Test Facility for a 20-25kN LOX/LNG Engine
Executive Summary Report

1 Overview

This GSTP programme involves the construction and commissioning of a LCH4/CH4 feed system for a 25kN engine to meet an ESA testing requirement. Originally this was for liquid natural gas (LNG) and not liquid methane (LCH4), but the feed system was redesigned to meet a change in ESA's requirements. This redesign required extra labour and additional hardware to support the liquefaction of purified methane using liquid nitrogen (LIN). A further gaseous methane feed was also added to the system as a de-risking measure, to meet ESA's timeline to ensure that a fuel system was operational by the 2022 ministerial. Due to an unrelated delay in the customer's engine development programme, it then became clear that it was not possible to test an engine by this deadline.

The extra labour and hardware for the additional features has exceeded the budget for this GSTP programme and work has therefore been halted. A CCN request was submitted to cover these additions (AEDN-1658 01/07/2022) but ESA has now stated that it is not possible to authorise a CCN with this particular type of contract. It has been suggested by ESA that the current activity should be concluded at this point, and the residual work packages and deliverables transferred to a new activity which will complete the goals of this programme.

This document summarises the test rig design and project status at the close of this programme. A follow-on activity is then proposed, with unresolved deliverables and work packages transferred to this new activity. The business case for completion of this facility is described. Based on interactions with potential customers since the initiation of the project, the inclusion of several additional upgrades to the facility is also recommended for inclusion into the follow-on activity, in order to improve this business case further and maximise the return on investment.

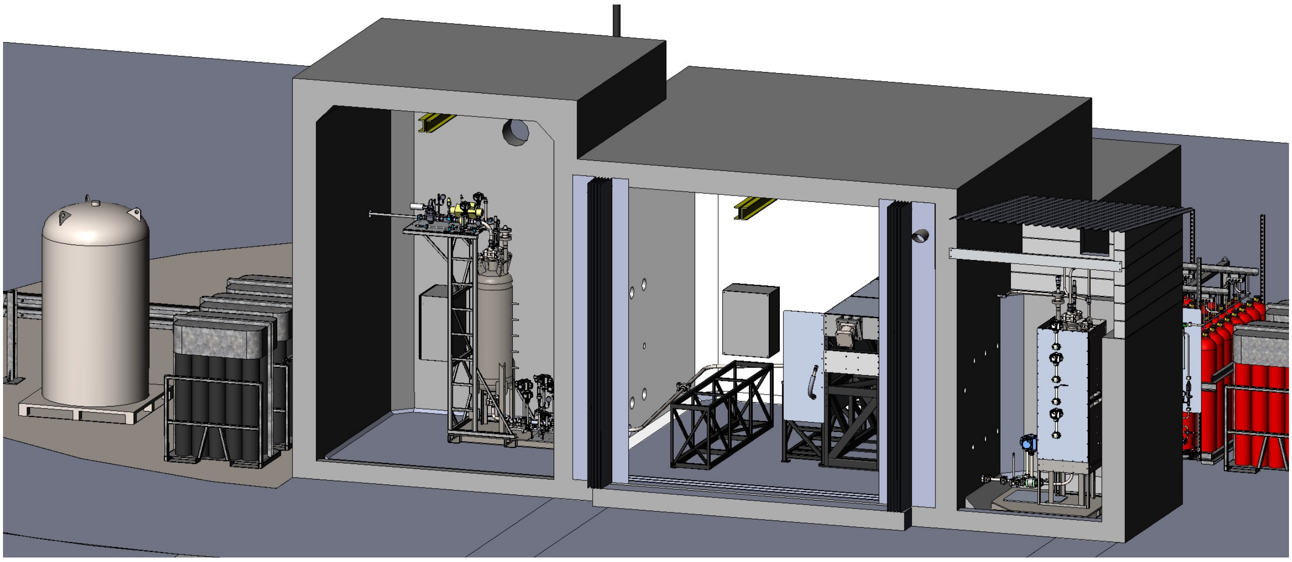


Figure 1: Overview layout of the LOX/LCH4 facility designed under this programme.

