Accommodating Science and Technology Development Sortie Missions in the Post Space Shuttle Era

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Sortie missions during the Space Shuttle era provided a unique opportunity for investigators to conduct experiments and technology demonstrations using standardized payload hardware. With the advent of a developing fleet of crewed and uncrewed space vehicles a new opportunity for sortie missions may be viable. These vehicles provide options for accommodating laboratory space for sortie payloads, either in dedicated missions or as part of other activities like resupply. These missions would be analogous in a small way to earlier Space Shuttle, Spacelab, and Spacehab sortie missions. Advantages of sortie missions include the ability to run multiple independent experiments or a series of related experiments. With multiple smaller spacecraft being developed for rendezvous with ISS, researchers might have more frequent opportunities. If automated, reduced integration costs could be achieved and possibly some legacy payload equipment reused without extensive refurbishment. Uncrewed vehicles can provide capabilities for investigations not previously accommodated due to risk, cost, or schedule issues. One concept being considered for supporting sortie science and technology demonstration missions is the Dream Chaser Cargo System (DCCS). This Dream Chaser variant, designed for International Space Station (ISS) Cargo Resupply Services (CRS2) missions, can remain in space for weeks or months and contains mechanical, electrical, and data interfaces to support a wide variety of payload types. The Dream Chaser could also mate with habitat modules to act either as a temporary laboratory or to transport specimens and experiments between the habitat and Earth. As a lifting body vehicle, Dream Chaser's shuttle-like gentle entry deceleration results in minimal impacts to specimens and the pinpoint runway landings onto commercial runways allow investigators immediate access to returned specimens, which minimizes confounding influences of the 1g environment.

Nomenclature

CEPA	=	Columbus External Payload Adapter
CRS2	=	Commercial Resupply Services Phase 2
CTBE	=	Cargo Transfer Bag Equivalents
DCCS	=	Dream Chaser Cargo System
ExPA	=	Express Pallet Adapter
ESA	=	European Space Agency
EUE	=	Experiment Unique Equipment
FRAM	=	Flight Releasable Attachment Mechanism
ISS	=	International Space Station
JEM-EF	=	Japanese Experiment Module - Exposed Facility
LAPA	=	Large Adapter Plate Assembly
LEO	=	Low Earth Orbit

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MAPA	=	Medium Adapter Plate Assembly
MAR	=	Middeck Accommodations Rack
MLE	=	Middeck Locker Equivalent
MSFC	=	Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
PI	=	Principal Investigator
RAM	=	Research and Applications Module
SAPA	=	Small Adapter Plate Assembly
SNC	=	Sierra Nevada Corporation

THE sortie missions flown during the Space Shuttle era provided a unique opportunity for scientists to conduct research using standardized payload hardware. As the Space Shuttle was phased out, the opportunity for sortie type missions decreased and NASA moved more toward the development of permanent research facilities on the ISS. The model for these facilities is that investigators adapt their research to be compatible with ISS facilities and then provide specimens and any Experiment Unique Equipment (EUE) necessary to conduct their experiments or tests.

With the advent of a developing fleet of crewed and uncrewed space vehicles, a new opportunity for sortie missions may be viable. These vehicles provide options for accommodating laboratory space for sortie payloads, either in dedicated missions or as part of other activities like resupply. These missions would be analogous in a small way to earlier Space Shuttle, Spacelab, and Spacehab sortie missions.

I. Sortie Mission Concept

The term sortie is defined as "a going out", an excursion or expedition, often as part of a coordinated campaign. A sortie mission usually infers a limited scope and relatively low costs. NASA generally used this term to designate an activity of limited duration with a specific goal, though the use of the definition can vary with organization or program. During the Space Shuttle development, NASA used the term to indicate primary objectives related to research and experimentation rather than activities like satellite deployment or construction of infrastructure, and therefore developed concepts[1,2] (see Figure 1) to provide this capability.

