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FATEPEN, A MODEL TO PREDICT TERMINAL BALLISTIC PENETRATION AND DAMAGE TO MILITARY TARGETS

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ABSTRACT

This paper describes the Fast Air-Target Encounter Penetration (FATEPEN) model used in the design, development and evaluation of new anti-air weapon systems. FATEPEN is a set of fast running algorithms that simulate penetration of, and damage to, spaced target structures by compact and noncompact warhead fragments, and long rods at speeds up to 5 km/sec. Our paper begins with a discussion of the role of simulation in the development of weapons systems and more specifically in the design of anti-air missile warheads. The FATEPEN terminal interaction model is then described including our approach to penetration model development, illustrations of high velocity penetration characteristics addressed by the code, a listing of the models required for accurate terminal effects simulations, and an overview of the FATEPEN computer code including sample model predictions. The paper concludes with brief descriptions of FATEPEN documentation, the current code validation database, the corresponding code prediction accuracy statistics and a summary of current FATEPEN usage in the weapons system effectiveness community.

INTRODUCTION

Anti-air warfare is a critical component of U. S. national defense and a thrust area for the Naval Surface Warfare Center, Dahlgren Division (NSWCDD). In this area, simulation plays an ever-increasing role in the design, development, test, and evaluation of new weapon systems. The use of simulations in weapon technology and system development processes:

- Allows evaluation of a large number of initial concepts or variants
- Allows the final optimization of a specific design
- Allows evaluation in system operating regimes that cannot be tested
- Reduces the number of developmental and operational tests required to evaluate system performance

The overall result is significant cost savings and increased battlefield performance. These gains are realized, however, only if the simulations are sufficiently accurate representations of the real world.

ANTI-AIR MISSILE SIMULATION AND WARHEAD DESIGN

The mission of an anti-air missile warhead is to defeat a threat target by inflicting a predetermined level of damage on the target so that it can be declared "killed". Simulation of this process involves modeling the intercept kinematics of the missile and target, the fuzing and detonation of the missile warhead, and finally the critical and complex interaction of the warhead fragment damage effects on the target and its components.

An anti-air missile must engage a large variety of target types over a large range of altitudes and kinematic conditions. Because of limits in missile guidance and maneuver capabilities, this can result in significant miss distances and a large range of relative orientations of the missile and target. It becomes the job of the warhead and its target detection device, or fuze, to compensate for these variations in targets and intercept conditions and maximize the probability of doing sufficient damage to the target. This paper focuses on warhead design parameters and on the warhead fragment-target interaction model required to optimize the warhead design.

The basic design parameters for conventional types of missile warheads, given a constraint of total weight, are fragment size, shape, number, material (steel, tungsten, etc.), initial velocity after warhead detonation, and the fragment dispersion angles. Each of these parameters is affected by specific selections of the others. If one were to analyze all possible combinations, the number of possible designs would be enormous. However, design experience and the results of prior analyses reduce this to a tractable number.

An initial warhead concept down-select process consists of running the missile-target intercept simulation parametrically, varying all parameters over the ranges of interest. That is, each warhead concept is evaluated for its capability to defeat each target over a large range of intercept conditions. The concepts that achieve the highest average probability of defeating all targets are selected for the next iterative level of design, test and evaluation. A critical part of the simulation is the calculation of damage and defeat of the target by the warhead fragments. The model that calculates this damage must be of sufficient accuracy and fidelity to be sensitive to changes in warhead design parameters.

FATEPEN TARGET INTERACTION MODEL

FATEPEN was originally developed to simulate compact fragment penetration of thin to moderately thick, spaced plates at impact velocities up to about 5 km/sec. Recent model developments have extended FATEPEN applications to long rod penetrators and thick plates. Over the intervening years (1983-1998), improvement and extension of FATEPEN have been the unifying focus of many otherwise independent experimental and analytical efforts to investigate high velocity and hypervelocity penetration characteristics for a wide variety of penetrator and target materials and structures.

The model predicts penetrator deformation, mass loss, velocity loss, trajectory change, and tumbling throughout a target. The mass loss model includes a robust impact fracture model that transforms an incident intact warhead fragment into an expanding, multiparticle debris cloud which FATEPEN then tracks through the remaining target structure. FATEPEN also predicts multiparticle loading and damage to plate structures. The primary application of the code has been weapons effectiveness assessments involving air targets and lightly-armored surface targets.

Target Descriptions and Representations

Warhead terminal effects simulations, utilize detailed target models comprised of thousands of geometric elements as illustrated in Figure 1. The target models mathematically describe the spatial distribution of target materials and structures. The target descriptions are probed by shotline models to determine which target structures will be intercepted along specific fragment trajectories. For penetration calculations, the target structures are represented by flat plates or fluid-filled volumes with properties defined by the target description at the intersection points.

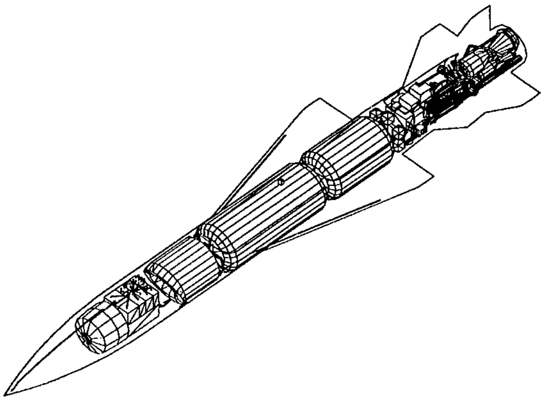


Figure 1. Cruise Missile Geometric Model

Approach to Model Development

FATEPEN predicts the sequential transformations in a penetrator (changes in mass, velocity, orientation, etc) and corresponding target damage as the penetrator passes through the series of spaced plates and/or fluid volumes. Considering the large number of shotlines in a typical simulation, the number of target intersections along each shotline, and the wide variety of penetrator threats and target materials, terminal interaction models must be fast-running and also quite general in their application. FATEPEN meets these dual requirements through a collection of analytical/empirical, terminal interaction models.

