

Safe Escape for the Army Helicopters

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Abstract: During recent wars, U.S. Army aviation units have found themselves involved more in urbanized terrain operations. In a typical urban terrain engagement, an aviation unit conducts direct fire at close range, low altitude, and in proximity to friendly units in contrast to maximum range for open terrain engagement. The risk of firing at close range is exposing the aircraft to exploding fragments from its own launched munitions. A need for an analysis tool to determine the minimum safe range for helicopters to release weapons has been identified. The Army Safe Escape Analysis Tool (ASEAT) was developed to meet this need. The ASEAT consists of MSC Adams, MSC Easy5, 3D-CAD models of aircraft, weapon fly-out models, and warhead arena data. An aircraft model is hard-wired to fly in Adams and transfers initial conditions for release of its weapons. At impact, random fragments from the arena data are picked to randomly fly into the sky. Miss-distances between the aircraft and fragments are computed to determine hit or miss. The probability-of-hit (P_h) and hit-fragment data can also be used for probability-of-kill (P_k) computation.

As the world's population increases, more people are leaving rural areas to relocate to urban areas. In the future, military operations will more likely be in urban areas. This has already been experienced in Iraq operations.

In a typical urban terrain engagement, an aviation unit conducts direct fire at close range, low altitude, and in proximity to friendly units. This engagement is in contrast to operating at maximum weapon range for an open terrain engagement. Many rotary-wing engagements will be conducted at very close ranges between 50 meters and 500 meters. In the Aviation Urban Operation, Multi-service Procedure for Aviation Urban Operations, two typical scenarios are presented: Running/diving fire (Figure 1) and Hover Fire (Figure 2.)

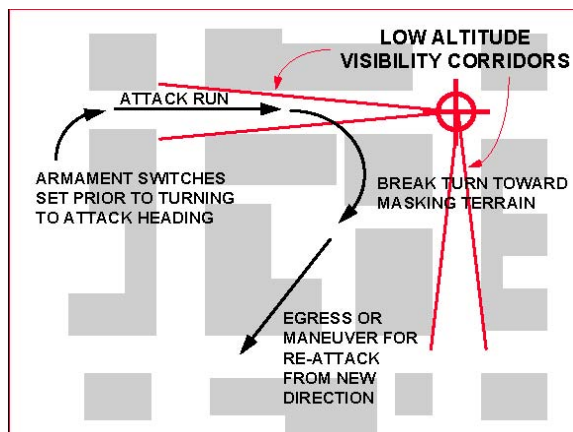


Figure 1. Running/Diving Fire Engagement

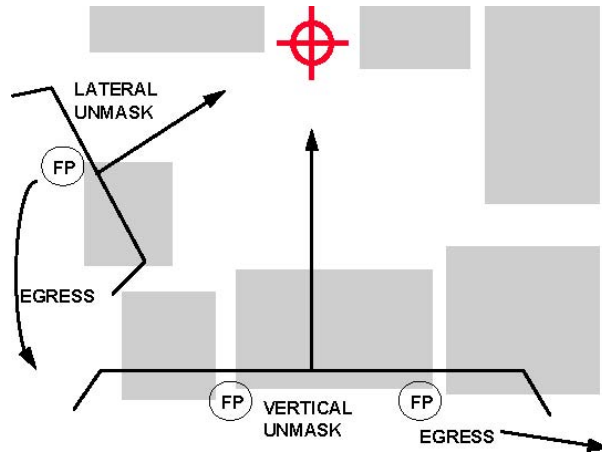


Figure 2. Hover Fire Engagement

In addition to the above scenarios, the U.S. Army Aviation Engineering Directorate recently investigated and authorized expansion of AH-64A/D Apache maneuvering limits to ± 60 degrees in pitch and ± 120 degrees in roll. This maneuvering expansion allows the Army pilots/gunners to perform more effective combat maneuvers within the cities of Iraq. A typical application of this maneuvering expansion is a sharp-turn-around and a quick-fire at any spotted target. This type of engagement will put the aircraft at a very close range to the enemy target at the time the pilot or gunner pulls the trigger. One of the risks for firing at close range is exposing the aircraft to exploding fragments from its own launched munitions. The question is, “At what range can a munition be released from the aircraft without itself being damaged by the fragments from the down-range exploding munition?”

