National Aeronautics and Space Administration

Commercial Crew Program
John F. Kennedy Space Center

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Crew Transportation System
Design Reference Missions

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TABLE OF CONTENTS

1.0 Introduction

The U.S. Government, through the National Aeronautics and Space Administration (NASA), is investing in the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost effective access to and return from the International Space Station (ISS). NASA's primary objective for the Commercial Crew Program (CCP) is transporting crew to and from the ISS, yet satisfying additional commercial mission scenarios can potentially enhance the Commercial Partner's mission base, and also be applied toward achieving increasingly safe, reliable, and cost effective crew transportation, benefiting NASA missions to the ISS.

1.1 Purpose

The purpose of this document is to describe design reference missions (DRMs) representative of the end-to-end Crew Transportation System (CTS) framework envisioned to successfully execute commercial crew transportation to orbital destinations. The initial CTS architecture will likely be optimized to support NASA crew and NASA-sponsored crew rotation missions to the ISS, but consideration may be given in this design phase to allow for modifications in order to accomplish other commercial missions in the future. With the exception of NASA's mission to the ISS, the remaining commercial DRMs are notional. Any decision to design or scar the CTS for these additional non-NASA missions is completely up to the Commercial Partner. As NASA's mission needs evolve over time, this document will be periodically updated to reflect those needs.

1.2 Scope

The sample DRMs contained in this document are top-level mission scenarios applicable to potential missions to low Earth orbit (LEO) destinations. As described in the parent certification document, *Commercial Crew Transportation System Certification Requirement for NASA Low Earth Orbit Missions* (CCTSCR-12.10), "NASA plans to purchase commercial crew space transportation services to LEO and the ISS as part of NASA's exploration plans and policies."

This document describes concept DRMs and is not a requirements document. For the ISS DRM, this document works in conjunction with the processes defined in *Crew Transportation Plan* (CCT-PLN-1100) and *Crew Transportation Technical Management Processes* (CCT-PLN-1120), the requirements defined in *ISS Crew Transportation and Services Requirements Document* (CCT-REQ-1130), the additional requirements defined in *ISS to Commercial Orbital Transportation Services (COTS) Interface Requirements Document* (SSP 50808), and the standards found in *Crew Transportation Technical Standards and Design Evaluation Criteria* (CCT-STD-1140) and *Crew Transportation Operations Standards* (CCT-STD-1150). NASA will not be involved in the certification of commercial systems supporting non-NASA missions which do not involve NASA crew or NASA-sponsored activities.

1.3 Delegation of Authority

This document was prepared by and will be managed by NASA's CCP. CCT-DRM-1110 will be maintained in accordance with standards for the CCP documentation.

2.0 Design Reference Missions

The Commercial Partner is responsible for the design, development, production, operation, management, and integration of the end-to-end CTS. The CTS is composed of flight system elements and ground system elements needed to support the execution of all phases of a mission. The flight system is composed of a launch vehicle, crewed spacecraft, cargo to be transferred to the destination satellite, and flight crew equipment. The ground systems are composed of the equipment, infrastructure, facilities, and personnel that support mission design, production, assembly, integration, test, launch preparation, launch operations, flight operations, and recovery activities.

The DRMs can influence the systems architecture and operational concepts for the end-to-end CTS.

Figure 1-1 depicts a general DRM to an orbital destination. The launch vehicle inserts the crew transportation spacecraft into orbit and multiple orbital maneuvers are subsequently executed to rendezvous in the destination orbit with the satellite. After mission objectives with the satellite are completed, the spacecraft departs and returns to Earth.

