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THE STRATHCLYDE CONCURRENT AND COLLABORATIVE DESIGN STUDIO: PAST, PRESENT AND FUTURE

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ABSTRACT

Since opening in October 2015, the Concurrent & Collaborative Design Studio (CCDS) at the University of Strathclyde has been used to foster and promote innovation in the field of aerospace engineering across a wide variety of educational and industrial projects. This paper will describe the development process of the CCDS to now, including a discussion on how it currently operates. In so doing, the paper will go on to present the successes and failures of hosting a concurrent design facility (CDF) in an academic environment, focussing on the provision of teaching and learning as well as industrial engagement. Based on this, a development plan has been proposed to optimise the use of the facility in the future.

1. INTRODUCTION

A Concurrent Design Facility (CDF) is a state-of-the-art facility equipped with a network of computers, multimedia devices and software tools which us used to enable 'concurrent engineering' based on teamwork. From a space systems perspective, the focus of concurrent engineering is traditionally on the design of future space missions and industrial reviews. It relies on the use of a common design model which evolves iteratively in real time as the different subsystem experts provide their contributions. In this regard, designers and customers agree on requirements and take decisions in real time to allow the best design for the right cost and within the programmatic constraints [1,2].

The University of Strathclyde has its own CDF called the Concurrent & Collaborative Design Studio (CCDS) located within the Technology & Innovation Centre (see Figure 1), situated in the heart of the Glasgow City Innovation District (GCID). The GCID is a hub for entrepreneurship, innovation, and collaboration which builds on Scotland's rich tradition of scientific excellence and industrial collaboration. It brings together a variety of ambitious, forward-thinking stakeholders and organisations to tackle societal and global challenges whilst driving inclusive economic growth [3]. This makes the CCDS a valuable asset to the GCID, particularly given that it is currently the only CDF located in Scotland and one of only four in the United Kingdom (UK) [4]. For this reason, as well as being using for academic purposes, the CCDS has already made a valuable contribution to the advancement of various industrial space system engineering studies across Glasgow, Scotland, the UK and beyond.

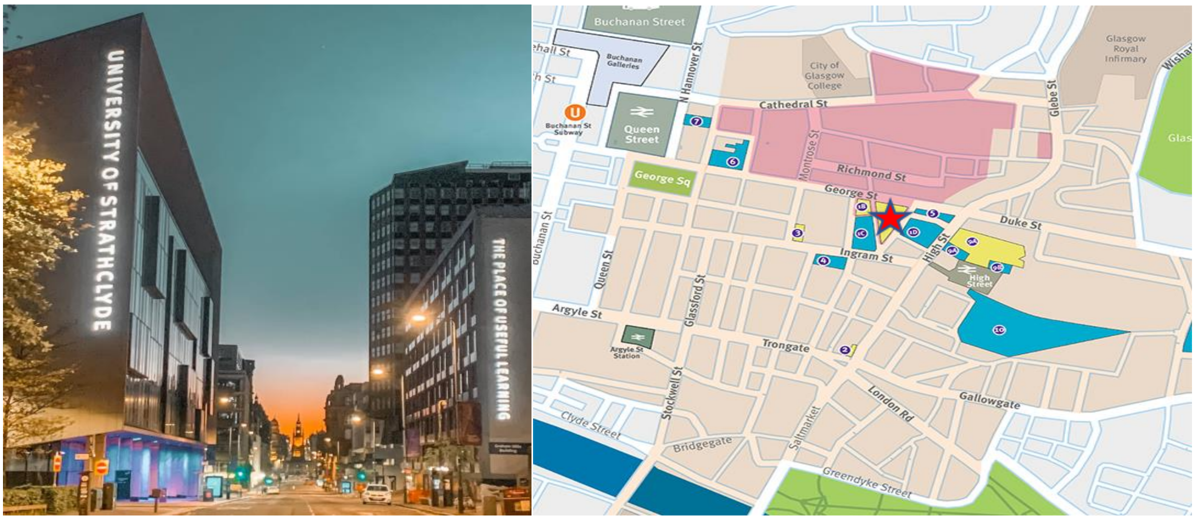

Fig. 1. The TIC building (left) which hosts the CCDS and its location (right) within the GCID area of Glasgow [3]

As such, this paper will provide an overview of the CCDS at the University of Strathclyde. In particular, Section 2 will describe the past development and current operation of the facility, whilst Section 3 will go on to present the successes and failures of hosting a CDF in an academic environment, focussing on teaching and learning as well as industrial studies. Section 4 will then outline a development plan for future use of the facility, before concluding with Section 5 which offers a summary to the paper.

