A Cargo UAS Design and CONOPS

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Abstract

An unmanned vertical lift aircraft system is needed by the US military to transport cargo (i.e., Cargo UAS). A Cargo UAS design and concept of operations (CONOPs) to address this need are examined in this paper. Validated technologies and subsystems are integrated into the design of: a) a Mono Tiltrotor (MTR) based Cargo UAS, b) a lightly modified commercial cargo ship, and c) high throughput methods for selectively offloading cargo from the ship at sea and delivering the cargo directly to dispersed points of need at long range and high speed.

Introduction

The US Marine Corps has approved a documented need for a future Cargo UAS [1]. In accordance with this document, breakthrough range and speed compared to legacy helicopter concepts are necessary. One aircraft design that is projected to achieve these breakthroughs is the Mono Tiltrotor Scaled Demonstrator (MTR-SD) [2, 3, 4, 5] Figure 1. This technology demonstrator aircraft's design is to distribute 3000 pounds of cargo carried in two Joint Modular Intermodal Containers (JMICs) to four dispersed locations, while on a 750 nautical mission and cruising at 200 knots and 20,000 feet altitude. The aircraft design gross weight is 9400 pounds, the rotor diameter is 25 feet, and the aircraft is designed to fold and fit within a 20 foot ISO container for stowage and transport. The key innovative features of this aircraft design are its pitch axis suspended cargo pod, aerodynamically deployed wing panels, and tilting center-line coaxial proprotor.

Recent studies have examined the operational suitability of this aircraft design for the future Cargo UAS mission. Government funded research included an operational study contract performed by Bell Helicopter Textron [6]. A summary of the aircraft design impacts resulting from this and other concept of operation (CONOP) related studies will be reported below. An associated notional ship design and point of need delivery CONOPs will also be reported.

Figure 1: Mono Tiltrotor Scaled Demonstrator (MTR-SD) Rendering.

Subject

Government funded studies beginning in 2004 have concluded that the Mono Tiltrotor (MTR) air vehicle architecture offers a long range vertical lift capability at half the size, one-third the weight, and one-third the fuel burn compared to legacy rotorcraft designs [7, 8]. The 3000 pound cargo weight MTR-SD preliminary/conceptual design was completed in 2006 [9, 10, 11, 12, 13], and then independently assessed and functionally demonstrated at a small scale in 2008 [2, 3, 14, 15]. In 2009, the Office of Naval Research hired Bell Helicopter Textron to assess this design as a Cargo UAS [16], and subsequently contracted with Baldwin Technology Company, LLC to examine the flight dynamics and autonomous control of the MTR as a Cargo UAS operating in a shipboard environment [17]. The dynamics and control work is ongoing, using methods reported at the AHS Forum in 2009 [18] and 2010 [19].

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Purpose

Any proposed solution to the military's stated Cargo UAS need will include an aircraft and a CONOPs. Both influence one another, and it is the purpose of this paper to introduce one possible CONOPs that leverages the advantages of the MTR design. This paper and its associated video are intended to start a discussion, and are not expected to be conclusive.

This paper also presents design features of the MTR for a Cargo UAS mission. While many recent design features added to the MTR have resulted from the unique challenges of shipboard operations, some of these features may ultimately become part of the fundamental MTR aircraft design.

Scope

The scope of this paper is the design of material solutions and the development of a CONOPs for selective offload of cargo from a ship at sea, the vertical delivery of this cargo directly to dispersed points of need, and the retrograde of empty containers back to the ship. Material solutions will be presented that are grounded in: a) prior MTR design reports; b) currently available operational systems such as the Aircraft Ship Integrated Secure and Traverse (ASIST) system [20]; and c) methods for converting commercial container ship designs into a military cargo ship.

Research Methodology

A creative solution to the design challenges of Cargo UAS operations from a shipboard environment was conceptualized, modeled, animated, and rendered. The process involved the following synergistic activities: a) identifying the challenges revealed by Cargo UAS CONOPs studies; b) researching fielded and proposed systems and methods that address these challenges; and c) synthesizing an enhanced MTR design and ship system from these systems and methods.

