Hypervelocity Penetration of Near Earth Objects

Washington DC
24 October 2008

1Lt Christopher Engelhardt
Air Force Research Laboratory
Munitions Directorate
Eglin AFB, FL

Introduction

- Purpose
  - Apply a basic understanding of penetration mechanics to the penetration capability of Near Earth Objects
  - Examine effects of penetration and the ability to mitigate threatening Near Earth Objects
- Objectives
  - Derive mathematical penetration model to simulate projectile impact
  - Apply models to a range of scenarios

Background

- **Alekseevskii-Tate Model**
  - **Jet penetration requirement**

$$\frac{\rho_p v^2}{\sigma_t} >> 1$$

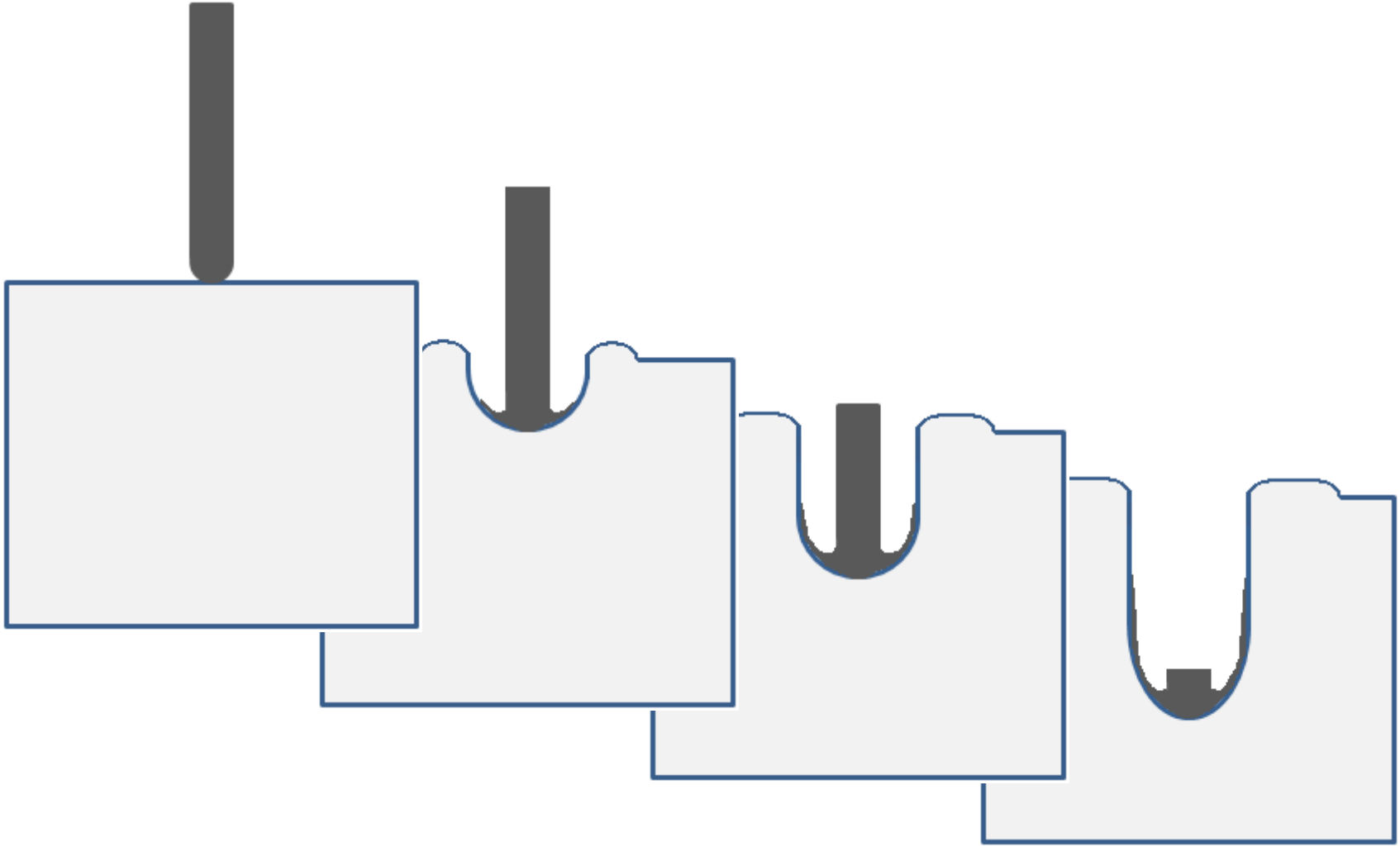
  - **Pressure of impact is significantly larger than internal resistance forces, hypervelocity**
  - **Modified Bernoulli equation applies**

