

HAZX Part 1
An Explosives Hazard Assessment Tool

Principal Author: Jon D. Chrostowski and Wenshui Gan
Organization: ACTA Inc.
Mailing Address: 2790 Skypark Drive, Suite 310, Torrance, CA 90505
Phone: 310-530-1008
Fax: 310-530-8383
Email: chrostowski@actainc.com/gan@actainc.com

Co-Author: Daniel Murray and William Pollan
Organization: FAA/AST – AF 45th Space Wing, Weapons Safety Office
Mailing Address: FAA/Commercial Space Transportation, DC/AF 45SW/SELR, PAFB, FL
Phone: (202) 267 9237 / (321) 494-3266
Email: daniel.murray@faa.gov/ william.pollan@patrick.af.mil

ABSTRACT

HAZX is an explosives safety software tool that can be used to assess the hazards and/or risks when Quantity-Distance (Q-D) safe separation distances are violated. Part 1 of the presentation focuses on the HAZX hazard module which includes a GUI/GIS interface to simplify user inputs, spatial analyses and the display of results and reports. The risk tool is being developed using alternative methods to the algorithms and methods documented in DDESB's Technical Paper No. 14. The underlying fragmentation model performs multiple simulations of drag-corrected fragment throw to account for uncertainties in their characteristics and automate the pseudo-trajectory normal method to compute hazardous fragment density considering 3D bounce/roll over uneven terrain. The hazard tools have been used to support equivalent protection and consequence explosion analyses launch vehicles and conventional weapons by the AF, FAA and Army. The HAZX hazard tool is demonstrated including the capability to compute: a) air blast and hazardous fragment density, and b) consequences of air blast and fragment impacts to ES's (damage, injury and fatality).

INTRODUCTION

Figure 1 shows the four step process that the DOD Explosives Safety Board (DDESB) recommends for evaluating explosive hazards, consequences and risk in order to gain an explosives site plan approval. Note that all four steps do not have to be performed for approval; meeting the acceptance criteria for any of the four steps is sufficient. For example, if the explosives site plan is in conformance with the DOD Quantity-Distance (Q-D) criteria the other three steps need not be performed. Similarly, if equivalent protection is provided the corresponding analysis can be used to gain site approval even if the Q-D safe separation distances are violated.

Equivalent protection criteria are met by performing site-specific explosives hazard analyses¹ to compare the computed distances for a specified incident overpressure level and hazardous fragment density. For Inhabited Building Distance (IBD) the Explosives Standards specify that: a) the incident overpressure level at an ES be less than or equal to 1.2 psi for NEW's less than 45 Klb, TNT and 0.9 for NEW's greater than 250 Klb, TNT, and b) the hazardous fragment (≥ 58 ft-lbs) density be less than one per 600 square feet.

Consequence criteria have not yet been specified by the Explosives Standards but clearly the damage to buildings (structural and window) and the likelihood of injuring people in the open and inside buildings must be evaluated and minimized.

¹ A hazard analysis assumes the explosion accident occurs.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|------------------------------------------|----------------------------------|
| 1. REPORT DATE JUL 2010 | 2. REPORT TYPE N/A | 3. DATES COVERED - | |
| 4. TITLE AND SUBTITLE HAZX Part 1 An Explosives Hazard Assessment Tool | | 5a. CONTRACT NUMBER | |
| | | 5b. GRANT NUMBER | |
| | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER | |
| | | 5e. TASK NUMBER | |
| | | 5f. WORK UNIT NUMBER | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) ACTA Inc. 2790 Skypark Drive, Suite 310, Torrance, CA 90505 | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S) | |
| | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited | | | |
| 13. SUPPLEMENTARY NOTES See also ADM002313. Department of Defense Explosives Safety Board Seminar (34th) held in Portland, Oregon on 13-15 July 2010, The original document contains color images. | | | |
| 14. ABSTRACT HAZX is an explosives safety software tool that can be used to assess the hazards and/or risks when Quantity-Distance (Q-D) safe separation distances are violated. Part 1 of the presentation focuses on the HAZX hazard module which includes a GUI/GIS interface to simplify user inputs, spatial analyses and the display of results and reports. The risk tool is being developed using alternative methods to the algorithms and methods documented in DDESBs Technical Paper No. 14. The underlying fragmentation model performs multiple simulations of drag-corrected fragment throw to account for uncertainties in their characteristics and automate the pseudo-trajectory normal method to compute hazardous fragment density considering 3D bounce/roll other uneven terrain. The hazard tools have been used to support equivalent protection and consequence explosion analyses launch vehicles and conventional weapons by the AF, FAA and Army. The HAZX hazard tool is demonstrated including the capability to compute: a) air blast and hazardous fragment density, and b) consequences of air blast and fragment impacts to ESs (damage, injury and fatality). | | | |
| 15. SUBJECT TERMS | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT |
| a. REPORT unclassified | b. ABSTRACT unclassified | c. THIS PAGE unclassified | SAR |
| | | | 18. NUMBER OF PAGES 44 |
| | | | 19a. NAME OF RESPONSIBLE PERSON |

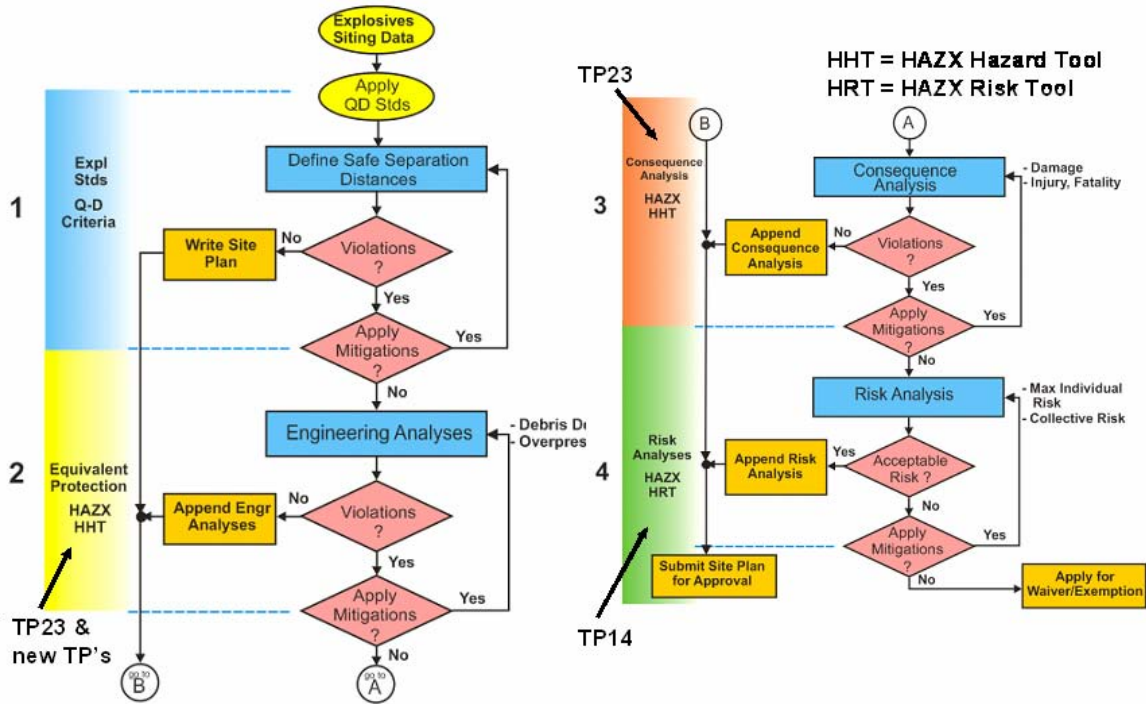


Figure 1. DDESB Process for Explosives Site Plan Approval.

HAZX Hazard Tool (HHT)

A top level view of the HAZX architecture is shown in Figure 2. A Graphical User Interface (GUI) with an embedded Geographical Information System (GIS) acts as the interface between the HAZX Hazard Tool (HHT) and the HAZX Risk Tool (HRT). This paper focuses on the HHT while a companion paper (Reference [2]) describes the HRT. The HHT is designed to perform equivalent protection and consequence analyses. Currently, the HHT performs air blast and fragmentation assessments but could include additional capabilities to consider thermal, toxic and lightning hazards.

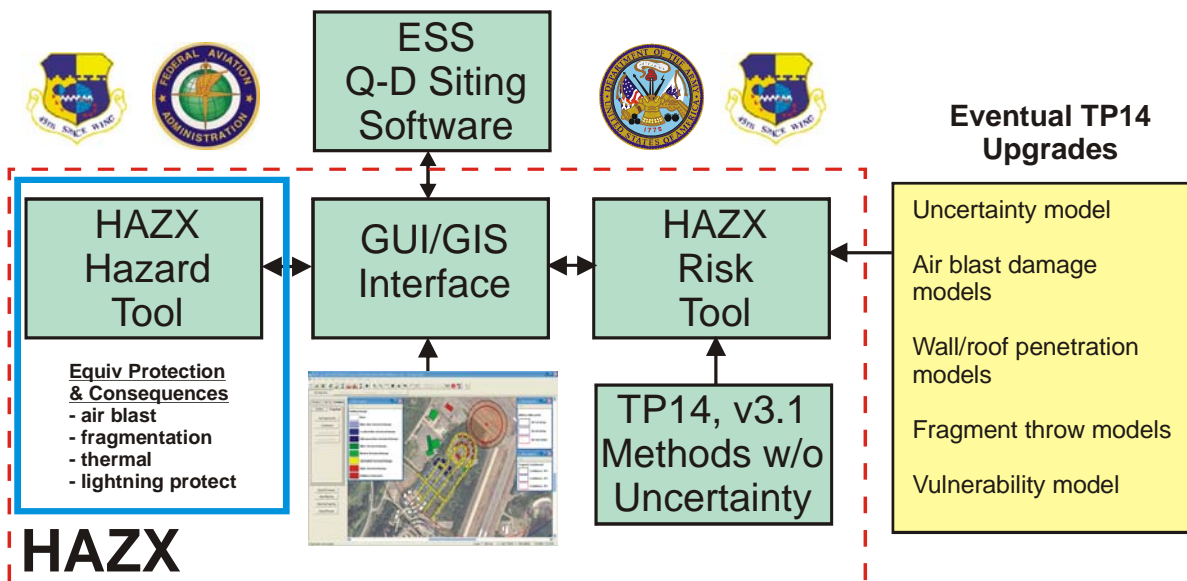


Figure 2. HAZX Architecture.

HHT PROBLEM SETUP

When HAZX is run, it asks the user to open an existing project or to create a new “hazard” or “risk” project. For the present discussion, an existing hazard project is loaded as shown in Figure 3. The project includes an aerial photo which was automatically registered (calibrated) and placed on a HAZX GIS layer. The GUI/GIS includes a Menu Bar and a Tab Bar on the left that allows a user to: a) input a single PES and multiple ES’s including people in the open, occupied buildings and populated roads and, b) perform equivalent protection and consequence analyses.

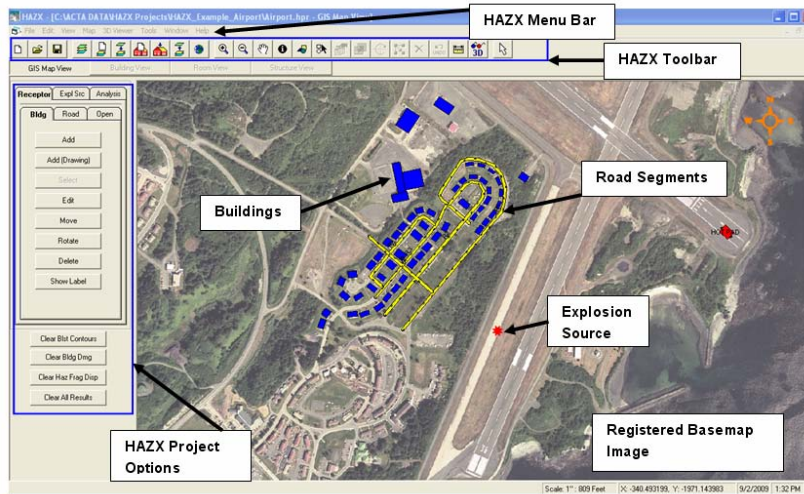


Figure 3. Example Project Opened in HAZX GUI/GIS.

EXPLOSION SOURCE

For a hazard analysis project only one explosion source can be defined. As Figure 4 shows, the “Expl Src” tab can be used to Add, Edit, Move or Delete an explosion source. For example, if we click on Add and then click a location on the base map (as shown in Figure 5) the Explosion Source dialog box appears and shows the attributes needed to define the explosion.

If the user is defining a new explosion source, he would need to enter the required data (for our example problem, the data has already been entered). There are two tabs on the Explosion Source dialog box: 1) Explosive and 2) Fragment. On the Explosion Source tab the user enters the explosive weight in pounds and picks the explosive type from a drop down list (e.g., TNT, Composition B, C4, etc.). For the example, we have entered 40,000 lbs with an explosive type of TNT. Based on these selections, HAZX calculates a net explosion weight (NEW) to be used in calculating the air blast overpressure and impulse (a measure of the blast duration) as a function of distance from the explosion source. Depending on the explosive type selected the NEW may be different for calculating overpressure and impulse; in our TNT example, the NEWs are the same. The user can enter the probability of the explosion occurring (currently this is only used to scaled the air blast results up or down for the expected dollar lost due to damage and the expected number of casualties and fatalities). Finally, the user enters the explosion height above ground level.

The fragmentation associated with the explosion is defined by clicking on the Fragment Source Tab as shown in Figure 6. Currently, the user is responsible for generating the fragment list.² Fragment groups can be defined to consider those with similar characteristics. The deterministic parameters defining a fragment group are: number of fragments in the group, average fragment weight, group weight, fragment type, and fragment description. Uncertain fragment parameters are: a) ballistic coefficient, (W/Cd^*A), b) initial velocity, c) takeoff height, d) elevation angle, e) azimuth angle, e) projected area, and f) shape (to perform 3D bounce).

² The FAA is funding a tool to allow a user to generate a fragment list for launch vehicle breakup based on minimal vehicle and this tool will be incorporated into HAZX in the coming year.

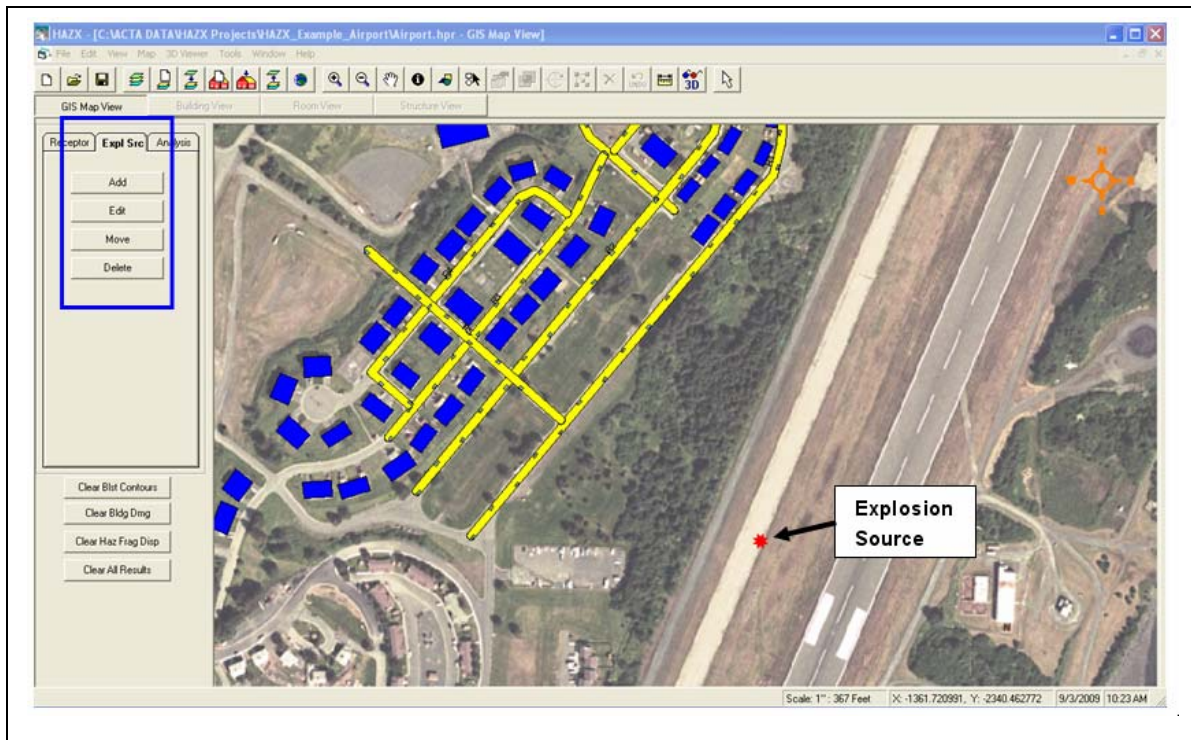


Figure 4. Definition of Explosion Source.

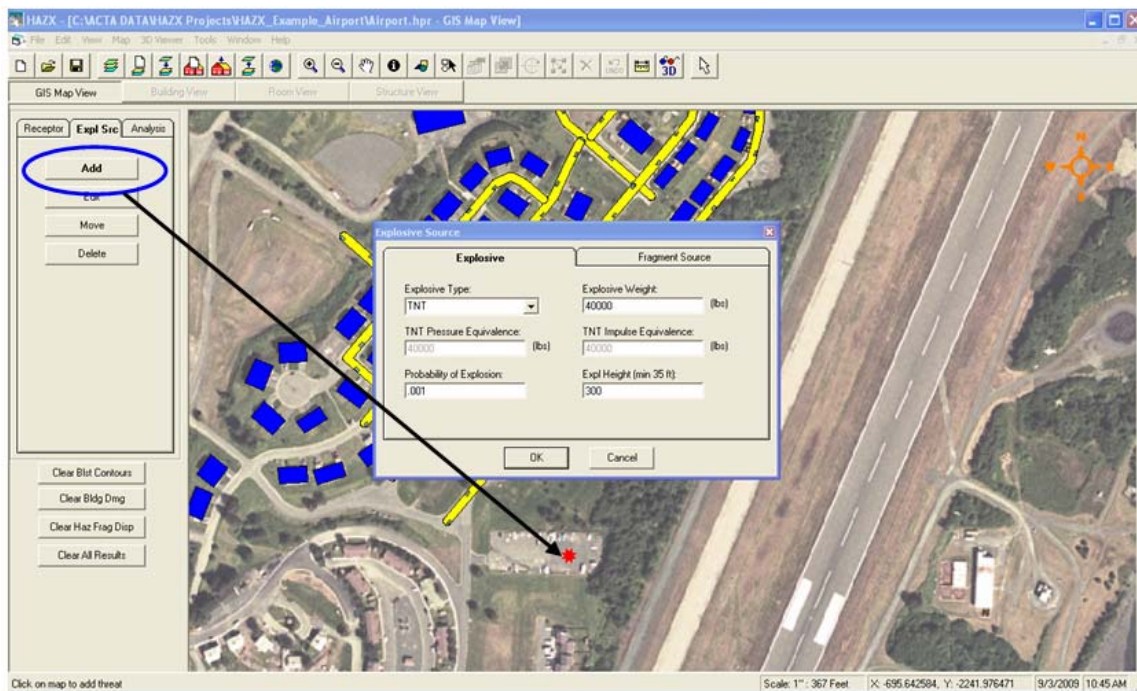


Figure 5. Adding/Editing Explosion Source Attributes.

