Accident Scenario Baseline

Our baseline scenario inputs for collision are:

- Ship speed (independently chosen for each ship)
- Collision angle
- Bow entrance angle (for the striking ship)
- Minorsky energy coefficient
- Initial collision contact point
- Striking ship mass

The scenario inputs for grounding are:

- Ship speed
- Ship trim angle
- Rock eccentricity (non-dimensional distance from the ship centerline)
- Rock elevation
- Rock tip radius
- Rock cone angle

Baseline pdfs for each of these scenario inputs were developed by Rawson et.al. (1998). Scenario pdfs were estimated based on limited data, rational argument, expert opinion and sensitivity analysis. Once initial scenario pdfs were established, they were calibrated and refined.

Ship velocity is modeled using a bi-modal normal distribution, centered around a five knot maneuvering speed and a 10 knot cruising speed. Maximum speed is 14 knots and minimum speed is two knots. The standard deviation for both curves is one knot. The area under each bell curve is assumed to be equal, which implies that grounding is equally likely to occur in a maneuvering scenario or a transit scenario. This pdf is used for ship velocity in grounding and both struck and striking ship velocities in collision. Figure 1 shows the specified velocity pdf and a histogram representing bins of velocity values chosen in a Monte Carlo simulation of the process. A total of 6000 damage cases are represented in this histogram.

Ship trim is modeled using a uniform distribution with a range of -1 degree to +1 degree. Any discrete value of trim within this range is equally likely. An attempt was made to estimate trim over a typical route, but informal feedback from tanker operators indicated that a uniform distribution is more reasonable. Figure 2 shows the trim pdf and simulation histogram.

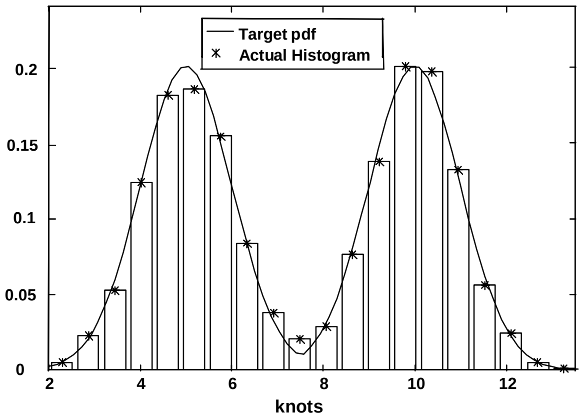

Figure 1. Input Scenario - Ship Velocity pdf

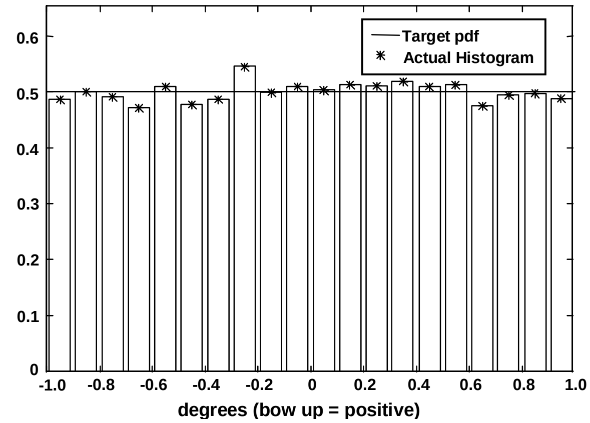

Figure 2. Input Scenario – Ship Trim pdf

The location of the obstruction or rock is defined using two parameters, eccentricity and elevation. Eccentricity or the non-dimensional distance from the ship centerline (d/half beam) is modeled using a uniform distribution with a range of zero (centerline) to one (half beam). This is consistent with the IMO pdf for transverse location of bottom damage. Figure 3 shows the rock eccentricity pdf and simulation histogram. Rock elevation or non-dimensional height above baseline (h/Depth) is modeled using a linearly decreasing pdf from the baseline up to some maximum height below the waterline. Elevations below the baseline do not cause grounding. Elevations above the waterline are visible obstructions. The final value chosen for maximum non-dimensional height was 0.2. This value was determined by calibration to the IMO pdfs. Figure 4 shows the rock elevation pdf and simulation histogram.