2. FACILITY OPERATIONS

According to Bandecchi et al. [5], concurrent engineering is "a systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of cooperation, trust and sharing, in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle." They go on to outline that there are five key elements on which CDF implementation is based, those being: a facility, a process, a multidisciplinary team, infrastructure and an integrated design tool. The following subsections, will describe these elements in relation to the development process of the CCDS at the University of Strathclyde to now, including how it currently operates.

2.1. Room Infrastructure

The CCDS was officially released on 5th October 2015, shortly after the formal opening of the TIC building by Her Majesty the Queen and the Duke of Edinburgh on 3rd July 2015. Over the next two years, a considerable effort was made to raise the profile of the facility to a professional standard. This consisted of buying, creating and installing new hardware and software in an effort to make the room as multifunctional as possible and fixing any existing technical problems. This also allowed the room's infrastructure to be orientated as closely as possible to the CDF at the European Space Agency (ESA) whilst at the same time making it more aesthetically pleasing. The final result can be seen in Figure 2 below.

Fig. 2. The internal layout of the CCDS

Overall, the room currently consists of 18 workstations equipped with Linux and Windows operating systems. Each workstation is dedicated to a specific subsystem, with each computer hosting dedicated domain-specific tools (Mission Analysis, Flight Dynamics, GNC/AOCS, Operations, Telecom, Propulsion, Structure, …). There is one workstation for the System Engineer and another for a laptop and/or the customer of the study. Each workstation is media (video/audio) connected to the system engineering workstation for sharing video and audio content within the room. Video conference capabilities such as Polycom, Skype, Zoom, Teams, GoToMeeting and other major web-based video conferencing systems are all supported. There are three main cameras, one webcam for each workstation, main room audio with recording facility, a main digital interactive display, and a microphone for each workstation.

2.2. Process and Methodology

By early-to-mid 2017, the facility infrastructure had reached a stage where it was ready to host concurrent engineering studies. At this point, the corresponding author of this paper applied on behalf of the university to attend the ESA Concurrent Engineering Workshop in Redu (Belgium) to learn how to use the concurrent engineering approach. This allowed him to understand how to operate a CDF and bring back the lessons learned in order to train others in using the facility for concurrent engineering studies. For this reason, the methodology applied within each study run at the CCDS thus far has been principally based upon the ESA concurrent engineering philosophy, as exemplified through ESA Academy's Concurrent Engineering Workshop [6,7].

In terms of the schedule, studies which take place within the CCDS start with a plenary meeting where representatives of all space engineering domains participate. This is relevant for all studies from early phases (requirement analysis) to the end of design (costing). In total there are between six and ten sessions per study which last for an average of around four hours per session. The team leader has ultimate responsibility for co-ordinating the study with customer participation. Each session is highly co-operative and interactive. This is because they are model driven (see Subsection 2.4) with design option comparisons and trade-offs being a common feature. The frequency of study sessions has tended to vary depending on customer requirements (e.g., intensive one-week studies or bi-weekly sessions).

Moreover, the CCDS has also been used to test and experiment with new or altered methodologies for concurrent engineering. For example, the adaption of the approach previously outlined towards a remote CDF was also trialled for the first time by Wilson & Berquand due to the COVID-19 pandemic [8]. The findings of this study highlighted that whilst CDF sessions could still be successfully conducted virtually, a greater emphasis must be place on the process in the absence of a physical CDF in order to provide satisfactory levels of support for the concurrent engineering session (as highlighted in Figure 3).

