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If you can't get a bigger target...

Dispersion Simulation & The Case Against Smooth-Bore Tubes

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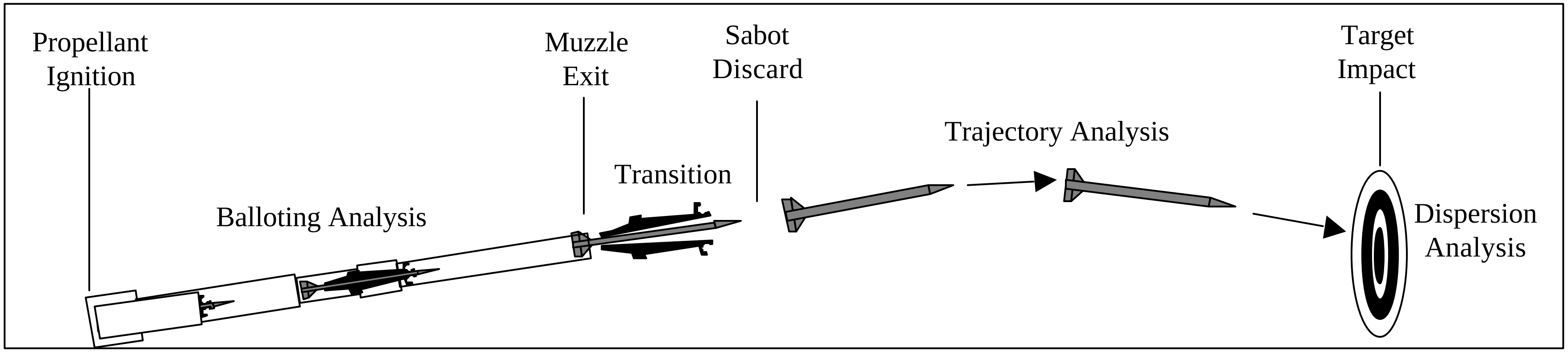
PRODAS 2000

Goal: Model the Complete Projectile Environment

- ***Propellant Ignition to Muzzle Exit***
  - In-Bore Balloting Analysis
- ***Muzzle Exit to Sabot Discard***
  - Transition to Free Flight
- ***Sabot Discard to Target Impact***
  - Free Flight Trajectory Analysis



Balloting

- **Balloting:** any transverse motion of a projectile in the gun tube.
- **Causes of Balloting:**
  - **Non-concentric Projectiles (e.g. center of gravity (CG) and principal axis offset from the bore centerline)**
  - **Insufficient stiffness of the projectile / gun tube interface**
  - **Gun tube curvature (including bore irregularities) exists in all gun tubes.**
  - **Gas dynamics produce asymmetric pressures at the projectile base.**
  - **Projectile spin interaction w/ projectile/gun tube structure**

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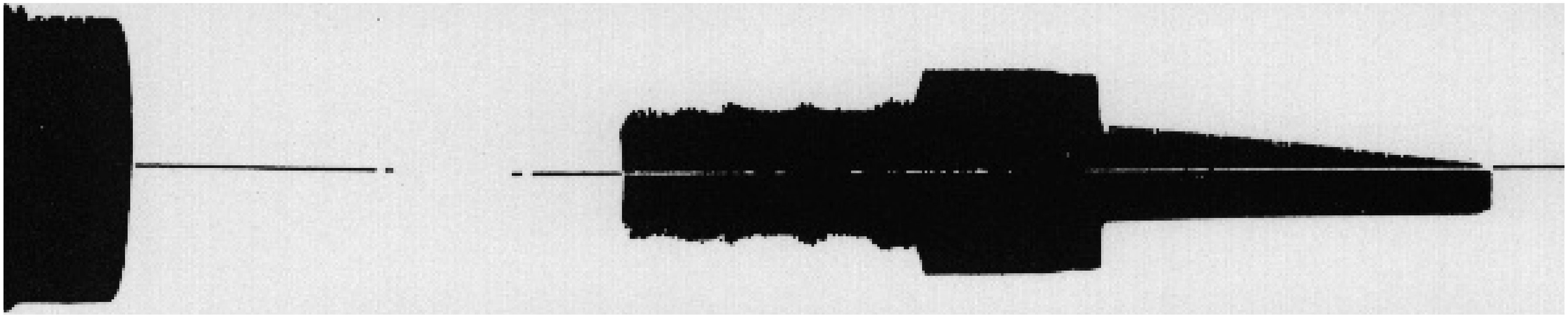
BALANS: History



