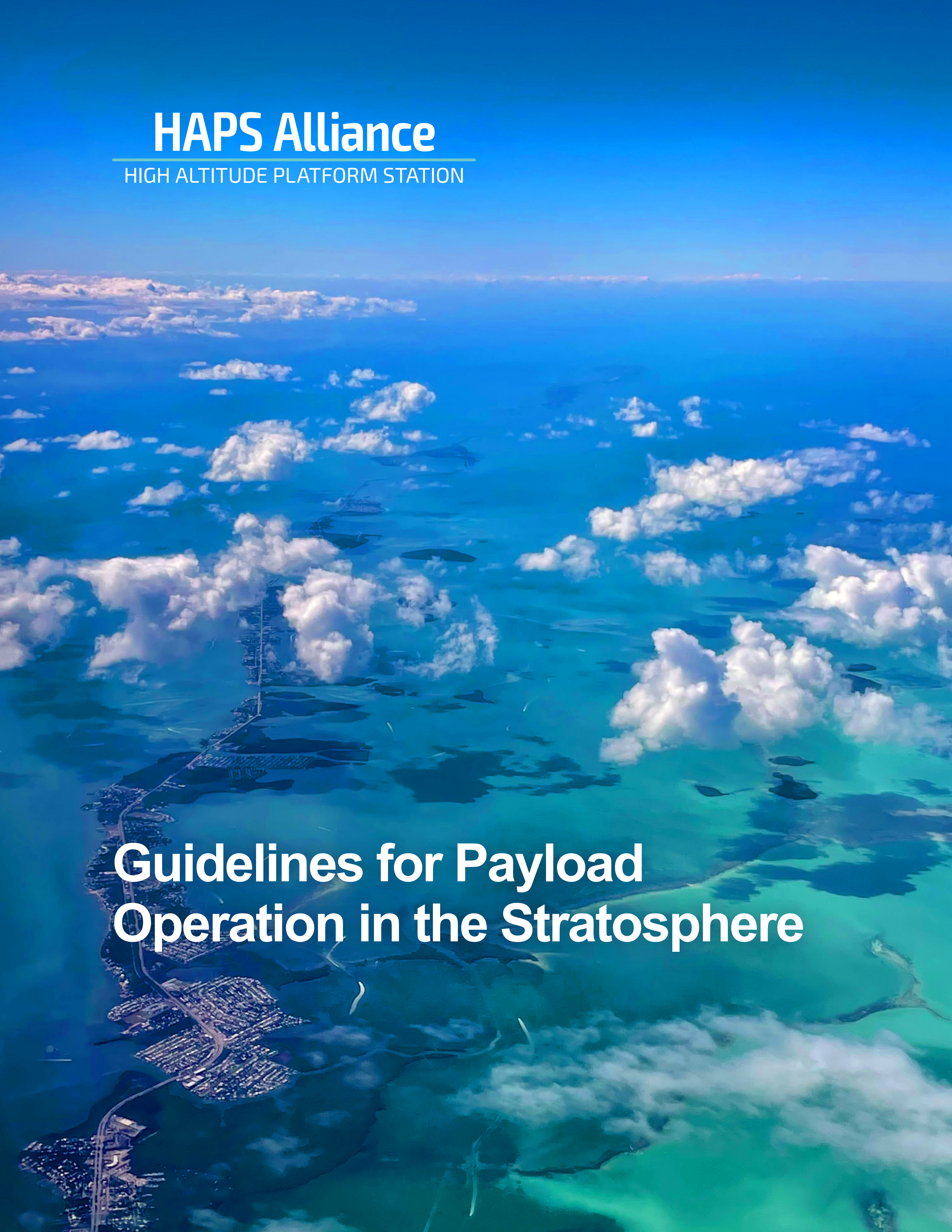
HAPS Alliance

HIGH ALTITUDE PLATFORM STATION



Guidelines for Payload Operation in the Stratosphere

Contents

OVERVIEW

The purpose of this document is to provide integration and environmental guidelines to consider when developing a payload for operation on a flight vehicle in the stratosphere. The guidelines are intended to help potential payload providers understand the unique operating environment and the demands of aviation safety for stratospheric platforms and apply test methods to assess basic feasibility of payload operation in the stratosphere. The scope of the guidelines is to cover the factors that *any* potential payload should consider, rather than suggest types of payloads (e.g., sensors, radios) and their unique specifications. In addition, the guidelines are general, and each unique flight vehicle from any one provider will likely have additional specifications that exist for that specific vehicle.