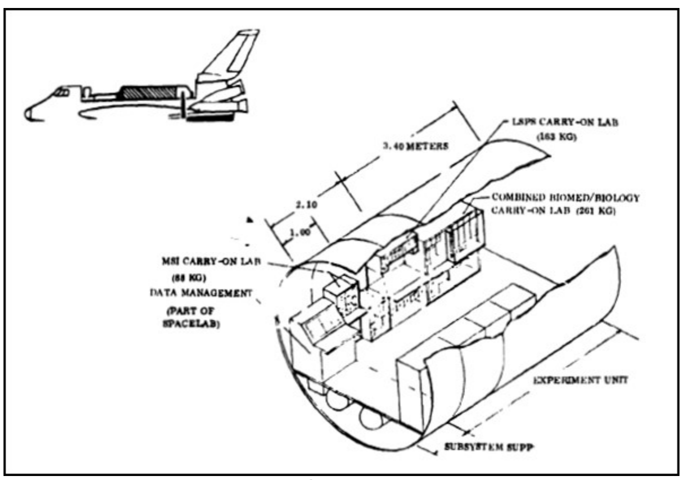

Figure 1. NASA Spacelab with Carry-on Lab concept[3] (credit-NASA).

II. Benefits of Sortie Missions

The benefits of sortie missions include a short lead time from concept to implementation, a streamlined payload integration process, the ability to accommodate numerous diverse experiments, the ability to rapidly turnaround experiments and the associated ability to iterate an experiment multiple times. Sortie missions have been used to conduct multidisciplinary research involving several diverse investigators, and have demonstrated the ability for rapid return of high quality data[4,5]. These missions would benefit life science and physical science experiments that do not need long duration testing on ISS, and would provide a relatively robust post–ISS research capability. Some examples of research disciplines that sortie missions would benefit are shown in Figure 2. Sortie missions also have significant value as technology demonstration opportunities. Longer duration sortie missions with an uncrewed vehicle could support Earth observation, space, and astronomical sciences.

A personal example (from one of the authors) of how a series of sortie missions can be used to develop and validate new capabilities is the Astroculture flight series flown on the Space Shuttle (middeck, Spacelab, and Spacehab) in the 1990s. The first flights in this series were used to validate new subsystem technologies (e.g. lighting, water and nutrient delivery, humidity control and condensate recovery, ethylene scrubbing) for growing plants in a microgravity environment[6], leading to follow-on flights with plant specimens[7,8,9]. These technologies ultimately became the foundation for subsequent on-orbit plant research facilities, including the Advanced Plant Habitat facility currently in use on the ISS[10].

Figure 2. Sortie missions could benefit a wide variety of research disciplines.

Sortie missions can also support commercial space developments, helping alleviate issues such as inability to access the microgravity environment on a regular basis, delays in retrieving samples, and burdensome and expensive experiment integration processes[11]. Commercial sortie missions could provide an operational environment that allows customers to fly tailored missions to meet distinct needs, enabling investigators to have complete control of their own payloads, including preservation of intellectual property rights. Sortie missions are also an effective platform for allowing access to the space environment for education activities related to technology development, biological sciences, physical sciences, and other space sciences[12].

III. Sortie Payload Carrier History

As originally conceived, the Space Shuttle was planned for use in three modes: to transport unmanned planetary and interplanetary missions into Earth parking orbits, to launch and retrieve spacecraft into and from low earth orbit, and to conduct sortie missions[13]. The original concept included a family of payload carriers suitable for transport in the Shuttle cargo bay, including automated free-flyers serviced by the orbiter. The basic concept being developed at that time was for a pressurized module where a variety of different payloads could be quickly configured between missions. Provision would also be made for experiments requiring access to the space environment. It was anticipated that more advanced modules would be developed for particular disciplines such as materials science. These concepts ultimately were consolidated and implemented as the NASA Spacelab.

The Spacelab development was assigned to MSFC as the Lead Center, partially based on their experience with Skylab[14]. Since the Space Station was deferred to develop the Space Shuttle, NASA envisioned short-duration Shuttle flights, or sortie missions, employing Research and Applications Modules (RAMs) for experimental work in astronomy, materials science, and manufacturing in space. In 1972 the concept for a Sortie (Can) Laboratory (Figure 3) was developed and evolved to the Spacelab reusable laboratory used on the Space Shuttle (Figure 4). MSFC partnered with ESA to develop the Spacelab flight modules, of which two were flown. A total of 22 major Spacelab missions were used for microgravity science between 1983 and 1998[15].

