DOI: 10.13009/EUCASS2023-537
Aerospace Europe Conference 2023 – 10TH EUCASS – 9TH CEAS

ReFEx: Reusability Flight Experiment- Planning a MORABA Campaign in South Australia

Alexander Schmidt†, Andreas Kimpe*, Dietmar Kail*, Philipp Rosenheimer*, Sebastian Weiß*, Markus Wittkamp**
** DLR-German Aerospace Center*
Münchnerstrasse 20 82234 Wessling
alexander.schmidt@dlr.de, andreas.kimpe@dlr.de, dietmar.kail@dlr.de, philipp.rosenheimer@dlr.de, se.weiss@dlr.de, markus.wittkamp@dlr.de
† Corresponding Author

Abstract

The ReFEx mission by DLR is planned to launch from Koonibba Test Range in July 2024. DLR's Mobile Rocket Base is together with the South Australian company Southern launch responsible for the conduct of the campaign. In this paper we describe the necessary background of the mission and the test range as well as MORABA's contribution to the range assembly and onboard systems.

1. Introduction

The ReFEx mission is about to launch an experimental reusability test vehicle. A detailed description of the experimental goals can be found in [1], [2]. DLR's Mobile Rocket Base MORABA is strongly involved into the ReFEx mission in two ways: On the one hand, MORABA contributes to some on-board systems and takes care of all the data handling on-board the ReFEx vehicle. This includes also the processing of all scientific, navigation and housekeeping data to generate a telemetry data stream to be sent to the ground for further usage. Furthermore, it includes the implementation of a Flight Termination System (FTS) which would force the vehicle into a controlled crash in case it would violate the flight safety requirements.
The launch vehicle will be a VSB-30 rocket [3]. The present paper focuses on the interaction between on-board systems and campaign and ground infrastructure preparation and their impact on the safe conduct of the mission. Especially the usage and interplay of the systems mentioned above to ensure the flight safety requirements for the mission is a new challenge, because the intended launch place near the South Australian village Koonibba was never used before for a mission of such size.

2. The ReFEx Campaign – Using a New Launch Site and Developing a Campaign In-frastructure

The ReFex mission introduces a variety of novelties. Besides the exciting reusability experiment itself and the new, to be tested navigation systems and algorithms on-board, this will also be the first time that MORABA launches a rocket from the new Koonibba Test Range (KTR), near Ceduna in South Australia.
The choice for this new launch site has been made for several reasons. To fulfill its scientific goal, the ReFEx mission needs a lot of space for its trajectory, therefore it is not possible to launch ReFEx within Europe, unless one uses launch ranges where one can shoot to the ocean. However, ReFEx aims for a recovery and due to the limited space on the vehicle there was no space for a recovery system or even a sea recovery system. Therefore, a part of the earth where one can fly a long trajectory and in addition to recover over land was searched for. Australia with its wide, unpopulated areas was the perfect choice for this type of misssion.
The original intention was to use Woomera Test Range, as it was done several years ago for the HiFIRE campaigns. However, Woomera is mostly used for military purposes and so there are some additional constraints making a sound campaign planning more difficult. Fortunately, a new company in South Australia named Southern Launch came into play and offered their new launch range Koonibba Test Range, near the small town Ceduna in South Australia, as a launch place.