This document refers to existing test methods and specifications, such as MIL-STD-810 or RTCA DO-160. However, following these methods alone does not guarantee success, nor does not following them guarantee failure. These references are to be used as a guideline for test methods and conditions, and this document provides further qualifications and considerations unique to stratospheric operation.

By sharing knowledge of stratospheric operation, the HAPS Alliance aims to reduce technical barriers and challenges for new entrants in this industry. Further, by having common guidelines, the HAPS Alliances aims to increase interoperability of payloads across flight vehicles through standardization. With more participants, more knowledge will be gained, and this document shall be updated to reflect these new insights.

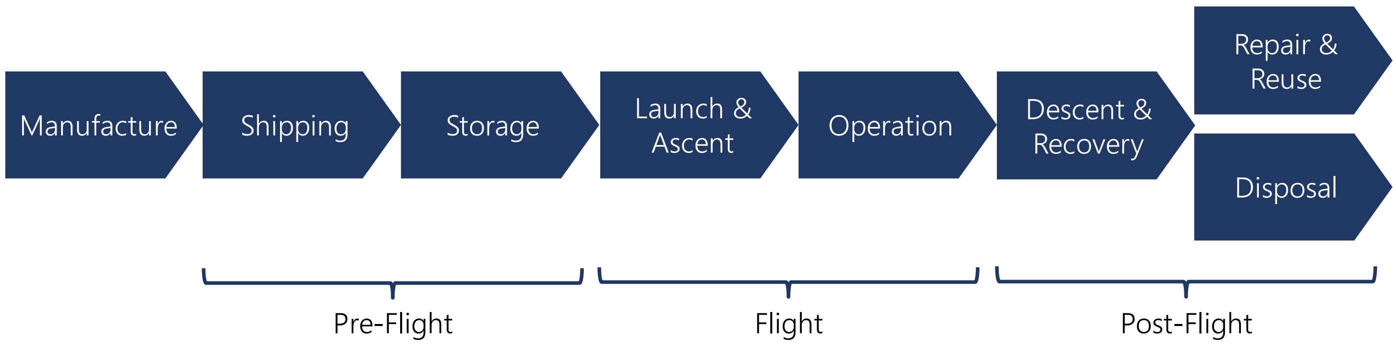
FLIGHT VEHICLES

Three categories of flight vehicles are described below and are referred to throughout the document. Each vehicle may subject the payload to different or unique operating conditions. Major differences across the flight vehicles are their airspeeds and the amounts of forced convection to which the payload may be exposed, leading to implications in thermal design (discussed in a following section). In addition, vibration considerations may also vary significantly, depending on the category of vehicle.

Category	Description
Fixed Wing	Propulsion is used to generate aerodynamic lift and is used for lateral control; control surfaces change attitude and altitude.
Balloon	Lighter-than-air gas is used to generate buoyant lift; the vehicle may have altitude control by changing the net buoyancy.
Airship	Lighter-than-air gas is used to generate buoyant lift; the vehicle has altitude control and propulsion used for lateral control.

PAYLOAD LIFE CYCLE

To ensure mission success, a payload should be designed for the course of its entire life cycle. The flight phase is defined from launch, ascent to the stratosphere, operation in the stratosphere, descent to the ground and landing. The focus of this document is payload operation in the stratosphere. However, there are also important considerations during pre-flight phases from shipping and storage that may be highlighted (e.g., exposure to humidity).