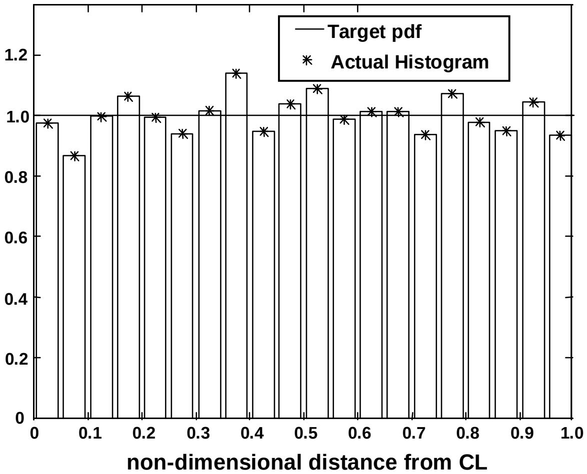

Figure 3. Input Scenario – Rock Eccentricity pdf

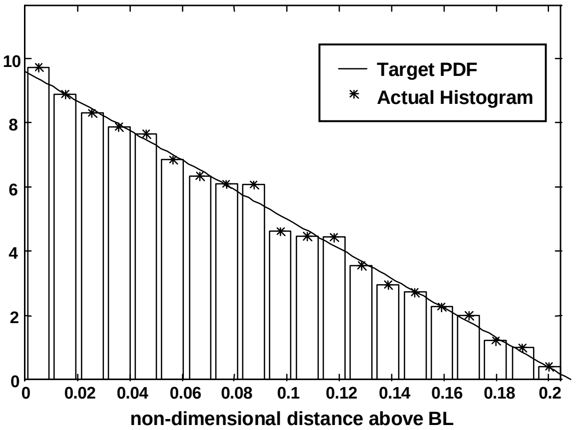

Figure 4. Input Scenario – Rock Elevation

The shape of the rock is described using two variables, rock cone side angle and rock tip radius. Pdfs for both of these parameters are modeled using a normal distribution. Rock cone side angle has an upper bound of approximately 55 degrees determined by the limits of the model. The mean value for cone side angle is taken to be half this upper bound or 27.5 degrees with a standard deviation of 3 degrees. Figure 5 shows the side angle pdf and simulation histogram. The mean value chosen for cone tip radius is 5 meters with a standard deviation of 3 meters. This value is determined by calibration to the IMO pdfs. Figure 6 shows the tip radius pdf and simulation histogram.

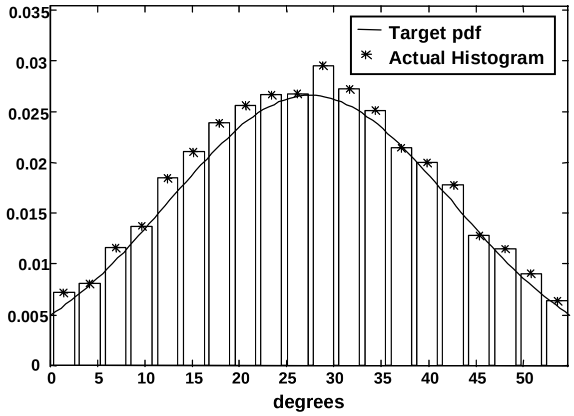

Figure 5. Input Scenario-Rock Cone Side Angle

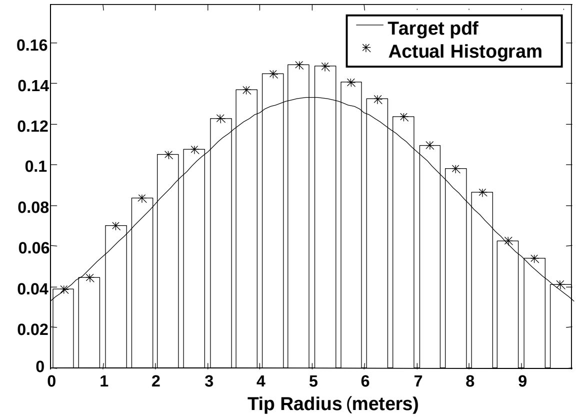

Figure 6. Input scenario - Rock Tip Radius

Collision angle is the angle of incidence between the colliding ships at the moment of impact as shown in Figure 7. Collision angle is modeled using a uniform distribution with a range of zero to 180 degrees. This distribution is very dependent on the waterway transit geometry. The uniform distribution represents a compromise for a generic tanker in worldwide trade. Collisions occurring at a relative angle of zero degrees are constrained to have an initial impact point at the bow of the struck ship. Collisions occurring at a relative angle of 180 degrees are constrained to have an impact point at the stern, and are only allowed if the striking ship's speed exceeds the struck vessel's speed. Figure 8 shows the collision angle pdf and simulation histogram.