FATEPEN incorporates "engineering" terminal ballistic penetration models in contrast to "first principle" finite-element/finite- difference codes. The core penetration models have been developed, as much as possible, by applying the laws of mechanics to the dominant terminal ballistic loading and response mechanisms as revealed by penetration experiments and first principle code calculations. Some of these models pertain to ideal impact geometries such as unyawed cylinders impacting plates at normal obliquity. The ideal models are extended to non-ideal impact geometries by employing supplemental relationships to approximate the effects of impact geometry on the dominant penetrator and target inertial and strength factors. Additional relationships are included to provide for rational and smooth transitions between ideal models as functions of the appropriate encounter variables. For example, a function of penetrator normalized length, L/D, is used to interpolate between penetration predictions from the compact fragment model and those from the long rod penetration model.

Finally, empirical model parameters are incorporated as needed to account for loading and response effects that could not be modeled either because of their complexity or because of time and funding constraints. The empirical parameter values in FATEPEN are collectively one of the greatest assets of the code. Evaluation of these parameters, either through testing or first principle code calculations, furnishes a straightforward means for extending the code to new penetrator and target materials and structures. The empirical parameter values also provide a very useful legacy for the many penetration experiments used in developing and validating the models and computer code.

High Velocity Penetration Characteristics

At low speeds, fragments perforate thin plates without deformation or mass loss. As impact velocity increases, impact pressures become more intense, and fragments begin to "mushroom". Against harder and/or heavier plates, penetrator material extruded beyond a certain radius will be sheared from the fragment as it passes through the plate (see Figure 2). At higher impact speeds, the relative velocity between the penetrator and the moving impact interface will exceed the speed at which plastic deformation can propagate into the penetrator. When this occurs, a shock wave forms in the penetrator just upstream of the impact interface and penetrator material passing through it will be ejected radially outward (see Figure 3). Later in the perforation, when the relative velocity falls below the plastic wave speed, the relative motion can be accommodated by plastic deformation in the penetrator and shock erosion gives way to extrusion-shear mass loss. Above a material dependent critical impact speed, fragments will also fracture or shatter upon impact (see Figure 4) and the fractured pieces disperse radially behind the plate. Threshold fracture speeds are sensitive to fragment shape and impact orientation.

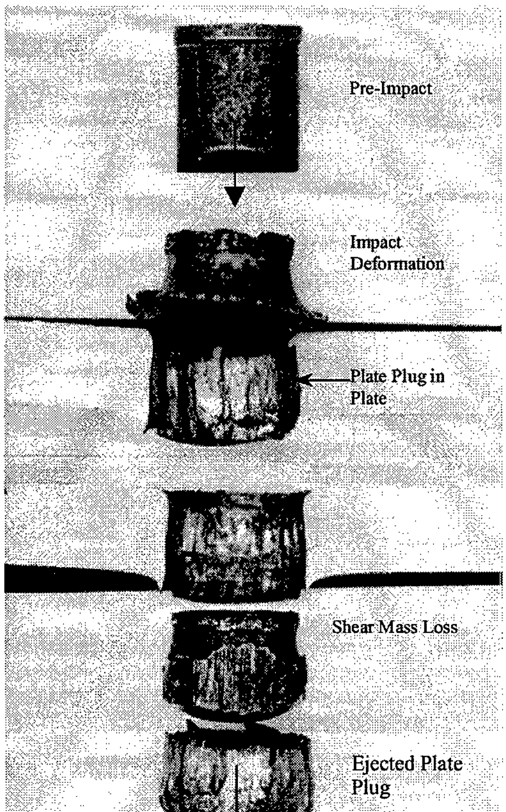


Figure 2. Extrusion-Shear Mass Loss in a Steel Fragment Simulating Projectile (FSP) Perforating a Mild Steel Plate

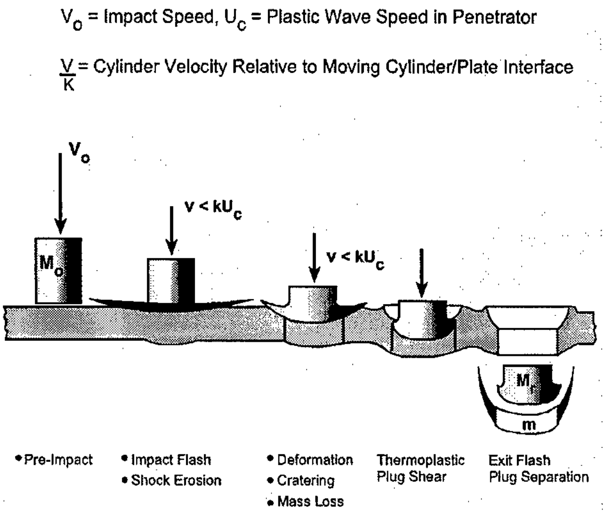


Figure 3. Shock Erosion and Extrusion Shear Mass Loss - FATEPEN Compact Fragment Penetration Model

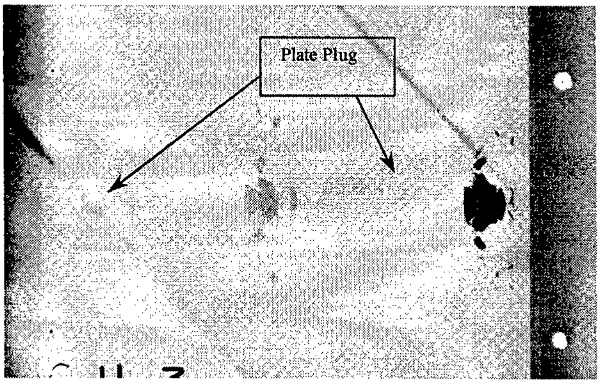


Figure 4. Impact Fracture. Double-Exposure Radiograph of a 240-Grain Steel Cube After Perforating a 1.6-mm Aluminum Plate at 2.05 km/s.