The list of challenges included the following key areas: design details of the cargo pod for efficient loading, selective offloading, and retrograde; design of a landing gear system for shipboard operations; and capture and traversal of the cargo pod and the aircraft when operating in a high sea state. A related challenge is selective offload of Joint Modular Intermodal Containers (JMICs) from a container ship.

The MTR Scaled Demonstrator design was selected as the basis for designing the Cargo UAS. Modifications to the cargo pod and landing gear system were designed and kinematically analyzed in a computer simulation. This same simulation environment was used to model a commercial container ship, and illustrate light modifications to this ship for selective offload of JMICs.

The Aircraft Ship Integrated Secure and Traverse (ASIST) system was researched and used as a basis for simulating Cargo UAS operations on the deck of the modified container ship.

This methodology will be better understood by examining the results and discussion, and viewing the video referenced below.

Results and Discussion

Solutions to the design challenges are reported below in the following three categories: air vehicle design, ship design, and CONOPs. These solutions may be better appreciated by viewing video renderings, a copy of which is available at http://www.baldwintechnology.com/deepdive.html .

Air vehicle design

The air vehicle design challenges were in two areas: cargo pod design and aircraft landing gear design.

Cargo pod design

The cargo pod is designed to capture, retain, envelop, streamline, and stabilize in flight two JMICs, and to be able to selectively release each individual JMIC, or tilt a JMIC so that its contents may be discharged. The cargo pod (Figures 2 thru 4) comprises: (a) a spreader bar suspended from the MTR aircraft; (b) actuated pins to retain the JMICs to the spreader bar; (c) collapsible nose cone and tail cone; (d) upper and lower structural frame with cargo doors and landing skids; and (e) flexible side panels.

The cargo pod's transport procedure comprises: (a) positioning the cargo pod over the JMICs with the nose and tail cones collapsed, the flexible side panels folded, and the cargo door open; (b) engaging actuated pins with the JMIC fittings to secure the JMIC to the spreader bar; and (c) enveloping within an aerodynamic enclosure the JMICs secured to the spreader bar, by expanding the nose and tail cones, unfolding the flexible side panels, and closing the cargo door. The delivery procedure comprises: (d) exposing the JMIC by opening the cargo door, collapsing the nose and tail cones, and folding the flexible side panels; and (e) disengaging the actuated pin from the JMIC fitting on either one side to tip the JMIC and discharge its contents, or on both sides to drop the JMIC.

Positioning of the cargo pod over the JMIC is performed with the MTR on the flight deck for delivery operations, and with the MTR in hover for retrograde operations. These procedures are presented later in the CONOPs discussion.