The Army Safe Escape Analysis Tool (ASEAT) was developed to determine the minimum safe range for weapons release. The tool utilized software packages such as Adams, Easy5, 3D-CAD aircraft models, weapon fly-out models, and warhead arena data.

The Adams and Easy5 simulation tools are products of MSC Software Corp. Adams is a multi-body mechanical system, dynamics simulation tool for analyzing the complex behavior of mechanical assemblies. Adams is used by the major automotive, defense, marine, manufacturing, and aviation industries. It solves six degrees-of-freedom (6DOF) motion of numerous bodies with algorithms and error-reducing routines. Adams provides a capability for modeling, analysis, and visualization. It gives visual feedback for faster and better understanding of the model and motion behavior. Figure 3 is an example of an inflatable boat jettison from a Blackhawk helicopter. It was used to determine whether there would be any interference with the aircraft.

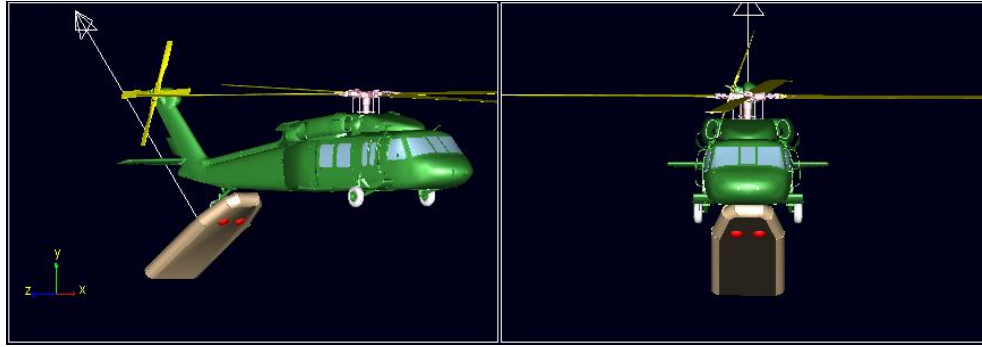


Figure 3. Jettison of Inflatable Boat

Easy5 is a system-level modeling tool. It is based on schematic block-diagram view of engineering systems that contain hydraulic, control, pneumatic, mechanical, thermal, electrical, and digital subsystems. In Easy5, systems can be modeled using functional blocks and pre-defined components that represent physical elements. Various analysis tools are available for nonlinear simulation, steady-state analysis, control system design, data analysis and plotting. Easy5 has the capability to generate source code automatically to support real-time requirements. An open architecture provides links to a broad set of popular computer-aided engineering software and hardware tools such as Adams and MatLab/Simulink. Figure 4 shows an example of a link between Easy5 and Adams.