2 Test rig design

The test rig is composed of several different subsystems:

1. The LOX system
2. The gaseous pressurant system for the LOX run tank
3. The LCH4/LNG system
4. The gaseous CH4/CNG system
5. The data acquisition and control system.
6. Auxiliary systems such as igniter feeds and purge lines

In the previous de-risk programme, the LOX system was designed and key LLIs for the LOX system were procured. Initially a kerosene feed system was designed, and then subsequently the system was redesigned to support LNG at ESA's request due to a change in requirement from the engine customer. At the start of this programme, however, there was a further change in specification to support purified LCH4 rather then LNG. Whilst this is a simple switch from a fluid handling and material compatibility perspective, it is not a simple switch from a procurement or bulk storage perspective. LNG is cheap and commonly available, whereas purified liquid methane is not commonly available in the UK. There are only one or two places in Europe that can provide it, and it would not be economic to transfer comparatively small quantities of of LCH4 from these locations.

A large fraction of the fuel system therefore had to be re-designed in order to support the liquefaction of purified methane gas, which is commercially available. This required extra labour at the start of the programme in order to order LLIs as early as possible. Labour was therefore shifted from the installation of the LOX system to focus on the redesign of the fuel system. The LOX system would only be necessary for firing operations once the fuel system was operational, so this did not affect the total build time for the test rig.

The following sections give a brief overview of the design of the different test rig subsystems and their current status.

2.1 Liquid oxygen system

The liquid oxygen system consists of a vacuum jacketed bulk tank provided by the liquid supplier, a low pressure fill line, a high pressure run tank, a high pressure run line, and a metering valve with active feedback control.

The liquid oxygen system has a 2000L gas-supplier provided forkliftable bulk tank. The LOX is decanted into a 200L high pressure tank for high pressure test runs, via a low pressure fill line, although it is possible to run directly from the bulk tank for low-pressure, low-flowrate runs. The high pressure tank is custom pressure vessel made from stainless steel with an inbuilt cooling / heating coil for optional thermal conditioning of the propellant, and inbuilt thermowells for temperature measurement. The coil could be used with liquid nitrogen for cooling or gaseous nitrogen for heating. Figure 2 shows the layout of the LOX run tank skid, which also has the required fill, isolator and pressurant valves and a local instrumentation cabinet. The pressurant can be any of nitrogen, helium or oxygen depending on test programme requirements.

In summary, the LOX system should be capable of feeding a 20kN engine for 30s with a maximum delivery pressure of around 90bar, with thermally conditioned LOX if necessary. There is some margin here, and depending on the results of the commissioning it may also be able to supply a 30kN class engine for 20s. The J1 test cell would not be suitable for thrust ranges much above this. It is anticipated