Space shuttle middeck lockers began to be considered as a location for science payloads as early as 1983, when NASA evaluated the middeck's potential to accommodate experiment payloads[16]. Location of small payloads in the middeck allowed for late loading before launch and early recovery after landing. Quick post-flight access allowed researchers to examine the effects of microgravity on living systems before the organisms could readapt to Earth gravity. Use and reuse of existing hardware minimized development costs and the lag time between initial experiment proposal and actual flight. These payloads were flown with short preparation time, allowing investigators to repeat experiments and verify data on subsequent missions. Significant crew interaction with experiments was not possible since the middeck had no laboratory facilities[17]. The use of middeck cabin Middeck Accommodation Racks (MAR) expanded the volume available to payloads to be flown in the middeck area[18].

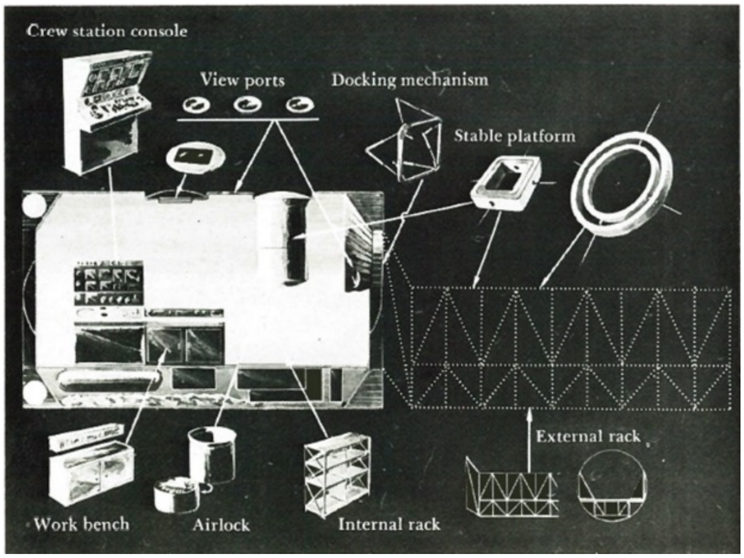

Figure 3. Early concept of sortie module[13]. This was the precursor to Spacelab.

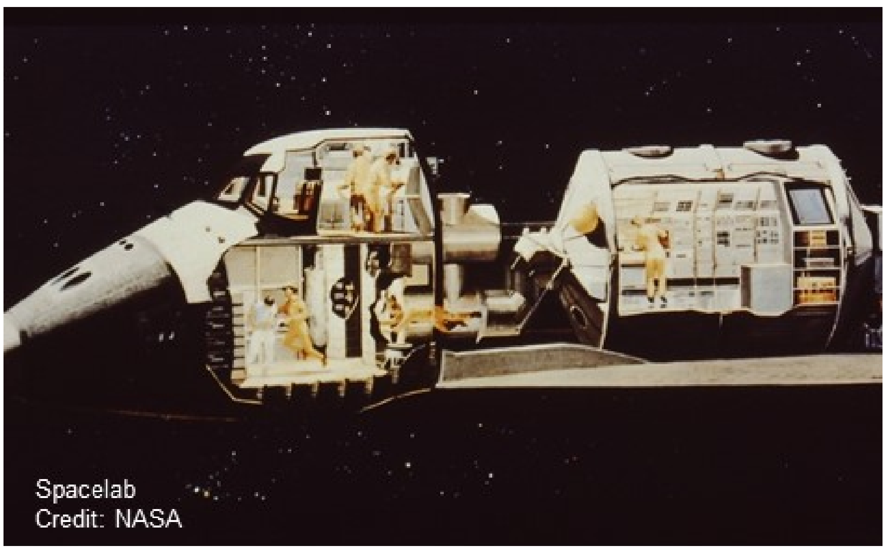

Figure 4. Artist conception of Spacelab module in cargo bay of Space Shuttle.

