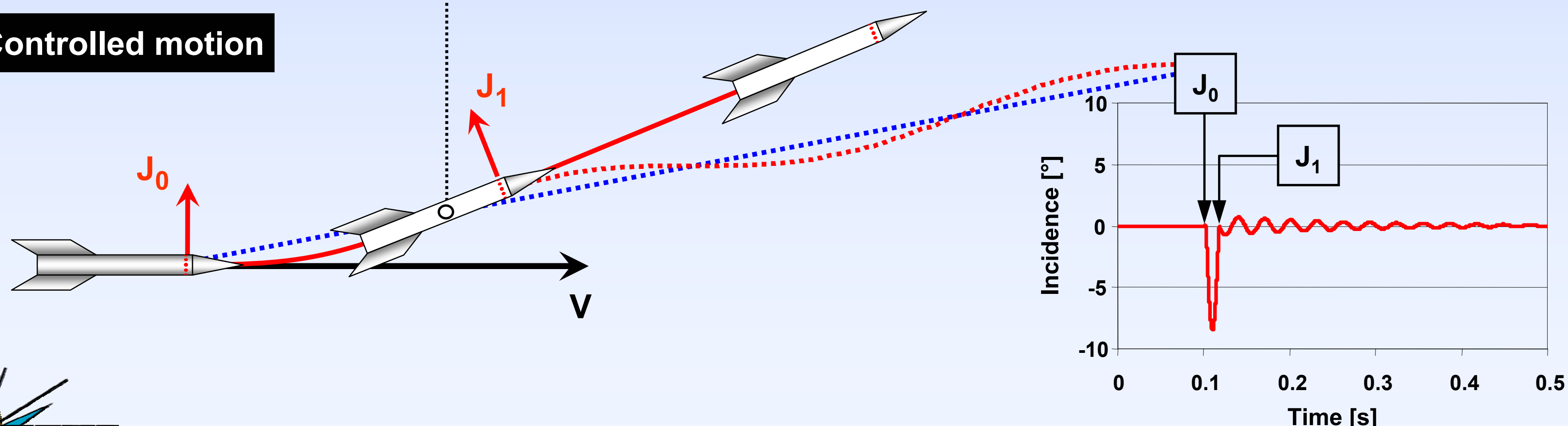
$$m\Delta V = 2J + \int_{t_0}^{t_0+T} L(t)\,dt = 2J + \int_{s_0}^{s_0+\Lambda} L(s)\frac{d}{V}ds$$