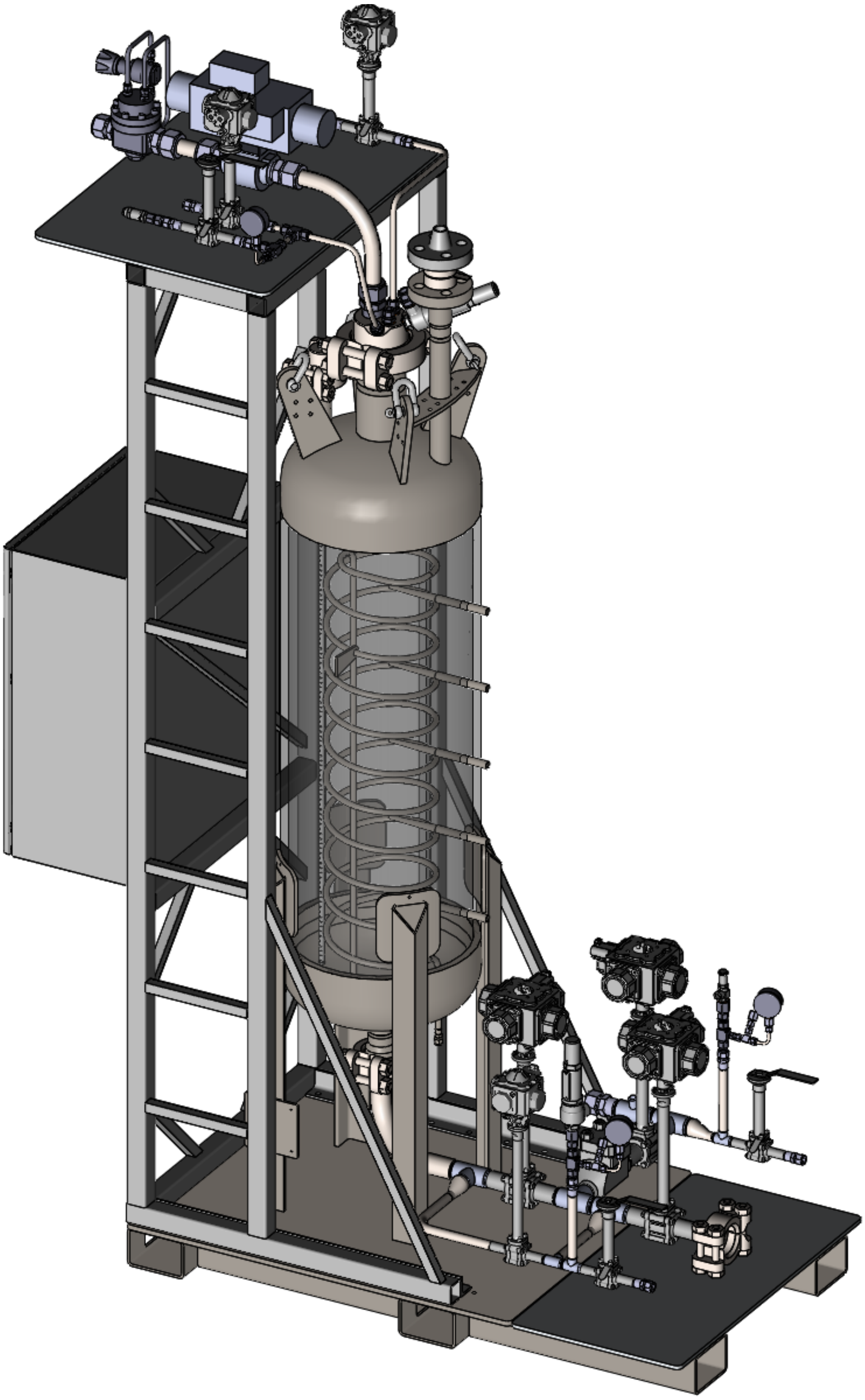


Figure 2: Layout of the LOX run tank skid, including the run tank, termination of the low-pressure fill line, and high-pressure isolation and venting valves. The valves at the top of the tank are for tank venting and the dome regulator and run valve for the pressurant system. The tank shell is shown with transparency in order to view the internal coil and thermowell arrangement. The top of the tank is accessed via a ladder and frame which also supports a local instrumentation cabinet. Insulation and piping supports are not shown for clarity.

that refilling an already chilled run tank will take approximately half an hour including depressurisation and safing procedures.

The design of the LOX system and ordering of the long lead time items was completed as part of the previous de-risk programme. Ordering the auxiliary components for the LOX system was the focus of WP3100 of this programme, their installation in WP3200 and commissioning of the system was planned for WP3300. The LOX run tank skid was constructed (Figures 2 and 3a), including mounting the pressurant inlet valves and all cryogenic valves and then insulated (Figure 3a).