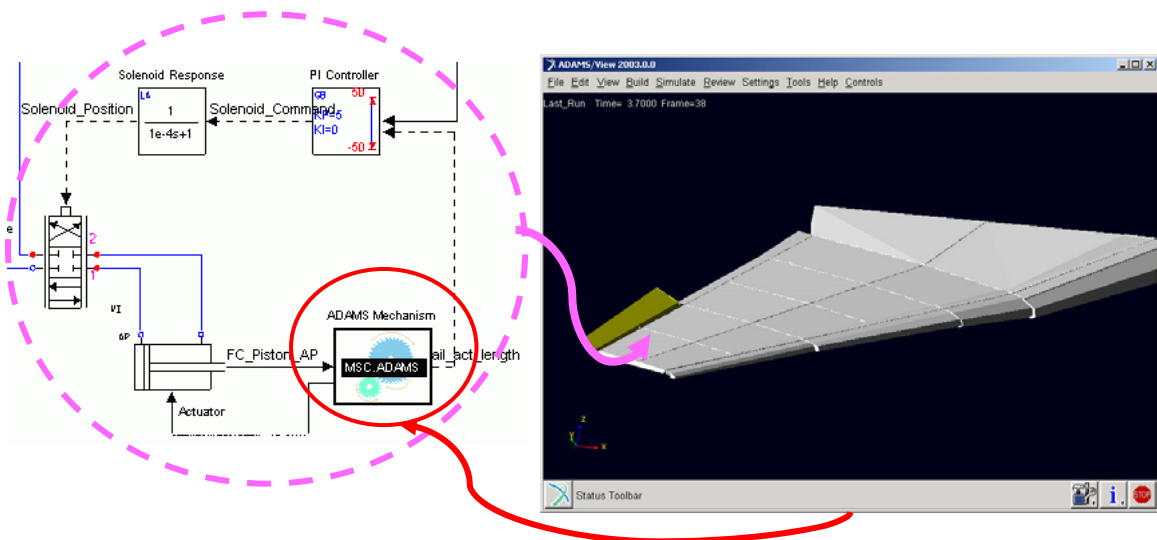


Figure 4. Easy5 and Adams System Level Simulation

An ASEAT analysis will consist of two passes: Pass1 is for initialization and crude estimate of fragments that will potentially hit the aircraft (Figure 5).

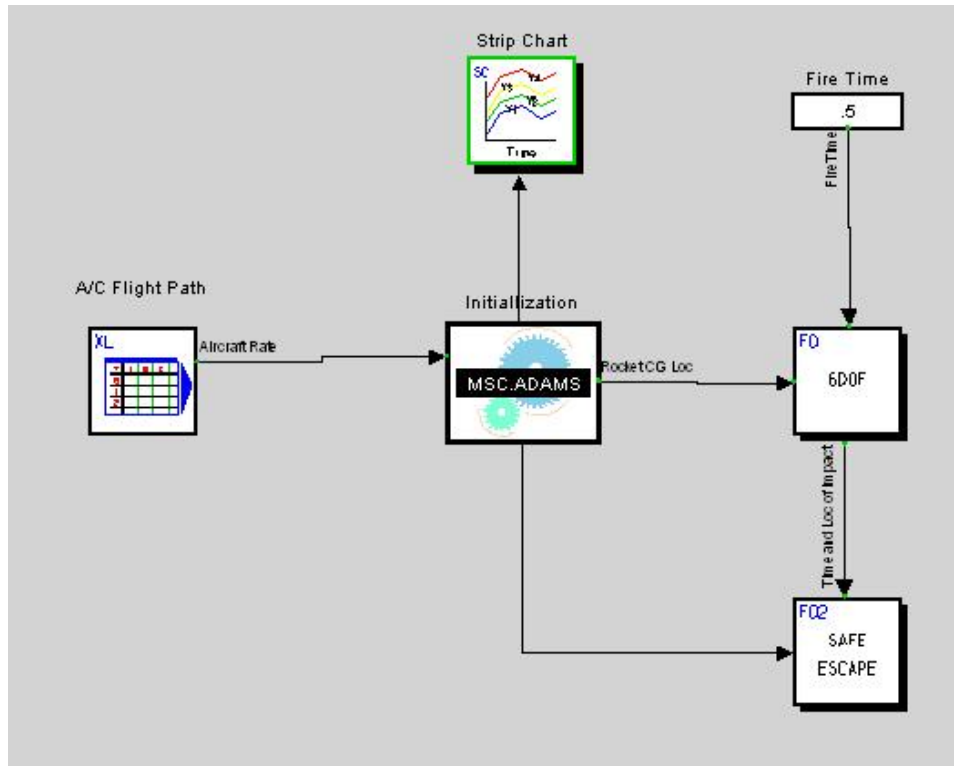


Figure 5. Easy5 Model of ASEAT Pass 1

The system model starts out with 3D-CAD models of the aircraft and its weapons. They can be imported to or created inside Adams. All necessary motions, forces and control inputs/outputs are developed in Adams to fly the aircraft or its munitions (Figure 6.)