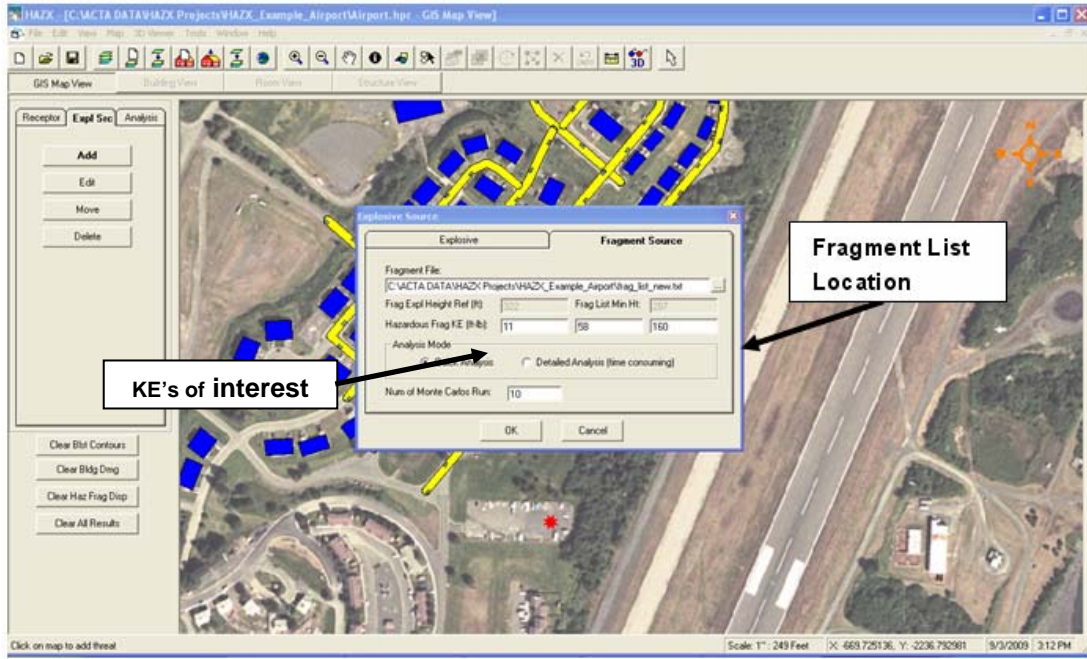


Figure 6. Defining the Fragment List Associated with the Explosion.

Once the fragment list is defined, the user can define up to three impact kinetic energies of interest (this is used in computing the hazardous fragment density distance, the distance at which the number of fragments of the specified kinetic energy drops below one per 600 square feet).

To perform fragmentation analyses, HAZX runs multiple random simulations of fragment throw and averages the results across all simulations. The user can choose to have HAZX perform either a straightforward (and quicker) Monte Carlo sampling or a more detailed “smart” sampling option (the default is the Quick Analysis), and then enter the number of random simulations desired (this is a balance between run time and accuracy).

BUILDING RECEPTORS

HAZX currently allows the user to define two types of receptors: a) occupied buildings, and b) vehicles on roads. The example problem includes a multitude of buildings and road segments. The buildings are shown by the blue rectangles in Figure 9 and the road segments by the yellow line segments. This section describes the HAZX building receptors.

Adding a Building to the Project

If the user wants to add a new building he has two choices: a) add, and b) add by drawing. When the Add button is selected the user simply clicks on the location of the base map where he wants to locate the center of the building. Upon clicking, the Building Attribute dialog box will appear and he can enter all the required building data. When complete the building will be displayed on the base map. The user can then use the edit, move, rotate and delete buttons on the Bldg Tab to adjust the location and orientation of the building in the GIS window.

To add a building by drawing, the user clicks on the Add (Drawing) button on the Bldg Tab and then begins to click on the base map where he wants to draw a shape. With each succeeding click a polygon shape appears and grows. To end the drawing process, the user double-clicks on the last point and HAZX will convert the user entered multi-sided polygon into a rectangle with an area equal to the polygon area and display the Building Attribute dialog box so the user can enter the building data. In this case, HAZX determines the building length, width and azimuth; the user need only supply the building height. Figure 7 and Figure 8 show the process of adding a building by drawing.

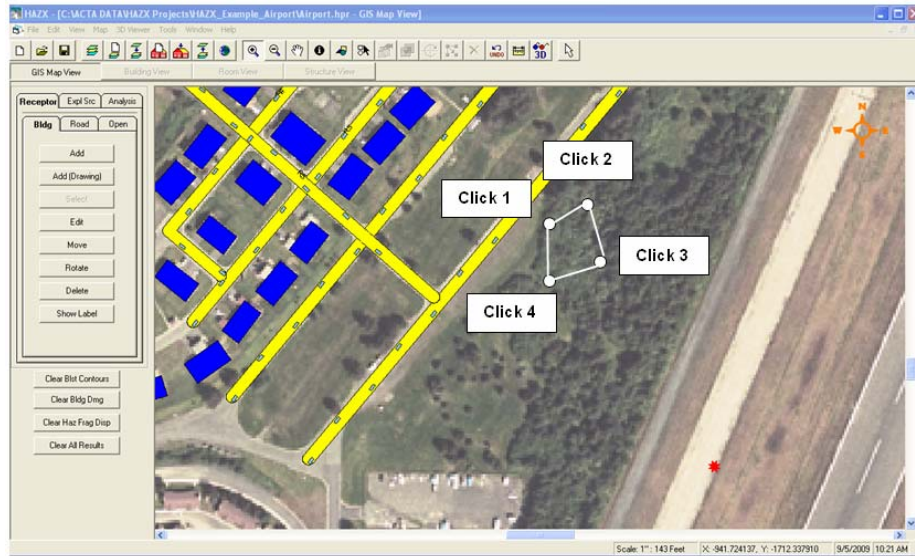


Figure 7. Add a Building by Drawing a Polygon.

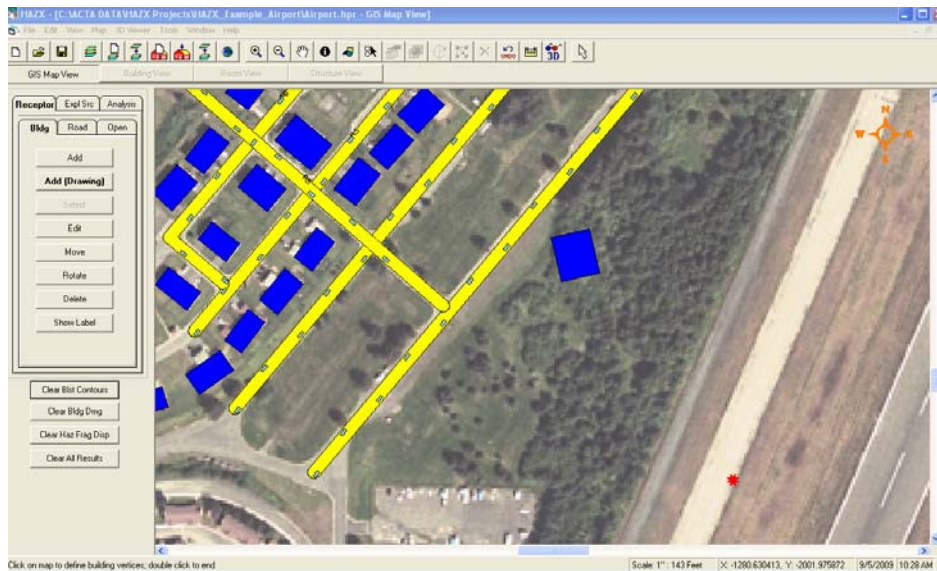


Figure 8. Result of Adding a Building.

Editing Existing Building Attributes

If the user clicks on the “Bldg” tab, the edit tab and then clicks on a building as shown in Figure 9, a Building Attribute dialog box comes up where building attributes can be edited or defined if the user is adding a new building. There are three tabs on the Building Attribute dialog box. The first is general information where the user can enter a Building ID (required) and optional descriptions. The user can enter/edit the building length, width and height along with the azimuth relative to north. The floor height information is for a future HAZX release and is not currently used. The construction tab (see Figure 10) is used to define the building construction and window type(s). The user can select a building construction type from the drop-down list as shown in Figure 11. Available construction types are summarized in Table 1.

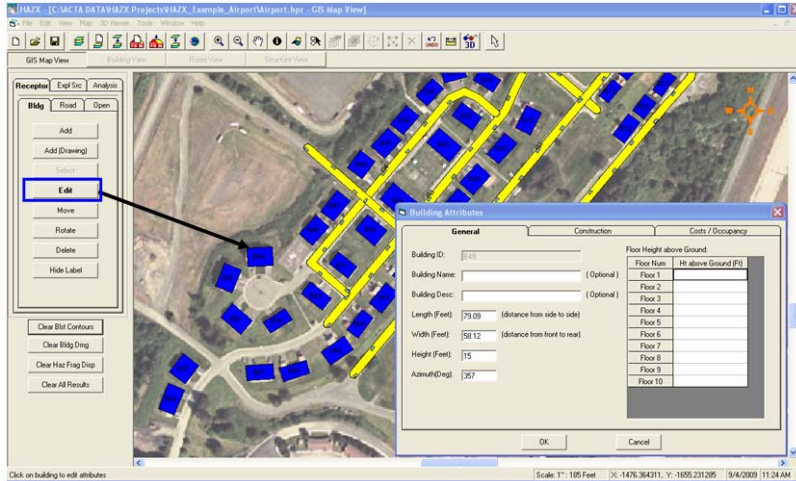


Figure 9. Editing/Adding Building Receptors in HAZX.

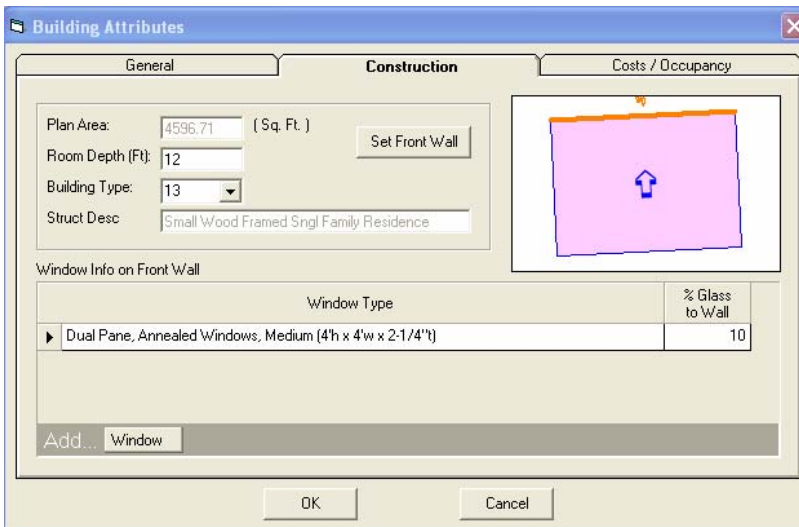


Figure 10. Building Construction Tab.

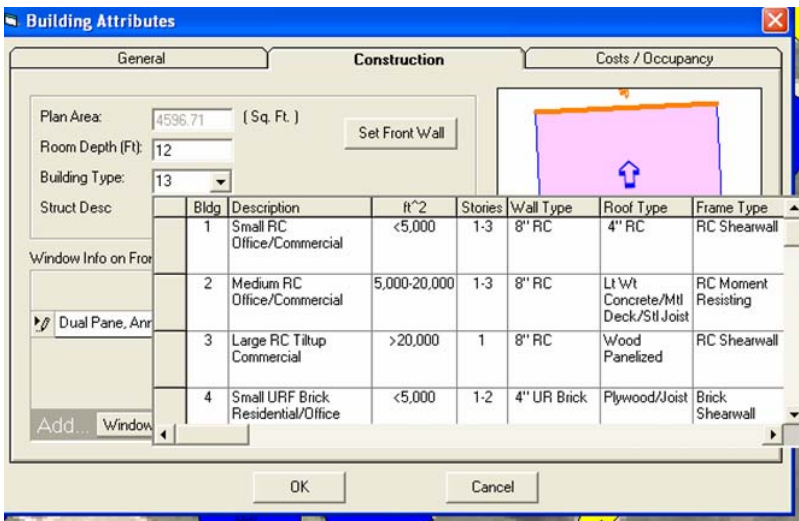


Figure 11. Building Type Drop-down Selection.

Table 1. HAZX Structure Types.

| Structure Number | General Description | Size | No. of Story | Structural Characteristic | | |
|------------------|-------------------------------------------------------|--------|--------------|---------------------------|------------------------------|----------------------------------|
| | | | | Walls | Roof | Frame |
| 1 | Small Reinforced Concrete Office/Commercial | Small | 1-3 | Reinforced Concrete | Reinforced Concrete | Concrete Shearwall |
| 2 | Medium Reinforced Concrete Office/Commercial | Medium | 1-3 | Reinforced Concrete | Lt Wt Concrete on Metal Deck | Concrete Moment Resisting |
| 3 | Large RC Tiltup Commercial | Large | 1 | Reinforced Concrete | Wood Panelized | Concrete Shearwall |
| 4 | Small Unreinforced Brick Residence/Office | Small | 1-2 | Un-Reinforced Brick | Lt Wt Wood | Un-Reinforced Brick Bearing Wall |
| 5 | Med Unreinforced Masonry Office/Apartment | Medium | 1-3 | Un-Reinforced Block | Wood Panelized | Concrete Moment Resisting |
| 6 | Large Unreinforced Masonry Office | Large | 1-2 | Un-Reinforced Block | BuiltUp or Composite | Concrete Moment Resisting |
| 7 | Small Reinforced Masonry Residence/Office/Commercial | Small | 1-2 | Reinforced Block | Lt Wt Wood | Reinforced Block Bearing Wall |
| 8 | Medium Reinforced Masonry Office/Commercial | Medium | 1-3 | Reinforced Block | Lt Weight Metal on Joist | Steel Moment Resisting |
| 9 | Small Light Metal Office/Storage | Small | 1 | Light Metal | Lt Weight Metal on Joist | Steel Braced |
| 10 | Medium Metal Office/Commercial | Medium | 1 | Light Metal | Lt Weight Metal on Joist | Steel Moment Resisting |
| 11 | Medium Metal Stud/Clad Office/Commercial | Medium | 1-3 | Metal Stud | Lt Wt Concrete on Metal Deck | Steel Moment Resisting |
| 12 | Large High Bay Metal Office/Storage/Hangar | Large | 1 | Heavy Metal | Heavy Metal on Steel Girder | Steel Moment Resisting |
| 13 | Small Wood Framed Residence | Small | 1-2 | Wood Stud | Lt Wt Wood | Wood Stud |
| 14 | Medium Wood Frame Residence/Apartment | Medium | 1-3 | Wood Stud | Wood Panelized | Wood Stud s |
| 15 | Wood Trailer/Modular Units Residence/Modular Office | Small | 1 | Wood Stud | Lt Wt Wood | Wood Stud |
| 16 | Passenger Vehicle | Small | 1 | Metal Doors | Metal Roof | NA |
| 17 | Ground-Based Radar Flight Safety Equipment | Small | NA | Metal structure | NA | NA |
| 18 | High Bay Metal Vertical Assembly Building | Large | 1 | Metal | Metal/Joist | Steel Moment Resisting |
| 19 | Blast Resistant Reinforced RC Blockhouse/Control Room | Small | 1 | 12"-16" RC | 12" RC | Concrete Moment Resisting |
| 20 | Medium Reinforced Masonry Office/Commercial | Medium | 1-3 | Reinforced Block | Reinforced Concrete | Reinforced Block Bearing Wall |

HAZX uses the selected structure type to estimate the damage to the building and injury/fatality to occupants due to air blast based on Pressure-Impulse (P-I) diagrams. A sample of the P-I's diagrams for Building Type 1 (Small, Reinforced Concrete structure) is shown in Figure 12. The complete set of structural P-I diagrams are documented in Reference [4].

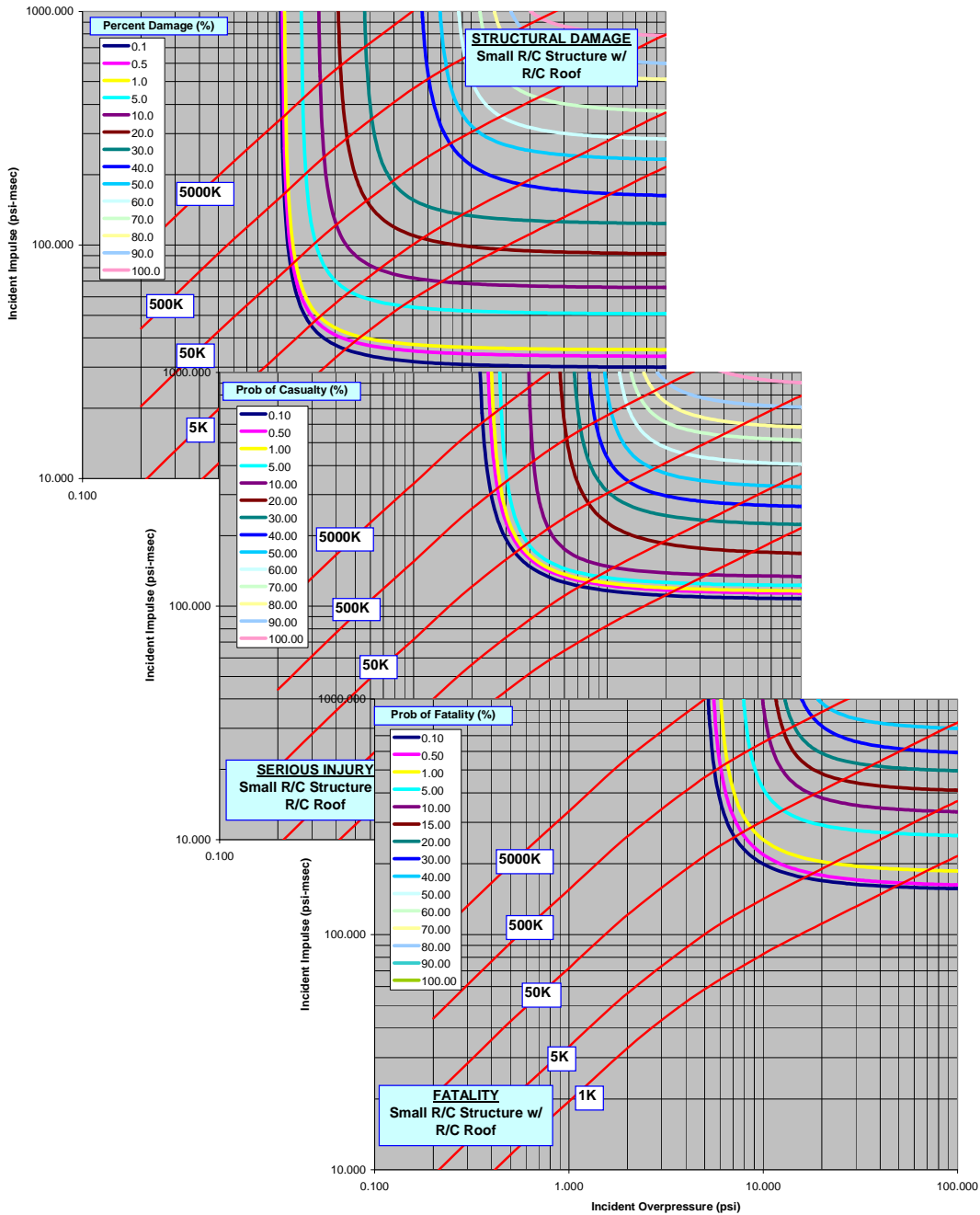


Figure 12. P-I Diagrams for a Small, Reinforced Concrete Wall and Roof Building.

The user can also specify the windows on each side of a building from the construction tab. First, the user clicks on the side of the building in the diagram for which he wants to define the windows (see Figure 13). Next he clicks on the Add Window button at the bottom of the dialog box (underneath the drop list in Figure 13). Then by clicking the Window Type drop-down arrow he can select from a set of pre-defined window types, sizes and thicknesses. The window types available in HAZX are summarized in Table 2. Finally, the user specifies the number of windows of the selected type by entering the “% Glass on Wall”. The value entered is the percent of the wall elevation surface that is covered by this window type.

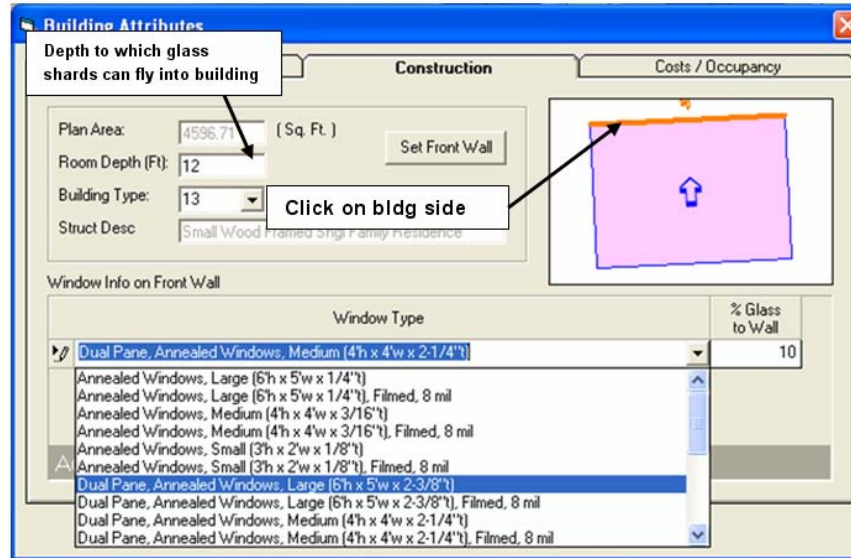


Figure 13. Defining Windows in HAZX.

