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ICE Cubes Media Set - Adding new capabilities to the ISS by enabling user friendly live outreach and media events during the commercial Axiom-1 mission

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Abstract

The ICE Cubes Service is a commercial initiative offering to its customers fast-track access to the International Space Station (ISS) by means of the ICE Cubes Facility (ICF) installed in the European Physiology Module (EPM) in the Columbus Laboratory. The facility was installed in 2018 and has been operated by the ICE Cubes Mission Control Center (ICMCC) almost continuously 24/7 since then. As an augmentation of its service, the ICE Cubes Media Set was launched in December 2021 providing a lightweight implementation for real-time interactive two-way Audio and one-way Video sessions between crew and ground, adding this new capability to the ISS.

The flight hardware, consisting of a modified GoPro HERO9 and a speaker, connected to the ICE Cubes Facility through USB, is supported by the extended ICMCC ground segment to allow videoconferences with external parties. While up to then, in-flight crew calls and public outreach (PAO) events were performed using NASA assets, the ICE Cubes Media Set only relies on the existing ESA Internet Protocol (IP) data link between the ICE Cubes facility and ground for transmission of commands, telemetry, and scientific data of ICE Cubes payloads.

After its successful commissioning in March 2022, the first use case was the support of the Axiom-1 mission in-flight crew call and public outreach events. During the Axiom-1 mission, 42 interactive events with the Axiom-1 crew were successfully completed over a period of 8 days resulting in a total of 708 minutes of conference time between the astronauts and 150+ users worldwide. The success of the ICE Cubes Media Set during this mission was due to the ease of use by the private crew, the short preparation time necessary on ground prior to an event, and the straightforward accessibility for the end users. However, the execution of these events was only possible thanks to the preparatory activities supported by all involved partners, NASA, ESA, Axiom, and the ICE Cubes Service.

This paper focuses on the operational aspects of the mission. It presents the set-up of the Media Set service and its various capabilities, and explains the operations concept that was established with the various partners to host this high number of events with four different crew members in a very short period. In order to achieve this novel service, new operational agreements and procedures had to be put in place, identifying the roles and responsibilities between all entities, and taking the commercial implementation into account. The challenges encountered during this short duration mission had to deal with the volatile crew planning, short notice changes and technical aspects when working with many external parties and several back-to-back events. The lessons learned, together with the feedback from the crew, revealed additional insights into the requirements for the future use and possible improvements of the service.

Keywords: Axiom-1, Commercial Space Operations, ICE Cubes Media Set, International Space Station, Outreach, Video conferences

Acronyms/Abbreviations

2FA	Two-Factor Authentication
AI	Artificial Intelligence
AOS	Acquisition of Signal
AR	Augmented Reality
AXOL	Axiom Operations Lead
AV	Audio&Video
CASA	Crew Alternate Sleep Accommodation
CET	Central European Time
Col-CC	Columbus Control Center
Col FD	Columbus Flight Director
COTS	Commercial Off-The-Shelf
EAC	European Astronaut Center
eDPC	evening Daily Planning Conference
EFN	Electronic Flight Note System
EPM	European Physiology Module
ESA	European Space Agency
EUROCOM	European Communicator and Medical Operations
FD	Flight Director
FoV	Field of View
ICE	International Commercial Experiment
ICF	ICE Cubes Facility
ICMCC	ICE Cubes Mission Control
IP	Internet Protocol
IPS	Internet Protocol Service
ISS	International Space Station
JSC	Johnson Space Center
LAN	Local Area Network
LCD	Liquid Crystal Display
LEO	Low Earth Orbit
LOS	Loss Of Signal
mDPC	morning Daily Planning Conference
MPCC	Multi-Purpose Computer & Communication
Mk	Mark
NASA	National Aeronautics and Space Administration
OIP	Operations Interface Procedure
OPTIMIS	Operations Planning Timeline Integration System
PAO	Public Affairs Office
P/L	Payload
PR	Public Relations
SD	Secure Digital
SSH	Secure Shell
SW	Software
TM	Telemetry
USB	Universal Serial Bus
VPN	Virtual Private Network
VR	Virtual Reality
WAP	Wireless Access Point

1. Introduction

The International Commercial Experiment Service (ICE Cubes Service) was launched in 2017 as a partnership between Space Applications Services N.V. and ESA, to enable a fast-track and affordable access for research and technology experiments on the International Space Station (ISS). The ICE Cubes Facility (ICF) housing the

experiments, also called Experiment Cubes, was installed in the European Physiology Module (EPM) within the Columbus Laboratory in 2018 and has been semi-continuously operated since then hosting a variety of experiments from different customers.

All live public ISS in-flight crew calls and public outreach (PAO) events up to now have been performed using NASA assets, requiring upfront coordination and significant set-up time. The approach of the ICE Cubes Service is to enable two-way audio and one-way video from the ISS via an easy setup and with a minimum of coordination. Therefore, the ICE Cubes Facility was augmented by an additional service through the use of an external device, the so-called Media Set. The Media Set was launched with SpX-24 and commissioned by ESA astronaut Matthias Maurer in March 2022. The first use case was the Axiom-1 mission, where the Media Set was extensively used by the Axiom-1 private crew members during their 10-day mission in April 2022. This paper focuses on the operational aspects of the Media Set, from the "road to operations" to the final execution of the 42 live events with the Axiom-1 crew.

