Federal Aviation
Administration

Supplemental Application Guidance for Unguided Suborbital Launch Vehicles (USLVs)

Commercial Space Transportation

Introduction

Current Practice[1]

The FAA's current regulatory practice with respect to the launch[2] of small-scale rockets is to combine current Air Traffic and AST regulations, internal FAA policy, and a guidance document to ensure the safety of small-scale rocket launches. The current practice of individuals who launch small-scale rockets is influenced in part by FAA regulations and policy, but is also influenced by State, local, and self-regulation.

AST Regulations

Under 49 U.S.C. Subtitle IX, ch. 701, popularly referred to as the Commercial Space Launch Act of 1984, as amended (CSLA or the Act), any person proposing to launch a launch vehicle within the United States, and any U.S. citizen proposing to launch a launch vehicle outside the United States, must obtain a license authorizing the launch. 49 U.S.C. 70104(a). AST authorizes launches by the private sector to protect public health and safety, safety of property, and national security interests and foreign policy interests of the United States.

The first regulations implementing the Act were issued in 1988. The 1988 final rule, Commercial Space Transportation Licensing Regulations, 14 CFR Ch. III, exempted certain small-scale rocket activities from licensing requirements. That aspect of those regulations is still in effect.

In the regulations, launches of small-scale rockets of limited performance were termed "amateur rocket activities." Under 14 CFR 401.5, a launch constituting an amateur rocket activity is one that takes place from a private site and involves a rocket that meets all three of the following criteria:

- The rocket motor(s) has a total impulse of 200,000 pound-seconds or less; and
- The rocket motor(s) has a total burning time or operating time of less than 15 seconds; and
- The rocket has a ballistic coefficient - i.e., gross weight in pounds divided by frontal area of rocket vehicle - less than 12 pounds per square inch.

Air Traffic Regulations

Regardless of whether a launch is licensed, individuals wishing to launch unmanned rockets must comply with 14 C.F.R. Part 101. Part 101 applies to all unmanned rockets except model rockets that use not more than four ounces (113 g) of propellant and weigh not more than 16 ounces (453 g), including the propellant. Its provisions include the prohibition against operating an unmanned rocket in a manner that creates a hazard to other persons or their property, or dropping an object from the rocket if such action creates a hazard to other persons or their property.

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[1] As of June 1, 2001.

[2] This paper does not address the storage or transportation of rocket motors, which are regulated by the Bureau of Alcohol, Tobacco and Firearms (ATF) and Department of Transportation (DOT), respectively.

No person may operate an unmanned rocket in a manner that creates a collision hazard with other aircraft; in controlled airspace; within five miles of the boundary of any airport; at any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails; at any altitude where the horizontal visibility is less than five miles; into any cloud; within 1,500 feet of any person or property that is not associated with the operations; or between sunset and sunrise.

Internal FAA policy

Persons planning to launch unmanned rockets into controlled airspace must apply to the nearest air route traffic control center for a waiver. Requests for waivers to 14 C.F.R. Part 101 are normally handled at FAA regional offices without headquarters involvement. As of 1998, requests for waivers to 14 C.F.R. Part 101 that involve launches that have a predicted altitude greater than 25,000 feet are forwarded to FAA headquarters for review by AST, and the Air Traffic Airspace and Rules Division, ATA-400. In addition, regardless of the altitude, waiver requests are forwarded to headquarters for all launches that involve rockets that do not meet AST's definition of amateur rocket activities.

Many launch vehicles can reach altitudes greater than 25,000-ft. and still meet the current criteria of an amateur launch under 14 C.F.R. § 401.5. Therefore, the FAA's only regulatory mechanism is the waiver process under 14 CFR Part 101. The FAA will not grant a waiver unless the FAA determines that public health and safety is ensured. Whether the FAA reviews a proposed launch as a request for an exemption under 14 CFR Part 101 or a license under 14 CFR Chapter III, the FAA will carefully address all relevant safety issues before issuing an exemption or a license.

Guidance Document

In order to assist applicants proposing to launch unguided suborbital launch vehicles (USLV's), AST has prepared guidance material that specifically addresses the unique safety issues associated with these vehicles. This document, "Supplemental Application Guidance for Unguided Suborbital Launch Vehicles" (Supplemental Guidance), is attached and is a supplement to AST's general license requirements.

The supplemental guidance document outlines what the FAA considers safe launch operations for USLVs. Because it is intended to cover all applications to launch unguided suborbital launch vehicles, the FAA expects that not all provisions will apply to all launch proposals. The nature of the proposed launch and the location of the proposed launch site play a major role in what is required to ensure safety. For example, the ship impact criteria would not apply to inland launches.

The FAA anticipates that applicants may have alternative methods to ensure safety. Applicants should work with AST during pre-application consultation to address the applicant's specific launch proposal, including any alternative methods to perform certain analyses and conduct certain operations. The FAA will approve launches that meet an equivalent level of safety.

Current Practice of Individuals Who Launch Small-Scale Rockets

Both the National Association of Rocketry (NAR) and the Tripoli Rocketry Association (TRA) have safety codes to protect its members and the public during rocket launches. The National Fire Protection Association (NFPA), Batterymarch Park, Quincy, Massachusetts, has published two safety codes for rocketry: (1) NFPA 1122, which covers model rocketry, and 2) NFPA 1127, which covers high power rocketry. NFPA 1122 includes requirements for rocket construction and operation, including launch site size and launch safety, and requirements for rocket motor use including motor testing and certification. TRA uses NFPA 1127 with additional Tripoli rulings. NFPA 1127 includes requirements for rocket construction, launch sites, and launches, and requirements for rocket motor use including motor testing and certification. All participants in Tripoli sanctioned launch events are required to follow this code.

NFPA 1122 and NFPA 1127 adequately protect the public for most small-scale rocket launches. Small-scale rocket launches that are outside the scope of those standards would most likely be reviewed by AST, using the standards within the ”Supplemental Application Guidance for Unguided Suborbital Launch Vehicles."

GUIDANCE DOCUMENT

SUPPLEMENTAL[3] APPLICATION GUIDANCE FOR UNGUIDED SUBORBITAL LAUNCH VEHICLES (USLV's)

Flight Safety Goal: A licensee should preclude a launch vehicle impact that might endanger human life or cause damage to property. This is done through safety analyses, to determine limitations on launch operations, and through operational procedures.

General

The following supplemental material is applicable to all proposals to launch unguided suborbital launch vehicles (USLV's). It is written for the wide range of launch proposals the FAA expects to see from applicants launching USLV's, including CATS prize participants. It is, therefore, comprehensive in scope.[4] The material is based on standard practices used in the unguided suborbital launch vehicle industry to protect public safety.

Due to the general nature of these requirements, applicants must use pre-application consultation to tailor their applications to the unique aspects of their proposals. The complexity of the license process is proportional to the complexity of the public safety issues involved with an applicant's proposed launch. The greater the potential exposure of the public (people and property), the greater the scope of the safety demonstration that will be required.

The material that follows begins with the FAA's minimum flight safety criteria by which all launch proposals will be judged. These are followed by license application requirements - an outline of what an application should contain in order to demonstrate to the FAA that the flight safety criteria have been satisfied. Lastly, four attachments are included to provide technical guidance to applicants.

