Federal Aviation
Administration

# FAA SAFETY MANAGEMENT

# SAFETY RISK MANAGEMENT GUIDANCE: APPLYING THE ACCEPTABLE LEVEL OF RISK (ALR) APPROACH TO COMMERCIAL SPACE MISSIONS IN THE NATIONAL AIRSPACE SYSTEM (NAS)

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# Federal Aviation Administration Safety Risk Management Guidance: Applying the Acceptable Level of Risk (ALR) Approach to Commercial Space Missions in the National Airspace System (NAS)

## AVP-300-009

## Purpose

The purpose of this document is to provide guidance on applying the Acceptable Level of Risk (ALR) approach to commercial space missions' in the National Airspace System (NAS) conducting Safety Risk Management (SRM).

## Scope

The FAA Safety Management System (SMS) Executive Council approved the use of the ALR approach for various commercial space missions' traversing the National Airspace System (NAS). The ALR approach and the missions to which the ALR approach can be applied are identified and described in this document. In general, commercial space missions include any mission that is overseen by the FAA Office of Commercial Space (AST).

**Approval:** Paula Martinez

FAA SMS Committee Chair

# REVISION HISTORY

| Revision Number | Description of Change | Effective Date |
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| 0 | Original Document (Version 1.0) | April 27, 2018 |
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# Background of the ALR Approach

The National Airspace System (NAS) is dynamic, evolving in ways that often affect aviation safety. The expansion of commercial space operations increases the complexity of the system and, like every other operation in the NAS, requires the Federal Aviation Administration's (FAA) continued examination to ensure that safety risk is appropriately managed. Accommodating new entrants into the NAS, while maintaining the accepted level of safety, is a challenge and has led the FAA to take a closer look at its Safety Management Systems (SMS) and safety risk acceptance criteria.

Aviation and space safety methods and standards have developed over time through the work of different parties operating under different circumstances. The FAA Office of Commercial Space Transportation (AST) and the Air Traffic Organization (ATO) have separately established public safety risk acceptance criteria that are expressed using different terminology and numerical values. The ATO proposed using the Acceptable Level of Risk (ALR) approach to temporarily bridge the differences and accommodate the growth of commercial space launches in the NAS.

The FAA SMS Executive Council established the ALR Tactical Team in January 2017 under the Safety Data and Analysis Team (SDAT) to review and, if necessary, refine ATO's proposed ALR approach for commercial space launches with fly-back operations and consider application of the ALR approach to all known commercial space launch and reentry mission types. In June 2017, the FAA SMS Executive Council approved the ALR approach as refined by the ALR Tactical Team for application to commercial space launches with fly-backs and in December 2017, the FAA SMS Executive Council approved additional refinements to the ALR approach and the mission type applicability recommended by the ALR Tactical Team.

# Overview of the ALR Approach

Conceptually, the ALR approach is a way to address air traffic operations that interact with commercial space operations and do not meet existing ATO safety standards. The ATO's current safety standard is a relatively simple standard of less than $1\times10^{-9}$ probability of a catastrophic event. Conversely, the ALR approach has criteria that are more complex and requires several conditions to ensure that the proposed level of acceptability is met.

The FAA uses Aircraft Hazard Areas (AHAs) during launch and reentry operations to segregate launch vehicles from other NAS operations. An AHA is a region of airspace in which an occupant of an aircraft would be exposed to a risk of becoming a casualty from an off nominal event, including falling launch vehicle debris, in excess of the limits under Title 14 Code of Federal Regulations (CFR) Chapter III. For a given commercial launch or reentry, the location, extent, and duration of an AHA for commercial launches and reentries are computed to meet the 14 CFR § 417 requirement of $1\times10^{-6}$ probability of individual casualty (fatality or serious injury) per aircraft per launch. As they were developed separately by different parties under different circumstances, the ATO's $1\times10^{-9}$ safety standard and the AST $1\times10^{-6}$ regulation are not directly comparable. Table 1 summarizes these differences.

**Table 1: Mapping of AST and ATO Risk Criteria**

| Element | AST | ATO |
|---|---|---|
| Safety Standard | $1 \times 10^{-6}$ for casualty-producing collisions | $1 \times 10^{-9}$ for catastrophic hazards |
| Period | Per aircraft, per launch/fly-back operation | Per affected flight hour or air traffic control operation |
| Consequence | Casualty of an aircraft occupant | Fatality of an aircraft occupant |

The AHA is based on risk contours. Risk contours are composed of isolines where the calculated risk to an individual on a given aircraft is constant along each line. The isolines demarcate regions surrounding a launch trajectory that define per-aircraft probabilities of impact with debris capable of causing a casualty to an occupant (see Figure 1).[1]

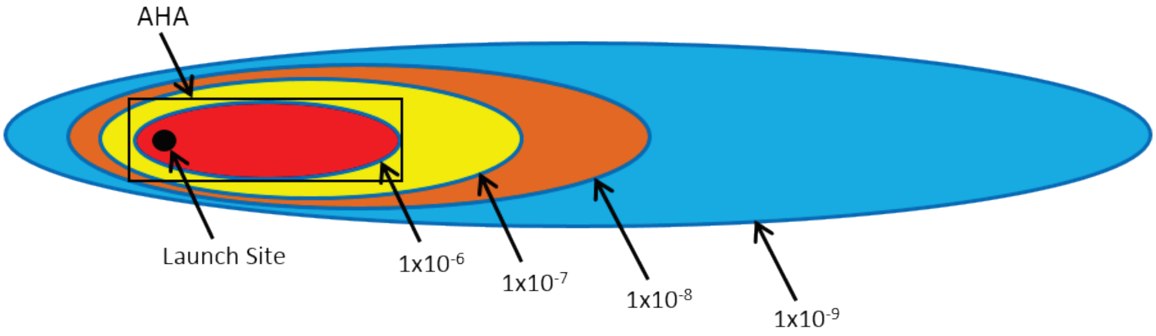

**Figure 1: Notional Risk Contours/Isolines and AHA**

The ALR approach defines an alternative method for accepting individual and collective catastrophic risk to air traffic interacting with commercial space launches. It permits the exposure of individual aircraft to higher risk, but limits the total number of aircraft exposed until NAS infrastructure, policies, and procedures are updated to fully integrate these launches.

The ALR approach is a temporary solution to allow commercial space operations in the NAS and would be employed only when the individual risk of a given hazard does not meet the existing ATO standard. In accordance with FAA Order 8040.4, *Safety Risk Management Policy*, risk can be accepted for a period of time while mitigations are developed and implemented. Various mitigations are planned for NAS implementation in the next several years, and are expected to reduce risk such that the ATO standard would be met without the ALR approach.

The ALR approach has two primary components related to acceptable level of risk—individual risk and collective risk criteria.

## Individual Risk

Individual risk is the probability that at least one passenger on an exposed flight experiences a fatality because of a space launch. The upper limit of the individual risk of the ALR approach is $1 \times 10^{-7}$ probability of fatality per ATC operation during a launch. This means that an acceptable

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[1] More information regarding AHAs can be found in 14 CFR § 417, FAA Order 7400.2, *Procedures for Handling Airspace Matters*, and *Flight Safety, Range Safety Office Training Manual*, National Aeronautics and Space Administration (NASA)/Wallops Flight Facility.

airspace must ensure that exposed aircraft do not experience a probability that at least one passenger experiences a fatality due to a space launch greater than $1 \times 10^{-7}$. This limit is determined primarily based on what is practical for short-term application. It was determined that the mitigations that would likely bring down the risk to the level required by the existing ATO standard of $1 \times 10^{-9}$ would take a number of years to develop and implement. Therefore, the ALR approach is employed when the individual risk from commercial space launches ranges between $1 \times 10^{-9}$ and $1 \times 10^{-7}$. If the individual risk to exposed aircraft during a launch is below $1 \times 10^{-9}$, it meets ATO's existing standard and does not require the application of the ALR approach. On the other hand, if the risk of fatality per exposed flight exceeds $1 \times 10^{-7}$, it does not meet the ALR approach's individual upper limit requirement, and hence, the ALR approach cannot be employed.

### Collective Risk

The collective risk criterion is the expected value of the number of fatal accidents due to space launch debris in the affected regions of the NAS over a specified period of time. As a result of exposing a "small" number of flights to a risk level higher than the ATO's existing standard of $1 \times 10^{-9}$, the collective risk ensures with a relatively high confidence that no fatal accident will occur in an average person's lifetime. With a maximum individual risk of $1 \times 10^{-7}$ probability of fatality per ATC operation per launch, the FAA seeks to limit the number of ATC operations exposed to debris risk such that there is 95% confidence that no fatal accident will occur in a typical lifetime of 80 years. By implementing a collective risk limit in addition to an individual limit, the FAA can confine the exposure rate of a higher individual risk to a smaller number of aircraft flying in the NAS.

