Artemis operational report and statistics

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Introduction

This was the final year of the Artemis upgrade project, which saw Artemis move into the Research Complex at Harwell, adding a new 100 kHz laser system and a third XUV beamline to its capability. Only one external experiment was scheduled, with the remainder of the time dedicated to engineering and commissioning tasks, or lost due to lockdowns.

Activities

During the shutdown period, the Artemis team carried out data acquisition projects on a new detector for the angle-resolved photoemission end-station, and for a new small chamber for measurements of the magneto-optical Kerr effect (MOKE). The team also numerically modelled the optical design of the 100 kHz XUV beamline, to allow both small spot sizes (for inhomogeneous samples and devices) and larger spot sizes (for lower space charge) to be used.

Once staff were allowed back in the lab, substantial staff effort went in to bringing the 1 kHz Ti:Sa system back into operation, as this 12-year old system had been brought across the lab and reconfigured just before shutdown. The laser interlock system was commissioned and the installation of the two 1 kHz beamlines and their vacuum control systems was completed. The beamline with monochromator was redesigned and refurbished as part of the project. Following re-commissioning, we measure ten times higher XUV flux.

The first experiment in the new labs took place in October 2020 (Figure 1). This was an all-optical experiment using the 1 kHz laser system and the new MOKE chamber, with users participating remotely from Paris.

We found problems with the pump laser for the new 100 kHz laser system just before lockdown. This laser was sent back to the manufacturer for complete refurbishment, and re-installed in December 2020. Commissioning of the full 100 kHz laser system (an infrared OPCPA) started in January 2021, with remote support from service engineers in France and Germany. Simulations, design and procurement for the optical parametric amplifiers that will be pumped by the new laser were completed during this period.

Finally, mechanical design, manufacturing and procurement of the 100 kHz beamline was completed in this year, with all major components delivered and ready for assembly by the end of the financial year.

Figure 1: First user experiment in the new Artemis labs, October 2020

<table>
<tr><th>w/b</th><th>Activity</th></tr>
<tr><td>30/03/2020</td><td rowspan="10">COVID lockdown #1: beamline design and software upgrades</td></tr>
<tr><td>06/04/2020</td></tr>
<tr><td>13/04/2020</td></tr>
<tr><td>20/04/2020</td></tr>
<tr><td>27/04/2020</td></tr>
<tr><td>04/05/2020</td></tr>
<tr><td>11/05/2020</td></tr>
<tr><td>18/05/2020</td></tr>
<tr><td>25/05/2020</td></tr>
<tr><td>01/06/2020</td></tr>
<tr><td>08/06/2020</td><td rowspan="17">Engineering and restart of 1 kHz laser</td></tr>
<tr><td>15/06/2020</td></tr>
<tr><td>22/06/2020</td></tr>
<tr><td>29/06/2020</td></tr>
<tr><td>06/07/2020</td></tr>
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<tr><td>17/08/2020</td></tr>
<tr><td>24/08/2020</td></tr>
<tr><td>31/08/2020</td></tr>
<tr><td>07/09/2020</td></tr>
<tr><td>14/09/2020</td></tr>
<tr><td>21/09/2020</td></tr>
<tr><td>28/09/2020</td></tr>
<tr><td>05/10/2020</td><td>Hricovini 17120011 (set-up)</td></tr>
<tr><td>12/10/2020</td><td rowspan="2">Hricovini 17120011</td></tr>
<tr><td>19/10/2020</td></tr>
<tr><td>26/10/2020</td><td>Engineering and a/c work</td></tr>
<tr><td>02/11/2020</td><td rowspan="2">Hricovini 17120011</td></tr>
<tr><td>09/11/2020</td></tr>
<tr><td>16/11/2020</td><td>Laser maintenance</td></tr>
<tr><td>23/11/2020</td><td>Hricovini 17120011 (2 days)</td></tr>
<tr><td>30/11/2020</td><td rowspan="4">Engineering and 100 kHz laser installation</td></tr>
<tr><td>07/12/2020</td></tr>
<tr><td>14/12/2020</td></tr>
<tr><td>21/12/2020</td></tr>
<tr><td>28/12/2020</td><td>Christmas</td></tr>
<tr><td>04/01/2021</td><td rowspan="13">100 kHz laser commissioning and beamline alignment</td></tr>
<tr><td>11/01/2021</td></tr>
<tr><td>18/01/2021</td></tr>
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<tr><td>01/02/2021</td></tr>
<tr><td>08/02/2021</td></tr>
<tr><td>15/02/2021</td></tr>
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<tr><td>01/03/2021</td></tr>
<tr><td>08/03/2021</td></tr>
<tr><td>15/03/2021</td></tr>
<tr><td>22/03/2021</td></tr>
<tr><td>29/03/2021</td></tr>
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Table 1: Artemis operations by week in 2020/21