Bent Penetrator Exposed in a Flash X-Ray Taken at Muzzle Exit in 1973

This event prompted Dr. B.K. Stearns (Co-founder of Arrow Tech) to develop a balloting code to assist in the re-design of the 30mm GAU8 API projectile.

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BALANS 2000: New Features

- Use of PRODAS editor to model gun tubes
- Improved lumped parameter modeling
  - Takes advantage of PRODAS model structure
- Input measured interior ballistics data
- Ability to estimate sabot discard effects
- Automatically performs BF 6DoF trajectory sensitivity analyses

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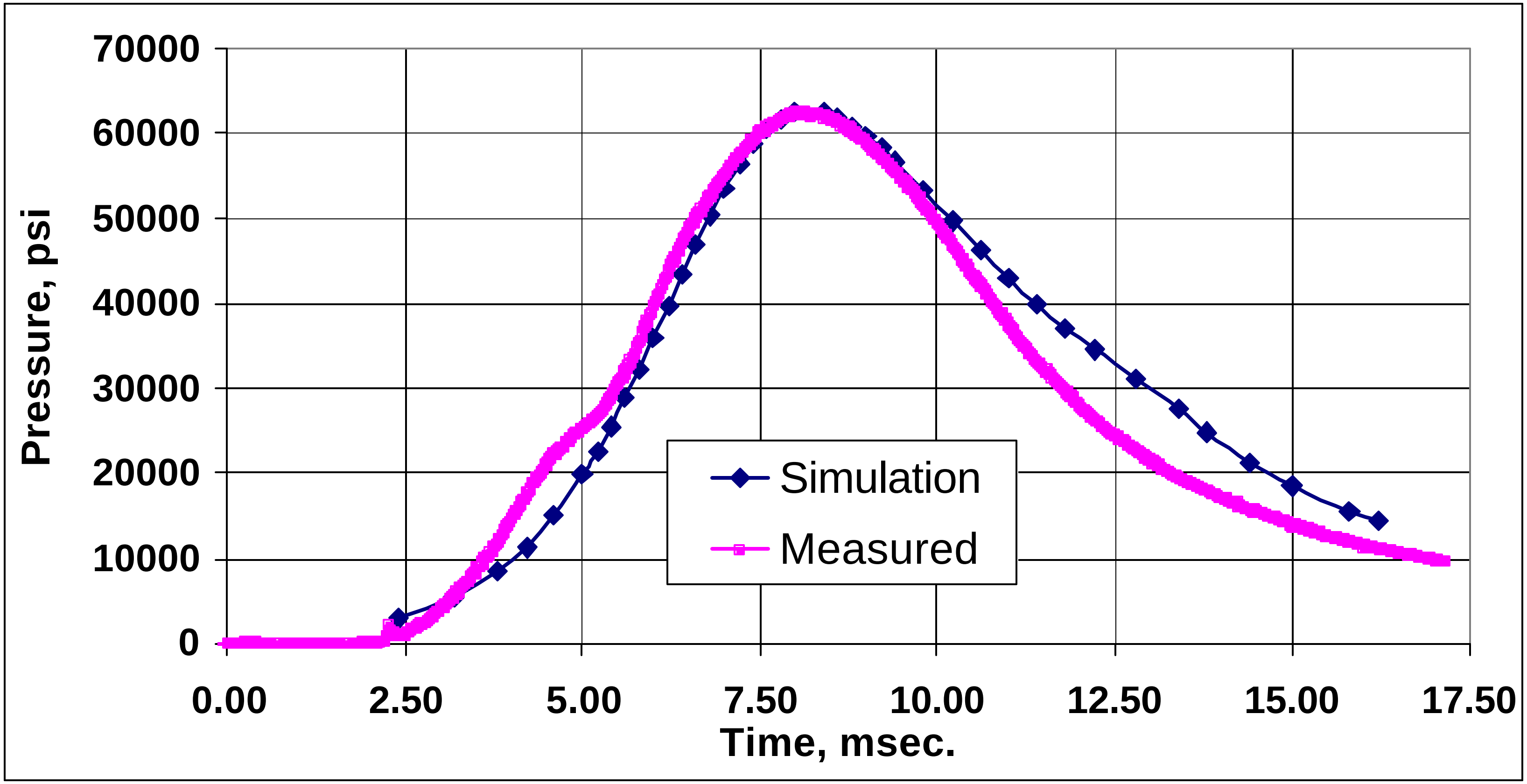
Measured vs. Simulated P-T History