By the mid-1980s a concept was developed for a pressurized module that could be seated in the payload bay to accommodate a large number of middeck lockers allocated for research. This concept was developed and implemented by a commercial entity, SPACEHAB Incorporated. Two Spacehab (Figure 5) modules were delivered in 1992 that were capable of carrying, in its original configuration, 79 middeck lockers, or a combination of Spacelab type racks and middeck lockers[18]. This capability allowed commercial payloads to be easily incorporated and rapidly manifested and helped clear a backlog of middeck sortie type payloads that existed at the time. Various configurations of SPACEHAB modules supported many sortie experiments from 1993 to 2007[19].

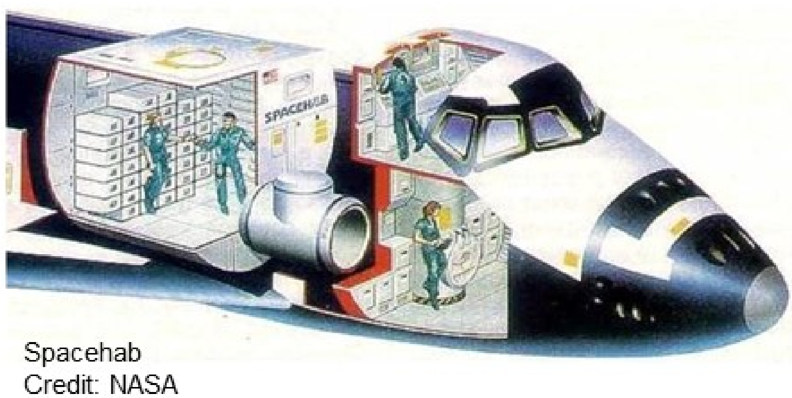

Figure 5. Image shows SPACEHAB module in Space Shuttle cargo bay. Middeck area with lockers is also shown.

IV. Dream Chaser as Sortie Payload Carrier

During the Space Shuttle era the Spacelab, Spacehab, and Shuttle middeck provided a unique opportunity for scientists to conduct experiments using a broad range of payload hardware. In the ISS era, research has evolved toward the use of more or less permanent research facilities that accommodate multiple investigators. Now in the post-shuttle era, with the ISS being in the late stages of its operational life, the development of multiple commercial space vehicles and habitats could again provide opportunities for science and technology demonstration payloads, either as dedicated missions or as part of activities such as resupply. This new generation of vehicles provide the potential as autonomous or crew-tended payload carriers for both LEO and new environments like cis-lunar space.

SNC's Dream Chaser spacecraft is a multi-mission space utility vehicle currently being designed for reaching low-Earth orbit (LEO) destinations such as the International Space Station, with an initial objective of providing cargo delivery, return, and disposal services for the ISS. The nature of this vehicle makes it a strong candidate for a free-flying microgravity science and technology development laboratory for commercial, governmental, and international customers. The Dream Chaser can land on any suitable runway around the world without requiring specialized equipment[20]. Unlike the Space Shuttle orbiters, which required a significantly longer runway, the Dream Chaser can land on a compatible runway that meets the desired length (10,000 feet/3,050 meters long) and desired width (150 feet/46 meters) requirements. This capability opens the door to broader landing locations and opportunities for space-based science to be more accessible post-flight. Additionally, the Dream Chaser will have a low-g reentry (<1.5g) and use all non-toxic fluid consumables, including propellants, allowing near immediate access to cargo post-landing. The Dream Chaser will initially fly in an uncrewed configuration (Figure 6).