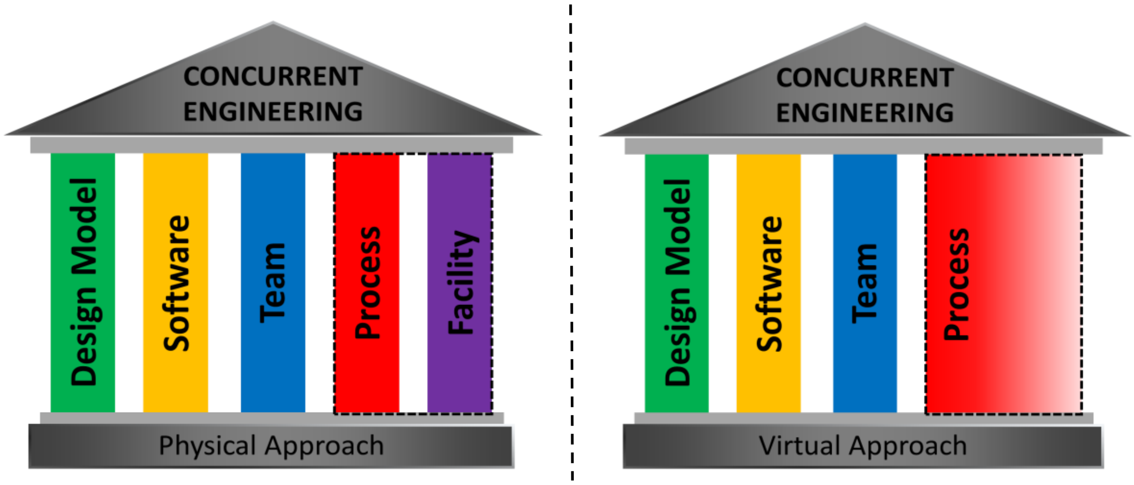

Fig. 3. Basic elements of the concurrent engineering approach applied at the University of Strathclyde [8]

2.3. People and Expertise

Design sessions in the CCDS are supported by several different people pulled from different departments. The core expertise is in the Aerospace Centre of Excellence (ACE) within the Department of Mechanical & Aerospace Engineering where academic staff cover key areas like astrodynamics and mission analysis, attitude dynamics and control, structural and thermal analysis, aero-thermal dynamics and design for demise, life cycle assessment/ecodesign, systems engineering and optimisation, uncertainty quantification. Other key areas of expertise, such as payload design and integration, TT&C, on board computer and data handling, power generation, storage and management, are covered by staff in the Department of Electronic and Electrical Engineering, Physics and Computer Science, who belong to the Strathclyde Space Cluster.

The team composition changes depending on the type of study and is normally a mix of senior staff, post-doctoral research associates and PhD students working in the respective areas of expertise (such as those shown in Figure 4). For studies that specifically involve undergraduate projects, a team of master and bachelor students is normally trained at the start of the academic year to use the tools in the CCDS and work in a concurrent engineering environment. Often, these students will initially be placed on a specific subsystem and paired with a member of staff, post-doctoral research associate or PhD student on a specific subsystem with sufficient knowledge to guide the student until such times as they are individually competent. However, experts consistently remain on-hand to assist the students should they run into any difficulties and oversee the engineering model.

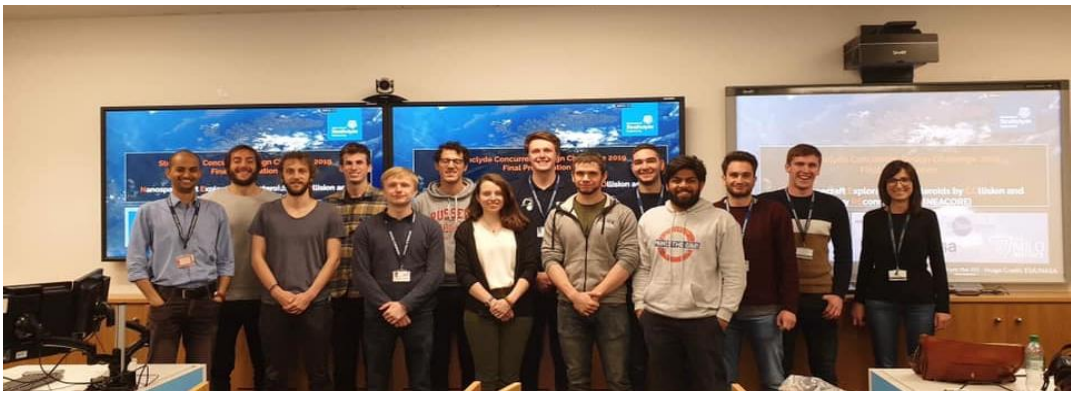

Fig. 4. Participants of the NEACORE study

Besides the expertise specifically required to complete mission and system level studies, the Aerospace Centre of Excellence has developed expertise in the development of methods and tools that are relevant to design of space missions and systems. In particular, artificial intelligence agents to support mission and system design, including the ESA supported conversational agent SCARLET, system level multi-disciplinary optimisation tools, and space traffic management frameworks like CASSANDRA or multi-fidelity re-entry analysis tools like TITAN, and the Strathclyde Space Systems Database (SSSD) tool for life cycle sustainability assessment of space system, all of which are partially supported by ESA (see Subsection 2.5 on tools and software). Thus, the CCDS is routinely used as a virtual room to test these tools and experiment with their applicability to future missions, creating further allure for industrial clients.