- **Simulation Matches P_{max}, V_{muz}, 5%-95% Rise Time**
- **Still Misses Start-up Dynamic, 6% higher impulse @ peak**

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BALANS: Applications (1979-2002)

Large Caliber Long Rods (1979-1999)

	Projectile	Year
105mm	M735	1979
	M774/M833	1980
	M9xx	1982-84
	M900	1988-89
120mm	M829A1	1986
	M865	1987
	M865SS	1987
	FMS-KET	1987-88
	M829A1	1987-89
	M829	1988-89
	M829E2	1989-91
	M865SS/M831	1990
	M831A1	1994
	M865SS	1994
	M865SS	1998
	M829E3	1995-02

BALANS: Applications (1979-2002)

- Assess influence of bourrelet diameter, sabot stiffness and exit spin on dispersion
- Investigation of structural integrity.
- Perform sabot design study.
- Used in rapid design/build cycle; achieve first design success.
- Used SPC data to assess production tolerance effects.
- Predict in-bore performance and aerodynamic resonance.
- Assess influence of peak pressure, muzzle velocity, and in bore clearances on peak and time-integrated bourrelet loads.

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BALANS 2000: Integrated with PRODAS

- **Analysis module in PRODAS 2000**
  - **Consistent user interface**
  - **All data in a single file/database**
  - **Material, gun tube, propellant reference books**
  - **Cut, copy, paste of tables and graphs**
- **Integration with other PRODAS modules and Reference Books**
  - **Trajectory modules**
  - **Interior Ballistics modules**
  - **Gun Tube Reference: Twist vs. Travel**