## Parameters, Conditions, & Restrictions of the ALR Approach

To use the ALR approach, the following parameters, conditions, and restrictions must be applied:[2]

- For the purpose of the ALR approach, the method used to compute risk contours must satisfy the following conditions:
  - Continuous presence of an aircraft, which would allow any flight operations (e.g., maneuvers such as circling/holding patterns, and vectoring),
  - Debris large enough that it could cause casualty, and
  - Use of the largest commercially available transport category aircraft.
- No operations are permitted in the AHA.
- No operational restrictions for all flights in the region corresponding to risk contours of less than $1 \times 10^{-7}$ (outside the $1 \times 10^{-7}$ contour).
- To fly in the region between the $1 \times 10^{-6}$ and the $1 \times 10^{-7}$ risk contours, there are two restrictions:
  - No hovering or circling maneuvers are permitted.
  - Flight routes must have an angular difference, relative to the launch vehicle path, of at least 30 degrees (routes with an angular difference less than 30 degrees are closed). When the 30-degree angular restriction cannot be applied because of the geometry of the launch path, AST will add an

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[2] Restrictions do not apply to aircraft operations supporting the launch mission.

additional area (or risk buffer) to the AHA to ensure that the $1 \times 10^{-7}$ individual risk limit of the ALR approach is met.[3]

- ATC Services will not be provided to airports that are between the $1 \times 10^{-6}$ and $1 \times 10^{-7}$ risk contours (ATC Services will be provided to airports that are outside of the $1 \times 10^{-7}$ risk contour).[4]
- Collectively no more than 6,412 exposed operations in a rolling 12 months are permitted.[5]

An *exposed operation* is any flight that passes inside the $1 \times 10^{-8}$ risk contour from launch time until the space vehicle is declared to have entered in orbit, typically 10 minutes, and, if applicable, any fly-back is complete (i.e., the reusable portion of the vehicle has landed). It is ATO's responsibility to count the number of exposed operations for each launch and maintain an annual running count of the exposed operations to ensure that the limit of 6,412 is not met. AST is responsible for providing the AHA and $1 \times 10^{-7}$ and $1 \times 10^{-8}$ risk contours to the ATO to enable the ALR approach's parameters, conditions, and restrictions to be met.

Failure to implement these specific parameters, conditions, and restrictions as part of the adoption of the ALR approach may result in risk that is not acceptable as specified in the ALR approach. Therefore, these parameters, conditions, and restrictions cannot be applied piecemeal. They all have to be applied or the ALR approach cannot be used. In addition, please note that the ALR approach's parameters, conditions, and restrictions are not the same as the safety risk mitigations/controls or safety requirements identified/developed and approved through SRM. The ALR approach's parameters, conditions, and restrictions have to be met in order to apply the ALR approach. When SRM is conducted, it is likely that additional safety risk mitigations/controls or safety requirements will be identified and approved by the appropriate management official. Any safety risk mitigations/controls or safety requirements identified/developed and approved through SRM do not supplant, nor can they conflict with the ALR approach's parameters, conditions, and restrictions.

## Applicability of the ALR Approach

When conducting SRM in accordance with FAA Order 8040.4, the ALR approach may be used as an alternative to the risk acceptance criteria described in Appendix C in FAA Order 8040.4 and the ATO's safety risk standard described in its SMS Manual. For more information regarding conducting SRM in accordance with FAA Order 8040.4, please refer to *Safety Risk Management Guidance: The 5 Step Process* and *Guidance for Coordinating Cross-LOB Safety Risk Assessments*.

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[3] The operational restriction that flight routes must have an angular difference, relative to the launch vehicle path of at least 30 degrees, can only be applied to the mission types in which the vehicle's launch path has a sufficient horizontal component (i.e., there is a component of the launch that is not perpendicular to the surface of the earth).

[4] Regardless of the ALR approach, the AHA is closed to the public.

[5] Assuming that 50 flights are exposed per launch, this equates to 128 launches per rolling 12-month period. The ALR approach's collective risk criterion was set by requiring that, with 95 percent confidence, no fatal accidents occur during an average person's lifetime (taken to be 80 years). This leads to a maximum expected rate of one fatal accident per 1,560 years due to any single hazard. This is satisfied by a limit of 128 commercial space launches per year, each exposing an average of 50 air traffic operations to an individual fatal accident rate of one in ten million (i.e., $1 \times 10^{-7}$).

The FAA SMS Executive Council approved the use of the ALR approach as described in the sections below.

## Missions Using the ALR Approach With the 30-Degree Angular Restriction

The ALR approach can be applied to the following mission types using the 30-degree angular restriction in the area between the $1 \times 10^{-6}$ and the $1 \times 10^{-7}$ risk contours:

- Launch Barge Fly-Back
- Launch Site Fly-Back
- Capsule Reentry
- Expendable Launch Without Fly-Back
- Horizontal Orbital
- Captive Carry Orbital (for the launch phase[6])

## Missions Using the ALR Approach With a Risk Buffer

The launch or reentry paths of some mission types do not have a sufficient horizontal component to apply the 30-degree angular restriction. Therefore, for these missions, AST will calculate the appropriate risk buffer (or additional area around the AHA) for each launch to ensure that the $1 \times 10^{-7}$ individual risk limit of the ALR approach is met and provide that information to the ATO to apply. No aircraft would be allowed in the risk buffer that is added to the AHA. In general, based on the knowledge the FAA has today regarding the missions, the following mission types do not allow the application of the angular restriction and thus, would require a risk buffer be added to the AHA:

- Horizontal Suborbital
- Captive Carry Suborbital (for the launch phase)
- Vertical Launch Suborbital Expendable Booster
- Vertical Launch Suborbital Reusable Booster

## Missions to Which the ALR Approach Cannot Be Applied at This Time

The ALR approach cannot be applied to the following mission types at this time either because the FAA was not able to identify the appropriate parameters, conditions, and restrictions that would allow the application of ALR (and meet the individual risk limit) or there is not enough information known about these mission types to make a determination:

- Winged Reentry
- Stratospheric Manned Balloons
- Balloon Launch
- Point-to-Point
- Tube and Rail Launchers

For descriptions and diagrams illustrating these mission types, please see Appendix A.

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[6] For captive carry missions, the launch phase is the part of the mission after the launch vehicle is released from the aircraft.

# Appendix A: Commercial Space Mission Types

The sections that follow provide descriptions and diagrams for each of the 15 mission types listed in the Applicability of the Acceptable Level of Risk (ALR) Approach section.

## Launch Barge Fly-Back

*Mission Summary.* The launch with barge fly-back mission type might consist of the following phases: liftoff, main engine cutoff, stage separation and second stage ignition, boostback burn/ reentry/soft touchdown, second stage engine cutoff and payload separation. The booster stage may separate from the second stage at an altitude between 225,000 feet to 350,000 feet, approximately 25 to 100 miles downrange from the launch site. The booster landing site is typically between 150 and 300 miles from the launch site, but it could be closer. Figure A1 depicts the launch barge fly-back mission type.

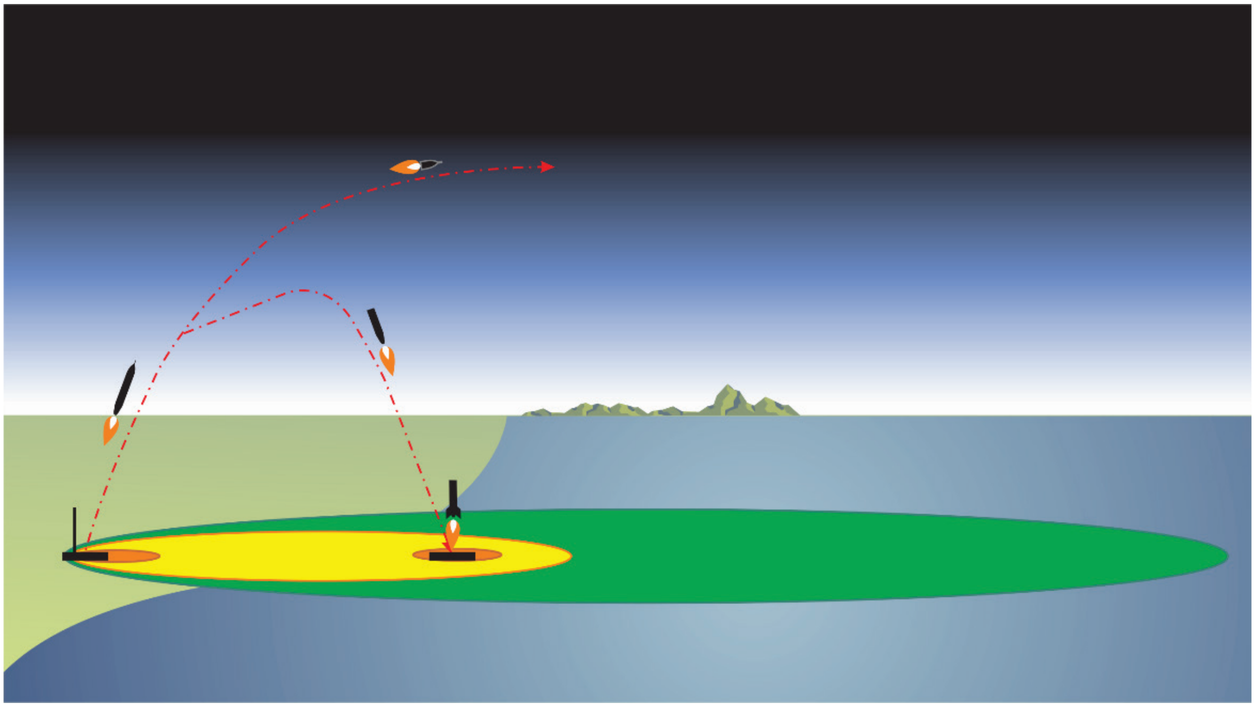

**Figure A1: Launch Barge Fly-Back**

*System Examples.* Specific examples of vehicles capable of barge fly-back include: SpaceX Falcon 9 (current system); and future concepts Falcon Heavy, the Blue Origin New Glenn, European Ariane 5, and Russian Angara.

*Risk Contours.* The dimensions of the risk contours are variable depending on the mission and vehicle, but will likely range in width from 20 to 100 miles and in length from hundreds to thousands of miles. In Figure A1, two orange ($1\times10^{-6}$) regions are depicted—one associated with the launch site and the other associated with the barge/touchdown site.

## Launch Site Fly-Back

*Mission Summary.* The launch site fly-back mission type is similar to the barge fly-back mission. Figure A2 depicts the launch site fly-back mission type.

