

THE OFFICE OF NAVAL RESEARCH

Autonomous Aerial Cargo Utility System (AACUS)

Concept of Operations (CONOPs)



Dr. Mary Cummings, Program Officer
(703) 696-2079
mary.cummings@navy.mil

Mr. Angelo Collins, CENTRA Technology Inc.
(703) 894-6942
collinsa@centratechnology.com

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**Autonomous Aerial Cargo/Utility System (AACUS)
Innovative Naval Prototype (INP)
Concept of Operations (CONOPs)**

EXECUTIVE SUMMARY

The primary focus of Autonomous Aerial Cargo/Utility System (AACUS) is the development of advanced autonomous capabilities to enable unmanned and optionally manned Vertical Take Off and Landing (VTOL) air systems to be fully capable of affordable and reliable rapid response cargo delivery to distributed small units in demanding conditions. AACUS encompasses the development and implementation of VTOL-based obstacle detection and avoidance, as well as autonomous unprepared landing site selection and dynamic execution to the point of landing with goal-based supervisory control by any field personnel with no special training. These capabilities, expected to form part of an open architecture framework in order to be used across different VTOL platforms, should have sufficient reliability to be entrusted with precision cargo delivery and evacuating human casualties from remote sites.

While the AACUS program is focused on the development of a capability that can be used across multiple platforms due to its mission-centered open architecture framework, the general air vehicle type is expected to be one that can carry ~1600 lbs of payload (with some internal capacity for casualty evacuations) with a range of ~200 km. Desired attributes of AACUS include the capability to rapidly respond to requests for support in all weather conditions, be able to be launched from sea and land, to fly in high and hot environments, and autonomously detect and negotiate precision landing sites in potentially hostile settings, which could require significant obstacle avoidance and aggressive maneuvering in the descent-to-land phase.

Core assumptions for AACUS include the existence of a beyond line of sight command and control capability (i.e., an air operations center has the ability to task and redirect any UAV operating in its area), the ability to negotiate with other manned and unmanned aircraft in shared airspace, the presence of advanced weather radars, and other typical technologies found on present-day unmanned systems. While enablers for the AACUS vision, these core assumptions will not be the focus of any major research and development efforts under the current AACUS program.

Navy & Marine Corps Operational Relevance

1) Expected operational outcomes/end state/results

The Autonomous Aerial Cargo/Utility System (AACUS) project is an Innovative Naval Prototype (INP) sponsored by the Office of Naval Research (ONR). The goal of the AACUS INP is to develop and demonstrate intelligent autonomous capabilities for a future aerial cargo and utility system that provides rapid, affordable, reliable, shipboard-compatible, supply and casualty evacuation. AACUS technology is intended to support these missions when other cargo and insertion/extractions options are not available, or when the risk of using manned aircraft is too great.

The core of the AACUS effort is the development of technology that affords autonomous obstacle and threat avoidance and unprepared landing site selection, with autonomous precision landing capabilities including contingency management until the point of landing. This system should include a goal-based supervisory control component such that any field personnel can request and negotiate a desired landing site. Moreover, this system should communicate with ground personnel for seamless and safe loading and unloading. This system should be VTOL platform agnostic with an associated open architecture framework that allows it to be used across different air vehicle platforms.

2) Operational capability gaps and payoffs

a) Capability Gaps/ Shortfalls

- i) "Executing resupply in the non-linear current conflict is significantly challenging due primarily to the geography of the AO [Area of Operations]. The lack of paved roads coupled with difficult, mountainous terrain has diminished effectiveness of traditional means of overland logistics movement using ground transportation. The Joint Force needs an alternate means to provide sustained, as well as time-sensitive, logistics support over widely dispersed locations." *2011 Joint Cargo Unmanned Aircraft Systems Concept of Operations*
- ii) "Current external slingloads are not sufficiently stable for anticipated future routine resupply. Incorporation of the Cargo UAS should eliminate exposure to the MV-22 for resupply missions while reducing the overall resupply mission of the CLH- 53." *Universal Needs Statement (UNS) For the Cargo UAS*
- iii) "...combat in urban environments has shown that moving a casualty can be difficult and time consuming. Moving an individual only a few hundred yards can take an hour or more. The extended lines of communication between forces and their FOBs (inclusive of MEDEVAC by aircraft) are at risk of enemy ambush or improvised explosive device (IED) attack." *Unmanned Aerial System Casualty Evacuation Concept of Operations and Safe Ride Standards*

b) New Capability

The AACUS program aims to address the capability gaps discussed previously. There are three different aspects that make it unique as compared to other VTOL (and conventional) cargo UAS programs. They are:

