MSC Software

CASE STUDY

MSC Software: Case Study - General Dynamics Land Systems

# Compressing Product Development Cycles

## Co-simulation enabled GDLS engineers to accurately model the performance of the complete system prior to the prototype phase

The gun turret drive on a combat vehicle presents a very complex design challenge. When the vehicle travels over rough terrain, the gun turret drive compensates for the vehicle's motion and keeps the gun pointed precisely at its target with 99.5% accuracy. In the past, General Dynamics Land Systems (GDLS) engineers used separate simulations to evaluate different aspects of the gun turret drive design, such as the rigid body structures, flexible bodies and control system. But engineers were not able to evaluate the performance of the gun turret drive as a complete system until they built and tested prototypes.

In the last few years, GDLS engineers have begun using a multidisciplinary-based co-simulation process to model the operation of the gun turret drive system while taking into account all of the key physics involved in its operation.

The centerpiece of this simulation effort is the use of Adams dynamics software to model the rigid bodies, nonlinear joints and contacts in the gun turret drive. Adams was selected because of its nonlinear contact capabilities. The accuracy and relatively few assumptions required by this approach provide more accurate simulation predictions and reduce the time required for troubleshooting physical root causes, resulting in a significant reduction in time to market.

## Key Highlights:

### Industry

Defense

### Challenge

Create the multidiscipline model for the gun turret drive. Early prediction of the jamming condition in the gun turret drive.

### MSC Software Solutions

Adams

### Benefits

- Quick verification of results
- Shorter product development cycle
- Cost saving

# "With Adams, the early identification and understanding of the jamming condition in the gun turret drive saved a considerable amount of time and money in troubleshooting."

Zhian Kuang, General Dynamics Land Systems. Sterling Heights, Michigan

## Need to Consider Multi-Physics in Design Process

GDLS builds a variety of combat vehicles such as the Abrams M1 tank, Stryker mobile gun system and MRAP blast- and ballistic-protected personnel carriers. Designing these products for optimal performance requires consideration of a wide range of physics including rigid body structures, flexible bodies, suspension systems, nonlinear body to body contact, nonlinear large scale deformation, thermal, electrical, electromagnetic, fluid, and others.

GDLS has developed the capability to model each of these physics individually and single-physics simulations are performed frequently during the design process. But each of these simulations is heavily dependent on other physical processes outside its scope which makes it necessary to make assumptions that have a negative impact on accuracy. Traditionally, designers working on actuators, controllers and associated electronic circuitry have to wait for mechanical hardware to be procured and tested before tuning their systems to meet mechanical requirements. This process is normally the controlling factor for the delivery leadtime of a new product.

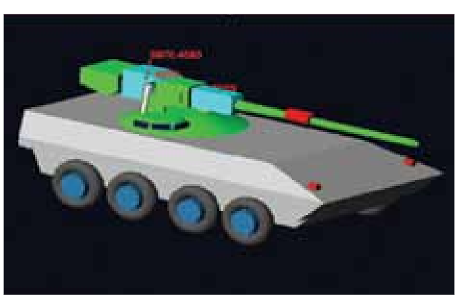
## Overview of Co-Simulation Process

The new co-simulation process cooperatively solves the dynamic and nonlinear contact behavior of the mechanical system interacting with the discrete behavior of the digital motor/controller system. The co-simulation process is initiated and controlled from the MATLAB/Simulink environment using the "Adams plant model" (which accounts for all rigid body dynamics and flex body dynamics). Co-simulation allows the control system model to process discrete models using the ode4 Runge-Kutta integrator based on the variables received from Adams. At the completion of each time step, Simulink sends its output to Adams and waits for the Adams solver to calculate the solutions to its set of variables using the GSTIFF integrator. Upon solving the state variables, Adams sends its data over the PIPE communications line to Simulink and the process advances to the next time step.

Control models were simulated in Simulink. The control system was designed for two modes of operation. Inertial stabilized mode stabilizes the weapon in space with respect to perturbations in pitch and yaw. Non-stabilized mode controls the gun in elevation and azimuth in the local reference frame of the vehicle. Control algorithms were designed to include compensation for both the rigid body dynamics along with the bending modes of the gun/cradle system.