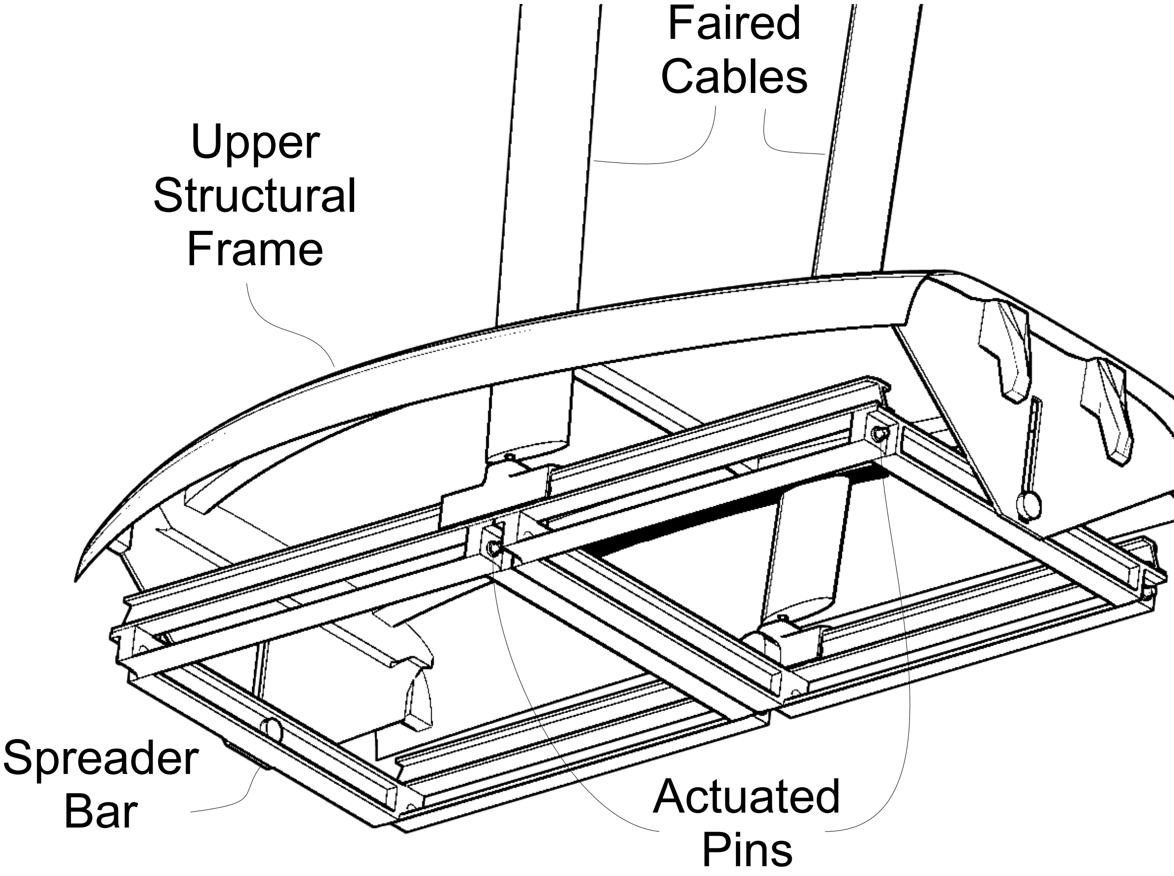

Figure 2: Cargo Pod Illustration-1.

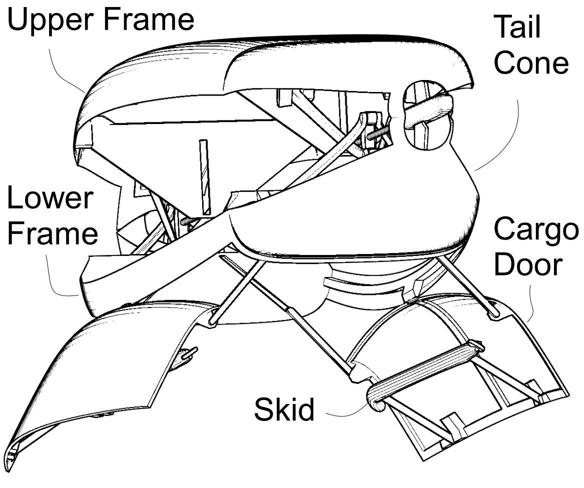

Figure 3: Cargo Pod Illustration-2.

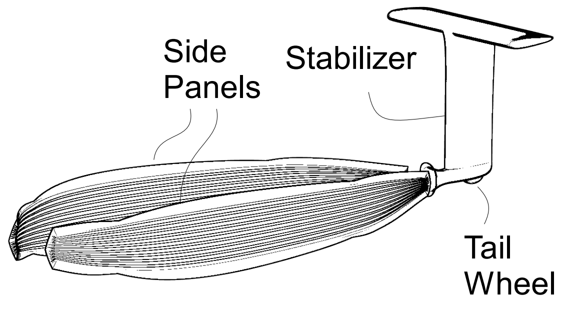

Figure 4: Cargo Pod Illustration-3.

