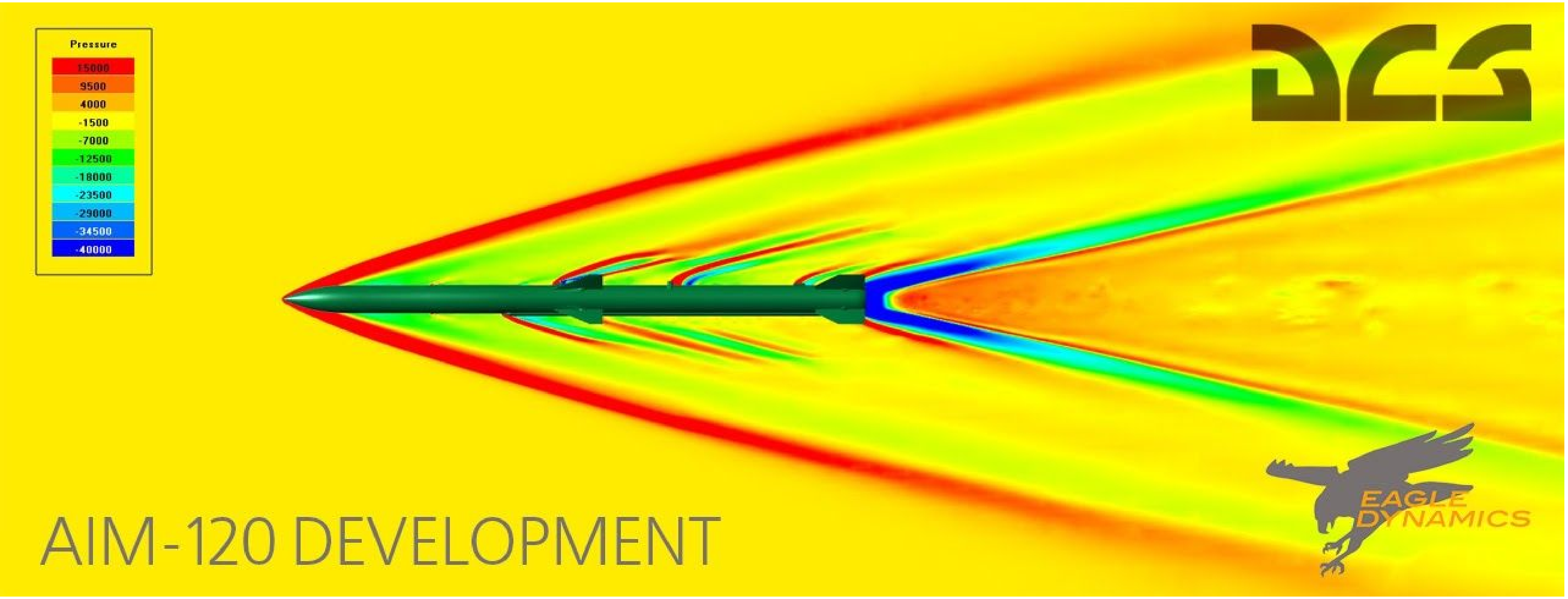


Introduction

We at Eagle Dynamics pride ourselves in bringing you the most realistic flight simulations possible, and regarding modern aerial combat, an important aspect of that is air-to-air missile simulation. We recognized that there have been shortcomings in this modeling, and over the past year we have been remodeling how these systems behave in DCS. We greatly appreciate all the fantastic feedback you have provided, and it has in large part allowed us to bring air-to-air missile simulation to a new level.

Let us discuss how we now model air-to-air missiles in DCS, with the AIM-120 as the example. This is planned for all our air-to-air-missiles.

FLIGHT MODEL

As was stated in earlier newsletters, we have spent a lot of time performing Computational Fluid Dynamics (CFD) research. Almost 250 different calculations for every missile variant were made. So much research has been conducted that it has allowed us to simulate main aerodynamic characteristics at a much more accurate level. We have also calculated missile mechanical properties such as center of gravity and moment of inertia before motor ignition and after burnout.