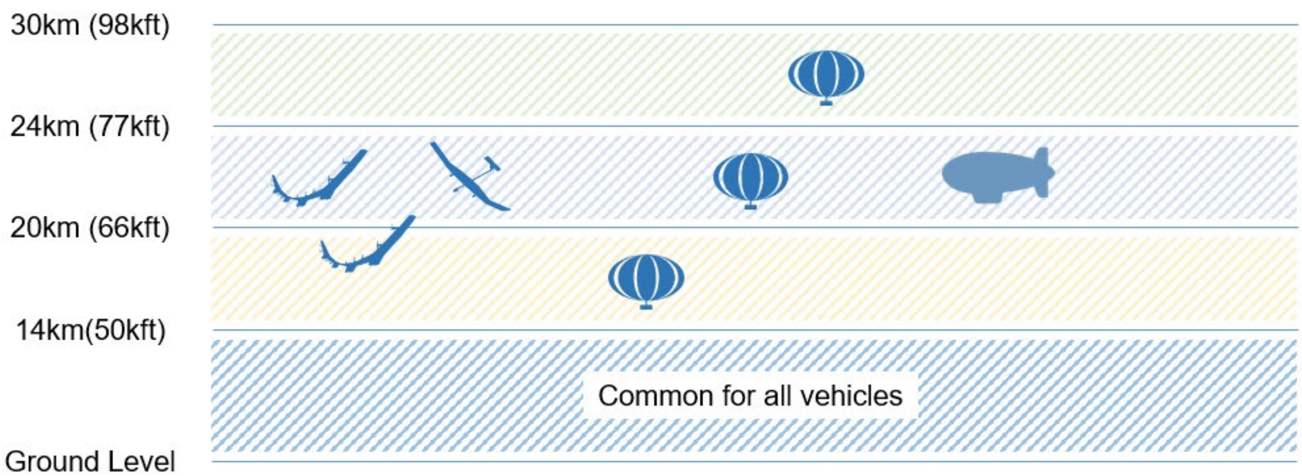
PAYLOAD COMPONENTS

The table below categorizes payload components in two ways: integration with the flight vehicle (whether electrical or structural), and environmental exposure (whether directly exposed externally or integrated internally to the flight vehicle). The guidelines that follow may be applicable to some or all of the categories below and are called out as such.

		Integration with Flight Vehicle	
		Payload Electronics (PE)	Payload Structural Components (PS)
Environmental Exposure	External (Ext)	*Category Ext-PE* Electronic boards and communications equipment directly exposed to external environment (e.g., antennas, sensors)	*Category Ext-PS* Structural (non-electronic) components contained and directly exposed to the external environment (e.g., fairing, gondola)
	Internal (Int)	*Category Int-PE* Electronic boards and communication equipment not directly exposed to the external environment (e.g., computer boards, power units)	*Category Int-PS* Structural (non-electronic) components contained and not directly exposed to the external environment (e.g., mount trays, electronic housings, gimbal frames)

FLIGHT ENVIRONMENT GUIDELINES

The altitude bands below are used as approximate indication of the different operating regions of flight vehicles. Pressure and temperature change across these altitude bands lead to implications in the design of thermal solutions, sealed enclosures, electronic board layout, etc.



ALTITUDE BANDS AND THERMAL SOLUTIONS

One important consideration for thermal solutions for stratospheric operations is convective cooling, which may vary by flight vehicle and altitude. For example, fixed-wing flight vehicles at 20km altitude with high relative airspeed may rely on convection more than balloons at 30km altitude with zero relative airspeed. As altitude increases (pressure and density decrease), and relative airspeed decreases, payloads should rely more on conduction-radiation for heat transfer.

At ground level prior to launch, the payload components should be protected against potential overheating. The higher ambient ground temperatures and denser air (and potentially humidity) act as "insulation" against radiator plates and lead to less heat rejection at ground level than in the stratosphere. To address this, ground equipment may require fans blowing air over the radiator plate. Alternatively, the payload may only be powered for short periods (to prevent overheating) or at lower power levels than during operation (e.g., an "idle" mode).

During the ascent phase, forced convection affects all flight vehicle types. The ascent rate varies by flight vehicle. During ascent, the temperature decreases linearly from the ground to the bottom of the tropopause. The tropopause is isothermal and at the coldest temperature. The tropopause can vary by location and time of year, but this document assumes that this altitude band is about 14 to 20km. This band will set limits for operational cold case testing.