## Modeling of Mechanical Systems

The gun turret drive CAD model was imported into Adams including all of the assembly tolerances required for the final product release. In complicated machinery it's very common



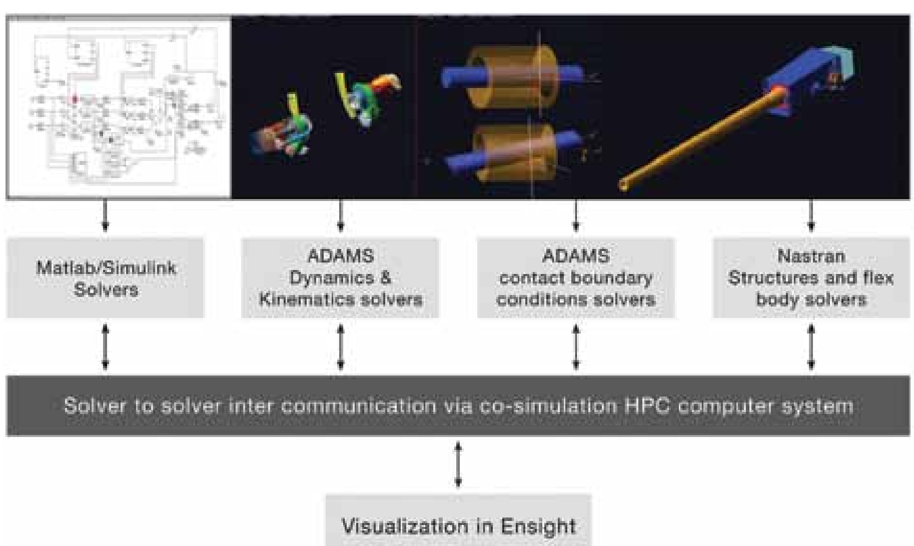



Figure 1: Overview of co-simulation process

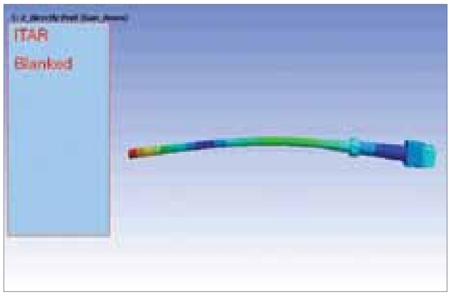



Figure 2: First mode for gun assembly is within range of interest so it was modeled as flexible body

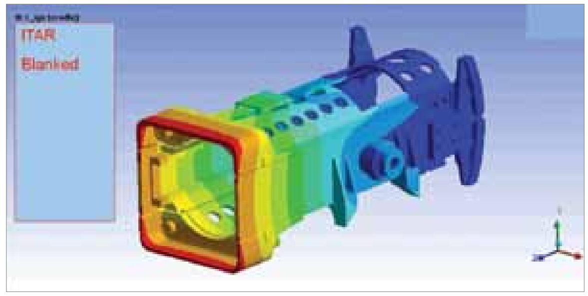



Figure 3: First modal frequency for cradle is outside bandwidth of interest so it was modeled as rigid body

Figure 4: Adams model of DC gear motors

for cumulative tolerances to cause problems that aren't identified until prototype testing. The Adams model overcomes this problem by incorporating the tolerances of the individual components and providing 3D redundant constraints that incorporate the impact of the cumulative tolerances. This makes it possible for engineers to determine the impact of tolerances on product behavior and investigate the impact of tightening or loosening tolerances prior to the prototype phase.

In this highly complex weapons system, the ability to account for nonlinearities is critical to accurate simulation. The key advantage of Adams is that it accounts for the nonlinearities in this system through its ability to model nonlinear on/off contacts, large displacements associated with part deformations and nonlinear materials.

Mechanism analyses are done in Adams to determine which bodies can remain as computationally economical rigid bodies and which need to be converted to computationally more intensive flexible bodies. For example, if the first mode frequency of a component is well above the frequencies likely to be experienced in operation then it is normally modeled as a rigid body. The first mode for the assembly consisting of the gun, breech block and adapter is within the range of interest in free-free modal analysis and also when constrained by assembly conditions so it was modeled as a flexible body. On the other hand, the first mode of the cradle is outside the bandwidth of interest when constrained
for assembly conditions so it was modeled as a rigid body.

DC gear motors were used as actuators to control the elevation of the gun. Each motor was mechanically modeled in Adams including the motor brake, rotor, stator and a geared output shaft. GDLS electronic circuitry for motor controllers was modeled in Simulink. Torque commands from the Simulink control system model are assigned to the output shaft. The output shaft gear engages a sector gear that drives the gun assembly in the reference frame of the turret with the motion profile incorporating the assembly tolerances.

