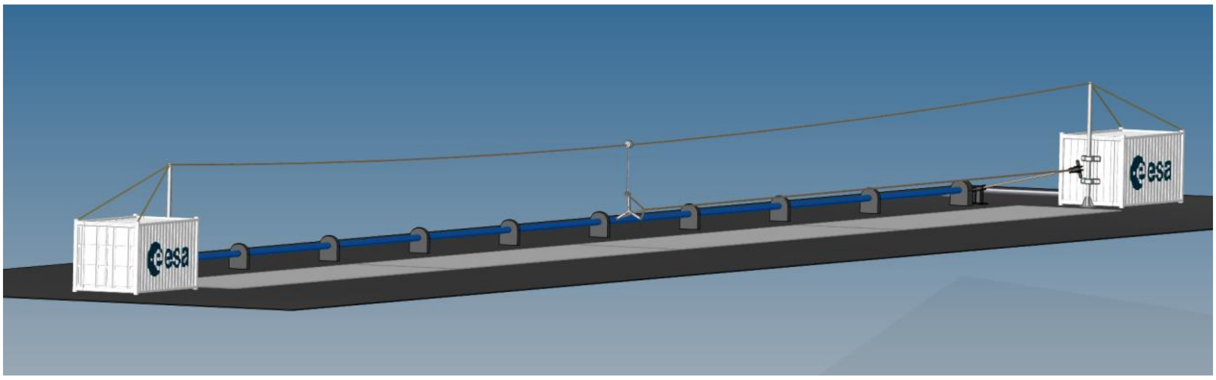
Parachute Dynamic Extraction Test Rig



Executive Summary Report

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SUMMARY

When parachutes are deployed, the parachute material is extracted from the deployment bag at high speed. Interaction with the parachute bag during deployment can cause damage which can propagate and cause parachute failure during inflation.

After a parachute has failed during inflation, it is impossible to determine whether the initial damage was caused during deployment or inflation. A parachute extraction rig thus provides an invaluable tool for testing parachute deployment before committing to expensive system flight tests of the system.

The only existing parachute extraction rig is located at JPL in the USA. A European rig would be of benefit for ESA programmes.

A transportable parachute extraction test rig has been designed which has the capability to test deployment of the parachutes for all current and planned missions. The rig uses compressed air for acceleration of either pilot-chute-deployed or mortar-deployed parachutes to representative extraction velocities.

The rig has been designed so that it can be relocated easily between test sites and can be packed into a small volume (3, 20 ft shipping contains) between campaigns.

This programme has advanced the European TRL from 1 to 3. A 13 month development plan has been defined for its detailed design, manufacture and commissioning which will achieve TRL 8.

The rig will be of vital importance for upcoming ESA exploration and cargo return missions.

This report summarises the work undertaken to design the European Dynamic Extraction Test Rig.

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REVISION RECORD

Issue	Date	Pages	Sections affected	Brief description of change
01	2024-12-10	13	All	First issue
02	2024-12-16	13	All	Copyright and distribution text removed i.a.w. ESA request

This document contains 4 introductory pages, 9 pages of core text and 0 pages of annexes.

AUTHORISATION

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1 INTRODUCTION

1.1 Purpose and scope

This report summarises the main outputs of the preliminary assessment and design of a system for parachute dynamic extraction tests programme.

1.2 Applicable documents

AD	Title	Reference	Issue	Date
AD-01	Statement of work	ESA-TECMPA-SOW-2023-001147	01	23/03/2021

1.3 Acronyms and abbreviations

DET	Dynamic Extraction Test
JPL	Jet Propulsion Laboratory
LDSD	Low-Density Supersonic Decelerator
MP1	Main Parachute 1 (ExoMars design)
PDR	Preliminary Design Review
RSP	Rover and Surface Platform
RTB	Rigging Test Bed

2 OBJECTIVES

Many space missions include parachute systems as key elements of their design. Before operation, parachutes will always be contained in a deployment bag (a parachute pack). When designing a parachute system, correct extraction of the parachute from its bag without damaging it is a key requirement. “The best designed parachute will not operate reliably if not deployed properly (1)".

Development and qualification of an effective parachute deployment system requires the ability to test the deployment phase. Although this can be tested as part of a full system (i.e. flight) test, it is better to test this phase as a separate stage since:

- any damage can be attributed unequivocally to the deployment rather than the subsequent inflation; and
- cameras can be situated very close to the test article for detailed analysis of the extraction, which is not the case for flight tests.