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Gemini operational statistics

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During the reporting year, April 20 – April 21, a total of two complete experiments were delivered in the Astra-Gemini Target Area and one experiment in TA2. In total of 21 high power laser experimental weeks were delivered the Gemini Target Area and four weeks to TA2. The delivered schedule is presented in Figure 2.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 78% during normal working hours, rising to 124% with time made up from running out of normal working hours. The reliability of the Gemini laser was 85%. An individual breakdown of the availability and reliability for the experiments conducted is presented in Figure 1.

TA2 availability was 95% during normal working hours, rising to 139% with time made up from running out of normal working hours. The reliability of the laser delivery to TA2 was 97%.

The high levels of total availability were made possible by the continued unique operational model employed on Gemini, which involves running the laser late into the evening. In addition, frequent weekend operational days were made available.

During the reporting year, the COVID-19 pandemic had a significant impact on facility operations. The laboratory was shut down for the first four months, and difficulties in arranging laser servicing from overseas companies severely impacted the Kettle campaign.

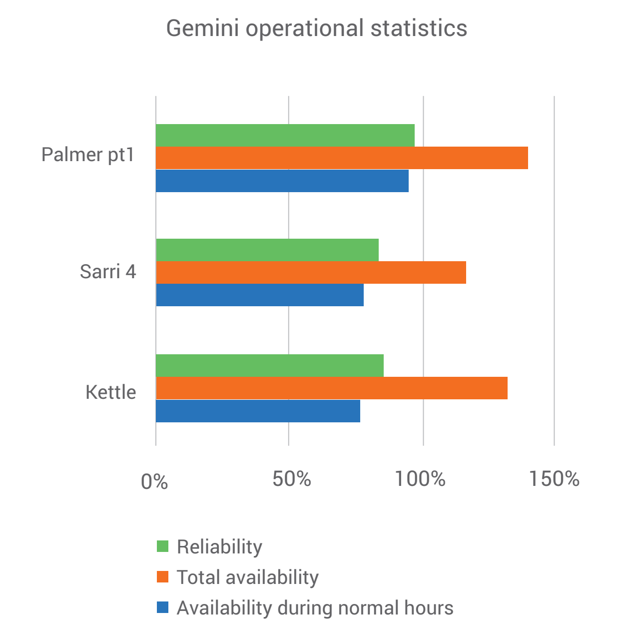

Figure 1: 2020/21 Gemini/TA2 operational statistics

w/b	Gemini	TA2
06/04/2020	Shutdown and preparations for operational restart	Shutdown and preparations for operational restart
13/04/2020		
20/04/2020		
27/04/2020		
04/05/2020		
11/05/2020		
18/05/2020		
25/05/2020		
01/06/2020		
08/06/2020		
15/06/2020		
22/06/2020		
29/06/2020		
06/07/2020		
13/07/2020		
20/07/2020		
27/07/2020		
03/08/2020	LWFA optimisation	
10/08/2020		
17/08/2020		
24/08/2020	Kettle **19210012**	
31/08/2020		
07/09/2020		Compressor work
14/09/2020		
21/09/2020		
28/09/2020	Extension	
05/10/2020		
12/10/2020	Laser maintenance and repair	
19/10/2020		
26/10/2020		
02/11/2020		System access Source development
09/11/2020		
16/11/2020	Extension	
23/11/2020		
30/11/2020		
07/12/2020		
14/12/2020		Target Fab Plant Servicing
21/12/2020		
28/12/2020		
04/01/2021		
11/01/2021	Ops Shutdown	Ops Shutdown
18/01/2021		
25/01/2021		
01/02/2021	Sarri **19210006**	System Access
08/02/2021		
15/02/2021		
22/02/2021		
01/03/2021		
08/03/2021		Palmer (part 1) **20110001**
15/03/2021		
22/03/2021		
29/03/2021	3 days	