- i) Autonomous detection and negotiation of precision landing sites in potentially hostile settings, which could require significant obstacle and threat avoidance, and aggressive maneuvering in the descent-to-land phase.
 - (1) While this a critical focus for AACUS, such a capability would substantially improve all unmanned VTOL programs (i.e., those currently focused on ISR missions). It could also provide additional capability for manned aircraft as a back up mode, and lastly, would have long-term civilian and commercial applications, particularly for first response agencies.
 - (2) This capability is explicitly called out in the *Universal Needs Statement (UNS) For the Cargo UAS*, i.e., “Flight controls and navigation systems must support continuous autonomous operations with an ability to redirect resupply missions enroute. Incorporation of autonomous UAS/UAV collision avoidance technology must be considered.”
 - ii) While the primary mission focus of AACUS is on resupply/retrograde, a long-term focus is on CASEVAC, and possibly MEDEVAC missions.
 - (1) This capability also has significant civilian, as well as military, implications.
 - (2) Given that reliability, trust, and cultural acceptance are significant drivers of the success of human payloads, it is recognized that these are longer term goals.
 - iii) A focus on developing a user interface that requires little-to-no training for field personnel.
- c) Warfighter payoffs**
- i) Introduction of AACUS technology for Cargo and CASEVAC UASs will provide increased operational support for deployed units and will provide the payoffs needed by the warfighter previously identified in the JUONS MARCENT, Cargo UAS Services, 11 Jan 2010:
 - (1) “...the CORPS will need an alternate means to provide time-sensitive logistics support to greatly dispersed locations. Cargo UASs can provide a solution to move tailored ammunition, supplies, fuel/water, or weapons packages in adverse weather from the sea or ashore over harsh terrain as required (24/7).” *Universal Needs Statement (UNS) For the Cargo UAS*”
 - (2) “The need is for a “Flying Truck” that can be risked in adverse weather vice manned aircraft.” *Universal Needs Statement (UNS) For the Cargo UAS*
 - (3) “Incorporation of the Cargo UAS will better enable the Marine Air Ground Task Force (MAGTF) Common Operating Picture by improving visibility over resupply operations, identifying key logistic sites, and maintaining unit mission readiness.” *Universal Needs Statement (UNS) For the Cargo UAS*
 - ii) As previously mentioned, AACUS technologies can also transition into manned aircraft, and can complement mission planning systems for manned systems, thereby reducing the cost of development for these systems and reducing the operational risks to manned aircraft.
- d) Requirements**
- i) JUONS MARCENT, Cargo UAS Services, 11 Jan 2010. Approved by J8 and assigned to USMC by Joint Rapid Acquisition Cell, (JRAC) for immediate USMC resolution.

- ii) In general, the basic requirements are listed below, with the understanding that the AACUS program is attempting to advance the state-of-the-art in a high-risk setting, and thus these are guidelines instead of strict specifications.

Characteristic	Objective	Threshold
Range	250 km	200 km
Speed w/full Cargo Load	100 kts	70 kts
Payload at 12K ft	1600 lbs	750 lbs
Delivery Point Accuracy	As close to requested site as possible (<10 m error from computer-designated landing site center point)	
Operate at Night and in All Weather Conditions	Yes	

AACUS Operational and Mission Descriptions

Ultimately, the operating environments for AACUS technology are the same as the operating environments for all Navy and Marine Corps units. Of particular interest to the USMC are operations in high/hot environments with steep terrain. One of the goals of AACUS is to dramatically expand on the operating environments of existing UASs, while also making inroads into operating environments that present significant risks to manned aircraft (i.e., weather, threat, terrain, etc.)

The subset of missions and tasks addressed by the AACUS INP include:

- Near-term: Logistics (including replenishment, resupply, transport, and equipment retrograde)
 - Including sling-load capabilities
- Long-term: CASEVAC and potentially MEDEVAC.

Figures 1-3 depict routine and urgent Cargo UAS logistics missions, as well as a CASEVAC mission. These three figures represent typical missions that AACUS technologies would support, as well as the major functions of such missions with corresponding increasing autonomous capabilities and timelines for achieving these desired goals. The high-level functions (i.e., Mission Request, Mission Planning, Autonomous Flight, etc.) described at each step in the Mission Diagrams are accompanied by increasing potential levels of autonomy with corresponding color-coded boxes. The color of each box reflects the level of maturity estimated for the technologies needed to accomplish each capability.

For example, for the Autonomous Flight function (#3) in Figure 1, the four supporting capabilities for that task are: Planned Route, Obstacle Avoidance, Air Traffic Avoidance, and Weather Avoidance. Both “Planned Route” and “Obstacle Avoidance” are coded as Green because technologies exist that have demonstrated such capabilities. Global Hawk, Predator, and other UASs already perform autonomous flight along planned routes using COTS GPS/INS systems. Also, there have been several DoD and commercial UASs that perform autonomous detection and avoidance of stationary obstacles. Though these systems are not on operational

UASs at this time, they have been successfully demonstrated and could rapidly be integrated into AACUS technologies.