$$\frac{1}{2}\rho_p (v-u)^2 + Y_p = \frac{1}{2}\rho_t u^2 + R_t$$

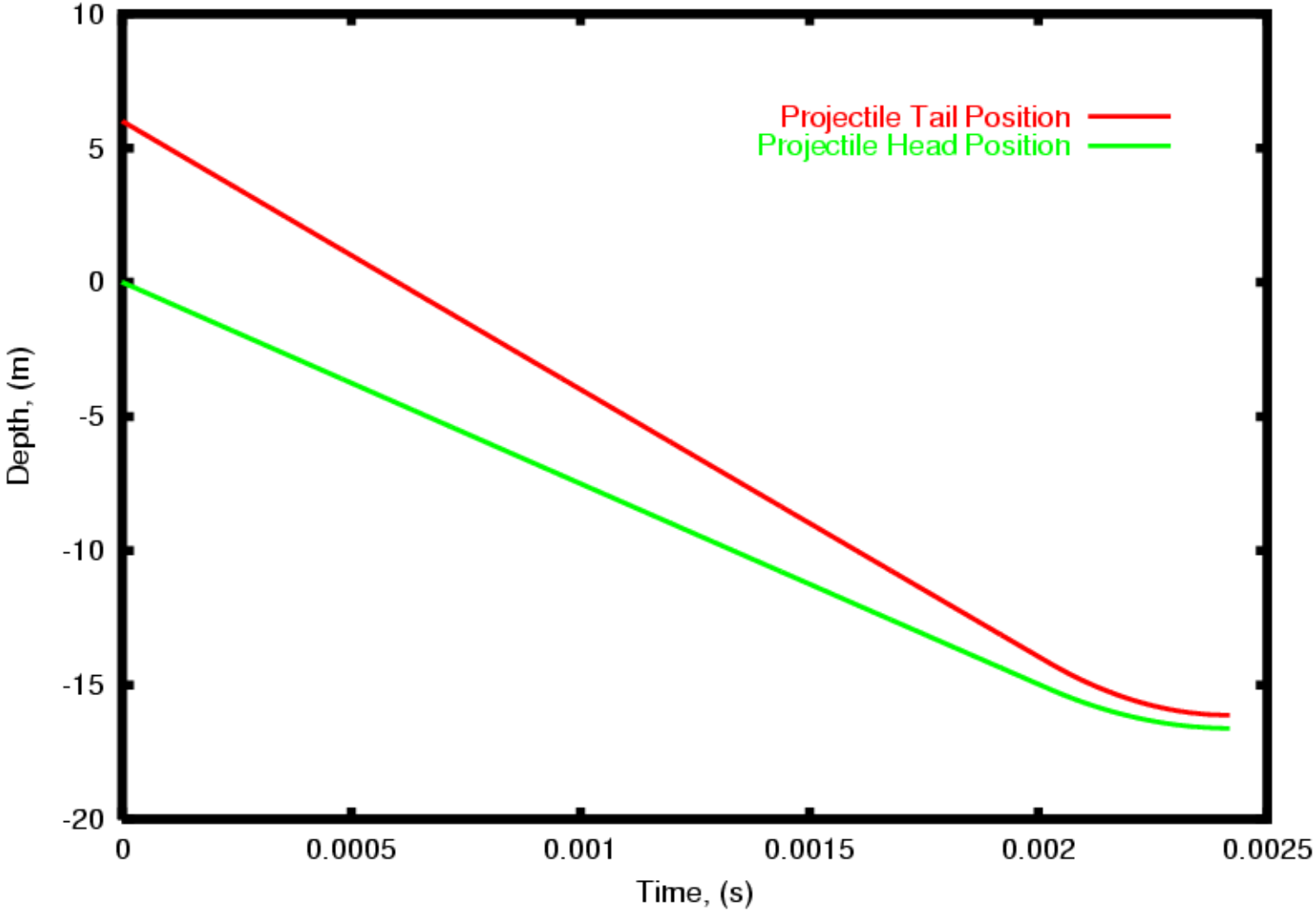
Governing Equations

- **Alekseevskii-Tate Penetration Equations**
  - **Eroded length** $$\frac{d\eta}{d\tau} = \xi(1-A) + \frac{B}{\xi}$$ $$A = \frac{1}{1+\sqrt{\frac{\rho_t}{\rho_p}}}$$
  - **Penetration depth** $$\frac{d\Theta}{d\tau} = \xi A - \frac{B}{\xi}$$ $$B = \frac{R_t - Y_p}{v_0^{\,2}\sqrt{\rho_t \rho_p}}$$
  - **Tail velocity** $$\frac{d\xi}{d\tau} = -\frac{C}{1-\eta}$$ $$C = \frac{Y_p}{\rho_p v_0^{\,2}}$$
  - **Cavity diameter** $$\varsigma = \left(\frac{\left(\xi^2 - 2C\right)\left[\xi^2(1-A)+B\right]}{C_0\left(\xi^2 A - B\right)}\right)^{1/2}$$ $$C_0 = \frac{2a}{\rho_p v_0^{\,2}}$$