Section 2 of this paper details the set-up with a description of the ICE Cubes Facility followed by the addition of the Media Set and the ground segment. The Concept of Operations for the Axiom mission with respect to the Media Set is detailed in Section 3, while Section 4 provides a brief overview of the mission execution. Finally, we conclude the paper with lessons learned (Section 5) and the outlook for future missions (Section 6).

2. Media Set Set-up

The Media Set service consists of an on-board set-up that is relatively straight forward and a more complex ground segment set-up.

2.1 On-board Set-up

Prior to describing the set-up of the Media Set itself, the configuration of the ICE Cubes Facility is briefly explained as the Media Set uses its capabilities.

2.1.1 ICE Cubes Facility

The ICE Cubes Facility comprises a framework that can accommodate up to 20 single-unit Experiment Cubes or a smaller number of multi-unit Experiment Cubes. The size of the Experiment Cubes is set to mimic the CubeSat standard, i.e. 10x10x10cm (1 litre) for a 1U Experiment Cube, 20x10x10cm for a 2U Experiment Cube, etc. with one principal difference: the Experiment Cubes can be scaled along two axes in order to offer more flexibility to customers. As such, a 4-litre Experiment Cube could, for example, be in the 4U or the 2Ux2U configuration. Furthermore, 9-litre or 12-litre Experiment Cubes could also be possible in the 3Ux3U or 4Ux3U configurations, but no concave shape are allowed. Furthermore, the ICF allows for additional external Cubes/payloads to be either physically plugged to the ICF front panel or wirelessly through the ICF Wireless Access Point (WAP) (private network). A picture of the ICF with the Framework and the Experiment Cubes is shown in Fig. 1.

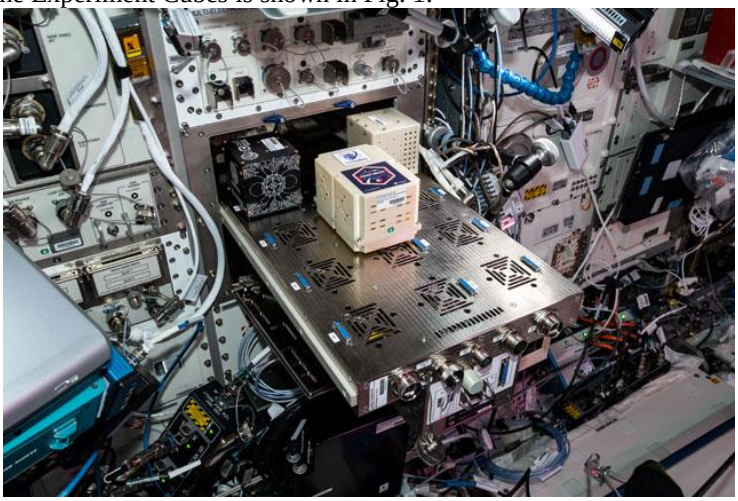

Fig. 1. ICF framework (extracted) with Experiment Cubes installed

Independent of their dimensions, the Cubes have standardized physical and operational interfaces. Each Experiment Cube may be equipped with Commercial Off-The-Shelf (COTS) components, which significantly reduce the cost and duration of development and allow for the utilisation of the latest technologies. This standardisation approach greatly

reduces complexity and allows academia, industry and the general public to develop and build low-cost experiments for the ISS.

The main functions of the facility can be summarized as follows:

- Mechanical interface to each Experiment Cube
- Power conversion and routing/switching to the various Experiment Cubes
- Near real-time telecommand routing to the various Experiment Cubes from ground
- Near real-time routing of TM from the various Experiment Cubes to ground
- Data storage and data synchronization
- Temperature monitoring and support to thermal cooling
- Time service
- IP connections between the experiment Cube and the Cube owner allowing a direct experiment ground control by the customer
- SSH connection with the ICE Cubes Mission Control Center

The use of the ICF for 'plug-and-play' Experiment Cubes requires a limited amount of resources (power, data) and crew time. The monitoring and control of the ICF and the Experiment Cubes makes use of the Ku IPS, through ESA's MPCC Service. The use of IP-based protocols allows for easy and flexible ground access to the Facility.

2.1.2 Media Set

Acting as an external payload, the Media Set is developed to augment the commercial offer of the ICE Cubes Service.

The core of the system is a modified GoPro action camera model HERO9 Black, associated with a speaker set and a USB Hub. Additional elements of the ensemble are a USB extension cable and a support bracket. The Media Set can be mounted on seat tracks or directly hand-held by crew, depending on the specific tasks of the session (Fig. 2).

The Media Set is connected with the ICF via a USB cable that connects one of the external ICF USB ports with the USB hub situated within the casing of the Media Set. This hub merges the internal subsystems of the Media Set consisting of the GoPro Camera and the USB speaker set. The USB speaker set can be turned on/off by means of a switch and the audio volume can be adjusted both from ground (via software) and by crew via a volume knob. The USB powered speaker set is able to process digital audio via the ICF front panel USB connection and forward it to the speaker. This enables audio transmission from ground towards the crew and is used in case of interactive sessions between crew and a remote user on ground.

Fig. 2. Media Set mounted on seat track

Crew interfaces for the handling of the Media Set are:

- Power on/off button of the GoPro camera
- Power on/off switch of the USB speaker
- Knob for regulating the volume of the USB speaker
- Connector for the USB Extension Cable
- Positioning knobs of the ICF Media Set Bracket

Installing the Media Set on the seat track is straightforward and takes not more than 10 minutes of crew time. As a design choice, no internal SD card nor a battery are available in the GoPro. As such, today the Media Set cannot be used as stand-alone device.