Figure 2: 2020/21 Gemini experimental schedule

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Octopus and Ultra operational statistics

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Octopus facility
In the reporting period (April 2020 to March 2021), 23 unique User groups submitted a total of 26 proposals bidding for time at the Octopus facility. 14 experiments comprising 43 weeks of access time were awarded to the UK User community throughout the year. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 1, indicating an oversubscription ratio of 1.81:1. Figure 3 shows that Biology and Bio-materials formed the majority of applications.

A total of 25 formal reviewed publications were recorded throughout the year.

Ultra facility
In the reporting period (April 2020 to March 2021), 15 unique User groups submitted a total of 15 proposals bidding for time at the Ultra facility. 12 experiments comprising 30 weeks of access time were awarded to the UK User community. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 2, indicating an oversubscription ratio of 1.27:1. Figure 4 shows that Chemistry formed the majority of applications. Ultra also facilitated one week of industrial access.

A total of 18 formal reviewed publications were recorded throughout the year.

Octopus and Ultra availability and user satisfaction feedback
A total of 49 hours downtime was reported over the combined 61 weeks of delivered access during this reporting period. Eight weeks of user access was not delivered due to the COVID-19 pandemic. Figure 5 shows an average user satisfaction rating of 91.8% over the five surveyed categories.

Figure 1: Octopus experiments by subject

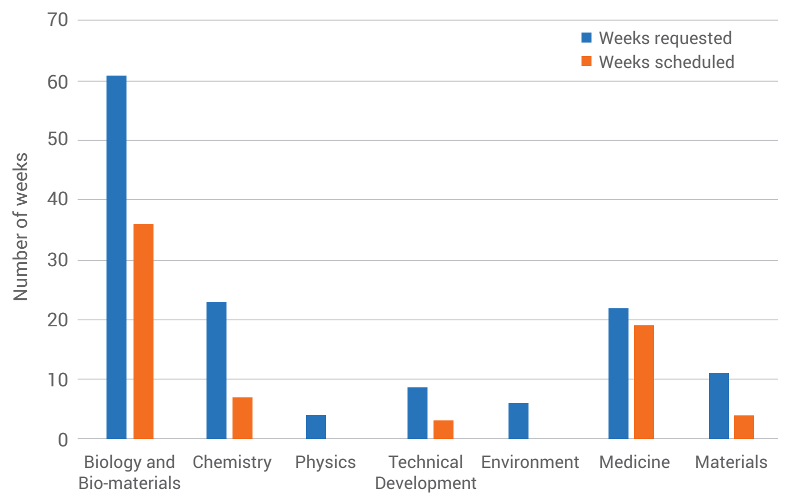


Figure 2: Ultra experiments by subject

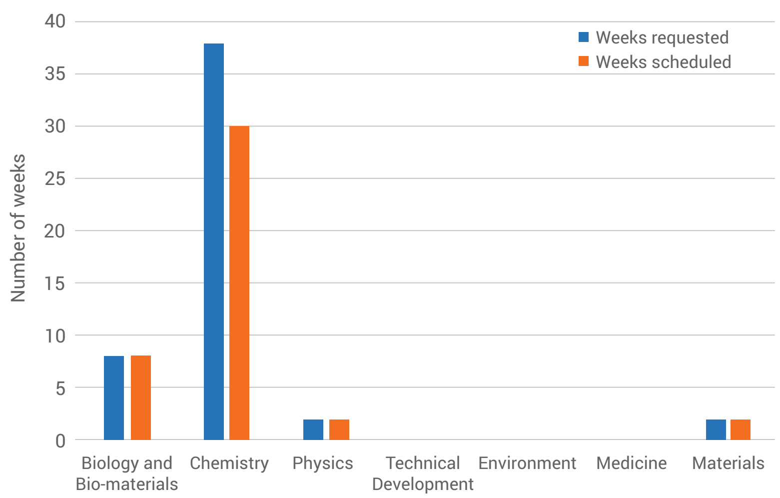


Figure 3: Octopus experiment bids by subject group

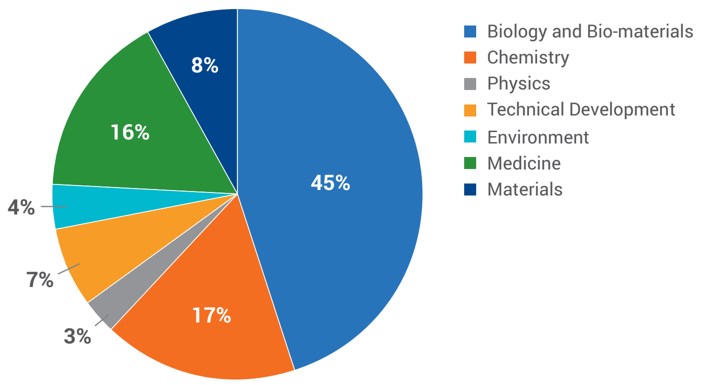


Figure 4: Ultra experiment bids by subject group

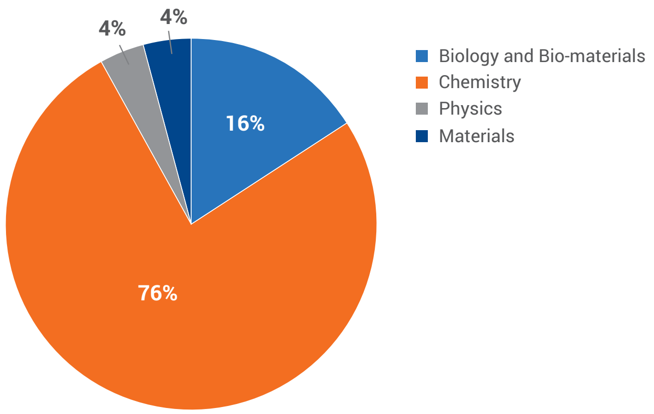
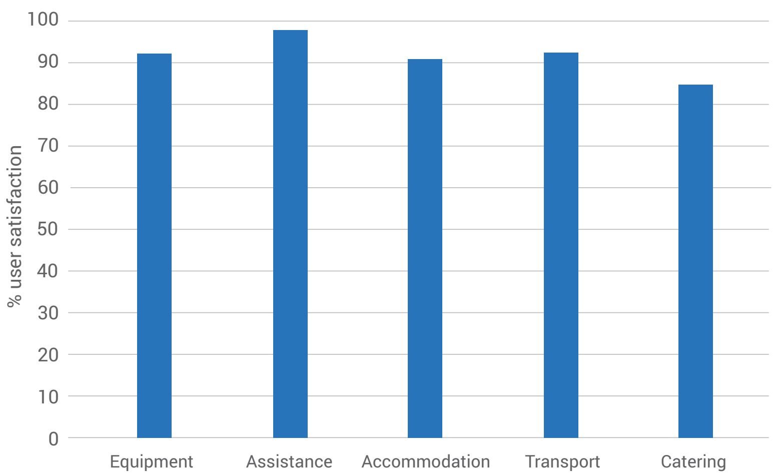


Figure 5: Average user satisfaction



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Target Fabrication operational statistics

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Introduction
This report documents the experimental support offered by the Target Fabrication Group to the high power laser user community from January 2020 to April 2021. The Vulcan TAP and TAW target areas, as well as those in Gemini TA2 and TA3, are covered. Support to external facilities is also detailed. Experimental operations were hindered due to the COVID-19 pandemic, resulting in a postponement of experiments between 23rd March and 10th August 2020. This is reflected in the lower number of experimental support weeks compared with earlier years: the Target Fabrication Group provided 50 weeks of experimental support in the 2019-20 reporting period compared to 38 weeks offered in 2020-21.