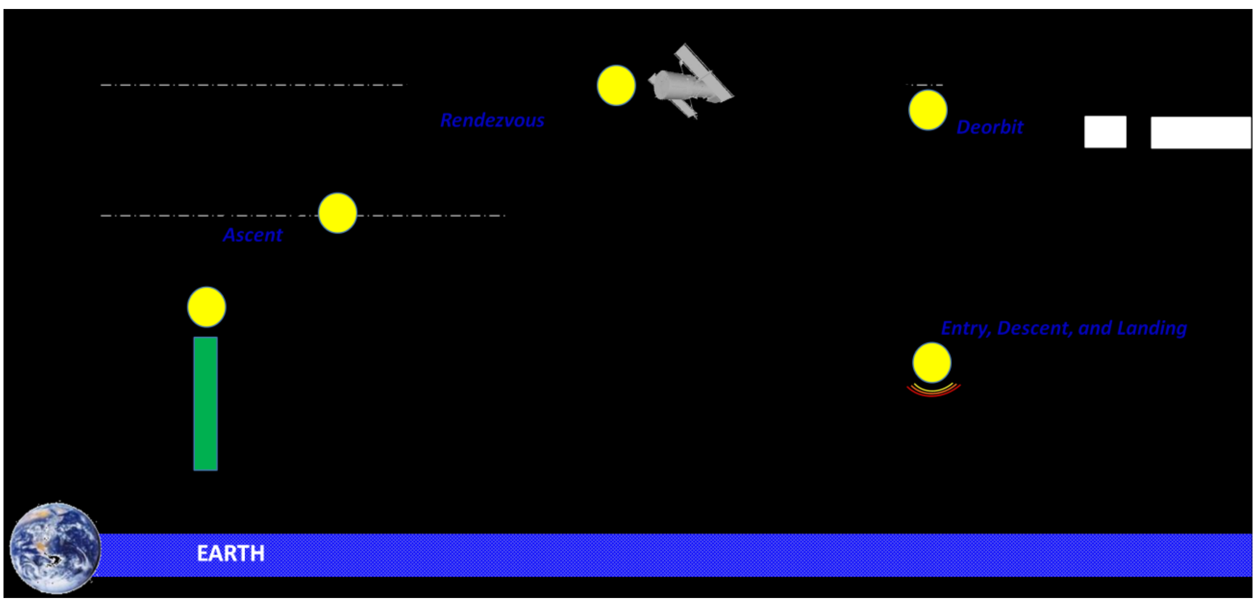

Figure 1-1: General DRM to Orbital Destination

Common to all DRMs in this document are the following mission and system capabilities[1]:

a. Support multiple launch opportunities in a week in order to accomplish a single mission.
b. Transport crew and cargo to the orbital destination.
c. Transport flight crew equipment, including items such as food, water, clothing, hygiene supplies, sleep accommodations, trash volumes, and medical equipment, to support the crew during orbital free-flight operations.
d. Provide one extra day of orbital flight operations prior to or after mated operations in order to support a contingency re-rendezvous activity, plus an additional day for deorbit waveoff due to system anomalies or unanticipated weather issues.
e. Provide contingency early mission termination and safe return of the crew throughout the mission. This includes anytime aborts during ascent, as well as expedited return during the orbital phase.
f. Support crew rescue for off-nominal, contingency landings, following expedited coordination with the commercial mission control center. When possible, additional personnel (e.g., flight surgeon) will also be deployed to the contingency site.
g. Provide orbital collision avoidance notifications and any necessary mitigation real-time operations for all flight phases.
h. Return crew and cargo back to Earth.
i. Provide safing and disposition of all landed vehicle hardware, including any required environmental cleanup (e.g., toxic propellants, maritime hazards, etc.).

[1] Note that these are expected capabilities. As noted in Section 1.2, specific requirements derived from each DRM are provided in separate documents (e.g.; CCT-REQ-1130).

3.0 NASA Design Reference Missions

3.1 ISS Design Reference Mission[2]

The CTS has two top-level objectives in support of the NASA mission of providing services to the ISS. The primary objective is to provide for crew rotation capability for up to four NASA or NASA-sponsored crewmembers, henceforth called NASA crew, and to provide for an emergency crew return capability for these crewmembers at any time while the commercial spacecraft is docked to the ISS. Secondary objectives include transporting a limited amount of ISS Program-specified pressurized cargo to the ISS, and returning pressurized cargo from the ISS, along with providing for a crew safe haven capability when the spacecraft is docked to the ISS. These objectives can be met by either a single Commercial Partner or multiple providers which are able to satisfy a subset of these objectives, such that the total portfolios of Commercial Partners meet all of the ISS DRM objectives.

