GPS Guided Parafoil Descent System

Executive Summary Report

ESA Contract No. 4000136452/21/NL/GLC/zk

	Name	Function	Signature	Date
Approved	J. Moth	Managing Director	Jack Moth	08/12/2023

Copyright Notice

Table of Contents

1 Summary

The reduction of space debris is a priority for governments, space organisations and industry. The increasing number of applications that require space infrastructure means more launches and an ever-increasing number of satellites. Removing and preventing space debris is becoming increasingly important to preserve access to space and operational capability. It is therefore imperative that government and industry develop de-orbit and descent solutions that return space components to Earth for re-use, the Glide2 product addresses many of these areas.

This executive report provides a summary of the work undertaken and the conclusions reached under GSTP study “GPS Guided Parafoil Descent System” which was under the responsibility of NewSpace Systems Ltd and Vorticity Ltd acting as a subcontractor. The study was supported by the UKSpace Agency, and managed by the European Space Agency in Noordwijk The Netherlands. The study focused on analysing an existing terrestrial guided parafoil system (Glide2) from Newspace Systems to see if it could be used as the basis of a recovery system for a range of non-manned space missions.

Three non-crewed mission applications were selected; recovery of payload from high-altitude balloon, vehicle return from orbit and launcher component recovery. The reasoning behind the selection of these mission types was that the performance parameters and flight profile after the parafoil deployment are very similar. A set of baseline parameters that included maximum payload weight (up to 2500kg), mission duration (up to 90 days) and landing accuracy (better than 100m) were then defined.

A number of landing options were also considered; landing on-land, ocean and mid-air retrieval. For ocean landings and mid-air retrieval, the assumption was made that the same descent and landing parameters apply. While in the case of an on-land landing a higher landing shock was considered. For a mid-air retrieval the end flight profile is also different as the control system is required to keep the Host/payload on a predefined heading and the final recovery and landing is undertaken by an aircraft or helicopter.

Depending on mission type, its duration, and payload weight, different qualification and performance parameters were considered. For launcher component recovery and return from orbit type missions flight-level qualification is required. Whereas for a high-altitude balloon mission the ascent/descent speed is slower and the mission altitude is lower, so the qualification level can be relaxed. However, to achieve a wider market acceptance the study assumed that the system will achieve the representative flight qualification level.

1.1 Key performance aspects

A number of key performance aspects were considered during the study, these included analysis of a suitable architecture, autopilot performance, payload weight and mechanical configuration. Operational requirements differ between the application missions, in the case of the high-altitude balloon the requirement for a distributed architecture and interfacing to the on-board system is less of a driver than for a launcher or capsule. For launcher component and return from orbit type missions, drivers such as weight and space restrictions mean the system must be mass-efficient and have a distributed architecture.

The approach taken was to design a system that could be implemented as either stand-alone or as separate modules. The architecture contains the necessary battery capacity, on-board computer, interfaces, sensors, navigation processor, up/down S-band communication links and interfaces to ground support equipment for integration and pre/post flight data evaluation.

One of the main drivers for the system design was the size and power requirements of the actuator motors, these are used to control the parafoil in flight. Analysis showed that by applying an approach that assumed a variable winding speed and a reduced steering line force estimation based on the Glide2 flight experience. The motor power could then be reduced to around 500W which gave significant saving in motor weight and battery power.

For long duration missions without access to on-board power it is important to maintain battery capacity to ensure power availability during the parafoil flight phase. The main driver for the capacity is the power required to maintain thermal housekeeping. Analysis showed that an architecture based on a primary and secondary battery approach offered the best solution.

The current Glide2 autopilot is optimised for non-lifting payloads up to 1000Kg, the functioning of the autopilot is based on in-flight determined aerodynamic characteristics of the actual parafoil, this in combination with real-time GPS data and attitude information allows the Glide2 system to calculate the wind velocity and compensate for it autonomously during the flight and landing phases.

It was thought that the increased payload weight would impact the landing accuracy of the autopilot, trajectory simulations undertaken during the study showed that without any modification to the current autopilot or fine tuning of the parafoil parameters a landing accuracy of 150m was already achievable. The conclusion is that this accuracy figure can be further improved by implementing a number of recommendations made by the study.

1.2 Aerodynamics characterisation

During the study aerodynamic databases were derived for a small 36 m² canopy, 164 kg payload MC-4 parafoil and for a 300 m² to 400 m² large parafoil designed to carry a 2500 kg to 3000 kg payload using the Glide2 controller. The databases were split into separate canopy, suspension line and payload contributions. The effects of angle of attack, angle of sideslip and canopy control deflections were included.

The inflated shapes of both the MC-4 and large parafoil canopy were successfully generated for various control deflections using finite element analysis (FEA). The MC-4 results closely matched flight images (Figure 1), showing that FEA simulation can accurately predict inflated canopy shapes.

