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Pathfinding for Airspace with Autonomous Vehicles (PAAV) Tabletop 4 Final Report

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March 2023

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Acronyms and Definitions

ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	above ground level
AOC	Air Operator Certificate
ARTCC	Air Route Traffic Control Center
ATC	air traffic controller
ATIS	Automatic Terminal Information Service
C2	Command and Control
CTAF	common traffic advisory frequency
DAA	detect and avoid
EDC	estimated departure clearance
EFC	expect further clearance
FAA	Federal Aviation Administration
FLEX	Flexible Method for Cognitive Task Analysis
FMS	flight management system
GCS	ground control station
IAF	Initial Approach Fix
IFR	instrument flight rules
ILS	Instrument Landing System
IT	information technology
LC2L	lost C2 link
m:N	multi-vehicle control
MASPS	minimum aviation system performance standards
MOPS	minimum operation performance standards
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
nm	nautical miles
PAAV	Pathfinding for Airspace with Autonomous Vehicles
PDT	Pacific Daylight Time
PIC	pilot in command
RA	Resolution Advisory
RP	remote pilot
RPIC	remote pilot in command
SA	situation awareness
SATCOM	satellite communication
SME	subject matter expert
STAR	Standard Terminal Arrival
TCAS	Traffic Collision Avoidance System
TMU	Traffic Management Unit
TRACON	Tower, Terminal Radar Approach Control
UA	uncrewed aircraft
UAS	uncrewed aircraft system
UI	User Interface
VFR	visual flight rules
VMC	visual meteorological conditions

Pathfinding for Airspace with Autonomous Vehicles (PAAV) Tabletop 4 Report

Cynthia A. Wolter[1], Kristina Davikoff[1], and Conrad Rorie[2]

Executive Summary

There is a desire from industry stakeholders to utilize uncrewed aircraft (UA) to address increasing air cargo operations and current pilot shortages. A primary goal of the Pathfinding for Airspace with Autonomous Vehicles (PAAV) subproject has been to outline a seamless and scalable progression to integrate these kinds of operations into the National Airspace System (NAS) with minimal disruptions to current-day operations. To aid the PAAV concept, the most recent of four tabletop workshops tasked researchers with gathering opinions from 13 subject matter experts (SMEs) to uncover issues that may pose barriers to integrating autonomous cargo operations into the NAS, specifically while in multi-vehicle control (m:N) pilot configurations.

Researchers used the Flexible Method for Cognitive Task Analysis (FLEX) technique to structure data collection, hosting three virtual sessions of group discussions over eight days in May of 2022. Participants were asked to envision probable solutions to anticipated operational challenges that could be implemented with little impact to current-day NAS structure and procedures. The first session included commercial pilots with cargo experience, military remote pilots (RPs), and an experienced dispatcher. After initial inputs were gathered from the first group, the second session's air traffic controller (ATC) participants had an opportunity to review the same material, identify new issues, and pose counterarguments or improve upon the prior group's solutions. Insight from this session was provided by six retired air traffic controllers with extensive experience in Tower, Terminal Radar Approach Control (TRACON) and center facilities. The third and final session brought all 13 participants together from the previous two sessions to recount their unique perspectives on a selection of issues and solutions with the goal to resolve differing opinions.

The researchers predicted that issues to overcome when integrating UA in the NAS would largely revolve around certain aspects of flights, including route planning, ensuring adequate separation and flow management, integrating into traffic patterns, managing contingencies (i.e., lost command and control link [LC2L]), radio and data link communications, and operating in complex terminal and airport surface environments. Therefore, researchers constructed a series of scenarios specially designed to probe further into each of those areas with ATC, pilot, and dispatcher participants. Participants were briefed on a series of initial assumptions but were encouraged to modify those assumptions to best enable m:N operations in this phase of the concept evolution.

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Controllers and pilots alike all regarded predictability as one of the most important considerations when developing best practices for enabling seamless m:N cargo operations in the NAS. Additionally, it was revealed during the tabletop that the remote pilot's workload and situation awareness levels will likely be the primary contributors to the challenges facing the move towards a future where m:N is possible. Researchers had expected that the volume of automation and technology-driven solutions generated over the course of the tabletop would be high, which proved true. Many technological solutions were suggested, including, but not limited to data link communications versus multiple radio frequencies, autonomous UA action with human oversight, ground control station (GCS) computational and decision-making support tools, and general user interface (UI) design considerations. Discussions also frequently focused on solutions regarding team roles and responsibilities which closely aligned with assumptions about best practices for the physical structure of the team supporting these flights. To increase a m:N RPs' performance, participants expressed their preference to co-locate RPs within a "cell" of other RPs with additional supporting personnel located nearby. Unsurprisingly, researchers found that as situations increased in complexity, the number of aircraft that the participants thought these future remote pilots would be able to handle decreased. Airspace complexity, communication architecture, and the level of advancement in technology are a few examples of factors that would likely impact the viability of m:N operations. This report serves to identify variables which contribute to the barriers for seamlessly integrating m:N remotely piloted cargo UA into the NAS and to document SME suggestions of ways these challenges could be conquered.

