IMPROVED RANGE SAFETY METHODOLOGIES FOR LONG-DURATION HEAVY-LIFT BALLOON MISSIONS OVER POPULATED REGIONS

George M. Lloyd[(1)], Kevin Benn[(1)], Jerry Haber[(1)], Danielle Franklin[(2)]

[(1)] ACTA Inc., 2790 Skypark Drive Suite 310, Torrance, California 90505-5345, lloyd@actainc.com
[(2)] Pacific Missile Range Facility, PO Box 128, Kekaha, HI 96752

ABSTRACT

This paper reviews the development of a new probabilistic risk methodology that has been developed to address concerns raised by long-duration fatality level exposures to aircraft and ground-level receptors from long/ultra-long duration balloon (U/LDB) flights. The methodology addresses risks during the launch and ascent to float phase, and for any float manoeuvres and planned descent and recovery operations. It is computationally feasible in that it allows for T-1 day or even day-of-launch risk assessments to be generated within a few hours so as to accommodate the most favourable launch conditions. This capability minimizes risks to people and infrastructure while simultaneously expediting the launch go/no-go decision process because deterministic limit line exclusion areas are replaced with risk-informed information. The methodology has been successfully applied to NASA's LDSD 2015 Campaign, notional elements of which are used as a demonstration.

1. INTRODUCTION

Range safety methodologies for scientific and military testing are typically designed for rocket-borne missions that complete within minutes, if not sooner. One result of high velocity flight on a linear trajectory is that incidental exposure to planned debris can be readily identified and mitigated. Moreover, the potential exposure of aircraft and ground receptors to unplanned debris can be quantified by accounting for debris aerodynamic properties and atmospheric uncertainties and propagating ensembles of representative break-up fragments to receptors such as aircraft, ships, and people. For both planned and unplanned debris, the dispersions arising from vehicle path and falling fragment uncertainties can be simulated using well developed aerodynamic modelling techniques. The process is often very computationally expensive, but the calculations can be done well in advance while still accounting for much of the launch-day uncertainties.
A category of lift vehicles with a long history that is gaining popularity for deployment of large payloads to the stratosphere and lower mesosphere is the long/ultra-long duration balloon (U/LDB), an example being NASA's zero pressure difference helium balloons. This class of balloons has several advantages for both scientific and military testing as well as commercial applications [2, 13, 14–16, 19].

For example, balloons are typically less expensive than rockets and enjoy the flexibility of being deployed from mobile launch facilities. Because control and FTS systems are simpler, flight readiness is simpler to verify, and because helium is inert and the balloon lift assembly does not contain propellants, balloons permit quick turn-around schedules. The absence of propellants also limits ground and near-ground catastrophic hazards that are possible from explosive motor failures. Balloons can be designed to lift sensitive payloads of over 3500 (kg). Because balloons can ascend and loiter into the lower mesosphere, they can serve as stable platforms for long-duration high-altitude missions lasting several hours or days. LDB balloon flights customarily last up to 3 weeks. With sufficient gas reserve and ballast (typically 6–8% of system mass) so that this neutrally-stable vehicle can response to diurnal changes, projected loitering times are expected to become hundreds of days in the case of ULDB's [5, 8].

Although launches are routinely conducted without incident, the un-powered nature of U/LBD's and their large hazard area for planned debris coupled with the ascent dispersion and their large payload capacity means that large populations can be placed at risk. Moreover, unplanned incidents have a high probability of being catastrophic and resulting in fatalities. Stated in other words, the risks from balloons derive from a small inventory of large, *high ballistic* coefficient fragments. In contrast to balloons, for rockets much of traditional flight safety methodology as drawn from RCC 321-10 and other standards revolves around quantifying the <u>descent</u> hazards from *low ballistic* coefficient wind-dispersed fragments which intrude into aircraft corridors and onto ground receptors.

For balloon launches the converse is true. Much of the uncertainty is dictated by wind-driven dispersion during <u>ascent</u>, while the footprints from planned and unplanned debris (such as large recovery parachutes and gondolas) during descent are moderated by the simpler vehicle and the lack of significant forward velocity and ΔV's [11]. Because much of the wind uncertainty for the ascent phase cannot be resolved until day-of-launch for U/LDB's, there is a much greater need for real-time risk assessment methodologies for both planned and unplanned debris in order to minimize any catastrophic risks to people and infrastructure. With these distinctions between the two risk management problems in mind, this paper illustrates the development of a new probabilistic risk methodology that has been developed to address the differences by quantifying the long-duration fatality-likely exposures to aircraft and ground-level receptors to U/LDB flights.