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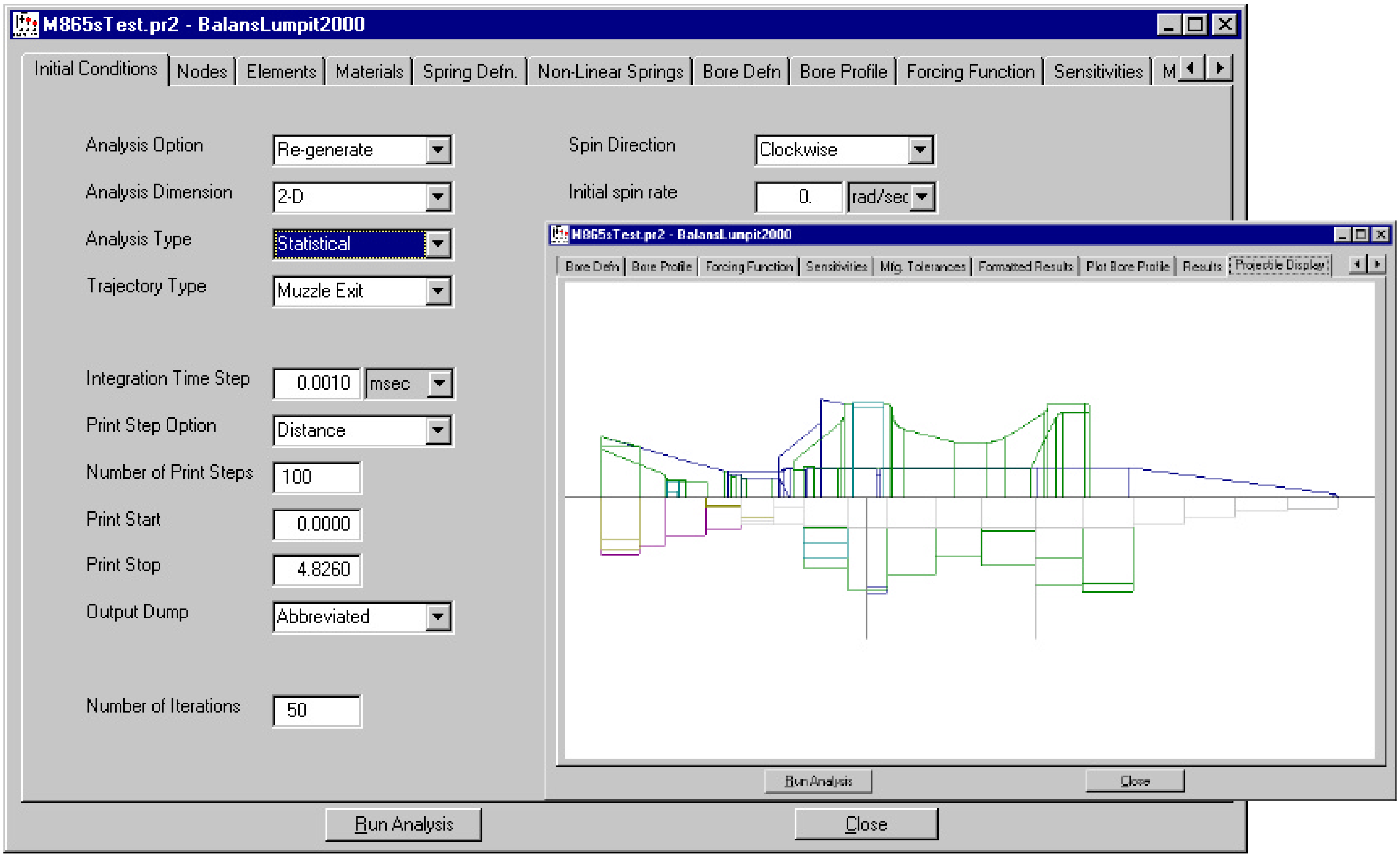
BALANS 2000: User Interface



