MRAAS Weapon Stabilization Assessment

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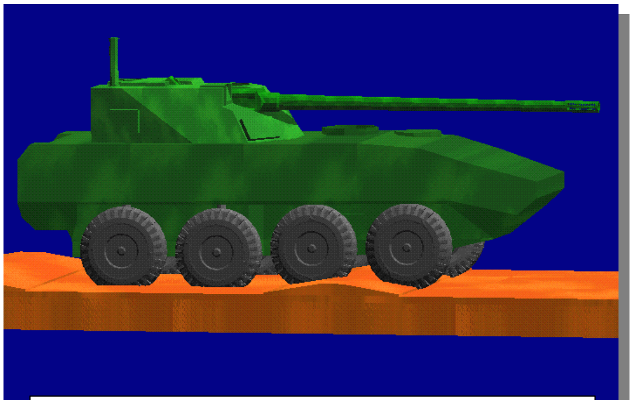
ABSTRACT

The Future Combat System has become the platform of choice for the U.S. Army to lead its transformation to a highly mobile fighting force. Direct and in-direct fire engagement requirements dictate a potential need to mount a large caliber gun system on a relatively lightweight, wheeled vehicle platform. To meet this need, the U.S. Army Armament Research, Development, and Engineering Center initiated development of the Multi-Role Armament and Ammunition System (MRAAS), which consisted of an autoloading 105 mm gun system, mounted on a light ground vehicle with a combined system weight goal of under 19 tons. The integration of a large caliber yet lightweight gun and vehicle system presents many design challenges, particularly in the area of fire on the move weapon stabilization. In this study, concept-level simulations of the MRAAS wheeled vehicle dynamics, gun pointing control system, and armament structural flexure are developed to assess these challenges. Simulated gun pointing disturbance inputs due to vehicle motion over terrain at varying speed are combined with parametric descriptions of expected gun pointing disturbance rejection performance to form initial estimates of gun pointing error. A parametric evaluation of the gun pointing stiffness requirements is also described, evaluating the trade-offs of changes in gun mount and gun drive structural configurations. From these studies, a set of weapon stabilization design requirements is identified. Finally, an MRAAS concept is evaluated by coupling the pointing servo control model with a multibody representation of the armament system mounted on a wheeled vehicle suspension, creating a virtual prototype for rapidly evaluating fire on the move weapon stabilization performance.



MRAAS Stabilization Assessment Model traverses the RRC-9 Stabilization Bump Course

1.0 INTRODUCTION

The 105 mm Multi-Role Armament and Ammunition System was intended to give the Future Combat System both direct fire (Line of Sight – LOS) and indirect fire (Beyond or Non-Line of Sight - BLOS/NLOS) capabilities. Accurate weapon stabilization for the direct fire mission will be the most challenging of the two,

Paper presented at the RTO AVT Symposium on "Functional and Mechanical Integration of Weapons and Land and Air Vehicles", held in Williamsburg, VA, USA, 7-9 June 2004, and published in RTO-MP-AVT-108.

due to the desire for FCS to engage LOS targets out to 4 or 5 km. Achieving kinetic energy kills at that range while firing on the move (FOTM) will require an unprecedented level of pointing accuracy. The MRAAS must do so while meeting a major requirement for FCS: be C-130 transportable, with no more than an 18 to 19 ton total system weight. During MRAAS concepting, it became apparent that these challenges would be complicated by a relatively large gun unbalance (CG offset longitudinally from the trunnion axis) produced in part due to a novel "swing chamber" design feature [1]. United Defense, L.P. was thus tasked by U.S. Army ARDEC to quantify the impact of these effects on weapon pointing stabilization over varying terrain, and subsequent structural design and gun drive power requirements. Although the MRAAS program has since evolved (in a somewhat different configuration) into the FCS Mounted Combat System, the methodology and general results described are still applicable.

1.1 Vehicle Concepts and General Approach

The resulting investigation was accomplished by combining multiple simulation and parametric analysis methods to form a physics-based virtual prototype model of the MRAAS weapon system mounted on a surrogate wheeled chassis. The mass properties and suspension characteristics for two different armament configurations were estimated in an effort to span the potential design range and provide an indication of the sensitivities to gun CG offset. As shown in Figure 1, the offset was varied from a worst case forward position for Concept 1, to a position near the trunnion for Concept 2. A vehicle dynamics model was then developed for each of these configurations to assess fire on the move (FOTM) mobility response, using the general purpose multibody dynamics simulation software DADS. In parallel, a preliminary Gun Pointing Control System (GPCS) model was developed using the MATRIXx controls simulation and analysis software. By combining the gun pointing disturbance predictions from DADS with the expected disturbance rejection transfer function estimated by MATRIXx, a preliminary assessment of gun pointing accuracy was made for different terrains and vehicle speeds. Requirements for the GPCS bandwidth and pointing stiffness could then be derived to meet specified accuracy for a given terrain and vehicle speed. Parametric finite element analysis (FEA) models of the armament and effective gun drive compliance were also developed using NASTRAN software to further explore the feasibility of meeting the pointing stiffness requirement. The final step was to combine the DADS and MATRIXx models via a module of DADS called DADS/Plant, providing a single model coupling the servo control response with the gun and chassis suspension dynamics (similar to the approach described in [2]). By doing so at the concept level, a high fidelity simulation of the weapon stabilization performance was created to evaluate gun pointing accuracy performance and gun drive power requirements at a relatively early design stage.

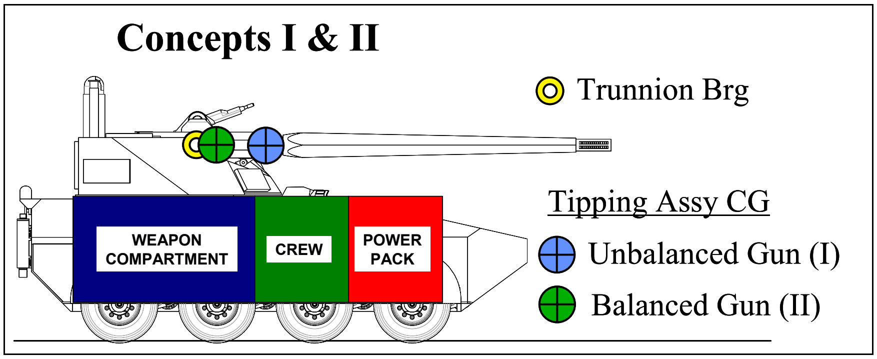


Figure 1: MRAAS Study Concepts

1.2 System Accuracy Requirements

MRAAS weapon stabilization was evaluated against the following main requirements:

- The Fire Control System shall support MRAAS Main Armament Weapon Positioning Error for Line Of Sight engagements (direct fire) under dynamic conditions of no greater than θ_{total} mils elevation and θ_{total} mils azimuth. (1 Standard Deviation).
- Muzzle stabilization error shall be no more than θ_{stab} mils.