Above the tropopause and in the stratosphere, the ambient temperature begins to increase. This document considers two altitude bands: from 20 to 24km and from 24km to 30km. (Note that the stratosphere extends above 30km, and some platforms operate at these higher altitudes, but these altitudes are not in the present scope of this document.) The separation of the bands is based on the relative effect of convection, where the higher band is lower pressure (e.g., about half when comparing the upper limits, and 10℃ warmer). These bands will set limits for operational hot case testing.

While in the operation phase in the stratosphere, the payload may experience temperature extremes during the day and night. During the day, solar radiation adds additional heat that needs to be rejected. In contrast, at night, heat rejection needs to be minimized. Thermal solutions such as heat pipes help manage these extremes, and heaters may be used to augment internal heat at night. Some or all payload components may be thermally managed by the flight vehicle, especially the internal ones. Generally, the higher power the payload, the more challenging the thermal control will be, balancing high heat rejection during the day, while trying to minimize heat rejection at night in a standby state. External components are subjected to the most extreme conditions. Due to radiation at night, they could see surface temperatures below ambient, and during the day, without shading from the sun, these components are likely to see surface temperatures above ambient.

TEMPERATURE AND PRESSURE

The pressure and temperature ranges described here are based on the MIL-HDBK-310G 1% worst-case conditions. Please note that the range may be even wider in the actual environment of the stratosphere and may vary significantly between locations and by time of year.

Altitude Band	Pressure	Temperature
24-30km (77-98kft)	3.5～0.7kPa	-17～-86℃
20-24km (66-77kft)	6.5～2.0kPa	-29～-87℃
14-20km (50-66kft)	16.8～4.0kPa	-30～-88℃

The above table describes the ambient temperature environment; however, the object of testing should be the testing of the payload-flight vehicle combined thermal solution as a whole within the ambient environment. The electronic components within the payload may need to remain at a warmer temperature range, and thermal management solutions (e.g., heat sinks, heaters) may exist on the payload and/or the flight vehicle. In payload-flight vehicle integration, generally the strategy should be to ensure that payload components have a thermal path to the chassis and/or thermal management solution (e.g., heat pipes) and temperature differences along the thermal path are minimized. In addition, heat rejection by convection will be reduced under low atmospheric pressure, as described in the section on altitude bands.

Considerations for temperature and pressure testing include:

- The payload components shall meet the specification for all the altitude bands if they are turned on during launch, ascent, and descent phases.
- The payload must operate continuously within the above altitude range.
- The payload should be able to start up arbitrarily in the operation range described above.
- The payload should be able to run on the ground surface for a period of time sufficient for the verification of operation and the demonstration of its performance. However, when operating on the ground surface for pre-flight check, there may be a limit on operating time, or extra ground support equipment supplied, to prevent overheating.

Some materials have low-temperature brittleness, which causes a sudden loss of strength at low temperatures. Therefore, payload design should select materials without low-temperature brittleness as much as possible. For example, avoid using ferritic stainless steel for fixing bolts and use austenitic stainless steel. If different materials are bonded together, they may be destroyed due to the difference in expansion rates at high and low temperatures. Designs should be implemented considering the distortion caused by the expansion rate. In a stratospheric environment, the outside air may be cold, but the inside of the fairing may be warm. Also, in a low-pressure environment, heat dissipation is expected to be reduced by about 1/2 for natural convection and 1/3 for forced convection.

Specific to testing ambient pressure is to consider breakdown voltage where air no longer can be used as an electrical insulator (refer to Paschen's Law). Payloads should consider increasing the distance between points of voltage difference and applying conformal coatings to avoid this problem. Note that this guidance does not apply when the device is enclosed in an airtight container and operated in an environment with the internal pressure maintained. The airtight container itself must have sufficient capability to work in the operating environment (including testing to confirm that pressure seals work across expected temperature range and do not contract).

The table below describes the combination of pressure, temperature to test for operation and strength of components.