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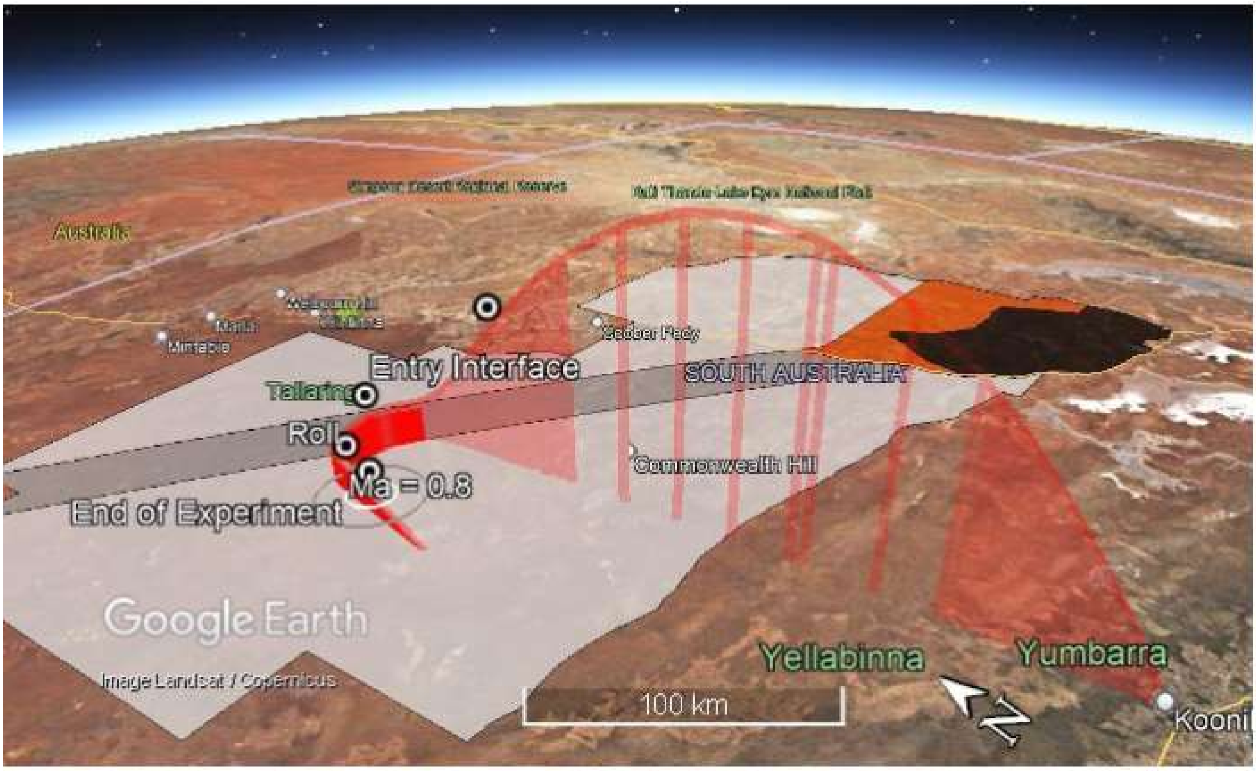

Figure 1-ReFEx Trajectory

3. The ReFEx Campaign – Facing New Challenges

During the last 56 years MORABA has gained significant experience in conducting sounding rocket campaigns. MORABA has launched more than 550 vehicles since then, also for technology development as for the ReFEx mission [4]. MORABA is capable of conducting full mobile campaigns using its own mobile infrastructure and equipment [5]. However, during the last decades it was logistically more advantageous to use already existing launch ranges providing a fixed installed infrastructure. Almost all MORABA sounding rocket missions during the last years have been launched therefore from Esrange Space Center, Kiruna, Sweden or Andøya Space at Andenes in Norway. Despite the advantages of both ranges, neither of them could fulfill all the requirements of the ReFEx flight as described in the former paragraph.

The geographic advantages of KTR launch site for the ReFEx mission however come along with some challenges. Due to the fact that KTR is a very new place for launching rockets the main challenge is to set up a complete infrastructure to fulfill all the need for the ReFEx mission. This includes also the assembly of a ground infrastructure using MORABA's mobile infrastructure and the experience of Southern Launch. Southern Launch already had two launch attempts form KTR at this moment in time. However, these have been small meteorological rockets which did no need sophisticated campaign infrastructure as the more complex ReFEx mission will need.

To ensure a safe mission, MORABA's on-board systems as well as the ground infrastructure to be assembled together with Southern Launch will be essential to fulfill all the flight safety requirements. The following sections describe some of these systems and their interplay in greater detail.

4. Overcoming the Challenges Part One – On-board Systems

On the on-board site MORABA contributes with several systems to ensure a safe mission. There are several main parts contributing to this and playing a key role in the attempt to achieve this goal. In the following we describe these components and the interplay between them.

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4.1 Flight Termination System

The probably most crucial on-board part to ensure flight safety in case of unexpected deviations of the trajectory is the on-board Flight termination system (FTS). The main purpose of the FTS is to activate actuators which will lock the canards of the ReFEx experimental vehicle in case there is a very high probability that it will leave the flight safety zone. If locked, the canards cannot be moved anymore and the stable flight mode of the vehicle will change into an unstable mode. As a consequence, the vehicle will impact within the flight safety zone and crash to the ground.