Flight Safety Criteria

The FAA will not approve a launch unless an applicant has demonstrated that the following flight safety criteria are met:

1) Public Expected Casualty (Ec): The collective public risk shall not exceed an estimated casualty (E_c) of 30×10^{-6} per launch.

2) Ship Impact: For flight over water, the probability of impacting a vessel (P_i) shall not exceed 1×10^{-5} per launch.

3) Aircraft Impact: The probability of impacting an aircraft shall not exceed 1×10^{-7} per launch.

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[3] Supplemental to AST regulations at 14 C.F.R. Chapter III.

[4] Note that no criteria are included for toxic materials. Launch proposals that involve toxic hazards will be reviewed on a case-by-case basis.

4) Overflight/Impact on Public Land: Public land is land other than land owned by the applicant or land for which the applicant has attained written agreements with the land owner for exclusive use for the proposed launch.
   - No public land overflight or impact shall occur within an impact hazard area (defined below).
   - No non-launch participants may be within the impact hazard area.

   An impact hazard area is defined as two circles and straight lines connecting the circles at tangent points to the circles. The first circle, with origin at the launch vehicle's launch point, has a radius of 1 nautical mile. The second circle, with an origin at the nominal no wind impact point of the last launch vehicle stage, has a radius of 3 σ (sigma) of the nominal trajectory as defined in Attachment 1.

5) Collision Avoidance (COLA): No launch shall take place with a predicted point-of-closest-approach between the launch vehicle and an inhabitable spacecraft in earth orbit of less than two hundred kilometers.

6) Wind Weighting: An applicant launching an unguided suborbital launch vehicle with sufficient energy for the launch vehicle, or any component thereof, to reach public lands, shall base launcher azimuth and elevation settings on measured launch day wind conditions at the launch site so that the launch vehicle's final stage will impact at its predicted nominal impact point. A wind weighting procedure shall be used to determine launcher azimuth and elevation settings based on the results of a trajectory analysis that employs winds measured near the time of launch.

7) Recovery: All launch vehicle components that impact on public land, as defined in (4) above, as a result of a mishap, must be recovered.

8) Vehicle Stability: A proposed launch vehicle shall have a rigid body stability of at least 2.0 calibers throughout powered flight, i.e. the center of pressure (C_p) shall be located behind the center of gravity (C_g) and the distance between the center of pressure and the center of gravity divided by the largest frontal diameter of the launch vehicle shall be at least 2.0.

9) Maximum Nominal (no wind) Launch Angles: No launch angle limits (i.e. launcher azimuth and elevation settings) are imposed if an applicant's proposed launch vehicle does not have sufficient energy for the launch vehicle, or any component thereof, to reach populated areas (see Figure 1).

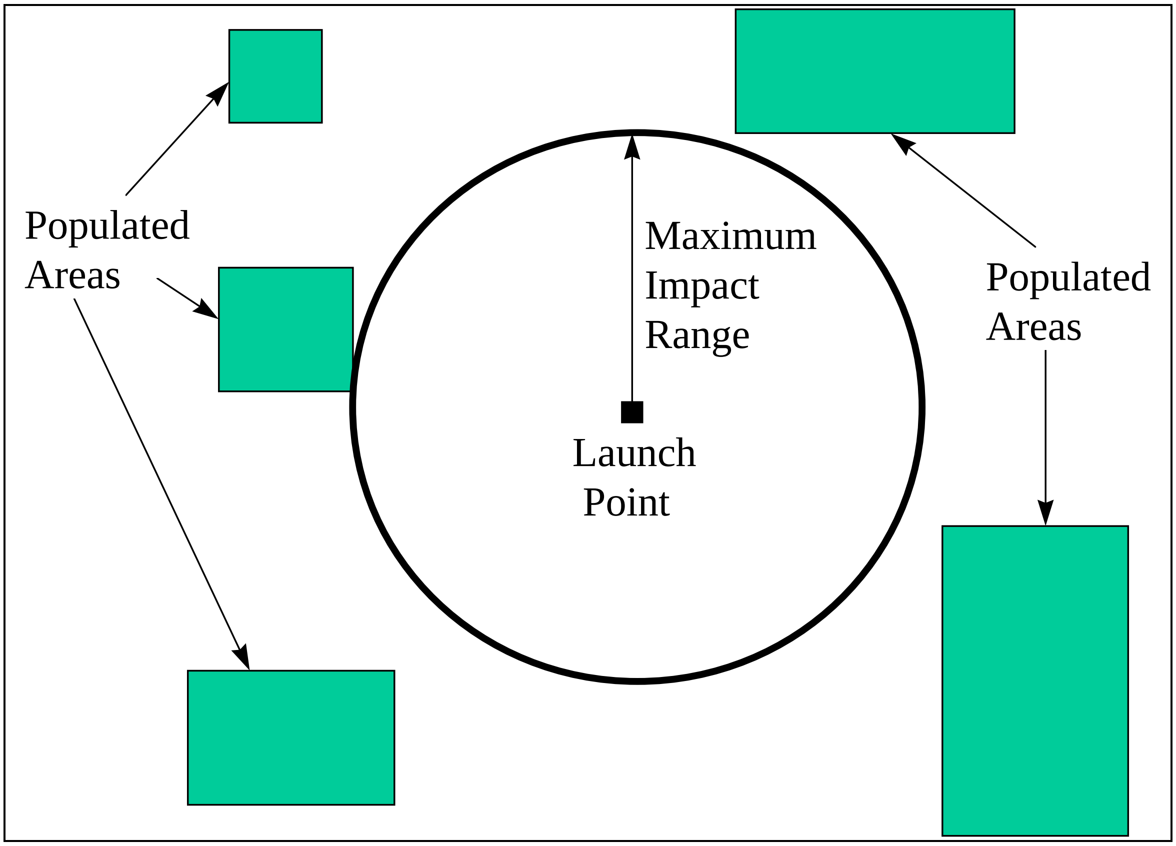

Figure 1. Allowable Maximum Range Condition

Applicants whose proposed launch vehicle has sufficient energy for the launch vehicle, or any component thereof, to reach populated areas (see Figure 2) shall comply with the following launch angle limits:

- The maximum nominal elevation angle shall not exceed 84°, and will be determined based on the proximity of population at the launch site.
- The nominal azimuth limits shall be the azimuth sector that contains no populated areas within the impact hazard area.