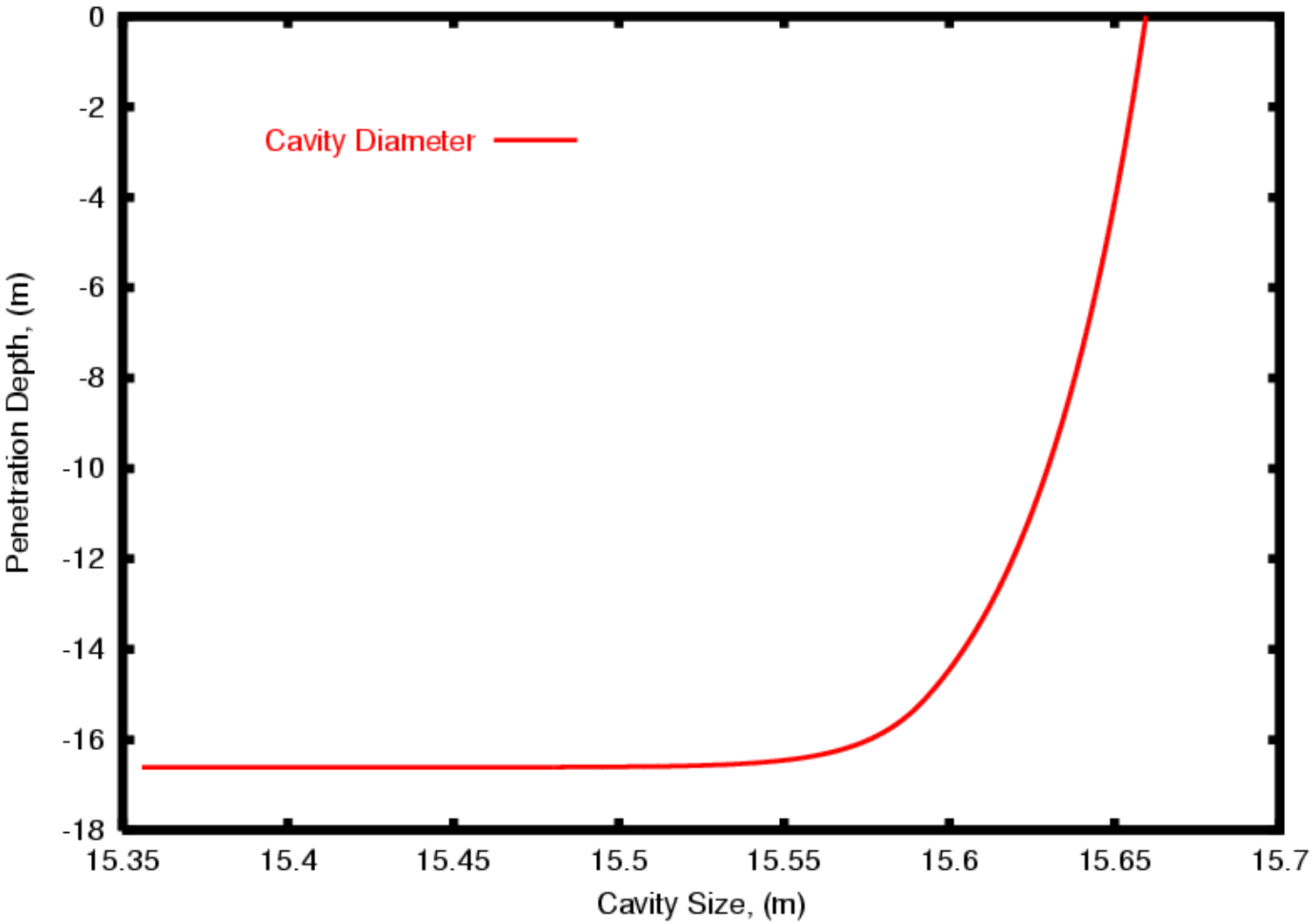
Jet Penetration



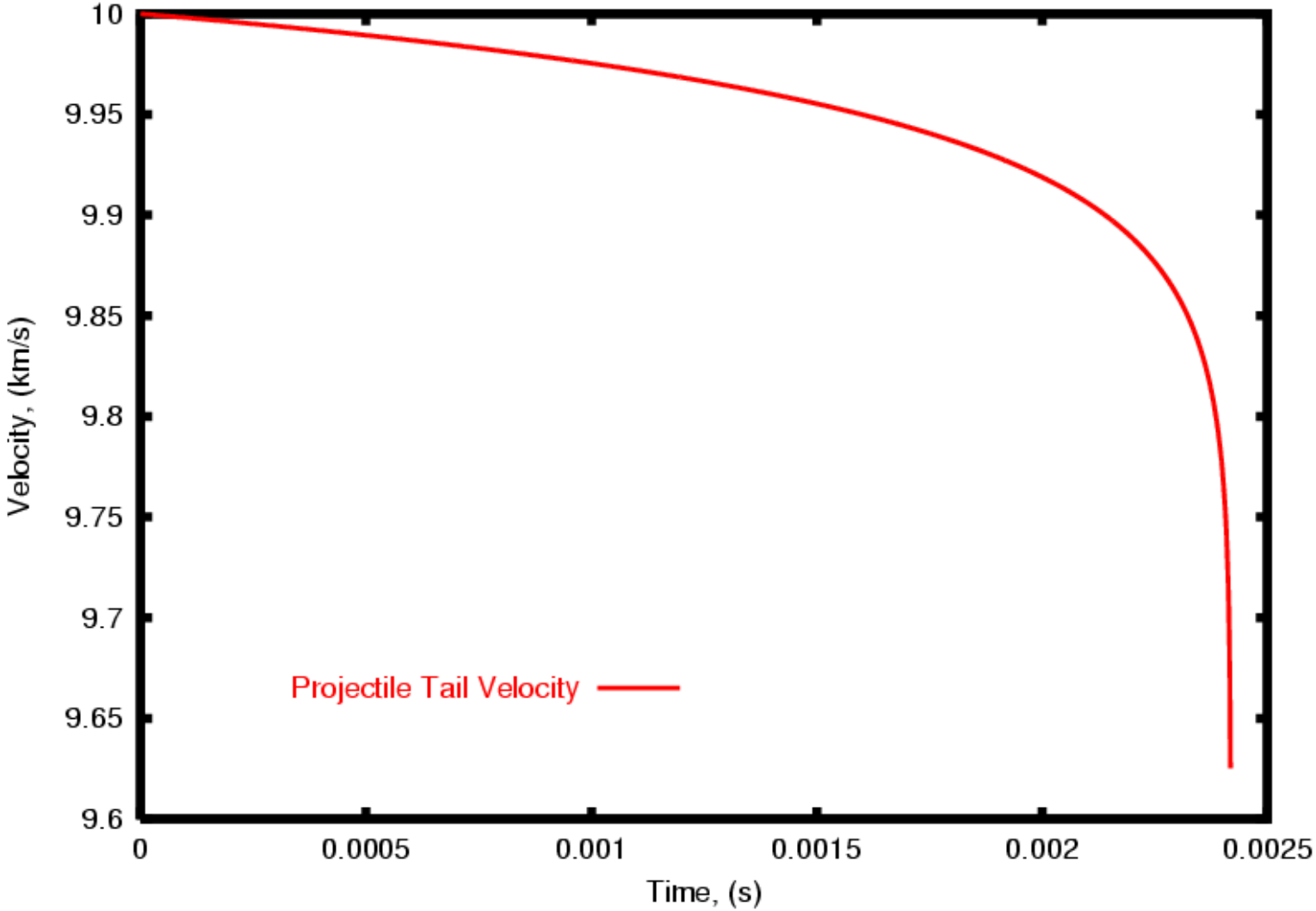
2004 VD17 Impact
6 m by 0.65 m Tungsten Alloy at 10 km/s



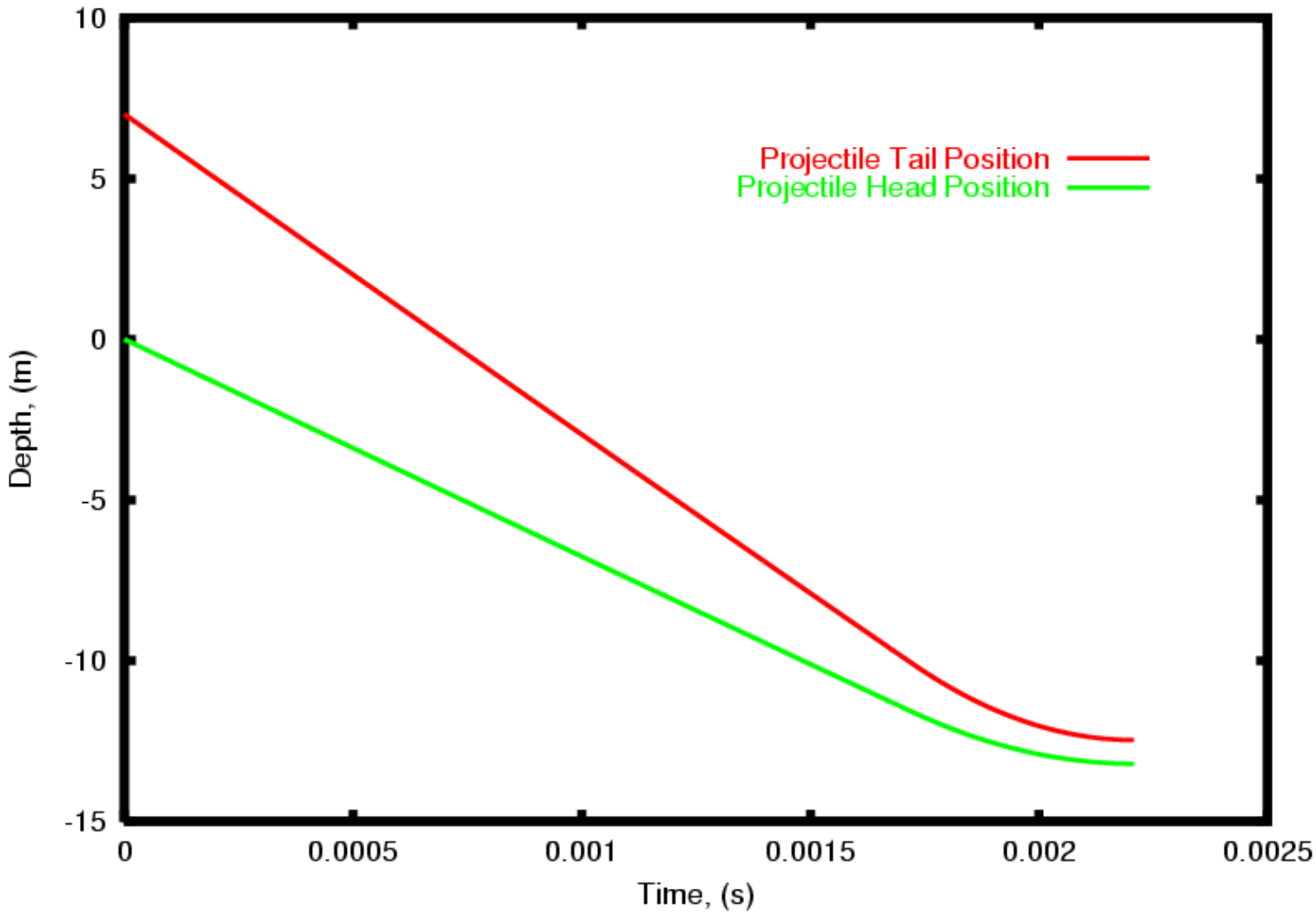
2004 VD17 Impact
6 m by 0.65 m Tungsten Alloy at 10 km/s