The reporting period saw a total of three supported experiments in the Vulcan areas, and three experiments in Gemini. The Target Fabrication Group also provided numerous diagnostic elements, such as filter packs and fiducial arrays, as well as lens assemblies for cryo-fluorescence microscopy for other experiments across the CLF, which are not documented as part of these statistics. For example, the Target Fabrication Group provided non-targetry support for the 0321 TA2 Palmer Liquid Targetry experiment (proposal 20110001), as detailed in Bourgeois *et al.* "*Deploying the SLAC liquid target at RAL*."[1]

Supported Experiments
Table 1 details the experiments supported over the reporting period and their duration, including extension weeks.

Proposal Number	Date/Area/PI	Supported Weeks
19210013	0120 TA3 Higginbotham	5
19210012	0320 TA3 Kettle	7
19210006	0221 TA3 Sarri	8
20110009	0620 TAP Kar	6
19210011	0320 TAW Palmer	6
19210003	0221 TAW Scott	6
	Total	**38**

Table 1: Experiments supported by the Target Fabrication Group through the 2020-21 reporting period

Due to the difference in energy and repetition rate of the lasers and the area of physics that they are tailored to investigate, target types often differ from area to area and experiment to experiment. On Vulcan experiments, the predominant target type is that of a single target on a stalk, or a cluster of components in an assembly, often multi-layered or complex in nature, that is ideally suited to lower repetition rate experiments. Targets for the Gemini target area are primarily simple foils held on an array mount, with tens of targets on a single mount, and up to ten mounts loaded onto a target wheel. Over the last two to three years, Gemini experiments are seeing an increase in targets manufactured on a tape substrate, following the design and fielding of a tape-drive targetry system designed by the Target Fabrication Group[2][3] another technology the Group have made available to the HPL community.[4]

The varying target types are categorised as Class 1, 2 and 3 targets, which provides a method of classifying the complexity and research/planning necessary for experimental delivery. These definitions are somewhat subjective in nature but are typically classified as follows:

- **Class 1 targets** require fewer specialist resources to manufacture. Materials are typically procured 'off-the-shelf' and minimal specialist equipment is required for assembly. Typical targets include micron-thick foils or alignment wires glued to posts.
- **Class 2 targets** require the use of specialist manufacturing equipment and knowledge, and would be a very involved process for a non-Target Fabrication entity to replicate. Examples include nanometres-thick thin-film and multilayer coatings. Tape Targets that have been previously produced and are not R&D projects fall into this category.
- **Class 3 targets** require long-term R&D projects to establish and perfect, and are often referred to as "high-specification targets". Such targets include complex 3D assemblies, MEMS produced components, low-density materials such as aerogels and foams, and processed (coated or etched) tape targets that are novel and require R&D.

Classifying each target type provides a metric of how the Target Fabrication Group's resources are used throughout the year, and is shown in Figure 1. It can also prove useful to distinguish the distribution of shots that require a high number of low complexity target types, compared to those that require fewer, higher complexity targets (Table 2).

Target Supply
The 2020-21 reporting period saw a total of 2,959 targets supplied across the six experiments supported in the CLF, with 83% being provided to Gemini experiments and the remaining 17% to Vulcan.

Gemini	Total Targets	Class 1	Class 2	Class 3
0120 TA3 Higginbotham	621	619	2	0
0820 TA3 Kettle	1,134	12	1122	0
0221 TA3 Sarri	696	696	0	0
Total	**2,451**			

Vulcan	Total Targets	Class 1	Class 2	Class 3
0221 TAW Scott	169	15	0	154
0320 TAW Palmer	154	91	4	59
1020 TAP Kar	185	19	0	166
Total	**508**			

Table 2: Breakdown of targets supplied to a) Gemini experiments and b) Vulcan experiments over the 2020-2021 reporting period

The disparity in target complexity is highlighted in Figure 1, which shows that Vulcan experiments had a large proportion of complex targets (65%), whereas Gemini had none over the year. The majority of Vulcan targets were complex 3D micro-structures, which require a combination of specialist skills, high accuracy characterisation, and thin-film coating to assemble. The vast majority of Class 2 Gemini targets were thin-film coated and laser-etched tape driven targets, the production process for which had previously been established for the 0218 TA3 Kettle campaign in February 2018. While they are still very complex targets to produce, due to the specialism and expertise required in the manufacturing steps, their fabrication has formed a research project within the Target Fabrication Group over the last three years; therefore, because it is an established process, they are categorised as Class 2 targets.