Only the elevation axis was studied because of the greater challenge to correct potential disturbances due to gun CG unbalance and the predominance of vehicle pitch motion during mobility. As listed, the requirements have been allocated down to the final gun pointing stabilization requirement, given in 1 standard deviation root mean square (1 σ RMS) error. The values (not shown) reflected the high accuracies required for engagements at 4-5 km, with $\theta_{stab} < \theta_{total}/2$.

The conditions creating the dynamic environment for MRAAS were chosen in terms of vehicle speed and terrain roughness. For this study, the analysis was performed for two varying terrain courses from the U.S. Army Aberdeen Test Center at the Aberdeen Proving Ground (ATC/APG). The relatively smooth ATC Munson Gravel Course and the more severe RRC-9 Stabilization Bump Course (comprised of concrete trapezoidal obstacles of varying heights and spacings) were simulated at vehicle speeds from 5 to 30 mph in an attempt to bound the sensitivity to speed and terrain.

2.0 PARAMETRIC ANALYSIS APPROACH

Initial estimates of the MRAAS gun pointing error RMS were performed parametrically using a stochastic approach. Figure 2 illustrates the data flow for this technique. Vehicle angular pitch and trunnion translational heave (vertical component) acceleration time histories are first predicted using the DADS mobility vehicle dynamics model, simulating one of the vehicle concepts driving over a given course profile, Z(x), at a given speed. The pitch and heave time histories can be combined into a single gun pointing elevation rate disturbance by extracting their components from the equation of motion for the gun body.

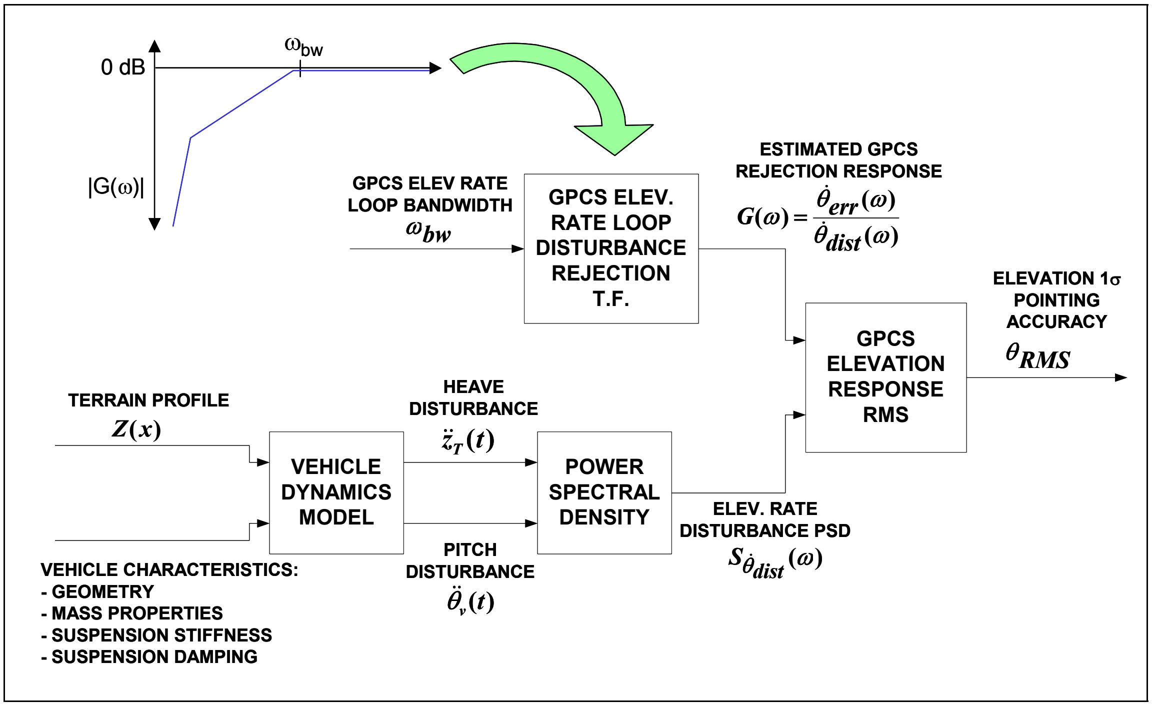


Figure 2: **Stochastic Pointing Error Estimation Approach**

Or, assuming that the gun CG is close to the bore axis,

$$\dot{\theta}_{dist} = \int (\ddot{\theta}_v + \frac{mx_{CG}}{I_T}\ddot{z}_T)dt \quad + \ldots \text{ (negligible terms)} \tag{1}$$

where,

$\dot{\theta}_{dist}$ = Elevation rate disturbance

$\ddot{\theta}_v$ = Vehicle pitch rate (DADS time history)

$\ddot{z}_T$ = Vertical acceleration component at the trunnion (DADS time history)

m = Elevating mass

x_{CG} = Distance from elevating mass CG to trunnion axis

I_T = Elevating mass moment of inertia about trunnion axis

The elevation rate disturbance time history is then converted into the frequency domain by taking the power spectral density (PSD, or equivalently, the mean square spectral density).

The next step in the stochastic process is to estimate the Gun Pointing Control System (GPCS) elevation rate loop disturbance rejection transfer function (TF). Initially, a simplified estimate of a notional disturbance rejection TF was formed using a two pole rationalization of a typical servo error rejection response, or

$$G(\omega) = \frac{\dot{\theta}_{err}(\omega)}{\dot{\theta}_{dist}(\omega)} \cong \frac{s^2}{(s+\omega_{BW})(s+0.1*\omega_{BW})} \tag{2}$$

where,

$\boldsymbol{G}$ = Error rejection frequency response

$\dot{\theta}_{err}$ = Elevation rate error

ω_{BW} = Expected Rate loop bandwidth

The error rejection response was varied parametrically by changing the expected rate loop bandwidth (shown as an input in Figure 2).

Early in the analysis, this method was used to compute a rough order of magnitude estimate of GPCS performance. However, it became clear that the bandwidth required for this type of conventional servo control system would not be achievable in the pointing design. Servo control systems that are subject to base motion disturbance while trying to accurately track a command signal typically use a technique called rate feed forward compensation to improve disturbance rejection [3]. In order to model this characteristic with higher fidelity, a preliminary elevation rate loop control system model was developed in MATRIXx. A better estimate of the feed forward dynamics and resulting error disturbance transfer function could then be made via frequency domain analysis techniques (Bode methods) using MATRIXx analysis tools.