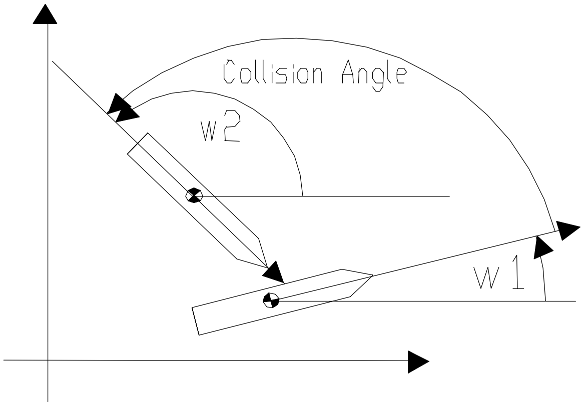

Figure 7. Collision Scenario Geometry

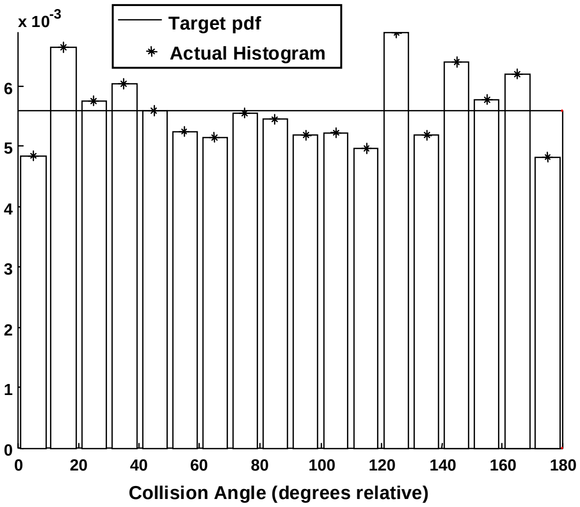

Figure 8. Input scenario – Collision Angle

The point on the struck ship where the striking ship's bow initially makes contact is the impact point. Impact point location is modeled using a uniform distribution with a range from bow to stern. This location is also waterway dependent, and the uniform distribution represents a compromise for worldwide trade. Figure 9 shows the impact point pdf and simulation histogram.

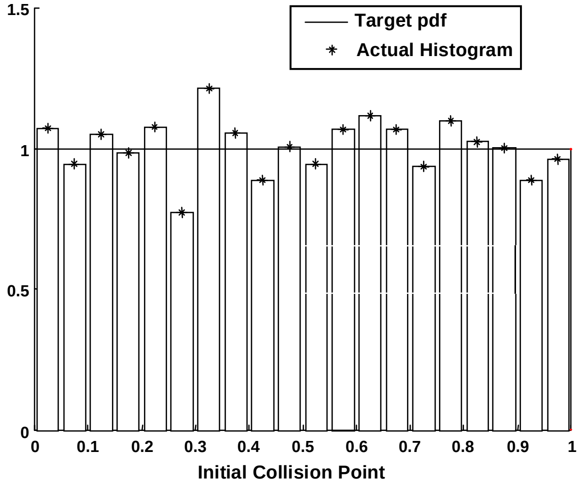

Figure 9. Input scenario – Collision Impact Point

The bow shape of the striking ship is important because it determines the volume of structure damaged during the collision. In this analysis, the shape of the striking ship's bow is idealized as a triangle, with no rake. The bow half-entrance angle is modeled using a normal distribution with a mean value of 38 degrees and standard deviation of 5 degrees. This distribution is based on data presented in Reardon and Sprung (1996) and Keith, Heid and Vann (1995). Adjustments were made in pdf calibration. Figure 10 shows the bow half-entrance angle pdf and simulation histogram.