Two methods of parachute deployment are most used: mortar deployment and pilot chute deployment.

In a mortar deployment, the parachute is ejected from the payload at high velocity using a pyrotechnic mortar (sometimes known as a Parachute Deployment Device). This method is generally used for the first parachute in a sequence of parachutes but may be used for later parachutes. Mortar deployments are generally characterised by a rapid initial acceleration of the parachute pack (being pushed by a pyrotechnic charge) followed by a gradual deceleration during deployment.

In a pilot chute deployment, an already-inflated parachute pulls out the next parachute in sequence. Pilot chute deployments are generally characterised by a continuous acceleration as the parachute bag moves away from the payload which results in a high extraction velocity of the canopy from the bag. Pilot chute deployments are challenging since the parachute must be retained in its bag against the bag acceleration.

The most representative deployment test is one where the system acceleration and extraction velocity from the bag are matched. For a mortar-deployed parachute this can best be achieved using a mortar test. For a pilot-chute-deployed parachute a ground test requires a dedicated test rig, known as a Dynamic Extraction Test (DET) rig.

The objective of this activity is to progress the design of a European parachute dynamic extraction test (DET) rig to PDR design maturity.

3 BACKGROUND AND APPROACH

3.1 Previous extraction testing

High speed extraction tests have been performed on very few parachutes historically. Terrestrial parachutes have been tested in low altitude flight tests, which are relatively inexpensive. Testing of space parachutes has been limited to those where high speed deployment has been identified as a risk factor, frequently *after* a failed flight test.

The earliest DET was a test of the Galileo parachute system. As the extraction velocities on Jupiter were close to the range where canopy damage could occur, extraction testing was conducted to verify the new design after an early high altitude drop test failure. The Galileo rig used the US Navy's aircraft launch steam catapult to provide the extraction force.

Extraction of the main parachute and stabilizing drogue at high speed and cryogenic temperature was identified as a risk for the Huygens mission. A parachute extraction rig was designed and built in 1993 to perform high speed extractions of the main parachute and stabilising drogue prior to the system drop tests. It was used for development and qualification extractions of the parachutes.

JPL identified parachute deployment as a risk in the Low-Density Supersonic Decelerator (LDSD) programme (2). A rigging test bed (RTB) was developed (3) (4) to allow rapid deployment of a parachute vertically from the ground. The objective was to conduct multiple parachute deployment tests, not including inflation, under representative flight conditions.

Dynamic extraction testing of the ExoMars RSP parachutes was undertaken following parachute damage in the early high altitude drop tests of the system. These were undertaken by JPL using a modified version of the RTB used for the LDSD testing.

3.2 Current and future applications

All future space missions that use parachutes would benefit from dynamic extraction testing. These tests are invaluable in identifying and rectifying issues in parachute deployment systems. Some examples of potential applications are ExoMars RFM, parachutes for Low Earth Orbit Cargo and Crew Return, Ice Giant exploration, Mars Sample Return and any re-usable space transportation system parachute system.

3.3 Requirements Definition

The European dynamic extraction rig was designed to exceed the capabilities of the currently available non-European rigs while being easily accessible to ESA parachute manufacturers and system integrators.

4 BASELINE CONFIGURATION SELECTION

Multiple candidates test rig configurations were considered and traded off against each other to arrive at the configuration chosen for this programme. Numerical models of the candidate configurations for both pilot cute deployment and mortar deployment were traded off against each other based on test cases that are representative of current and future parachute systems.

The configurations that had appropriate performance were further traded off against each other based on operational, functional and safety requirements.

The configurations chosen were a compressed air propelled solution for pilot chute deployments and an air mortar for mortar-based deployments.

5 PRELIMINARY DESIGN

5.1 Pilot extraction

The general layout of the testing rig is ISO 20ft container assemblies at each end of the testing track, with a guidewire suspended between them. The parachute being tested is suspended from this guidewire and pulled along at a representative speed by a compressed air system. The moving elements are then stopped by a catch net braking system.

One of the main aims of the design is to utilise the shipping containers for transport and storage of the test hardware. Any modifications that would require special handling procedures or equipment will be avoided. Additionally, the containers will provide sufficient storage volume to pack and secure all the equipment associated with the extraction rig after a test and for long-term storage. This will allow the entire facility to be transported and assembled at various locations to suit the customer.