The technologies for autonomous “Air Traffic Avoidance” are less mature and are coded as Yellow. There have been numerous UAS flights that have demonstrated autonomous air traffic detection and avoidance. While established in the commercial aviation community for collision avoidance (i.e., TCAS II), these systems need maturation for UAS applications, but it is expected that one or more of these technologies will be sufficiently reliable in the near term that they could become AACUS technologies. The final supporting capability under Autonomous Flight is the technology for the “Weather Avoidance” task, which is coded as Red/Yellow due to a lack of a mature and established technology. There are some technologies that might successfully accomplish the weather detection and avoidance task, but none have been demonstrated on a UAS.

It should be noted that replanning or dynamic retasking is an element of all of the mission areas. This reflects the realities of the battlefield, where either the command organization in charge of the UASs determines that an in-flight change in tasking is required, or the UAS automatically determines that it cannot execute the planned mission and must either replan or divert to another destination (perhaps because of hostile action, damage, or internal system malfunction). If the command dictates a change of plan, then it is expected that the new mission plan be generated at the GCS and uploaded to the UAS. If the UAS autonomously makes a significant change to its mission plan then it must notify both an operational supervisor and the operator who requested the support (which might result in an override or modification to the Cargo UAS (CUAS) new plan).

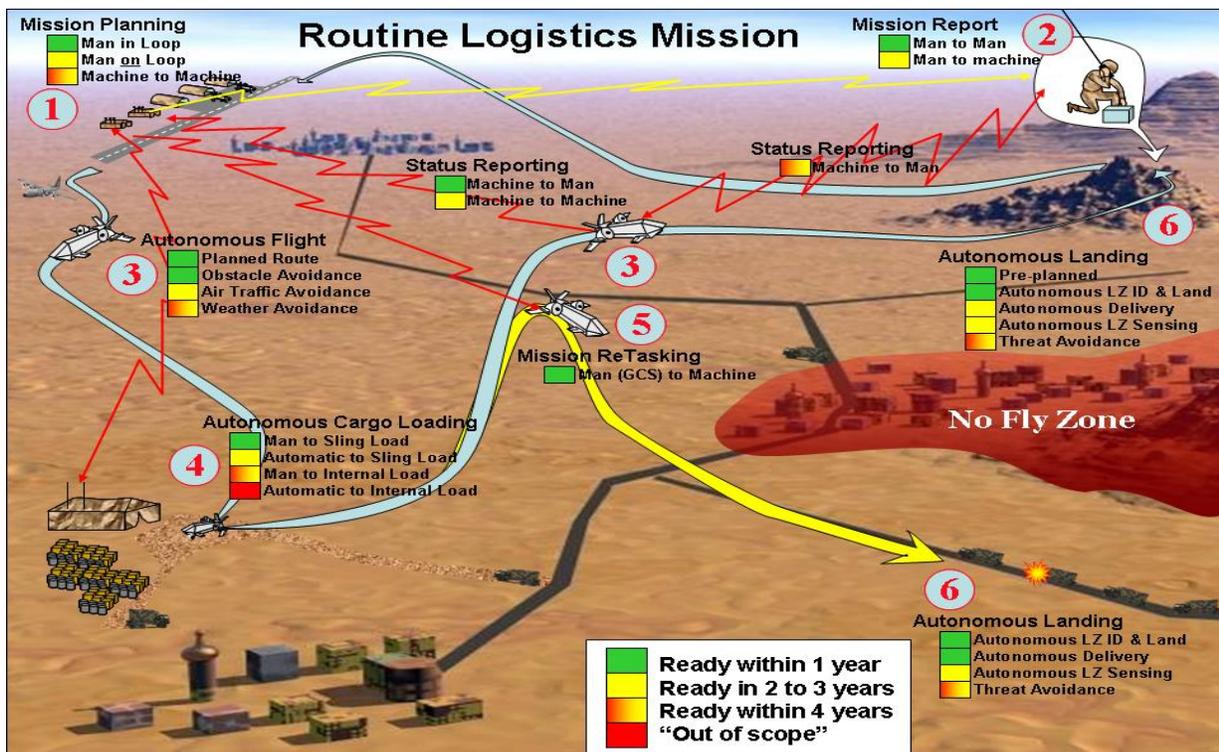


Figure 1 Routine AACUS Logistics Mission with Replanning

The primary focus area for AACUS in Figures 1-3 is the Autonomous Landing function, whose sub-functions overlap with many of the other functions. Table 1 lists core capabilities AACUS technologies should support that are above and beyond those supported in current and expected future UAS operations (i.e., terrain and collision avoidance, on-board systems diagnostics, and airspace integration and deconfliction capabilities are systems that either are or will be expected to be on all future UAVs). An example scenario for AACUS is detailed in Appendix A of this report.

In the legends, the timeframes associated with the development of the associated technologies should not be interpreted literally, rather they indicate a likely progression in time. The expectation is that the successful development and testing of the related technologies in nominal and off-nominal (i.e., contingency) settings would happen prior to FY17.