Operating in Webcam mode, the GoPro camera streams Audio&Video (AV) directly to the ICF via a network stream over the USB connection. As such, the ICF recognizes an external webcam and microphone as input. With this set-up the use of the Media Set is quite straightforward to the crew, as they only need to connect the USB cable to the ICF front panel, switch on the speaker and switch on the camera. From this point onwards ground takes over and manages the entire event.

2.2 Ground Set-up

The control center for the ICE Cubes facility is the ICE Cubes Mission Control Center (ICMCC) and is located at the headquarters of Space Applications Services in Zaventem, Belgium. The ground segment, for the use of the Media Set, has been deployed on top of the existing ICMCC infrastructure allowing a secured connection to the ICF through the ESA Ku IPS connection system, referred to as MPCC. The high level architecture of the Media Set communication paths is depicted in Fig.3.

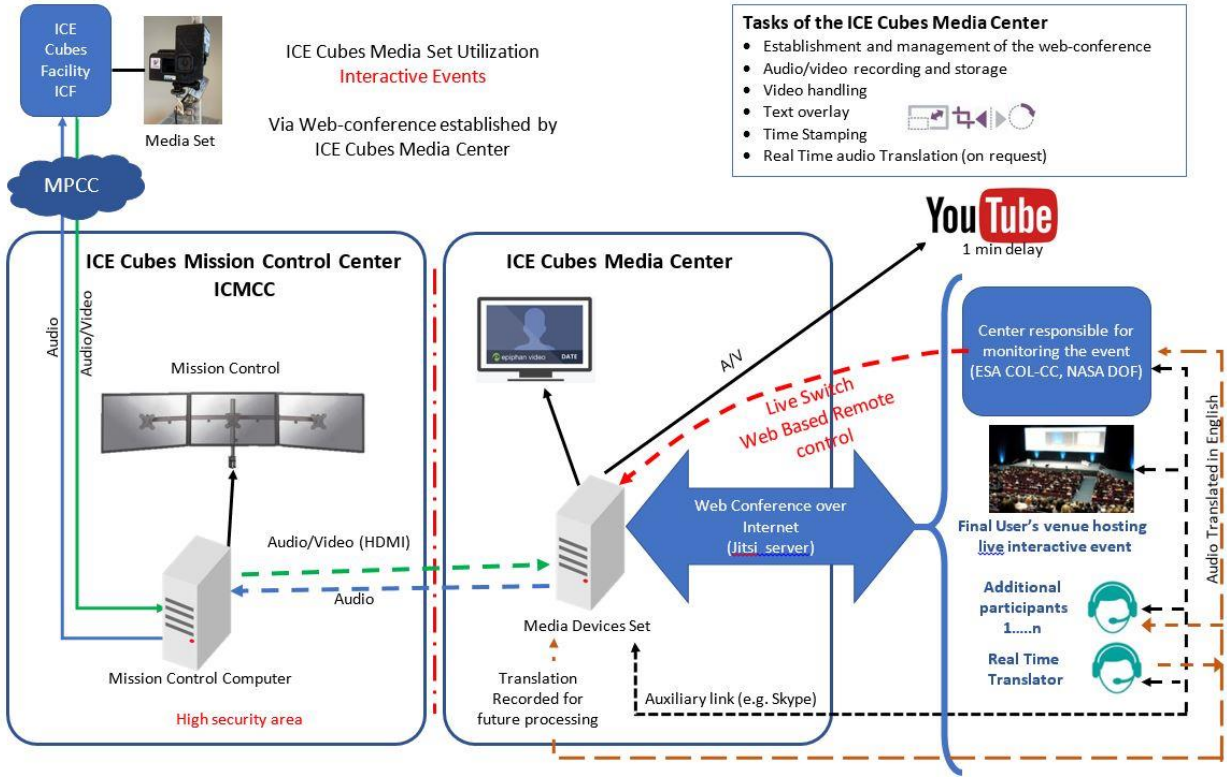

Fig. 3. Media Set Ground Segment Architecture

In order to receive data (audio and video) from both the GoPro and forwarding audio to the speaker set, the ICMCC Mission Control Computer hosts a video conference between ground and the ICF on board with only 2 participants: ICF on board and the Mission Control computer as conference controller. The ICF has a lightweight client side SW making it able to join that video conference. The GoPro's camera and microphone stream are added to the conference as input for the client. The speaker is used as audio output during the conference. As such the video conference takes care of AV downlink and audio uplink between space and ground.

For security reasons it is crucial to segregate the operations environment connecting to the ISS (Mission Control Center) and the network to which the external end users connect (Media Center). This is performed by a frame grabber capturing the video conference running on the main Mission Control Computer and forwarding the audio/video stream through an HDMI interface towards the ICE Cubes Media Center. In return, the Media Centers Media Computer forwards the digital audio from the connected end users to the Mission Control Computer, which is handled as a microphone input for the video conference. This allows for a full segregation of networks.