1. Introduction

1.1. Need and Background

Over the next twenty years, domestic U.S. cargo operations in the National Airspace System (NAS) have been forecasted by the Federal Aviation Administration (FAA) to increase by 2.6 percent every year from 2022 to 2042 [1]. Similarly, domestic U.S. passenger operations are also forecasted to increase, though by slightly more, at 4.8 percent per year. Over the same timeframe, Boeing has predicted that the demand for commercial passenger pilots will increase by 128,000 to meet a similar increase in flights [2]. Although the future demand for domestic cargo pilots was not calculated, it can be reasonably assumed that this demand will follow a similar trend. When coupled with the ongoing global pilot shortage, these assumptions are the primary reasons for industry's desire to begin a transition from crewed flights to remotely piloted autonomous flights.

The NAS is a highly regulated system, designed with regard for efficiency and rigorous standards for safety. As such, the transition to autonomous flight must be approached carefully and systematically. Due to the absence of complexities that accompany passenger operations, air cargo operations are prime candidates for exploring the concepts of remotely piloted, remotely supervised, and autonomous operations. To research this move towards autonomous operations, the National Aeronautics and Space Administration (NASA) Pathfinding for Airspace with Autonomous Vehicles (PAAV) subproject is focused on the cargo perspective of that integration process. The PAAV subproject has been developing a concept that aims to define a scalable pathway to transitioning from crewed to uncrewed aircraft (UA), leading to remotely supervised, and eventually fully autonomous, air cargo operations.

To be a seamless solution to meet market demands, uncrewed cargo operations must be able to perform similarly to crewed aircraft, including following instrument flight rules (IFR) and conventional NAS structure and procedures. Operations must include turboprop aircraft that are similar to aircraft that are typically used for current-day regional air cargo operations. These aircraft must be capable of flying into and out of airports that meet freight carriers' logistical needs, including regional airports [3] as well as Class C and Class B airspace. In addition to these practical assumptions, the PAAV project presumes that over a period of time similar to the FAA's 20-year outlook, these operations will scale and mature, following a logical progression from "near-term" to "far-term" in regard to the level of autonomy and locus of control [4] of each operation (Figure 1). In order, from near- to far-term, the five automation and control locus levels that have been identified to guide this research effort are as follows:

Automation Levels
Human > Shared > Supervisory > Automated > Fully Automated Control

Control Locus Levels
Centralized > Collaborative > Delegated > Distributed with Oversight > Fully Distributed

Figure 1. Five levels of Automation and Control Locus.

With an overarching goal to maximize the human operator/remote pilot (RP)-to-aircraft ratio for stakeholder business models, a multi-vehicle control (m:N) pilot-to-aircraft ratio is being explored by the subproject as a mid-term steppingstone, one with an increased level of automation and more distributed control than is present in current day uncrewed operations. In March of 2021, in collaboration with industry partners, NASA established the Multi-Vehicle Control Working Group to explore a concept where operations are configured with multiple remote pilots (m) controlling multiple aircraft (N) at the same time [5]. While the m:N (read as "m-to-N") Working Group spans a broad range of topics from Urban and Advanced Air Mobility to infrastructure inspection and disaster response, for the current activity PAAV researchers worked with this group to explore the specific application of m:N concepts within the domain of air cargo operations. This investigation is being conducted with hope that m:N may serve as a viable bridge to span the distance between a single pilot remotely operating one vehicle at a time (1:1) and an end state where fully autonomous (with human oversight) operations is reached.

1.2. Purpose

This paper describes the results from a tabletop workshop, the fourth in the PAAV series, which aims to identify barriers to integrating uncrewed mid-sized cargo aircraft into the NAS and potential solutions to overcome those barriers. While the previous tabletops focused on potential impacts to air traffic controllers (ATCs) in the near-term evolution of uncrewed cargo operations, the current one had a further-term vision where more automation is leveraged and there is less centralized control. This tabletop aimed to provide solutions that would minimize the impact of these operations on ATC while addressing the challenges associated with pilots managing multiple aircraft.

One standout concern for m:N operations is the ability of the human to meet performance expectations under these new and potentially more complex conditions. For example, what kinds of effects on RP workload might one expect from maintaining situation awareness (SA) of multiple UA simultaneously? How might the phase of flight, environmental and/or off-nominal conditions affect RP performance? What are the potential tools, technologies, rules, and/or procedures that could be implemented to help a human operator perform better under these circumstances?

In addition to the impact on pilots when introducing m:N operations, researchers supposed that there may also be an impact to other roles such as: air traffic controllers and their supporting automation, RP ground control stations (GCS) including any associated GCS automation, dispatchers and support personnel, and the uncrewed aircraft itself. These impacts could reveal themselves as potential changes to roles and responsibilities, regulatory and procedural changes, training requirements, and common understanding of newly established best practices. The current tabletop enlisted the aid of pilot, controller, and dispatcher subject matter experts (SMEs) to explore research questions related to the feasibility of m:N remotely piloted domestic cargo flights. Participants were asked to assume that the UA being discussed will primarily fly regional operations, be similar in size and capability to an aircraft like the ATR 42 and have an airworthiness certificate for commercial operations under Code of Federal Regulations Title 14, Parts 121 or 135. This hypothetical UA was also assumed to have the ability to leverage technologies for advanced traffic, weather, and terrain and obstacle collision avoidance, detect and avoid (DAA), digital communication to/from ATC, and command and control (C2) connectivity throughout the duration of a flight.