Landing gear design

The landing gear is designed to absorb the energy of impact during a vertical landing, stabilize the aircraft on the flight deck in a high sea state, and connect through a universal tow bar to an aircraft tug. Prior design reports and papers depict the basic landing gear design, and what is shown here are enhancements that enable the wingtips to act as outriggers and allow the tailwheel to be a tow bar attachment point. Discussion of methods for vertical kinetic energy absorption and methods for retaining the aircraft on the flight deck complete this section of the paper.

Wing panel droop in hover is mechanically limited and the wing panels lock in drooped position so that their tips perform as outriggers to prevent rollover. (Figures 5 and 6) The apparatus for attaching the hinged wing panel to the Cargo UAS comprises: (a) an inboard spar connected to the tailboom; (b) an outboard spar; (c) a hinge; (d) a slider; and (e) a tie rod. The inboard and outboard spars are rigidly joined, while the hinge connects the wing panel to the outboard spar. The slider traverses the outboard spar. The tie rod is connected to the slider at one end and the wing panel at the opposite end. The hinge and the slider are arranged so as to enable the wing panel to rotate away from the outboard spar to an orientation limited by the tie-rod. Further mechanisms lock the slider's position along the spar when the wing panel is in a drooped position, and lock the wing panel to the outboard spar when the wing panel is fully deployed.

With the wing panels locked in the drooped configuration, the wing tips behave as outriggers to prevent aircraft rollover.

The tailwheel pivots about a hinge to permit towing and turning of the aircraft by means of a a universal tow bar attached to an aircraft tug.

The method for absorbing vertical energy at the tailwheel is yet to be decided. A conventional approach would be to stroke the tailwheel with a viscoelastic device. An alternative approach is to stroke the tailboom at the conversion actuator, which will also draw vertical energy absorption away from the main gear. A shock damping mechanism is also intended at the wing hinge lock, so that vertical energy transmitted through the wingtip is absorbed at the tie rod interface to the outboard spar.

Retention of the aircraft on landing surface can be effected by a harpoon structurally tied to the gearbox and located beneath the fuel tank in hover. The use of a harpoon with a securing and traverse system will be discussed in the CONOPs section below.

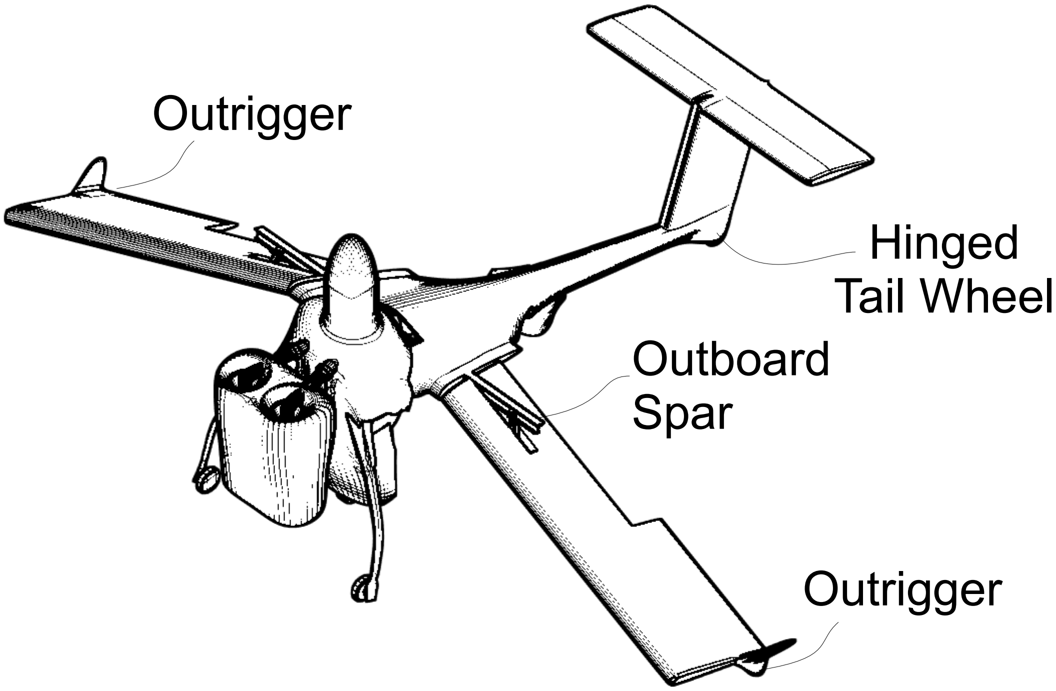

Figure 5: Landing gear design.