Aerodynamics

In contrast to the old missile dynamics model, the new one includes stability and control characteristics. This is one of the main features of the new dynamics. Stability and control characteristics include static stability, fin effectiveness, and aerodynamic damping. All these parameters are necessary for a realistic simulation of transient response and overall missile flight. Missile maneuverability and guidance accuracy depends on them.

We have also refined missile lift and drag characteristics. Please see the chart below. It displays how much induced drag had changed/improved. The old missile version had overrated induced drag. Using CFD simulations, we obtained the correct lift and drag values up to Mach 5. The maximum lift-drag ratio is now corresponding to typical values for air-to-air missiles. The new missile will lose less energy during maneuvering.

Zero-lift drag was also changed according to CFD data. As illustrated below, you can see old and new drag values. Another interesting feature is a reduction in the zero-lift drag due to motor burn. Motor exhaust increases pressure behind the missile body, which leads to drag reduction.

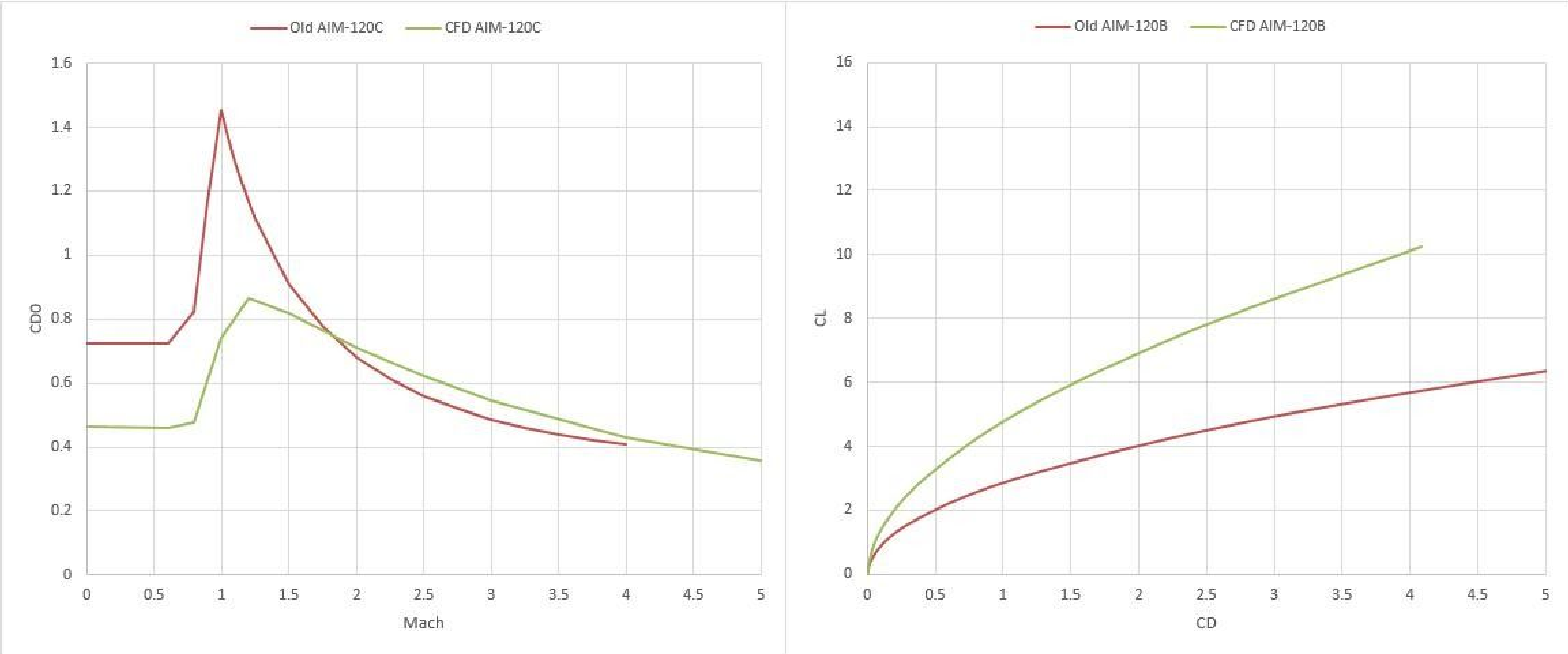


Figure 1. Missile zero-lift drag and induced drag polar at Mach 2.