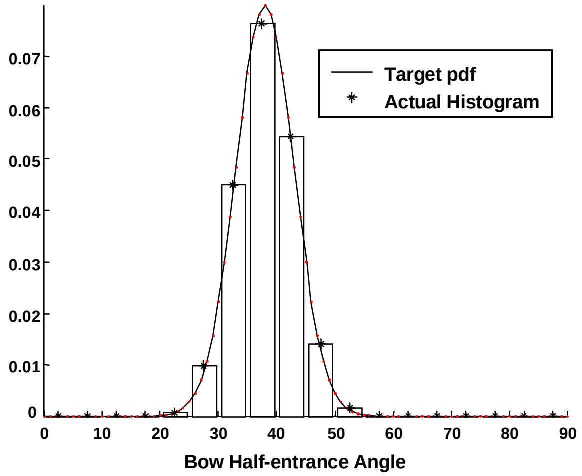

Figure 10. Scenario–Bow Half-Entrance Angle

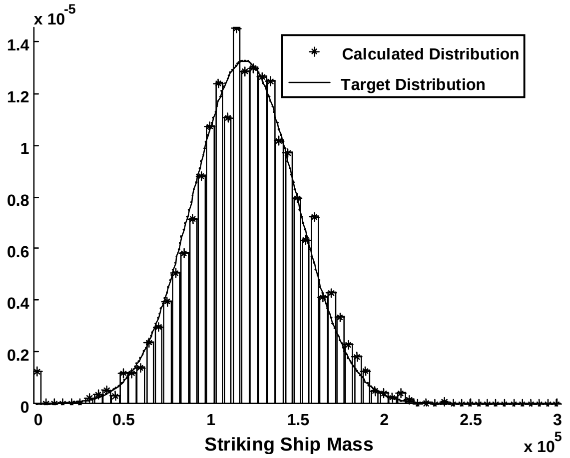

Figure 11. Scenario–Striking Ship Displacement

The striking ship displacement is modeled using a normal distribution with a mean value of 120,000 metric tons, and a standard deviation of 50,000 metric tons. The choice for this distribution is based on data from McDermott et al. (1974), and adjusted in the calibration process. A common approach to this problem is to assume that the striking ship and the struck ship are identical in all respects. This is based on the assumption that "like ships" travel the same waterways (being engaged in the same trade), and are therefore more likely to have collisions. This approach is not used in this analysis based on the recommendation of tanker operators in the MIT Tanker Safety Project. Figure 11 shows the striking ship displacement pdf and simulation histogram.

For each collision scenario, a particular value is selected for the Minorsky constant which defines the relationship between energy absorption and volume of damaged structure. A pdf is also used to describe this parameter. The Minorsky constant pdf is modeled using a normal distribution with a mean of 47.1 MJ/m3 and standard deviation of 8.8 MJ/m3. This distribution is based on a validation of Minorsky's original work by Reardon and Sprung (1996), including the addition of new data points from collisions that have occurred since Minorsky's work in 1959.

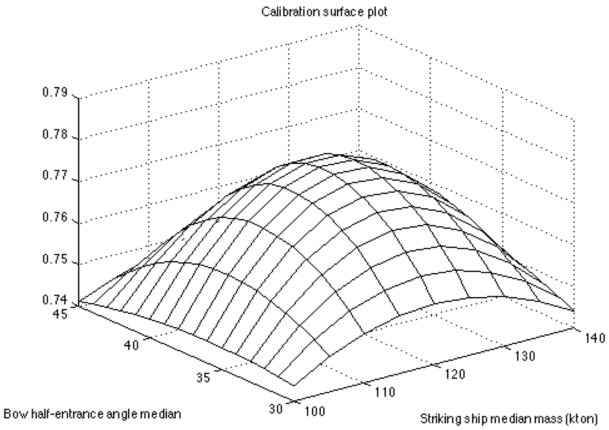

Figure 12. Scenario pdf Calibration Surface

Once initial scenario pdfs are established, they were calibrated and refined by using them to predict damage extents for a representative single hull MARPOL tanker, and modifying them to best match the predicted damage extents to the damage pdfs specified in the IMO Guidelines. Since the IMO pdfs include only cases where the outer hull is ruptured, all non-rupture cases are removed from the predicted pdfs before comparison. A simple fit function is maximized for a matrix of grounding and collision scenario pdf alternatives. Figure 12 shows a two-parameter calibration surface for striking ship mass and bow half-entrance angle. A mean striking ship mass of 125000 mton and mean bow half-entrance angle of 38 degrees are chosen using this surface.

Generally, the damage extent pdf's for bottom damage predicted using the scenario pdf's matched well with the IMO damage pdfs. A notable exception is in the prediction for transverse extent of bottom damage. This comparison is shown in Figure 13. In this case, the simulation cannot account for damage extents as large as that seen in the class data since the width of damage is directly related to the width of the object impacted upon the vessel. A wide reef cannot currently be modeled with the *DAMAGE* obstruction geometry.

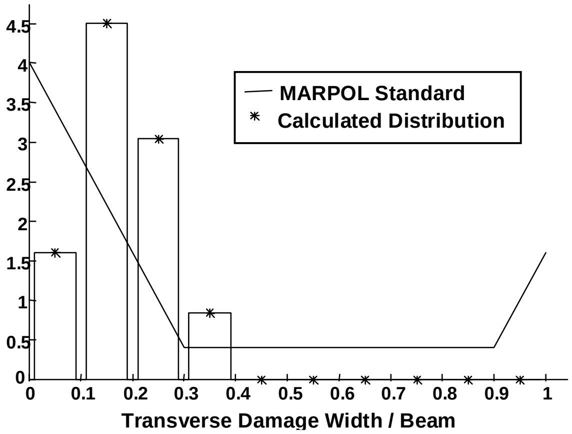

Figure 13. Grounding Transverse Damage