Request For Proposal: Canadian Space Agency

Improving Gondola Cargo Carriers for the Canadian Space Agency’s Stratospheric Balloon Experiment

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Abstract

This Request for Proposal frames an opportunity to redesign the Canadian Space Agency's stratospheric balloon program (STRATOS) gondolas to better protect onboard cargo and improve the structure's durability. STRATOS regularly launches experiments and new technology in gondolas attached to helium balloons which lift them to the unique high-altitude environment of the earth's stratosphere [1]. Since 2018, the CSA has partnered with Students for Exploration and Development of Space (SEDS) to launch smaller-scale packages containing experiments of university design teams as part of the Canadian Stratospheric Balloon Design Challenge (CAN-SBX). This RFP has been scoped down to intently focus on designing CAN-SBX gondolas.

In comparison to satellites and rockets, stratospheric balloons are widely recognized as the fastest and cheapest means of testing technology and scientific experiments in a near-space environment due to short flight times [1] and the absence of active propulsion [2]. Such balloons are an attractive alternative for stakeholders including students and scientists who seek affordable and time-constrained access to stratospheric conditions.

Currently, the launched experimental cargo is stored in gondolas which are attached to helium-filled balloons; they return to the surface with significant data for astrophysics, aeromagnetics, and other aerospace research fields [3]. However, the cargo is frequently damaged and contaminated upon landing on trees, water, soil, and other natural terrains. Due to an insufficiently protected gondola carrier, compromised cargo results in financial, technical, and timely setbacks in data collection from the equipment stored aboard. Furthermore, the benefits of improving the CAN-SBX gondola design extend to the full-sized CSA gondola.

This document proposes a requirements model which focuses on high-level objectives to design a more protective and durable gondola while maintaining current functionality specifications. With consideration to the lived experiences of stakeholders, quantifiable metrics are used to analyze the effectiveness of reference designs and potential solutions. Current large-scale gondolas for telescopes fall short in versatility, while bus gondola systems have setbacks in cost and weight. Conceptual reference designs such as expanding/shrinking ball toys and crumple zones provide design teams low technicality inspiration for new designs. Supplementary research regarding the launch, flight, and landing processes is also provided to help lay out a holistic understanding of stratospheric balloons.

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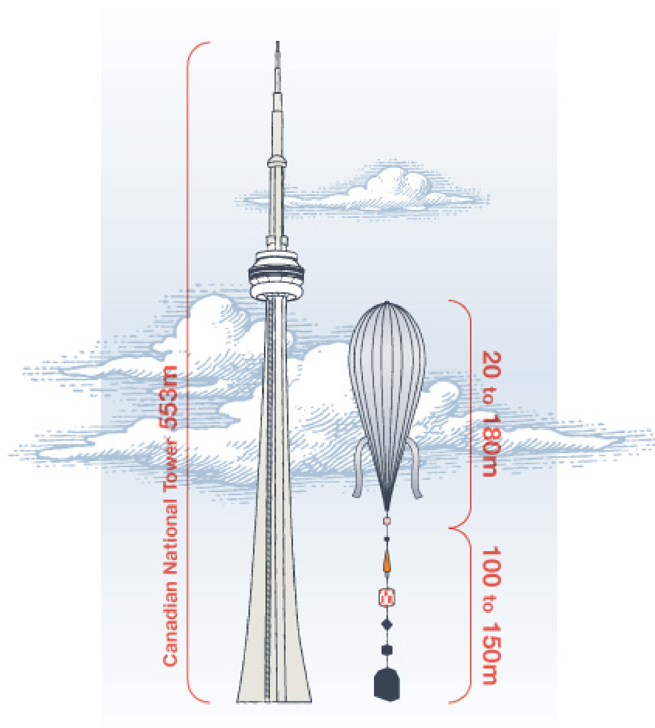
[1] *About stratospheric balloons*. (2018, July 25). Government of Canada. https://www.asc-csa.gc.ca/eng/sciences/balloons/about-stratospheric-balloons.asp

[2] Active propulsion entails the use of some fuel or powered system to produce thrust

[3] *Canadian Stratospheric Balloon Experiment Design Challenge (CBN-SBX)*. (2022, February 15). SEDS Canada. https://seds.ca/projects/can-sbx/

1. Introduction

The purpose of this Request for Proposal (RFP) is to outline an opportunity to redesign the gondola cargo carrier for the Students for the Exploration and Development of Space (SEDS). In partnership with Canadian Space Agency's (CSA) Stratospheric Balloon Program (STRATOS), SEDS regularly launches smaller-scale expandable helium balloons to test space mission technology and experiments in the stratosphere's near-space environment [1.1] (Figure 1.1). According to Dr. Alfred Ng, Deputy Director of Engineering and Capability Demonstration at the CSA, a lack of internal cargo protection and reusability of the gondola are the two principal concerns of the current design. In order to prevent fiscal and time costs associated with the technical setbacks of damaged experimental equipment, the goal of a new design would be to ensure the safe return of cargo [1.2] and allow for multiple launches, while maintaining mission functionality. The same problems and benefits of improvements hold true for full-sized CSA Stratospheric Balloon gondolas. This RFP provides an overview of the Canadian Space Agency, their goals, as well as the current challenge they face with the existing high-altitude balloon gondolas. It also proposes a requirements model on how to objectively and effectively approach the solutions design process. Supplementary researched references for existing engineering designs also provide potential starting points for improving SEDS stratospheric balloon gondola.



[Figure 1.1: Size comparison between the CN tower and the Full Sized CSA stratospheric balloon.] [1]

2. Team Values and Biases

2.1 Team Values

As Engineering Science students, after completing our course in Structures and Materials (CIV102), we found interest in investigating material properties and structure when accommodating various factors to optimize designs. Ultimately, this motivated us to seek out an opportunity related to structural design which can invite multiple approaches in creating solutions for the opportunity. Our team values closely align with the CSA's investigative and explorative values [35]. In addition, we quickly found ourselves intrigued by the engineering design problems they face in their activities. All of this culminated in our decision to choose the CSA as our partnering community.

2.2 Biases

Initially, regarding the subject of astronomy as something unrelated to our daily lives, we were hesitant in reaching out and seeking aerospace-related opportunities. Also, since most of the projects at CSA were conducted in ISS or at high-altitude environments around the exosphere, we assumed it to be a challenge to find an opportunity that suits our assignment time and feasibility criteria. However, further research and the active discussion with Dr. Ng taught us more about the functionality and significance of stratospheric balloons.

3. Community Introduction

The Canadian Space Agency (CSA) is a federal government agency responsible for the management of all "civil-space-related activities" [6]. The main focuses of the CSA's activities include the exploration, observation, and collection of data from space, and the applications of space technologies on Earth.

3.1 Values

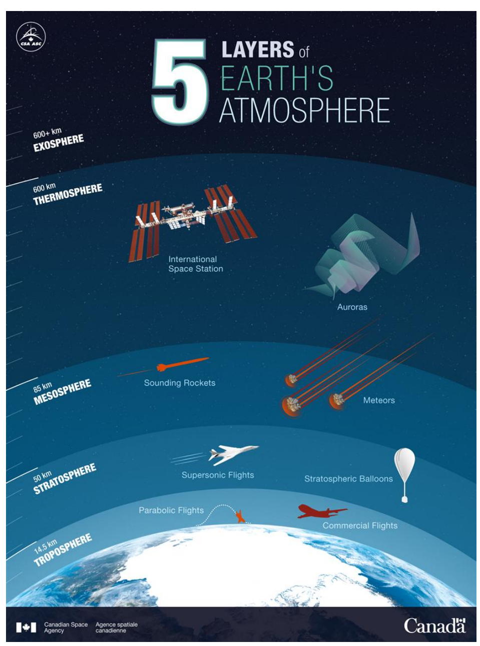
The CSA's core organizational values include innovation, inclusiveness, and collaboration [35]. Many of the numerous collaborative projects between the CSA and external organizations focus on the innovation of new technologies and research. The CSA's value of inclusivity is also demonstrated by their openness to sharing information with us, the RFP team, to further our project and provide us with a suitable opportunity. The CSA achieves their values through partnering often with various space agencies such as NASA and the ESA [33], industrial sectors, and academic institutions such as SEDS [6].

3.2 The STRATOS Program

In 2012, the CSA established STRATOS in collaboration with the French space agency, the Centre National d'Études Spatiales (CNSE) [24] to launch balloon campaigns annually (Figure 3.2A). A stratospheric balloon is made of latex or chloroprene [34], inflated with helium, and released to approach the stratosphere. An ideal atmospheric elevation where it is too low to have satellites and too high for aircrafts to fly [1.1], as shown in Fig. 3.2B. Multiple gondolas containing technological demonstrations are attached to the balloon.

These balloons carry out significant experiments while making flights to near-space environments much more accessible to scientists and entrepreneurs due to the cost and timeliness. Due to its lack of fuel and lesser amount of materials, the cost of an experiment conducted using a balloon is 1/40th of that of performing the same experiment using satellites [1.1]. Satellites, on average, take 7.5 years to fully launch and develop [37], and Nasa's most recent rocket required 11 years to build [38], while a stratospheric balloon can be launched and landed within one day [1.2]. As a result, the CSA's STRATOS program greatly benefits the aerospace technology industry.

[Fig. 3.2A: Photo of the first STRATOS campaign done in 2013.] [24]



[Fig. 3.2B: Infographic of where a stratospheric balloon is placed.] [1]

3.3 SEDS and the CAN-SBX Design Challenge

In 2021, SEDS launched the Canadian Stratospheric Balloon Experiment (CAN-SBX) Design Challenge in collaboration with the CSA. CAN-SBX works with post-secondary student teams to design and test small-scale experiments aboard a CSA stratospheric balloon (smaller versions of STRATOS). In the previous iteration of this challenge last year, student teams designed experiments for a CSA gondola that was a part of the STRATOS collaboration. The challenge is set to repeat in 2022 as well.

[Fig. 3.3A: Balloon and gondola for the small scale payload, 2022 iteration.] [5]

4. Stakeholder Analysis

4.1 Primary Stakeholders

The Canadian Space Agency is the primary stakeholder of this opportunity, as their experiments will be carried out using the stratospheric balloons. Designing an efficient and safe gondola for the instruments during flight missions is critical. The CSA has a vested interest in ensuring that their experiments are conducted as smoothly as possible to minimize monetary and time expenses. This means that reusability is a major factor to consider in the final design, as longer-lasting designs lower costs spent on manufacturing, which was also highlighted in the discussion with Dr. Ng [Appendix B]. In addition, the engineers and designers employed at CSA also hold stakes in the realization of this opportunity, since they are responsible for the execution of experiments. Their main priority would be the success of flight missions.

The gondola would serve to protect the cargo designed for CAN-SBX, a competition hosted by SEDS-Canada. Therefore, SEDS-Canada and the design teams involved in the competition would also be the stakeholders in which their needs must be considered. Examples of previous design teams participating in CAN-SBX have come from MacMaster University, Western University, University of British Columbia, and University of Alberta.

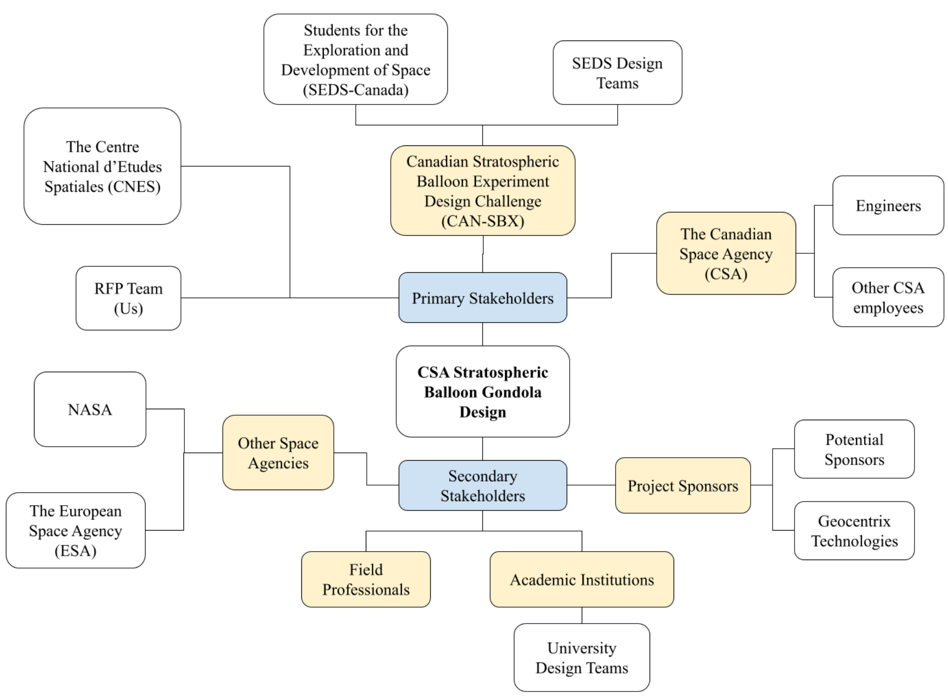
Since the CAN-SBX project was established as a part of the STRATOS program, which in turn was established in collaboration with France's space agency, the Centre National d'Etudes Spatiales (CNES) is also a primary stakeholder. The CSA-CNES agreement has the primary goal of providing "Canadian experts with access to French stratospheric balloon flight opportunities in Canada and abroad." [24]

Finally, as the authors of this RFP, our team is interested in designing a gondola that meets the needs of the stakeholders. Each member of the team contributes their personal and engineering design values to the realization of this opportunity in order to satisfy the interests of all of the stakeholders as mentioned above.