The CTS spacecraft will nominally be capable of transporting NASA crew to the ISS within 48 (TBC) hours of launch. Mission launch opportunities must be accomplished within NASA specified timeframes to accommodate ongoing ISS science operations and to minimize ISS traffic model impacts associated with other visiting vehicles. Prior to launch, the CTS supports a NASA-provided pre-launch health stabilization program for NASA crewmembers and NASA-sponsored crewmembers. The CTS also assures comparable heath stabilization for any other crewmembers. Lift-off occurs when the U.S. (or State Department approved) launch site is within the ISS's orbital plane. Daily launch opportunities then depend on the resulting phasing; an everyday launch opportunity is desirable, but not required. Launch and ascent into the 51.6 degree inclination must meet Range Safety constraints associated with the launch site. Following ascent, an orbital insertion maneuver is executed and becomes the first of several orbital rendezvous maneuvers to be performed. These maneuvers bring the CTS spacecraft closer towards the ISS. ISS standard communications are used when the CTS spacecraft closes to within tens of kilometers to the ISS, and ship-to-ship voice communications are established. Relative navigation is performed by the CTS spacecraft using available cooperative and non-cooperative assets on the ISS. During these integrated operations, communication and telemetry monitoring will be shared between the commercial mission control center and the ISS Mission Control Center – Houston (MCC-H). When in close proximity to the ISS, after receiving approval from both the spacecraft and MCC-H, the CTS begins a final approach to a NASA specified docking port on the ISS. After docking, the vestibule between the ISS and the CTS is pressurized and verified not to be leaking. The CTS spacecraft hatches are opened and the crew transfers into the ISS, placing the newly arrived CTS in a semi-quiescent state.

Because of the short time duration from launch to docking, extensive internal maintenance of the spacecraft will not be possible, nor does the crew require certain complex habitability items for food and waste management that can be found on longer duration vehicles like the Space Shuttle or the ISS. Extravehicular Activity (EVA) will not occur because the complexity of preparing for and executing an EVA is precluded due to the short time in the spacecraft early in the mission. Similarly, EVA will not be performed during the short free-flight duration from undocking to landing.

Due to limitations in the number of docking ports on the ISS, the spacecraft may need to be relocated from one docking port to another during ISS increment operations in order to accommodate other arriving vehicles.

[2] The ISS DRM is documented here and in CCT-REQ-1130. In case of conflict, 1130 takes precedence.

The spacecraft will be designed to be attached to the ISS for 210 days, although nominal crew rotations will occur at approximately 180-day intervals. The CTS remains quiescent and requires minimal maintenance during docked operations. The commercial mission control center will provide routine, periodic support for these docked operations, in association with MCC-H. The ISS will provide power and environmental resources to the spacecraft in order to maintain the vehicle in an Earth-return-ready state.

During this timeframe, the spacecraft also provides a contingency "safe haven" capability allowing the crew to retreat to the spacecraft, close the hatch, and remain in a safe environment for up to 24 hours. The ISS will provide for nominal power transfer and attitude control during this 24 hour period.

While attached to the ISS, the spacecraft will serve as an emergency return vehicle for contingencies requiring the return of the crew brought to the ISS. Emergencies could result from ISS system failures, an uninhabitable crew environment, or a medical event requiring the return of the crewmembers. The crew will be fully trained to execute these contingency return-to-Earth operations.

Due to the limited size and power available, the CTS spacecraft is expected to have basic first aid and life support capability to respond to immediate medical conditions in the free-flight mode.

The launch of the next rotation mission can occur prior to the departure of the current increment crew working on the ISS, resulting in a handover period where two commercial spacecraft would be docked to the ISS for approximately 7-10 days. If the Commercial Partner has received NASA approval to fly non-NASA crew to the ISS, the CTS will need to provide food, water, clothing, and other logistics for these crewmembers for the docked timeframe, since NASA does not generally pre-position these supplies on the ISS.