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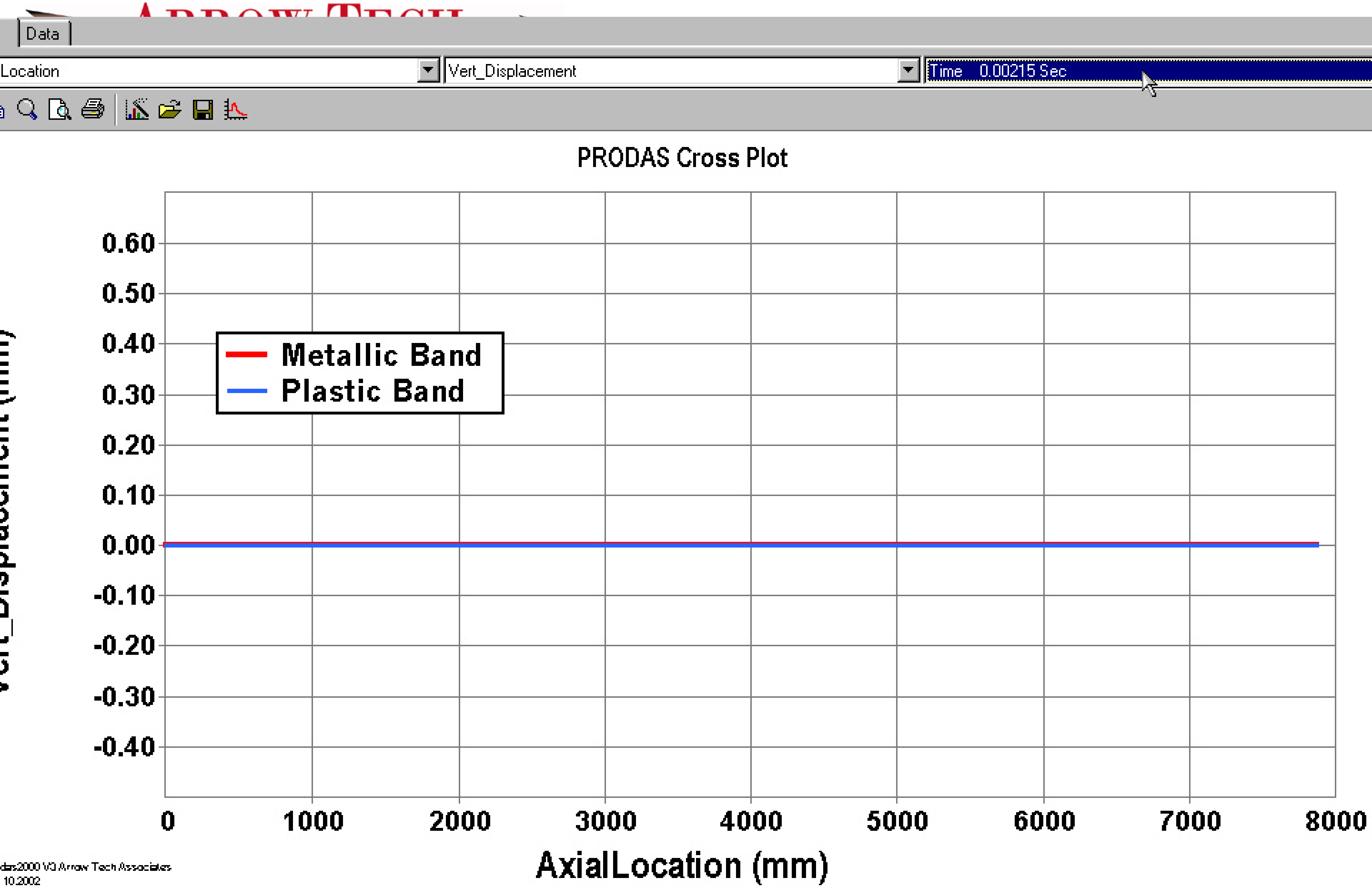
Dispersion Simulation

Inputs:

- Dimensions/Tolerances for Orienting the Projectile
- Gun Tube Definition: Geometry, Material, Supports, etc.
- Interior Ballistics Forcing Function, sigma
- Projectile Aerodynamic Characteristics & Sensitivity Factors
- Misc. Error Estimates: Bore Site, Discard, Winds

Output: Muzzle Exit Conditions:

- Mean & Sigma Yaw Angle, Dispersion Contribution
- Mean & Sigma Angular Yaw Rate, Dispersion Contribution
- Mean & Sigma Barrel Transverse Velocity at Exit, Dispersion Contribution



Data
Location
Vert_Displacement
Time 0.00215 Sec
PRODAS Cross Plot
Metallic Band
Plastic Band
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
0
1000
2000
3000
4000
5000
6000
7000
8000
AxialLocation (mm)