4.2 Secondary Stakeholders

Other space agencies such as NASA and the European Space Agency (ESA) are considered to be secondary stakeholders as they are also involved in various balloon projects at the CSA [33]. Improvements in the small-scale gondola design are applicable to the full-size gondola, therefore, those space agencies are indirectly relevant to this opportunity. Field professionals transporting, navigating, and launching the full-sized CSA balloon are also primary stakeholders when retraining, operating, and accommodating for a new gondola design.

Additionally, the sponsors of CAN-SBX have an interest in promoting the programs at CSA. A past sponsor is Geocentrix Technologies, a contracting and management company that collaborates with institutions in Canada and internationally with expertise in satellite missions [36].



[Figure 4: Tree Diagram of Stakeholders.]

5. How Stratospheric Balloons Work

High altitude balloon experiments are an invaluable tool of scientific research and academia as they provide a low-cost alternative to exploring the unique environmental conditions of the upper atmosphere and frontiers of space. It is therefore necessary that the balloons come in a wide range of payload capacities; some carrying only a few grams of weather monitoring tools and others supporting more than a ton of telescopic instruments. However, the underlying principles that allow them to fly so high remain the same. The supplementary information provided here regarding the fundamentals of the launch, flight, and landing processes will give design teams a comprehensive understanding of the existing technology before proposing improved gondola designs.

5.1 The Ascent

Perhaps the most important concept to understand is how and why a high altitude balloon, filled with helium, is able to lift payloads to such great heights. The foundation of explaining this phenomenon was laid by Archimedes' Principle. It framed the law of buoyancy and included two very important discoveries:

1. A body that has been partially or completely submerged in any fluid, experiences an upward reaction (buoyant) force with a magnitude equal to the weight of the fluid displaced by the body.
2. The volume of fluid displaced by a partially or completely submerged body is equal to the total volume of the body submerged in the fluid.

From these two principles, it can be deduced that a less dense gas, submerged in a denser one, experiences a buoyant force that is greater than its own weight. As a result, it is pushed upwards. Since helium has a density of 0.1785 kg/m^3 while regular air at STP (at one atm, 0 C°) is 1.225 kg/m^3, a balloon filled with helium floats and ascends at upto 1000 ft/min [29]. A greater volume of helium (bigger balloon) displaces a larger volume of air and consequently experiences a larger buoyant force [27]. This allows it to lift heavier payloads into the atmosphere.

5.2 The Pop

As the balloon rises, the density of the atmosphere decreases, and consequently, the force pushing **inwards** on the outside of the balloon decreases. At maximum altitudes, the atmosphere is 100 to 200 times less dense than at Standard Temperature Pressure [30]. As a result, the relative pressure within the balloon increases so that the trapped gas begins to expand and exert a greater force pushing **outwards** on the walls of the balloon.

For the same reason, balloons are not filled to full capacity before launch. This gives the helium room to expand through the journey. The amount of helium needed to fill the balloon is calculated before launch to ensure that the balloon reaches the desired altitude without exploding.

Once the maximum float-altitude is achieved, the helium's force on the balloon exceeds the restorative elastic force of the latex. This causes it to rupture and drop into free fall [30].

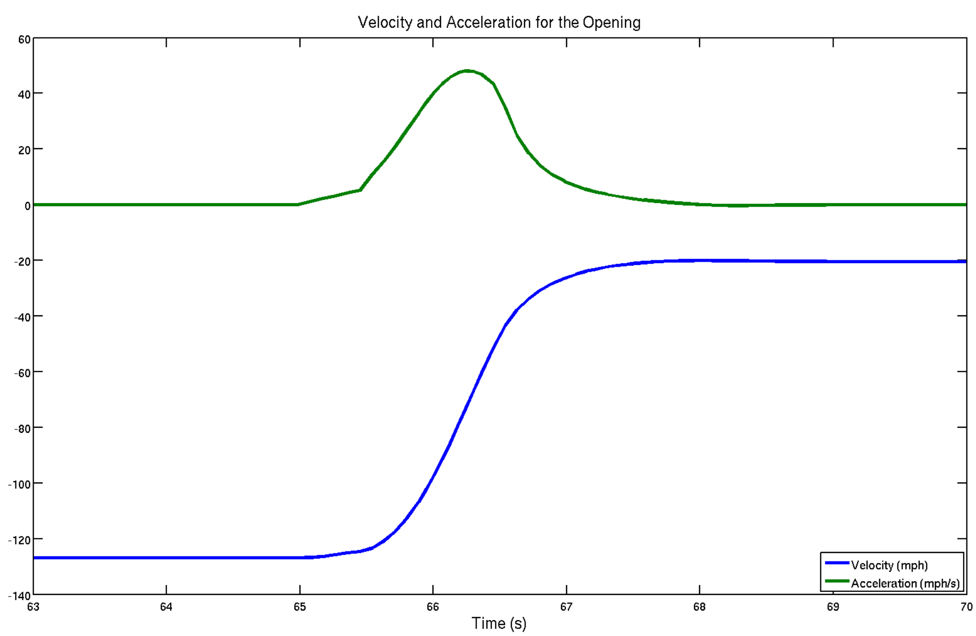
5.3 The Recovery

As the gondola plummets to the surface of the earth, its velocity increases until it attains terminal velocity. A pilot chute deploys to create drag forces and tails the falling gondola while remaining connected to the trigger pin for the primary chute.

Steadily, the surrounding atmospheric pressure increases and applies greater air resistance on the pilot chute. This force is transmitted directly to the trigger for the parachute. When the force crosses a certain threshold, indicating that the gondola has reached deployment altitude, the pin is released and the parachute opens. Although the release takes only a couple of seconds, the gondola experiences high dynamic loading. It can undergo as much as four to five times the acceleration of gravity.

Furthermore, the final impact with the ground can pose detrimental to the precious cargo on board. While the mission is planned by taking into consideration multiple factors such as weather conditions and wind patterns to predict the landing location of the gondola, it is almost impossible to precisely predict the terrain that the gondola might encounter upon touchdown. As Dr. Alfred Ng recalls, there have been times that the gondola's cargo has been impaled by trees or has landed in a lake [Appendix B].

It is mission-critical to design a gondola that resists the various conditions that it may encounter in order to successfully protect the onboard cargo.



[Figure 5.1: Velocity and Acceleration vs time graph during free fall.] [31]

6. Opportunity Scope

6.1 Opportunity Statement

"What we need is a gondola that is strong enough (...) and can be used through multiple missions." - Deputy Director Dr. Alfred Ng

From Dr. Ng's interview statements, the crux of this opportunity lies in an improved **gondola's ability to protect the interior cargo and preserve the exterior structure for future launches, while maintaining existing designated functionality**.

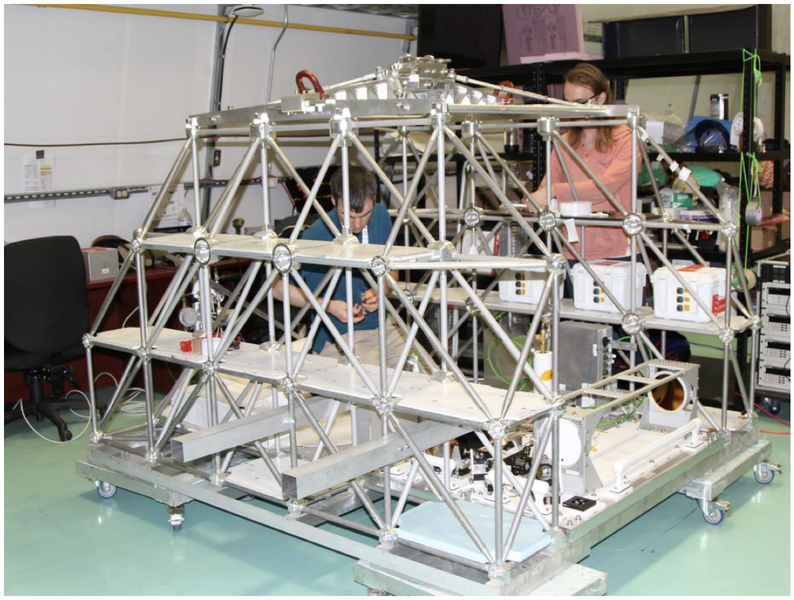
According to other interview statements [Appendix A] and SEDS website [7], throughout the creation of the CAN-SBX campaign, the CSA was focused on developing the sensor arrays, tracking technology, and parachute deployment mechanism while also supporting student teams in optimizing the technical cargo being launched. The experiments were intricate and sensitive pieces of technology for astrophysical, atmospheric, magnetic field, and biological research which required in-depth knowledge in their respective developments. In comparison, the design of the vessel for storing the experiments, the gondola, was not dedicated as many resources.

In reference to 4.2B, the hexagonal shape of the gondola is arbitrary, "it could have very well been a rectangle, cube, sphere, anything" (Appendix B-2). Furthermore, the exposed space between the wooden and metal frames allows for trees and other natural elements (water, soil) to puncture and contaminate the internal cargo during landing. "It met the requirements at the time but may not always" (Appendix B-3). "We have had gondolas be damaged due to cargo being impaled by trees" (Appendix B-3). Individual design teams even attached rudimentary plastic zip-ties to secure their cargo more effectively [5].

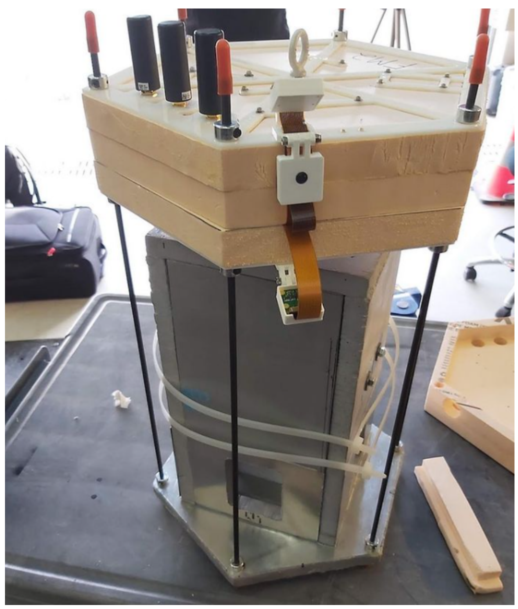
6.2 Scope Details

To clarify the scope of our opportunity and given the constraint of a 6-week timeline, the design should be made for the SEDS launch. While the implications of the benefits for an improved gondola design (found in Community Background Section) hold for both the smaller SEDS and the larger CSA scale launches (Figure 4.2), design for the SEDS launch is of higher priority for CSA and requires greater attention due to being unoptimized.

In partnership with the CSA, SEDS hosts a competition for university design teams to create and launch compact near-space experiments on gondolas attached to stratosphere balloons [5]. Teams' smaller scale experiments are stored in styrofoam boxes and loaded onto the gondola. Smaller dimension constraints of the experimental cargo are found in the Requirements Model Section.



[Figure 6.2A: Full-sized CSA Launch Gondola (Metal and Wooden Frame), carries 1.1 tons (1100 kg) loa===d.] [4]



[**Figure 6.2B: Small scale SEDS Launch Gondola (Metal and Wooden Structure with Black Bars), carries 3kg load.] [5]**

7. Requirements

This requirements model outlines specific goals and guidelines which instruct designing improvements to the CAN-SBX Gondola. In order to meet the needs of the stakeholders, high-level objectives were formed in consideration of the following DfXs:

1. Design for Safety: Maintain the safety of the cargo stored in the gondola carrier from the launch to the landing of the balloon.
2. Design for Functionality: Accommodate the dimensions and functionality of the cargo, parachute, control system, and all other launched components.
3. Design for Durability and Versatility: Is reusable for future launches.
4. Design for Cost: Is cost-efficient.
5. Design for Manufacturability: This is replicable for numerous manufacturing instances; the gondola is consistent across all physical productions of the design.