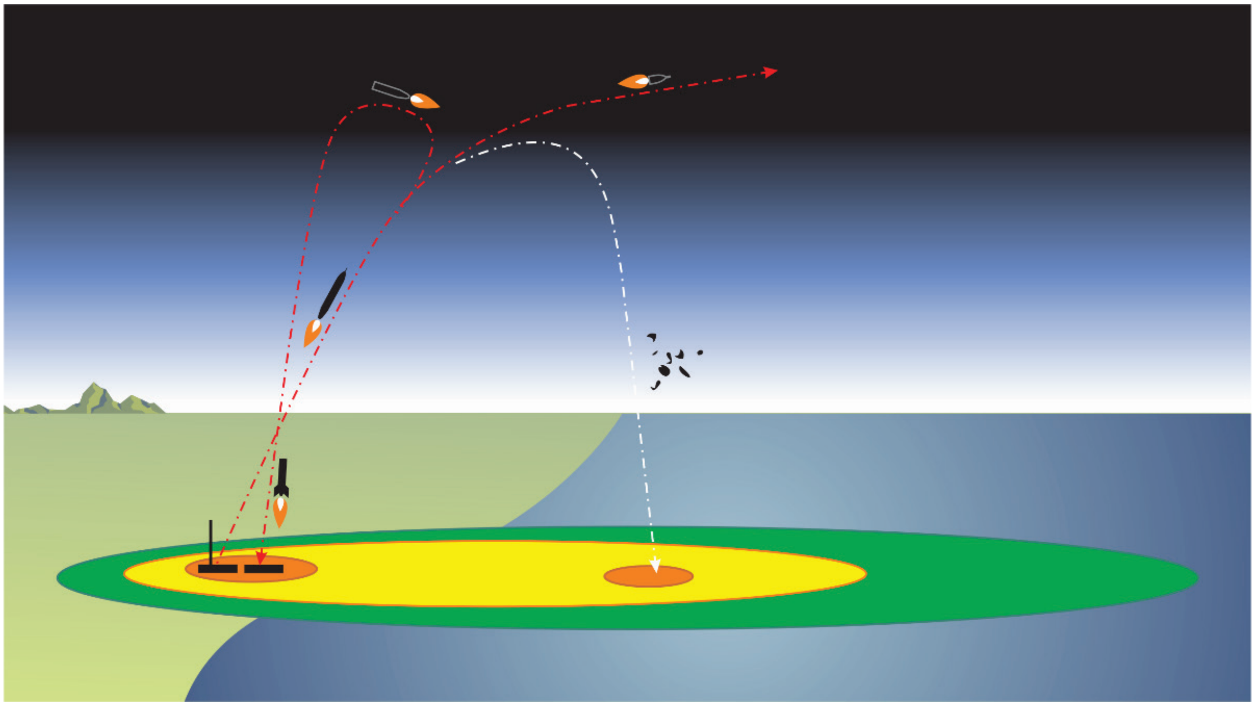

**Figure A2: Launch Site Fly-Back**

*System Examples.* Specific examples of vehicles capable of barge fly-back include: SpaceX Falcon 9 (current system); and future concepts Falcon Heavy, the European Ariane 5, and Russian Angara.

*Risk Contours.* The configuration of the risk contours differs from that of the barge fly-back mission type, since fly-back in this case is to the launch site. However, in Figure A2, the second (right most) orange region accounts for possible jettisoned items such as payload fairings.

## Capsule Reentry

*Mission Summary.* The capsule reentry mission type encompasses parachute or powered reentry vehicles. Figure A3 depicts the capsule reentry mission type.

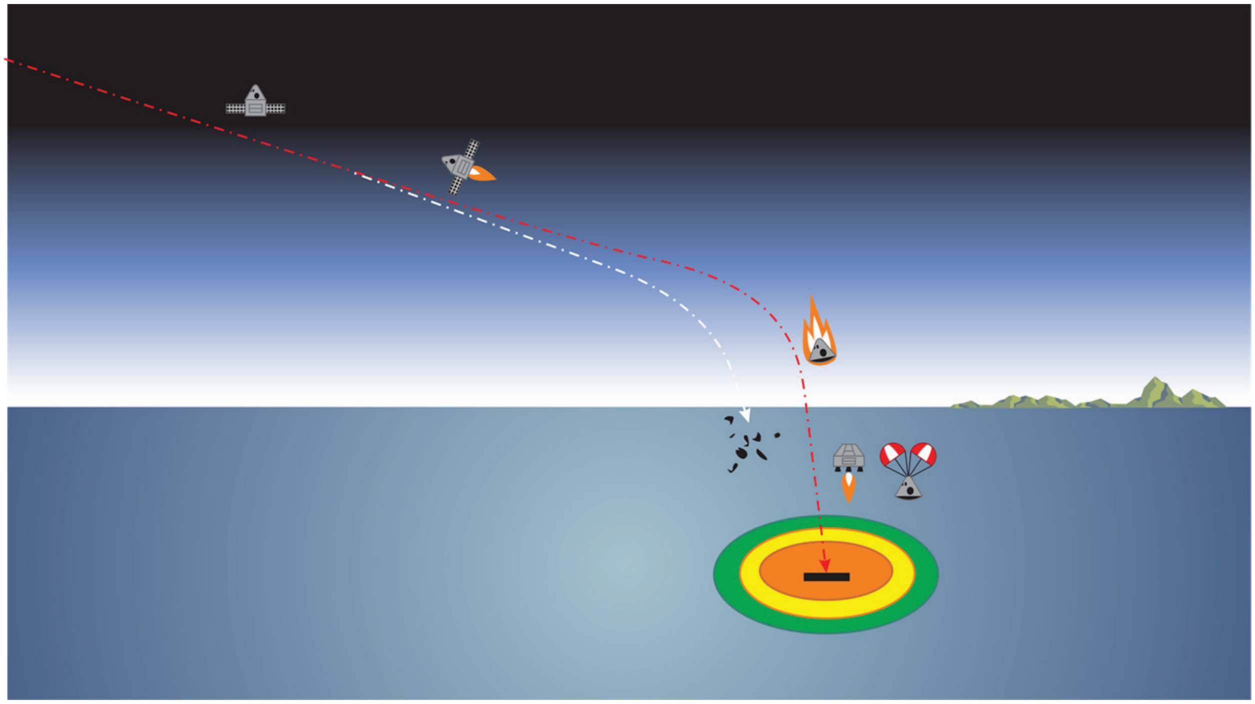

**Figure A3: Capsule Reentry**

*System Examples.* Russian RKK Energia Soyuz spacecraft, SpaceX Dragon, and Orbital ATK Antares are examples involving capsule reentry today. The Boeing CST-100 Starliner capsule is a future concept.

*Risk Contours.* Risk contours associated with capsule reentry may be highly variable depending on the demonstrated accuracy of the vehicle de-orbit burn. The green contour may range from 100 by 150 miles to 200 by 400 miles. The extent of the contours is primarily driven by the probability and characteristics of potential vehicle breakup at high altitude.

## Expendable Launch Without Fly-Back

*Mission Summary.* Expendable launch vehicles (ELVs) are designed to be used only once, “expended” during a single flight to carry a payload into space. ELV components are not recovered for reuse after launch. Typically, the vehicle consists of several rocket stages, which are jettisoned during the vehicle ascent. Therefore, in practice, there may be multiple risk contours. Figure A4 depicts the expendable launch without fly-back mission type.

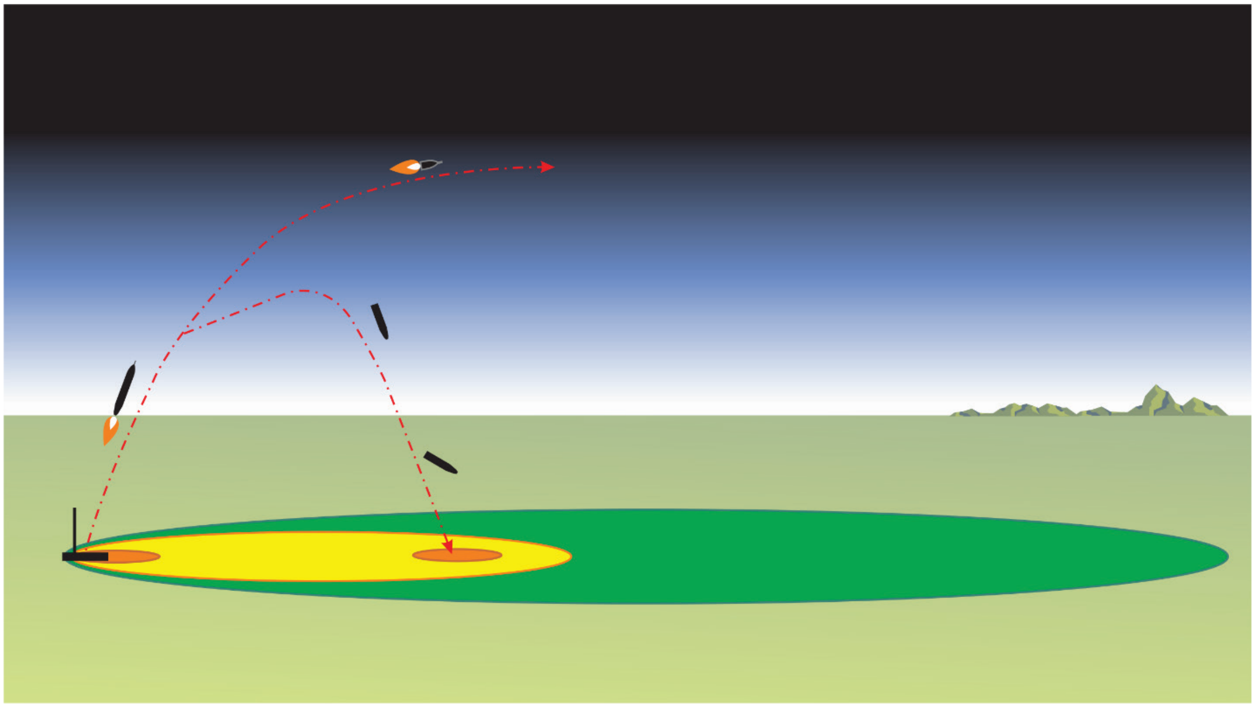

**Figure A4: Expendable Launch Without Fly-Back**

*System Examples.* There are numerous operational examples of this mission type including: United Launch Alliance (Lockeed Martin-Boeing joint venture) Atlas V and Delta IV, Orbital ATK Minotaur, SpaceX Falcon 9, Titan, European Ariane, Chinese Long March (Changzheng) rocket, Russian Proton, and R-7 (including Semyorka, Molniya, Vostok, Voskhod, and Soyuz).