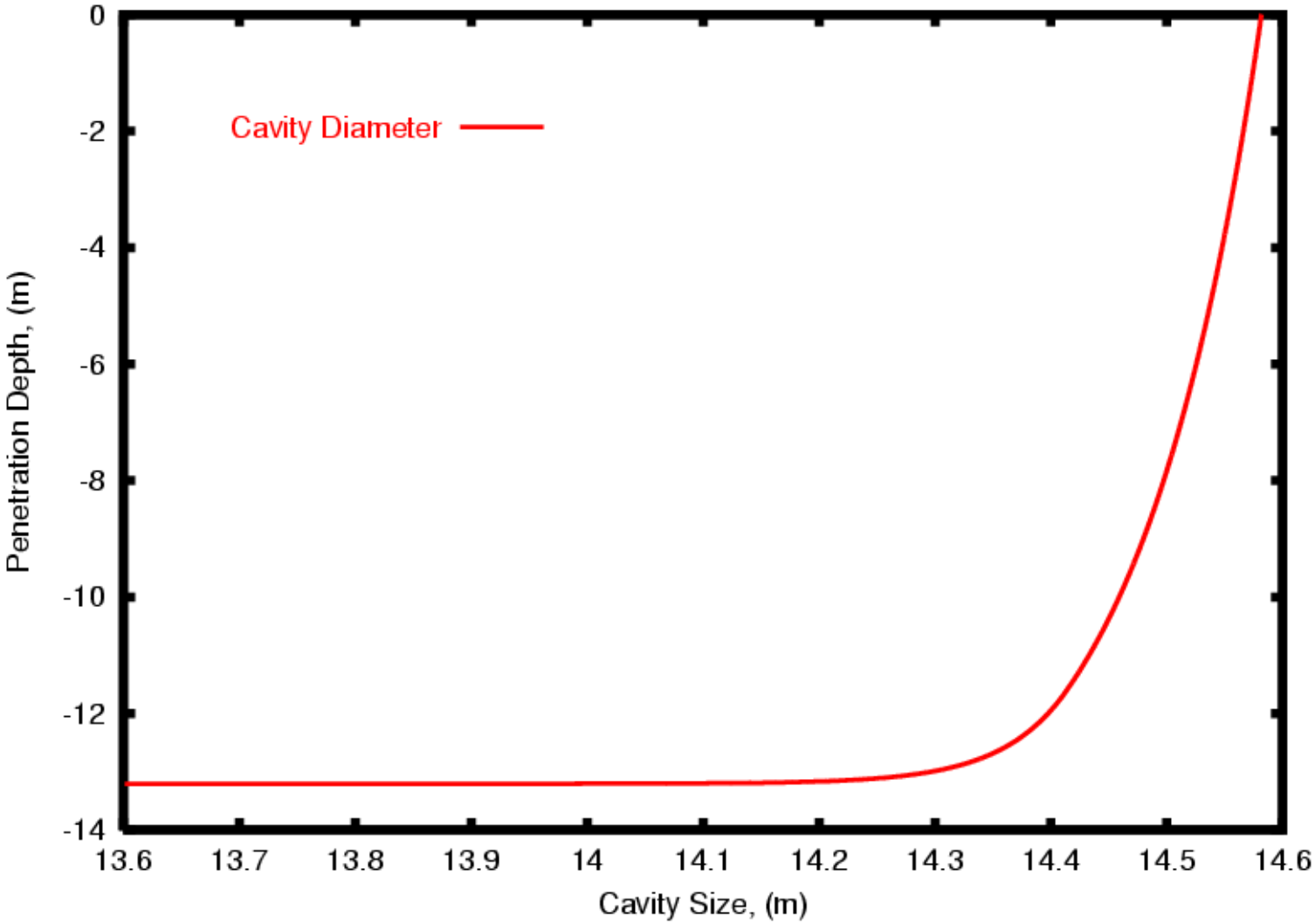
2004 VD17 Impact
6 m by 0.65 m Tungsten Alloy at 10 km/s



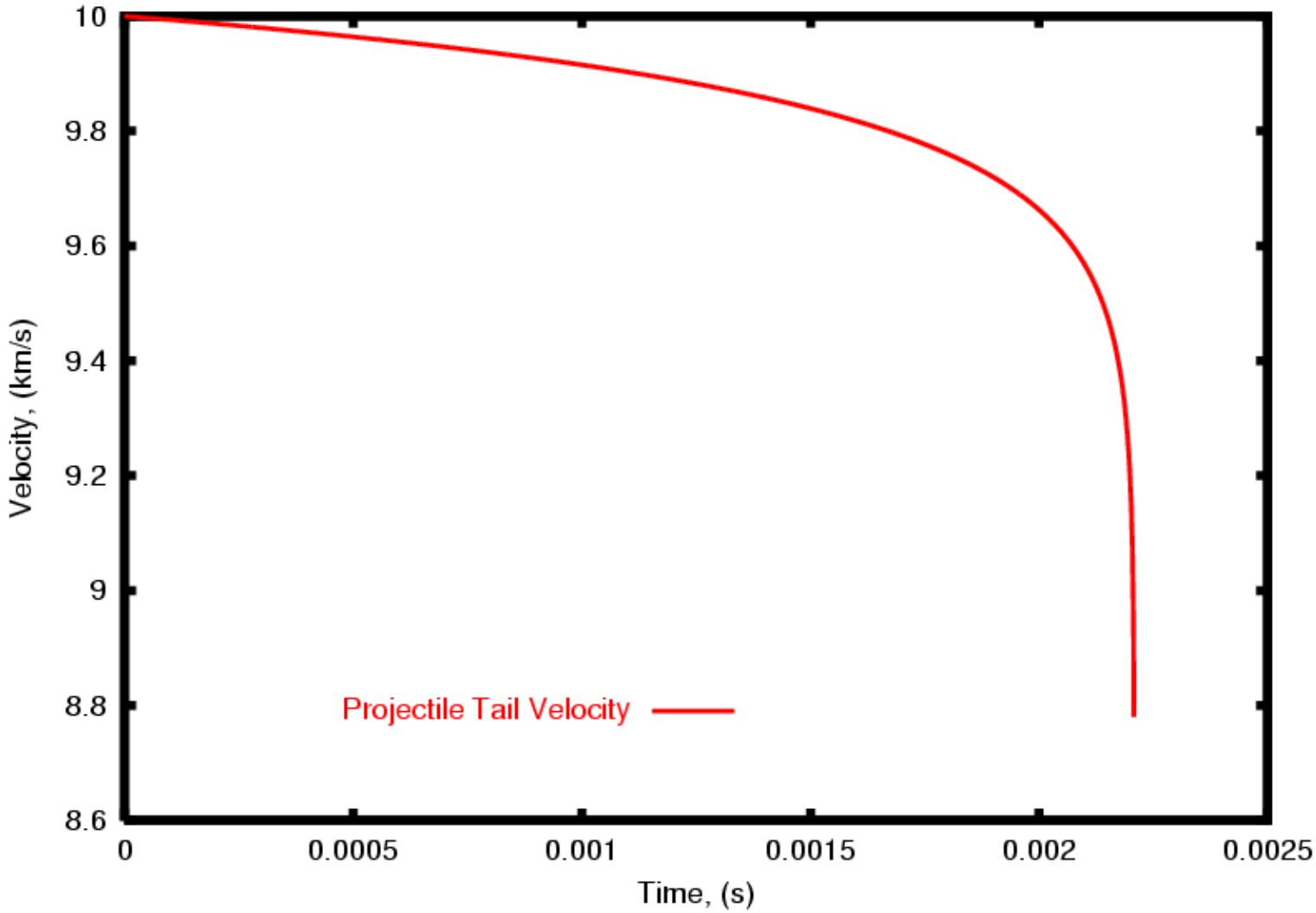
Apophis Impact
7 m by 1 m Titanium Alloy at 10 km/s