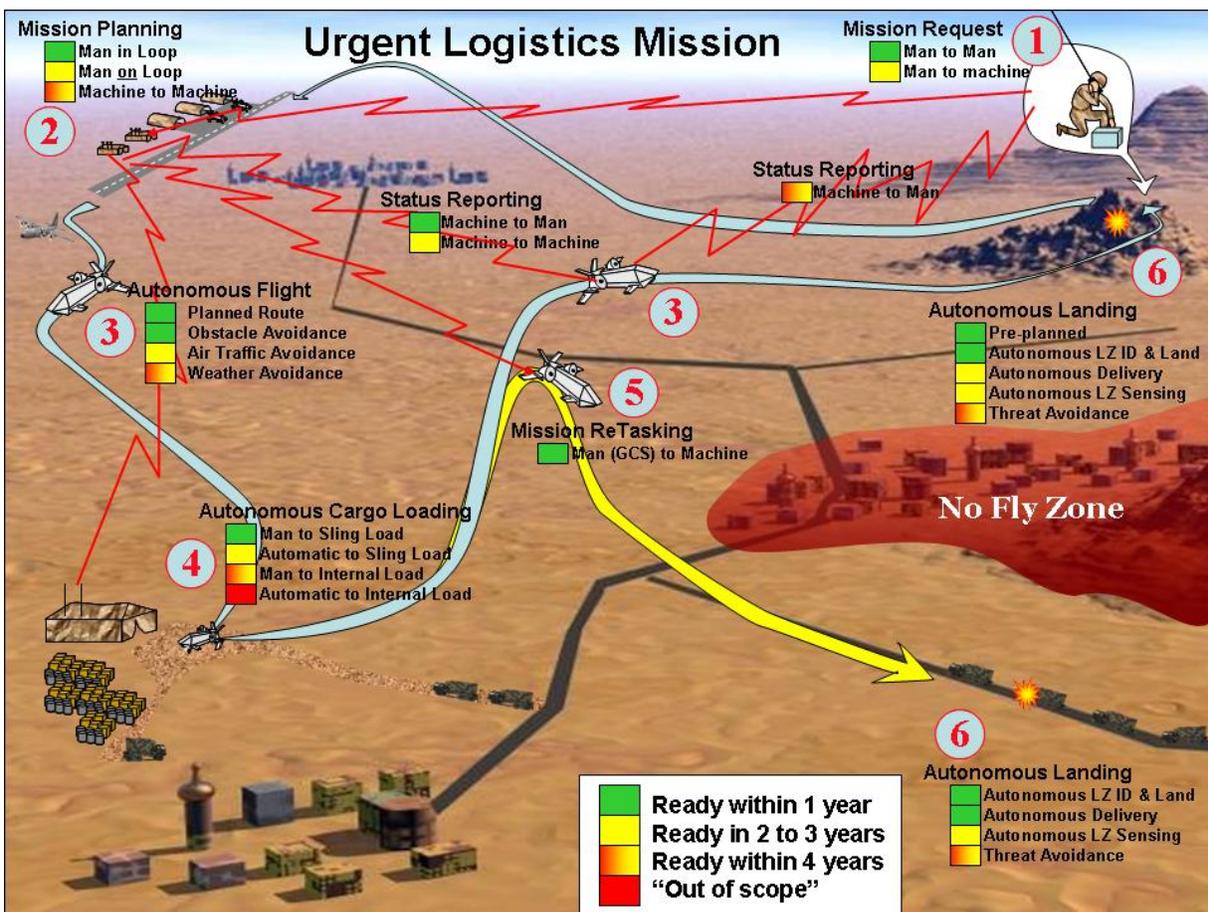


Figure 2 Urgent AACUS Logistics Mission with Replanning

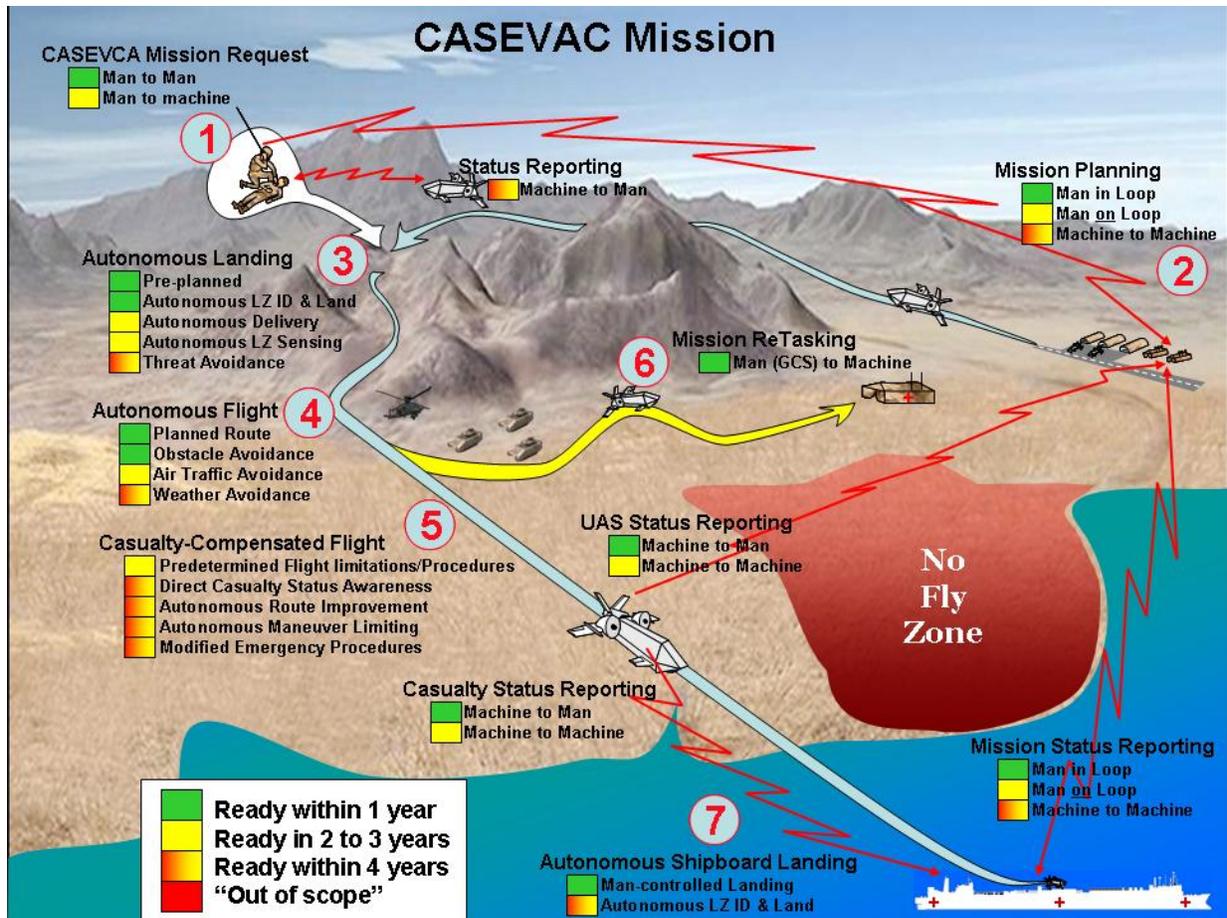


Figure 3 AACUS CASEVAC Mission with Replanning

Table 1: Expected AACUS Capabilities

The AACUS-enabled Cargo UAS (CUAS) should be able to autonomously land and takeoff from unprepared sites in Instrument Meteorological Conditions (IMC) and non-icing conditions, in high and hot environments, as well as in dust and sand conditions with minimum visibility.
The AACUS-enabled CUAS should be able to avoid obstacles (both static and dynamic) in flight as well as in the descent-to-land phase.
The AACUS-enabled CUAS shall be capable of generating complete paths from takeoff to landing, with identified waypoints modifiable by a human-on-the-loop (HOTL) Operations Center Supervisor (OCS) in real-time. It should autonomously navigate this route and notify the supervisor and requesting operator of any substantial deviations.
The AACUS-enabled system shall be capable of remote guidance at any point in the mission across various agencies (i.e., field personnel, trauma unit, AOC supervisors.)
Field operators should not be expected to be co-located with the landing vehicle, nor should they be required to have visual contact with the vehicle during landing.
The AACUS-enabled CUAS shall be capable of mission replanning (including path and goal modifications) from a GCS while in flight, both within data link range and BLOS.
All AACUS-enabled CUAS altitudes will be determined by the onboard sensing and flight

control system, with the expectation that the vehicle will have knowledge of other aircraft filed flight plans.

During flight, the AACUS-enabled CUAS shall:

- Execute preset lost-link procedures to attempt to reacquire the link in the event of data link loss within data link range;
- Execute contingency plans in the case of failure of data link reacquisition, a last-minute change in the safety of the landing site, or upon wave-off command by a human in the loop.
- In the event of lost comms, if mission criticality dictates, the CUAS should land at the initially confirmed landing site, with an alternate form of communication to ground personnel as to its status when on the ground.

The AACUS-enabled CUAS shall be able to be terminally guided from a variety of end-users with no specialized training as well as from various locations (field personnel, medical personnel, supply personnel, OCS), which could be BLOS from the launch location with an unobtrusive device. Terminal guidance shall consist of the following options at the destination location:

- Update the requested point of landing at any point in the landing sequence
- Abort delivery to hold at a remote location.
- Abort delivery to return to launch location with original load (or any other location specified by the OCS).
- Users should be able to specify different flight profiles for supply vs. CASEVAC missions

The AACUS-enabled CUAS should communicate with ground personnel for expeditious and safe loading and unloading.