*Risk Contours.* In Figure A4, there are two $1 \times 10^{-6}$ risk contours—one associated with launch and another associated with the jettison of a rocket stage. The position and number of contours depends on vehicle and mission specifics. For example, in the case of SpaceX, stage jettison may occur at an altitude between 225,000 to 350,000 feet, although this varies across the industry. Similarly, jettison may occur as close as 25 miles downrange from the launch site or hundreds of miles downrange. The actual point of ground impact for various stages may be hundreds or thousands of miles downrange.

## Horizontal Orbital

*Mission Summary.* In concept, this mission type would involve a rocket powered winged launch vehicle that takes off from a runway and accelerates to earth orbit. For the purposes of this report, the reentry portion of a horizontal orbital operation is classified as its own mission type (winged reentry), and is described separately in another section. This follows because computed risks may be different for "takeoff-to-orbit" and "reentry-landing" phases. Figure A5 depicts the horizontal orbital mission type.

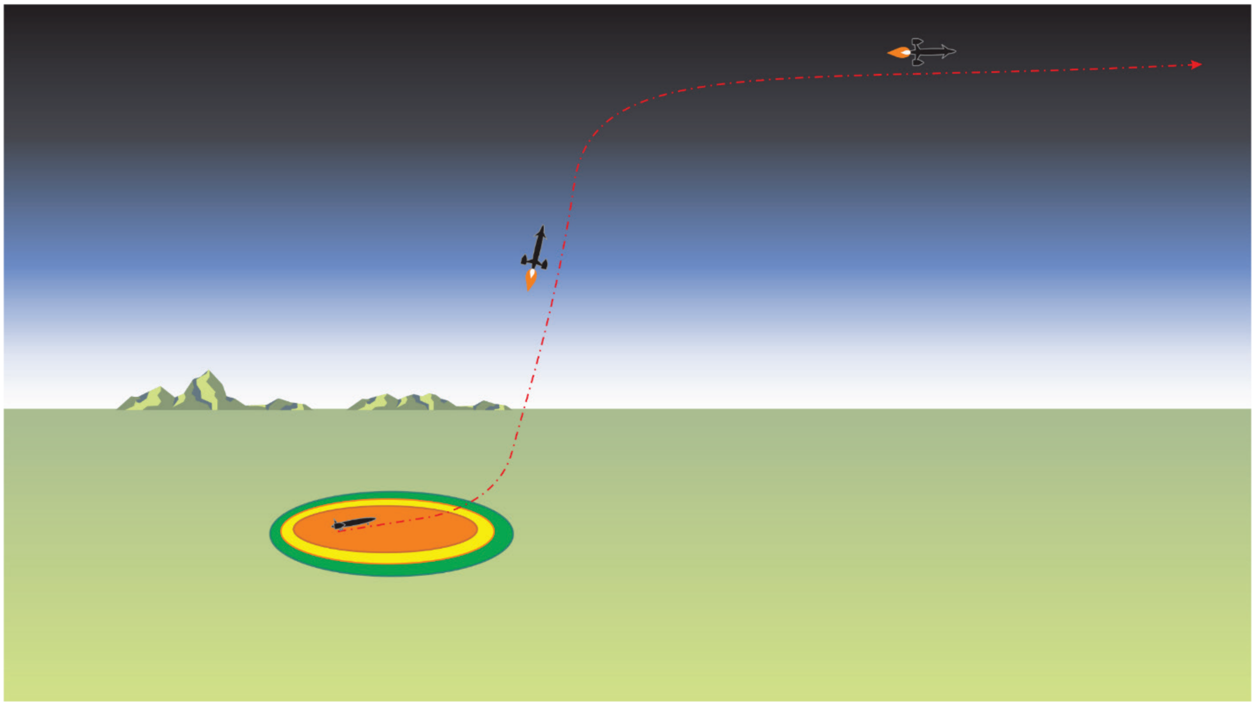

**Figure A5: Horizontal Orbital**

*System Examples.* Future concept.

*Risk Contours.* The dimensions of the representative risk contours are not well defined, as no operational vehicles or prototypes exist. However, if contours are required, they are likely to be of the same order of magnitude as vertical launch vehicles—20 to 50 miles wide and hundreds or thousands of miles long.

## Captive Carry Orbital

*Mission Summary.* The captive carry orbital mission type might include the following phases: aircraft/rocket climb-to-launch altitude (captive carry phase), rocket ignition/launch, carrier aircraft return to aerodrome/spaceport, jettison of stages, and rocket entry into orbit. The carrier aircraft may execute a circling climb to reach the launch altitude of 40,000 to 60,000 feet. Figure A6 depicts the captive carry orbital mission type.

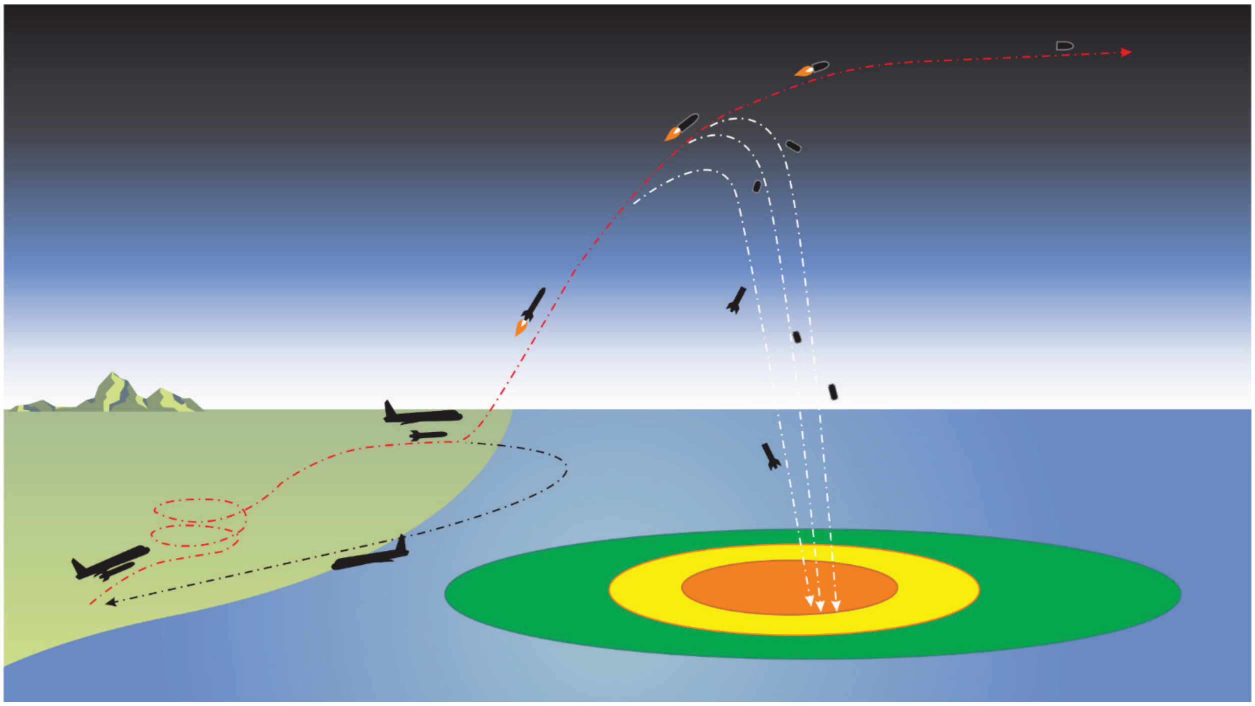

**Figure A6: Captive Carry Orbital**

*System Examples.* Examples of this mission type include:

- Orbital ATK (merger of Orbital Sciences Corporation and Alliant Techsystems, ATK) Pegasus. The carrier aircraft is a Lockheed L1011, which would climb to approximately 40,000 feet over the ocean for launch. When the Pegasus is released, it free falls in a horizontal position for five seconds before igniting its first stage rocket motor. The Pegasus consists of an inertially guided, expendable three-stage rocket that boosts small satellites weighing up to 1,000 pounds (450 kilograms) into low-earth orbit.
- Virgin Orbit Launcher One. The carrier aircraft, a Boeing 747-400, transports Launcher One to an altitude of 35,000 feet before release. The Launcher One consists of an expendable two-stage rocket. After release, Launcher One ignites its main stage, 73,500 pounds of force (lbf) LOX/RP-1 rocket. According to company information, this engine will fire for about three minutes. After main stage separation, the upper stage 5,000 lbf rocket carries the payload to orbit. Stratolaunch is anticipated to use a similar concept.
- Generation Orbit, GOLauncher 2/3. The GOLauncher 2 carrier aircraft is a modified Gulfstream IV. According to company information, the Launcher2 is an expendable two-stage rocket that transports payloads up to 40 kilograms to low-earth orbit. GOLauncher 3 Mini uses a larger transport aircraft, such as the DC-10. The Launcher 3 is an all-liquid rocket capable of transporting payloads of up to 150 kilograms to sun synchronous orbit. GOLauncher 3 Heavy uses an all-liquid rocket capable of transporting payloads up to 500 kilograms to sun synchronous orbit.