Figure 6. Apache-D Model with M261 Rocket Launcher and a Single Rocket

The Adams block in Figure 5 is an export from Adams/Control. It contains all aircraft and weapon data. Control inputs to fly the aircraft come from the flight maneuver table that consists of aircraft rates and attitudes. At the time to launch a munition, initial condition of the munition's center-of-gravity (CG), which is provided by Adams, will be transferred to the munition's 6-DOF model. The munition's 6-DOF model flies the round to the target and provides the Safe-Escape (SE) block with the round's impact time, location, and impact angle for estimation of fragments that could hit the aircraft. Figure 7 shows how the coordinate systems are defined.

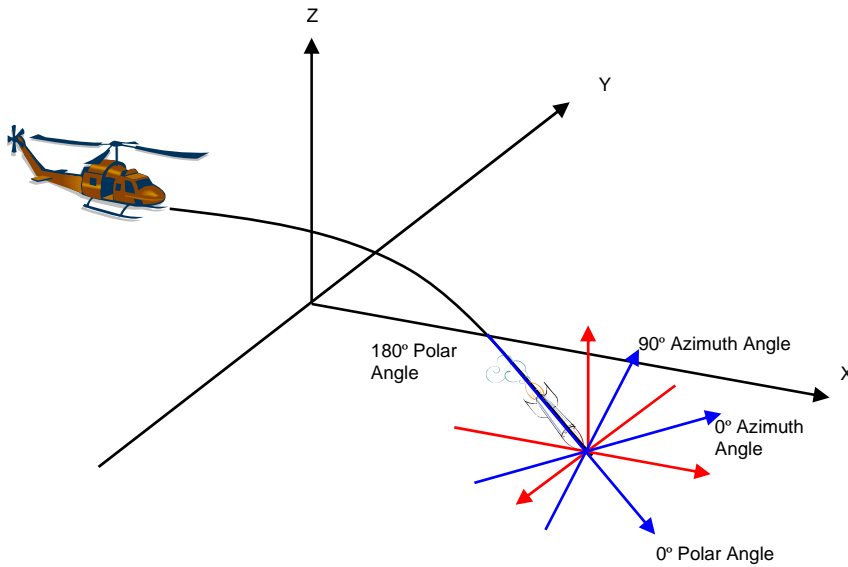


Figure 7. Coordinate Systems

After the round's impact, the aircraft model continues to fly for an additional 5 seconds to generate flight data for the SE block. At the end of the flight, a Monte Carlo simulation of a million iterations for a million fragments is used. The SE block will randomly pick fragments from arena data to randomly fly them into the sky. Currently, the U.S. Army aircraft weapons list consists of Hellfire missile, 2.75 inch rocket, 30mm High Explosive Dual Purpose (HEDP) gun, 7.62mm minimum, and Stinger missile (Table 1).

MH-6	USA (special operations)	Hellfire missile, 2.75 inch rockets, .50 caliber gun, 7.62mm minigun
AH-64	USA	Hellfire missile, 2.75 inch Rockets, 30 mm HEDP gun
MH-60	USA (special operations)	Hellfire missile, 30 mm HEDP gun, 2.75 inch rockets, .50 caliber gun, 7.62mm minigun
OH-58D	USA	Hellfire missile, 2.75 inch rockets, .50 caliber gun, Stinger missile

Table 1. U.S. Army Aircraft and Weapons

The minimum safe range for Hellfire is not less than 500 meters while fragments of 30mm HEDP or 7.62mm rounds are not a concern for helicopters at a range of 150 feet or greater from a target. The 2.75 inch rocket warhead fragments might be dangerous to the firing aircraft during a close range combat. Figure 8 is arena data of the rocket M151 warhead. During fragment fly-out, miss-distances between aircraft and fragments are computed to determine hit or miss. Fragments that hit the aircraft will be recorded for further processing.