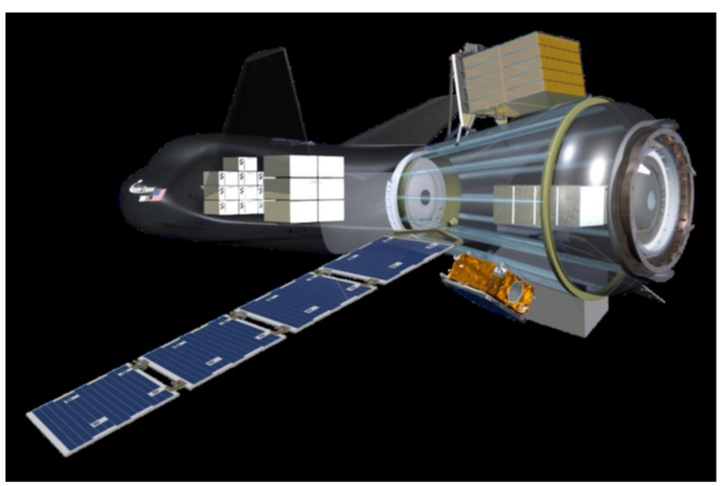

Figure 6. Dream Chaser uncrewed configuration showing vehicle internal storage and detachable cargo module storage with external payload mounts and deployment mechanisms.

A. Payload Configurations

The Dream Chaser is configured to carry both pressurized and unpressurized cargo to orbit, and provide return of pressurized cargo, and/or disposal of pressurized and unpressurized expendable materials (Figure 7.). Each of these capabilities is discussed in the following sections.

1. Pressurized Cargo

Dream Chaser pressurized volume can be configured with standard middeck locker equivalent (MLE) sized experiment carriers (Figure 8). This configuration has been demonstrated over the years to be able to accommodate a wide variety of science and technology demonstration payloads. A configuration using standardized MLEs is modular in nature and supports open, reconfigurable laboratory architectures that can be easily reconfigured to adapt to new research disciplines, techniques, and instrumentation. Modular retrofits support iterative investigations which can greatly enhance results. Middeck lockers are heritage from the Space Shuttle (Spacelab, Middeck, Spacehab), and are currently a broad standard used on ISS. A single locker is 20.3 in x 18.1 in x 10.8 in and a double locker is the equivalent of two single lockers. Custom payloads could be accommodated using standard interfaces as a starting point and the vehicle can accommodate a variety of cargo transfer bag types and sizes.

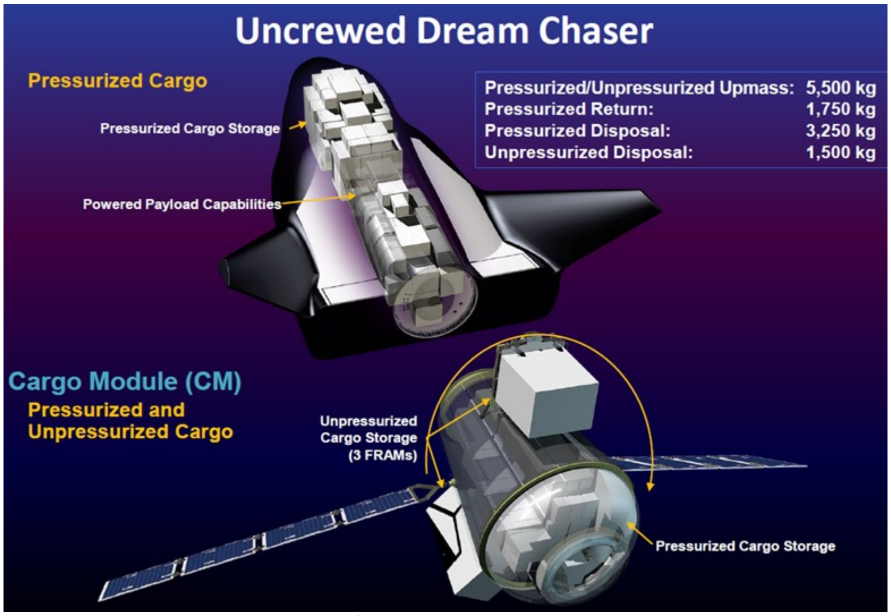

Figure 7. Dream Chaser Cargo System overview[21].

Figure 8. Early mockup of Dream Chaser sortie mission payload configuration based on use of middeck locker equivalent experiment carriers.