In this tabletop, 13 pilot, controller and dispatcher SMEs participated in tabletop discussions that spanned eight days between May 16, 2022, and May 27, 2022. Participants were guided through discussions with the aid of detailed scenario walkthroughs and structured questions designed to elucidate barriers to autonomous cargo operation implementation and develop practical solutions to overcome those barriers. During discussions, issues that were most frequently brought up were related to human factors topics like situation awareness and workload, technology gaps or limitations, and unspecified procedures or rules. These issues were present within seven operational challenge categories, categories which aligned with those highlighted in the initial PAAV concept documentation: flight route planning, separation and flow management, traffic pattern integration, contingency management, taxi takeoff and landing, communication, and general m:N challenges.

2. Method

2.1 Design

The method for the fourth tabletop activity to elicit SME feedback on the PAAV concept diverged from the bowtie analysis method used for the first three tabletops [6]. The bowtie analysis is an established and effective tool for assessing the impacts of modifications to an existing system by exploring hazards, mitigations to those hazards, and assessing pre- and post-intervention risks [7]. However, the nature of Tabletop 4's further-term emphasis was better served by exploring a different means to understand the issues surrounding the m:N concept and the potential solutions that might ease the path to seamless autonomous cargo implementation in the NAS. The assumptions about the level of autonomy and locus of control were not as near-term as the previous tabletops, thus requiring participants to employ more imaginative and creative thinking to envision the proposed operations, the environment, and the technological or procedural innovations that would be advantageous to employ. For these reasons, the research team structured the tabletop workshop to align with the Flexible Method for Cognitive Task Analysis (FLEX) technique proposed by the United States Army as a knowledge elicitation method for future concepts [8].

With the FLEX method, subject matter experts are grouped by their type of expertise and interviewed sequentially, with each group building upon the comments and suggestions of the previous group. Participants are encouraged to challenge and improve upon the ideas from the group before, and the previous groups are then allowed an opportunity to view those challenges and improvements and provide additional feedback. The goal is that by using this method, the end product of the research activity will have been self-vetted by participants as a part of the data collection process.

2.2. Data Collection

Tabletop 4 took place virtually via Microsoft Teams over two weeks in May of 2022 and followed the FLEX method. Since the PAAV concept aims to limit the effects of autonomous cargo operations on current-day ATC operations, remote pilots and their support personnel were expected to be the human operators who will theoretically experience the most impact. With this in mind, researchers scheduled three sequential sessions with participants, beginning first with the Pilot and Dispatcher group, followed by the ATC group, and finally a single day session which brought all individual participants together for a large group discussion. Session 1 (Pilots and Dispatcher) occurred over four days (Monday–Thursday), Session 2 (ATC) occurred over three days (Tuesday–Thursday), with a single-day combined Session 3 immediately following on Friday. A strategic break was scheduled between Session 1 and Session 2 to allow researchers to prepare amended materials based on Pilot and Dispatcher contributions for the next stage of ATC data collection. Topics for the joint Session 3 were comprised of those comments from Session 1 which were amended by the ATC group during Session 2, as well as topics participants identified that they would like to have an opportunity to discuss with the larger group.

All participants received an advance package of materials one week prior to the beginning of the tabletop which included a teleconferencing best practice guide and instructions for joining a Teams meeting. On the first day of Sessions 1 and 2, participants were introduced to the PAAV subproject and the tabletop 4's expectations before being given time to review and return their signed consent forms. Participants were then guided through training that was designed to describe the solution space and baseline assumptions to be used during group discussions. After training was completed, moderator-led scenario walkthroughs began, with each walkthrough followed by scenario-specific, question-driven discussions. Each day began at 9am (PDT) and concluded no later than 5pm (PDT). The days were split into morning and afternoon blocks, with a one-hour lunch break between each block. The moderator also assigned 15-minute breaks approximately every two hours at their discretion.

All three tabletop sessions were recorded, automatically transcribed, and stored securely to preserve participant confidentiality. For additional data collection, two researchers were tasked with taking real-time notes for the duration of the discussions. Two researchers were designated moderators for the sessions in alternating shifts. To minimize disruptions, one researcher was assigned to monitor a private chat channel where other members of the PAAV team could propose their own follow-up questions which, if appropriate, the chat monitor would then ask verbally during the session. The participants and moderators were all encouraged to turn their cameras on to promote animated engagement by all.

2.3. Participants

Participants were recruited for the tabletop based on their professional experience and qualifications. A total of 13 SMEs participated in the tabletop including: six air traffic controllers, three commercial pilots, three remote pilots, and one dispatcher.

All ATC participants were Certified Professional Controllers with total years certified ranging from 9–34 years (M = 28.72). Specifically, four had tower experience, five had Terminal Radar Approach Control (TRACON) experience, and four had ARTCC experience.

The three commercial pilot participants all had Airline Transport Pilot licenses with instrument and multi-engine ratings. Their total flight hours ranged from 3,500 to 7,500 hours. The three commercial pilot participants collectively represented 15,000 total flight hours of experience combined. They had experience on the type of aircraft of interest for this tabletop (e.g., ATR-42, DHC-6 Twin Otter, DHC-8, Cessna 208, Beechcraft 1900, or King Air). Two pilots had commercial air cargo experience and two were certified flight instructors.