- Cube Cab, Carrier Aircraft Lockheed F104. Rocket characteristics are in development, but according to company information, the target market is for payloads up to 5 kilograms.

*Risk Contours.* In Figure A6, the point at which the rocket is released and separated from the aircraft is where the red and black dashed lines diverge, which is when the rocket engine ignites. Current designs have a demonstrated probability of vehicle failure, prior to engine ignition, less than $1\times10^{-6}$, so risk contours are not computed for this region.

In the diagram, the risk contours are skewed toward the point of rocket engine ignition. However, separate risk contours may also be computed for the area associated with stage drops. In other words, for some operations there could be multiple $1\times10^{-6}$ regions, as there can be for multistage vertically launched vehicles. While staging times and altitudes for multi-stage vehicles are highly variable, generally staging is separated by hundreds of thousands of feet in altitude. Hypothetically, the region associated with $1\times10^{-6}$ casualty risk would be 20 to 40 miles wide and up to 100 miles long. The outer most region (green) may be 30 to 100 miles wide and hundreds or thousands of miles long.

## Horizontal Suborbital

*Mission Summary.* For this report, the horizontal suborbital mission type might include the following phases: horizontal takeoff, powered ascent, coast to altitude, vehicle reentry, glide and circle, and horizontal landing. Total flight time may be approximately 60 minutes, reaching or possibly exceeding 100 kilometers above sea level. Figure A7 depicts the horizontal suborbital mission type.

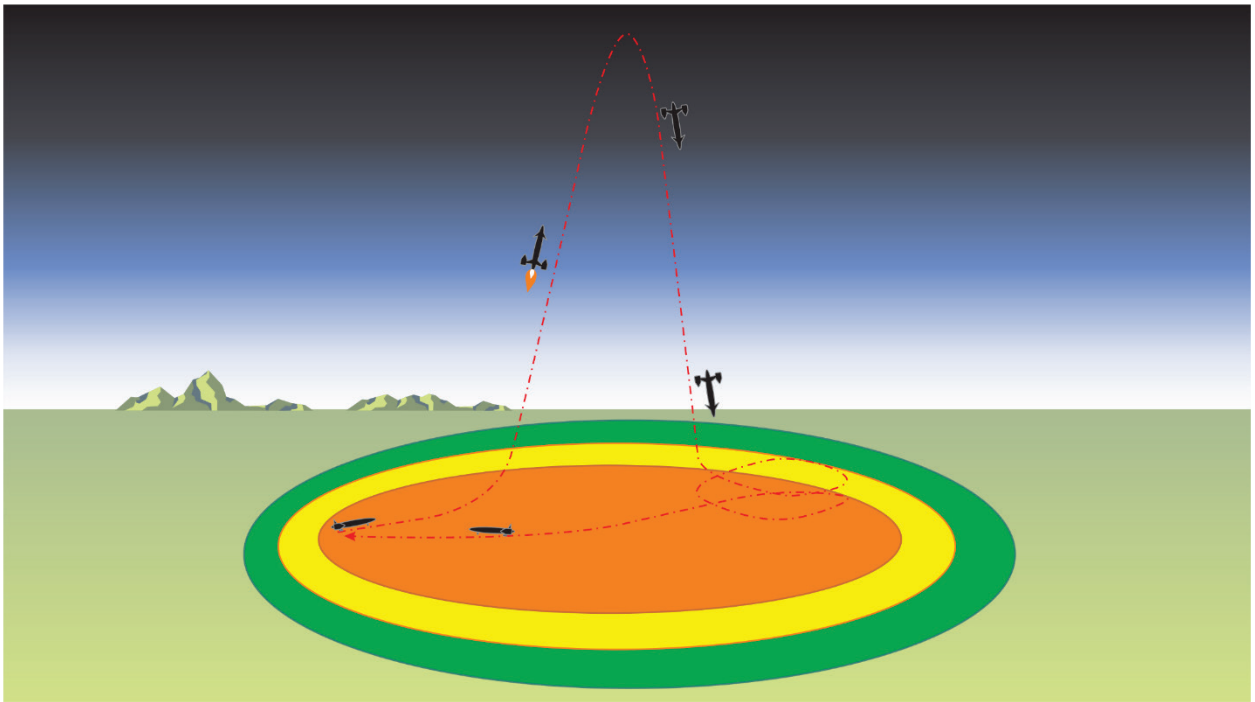

**Figure A7: Horizontal Suborbital**

*System Examples.* An example of a vehicle operating under this mission type is the now halted XCOR Lynx launch vehicle.

*Risk Contours.* While the illustrated risk contours are meant to be circular (in perspective), no operational vehicles for this mission type exist, so this representation is an approximation. The size of the contours depends on the vehicle and mission details, but will likely be the same order of magnitude as vertical suborbital launch vehicles—20 to 50 miles in radius.

## Captive Carry Suborbital

*Mission Summary.* The captive carry suborbital mission type might include the following phases: aircraft/space vehicle climb-to-launch altitude (captive carry phase), space vehicle ignition/launch, carrier aircraft return to aerodrome/spaceport, space vehicle powered ascent and coast to altitude, space vehicle reentry, glide and circling maneuver to reduce altitude, and return to aerodrome/spaceport for horizontal landing. The maximum space vehicle altitude would be approximately 100 kilometers. Figure A8 depicts the captive carry suborbital mission type.

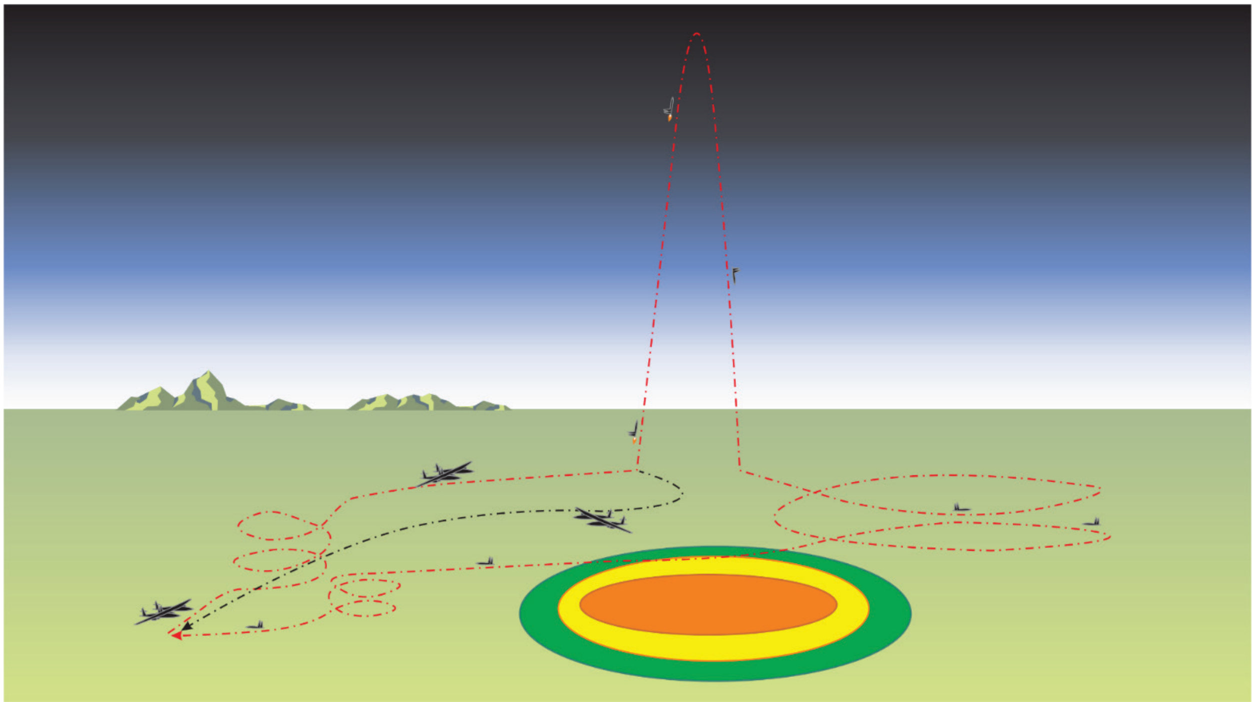

**Figure A8: Captive Carry Suborbital**

*System Examples.* Examples include WhiteKnightTwo carrying Virgin Galactic SpaceShipTwo. SpaceShipTwo is a piloted vehicle.

*Risk Contours.* The risk contours in Figure A8 are hypothetical, but would likely be 15 to 20 miles in radius for the orange region and up to 50 miles in radius for the green region. In practice, the configuration of the contours would depend on the particular space vehicle and its mission. For example, the figure assumes that for the captive carry mission phase, the operator would establish compliance with 14 Code of Federal Regulations (CFR) Chapter III by demonstrating that the probability of vehicle failure is less than $1 \times 10^{-6}$. In this case, risk contours would not be required.

In the figure, the orange region is depicted as beneath the apex of the flight. This represents the mission phase where the vehicle is either thrusting or reentering. The vehicle has the most dwell time in this region, thus the highest risk is typically in this area. The space vehicle “glide and circling maneuver” may be associated with its own set of risk contours, again depending on the vehicle and mission. If the glider has demonstrated a vehicle failure probability less than $1 \times 10^{-6}$, then contours would not be computed.