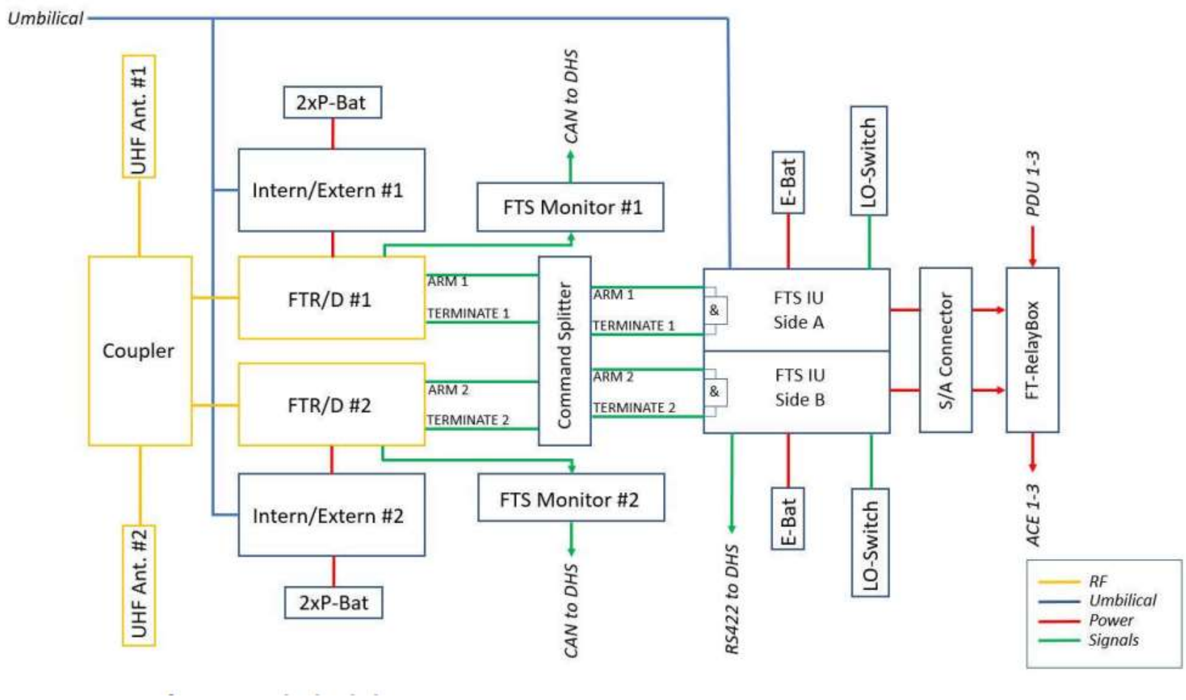

Figure 2-FTS Block Diagram

The picture above shows a block schematic of the on-board FTS-System. Together with its corresponding ground station it fully implements the IRIG 319-19 FTS commonality standard.

The system is built up fully redundant with two identical, independent subsystems. In case a flight termination is required the ARM and TERMINATE commands will be sent from ground and the Ignition Units start the flight termination sequence. The command chain uses the usual necessary components, i.e. telecommand receive antennas, a coupler to combine the signal from both antennas for proper signal reception, two flight termination receivers to decode the tones and a command splitter to distribute the signal to the respective ignition units. Furthermore, the two FTS monitors for monitoring the health status of the system.

4.2 Data Handling System

The core of the ReFEx communication system for telemetry and telecommand is the so-called Data Handling System (DHS). It basically consists of the ReFEx Data Handling Box (ReDBox), a precise oscillator, two flight termination monitors and a multiplexer for analogue signals. RF components like transmitters, receivers and a radar transponder are used for communication and localization of the vehicle during flight. Figure [3] gives an overview. MORABA builds and uses this system regularly within other sounding missions.

Almost all instruments and devices on the vehicle are connected directly to the DHS to send data to ground and get commands from the ground segment. The system encapsulates this data in an IRIG 106 compatible transfer layer and provides a synchronous data stream for the transmitters.

The frame generator relies on a precise oscillator for one-way ranging (Slant-Range). A reference oscillator in the telemetry station allows the calculation of the distance between transmitter and receiver. Using the range, pointing direction and location of the antenna, the position of the vehicle during flight can be computed. The device sends housekeeping data on the internal CAN bus.