Test Case	Description
Cold Case: Operation	Use lowest ambient temperature and the highest ambient pressure expected in altitude band. Simulate operation phase with *expected* convection (not necessarily negligent depending on flight vehicle). Run payload at expected operating power, as well as any lower power/idle modes, and determine whether thermal solution is sufficient at keeping payload components in their temperature ranges.
Cold Case: Ascent	Use lowest ambient temperature and the highest ambient pressure expected in altitude band. Simulate ascent phase with *maximum* convection (varying by flight vehicle/ascent rate). Run payload at expected operating power and determine whether thermal solution is sufficient at keeping payload components in their temperature ranges.
Cold Case: Startup	Use lowest ambient temperature and the highest ambient pressure expected in altitude band. Simulate operation phase with *expected* convection (not necessarily negligent depending on flight vehicle). Keep payload off, allow to achieve steady-state temperature with ambient environment, then turn on payload/thermal solution, monitoring component performance for damage if they were cold soaked (but not operating) outside their temperature ranges. This test may be modified to find the failure temperature by incrementally decreasing ambient temperature from a known passing condition.
Hot Case: Operation	Use highest ambient temperature and lowest ambient pressures expected in altitude band. Simulate operation phase with *expected* convection (not necessarily negligent depending on flight vehicle). Run payload at expected operating power as well as any maximum power modes, add expected thermal loading due to solar radiation (if possible) and determine whether thermal solution is sufficient at keeping payload components in their temperature ranges. Simulating additional thermal loading due to solar radiation on the ground may not be possible and may need to be assessed analytically only. However, the test case outlined above should serve as a minimum test criterion, and flight testing under actual conditions is indispensable.

For all cases, refer to MIL-STD-810G 500.5 Procedure II (Operation/Air Carriage) for pressure test method, using worst-case temperatures from MIL-HDBK-310G, with consideration of the table above. Check the operation for more than one hour to verify that there is no abnormality in functions or material strengths.

ADDITIONAL ENVIRONMENTAL GUIDELINES

The sections below highlight additional considerations for payload design that are mainly related to the pre-flight conditions, but may have impact during flight. Again, designing for mission life cycle is recommended.

HUMIDITY

In the stratosphere, humidity will be almost 0%RH. However, the components may be exposed to high humidity during shipping or storage, or on the launch pad. Humidity may condense on boards and corrode electronic components or interconnections. In addition, moisture on components may freeze during ascent as the temperature decreases. Use of conformal coating boards (categories Int-PE, Ext-PE) is the primary mitigation. This treatment is also effective as anti-electrical breakdown/discharge and anti-dust.

Additional strategies for shipping and storage rest on limiting the exposure of payload to humidity and/or indications of extent of exposure. Sealed enclosures (e.g., NEMA-rated), desiccants, color-changing humidity indicator cards, etc. are some of the measures that should be considered in container design.

Operation in extremely low-humidity environments may inform additional payload testing if there are moving contacts without lubrication, because the friction may increase.

WATER

The waterproof performance of external components (categories Ext-PE, Ext-PS) should match the specifications of the vehicle. Most vehicles will be above any precipitation during normal operations, but acceptable weather and precipitation conditions for launch, ascent and descent may vary by flight vehicle or mission. The external structures may help prevent water intrusion for internal components; see Ingress Protection (IP) numbers for more guidance. Shipping/storage containers should be equal or even more stringent in protection than the flight vehicle/payload. The electronic components (categories Int-PE, Ext-PE) should follow the same guidance for conformal coating listed in the humidity section.

SALT DAMAGE/CORROSION

All components should minimize the corrosion of metals, sticking or restraint of moving parts due to salt adhesion, insulation failure and the impact of damage to contactors and bare wires. Therefore, it is recommended to design with and use materials that have been processed to prevent corrosion. Even if a single material alone is not easily corroded, corrosion can occur when dissimilar metals are joined together. Dissimilar metals (e.g., aluminum + stainless steel, CFRP + aluminum, etc.) should not be combined, or they should be insulated. Exposure to salt spray may occur at the launch phase, and electronic components (categories Int-PE, Ext-PE) should follow the same guidance for conformal coating listed in the humidity section.