Components of the pressurized cargo support system include:

Mechanical System

The mechanical system provides mounting interfaces and structural support to accommodate single and double lockers, M Bags, Cargo Transfer Bags, and Double Coldbags. It also provides a dorsal access panel designed to support ground loading and an aft hatch opening sized to load and unload cargo and payloads.

Electrical Power System

The electrical power system provides power to payload lockers, provides power allocation and sharing for payload operation, and provides lighting. The Dream Chaser Cargo System would allocate a minimum of 75W continuous for each single MLE and 150W for each double MLE from handover at pre-launch until handover to the ISS, and from installation into the vehicle on ISS until handover post-landing. The DCCS will have six single locations in the baseline configuration internal payload location. Internal payload power availability can be reconfigured for different missions.

Avionics, Software & Communication System

The Dream Chaser Cargo System (DCCS) provides Ethernet connectivity, provides cargo/payload command and data, and provides vehicle data. This system will provide Ethernet data connections for each powered internal payload location and transmits payload health and status data to investigators.

Environmental Control and Life Support System/Thermal Control System

The DCCS provides control of ambient temperature, pressure, and humidity levels for internal cargo, including metabolic support for rodent lockers.

2. Unpressurized Cargo

The DCCS cargo module provides external payload mounts for unpressurized cargo, fixed payloads, or deployable satellites such as CubeSats. The fixed payloads would be analogous to the Pallets on Spacelab and the EXPRESS Pallets on ISS used to mount experiments that require exposure to space. Components of the unpressurized cargo support system include:

Mechanical System

The DCCS spacecraft can accommodate FRAM-based, JEM-EF, and direct-mount unpressurized cargo, with up to three unpressurized cargo items in a single compliment. Provided locations are capable of ExPA/CEPA FRAM types, JEM-EF cargo items, SAPA/MAPA/LAPA FRAM types, and other direct mounts.

Electrical Power System

The DCCS spacecraft will provide electrical power at the unpressurized cargo interface, with an allocation of about 300 W of continuous power.

Avionics, Software & Communication System

The DCCS will provide the capability to command powered unpressurized payloads while installed in DCCS from the time period between launch vehicle fairing jettison through transfer to ISS during attached operations or end of attached operations if payloads remain in place. It also provides Ethernet connections, cargo/payload command and data, vehicle data, and external cameras for cargo ops.

Thermal Control

The DCCS will provide a capability to maintain the thermal environment of unpressurized cargo during on orbit free-flight and while attached to the ISS. Methods to control the environment may include attitude control during free-flight, enclosures, or other active or passive means.

B. Payload Accommodations

The Dream Chaser winged configuration provides landing site flexibility that allows early specimen access (Figure 9). The ability to land at a large variety of airports and spaceports provides the capability to get samples as close to the PI's laboratory as possible to allow specimen processing with a minimum of the transportation and handling steps often required to get specimens and hardware to investigators. The Dream Chaser will have the capability at the primary landing site to handover payload hardware and specimens within 3 hours after landing. The DCCS will maintain power to the powered lockers from installation in the DCCS spacecraft until powered lockers are removed from DCCS (e.g., turnover post-landing). The DCCS spacecraft will also provide active payload health and status data beginning with installation of the cargo into the vehicle prior to launch, and ending with removal of the cargo from the vehicle following retrieval on Earth. Other advantages of the Dream Chaser ability to land on a runway include the fact that salt water intrusion damage to science that can occur with water landings is avoided, and the 1.5

g landing load (as opposed to 3g splash down loads) minimizes risk to live specimens. Drivers for early access to specimens and a benign reentry environment include[20]:

- Preventing reversion of any changes induced in samples in microgravity upon return to a 1-g environment
- Minimizing changes to preserved samples (particularly frozen samples) from thawing or being damaged before they can be retrieved from carriers
- Minimizing the time spacecraft systems must sustain live specimens, causing risk of degradation or stress to the samples

Figure 9. Concept showing rapid recovery of payloads for transport to nearby laboratory facilities.