After handover is completed, the current increment crew will return in the CTS spacecraft. They will enter the spacecraft, close hatches, depress the vestibule, perform a hatch leak check to verify seal integrity, and depart the ISS. They will potentially circumnavigate the ISS to assess the external configuration prior to deorbiting.

The timeframe from undocking through landing is envisioned to be a short 4 to 8 hour free-flight duration. Landing will occur at a U.S. State Department approved landing site for nominal landing. This reduces risk by minimizing recovery force assets, increasing proximity to U.S. medical facilities, increasing security, and ensuring a prepared landing site free of hazards. Returning crew will be deconditioned and potentially have impaired musculoskeletal, cardiopulmonary, and neurovestibular capabilities as a result of long duration exposure to the micro-gravity and space environment, resulting in degraded crewmember performance in the post-landing timeframe. Because of the deconditioned state of the crew, special considerations need to be provided for crew recovery, medical care, and other post-landing care activities.

Upon arrival at the landing location, the NASA crew will be met with a recovery crew that will assist the astronauts in egress operations and removal of time critical cargo. NASA personnel will begin post-flight medical and science evaluations soon after egress is complete.

After recovery operations are complete, the CTS spacecraft will be safed and transported to a location for subsequent post-flight evaluation.

3.2 Additional NASA Design Reference Missions

Currently, no other NASA design reference missions have been defined. As NASA's mission needs evolve over time, this document will be periodically updated to reflect those needs.

4.0 Potential Commercial Design Reference Missions

The following potential commercial DRMs are presented to provide insight into how additional missions beyond those acquired by NASA may influence early design decisions for the CTS architecture.

4.1 Commercial Space Station Design Reference Mission

The CTS top-level objectives for this DRM are to provide crew access, and potentially cargo transfer, to a commercially sponsored space station (CSS)[3] in LEO. Note that NASA currently has no plans to fly NASA Astronauts to any space station other than the ISS.

The CTS spacecraft will typically be capable of transporting crewmembers to the CSS within a 48 (TBC) hour timeframe. Depending on the chosen launch site and CSS inclination, launch and ascent may require different ground and flight assets to meet Range Safety constraints than those used to support ISS missions. Similarly, additional ground tracking and communications infrastructure may be required for mission operations. To support ascent aborts, rescue forces must be properly postured and consistent with the CTS ascent ground track, in order to assure expedited recovery of the crew.

Once in orbit, rendezvous maneuvers are performed to bring the CTS closer to the CSS. CSS-compatible relative navigation and communications systems are used to complete the rendezvous with the CTS, subsequently docking to the CSS at an available docking port.

Once docked, the attached phase mission duration is expected to be on the order of one to two weeks. During attached operations, the spacecraft also provides a contingency “safe haven” capability allowing the crew to retreat to the spacecraft, close the hatch, and remain in a safe environment for up to 24 hours. The CTS will also serve as an emergency return vehicle for contingencies requiring expedited return of the crew.

Upon completion of mission objectives, the CTS spacecraft will separate from the CSS, deorbit, and land at appropriately chosen landing sites consistent with the CSS inclination.

4.2 Satellite Servicing Design Reference Missions

The top-level objective for this series of DRMs is to provide servicing of commercial satellites.

In general, each satellite servicing mission will have a unique inclination and altitude, along with unique servicing needs. Depending on the satellite’s orbit, launches from different launch sites may be necessary. Cargo carrying capability for these servicing missions must include all hardware and tools necessary to perform the servicing, and the return of any items required for post-flight analysis.

Potential servicing may include planned change-out of orbit-replaceable units (ORUs), unique unplanned hardware servicing tasks, or refueling. The satellite to be serviced is not expected to have a standard crew transfer docking mechanism, and potentially has no cooperative features to aid in rendezvous. The satellite may be disabled and not capable of maintaining a stable nominal attitude (the Space Shuttle has a rich history of repair to such satellites).

[3] This DRM does not propose an architecture. The limited descriptions here are only provided to set the context for the reference mission needs.