Once the error rejection transfer function was established, the final steps to estimate the rate error and ultimately the 1 σ RMS position error were performed. The process used assumes that the system is linear, and is being excited by a stationary random process. This means that the rate response of the linear system will also be a stationary random process, and the PSD of the position response can then be derived from the rate response PSD per Reference [4] using,

$$\boldsymbol{S}_{\theta} = \frac{1}{\omega^2}\boldsymbol{S}_{\dot{\theta}} = \frac{1}{\omega^2}\left|\boldsymbol{G}(\omega)\right|^2 \boldsymbol{S}_{\dot{\theta}\,dist} \tag{3}$$

where,

$\boldsymbol{S}_{\theta}$ = Elevation position error PSD

$\boldsymbol{S}_{\dot{\theta}}$ = Elevation rate error PSD

$\boldsymbol{S}_{\dot{\theta}\,dist}$ = Elevation rate disturbance PSD

Then, the 1 σ RMS pointing error was found by integrating the position error across the frequency range of interest (assuming zero mean), or

$$\theta_{RMS} = \sqrt{\int \boldsymbol{S}_{\theta} d\omega} \tag{4}$$

Using this method and varying the bandwidth assumption parametrically, estimates of the GPCS bandwidths required to meet a range of given accuracy levels were established for each vehicle configuration, at each speed and terrain combination. The MRAAS mobility disturbance PSD inputs are described next in Section 2.1. The estimated disturbance rejection transfer functions derived from the MATRIXx model are developed in Section 2.2. Results generated using this stochastic approach are then presented in Section 2.3.

2.1 Vehicle Dynamics Modeling (DADS)

The DADS vehicle dynamics model free body diagram is presented in Figure 3. Each DADS rigid body model contained separate bodies for the recoiling assembly, gun mount, turret, chassis, and wheel assemblies. The armament bodies were then connected to the turret using either a bracket joint or revolute joint, depending on whether the GPCS elevation stabilization response was modeled. The turret was typically fixed to the chassis through a bracket joint.

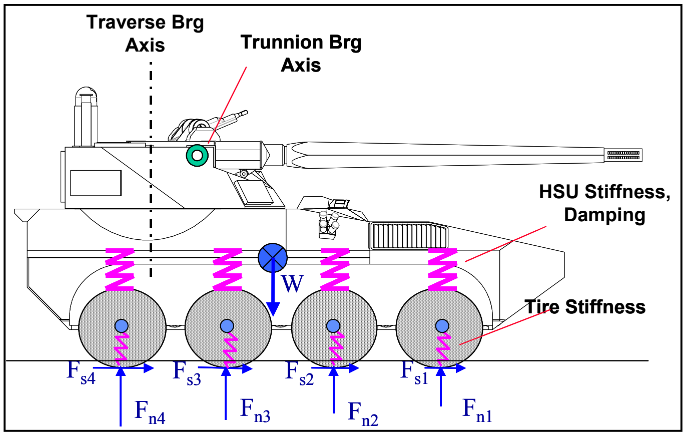


Figure 3: **Vehicle Dynamics Model Free Body Diagram**

The MRAAS suspension was modeled assuming a simplified 8-wheeled configuration. Non-linear stiffness and damping characteristics were estimated from similar vehicle classes to reflect hydropneumatic suspension unit (HSU) characteristics. A combination of spring and DADS Tire Elements were used to model the preload, stiffness and damping for each HSU and tire assembly. For MRAAS, model parameters were chosen to produce suspension modes near 1.5 Hz heave (vertical translation) and 0.75 Hz pitch (rotation), with near critical damping to reflect typical high mobility performance. As discussed, time histories of the heave and pitch accelerations were measured in the DADS simulations, as the vehicle concepts were driven at varying speeds. The time histories were then converted to PSD's for the stabilization assessment.

For illustration, Figure 4 indicates the vehicle pitch rate disturbance PSD data generated for Concept I at 5, 10, 20, and 30 mph. The predominant pitch mode can be seen as the middle peak, occurring roughly between 0.75 and 1.0 Hz. As expected, the RRC-9 course shows about 2 orders of magnitude more vehicle response

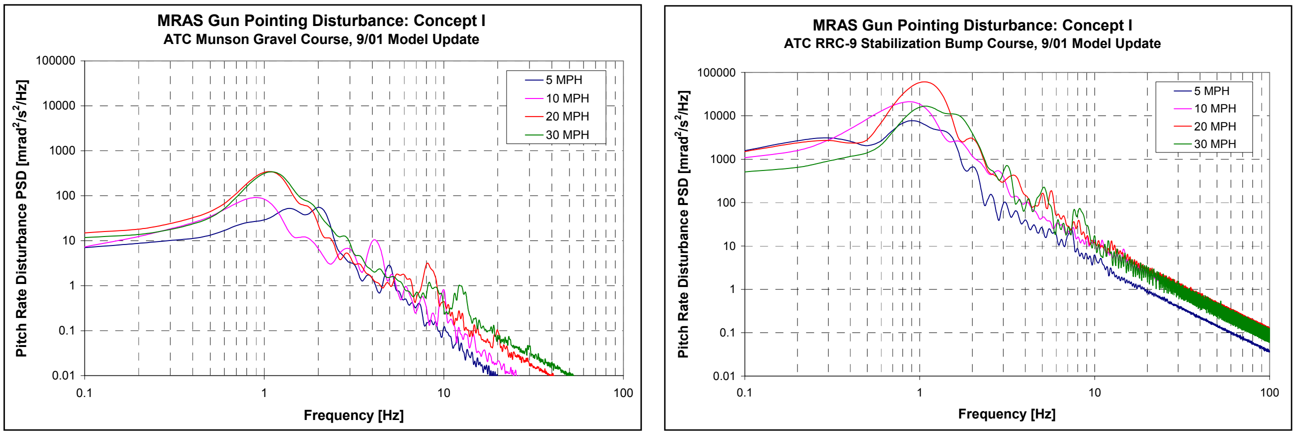


Figure 4: **Vehicle Pitch Rate Disturbance PSD's: ATC Munson and RRC-9 Courses**

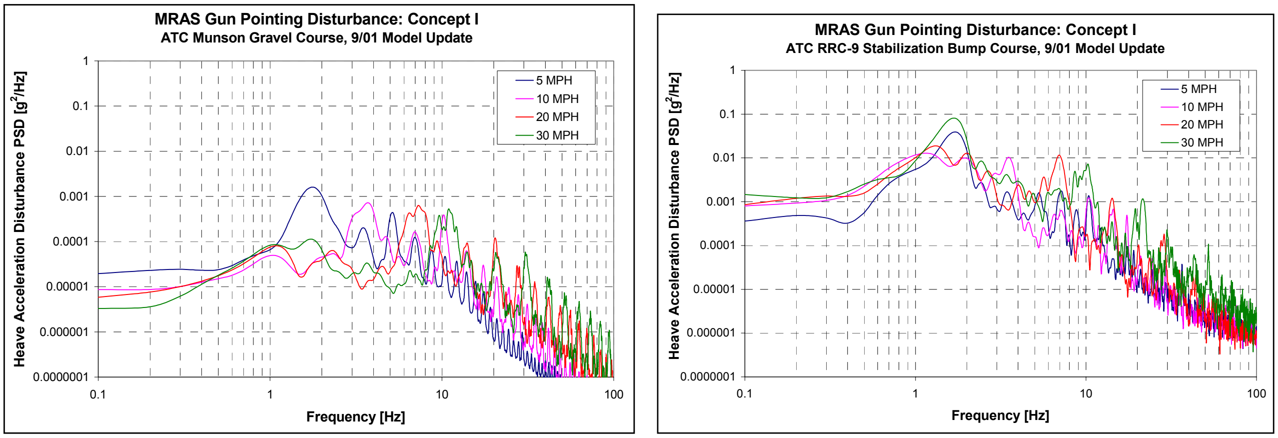


Figure 5: Vehicle Heave Acceleration Disturbance PSD's: ATC Munson and RRC-9 Courses

than the gravel course. Figure 5 then provides PSD comparisons of the heave acceleration at the trunnion. The heave acceleration PSD's verify that the suspension heave mode will be close to 1.5 Hz, with the bump course again producing 2 orders of magnitude higher response than the gravel course. Similar simulation data was produced for the two vehicle configurations over both courses at the different vehicle speeds.