Control of the Yaw Motion

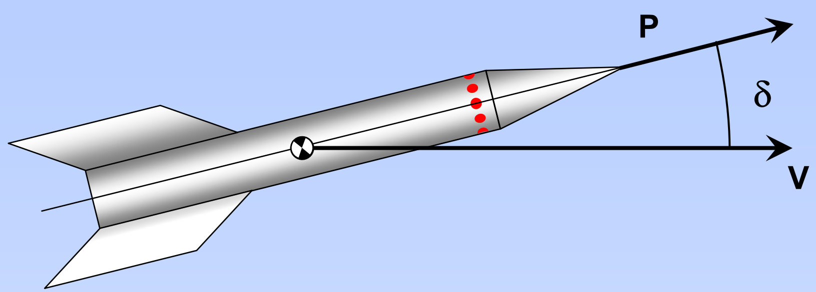
Free motion



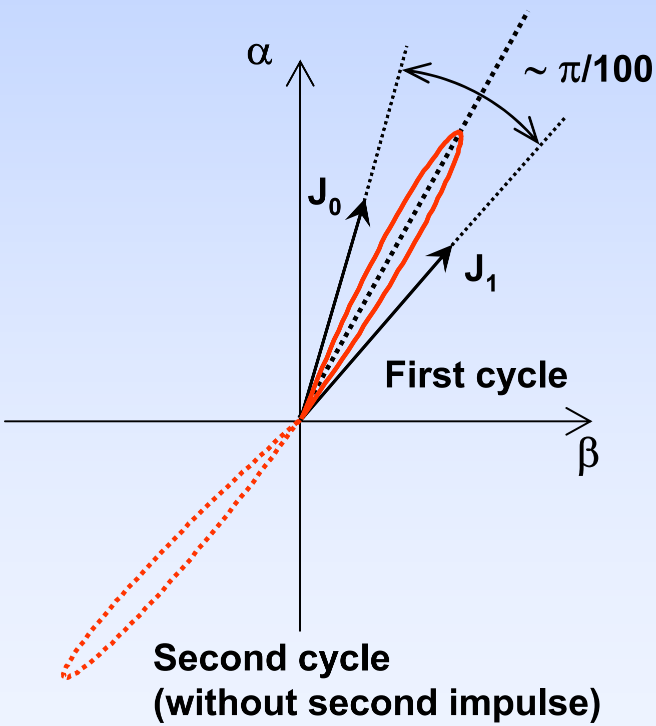
Controlled motion

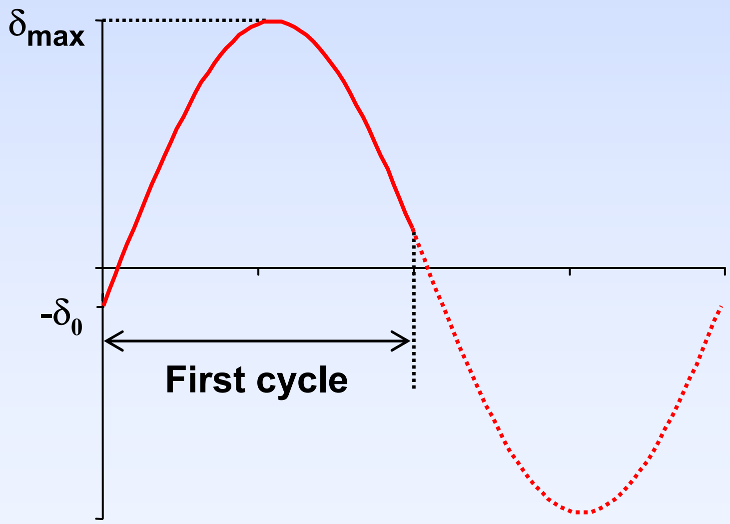


Linearized Yaw Motion

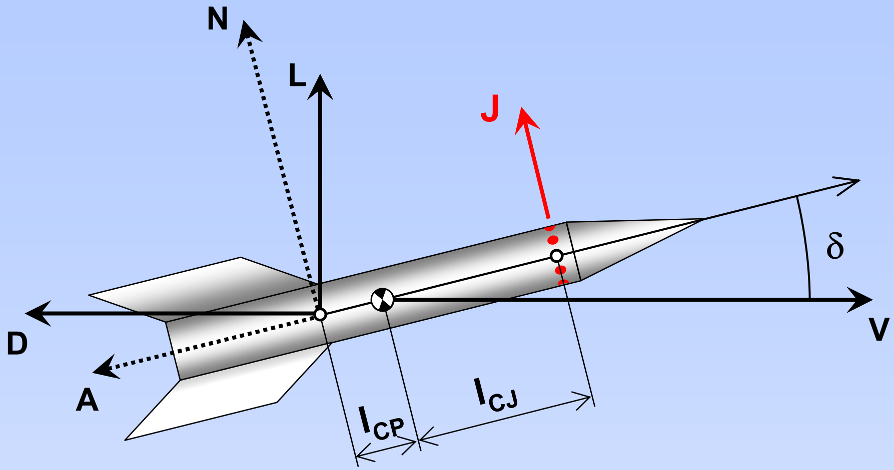


