United Defense

# Physics Based Modeling of Recoil Dynamics for Light Vehicle Mounted Cannons

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# Motivation for Modeling Firing Dynamics

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- Force Transformation will require powerful cannons mounted on light armored vehicles
- Firing the cannon causes a dynamic response by the vehicle
- The firing impulse causes a large angular reaction (pitch and roll) by the vehicle
- The firing peak force imparts a large acceleration on the vehicle crew
- These angular reactions and crew accelerations must be small enough for the vehicle and crew to fight effectively
- Modeling important tool in designing towards this goal

# Types of Dynamic Models for Firing Dynamics

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- **2 types of models used to predict vehicle stability: detailed DADS models and Physics Based models**
- **DADS (Dynamic Analysis and Design System) model includes higher geometric detail and component compliances, allowing detailed time based simulation**
- **Physics Based model includes lower geometric detail and no compliances, resulting in reduced modeling fidelity. These models allow much quicker analyses and trend studies**
- **Both types of models are physics based – the difference is the level of detail modeled**
- **This presentation focuses on Physics Based models as employed at United Defense for rapid concept development**

# Description of Physics Based Model



- **Model is Spreadsheet Based**
- **Model is designed to be as flexible as possible**
- **Calculation allows either indirect or direct fire cannons**
- **Limited or full traverse can be accommodated**
- **Vehicles with or without spades can be modeled**
- **Model can use wheeled or tracked suspensions**
- **Vehicle diagrams show a notional 18 ton tracked vehicle mounting a 155 mm howitzer with full traverse and four spades**
- **Vehicle analyzed in this briefing is more specific: an 18 ton vehicle mounting a 120 mm cannon with full traverse (no spades)**

# Notional Vehicle Free Body Diagram

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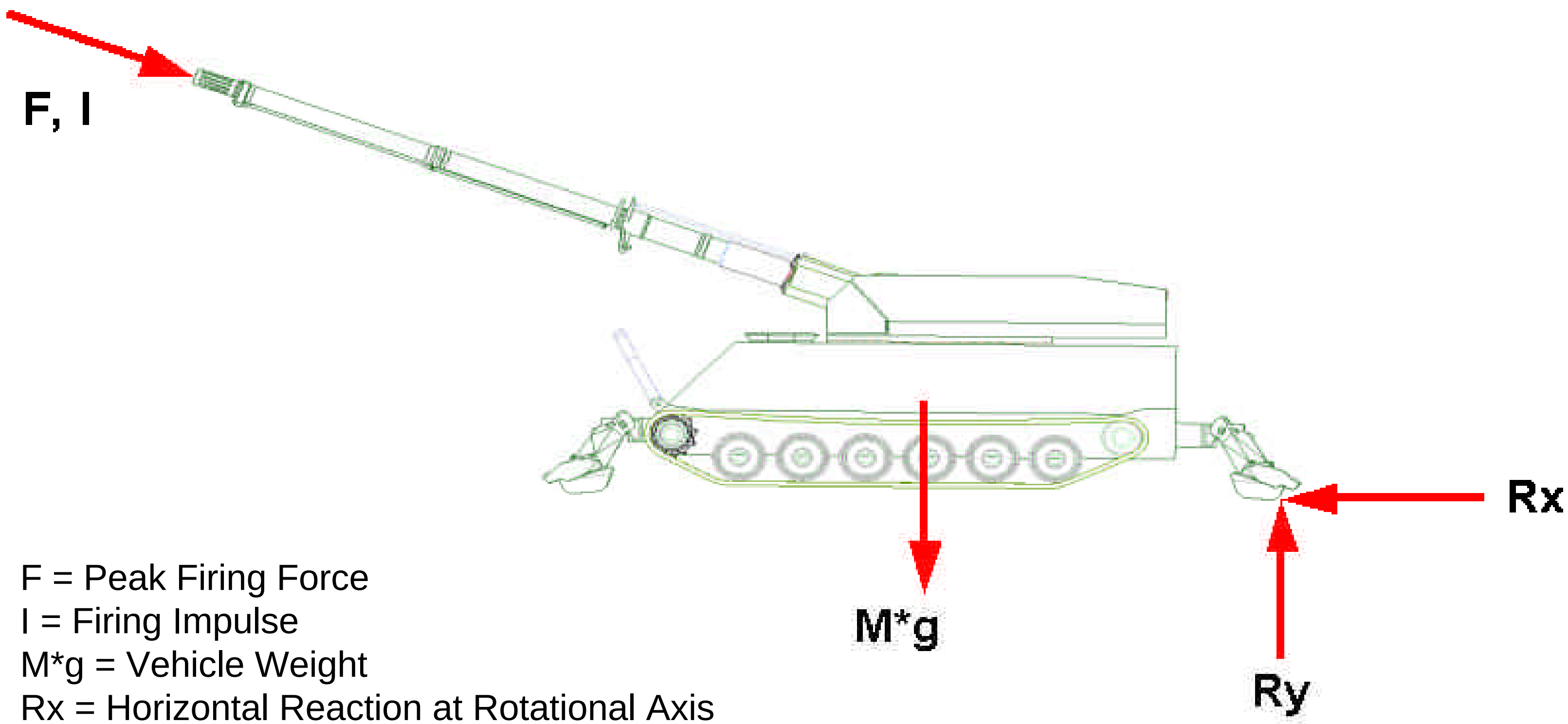


F = Peak Firing Force
I = Firing Impulse
M*g = Vehicle Weight
Rx = Horizontal Reaction at Rotational Axis
Ry = Vertical Reaction at Rotational Axis

# Notional Vehicle Free Body Diagram

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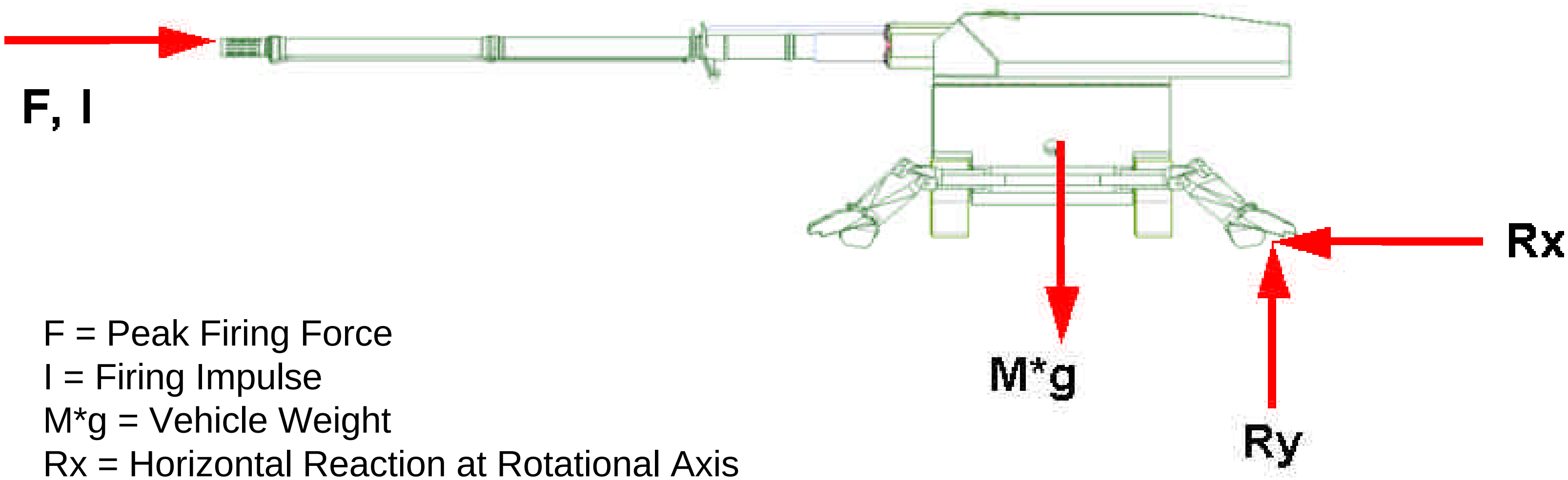