Steel cylinders (Rc 30) impacting mild steel plates begin to deform when impact velocity exceeds about 450 m/s. The onset of extrusion-shear mass loss occurs at a velocity near 600 m/s, and shock-erosion mass loss will occur at speeds above about 750 m/s. Flat impacting mild steel cubes begin to fracture at speeds near 730 m/s when impacting steel plates and at speeds near 900 m/s on impact with aluminum plates.

The severity of fracture and the number of debris particles increase with increasing impact speed above the fracture threshold.

The multiple plate penetration damage caused by the steel cube in Figure 4 is shown in Figure 5. The double exposure, flash radiograph in Figure 4 shows dispersion of the fractured cube behind the first plate in Figure 5. The cross-shaped hole pattern in the second plate is typical for a fractured cube and reflects separation along diagonal planes. Hole patterns in subsequent plates are consistent with a progressive stripping away of the outer debris particles.

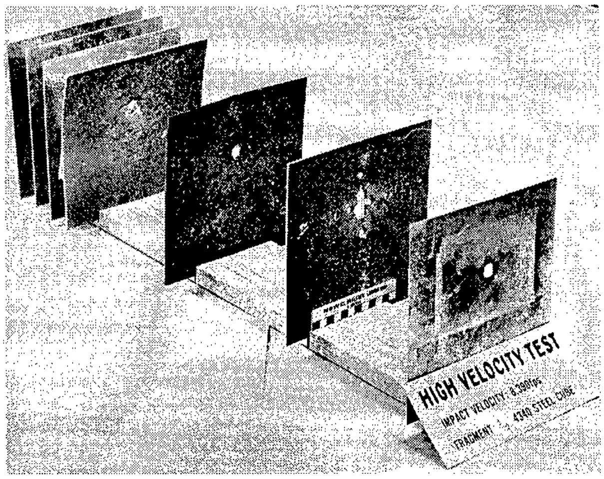


Figure 5. High-Velocity, Multiple-Plate Penetration Damage Caused by Steel Cube shown in Figure 4

The multiple exposure radiographs in Figure 6 were obtained from recent experiments to investigate and model the penetration characteristics of long rods involved in non-ideal impacts (combinations of impact yaw and obliquity). For the same impact conditions against a normal plate, the rod would lose about 10% of its length to erosion and extrusion shear mass loss. The rod in Figure 6 lost about 40% of its length in penetrating the oblique plate and was severely bent in the process and can be seen to be rotating behind the plate. FATEPEN rod penetration model predictions (rod length loss, deformation, trajectory deflection and tumbling) are illustrated by the scaled rod images above the radiographs in Figure 6. In this case, FATEPEN predicts a clockwise tumbling in the elevation plane due to the transverse impulse associated with exit from the oblique plate. The apparent counter-clockwise rotation in the radiographs could be due to continued deformation behind the plate or to rotation (and tail contact with the edge of hole) prior to the rod clearing the plate. Most impacts in real targets involve non-ideal impact geometries, which often result in significant transverse loading and deformation and fracture in long rod penetrators. These effects severely limit the subsequent penetration effectiveness of the rods and must be modeled for accurate lethality assessment for warheads utilizing this kind of penetrator.

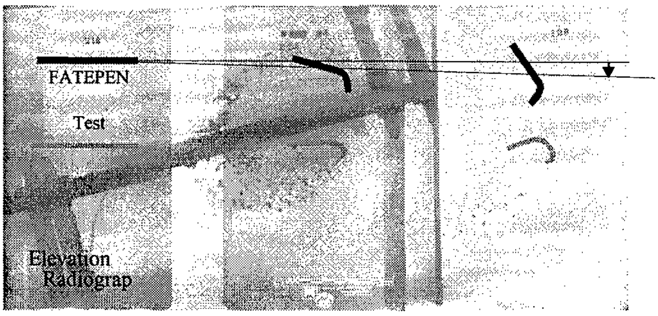


Figure 6. Response to Transverse Penetration Loads. Tungsten Rod (L/D = 20) vs. Steel Plate (T/D=2) at 75° Obliquity, V = 1833 m/s.

FATEPEN Penetration Model Overview

Figure 7 contains a flow chart mapping the penetration computational loop in FATEPEN. A typical run begins by specifying the initial penetrator (primary fragment) characteristics, the plate array characteristics and the encounter conditions (impact velocity, penetrator orientation and spin rate). Penetrator shapes and target structures currently recognized in FATEPEN are shown in Figure 8. The PC version of FATEPEN is an interactive program and the user may select preprogrammed penetrator characteristics from a default catalog, define new fragments by editing the catalog entries or by reading previously saved penetrator files. Likewise, plate array characteristics can be changed by editing the default plate array or by reading and editing previously saved FATEPEN plate array descriptions.

Possible penetrator materials include: steel, aluminum, tungsten alloy, depleted uranium, tantalum, and titanium.

Allowable plate materials include: steel, aluminum, titanium, magnesium, doron, phenolic, pine, oak, cast iron, copper, lead, tuballoy, unbonded nylon, bonded nylon, lexan, cast plexiglas, stretched plexiglas, bullet-resistant glass, face hardened steel, and graphite epoxy fiber reinforced composites. Fluids are specified by their specific gravity.