C. Sortie Science and Technology Demonstration Mission Profiles

Dream Chaser could accommodate a wide range of sortie mission profiles, from 2 days to multiple weeks in duration. It could operate as a temporary laboratory docked to ISS or other habitats, or as a free flyer. Automated loiter ability allows very low g levels for sensitive experiments (low vibration, low disturbance). Flying as an automated free flyer, it could possibly support payloads that might be considered too hazardous to be feasible in a crewed vehicle. Examples of mission profiles that have been used by previous carriers and that could be met by Dream Chaser capabilities are shown below.

1. Mission: Sortie –uncrewed free flyer
Duration: From 2 to 90 days depending on experiment and vehicle logistics.
Previous examples: U.S. biosatellite, Russian Bion biosatellite, CubeSats

"Free flyer" payload carriers are unmanned carriers that support an on-board set of experiments in the space environment. These systems can support a wide variety of science and technology demonstrations with fewer resources than a crewed mission. One disadvantage of these systems in general is the difficulty in getting access to specimens and the payload hardware after completion of the mission objectives. An uncrewed Dream Chaser would provide the capability to return these materials to a location that could readily be accessed by the researchers. The DCCS vehicle could accommodate both internal and external experiments, and possibly used to launch and retrieve small experimental satellites.

2. Mission: Sortie -crewed
Duration: 7-14 days
Previous examples: Space Shuttle middeck, Spacelab, and Spacehab missions.

A crewed vehicle would provide the opportunity to conduct sortie science campaigns that have the advantages of trained crew to operate payloads. Potentially, the use of Payload Specialists as was sometimes done with Spacelab would enhance the effectiveness of the experiments or tests being conducted.

3. Mission: Vehicle docked at habitat
Duration: Crew stay up to 270 days or uncrewed
Previous examples: Shuttle docked to ISS

The DCCS vehicle can dock or berth to the ISS or other habitat (Figure 10) and be used to transport payloads and specimens to and from the habitat. In addition, it can provide additional capacity for experiments while docked. It could also allow crew interaction with payloads that are then sent out as an uncrewed free flyer that can come and go to the habitat until the vehicle is finally returned to the ground. This profile would be of particular interest for payloads that need a quiescent environment, since vibration levels would be much lower than on the crewed ISS.

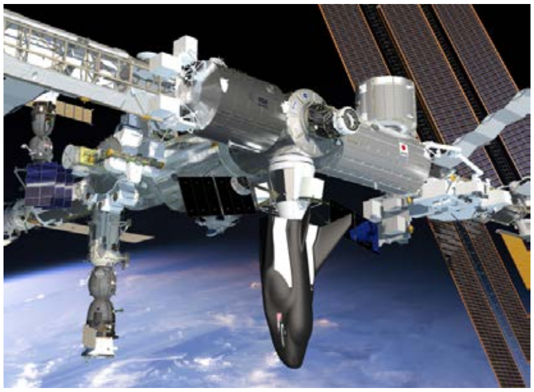

Figure 10. Concept showing Dream Chaser docked to ISS.

V. Conclusion

Features such as low-g reentry, the capability to land on standard aircraft runways near laboratory facilities, payload late load and early access capabilities, pre and post-flight power and data support, and the ability to support live organisms allows the Dream Chaser to provide a benign payload environment that would minimize the chance of contamination, damage, or degradation of payload specimens and samples that would confound test results.

A dedicated sortie mission carrier would greatly expand the opportunity to fly science and technology development payloads in the post space shuttle era, particularly in cases where long durations and advanced microgravity support facilities are not required. This would benefit a wide range of investigators, particularly commercial and international researchers who might not have ready access to space research facilities such as the ISS. Sortie capabilities would be available to academic researchers, student researchers (it might be particularly useful in the support of graduate student researchers who have had difficulty accessing space in a timely enough manner to complete research in support of advanced degrees), commercial hardware developers, and other entities. The Dream Chaser Cargo System can provide pressurized and unpressurized (external) payload slots, powered and passive payload support, flight releasable attachment mechanisms, expedited payload integration, flexible operating requirements and environments, and intellectual property control. The current DCCS configuration is uncrewed, but in the future crewed and/or tele-operational configurations could become available. The Dream Chaser concept is compatible with multiple launch vehicles, and has the potential to provide a tool for advancing space sciences and engineering over a long period of time. The Dream Chaser Cargo System's first launch to the ISS is currently scheduled for late 2020.