F = Peak Firing Force
I = Firing Impulse
M*g = Vehicle Weight
Rx = Horizontal Reaction at Rotational Axis
Ry = Vertical Reaction at Rotational Axis

# Notional Vehicle Geometric Variables

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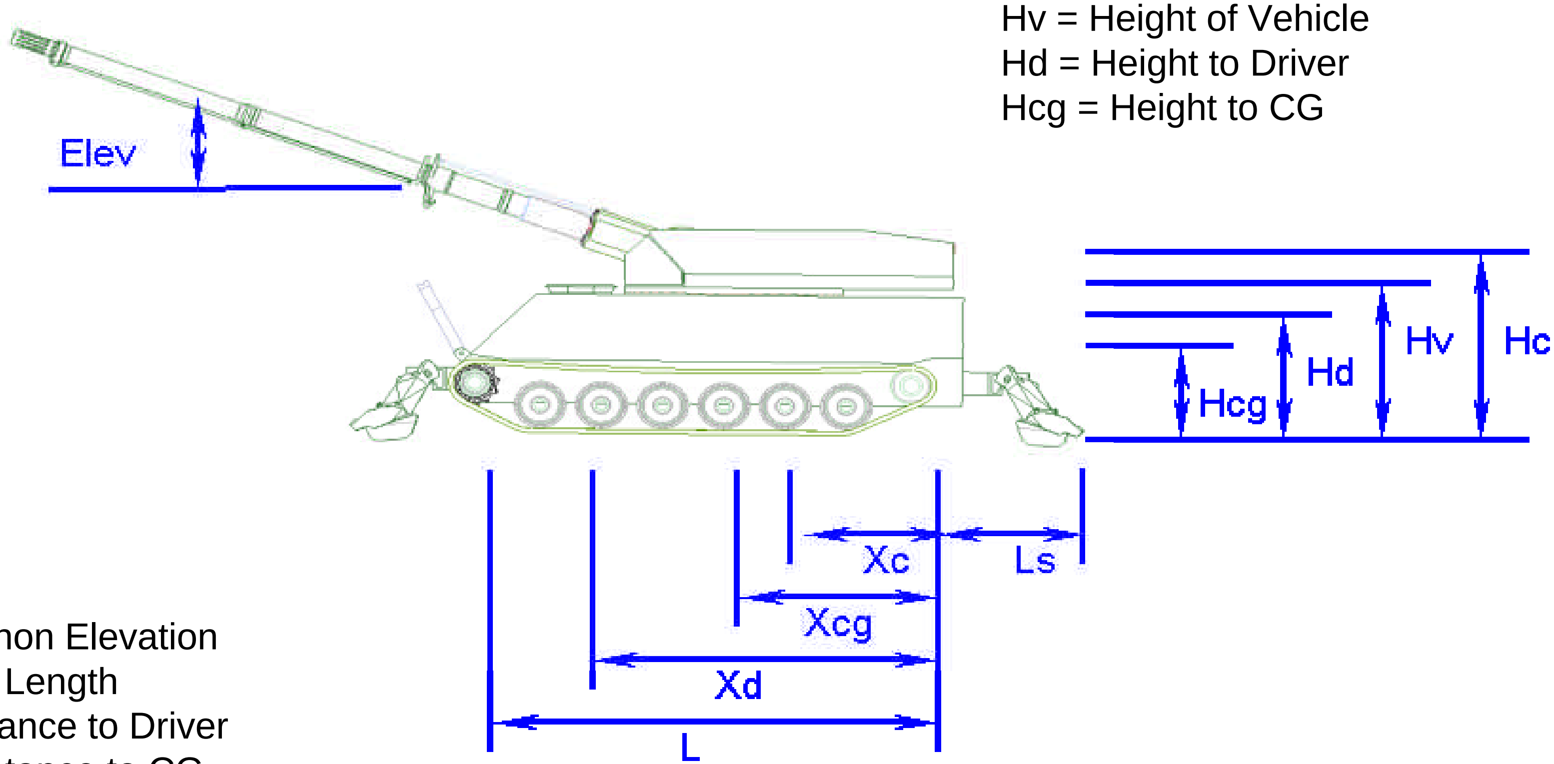
Hc = Height to Cannon Trunions
Hv = Height of Vehicle
Hd = Height to Driver
Hcg = Height to CG




Elev = Cannon Elevation
L = Vehicle Length
Xd = X Distance to Driver
Xcg = X Distance to CG
Xc = X Distance to Cannon Trunions
Ls = Length of Spades

# Notional Vehicle Geometric Variables

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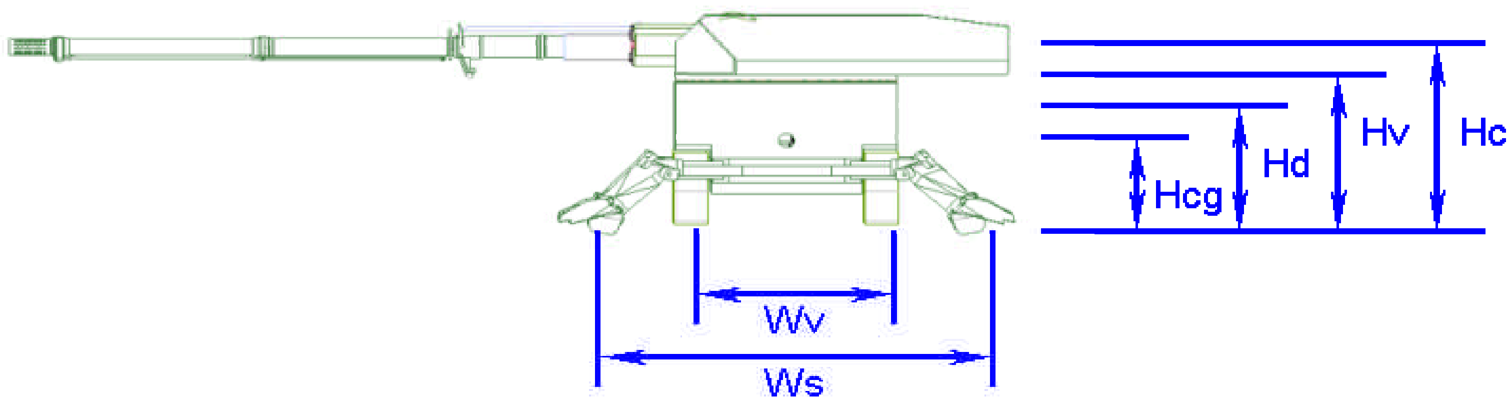


Ws = Width of Spades
Wv = Width of Vehicle

# Physics Based Model
# Method of Calculation

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- Cannon firing impulse and peak trunnion force are the primary inputs
- Cannon elevation, cannon traverse, and vehicle side slope are secondary inputs
- Basic vehicle mass properties, geometry, and spade position then determine vehicle response
- When vehicle does not use spades the ground reaction is where the wheels/tracks contact the ground
- Model assumes no elastic deformation occurs
- Model tuned to correlate with results from test firing data and DADS models

# Calculation of Maximum Vehicle Reaction Angle

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- Use cannon firing impulse to calculate the initial upward angular velocity of the vehicle
- Use conservation of energy to calculate the height that the vehicle CG rises
- Calculate reaction angle that would raise the CG that height
  - this is the maximum reaction angle
- Plot maximum reaction angle vs. cannon firing impulse, a key design parameter