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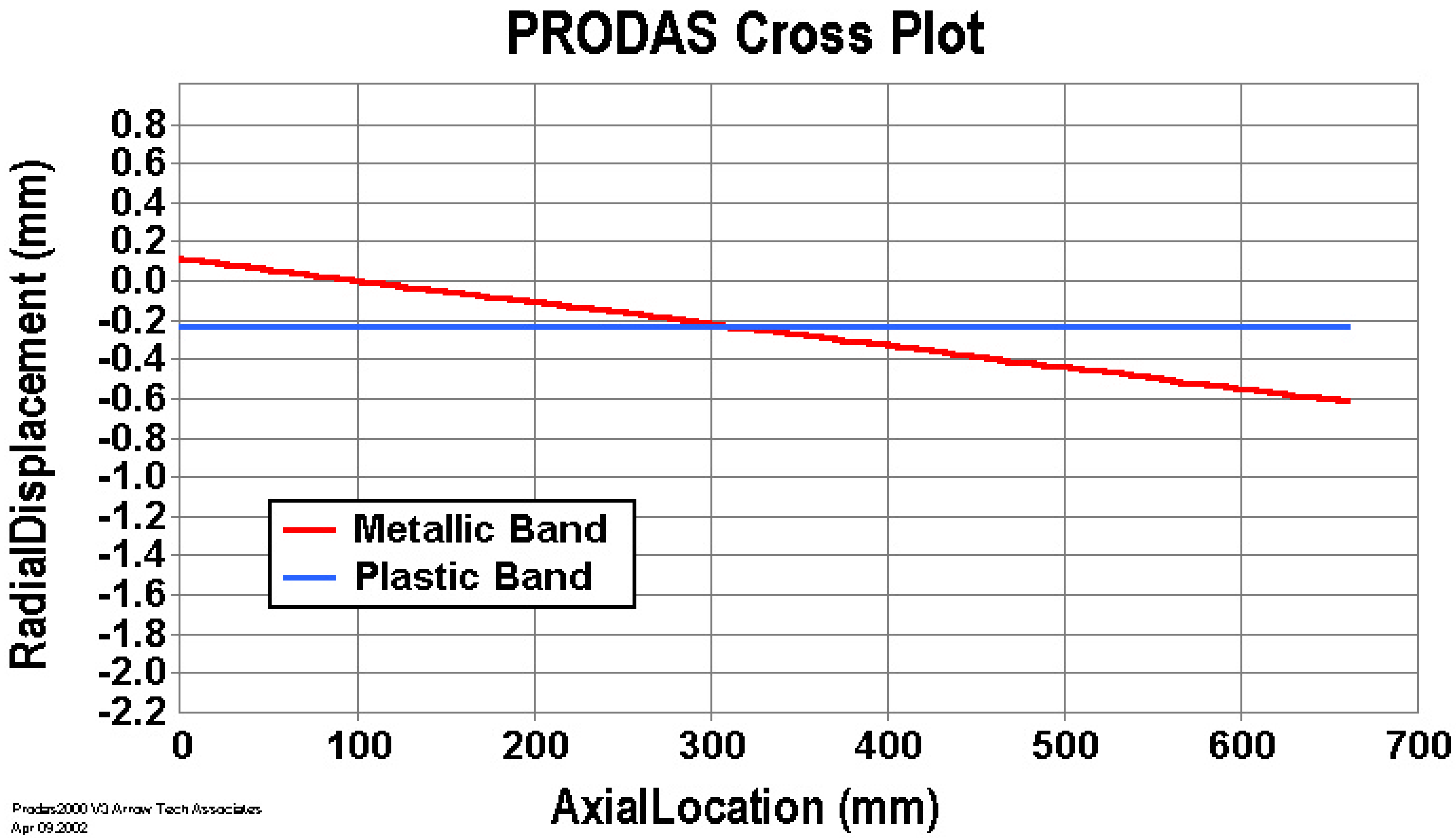
Projectile In Bore Motion



- **Differences in Projectile In Bore Motion Caused by Alternate In-Bore Projectile Support**

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The Case Against Smooth Bore Tubes