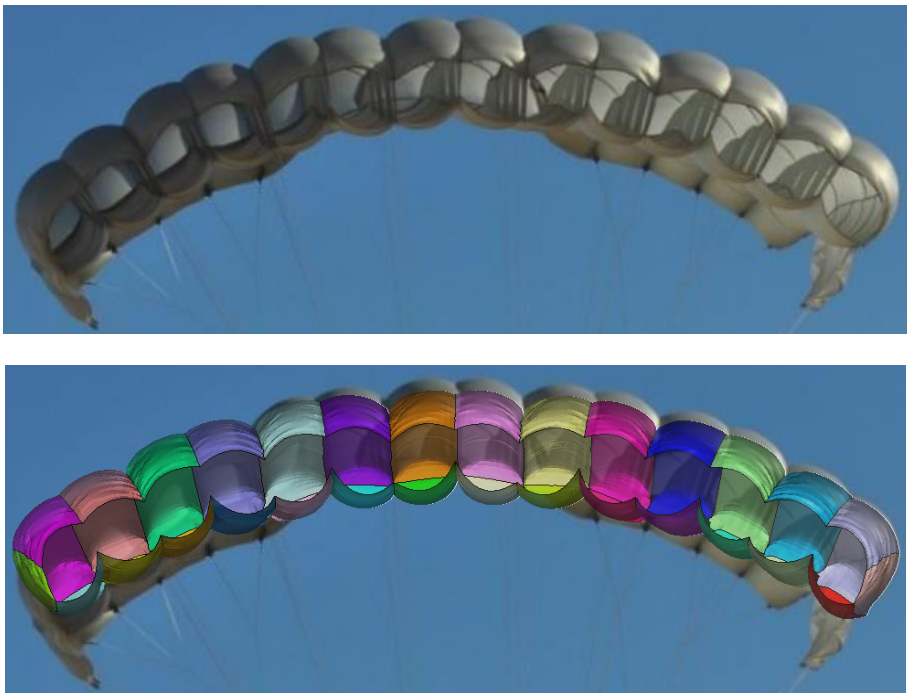

Figure 1: MC-4 canopy in flight (above) and overlaid with simulated inflated geometry (below)

The individual drag and lift contributions of all suspension lines were calculated and combined, using the flying configuration simulated by FEA. FEA simulations also allowed estimates of control line loads and maximum deflections. The canopy drag and lift aerodynamics were adapted from existing wind tunnel data, informed by 2D CFD simulations of the canopy cross-section.

1.3 Flight dynamics simulation

The NewSpace Glide2 GNC was successfully integrated into Vorticity's flight dynamics and trajectory simulation code Anybody6D and used for landing accuracy simulations. These simulations included the dynamics of the canopy, suspension lines and payload (Figure 2), under realistic wind profiles. Wind profiles compliant with MIL-STD-1797A were randomly generated, including variation with altitude, turbulence and low altitude wind vector shear. Monte Carlo simulations of the MC-4 parafoil miss distance closely matched the results of historical flight data from NewSpace, validating the use of Anybody6D simulations to predict landing accuracy (Figure 3).

Monte Carlo simulations of the large parafoil landing error (Figure 4) showed that the 90th percentile miss distance (422 m) was significantly larger than the median miss distance (168 m), because of a small number of 'bad misses'. Further investigation of the simulated trajectories showed that this was mainly due to errors in the estimates of wind magnitude and direction.