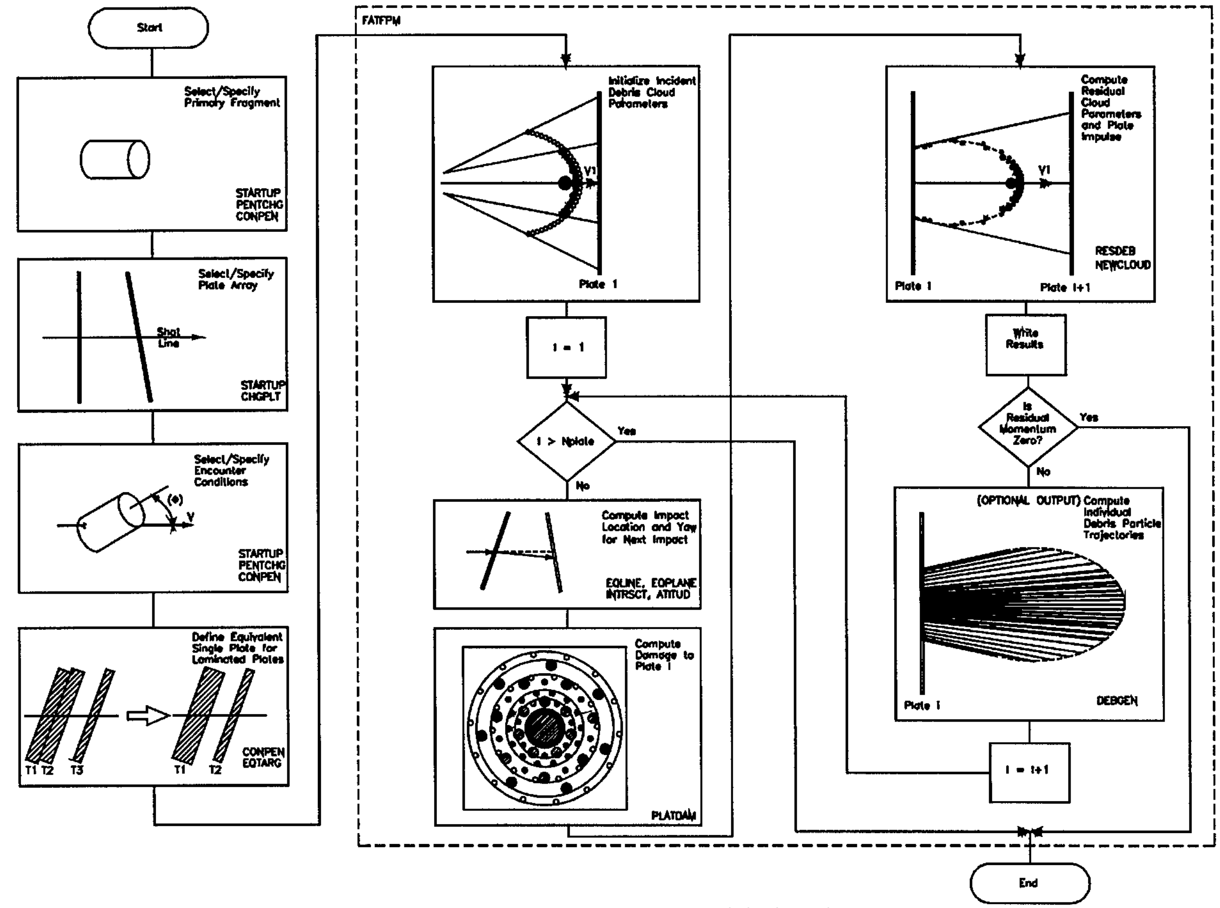


Figure 7. FATEPEN Penetration Model Flowchart

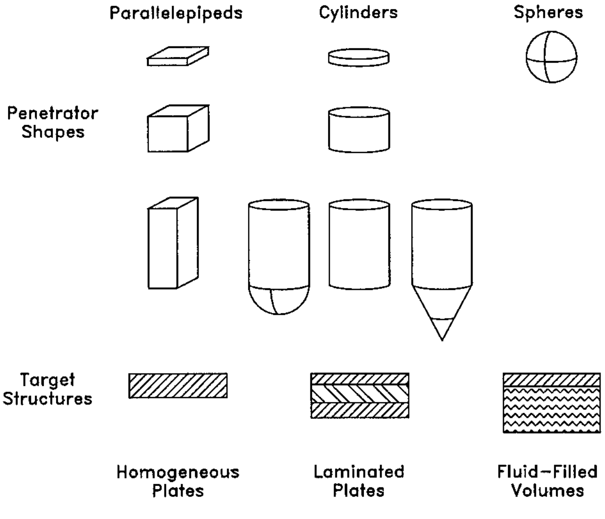
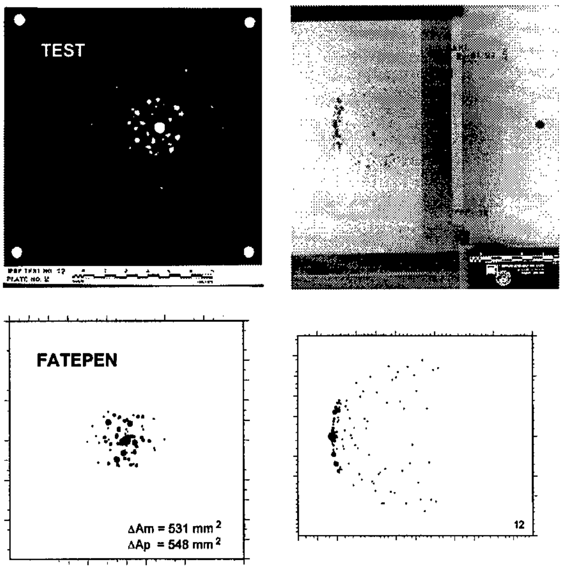


Figure 8. FATEPEN Penetrator Shapes and Target Structures

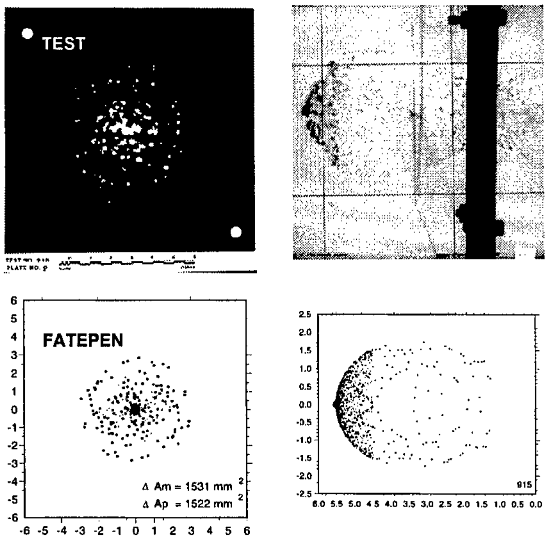
After the primary fragment, plate array, and encounter conditions are specified, FATEPEN searches the input plate array for laminated plates and replaces them with equivalent single plates for the penetration calculations. FATEPEN then assigns values to parameters describing characteristics of the secondary particles in the debris cloud incident on the first plate.