Appendix A

AACUS Example Scenario Support of forward deployed small unit

A forward deployed unit has established a combat outpost (COP) near a mountaintop overlooking a valley. From their vantage point they can call in air strikes on insurgent caravans transporting weapons. The unit was inserted at night by helicopters to a plateau about 500 feet down the backside of the mountain. This plateau also serves as the supply delivery point for the unit, and the Marines have to carry everything up to the crest of a ridge and then down to the COP. The helicopters fly at night, but villagers have heard them, and there are enemy groups searching for the COP. Eventually the unit comes under fire. There are two serious casualties, but they are in stable condition. The unit is also running low on supplies.

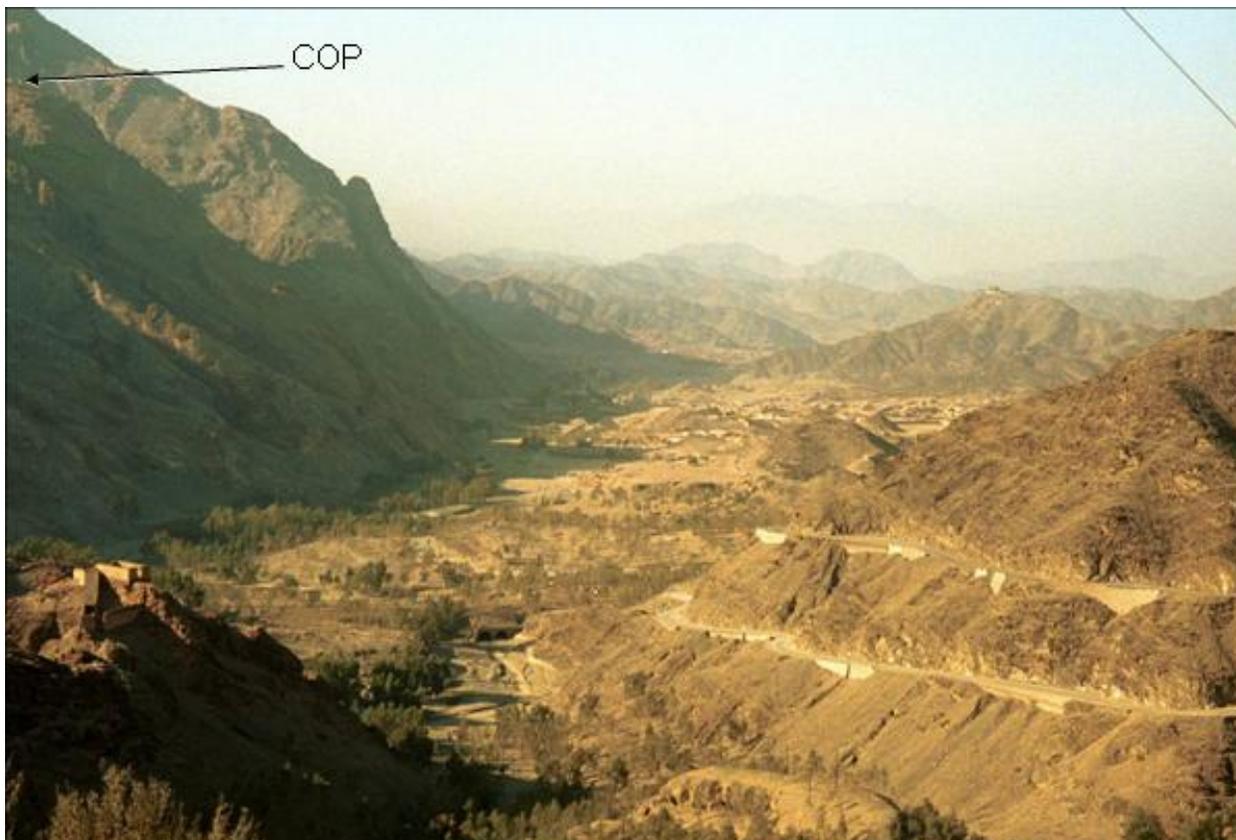


Figure 4 AACUS Scenario 1 depiction

The unit calls the FOB for air support and supplies but no manned assets are available. They are told that a Cargo UAS mission will be sent in later that night. The unit sends its requested landing site, supplies needed, and any time constraints to the FOB. The FOB forwards the unit position and supply list directly to the logistics support center.