# Calculation of Maximum Crew Acceleration

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- Use cannon peak trunnion force to calculate the rolling moment and horizontal force on vehicle at instant vehicle starts rotation
- Calculate angular and linear acceleration at crew stations
- Calculate the resultant acceleration - this is the maximum crew acceleration
- Plot maximum crew acceleration vs. peak firing force, a key design parameter
- Simulation uses 120 mm cannon fired at high zone: firing impulse of 5700 lbf-sec and recoil stroke of 20 in
- Vehicle is an 8x8 wheeled design with a weight of 18 tons

# Reaction Angle vs. Firing Impulse

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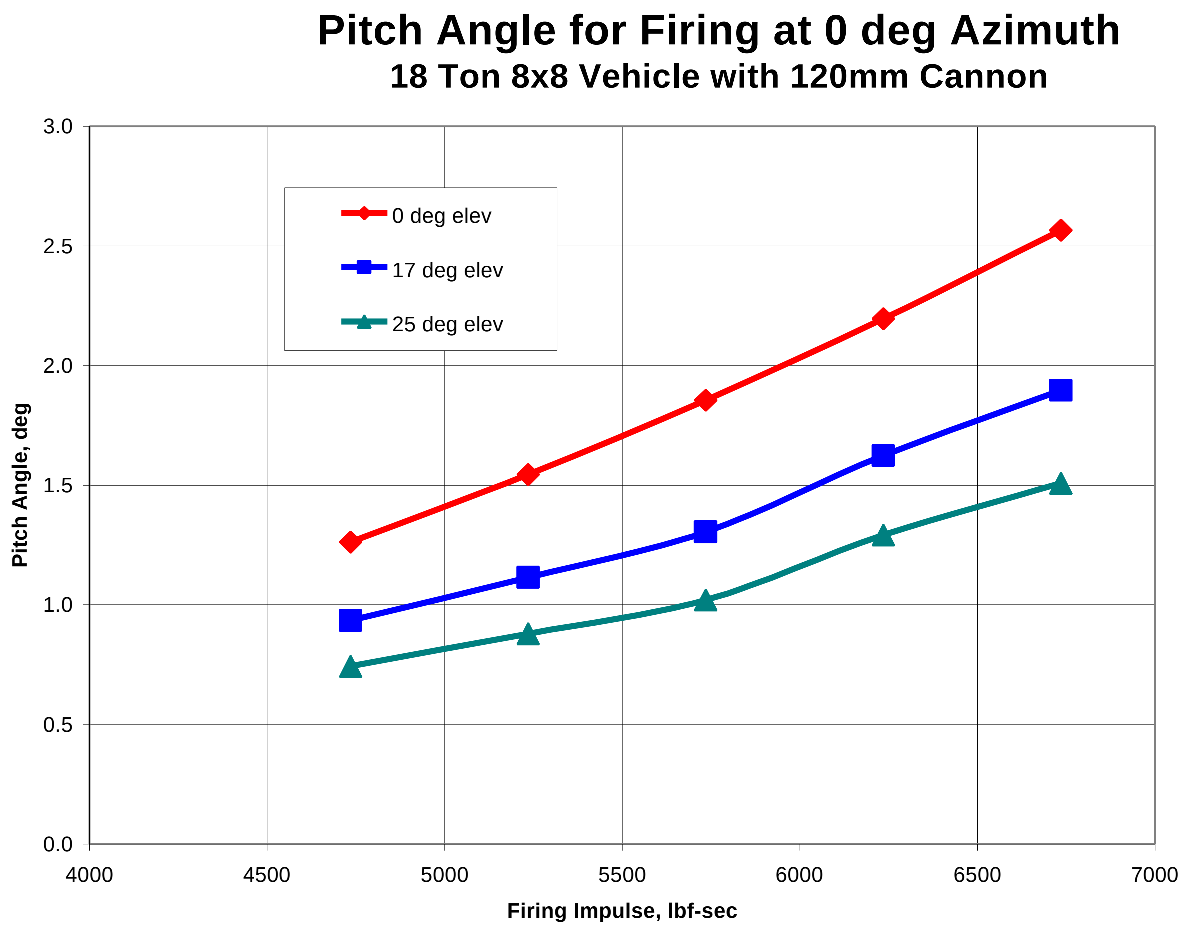

# Crew Acceleration vs. Peak Firing Force

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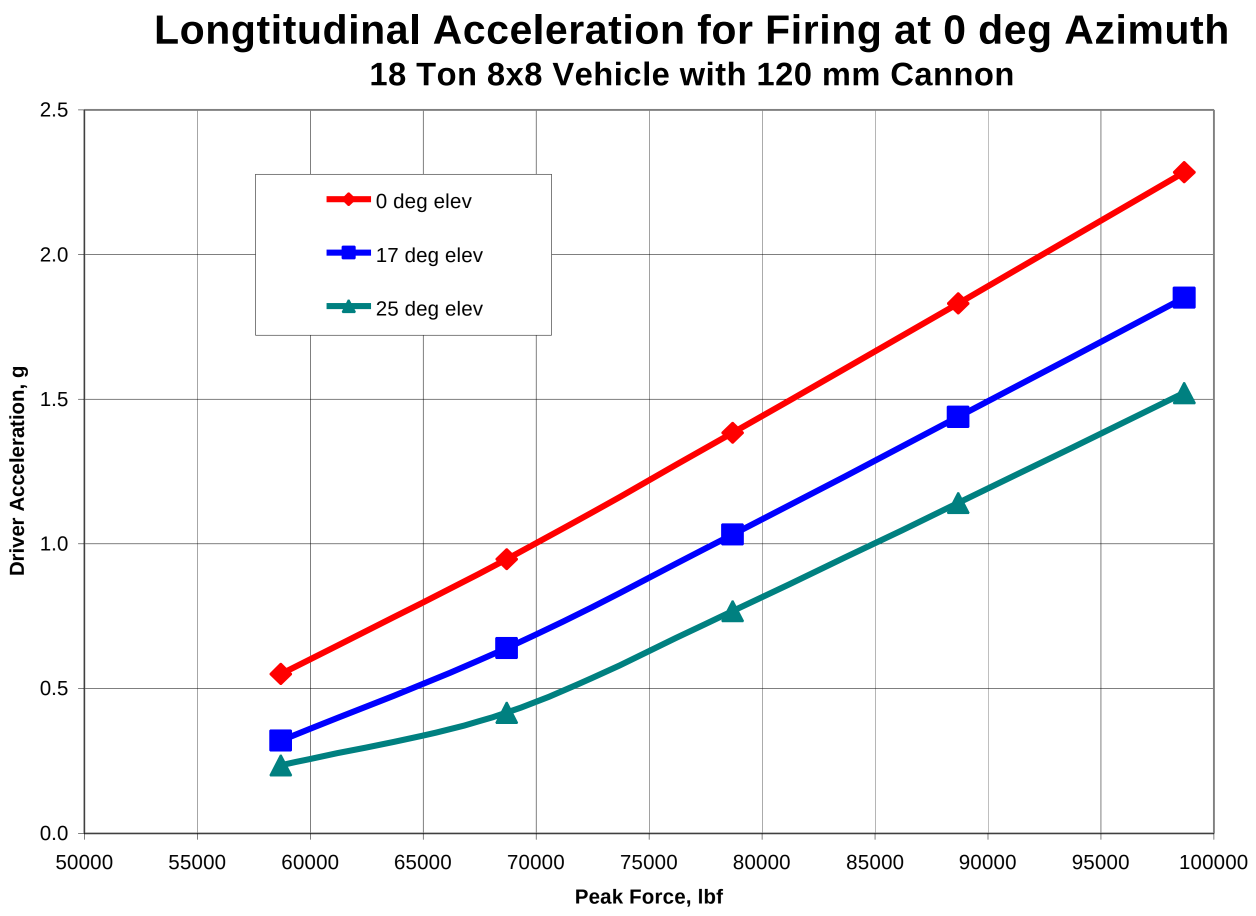