## Vertical Launch Suborbital Expendable Booster

*Mission Summary.* The vertical launch suborbital expendable booster mission involves a non-reusable rocket used to carry payloads on a roughly parabolic trajectory. These systems may have one or multiple stages. Figure A9 depicts the vertical launch suborbital expendable booster mission type.

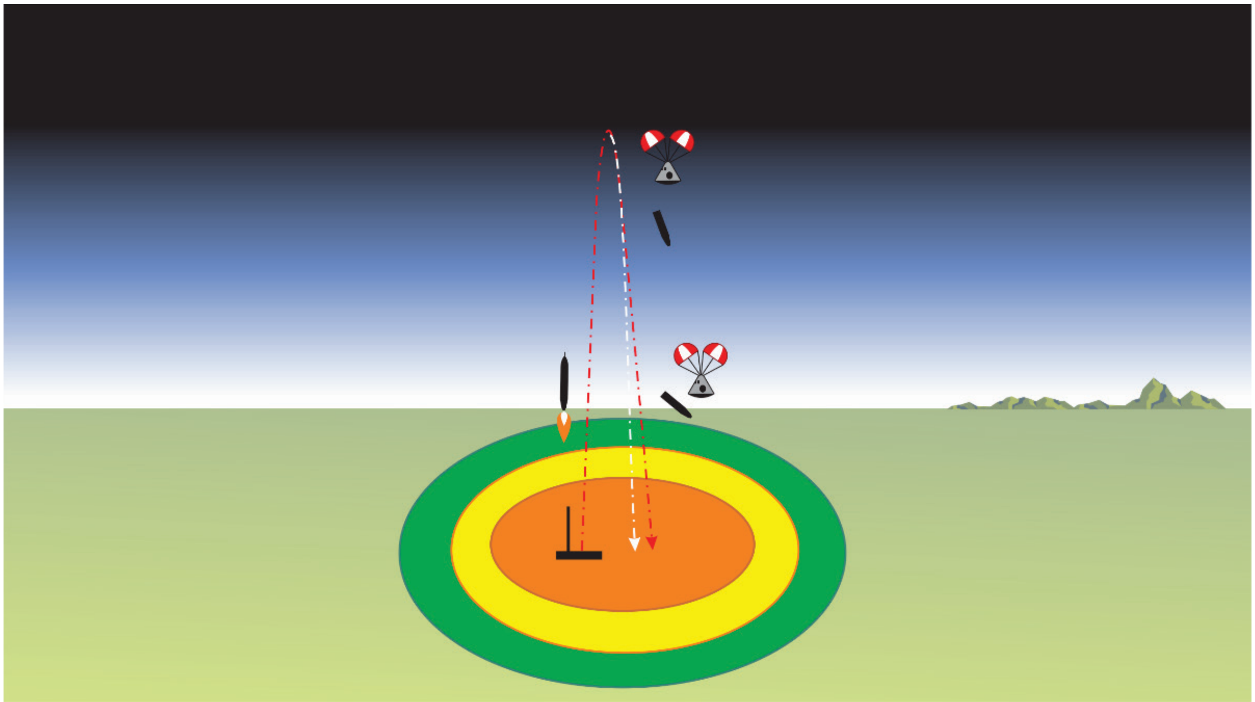

**Figure A9: Vertical Launch Suborbital Expendable Booster**

*System Examples.* An example of this mission type is a sounding rocket—a research rocket designed to carry instruments from 50 to 1,500 kilometers above the earth's surface. Examples of sounding rockets include: Aerobee, Astrobee, Black Brant, and Mesquito.

*Risk Contours.* The dimensions of risk contours vary depending on the vehicle and mission, and range from between 5 to 50 miles in diameter. The apex altitude depends on the size of the vehicle and ranges between 10,000 and 650,000 feet.

## Vertical Launch Suborbital Reusable Booster

*Mission Summary.* The vertical launch suborbital reusable booster mission type differs from the previous case in that the booster is recovered for reuse. Phases for this mission type might include: liftoff, rocket/capsule separation, booster rocket powered landing, and capsule parachute landing. Figure A10 depicts the vertical launch suborbital reusable booster mission type.

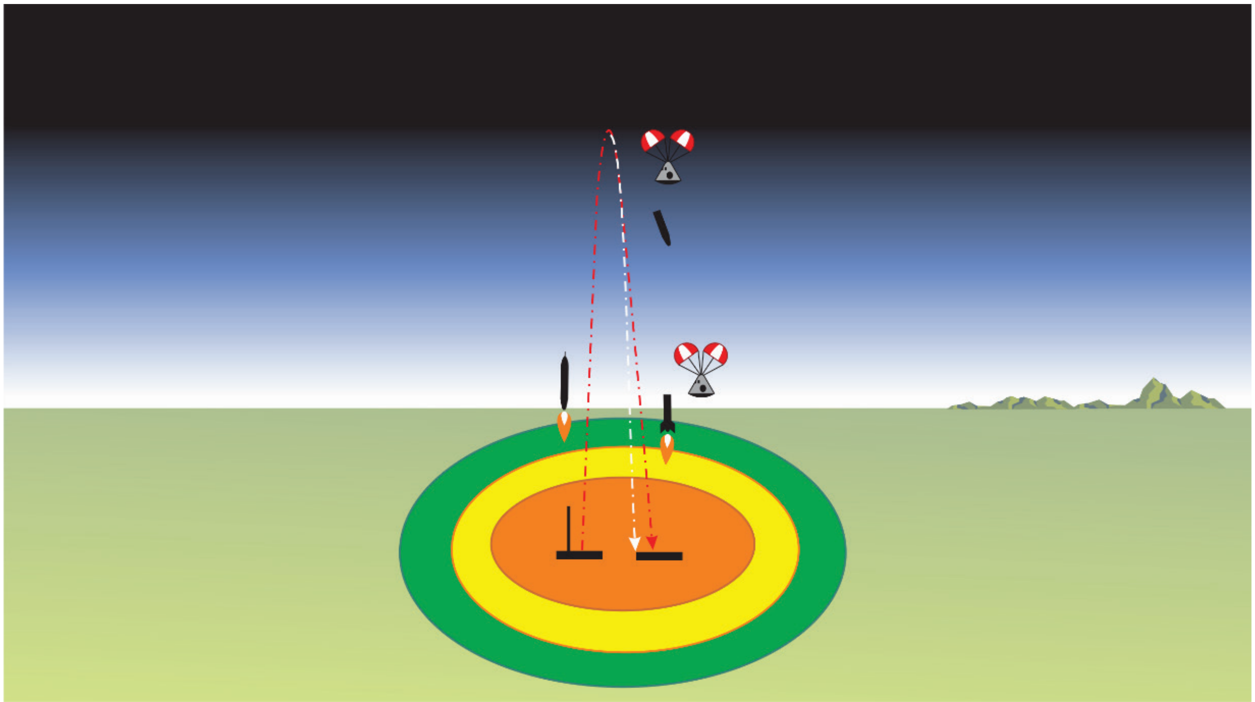

**Figure A10: Vertical Launch Suborbital Reusable Booster**

*System Examples.* An example of this mission type is the Blue Origin New Shepard vehicle.

*Risk Contours.* For current example vehicles, the risk contours range from 15 to 50 miles in radius. The apex altitude is most likely to be above 100 kilometers above sea level.

## Winged Reentry

*Mission Summary.* In concept, this mission type would involve a rocket powered winged reentry vehicle that returns for a horizontal landing. Figure A11 depicts the winged reentry mission type.

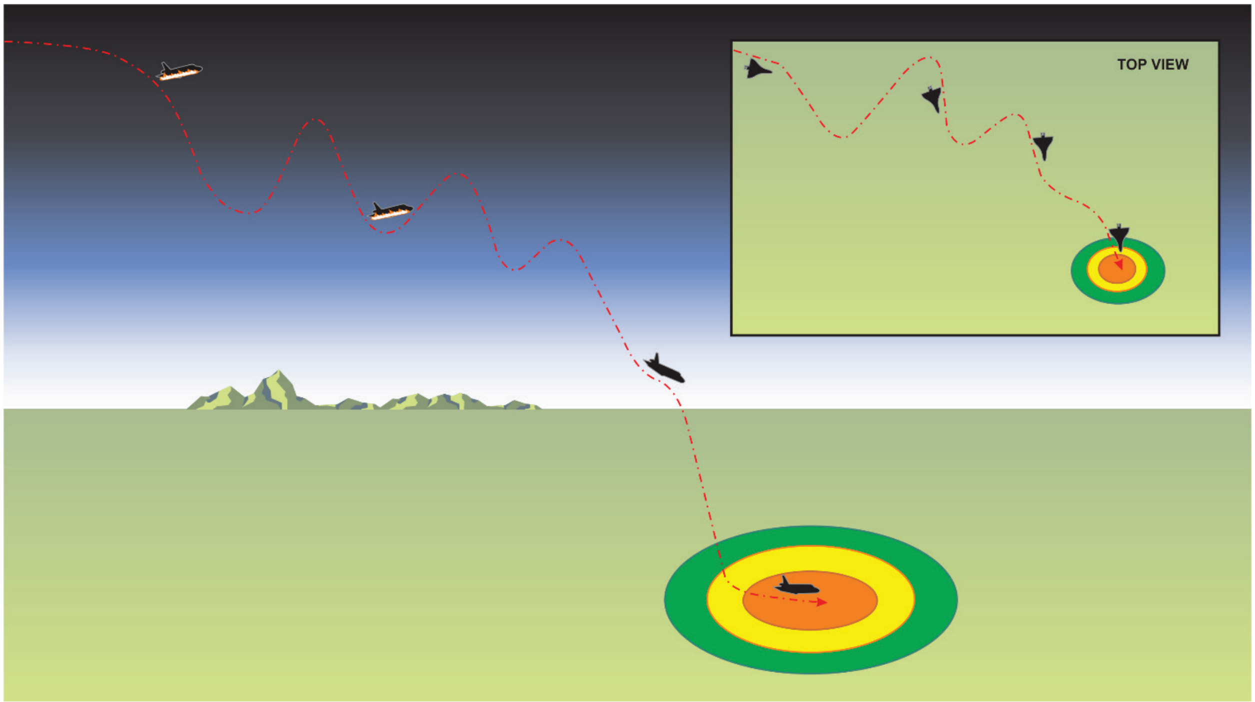

**Figure A11: Winged Reentry**

*System Examples.* Examples include the Sierra Nevada Corporation DreamChaser, Boeing Phantom Express, and the NASA Space Shuttle.