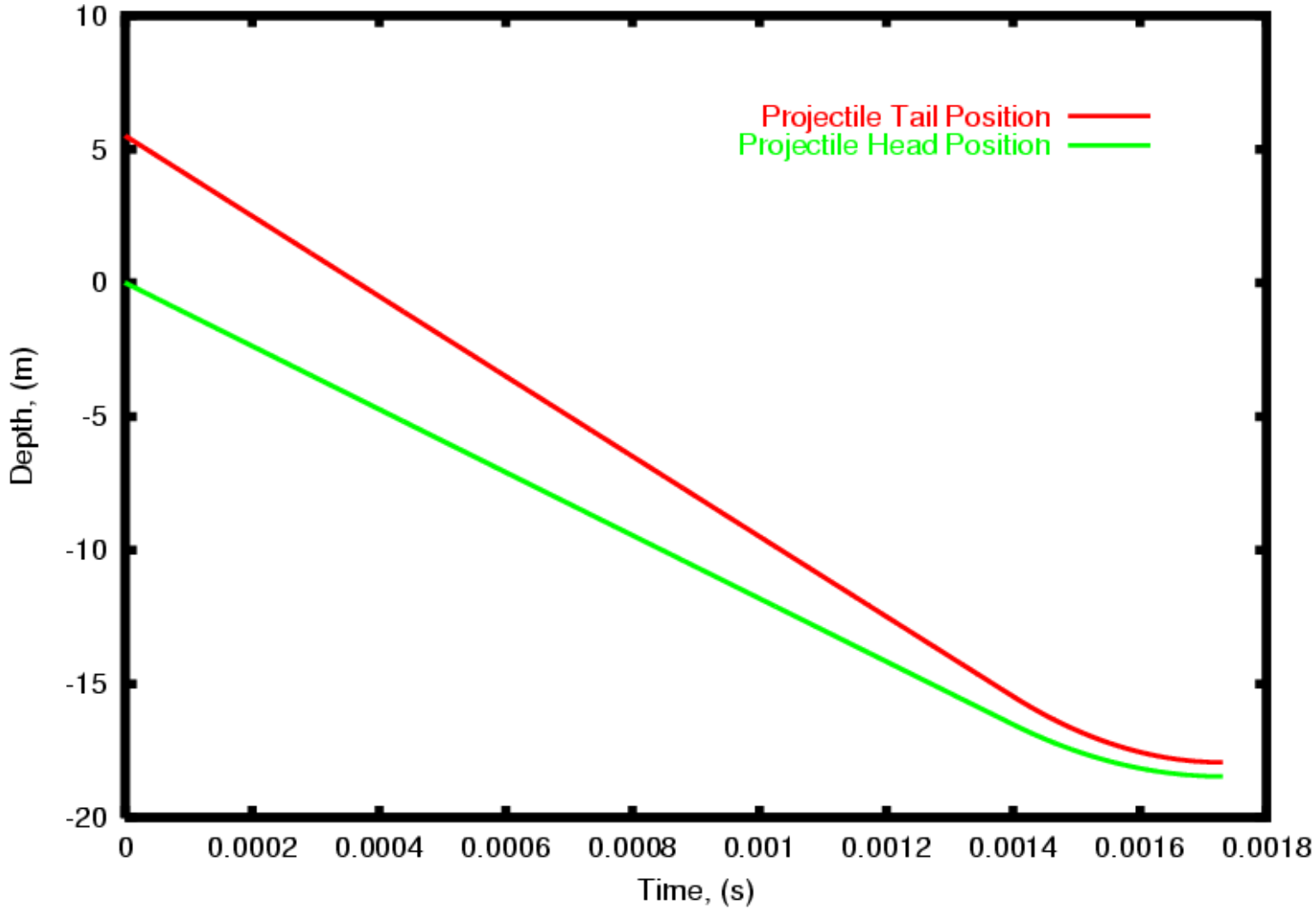
Apophis Impact
7 m by 1 m Titanium Alloy at 10 km/s



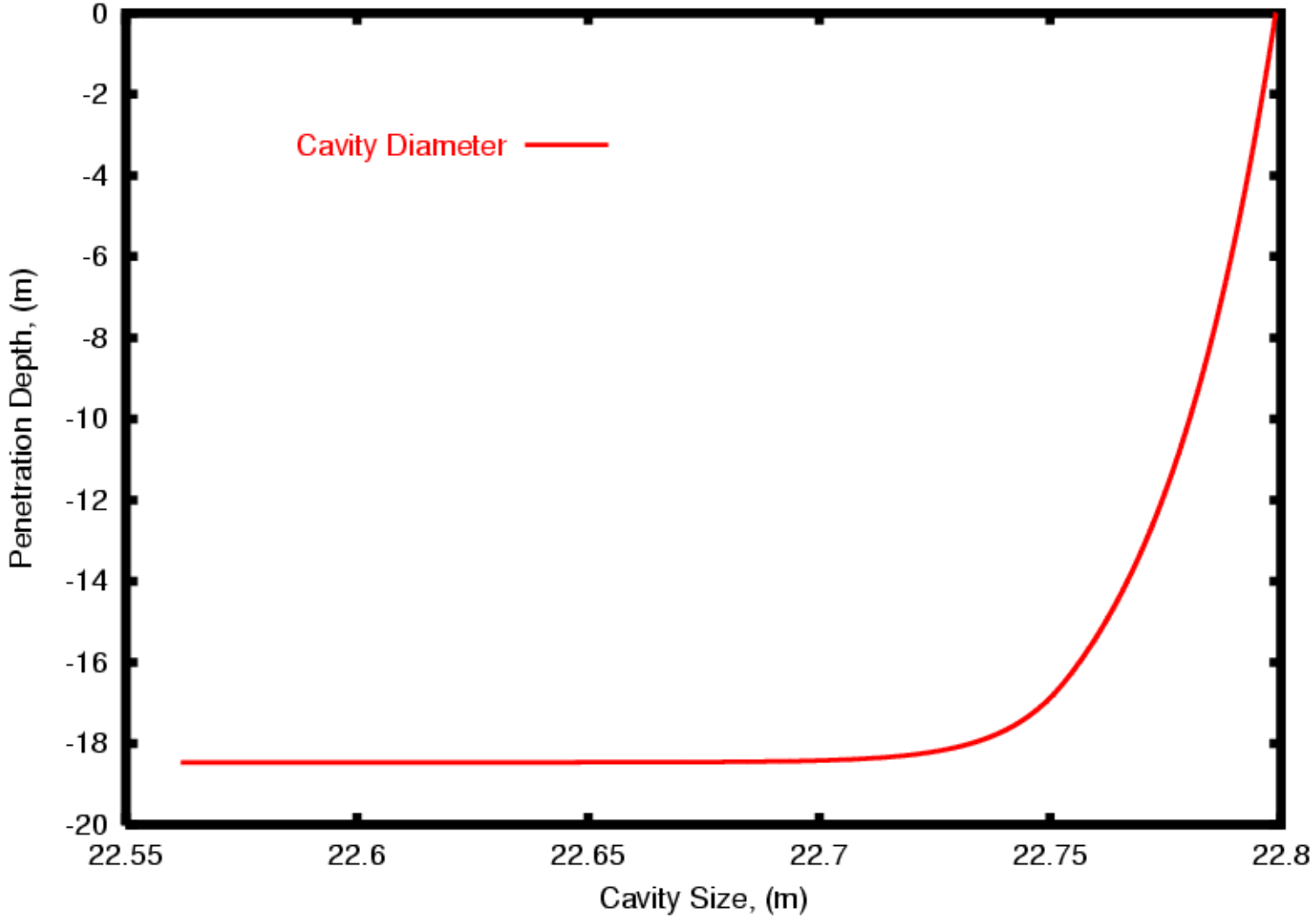
Apophis Impact
7 m by 1 m Titanium Alloy at 10 km/s