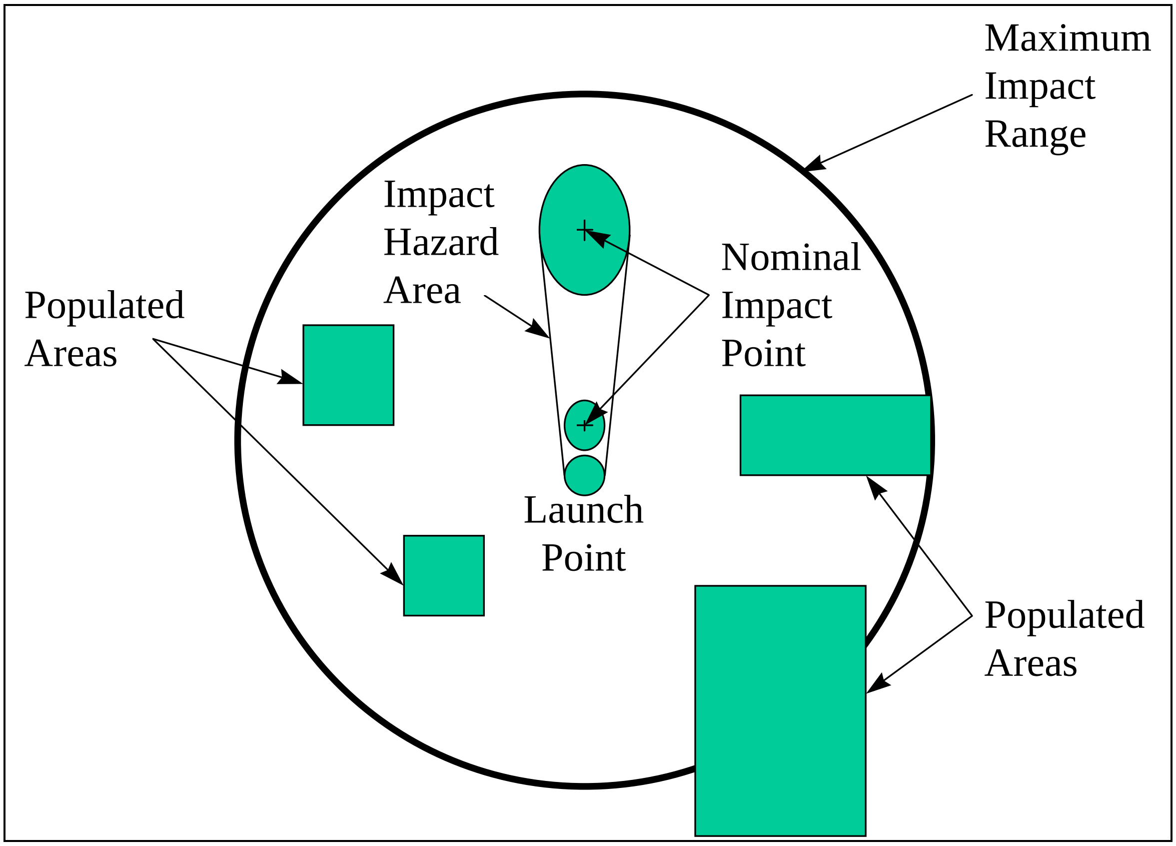

Figure 2. Restricted Launch Angle Condition

<u>Application Requirements</u>

In order to demonstrate to the FAA that the applicant can meet the flight safety criteria above, an applicant shall include in its application a description of the launch vehicle design, including its structure, physical dimensions and weight, propulsion systems, safety critical systems, and the location of the vehicle's C_p in relation to its C_g. An applicant shall also include the analyses listed in (1), (2), and (3) below, including the items listed in the "output" sections of Attachments 1, 2, and 3. An applicant shall include the applicant's operational constraints and procedures in accordance with (4) below, and the flight safety plan in accordance with (5) below.

1) Trajectory/dispersion analysis.

   An applicant shall develop a nominal trajectory, a maximum impact range boundary, and three sigma vehicle impact dispersions in accordance with the definitions, input, methodology, and output described in **Attachment 1**.

2) Hazard area analyses.

   An applicant shall calculate hazard areas for a nominal mission, to include:
   - Impact hazard area, in accordance with **Attachment 2**.
   - Ship hazard areas, in accordance with **Attachment 2**.
   - Aircraft hazard areas, in accordance with **Attachment 2**. This will satisfy flight safety criteria number 3.
   - A Collision Avoidance Analysis (COLA) in accordance with **Attachment 2**.

3) Risk analyses.

   An applicant shall perform an overflight risk analysis to determine the expected public casualty (E_c) of the proposed launch in accordance with **Attachment 3**. Unless an applicant can demonstrate otherwise, the risk analysis should be based on a probability of failure of 50% ($P_f = 0.5$).

4) Operational constraints and procedures.

   An applicant shall provide the operational constraints and procedures necessary to ensure a safe flight, to include:
   - Launch angle limits - constraints on launch angles (e.g. nominal azimuth and elevation angles, and actual azimuth and elevation settings).
   - Weather constraints - constraints on allowable launch time weather, to include maximum wind, wind variability limits, visibility, and lightning potential.
   - Wind weighting procedures, in accordance with **Attachment 4**.
   - Ship surveillance procedures, as required, for near coast ship traffic, as agreed upon with the U.S. Coast Guard.
   - Air traffic control coordination procedures, worked out with the applicable FAA regional office or Air Route Traffic Control Center (ARTCC).
   - Collision Avoidance (COLA) procedures, if required.
   - Launch vehicle recovery procedures.

5) Flight Safety Plan.

   An applicant shall describe the measures used to conduct a proposed flight safely. A flight safety plan shall be used by launch personnel as a working document during launch operations, and shall include:
   - Maximum impact range area.

- Predicted nominal impacts.
- Impact dispersions.
- Impact hazard area.
- Aircraft and Ship hazard areas.
- Launch angle limits.
- Weather constraints.
- The measurement of winds.
- Responsibilities of flight safety personnel.
- Other items necessary for launch personnel.

6) Post-Launch Report.

A licensee shall provide to the FAA a post-launch report within 30 days of flight, to include:

- Actual impact location of all impacting stages/ejected components.
- A comparison of actual versus predicted nominal performance.
- Investigation results of a launch anomaly.

ATTACHMENT #1

Trajectory Analysis

GENERAL

1. An applicant shall conduct a trajectory analysis in accordance with the definitions, input, methodology, and output prescribed below.

2. The launch vehicle's ability to fly a perfect trajectory (i.e. zero error) is undermined by quantifiable perturbing forces that cause drag impact point offsets in the uprange, downrange, and cross-range directions. The perturbing forces are categorized by their individual sources and are normally associated with launch vehicle performance variations. Hence, each source is referred to as a key dispersion parameter. These key parameters are crucial to determining the three-sigma vehicle dispersion, defined below.

DEFINITIONS

1. Crossrange - The distance measured along a line whose direction is either 90 degrees clockwise (right crossrange) or 90 degrees counter-clockwise (left crossrange) to the projection of the launch vehicle velocity vector azimuth into a horizontal plane. This plane is tangent to the ellipsoidal earth model at the intersection point of a line and the earth's surface where the line is normal with the earth's surface and passes through the launch vehicle's current earth centered position.

2. Downrange - The distance measured along a line whose direction is parallel to the projection of the launch vehicle velocity vector azimuth into a horizontal plane. This plane is tangent to the ellipsoidal earth model at the intersection point of a line and the earth's surface where the line is normal with the earth's surface and passes through the launch vehicle's current earth centered position.

3. Drag Impact Point (DIP) - The drag impact point is defined at the intersection of a launch vehicle stage's or other impacting component's predicted ballistic trajectory with the earth's surface. This method of trajectory prediction includes the effects of atmospheric influences as a function of drag forces and Mach number.

4. Maximum Range Trajectory - The maximum range trajectory is an optimized nominal "type" trajectory extended to fuel exhaustion of each stage. This trajectory is computed at the flight elevation angle that produces the maximum downrange DIP at any given time after lift-off.

5. Nominal Trajectory - The nominal trajectory is the trajectory that the vehicle will fly if all vehicle aerodynamic parameters are exactly as expected, if all vehicle internal

and external systems perform exactly as planned, and there are no external perturbing influences (e.g. winds) other than atmospheric drag and gravity.