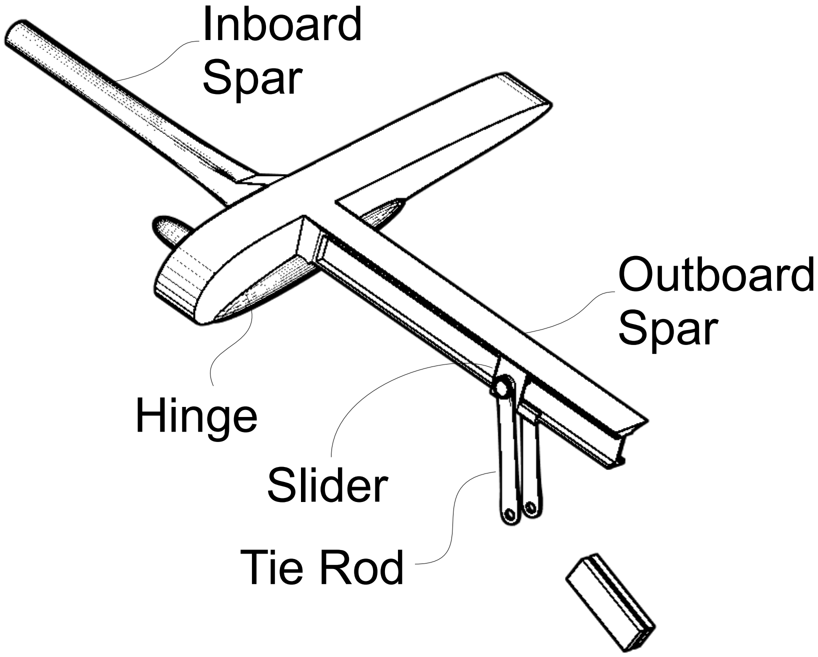

Figure 6: Wing hinge design.

Ship design

The US Navy Military Sealift Command operates cargo ships designated as T-AK class, many of which are derived from commercial container ships. The approach taken in this notional CONOPs is to lightly modify a PANAMAX class, 5000 twenty-foot equivalent unit (TEU) commercial container ship design for selective offload of JMICs, and for Cargo UAS flight operations.

A typical PANAMAX class ship holds stacks of International Standards Organization (ISO) containers six-high in container cells, and another six-high above the deck on top of the cell hatch covers. Lashing bridges secure the containers above the deck. The design modification is to eliminate the hatch covers and mount 3-ton gantry cranes between the lashing bridges. (Figure 7) Flatracks with JMICs are stowed in the cells below the gantry cranes, providing immediate selective access to all JMICs in the top rows of all cells – immediate access to any one of over 800 JMICs which represents 8% of total inventory for full container cells, and a greater percentage as the cells become depleted. Full inventory visibility is provided by active radio frequency identification (RFID) which is a standard JMIC feature, and inventory security is provided by lockable doors which are also a standard JMIC feature. A pair of monorail conveyors move the selected JMICs aft towards the crew accommodation, where the JMICs are lifted up to the flight deck level. Sections of flight deck are secured atop the lashing bridge. This modified ship design with gantry cranes, two conveyors, and two flight deck lifts facilitates selective JMIC access for Cargo UAS operations.

As a further improvement the flight deck can incorporate an ASIST system to secure and traverse the Cargo UAS, and a derivative of the ASIST system can be used to secure and traverse the cargo pod with JMICs. (Figure 8) Instead of simply traversing between the flight deck and the hangar, this ship design assumes that ASIST-like traversal can be extended into a loop about the flight deck.