2.2 Gun Pointing Control System Modeling (MATRIXx)

Initial pointing assessment using the simplified error rejection transfer function described by Eq. 2 clearly indicated that the specified pointing accuracy would likely not be achievable for MRAAS, without using some form of platform rate feed forward compensation. This is typical for most high accuracy pointing control systems subject to significant base motion disturbances. To look at the possible increases in performance and improve the fidelity of the accuracy predictions, a preliminary model of the elevation rate loop was created using MATRIXx. As discussed, this model was initially used to create a transfer function of the error rejection performance of the elevation axis that included the effects of rate feed forward compensation. Including the feed forward effect was not straightforward to do with the simplified model of Eq. 2.

The preliminary Elevation Gun Pointing Control System (GPCS) model created consisted of an outer gyro inertial rate loop, wrapped around an inner motor relative rate loop. Both loops contained proportional plus integral (P+I) compensation to improve tracking and provide steady state error removal. As indicated in Figure 6, The outer rate loop compared the inertial load rate provided by a rate gyro sensor (fixed to the weapon) with an inertial rate loop command. For a direct fire weapon, the inertial rate loop command would typically be formed via the target tracking rate from a stabilized electro-optic sight (e.g. gun slaved to sight). The difference between the inertial load rate and the command formed the inertial rate error, which was passed through a P+I compensator to form a motor relative rate command. This command was reflected to the relative motor rate by a notional 1000:1 gear ratio, used to approximate a reasonable motor-to-load gear reduction. The scaled rate command was then passed through a notch filter, required to remove the gun pointing mechanical resonance from the control response. The resulting filtered motor rate command provides the reference input to the inner motor rate loop.

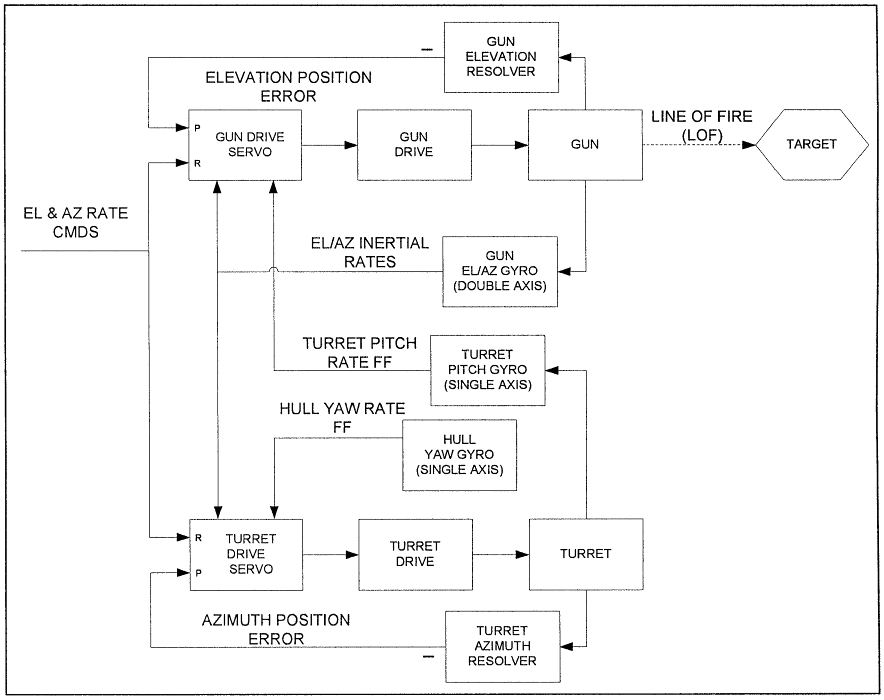


Figure 6: **Gun Pointing Control System (GPCS) Diagram**

The feed forward compensation assumes a rate gyro or equivalent sensor will be in the turret to provide measurement of the body fixed vehicle rates. These base rates were filtered (to simulate sensor roll-off) and applied as a canceling rate command to the filtered motor rate command from the outer loop. By comparing the sum of these two signals with the derived motor relative rate feedback (typically derived from the motor resolver), the motor rate loop error was formed. Passing the motor rate error through the inner loop P+I compensator generated the motor torque command. In this way, the outer inertial rate loop wrapped around the inner relative motor rate loop and formed the core pointing control algorithm that would be used to stabilize the weapon for direct fire operation.

To estimate the vehicle disturbance rejection performance, a frequency response of the Elevation GPCS load rate response due to a base rate disturbance was performed using the MATRIXx model. Figure 7 shows the resulting Bode magnitude plot of the disturbance rejection performance achievable assuming hull rate feed forward compensation. With feed forward, the amount of disturbance reduction achievable at 1 Hz is about -42 dB, or a factor of 125 reduction. This means for a 10 mrad/sec RMS vehicle pitch rate disturbance at 1 Hz, the GPCS could achieve up to 0.08 mrad/sec RMS pointing error in elevation. For use with the disturbance PSD’s, curve fits of the Bode magnitude plots were used to form rationalized polynomials of the disturbance rejection transfer functions, replacing the simplified $G(\omega)$ in Eq. 2.