Rocket motor

Rocket motor performance directly affects missile ballistics and range, so we decided to also revise motor data. Using known data for other reduced smoke motors with HTPB/AP propellant, exhaust nozzle dimensions, and some handbook data, we estimated the propellant characteristics. We then estimated the AMRAAM motor burn change using gas-dynamic functions and nozzle geometry, and this provided motor thrust and specific impulse. As a result, we have decreased the motor specific impulse by about 10% to meet realistic HTPB/AP propellant characteristics.

AUTOPILOT MODEL

To control the missile with realistic flight dynamics, we developed a velocity-altitude adaptive autopilot. It has four variable gains that provide precision and fast missile control in a wide velocity range from sea level to 100,000 ft. When building the autopilot, we conducted research of control theory to obtain missile characteristics as an object of control. These characteristics helped us to understand how a missile should behave and which filters and gains we should choose to correct unwanted behavior. The first such characteristic is the frequency response.

Frequency response

Have you tried flying the DCS: F-5E-3 with dampers off? Have fun with that. The aircraft begins to oscillate after any careless movement of the stick. Missiles behaves the same. After an abrupt control command, they oscillate at a certain frequency called natural frequency. Frequency response allows us to see and analyze these oscillations. Please examine the left image below. The red solid line has a high peak at 15 rad/sec frequency with 35db amplitude, which means there are significant oscillations. How can we avoid such oscillations, especially for what dampener is needed? By passing an inverted and amplified signal from missile body rate gyros to the fins, we can eliminate oscillations. The green solid line is the frequency response of the missile with a dampener.

There are no peaks, but another problem presents itself. At low frequencies, as seen in the line at -5db amplitude, the guidance command performed by a missile will be lower than requested. To fix this, an acceleration feedback can be used. Without going into head-spinning detail, we inverted the signal from accelerometer sums with guidance command, integrate them, and pass then through special filters that go to the control-fin actuators. The blue lines on the right of the chart represents missile frequency response with dampener and a closed acceleration feedback loop. The amplitude line is close to zero at all usable frequencies now, and the missile should perform precise commands. The blue dashed line indicates the missile phase shift. Larger negative phase values mean that the performed command has more and more lag over the requested command. To eliminate phase shift and provide a fast missile response acceleration loop we have included an additional filter.