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Two data transmitters sending out telemetry data in S-Band using frequency diversity: a single stream using different frequencies. These transmitters sharing the antenna network with two TV transmitters. Users issuing command messages on demand in the ground segment. These messages are collected within the ground segment, encapsulated and send on a RF link. The on-board system uses redundant receivers to decode the commands for the devices and instruments on the vehicle.
A copy of the collected telemetry data is stored on a data recorder. These devices is controlled either by tele-commands or automatically. The device stores data on a SD-card, large enough for the whole flight. A rugged housing gives a good chance of data-recovery even in hard landing scenarios.
Up to eight analog TV signals can arbitrarily multiplexed to two TV transmitters. The channel assignment is pre-defined and controlled by an automated time-line, but the operator can also send commands to switch to a different channel if needed.
The ReFEx power distribution unit (PDU) is actually not part of the DHS, but the control runs on the processor of the DHS. An operator can switch devices and read monitoring information such as power, current and voltage of batteries and connected devices. The automatic time-line service allows to turn on and off devices based on a flight-time. The PDU control messages using the second CAN bus of the ReDBox.
In order to use the time-line service, the on-board system needs to find the absolute time for time-tagging sensor readings and the current flight-state to run services like the time-line. This information is distributed by the Hybrid Navigation System (HNS [6]) on-board, based on GNSS time. The flight-state is basically the information if the rocket is still on the launcher or already in flight. The transition between these states are defined as t equals zero for the relative flight-time.
For safety reasons flight termination systems are autonomous devices implementing their own logic and using independent power supplies. Their monitoring interfaces are not directly compatible to the ReDBox to read their state. Therefore, two FTS Monitors acts as bridge devices to read the FTS states and send them to ground, together with other housekeeping information.

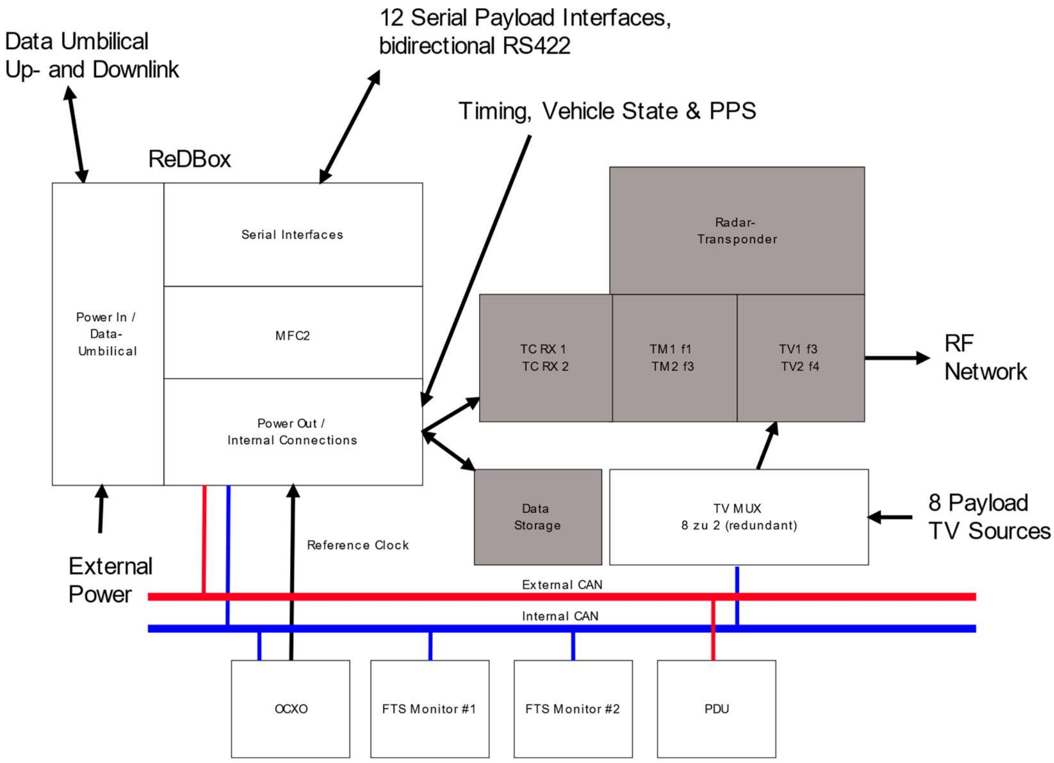

Figure 3 DHS Block Diagram

4.3 Radar Transponder

A radar system will be used which provides active tracking of the vehicle. For the on-board part there is a C-band radar transponder mounted into the rear end of the vehicle together with a power divider, couplers and two antennas. This device will be triggered by the radar signal to send signals back to the radar, so it is an active system, depending on on-board power