Remote pilot participants reported an average of 7.66 years of experience as a civilian or military UA pilot, ranging from five to 13 years. They had a combined 6,085 hours of uncrewed aircraft system (UAS) experience, with a majority (5,800) of those hours flying MQ-9 aircraft. Additionally, two RPs reported experience piloting MQ-1 and MQ-9X aircraft. Two RPs had private pilot licenses, two had commercial pilot licenses with instrument ratings, and one of these RPs had a multi-engine rating.

The dispatcher participant was licensed with 43 years of professional experience with Part 121 and 135 operations. Time spent in different positions overlapped so that 33 years of this experience was as a line dispatcher, 25 years as an instructor, 15 years as a supervisor, and 20 years as an ATC coordinator.

2.4. Training and Assumptions

Participant training began with an overview of the PAAV subproject and tabletop objectives. The cited objectives included: 1) to identify gaps in practice, procedures, and technology that present barriers to the integration of uncrewed mid-size aircraft into the NAS in m:N configurations; and 2) to make recommendations regarding procedural and technological mitigations that would facilitate the integration of these UA. SMEs were told that researchers hoped to leverage their individual expertise on how different types of flights currently operate (e.g., major airline transport, regional passenger transport, regional cargo transport, or remotely piloted military flights) and then translate that knowledge into the m:N domain. Researchers led instruction on the uncrewed aircraft system (UAS) and flight assumptions to be discussed, including Command and Control link capabilities, the Detect and Avoid system, and notional m:N architectures.

2.4.1. UAS Assumptions

Researchers gave participants an overview of the following UAS and flight characteristics to consider throughout all tabletop discussions:

- Aircraft is a remotely piloted aircraft system.
- Flight is operated by a commercial cargo carrier.
- Operations are under Code of Federal Regulations Title 14, Part 121 or Part 135.
- ATC Communications transit to/from a ground control station, via a C2 link with the UA as a relay.
- Command and control of the UA also utilizes a C2 link.
- In the event of a loss of the C2 link (LC2L), contingency plans are dynamic with well-defined automation and human roles.
- UA will fly IFR and leverage digital and/or visual-like flight rule behavior where available.

- Avionics Equipage: Doppler radar, flight management system (FMS), ground proximity warning system, surveillance equipment (e.g., Automatic Dependent Surveillance–Broadcast [ADS-B] In/Out, 4096 capable Mode C or Mode S transponder and air-to-air radar), visual technology for airborne and ground-based hazard detection, detect and avoid (DAA), and C2 systems, including weather and terrain avoidance.
- Communication, navigation, and surveillance may use advanced methods including more digital communication between ATC and the ground station operator, leveraging satellite and terrestrial technologies as feasible, and more advanced networked communications where available.

2.4.2. Command and Control Link

C2 links were expected to be central to several scenario discussions throughout the sessions, thus, there was a need to explicitly define the C2 concept for all participants to facilitate the coming discussions. Researchers consulted the minimum aviation system performance standards (MASPS) (DO-377A [9]) and minimum operational performance standards (MOPS) (DO-362A [10]) for the C2 link system published by the RTCA Special Committee 228 (SC-228). Outlined below is the system that was described to participants as being utilized by the tabletop's hypothetical UAS.

The C2 link is used for multiple purposes:

- The RP uses the link to command maneuvers of the UA (uplink).
- The UA uses the link to send state and subsystem telemetry data to the RP (downlink).
- The RP and ATC communicate via two-way voice and digital transmissions.
- The UA and GCS send/receive surveillance data transmissions.
- The UAS sends limited low-frame-rate video to the GCS for takeoff and landing. With future advancements, additional high-resolution data may also be transmitted through these links in other phases of flight.

There are two possible link systems illustrated in Figure 2, terrestrial and satellite communication (SATCOM). Terrestrial links rely on radio frequencies within line-of-sight of ground radio stations and the UA. SATCOM links provide coverage within their system spot beam areas. By utilizing both types of links, the system can select the most robust link at any given time, enabling continuous connectivity for end-to-end flight operations. The system for this UAS utilizes a relay-through-the-UA arrangement for RP-to-ATC and ATC-to-RP communications.