On the side of the Media Center, the AV stream from the frame grabber is altered before forwarding it to the web conference with the external end users or any other streaming device. Streaming SW located on the Media Computer

will use the frame grabber AV stream as input. An overlay of text, banners, logos or any other conference relevant information can be added on top of the stream. Custom static display scenes with e.g. pre-event, LOS or post-event slides can be easily set-up and controlled via a switchboard. Both the overlay and scenes help to guide and relay information in between/during the actual Media Set streaming from on-board

Following the customer's request, the interactive session can also be streamed to other services (e.g. YouTube). This streaming is configured with a 1-minute delay to allow for necessary intervention by the operational partners. To enable this intervention, additional streaming to a secured web service is provided for mandated persons by NASA and ESA only to follow the web conference in real-time without participating to it.

2.2.1 Concept of Live Switch

As a requirement by ESA for broadcasting real-time events, a so-called Live Switch function is implemented within the ICE Cubes Media Center to allow authorized entities like ESA Flight Controllers or the customer to cut the external transmission and broadcasting. This allows to cut the streaming in case of Emergencies on board or for other reasons which might require intervention. For situational awareness, the Columbus Flight Director is able to see what is being transmitted and to check the A/V stream is actually cut, when the instruction is given to do so. Thanks to the one minute delay the cut shall always occur in time.

The Media Centers Media Computer hosts a web service, by means of a website, that enables multiple mandated users to simultaneously control the streaming SW and activate the Live Switch. This control is implemented by switching the transmitted/broadcasted A/V from live on-board video to a predefined static image.

2.2.2 End user

Each user participating to the web conference or accessing the webpages is granted access by individually provided user credentials with Two-Factor Authentication. The end users participating to the web conference also have access to the supporting operations tools, namely:

- Chat: allowing communication between ICMCC and end-users
- Timeline: visualization of the timeline where the Media Set events are displayed based on the activities in NASA provided overall ISS timeline tool OPTIMIS. Data is augmented with ISS day/night passes, planned S-band/Ku-band outages, Acquisition of Signal (AOS) and Loss of Signal (LOS)

3. Concept of Operations

The service considers three different types of use of the Media Set Service:

- Interactive sessions
  These are the most typical events where the crew interacts with one or more persons on ground.
- Standalone
  Standalone sessions are similar to Interactive sessions without having the end user interacting with crew. The Media Set speaker is not actively used.

  Both sessions are by default recorded in the ICE Cubes Media Center for future use by the customer. Additionally, the sessions can be broadcasted (e.g YouTube). For these broadbasted events, an external broadcasting service is added to the set-up. For this, the end users provide their streaming keys and at the start of the event the streaming is initiated, with a 1-minute delay.

- Recorded sessions
  A recorded session records the AV stream from the GoPro directly on the ICF data drives. At the end of the session the recording is downlinked to the Mission Control Computer. The Media Set speaker is not used as part of the recording, but only in case support to the crew is beneficial. Further on in the process, the video file will be distributed to the different parties for content-checking and end use.

During the Axiom-1 mission only interactive sessions were requested, mostly also including broadcasting. Initially the mission targeted 60 events which was then narrowed down to 44 events over 8 days, each with a duration from 15 to 45 minutes. Many of them would be conducted by private astronaut Eytan Stibbe, who took ~ 50% of the events on his account.

The fact that Axiom was working with NASA for the overall mission integration activities, while the ICE Cubes facility is an ESA/Space Applications Services asset, using European resources and support centers, required broad coordination. Moreover, this was the first time many public interactive events in such short timespan would be

organised with commercial crew and under ESA sponsorship. Following this, clear agreements required to be set-up on the planning and use of the Media Set, avoiding to jeopardize the on-going mission and science objectives of the Columbus Laboratory. With the cooperation and participation of all partners, namely ESA, NASA, Axiom Space and Space Applications Services the concept of operations was set-up. This section will describe the challenges that were tackled in the discussions prior to the mission and documented in the concept of operations and reflected in a formal Operations Interface Procedure (OIP).

3.1 Supporting centers and communication flow

As already mentioned in the previous section, several control centers were involved in the support of the Axiom-1 Media Set events and coordination needed to be agreed upfront.

Fig. 4 shows the agreed communication flows between the centers.