2.4. Design Models

Design models are client/server software packages used to create engineering models based on a model-based engineering approach. The CCDS originally used the ESA Open Concurrent Design Tool (OCDT) but has since moved to RHEA Group's Concurrent Model-Based Engineering Tool – Integrated Modelling Environment (COMET-IME) as its central design tool which is hosted on an Ubuntu 14.04.4 virtual server. This switch was made as COMET-IME is expected to replace the OCDT at ESA. Additional advantageous features of the tool include its ability to create mass and power budgets whilst being fully backward compatible with previous design tools such as the OCDT, so all existing CCDS models can be reused as needed. It is also based on and is compliant with the draft open standard defined in the ECSS-E-TM-10-25 System Engineering - Engineering Design Model Data Exchange (CDF) Technical Memorandum.

Connection to COMET-IME is made through an OCDT web-services processor. The design tool has both a desktop application and Excel integration, allowing participants to use whatever they prefer. Amongst more experienced participants, the desktop application is generally used more whilst Microsoft Excel is the primary user interface for students, likely because they are more comfortable with its use due to familiarity. The system engineer generally takes control of the engineering model, publishing values, overseeing the product tree and updating the mass and power budgets when necessary. An overview of a CCDS engineering model derived using the concurrent engineering method is provided in Figure 5 below.

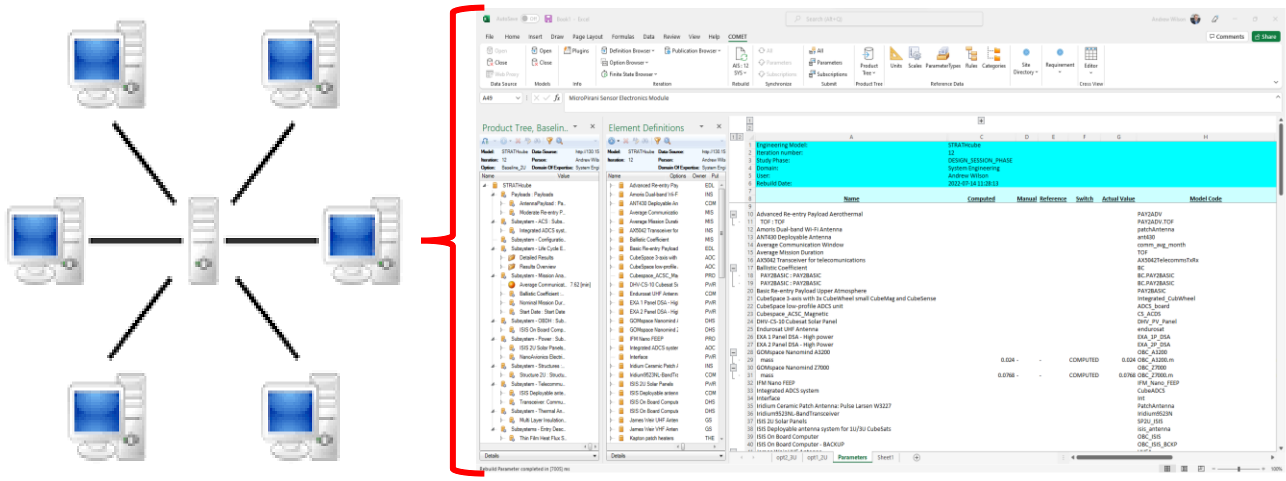

Fig. 5. Overview of the design server with the engineering model of the STRATHcube mission from a systems perspective

2.5. Software and Tools

The software available in the CCDS comprises all the licensed software available on campus for structural and thermal analysis and CAD. On top of this, specialised tools like GMAT and DRAMA are also available. All these third-party software tools are generally not subject to further development and are used as they are. They are also complemented by research software tools collected in the Strathclyde Mechanical and Aerospace Engineering Toolbox (SMART), which is a collection of repositories on Github that span from trajectory optimisation to system level design and optimisation to space traffic management. It also contains current developments on design assistants and conversational agents like SCARLET. SMART is constantly developed and maintained by the research staff and students in the ACE and by a number of external collaborators within and outside Strathclyde. Figure 6 provides an illustration of the official logo of SMART.