7.1 Requirements Model

1. Design for Safety	
1.1	**Mitigate damage to cargo**
	Metric: Presence of visible fracture after landing (Y/N) **Constraint:** must not have a visible fracture
1.2	**Resistant to water**
	Metric: Amount of water leaked inside the gondola after immersion in milliliters (mL) [13] **Criteria:** Less is preferred **Constraint:** should have no water leakage inside when subject to temporary immersion in water (greater than or equal to IPX 7)
1.3	**Resistant to vibration**
	Metric: Structural vibration in hertz (Hz) [10] **Criteria:** Less is preferred **Constraint:** must not be greater than 20 Hz (the vibration of the reference design)
	Justification: One of the key issues upon landing is the damaging of the equipment contained inside the gondola. It is part of the stakeholder's interest to have the cargo safely arrive back at the landing site (in water, on land, etc.). Therefore, it is necessary to minimize the damage and the leakage of water inside the gondola.

2. Design for Functionality		
2.1	**Minimize structural deformations**	
[2.1]	**Metric:** Mass of payload the gondola can withstand before it ruptures (kg) **Criteria:** Greater is preferred **Constraint**: Must support at least three (3) kilograms	**Metric:** Structural deflection in millimeters (mm) under maximum dynamic loading (15G) **Criteria**: Less is preferred
2.2	**Have sufficient capacity in the payload bay to accommodate cargo**	
[2.1]	**Metric:** Usable volume within payload bay measured in cubic millimeters (mm^3) **Criteria:** Greater is preferred **Constraint:** Must accommodate a cylindrical payload with 524 mm height and 285 mm diameter	
2.3	**Resist all encountered high altitude environmental conditions**	
[2.1] [1.3]	**Metric:** measurement deviation from required performance (°C, hPa) **Criteria:** Less is preferred	
	Constraint: Must withstand temperature difference from -56 to 0 °C	**Constraint:** Must withstand atmospheric pressure difference from 250 to 1 hPa
2.4	**Be lightweight**	
	Metric: Mass of complete system in kilograms (kg) **Criteria**: Less is preferred **Constraint** : Must be less than seven (7) kilograms [Appendix B-1]	
2.5	**Have the reserved volume for accommodating the parachute deployment mechanism and control system electronics**	
	Metric: Reserved volume measured in cubic millimeters (mm^3) **Criteria**: Greater is preferred **Constraint** : Must be at least 1200×10^6 mm^3 [2]	
2.6	**Secure payload during flight**	
	Metric: Movement of payload during vibration test measured in mm [10] **Criteria**: Less is preferred	
2.7	**Be balanced**	

[2.1]	**Metric**: Eccentricity (deviation of the center of mass) of the gondola during the flight in millimeters (mm) **Criteria**: Less is preferred
2.8	**Allow unrestricted transmission of radio signals**
	Metric: Penetration depth in millimeters (mm) **Criteria**: Greater is preferred **Constraint**: Must allow free communication from a distance greater than 42 km [1]

Justification: The primary objective of a stratospheric balloon is to lift apparatuses and equipment to high altitudes where the unique conditions of the atmosphere can be analyzed and utilized to conduct specialized experiments. In order to accomplish this, the balloon must be capable of safely transporting the payloads, be impervious to extreme conditions, be weight-conscious, and permit unobstructed radio signal transmission during the flights.

The gondola can be expected to experience high dynamic loading due to the strong G-forces experienced during parachute deployment. It is important to take this into consideration when designing the gondola as having a fragile structure could be detrimental to the mission. A basic requirement is for it to carry a load of 3 kilograms that is experiencing 15 Gs of acceleration (with a factor of safety of two) [3]. Simultaneously, it should be ensured that the gondola has the appropriate volume, dimensions, and anchor points to successfully secure the cargo.

Furthermore, since the gondola is to be lifted into the upper extremities of the stratosphere, it must be able to resist the negative effects of rapid temperature changes. For example, the stratosphere has an average temperature of -51°C while the balloon experiences much warmer weather close to the surface[16]. Therefore, the use of temperature-sensitive materials would not be appropriate.

In addition, a heavier gondola would require a larger balloon to counteract the effects and would increase the cost of the mission. Furthermore, since the gondola would be subject to significant wind force during the flight, the gondola must be balanced to reduce the vibration of the system and thus the damage to the payload.

Since the gondola contains electronic communication equipment and a parachute deployment system, the design must reserve space for the accommodation of these, and the materials used in making the gondola should be permeable to radio waves for unrestricted communication.

3. Demonstrate versatility and durability		
3.1	**Material is resilient**	
	Metric: Resilience of most prominent material in the gondola in J/m^3 **Criteria:** Less is preferred **Constraint:** Should be greater than the resilience of aluminum (3×10^5 J/m^3) (current material)	
3.2	**Maximize reusability**	
[2.1]	**Metric:** Number of hours the gondola is functional (hr) **Criteria:** more is better **Constraint:** must be greater than 3 hours	**Metric:** Number of times the gondola can be reused **Criteria:** more is better **Constraint:** more than once (the number of times currently reused)
3.3	**Resistant to dynamic loading (G-force) during the flight**	
	Metric: Magnitude of G forces the gondola can resist before failure measured in m/s^2 [Appendices 12.1] **Criteria:** more is better **Constraint:** should be greater than 15G [3]	
3.4	**Minimize abrasion damage (wearing away of material)**	
[2.1]	**Metric:** Tensile strength measured in Megapascals (MPa) [11] **Criteria:** More is better **Constraint:** Greater than the tensile strength of Aluminum, the material currently used (95 MPa) [25]	
3.5	**Have a venting area**	
	Metric: Surface area in cm^3 **Criteria:** Greater is preferred **Constraint**: Must be greater than 2 cm^3 [18]	
	Justification: In consideration of the various costs associated with launching stratospheric balloons, a durable gondola enables it to be reused and increases the ease of access to balloon observations. One of the specifications enlisted on the payload requirements is the resistibility against the fluctuation in pressure [18]. The same applies to the gondola, so a venting system must be put in place. To accomplish this objective, the material used for the gondola must be strong, which can be measured by assessing the resilience and the toughness of the materials to	

	ultimately maximize the number of times the same gondola can be reused. Also, the outer structure of the gondola must be organized in a way to distribute the loading imposed upon landing. Previous materials used include metal, aluminum metal, and wood.

4. Design for Cost	
4.1	**Minimize cost**
	Metric: Price in dollars (CAD) **Criteria:** Less is better
	Justification: Excluding the cargo to be stored inside, the price of materials, manufacture, transportation, and all other labor contributing to the physical creation of the gondola is covered by CSA's government funding. Alfred indicated that other projects have a higher priority for allocated financial resources.

5. Design for Manufacturability			
5.1	**Ease of assembly**		
	Metric: Number of people required to assemble design **Criteria:** Less is better	**Metric:** Number of steps to assemble and operate design **Criteria:** Less is better	**Metric:** Time to fully assembly in hours (hr) **Criteria:** Less is better
5.2	**Easy to store**		
	Metric: Volume of space occupied by design when not in use (m^3) **Criteria:** Less is better (Potential folding/shrinking mechanism)		**Metric:** Volume of space occupied by design when disassembled (m^3) **Criteria:** Less is better
	Justification: Given the amount of higher-priority projects requiring the resources of CSA's in-house manufacturing, ease of assembly ensures that the gondola will not be an inconvenience or neglected by production, labor, and storage. Furthermore, it is favorable for the design to not require advanced training for the launching team to operate the gondola to make replication easier. Considering the client stakeholders designing internal cargo, understanding the gondola's storage mechanisms through simple assembly steps will allow for more freedom in cargo design.		

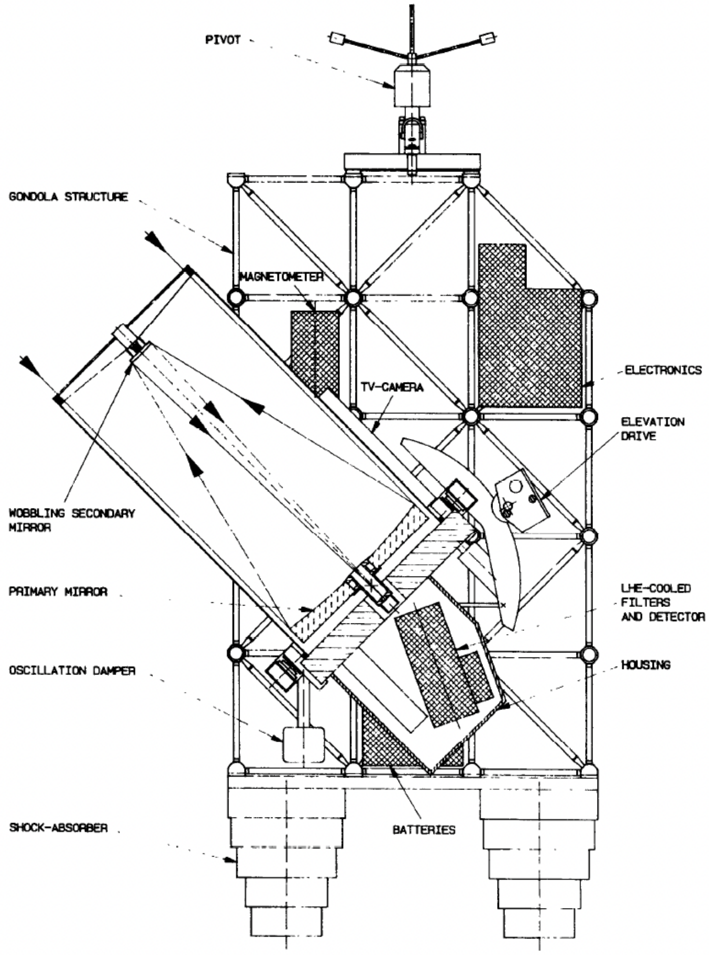
7.2 Requirements Model Visual Representation (Appendix A, magnified version)

	High Level Objectives	Low Level Objectives	Metrics	Criteria	Constraints
Requirements for CAN-SBX Gondola	Safety	Mitigate damage to cargo	Presence of visible fracture after landing (Y/N)		no visible fractures
		Resistant to water	Amount of water (mL)	Less	
		Resistant to vibration	Structural vibration (Hz)	Less	
	Functionality	Minimize structural deformations	Mass of payload gondola ruptures (kg)	More	minimum 3 kg
			Structural deflection (mm)	Less	
		Have sufficient capacity for cargo	Usable volume in payload bay (mm³)	More	accommodate a cylindrical payload with 524 mm height and 285 mm diameter
		Resist all encountered high altitude environmental conditions	Measurement deviation from required performance (°C, hPa	Less	withstand temperature range -56 to 0 °C
					withstand pressure range 250 to 1 hPa
		Be lightweight	Mass of complete system (kg)	Less	maximum 7 kg
		Have the reserved volume for accomodating the parach	Volume measured in cm³	More	minimum 12000 $*10^5$ mm³
		Secure payload during flight	Movement of payload during vibration test	Less	no movement
		Be balanced	Eccentricity during the flight (mm)	Less	
		Allow unrestricted transmission of radio signals	Penetration depth in millimeters (mm)	More	communication distance greater than 30 km
	Durability	Material is resilient	Resilience of the gondola in J/m³	Less	more than the resilience of aluminum (3×10^5 J/m³)
		Maximize reusability	Number of hours the gondola is functional (hr)	More	more than 3 hours
			Number of times the gondola can be reused	More	more than 1 (once)
		Resistant to dynamic loading (G-force) during the fligh	Magnitude of G forces resisted before failure (m/s²)	More	more than 15 G
		Minimize abrasion damage (wearing away of material)	Tensile strength measured in Pascals (Pa)	More	
		Have venting area	Surface area in cm³	More	
	Cost	Minimize cost	Price in dollars (CAD)	Less	
	Manufaturability	Ease of Assembly	Number of people required to assemble design	Less	
			Number of steps to assemble and operate design	Less	
			Time to fully assembly in hours (hr)	Less	
		Easy to store	Volume of space when not in use (m³)	Less	
			Volume of space when disassembled (m³)	Less	