Non-conformances by the LOX valve manufacturer led to delays in the construction of the LOX system, because all ball valves had to be returned for servicing. The current status of the LOX system is that major sections have now already been completed or are nearing completion, but final assembly and commissioning has not been completed. The re-cleaned valves have now been returned to AEL and are in the process of being reassembled into the LOX system. The LOX run table has also been manufactured (Figure 3e). The LOX bulk dewar has now been placed on-site ready for propellant delivery (Figure 3b).

2.2 Liquid methane system

At the beginning of this programme the fuel was specified to be LNG, and a feed system had been designed in the previous de-risk programme. At the start of this programme, however, ESA requested a change to purified LCH4 to meet a change in the engine customer's requirement. Unlike LNG, purified LCH4 is not readily available, nor economic in the comparatively small quanitities required. After exploring various supply options, it was decided that the most cost-effective option was to liquefy methane in-situ using pressurised liquid nitrogen, because purified methane gas is available commercially.

Despite the handling similarity of LNG and LCH4, the fuel system required a major redesign. The LNG bulk storage dewar and storage area groundwork was removed from the design, as was the low pressure piping and valves to transfer LNG from the bulk storage tank to the high-pressure run tank. A liquid nitrogen jacket was designed on the main run tank for the liquefaction, and a tube-in-tube heat exchanger to pre-chill the incoming methane gas using the residual cold of the vapourised nitrogen. Extra valves and plumbing were required to handle the incoming methane gas feedstock. Based on calculations for laminar condensation, it should be possible to refill the run tank with liquefied methane in under two hours.

The liquid methane system consists of a high pressure run tank, a high pressure run line, and a metering valve with active feedback control. The high pressure tank is a custom pressure vessel made from stainless steel with an inbuilt external cooling jacket for liquid nitrogen. This serves several purposes: first, to liquefy the methane gas, second, to thermally condition the propellant, third, to initially chill down the tank with liquid nitrogen, in order to reduce the amount of flammable gas vented, and fourth, to de-pressurise the tank by liquefying the methane gas in the headspace (it is autogenously pressurised). The tank also has thermowells for propellant temperature measurement and external thermocouples for monitoring the chilldown of the tank.

The LCH4 system has two separate delivery lines, the primary line for full mass flow, and the secondary line for smaller flow rate auxiliary feeds. These may be used for separate ignition or gas generator feeds. The outlet of all PRVs and vents are routed to a single vent stack shared with the CH4 system, with the exception of the burst disc on the high pressure tank, which has a dedicated emergency vent stack.

In summary, the LCH4 system should be capable of supplying a 20kN LNG/LCH4 engine for 30s, with thermally conditioned propellant if necessary. As per the LOX system, there is some margin here, and depending on the results of the commissioning it may also be able to supply up a 30kN class engine for

20s. The J1 test cell would not be suitable for thrust ranges much above this. In addition to this, all of the wetted valve parts and manufactured parts (run tank, pipework etc.) should have the required materials compatibility and cleanliness requirements for propane (including subcooling).

Th run tank has now been fabricated and delivered to AEL (Figure 3d). The new methane bay has had the wall height extended and a new roof fitted ready to house the pressure vessel. All main valves and LLIs have been ordered and are mostly already received.

2.3 CH4 system

The LCH4 high pressure system is pressurised using a separate CH4 bank. CH4 is used as a pressurant gas in order to ensure purity of the delivered LCH4, because LCH4 can absorb significant proportions of other pressurants like nitrogen. Alternatively, Helium could have been used, but this was dismissed both on cost and availability grounds, and on the secondary function of the CH4 system to reduce the necessity for a flare stack during normal LCH4 operations. This was deemed important due to the increase in cost of a flare stack, and the difficulties in locating it due to the tight space available at the J1 site.