Three additional features complete the T-AK concept. First, exterior walls surround the gantry crane area, providing a water-tight space. Second, 40ft ISO containers on the port and starboard sides of the lashing bridges contain stowed Cargo UASs that can be raised to the flight deck for assembly and flight operations. Third, hangar space at flight deck level, fore and aft of the accommodation, provides some protection for the Cargo UAS when not in operation.

Finally, the large open space below the flight deck at the lift can be configured for cross-docking and mixing the contents of the JMICs by logistics personnel in a controlled and protected area before they are lifted to the flight deck.

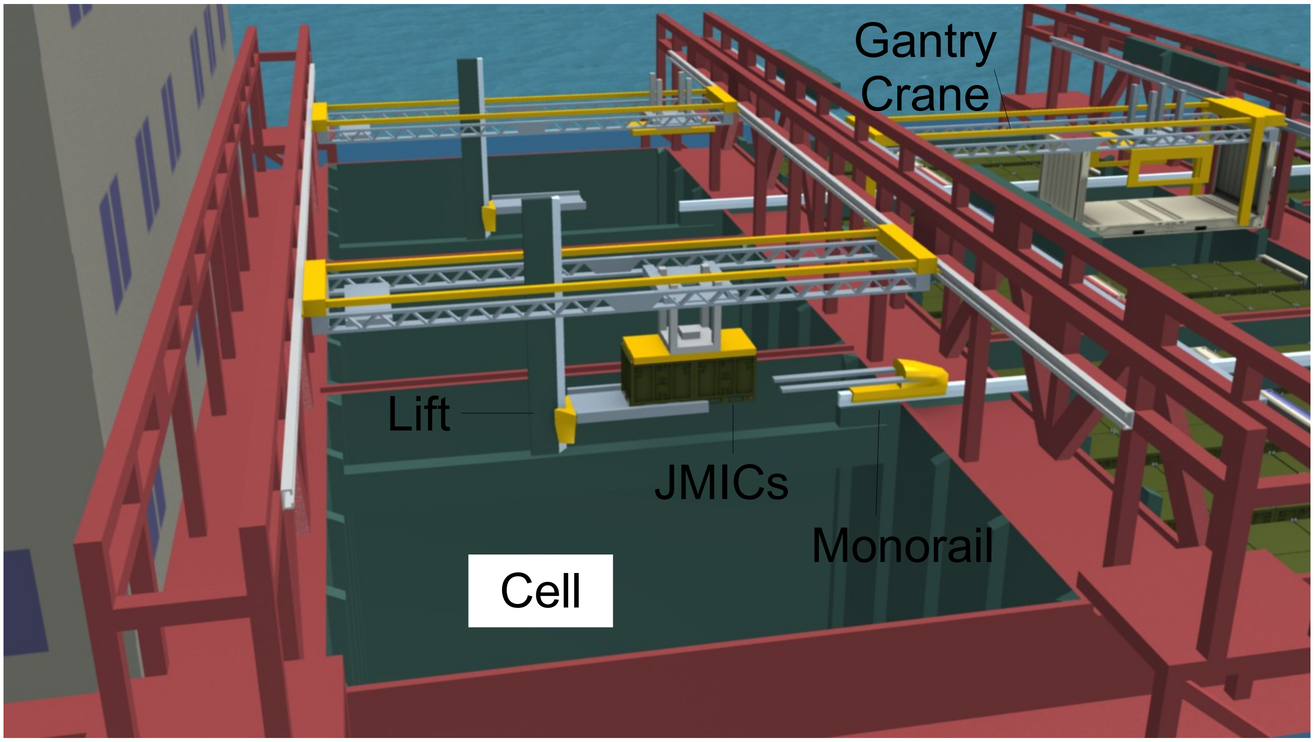

Figure 7: Modified container ship.