8. Reference Designs

8.1 Large Scale Stratospheric Balloon Gondola for Telescopes

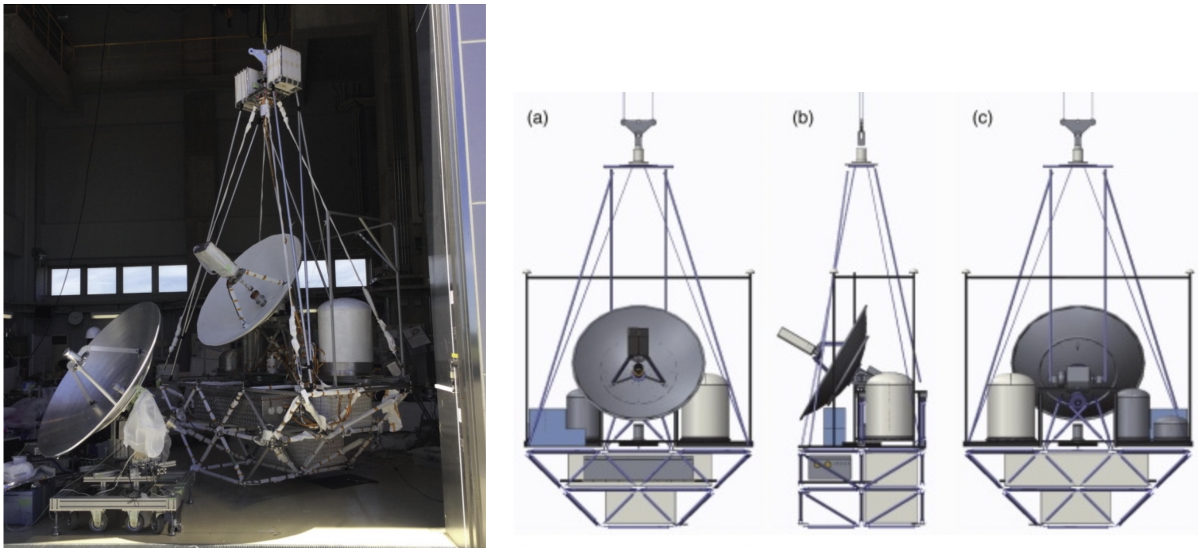
This reference design is structured to address stability, energy absorption at landing (deformation without rupture), and the ease of repairing. The structure is made of medium-hard aluminum alloy and has a layered outer covering of Dacron-aluminized polyester mesh-Dacron to protect from the lowering temperature in the stratosphere. It establishes greater rigidity with the stiffeners, diagonals, and crosses in the structure. Additionally, the empty spaces are filled with styrofoam blocks to minimize the movement of the instruments. Shock absorbers are placed on the legs to prevent ruptures. Given that the gondola was specifically designed for containing a telescope, the interior of the structure lacks flexibility in the items that can be stored. For instance, the shape of the styrofoam must be adjusted every time a different instrument is placed inside. Therefore, it falls short in versatility, so a modification for a more adaptable gondola is critical. The gondola design for our scoped opportunity is not for telescopes and instead must accommodate a cylindrical payload that is 524 mm in height and 285 mm in diameter (Requirements Model, Objective 2.2).



[Figure 8.1: Schematic side view of the gondola and the telescope.] [9]

8.2 Bus Gondola System

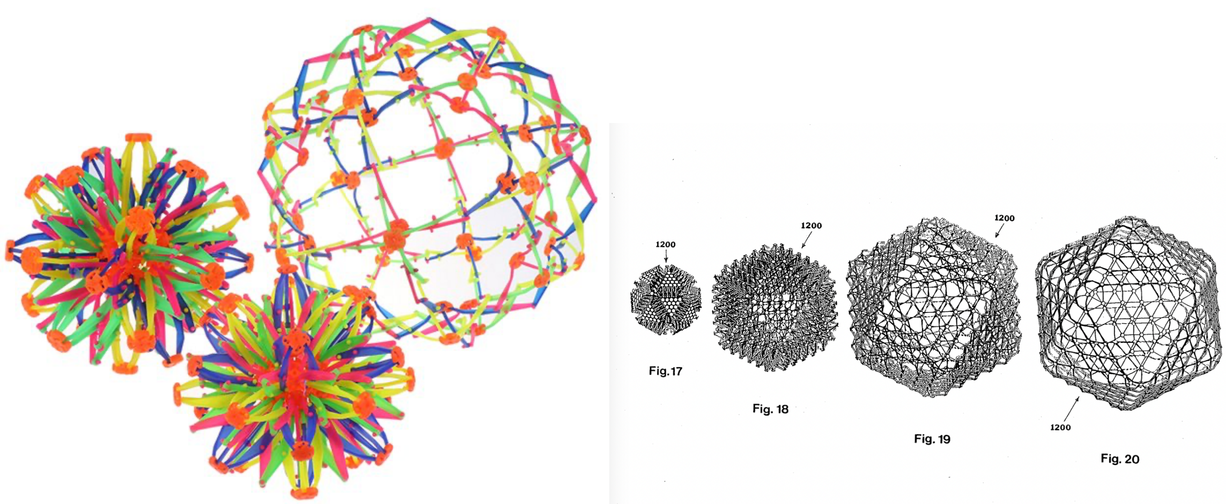
This reference design incorporates a boat-shaped truss structure as the base frame, which is formed from SUS304 (stainless steel) pipe rods to decrease elasticity and increase the rigidity of the gondola; SUS304 has a high modulus of elasticity measurement of 193-200 GPa (higher modulus indicates greater stiffness) [20, 21]. An aluminum material was used to resist the brittleness and to ensure the functionality of the geomagnetic sensor at lower temperatures in high altitudes. To accommodate for thermal deformation during the flight, the truss structure and the aluminum frame were secured with a degree of freedom. Assuming that the gondola would be retrieved from the sea upon landing, floatable polystyrene foam is included inside the truss structure. Additionally, iron powders are loaded at the base as ballasts to ensure the floating of the gondola. Although this design is feasible, it failed to meet the objective of cost and weight in the original larger-scale project. The two problematic aspects also hold true for the scoped smaller-scale opportunity, so usage of other materials and structures must be considered to address those issues.



[Figure 8.2: Truss structure and aluminum frame supporting the antenna.] [26]

8.3 Expanding and Shrinking Ball Toy

This reference design serves as an inspiration for a shrinking and expansion mechanism for gondolas. Having a double-curved truss structure made out of closed-loop assemblies allows the system to be reversibly expandable and shrinkable (Figure 8.3). This feature is convenient when inserting the cargos inside the gondola and accommodating to the change in payload size. The shrinking mechanism could be useful in molding around and protecting the valuable cargo during flight. Furthermore, if the structure were to expand prior to impact, it would help distance the cargo from the point of impact, thereby adding increased protection. The layered structure also provides a smooth distribution of the load and, consequently, reduces the overall burden on the gondola. A flexible container like this is ideal to protect the cargo while preserving the convenience of accommodating the payloads. This reference design especially satisfies Objective 5 regarding design for manufacturability (easy to store and assemble).

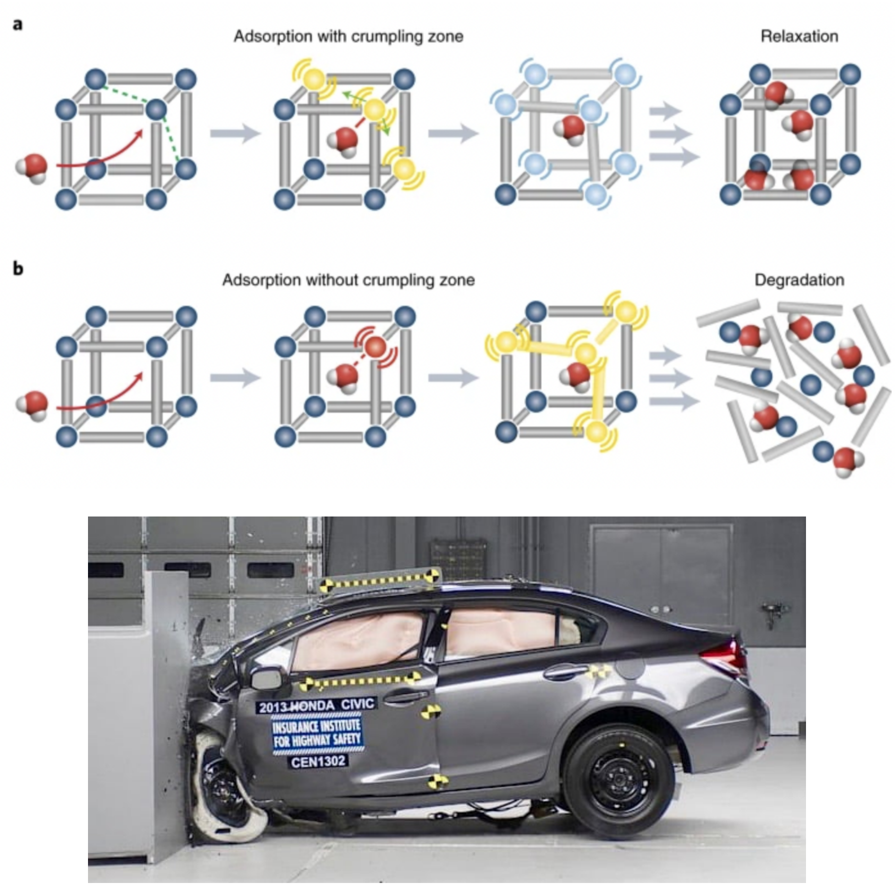


[Figure 8.3A: Stretching and shrinking ball sphere toy.] [19]

[Figure 8.3B: Diagram of the double-curved structure.] [19]

8.4 Crumple Zones

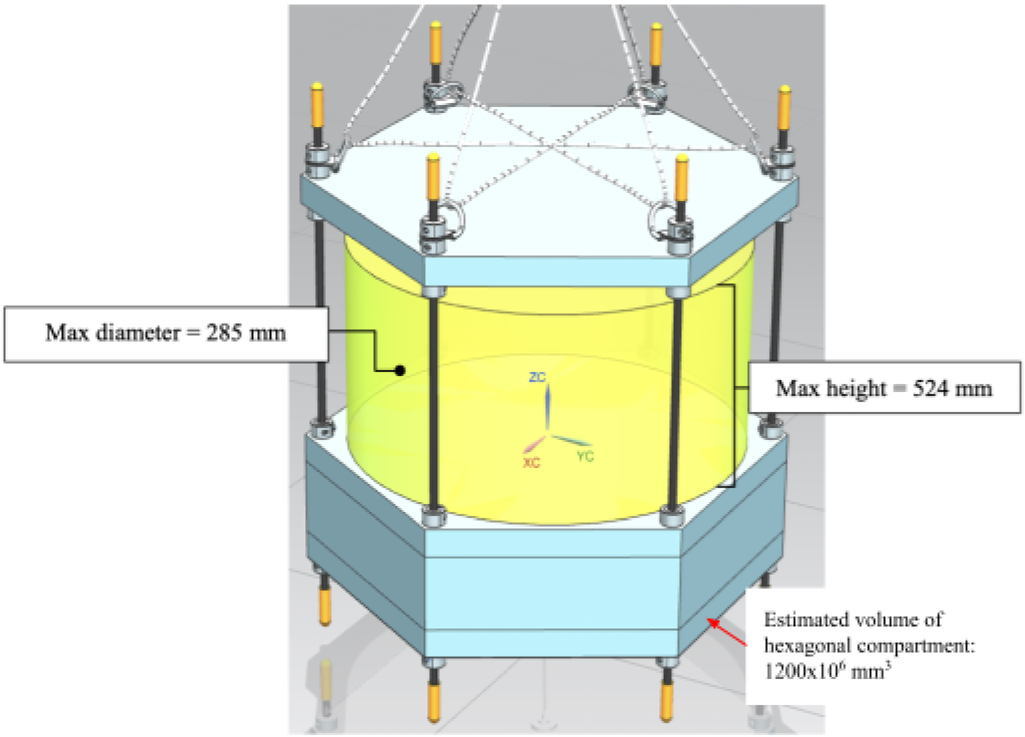
A mechanism called "crumple zones" is implemented into automobiles. Automotive engineers intentionally set aside parts of the exterior to deform upon collision. The deformation absorbs the collision energy and functions to protect the sensitive areas, namely the passenger seats in the case of automobiles (yellow/black taped zone indicated in Figure 8.4). This implementation is only feasible for automobiles because it assumes that collisions do not happen frequently. In the case of potential gondola designs, it would not satisfy Objective 3, Design for Durability and Versatility, since it would deform every launch as it absorbs impacts upon landing. Ideally, a structure that produces a regenerative crumple zone with the capability to be reused should be introduced to gondolas.



[Figure 8.4: Diagram of the crumple zone mechanism.] [22] [23]

8.5 2021 CAN-SBX Gondola Payload Bay

While not optimized, the gondola used in the 2021 CAN-SBX competition had a hexagonal structure made out of aluminum and wood. Teams had the option to cover the exterior with hexagonal foams to provide extra cushion to the system. Plus, the triple layered structure at the bottom ensured more resistance to impact. This design had various issues such as the lack of insulation to protect the cargos and also failed to meet the majority of other requirements. Still, it attained the minimum requirement to carry the payloads, so it would serve as the baseline for future designs.