A render of the general layout of the test rig in the pilot extraction configuration is shown in Figure 1.

The pneumatic system provides the extraction force to accelerate the parachute assembly along the guidewire. The parachute assembly will be attached, via a pull line and pulley system, to a piston housed inside a cylinder. The cylinder needs to be at least as long as the test article system length, plus additional length for cylinder venting and piston deceleration. To achieve this, a local supply of pressurised gas, nominally air, is required and fed into a cylinder to propel the piston.

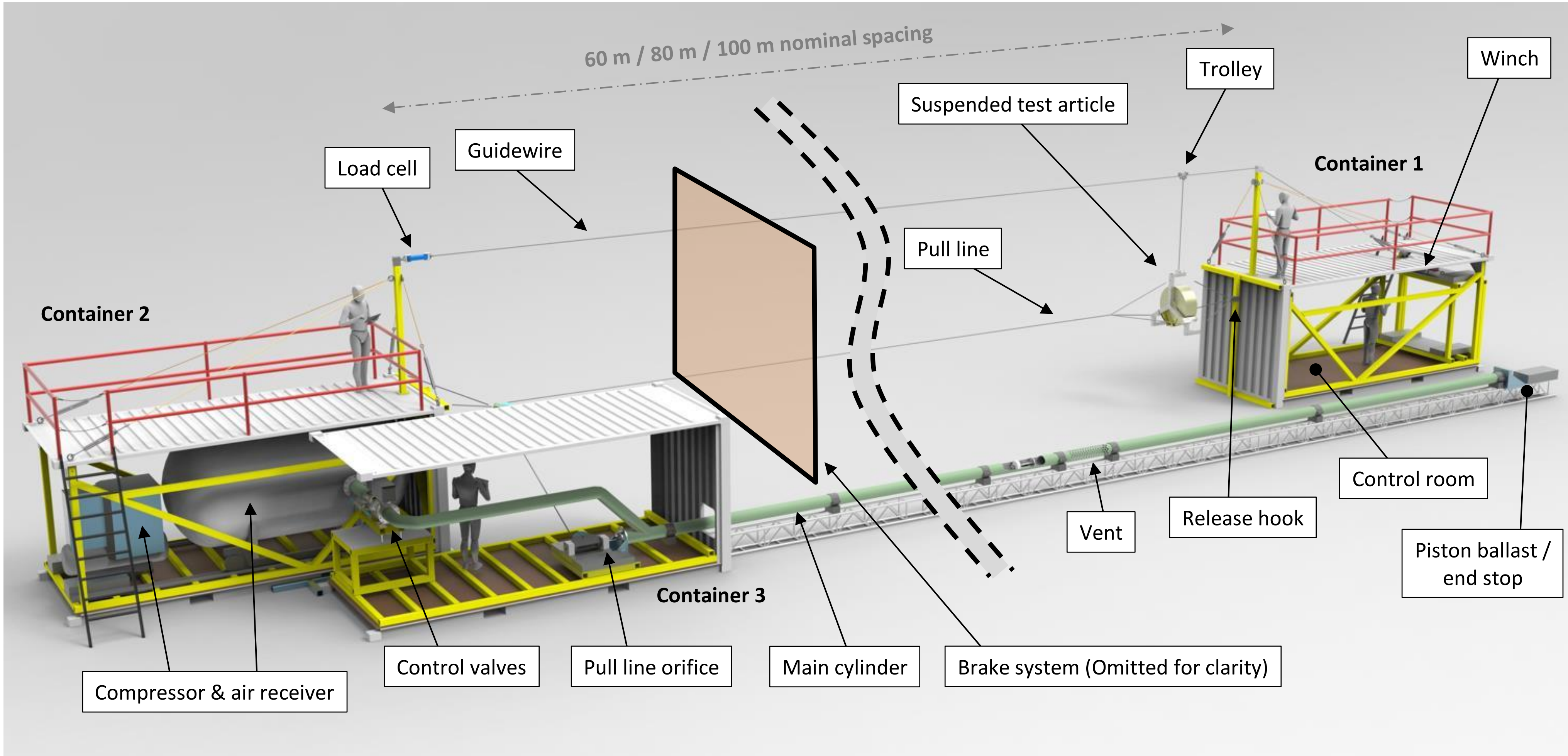

Figure 1: Pilot extraction test rig configuration (container separation not to scale)

5.2 Mortar deployment

The air mortar deployment system uses compressed air to propel a piston and parachute pack to simulate a pyrotechnic mortar extraction. Figure 2 shows the overall configuration of the air mortar deployment system including the support frame.