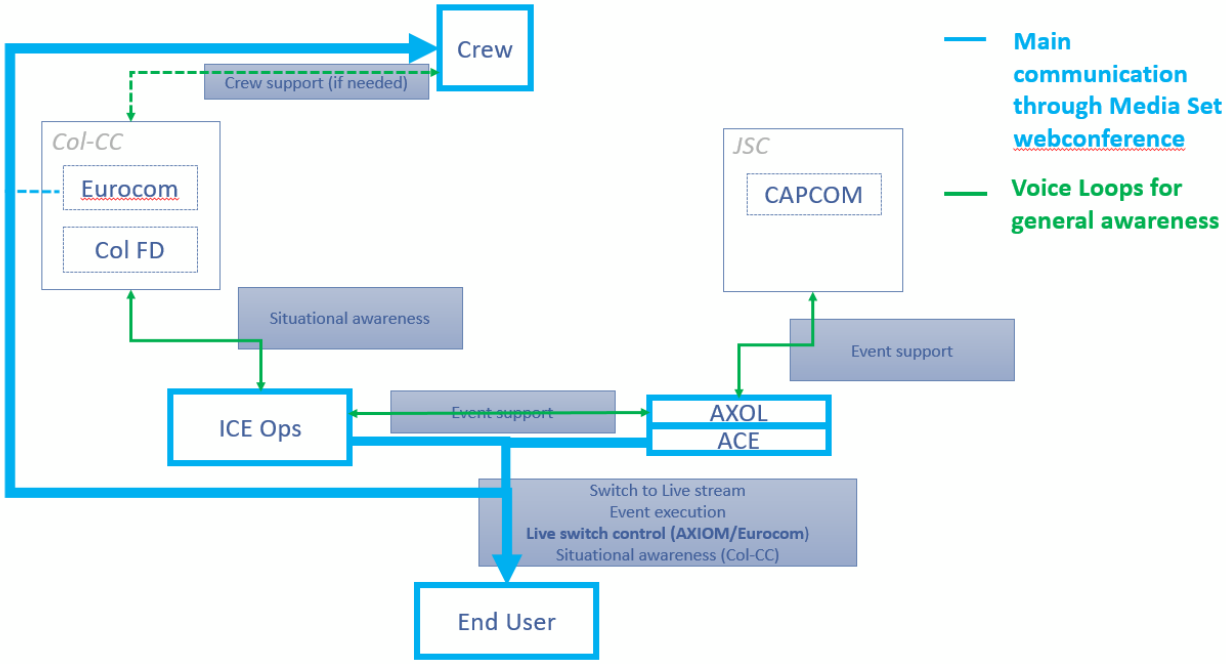

Fig. 4. Ops Centers communication flow

As shown in Fig. 4, the following centers are actively involved:

- NASA Johnson Space Center (JSC): The Axiom Operations Lead (AXOL) sat on console in the JSC control room and supported the crew activities from there. The overall crew timeline was managed by JSC and Axiom Space, hence close coordination was required with the other centers to cope with near-real time and real-time changes.
- Columbus Control Center (Col-CC) is responsible for the Columbus Laboratory, ensuring the provision of the necessary resources for the Media Set as well the availability of the Laboratory during the planned events. As coordinated with the Columbus Flight Director (Col FD), parallel crew activities in Columbus Laboratory were avoided; a specific S/G voice loop was restricted for this event only. Prior and after the event the EUROCOM communicated directly with the commercial crew in support of the activity. Once the event was started, the communication was handed over to the web conference and led by the Axiom Space Communications representative ACE at the Axiom Media Center.
- ICE Cubes Mission Control Center (ICMCC): ICE Ops responsible for the ICE Cubes Facility and Media Set. ICE Ops reports directly to Col-CC during real-time operations. ICE (Media) Ops, an additional position, was in charge of ensuring the proper set-up, performing a voice check with the crew through the web conference system and initiating the actual public event.
- Axiom Media Center at Axiom Space headquarters responsible for the overall coordination of all Axiom-1 Public Relations (PR) events. They standardly participated to all web conferences and were in contact with AXOL through phone.

3.2 Event scripts

As per ISS regulations, all public events need to be documented upfront in what is referred to as 'scripts'. These scripts provide details of the event such as timing, activity reference on the timeline, audience, items to take along like a t-shirt or accessories to show, type of activity, kind of questions etc. As Axiom Space was responsible for the content of the events, they prepared the scripts together with the PR teams of the four astronauts. Draft scripts had been reviewed in advance and the final scripts were reviewed a week before the start of the mission through the NASA Electronic Flight Note System (EFN) by all involved parties and positions.

3.3 Activity Constraints

Taking into account the large number of events and the fact there were seven International Partners expedition crew members on-board during the Axiom mission, a very thorough pre-coordination was required on what was allowed to be streamed and what not. Following a discussion with ESA and NASA representatives, the following constraints were identified for the camera Field of View (FoV) during the events:

- No unintended ISS Expedition crewmember should appear in the FoV during any event.
- All events shall respect the typical crew privacy constraints. As such the new crew quarter (sleeping facility) CASA in Columbus shall have its doors closed during events and all personal laptops shall have closed lids.
- The FoV shall avoid pointing to ISS Node 2.

These constraints were captured in the formal Ground Rules and Constraints so that all positions were aware. Additionally, being a commercial initiative, large NASA or ESA logos should not appear, while nominal Columbus rack fronts and facilities were not an issue.

For the events themselves, it is clear they were required to respect NASA and ESA's values and standards. This was ensured through the thorough review as detailed in Section 3.2.

3.4 Planning of activities

Some planning constraints were also agreed for the timing of the Media Set events. As such, no events could be planned before the morning Daily Planning Conference (mDPC) and after the Evening Planning Conference (eDPC) as this is outside nominal working hours of all crew members. Also, no activity should coincide with nominal planned crew conferences with ground staff.

With the overall crew timeline being handled by Axiom and NASA, but the Columbus activities being handled by Col-CC and ESA, upfront agreements were required as well. As such, the following process was concurred to and applied:

1. NASA Planning integrated Axiom's Media Set planning inputs into the different planning products and ESA reviewed the planning against their own objectives.
2. Prior to 7 days before the mission start all changes were handled by the backroom offices. Here, changes to the Axiom timeline impacting the Media Set planning required email pre-coordination with ESA Planning Team and ICMCC.
3. As of 7 days before the mission start, planning changes were handled through the real-time console positions. It was agreed that all parties would be consulted as soon as the need for change was identified. Changes requested by Axiom 1 day prior to the event were conditionally upon Col-CC's availability.

For awareness of all crew members, the Media Set planned events had a crew constraint indication on the timeline so that crew members were aware an event was scheduled and AV was being streamed to ground from the Columbus Module.