In general, the debris cloud may include the primary penetrator particle, as described above, two sizes of secondary penetrator particles and one average size for plate particles. A fourth penetrator debris category is reserved for broken long rod penetrator pieces.

Following definition of the initial debris characteristics, the main computational loop is entered. The primary fragment velocity and angular momentum vectors are first used to compute the impact location, obliquity, and orientation at the next plate. Plate damage caused by the incident primary fragment and debris cloud is computed next as shown in Figure 7. Possible plate damage includes holes and/or craters made by individual particles and a central hole-out region caused by the particles acting in unison.



V=2.4 Km/sec.



V = 4 Km/sec

Figure 9. Debris Clouds and Witness Plate Damage, 3.6 gram Steel Sphere vs. 2.4 mm Copper Shatter Plate and Aluminum Witness Plate.

The residual debris characteristics and plate impulse are determined after the plate damage calculations. In general, some of the incident debris particles will penetrate and some will be stopped. Those particles that penetrate will generally lose mass and velocity and drive additional new plate particles into the residual debris cloud. The primary penetrator particle is monitored separately. It may fracture on any impact in addition to losing mass to the other mechanisms listed above. The primary penetrator may also generate single or multiple plate particles. When the primary penetrator particle and/or its plate plug fractures, it produces a new debris cloud. The primary fragment residual velocity and angular momentum vectors are computed for use in determining the encounter conditions for the next impact. Lateral loading and response is computed for rod penetrators (L/D > 2) including the bend angle and, if the rod fractures, the sizes of each piece are assigned to the fourth penetrator debris category.

Typical FATEPEN compact fragment penetration model predictions are compared with test results in Figure 9. The photographs in Figure 9 illustrate the effects of increasing impact speed on impact fracture and debris cloud constituents and on plate damage. The graphical depictions of the debris clouds were generated from the predicted secondary particle velocity and trajectory distributions behind the first plate. The predicted plate damage maps derive from the hole size calculations and trajectory distributions behind the first and second plates.

Summary of FATEPEN Penetration Models

The fragment penetration models required for accurate weapons effectiveness simulations are listed in Table 1, and the primary penetration models installed in FATEPEN are listed in Table 2.

Table 1. Penetration Model Requirements for Weapons Effectiveness Simulation

- Primary Fragment Residual Mass and Debris Cloud Constituents
- Primary Fragment Residual Velocity and Debris Cloud Velocity Distribution
- Rod Penetrator Deformation and Fracture
- Trajectory Deflections
- Primary Fragment Tumbling or Gyration
- Plate Damage

In general, preliminary penetration experiments are used to reveal the primary penetration loading and response mechanisms. Preliminary analytical models are then developed and first principle code calculations are used to confirm or reveal loading and response details that cannot be observed experimentally. More extensive experiments are conducted later to verify and/or modify the models as needed and to evaluate any required empirical parameter values

Over 1900 impact experiments have been conducted in support of FATEPEN model development.

Table 2. FATEPEN Primary Penetration Models

Subroutine Name	Computation	Penetrator
IMPED/RESMAS	Erosion/Extrusion Shear Mass Loss	Compact Fragments
MHYDRO+IMPED/RESMAS	Erosion/Extrusion Shear Mass Loss	Rod Penetrators
LATERO	Lateral Erosion Mass Loss	Compact and Rods
SHATR	Impact Fracture and debris Particles	Compact and Rods
VRPLATE	Plate Perforation Residual Velocity	Compact and Rods
VRFLUID	Fluid Penetration Velocity Decay	Compact and Rods
RODCON + RODSHEAR	Lateral Loading and Response	Rod Penetrators
RAM	Residual Angular Momentum	Compact and Rods
ATITUDE	Penetrator Orientation Changes	Compact and Rods
HOLE	Individual Particle Hole Size	Compact and Rods
PUNCH	Multi-Particle Hole Enlargement	Compact and Rods

FATEPEN DOCUMENTATION AND VALIDATION

The development of FATEPEN has been continuously documented in over sixty technical reports and papers. The current version of the model is completely described in three reference manuals as follows[1].

Volume I – Analysts Guide.

The Analysts Guide describes the analytical foundation of FATEPEN and serves to promote more informed decisions regarding its application, to aid in interpreting the output of the code, and as a reference for future improvements. This volume summarizes the development history of FATEPEN (including an annotated bibliography of all model development papers and technical reports), describes the penetration phenomenology addressed by the code, provides an overview of the model, describes penetrator and target input conventions, and summarizes each of the primary terminal interaction models and algorithms including the principal formulas and the assumptions and limitations associated with their development.

Volume II – User's Guide.

The User's Guide provides instructions regarding installation of FATEPEN onto a PC, how to activate the code, and includes detailed instructions explanations, and screen displays describing how to use of the code for penetration problems and for component vulnerability analysis.

Volume III – Validation Document.