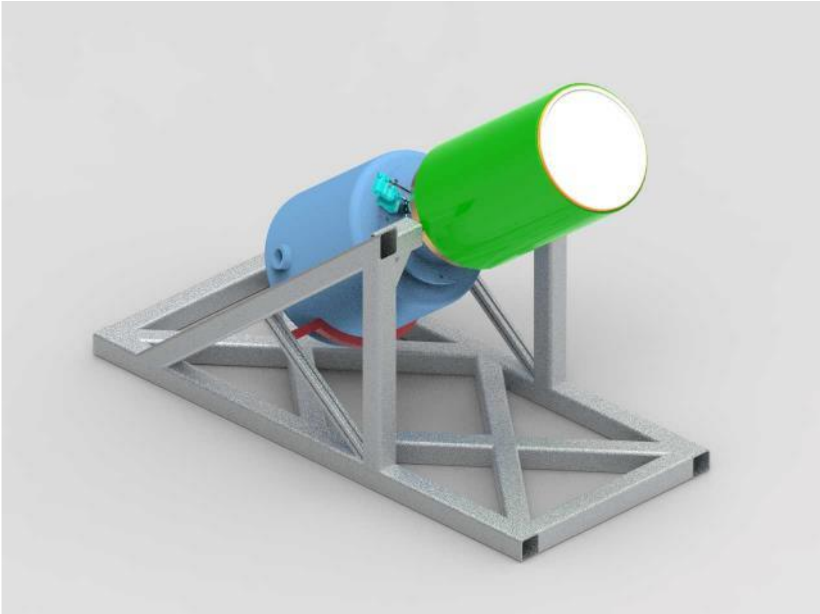

Figure 2: Render of air mortar concept

The pneumatic system for the air mortar deployment comprises a compressor (common with the pilot extraction system), a high-pressure tank, a dual burst disc release system, a test-specific mortar tube and piston, a load collar, and a support frame. The system is designed to simulate a representative extraction for a variety of mortar-deployed parachute systems. The high-pressure tank is required to provide a propulsive force to the piston to eject the parachute pack out of the mortar tube. A compressor is required to pressurise the tank. A release mechanism is required to allow the tank to fully pressurise before the piston is allowed to move. A dual burst disc design is the most suitable system to achieve this. The reaction force imparted on the mortar from the ejected pack must be transferred through the load collar and frame to the ground to avoid damage to the assembly.

6 DEVELOPMENT PLAN DEFINITION

6.1 Development Plan

6.1.1 Development logic

The development logic is shown in Figure 3.

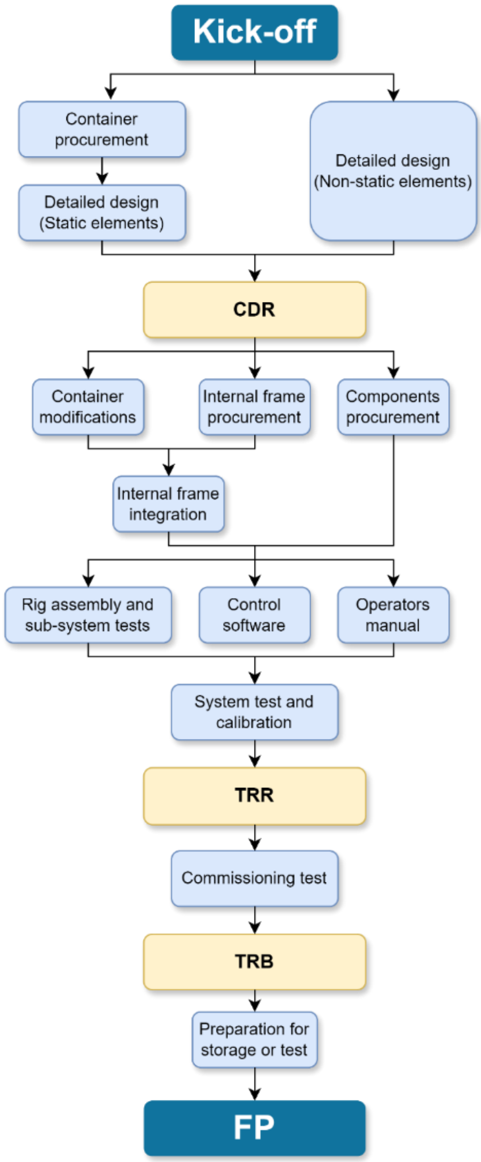

Figure 3: Development logic

6.1.2 Schedule

The development of the extraction rig is predicted to take 13 months from start to completion of the commissioning test. A GANTT chart based on a notional kick-off date of 1st January 2025 is shown in Figure 4.