Table 2. HAZX Generic Window Types.

| Window Type | Dimensions (in) | Thickness (in) | Glazing | Layup | Airgap | Laminate |
|-------------|----------------------------------------------------------------------------------------------------|------------------------|----------|------------|--------|----------------|
| 1 | 24 x 36 | 1/8 (0.115) | Annealed | Monolithic | 150 | NA |
| 2 | 48 x 48 | 3/16 (0.180) | Annealed | Monolithic | | |
| 3 | 60 x 72 | 1/4 (0.219) | Annealed | Monolithic | | |
| 4 | 24 x 36 | 1/4 (0.219) | TTG | Monolithic | | |
| 5 | 48 x 48 | 1/4 (0.219) | TTG | Monolithic | | |
| 6 | 60 x 72 | 1/4 (0.219) | TTG | Monolithic | | |
| 7 | 24 x 36 | 2 x 1/8 (2 x 0.115) | Annealed | IGU | 0.5 in | |
| 8 | 48 x 48 | 2 x 1/4 (2 x 0.219) | Annealed | IGU | 0.5 in | |
| 9 | 60 x 72 | 2 x 3/8 (2 x 0.355) | Annealed | IGU | 0.5 in | |
| 10-18 | Identical to 1-9, except for the addition of 8 mil of anti-shatter film using daylight application | | | | | |
| 19 | 24 x 36 | * | TTG | Laminated | NA | 2 x 45 mil PVB |
| 20 | 48 x 48 | 3 x 1/8 (3 x 0.115) | TTG | Laminated | NA | 2 x 45 mil PVB |
| 21 | 60 x 72 | * | TTG | Laminated | NA | 2 x 45 mil PVB |

Probability of breakage P-I diagrams were developed for the 21 window types using the HAZL program [5]. Figure 14 shows the P-I diagram developed for a single-paned, small annealed glass window. The complete set of breakage P-I diagrams is provided in Reference [4]. To define lethality, the three hazard P-I curves output by HAZL (Figure 15): (a) the lower bound of minimal hazard; (b) the lower bound of low hazard; and (c) the lower bound of high hazard were used. These were supplemented with a curve defining no lethality and one for maximum lethality. The resulting P-I lethality diagram for a small, annealed glass window is shown in Figure 16.

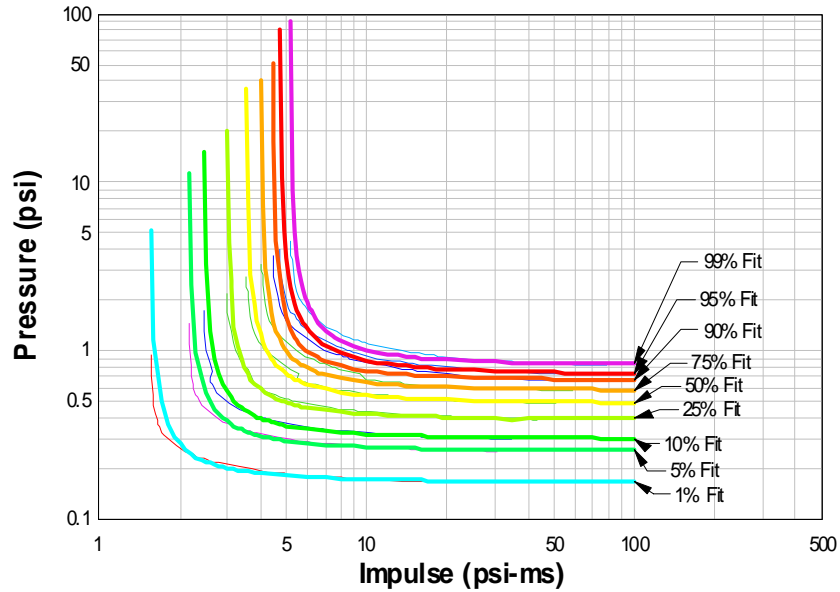


Figure 14. Probability of Breakage Curves for a Small Annealed Glass Window (Thin lines = HAZL model, Bold lines = Fit).

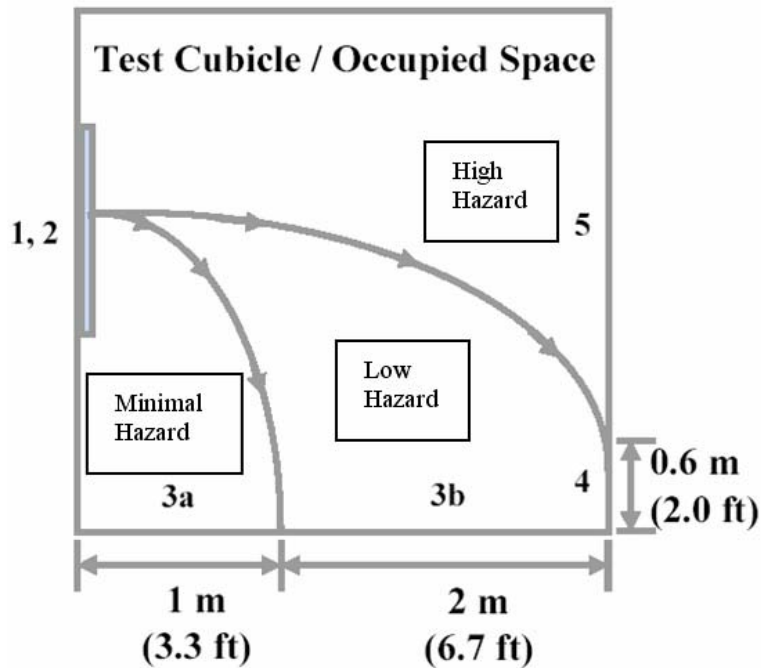


Figure 15. HAZL Hazard Levels.

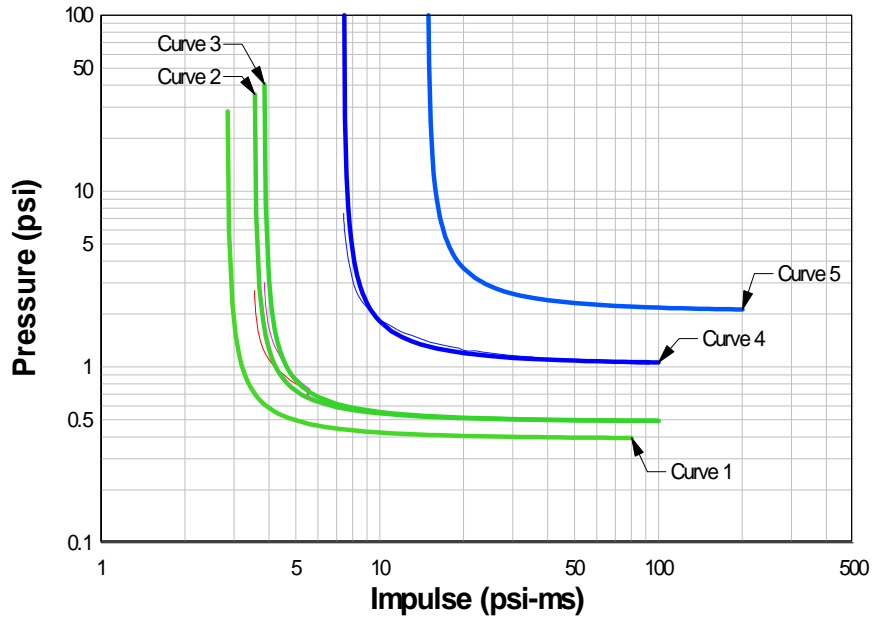


Figure 16. Lethality Curves for Single-Paned, Small Annealed Glass Window.

For each of the lethality curves, a correlation was made between the hazard levels and the expected levels of serious injury and fatality. A summary of the values used to make these correlations is presented in Table 3. In general, an increased hazard level produces a higher probability of lethality. A description of the rationale used to obtain the hazard-lethality relationships is provided in Reference [4].

Table 3. Probability of serious injury and fatality associated with each lethality curve.

| Curve # | Source | Hazard Level | Probabilities of Casualties | | | | | | | |
|---------|--------------------------|-------------------|-----------------------------|----------|-----------|----------|-----------|----------|------------------|----------|
| | | | Annealed | | Dual Pane | | Tempered | | Laminated/filmed | |
| | | | Ser. Inj. | Fatality | Ser. Inj. | Fatality | Ser. Inj. | Fatality | Ser. Inj. | Fatality |
| 1 | F ₁ x Curve 2 | Zero | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | HazL | Threshold minimal | 0.04 | 0.00 | 0.05 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| 3 | HazL | Threshold low | 0.10 | 0.00 | 0.125 | 0.00 | 0.05 | 0.00 | 0.20 | 0.01 |
| 4 | HazL | Threshold high | 0.50 | 0.0133 | 0.667 | 0.020 | 0.25 | 0.010 | 0.50 | 0.10 |
| 5 | F ₅ x Curve 4 | Maximum | 1.00 | 0.0333 | 1.00 | 0.050 | 1.00 | 0.020 | 1.00 | 0.50 |

The last set of user inputs defines a building's occupancy and cost data which is on the third tab of the Building Attribute dialog box (Figure 17). The user clicks on the Add Exposure Group button or simply edits the existing data. Currently, only one exposure group is allowed per building. The population group can be given an optional description and the population type can be selected (mission essential or general public); currently the population type does not affect the hazard calculations (but will affect the risk module calculations). Next, the number of people in the group is entered. The percent of people in the perimeter (that will be affected by glass shard throw) can be entered or if the "Is Pop Uniform" check box is selected HAZX will calculate the percent based on the building footprint dimensions, the room depth and assuming a uniform distribution of people in the building.

| Group | Group Desc | Type | # of People | % Pop in Perimeter | Is Pop Uniform | Hours /Day | Days /Wk | Wks /Yr | Avg Ann Exposure |
|-------|------------|----------------|-------------|--------------------|-------------------------------------|------------|----------|---------|------------------|
| 1 | | General Public | 3 | 59.11 | <input checked="" type="checkbox"/> | 24 | 7 | 52 | 3.01 |

Figure 17. HAZX Cost/Occupancy Data.

The number of hours/day, days/week and weeks/year can then be entered. Note that if the user wants the number of people he specifies to be fully exposed a value of 24 hr/day, 7 days/wk and 52 wk/year should be entered, anything else will reduce the exposure. At the top of the tab, the user can specify how many of the people in the population group would be outside the building (e.g., on break, in the parking lot, etc.) and also the replacement cost of the building and the windows. Finally, the user can also enter the replacement cost for the building separately from the window replacement cost.

ROAD RECEPTORS

HAZX allows the user to draw road segments and automatically populates the segment with vehicles based on their average speed, number of people per car, number of cars per day on the segment as well as the number of days per week, and number of weeks per year.

To draw a road segment, the user selects the Road Tab and then clicks on the Add(Drawing) button. Then the user simply begins clicking along the road segment to be entered (in our example this was easy because we simply followed along the image of the shown on the base map). As Figure 18 shows, this capability allows a user to enter straight segments or curved segments. In the figure we simulate entering a curved road by clicking along a segment and double clicking to end the drawing process. Upon double clicking, the Road Segment Attribute dialog box appears and the user can enter the required information (see Figure 19). Our example already has the road segment entered but if this were a new road segment, the user would have to supply the required information.

To define a road segment, the user gives it an ID and an optional description(s) if desired, and then enters the road width and whether it is a 1-way or 2-way road. Finally, the user enters the interval along the segment where he wants to locate a vehicle receptor (the shorter the interval the better the accuracy); however, a reasonable spacing should be selected to avoid locating vehicles right next to each other and to minimize the number of receptors created.

The user then adds the road segment's exposure data by clicking on the Add Exposure Group button. Currently, only one exposure group is allowed. The user enters the group ID, the exposure type (unrelated or related, although the hazard analysis does not distinguish between these two). The user then enters the average vehicle speed, the number of people per vehicle, the number of vehicles per hour, the number of hours per day, the number of days per week and the number of weeks per year. Based on these entries, HAZX calculates the average number of people to place in each vehicle location at the intervals specified by the user. The final data required for a road segment is the vehicle data (see Figure 20). These data are entered by clicking on the Vehicle Tab. The user enters the vehicle length, width and height and the replacement cost of the vehicle and windows. When finished, HAZX will draw the road segment and display the vehicle receptors. Other options on the Road Tab are to Select a Segment, Edit a Segment, Delete a Segment and Show/Hide Labels.

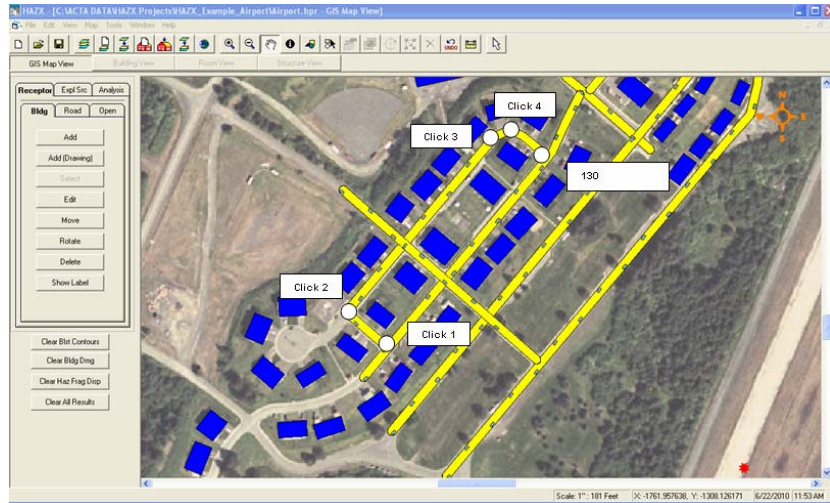


Figure 18. Drawing a Road Segment in HAZX.

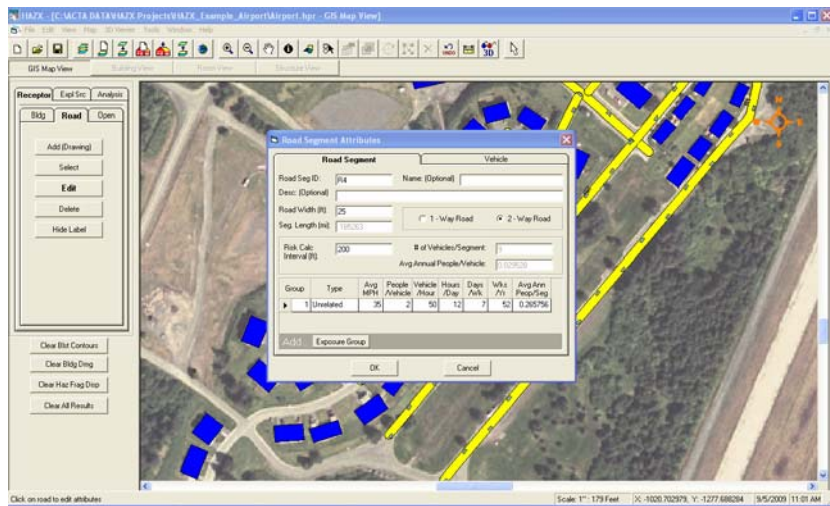


Figure 19. Road Segment Attribute Screen.

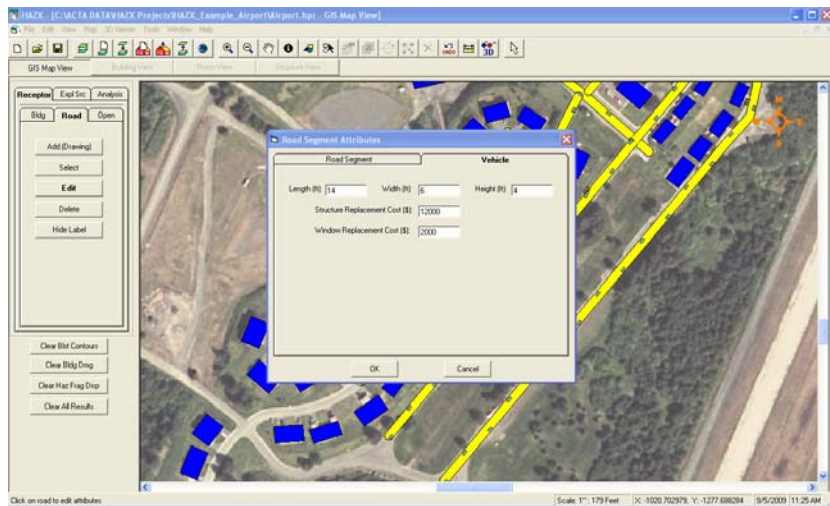


Figure 20. Road Segment Vehicle Screen.

PEOPLE IN THE OPEN RECEPTORS

A tab has been added to the Receptor Tab called “Open”. This tab is a placeholder and will eventually allow the user to draw in a region (much like is done to draw a building) and populate it with unsheltered people to simulate a group of people or crowds. This option is currently being funded by the FAA/AST and will be completed this year.

HRT AIR BLAST RESULTS

EQUIVALENT PROTECTION

The HAZX analysis options are available by clicking on the Analysis Tab which brings up two sub-tabs labeled Air Blast and Frag Anal. Currently, the air blast and fragmentation analyses are performed independently; that is, the consequences due to both hazards acting on a receptor are not combined. Let's first look at the air blast results.

Figure 21 shows, clicking on the Pressure button overlays the incident overpressure contours on the base map. To clear the contours, click on the “Clear Blst Contours” button at the bottom of the tab. Figure 22 shows the Scaled Distance (SD) arcs typically used by the Explosives Safety Community and the Explosives Standards to evaluate blast hazards. The scaled distance arcs are called K factors where scaled distance is defined as SD or $K = (\text{distance-ft})/(\text{W-lb})^{1/3}$, therefore, for K40 the arc has a $\text{Dist(ft)} = 40(\text{W-lb})^{1/3}$.

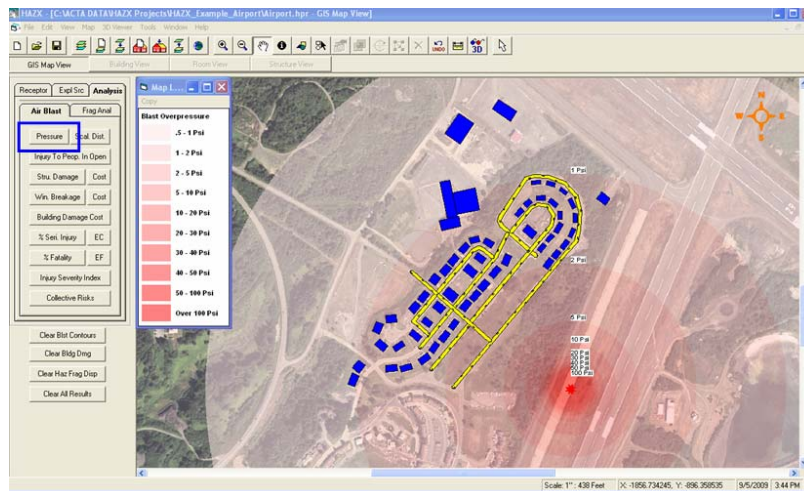


Figure 21. Air Blast Results – Incident Overpressure Contours.

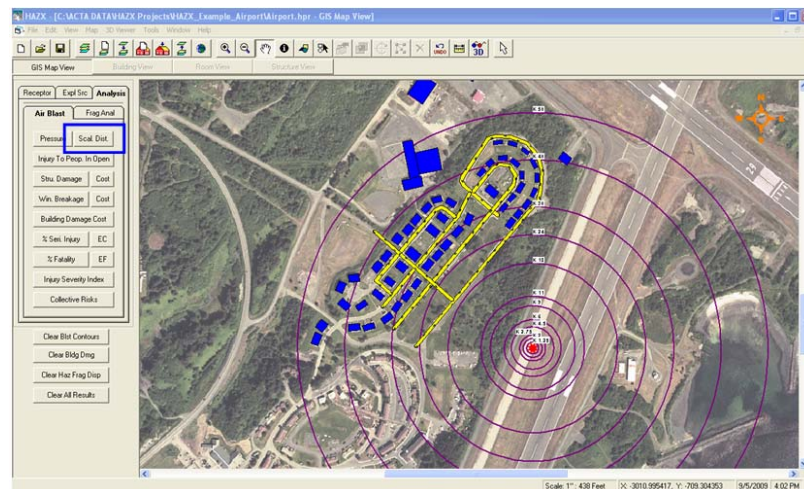


Figure 22. Air Blast Results – Scaled Distance Arcs.