The Validation Document presents the results of comparisons between FATEPEN model predictions and numerous test results contained in an expandable terminal ballistics database. The database encompasses a wide range of encounter conditions to thoroughly test the model. The comparisons establish the prediction accuracy of the model and confirm its applicability to a wide range of encounter conditions. The comparison statistics and the associated graphs provide a benchmark to track prediction performance for future releases of the code and to compare prediction accuracy between similar codes. The validation process has been automated for re-application with each new update to the code and future expansions of the FATEPEN model development and validation terminal ballistics database.

Validation of FATEPEN (Version 3.0.0)

High quality test results from three sources have thus far been compiled into the FATEPEN model development and validation database. The database currently contains required FATEPEN input and the test results for 1117 penetration tests. The ARA/DRI Impact Fracture Database contains 597 tests involving steel cubes impacting thin plates[2]. The majority of these tests were designed to reveal variations in primary fragment residual mass with impact speeds near the threshold fracture speed. The SwRI Penetration Mechanics Database contains 2237 impact tests of which 389 have thus far been included in the FATEPEN validation database. These test involve long rod penetrators impacting plates near and above the ballistic limit velocity[3]. The third data source, the NRL Rod Lethality Database, contains 275 hyper-velocity rod impact tests for various metallic penetrator and plate materials of which 131 have been included in the validation database[4]. A total of 270 hypothetical check cases are also included in the database to thoroughly exercise the model for all the penetrator material and shape options and the target material and structure combinations. These test cases serve to reveal inadvertent bugs that get introduced during model improvement efforts and to track model predictions from one release of the code to the next.

FATEPEN validation includes two types of comparisons between model predictions and the test data. The first kind are point-by-point comparisons wherein the measured impact conditions are input to FATEPEN and the model predictions are compared on a point-by-point basis with the corresponding test results. The point-by-point comparison statistics establish the model predication accuracy for the characteristic encounter conditions associated with each Data Report. Figure 10 contains the point-by-point residual mass scatter plot (upper graph) and associated accuracy distribution histogram (lower graph) for the ARA/DRI impact fracture database. The stochastic nature of impact fracture near the threshold fracture speed is evident in the data scatter in the upper graph of Figure 10. The percentages of the comparisons falling within positive and negative 10% error bands about the diagonal of the scatter plot are provided by the histogram. It can be seen that about 43% of the comparisons fall within the ± 5% error band and about 75% of the comparisons fall within ± 15% error.

The second type of comparison is a trendline comparison where predictions and test results for a particular penetration variable are compared over a range of values for some independent variable. The trendline graphs reveal singularities and discontinuities and generally show how "well-behaved" a model is. The current validation document includes trendline comparisons of penetrator residual mass and velocity versus impact speed. A typical set of trendline comparison graphs for the ARA/DRI impact fracture database are included in Figure 11. The trendline comparisons juxtapose trends in model prediction and test results and thereby provide a meaningful context for the point-by-point comparison statistics. For example, it can be seen in Figure 11 that the deterministic FATEPEN fracture model predictions generally pass through the middle of the data and provide a good representation of the results. This is especially true with regard to the onset of fracture and the abrupt drop in primary fragment residual mass with increasing velocity above the fracture threshold. These facts are not revealed in the point-by-point scatter plots.

Similar FATEPEN residual mass and residual velocity point-by-point comparisons and the associated scatter plots and accuracy distribution histograms were generated for the SwRI and NRL rod penetration databases. The individual comparison statistics for each of the three databases are summarized in Table 3. The relatively small mean errors for all comparisons except the NRL residual velocity comparisons indicate a fairly even distribution of positive and negative comparison errors and thus no significant systematic error in the model for these encounter conditions. On the other hand, the NRL residual velocity comparison mean error of – 9.1 % indicates a consistent under-prediction of residual velocity for hypervelocity impacts against thin plates. The under-prediction is attributed to neglecting impact shock effects on plate plug acceleration ahead of the penetrator.

From the combined database sample statistics tabulated at the bottom of Table 3, it can be seen that, over a large sample of comparisons involving a wide variety of impact conditions ***against single plates***, one can expect FATEPEN residual mass and velocity predictions to agree with test results to within ±5% about half the time. Likewise, the overall average standard deviation of 15% indicates (for a normal distribution of errors) that for the same comparison sample, one can expect agreement to within ± 15% (about the mean) about 68% of the time and to within ± 30% about 95% of the time.

The FATEPEN automated validation procedures are designed to easily accommodate additions to the validation database and to the list of penetration variables included in the comparisons. Future plans in this regard include the addition of target damage and post-perforation debris characteristics for single plates and for more complex targets including multiple spaced plates and real target structures. Prediction accuracy can be expected to decrease with increasing target complexity because of the propagation of errors over multiple impacts and because actual encounter geometries will deviate from the ideal flat plate impact geometries underlying the penetration models.

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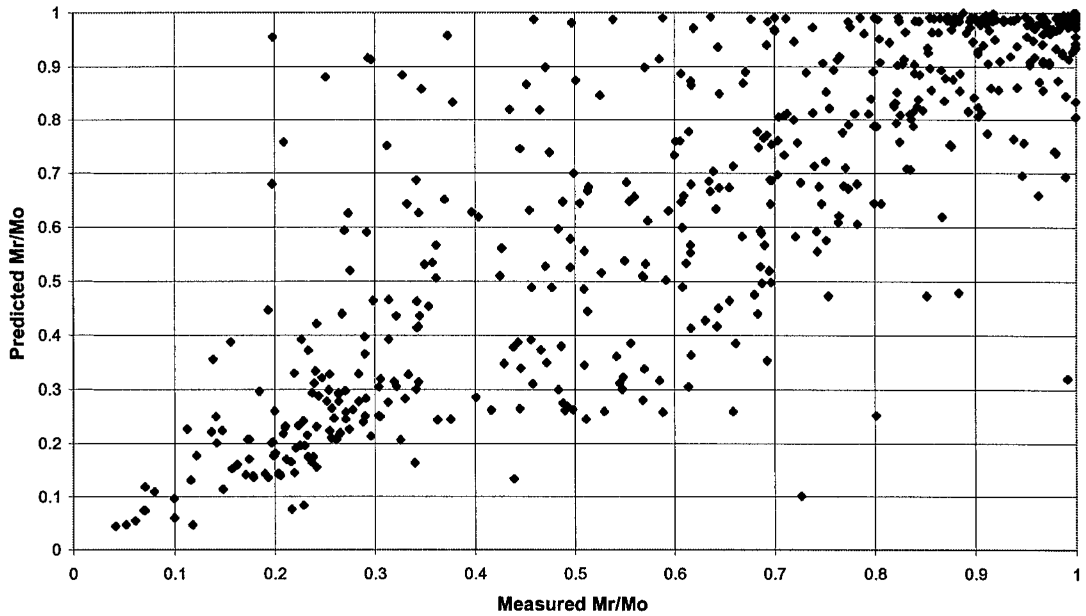
ARA/DRI Impact Fracture Database
Predicted vs. Measured Normalized Residual Mass