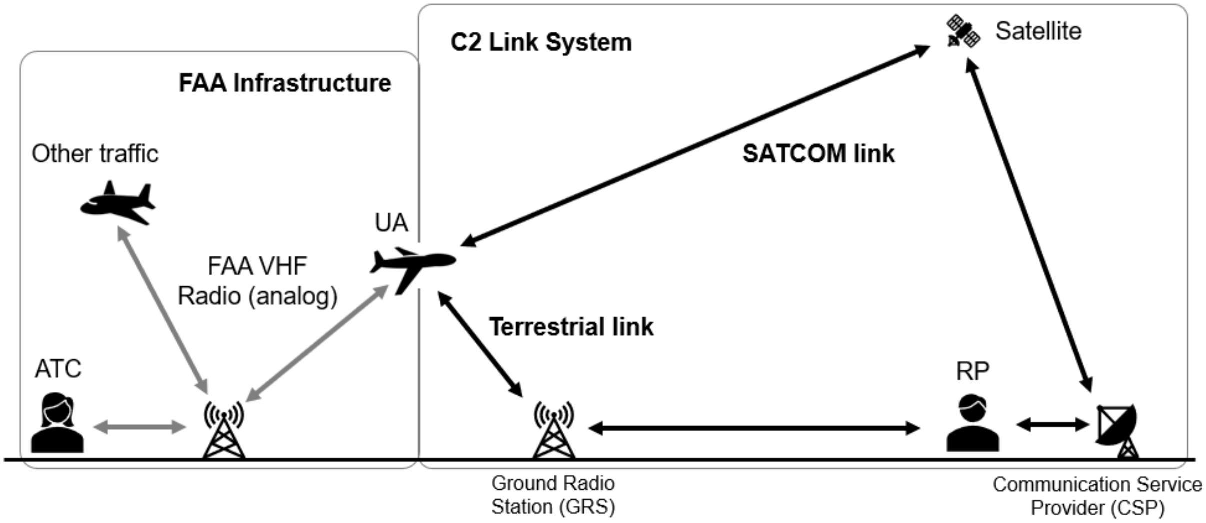

Figure 2. C2 Link system.

2.4.3. Detect and Avoid

Detailed instruction on DAA systems was given to all participants, describing it as an alternate means for complying with "see and avoid" Part 91 requirements for UA [11, 12]. The system utilizes surveillance equipment to generate alerting and guidance information to warn the RP to correct for collision hazards and remain "well clear" of other aircraft. Based on defined parameters, the DAA system issues caution- and warning-level alerts, where caution alerts indicate that immediate attention is required and a maneuver may soon be necessary, whereas warning alerts require immediate action/avoidance maneuvering on the part of the RP (or vehicle/GCS automation). Along with describing specific parameters for DAA calculations, trainers also explained that both cooperative aircraft with electronic identification (i.e., transponder or ADS-B), as well as non-cooperative traffic, are included in the system. Researchers noted that DAA would not currently be applicable to surface operations, operations within a VFR traffic pattern and/or operations below 400 feet above ground level (AGL).

2.4.4. m:N Architectures

An overview of the basic m:N concept was given to participants to focus discussions on enabling multi-vehicle operations. The m:N approach was defined as a conceptual framework whereby multiple remote pilots cooperatively manage multiple aircraft, where "m" is the number of remote pilots and "N" represents the number of aircraft, with "N" assumed to be larger than "m." This diversion from 1:1 operations would necessitate a shift in the level of automation required for a flight and the locus of control (see Figure 1 above). Where tasks for current-day flights have already begun shifting from human-control to shared-control, m:N pushes this concept even further towards the human acting in a supervisory role. There is a desire for a similar trend to emerge regarding the locus of control as remotely operated m:N flights move towards delegated, or even distributed, control. Having been instructed on this, participants were presented with sample m:N configurations (Figures 3–5) to spark their imaginations for the problem space; however, it was stressed that the given 1:2, 1:5, and 2:5 ratios were only notional, and they were encouraged to think further outside of the box. Participants were told that the m:N ratio could change depending on the phase of flight, and that example roles could include Ground, Terminal, and En route RPs. Lastly, the area of their operations, whether they were assigned geographically or sequentially, was left undefined by researchers. A briefing on RP-to-RP handoffs—i.e., the transfer of control of one or more vehicles from one RP to another—included a brief discussion on handoffs due to planned events (e.g., proximity to the destination airport) and unplanned events (e.g., an onboard emergency). However, as with all given starting assumptions, participants were encouraged to challenge these ideas as they thought of alternative options.

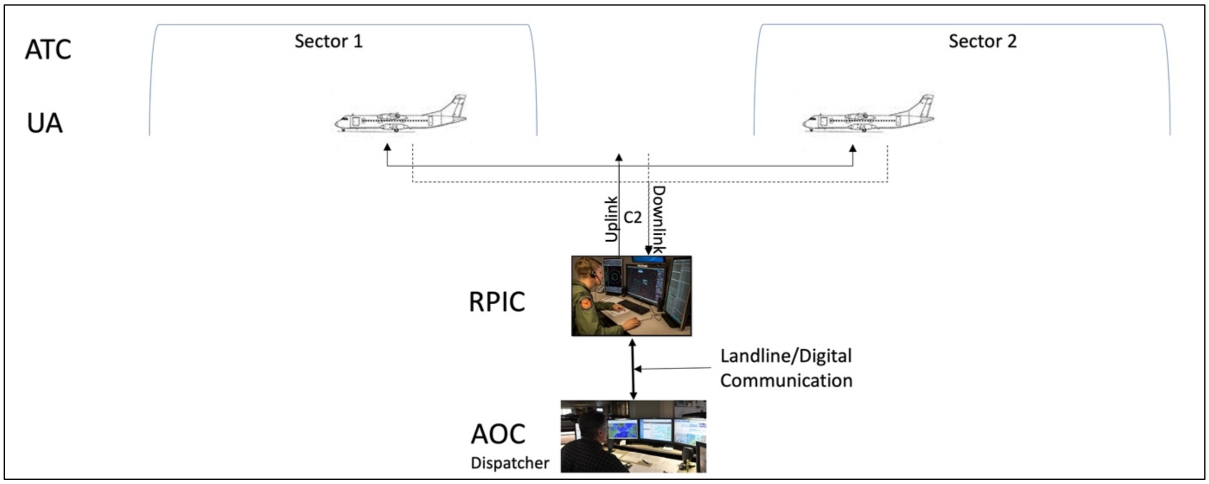

Figure 3. Hypothetical 1:2 RP-to-UA ratio. Note: ATC Frequencies are dialable for each aircraft. C2 is specific to each aircraft. AOC = Air Operator Certificate.