Roll rate: one half revolution during one cycle of the angular motion





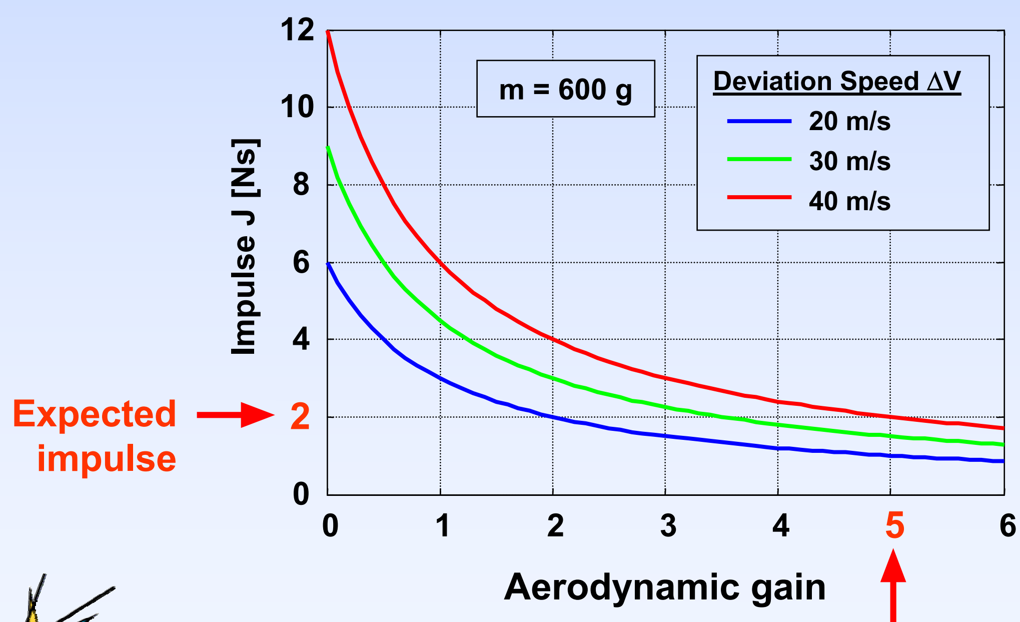
Control Law



$$\Delta V = 2\,\frac{J}{m}\left(1 + l_{CJ}\,\frac{CL_\alpha}{|CM_\alpha|}\right)$$

$$= 2\,\frac{J}{m}\left(1 + \frac{l_{CJ}}{l_{CP}}\left(1 - \frac{CX_0}{CN_\alpha}\right)\right)$$