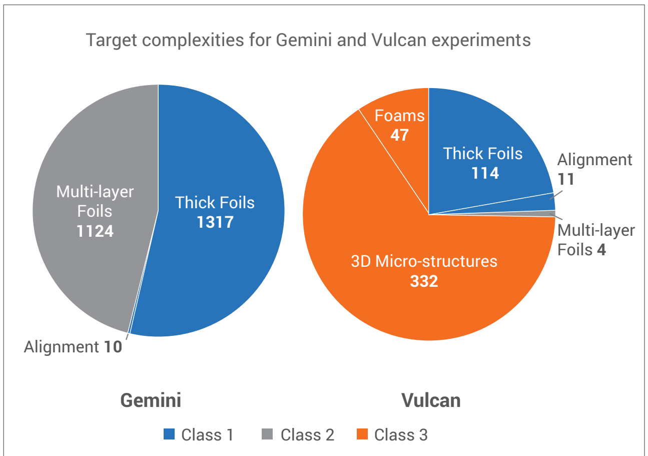

Figure 1: A breakdown of the complexity of targets requested by Gemini and Vulcan target areas over the 2020-2021 period.

Historical target supply
The supply of solid targets is having to evolve, due to the driver technologies increasing in repetition rate. Consequently, over the last few years the Target Fabrication Group have established numerous R&D projects to address the anticipated increase in production requirements.

Gemini experiments have been somewhat of a testbed for the aforementioned increased repetition rate experiments since 2018, with three tape target experiments having greatly contributed to the increase in targets produced. It is worth noting that there were twice the number of experiments in 2017-18 compared with 2018-19, 2019-20 and 2020-21, showing a definite upward trend in target supply per experiment. Figure 2 shows the total targets supplied over the yearly reporting periods since 2011-12.

Figure 2: Total targets supplied to CLF solid target experiments throughout each reporting period [5-14]

With EPAC coming online in 2023 target supply is expected to increase exponentially over the next three to four years, which is reflected in the trendline on Figure 2.

Adapting to Demand

One of the major strengths of the CLF is direct access to state-of-the-art fabrication and characterisation equipment, and to expertise within the department. Having a dedicated Target Fabrication Laboratory allows the CLF to adapt to the demand of its users mid-experiment, which can and does often lead to the success of an experimental campaign.

Target Fabrication support offers the ability to thin-film coat a multitude of materials to a very fine thickness tolerance, laser machine components to high levels of precision, and be able to characterise material thicknesses, composition and densities.

The benefit of these capabilities is shown by the yellow bars on Figure 2, which detail the total number of modified targets, i.e. the quantity of targets issued over the operating period that were not initially requested in the planning processes. These modified targets require additional effort during the experimental runs, but maximise the science output from the limited shots available. Although the total percentage of modified targets seems to have significantly dropped in the last few years, this is due to the large contribution of tape driven targets since 2018, which a) required a significant planning process to fabricate and were not modifiable mid-experiment and b) were planned many weeks prior to beam-time.

Of the 2,451 targets delivered on Gemini experiments, only nine (0.4%) were modified from the original target list (due to the reasons mentioned above). For example the 0820 TA3 Kettle experiment was attempting to obtain as much data as possible using only two germanium target thicknesses whilst having flexibility within their specified parameters.

By contrast, on Vulcan, 198 of the 508 total targets delivered (i.e. 39%) were modified targets. The majority of these targets were thick foils or multi-layer foils on single target stalks, or complex 3D assemblies. The main benefit of these targets is that users can home in on specific materials and thicknesses, and to a lesser extent geometries, to achieve their scientific aims. The targets for such experiments are typically categorised as being more complex in design and as having a lower output (as shown in Figure 1), demonstrating why on-site Target Fabrication support is crucial for the success of such experiments and is a key capability of the CLF.

Production Economy and Waste Management

One of the challenges for Target Fabrication is striking a balance between pre-production of targets and just-in-time production during the run. Being able to deliver the requested targets, but not over supply in the event that targets are not required for science reasons, allows staff effort and resources to be allocated to other experiments as needed.