"Typical" Error Budget

Dispersion Source	Smooth Bore Gun Horiz. mils	Smooth Bore Gun Vert. mils	"Slow Twist" Gun Horiz. mils	"Slow Twist" Gun Vert. mils
Balloting	0.097	0.097	0.097	0.097
Velocity Sigma	0.000	0.052	0.000	0.052
Wind Error	0.125	0.000	0.125	0.000
Bore Site (est.)	0.050	0.050	0.050	0.050
Sabot Discard (est.)	0.050	0.050	0.050	0.050
Aero/Mass Asym.	0.092	0.092	0.000	0.000
a_{gun} x spin	0.000	0.000	0.012	0.012

Composite Totals

Smooth Bore Gun ~0.178

"Slow Twist" Gun ~0.153 (~ 16% less!)

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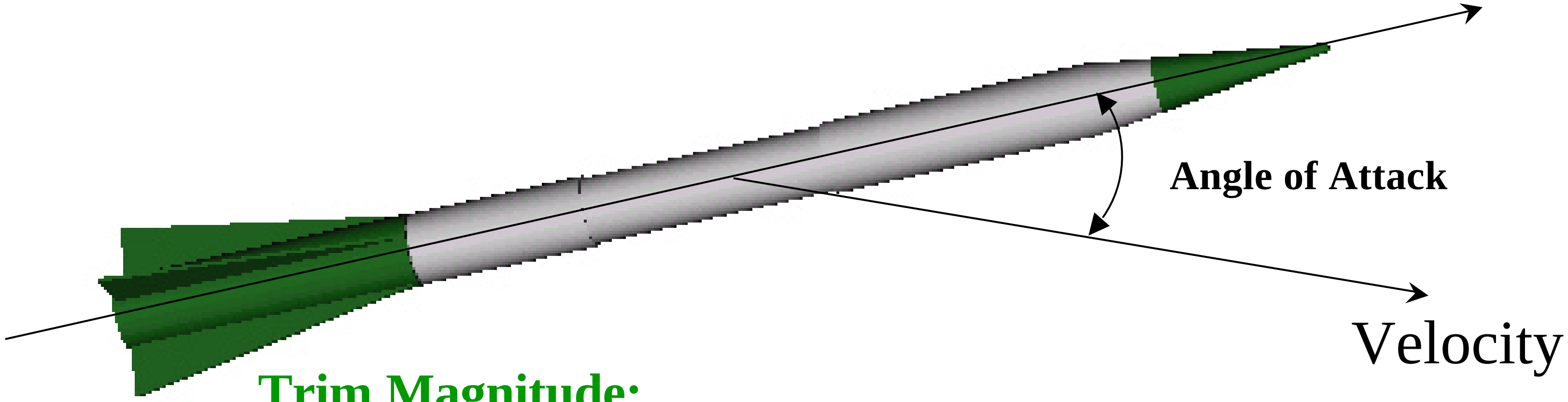
Aerodynamic Trim



Trim Magnitude:

- ~ 0.1-0.3 Deg. for Large Caliber Finners

Trim Sources:

- Component Curvature
- Component Mfg. Run-out
- Assembly Clearances

Causes:

- Small Initial Angle of Attack
- Swerve (Dispersion) until small roll rate is achieved

Tube Twist Considerations

Initial Twist:

- **Start at 0 Deg. (avoid torque spike due to FC wear)**

Exit Twist:

- **Above Aero Resonance (Long Rod or HEAT Designs)**
- **Below Structural Resonance (Long Rod)**

"Rifling" Profile:

- **"Rounded" to reduce localized melting & cracking**
- **# drive features based on torque & allowable stress**

Summary

- **Projectile & Gun Tube dynamic motion can be quickly and accurately simulated**
- **SPC data can be incorporated for most accurate balloting simulations (exit state)**
- **Slow Twist Rifling can reduce ballistic projectile dispersion by approx. 20%**
- **Exit Twist Angle must be assessed for each unique application**