$$l_{CJ}\,\frac{CL_\alpha}{|CM_\alpha|} = \text{Aerodynamic gain}$$



OPTIMIZATION

- ↘ CX / CN_α
- ↘ l_{CP}
- ↘ m
- ↗ l_{CJ}
- ↗ J

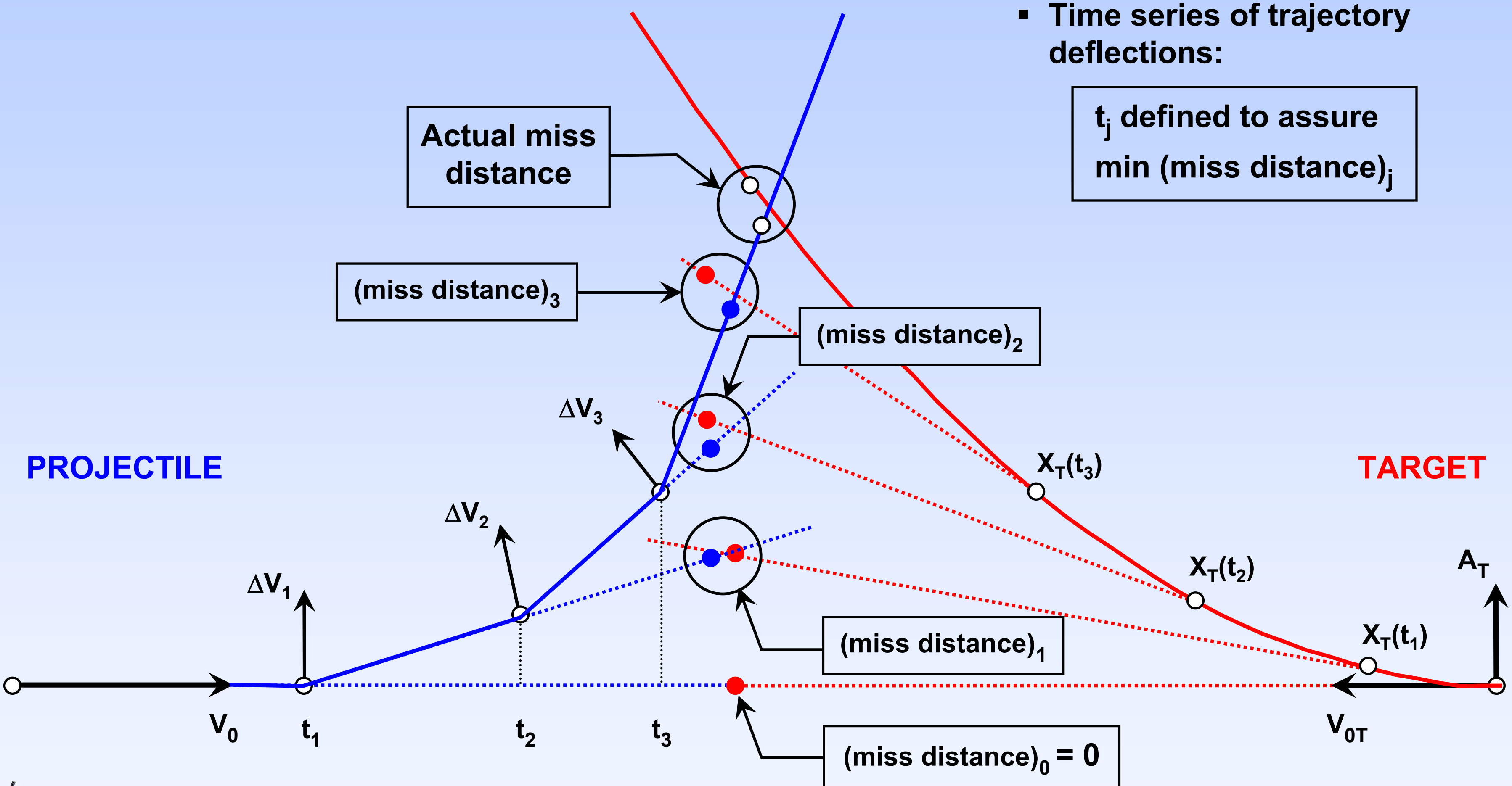
CONSTRAINTS

- Stability
- Maximum yaw angle

Guidance Scheme

- Estimated target positions updated using linear model
- Time series of trajectory deflections:

t_j defined to assure min (miss distance)$_j$



Guidance Performance

Projectile

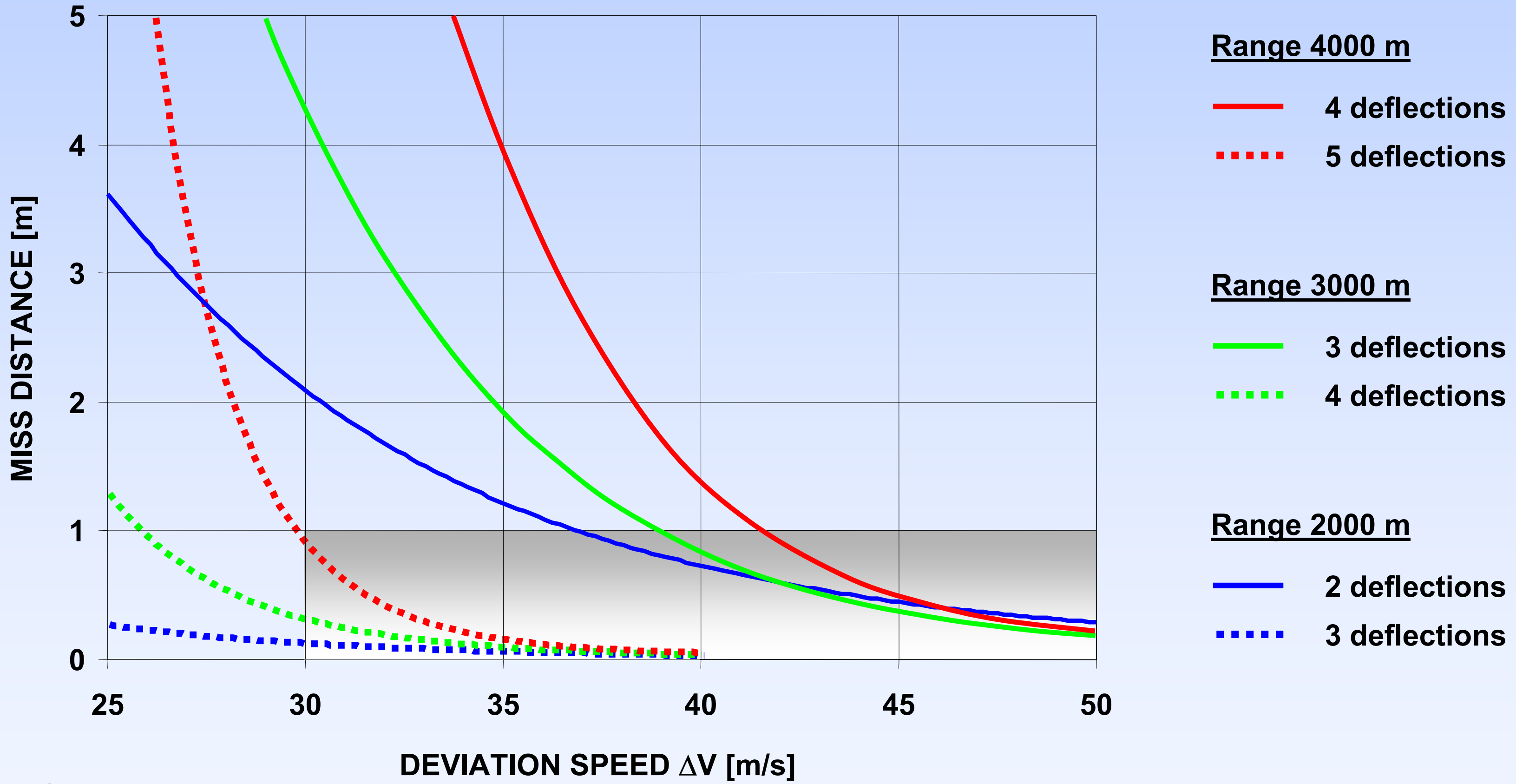
D = 30 mm V_0 = 1100 m/s

m = 600 g CX_0 = 0.25

Target

V_0 = 300 m/s

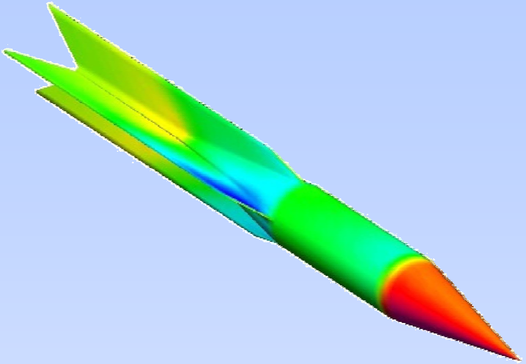
A_T = 30 m/s^2

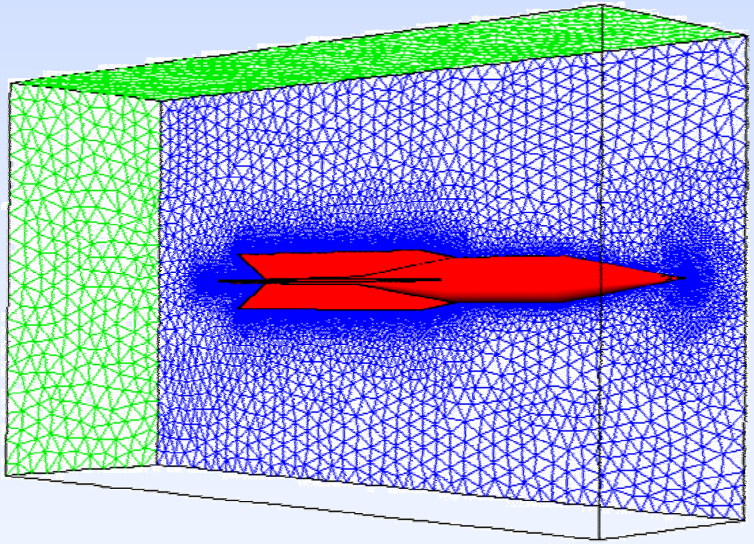


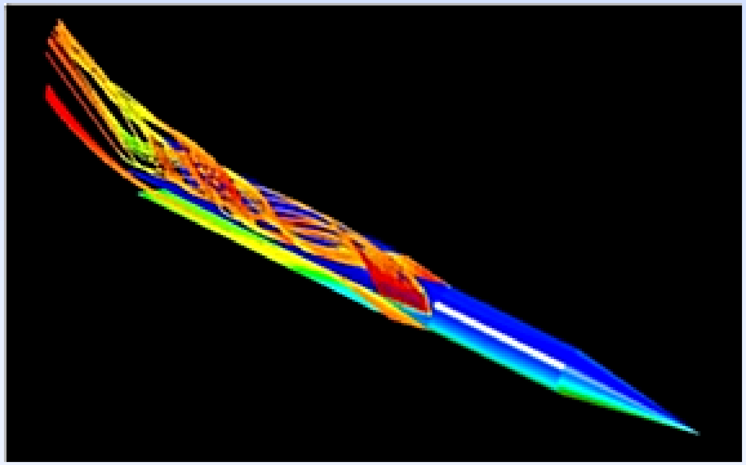