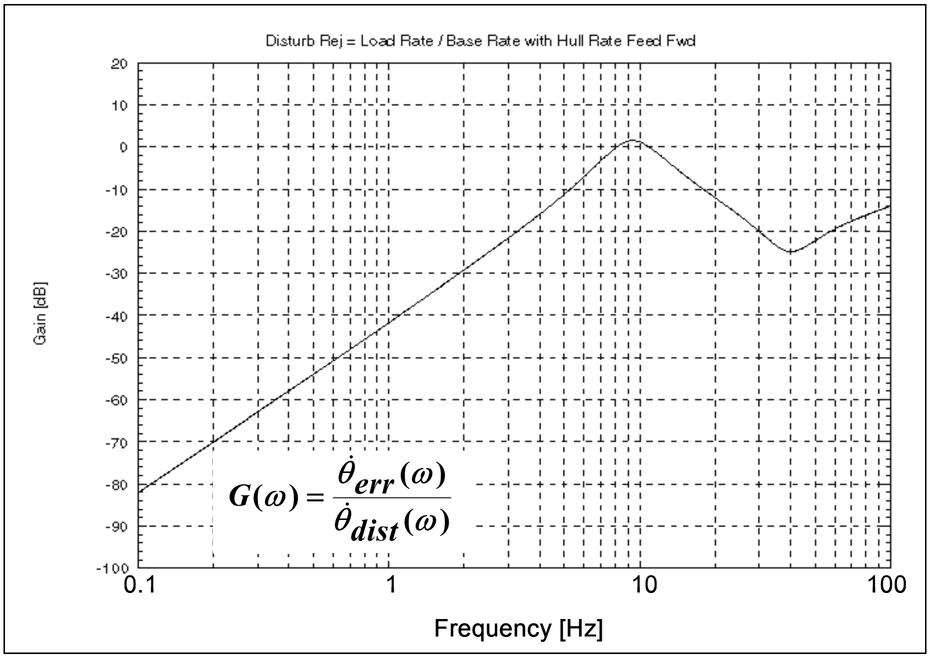


Figure 7: Elevation Disturbance Rejection With Hull Rate Feed Forward

2.3 Stochastic Pointing Error Estimation

After using the MATRIXx model to replace the simplified transfer function of Eq. 2, improved estimates of MRAAS pointing accuracy were made by combining the new transfer function in the frequency domain with the vehicle disturbance PSD's, using the relationship in Eq. 3. The resulting RMS accuracy could then be determined from Eq. 4. The diagram in Figure 2 further describes the steps in this process.

An advantage of this method is the ability to easily scale the transfer function for different gun pointing natural frequency and rate loop bandwidth. In general, the frequency response shape should be fairly consistent as the bandwidth and natural frequency change. Therefore, at the concept level it was acceptable to scale the disturbance rejection as a function of the shift in frequency to quickly assess the performance variation. The bandwidth required to meet each level of accuracy was determined by scaling the original transfer function, which assumed a 4 Hz minimum rate loop bandwidth with a 10 Hz locked rotor pointing first mode.

Figures 8 and 9 show the results from this approach for MRAAS Concepts I and II, which indicates the controller performance (in terms of rate loop bandwidth) required to meet various levels of pointing accuracy over the ATC Munson Gravel Course and the RRC-9 Stabilization Bump Course. In general, the results for both concepts show how the performance degrades as the terrain roughness and vehicle speed increase. For example, Figure 8 indicates for Concept I to meet a 0.4 mrad RMS pointing accuracy at 20 mph on the RRC-9 course, the GPCS will require an elevation rate loop bandwidth near 5 Hz. At 30 mph with the same bandwidth, the pointing error will degrade to 0.55 mrad.

Removing the large CG offset of the tipping parts for Concept I would significantly improve gun pointing performance, as indicated by the performance for the balanced gun Concept II shown in Figure 9, particularly over the more severe RRC-9 Bump Course. Balancing the gun CG at the trunnion would reduce the bandwidth and pointing stiffness requirements necessary to meet 0.4 mrad accuracy at 20 mph from 5 Hz to about 3.75 Hz, or approximately 25%. Conversely, for equivalent 5 Hz systems, balancing the CG would reduce pointing error from 0.4 mrad to 0.2 mrad, for up to 50% reduction over rough terrain. Based on control system design experience for high performance systems, the design goal for the gun pointing first mode should be a factor of 2.5 to 3 times higher than the rate loop bandwidth for good stability margins and performance. While these are preliminary results for single point design concepts, they illustrate the importance of maintaining overall armament, turret, and gun drive stiffness.