Fig. 6. SMART logo

In particular, some SMART repositories are very relevant to the use of the CCDS as a space mission design studio. SMART-astro, SMART-sys, SMART-o2c, SMART-sense, SMART-uq contain a range of tools for astrodynamics and mission analysis, systems engineering, optimal control and optimisation, sensor analysis and design, uncertainty quantification and propagation.

In addition to these generic repositories, SMART contains more specialised tools, like the SSSD. The SSSD is contained within the Strathclyde Design and Optimisation Toolbox of SMART. This toolbox is also linked with the Space Systems Toolbox where together, their purpose is to support design automation of complex space systems using one or multiple performance criteria. Thereby the SSSD can assist in this process by evaluating the environmental, social and economic aspects of a variety of space systems for the development of next generation sustainable space systems [9]. Other tools contained within SMART include CASSANDRA (Computational Agent for Space Situational Awareness and Debris Remediation Automation) framework, dedicated to space traffic and environment management, TITAN, our multi-fidelity re-entry and aero-thermal analysis tool, MODHOC for multi-objective optimal control and trajectory optimisation, CALYPSO for long term orbit propagation, ATHENA for navigation and state estimation.

Generic repositories contain building blocks with elementary functions that are used to construct more complex applications, like CASSANDRA for example, or can be used individually for simple analyses.

3. SUCCESSES AND CHALLENGES

As previously mentioned, the CCDS is available for hiring by professionals who wish to run concurrent engineering design sessions [10]. Proprietary disciplinary software can be temporarily installed, and consultancy contracts can be put in place with a wide range of discipline experts, as well as system engineers. However, beyond this, the facility can also be used as part of teaching and learning practices. Whilst concurrent engineering is not taught as part of the core syllabus of taught degree programmes, the university hosts an annual 'Strathclyde Concurrent Design Challenge' which affords students the opportunity to learn about concurrent engineering through practical participation in the design of a space mission, guided by academics.

Clearly, the preparation and use of the facility for both purposes are often quite divergent in nature. This has meant that using the CCDS for each study type has created a diverse range of successes and challenges, some of which will be discussed here to frame the university's experience of hosting a CDF in an academic environment.

3.1. Teaching and Learning Studies

The concurrent design approach is gradually becoming more integrated within student research projects. Student applications to participate in the 'Strathclyde Concurrent Design Challenge' has seen a steady increase in recent years to a point where the selection process is now quite competitive. Not only does this opportunity provide students with an extracurricular experience which is advantageous to their future career prospects, but it also helps to advance internal or external studies. In this regard, the CCDS can be adapted to a much wider range of projects. For example, the STRATHcube study (an in-house student satellite project) allowed for validation of several SMART software and models whilst also contributing towards the verification of project requirements.

Student satisfaction surveys always highly positive, as outlined in Wilson & Berquand [8] and Jenkins et al. [11], despite the need to steep learning curve and the need to work in a team-oriented fast paced environment. Feedback reveals that every students has had a positive experience and benefitted from their participation to some degree, with many citing that they had enjoyed the opportunity to work on a practical engineering project with support and guidance from PhD students and staff. Other commonly cited benefits included increased levels of industry-relevant knowledge, the practical experience as an effective learning method for advancing professional development and skill enhancement, with particular reference to space system design, teamwork, communication, organisation and technical competencies. However, a commonly cited challenge is the steep learning curve, particular on the use of the design model.

3.2. Industrial Studies

Similar to the observations of Ivanov et al. [12], it is clear that the major difference between a CDF facility in an industrial setting (such as ESTEC, JPL or a commercial company) and a CDF facility in an educational institution (such as the CCDS) is that it is more difficult to train and retain experts for studies due to high staff and student turnover. As a result, it is important that experts are trained and supported for each and every study. Another downside is that studies cannot be performed in any given study in one week, similar to timescales of industrial CDFs, particularly during term time when teaching responsibilities are scheduled.