## Comparison to Measured Data

The frequency response of the Adams plant was compared to measured data. The simulation was run in assembly mode incorporating the full range of potential design positions of all parts based on their tolerances. The percentage difference between the simulation predictions and physical measurements for the frequencies of the first five modes were respectively 3%, 18%, 10%, 10% and 17%. Allowing the system to settle with gravitational loading closed up some tolerances and reduced the difference for the four and fifth modal frequencies to 0.1% and 0.25%. It's important to note that these simulation predictions were generated on the first cut analysis without tweaking the model to match the measured data. Adjusting the details of the joints at the attachment points affected the frequency of modes 1 and 2, allowing engineers to understand how joints and contact forces influence the frequency response of the mechanical system. GDLS engineers compared the performance of simple bushings, 3D contacts, classic joints and forces to understand what each component contributed to the responses measured in the prototype.

## Detecting and Troubleshooting Jamming

One of the most critical considerations in the gun turret drive is the potential for jamming, a condition in which side loading on rotating components causes the shaft to flex and increases the frictional force between the shaft and bearing. In some cases, the frictional force can rise to a level that stops the shaft from rotating. Components subject to jamming are normally modeled as flexible bodies to increase simulation accuracy.

One of the key benefits of Adams is its ability to identify jamming prior to the prototype phase through the use of nonlinear contacts in which friction varies depending on the loads on the shaft and bearings and other factors. In this application, Adams identified a jamming condition even though the designer was certain that the shaft would not jam. Later when the prototype was built it was determined that jamming did occur in the original design. The early identification and understanding of the problem saved a considerable amount of time and money in troubleshooting.

A key advantage of Adams is that relatively few assumptions are required for the plant model. The accuracy and relatively few assumptions required for the multiphysics approach enables GDLS engineers to understand, negotiate and trade off both upstream and downstream requirements with much greater visibility to their impact on system requirements than was possible in the past. Knowing the impact of subsystem performance based on physics enables the system integrator to play a more active role in requirements and cost control tradeoffs as opposed to be solely driven by suppliers' perspectives as often occurred in the past.

In summary, multiphysics co-simulation requires fewer assumptions and is easier to use for troubleshooting physical root causes than other computer aided engineering methods. Co-simulation of the gun turret drive enabled GDLS engineers to accurately model the performance of the complete system prior to the prototype phase. The ability to identify problems and evaluate potential solutions and to understand the effect of component specifications on system performance helped significantly compress the product development cycle. This is why GDLS engineers called the model a 'Virtual Machine' built by using Adams. And the virtual machine is producing cost savings, especially in product R&D processes.

## About MSC Software

MSC Software is one of the ten original software companies and the worldwide leader in multidiscipline simulation. As a trusted partner, MSC Software helps companies improve quality, save time and reduce costs associated with design and test of manufactured products. Academic institutions, researchers, and students employ MSC technology to expand individual knowledge as well as expand the horizon of simulation. MSC Software employs 1,000 professionals in 20 countries. For additional information about MSC Software's products and services, please visit www.mscsoftware.com.

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## About Adams

*Multibody Dynamics Simulation*

Adams is the most widely used multibody dynamics and motion analysis software in the world. Adams helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

Traditional "build and test" design methods are expensive, time consuming, and impossible to do sometimes. CAD-based tools help to evaluate things like interference between parts, and basic kinematic motion, but neglect the true physics-based dynamics of complex mechanical systems. FEA is suited for studying linear vibration and transient dynamics, but inefficient at analyzing large rotations and other highly nonlinear motion of full mechanical systems.

Adams multibody dynamics software enables engineers to easily create and test virtual prototypes of mechanical systems in a fraction of the time and cost required for physical build and test. Unlike most CAD embedded tools, Adams incorporates real physics by simultaneously solving equations for kinematics, statics, quasi-statics, and dynamics.

Utilizing multibody dynamics solution technology, Adams runs nonlinear dynamics in a fraction of the time required by FEA solutions. Loads and forces computed by Adams simulations improve the accuracy of FEA by providing better assessment of how they vary throughout a full range of motion and operating environments.

Optional modules available with Adams allow users to integrate mechanical components, pneumatics, hydraulics, electronics, and control systems technologies to build and test virtual prototypes that accurately account for the interactions between these subsystems.

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