The user can choose to display numerous other results including:

- Injury to people in the open
- Structural damage and associated costs
- Window breakage and associated costs
- Combined air blast damage costs
- Percent and expected number of injuries to sheltered people, and
- Collective damages, injuries and fatalities

Figure 23 to Figure 33 show samples of the HAZX displays for the results highlighted above.

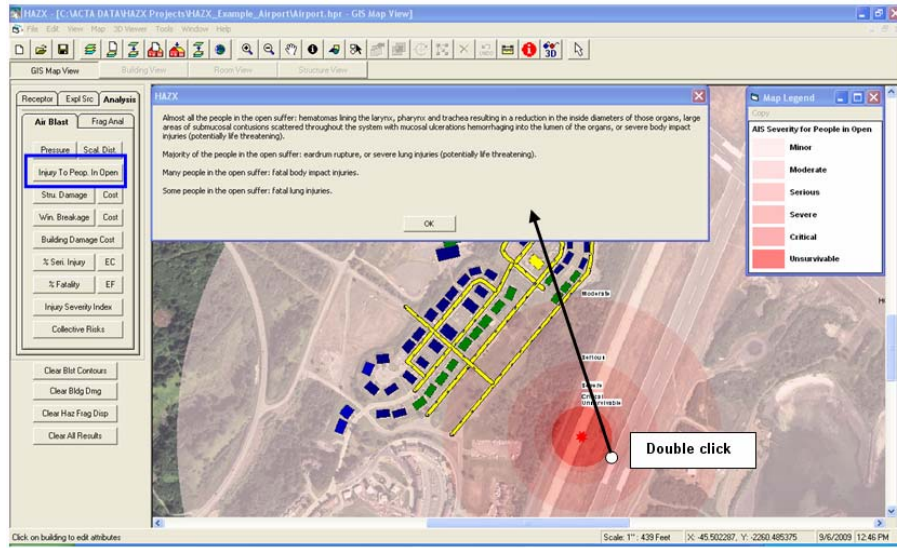


Figure 23. Air Blast Results – Injury to People in the Open.

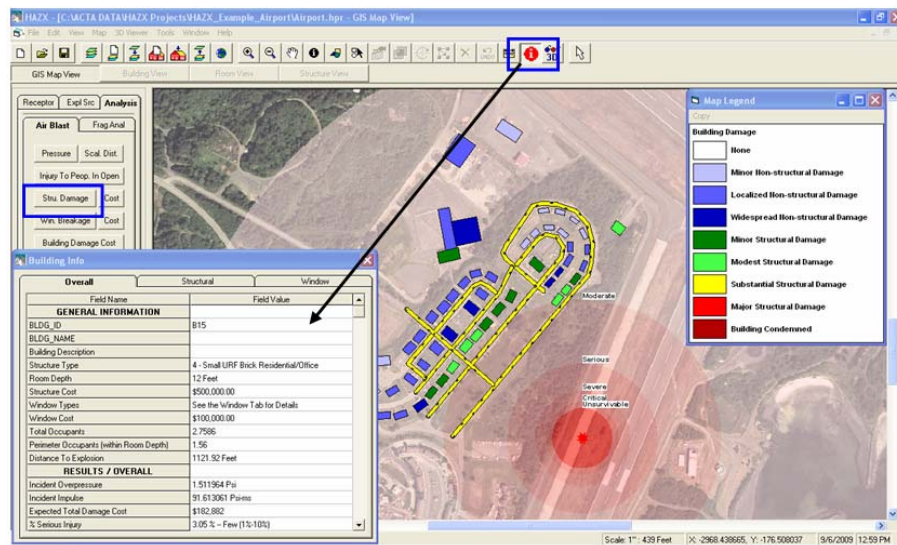


Figure 24. Air Blast Results – Structural Damage.

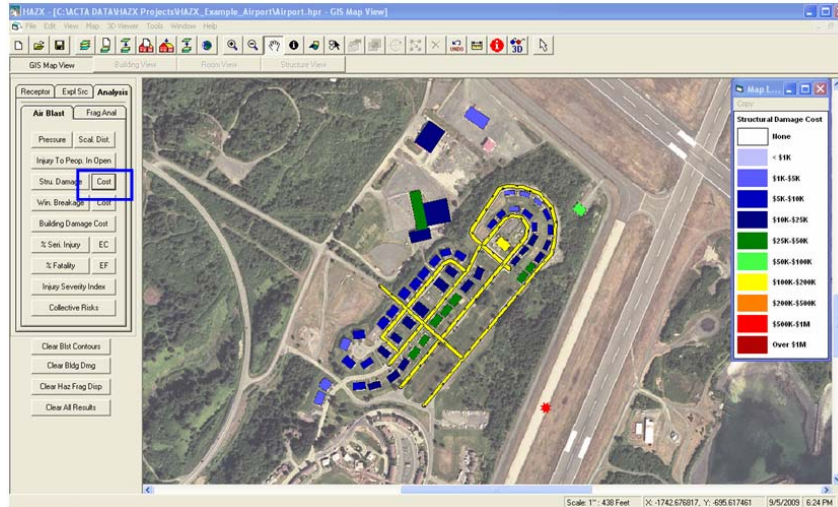


Figure 25. Air Blast Results – Structural Damage Costs.

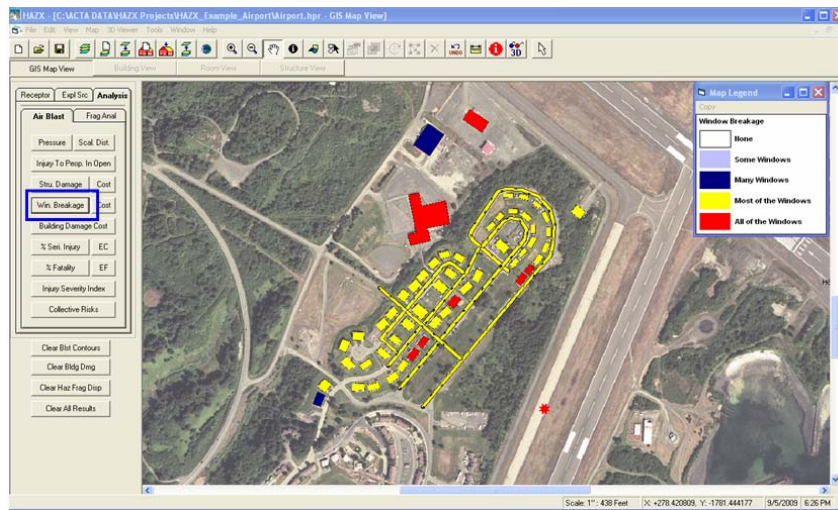


Figure 26. Air Blast Results – Window Breakage.

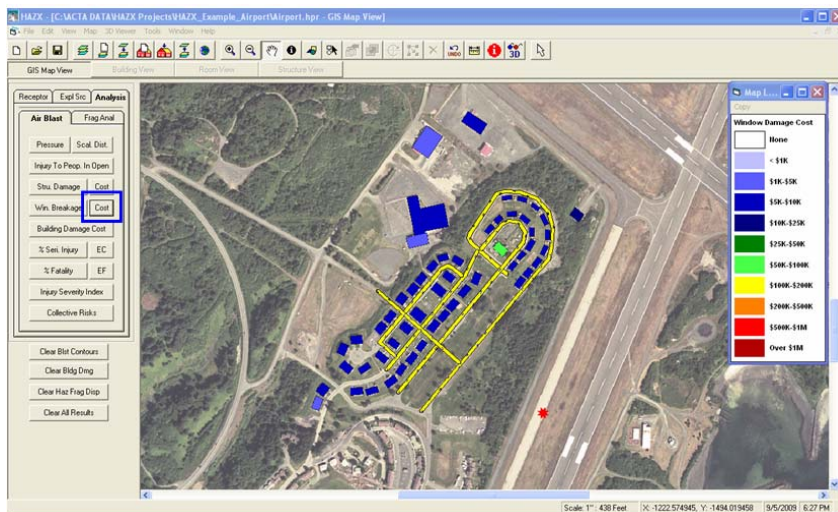


Figure 27. Air Blast Results – Window Costs.

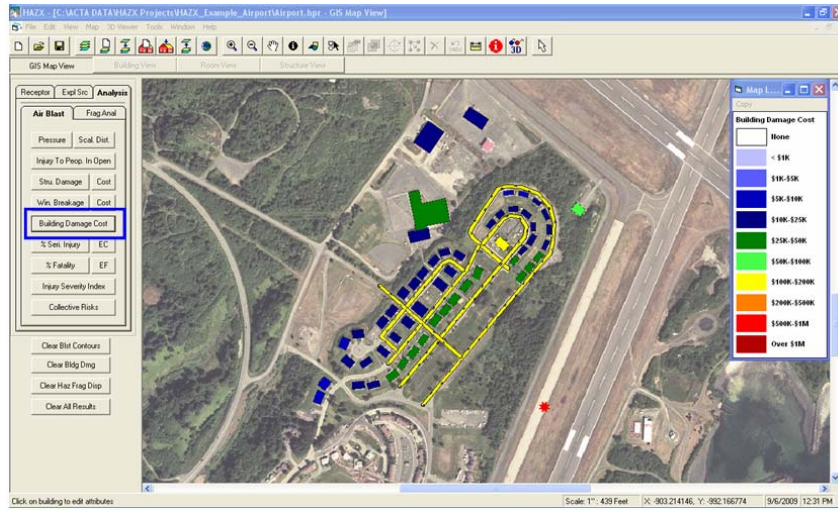


Figure 28. Air Blast Results – Building Damage Costs.

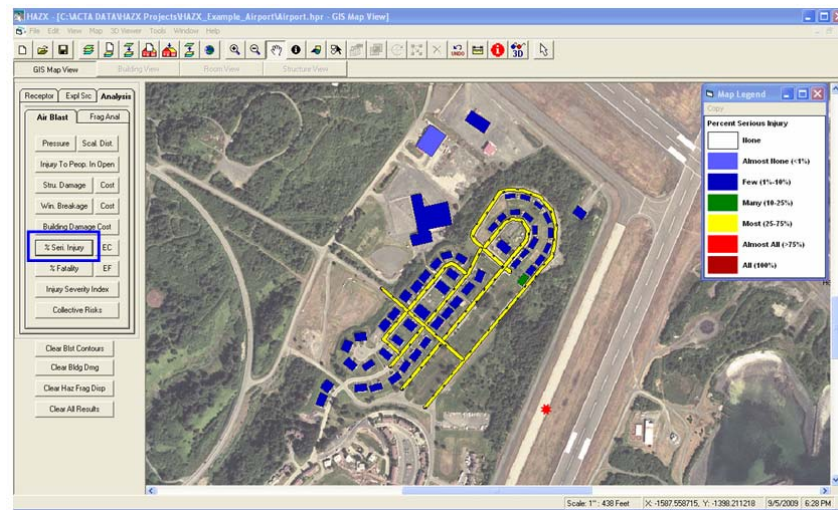


Figure 29. Air Blast Results – Percent Serious Injury.

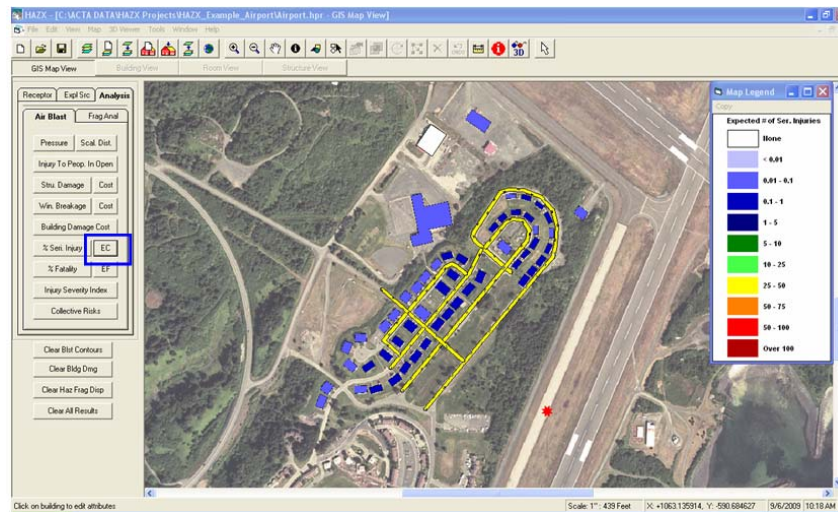


Figure 30. Air Blast Results – Expected Number of Injuries.

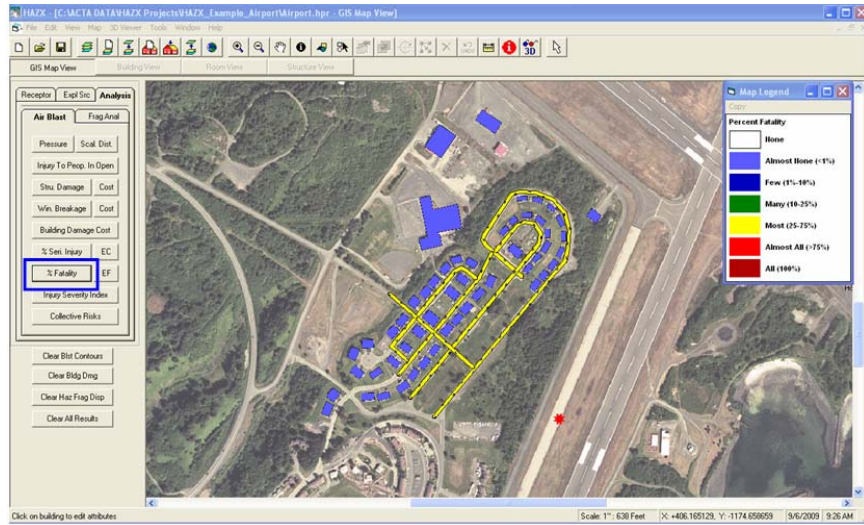


Figure 31. Air Blast Results – Percent Fatalities.

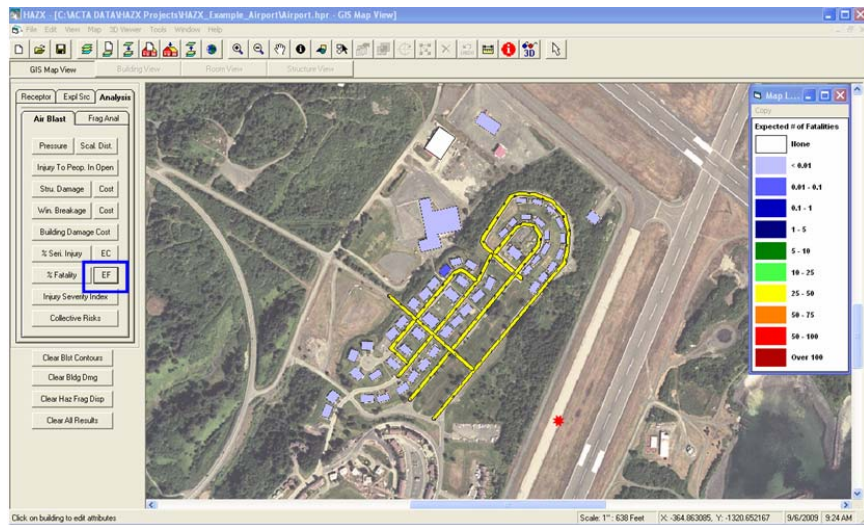


Figure 32. Air Blast Results – Expected Number of Fatalities.

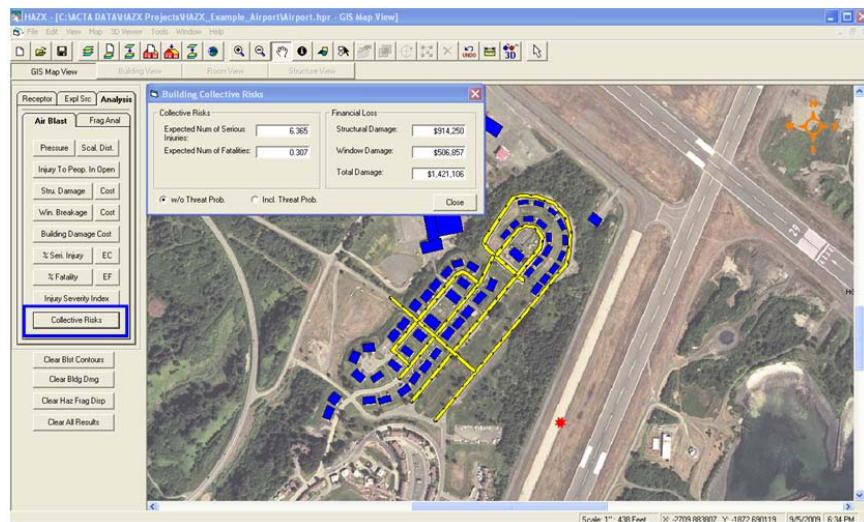


Figure 33. Air Blast Results – Collective Consequences.

HRT FRAGMENTATION RESULTS

To perform fragmentation equivalent protection analyses, the user clicks on the “Analysis” tab and then on the “Frag Anal” tab. Currently, the user can perform a hazardous fragment density analysis and/or a fragment containment analysis. The fragment density analysis performs random throw simulations using the user specified fragment list and averages the simulation results to determine the distance at which the density of fragments (with the user specified kinetic energies) drops below one per 600 square feet.. Figure 34 shows the hazardous fragment density distance (HFDD) for the example problem. The three smaller circles are the HFDD’s for 11, 58 and 300 ft-lbs; the large circle is the 1250 foot fragmentation distance recommended by the Explosives Standards. In this example, the site-specific fragmentation analysis shows that the explosives standards’ Q-D distance is overly conservative.

Figure 35 shows the fragment containment circles for the example problem. Three circles are shown, one associated with a non-exceedance probability of 99%, one for 95% and one for 90%. The 99% non-exceedance circle means that if 100 similar explosion accidents occurred only one of them would result in a fragment that would travel beyond that distance. Note that the containment circles are (not surprisingly) much larger than the explosives standards’ HFDD of 1250 feet. There will always be a few bad actor fragments but requiring that all fragments be contained is a much too conservative criterion.

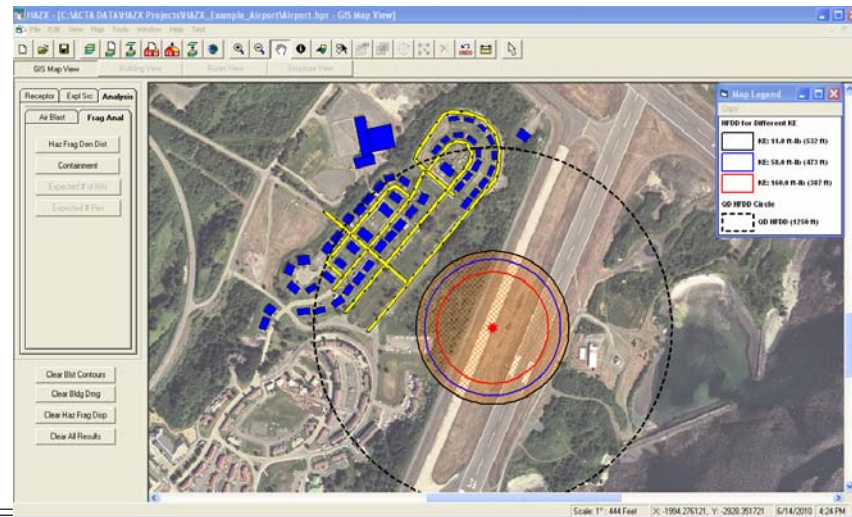


Figure 34. Hazardous Fragment Density Arcs (KE = 11, 58 & 300 ft-lbs).