Name	Start	Finish
KO	01/01/25 ...	01/01/25 ...
CDR	30/04/25 ...	30/04/25 ...
TRR	03/12/25 ...	03/12/25 ...
FP	30/01/26 ...	30/01/26 ...
WP1 - Container procurement	01/01/25 ...	28/02/25 ...
WP2 - Detailed design (static)	03/03/25 ...	30/04/25 ...
WP3 Detailed design (non-static)	01/01/25 ...	30/04/25 ...
WP10 - Container mods	01/05/25 ...	30/06/25 ...
WP11 - Internal frames procurement	01/05/25 ...	30/05/25 ...
WP12 - Components procurement	01/05/25 ...	31/07/25 ...
WP13 - Internal frames integration	01/07/25 ...	31/07/25 ...
WP14 - Rig assembly and SS tests	01/08/25 ...	31/10/25 ...
WP15 - Control software	01/05/25 ...	31/10/25 ...
WP16 - Operators' manual	01/05/25 ...	31/10/25 ...
WP20 - System test and calibration	03/11/25 ...	03/12/25 ...
WP30 - Commissioning test	04/12/25 ...	31/12/25 ...
WP40 - Prep for storage or first test	01/01/26 ...	30/01/26 ...

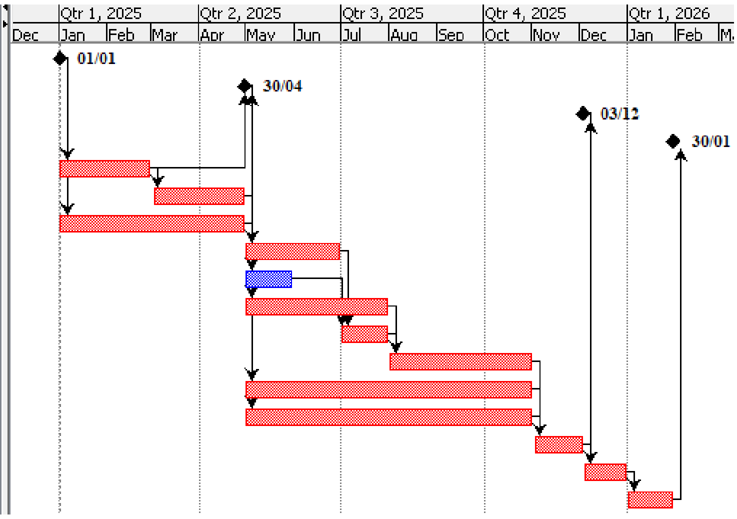

Figure 4: Schedule

6.2 Qualification plan

The extraction rig will be qualified by means of a series of tests, starting at sub-system level and working up to full system tests and qualification tests. This approach will allow issues with the rig to be identified at an early stage and will provide confidence in the later tests.

6.3 Life cycle costs

The life cycle costs of the testing rig, in 2024 economic conditions, are shown in Table 1.

Item	Frequency	Cost
Manufacture & commission	Once	€935 k
Annual storage and maintenance	Annual	€25 k
Setup and tear-down for series of tests	Once per test series	€30k
Single test one rig has been set up	As required	€10k

Table 1: Lifetime cost summary

7 CONCLUSIONS

A dynamic extraction test rig has been developed to PDR design maturity level (TRL 3).

A development plan has been defined, outlining the steps required to advance the design from preliminary design maturity level to being ready for testing. The development will take 13 months from award of contract to completion of the commissioning tests. The cost will be €935k.

Tests will cost €30k per campaign plus €10k per test and the annual storage and maintenance cost is estimated to be €25k. These numbers assume the rig will be stored and used close to Vorticity premises.

8 REFERENCES

1. **Wolf, Dean.** *Parachute Deployment.* Portsmouth, VA : H.G. Heinrich Parachute Systems Short Course, 2018.

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