FATEPEN© 3.0.0b Run Date: 10/27/98
ARA/DRI Impact Fracture Database
Normalized Residual Mass Histogram
Sample Mean = 1.9%, Sample Standard Deviation = 16%
Sample = 576, Missing Data = 21

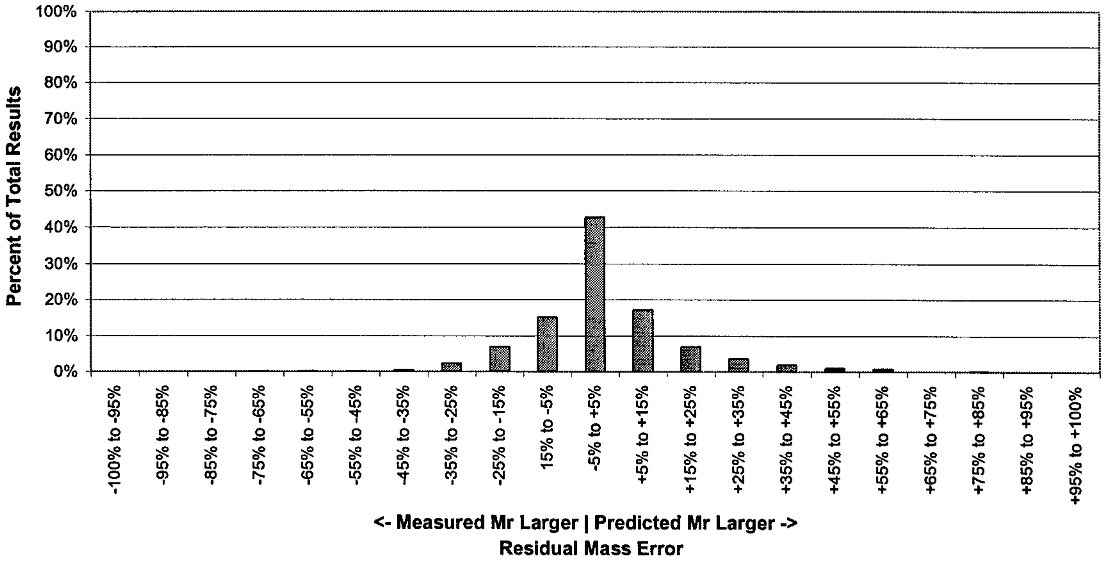


Figure 10. Point-By-Point Scatter Plot and Accuracy Distribution Histogram for ARA/DRI Impact Fracture Database.

FATEPEN© 3.0.0b Run Date: 10/27/98

ARA/DRI 69	0.313 Inch, 60 Grain, 4140 Steel Cube (L/D = 0.9, BHN = 290) vs. 0.04 Inch Aluminum Plate (T/D = 0.13, BHN = 120, Obliquity = 0°)	ARA/DRI 69