6. Normal Flight - Normal flight refers to all possible trajectories of a properly performing launch vehicle whose Drag Impact Point (DIP) location does not deviate from the nominal location more than three standard deviations (three-sigma) in the uprange, downrange, left-crossrange, or right crossrange directions.

7. Three-Sigma Vehicle Dispersion - Three-sigma dispersions define the expected uprange, downrange, and crossrange limits of normality for the launch vehicle. Impact dispersion of a launch vehicle is the statistical deviation of the actual impact point from the predicted nominal impact point. It is used to calculate the probability of impacting within a given distance of the nominal impact point. The dispersion distance is in terms of a standard deviation value (referred to as sigma). Theoretical dispersion is used when insufficient launches have occurred to adequately define flight dispersion with a high degree of confidence, and is determined by varying each of the parameters that affect impact range or azimuth. Each parameter is varied by its three sigma value, and then used to determine its individual effect on the vehicle's impact dispersion. The square root of the sum of the squares of the individual impact dispersions provides the total 3 sigma impact dispersion of the vehicle. Assuming a normal distribution, this represents the area in which 99.7% of all impacts will occur.

8. Uprange - The distance measured along a line whose direction is 180 degrees to the projection of the launch vehicle velocity vector azimuth into a horizontal plane. This plane is tangent to the ellipsoidal earth model at the intersection point of a line and the earth's surface where the line is normal with the earth's surface and passes through the launch vehicle's current earth centered position.

INPUT

The trajectory analysis requires inputs necessary to produce a 6-degree-of-freedom trajectory. Trajectory data computed with commercially available software products shall consider the following parameters in the trajectory computations:

1. Launcher Data: geodetic latitude and longitude; height above sea level; position (location) errors; and launch azimuth and elevation.

2. Reference Ellipsoidal Earth Model: name, semi-major axis, semi-minor axis, eccentricity, flattening parameter, gravitational parameter, rotation angular velocity, gravitational harmonic constants (J2,J3,J4), and mass of earth.

3. Vehicle characteristics (per stage): nozzle exit area, distance from nose-tip to nozzle exit, reference drag area, reference diameter, thrust vs. time, propellant weight vs. time, coefficient of drag vs. mach number, distance from nose-tip to center of gravity vs. time, yaw moment of inertia vs. time, pitch moment of inertia vs. time, pitch damping coefficient vs. mach number, aerodynamic damping coefficient vs. mach

number, normal force coefficient vs. mach number, distance from nose-tip to center of pressure vs. mach number, axial force coefficient vs. mach number, roll rate vs. time, static stability margin vs. time, gross mass, burnout mass, vacuum thrust, vacuum $I_{SP,}$ stage dimensions, weight of each spent stage.

4. Launch events: stage ignition times, stage burn times, and stage separation times, referenced to ignition time of first stage (T-0).

5. Atmosphere: density vs. altitude, pressure vs. altitude, speed of sound vs. altitude, temperature vs. altitude

6. Wind errors: error in measurement of wind direction vs. altitude and wind magnitude vs. altitude, wind forecast error (i.e. error due to time delay from wind measurement to launch).

METHODOLOGY - Nominal No-Wind Trajectory

To generate the nominal no-wind trajectory, the following procedure is acceptable.

1. Identify individual launch vehicle key performance parameters. Typical key performance parameters include thrust, weight, aerodynamic drag, staging times, stage separation-force, launcher height, launcher elevation, and launcher azimuth. The applicant is responsible for including all key performance parameters in the trajectory analysis computations.

2. Run a no-wind trajectory simulation using a 6-Degree-Of-Freedom (6-DOF) model. Generally, the six degrees-of-freedom are launch vehicle position translation along three axes of an orthogonal earth centered coordinate system, and launch vehicle orientation in roll, pitch and yaw. The 6-DOF program computes the translations and orientations in response to internal and external forces and moments. The following assumptions may be incorporated in the 6-DOF program with accompanying justification: (1) the air-frame is a rigid body, (2) the air-frame has a plane of symmetry coinciding with the vertical plane of reference, (3) the vehicle has aerodynamic symmetry in roll (4) the air-frame has six degrees-of-freedom, and (5) the aerodynamic forces and moments are assumed to be functions of mach number and are linear with small flow incidence angles of attack.

3. At each staging event time tabulate the geodetic latitude and longitude of the nominal DIP location for each impacting vehicle stage or component.

METHODOLOGY - Maximum Range Trajectory

This trajectory provides the maximum possible downrange DIP for each launch vehicle stage or impacting body. The applicant shall use the nominal trajectory methodology above modified to optimize the launch vehicle performance and flight profile to create the desired conditions for maximum downrange DIP. For liquid systems, this shall include a fuel exhaustion trajectory.

METHODOLOGY - Trajectory Dispersions

To generate the three-sigma dispersions in terms of DIP distance from the nominal DIP location, the following procedure is suggested.

1. Identify individual key dispersion parameters that contribute to the dispersion of the vehicle's DIP. These should include thrust misalignment, thrust variation, weight variation, fin misalignment, impulse variation, aerodynamic drag variation, staging timing variation, stage separation-force variation, uncompensated wind, launcher elevation error, launcher azimuth error, launcher tip-off, and launcher location error. The applicant is responsible for including all key dispersion parameters in the trajectory analysis computations.

2. Estimate the values of the three-sigma variations for each of the individual key parameters.

3. Run a series of no-wind trajectory simulations using a 6-Degree-Of-Freedom (6-DOF) model where only one three-sigma value of a key parameter is introduced into each trajectory simulation.

4. For a one stage launch vehicle, tabulate the individual three-sigma downrange, uprange, left-crossrange, and right-crossrange DIP deviations, measured from the nominal DIP location, accumulated by each of the key parameters over the entire stage action-time. Calculate the square root of the sum of the squares (RSS) of all the individual DIP deviations in the downrange, uprange, left-crossrange, and right-crossrange directions. The RSS value, at each staging time, for each direction is the three-sigma downrange, uprange, and crossrange DIP deviation.

5. For a two stage vehicle, impact dispersions can be determined using the following two step process:

    a. Compute first stage impacts resulting from first stage deviations and root sum square their difference from the nominal first stage impact to determine first stage dispersion.
    b. Compute second stage dispersion by:

(1) Simulating first stage deviations with nominal second stage performance to determine the difference from nominal second stage impact.
(2) Simulating nominal first stage performance and injecting second stage performance deviations to determine the difference from nominal second stage impact.
(3) Root sum square the impact deviations determined in 1 and 2 above to determine second stage dispersion.

Note: Applicants wishing to use a different procedure (such as a Monte Carlo trajectory analysis), shall provide a description of the method used to generate the nominal trajectory, maximum range trajectory, and three-sigma dispersions and the rationale for why it produces equivalent results.

OUTPUT

The data items listed below are the minimum requirements. Additional requirements may be established in the application review process.

1. The applicant shall provide a brief discussion of the process that was used for the trajectory simulation.

2. The applicant shall provide a brief discussion of all assumptions and procedures used in deriving each of the key parameters and their standard deviations.

3. Launch point origin data: name, geodetic latitude (+N), longitude (+E), geodetic height, launch azimuth measured clockwise from True North.