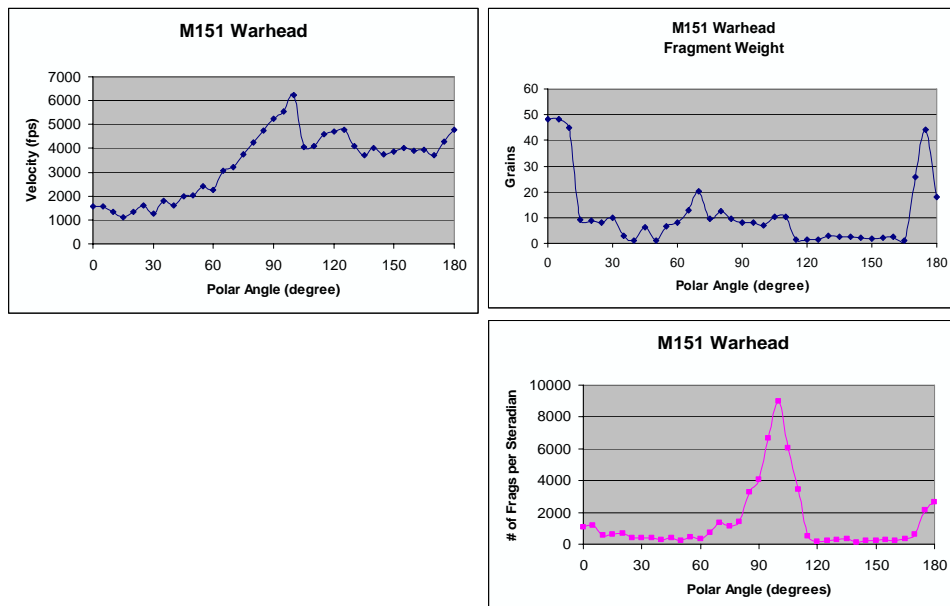


Figure 8. 2.75 inch Rocket M151 Warhead

The aircraft model in the SE block is a “shoe-box” model of the size that can enclose the entire aircraft. The reason for this shoe-box approach is the total time to complete an analysis. It is possible to perform the Monte Carlo analysis for fragment to fly-out directly inside the Adams aircraft/weapons model. However, this is a time consuming process. Fragments fly very fast and require very small time integration step for better miss-distance computation. In the co-simulation mode, it will take two to three minutes to complete a single iteration. One million iterations would take forever to complete. So the idea is to use the shoe-box to represent the aircraft to collect data on those fragments that have a good chance to hit the aircraft for further investigation in the second step. The entire Monte Carlo run is processed inside the SE block with no further communication with other components outside the block until completion. It takes two to three minutes to complete one million iterations.

After the initialization step, the following data then becomes available for Pass2 of the analysis: Potentially-hit-fragments data (PHFD), impact time, impact location, and weapon trajectory data. The Easy5 model for Pass2 of the analysis has the same Adams block and flight maneuver table as for Pass1. In Figure 9, the Weapon-Motion table contains weapon trajectory and attitude that are created in Pass1. It will guide the weapon along its trajectory for visualization and animation purpose. The remaining blocks are for the fragment’s three velocity components, fragment mass, drag-force computations, and integrations to determine fragment location in the earth’s frame of reference. Fragment trajectory data serves as control-input to fly the fragment in Adams. With both aircraft and fragment movement in space, their miss-distance and hit location can be precisely determined.

