Report on the Effects of Parachutes on Risk Mitigation to Third-party Property and Individuals

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Prepared for

Office of Commercial Space Transportation

March 1993

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This report is a response to an OCST request that a "quick-turnaround" study be conducted on the subject topic. The research was conducted under the auspices of an existing contractor instruction on Additional Data Sources and included a review of References 1-17.

Issue definition: A study on the public's exposure to risk caused by an object or payload landing upon its arrival from an orbital or suborbital flight trajectory. An investigation was conducted looking for research that may have been done or information that may have been gathered that is able to qualitatively or quantitatively discuss the magnitude of risk, or differential (delta) due to the presence of a parachute, to people or property on the ground in comparison to the risks of an object descending in free fall; essentially ballistically. The basic question the study seeks to answer is this. "Why is it safe to release an object on a parachute while it is unsafe to release it without a parachute?"

Discussion: The study did not reveal any existent research that included a side-by-side comparison of objects; one with an aerodynamic decelerator (parachute for this study) and one in ballistic free fall. However, the research conducted and the references and sources contacted do allow for certain comparisons and observations to be made.

Table 1 summarizes those comparisons and findings. The sections that follow Table 1 contain a more detailed discussion of those comparisons and observations and contain the rationale for the statements in the Table. The text also contains information on parachute reliability and concludes with a bibliography of
References 1-17.

Table 1. Comparison of various factors as they relate to the presence or absence of an operating parachute

Factor	Without a parachute	With a parachute
Landing dispersion	More precise calculation of the object's landing site and therefore less uncertainty about where the object will land.	Less precision while determining landing area. The landing area predicted therefore will be larger.
Potential injury or casualty causing area	The object's casualty causing area is roughly double the object's frontal area in any calculation that uses such information.	The object's casualty causing area is larger than the object's frontal area but not to the point of being doubled.
Impact forces	Impact force or kinetic energy is a function of velocity^2. With an object of any size this can be a considerable force.	Objects will have much lower kinetic energy due to having greatly reduced velocity.
Sheltering	Only structures of a certain size and strength can provide adequate sheltering and protection from even relatively small objects.	Depending on the object's weight, most structures will provide some or total protection for its occupants.
Objects hitting the ground	Trees, buildings, poles, etc. will have slight effect on reducing an object's ground impact force and almost no effect on the likelihood of the object actually reaching the ground.	Almost any object that extends above ground level will have a tendency to either snag or slow the descent of an object.
Location	Persons located outdoors will not see or be aware of the object prior to its impact.	Persons outdoors are likely to see the object during its descent.
Visual detection	The object will not lend itself to being visually detected because of its relatively small size and high velocity.	Detection is possible because of the parachute's size and coloration and the object's much slower velocity.
Collision with aircraft	Extremely unlikely but if it did occur, the aircraft probably would be destroyed.	Even more unlikely to occur but if it did, the aircraft might not be lost.
Weather	Weather will have little effect on the object's descent path.	Humidity, pressure, precipitation and especially wind will have an effect.

Discussion and Rationale

Landing Dispersion:

The absence of a parachute or other aerodynamic deceleration devices will result in a more reliable prediction of an object's projected landing point. The projected impact dispersion of a ballistically returning object can be mathematically calculated and plotted. The landing dispersion of an object on a parachute is less straightforward to calculate and when displayed, will encompass a larger area.

This is due to two factors that serve to shrink the dispersion pattern for a ballistic object. The first factor is that the object will, by itself, be smaller and will be less effected by atmospheric effects such as winds and air density. The second factor is that the time length of exposure to any atmospheric phenomena will be considerably less for an object that is not being mechanically decelerated. On the one hand is an object coming down on a parachute at 20-25 feet per second and on the other hand is one in free fall, attaining a terminal velocity probably on the order of 300 miles per hour (440 feet per second). Similarly, between objects coming down on parachutes but at different velocities, the system that takes longer to reach the ground will have the larger landing dispersion area.