# Analysis of Response at 0 deg Traverse

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- Cannon firing impulse is a key design variable for reducing vehicle reaction angle
- Peak firing force is a key design variable for reducing crew acceleration
- Nominal design has reaction angle of 1.8 deg and a crew acceleration of 1.1 g
- Plots of vehicle response versus other parameters are included in the back-up slides

# Polar Plots of Firing Response

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- Firing response is calculated as a function of traverse
- Results are presented using a polar plot (360 degrees of traverse) showing a top view of the vehicle
- Results are vehicle reaction angle and crew acceleration versus cannon azimuth
- Simulation uses 120 mm cannon with a firing impulse of 5700 lbf-sec and recoil stroke of 20 in
- Two 18 ton vehicle designs are presented:  an 8x8 wheeled design and a tracked design
- Data points from DADS simulations are also plotted

# DADS Simulation: Time Based

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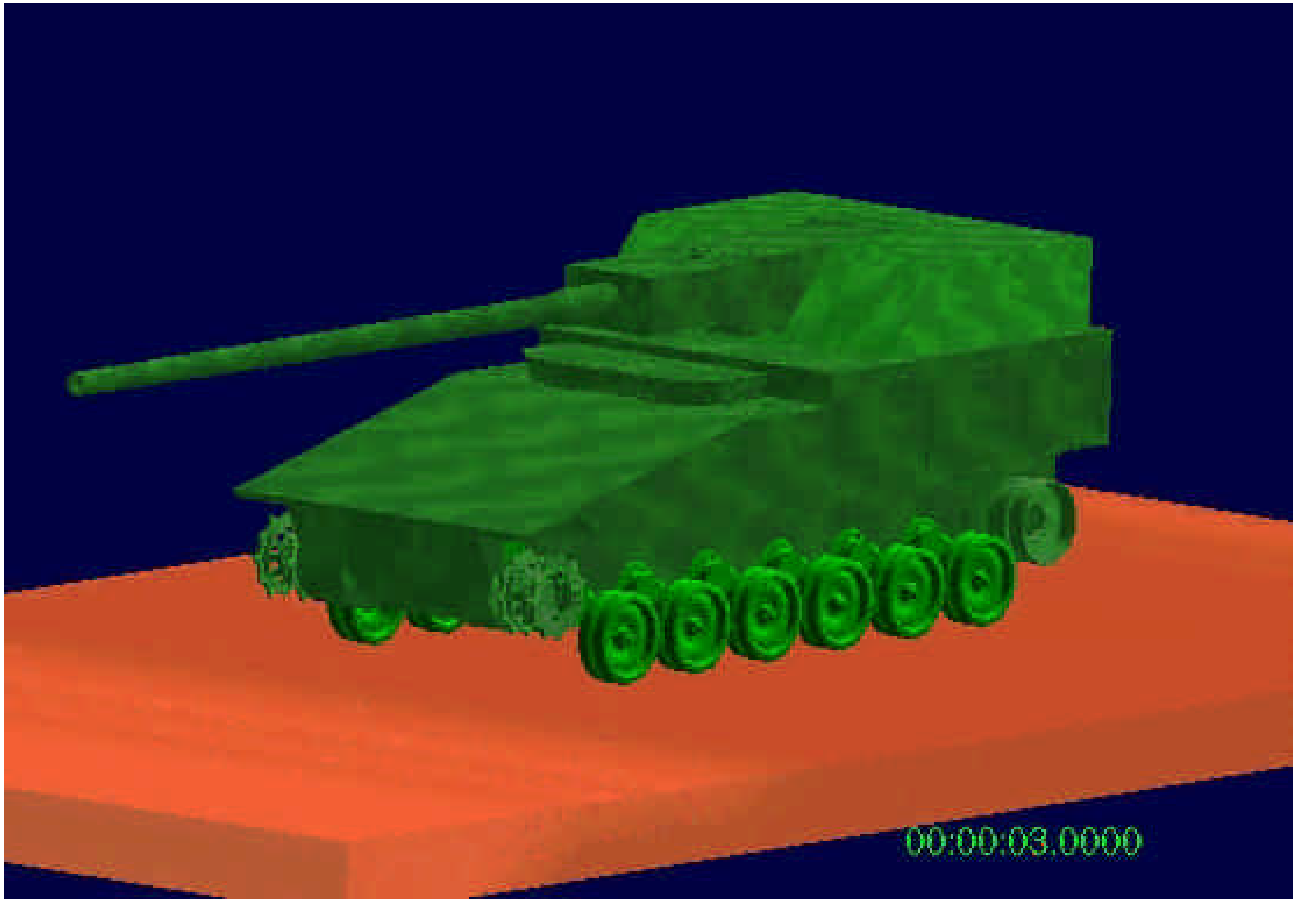

# Reaction Angle for Wheeled Vehicle

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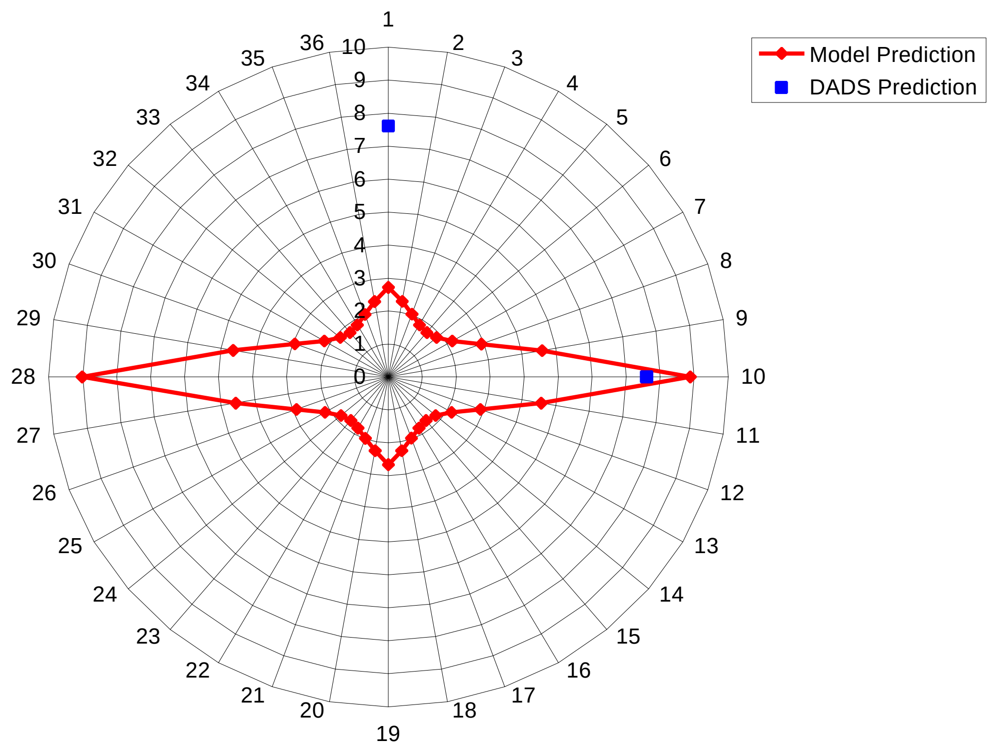
**Reaction Angle versus Azimuth**
**18 Ton Wheeled Vehicle with 120 mm Cannon**