References

[1] Lord, D.R. 1986. Spacelab, an International Success Story. NASA SP-487.

[2] National Academy of Sciences. 1974. Scientific uses of the Space Shuttle. NRC Space Science Board, Washington D.C.

[3] General Dynamics. 1974. Life Sciences Payload Definition and Integration Study Volume 1-Executive Summary. Report No. CASD-NAS-74-046. (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740026197.pdf). (Accessed 4/14/18).

[4] ESA. 2011. Spacelab. https://esamultimedia.esa.int/hsf/SpacelabBR250.pdf (Accessed 5/10/18).

[5] NASA. 1997. Summary of Shuttle Payloads and Experiments. https://history.nasa.gov/pocketstats/sect%20B/P&E.pdf (Accessed 5/11/18).

[6] Morrow, R.C., R.J. Bula, T.W. Tibbitts and W.R. Dinauer. 1994. The Astroculture Flight Experiment Series, Validating Technologies for Growing Plants in Space. Adv. Space Res. 14:29-37.

[7] Morrow, R.C., N.A. Duffie, T.W. Tibbitts, R.J. Bula, D.J. Barta, D.W. Ming, R.M. Wheeler, and D.M. Porterfield. 1995. Plant Response in the Astroculture Flight Experiment Unit. SAE Technical Paper Series 951624.

[8] Zhou, W. 2005. Advanced Astroculture Plant Growth Unit: Capabilities and Performances. SAE Technical Paper Series 2005-01-2840.

[9] Morrow, R.C., J.T. Iverson, R.C. Richter, and J.J. Stadler. 2004. Biomass Production System (BPS) Technology Validation Test Results. SAE Technical Paper Series 2004-01-2460.

[10] Morrow, R.C., R.C. Richter, G. Tellez, O. Monje, R.Wheeler, G. Massa, N. Dufour, and B. Onate. 2016. A New Plant Habitat Facility for the ISS. 46th International Conference on Environmental Systems. Paper ICES-2016-320.

[11] McPherson, A. and L.J. DeLucas. 2015. Microgravity Protein Crystallization. npj Microgravity 1, 15010;

doi:10.1038/npjmgrav.2015.10; published online 3 September 2015.

[12] http://nanoracks.com/markets/educational/ (Accessed 5/15/18).

[13] von Braun, W. 1972. The Reusable Space Transport. American Scientist 60:730-738.

[14] Dunar, A.J. and S.P. Waring. Power to Explore - History of Marshall Space Flight Center 1960-1990. National Aeronautics and Space Administration, NASA History Office, Office of Policy and Plans, Washington, DC. 1999, Chap XI. (ISBN 0160589924).

[15] ESA. 2011. Spacelab. https://esamultimedia.esa.int/hsf/SpacelabBR250.pdf. (Accessed 3/30/2018).

[16] Michel, E.L. and W.J. Huffstetler. 1986. Economy of Middeck Payloads. The Space Congress Proceedings. Papr 3. http://commons.erau.edu/space-congress-proceedings/proceedings-1986-23rd/session-3/3. (Accessed 3/30/2018).

[17] https://lsda.jsc.nasa.gov/Research/research_detail/14?researchtype= . (Accessed 4/2/18)

[18] Sivolella, D. 2017. The Space Shuttle Program: Technologies and Accomplishments. Springer Praxis. 360pp.

[19] https://www.nasa.gov/mission_pages/shuttle/behindscenes/lastspacehab.html. (Accessed 4/2/18).

[20] Allison, C.J. and F.W. Taylor. 2015. Rapid Access: Dream Chaser® Spacecraft Space Traffic Management and Operations to Enable Near-Immediate Payload Access for Responsive Mission and Payload Support. AIAA SPACE 2015 Conference and Exposition Paper AIAA 2015-4582. https://doi.org/10.2514/6.2015-4582.

[21] http://www.unoosa.org/documents/pdf/psa/activities/2017/GrazSymposium/presentations/Monday/Presentation12.pdf