Aerodynamic Optimization (CFD)

GOALS

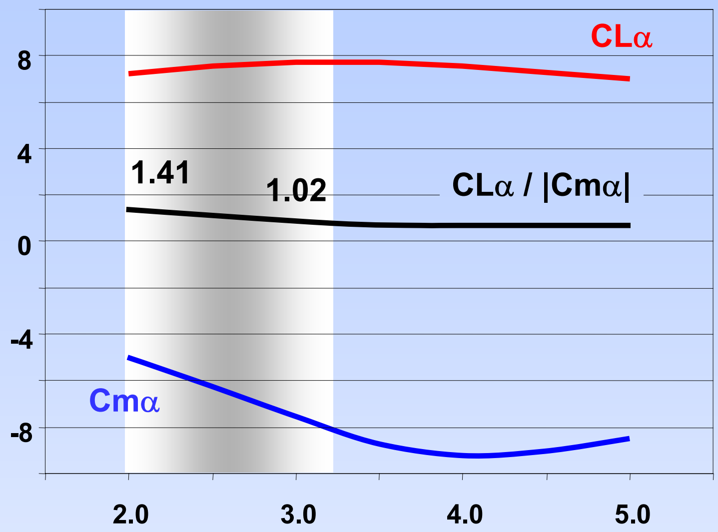
- Fin span limited to 40 mm
- Body caliber limited to 30 mm
- Minimize drag force D
- Maximize lift force L
- Assure projectile stability (static margin)



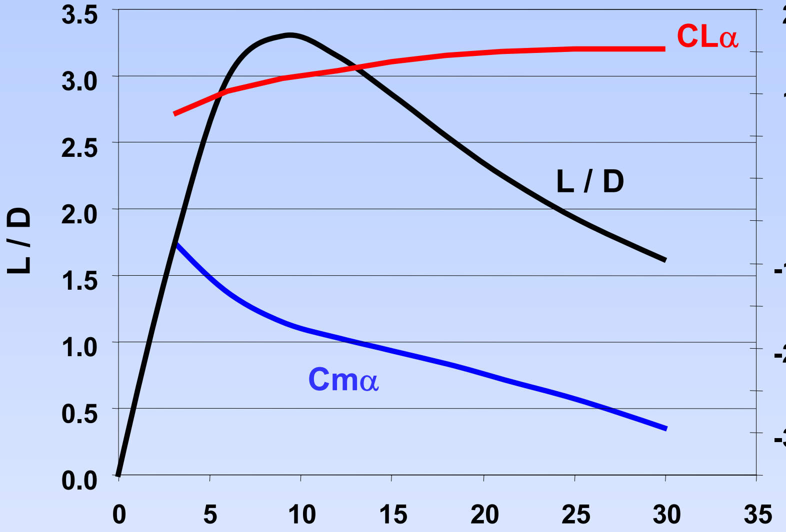




Aerodynamic Performance



Mach
(Incidence 3°)



Incidence [°]
(Mach 3.0)