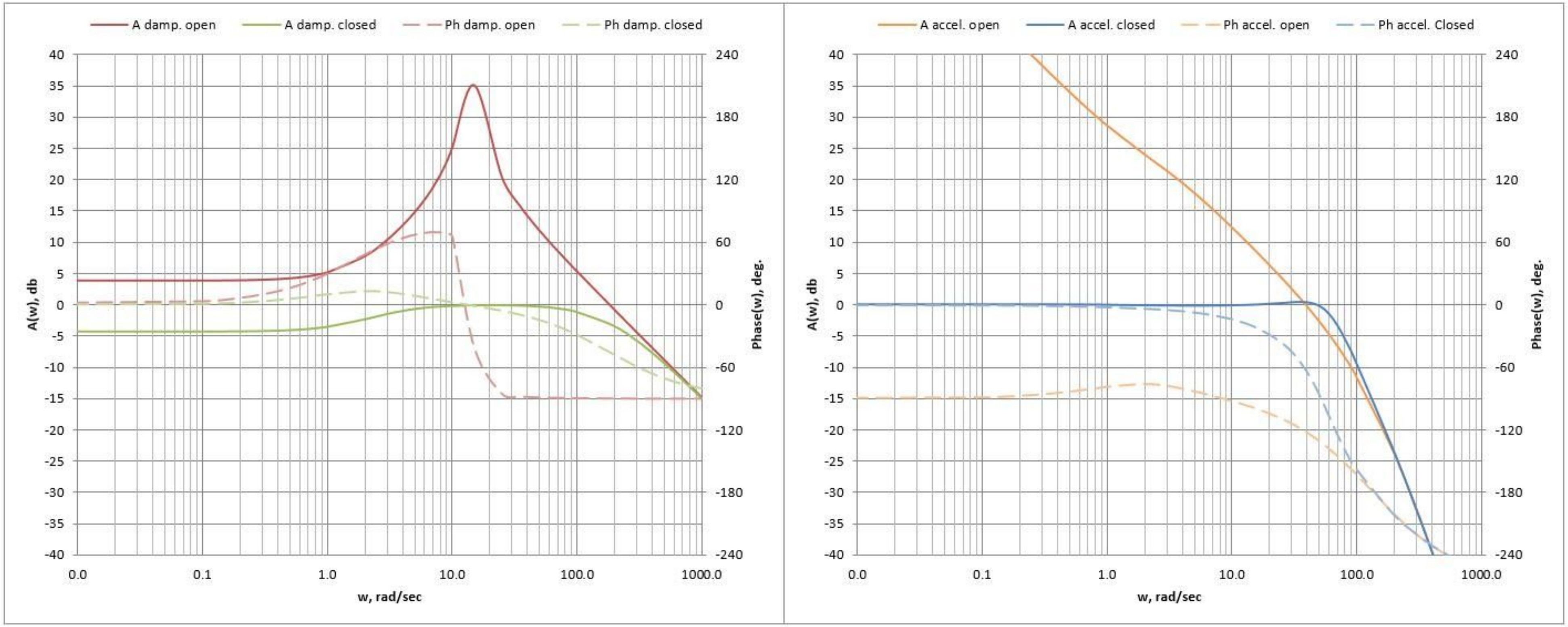


Figure 2. Missile frequency response.

Missile frequency response depends on many aerodynamic parameters, which in turn depend on current altitude and velocity. Therefore, to maintain desired frequency response, autopilot filters need to be velocity-altitude adaptive. However, the above frequency response is for a linear missile model and does not account for a nonlinear element: the fin actuator.

Electromechanical fin actuator

Perhaps the most important component of every missile control system is the fin actuation system assembly. Actuator parameters such as maximum slew angle and maximum slew rate (with and without load), directly affect missile control response and stability. To ensure realistic control system behavior, we built an electromechanical fin actuator model. Electrical part components consist of brushless DC motor model with controller, and the mechanical component consist of the ball screw gear.

Let's see how the missile model with autopilot and electromechanical actuators behaves in flight. For this, we will use other well-known system characteristic from control theory: the step response.

Step response

Step response is the reaction of a control system to abrupt input commands. It shows us how different parameters change with time after an input. To obtain the figures below we sent an autopilot input pulse command of 25 amplitude for a one second duration. The left figure demonstrates the missile reaction to commands at 1.5 Mach and 5Kft altitude, and the right figure illustrates the reaction to the same command at 3.5 Mach at 65Kft altitude. As you can see in the second case, the command is less than requested due to low air density and limited fins slew angle. So, at low altitude and supersonic speeds, missile normal acceleration rise time is 0.1-0.2 sec and overshoot is about 2g’s or 10%. At very high altitudes, IAS becomes small even at high Mach and missile acceleration rise time increases up to 0.5-0.6 sec.