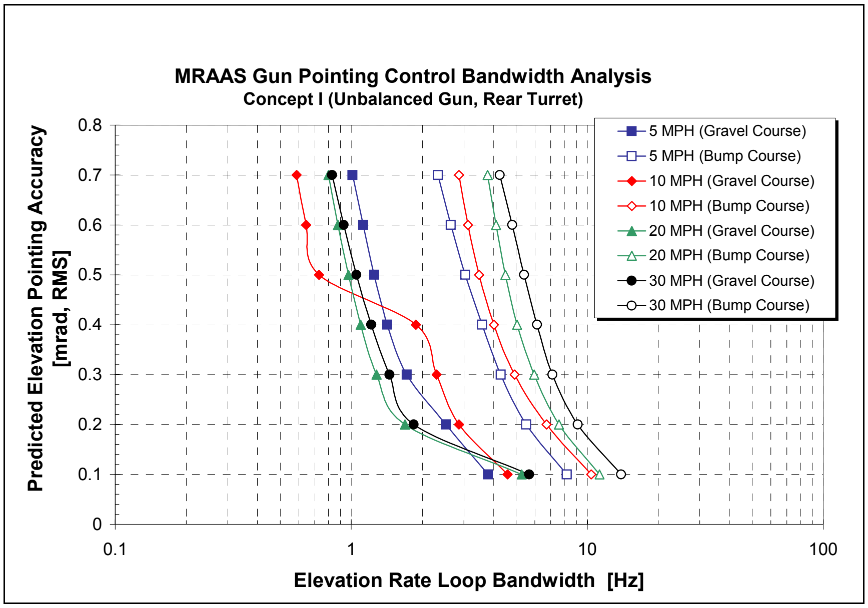


Figure 8: Pointing Accuracy Sensitivity to Terrain and Speed: Concept I

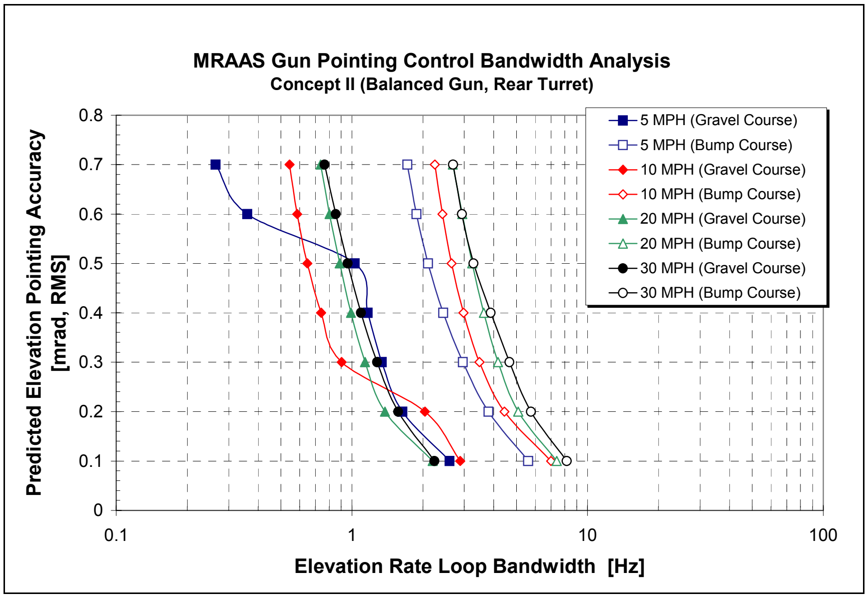


Figure 9: Pointing Accuracy Sensitivity to Terrain and Speed: Concept II

3.0 PLATFORM STABILITY ANALYSIS (DADS/PLANT)

As stated, the main advantage of the parametric method is the ability to quickly analyze multiple configurations, vehicle speeds, and terrains. The level of fidelity represented is appropriate for the concept-level stage, and was agreed to be the best approach for handling the wide range of simulations required for the assessment. However, it assumes that the gun pointing dynamics will not influence the vehicle motion (e.g. they are uncoupled). The next level of fidelity is to couple the suspension dynamics and gun pointing servo control dynamics in a single model. To evaluate the importance of this interaction and also verify the parametric method, the DADS vehicle dynamics model was dynamically coupled with the MATRIXx gun pointing control model via a module of DADS called DADS/Plant [5]. As indicated in Figure 10, DADS/Plant provides an interface between the two models, transferring control forces and torques from MATRIXx to the DADS model during the simulation. The DADS software then applies the forces to the model and calculates the predicted motion given joint constraints and other internal or external forces modeled in DADS. The resulting motions of the "plant" dynamics are fed back into the MATRIXx servo control model as sensor measurements, producing a true dynamically coupled simulation. Although each parameter variation requires running a discrete simulation, higher fidelity estimates of pointing accuracy, along with predictions of other aspects of the performance (including drive power requirements) can be made.

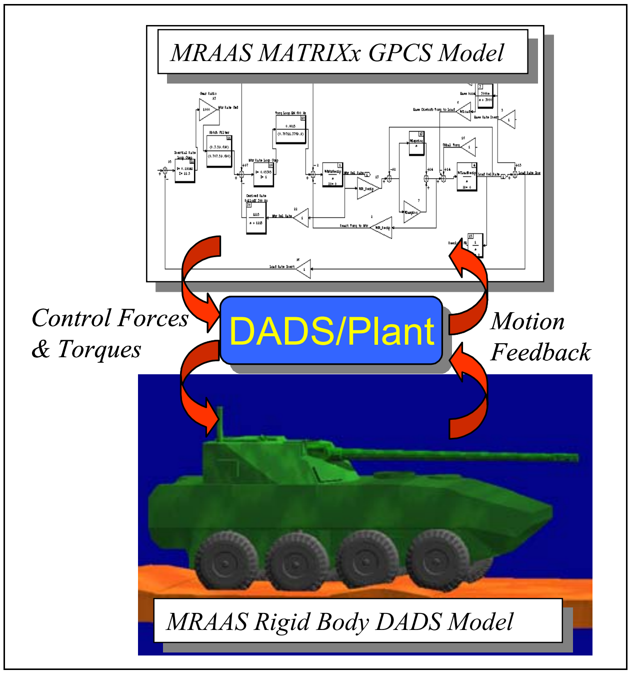


Figure 10: MRAAS Coupled Model Using DADS/Plant

For this analysis, the mechanical model of the load dynamics (i.e. the armament "plant") and external inputs of the vehicle disturbance were replaced by DADS rigid body elements modeling the armament, turret, and chassis with wheeled suspension dynamics. The pointing control system was tuned for the 10 Hz locked rotor frequency, which produced an inertial rate loop gain crossover frequency near 4.5 Hz. This can be considered as the minimum rate loop bandwidth. Note that the actual inertial rate loop closed loop bandwidth of the system was close to 9 Hz. However, the increase in bandwidth beyond the crossover is achieved at a cost of significant phase lag, which subsequently reduces the pointing accuracy RMS level. Therefore, the crossover frequency at 4.5 Hz was assumed to be a better measure of the rate loop bandwidth modeled in the DADS/Plant model for pointing accuracy purposes.

One of the objectives of using the higher fidelity DADS/Plant model was to verify the stochastic method used in the previous section. Figures 11 and 12 overlay the DADS/Plant predictions on the stochastic results presented previously for the RRC-9 course. As shown, the DADS/Plant model predictions were within 0.5 Hz of the bandwidth estimated by the stochastic method for the different speeds, for both the unbalanced and the balanced gun concepts. Conversely, the accuracy predication was within 0.05 mrad of the stochastic prediction.

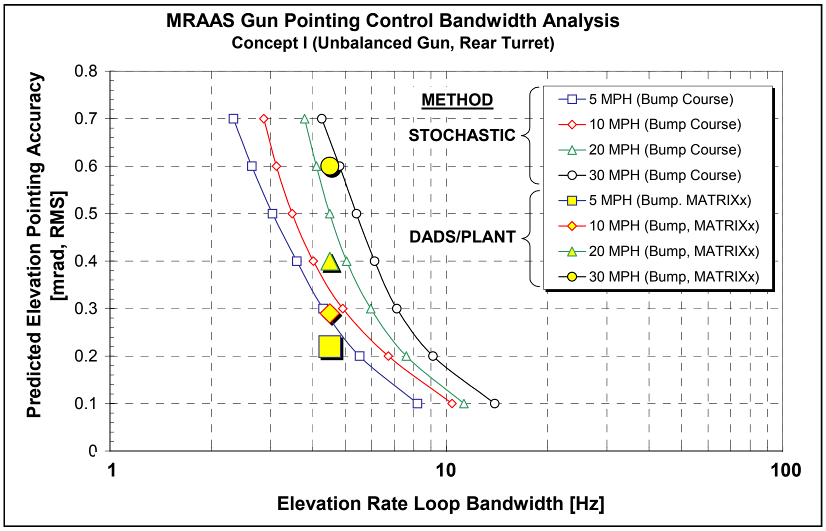


Figure 11: Comparison of DADS/Plant and Stochastic Accuracy Predictions: Concept I

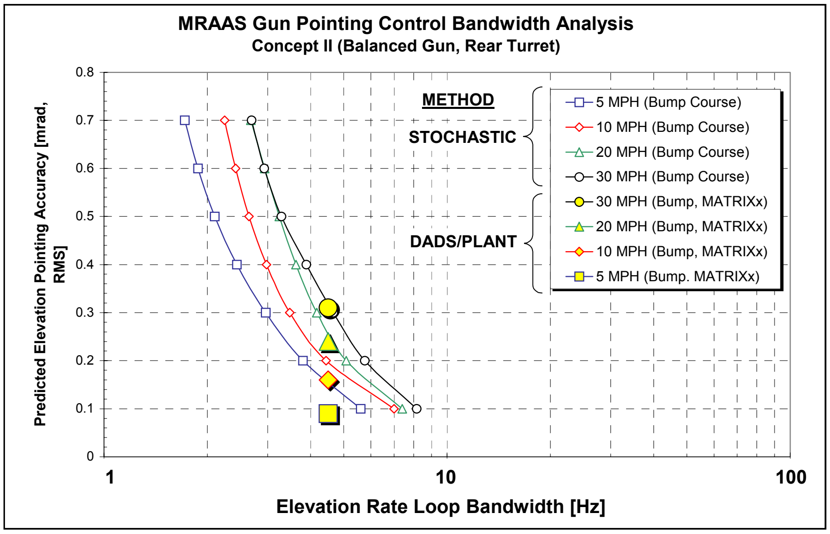


Figure 12: Comparison of DADS/Plant and Stochastic Accuracy Predictions: Concept II