# Reaction Angle for Tracked Vehicle

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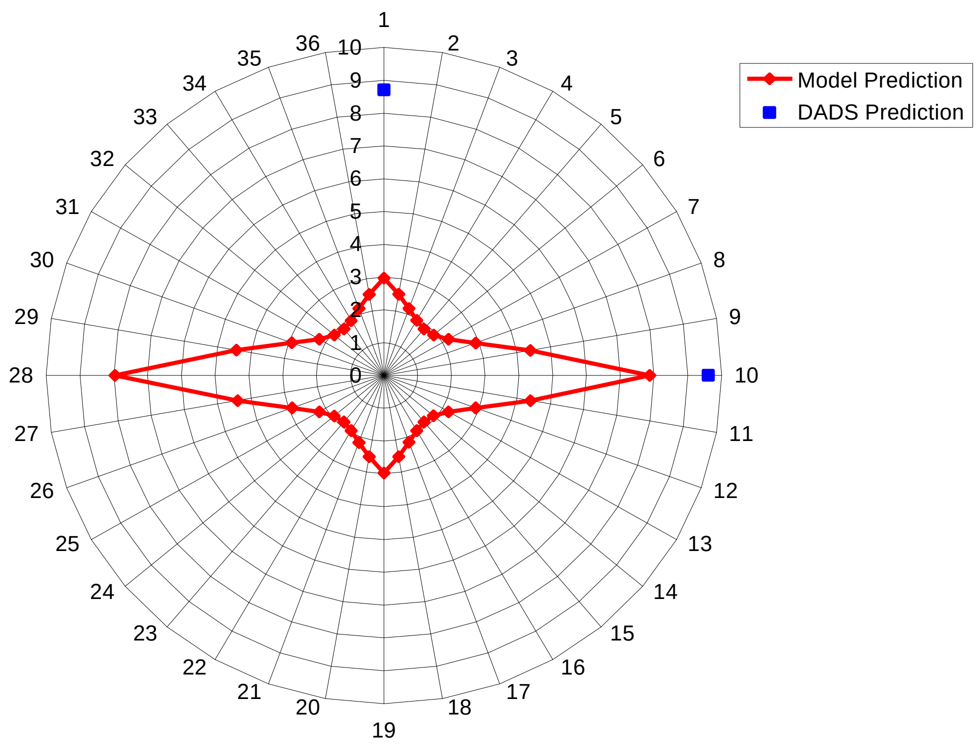
**Reaction Angle versus Azimuth**
**18 Ton Tracked Vehicle with 120 mm Cannon**



# Crew Acceleration for Wheeled Vehicle

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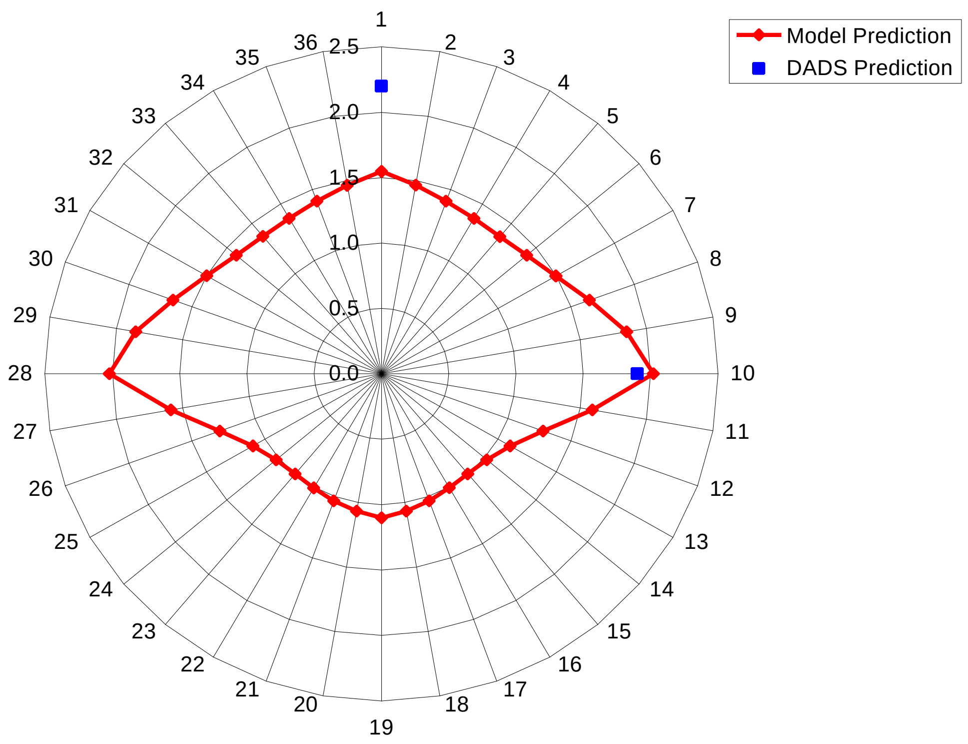
## Driver Acceleration Versus Azimuth
### 18 Ton Wheeled Vehicle with 120 mm Cannon



# Crew Acceleration for Tracked Vehicle

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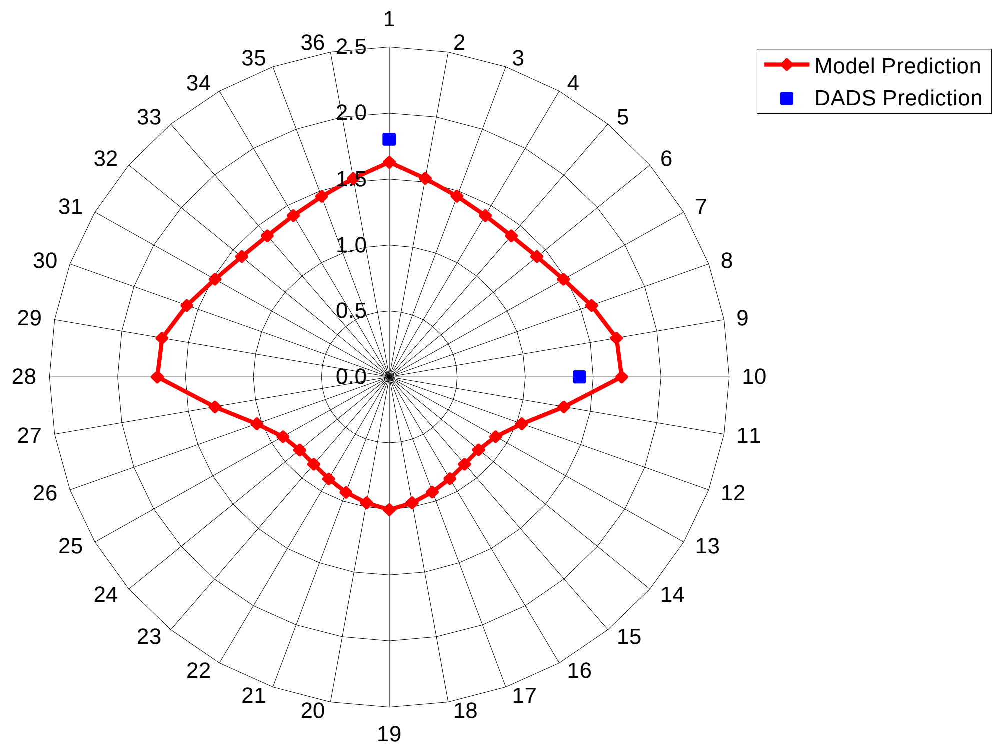
**Driver Acceleration Versus Azimuth**
**18 Ton Tracked Vehicle with 120 mm Cannon**