3.5 Live Switch responsibility

Following the list prepared by Axiom Space all Media Set events were categorized by the NASA Ax-1 Mission Manager indicating NASA's recommendation for the responsibility of the Live Switch. Taking into account the fact that these public events were conducted in the Columbus laboratory, under Columbus Control Center's responsibility, the following approach was applied:

- For all events: In case of Emergency, the Col FD should be able to actuate the live switch and to order via the Voice Loops the stop of the AV transmission. As main responsible center of the Ax-1 mission, Axiom monitors all events and has the ability to cut the video if deemed necessary.
- For Public Media Events: Media Set EUROCOM performs the content follow-up. This position is responsible for following the evolution of the event and stop the external transmission in case of inappropriate content or other major deviations from the script. To respect crew privacy, any non-intentional conversation or action

that is being heard/seen on ground and not destined for the scheduled event should be stopped for further broadcasting to the web conference.

- For Educational events and Crew Conferences: Axiom-CC performs the content follow-up. Here the Axiom communication position is responsible for following the evolution of the event and stop the external transmission in case of inappropriate content or other major deviations from the script. To respect crew privacy, any non-intentional conversation or action that is being heard/seen on ground and not destined for the scheduled event should be cut for further broadcasting to the web conference.

3.6 Conduct of activities

The following Figure provides a high level overview of the conduct of activities:

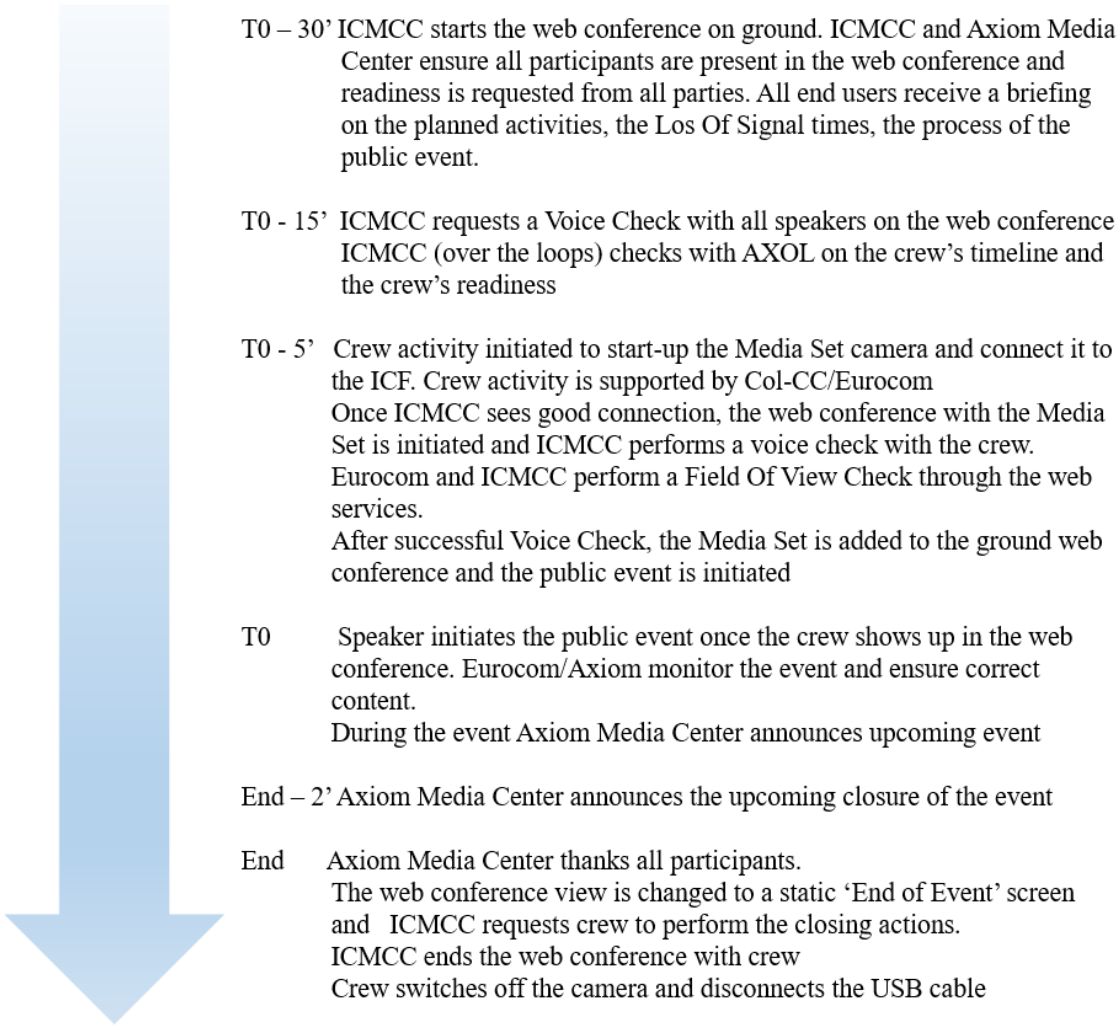

Fig. 5. Media events - Flow of activities

While the above was settled and properly documented the teams focused on the readiness of the actual mission.

4. Axiom-1 Mission

4.1 Axiom-1 Media Set Mission preparation

As stated, initially Space Applications Services and ESA received the request for over 60 events which was then narrowed down by Axiom to 44 events. In the preparation phase a list was consolidated by Axiom Space indicating:

- The event reference as shown on the overall timeline.