[Figure 8.5: Payload boundary envelope.] [3]

9. Conclusion

After launching the quickest and cost-effective trip to near-space [28], CSA's stratospheric balloon gondolas frequently damage sensitive cargo stored inside. The lack of protectiveness and durability leads to financial, technical, and timely setbacks for experimental results in CAN-SBX campaigns. The design opportunity to mitigate damage to cargo and gondola carriers will benefit innovative space technology tested in the earth's atmospheric environment. This RFP frames the core opportunity to improve experimentation under weightless environments supported by background information and high-level design objectives.

10. Contact Information

Dr. Alfred Ng (Deputy Director of Engineering and Capability Demonstration at the CSA): alfred.ng@asc-csa.gc.ca

11. Reference List and Source Extracts

[1] *About stratospheric balloons*. (2018, July 25). Government of Canada. https://www.asc-csa.gc.ca/eng/sciences/balloons/about-stratospheric-balloons.asp

[2] Students for the Exploration and Development of Space. (2021). *Canadian Stratospheric Balloon Experiment Design Handbook.* Government of Canada.

[3] Canadian Space Agency. (2021). *Canadian Space Agency Stratospheric Balloons Program.* Government of Canada.

[4] Luigi, E. (2019). Scientists prepare latest fleet of stratospheric balloons. https://www.timminspress.com/news/local-news/scientists-prepare-latest-fleet-of-stratospheric-balloons

[5] Polyorbite. (2021, November 19). Retrieved from https://www.instagram.com/p/CWejqJZLuOY/

[6] *About*. (2018, July 25). Government of Canada. https://www.asc-csa.gc.ca/eng/about/csa-organization.asp

[7] *Canadian Stratospheric Balloon Experiment Design Challenge* (2018, July 25). Students for the Exploration and Development of Space. https://seds.ca/projects/can-sbx/

[8] Huguenin, D. (1994). Design and performance of stratospheric balloon-borne platforms for infrared astrophysical observations. *Infrared Physics & Technology*, *35*(2-3), 195-202.

[9] Nock, K. T., Heun, M. K., & Aaron, K. M. (2002). Global stratospheric balloon constellations. *Advances in Space Research*, *30*(5), 1233-1238.

[10] International Organization for Standardization. (2021). *Space systems — Vibration testing* (ISO Standard No. 23670: 2021).

[11] International Organization for Standardization. (2014). *Geosynthetics — Abrasion damage simulation (sliding block test)*. (ISO Standard No. 13427: 2014).

[12] International Organization for Standardization. (2005). *Space systems — Fracture and damage control*. (ISO Standard No. 21347:2005).

[13] International Electrotechnical Commission. (1998). *Ingress Protection Expertise* (IEC Standard No. 60529).

[14] MIL-STD-810G, *DEPARTMENT OF DEFENSE TEST METHOD STANDARD: ENVIRONMENTAL ENGINEERING CONSIDERATIONS AND LABORATORY TESTS*

[15] IEC 61391-2, *Ultrasonics - Pulse-echo scanners - Part 2: Measurement of maximum depth of penetration and local dynamic range*

[16] National Weather Service. *Layers of the Atmosphere*. Retrieved February 19, 2022, from https://www.weather.gov/jetstream/layers#:~:text=Heat%20is%20produced%20in%20the,is%20located%20above%20cooler%20air

[17] Stasiowska, D. (2020). Can we be with Bee on Mars? Evaluating the Impact of a Rocket Flight on the Condition of Honeybees (). *Transactions on Aerospace Research*, *2020*(2), 36-46.

[18] Canadian Space Agency. (2021). *STRATOS Expandable Balloon Payload Requirements and User's manual.* Government of Canada. https://seds.ca/wp-content/uploads/2021/02/CSA-STRATOS-MAN-0011-Rev-A-Stratos-Expandable-Balloon-Payload-Requirements-and-Users-Manual.pdf

[19] Hoberman, C. (1990). *U.S. Patent No. 4,942,700*. Washington, DC: U.S. Patent and Trademark Office.

[20] All About 304 Steel (Properties, Strength, and Uses). (2022). Thomasnet. https://www.thomasnet.com/articles/metals-metal-products/all-about-304-steel-properties-strength-and-uses/

[21] Modulus of Elasticity for Metals. (2022). Amesweb. https://amesweb.info/Materials/Modulus-of-Elasticity-Metals.aspx

[22] Crumple Zones. (2020). Ontario Hyundai. https://www.ontariohyundaicars.com/2020/11/13/crumple-zones/

[23] Senker, J. (2018). Crumple zones in MOFs. *Nature Chemistry*, *10*(11), 1079-1081.

[24] Canadian Space Agency. (2018, July 25). *About Stratos, the CSA's Stratospheric Balloon Program*. Canadian Space Agency. Retrieved February 19, 2022, from https://www.asc-csa.gc.ca/eng/sciences/balloons/stratos.asp

[25] aalco. (2019). Aluminum Alloy Specifications. https://www.canada.ca/en/department-finance/programs/international-trade-finance-policy/measures-steel-aluminum-businesses/list-goods-remission-countermeasures.html

[26] Doi, A., Kono, Y., Kimura, K., Nakahara, S., Oyama, T., Okada, N., ... & Koyama, S. (2019). A balloon-borne very long baseline interferometry experiment in the stratosphere: Systems design and developments. *Advances in Space Research*, *63*(1), 779-793.

[27] Britannica, T. Editors of Encyclopaedia (2020, May 29). *Archimedes' principle*. *Encyclopedia Britannica*. https://www.britannica.com/science/Archimedes-principle

[28] NASA. (2020, April 20). B-Line to Space: The Scientific Balloon Story. YouTube. https://www.youtube.com/watch?v=sPQ-tMoAHkY

[29] Britannica, T. Editors of Encyclopedia (2020, November 4). *helium*. *Encyclopedia Britannica*. https://www.britannica.com/science/helium-chemical-element

[30] ScientificBalloons FAQs. (2022, January 28). Retrieved February 19, 2022, from https://www.nasa.gov/scientificballoons/faqs

[31] *Velocity and Acceleration vs time graph during free fall*. (n.d.). MIT Skydiving. Retrieved February 19, 2022, from http://skydive.mit.edu/faq.shtml#howmanyGs.

[32] *Canadian Space Agency*. (2021, December 8). Government of Canada. https://www.asc-csa.gc.ca/eng/Default.asp

[33] *Book 4 - CSA Partners*. (2020, December 21). Government of Canada. https://www.asc-csa.gc.ca/eng/transparency/briefing-materials/2020-book-4-csa-partners.asp

[34] *Canadian Stratospheric Balloon Experiment 2021 Campaign*. (2021, July 29). Government of Canada. https://www.asc-csa.gc.ca/eng/sciences/balloons/campaign-can-sbx-2021.asp

[35] *Canadian Space Agency Organizational Values and Ethic Code*. (2021, January 20). Government of Canada. https://www.asc-csa.gc.ca/eng/about/code-csa.asp

[36] *Geocentrix Technologies Ltd.*. Geocentrix Technologies Ltd. (n.d.). Retrieved February 19, 2022, from https://www.geocentrix.ca/

[37] Davis, L. A., & Phillip, L. (n.d.). (rep.). *How Long Does It Take to Develop and Launch Government Satellite Systems?* Aerospace. Retrieved February 19, 2022, from https://www.iceaaonline.com/ready/wp-content/uploads/2014/03/Davis-Satellite-ICEAASoCal-090915.pdf

[38] Brown, D. W. (2021, March 17). *NASA's last rocket*. The New York Times. Retrieved February 20, 2022, from https://www.nytimes.com/2021/03/17/science/nasa-space-launch-system.html

Source Extracts:

[1.1]

What is a stratospheric balloon?

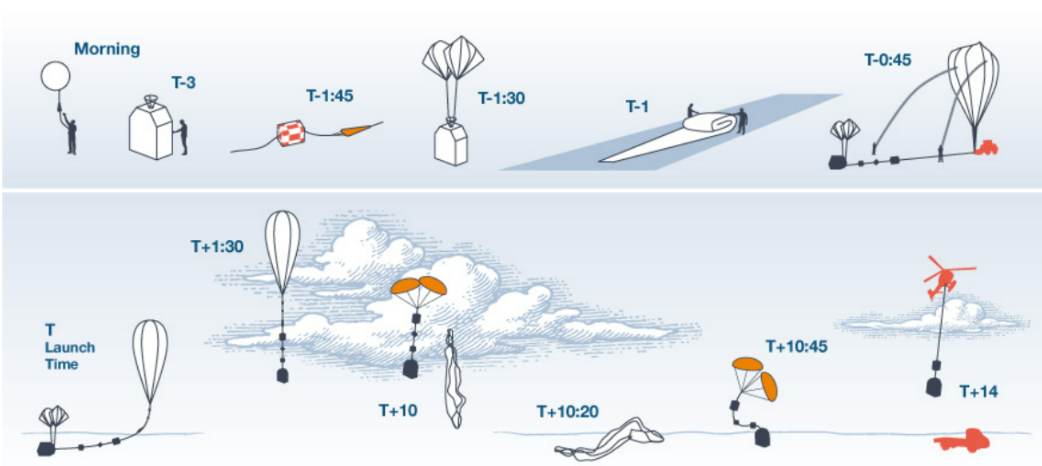
Stratospheric balloons are high-altitude balloons that are released into the stratosphere. They are the only type of balloons that can be operated in this region of the atmosphere (15 to 45 km in altitude), which is too low for satellites, too high for aircraft and cleared too quickly by rockets. The Canadian Space Agency uses stratospheric balloons to test and validate new technologies developed for long-duration space missions and to perform scientific experiments in a near-space environment.

Stratospheric balloons are typically made out of ultra-thin plastic filled with helium and can stretch into a gigantic upside-down "teardrop" shape more than half as tall as the CN Tower, or about the height of the Eiffel Tower. They are equipped with several gondolas suspended on the flight chain. The gondolas can carry science, astronomy, atmospheric chemistry, weather forecasting and technological demonstration payloads weighing up to 1.1 tons altogether.

These balloons require no engine and no fuel and are fully recovered after each flight. They can reach altitudes of up to 42 km, holding their instrument packages aloft for several hours. Some balloons can even conduct long-duration flights, lasting days, weeks and even months.

Stratospheric balloons are a platform of choice for scientists and engineers, as they can be used to test and advance space science for far less than the cost of a satellite (up to 40 times less) and provide an opportunity to carry out concrete scientific experiments in a short period of time and obtain results quickly.

[1.2]



Credit: CSA.

[1.3]

Objective 2.3

Stratosphere

Altitude: from 15 to 50 km, temperature: from -56 to 0 ºC and atmospheric pressure: from 250 to 1 hPa

- Stratospheric Balloons: 35 to 42 km
- Supersonic Flights

[2]

1.6. Flight Overview & Basic Requirements

For reviewers to assess the project proposal, hardware **must** meet the following constraints below:

Objective 2.1
- Maximum 3 kg weight limit

Objective 2.2
- The payload must be contained in a cylindrical volume of up to 524 mm in height and 285 mm in diameter, shown in Figure 1.
  - **Note:** You can propose a payload that has small components which protrude from the allowed volume (e.g. antennas). However, you must acknowledge in your proposal that you would need to complete a Request for Deviation for this requirement, and be aware that **a request may not be approved.**
- Self-powered - the balloon gondola will not provide power to the payload.

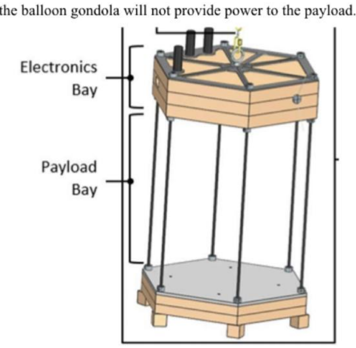


Figure 1: Payload volume must fit within the payload bay and not conflict with the 6 structural rods.

The experimental design **must** also be able to function under the following flight constraints:

Objective 2.7
- Non-pointing: balloon orientation is not controlled

Objective 2.3
- Non-insulated: balloon temperature is not controlled
- Flight will occur during the mornings or potentially late afternoons

Objective 3.2
- ~3-hour flight

  Not including launch and land time

6

Section 1.6, Page 6

[3]

Note: All payload components must remain within the payload volume (i.e. protruding bolts and fasteners must remain in the envelope). Upon approval by CSA, the payload enclosure may extend beyond the payload volume (teams may wish to use a hexagonal foam enclosure of the same perimeter as the gondola to enclose their payload).