The other main objective of using the DADS/Plant model was to derive the elevation gun drive power requirements, which could be conservatively calculated from the simulation results assuming the following relationship,

$$P_{Total} = \left(T_{unbalance} + T_{accel} + T_{stab}\right) \times \omega_{\max} \tag{5}$$

where,

P_{Total} = Total peak motor power

$T_{unbalance}$ = Static unbalance torque due to gun CG offset

T_{accel} = Slew acceleration torque

T_{stab} = Stabilization torque, 1 σ RMS

$\omega_{\max}$ = Maximum motor rate requirement

Since the motor parameters were not included in the current model, electrical losses were ignored at this stage. Again, the 10 Hz locked rotor pointing natural frequency was assumed with the notional 1000:1 gear reduction between motor and load. An actuation efficiency was also assumed to be 70%, to conservatively account for mechanical losses in the pointing system. Equilibration of the load was assumed to not exist for this concept due to limited space claim.

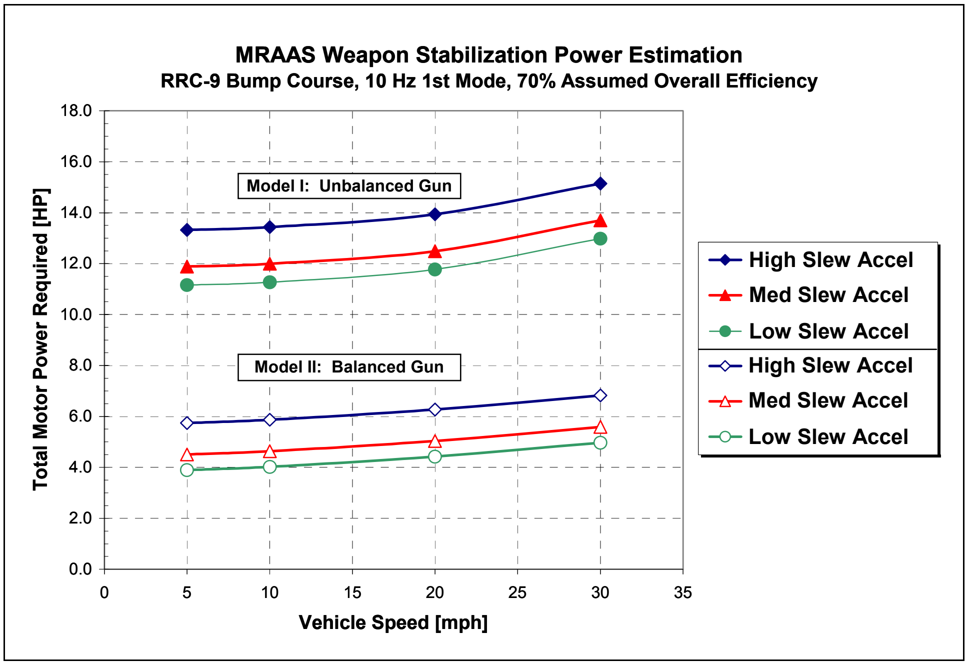


Figure 13: MRAAS Elevation Drive Power Requirements

Figure 13 shows the motor power requirement predictions from the DADS/Plant model for different slew acceleration levels at each speed over the RRC-9 course for the unbalanced (Model or Concept I) and balanced (Model or Concept II) vehicle configurations. Over the speed range evaluated, the power required for a given concept increased less than 20%. As expected, balancing the gun had a significant impact, reducing the power requirements by over 50%.

4.0 GUN POINTING STIFFNESS ASSESSMENT

The final objective of this study was to evaluate the structural stiffness requirements imposed by the stabilization system. As discussed, it was desired to achieve a first mode natural frequency at least 2.5 to 3 times higher than the required pointing control bandwidth. For the elevation pointing system, the natural frequency is determined to a large extent by the combination of the following major sources of compliance: gun drive actuators, turret structure, gun mount and drive mounting interfaces, and the gun tube. In order to quickly assess the current design and the potential for improvement, these major elements were reconciled for this analysis through a parametric finite element model (FEM) to determine potential configurations that could provide the natural frequency required to meet a given rate loop bandwidth. Three different gun mount configurations were studied as potential candidates for MRAAS – a long gun mount, a short mount, and a variation of the short mount with a forward tube support. All three were modeled, and sensitivity analyses were performed in an attempt to bound the effects of varying: mount and tube elasticity and cross-sectional area of inertias, elevation drive effective stiffness, gun mount structure extension lengths, and tube support extension lengths. The analysis outputs were eigenvalue extractions indicating the first mode natural frequency (and subsequent modes). All finite element analysis (FEA) for this study was performed using MSC/NASTRAN software.

Figure 14 shows the relation between effective elevation drive stiffness and overall gun pointing frequency. For the simplified analysis, the effective elevation drive stiffness was assumed to have three major sources of compliance – drive actuator with gun mount and turret mounting lugs – acting as springs in series. As shown, the natural frequency of the system approaches an asymptotic condition as the gun drive stiffness increases. Once the drive reaches and exceeds the optimal stiffness near 1E9 in-lbs/rad, the barrel acts like a cantilever beam. Attempting to achieve a gun drive stiffness beyond the optimum will not increase overall pointing stiffness beyond this natural limit. Similar studies were performed to investigate changes in gun mount structural stiffness and general support geometry (e.g. gun mount length). Combining the sensitivity analysis with the natural frequency requirements to achieve a given rate loop bandwidth (and subsequent pointing accuracy) provided a means to derive armament structural requirements for MRAAS design.