Regardless, the CCDS has already conducted several studies with external clients and organisations, with more scheduled to take place in the near future. Thus far, industrial studies have tended to comprise of a mixture of internal university staff and external representatives brought in by the client. They have also mostly been with organisations where the university have already got an established or pre-existing relationship. To help facilitate this the study, a systematic training exercise has been created for the CCDS which can be administered before any given study. This is applicable to both internal staff/students and external stakeholders who wish to use the facility and is designed to reduce the learning curve for study participants, in a similar manner to Hoffmann et al. [13].

3.3. Miscellaneous

Overall, the CCDS has been fairly successful to date, having produced several solid and sound design concepts which satisfy all mission objectives and requirements. An example of such concepts is provided in Figure 7 below. In particular, MÌOS was a precursor to the 'Strathclyde Concurrent Design Challenge', with the concept having been designed by University of Strathclyde students as part of the first ESA Academy's Concurrent Engineering Challenge series which acted as a trial on the operability of the CCDS. NEACORE was an industrial study, involving collaboration between ESA, CNES, the Paris Observatory, the MILO Institute, Massachusetts Institute of Technology and various other parties. STRATHcube is concept proposed by a student association known as the Strathclyde Aerospace Innovation Society which now forms part of an ongoing group dissertation project.

Nonetheless, beyond using the facility for teaching and learning purposes, as well as industrial studies, there has been a whole range of other outputs. For example, the CCDS has been extremely successful in the development and testing of new software and methods to advance concurrent engineering practice and techniques. For example, the use of life cycle engineering within the concurrent engineering process has already been demonstrated [14,15] whilst an adapted methodology was applied during the COVID-19 pandemic which proved that concurrent engineering could still take place remotely (even without being physically present) within the facility [8].

It should also be noted that these successes are not only in the eyes of the university. The reputation of the CCDS is international, which was proven by the University of Strathclyde being selected to host the 8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018) due to its work in concurrent engineering. At the event, the CCDS was showcased to the international community, where it received an array of prestigious compliments from many conference attendees and high-ranking officials.

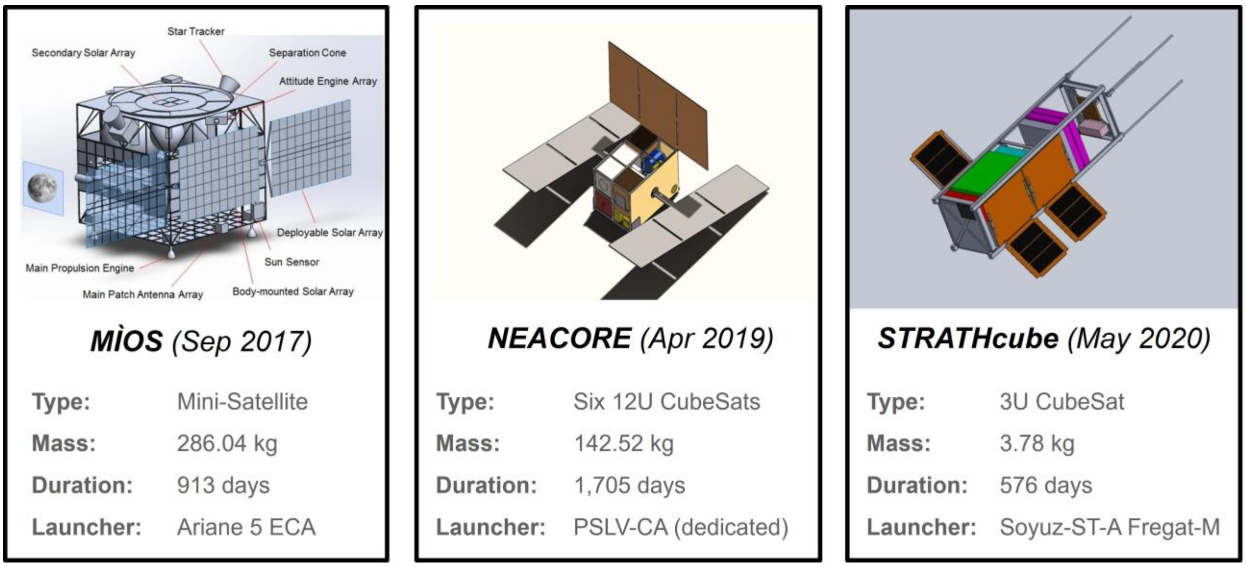

Fig. 7. Example of some space mission concepts generated using the concurrent engineering approach in the CCDS [15]

4. FUTURE PLANS

As part of the proposed TIC Zone Development Project (a carbon-neutral development spanning over two sites to the East and West of the existing TIC building), there is a plan to move the location of the current CCDS facility to either the TIC East or TIC West building by 2025. In the process, the CCDS is expected to be upgraded, funded by additional investment by the university as part of this project. For this reason, a future plan for the CCDS has been drafted by ACE to ensure the continued success of the facility, details of which are outlined further below.