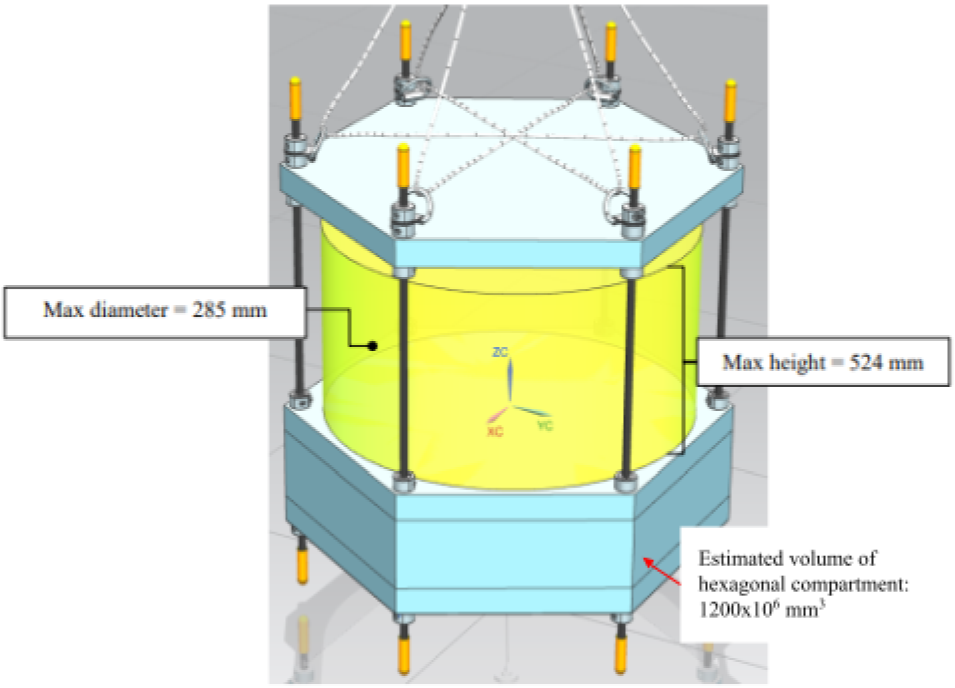


FIGURE 4-3: PAYLOAD BOUNDARY ENVELOPE

[6]

A bit of history

Established in March 1989, the CSA is a federal agency responsible for managing all of Canada's civil space-related activities. The **objects** and **functions** of the CSA are set out in the *Canadian Space Agency Act* (S.C. 1990, c. 13).

In 1996, the CSA building is officially designated as the John H. Chapman Space Centre, commemorating the scientist Canadians consider the father of their space program.

Learn more about the milestones in the Canadian space adventure and the history of the Canadian astronaut corps.

What does the CSA do?

The CSA focuses its activities and resources on three main areas:

- **Space exploration**: Participation in astronaut missions, astronomy and planetary studies, scientific research in space (execution and support).
- **Space utilization**: Earth observation by satellite and collection of space data.
- **Space science and technology**: Development of innovative space technologies and applications used on Earth.

Discover some of the ways in which space enhances your everyday lives!

The CSA also occupies an important place among the many space agencies the world. The organization boasts numerous **partnerships** with:

- government
- industry
- academia
- various international organizations.

The CSA is led by a President who reports to the Minister of Innovation, Science and Industry.

The CSA has approximately **670 employees**:

- Nearly 90% of its personnel work at its headquarters, the John H. Chapman Space Centre, located in **Saint-Hubert**, Quebec.
- The other staff members work out of the Gatineau office and the David Florida Laboratory, as well as in Houston, Washington and Paris.

[7]

CAN-SBX

2022

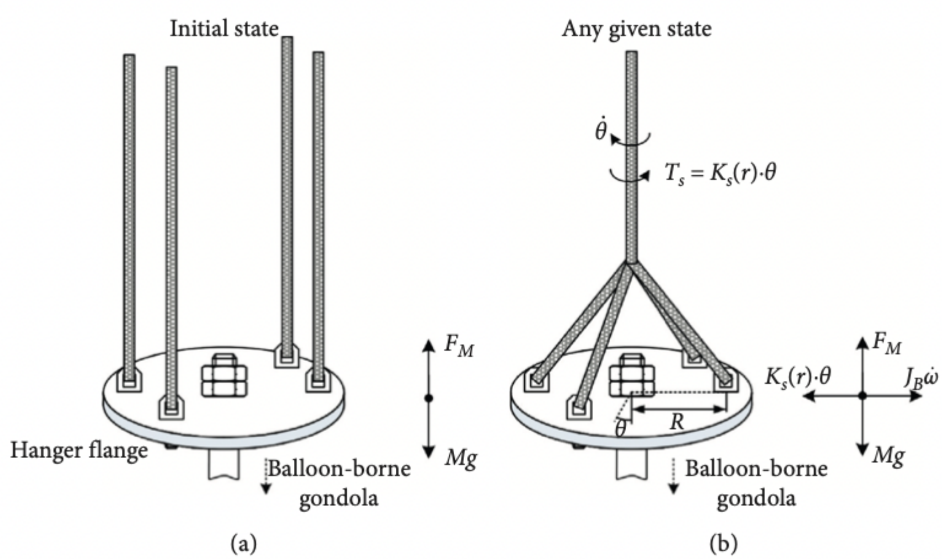
2021

The Canadian Stratospheric Balloon Experiment Design Challenge (CAN-SBX) is a competition for Canadian post-secondary students to design and test a small scientific experiment to fly on board a high-altitude balloon provided by the Canadian Space Agency. The CAN-SBX program allows post-secondary students to develop different experiments in areas such as astrophysics, Earth atmosphere, Earth magnetic field, biology, remote sensing, and technology demonstrations.

For the previous two iterations of the CAN-SBX Design Challenges, student teams designed and tested experiments for a CNES gondola, as part of the STRATOS partnership between the Canadian Space Agency and CNES. This year, the CAN-SBX Design Challenge will take advantage of the **new CSA balloon platform**, allowing for payloads of up to 3 kg to fly under expandable balloons. These launches will be on a smaller scale, so students will have to design payloads that are both compact and lightweight, which may be challenging for certain applications.

Any student team at a Canadian university or college may submit a proposal, and after careful evaluation, top teams will be selected to fully design, build and fly their experiments. Selected teams will have the opportunity to attend the launch campaign which will involve students in launch operations, flight tracking, and payload recovery. The goal of CAN-SBX III is for students to gain enough experience to eventually lead balloon launches from their home institutions. SEDS-Canada strives to create a tangible student-led impact in space exploration and development. This is a unique opportunity allows students to develop skills in STEM and conduct research in an environment that is unparalleled here on Earth. **For more details, check our our CAN-SBX Handbook (linked below).**

[8]



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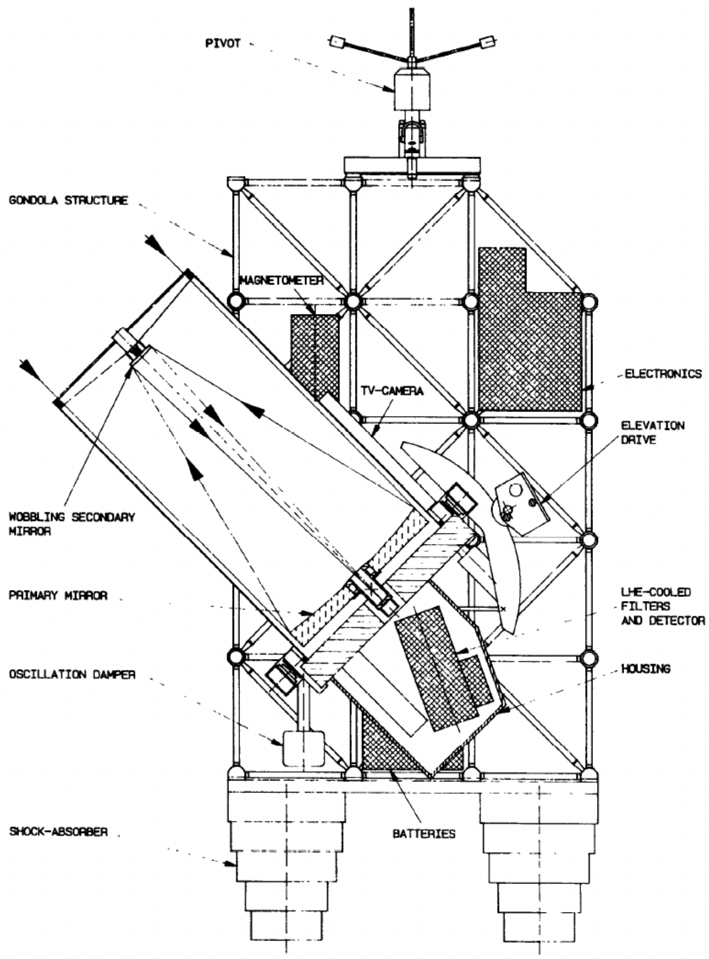
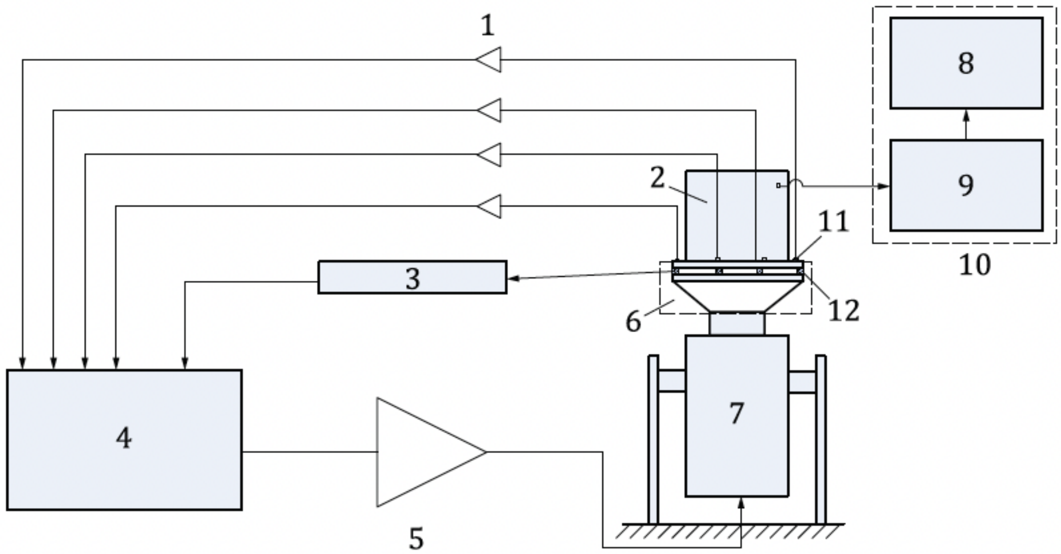

PIVOT
GONDOLA STRUCTURE
MAGNETOMETER
ELECTRONICS
TV-CAMERA
ELEVATION
DRIVE
WOBBLING SECONDARY
MIRROR
PRIMARY MIRROR
LHE-COOLED
FILTERS
AND DETECTOR
OSCILLATION DAMPER
HOUSING
SHOCK-ABSORBER
BATTERIES

[10]



Key

1	accelerance signal conditioner	7	shaker
2	test specimen	8	data storage and processing system
3	force signal conditioner	9	data acquisition system
4	vibration controller	10	measurement system
5	power amplifier	11	accelerometer
6	force measurement device (for FLV)	12	force gauge

Figure 1 — Illustration of a force limited testing system

The test facility, including all auxiliary equipment,

— shall provide the specified vibration environments,

— shall implement the required control strategies, and

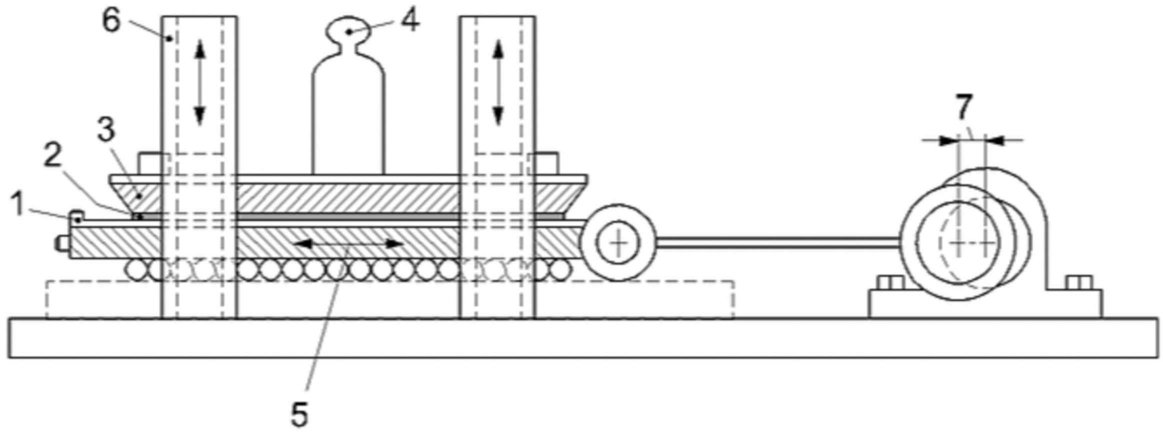
— shall meet the specified tolerances.