The CH4 bank is filled using a CH4 piston compressor that is either fed directly from fresh pallets of purified methane gas or from a return feed from the high pressure run tank. This allows the high pressure run tank to be de-pressurised without venting lots of flammable gas. The CH4 bank has a total volume of 2167L (32x68L)of 250bar gas bottles, manifolded into two halves, with valves for double-block-and-bleed isolation and equalisation between the two blocks of tanks. The high pressure run line uses standard Swagelok compression fittings. All relief valves and vents are connected to the same vent stack as the LCH4, with a flame arrestor at the outlet. The CH4 gas bank has been received and is in place at AEL (Figure 3c).

The CH4 system has three delivery feeds, one for pressurising the LCH4 run tank, one for a low-flow feed for ignition or gas-generators, and another high-flow propellant feed. This was requested by ESA as a de-risking method to ensure that a fuel system was ready earlier in the schedule, and to reduce risk for the customer by decoupling the cooling and combustion processes.

The outlet of all PRVs and vents are routed to a single vent stack shared with the LCH4 system. The vent stack is mounted above the roof of J1 and is terminated with a check valve and flame arrestor to prevent overpressure or combustible mixtures in the vent stack. All CH4/LCH4 lines will be purged with dry nitrogen during commissioning or after maintenance operations. As with the LCH4 system, flammable gas sensors will be required for monitoring storage areas and the firing bay.

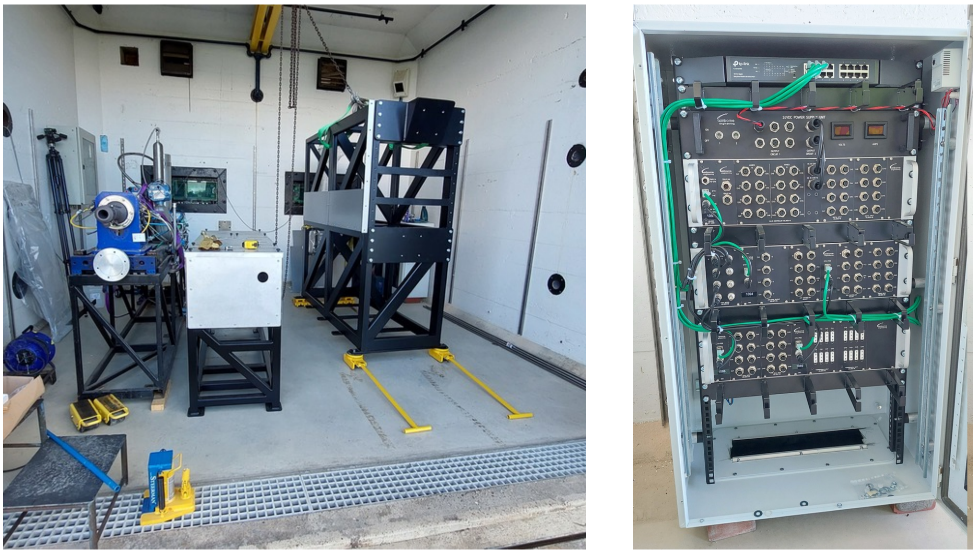
For the new gaseous propellant feed, the massflow is controlled by a custom AEL automatic metering valve (AMV), which uses a Venturi massflow meter (custom for the gas and flow rates) and a movable pintle to meter the flow, which is driven by a fast linear actuator.

3 Facility upgrades

The concrete floor in the firing bay has been replaced in order to house the new test stand and run valve equipment. A new test stand capable of at least 30kN thrust has been fabricated. Figure 3e shows this test stand during installation, alongside the LOX run table and the previous test stand, which has been truncated to accommodate the new equipment. Custom data acquisition equipment has been completed for the sensors required to monitor the LOX system, CH4/LCH4 system and the experiment. Figure 3f shows one of several data acquisition cabinets. Further custom data acquisition equipment has also been designed and fabricated in order to support specific requirements of ESA's engine customer, as part of the DM Engine integration work package.