The methodology addresses risks during to launch operations during the ascent to float phase, and for any float manoeuvres and planned descent and recovery. It is computationally feasible, allowing for day-of-launch risk assessments to be generated within a few hours so as to accommodate the most favourable launch conditions. Since break-up state vectors and associated debris are physically propagated to ground receptors, the methodology avoids the undesirable smoothing which can occur with kernel density estimator methods [7] and expedites launch decisions by avoiding the need for "hard" exclusion corridors for ground risk. The methodology has been successfully applied to NASA's LDSD 2015 Campaign, notional elements of which will be used as a demonstration.

2. DESCRIPTION OF PROBLEM

References [1] and [2] provide background on historical and recent developments in U/LDB's. These balloons have continued to increase in size and lift capacity such that payloads on the order of 3000 (kg) can be lofted to 40–45 (km), and above 50 (km) with smaller payloads.

These altitudes can be viewed in the context of the physical atmosphere depicted in Figure 1. The ability to inexpensively lift tons of payload above 99.7% to 99.9% of the atmosphere and permitting its safe recovery while minimizing launch debris is significant.

Figure 2 shows a typical altitude flight profile for these missions — in this case from the NASA-sponsored "Big 60" mission launched on August 25, 2002, Lynn Lake, Manitoba, Canada. Not atypically, the actual launch occurred after several weeks of weather delays. The balloon — designed to have an ultimate lift capacity of 750 kg — carried instrumentation weighing 690 (kg) for the study of cosmic rays. As Figure 2 shows, the balloon climbed to a peak altitude of 49.4 (km). The mission was terminated normally after approximately 23 hours of flight time.

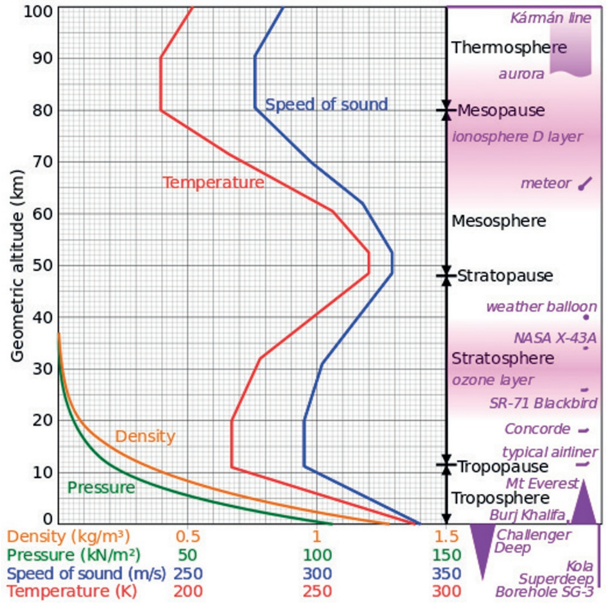

Figure 1. Atmosphere profile relevant to U/LDB operations. Earth balloons regularly ascend to densities of ≤ 0.033 (kg/m³). LDSD tests are conducted between 30 and 50 (km).

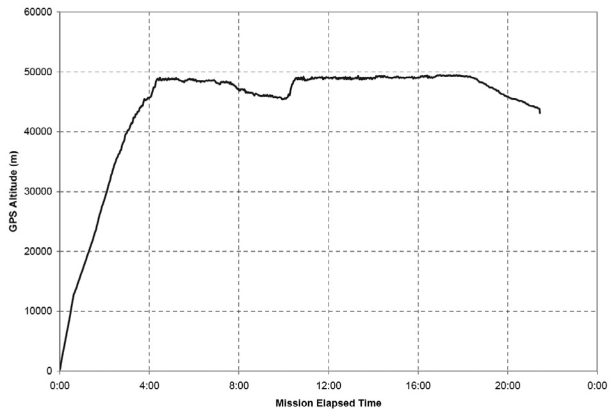

Figure 2. Balloon Flight Profile, 1.7 (Mm³) balloon, carrying 690 (kg) of instrumentation [2]. Horizontal axis is in hours.

A more interesting payload was provided by the LDSD mission, which is the focus of this paper. This is a NASA effort to develop inflatable pressure vessels called Supersonic Inflatable Aerodynamic Decelerators (SIADs) for delivering future payload and manned missions to the Martian surface. These drag devices are attached to the outer rim of an atmospheric re-entry vehicle and inflate at Mach 3.5 or greater, in order to decelerate the vehicle to Mach 2 where it becomes safe to deploy a supersonic parachute. An overview of the scientific program developed by NASA to test this concept in the earth's upper atmosphere, where conditions mirror those on Mars, is given in Refs. [2–3, 6].