Measurement transducers, data recording and data reduction equipment capable of measuring, recording, analysing, and displaying data shall be sufficient to document the test and to acquire any additional data required.

The facility shall be maintained in regular intervals and shall be checked before test campaign.

[11]

ISO 13427:2014(E)



Key

1 sliding block with emery abradant

2 geosynthetic specimen (testing area 50 mm × 200 mm) ± 1 mm

3 top plate

4 total mass (6 ± 0,01) kg

5 (25 ± 1) mm linear motion

6 vertical guidance

7 eccentricity 12,5 mm

Figure 1 — Example of testing apparatus with sliding block

[12]

5.1.4 Damage tolerance requirements

5.1.4.1 General

An FCI shall be demonstrated to possess the ability to resist failure due to the presence of flaws during the period of its entire service life multiplied by the required life factor. Unless otherwise specified, the life factor shall be four (4). Damage tolerance demonstrations shall be performed on all FCIs by analysis or testing.

5.1.4.2 Damage tolerance (safe-life) analysis

Damage tolerance analysis (also referred to as safe-life analysis) based on linear elastic fracture mechanics (LEFM) shall be conducted to demonstrate the damage tolerance capability of a metallic FCI stressed within the elastic range. In a damage tolerance analysis, it shall assume that crack(s) exist at critical location(s) and in the most unfavourable orientations with respect to the applied stresses and material properties. The most critical location of the assumed crack shall be identified first. Stress-concentration and environmental effects shall be considered during this process. In a case where the most critical location or orientation of the initial crack is not obvious, the analysis shall consider a sufficient number of locations and orientations such that the criticality of the item can be determined.

Unless otherwise specified, average values of fracture toughness (K_{Ic} or K_c) and fatigue crack growth rate (da/dN) data associated with each alloy, temper, product form or process, and thermal and chemical environments shall be used in the damage tolerance analysis. If proof test logic is used to establish the initial crack sizes, an upper bound fracture toughness value shall be used in determining both the initial crack size and the critical crack size at fracture. When the upper bound value is not available, a value that is 1,3 × average K_{Ic} or K_c shall be used.

A metallic FCI which experiences sustained stresses shall also show that the corresponding maximum stress intensity factor (K_{max}) during sustained load in service is less than the stress intensity threshold for stress corrosion cracking (K_{ISCC}) data in the appropriate environment. Detrimental tensile residual stress shall be included in the analysis.

In the damage tolerance analysis, the flaw shape ($a/2c$) changes for part-through cracks (PTCs) (including surface cracks or corner cracks) shall be accounted for. Retardation effects on crack growth rates from variable amplitude loading shall not be considered without the approval of the procuring authority.

The results of damage tolerance analysis shall be documented in a report that contains the following at a minimum:

a) description of the item with identification of material (alloy and temper), grain direction, and a sketch showing the size, location and direction of all assumed cracks; and

b) description of the analysis performed, including

   — reference to the stress report, if it is separated from the damage tolerance analysis report;

   — description of loading/environment spectrum and how it has been derived;

   — material data and how they have been derived;

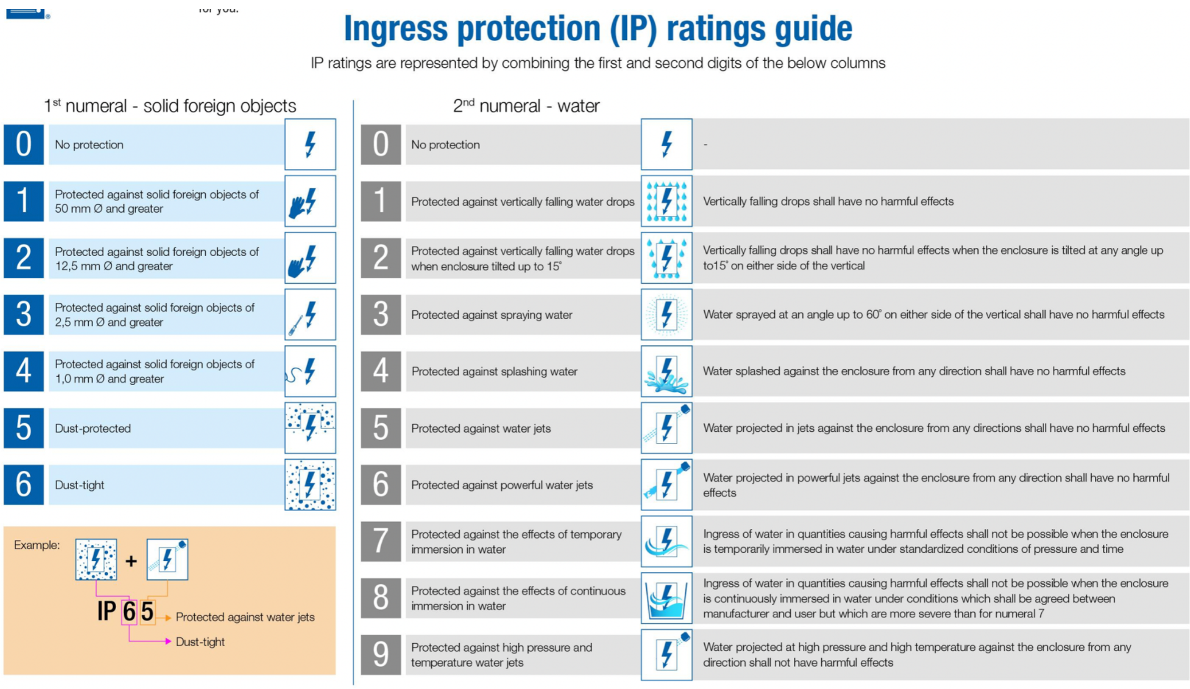
   — stress intensity factor solutions and how they have been derived;

   — initial crack sizes and NDE method(s) used;

   — analytical-life and critical crack size; and

   — summary of significant results.

[13]



Ingress protection (IP) ratings guide

IP ratings are represented by combining the first and second digits of the below columns

1st numeral - solid foreign objects

0	No protection
1	Protected against solid foreign objects of 50 mm Ø and greater
2	Protected against solid foreign objects of 12,5 mm Ø and greater
3	Protected against solid foreign objects of 2,5 mm Ø and greater
4	Protected against solid foreign objects of 1,0 mm Ø and greater
5	Dust-protected
6	Dust-tight

Example: +

IP 6 5 → Protected against water jets → Dust-tight

2nd numeral - water

0	No protection	-
1	Protected against vertically falling water drops	Vertically falling drops shall have no harmful effects
2	Protected against vertically falling water drops when enclosure tilted up to 15°	Vertically falling drops shall have no harmful effects when the enclosure is tilted at any angle up to15° on either side of the vertical
3	Protected against spraying water	Water sprayed at an angle up to 60° on either side of the vertical shall have no harmful effects
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effects
5	Protected against water jets	Water projected in jets against the enclosure from any directions shall have no harmful effects
6	Protected against powerful water jets	Water projected in powerful jets against the enclosure from any direction shall have no harmful effects
7	Protected against the effects of temporary immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time
8	Protected against the effects of continuous immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under conditions which shall be agreed between manufacturer and user but which are more severe than for numeral 7
9	Protected against high pressure and temperature water jets	Water projected at high pressure and high temperature against the enclosure from any direction shall not have harmful effects

[14]

4.3.1 Test interruption.
Test interruptions can result from two or more situations, one being from failure or malfunction of test chambers or associated test laboratory equipment. The second type of test interruption results from failure or malfunction of the test item itself during operational checks.

4.3.1 Interruption due to chamber malfunction.

a. General. See Part One, paragraph 5.11 of this standard.

b. Specific to this method.

(1) Undertest interruption. If an unscheduled interruption occurs that causes the test conditions to fall below allowable limits, note the immediate conditions of the test item (temperature, etc.) and the point in the composite mission cycle, and stop the test. Determine the root cause of the undertest condition (e.g., the store is not achieving the proper skin temperature because of a Temperature Conditioning Unit (TCU) failure, or the desired vibration response levels are not being met because an acoustic modulator valve assembly has failed). Take corrective action to get all test equipment in proper working condition. Return the test item to the required conditions prior to the interruption, and continue the test from that point.

(2) Overtest interruption. If the test item is exposed to test conditions that exceed allowable limits, give the test item an appropriate physical examination and operational check (when practical) before resuming the test. This is especially true where a safety condition may exist such as with munitions. If a safety problem is discovered, the preferable course of action is to terminate the test and reinitiate it with a new test item. (If this safety problem is not so resolved and test item failure occurs during the remainder of the test, the test results may be considered invalid.) If no problem is identified, reestablish pre-interruption conditions and continue from the point where the test tolerances were exceeded.

4.3.2 Interruption due to test item operation failure.
Failure of the test item(s) to function as required during operational checks presents a situation with several possible options.

a. The preferable option is to replace the test item with a "new" one and restart from Step 1.

b. A second option is to replace / repair the failed or non-functioning component or assembly with one that functions as intended, and restart the entire test from Step 1.

NOTE: When evaluating failure interruptions, consider prior testing on the same test item and consequences of such.

4.3.3 Functional monitoring.
Monitor test item functions continuously during the test. This may consist of a simplified measurement of overall performance. If so, perform a full functional evaluation at least once per environmental cycle. Full functional evaluations are recommended at both the high and low temperatures and at maximum vibration. Failures may be intermittent, irreversible, or reversible with changes in the environment. Ensure procedures for dealing with indicated failures are clearly defined. Verify functions that cannot be verified in the environmental test chamber by removing and testing the store at short intervals as compared to its expected MTBF. Note that any statistical

[18]

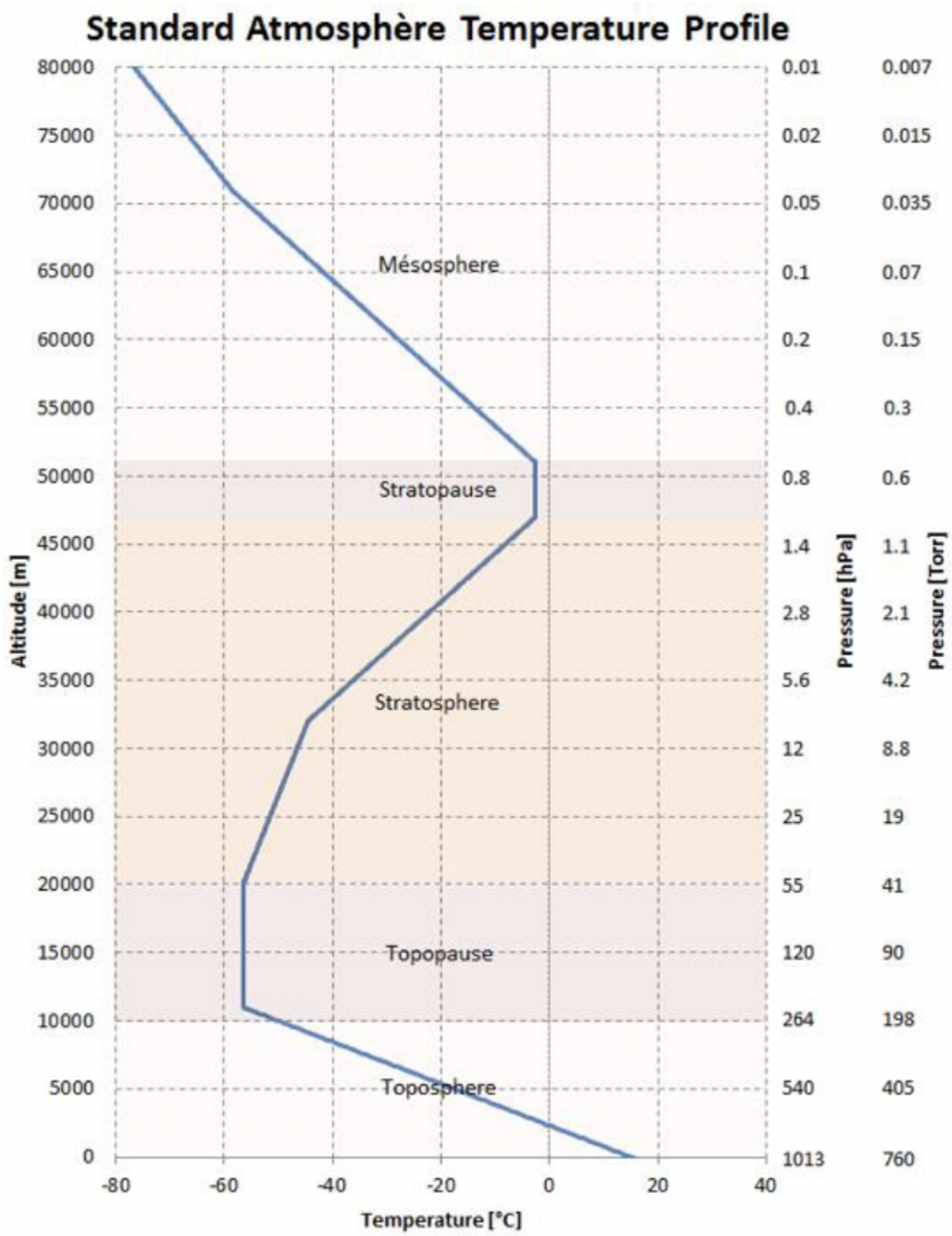


FIGURE 4-2: TEMPERATURE VS. ALTITUDE CURVE, SOURCE: NASA-TM-X-74335, U.S. STANDARD ATMOSPHERE, 1976

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Advancing the readiness of science and technologies

The Canadian Space Agency (CSA)'s stratospheric balloon program, STRATOS, provides Canadian academia and industry with an opportunity to test and validate new technologies and perform scientific experiments in a near-space environment, while inspiring and training the next generation of experts.