Firstly, given the growing breadth of activities on space environment management a further extension of the CCDS will be in the direction of space traffic management and operations. A range of sensors are being installed on the roof of the university, including optical sensors and passive radars. Thus, the CCDS will have a dual use, both as a space mission design and a space operations room. This dual use will be accompanied by an extension of the software available in the room. There is the plan to adopt and integrate GODOT alongside the existing tools in SMART and acquire more specialised software desiccated to operations. The CCDS will be soon connected also to a recently founded laboratory, called Advanced Space Systems Lab, for the development and testing of small satellites, where STRATHcube is currently under development. This will allow participants to perform mission design with hardware in the loop by connecting the CCDS to a flatsat in the Advanced Space Systems lab

Secondly, in terms of the infrastructure itself, the facility will be designed to have a more flexible configuration with dedicated breakout rooms and a sperate space to host the sever. An upgrade to the video conferencing systems will also be sought to enable the sharing of data in a better manner internally within the CCDS as well as with external (virtual) study participants. This includes also an updated and more modern digital interactive display and ability to connect to the server. There are also plans to connect the CCDS with a virtual reality environment and 3D printing facility.

Lastly, whilst this upgrade to the facility is expected to be mutually beneficial to the university and industry, there is also an identifiable potential for systematic integration of concurrent engineering studies into the student curriculum. As such, concurrent engineering could become as a key element of engineering education to bolster this learning further (rather than just concurrent engineering challenges as previously mentioned). Such a prospect is current being discussed and it is expected to be proposed to the syllabus in the near future. This also includes a named person who is purely responsible for the day-to-day coordination of the facility. Not only would this person be responsible for the coordination of student teaching and learning activities in the CCDS, but also industrial engagement to ensure that the facility is more impactful by attracting customers and is continuing to make a valuable contribution to the advancement of space system engineering studies. As such, this plan is expected to allow the university to make a significant contribution towards scientific excellence and industrial collaboration, in line with the goal of the GCID.

5. CONCLUSION

The CCDS at the University of Strathclyde has been operational for the last seven years. This paper has provided a general overview into the development and operation of this facility during that time, including the benefits and challenges of managing a CDF in an academic environment for both educational purposes and industrial space systems engineering studies. The approach which has been established and adopted to facilitate concurrent engineering for both use cases within the facility was discussed, with in-house software complimenting this to assist and improve the model-based systems engineering process.

These capabilities were demonstrated in numerous practical case studies, outlined in this paper, where the CCDS was used to advance professional studies and engage university students (often in tandem). In turn, this has enabled industrial partners to reduce lead time and costs, improve overall design quality and capitalise on corporate knowledge for further reusability. From a student perspective, such experiences have helped the university to create a plethora of graduates who are well-versed in the concurrent engineering concept with a multitude of hard and soft skills, thereby boosting their career prospects in the field of aerospace engineering.

Lastly, it was shown that the experience already gained from hosting a CDF coupled with the prospect of moving and updating the CCDS has numerous benefits. These benefits are outlined thoroughly in the future plan (see Section 4), which was created to further the university's capabilities in concurrent engineering whilst adding additional value to industry and student learning. It is expected that such an approach will guarantee the long-term success of the CCDS for many years to come, thereby ensuring that an even higher quality of professional level study can be achieved, and that the university continues to produce engineering graduates that are valued across industry.

6. ACKNOWLEDGEMENTS

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7. ABBREVIATIONS & ACRONYMS

ACE	Aerospace Centre of Excellence
CCDS	Concurrent & Collaborative Design Studio
CDF	Concurrent Design Facility
COMET	Concurrent Model-Based Engineering Tool
ESA	European Space Agency
GCID	Glasgow City Innovation District
IME	Integrated Modelling Environment
OCDT	Open Concurrent Design Tool
SSSD	Strathclyde Space Systems Database
SMART	Strathclyde Mechanical & Aerospace Research Toolbox
TIC	Technology & Innovation Centre
UK	United Kingdom

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