Mission duration for these servicing missions is expected to be on the order of one to two weeks. After rendezvous, the servicing timeframe itself may be several days. As such, the CTS spacecraft should support human habitability of crewmembers for timeframes consistent with the mission duration. Human habitability includes the ability to sustain the crew with sufficient food, water, clothing, hygiene supplies, sleep accommodations, trash volumes, medical equipment, etc., for the full mission duration, plus any extension days.

To optimize cost effectiveness, the CTS should generally have the performance and mission duration capability required to conduct the mission with a single launch. The CTS spacecraft should be configurable to provide all necessary human habitation capabilities, mission performance capabilities, rendezvous aids, docking mechanisms, and servicing mechanisms to execute the mission. The CTS spacecraft could be potentially designed in a dual-payload launch configuration where a separate servicing module is co-manifested on the same launch vehicle as the CTS spacecraft[4]. In the latter case, once on orbit, the CTS spacecraft will reconfigure and dock with the servicing module before beginning orbital rendezvous maneuvers.

Rendezvous operations are more complex depending on how cooperative the target satellite is, and whether or not a servicing module is being hauled by the CTS spacecraft. When in close proximity to the target, remote manipulator subsystems may be used to mate with the satellite while minimizing plume impingement from CTS spacecraft thrusters. If refueling is required, a small specialized docking mechanism interface might be used to complete the mating and to transfer the fuels. After mating, subsequent satellite servicing of hardware will be accomplished by a combination of remote manipulator operations and/or multiple EVAs.

For these servicing missions, the orbiting satellite is not a safe haven location where long duration and medical support accommodations are available.

Upon completion of the orbital servicing operations, the repaired satellite is deployed and the CTS spacecraft will depart the vicinity. Deorbit subsequently occurs within a few hours with landing at a location consistent with the servicing inclination.

[4] This DRM does not propose an architecture or set of possible architectures. The limited descriptions here are only provided to set the context for the reference mission needs.

Appendix A: Acronyms and Abbreviations

Acronyms	Phrase
CCP	Commercial Crew Program
CP	Commercial Partner
CSS	Commercial Space Station
CTS	Crew Transportation System
DRM	Design Reference Mission
ESMD	NASA Exploration Systems Mission Directorate
ESS	Exploration Spacecraft System
EVA	Extravehicular Activity
IP	International Partner
ISS	International Space Station
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEO	Low Earth Orbit
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
ORU	Orbit-Replaceable Unit
PCB	Program Control Board
TBC	To Be Confirmed
TRB	Technical Review Board

Appendix B: Definitions

Term	Definition
Abort	The forced early return of the crew to a nominal or contingency landing site when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return is required for crew survival. The crew is safely returned to a landing site in the space system nominally used for entry and landing/touchdown.
Ascent	The period of time from initial motion away from the launch pad until physical separation from the launch vehicle during nominal flight or during an abort.
Ascent Abort	An abort performed during ascent, where the crewed spacecraft is separated from the launch vehicle without the capability to achieve a safe stable orbit. The crew is safely returned to a landing site in a portion of the spacecraft nominally used for entry and landing/touchdown.
Cargo	An item (or items) required to maintain the operability of the ISS and/or the health of its crew, and that must be launched as soon as possible.
Contingency	Provisioning for an event or circumstance that is possible but cannot be predicted with certainty.
Crew	Any human onboard the spacecraft after the hatch is closed for flight or onboard the spacecraft during flight.
Crewmember	Persons onboard the vehicle that are certified to assist in its operation during any phase of flight, and/or certified to perform particular tasks during the mission (such as a robotic operation or an extravehicular activity).
Crew Transportation System (CTS)	The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the integrated space vehicle, space-based communication and navigation systems, launch systems, and mission/launch control. This definition is the same as the definition of Space System found in NPR 8705.2B.
CTS Element	One component part of the overall Crew Transportation System. For example, the spacecraft is an element of the CTS.
De-conditioned	"De-conditioned" defines a space flight crewmember or passenger whose physiological capabilities, including musculoskeletal, cardiopulmonary, and neurovestibular, have deteriorated as a result of long duration exposure to the micro-gravity and space environment and may result in degraded crewmember performance for nominal and off-nominal mission tasks. The space environment may include adverse effects of confinement, isolation, noise, deprivation of sensory and motor stimulation, and high workloads.
Docking	Mating of two independently operating spacecraft or other systems in space using independent control of the two vehicles' flight paths and attitudes during contact and capture. Docking begins at the time of initial contact of the vehicles' docking mechanisms and concludes when full rigidization of the interface is achieved.
Emergency	An unexpected event or events during a mission that requires immediate action to keep the crew alive or serious injury from occurring.