# Analysis of Response for 360 deg Traverse

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- **Reaction angles increase rapidly as the cannon traverse approaches 90 deg**
- **Crew acceleration is not as affected by cannon traverse**
- **Tracked design has approximately 5% higher reaction angle than the wheeled design**
- **Tracked design has approximately 25% lower crew acceleration than the wheeled design**
- **These results indicate that the tracked vehicle is dynamically more suitable for mounting a cannon**
- **Differences are primarily due to the higher trunion and higher CG locations on the wheeled vehicle design**

# Comparison of Model Results with DADS Analysis

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- **The model predicts lower pitch angles and higher roll angles than the DADS model. This is primarily due to the model assuming a rigid suspension (no springs/dampers), exaggerating the the effects of the long/narrow vehicle footprint on the ground**
- **The model predicts slightly higher crew accelerations than the DADS model, primarily due to the lack of suspension springs/dampers that would reduce peak acceleration values**
- **The Physics Based model can be run very quickly to close in on an approximate answer. The more detailed and lengthy DADS model can be run for more precise results**

# Back-up Slides

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- **Back-up slides show how trend analyses an be performed to define the design space for a light vehicle armed with a cannon**
- **Plot maximum reaction angle vs. different input parameters to display trends**
- **Plot maximum crew acceleration vs. different input parameters to display trends**
- **Simulation uses 120 mm cannon with a firing impulse of 5700 lbf-sec and recoil stroke of 20 in**
- **Vehicle is an 8x8 wheeled design with a weight of 18 tons**

# Reaction Angle vs. Vehicle Mass

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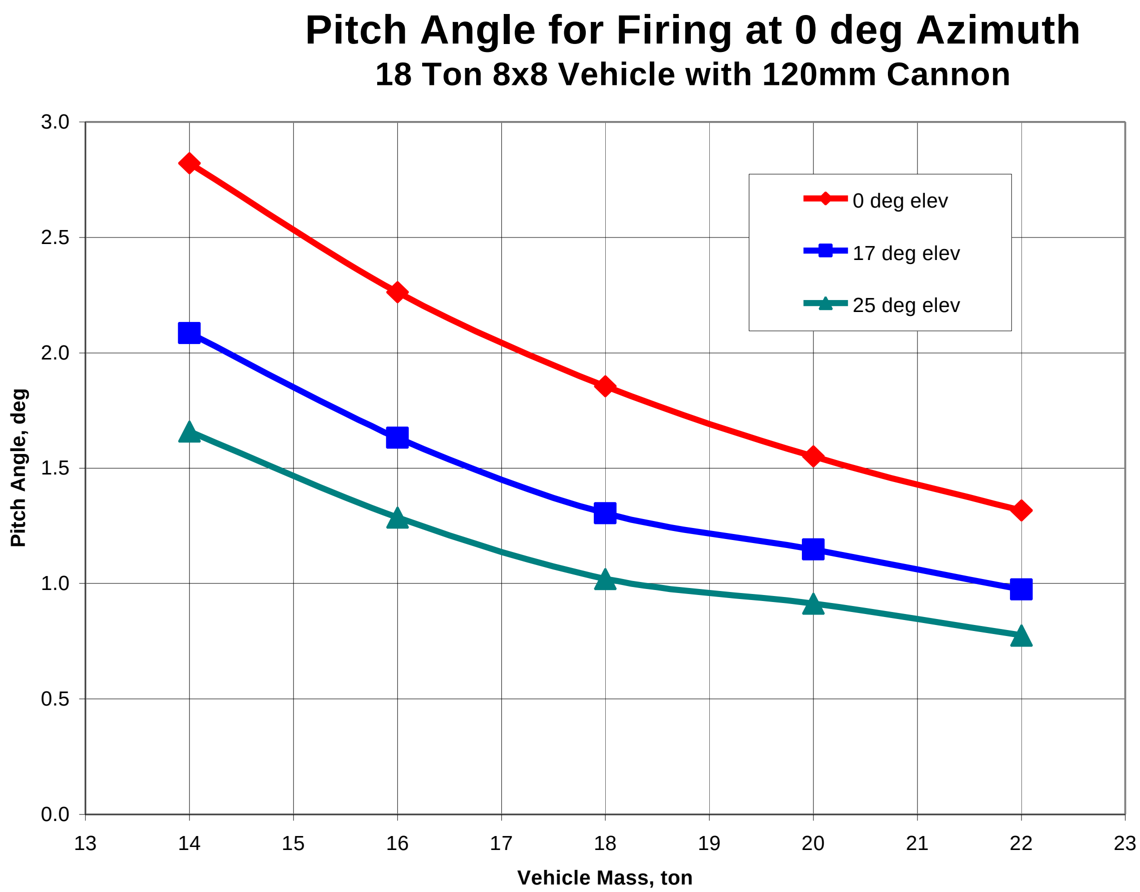