STRATOS was created in 2012 through the CSA's collaboration with France's space agency, the Centre national d'études spatiales (CNES). The CSA-CNES agreement provides Canadian experts with access to French stratospheric balloon flight opportunities in Canada and abroad.

Outcomes

Since 2013, STRATOS has allowed 24 Canadian instruments and experiments to be launched into the stratosphere. More than 150 Canadian experts have participated in the balloon campaigns, including 80 students.

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Aluminium Alloy Specifications

aalco®

Mechanical Properties

Aluminium can be severely deformed without failure. This allows aluminium to be formed by rolling, extruding, drawing,

machining and other mechanical processes. It can also be cast to a high tolerance.

Alloying, cold working and heat-treating can all be utilised to tailor the properties of aluminium.

The tensile strength of pure aluminium is around 90 MPa but this can be increased to over 690 MPa for some heat-treatable alloys.

Table 3. Mechanical properties of selected aluminium alloys.

Alloy	Temper	Proof Stress 0.2% (MPa)	Tensile Strength (MPa)	Shear Strength (MPa)	Elongation A5 (%)	Hardness Vickers (HV)
AA1050A	H12	85	100	60	12	30
	H14	105	115	70	10	36
	H16	120	130	80	7	-
	H18	140	150	85	6	44
	0	35	80	50	42	20
AA2011	T3	290	365	220	15	100
	T6	300	395	235	12	115
AA3103	H14	140	155	90	9	46
	0	45	105	70	29	29
AA4015	0	45	110-150	-	20	30-40
	H12	110	135-175	-	4	45-55
	H14	135	160-200	-	3	-
	H16	155	185-225	-	2	-
	H18	180	210-250	-	2	-
AA5083	H32	240	330	185	17	95
	0/H111	145	300	175	23	75
AA5251	H22	165	210	125	14	65
	H24	190	230	135	13	70
	H26	215	255	145	9	75

Does the balloon need to be fully inflated before launch? If not, why not?

No, the balloon is not fully inflated before launch. A measured amount of helium is put into the balloon that will give it enough lift to get off the ground and ascend to the desired float altitude. As the balloon rises, the gas inside the balloon expands because the atmospheric pressure surrounding the balloon drops. The atmosphere is 100 to 200 times less dense at the float altitudes than on the ground. If the balloon is fully inflated on the ground, the gas will either need to be vented out (zero-pressure balloons) and wasted as it expands. In the case of super-pressure balloons (closed system), the excess gas would exert excessive pressure on the skin and ultimately can cause it to rupture. A balloon that is fully inflated on the ground will also have way too much lifting force.

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Canadian Space Agency

We advance the knowledge of space through science and ensure that space science and technology provide social and economic benefits for Canadians.

Read the latest news

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How the balloons work

Expandable balloons are made of latex or chloroprene and are the same type used for weather soundings, which usually serve to gather data to feed environmental models to help predict the weather. As the balloon ascends into the stratosphere, it expands to the point of rupture. The CSA's high-altitude balloon system uses these balloons to lift scientific equipment into the stratosphere until the envelope bursts. At that point, the equipment drifts back to ground under a parachute and is recovered.

The balloon envelope itself is not re-used or recycled; however, the payload gondola and the elements of the flight train (parachute, separator) are re-used for future flights.

[35]

2. The CSA Organizational Values and Ethics Code

▶ **In this section**

The CSA Organizational Values and Ethics Code outlines in a single document both the values of the VECPS and those specific to the CSA.

The VECPS, which came into effect on April 2, 2012, outlines the expected behaviours that correspond to the values of the federal public sector:

- Respect for democracy
- Respect for people
- Integrity
- Stewardship
- Excellence

In order to better reflect the CSA's specific environment and culture, we have added the following values to our Organizational Code:

- Collaboration
- Inclusiveness
- Innovativeness
- Well-being
- Accountability

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5. Conclusion

Although there are examples of government satellites taking 10 years or more to develop and launch, the data shows that, on average, it takes 7½ years to develop and launch a first vehicle and just over 3 years to assemble and launch subsequent vehicles. The production timeline of subsequent vehicles is comparable to the 2 to 3 year duration of a typical commercial satellite program. The data and examples of commercial satellite development approaches suggest that a contributing factor to longer government timelines, particularly for first vehicles, is the degree of technology development at program start. Commercial manufacturers typically perform technology development prior to making a product available to customers. The examples provided show that when the appropriate comparisons are made, i.e. start of development to launch or start of assembly to launch, the durations are similar between government satellite programs and commercial satellite programs.

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Eleven years in the making, the most powerful NASA-built rocket since the Apollo program at last stands upright. Framed by the industrial test platform to which it is mounted, the Space Launch System's core section is a gleaming, apricot-colored column cast into relief by twisting pipes and steel latticework. The rocket is taller than the Statue of Liberty, pedestal and all, and is the cornerstone of NASA's astronaut ambitions. The launch vehicle is central to the agency's Artemis program to return humans to the lunar surface, and later, land them on Mars.

12. Appendices

12.1 Appendix A: Proxy test for G-force resistance

This test was designed to measure the maximum G-force a material can resist before rupturing. Since the requirement for the G-force a material should be able to withstand 15Gs of force, a system to accelerate an object from zero velocity to approximately 150 m/s in a second must be established. By placing an accelerometer on the object, the change in velocity can be measured, so iterate over multiple times until a system is confirmed to be capable of accelerating an object to the desired velocity in a given time. If such a system is difficult to create, dropping an object from a height of ten meters ten times onto a cushion that absorbs energy upon landing is also sufficient. If the object does not display any visible deformation after conducting the experiment, the specimen meets the standard posed by the requirements model.

12.2 Appendix B: Interviews/Stakeholder Testimony of Opportunity

B-1: Quote from the conservation with Dr. Alfred Ng

Alfred Ng: "So when we send out the balloons, at the end they have to fall back down to the Earth. There are parachutes that deploy and mitigate the damage, but there are still tremendous G-forces and impact when the balloon falls back down. Sometimes the balloon would fall into trees and be punctured completely. Even though there are layers of metal, aluminum metal, protecting the instruments, the gondola still gets destroyed. What we need is a gondola that is strong enough to withstand the g-forces and can be used through multiple missions."

B-2: Quote from the conservation with Dr. Alfred Ng

"Not too much time was put into designing it (CAN-SBX gondola). For example, there is no explicit reason why it's hexagonal - it could have very well been a rectangle, cube, sphere, anything! (...) If you look at it, it's completely exposed. It's very easy to damage the experiments. At this point, it's just something to hold the experiment, not protect it.(...)"

B-3: Quote from the conservation with Dr. Alfred Ng

Question: How do you control/predict the exact location of the gondola's landing?
Answer: "A lot of research and planning goes into the launch of a balloon. We use predictive models and analyze the current climatic conditions such as temperature, pressure, wind patterns. There is over 60 years of knowledge and experience that contributes to our decision of the launch site and time."
Question: How do you ensure that you avoid all obstacles and objects when descending?
Answer: "You cannot! We have had gondolas be damaged due to cargo being impaled by trees or rocks. There is the concern of it landing in a lake but that has only happened once since the beginning of these projects. The concern is the smaller obstacles."

B-4: Other important notes from meetings with Dr. Alfred Ng

- A major component of CSA projects are collaborations with international organizations

- CSA contributed Fine Guidance Sensor (FGS) and Near-INfrared Imager and Slitless Spectrograph (NIRISS)
- FGS is crucial in stabilizing images
- Can measure movement distance equal to the width of single human hair happening 1 kilometer away
- Canada get 5% of research output of James Webb
- Contributed Canadarm to ISS
- Collaborations with organizations makes it more affordable for Canada to engage in projects of larger scale and provides are scientists with high-quality information and research
- Another important and ongoing collaboration is the Stratos High Altitude Balloon project that takes place every year with France's space researchers.
- Just last year, started a new project to launch small-scale balloons with single small experiments
- Participants included Queen's University and Polytechnique Montréal
- Once possible opportunity for us is to work on redesigning the power system of the big gondolas.
- CSA requires more power to last a longer duration of time to be able to perform more complex and high-level experiments
- Current power is about 40 W for 3 hours
- Last year, Prof launched a telescope and attached solar panels to the gondola to improve the power plan
- Did not do much improvement
- How do we improve it

12.3 Appendix C: Requirements Visual Representation

	High Level Objectives	Low Level Objectives	Metrics
Requirements for CAN-SBX Gondola	Safety	Mitigate damage to cargo	Presence of visible fracture after landing (Y/N)
		Resistant to water	Amount of water (mL)
		Resistant to vibration	Structural vibration (Hz)
	Functionality	Minimize structural deformations	Mass of payload gondola ruptures (kg)
			Structural deflection (mm)
		Have sufficient capacity for cargo	Usable volume in payload bay (mm^3)
		Resist all encountered high altitude environmental conditions	Measurement deviation from required performance (°C, hPa)
		Be lightweight	Mass of complete system (kg)
		Have the reserved volume for accomodating the parachu	Volume measured in cm^3
		Secure payload during flight	Movement of payload during vibration test
		Be balanced	Eccentricity during the flight (mm)
		Allow unrestricted transmission of radio signals	Penetration depth in millimeters (mm)
	Durability	Material is resilient	Resilience of the gondola in J/m^3
		Maximize reusability	Number of hours the gondola is functional (hr)
			Number of times the gondola can be reused
		Resistant to dynamic loading (G-force) during the flight	Magnitude of G forces resisted before failure (m/s^2)
		Minimize abrasion damage (wearing away of material)	Tensile strength measured in Pascals (Pa)
		Have venting area	Surface area in cm^3
	Cost	Minimize cost	Price in dollars (CAD)
	Manufaturability	Ease of Assembly	Number of people required to assemble design
			Number of steps to assemble and operate design
			Time to fully assembly in hours (hr)
		Easy to store	Volume of space when not in use (m^3)
			Volume of space when disassembled (m^3)

Metrics	Criteria	Constraints
Presence of visible fracture after landing (Y/N)		no visible fractures
Amount of water (mL)	Less	
Structural vibration (Hz)	Less	
Mass of payload gondola ruptures (kg)	More	minimum 3 kg
Structural deflection (mm)	Less	
Usable volume in payload bay (mm^3)	More	accommodate a cylindrical payload with 524 mm height and 285 mm diameter
Measurement deviation from required performance (°C, hPa)	Less	withstand temperature range -56 to 0 °C
		withstand pressure range 250 to 1 hPa
Mass of complete system (kg)	Less	maximum 7 kg
Volume measured in cm^3	More	minimum 12000 $*10^5$ mm^3
Movement of payload during vibration test	Less	no movement
Eccentricity during the flight (mm)	Less	
Penetration depth in millimeters (mm)	More	communication distance greater than 30 km
Resilience of the gondola in J/m^3	Less	more than the resilience of aluminum (3×10^5 J/m^3)
Number of hours the gondola is functional (hr)	More	more than 3 hours
Number of times the gondola can be reused	More	more than 1 (once)
Magnitude of G forces resisted before failure (m/s^2)	More	more than 15 G
Tensile strength measured in Pascals (Pa)	More	
Surface area in cm^3	More	
Price in dollars (CAD)	Less	
Number of people required to assemble design	Less	
Number of steps to assemble and operate design	Less	
Time to fully assembly in hours (hr)	Less	
Volume of space when not in use (m^3)	Less	
Volume of space when disassembled (m^3)	Less	