(a) LOX high pressure skid (b) LOX bulk dewar

(c) Gaseous CH4 bank (d) LCH4 pressure vessel



(e) Firing bay and test stand (f) Data acquisition equipment

Figure 3: Status of key elements of the test rig.

4 De-scoping of current programme

The original budget of the programme is not enough to absorb the requested changes in scope. The additional costs are significant and large changes in global prices have more than removed any margin from the programme. Work cannot therefore continue until further budget is allocated. Having submitted a CCN request to ESA, it has not been possible to arrange a CCN due to the type of GSTP programme. ESA have therefore suggested that the current activity is closed out now and that a follow-on activity is begun in order to complete the project's goals.

There are several outstanding deliverables and work packages in the programme, which pertain to finishing the LOX and CH4 installations, rig commissioning and DM engine integration. The final parts of the installation and rig commissioning are being descoped to a follow-on activity.

5 Follow on activity

The follow-on activity will meet the goals of the extended-scope GSTP programme, by finishing construction of the LOX/LCH4 facility and commissioning it. All long lead time items have already been purchased, which means that the follow-on activity can concentrate on the installation and it there are no major technical risks due to the maturity of the test rig design.

An extension to the feed system is also suggested to enhance the LOX system in order to better meet customers needs. In order to decouple AEL activities from potential customer engine development issues, it is proposed that the test rig shakedown occurs either with cold flows only, or by using a simple AEL engine design for initial hot firings.

Many customer testing enquiries have required a higher delivery pressure of LOX than the test rig can currently provide, due to a limit on the pressure rating of the LOX ball valves. It is suggested that replacing some of the LOX valves with those of a higher pressure-rating would markedly increase the long-term business case of the facility. It is therefore proposed in the follow on that the system is initially installed and commissioned with the existing LOX valves whilst a new set of higher-pressure valves is procured. This allows AEL to gain experience of the facility and conduct initial tests whilst waiting for the valves to be manufactured.

5.1 Proposed activities

The proposed activities are therefore as follows:

1. Complete the LOX system installation using the existing valves
2. Commission the LOX system
3. Complete the gaseous methane system installation
4. Complete the liquid methane system installation
5. Complete the liquid nitrogen system installation
6. Commission the methane system (gaseous and liquid). This includes commissioning of the methane liquefaction system.
7. Shakedown testing with either cold flows only or hot-fire with an AEL engine, which can be a simplified design (e.g. ablative) to provide representative back-pressure conditions for the feed system.
8. Upgrade the LOX system pressure rating, which requires swapping the valves for higher pressure variants and re-commissioning of the LOX system.

At the end of the programme the test facility should therefore be ready for use by customers, including those who need extended performance in LOX pressure. At this point a test programme can be begun with ESA's engine customer.

6 Conclusion

Due to cost rises resulting from a change in ESA specification and global price rises this project cannot complete its goals under the current funding package because further labour and hardware are required. It was originally assumed that these extra costs could be provided by a CCN which would allow the project to conclude. Having submitted a CCN to ESA, however, it has not been possible for ESA to arrange a CCN to due the type of GSTP contract. ESA's recommendation is therefore to conclude this current GSTP contract and to begin a follow-on programme.

The business case for finishing this facility remains strong, and will be stronger in light of ESA's changes to the specification. AEL have already been contacted by seven new-space companies interested in testing at the facility. With some additional small modifications to meet their needs the facility will be extremely beneficial to the European propulsion community. The investment will represent good return to the UK in terms of testing fees and growth at AEL, and in terms of the growth of companies (often start-ups) who will be able to prove their technologies to unlock venture capital and progress their technology. This strongly aligns with the UK Space Strategy to build the supply chain for domestic launch capability.

Major lead time items have been ordered and received, and much of the liquid oxygen system has been constructed. Given that this facility is nearing completion but cannot be finished until further funds are secured, it is hoped that a new programme can be begun as quickly as possible such that the extended goals of the programme can be met in the follow-on activity.