1. The Integrated Mission Planning System (IMPS, a futuristic mission planning system) checks the status of all the Cargo UASs in flight, and on the ground and determines that no airborne

aircraft can acquire the necessary supplies or has enough fuel onboard to support the unit and therefore should not be re-tasked,

2. IMPS selects a Cargo UAS for the mission (tail # UCV-301) because it has the necessary fuel load and its internal monitors report that all systems are satisfactory.
3. IMPS automatically:
 - a. gets data from the Air Operations Center database for existing flight plans for all the manned and unmanned missions planned for the expected duration of the mission (including possible contingencies),
 - b. gets data from the Artillery Coordination Center (AFATDS) database for all the artillery missions planned for the next 45 minutes,
 - c. gets data for all the air-operations danger/avoid zones, the socio-political no-fly zones, and political/national boundaries from the GIS database,
 - d. gets data from the Tactical Ground Reporting System (or some similar distributed information sharing source),
 - e. gets the weather data for the area from the METOC database, and
 - f. plans an initial route for the UAS to safely and quickly go to the supply depot, and then to the COP, and then back to base,
4. The FOB Air Operations Supervisor (OCS) approves this flight plan.
5. IMPS sends the mission plan data to the Air Operations Center computer and the Artillery Coordination Center computer, and then
6. Sends the mission plan to UCV-301, which verifies all systems are satisfactory including appropriate fuel load and secure doors & access hatches, sounds a warning, turns on its running lights, receives a launch command from ground personnel, turns on its IFF transponder, starts its engine, takes off and begins flying to the supply depot,
7. UCV-301 provides ETA estimates to the supply depot, the OCS and the COP unit leader, and updates these continually.
8. UCV-301 autonomously detects and avoids any obstacles that were not on the GIS data in the terrain/features database that was uploaded along with the mission plan and returns to its planned route as soon as the obstacle is passed,
 - i. if the deviation from the planned route is greater than $\frac{1}{4}$ mile and/or brings it within close proximity to any other airborne asset, it computes an alternate path and automatically sends the revised path to IMPS, which relays it as a change in flight-plan to the Air & Artillery computers. The OCS is notified of significant path changes and be given the option of modification.
9. UCV-301 also scans for, detects, and autonomously avoids other aircraft, including small UAVs that may not have cooperative sense and avoid avionics (e.g., TCAS, ABS-B, or Mode 5 IFF transponders), as well as birds that could cause damage to the UAS. Since UCV-301 is a VTOL aircraft, it can quickly transition to hover (a mid-air “stop”) if necessary to avoid other air traffic. The OCS is notified of possible unresolved/ambiguous conflicts.
10. UCV-301 also monitors all of its onboard systems while in flight, and reports any anomalies to IMPS so they can be entered into the maintenance schedule.
 - a. If UCV-301 experiences a catastrophic system failure, it would report its problem/status immediately to the OCS and IMPS. All procedures and contingency plans for dealing with emergencies should be self-contained inside the UAV. In the case of an emergency landing, the UAS should autonomously look for a safe LZ, with a high priority for landing in a known secure area. The emergency plan should be communicated to the

- AOC Supervisor in real-time, with possible override capability in terms of landing site approval (management by exception). Once it lands and shuts down, it should notify IMPS and the OCS of its final status.
- b. If this happens, IMPS would begin scheduling another cargo UAS to take over the supply mission, and notify the supply system and the OCS of the change in ETA and Tail Number for the replacement UAS. The OCS would then notify FOB CC of the situation, and the location of the downed UAS, so that it can be retrieved (or destroyed if necessary).
 - c. One option that could be executed if the UAS had been carrying sensitive supplies, or had been operating in an area where there were no safe/secure emergency LZs, is that the mission plan could have included procedures for a full-speed crash into an open, unoccupied area. The OCS should have input into this decision in real-time, precluding any loss comm scenario (in which event, UCV-301 would execute a known contingency plan.)
11. In the case of normal operations, the supply depot computer identifies the necessary supplies,
 - a. the supply team pulls the supplies,
 - b. brings the load to the Cargo UAS LZ, and
 - c. waits outside the Safe Distance Circle.
 12. UCV-301 lands, and shuts down its engines and communicated to the supply team that it is safe to approach and load.
 13. The supply team confirms that the Tail Number on their supply order matches the Tail Number of the Cargo UAS that has landed.
 - a. The supply team then loads the UAS,
 - b. closes and locks the cargo doors,
 - c. gets outside the Safe Distance Circle.
 - d. Releases the UAS
 - e. At any time, the Supply Team should be able to abort the operation.
 14. UCV-301 sounds a warning, verifies all systems are satisfactory including appropriate fuel load and secure doors & access hatches, sounds a warning, turns on its running lights, turns on its IFF transponder, starts its engine. Once the engine is running and the onboard sensors report to the autopilot that all systems are satisfactory.
 15. The UCV-301 notifies IMPS upon completion of loading and takeoff. The OCS should have the ability to select notifications for an UCV state change.
 16. IMPS then sends data to the Air Operations Center computer and the Artillery Coordination Center computer reporting that UCV-301 is airborne and executing its flight plan to the COP.
 17. During the flight to the COP, the UCV-301 detects that there is a localized snow and ice storm flowing over the lee of a peak that is on its flight path.
 - a. It automatically determines a path around the bad weather, which may require a new path generation in the case of large deviations.
 - b. Then notifies IMPS and the OCS of the route change, and no potential conflicts are detected.
 - c. The OCS can override the system and modify the planned route.
 18. When UCV-301 is nearing the COP, it provides the unit leader with an estimate of how close and when it can get to the requested coordinates, as well as a set of alternatives if it cannot land at the requested site (as well as why it cannot land at the selected site). In this scenario,

UCV-301 determines initially that the requested site is acceptable and generates an estimated land time.