4. Name of reference ellipsoid earth model: If other than WGS-84, provide the following additional data: semi-major axis, semi-minor axis, eccentricity, flattening parameter, gravitational parameter, rotation angular velocity, gravitational harmonic constants (J2, J3, J4), and mass of earth.

5. The applicant may find it necessary to convert latitude and longitude coordinates between different ellipsoidal earth models in order to complete the trajectory analysis. If a conversion is necessary, the applicant shall provide the equations for geodetic datum conversions and a sample calculation for converting the geodetic latitude and longitude coordinates between the models employed.

6. The applicant shall provide a tabular listing of each performance and key parameter used in the trajectory computations, each key parameter's plus/minus three-sigma variation, and the one-, two-, or three-sigma DIP displacement from the nominal no-wind DIP caused by each key parameter.

7. Vehicle performance data. The applicant shall provide a graphical and tabular presentation of the nominal and maximum range trajectories from launch until impact of the final stage. Time steps for the graphical presentation shall be at even intervals, not to exceed one second increments during thrusting flight, and for times corresponding to ignition, thrust termination or burnout, and separation of each stage (or impacting body). If stage action times are less than four seconds, time intervals should be reduced to 0.2 seconds or less. The graphical presentation shall depict the total launch vehicle velocity vs. time, present-position ground-range vs. time, and altitude above the reference ellipsoid vs. time. The tabular presentation shall provide the time, altitude above the reference ellipsoid, present position ground range, and total launch vehicle velocity for ignition, burnout, separation, booster apogee, and booster impact of each stage (or impacting body).

8. Vehicle impact data. The applicant shall provide a graphical and tabular presentation of the launch vehicle's DIP for the nominal trajectory, the maximum impact range boundary, and the three-sigma drag impact point dispersion areas. The graphical presentation shall include an overall depiction showing: (1) the DIP for the nominal trajectory, (2) a circle whose radius is equal to the farthest downrange impact point range from the maximum range trajectory, and (3) the three-sigma drag impact dispersions for each stage (or impacting body). The tabular presentation shall include the geodetic latitude (positive North of the equator) and longitude (positive east of the Greenwich Meridian) of each point describing the nominal DIP positions, the maximum range circle, and the three-sigma impact dispersion area boundaries. The coordinates shall be rounded to the fourth decimal point. Each stage's dispersion area shall be described by a minimum of 20 coordinate pairs.

ATTACHMENT #2

Hazard areas

GENERAL

1. An applicant shall conduct analyses to define an impact hazard area, aircraft hazard areas, and ship hazard areas in accordance with the definitions, input, methodology, and output prescribed below. An applicant may also be required to conduct a collision avoidance analysis (COLA).

2. Hazard areas are created by nominal events when conducting launch operations. Access to hazard areas shall be controlled and public safety status may require monitoring. This is typically accomplished by controlling access to the area, and real-time surveillance of the area just prior to launch. The impact hazard area may not contain population, including permanent and transient population.

INPUT REQUIREMENTS

The following inputs are required to determine the hazard areas below:

1. Vehicle dispersion. The range and cross range impact dispersion information from Attachment 1.

2. Trajectory impact data: Latitude and longitude of each launch vehicle stage or ejected component nominal impact point from Attachment 1.

METHODOLOGY

1. Maximum Impact Range and Impact Hazard Area:

   a. Maximum impact range area. An applicant shall define a maximum impact range area by computing the launch vehicle's maximum range trajectory as defined in Attachment 1.
   b. Impact hazard area. An applicant shall determine the impact hazard area as depicted in Figure 2-1. The impact hazard area is composed of two circles and straight lines connecting the circles at tangent points to the circles. The first circle, with origin at the launch vehicle's launch point, has a radius of 1 nautical mile. The second circle, with an origin at the nominal no wind impact point for the final launch vehicle stage, has a radius of 3 sigma as defined in Attachment 1. No populated areas are allowed inside the impact hazard area.
   c. Intermediate stages. After wind weighting on launch day, an applicant shall verify that the wind drifted impacts of intermediate stages and their 3-sigma dispersion areas are within the impact hazard area cone.

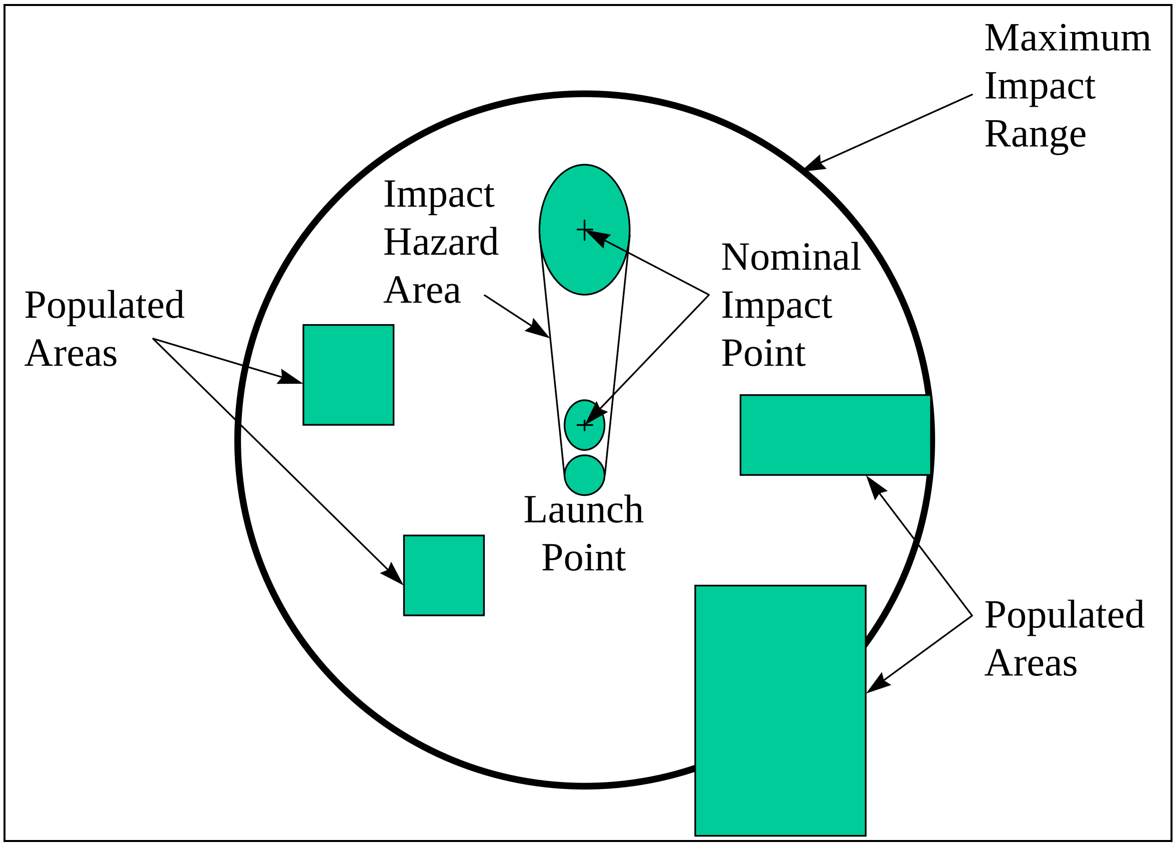

Figure 2-1. Impact Hazard Area

2. Aircraft Hazard Area:

   a. An applicant shall compute an aircraft hazard area for each impacting launch vehicle stage or component. The aircraft hazard area shall be clear of all aircraft from launch to impact of all stages.