ICE ACCRETION

The primary concern around ice accretion is condensing humidity freezing as discussed above, and it is possible that additional exposure may occur during the ascent/descent phase if the flight vehicle moves through precipitation. However, stratospheric vehicles operating mostly above the weather are much less likely to be affected by ice accretion than normal aircraft. No recommendations are made to mitigate ice accretion.

FUNGUS (MOLD)

In the stratospheric environment, it is difficult for fungus to grow. Fungus is primarily a concern during shipping and storage. Materials to consider using are listed in MIL-STD-810G Table 508.6B-I. Group I, and materials to consider avoiding are listed in MIL-STD-810G Table 508.6B-I. Group II. If any materials listed are in use, report where they are used.

DUST

Dust can cause contamination and/or clogging of moving parts, relays, filters, etc. by intrusion into cracks, crevices, bearings and fittings. It may form a conductive bridge, contribute to water vapor accumulation and create the possibility of corrosion as a secondary effect, and/or cause fluid contamination.

Like water consideration, internal components may be rated lower protection depending on external payload and/or flight vehicle components providing protection. Dust is not a significant concern once in the operating environment and mitigations should mainly be directed to the pre-flight phases. However, there may be special or additional protection at the landing/recovery phase, if the payload is desired to be repaired, re-qualified and re-flown.

ULTRAVIOLET RAYS/OZONE

Exterior components, such as fairings, can be degraded by UV light. Natural and synthetic polymers as well as aramid fibers are at high risk of UV degradation unless they are UV-stabilized or shielded from direct solar exposure. Shielding or accelerated UV testing of high-risk materials is recommended prior to long-duration flights.

The high levels of ozone in the stratosphere may further increase rates of degradation. Plastics in particular are greatly affected, and it is necessary to ensure that their performance will be met throughout the flight period. A list of commonly used materials and their susceptibility to ozone degradation can be found at http://www.ozonesolutions.com/info/ozone-compatible-materials. If materials are used that have a C-fair or D-severe rating, it is recommended that material testing be done by a qualified material test lab to quantify impact to applicable material properties in high concentrations of ozone prior to long-duration flight tests.

LIGHTNING

Exposure to lightning is most likely to occur during the ascent or descent phases, although acceptable operating conditions may vary by flight vehicle. One risk is that the ceiling of thunderhead/cumulonimbus clouds can exceed the 14km/50kft floor of the first operating band.

For all categories of components, but particularly external ones, it is necessary to ensure that they will withstand lightning effects. For lightning direct effect testing guidelines, refer to DO-160G Section 23.

Electronic components (categories Int-PE and Ext-PE) require the application of idealized waveforms to verify the ability of the device to withstand the effects of lightning-induced electrical transients. For lightning-induced transient susceptibility, refer to DO-160G Section 22.

MECHANICAL GUIDELINES

These guidelines refer primarily to the mechanical integration of the payload into the flight vehicle. Recommended test points will vary based on the specifications of the flight vehicle.

SHOCK

Refer to MIL-STD-810G Method 516.6 for test and demonstration methods for shock for all payload component categories. The following is a general description of the characteristics of each type of platform. The actual specifications are to be determined according to the requirements of the vehicle and its mission.

For operation on balloons, the peak shock loading is expected at launch, termination and landing. At launch the system lifts off the ground, creating a small shock load. At termination, the control and payload electronics may be subjected to parachute opening shock. At landing, the flight vehicle should provide methods for energy absorption for decelerating from the descent rate to no motion.

For electric fixed-wing platforms, the payload is not typically subject to great shock throughout its operation. The peak shock load would be expected at take-off or landing, which is the impact transmitted from its tires. Such impacts vary greatly depending on the vehicle design and/or its operation. Check where the vehicle takes off or makes landing, e.g., paved, unpaved runway, or over water, etc. In flight, in general, the larger and more flexible the airframe is, the less likely it is to be subjected to shock; conversely, the smaller and more rigid, the more likely subjected to shocks. It is still important to conduct shock tests for emergency situations.