CONOPs

This CONOPs description will trace the supply fulfillment process. A demand for supplies drives the RFID facilitated selection of two JMICs containing the needed supplies. Gantry cranes lower onto the selected JMICs, slide their interface locks to release the JMICs, lift the JMICs out of their cells, and move the JMICs to a monorail conveyor. At all times, the gantry cranes and the JMICs have zero degrees of freedom (except if negative vertical acceleration exceeds gravitational acceleration) and can be handled in high sea states. The monorail conveyor takes the JMICs from the gantry cranes aftward, where the JMICs are then lifted to the flight deck.

At the flight deck level, a cargo pod has been positioned by a secure and traverse system to receive the lifted JMIC. The JMIC is secured to the cargo pod, and both together are traversed forward towards a designated takeoff spot. An ASIST system secures and traverses the Cargo UAS ahead of the cargo pod, and before reaching the takeoff spot ground crew connect the cargo pod's cables to the Cargo UAS's suspension struts. The Cargo UAS is released by the ASIST system at vertical takeoff, and then the cargo pod with JMIC is released to complete the vertical takeoff maneuver. In forward flight, the Cargo UAS's wing panels aerodynamically deploy and lock, and then the coaxial proprotor drive rolls forward into a more efficient, high speed cruise configuration. The Cargo UAS climbs, cruises, and descends to the point of need. While approaching the point of need, the coaxial proprotor drive rolls back to a hover configuration. Cargo is dropped with the JMIC container at one point of need, and discharged from the JMIC container at another point of need. Discharge can occur at four different sites using two sides of each JMIC with a middle partition.

Vertical Replenishment (VERTREP) is an alternative mission, with an amphibious ship, for example, being the point of need. The cruising Cargo UAS descends and the coaxial proprotor drive rolls back to a hover configuration. Both JMICs are dropped onto the deck of the amphibious ship. Retrograde of empty, collapsed, and stacked JMICs is accomplished by adjusting the cargo pod trollies forward of its center of gravity so that the cargo pod tailwheel rolls along the deck. The Cargo UAS slews the cargo pod about its tailwheel towards the empty JMICs, and the skids, which are initially spread twice as wide as the JMICs, act as guide rails while closing in on the JMICs. Once captured, the cargo pod trollies move forward to the new center of gravity. It should be noted that the trollies also serve to trim the cargo pod in forward flight by balancing the cargo pod's pitching moment due to center of gravity offset with the cargo pod's pitching moment due to center of aerodynamic pressure offset.

Aircraft recovery at the aft deck of the T-AK ship is a two step process, first recovering the cargo pod before then releasing the suspension cables and recovering the Cargo UAS. Borrowing proven technology from the ASIST system, an optical positioning system tracks the cargo pod while the rapid securing device moves fore-aft along its track under the pod. Lateral alignment is