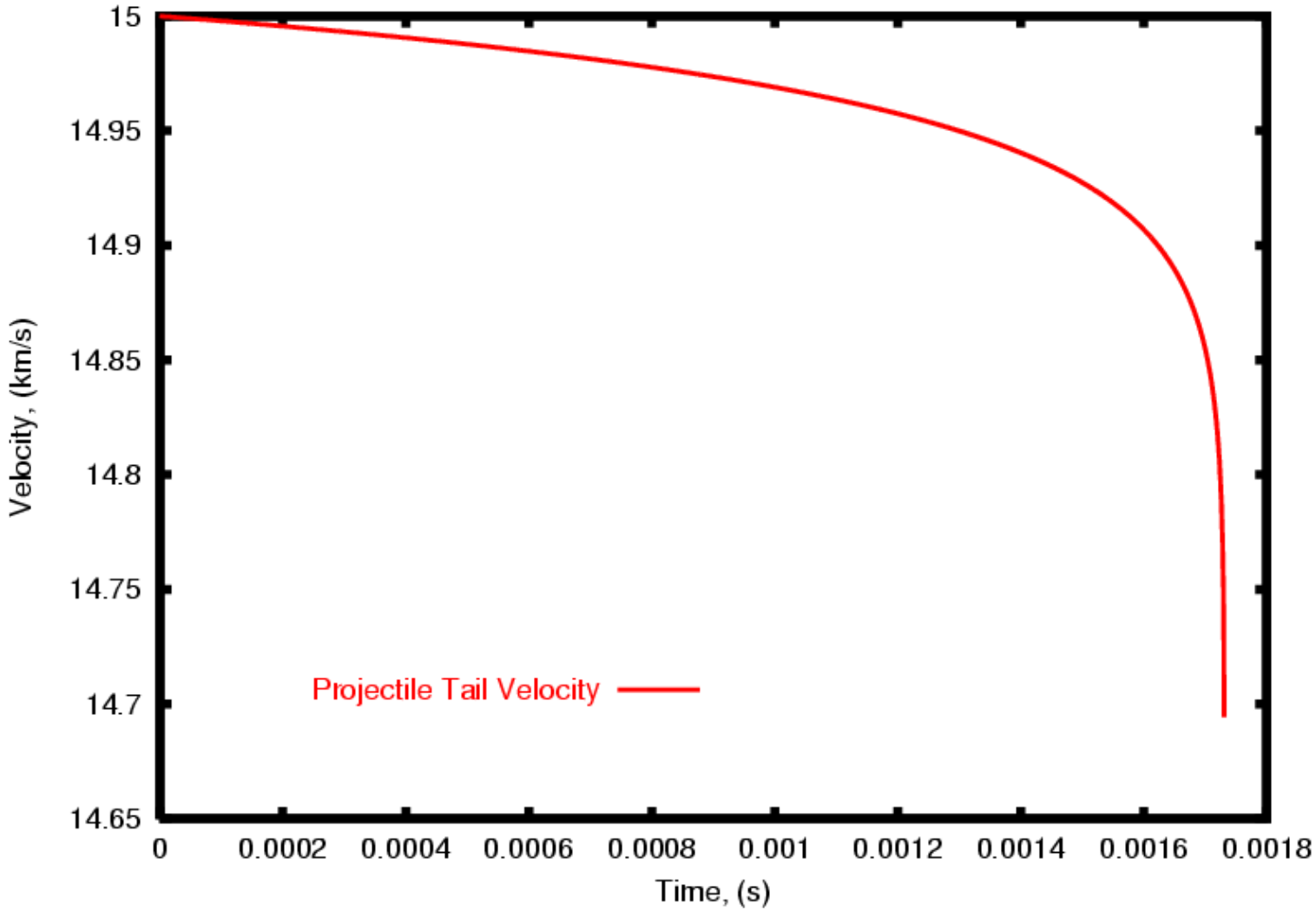
1999 JU3 Impact
5.5 m by 0.7 m Tungsten Alloy at 15 km/s



1999 JU3 Impact
5.5 m by 0.7 m Tungsten Alloy at 15 km/s



1999 JU3 Impact
5.5 m by 0.7 m Tungsten Alloy at 15 km/s



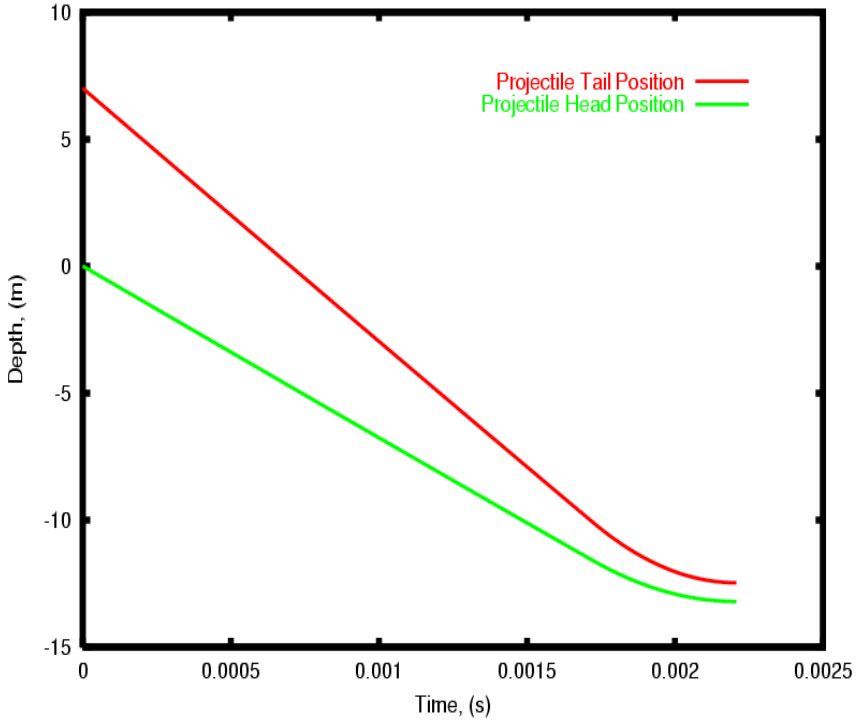
Impact Velocity Composition

- **7 m by 0.75 m cylindrical Titanium Alloy projectile**
- **1.0 g/cm^3 asteroid**

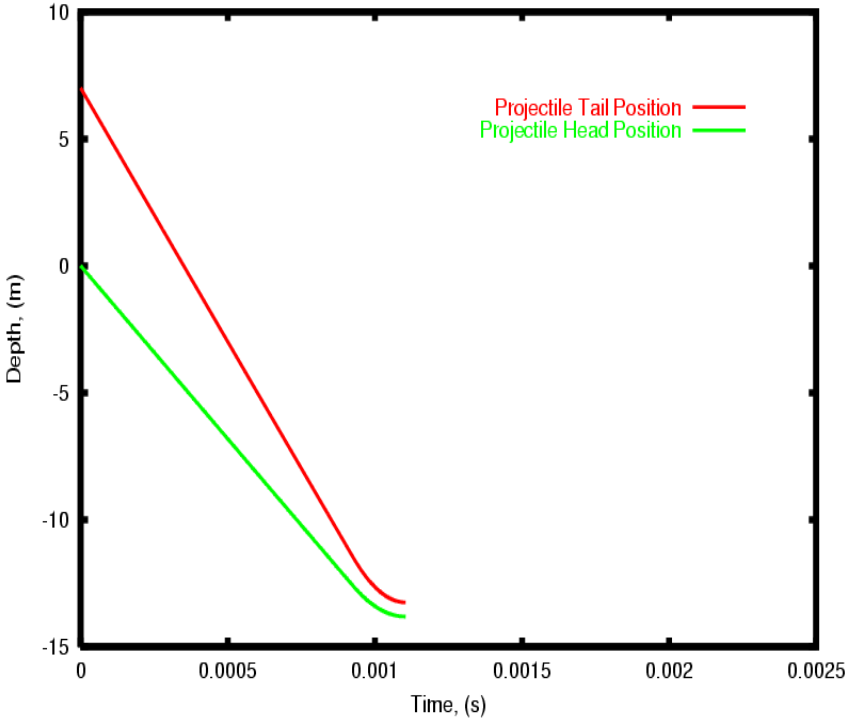
Impact Velocity (km/s)	Penetration Depth (m)	Cavity Diameter (m)
10.0	13.7	9.8
15.0	13.9	15.8
20.0	14.2	21.4
25.0	14.1	26.9
30.0	13.9	32.5