19. As it approaches the site in the last 25ft to descent, UCV-301 detects a boulder that makes it unsafe to land. It automatically executes a wave-off, contacts the unit leader to negotiate an alternate landing site.
20. The unit leader, also equipped with data from a distributed information sharing source), approves an alternate landing site, and UCV updates its expected time to land.
21. Once UCV-301 lands, it communicates to the unit leader and others in the COP that it is safe to approach for unloading/loading.
22. Two marines were wounded and are in need of immediate attention, so the unit leader contacts the OCS to request two casualties for evacuation on the UAS (this was not part of the original plan).
23. Once approved by the OCS, IMPS generates a new return path for the UAS so that it goes directly to the nearest Trauma Unit, and transmits the new instructions to UCV-301.
24. The two casualties are placed in the cargo compartment of UCV-301 along with their gear.
25. The cargo doors on UCV-301 are closed, and the unit leader gives the launch order. Once all personnel are clear.
26. UCV-301:
 - a. Verifies all systems are satisfactory including appropriate fuel load and secure doors & access hatches, and the landing site is clear of personnel.
 - b. Evaluates the terrain and obstacle data that it collected during its approach and descent, and computes a departure path.
 - c. Would normally execute a takeoff with rapid transition to high-speed forward flight to minimize threat risk and maximize stealth, but given the casualties on board, it executes a takeoff to minimize G-loads, rapid altitude changes, and maintains constant air pressure in the cargo compartment that matches the estimated air pressure for the altitude at the Trauma Unit which is at a lower altitude. Such a different takeoff/flight/landing profile should be selectable by a ground user.
 - d. Periodically updates the Trauma Unit on the ETA.
27. UCV-301 communicates to the Trauma Unit that it is on final approach, then executes an autonomous patient-specific onboard landing profile at the designated UAV LZ. Once it lands, it shuts down its engine, and communicates to medical personnel that it is safe to approach.

Appendix D

Acronym List

AACUS	Autonomous Aerial Cargo/Utility System
AFATDS	Advanced Field Artillery Tactical Data System
API	Advanced Programmer Interface
Arty	Artillery
ASL	Above sea-level
ASuW	Anti-surface warfare
ASW	Anti-submarine warfare
BLOS	Beyond line-of-sight
C2	Command and control
CASEVAC	Casualty Evacuation
CC	Company Commander
CG	Center of gravity
CM	Configuration management
COIN	Counter Insurgency Operations
CONOP	Concept of Operation
COP	Combat outpost
COTS	Commercial off-the-shelf
CUAS	Cargo Unmanned Aerial System
CVBG	Aircraft-carrier battle group
DA	Density altitude
DoD	Department of Defense
DOTMILPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities
EGF	Elite Guard Force
ETA	Estimated time of arrival
FAA	Federal Aviation Administration
G	Gravity or gravitational acceleration
GCS	Ground control system
GIS	Geographic information system
Govt	Government
GPS	Global Positioning System
helo	Helicopter
HOGE	Hover out of ground-effect
HW/SW	Hardware/software
ID	Identify or identification
IFF	Identification friend-or-foe transponder
IMPS	Integrated Mission Planning System
INP	Innovative Naval Prototype
INS	Inertial navigation system
ISR	Intelligence, surveillance and reconnaissance
JFACC	Joint Forces Air Component Commander
JRAC	Joint Rapid Acquisition Cell
JUONS	Joint Urgent Operational Needs Statement

K	Thousand
KM	Kilometer
kts	Knots (nautical miles per hour)
LOS	Line of sight
LZ	Landing zone
MAGTF	Marine Air Ground Task Force
MARCENT	U.S. Marine Corps, Central Command
MEDEVAC	Medical evacuation
METOC	Meteorology operations center
mi	Mile (statute mile)
MOE	Measure of Effectiveness
MOP	Measure of Performance
MPS	Mission Planning System
OCS	Operational Command Supervisor
ONR	Office of Naval Research
Ops	Operations
OR	Operating room
Plt	Platoon
PoR	Program of Record
RCS	radar cross-section
RF	Radio Frequency
RPG	Rocket propelled grenade
RTB	Return to base
SATCOM	Satellite communication
SUW	Anti-surface warfare
T&E	Test and evaluation
TBD	To be determined
U.S.	Unites States
UAS	Unmanned Aerial System
UAV	Unmanned Aerial vehicle
UCV	Unmanned Cargo Vehicle
UGS	Unattended ground sensor
US	Unites States
USMC	United States Marine Corps
USN	United States Navy
USS	Unites States Ship
USW	Anti-submarine warfare
VTOL	Vertical take-off and landing