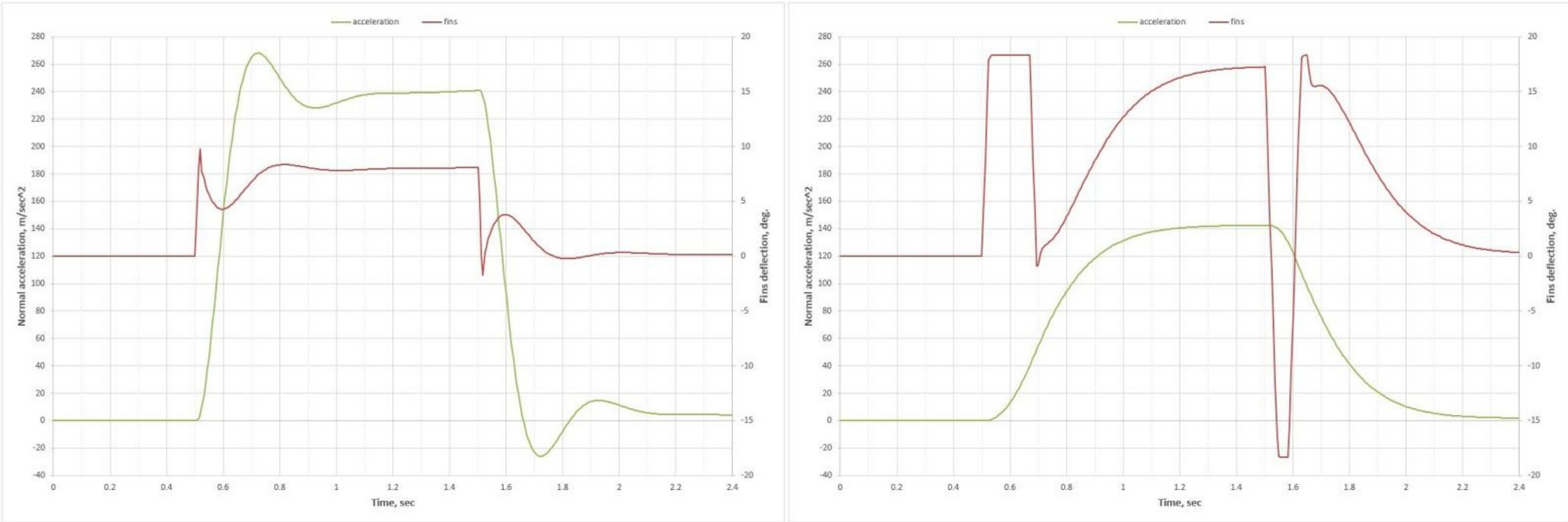


Figure 3. Missile step response.

Lofted trajectory

Autopilot also provides a lofted trajectory for long-range shots. Lofting allows missiles to fly at a higher altitude through less dense air. This results in lower drag that increases missile range and velocity at target intercept. However, due to the exponential character of air density-altitude dependence, lofting has different efficiency at low- and high-altitude. At sea level, a lofted trajectory is nearly ineffective, but as altitude increases, it becomes more and more efficient. Below are a couple examples of AMRAAM lofted trajectories against non-maneuvering target. The left figure shows lofted trajectory for max range co-altitude shot at 30Kft, 1.5 Mach fighter vs 1.5 Mach hot target, range at launch is 50nm. The right figure demonstrates a lofted trajectory for a look-down shot, 30Kft, 0.9 Mach fighter vs 5Kft 0.9 Mach hot target, range at launch is 36nm.

So, fly high and remember to pitch up the aircraft to 15-20 degrees to give you another 5-10% of range increase!