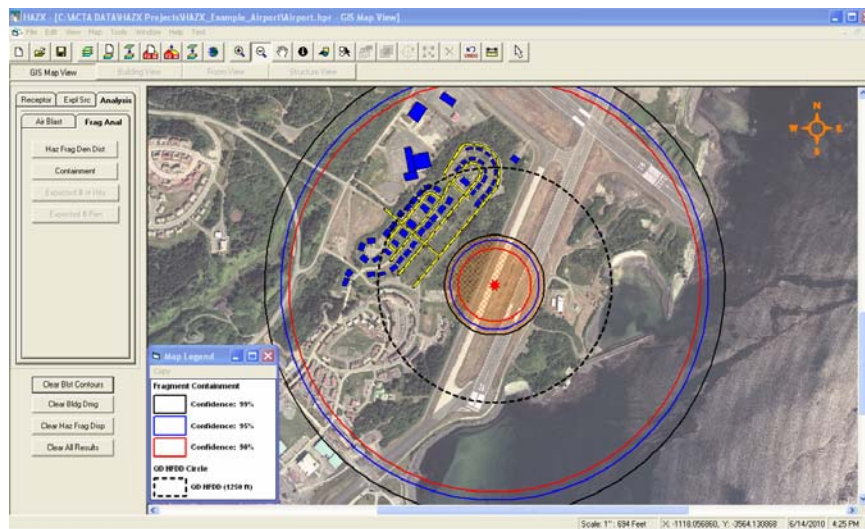


Figure 35. Fragment Containment Arcs (90, 95 & 99% confidence levels).

CONCLUSIONS

This paper summarizes the status of the HAZX hazard assessment tool (HHT). The HHT has evolved over several years to assist users in performing equivalent protection and consequence analyses that can be used to gain explosive site plan approval when Q-D criteria cannot be met.

The HHT is still evolving and new capabilities are being incorporated to better consider the hazards and consequences associated with explosions:

1. New 3D consequence models will be added to determine the air blast damage to buildings and windows by side and their effects on building occupants.
2. New 3D fragment models will be added to:
 - a. Consider the effects of terrain, fragment bounce, and impacts/penetrations of on 3D representations of buildings.
 - b. Consider the effects of fragments on groups of people in the open (e.g., representing crowds that may view a commercial space launch).
3. The capability to have the HHT develop a site-specific, explosion specific fragment list based on user inputs

These and other capabilities will be added to meet future customer needs in the coming years.

REFERENCES

- [1] DOD Ammunition and Explosives Safety Standards", DOD 6055.9-STD, Under Secretary of Defense for Acquisition, Technology & Logistics, 24 March 2009.
- [2] Chrostowski, J.D, et. al., "HAZX – Part 2, An Explosives Risk Assessment Tool", presented at the 2010 DDESB Explosives Safety Seminar, July 2010.
- [3] Chrostowski, J.D., "HAZX Explosion Effects Software", ACTA Technical Report No. 09-605/12, September 2009.
- [4] Chrostowski, J.D., et. al., "Methodology Manual for Human Lethality (HuLC), Version 1.0", ACTA Technical Report prepared for the Technical Support Working Group (TSWG), May 2004.
- [5] HAZL (Window Fragment Hazard Level Analysis) Version 1, U.S. Army Corps of Engineer Research and Development Center, June 2000.

HAZX – Part 1

An Explosives Hazard Assessment Tool

Author/Co-Author

Jon D. Chrostowski/Wenshui Gan
ACTA, Inc.

Co-Authors

Daniel Murray, FAA/AST
William Pollan, AF/45SE

2010 DDESB Explosives Safety Seminar
Portland, OR

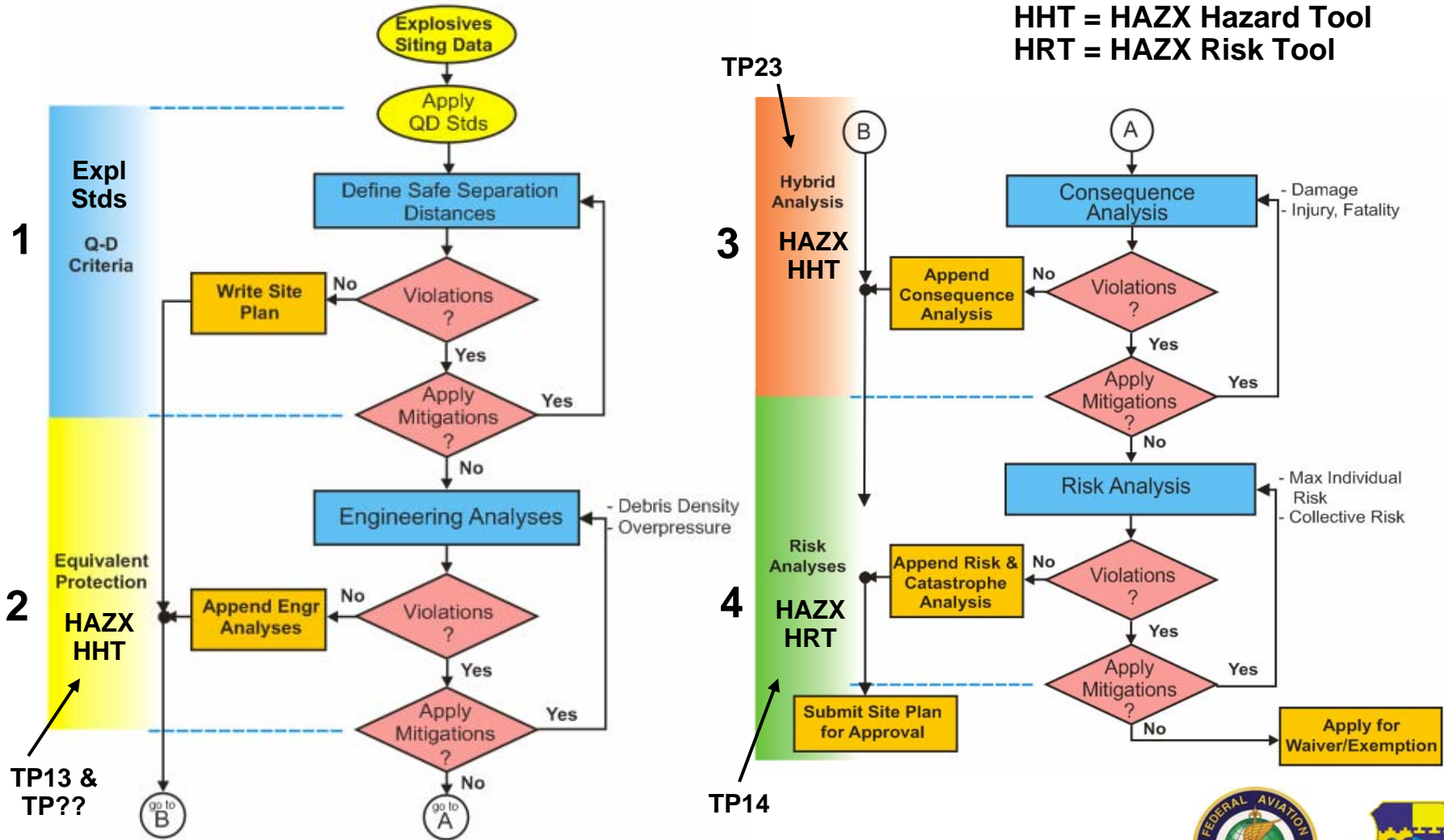
July 15, 2010



Outline

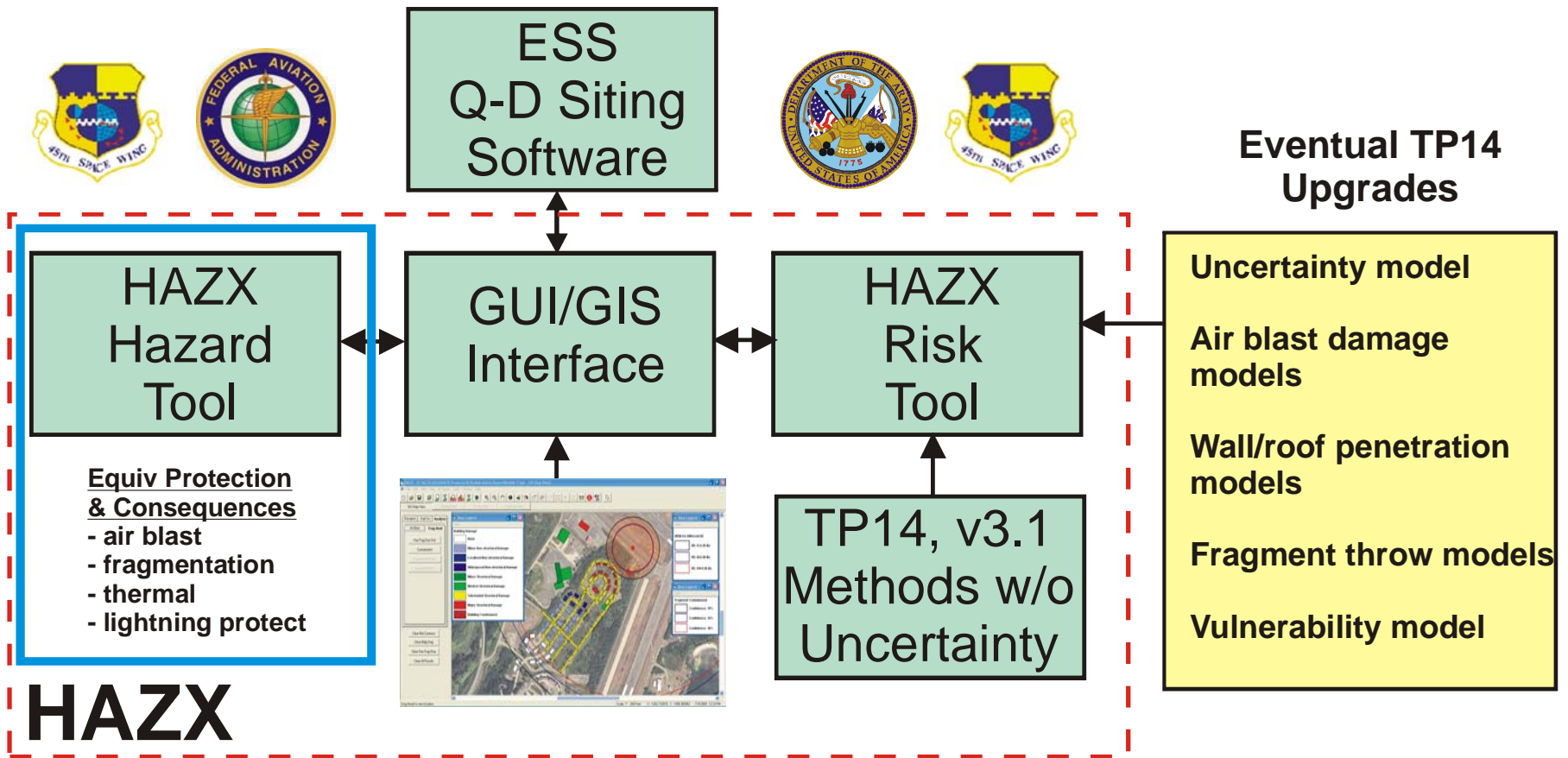
- **Explosives Safety Analysis Process**
- **HAZX Architecture**
- **HAZX Hazard Tool (HHT)**
 - *GUI/GIS*
 - *Entering Data*
 - *Hazard and Consequence Analyses*
 - Air Blast
 - Fragmentation
- **Conclusions**

Explosives Safety Analysis Process

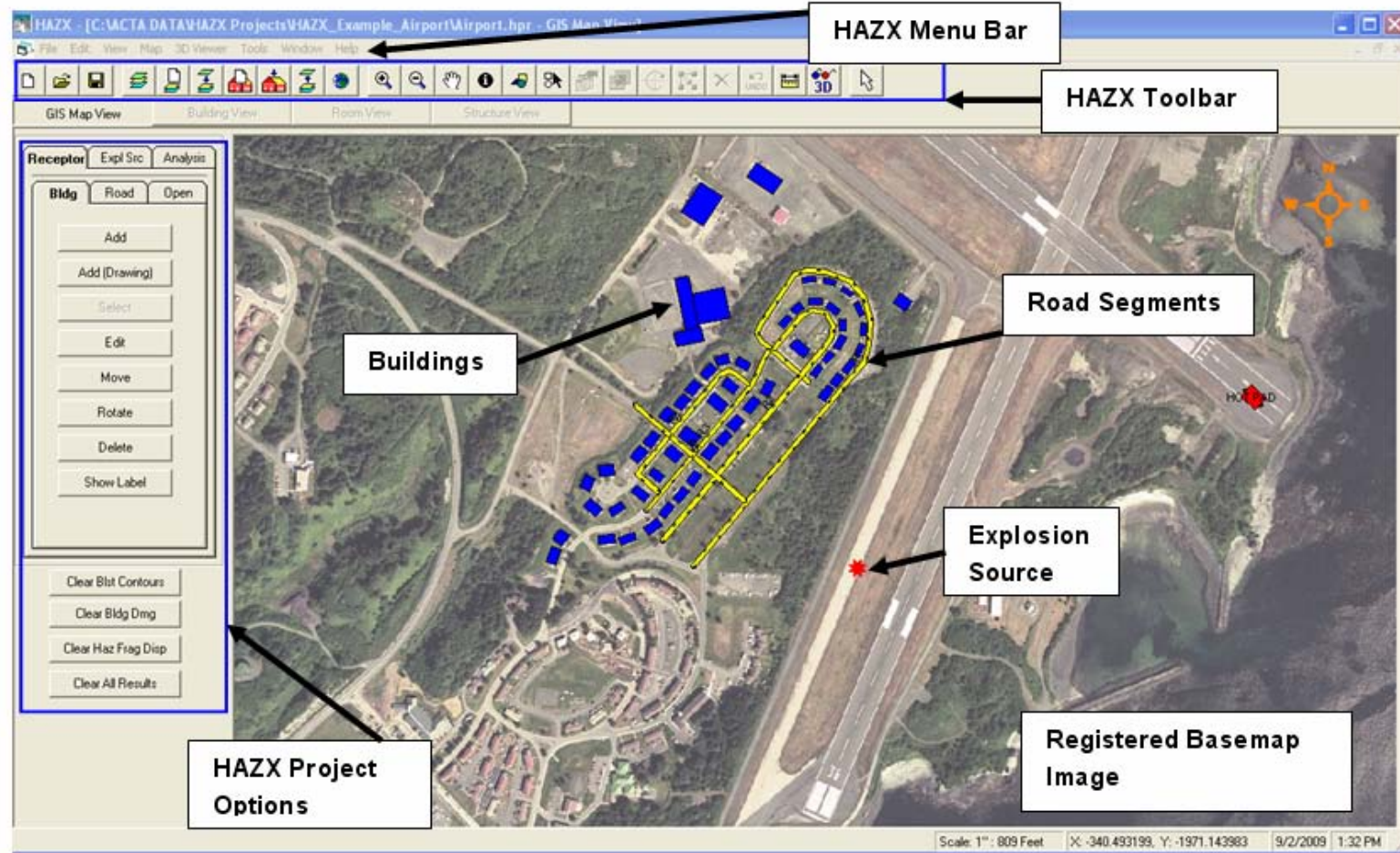


HHT = HAZX Hazard Tool
HRT = HAZX Risk Tool

HAZX Architecture

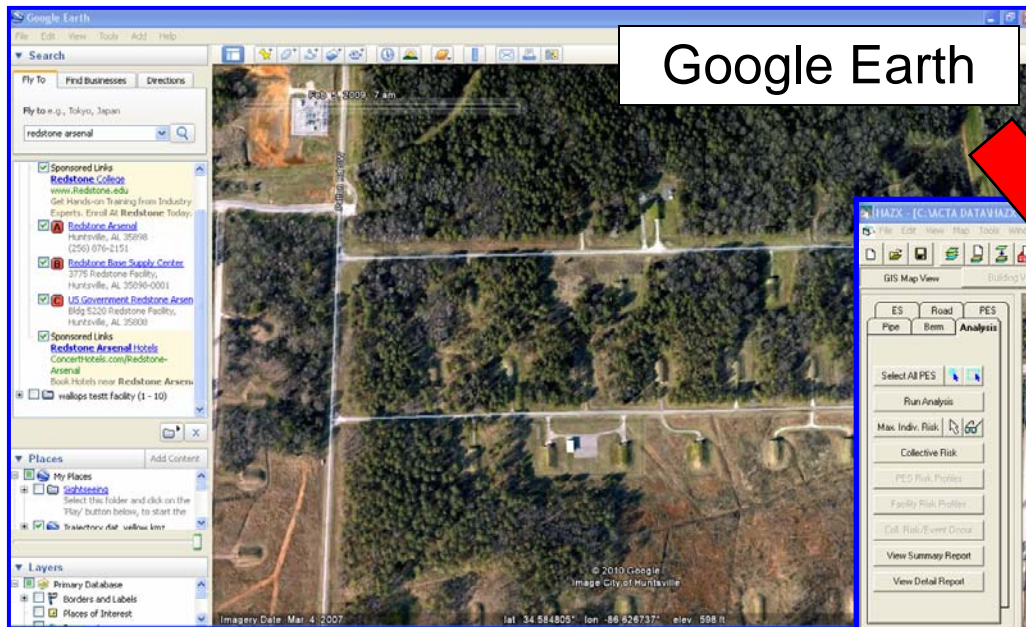


HAZX GUI/GIS

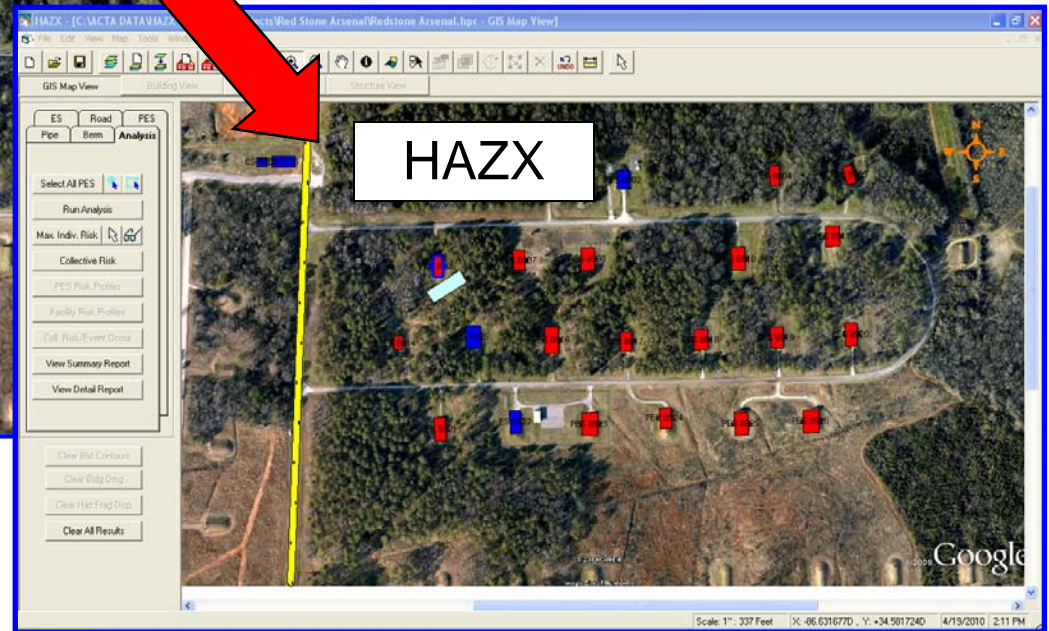


HAZX – Importing Base Maps

- The HAZX GUI/GIS has been designed to simplify the setup and execution of explosives safety hazard & risk analyses
 - *Aerial views & maps can be automatically imported from other applications*
 - *Bitmaps, JPEGs, etc. images can also be manually registered if necessary*
 - *All PESSs, ESs, Roads, Barricades & their attributes can be entered via the GUI/GIS*



Views could come from other tools such as MS Virtual Earth, ArcGIS Explorer, etc.