*Risk Contours.* The Airspace Hazard Area (AHA) is calculated for the landing portion of the mission. The vehicle makes turns that are not always predictable and the AHA does not extend to the phase of flight in which the turns are made.

## Stratospheric Manned Balloons

*Mission Summary*. Figure A12 depicts the stratospheric manned balloon mission type. Stratospheric manned balloon missions might consist of the following phases: liftoff from launch site, balloon/payload ascent to altitude, maintaining position, descent, and arrival at landing site. Under current designs, payloads may be kept in a specified area for a period ranging from hours to days or longer, at altitudes up to 46 kilometers. In the descent phase shown in Figure A12, the payload separates from the balloon and descends to earth via parachute or parawing. The distance between the liftoff and landing site may be as much as several hundred miles.

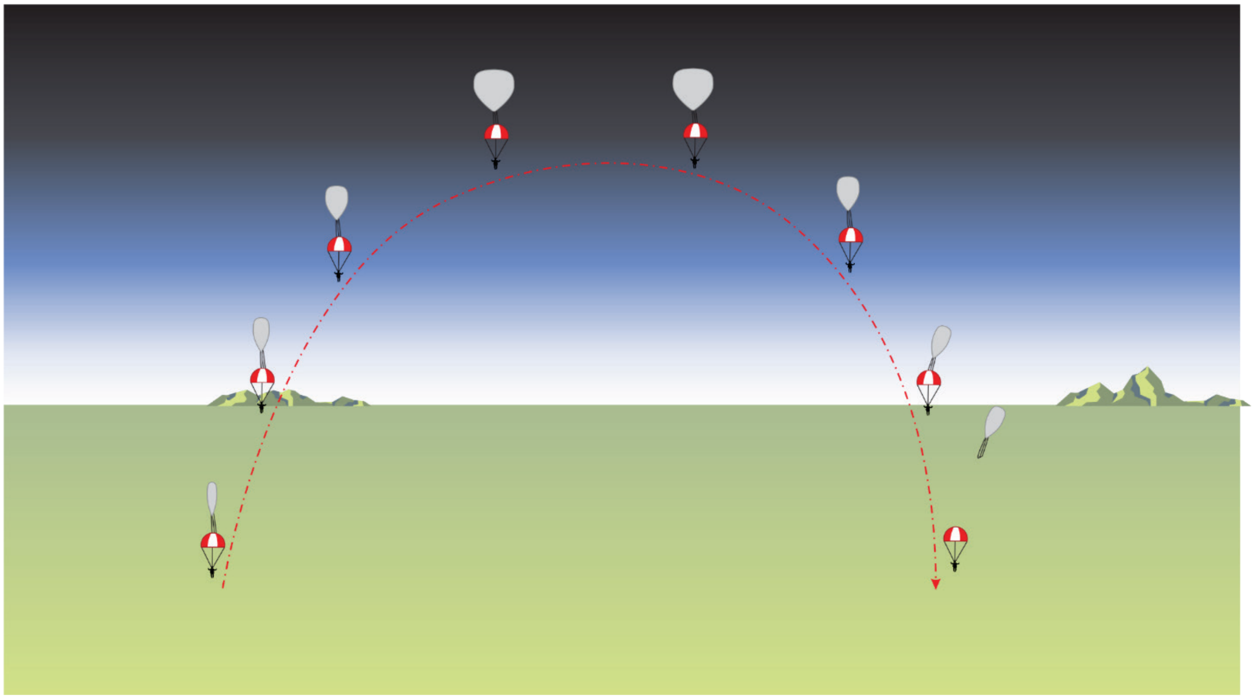

**Figure A12: Stratospheric Manned Balloon**

*System Examples.* An example is the World View Voyager. There are current unmanned concepts that share similar mission profiles, such as World View Stratollite Flight Services, but they are similar to what is expected for manned concepts. Test flights of the World View Stratollite are conducted under 14 CFR part 101 without an AHA. The operator anticipates continuing the practice for commercial operations of the Voyager.

*Risk Contours.* In Figure A12 (and under current concepts) the payload would not have its own propulsion system or propellant, and therefore, the team does not envision that an AHA or risk contours would be computed for this mission type, since a credible mechanism for generating debris at altitude has not been identified.

## Balloon Launch

*Mission Summary.* Balloon launches might include the following phases: balloon floating ascent to launch point, rocket engine ignition and launch, balloon drop and recovery, rocket cruise phase, rocket descent segment, and rocket recovery. The apex of the balloon flight is highly variable, possibly between 80,000 and 180,000 feet. The point of rocket launch could be between 50,000 and 100,000 feet. Figure A13 depicts the balloon launch mission type.

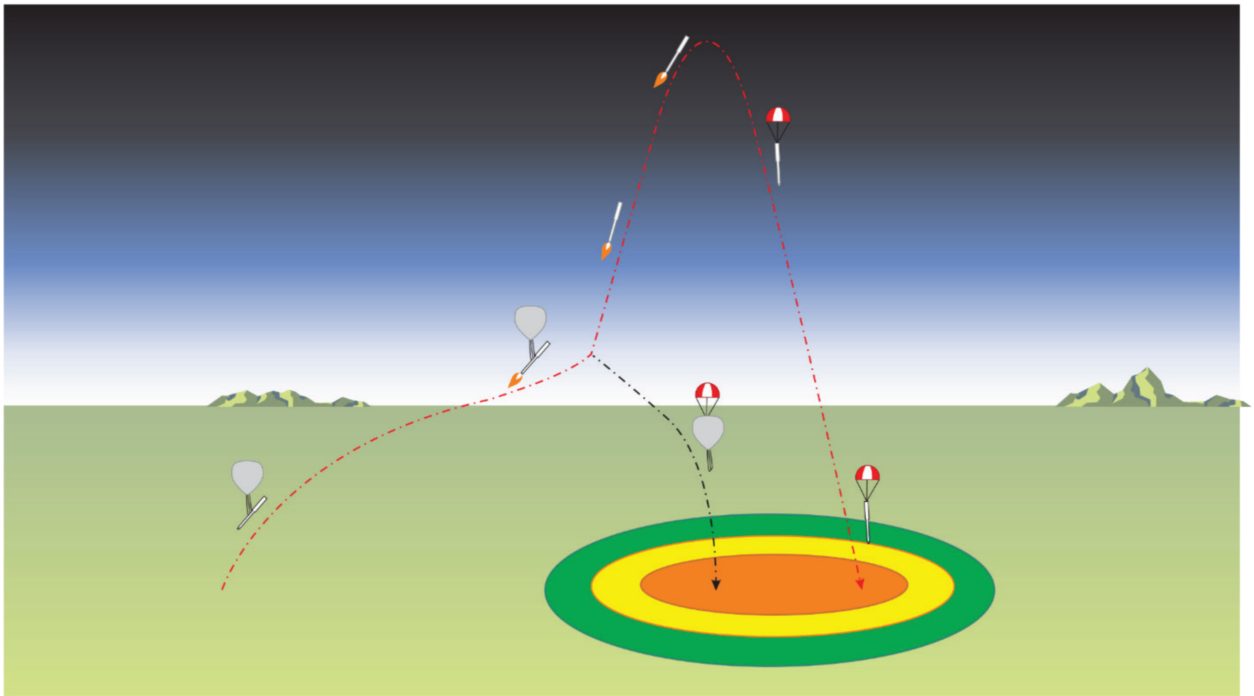

**Figure A13: Balloon Launch**

*System Examples.* An example of this mission type is Zero2Infinity SpaceBloostar (Spain).

*Risk Contours.* The risk contour positions and dimensions are poorly defined due to the uncertainty in balloon navigation, possibly on the order of 20 to 50 miles in radius.

## Point-to-Point

*Mission Summary.* Under some current concepts, point-to-point launch vehicles may be similar in appearance to aircraft but meet the legislated definition of a suborbital launch vehicle. They would possibly launch horizontally to minimize the time and resources involved in loading and unloading passengers and cargo. Typical operational phases for this mission type might include: takeoff or liftoff from the launch site (may be either horizontal takeoff or vertical launch), ascent and transition to space, reentry, and return to landing site (may be either powered flight, unpowered flight, or ballistic return). Figure A14 depicts the point-to-point mission type.