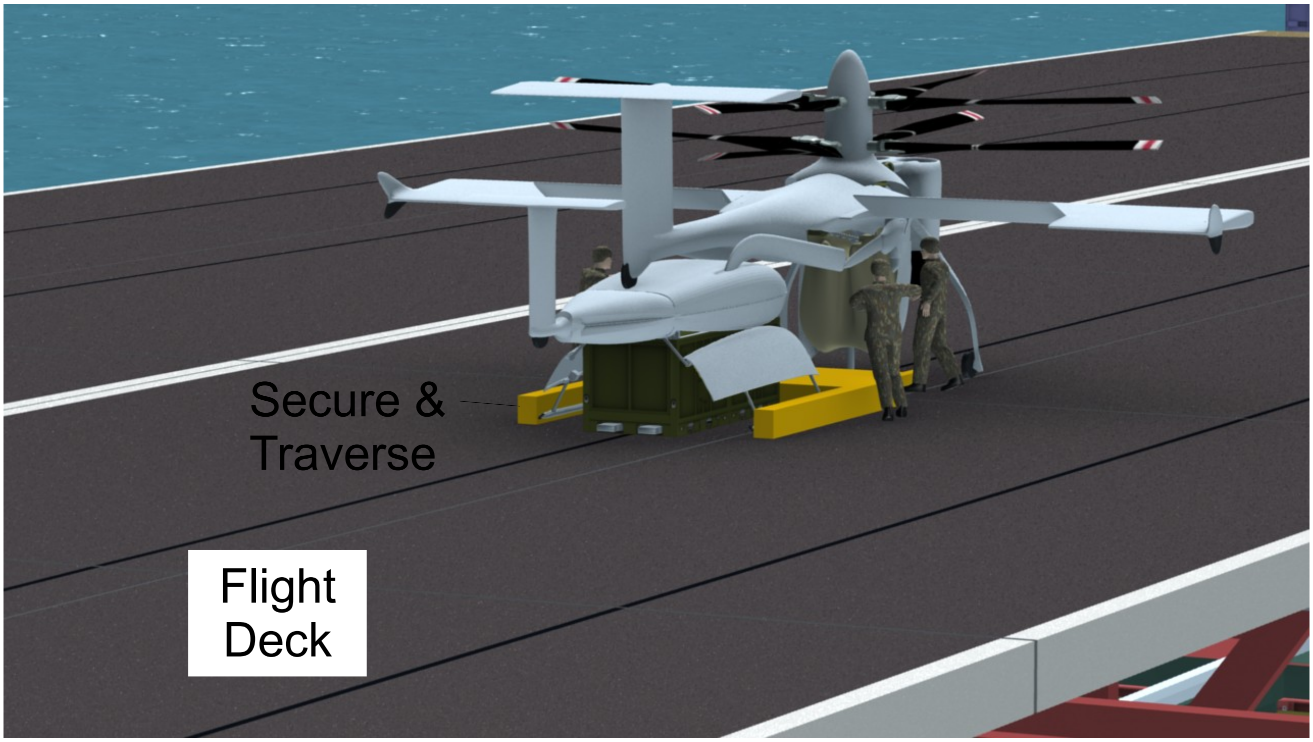

Figure 8: Secure and traverse.

achieved by narrowly spread cargo pod skids which widen until touching and being retained by the securing device. Pallet forks deploy from the securing device to lift any JMICs that may accompany the cargo pod. After the cargo pod is secure, the Cargo UAS descends and is secured by a conventional ASIST system. Both are then traversed forward to where newly selected JMICs are lifted to the flight deck for the next mission, and the complete point of need delivery cycle repeats. Take-off operations are physically separated from recovery operations by the crew accommodation and occur simultaneously on both port and starboard sides of the ship for high throughput.

While the primary mission for this T-AK concept is to provide vertical distribution from the sea, a secondary mission is to provide high throughput offload of cargo and Cargo UASs at a deep water port with dockside cranes. As if they were cargo hatches, the segments of the flight deck can be lifted by the dockside cranes to reveal the flatracks within the cells. The flatracks and containers can be lifted and placed on trailers or railcars for ground transport to a forward distribution node, where the Cargo UAS can then perform high speed, long range, point of need distribution.

Future work

Cargo UAS studies of the MTR indicate that further work is needed to understand any requirement for treatments to protect flight decks from hot engine exhaust, which is projected to be similar to V-22 Osprey heat soak on a flight deck. Also, infrared (IR) signature treatments at the point of need is a subject for future study that can be addressed in the Cargo UAS design, affecting aerodynamic drag and cruise range performance.

Conclusions

A Cargo UAS design and an associated cargo ship design and concept of operations (CONOPs) were examined. The Cargo UAS design was based on the Mono Tiltrotor Scaled Demonstrator (MTR-SD), and the ship design was based on a commercial PANAMAX class container ship. While both the aircraft and ship designs have merit independent of the other, the synergy of operating together was explored in a notional CONOPs. This paper and its associated video, which is available at http://www.baldwintechnology.com/deepdive.html , are intended to inform discussions and the development of future Cargo UAS solutions and CONOPs.

Acknowledgments

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