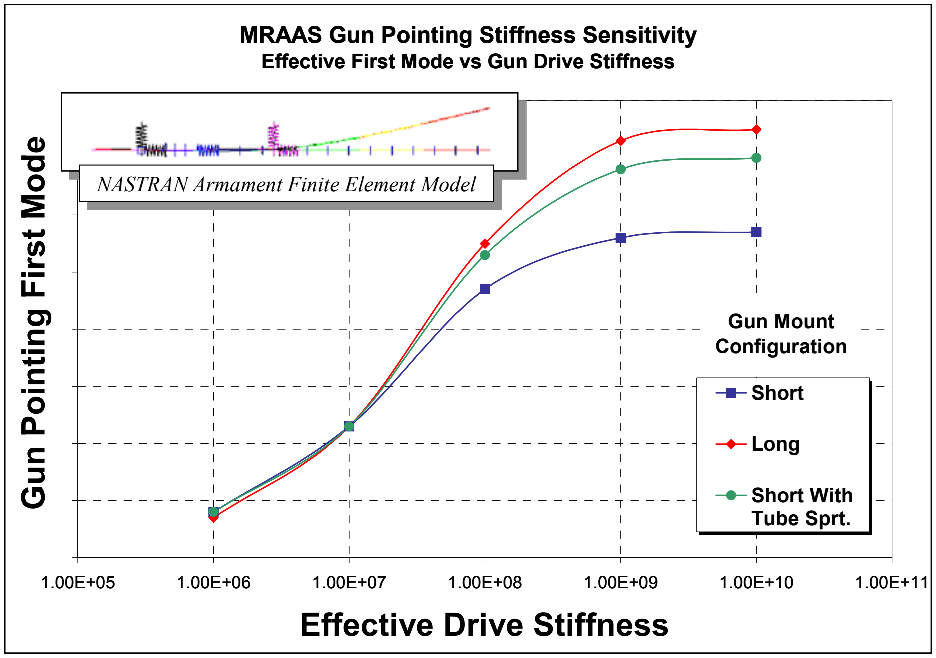


Figure 14: Gun Pointing First Mode Sensitivity to Gun Drive Stiffness

8.0 SUMMARY AND RECOMMENDATIONS

In summary, the analysis described was meant to provide a concept-level assessment of the MRAAS system in terms of fire on the move weapon pointing accuracy, evaluating the feasibility of integrating a large caliber gun system on a light vehicle. By combining increasingly detailed simulation models with a parametric approach, it was intended to quantify the design space and define what is feasible in terms of vehicle response, gun pointing control performance, gun drive power and armament pointing stiffness. At the beginning of the analysis, mass properties and suspension characteristics for two different MRAAS wheeled chassis configurations were estimated to provide an indication of the sensitivities to gun CG offset. A DADS wheeled vehicle dynamics model was developed for each concept to assess fire on the move mobility response. In parallel, a preliminary Gun Pointing Control System (GPCS) model was developed using MATRIXx. By combining the gun pointing disturbance predictions with expected disturbance rejection transfer functions using a stochastic parametric approach, preliminary assessments of gun pointing accuracy were made. An approach for defining GPCS bandwidth and pointing stiffness requirements to meet a specified accuracy for a given terrain and vehicle speed was demonstrated. Combining the DADS rigid body and MATRIXx controls models via DADS/Plant provided a single model, which was used to verify the stochastic approach used, as well as generate drive power requirements. The DADS/Plant analysis also confirmed that reducing the gun CG offset could reduce bandwidth and pointing stiffness requirements by up to 25%, and the maximum power required by up to 50%, depending on the slew acceleration requirements. NASTRAN parametric finite element analysis (FEA) models of the armament and effective gun drive compliance were also developed for three mount concepts in order to further explore the feasibility of meeting the pointing stiffness requirement.

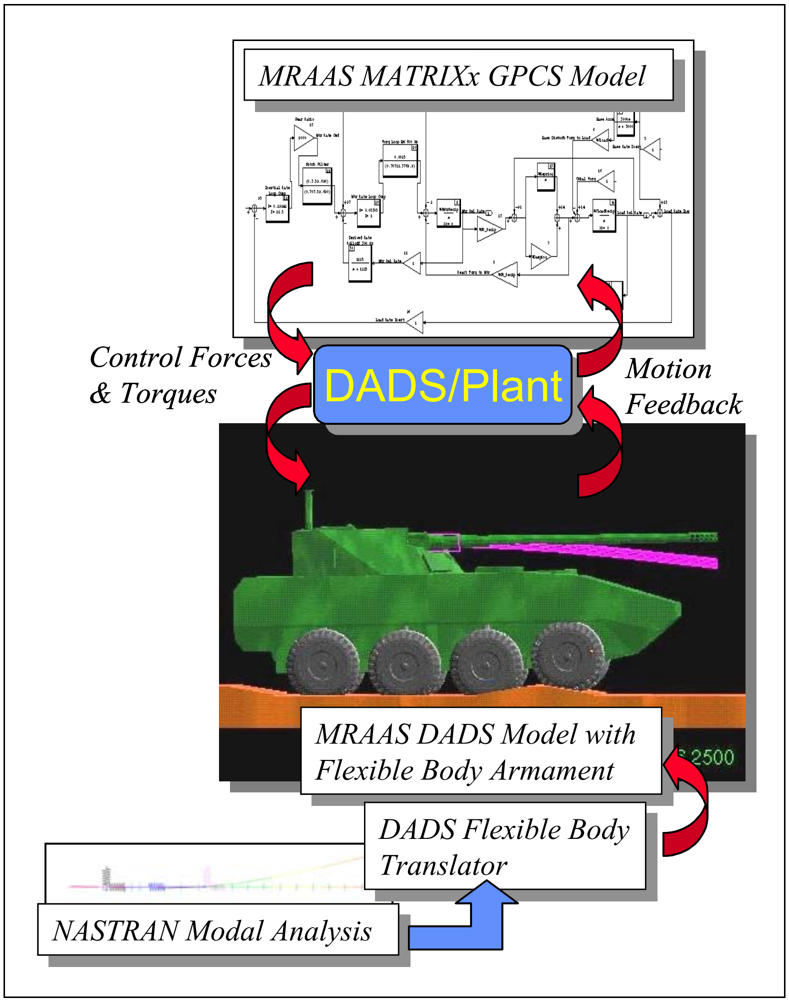


Figure 15: Stabilized Gun Pointing Model With Armament Flexure Example

In the end, this combined modeling approach produced a flexible, high fidelity physics-based model of the MRAAS weapon system. The experience gained lays the groundwork for future modeling efforts that would have to be continued and matured as a system under study moves from concept to design, and eventually to hardware. The concept-level modeling performed for MRAAS included the rate loop only (inertial rate loop closed at the breech). Follow-on analysis would need to close rate and position loops around the muzzle, which will require incorporation of an armament flexure model to capture the effects of tube and mount bending on pointing stability and nominal performance. Figure 15 shows an example of a model that could be used for this purpose. Using a demonstrated approach, the existing DADS/Plant model can be modified to include the NASTRAN model of the armament (and turret) via DADS flexible bodies. As more design detail becomes available, this type of model can be continually updated to explore on-going design trades, making the analysis an integral part of the weapon design as it matures from concept to production.

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ACKNOWLEDGEMENTS

This work was initiated and funded by the U.S. Army Armament Research, Development, and Engineering Center under Contract DAAE30-00-C-1060. The authors would like to thank Steven McDonald, Roger Kent, Ramon Espinosa, and Thomas Louzeiro at Picatinny Arsenal; and Stephen Krupski at Benet Labs for their timely assistance, review, and suggestions. Their team approach was key to the success of this study.