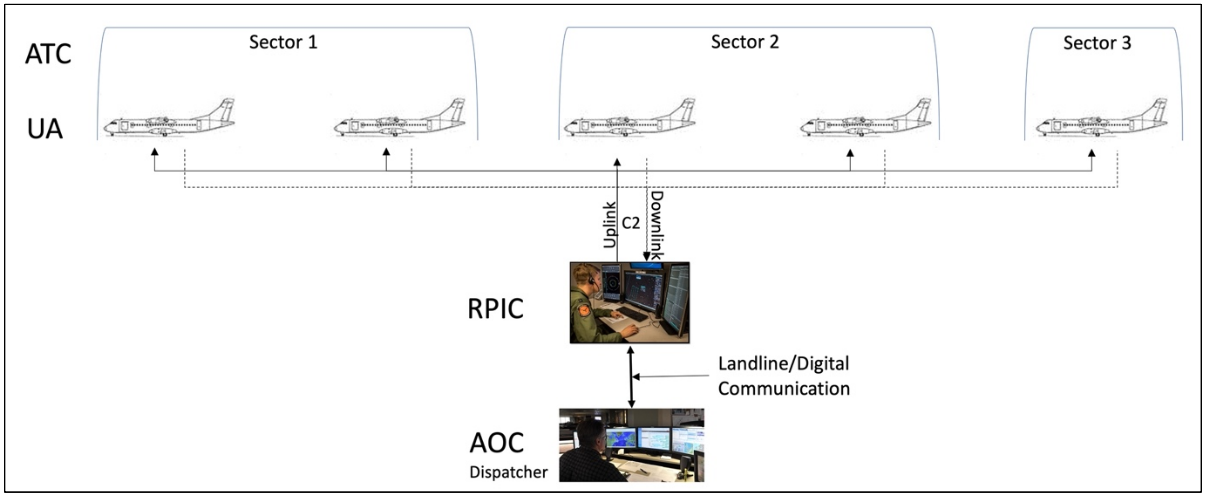

Figure 4. Hypothetical 1:5 RP-to-UA ratio. Note: ATC Frequencies are dialable for each aircraft. C2 is specific to each aircraft.

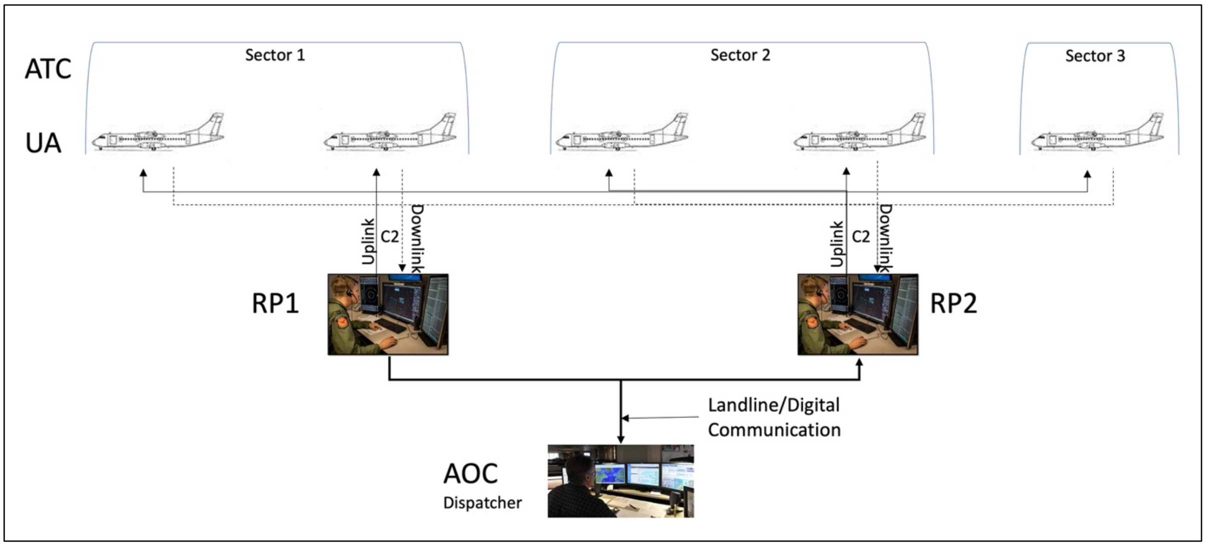

Figure 5. Hypothetical 2:5 RP-to-UA ratio. Note: ATC Frequencies are dialable for each aircraft. C2 is specific to each aircraft.

2.5. Materials

During data collection, researchers shared animated graphics for participants to view while the moderator read a scripted narrative of the scenario shown. Once clarifying questions were answered, the moderator then began the discussion by asking prepared questions in an order which best fit the flow of the dialogue. In the weeks prior to the tabletop, researchers met with NASA in-house SMEs to design questions that were specific to a particular scenario. In addition to these, a general list of questions to be asked in all scenarios was constructed to act as prompts for discussions about possible barriers to integration as well as about proposed solutions to those issues. Workload and situation awareness impacts on ATC, RPs and dispatchers arising from the issues and mitigations discussed were key focus areas within the prepared materials. Participants were encouraged to think beyond present-day technology and regulations, but not to the point of proposing fantastical solutions that would be unlikely to be realized within the general "far-term" timeframe.