Potential Injury or Casualty area:

The absence of a parachute or other aerodynamic deceleration devices, from an object that requires such a device in order to ensure its survivability, will have the effect of destroying the object, in this case a payload of some sort, either by impact forces or because of aerodynamic loads encountered. This has the effect of doubling the payload's potential injury-causing area either because the in-flight break up of the payload will create multiple reentering pieces or because a relatively intact payload will ricochet or break apart on landing and serve to double the area. The exception to this would be the payload that is partially or totally consumed by the reentry process.

An object on a parachute can also add to the potential injury-causing area by virtue of the horizontal component of its descent. The convention is to add one foot to the radius of the object when computing this potential injury-causing area.

Impact forces:

The absence of a parachute, assuming an object's terminal velocity on the order of 440 feet per second (fps), (300 mph), compared to a descent on a parachute at 25 fps, (17 mph), will increase the impact by a factor of 300 times. For example, let us consider an object weighing 1,000 pounds. At a descent rate of 25 fps its KE ($KE=\frac{1}{2} mv^2$) will be about 9,700 foot-pounds. In free fall at 440 fps, its KE will be 3,000,000 foot-pounds. This increase in impact energy will have a substantial effect on the survivability of a person hit or struck a glancing blow by the payload as well as having a substantial reduction in the protection that may be offered by any structures. Thus an object on a parachute will present an impact of much less kinetic energy than will the same object in free fall.

Another factor that might reduce the impact force would be any feature, in addition to the parachute, that would mitigate the kinetic energy forces. A system such as a deployable airbag would accomplish this and logically would only be installed on an object descending on a parachute or other decelerating device. An object expected to come down in free fall would not be expected to have such a device.

Sheltering:

The literature is fairly consistent on the benefit of sheltering. Reference 1, as revised by Reference 2, indicates that an object, if retarded by an operating parachute system, may not pose a hazard to people sheltered by buildings of various sizes and construction. The literature indicates that various type structures provide differing levels of protection as shown below:

<u>Three levels of protection</u>

Type 1: Buildings with concrete or reinforced roofs or floors except for the top floor in a multistory building.

Protection: Protects against KE from a minimum of 6,200 ft-lbs.

Type 2: Single-story buildings such as houses and trailers and the top floor of multistory buildings.

Protection: Protects from a minimum of 100 ft-lbs to a maximum of 3,200 ft-lbs.

Type 3: Unsheltered

Protection: None offered

Additionally, there are other factors that can contribute to how a structure enhances survivability. For example, the structure may be more sensitive to force per unit area (pounds per $foot^2$ or $inch^2$) than to overall kinetic energy and the descending object might be large to the point of exerting a relatively low force on impact. The structure may also be designed in such a way as to result in glancing blows to more of its exposed surfaces. When a glancing blow does occur, the normal force exerted on the structure is reduced as a function of the slope or angle of the structure. When this happens, the effective protection offered by the roof, or other part of the structure, is increased.

Objects hitting the ground

There is a well-founded belief that risks to people and property will be mitigated by a parachute's tendency to become entangled in trees, on buildings, telephone poles and the like. This is especially true in areas of significant and large foliage and it should be possible to estimate that probability of entanglement for any specific area once the percentage of forestation is known. The analysis would need to bear in mind that trees of differing sizes will have varying effects on the lethality or injury causing consequences of a ground impact. However, impact with a tree or other vegetation of almost any size will reduce the object's velocity and hence, its impact force on the ground. Those same trees would have some effect on an object in free fall but not to the same degree.

The same belief in mitigation of risk caused by entanglements holds for an urban complex. Just as a payload and parachute system would probably become entangled in a tree during a drifting (with the wind) descent, the same would happen in an urban area. Buildings could be hit and snag the parachute, poles, towers and spires could also arrest the parachute and the sheer mass of structures could likewise effect the parachute's descent. Additionally, as discussed elsewhere, the buildings themselves will have a significant effect on safety of the occupants.