   b. The aircraft hazard area shall be a three dimensional space from 60,000 feet to the ground, and shall encompass the 3 sigma dispersion area of each impacting launch vehicle stage or component from 60,000 feet until impact. A buffer shall be added to account for aircraft travel during launch vehicle flight to impact. The buffer shall be a minimum of aircraft speed (assume 700 miles per hour) times the launch vehicle's flight time to impact.

   c. An applicant shall establish procedures with the nearest Air Route Traffic Control Center for the issuance of a Notice to Airmen (NOTAM) prior to a launch, for the closing of air routes during the launch window, and other such measures as the Air Route Traffic Control Center deems necessary to protect public health and safety.

d. Real time coordination with the appropriate FAA center shall be made to receive a predicted verification that the hazard area is clear of all aircraft at the launch time.

3. Ship Hazard Area:

a. An applicant shall compute ship contour ellipses, with the same semi-major and semi-minor axis ratio as the launch vehicle impact dispersion, in which the hit probability of 1, 2, 5, 10, or 20 ship(s), located at the edge of the ellipse, is equal to 1×10^{-5} (see b and c below). See Figure 2-2. The size of ships will be assumed to be 120,000 square feet, unless information is available to reduce the ship size. Applicant shall establish ship contour ellipses for all launch vehicle stage or component impact areas.

b. To compute ship hit probability, an applicant shall compute the distance from the nominal impact point at which the impact probability is 1×10^{-5}. See Figure 2-3.

$$P_y = \frac{\left(\frac{|y_2 - y_1|}{\sigma_y}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(y_1/\sigma_y\right)^2}{2}\right) + 4 \cdot \exp\left[\frac{-\left(\frac{y_1 + y_2}{2\sigma_y}\right)^2}{2}\right] + \exp\left(\frac{-\left(y_2/\sigma_y\right)^2}{2}\right)\right)$$

$$P_x = \frac{\left(\frac{|x_2 - x_1|}{\sigma_x}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(\frac{x_1}{\sigma_x}\right)^2}{2}\right) + 4 \cdot \exp\left[\frac{-\left(\frac{(x_1 + x_2)}{2\sigma_x}\right)^2}{2}\right] + \exp\left(\frac{-\left(\frac{x_2}{\sigma_x}\right)^2}{2}\right)\right)$$

$$P_{si} = P_x \cdot P_y$$

where: X_1, X_2, Y_1, &Y_2 are distances from the impact point to the ship
σ_x = 1 sigma dispersion value in X direction
σ_y = 1 sigma dispersion value in Y direction
P_x = probability of hitting a ship in the X direction
P_y = probability of hitting a ship in a Y direction
P_{si} = probability of individual ship hit
P_s = Total probability of hitting ships

c. Place the ship at a constant range and cross range sigma distance and through an iterative process, increase the range until the ship hit probability equals 1×10^{-5} for the number of ships being calculated. This process shall be repeated for each ship contour line.

d. An applicant shall complete an agreement with the local U.S. Coast Guard district to establish procedures for the issuance of a Notice to Mariners prior to a launch and other such measures as the Coast Guard deems necessary to protect public health and safety.

e. Unless an applicant can demonstrate that the ship density in a particular region is low enough to assure that the number of ships located inside the ship contour ellipses are less than the maximum ship limit for each contour, during prelaunch operations, the applicant shall monitor ship locations to assure that the number of ships located inside the ship contour ellipses are less than the maximum ship limit for each contour.