To facilitate discussions, 25 scenarios with accompanying narratives were created describing various hypothetical situations in difference phases of flight (e.g., en route, approach, preflight, surface operations, and departure) (Table 1). Narratives included both nominal and non-nominal scenarios for: Class B or E en route, Class B or C regional TRACON approach, Class D or E non-towered approach including Common Traffic Advisory Facility (CTAF) environments, and Class B or C towered preflight, surface and departure operations.

Table 1. List of 25 Scenarios in Tabletop 4

Phase of Flight	*Scenario Number*	*Scenario Name*
En Route	E1	Weather Avoidance
	E1a	LC2L During Weather Avoidance
	E2	DAA Alerting and Guidance
	E3	Mid-Flight Pilot Handoff
	E4	GCS Position Relief Briefing
	E5	Managing Multiple ATC Frequencies
	E6	Data Link Management
Approach	A1	Metering
	A1a	LC2L Descent to Landing
	A2	Holding
	A2a	LC2L while Holding
	A3	Sequencing (Sensor Spacing)
	A4	TRACON Resequencing
	A5	Missed Approach and Diversion
	A6	DAA Alerting and Guidance
	A7	Class D Pattern Entry
	A7a	LC2L Class D Pattern Entry
	A8	CTAF Operations
	A8a	LC2L CTAF Operations
Surface Operations	S1	Hold Short with Tower
	S2	Detailed Taxi Instructions and Following Traffic (with Tower)
	S3	LC2L During Taxi
Preflight	P1	Preflight
Departure	D1	Position and Wait and Ground Delay Program
	D2	Rejected Takeoff

Narratives were divided by phase of flight and each phase began with an overview of the specific scenarios to be discussed. Researchers chose to begin the discussions with en route airspace due to its lower complexity, these were then followed by approach, preflight, surface operations and concluding with departure scenarios. The phase of flight overview graphics can be seen in Figures 6-9 along with brief descriptions of the scenarios within that phase. Full narratives for each scenario and their accompanying graphics can be found in Appendix A.

2.5.1. En Route Scenarios

The moderator guided participants through seven en route scenarios (Table 1) where one RP is initially flying three UA operating in different neighboring sectors (Figure 6). In one scenario, after departing a Class B airport, CARGO7 encounters a weather cell that requires an avoidance maneuver (Scenario E1) and then experiences a LC2L event during the deviation (Scenario E1a). In another scenario, all three UA are involved in traffic avoidance events (Scenario E2): CARGO12 requests a deviation for traffic observed on their DAA display, CARGO4 receives a DAA caution-level alert, and CARGO7 receives a Traffic Collision Avoidance System (TCAS II) Resolution Advisory (RA; a warning-level alert). Following this, the CARGO4 initiates a planned handoff to a Terminal RP as the UA nears the destination airport (Scenario E3). The expected series of communications between the RP and ATC within the above scenarios were recounted to explore radio and data link complexities in the remaining en route discussions (Scenarios E4, E5, and E6).

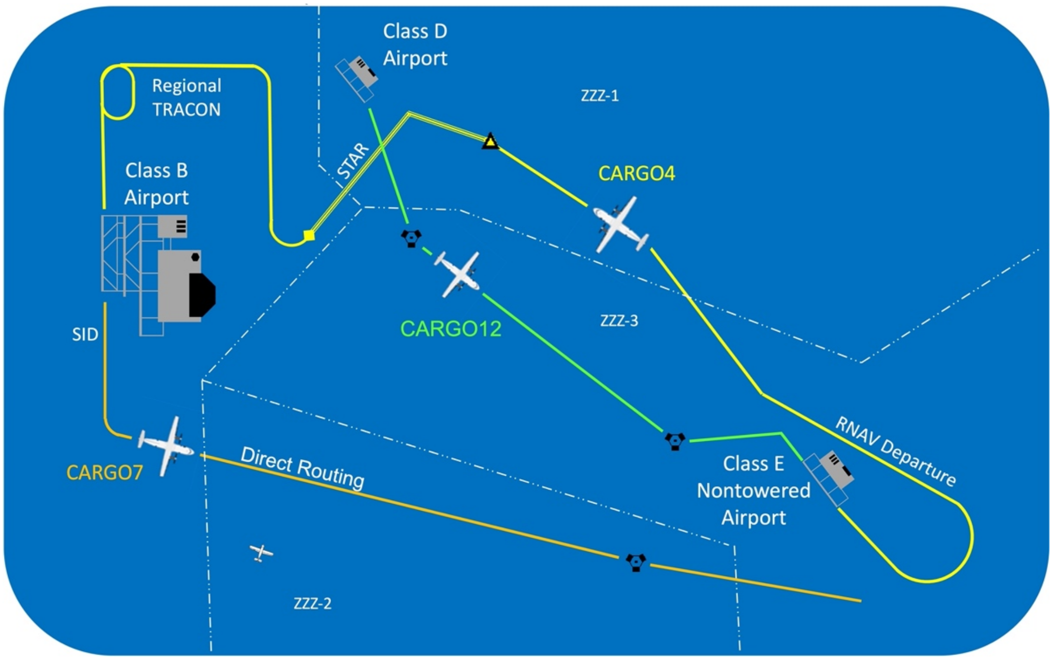

Figure 6. En route overview graphic depicting CARGO4, CARGO7, and CARGO12.