It is often the case that targets are not returned until some considerable time after the end of the experiment, making this a difficult metric to track. For experiments operating on a shot-by-shot basis, as is often the case on Vulcan, return percentages are typically considerably higher. Figure 3 shows the trend for returned vs total target supply over the last ten reporting periods, with 40 total returned targets for the 2020-21 year, all from Vulcan experiments.

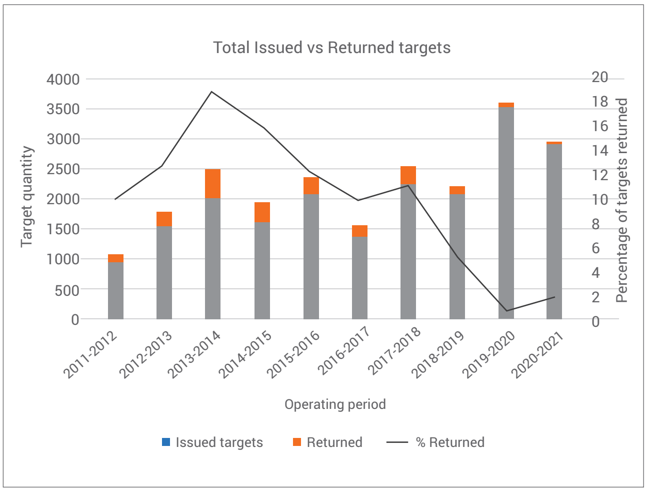

Figure 3: Returned targets vs total targets supplied over the last ten operating periods

Where possible, unused targets are stored for potential use in future experiments or recycled for components.

A further explanation for the reduction in returned target numbers is the addition of an additive manufacturing capability within the Target Fabrication Group. Target stalks, which were historically machined from metal at significant expense, are now primarily 3D printed (at a cost reduction factor of ~50) and not typically re-used or returned post-experiment. Consequently un-shot targets are typically kept (or discarded) by the users, which therefore leads to a reduction in target returns.

External Contracts

In the reporting period 2020-21 the operations of Scitech Precision Ltd (SPL), Target Fabrication Group's commercial spinout company, were heavily hit by the COVID-19 pandemic. The reduction of operations at many of its core customers subsequently led to a reduction in orders and turnover. A total of 21 institutions engaged with SPL for 63 individual contracts, generating a turnover of £182k. During the reporting period SPL moved to a new, dedicated laser-machining laboratory on the Rutherford Appleton Laboratory site, offering improved infrastructure. SPL also engaged in a programme of upgrades to its lasers, with the addition of a femto-second laser machining system and upgraded control systems and stages, to allow it to carry out more processes at a higher level of accuracy.

Summary

Over the 2020-21 reporting period, the Target Fabrication Group have delivered a total of 2,959 high power laser targets across six experimental campaigns within the CLF, over 38 experimental weeks. This includes set-up weeks and laser delays, as well as a significant impact to operations caused by the COVID-19 pandemic which paused experiments between March and August 2020.

The majority of the 2451 laser targets delivered on Gemini campaigns were in the form of tape-driven targets – a technology which the Target Fabrication Group have been researching over the last two years in preparation for EPAC. Such targets were mainly 'Class 2' targets.

The remaining 508 targets were issued for Vulcan experiments and were generally more complex to produce and characterise, comprising foams and 3D micro-structures, and are categorised as 'Class 3' targets. There were no ultra-thin foils requested for experimental campaigns during the operational period.

Total target production is continuing in an upward trajectory, even accounting for the significant drop in total HPL access weeks, and is expected to rise considerably over the next reporting period, dependent on pandemic recovery, particularly across Gemini experiments.

References

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2. *S. Astbury, W. Robins, C. Spindloe & M. Tolley, "Progression of a tape-drive targetry solution for high rep-rate HPL experiments within the CLF", CLF Annual Report 2018-2019*
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14. *H. F. Lowe, C. Spindloe & M. Tolley, "Target Fabrication Operational Statistics", CLF Annual Report 2010-2011, p76-77*

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Vulcan operational statistics

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Introduction

Vulcan has completed an active experimental year, with 27 full experimental weeks allocated to target areas TAW and TAP between April 2020 and March 2021; the schedule was interrupted from March 2020 due to COVID-19. Table 1 shows the operational schedule for the year, and reports the shot rate statistics for each experiment.