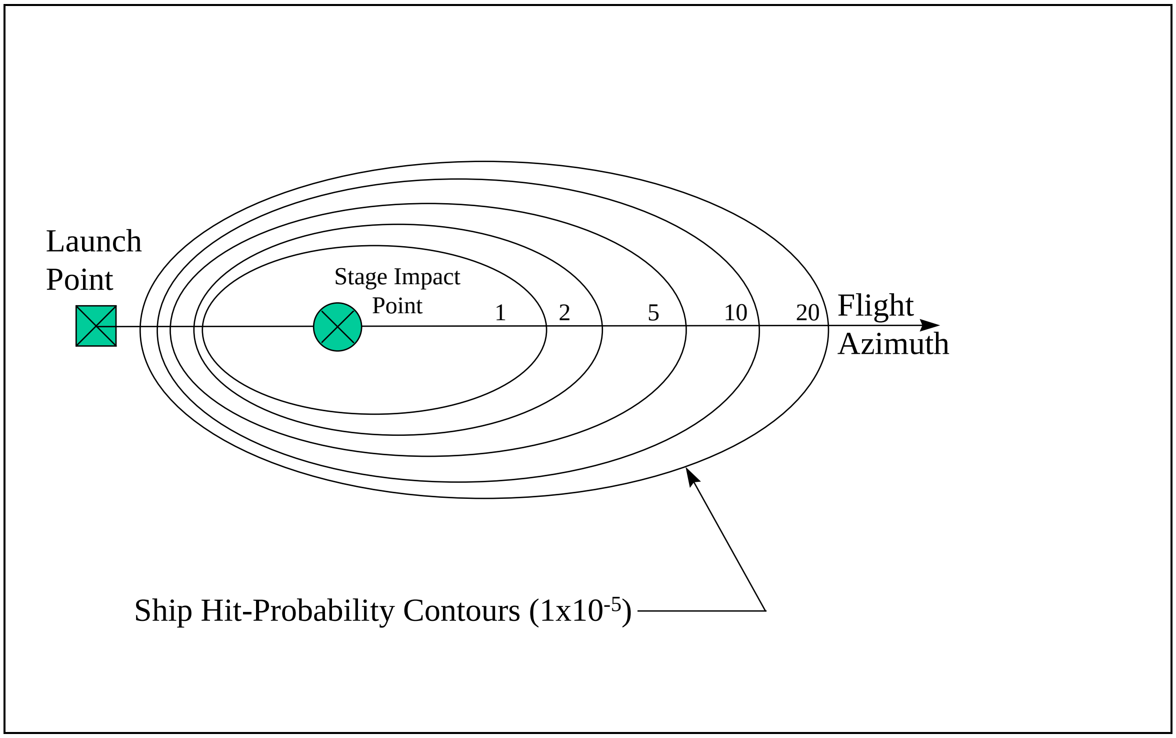

Figure 2-2. Ship Impact Contours

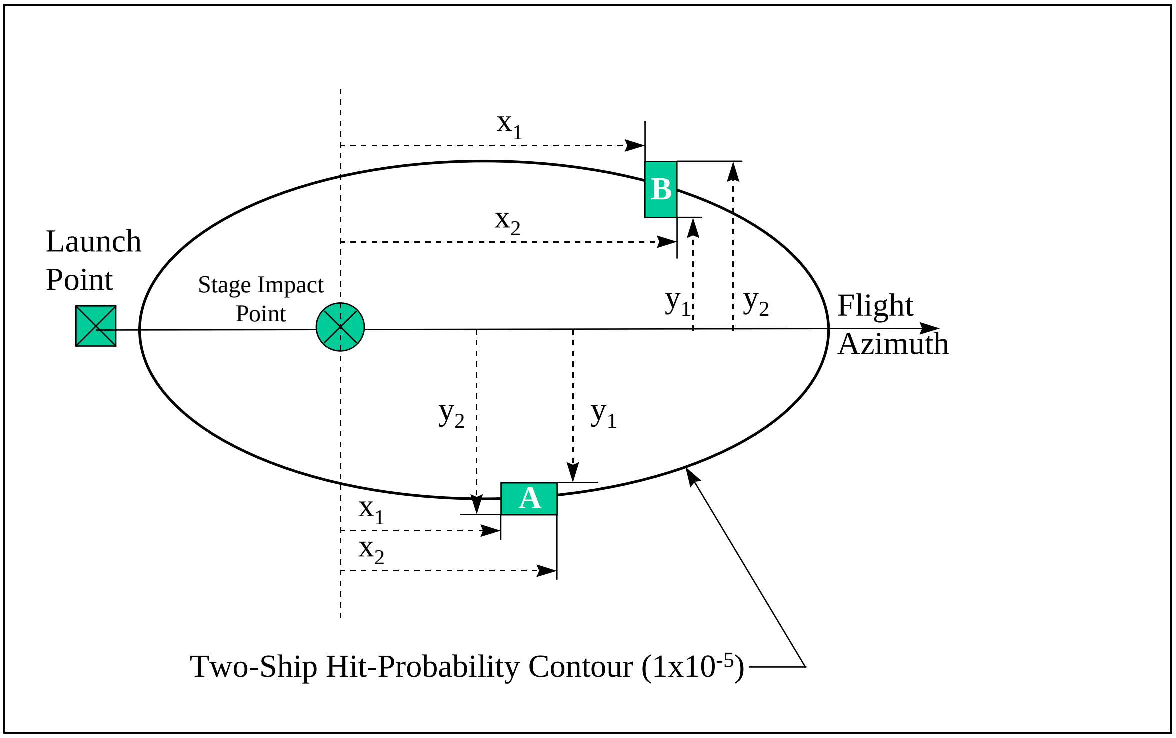

Figure 2-3. Ship Impact Computations

4. Collision Avoidance Analysis (COLA):

   If the performance of the applicant's launch vehicle is sufficient to potentially endanger manned or mannable objects in earth orbit, the FAA will work with the applicant to conduct a collision avoidance analysis (COLA).

OUTPUT

For each of the analyses defined above, the applicant shall document the methodology used, the source of input data, and a sample calculation. The resulting hazard areas shall also be documented. Each hazard area shall be presented graphically displaying the centroid of ellipses and lengths of semi-major and semi-minor axes. The presentation of the maximum impact range area and impact hazard area shall include geographical features such as buildings, cities/towns, roads, etc.

ATTACHMENT #3

Risk Analyses

GENERAL

1. An applicant shall determine the casualty expectation risk for all populated areas outside the impact hazard area in accordance with the definitions, input, methodology, and output prescribed below. Refer to Figure 3-1.

2. As part of the casualty expectation risk calculation, an applicant shall determine the impact probability of hitting populated areas.

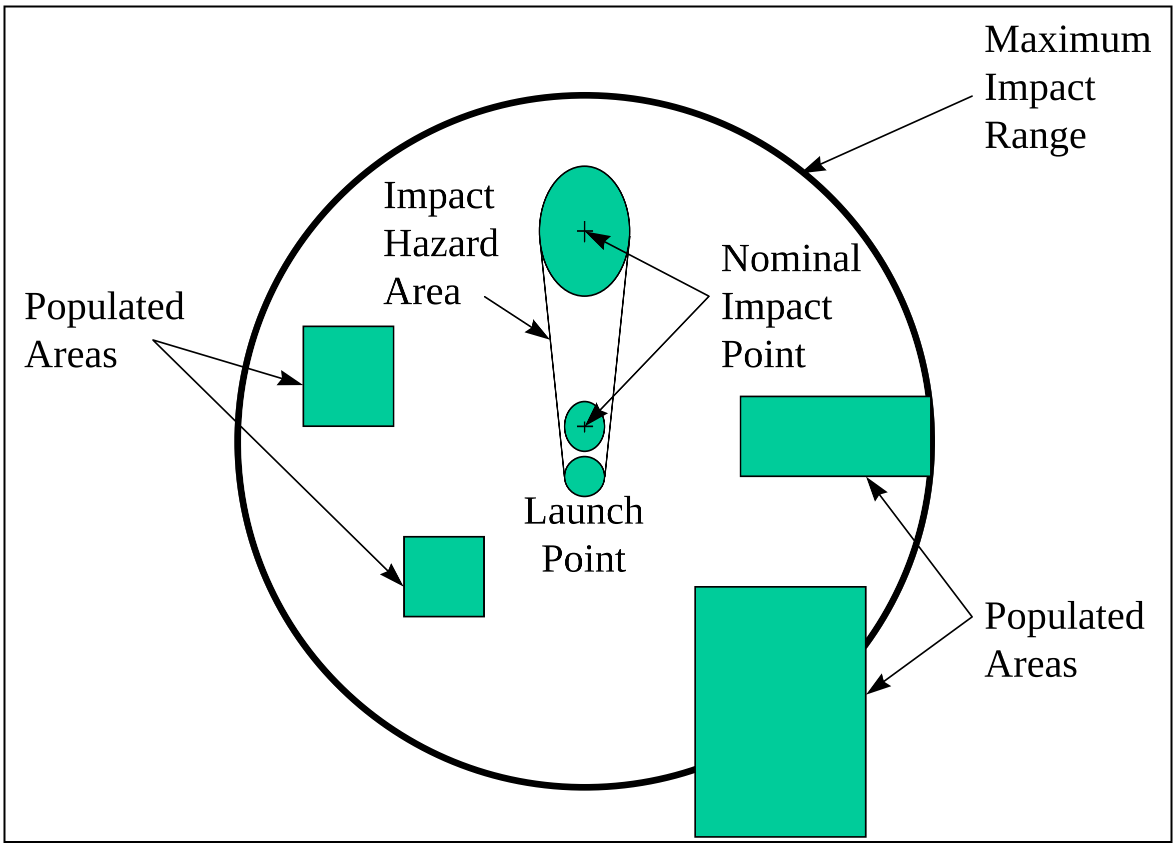

Figure 3-1. Populated Areas

INPUT

The following inputs are required to complete the risk analyses.

1. Vehicle failure data: The applicant shall use a probability of failure (P_f) = 0.5. Given a failure, the applicant shall use a probability of occurrence (P_o) of launch vehicle impact outside the impact hazard area of 0.15.

2. Vehicle dispersion. The range and cross range impact dispersion information from Attachment 1.

3. Trajectory impact data: Latitude and longitude of each launch vehicle stage or ejected components nominal impact point from Attachment 1.

4. Lethal Area: The lethal area produced by both nominal debris and failure debris is required. For the lethal area of an inert suborbital launch vehicle, an applicant may use the launch vehicle length plus 2 ft. times the largest vehicle diameter plus 2 ft. for nominal debris. For a vehicle failure, the applicant shall use the vehicle length times the largest vehicle diameter multiplied by 10. The safety factor of 10 is to account for a one foot radius applied about each piece produced from vehicle breakup.