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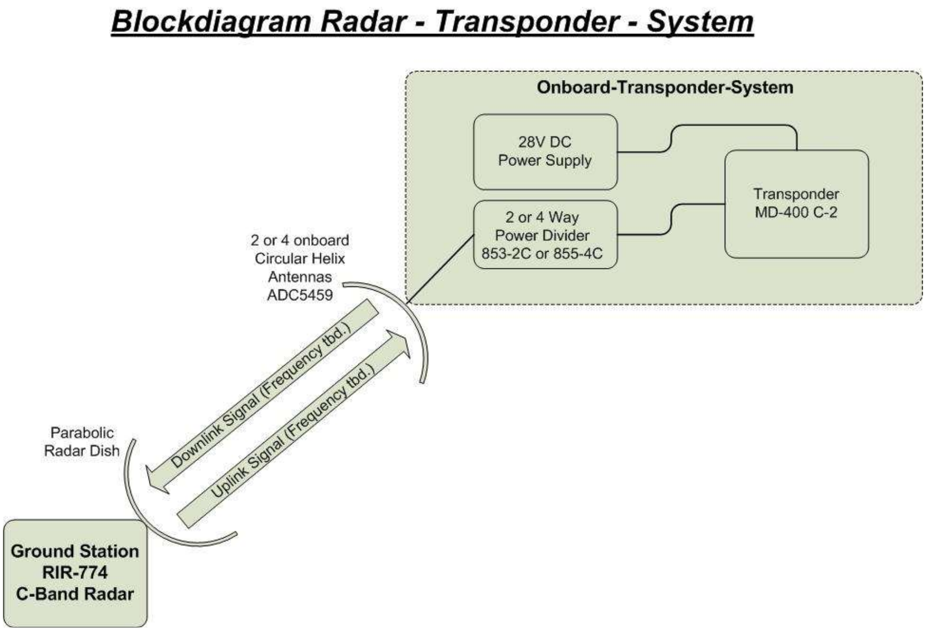

Figure 4 RADAR System

5. Overcoming the Challenges Part Two – Ground Infrastructure

To get as much information as possible about the vehicle during flight, proper ground data processing and distribution is necessary. Roughly this data set can be split in two categories: The pure science data as well as data which will be used for flight safety. For the last one the position data and their proper distribution play an important role. Consequently, different sources to gain these data will be used, comprising of on- board systems like the ReFEx Hybrid Navigation System [6] and on-board GPS.
Complementary, the MORABA TM-station will measure so called slant range as the distance in the direct line of sight via measuring the distance using the Doppler Shift of the signals and, independently, gaining data from the mobile tracking radar station.

5.1 FTS Ground Station

In paragraph 4.1 the FTS-on-board system was described. The corresponding ground station is a commercial system of the company TESTEM located near Munich. It is the FTS GSCU-2HU – Flight Termination System following the IRIG-Standard FTS319-92. For ReFEx the redundant version with a four-tone flight termination encoder will be used. In addition, a separate antenna to send the tones to the flight vehicle independent from the other telecommand station will be used.

Figure 5-FTS Ground Station

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5.2 Telemetry Container and the 5-m Dish

MORABA will bring its complete mobile telemetry equipment for the REFEX mission to South Australia.
The figure above shows all the main components of MORABA's mobile telemetry infrastructure. The control station is housed in the white container and equipped to simultaneously receive, record and support several telemetry and TV streams with various modulation schemes. It is self-contained and adaptable to a variety of configurations. The 5 m primary antenna is a segmentable parabolic reflector.
The main control station as well as the 5 m antenna will be placed at range head in Koonibba. The antenna will track the vehicle from the beginning on until it vanishes beyond the horizon.
A detailed description of the station and all its capabilities can be found in the MORABA portfolio [5].