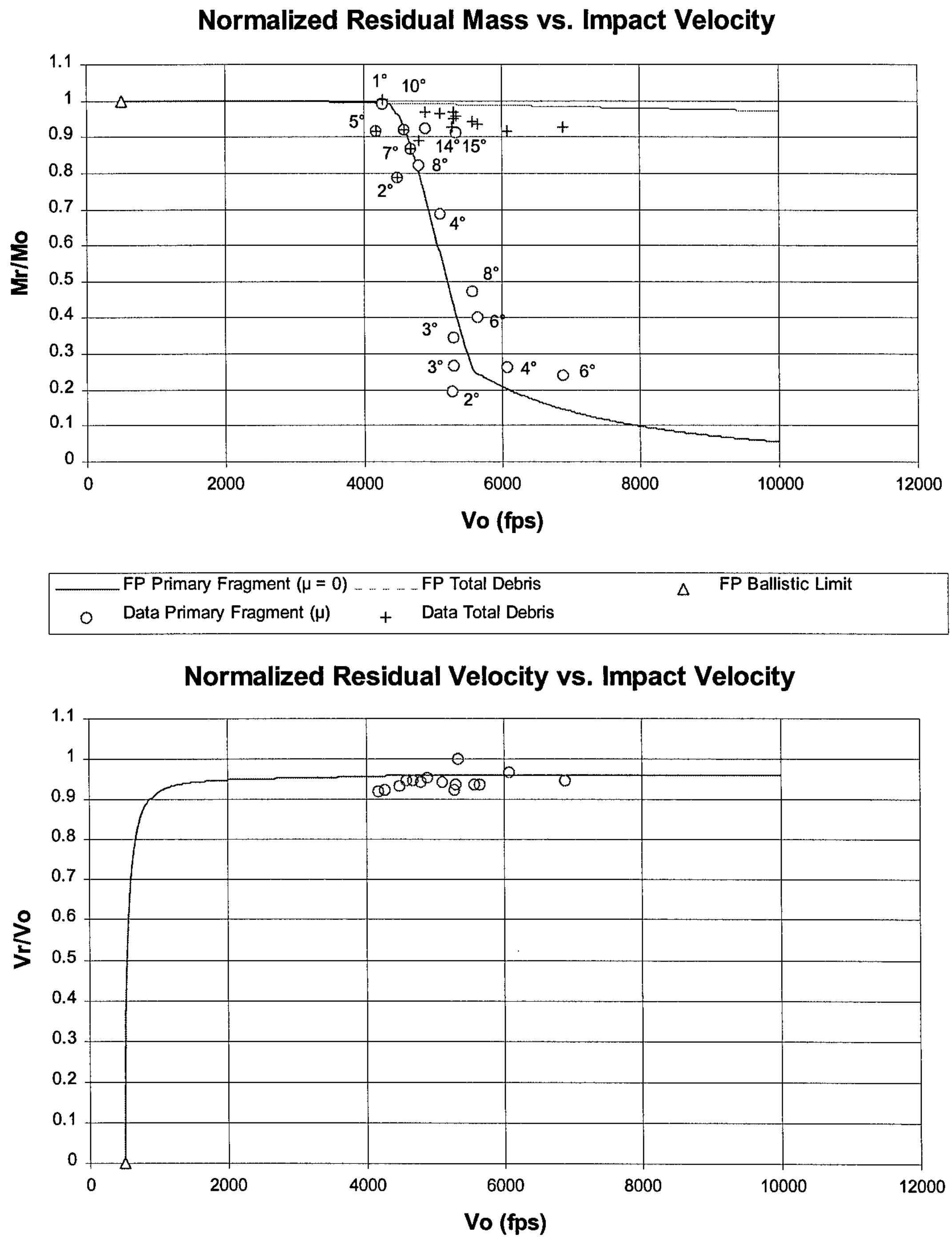


Figure 11. Sample Trendline Plot for ARA/DRI Impact Fracture Database.

Table 3. Summary of FATEPEN Comparison Statistics for Compact Fragments and Long Rods Perforating Single Plates.

Database	No. of Comparisons[1]		Percentage of Comparisons with error ≤ ±5%		Standard Dev. Of Comparison Errors (%)		Mean of Comparison Errors (%)	
	Mr/Mo	Vr/Vo	Mr/Mo	Vr/Vo	Mr/Mo	Vr/Vo	Mr/Mo	Vr/Vo
ARA/DRI (Cubes)	576	352	43	67	16.0	5.6	1.9	2.0
SwRI (Rods)	289	365	32	44	16.3	19.2	-3.5	-1.5
NRL (Hyper.Vel. Rods)	131	114	67	49	8.5	11.9	1.5	-9.1
All Databases	996	830	43	55	15.5	14.4	0.3	-1.1

[1] Number of comparisons are less than number of tests when either a required test result or FATEPEN input parameter value was not available for all tests.

FATEPEN TRANSITION AND USAGE

The FATEPEN model is being successfully used to evaluate weapon effects by a number of government agencies and by industry, both as a stand-alone model and as a submodel in higher level models and simulations. It has been accepted by both the Joint Technical Coordinating Group for Munitions Effectiveness, JTCG/ME, and by the Joint Technical Coordinating Group on Aircraft Survivability, JTCG/AS, as the standard model for predicting warhead fragment effects in aircraft. The JTCG/ME is in the process of accrediting the model for their use in the production Joint Munitions Effectiveness Manuals for anti-air weapon systems; these manuals are required for all weapon systems when they achieve initial operational capability.

FATEPEN has been incorporated as a submodel in other higher level models that evaluate the overall vulnerability of a platform or the lethality of fragments against specific targets. These higher level models include Computation of Vulnerable Areas and Repair Times (COVART), the standard model currently accepted by JTCG/ME and JTCG/AS and used by all three services to calculate the vulnerability of both air targets and non-armored mobile ground targets. The Advanced Joint Effectiveness Model (AJEM) is a new model developed by the JTCG/ME and JTCG/AS to evaluate the effectiveness of both warheads and small caliber projectiles against air targets, and it uses FATEPEN for penetration and damage calculations. The Army has incorporated FATEPEN in the Modular Unix-based Vulnerability Estimation Suite (MUVES) which evaluates the effects of a variety of weapons against ground mobile targets, including armored targets. The Air Force uses Modular Effectiveness/Vulnerability Assessment (MEVA) to evaluate air-to-surface weapons against underground targets and buildings, and this model also uses FATEPEN.

The Technical Cooperation Program (TTCP), involving Australia, Canada, the United Kingdom, and the U. S., established FATEPEN as an accepted comprehensive penetration methodology following a two and one-half year collaborative test and evaluation effort under their conventional weapons terminal effects technology panel.

A number of weapon acquisition programs are using FATEPEN as a part of comprehensive lethality or vulnerability, test and analysis programs, including Sidewinder (AIM-9X), Evolved Sea-Sparrow Missile (ESSM), Standard Missile (SM-2 Blk IVA), AMRAAM P3I (AIM-120), F-22, F-18E/F, and Joint Strike Fighter (JSF).

FATEPEN improvement and development has been continuing under various Navy research, development and acquisition programs in order to provide increased capability to evaluate the performance of new penetrator shapes and materials against new target materials, such as those found in ballistic missile targets.

SUMMARY

As acquisition programs continue to rely more and more on modeling and simulation to optimize their weapons to be more effective or more survivable for the warfighter, physical models of the interaction of weapon effects with targets must be made more accurate and of higher fidelity. Because of the generally long development period required for complex models, especially with limited funding, they must be developed initially under technology programs rather than under acquisition programs, which generally have a shorter development cycle. FATEPEN was initially developed under the Air and Surface Weaponry Technology Program sponsored by the Office of Naval Research. Improvement of the model has continued over many years under the Navy Air and Surface Weaponry Technology Programs and FATEPEN is now accepted and in use throughout government and industry.

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