↓

Variation of ΔV to be included in the guidance law

↓

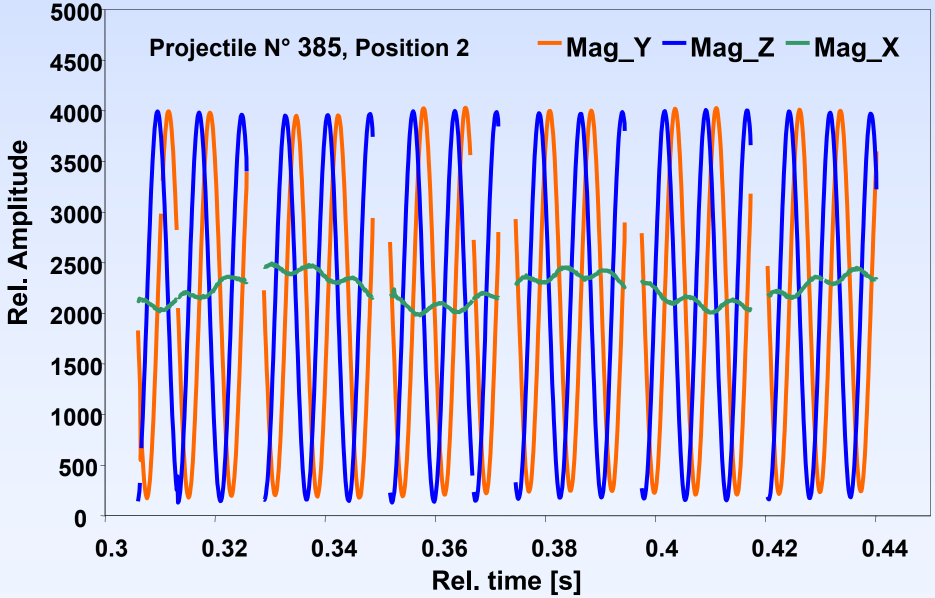
Control law to be validated by 6-DOF computation

Navigation: On-board Sensors

3-D Magnetic Sensors + 6-DOF Model

- Successful results from
  - 155mm artillery shell
  - 90mm tank ammunition
  - 30mm Air Force Finner
  - 30mm spinning finned projectile

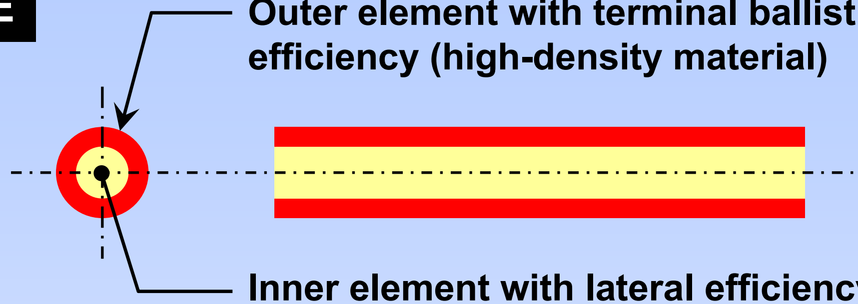
- Latest experiment
  - 120mm Flying Rod
  - V_0 = 1800 m/s
  - Acceleration: 55 000 g
  - 12-bit sampling at 8 KHz