- The crew member(s) that would participate to the event (usually one).
- The duration of the event.
- The target day (Day of Year) and flight day (where Flight Day one is the day of Launch)
- Possible constraints for the event. For example, 'only during CST school time'.
- A short description of the event. For example, 'Interview with school XYZ' or 'Interview with NBC'.
- The contact person.
- The speakers.
- Additional end users.

Each of the 44 events consisted of at least 2 speakers for which a user account was created. Additional users were created for ESA, NASA, and Axiom points of contacts, bringing the total to over 150 user accounts. As mentioned before, access to the system included a two-factor authentication ensuring the necessary level of security, but avoiding potential issues with Virtual Private Network (VPN) lines.

From January 2022 up to April 2022, all users were invited to a demonstration of the Media Set allowing for a full check-out of their audio and video systems as well a walkthrough of how to conduct/attend an event. During the demo session the users were guided through the Do's and Don'ts, the conduct of an event (as explained in Section 3.6), the use of the web conference software interface, the audio/video experience from the crew they would perceive (by having crew surrogate in front of Media Set Engineering Model), etc. Additionally, with Axiom ground controllers only, intensive dry runs were performed to exercise the swapping from one web conference to the other. Indeed, with 44 events planned on 8 flight days, the timeline was packed and there were some back-to-back conferences where ground required to swap from one to the other. During these dry runs, a surrogate crew member was included that participated to the web conference from the Space Applications Services clean room with the Media Set Engineering Model. This allowed for a proper end-to-end test of the ground segment. These dry runs, both with externals as well as ICMCC internal only personnel, turned out to be very valuable as the ground procedures were further fine-tuned up to the last weeks prior to the mission to shorten the preparation time for an event. The ICMCC Operator handling the web conference was required to perform some checks and configuration changes to ensure audio and video were forwarded only after the voice checks and the check of the field of view. Static screens were shown during LOS and after the events, while the on-board crew was informed. Moreover, external streaming (with 1 min delay) could only be started once the conference was started, but also stopped after the end of an event. All these small actions contributed to the success of an event and hence it was crucial they were performed in the right order, at the right time and fast.

As stated, crew member Eytan Stibbe planned over 20 events of which many were in Hebrew. To allow Axiom Space and the responsible(s) of the Live Switch to follow the on-going conversation, Space Applications Services ensured the provision of a real-time translator Hebrew-English which could be followed on one of the webpages of the web service.

As the timeline appeared on the NASA system OPTIMIS, the Axiom planning team provided daily the detailed planning on spreadsheet allowing ICMCC to inform the end users. This was achieved via calendar meeting invites with the actualized conference timing as well the ground conference web link. The week before the conference the users were asked to test their system once more time through a conference that was set-up with a video that was streamed. By confirming they had good audio and video, they got the confidence their personal system was ready to support the event(s).

Finally, ESA and NASA Flight Controllers were invited for a training session on the use of the web conference software interface, in parallel with the Live Switch Control and the view of the webpages.

4.2 Axiom-1 Media Set Events Mission Execution

At ICMCC the Axiom mission was supported by several console positions in order to guarantee a fluent setup and transition between the events. Since several events were booked back-to-back, the coordination with the audience of the next event needed to start while the previous event was still ongoing. The different roles at ICMCC consisted out of

- ICE OPS: responsible for the monitoring and control of the ICE Cubes Facility and coordination with the Flight Control Team at COL-CC as well as the Axiom Ops Lead position AXOL.
- Media OPS: in control of the Media Computer; performs the initial voice checks with the crew over the web conference and controls the web conference with connected end users.
- Media Support: backroom position supporting the audience in the web conference, monitoring the LOS and reporting and responding in the web conference chat.
- Ground Control position monitoring the status of the ground segment.

Each early morning an updated timeline was made available by the Axiom planning function, which was used by ICMCC to inform the end users of the possible shift of their events for the day to come and the following days. Col-CC on their end checked that the proposed updated timeline fitted the Columbus planning as well.

During the mission, 2 events were cancelled by Axiom following availability on the end user's site or prioritization on the crew's timeline. This resulted in a total of 42 public events within a period of 8 days from Sunday April 10 until April 17, one day even having 12 events.

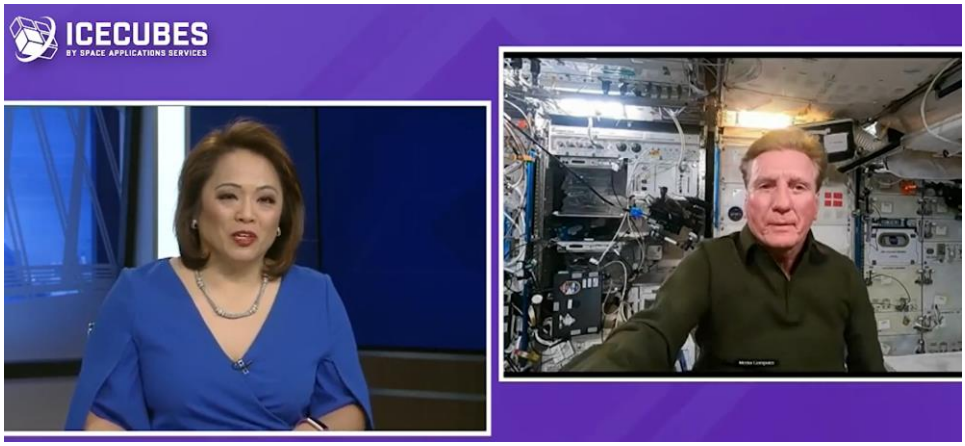

Fig. 6. Web conference with L. Connor (credits: Axiom Space, WBNS 10TV) [1]