Or, maps/images can be manually registered if desired

Defining an Explosion Source

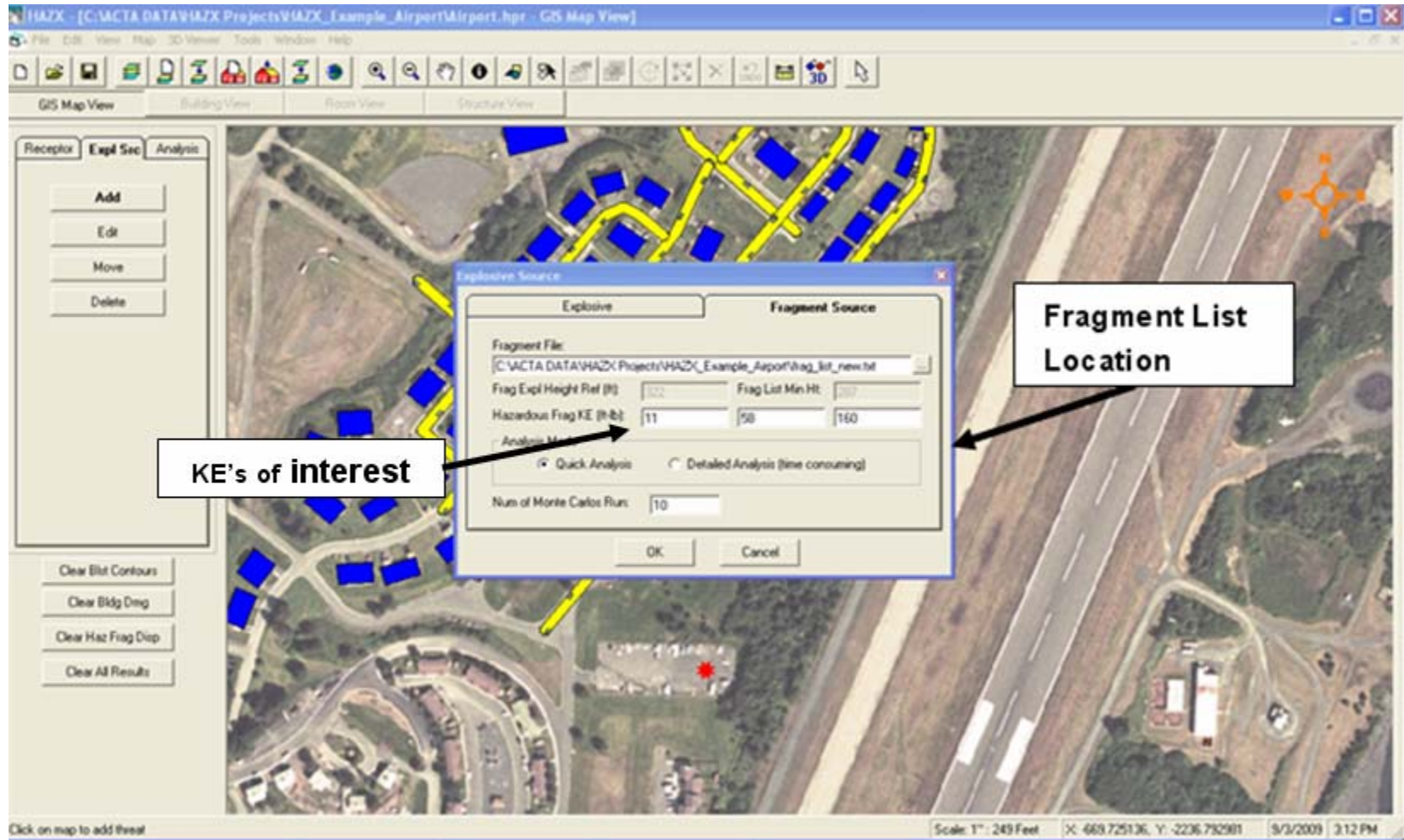
The image displays two screenshots of the HAZX software interface. The top screenshot shows the 'Explosive Source' dialog box with the following settings:

| Explosive | | Fragment Source | |
|---------------------------|-------------|--------------------------|-------------|
| Explosive Type: | TNT | Explosive Weight: | 40000 (lbs) |
| TNT Pressure Equivalence: | 40000 (lbs) | TNT Impulse Equivalence: | 40000 (lbs) |
| Probability of Explosion: | | Expl Height (min 35 ft): | 300 |

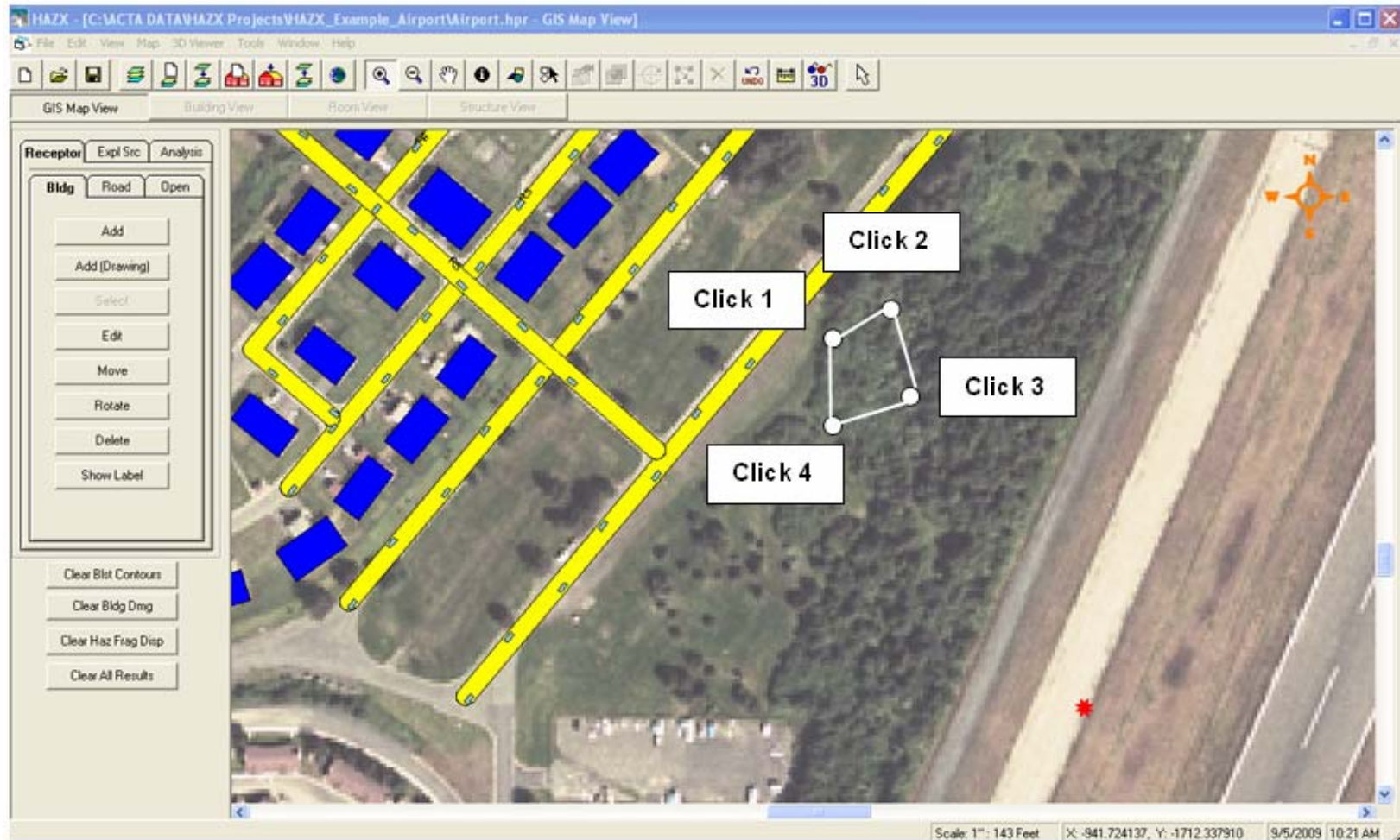
The bottom screenshot shows the main map view with a red star icon labeled 'Explosion Source' on a road. The 'Explosive Source' dialog box is also shown in a smaller inset view.



Defining Fragment List



Adding a Building Receptor



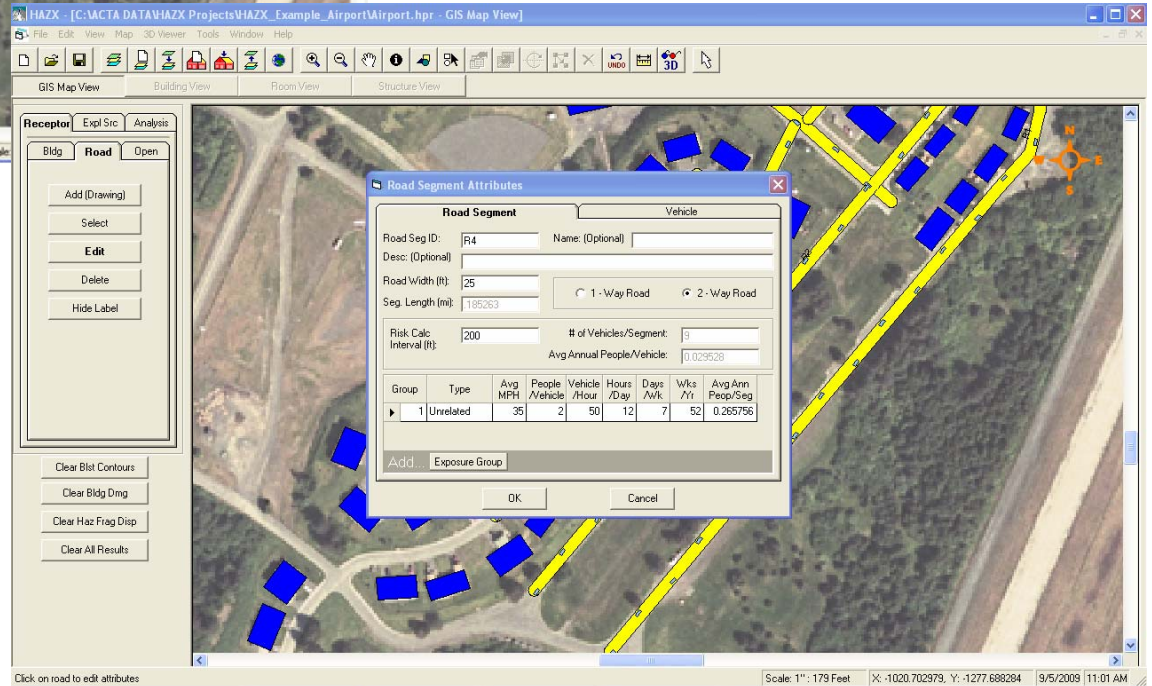
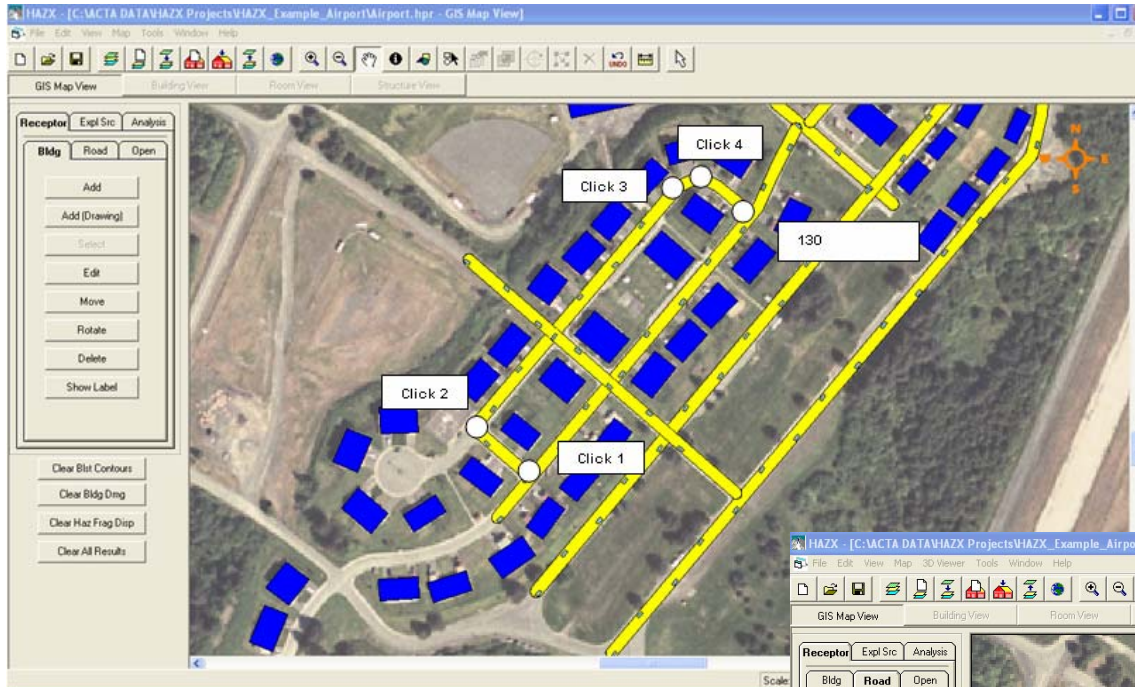
Defining Building Attributes

The screenshot displays the 'Building Attributes' software interface, specifically the 'Construction' tab. The 'General' section shows a Plan Area of 4596.71 (Sq. Ft.), Room Depth of 12, and Building Type of 13. A 'Set Front Wall' button is visible. A diagram shows a pink rectangular building footprint with a blue arrow pointing to its side. A table lists building types with columns for Bldg, Description, ft^2, Stories, Wall Type, Roof Type, and Frame Type.

| Bldg | Description | ft ² | Stories | Wall Type | Roof Type | Frame Type |
|------|------------------------------------|-----------------|---------|-------------|-----------------------------------|---------------------|
| 1 | Small RC Office/Commercial | <5,000 | 1-3 | 8" RC | 4" RC | RC Shearwall |
| 2 | Medium RC Office/Commercial | 5,000-20,000 | 1-3 | 8" RC | Lt Wt Concrete/Mtl Deck/Stl Joist | RC Moment Resisting |
| 3 | Large RC Tiltup Commercial | >20,000 | 1 | 8" RC | Wood Panelized | RC Shearwall |
| 4 | Small URF Brick Residential/Office | <5,000 | 1-2 | 4" UR Brick | Plywood/Joist | Brick Shearwall |

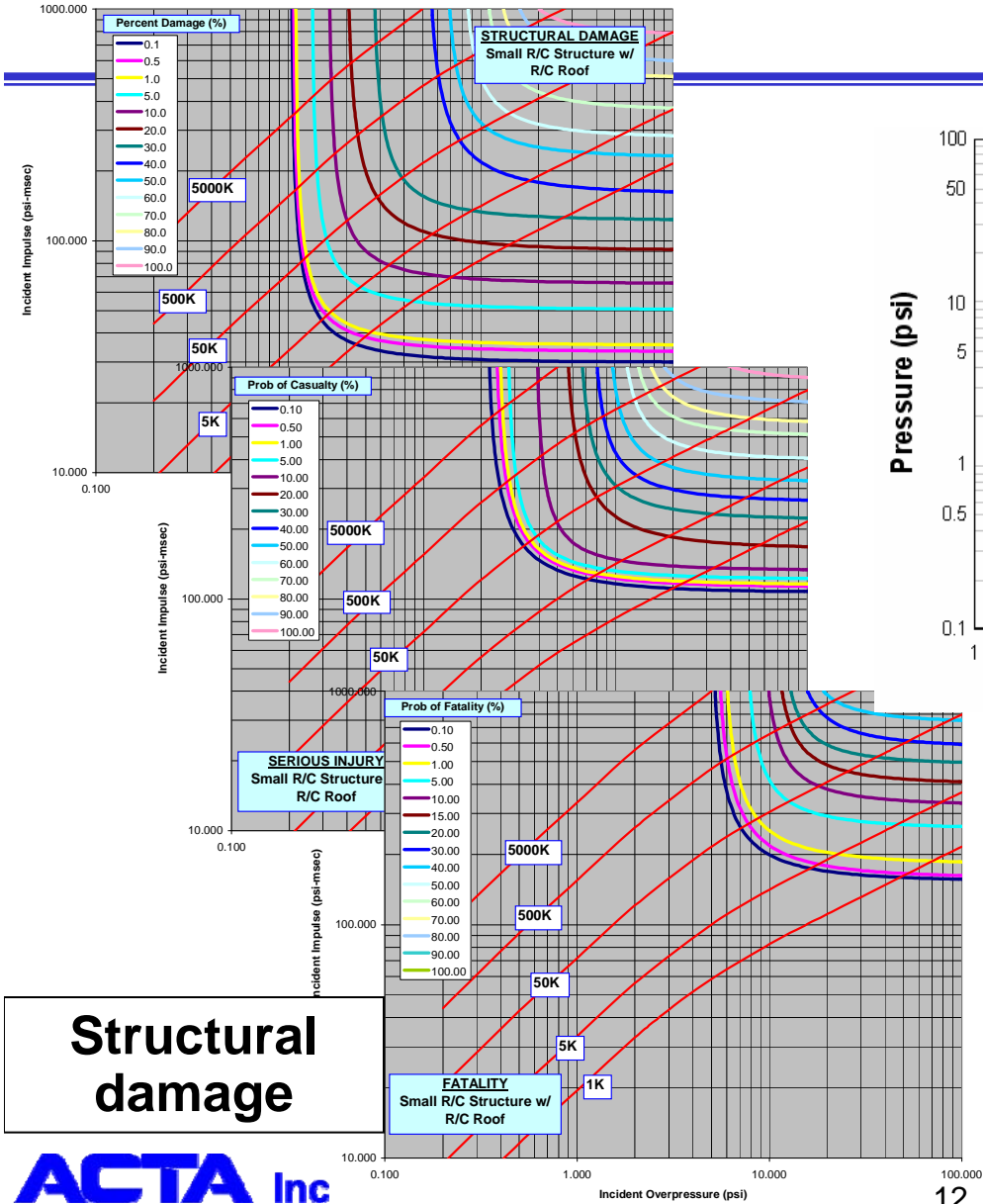
The 'Costs / Occupancy' tab is also visible, showing a 'Set Front Wall' button and a diagram of the building footprint. A callout box with an arrow pointing to the side of the footprint contains the text 'Click on bldg side'. Below this, a 'Window Type' dropdown menu is open, showing a list of window options such as 'Dual Pane, Annealed Windows, Medium (4'h x 4'w x 2-1/4"t)' and 'Annealed Windows, Large (6'h x 5'w x 1/4"t)'. The '% Glass to Wall' column shows a value of 10 for the selected window type.