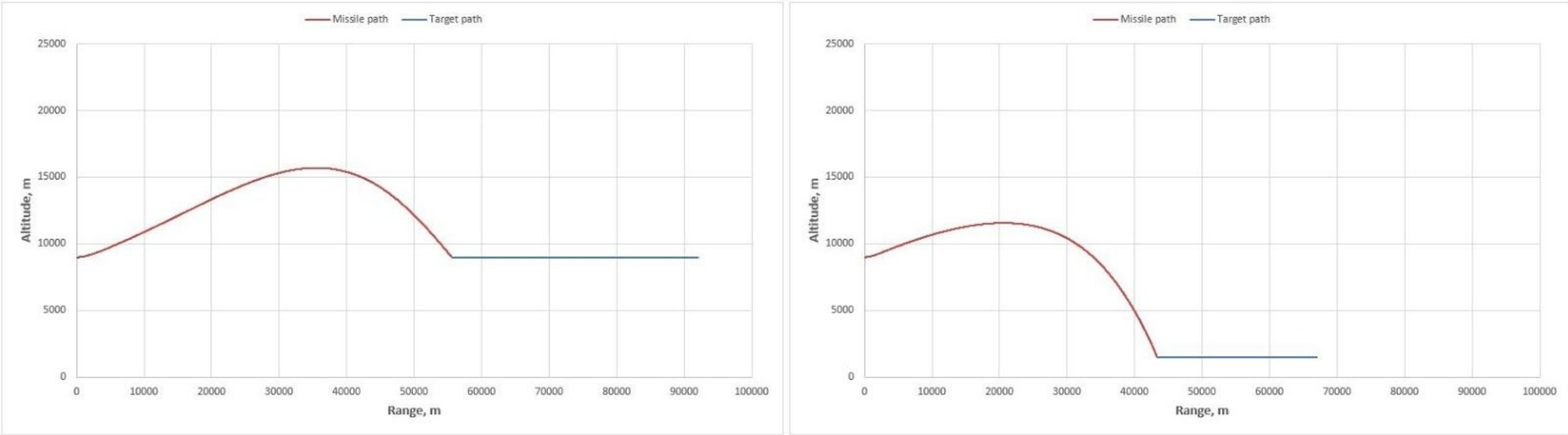
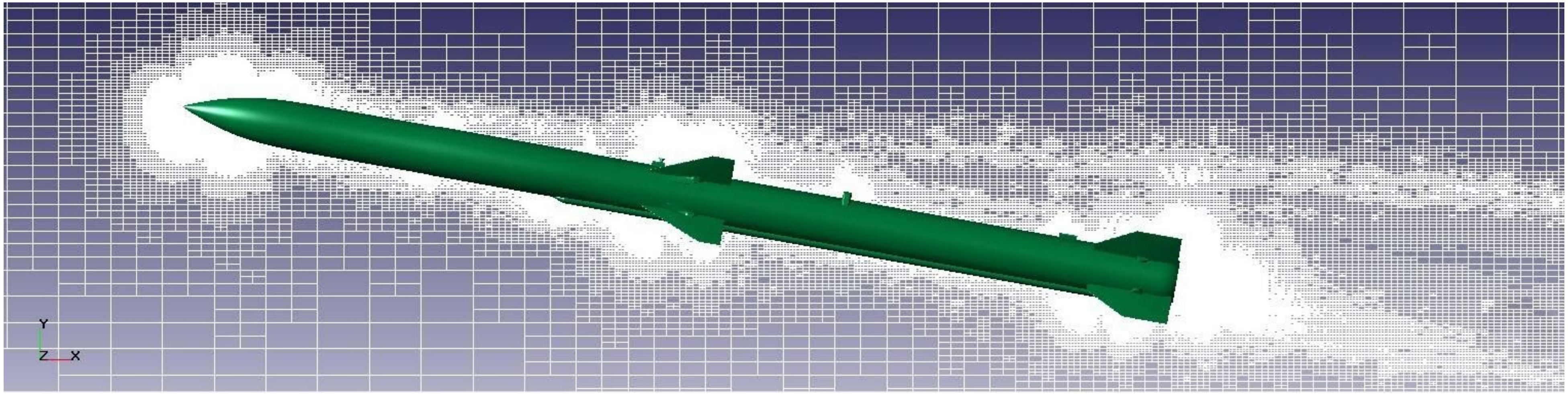


Figure 4. Examples of AMRAAM lofted trajectory.

Final words

Thank you for taking the time to read through this rather technical explanation of our new air-to-air missile modeling. Based on our internal testing, we have found that it provides a profound lethality in the AIM-120 in both range and tracking. We look forward to your feedback to continually improve all we do.



Thank you for your passion and support,
The Eagle Dynamics Team
2020