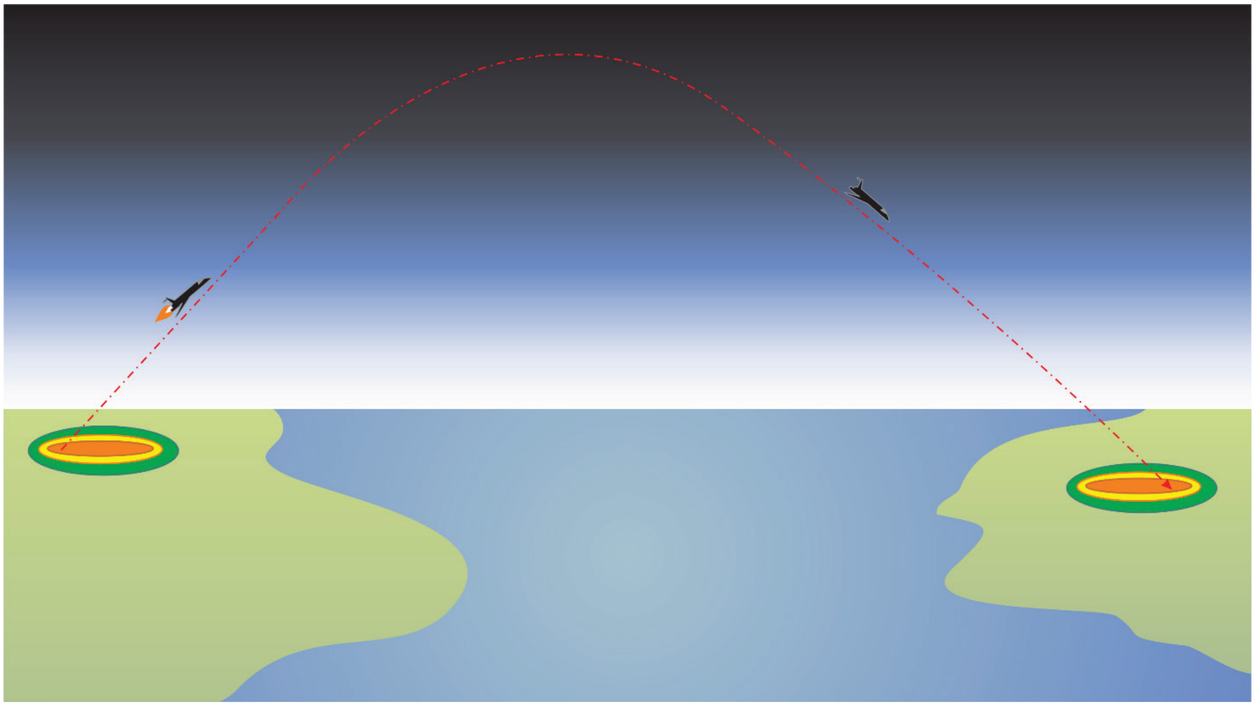

**Figure A14: Point-to-Point**

*System Examples.* There are no known current examples of this mission type.

*Risk Contours.* In Figure A14, two sets of risk contours are depicted, one for the departure site and one for the arrival site. The configuration and size of the contours would depend on the mission details (e.g., horizontal or vertical launch, whether the landing is powered or unpowered, the possible characteristics of vehicle breakup during liftoff and landing).

## Tube and Rail Launchers

*Mission Summary.* There are several possible variants of this mission type, but in general, they might involve the following phases: (1) launch that may not involve propulsion generated from the vehicle itself (e.g., launch may be accomplished via a rail gun using electromagnetic force to accelerate the vehicle or an airtight tube with a magnetically levitated vehicle); (2) ascent (which may involve an onboard propulsion system such as a scramjet); and (3) ascent to orbit (during which the payload is fired into orbit). These designs are seen as potentially advantageous in that they would require much less propellant than traditional liquid or solid-fuel rocket designs. Figure A15 depicts the tube and rail launcher mission type.

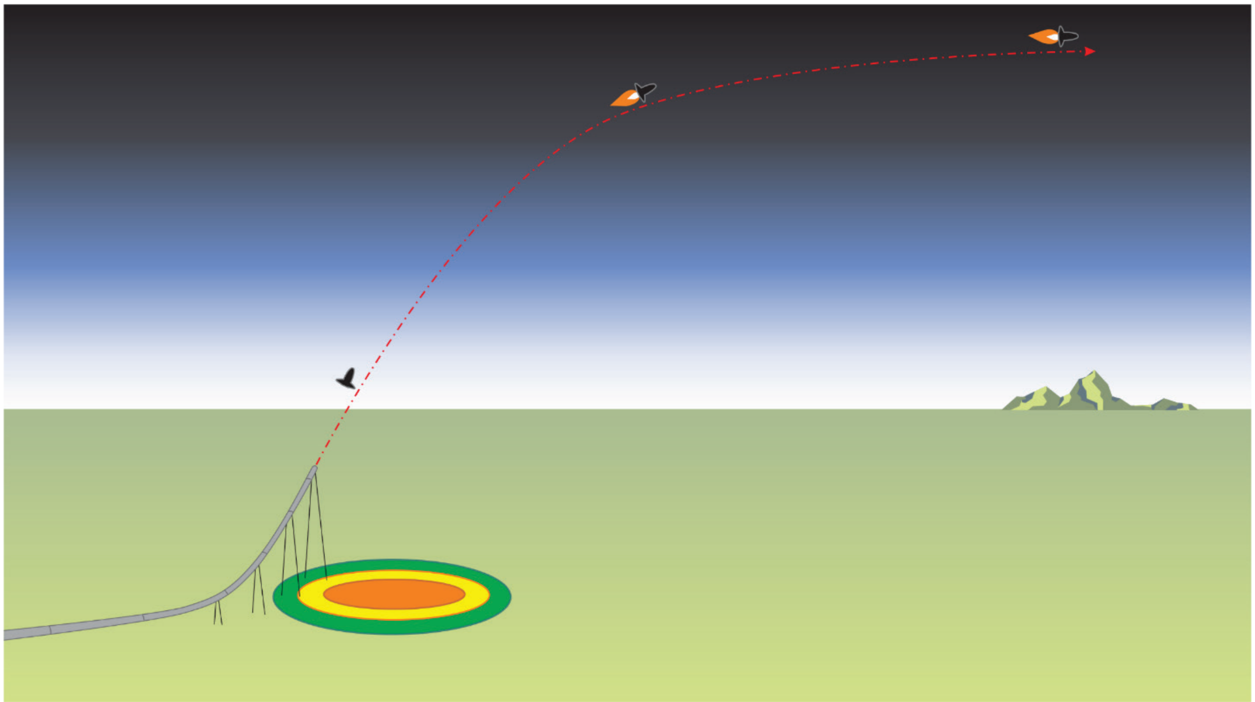

**Figure A15: Tube and Rail Launchers**

*System Examples.* There are no known examples of this mission type.

*Risk Contours.* The configuration of risk contours would depend on the mission specifics. For example, if an additional source of propulsion is required to achieve orbit, then the contours may be different that those depicted in Figure A15.

# Appendix B: Glossary

**Acceptable Level of Risk (ALR) Approach:** The ALR approach defines an alternative method for accepting individual and collective catastrophic risk. It permits the exposure of specific aircraft to higher risk, but limits the total number of aircraft exposed until National Airspace System (NAS) infrastructure, policies, and procedures are updated. This concept is not intended to conflict with other Safety Management System (SMS) language that determines whether hazards of some severity would occur at unacceptable likelihoods.

**Aircraft Hazard Area (AHA):** A type of temporary airspace restriction that defines an area of airspace that the Office of Commercial Space Transportation (AST), the launch operator, or the federal range operator computes in advance of a launch operation—that is associated with the proposed trajectory that protects from falling debris in the event of a failure, as well as areas where expected events like splashdowns and stage jettisons will take place. These areas represent the boundaries of airspace closed to the flying public to ensure the probability of impact (Pi) with debris capable of causing a casualty for aircraft does not exceed $1 \times 10^{-6}$. (Source: 49 Code of Federal Regulations (CFR) § 417.107)

**Collective Risk:** The expected value of the number of fatal accidents due to space launch debris in the affected regions of the National Airspace System over a specified time period.

**Contour:** An outline, especially one representing or bounding the shape or form of something. Synonyms: *isoline* and *contour line*.

**Expected Value:** A predicted value of a variable, calculated as the sum of all possible values each multiplied by the probability of its occurrence.

**Exposed Operation:** Any flight that passes inside the $1 \times 10^{-8}$ risk contour from launch time until the space vehicle is declared to have entered in orbit, typically 10 minutes, and, if applicable, any fly-back is complete (i.e., the reusable portion of the vehicle has landed). The terms “exposed operation” and “exposed flight” are synonymous.

**Fly-Back:** Any attempt to return a stage or component of a launch vehicle to the surface of the earth intact before it reaches orbit.

**Individual Risk:** The probability that an *exposed flight* will be involved in a fatal accident caused by space launch debris during a launch operation.

**Risk Buffer:** The area of airspace that is added to an Airspace Hazard Area (AHA) by AST to ensure that the $1 \times 10^{-7}$ individual risk limit of the ALR approach for those missions to which the 30-degree angular restriction cannot be applied. The risk buffer essentially expands the AHA that Air Traffic Organization (ATO) applies.

**Route:** A defined path, consisting of one or more courses in a horizontal plane, which aircraft traverse over the surface of the earth. (Source: Pilot-Controller Glossary (PCG) in FAA Order JO 7110.65, *Air Traffic Control*) See also:

> **Airway:** A Class E airspace area established in the form of a corridor, the centerline of which is defined by radio navigational aids.

**Jet Route:** A route designed to serve aircraft operations from 18,000 feet Mean Sea Level (MSL) up to and including flight level 450. The routes are referred to as “J” routes with numbering to identify the designated route (e.g., J105).

**Published Route:** A route for which an Instrument Flight Rules (IFR) altitude has been established and published (e.g., Federal Airways, Jet Routes, Area Navigation Routes, Specified Direct Routes).

**Unpublished Route:** A route for which no minimum altitude is published or charted for pilot use. It may include a direct route between Navigational Aids (NAVAIDs), a radial, a radar vector, or a final approach course beyond the segments of an instrument approach procedure.

**Temporary Flight Restriction (TFR):** A type of Notice to Airmen (NOTAM). A TFR defines an area restricted to air travel due to a hazardous condition, a special event, or a general warning for the entire FAA airspace.