# Reaction Angle vs. Cannon Height

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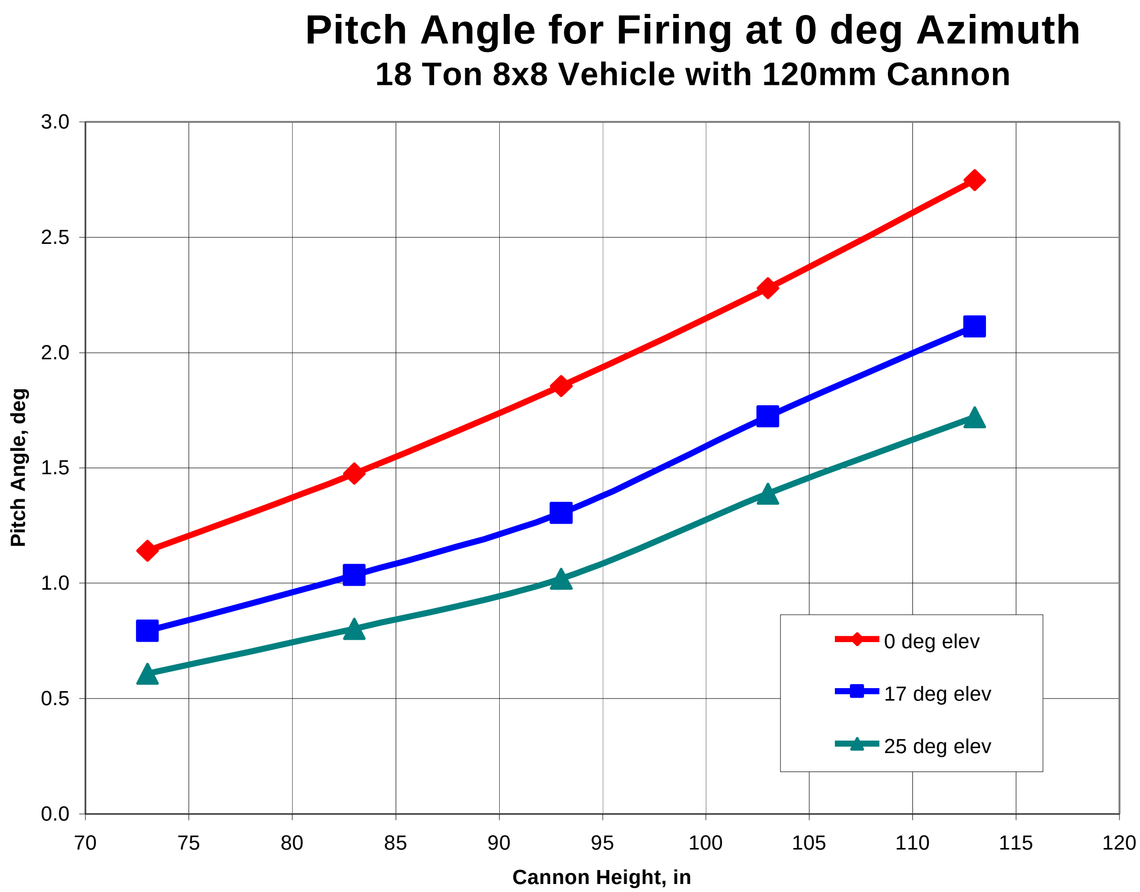
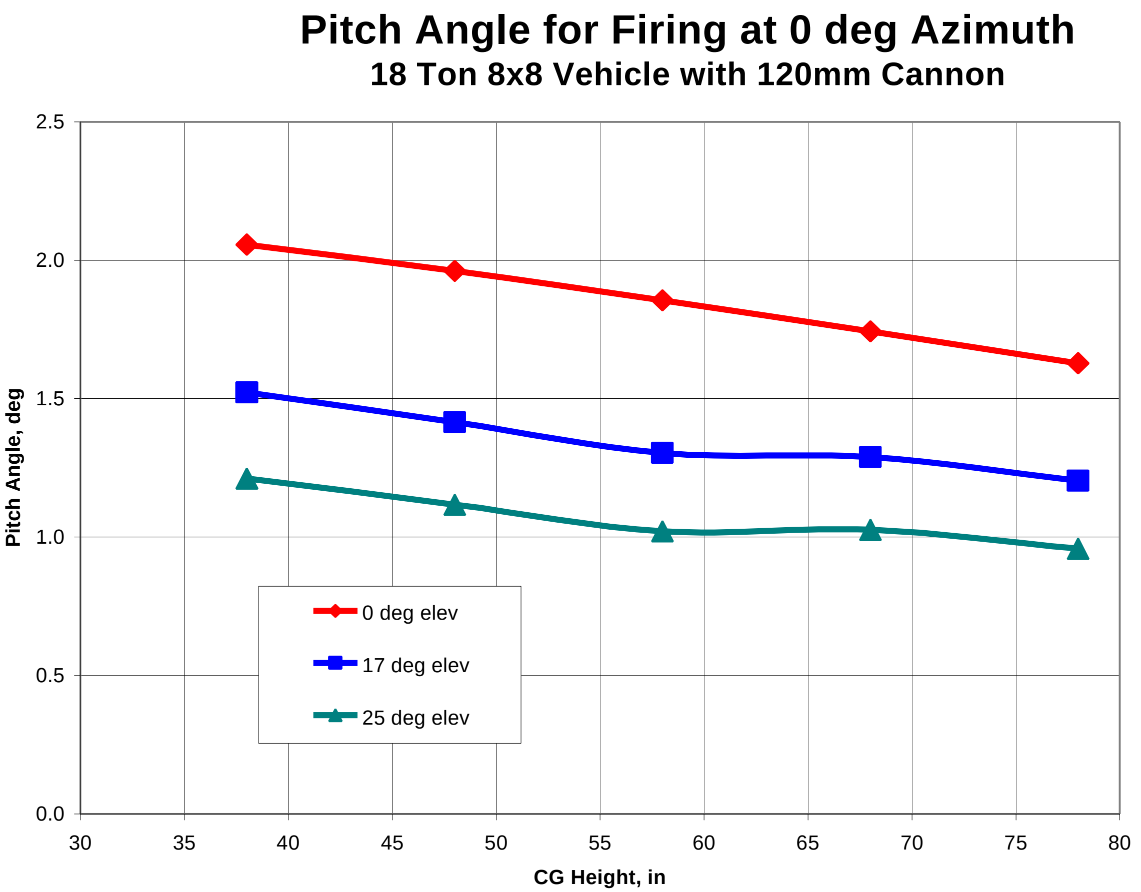