Figure 6-TM Mobile Infrastructure

5.3 Small Telemetry Container and the 1.5 m Dish

Due to the fact that the trajectory goes beyond the horizon the idea was to put a second antenna as close as possible to the impact point to get as much data from the flight as possible. Therefore, the pastoral station at Mobella, operated by Jumbuck, Adelaide, was chosen as a place for MORABA's 1.5 m antenna. For this antenna MORABA is currently building up a small control station containing of several racks in a small housing to protect the devices from the environment. The small station will be operated by two persons and be in contact with the range head via starlink internet.
The 1.5 m antenna will not be able to track the mission from the beginning. However, it will be provided with the latest nominal trajectory data and in this way gets a chance to follow the intended flight path from the beginning. As soon as the vehicle appears over the horizon the station has a chance to track on it. When the handover is successful the station can follow the vehicle nearly to the impact, depending on the exact position of the vehicle and the conditions in the landing zone.

5.4 Radar Station

In additions MORABA's mobile RIR-774 tracking station will be used as an independent active tracking source for the flight trajectory. The RIR-774 radar needs an on-board power source for the transponder to gain trajectory data. It uses an active C-Band transponder which answers when triggered by the radar signal. As usual, using duration of light travel through the atmosphere and Doppler shift one can determine the trajectory from the ground. DLR-MORABA's tracking radar RIR-774C is a highly mobile and highly accurate C-Band (5.4-5.9 GHz), monopulse, single target tracking radar. It is fully mobile and consists of four containers. Due to its importance for flight safety, the radar station will be placed as well at the range head in Koonibba.
A specification of the Radars capabilities can be found as well in MORABA portfolio [5].

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Figure 7 RIR 774 C Tracking RADAR

5.5 Ground Infrastructure Network and Communication

All above described stations have to be sewed together to ensure proper data flow for the mission. For this, a preliminary ground infrastructure was designed in iterations together with Southern Launch.
An Ethernet based LAN infrastructure with multiple segments is used to distribute vehicle data to the experimenters' computers and to Southern Launch infrastructure. This data includes scientific sensor readings as well as housekeeping data of the vehicle health, state and position. The operators can send telecommands as needed to enforce flight modes, change TV sources or restart sub-systems. IP Routers are used to connect all network segments and control the data path.
Data with high priority, such as position data and other tracking information using one of these segments. This approach allows a separation of critical flight safety information from pure scientific measures. This network segment forwards tracking information of the Telemetry Stations, the Radar Station and the three on-board sensors, two GNSS receivers and the HNS and connects the stations and the flight safety operators.
The second station in Mobella is connected via Internet link and VPN techniques to secure the link. Basically, all information from the main station is also available in Mobella to take over tracking and sending back the received data.
As any other sounding rocket mission, ReFEx will need a distributed count-down clock to coordinate the operations, visible to all personal. Usually the Range generates and operates this clock. States as "running" or "hold" are maintained from the Launch Officer together with Flight-Safety. Even the station in Mobella needs access to this clock.
Within the operation, communication between the operators, experimenters and range safety is crucial. Another network is used for such a multi-loop intercom allowing all operators in Koonibba and Mobella to read and speak.

6. ReFEx Campaign – Recent Status and Outlook

At the moment the construction and built up of the infrastructure at KTR is ongoing. Southern launch is currently building a launcher and constructing the necessary ground infrastructure for the launcher, consisting mainly of a

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concrete base plate where the launcher will be mounted as well as some small buildings for rocket motor assembly and integration. Eventually there will be also a rocket motors storage available until the beginning of 2024.
A close professional exchange with SL is ongoing and the iterative process of the technical campaign planning shows a very good progress, being fixed in a bunch of documentation like Campaign Requirements Plan, Ground Infrastructure Plan and Technical Security plan, to name a few examples.
Furthermore, Southern Launch is heavily working on all the necessary preparations and documentations to get a launch license from the Australian Space Agency as well as from all other stakeholders. Currently, in addition to the launch license from the Australian Space Agency itself, the ReFEx mission is waiting for getting a license to import the rocket motors and to fulfill all the export control requirements and regulations of all countries involved. Hopefully latest at the end of the year 2023 there will be no significant hurdles from any regulatory side for the campaign and that the transports to South Australia can be initiated to finally conduct the mission.
From a pure technical point of view the progress is perfectly on track on both the vehicle side as well as on the Mobile Rocket Base's and Southern Launch's campaign preparations side.

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