Location:

Reference 1 (NASA) estimated the location of people in rural areas as shown below:

	Day	Night
Outdoors	50%	5%
Indoors	50%	95%

Reference 15 (Air Force) contains a detailed analysis on percentages of people who would be under protective covering during working hours (Table B-2), only in much greater detail than the NASA report. The average in Reference 15 was that about 88 percent of the people are indoors at any given time during the day. The difference between the two references is caused by the inclusion of more typically urban occupations in the Air Force study. OCST can feel safe using the Air Force value when looking at urban or suburban communities.

The location of people does not bear on the presence or absence of a parachute but it is useful information on the percentage of the population exposed to risk in typical demographic profiles. (For those people who are located outdoors during the daylight hours, the belief is that most people will be able to see an object or objects on a parachute. Most people would not see an object in free fall. See below.)

Parachute visibility:

The probability of persons outdoors detecting an object descending on a parachute is estimated at 90 percent, for both day and night. That percentage was based on the presence of a large, brightly-colored chute and an operating strobe light. This comes from References 1 and 17. The parachutes discussed in those references are colored orange or with orange stripes. Reference 17 indicated that for other parachutes, the likelihood of being seen will vary.

There is also a belief that multiple parachutes or multiple objects, each on their own chute or chutes, will be more visible than a single chute. At its simplest, this would be because multiple chutes will scribe a larger visibility arc than would a single chute. There is a logical assumption that someone in a crowd of people would detect a parachute and alert others around him. This type of generic alerting would probably not occur with respect to an object in free fall unless the object were purposely being looked for.

For night time, the presence of a parachute, especially one without a strobe light, will have little effect on detection until the object is close enough to the ground, and any lighting, to be sufficiently illuminated.

Collision with aircraft:

The hazards to aircraft caused by a descending object were not quantified in the references but were viewed in the literature as being "acceptable" (Reference 1). Whether coming down by parachute or ballistically in free fall, the probability of any object (or any returning space debris for that matter) hitting an aircraft is extremely remote. An object on a parachute would be regarded as simply another conflict to traffic for which a pilot routinely and consistently scans. Professional pilots consider their environment as one in which conflicting traffic, and objects, are encountered as part of flying; which is why pilots are advocates of the "see and avoid" approach to safety.

Weather effects on parachutes:

Reference 11 was developed to assess the optimum drop altitude that would minimize damage to cargo but it did contain a brief section on weather effects. It stated that the effects on the descent of parachutes are humidity, pressure, precipitation and wind, with wind having the greatest effect. The Reference describes different wind states that might be encountered and includes the observation that "A non-gliding parachute will always horizontally decelerate to the horizontal velocity of such an air mass, regardless of the velocity of the air mass with respect to earth." Simply stated, this means the object will travel with the same velocity as the wind itself. An obvious statement but one that needs to be said.

Parachute reliability:

> In the NASA balloon program, the specific parachute failure rate for those parachutes used on non-heavy payloads is about .4 percent (Reference 17). This is a reliability of .996 (1.0-.004). As reported in Reference 16, the nominal failure rate for parachutes used to drop supplies and equipment is .7 percent; 19 failures out of 2,694 drops in the 1st quarter of 1992. This is a reliability of .993 (1.0-.007). These are all excellent reliability figures and indicate that if an object is supposed to come down by a parachute, it will do so in nearly all cases.

Summary:

The research indicates a large amount of qualitative information that allows one to conclude it is safer for an object to come down on a parachute than for it to come down in free fall. This applies not only to the object itself but to the people and property on the ground. There are many factors relating to parachutes that serve to protect the public as well as protecting the object descending on the parachute. If safety of the public is a concern, then operating parachutes are a material benefit.

It is also significant to note that there exists an extensive amount of research and mathematical support dealing with ballistic objects, those in free fall, while a much smaller amount exists for objects descending on a parachute. An inference might be drawn that the risks attendant to an object on a parachute are not significant enough to warrant such detailed mathematical analysis.

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