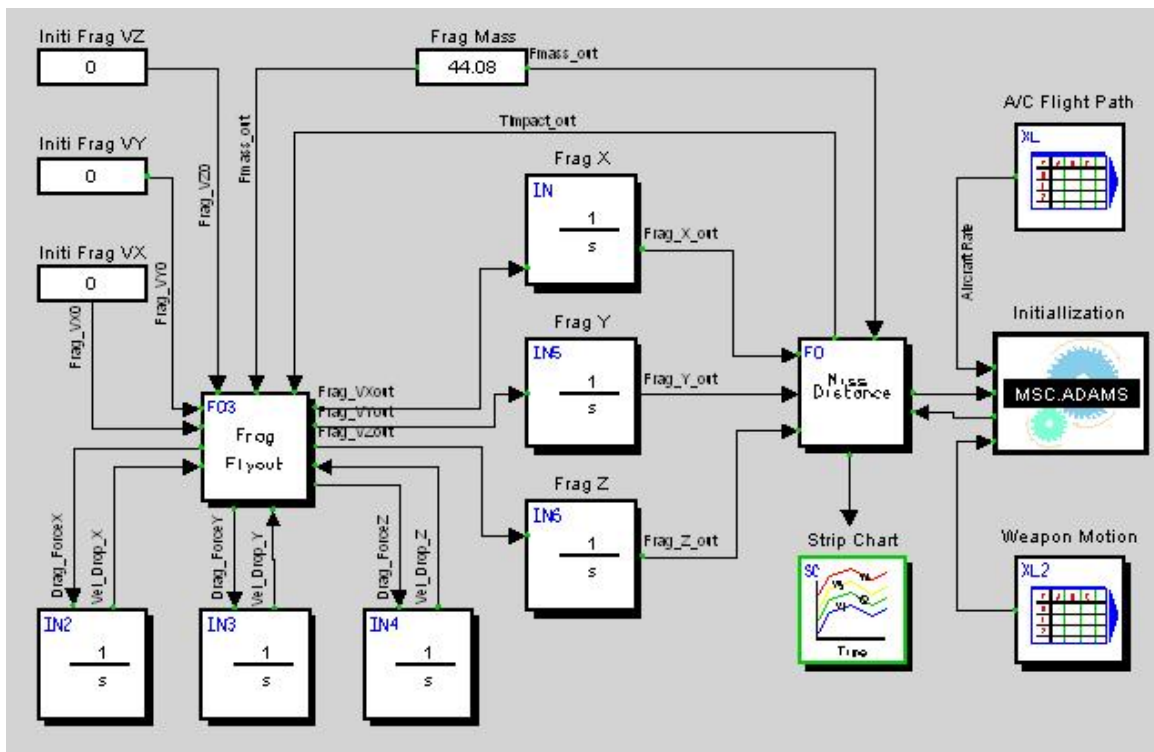


Figure 9. Easy5 Model of ASEAT Pass2

The final step of Pass2 is to run the model with fragment data from the PHFD file. Easy5's Matrix Algebra Tool has the ability to change or update the model's parameters. Script file (Figure 10) will load the PHFD. It has a loop that runs from one (1) to the total number of fragments in the PHFD. For each loop, the new fragment's mass and velocity components are loaded; analysis is carried out; and hit data will be recorded.

The 3D-CAD model is a high resolution representation of the aircraft. Therefore, Pass2 is used to refine the hit-list that is produced by Pass1. Actual collisions between fragment and various parts the aircraft can be detected by sensors. One way for the sensors to detect collisions is by contact forces between fragments and the aircraft. As a fragment hits the aircraft, the contact force will rapidly increase. The fragment's state can be recorded.

```

load C:\SafeEscape_12_05\PHFD.dat
delete Miss_All.txt;
params = PHFD;
[numruns, numvars] = size(params);
Command_Matrix= redim(string(zeros((2+numvars)*numruns,1)),2+numvars,numruns);
Mod_params=string(zeros(6,1));
for run=1:numruns
    Command_Matrix(1,run) = 'PARAMETER VALUES';
    Command_Matrix(2,run) = 'Fmass_out = '+sprintf('%.13g',params(run,1));
    Command_Matrix(3,run) = 'Frag_VX0 = '+sprintf('%.13g',params(run,2));
    Command_Matrix(4,run) = 'Frag_VY0 = '+sprintf('%.13g',params(run,3));
    Command_Matrix(5,run) = 'Frag_VZ0 = '+sprintf('%.13g',params(run,4));
    Command_Matrix(6,run) = 'CALC XIC,SIMULATE';
    for J=1:6
        Mod_params(J,1) = Command_Matrix(J,run);
    end
    delete Mod_matrix;
    save Mod_matrix Mod_params -ascii
    command='cat SE_RUN.simulation.ezanl sed ''s/CALC XIC,SIMULATE//''|cat - Mod_matrix >'+analysis_file.ezanl'
    system(command);
    system('easy5x -B outout +SE_RUN analysis_file.ezanl');

    F_ptr = fopen('Miss_All.txt', 'a');
    fputs('Case = '+sprintf('%.13g \n',run), F_ptr);
    fclose(F_ptr);
    system('cat MissDis.txt >> Miss_All.txt');
    delete analysis_file.ezanl;
end
delete one_column_matrix;
delete outout.ezrpd;
delete Mod_matrix;
delete Mod_params;
clear numruns numvars params Command_Matrix command;

```

Figure 10. Matrix Algebra Tool's Script File

A fragment with kinetic energy of 5 ft-lbs relative to the aircraft is considered to be safe. If a fragment with energy of less than 5ft-lbs hits an aircraft, it will not be considered as a hit. The ASEAT analysis is used to determine the minimum safe range that no fragments will strike a platform. If there is a need to fire at a target from a range that is shorter than the minimum safe range and it is possible that some fragments might hit the aircraft, then the probability of kill (Pk) can be determined by using hit-fragment

data and a software package such as AJEM. The Pk is an important piece of information for conducting risk assessment, a part of the Army Airworthiness process.