Impact Velocity Comparison

Impact at 10 km/s



Impact at 20 km/s



7 m by 0.75 m cylindrical Titanium projectile impacting a 1.0 g/cm^3 carbonaceous asteroid

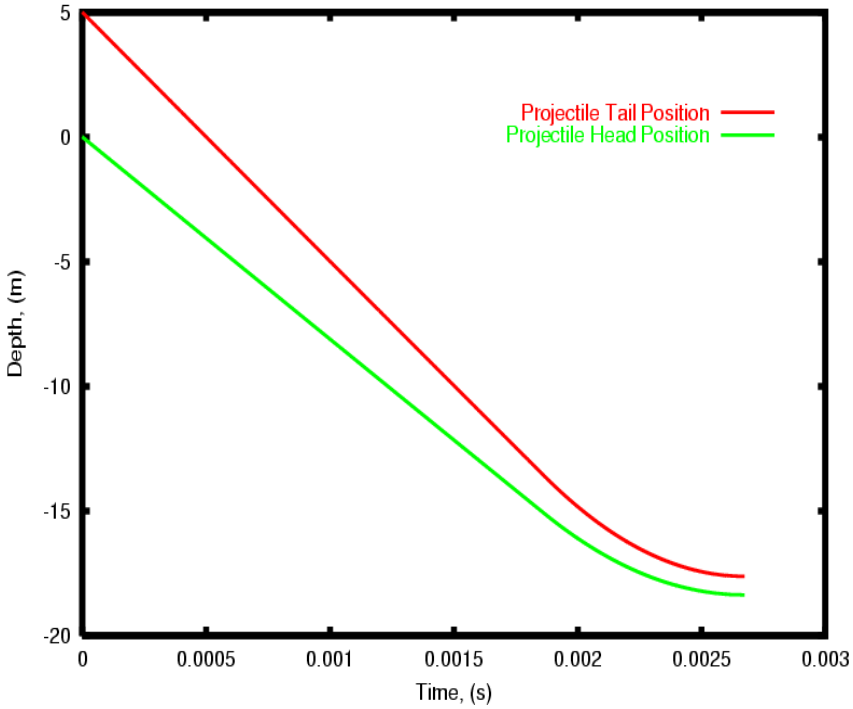
Projectile Size Comparison

- **Cylindrical Tungsten Alloy projectile**
- **1.0 g/cm^3 asteroid**
- **10 km/s impact velocity**

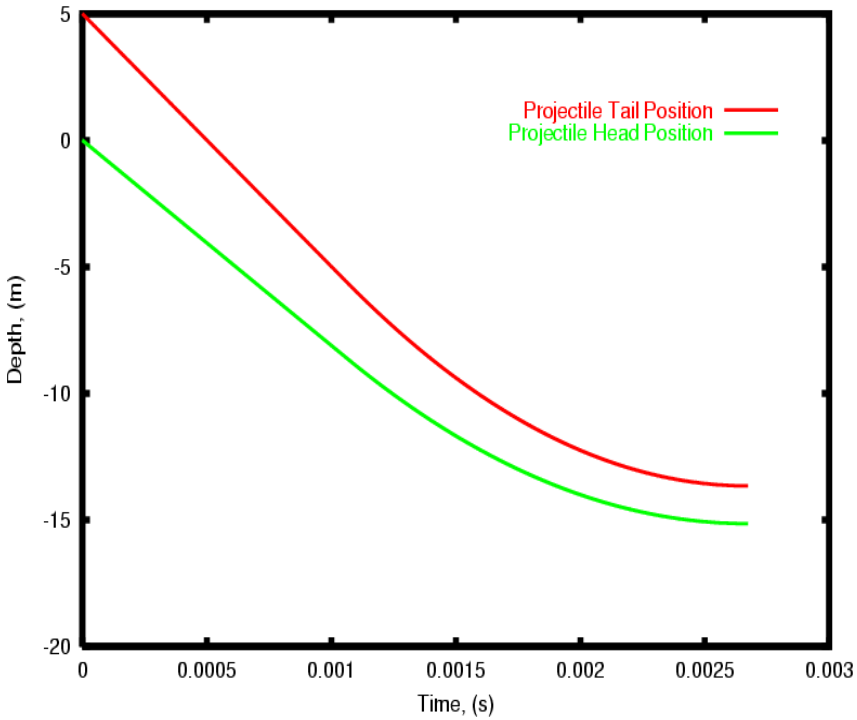
Projectile Length (m)	Projectile Diameter (m)	Penetration Depth (m)	Cavity Diameter (m)
5.0	1.0	18.4	19.6
5.0	2.0	15.1	39.1
7.5	1.0	29.2	19.6
7.5	2.0	25.9	39.1
10.0	1.0	40.0	19.6
10.0	2.0	36.7	39.1