Entry	The period of time that begins with the final commitment to enter the atmosphere from orbit or from an ascent abort, and ending when the velocity of the spacecraft is zero relative to the landing surface.
Flight Crew	Any human on board the space system during the mission that has been trained to monitor, operate, and control the space system; same as crew.
Integrated Space Vehicle	The integrated space vehicle consists of all the system elements that are occupied by the crew during the space mission and provide life support functions for the crew (i.e., the crewed elements). The integrated space vehicle also includes all elements physically attached to the crewed element during the mission. The integrated space vehicle is part of the larger space system used to conduct the mission. This definition is the same as the definition for crewed space system found in NPR 8705.2B. The following examples are provided for clarification: Example 1: A launch vehicle for a crewed spacecraft is part of the integrated space vehicle for ascent. Example 2: When the crew ingresses a vehicle for launch, the vehicle is physically connected to the launch pad. The specific launch pad systems that interface with the launch vehicle and spacecraft are considered part of the integrated space vehicle but not the entire launch pad.
ISS Integrated Operations	All operations starting at 90 minutes prior to the ISS Approach Initiation and last until the vehicle leaves the ISS Approach Ellipsoid on a non-return trajectory.
Landing	The final phase or region of flight consisting of transition from descent, to an approach, touchdown, and coming to rest.
Launch Vehicle	The vehicle that contains the propulsion system necessary to deliver the energy required to insert the spacecraft into orbit or provide the propulsion capability necessary to execute an ascent abort.
Launch Probability	The probability that the System will successfully complete a scheduled launch event. The launch opportunity will be considered scheduled at 24 hours prior to the opening of the launch window.
Maintenance	The function of keeping items or equipment in, or restoring them to, a specified operational condition. It includes servicing, test, inspection, adjustment/ alignment, removal, replacement, access, assembly/disassembly, lubrication, operation, decontamination, installation, fault location, calibration, condition determination, repair, modification, overhaul, rebuilding, and reclamation.
Mission	This term is used in this document to encompass the entire process of planning for and executing an orbital space flight. This includes pre-flight vehicle processing, hardware and software tests, facility preparations, flight operations, and post-flight activities.
NASA Crew	The NASA crewmembers or the NASA-sponsored crewmembers being transferred to and from the ISS. These include international partner

	crewmembers.
Post-Landing	The flight phase beginning with the actual landing event when the vehicle has no horizontal or vertical motion and ending with the last crew member egress from the spacecraft.
Proximity Operations	This flight phase starts just prior to the Approach Initiation and ends with the intentional contact of the vehicles' docking mechanisms or when the vehicle leaves the ISS Approach Ellipsoid.
Recovery	This phase of the mission occurs after the spacecraft comes to rest from landing.
Rendezvous	The flight phase of executing a series of on-orbit maneuvers to move the spacecraft into the proximity of its target. This phase starts with orbit insertion and ends just prior to the approach initiation.
Rescue	The process of locating the crew, proceeding to their position, providing assistance, and transporting them to a location free from danger.
Safe Haven	A functional association of capabilities and environments that is initiated and activated in the event of a potentially life-threatening anomaly and allows human survival until rescue, the event ends, or repair can be affected.
Spacecraft	All system elements that are occupied by the crew/passengers during the space mission and provide life support functions for the crew/passengers. The crewed element includes all the subsystems that provide life support functions for the crew/passengers. Defined as "crewed space element" in NPR 8705.2B.
Space System	The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the integrated space vehicle, space-based communication and navigation systems, launch systems, and mission/launch control.
System	The aggregate of the ground segment, flight segment, and workforce required for crew rescue and crew transport.