Defining Roads

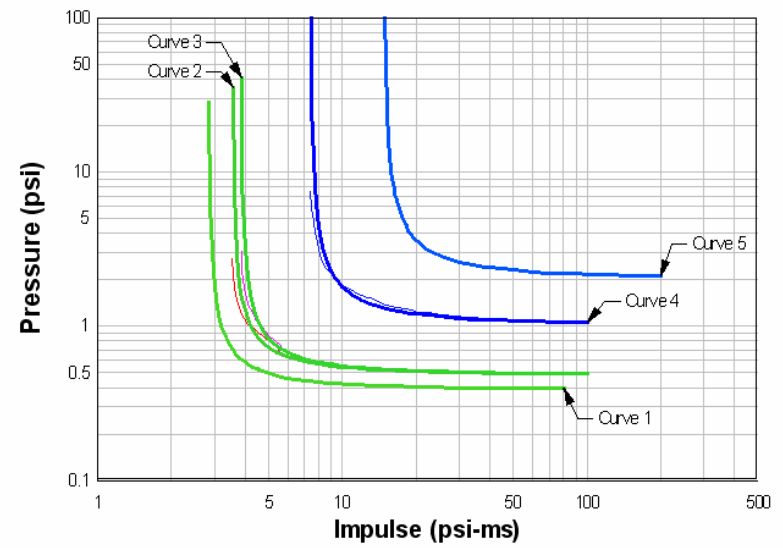
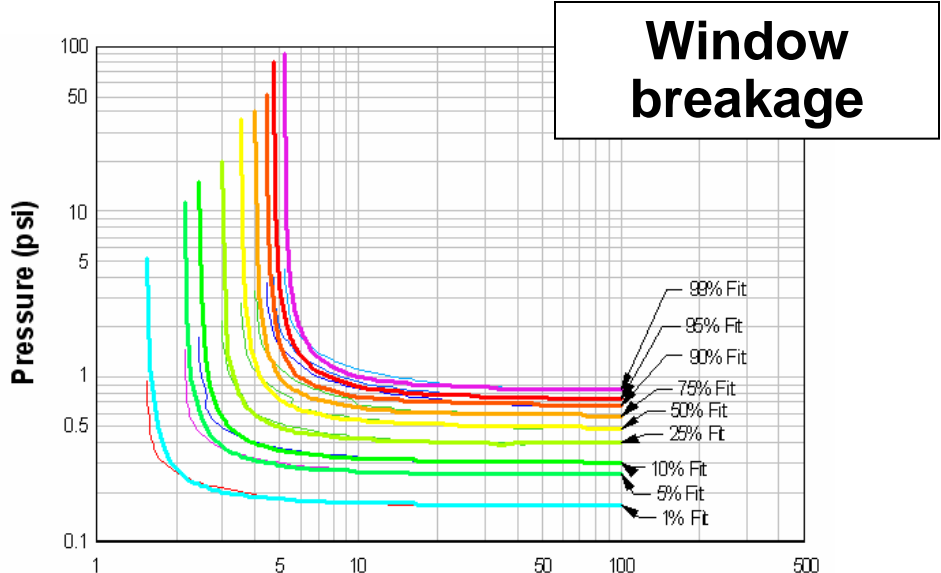


Click on road to edit attributes Scale: 1" = 179 Feet X: -1020.702979, Y: -1277.688284 9/5/2009 11:01 AM

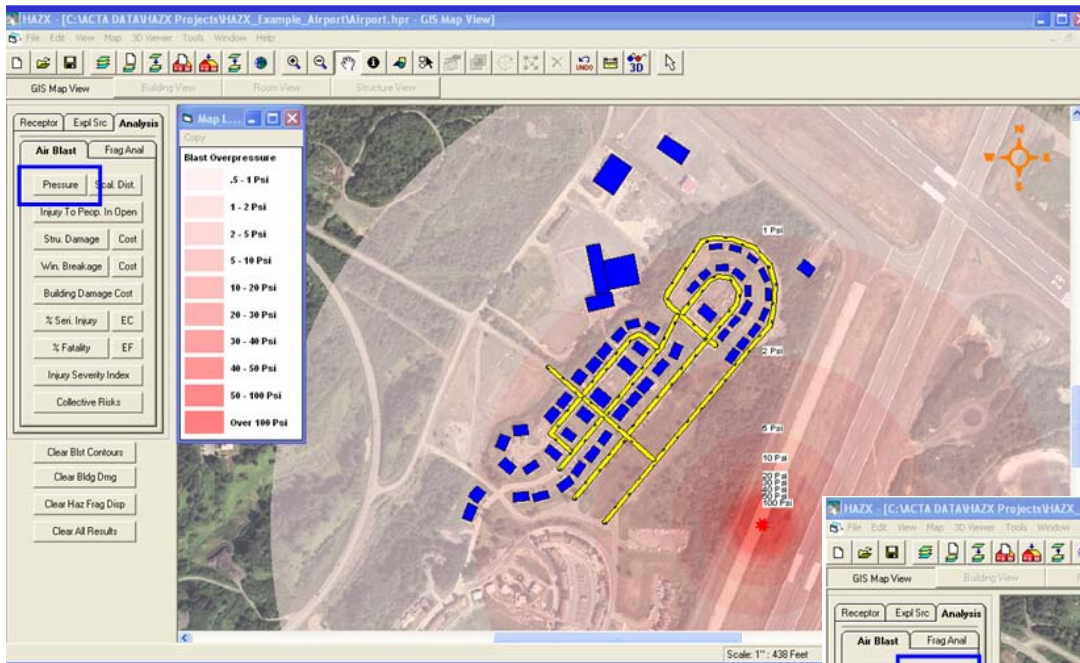
Building Consequence Models



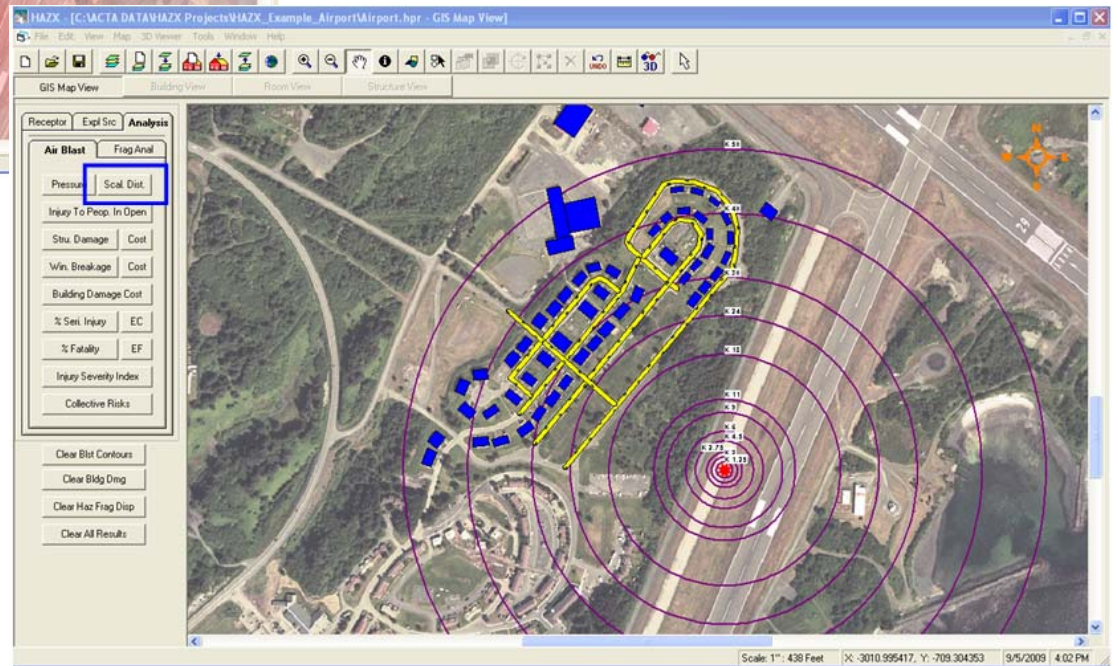
Structural damage



Air Blast Hazard Displays



Overpressure
Contours



Scaled Distance
Arcs

Air Blast Consequence Displays

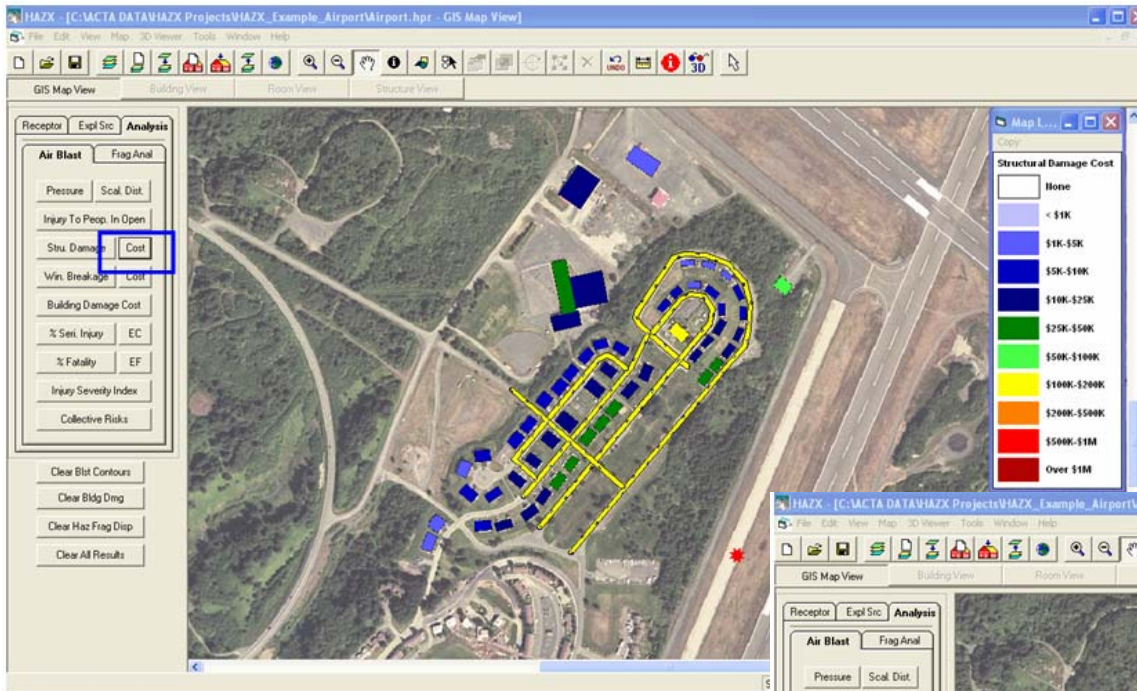
Injury to People in the Open

Structural Damage

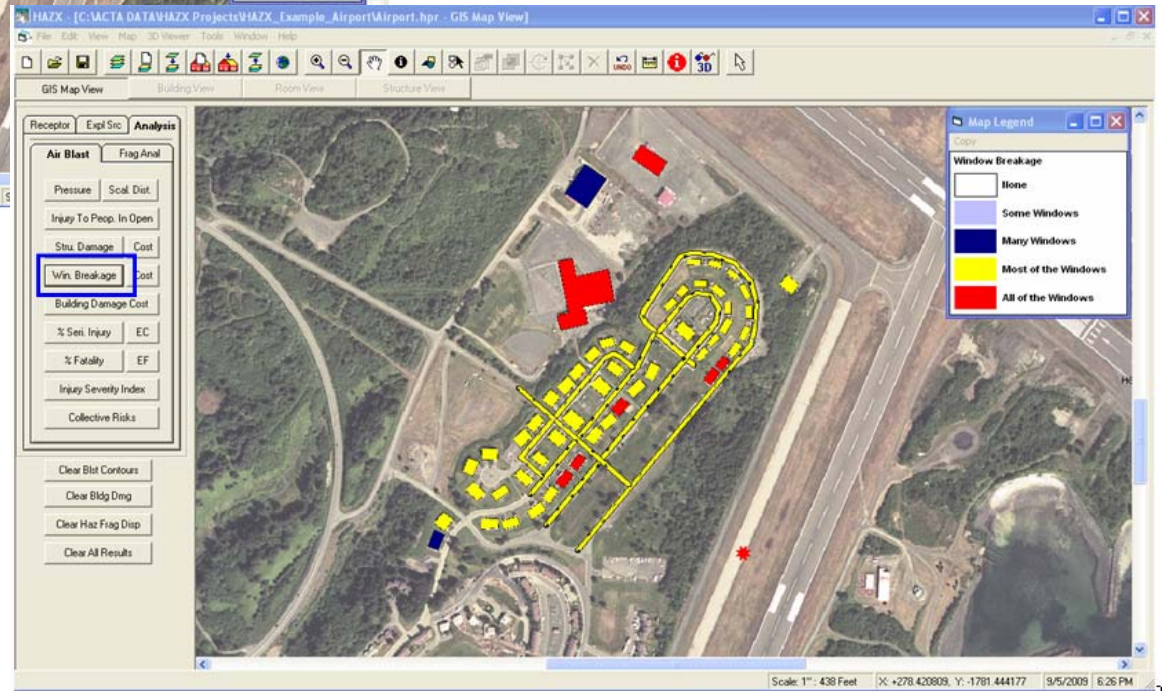
Building Info

| Field Name | Field Value |
|-----------------------------------------|----------------------------------------|
| GENERAL INFORMATION | |
| BLDG_ID | 815 |
| BLDG_NAME | |
| Building Description | |
| Structure Type | 4 - Small URF Brick Residential/Office |
| Room Depth | 12 Feet |
| Structure Cost | \$500,000.00 |
| Window Types | See the Window Tab for Details: |
| Window Cost | \$100,000.00 |
| Total Occupants | 2,7586 |
| Perimeter Occupants (within Room Depth) | 1,56 |
| Distance To Explosion | 1121.92 Feet |
| RESULTS / OVERALL | |
| Incident Overpressure | 1.511964 Psi |
| Incident Impulse | 91.613061 Psi-sec |
| Expected Total Damage Cost | \$182,882 |
| % Serious Injury | 3.05 % - Few (1%-10%) |