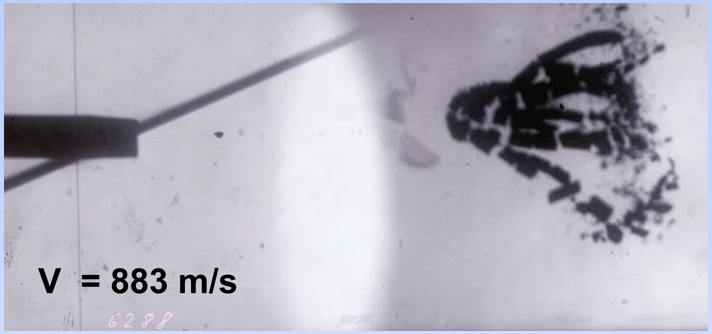


Required data:
roll angle only

Terminal Ballistics: PELE / ALP Projectiles

PELE

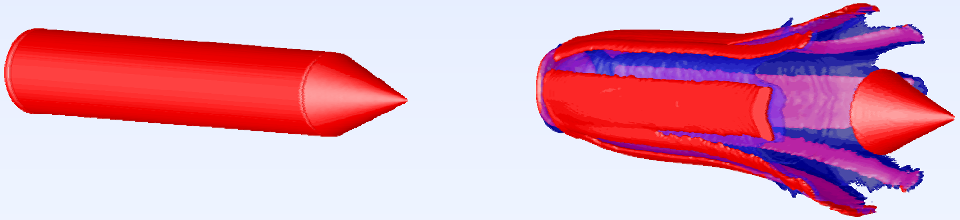


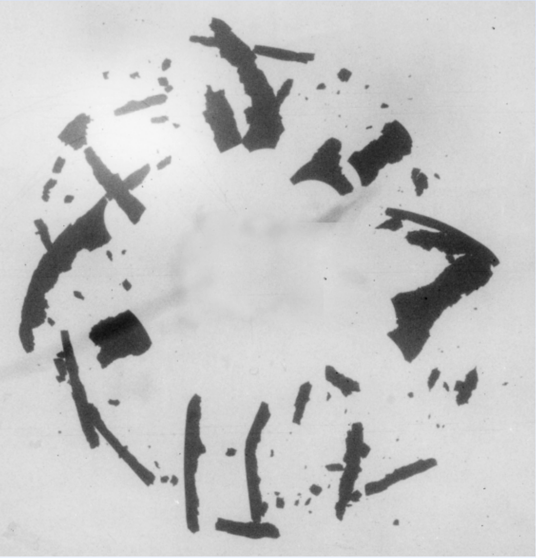


→ Reduction of the projectile mass
Direct hit required

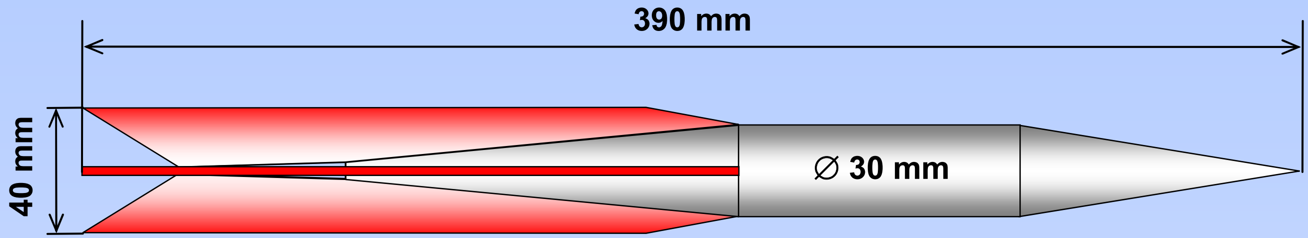
ALP

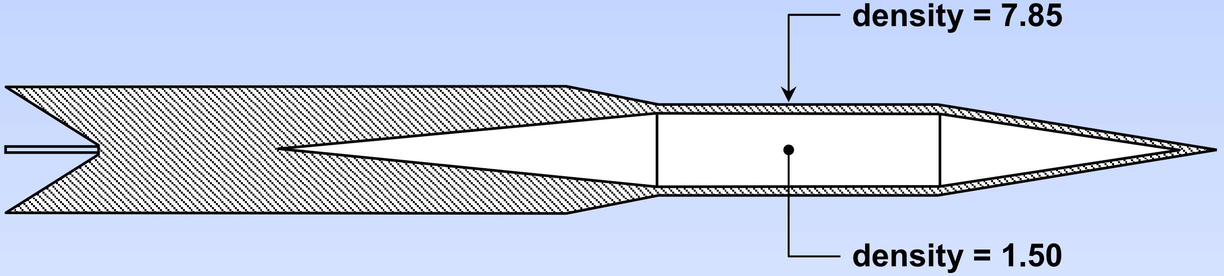
PELE structure + explosive trigger before impact
Spreading of fragments with low lateral velocity





Summary





Mechanical data

m	634 g
I_X / I_Y	1.7 10^{-2}
I_{CJ}	up to 3 cal

+

Aerodynamic data

CX_0	0.21
CN_α	7.86
I_{CP}	0.427 cal
Λ	1094 cal
T	30 ms

+

Command data

I_{CJ}	2.35 cal
J	2 Ns
p	16.7 Hz

=

Control data

Gain	5.36
δ_{max}	16 °
ΔV	40 m/s