5. Population Data: The total population within a populated area (N) and the total landmass area within the populated area (A) is required. Population data may be obtained as follows:
   a. Launch area - U.S. Census data is available at the census block group level.
   b. Downrange area - World population data is available from:

   Carbon Dioxide Information Analysis Center (CDIAC)
   Oak Ridge National Laboratory
   Oak Ridge, TN 37830-6335
   Database - Global Population Distribution (1990), Terrestrial Area and Country Name Information on a One by One Degree Grid Cell Basis (DB1016 (8-1996)

METHODOLOGY

1. An applicant shall depict the maximum impact range area and the impact hazard area on a chart that shows public areas. No public areas are allowed inside the impact hazard area.

2. Casualty Expectancy (E_C). For populated public areas between the impact hazard area and maximum impact range boundary, an applicant shall compute the casualty expectation (E_C) by solving the following equation for each populated area exposed and for each piece of debris:

   Casualty Expectation $E_C = \sum [P_i \bullet A_L \bullet P_d]$

   Where: P_i is the probability of impact for each populated area;
   A_L is the lethal area of the debris;
   P_d is population density of the populated area.

   a. Compute the probability of impact inside the populated area by:

   $$P_i = P_f \bullet P_o \bullet {}^{A_P}\!/_{A_{O3\sigma}}$$

where P_f is the probability of failure;
P_o is the probability of occurrence (0.15);
A_P is the area of the populated area;
$A_{O3\sigma}$ is the area inside the circle defined by maximum range radius, minus the area inside the impact hazard area

b. An applicant may subdivide a computation sector that contains a sparsely populated area and densely populated area by first computing the dense area. The next step is to subtract the dense area from the total sector area and then compute the E_C from the remaining population and the remaining area as a subsector.

c. The result of the casualty expectation must be no greater than 30×10^{-6}. If the result is greater, the proposed launch is unacceptable.

OUTPUT

For each of the risk analysis defined above, the applicant shall document the methodology used, the source of input data, a calculation sample for each analysis and the results of the mission E_C and land impact probability.

ATTACHMENT #4

Wind weighting

GENERAL

1. A wind weighting procedure shall be conducted in accordance with the following specified definitions, input, methodology, and output.

2. As part of the launch countdown process, a wind weighting analysis is used to predict the wind effect on impact point displacement during the thrusting phases of flight as well as the ballistic phase of each launch vehicle stage until impact.

3. The wind weighting system produces solution errors which are a function of the method used to measure the winds, the method used to compute the effects of winds, and the frequency of wind measurements. The resulting sum of these error components shall be no greater than those used as the wind error component in the launch vehicle dispersion analysis defined in Attachment 1.

4. The procedures must consider parachute recovery, if applicable. The applicant may wind weight for a parachute impact or for a ballistic impact of the final stage. If a ballistic impact method is used for wind weighting, the applicant shall perform a wind drift analysis to determine the parachute impact point.

5. The wind weighting procedures shall list needed assets, such as a wind tower, balloons, a GPS system, and a 6 DOF trajectory program.

DEFINITIONS

1. Ballistic Wind – A constant wind value acting from the ground to the top of the effective atmosphere that would produce the same effect on a trajectory of an unguided suborbital launch vehicle as the actual winds (direction and magnitude) encountered in flight.

2. Impact Point Displacement - A distance measured from the predicted, nominal, no-wind impact point to the impact point which is produced by the unguided suborbital launch vehicle's flight through winds.

3. Wind Weighting - A technique used to predict launcher azimuth and elevation settings for unguided launch vehicles such that a rocket's flight through a forecasted wind field will produce the predicted nominal drag impact point for the final launch vehicle stage.

INPUT

1. The wind weighting analysis below requires a six degree-of-freedom (DOF) computer program that can target an impact point. The minimum data requirements for the 6 DOF computer simulations shall be those sufficient to perform an analysis with winds.

2. The wind weighting analysis below requires inputs necessary to produce a 6-degree-of-freedom trajectory. Trajectory data computed with commercially available software products should consider the parameters used in the trajectory computations in Attachment 1. The data should also include launch day wind direction and wind magnitude vs. altitude measured to a height up to a maximum of 90,000 ft..

3. The wind weighting analysis below requires a computer program or method of editing wind data, recording the time the data was obtained, and recording the balloon number for each wind altitude layer.

METHODOLOGY

On launch day, the wind weighting processes shall include:

1. Using a wind measuring system, such as balloons with GPS, determine launch day wind velocity and direction. A wind measurement is required every 200 feet from ground level to the maximum altitude.

2. Measure winds to a “maximum altitude” not less than the altitude at vehicle burnout. If a parachute is employed, the balloon shall be sized to measure winds to the altitude at parachute deployment or 90,000 feet, whichever is less. Maximum altitude winds are required to be remeasured at least once every 6 hours, whenever a weather front passes the launch site, or whenever the top levels of a lower altitude balloon do not agree with the wind data measured by the “maximum altitude” balloon.

3. Measure winds to a “medium altitude” not less than 50,000 ft.. This measurement is required every 4 hours, whenever a weather front passes the launch site, or whenever the top levels of a lower altitude balloon do not agree with the wind data measured by the “medium altitude” balloon.

4. Measure winds to a “low altitude” not less than 5000 ft. This measurement is required twice within 30 minutes of launch.

5. Using the six DOF computer program with launch day winds and targeting for final stage impact, compute the launcher elevation and azimuth settings to achieve the nominal no wind impact point.

6. Using the trajectory produced in 5 above, compute the impact point which results from wind drift for all intermediate stages/ejected components. This is accomplished by performing a trajectory simulation, with the launch angles determined in 5 above, through the wind field until the applicable stage burnout.

7. If a parachute is used for the final or any intermediate stage/component, a trajectory simulation shall predict the wind drifted impact point. The change in aerodynamics at parachute ejection shall be modeled in the simulation. This simulation is in addition to any simulation of spent stages without parachutes. The requirement is to predict the impact location, for all impacting bodies, which results from flight through the winds.

8. Verify launcher settings are within established limits. The launcher adjustment due to wind weighting shall not exceed:
    a. ± 5^o for elevation, not to exceed 86^o, and
    b. ± 30^o for azimuth.

9. Verify that the actual launcher settings are the same as computed by the wind weighting program.

10. Monitor and verify wind variations and maximum wind limits are within launch constraints.

<u>OUTPUT</u>

1. An applicant's wind weighting procedure shall determine the following:
    a. Launcher azimuth and elevation settings which are derived from a trajectory simulation through launch day winds that achieve a final launch vehicle stage impact at the nominal no wind impact point.
    b. Wind drifted impact locations for each stage/ejected component.

2. Output data from wind weighting operations may be required in printed, plotted, or computer medium format for each impacting body. The output shall include:

    a. Wind data for each balloon.
    b. The results of each computer run made on each wind weighting balloon. Data includes but is not limited to, launcher settings, and impact locations for each stage or component.
    c. Anemometer data, recorded
    d. Final launcher settings, recorded.

3. In the applicant's application, provide a description of operational wind weighting methods including method and schedule of determining wind speed and wind direction for each altitude layer, and provide qualifications of the lead wind weighting person and each member of the team.