The use of the Media Set started with a test event where all four commercial crew members were involved. After an initial voice check, Axiom communication center shortly explained the crew the planning of the events and the handling of Loss of Signal, etc. As nominal on the ISS, events were interrupted by short LOS which introduced a 1 minute or more break into the on-going conference. While events were usually only scheduled for 15 or 30 minutes and taking the packed timeline into account, it was crucial that events could start on time. A minor delay in the start and some LOS could result in a shift of the next events. The crew had many other activities planned and therefore all ground positions were closely monitoring the schedule and fast coordination was essential. As such, the ICE Ops position was in close contact with the AXOL to have a view on the status of the crew's packed timeline and whether delays should be considered for the upcoming events.

Additionally as the sessions past by, ICMCC and EUROCOM managed to decrease the time used for the FoV check and the voice check to the minimum.

While dry runs were held and trainings had been foreseen, some additional backend support was required to the end users during the mission itself. For this, additional ICMCC personnel was available to support them in reconfiguring their accounts. Throughout the mission, the ground systems were further fine-tuned making them more robust, especially the set-up of the translator audio.

The execution of 42 public events in 8 days has never occurred before on the International Space Station and was a big achievement for all teams involved. The many ground positions to support these events, strict checklists and ground procedures were very valuable to mitigate risks. Also from the crew's perspective we understand the use of the Media Set is considered an asset. They strongly liked the ease of use and the simple set-up. Some suggestions from the crew were formulated which will be introduced in the upgrade of the system as detailed in Section 6.

5. Lessons learned

The success of the intensive mission showed that the rigorous pre-coordination and testing between all positions and Ops Centers was truly needed. Internal lessons learned were derived shortly after the mission of which the most relevant ones are repeated here.

As detailed in the previous sections, to enable an event there are a number of manual actions required such as performing the voice check, starting and controlling the web conference, starting the streaming, reporting the LOS to the audience. This is one of the reasons why the ICMCC console was staffed with several positions. Now that the sequence of these actions is determined and their criticality identified, time can be invested in further automating some of these actions which will reduce the risk of manual errors and make the system and service more sustainable. Additionally, in the light of being a commercial service, clear logging is required to have a good view on the service. An automated log system will be put in place to allow an easy retrieval of the duration of the event, the number of participants connected, the streaming performed, etc.

Based on the feedback from the crew it also became clear that the Columbus Laboratory can be a noisy environment and the speaker of the Media Set has a limit in its volume. Therefore the use of a headset or BlueTooth speaker is now considered for the next mission. Additionally, especially for the commercial crew, two way video would also be beneficial.

While the audience was informed on the LOS during an event through the chat, the crew was informed on the Loss Of Signals through the web conference itself by voicing it up. For future use of the recordings it was requested to have different means to inform the crew on an upcoming LOS. This is currently being investigated on what the best approach will be for the upcoming Axiom-2 mission.

6. Outlook

For the Axiom-2 mission currently planned in May 2023, Space Applications Services was asked to use the Media Set for the execution of a number of public events. While many of the agreements and processes will remain in place as detailed in the OIP, some of the lessons learned described above will already be implemented for this next mission.

Additionally, a number of upgrades to the system are currently under development or being planned, aiming for an expansion of the capabilities. The Media Set will be augmented by an additional module composed of a minicomputer Raspberry Pi 4B and a commercial LCD screen. This upgrade, called Media Set Mk2 will allow for two-way video during a live event.

The Media Set Mk2 is intended to be used in the Columbus Module, connected to the ICF, as well to other modules of the ISS, being connected via WI-FI with the ESA P/L LAN. The upgrade also include the utilization of headsets, to provide more comfort to crew and to facilitate private calls.

Moreover, the system is also under testing for supporting private conversations between the astronaut in orbit and persons on ground, such as real-time, one-to-one communication with medical staff or family.

Enabling such private conversations with medical staff also opens new avenues for the utilization of novel techniques for health monitoring and evaluation (e.g. facial recognition software), which can also be combined with the ICE Cubes AI-Box [2] hosted inside the ICE Cubes Facility. This can become part of the health check protocols and evaluation process, providing real-time elaboration of data in parallel with the assessment of the medical staff on ground. A dedicated software solution would complement the Media Set & AI-Box combo, to enable for the automatic analysis in orbit, while providing real-time connection, for comparison and cross-checking.

Combining the Media Set with edge computing capabilities in orbit (AI-Box) offers the opportunity to test new solutions and applications required by future deep-space longer term missions, where (near) real-time communication with ground (Earth) is not possible. Developing and testing such solutions is crucial for human spaceflight as we venture beyond LEO for longer periods of time. Such solutions may include machine vision applications, in-situ processing and analysis of data via AI-powered visual inspection, development of smart devices, robotic assistants and habitats, as well as Augmented Reality (AR)/Virtual Reality (VR)-based applications for future space activities and operations (in-orbit and on-ground).

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8. References

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