Projectile Diameter Comparison

5 m by 1 m Cylinder



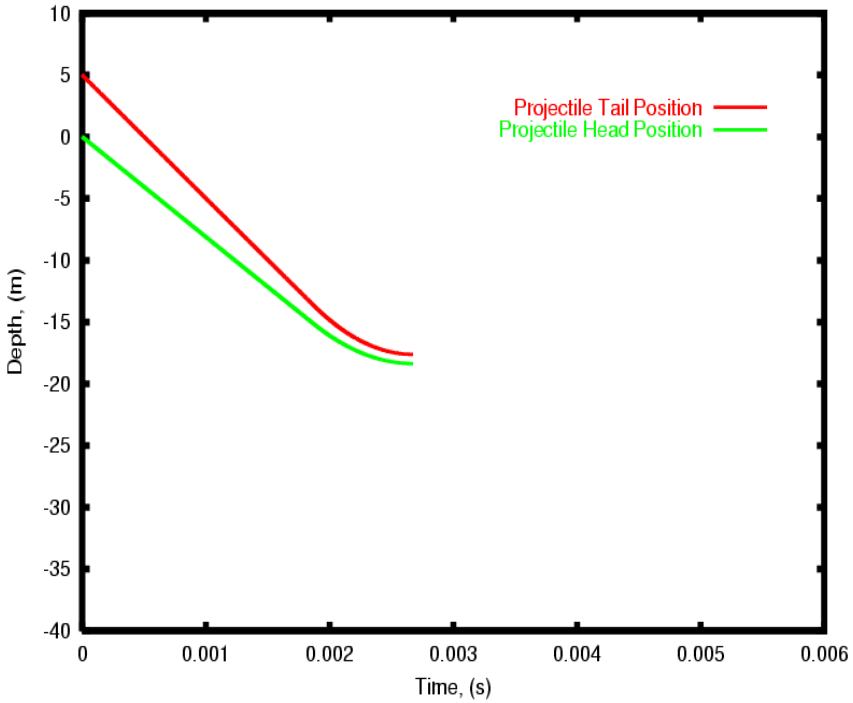
5 m by 2 m Cylinder



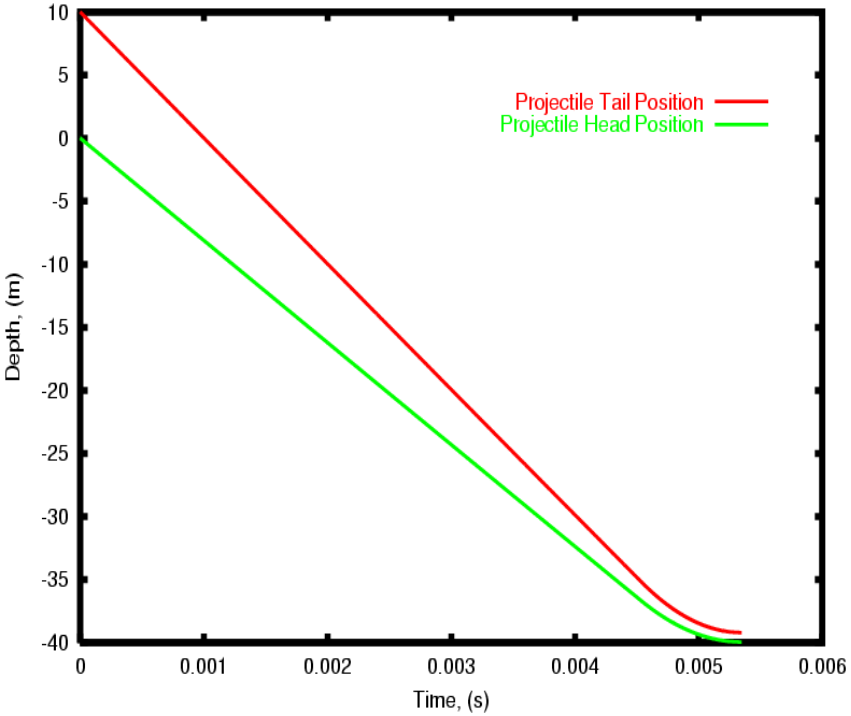
Cylindrical Tungsten projectile impacting a 1.0 g/cm^3 carbonaceous asteroid at 10 km/s

Projectile Length Comparison

5 m by 1 m Cylinder



10 m by 1 m Cylinder



Cylindrical Tungsten projectile impacting a 1.0 g/cm^3 carbonaceous asteroid at 10 km/s

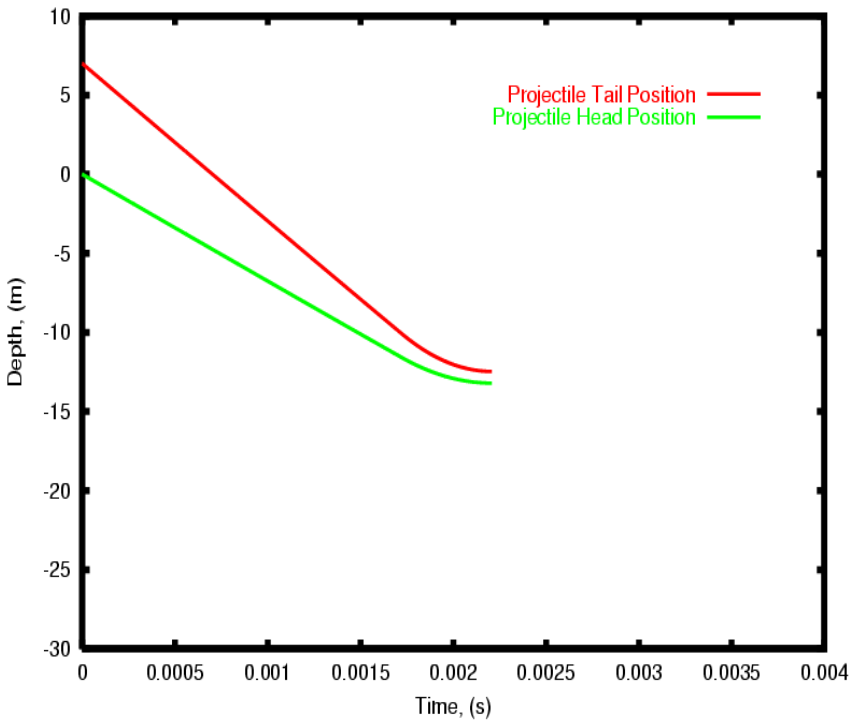
Projectile and Target Composition

- **7 m by 0.75 m cylindrical projectile**
- **10 km/s impact velocity**
- **Results obey hydrostatic limit**

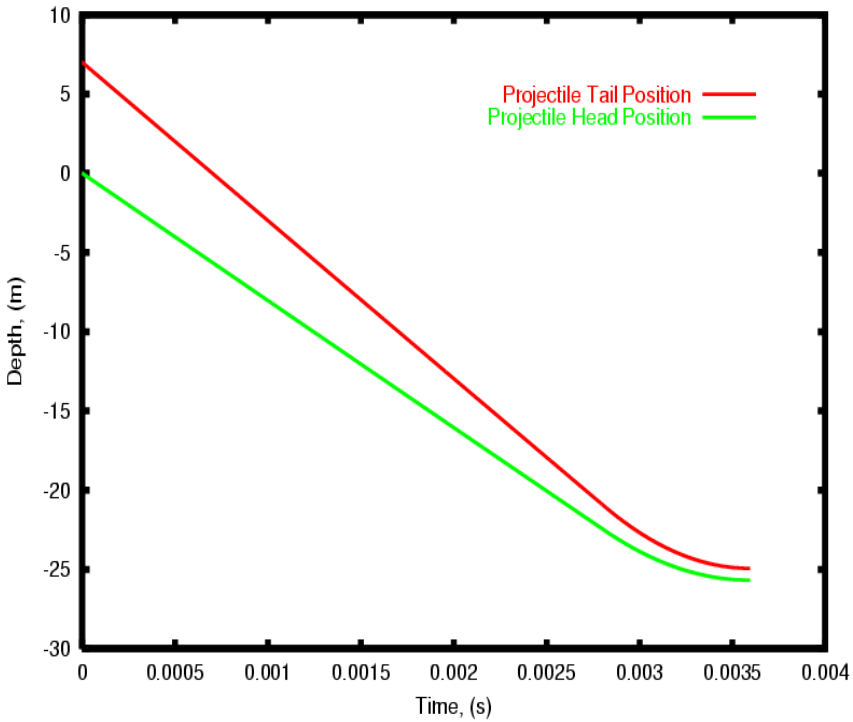
Projectile Composition	Asteroid Composition	Penetration Depth (m)	Cavity Diameter (m)
Tungsten Alloy	Carbonaceous	25.8	14.7
Tungsten Alloy	Silicaceous	17.6	18.6
Tungsten Alloy	Metallic	15.6	19.8
Titanium Alloy	Carbonaceous	14.3	9.8
Titanium Alloy	Silicaceous	9.1	12.7
Titanium Alloy	Metallic	8.1	13.6

Projectile Composition Comparison

Titanium Alloy



Tungsten Alloy



7 m by 0.75 m cylindrical projectile impacting a 2.0 g/cm^3 carbonaceous asteroid at 10 km/s

Results

- Penetration obeys hydrostatic limit
  - Penetration depth requires massive projectiles
  - Long and narrow advantageous within limits
  - Density versus launch capability tradeoff
- Cavity diameter sensitive to projectile diameter and impact velocity
- Penetration restricted by
  - Significantly higher impact velocities
  - Larger projectile diameters

Future Research

- Examine high fidelity hydrocode capabilities for computing results of rigid body motion of asteroid impacts
- Detailed asteroid material compositions
  - Inclusions, cavities, voids, ice
  - Asteroid chemical composition information useful
- Penetration impact on asteroid mass distribution

Summary and Conclusions

- Alekseevskii-Tate
  - Well suited for preliminary analysis
  - Hydrocode model required for deformable body mechanics and detailed simulations
- Penetration profile necessary for explosive predictions, momentum change ability
- Velocity profile necessary for design specifications