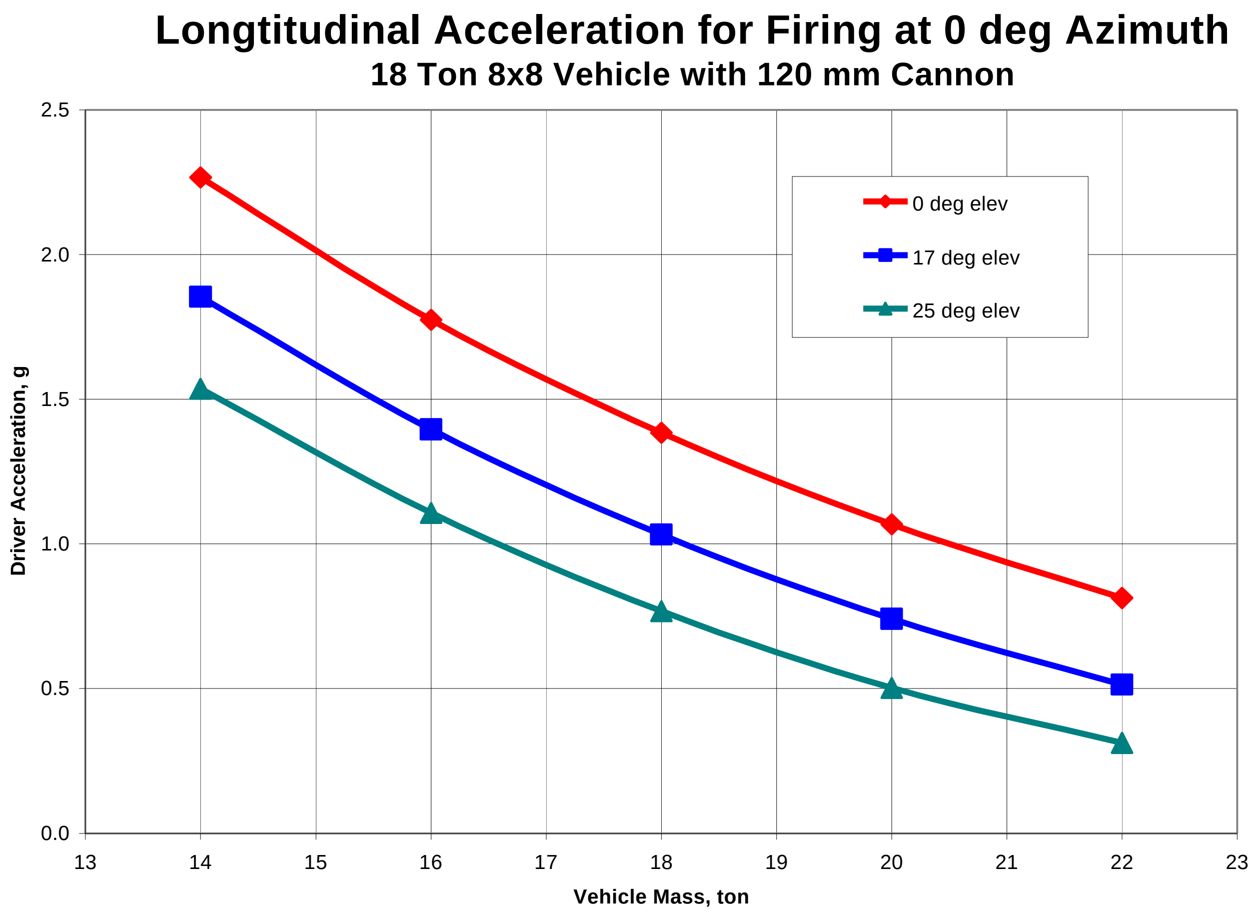
# Reaction Angle vs. CG Height

United Defense



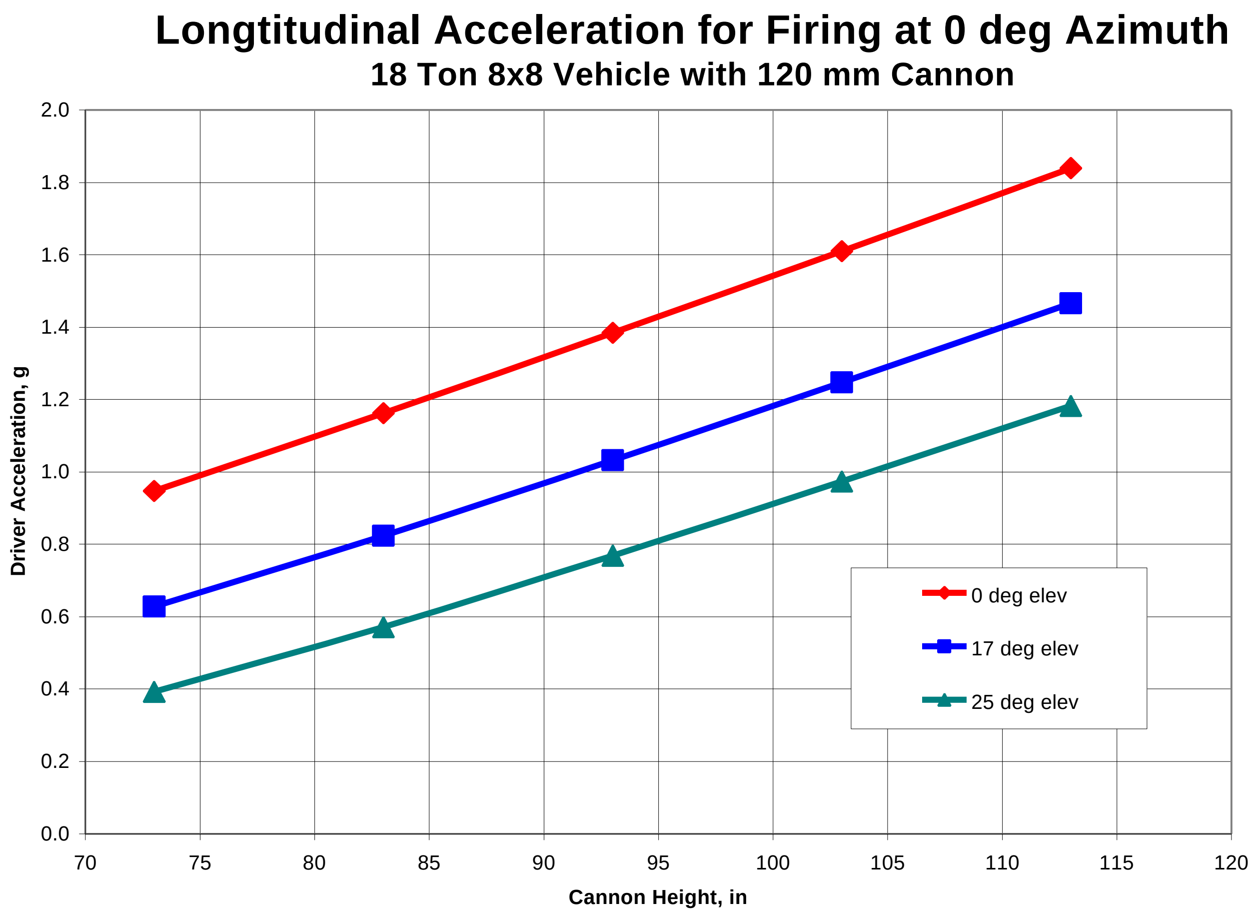
# Crew Acceleration vs. Vehicle Mass

United Defense



# Crew Acceleration vs. Cannon Height

United Defense



# Crew Acceleration vs. CG Height

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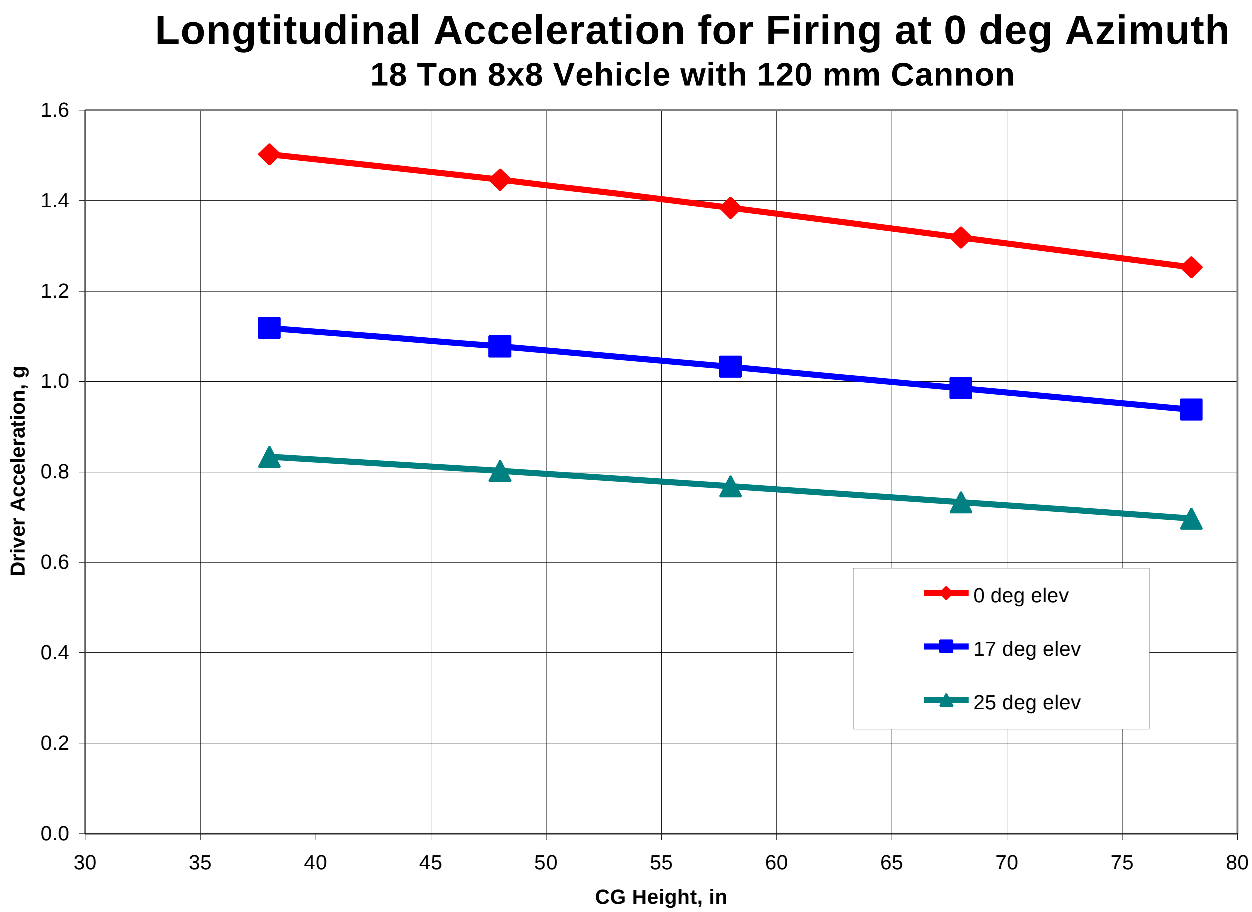

# Trend Analysis at 0 deg Traverse

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- Cannon impulse, elevation angle, and traverse angle are the primary drivers for reaction angle
- Peak trunnion force, elevation angle, and traverse angle are the primary drivers for crew acceleration
- Cannon height is key design variables for reducing reaction angle and crew acceleration
- Vehicle CG height is not as important a design variable
- Nominal design has reaction angle of 1.8 deg and a crew acceleration of 1.1 g