VIBRATION

For all vehicles, the transportation phase should be considered. Payload shipping containers should be designed to withstand vibration encountered during common shipping methods. The following is a general description of the characteristics of each type of platform. The actual specifications are to be determined according to the requirements of the vehicle and its mission.

For operation on balloons, vibration is minimal, and no testing is required.

For operation on fixed-wing flight vehicles, testing is recommended for payload components according to MIL-STD-810G Method 514.6 ANNEX D, Category 13 Fixed wing propeller aircraft. The vibration profile applicable to this test may vary depending on the type of aircraft. The vibration profile should be calculated based on the assumption for a particular aircraft; e.g., a fixed-pitch two-blade and the propeller rotation speed fluctuates between 800 and 2,000 rpm. Note that the vibration characteristics of the fixed-wing vehicle vary depending on its location. In general, the closer to the wing tips, the greater the vibration with low frequency; conversely, there will be less vibration near its center of gravity. There will be higher-frequency vibrations near the motor and propeller. The larger and more flexible the airframe is, the lower the vibration frequency will be; conversely, the smaller and more rigid, the more likely it will have small but high-frequency vibration.

ACOUSTIC VIBRATION

No guidelines are proposed at this time. Some considerations may be needed if the flight vehicle uses an engine.

FLUID SUSCEPTIBILITY

No guidelines are proposed at this time. Some considerations may be needed if the flight vehicle uses engine fuel or has a water-cooled temperature control system.

ELECTRICAL GUIDELINES

These guidelines refer primarily to the electrical integration of the payload into the flight vehicle.

ELECTROSTATIC DISCHARGE

For all payload electronic equipment (categories Int-PE and Ext-PE), it is necessary to investigate whether the equipment can continue to operate with specified functions and performances without having permanent performance deterioration caused by the discharge of an electrostatic pulse. This electrostatic discharge test shall apply to all the equipment and surfaces that are accessible during normal operation or maintenance work of the aircraft. Conduct the test according to DO-160G Section 25.

POWER INPUT

It is necessary to check the behavior of payload electronic equipment (categories Int-PE and Ext-PE) in multiple conditions: when turning on input power, in expected power fluctuations, and during transient and steady-state conditions. Payload devices often receive DC power from the vehicle after it has been rectified and converted by the vehicle power system. Input power specifications to the payload may differ from vehicle to vehicle, and it is important to test power conditions according to the specifications defined by the vehicle manufacturer.

As general guidance, input power testing can be completed with reference to DO-160G Section 16. Use of 28Vdc is encouraged, falling under Category Z. There is no definition for electric-powered aircraft in the current DO-160 test standard, but Category Z is the closest and is suitable to payload components. It may be also desirable if all the payload electronic components fall into a single category; then the components can be swappable between the platforms. Note that considerations like in-rush current require design and consideration on both the flight vehicle and the payload.

VOLTAGE SPIKES

For all payload electronic equipment (categories Int-PE and Ext-PE), it is necessary to ensure that a device can withstand impacts from voltage spikes that may occur on either AC or DC power leads. The impact of a voltage spike could cause permanent damage, component damage, dielectric breakdown, increased interference susceptibility or altered device performance.

Payload electronic components that receive power directly from the aircraft are classified as DO-160G Section 17 Category A and require a high degree of protection against damage caused by voltage spikes. Equipment that receives power through the vehicle power supply system (e.g., rectified/converted) is classified as DO-160G Section 17 Category B, which requires a relatively low level of protection against voltage spikes.

INDUCED SIGNAL SUSCEPTIBILITY

For all payload electronic equipment (categories Int-PE and Ext-PE), it is necessary to ensure that interconnecting circuits in the device can withstand the induced voltage generated by the device environment. Interference from magnetic or electric fields may cause signal processing to fail or malfunction.

Conduct the test according to DO-160G Section 19. Simulate the noise generated on other interconnected bundles close to the wire harness of the unit in the vehicle. The devices that are supplied with DC power are classified as follows: CC, ZC, AC, or BC according to intended use. Devices supplied with AC power are to be referred to the appropriate categories in the DO-160G Section 19.