Air Blast Consequence Displays

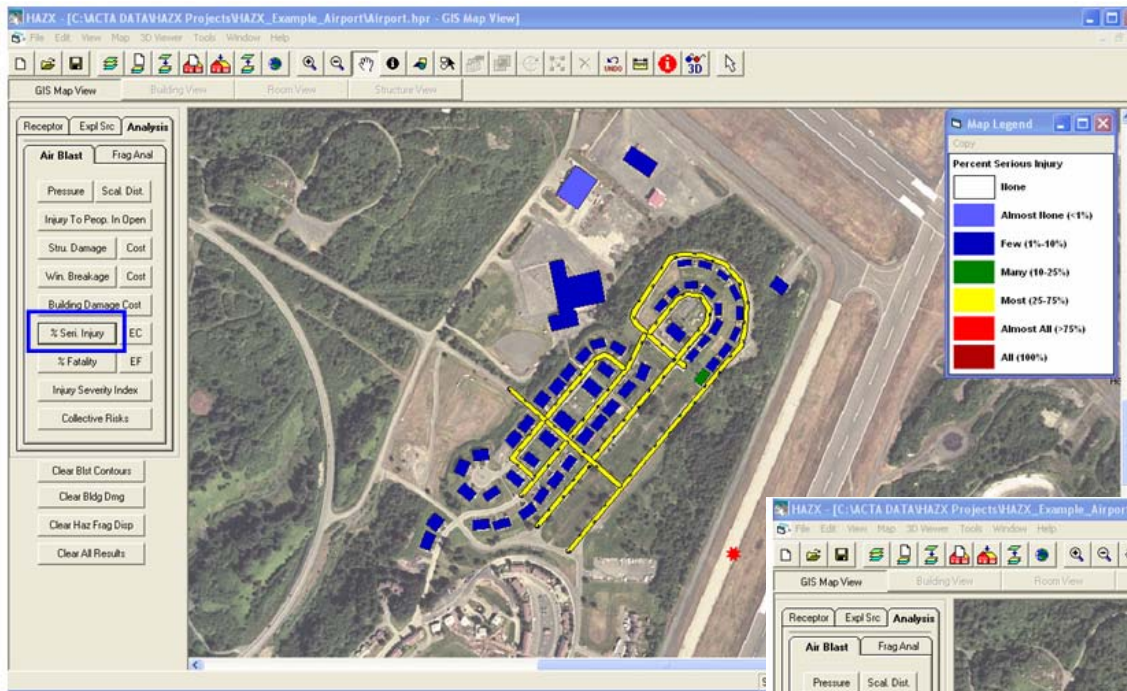


Structural damage & window breakage costs

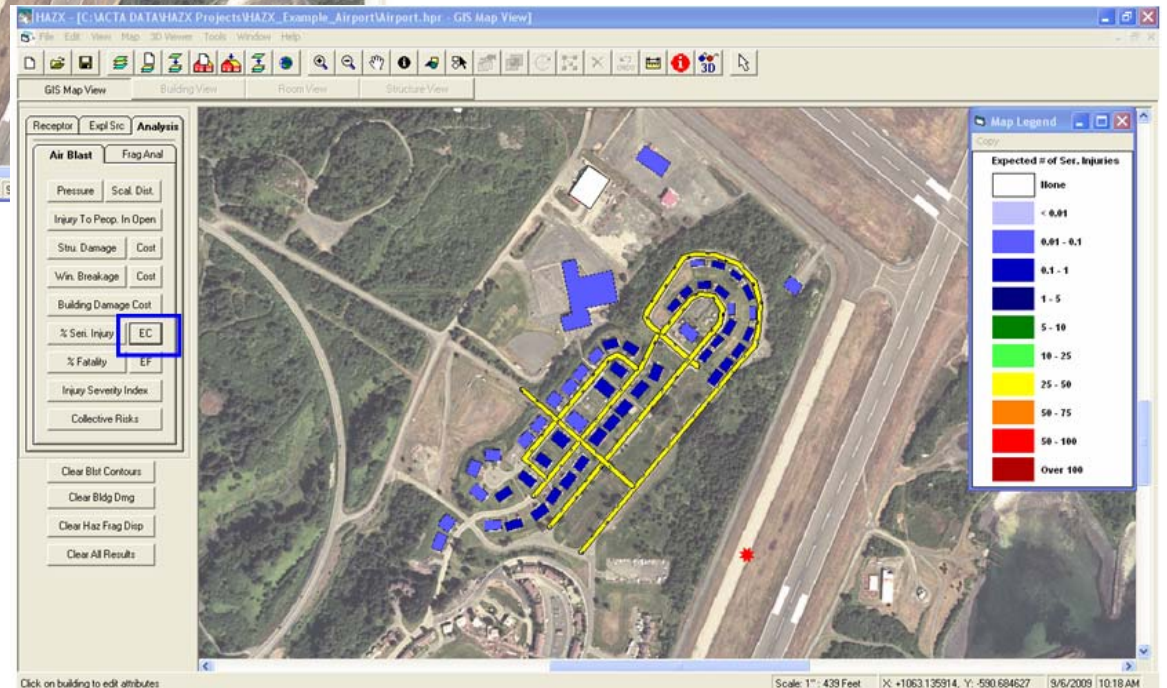


Window Breakage

Air Blast Consequence Displays

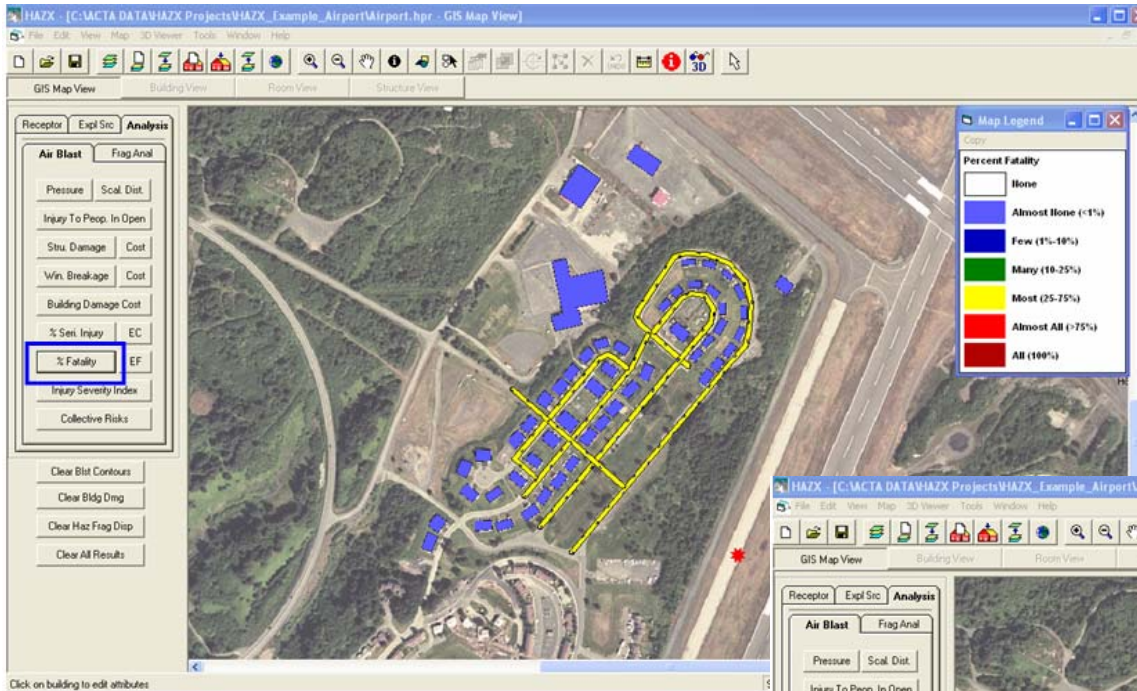


Percent Injury of building occupants

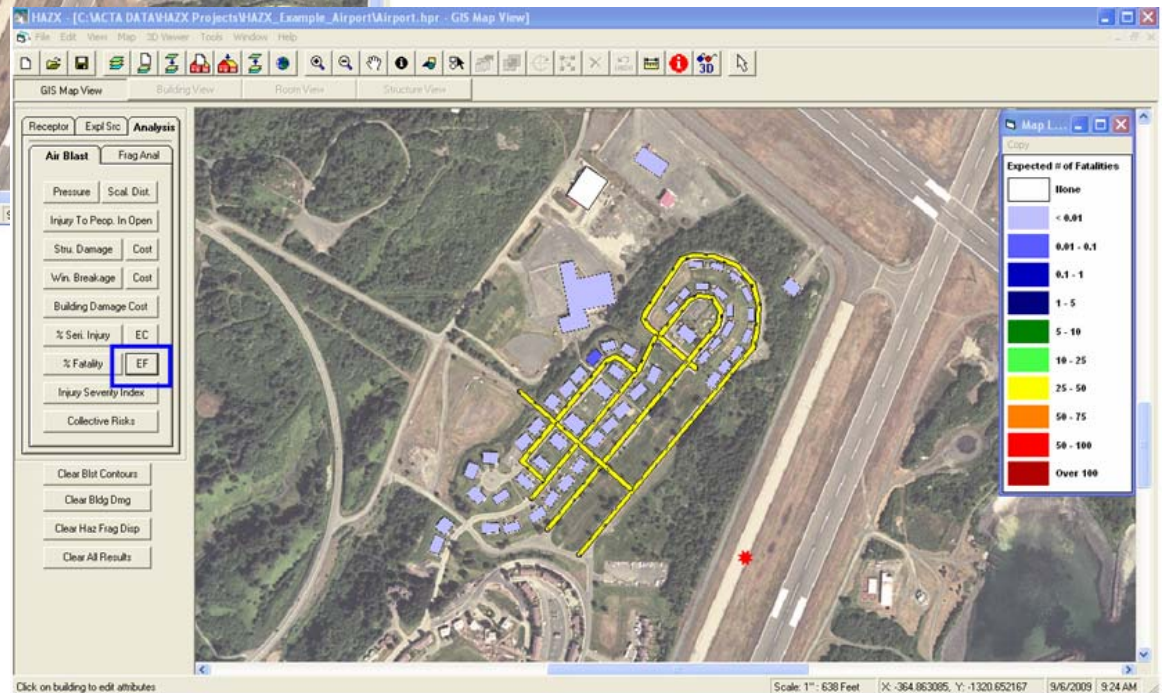


Expected number of bldg occupant injured

Air Blast Consequence Displays

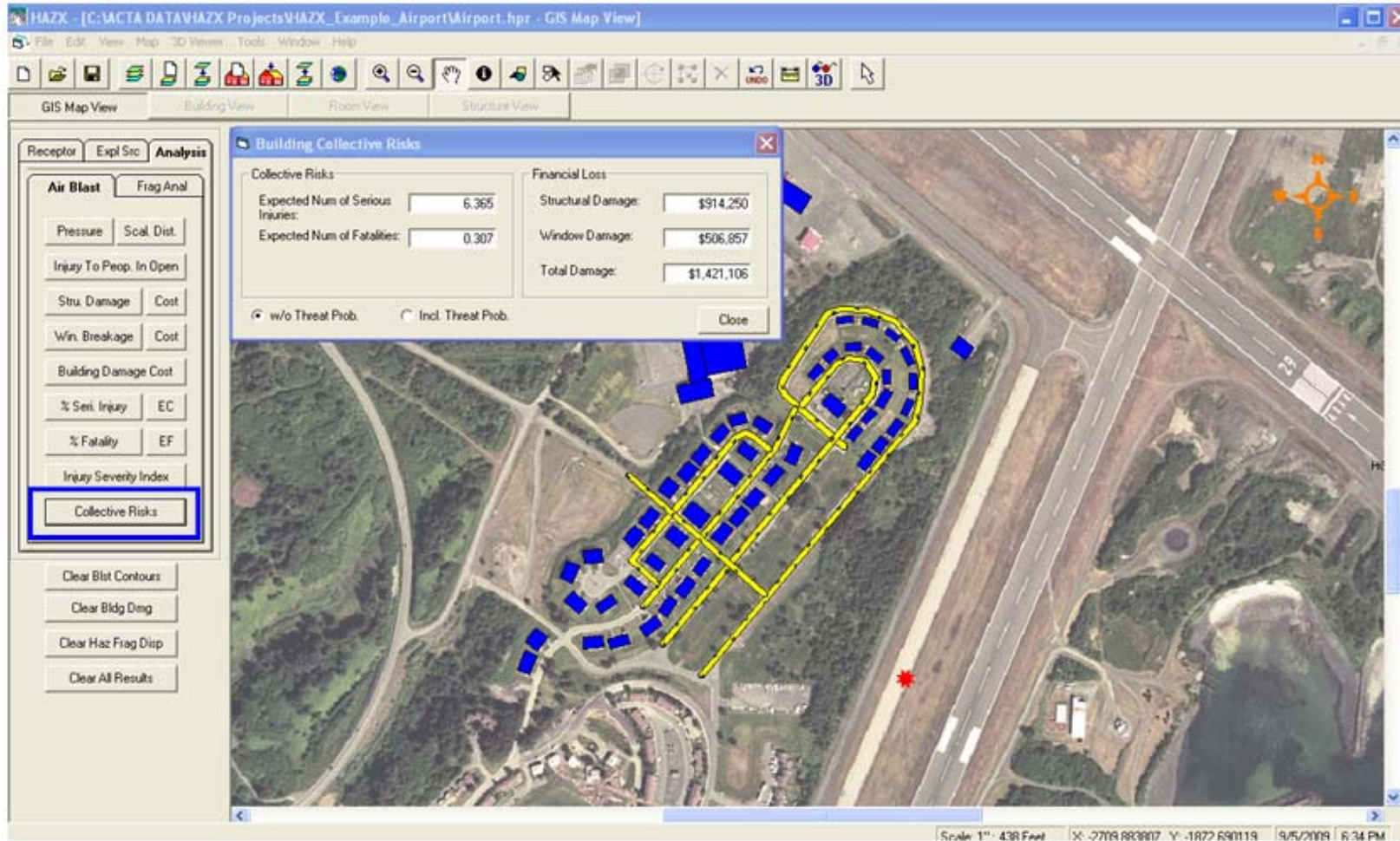


Percent fatality of building occupants

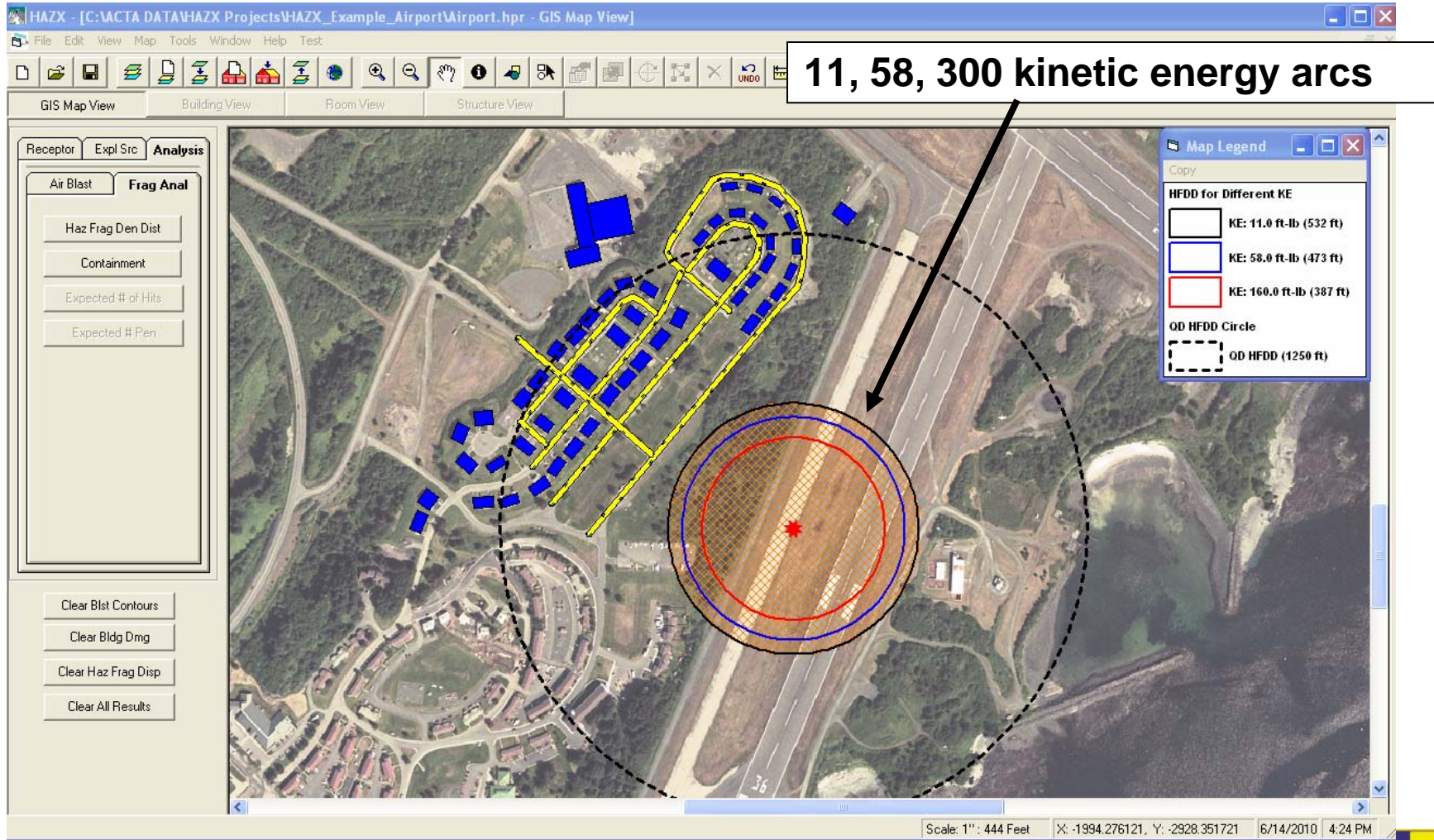


Expected number of bldg occupant killed

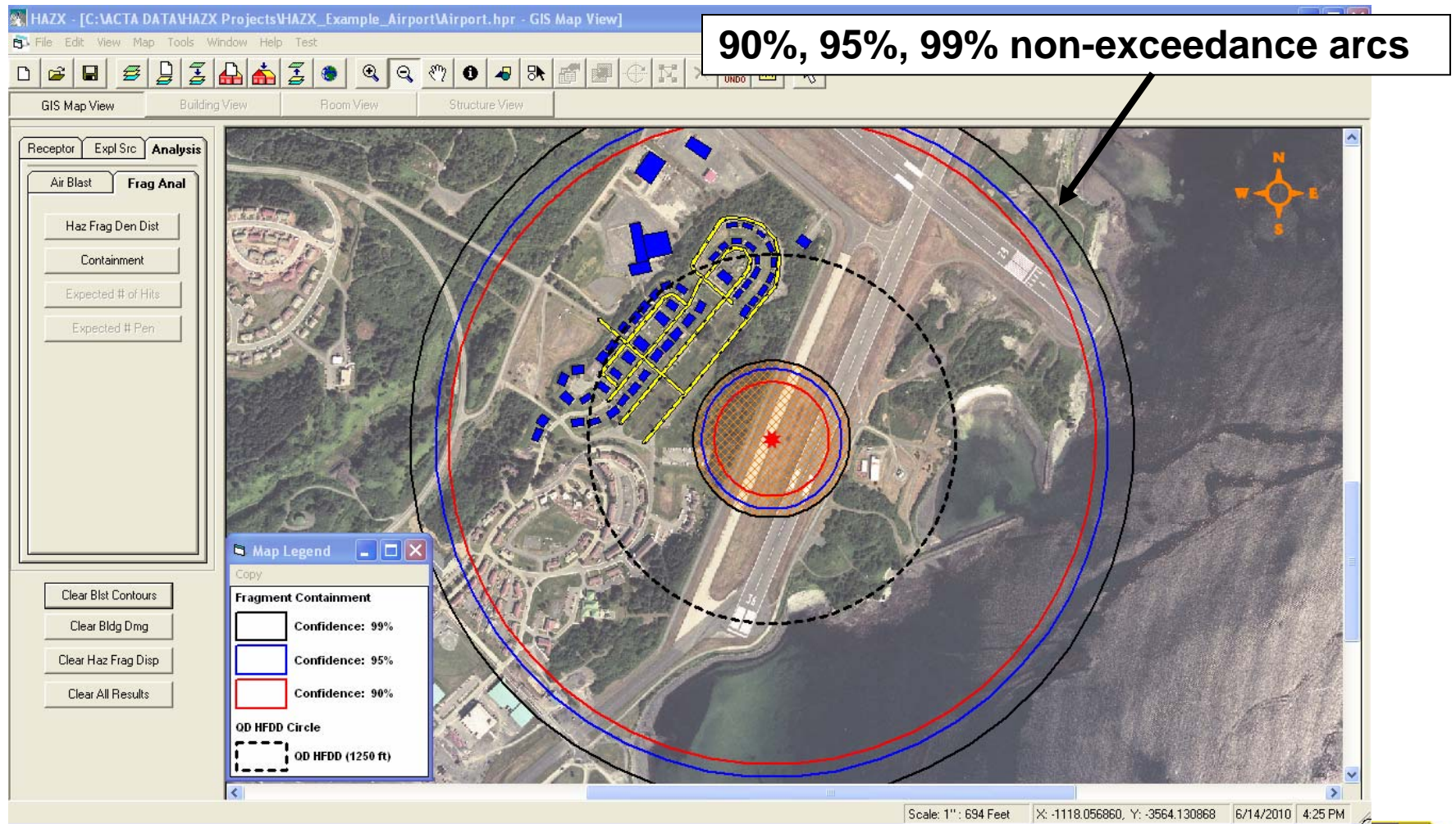
Air Blast Consequence Displays (Collective Losses)



Fragmentation Hazard Displays (Hazardous Fragment Density Distance)



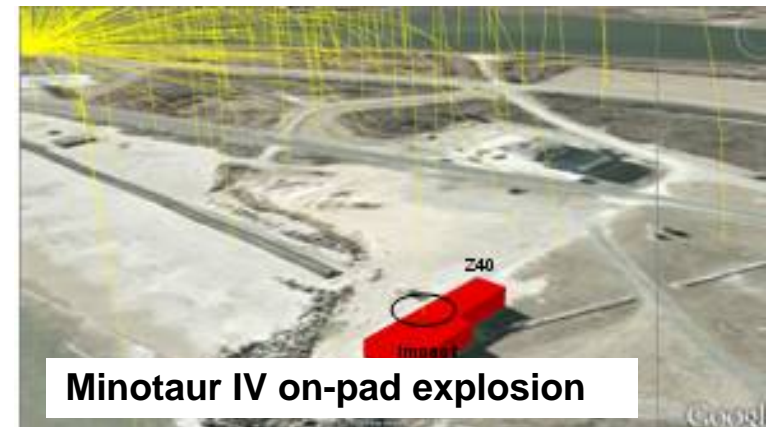
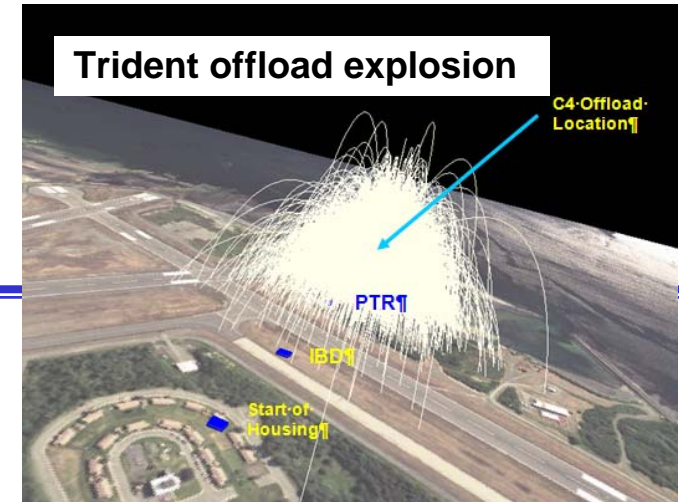
Fragmentation Consequence Displays (Containment Distance)



HAZX Hazard Tool (HHT)

Practical Uses

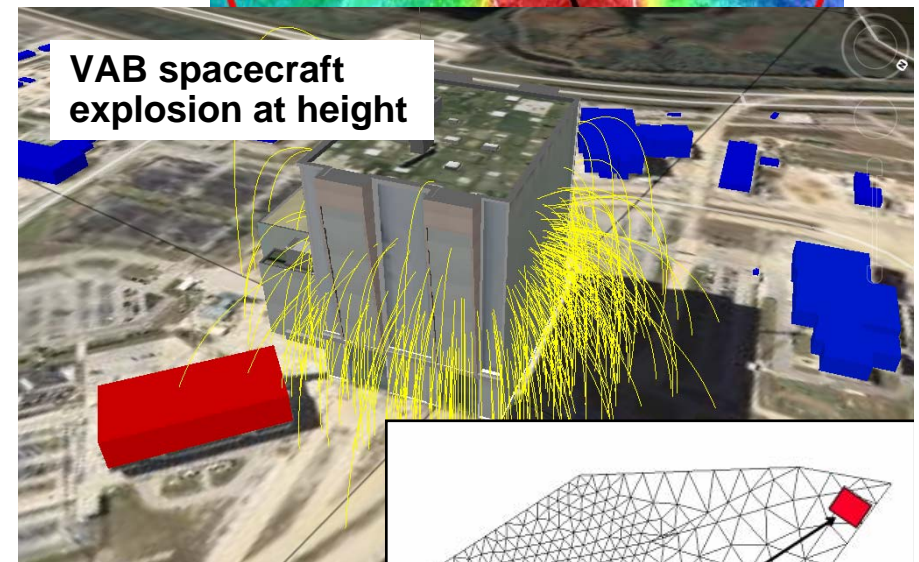
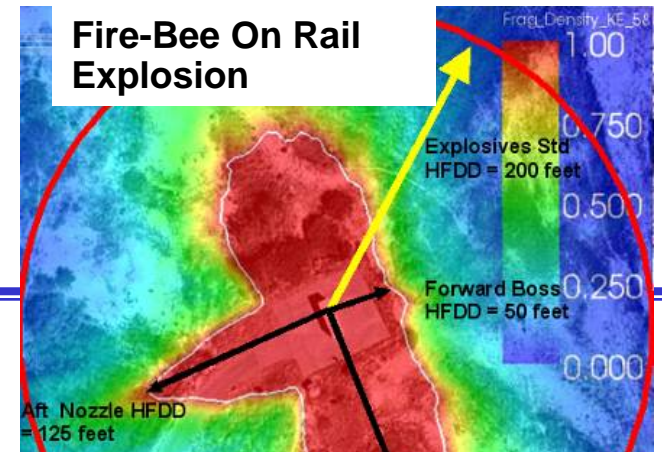
- Used to evaluate hazards and consequences of:
 - *Trident Stage (HD 1.1) air transport offload accident*
 - Consequences to unrelated residents of nearby Coast Guard housing area
 - *On-pad explosion of a Minotaur IV rocket*
 - Effect on occupied buildings and damage to critical assets
 - *On-pad explosion due to hot-fire of a Taurus II rocket*
 - Effect on occupied buildings and damage to critical assets



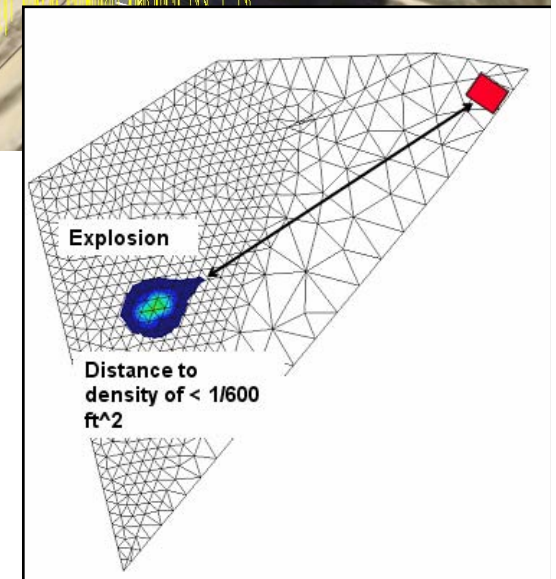
HAZX Hazard Tool (HHT)

Practical Uses

- *On-rail explosion of a Fire-Bee rocket assisted winged target*
 - Consequences to unrelated occupants of nearby buildings
- *Explosion of a hypergolic propellant spacecraft inside the NASA KSC VAB*
 - Effect on 40 occupied buildings adjacent to VAB
- *On-rail explosion of a Lance Missile*
 - Effect on launch team in nearby control house



On-rail explosion of Lance missile



Conclusions & Recommendations

- The HAZX HHT is a powerful tool for performing explosives air blast and fragmentation hazard and consequence analyses
- New capabilities are being incorporated to improve the analysis of explosion hazards/consequences
 - *Improved air blast consequence models*
 - *Improved fragmentation models*
 - 3D terrain
 - 3D extrusion of building footprints
 - 3D representation of people in the open
- HAZX will be available to all DOD government agencies when officially released