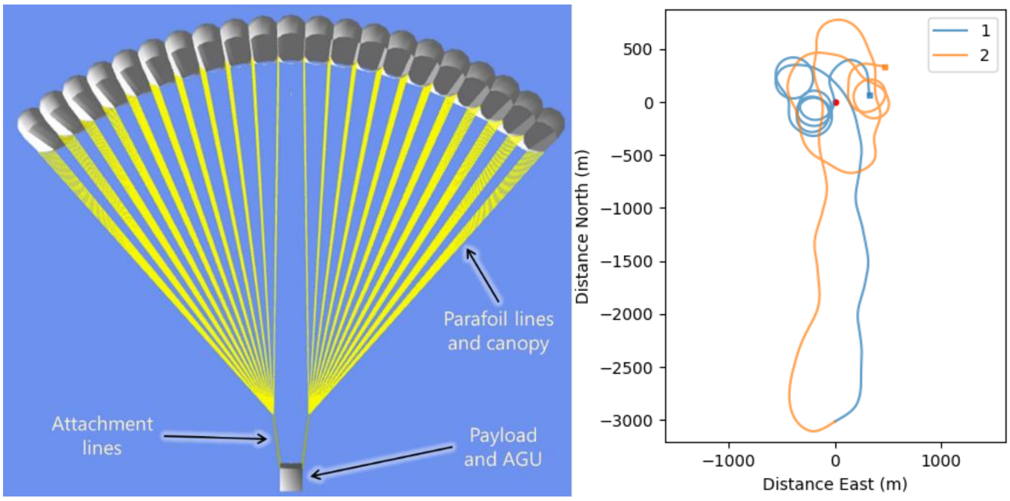

Figure 2: Anybody6D simulation of the large parafoil with 2500 kg payload

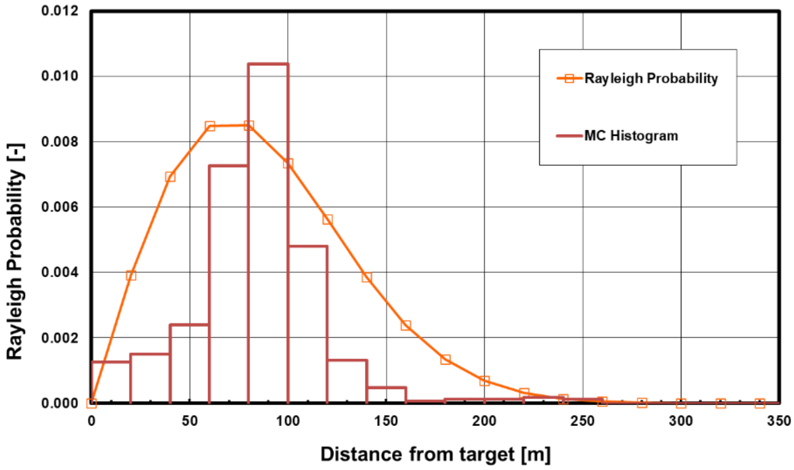

Figure 3: MC-4 parafoil miss distance probability distribution from flight data (orange line) and Anybody6D simulation (red histogram)

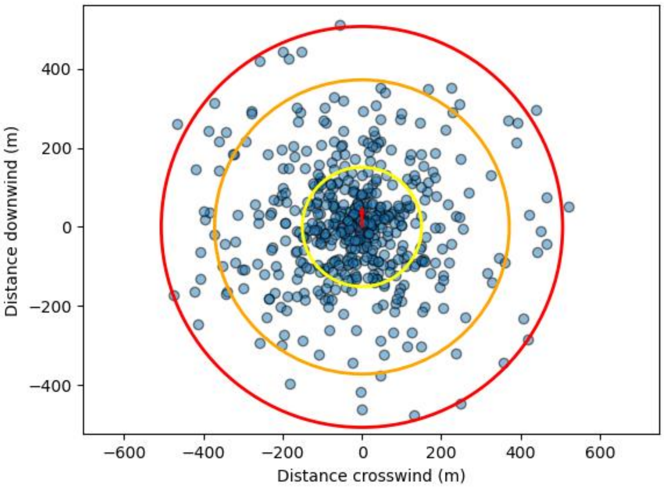

Figure 4: Simulated landings with 50th (yellow), 90th (orange) and 99th (red) percentiles

1.4 Methods for improved landing accuracy

The trajectory simulations showed that the Glide2 GNC required accurate tuning of the autopilot to the physical system, which is difficult to achieve without significant numbers of flight tests. The wind estimation had significant oscillations associated with turning, which caused the energy management phase to be inconsistent; this was the main source of landing error. The following landing accuracy improvements were recommended for future Glide2 development:

- Updated in-flight wind estimation algorithm (an example is shown in Figure 5)
- In-flight wind and system characterisation through dedicated manoeuvres
- Wind profiles informed by multiple wind data sources

All these improvements would be made to the Glide2 control algorithm; they do not require any hardware modifications. The new control algorithms could be tested and validated using the existing Anybody6D trajectory simulation environment before flight tests, reducing the overall cost and risk. If implemented, they would reduce the Glide2 median miss distance to ~150 m and 90th percentile miss distance to ~300 m.

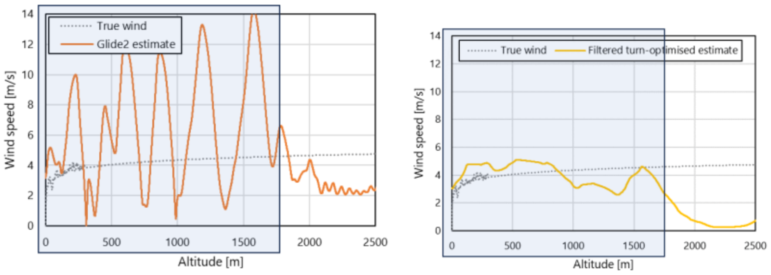

Figure 5: Wind speed estimates using Glide2 method (left) and new GPS-only method (right).

A survey of novel glide slope control techniques was completed, which could enable higher-precision landings in future. Glide slope control involves deliberately changing the ratio of parafoil forward speed to descent speed. Spoilers in the upper surface canopy are the most promising technique for achieving glide slope control. Hardware development and flight testing in collaboration with parafoil manufacturers would be necessary, as changes to the canopy are required. Glide slope control would offer a 50% reduction in median miss distance and a 40% reduction in 90th percentile miss distance, compared to existing parafoil controllers.

1.5 Conclusion

The results of the study confirmed that the concept of the Glide2 guided parafoil system can be used as the basis of a recovery system for a range of mission types and durations. The architecture developed under the study can form the basis of a system that can achieve the flight TLR levels required (8/9). Simulations with the autopilot and analysis of the performance data show that accuracy can be increased by implementing the recommendations given in the study. These results will form the basis of a follow-on phase focused on implementing a proof-of-concept system which will be validated by a series of low and high-level drop test campaigns.