The Adams Post Processing provides further confirmation about the fragment and its collision with the aircraft. Detail information can be obtained from clearance analyses, graphs, visualization, and animation. For each fragment in Pass2, there is a set of analysis-out files that can be imported into Adams for post processing. In Figure 11, the yellow line represents the miss-distance between the fragment and the main rotor blade.

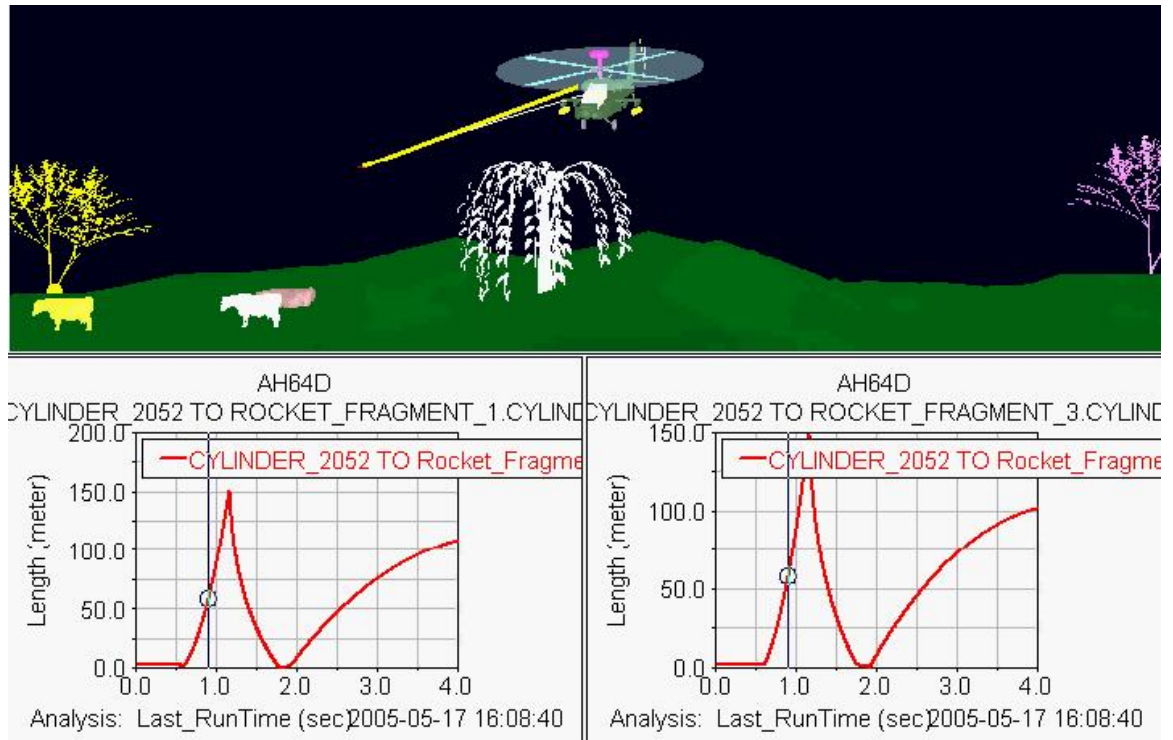


Figure 11. Clearance Analysis

In conclusion, urban combat requires aircraft weapon firing at short ranges that create a risk of damage from the exploding fragments from its own launched munitions. The ASEAT provides the Aviation Engineering Directorate with the capability to conduct minimum safe range analysis to support the Airworthiness Qualification Program and Airworthiness Release Process.