PERIOD	TAW	TAP
	2020	
02 Mar – 22 Nov	C Palmer *Laboratory investigation of dust charging and destruction in shocked plasma* (Shots 104, Failed 36, Reliability 65.4%) (Availability 74.0%, w extra hours 168.8%) (5 weeks + extra 7 weeks) 19210011	
02 Mar – 02 Dec		D Carroll *Investigation of EMP emissions for understanding the source mechanisms and the rules for tuning and employing them in high power lasers* (Shots 119, Failed 7, Reliability 94.1%) (Availability 67.4, w extra hours 88.9%) (5 weeks + extra 1 week 3 days) 19210019
	2021	
15 Feb – 13 Apr	G Scott *Direct laser acceleration of electrons to superponderomotive energies* (Shots 102, Failed 21, Reliability 79.4%) (Availability 72.0%, w extra hours 114.6%) (5 weeks + extra 3 weeks 2 days) 19210003	

Table 1: Experimental schedule for the period April 2020 – March 2021

(Total shots fired, failed shots, reliability) (Availability normal, additional hours)

Numbers in parentheses indicate the total number of full energy laser shots delivered to target, followed by the number of these that failed, and the percentage of successful shots. The second set of numbers shows the availability of the laser to target areas during normal operating hours, along with outside hours operations.

The total number of full disc amplifier shots that have been fired to target this year is 325. Table 2 shows how this figure compares with that for the four previous years. 64 shots failed to meet user requirements. The overall shot success rate to target for the year is 80%, compared to 90%, 86%, 81% and 84% in the previous four years. Figure 1 shows the reliability of the Vulcan laser to all target areas over the past five years.

Year	No of shots	Failed shots	Reliability
16 – 17	948	93	90%
17 – 18	934	132	86%
18 – 19	607	113	81%
19 – 20	653	102	84%
20 – 21	325	64	80%

Table 2: Shot totals and proportion of failed shots for the past five years

The shot reliability to TAW is 72%, down 10% from the previous year. The shot reliability to TAP is 94%, up from 84% in 2019-20.

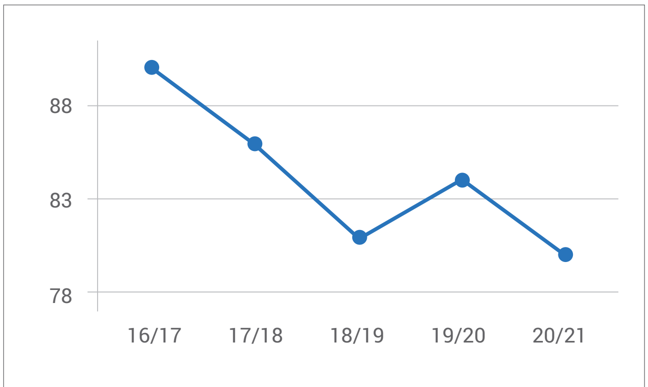

Figure 1: All areas shot reliability for each year 2016-17 to 2020-21

Analysis of the failure modes reveals that the overriding causes of failed shots are beam alignment, front-end related issues, and triggering. The first two causes are manifested in low or high energy output of the rod amplifier chain (outside of +/-20% of the requested energy). Instability in the pulse energy is introduced during propagation from the front-end room to the laser area. Novel methods of beam stabilisation are being investigated to improve this fault mode.

There is a requirement that was originally instigated for the EPSRC FAA that the laser system be available, during the five-week periods of experimental data collection, from 09:00 to 17:00 hours, Monday to Thursday, and from 09:00 to 16:00 hours on Fridays (a total of 195 hours over the five-week experimental period). The laser has not always met the start-up target of 09:00, but it has been common practice to operate the laser well beyond the standard contracted finish time on several days during the week. In addition, the introduction of early start times on some experiments continues to lead to improvements in availability.

On average, Vulcan has been available for each experiment to target areas for 71.2% of the time during contracted hours, compared with 86.7% for the previous year. The overall availability to all target areas has increased to 124.1% compared with 112.6% in 2019-20. The time that the laser is unavailable to users is primarily the time taken for beam alignment at the start of the day.

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