RADIO FREQUENCY SUSCEPTIBILITY

A HAPS vehicle and payload are equipped with many devices with very high radio power. The effects of these devices may cause signal processing to fail or malfunction. A co-site analysis should be performed between payload and flight vehicle as to whether there are radios or other RF sources that are operating within similar frequencies.

Conduct the test in accordance with DO-160G Section 20. The category specifies the radio frequency test level and also sets the minimum level of resistance to radio frequency of the equipment. The category may be indicated in the applicable device performance standard for the device. The category applied to the system or the device often has to be identified before the internal radio frequency environment of the aircraft is known. In addition, many systems or pieces of equipment are designed with the intention of being installed in several different types of aircraft. Therefore, when the equipment specifications do not clarify the category, the equipment manufacturer shall design, test and evaluate the device for the category that suits the expected mounting position, exposure and usage. Refer to DO-160G Section 20 for the list of categories.

EMISSION OF RADIO FREQUENCY ENERGY

For all payload electronic equipment (categories Int-PE and Ext-PE), it is necessary to ensure that the device does not emit unwanted radio frequency noise, to protect the operating frequency of the radio frequency sensors of the aircraft. Emitting unwanted radio frequency noise may affect GPS, C2 link, etc. and interfere with the control of the aircraft.

Conduct the test according to DO-160G Section 21 to check the radio frequency (RF) radiation by conduction and RF radiation by radiation. Refer to DO-160G Section 21 to choose the appropriate category based on the relative location of the payload to critical vehicle radio receivers.

SUMMARY

The guidelines for payload operation in the stratosphere are summarized in the table below.

Test area	Guideline	Applicability
Temperature and Pressure	MIL-STD-810G 500.5 Procedure II (Operation/Air Carriage) using worst-case temperatures from MIL-HDBK-310G, multiple test cases according to table	Int-PE, Int-PS, Ext-PE, Ext-PS All vehicle types
Humidity	Conformal coating, storage/sealing mitigations	Int-PE, Ext-PE All vehicle types
Water	Conformal coating, ingress protection	Int-PE, Ext-PE All vehicle types
Salt Damage/Corrosion	Conformal coating, avoid/mitigate dissimilar metals joined together	Int-PE, Int-PS, Ext-PE, Ext-PS All vehicle types
Ice Accretion	No guideline	
Fungus (Mold)	Avoid materials listed in MIL-STD-810G Table 508.6B-I. Group II.	All vehicle types
Dust	No specific recommendations, general guidelines	All vehicle types
Ultraviolet Rays/Ozone	Choose materials less susceptible to UV/ozone.	Ext-PS All vehicle types
Lightning	DO-160G Section 22 and DO-160G Section 23	Int-PE, Ext-PE All vehicle types
Shock	MIL-STD-810G Method 516.6	Varies by vehicle type
Vibration	MIL-STD-810G Method 514.6 ANNEX D, Category 13	Fixed wing Airship
Acoustic Vibration	No guideline	
Fluid Susceptibility	No guideline	
Electrostatic Discharge	DO-160G Section 25	Int-PE, Ext-PE All vehicle types
Power Input	DO-160G Section 16, Category Z	Int-PE, Ext-PE All vehicle types
Voltage Spikes	DO-160G Section 17, Category A or B depending on integration	Int-PE, Ext-PE All vehicle types
Induced Signal Susceptibility	DO-160G Section 19, category varies	Int-PE, Ext-PE All vehicle types
Radio Frequency Susceptibility	DO-160G Section 20, category varies	Int-PE, Ext-PE All vehicle types
Emission of Radio Frequency Energy	DO-160G Section 21, category varies	Int-PE, Ext-PE All vehicle types

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About the HAPS Alliance

The HAPS Alliance is an industry association of High Altitude Platform Station (HAPS) industry leaders that include telecommunications, technology, aviation and aerospace companies, as well as public and educational institutions. United by a vision to address diverse social issues and create new value through the utilization of high-altitude vehicles in the stratosphere, the Alliance is working to accelerate the development and commercial adoption of HAPS technology by promoting and building industry-wide standards, interoperability guidelines and regulatory policies in both the telecommunication and aviation industries. For more information, please visit https://hapsalliance.org/.