2.5.2. Approach Scenarios

The approach phase of flight included four UA involved in 12 scenarios (Table 1) with both en route and Terminal RPs each flying multiple of these UA simultaneously (Figure 7). As CARGO16 is approaching its destination, the UA loses C2 link (Scenario A1a) while following vectors for spacing per ATC metering instruction (Scenario A1). In another variation, CARGO16 enters an ATC instructed hold (Scenario A2) before losing its C2 link (Scenario A2a). CARGO8 has been instructed to follow a preceding aircraft while on the downwind to the destination airport (Scenario A3) and CARGO4 gets re-sequenced due to nearby aircraft requesting an emergency landing (Scenario A4). CARGO42 executes a missed approach and requests to divert to an alternate Class D airport (Scenario A5). The steps for CARGO42's traffic pattern entry are detailed nominally (Scenario A7) and then revisited for a LC2L event approximately 10 miles from the destination airport (Scenario A7a). A variation of these steps was reviewed for a CTAF airport scenario where CARGO42 again experiences a lost link (Scenarios A8 and A8a). A scenario where DAA caution-level alerts are issued to three of five UA being controlled by a single RP was also discussed (Scenario A6).

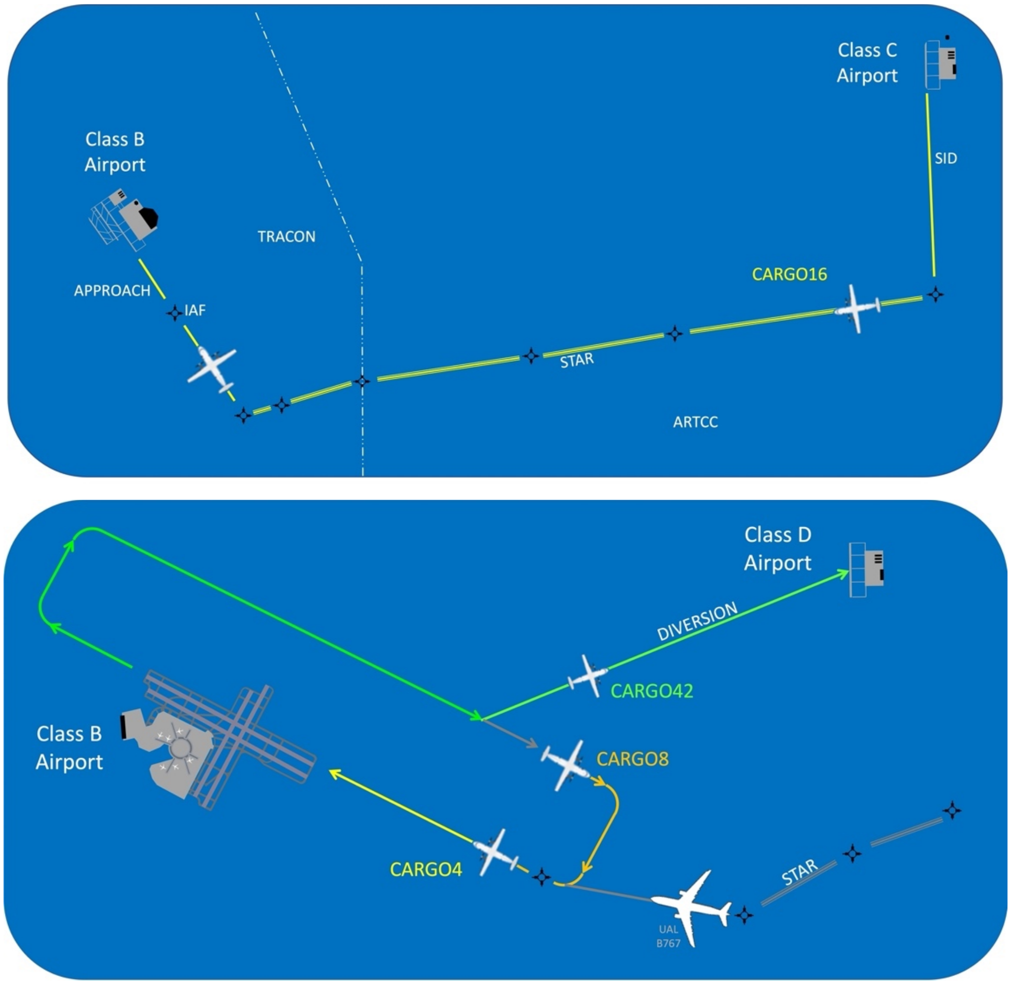

Figure 7. Approach overview graphic depicting CARGO16 en route to a Class B Airport (top) and CARGO4, CARGO8, and CARGO42 in TRACON airspace (bottom).

2.5.3. Surface Operation Scenarios

Three UA were described in surface operations across three scenarios (Table 1; Figure 8). In Scenario S1, CARGO3 is given amended taxi instructions while mid-taxi due to a runway change, including hold-short instructions. In Scenario S2, the CARGO9 RP is given complex taxi instructions by ATC and must identify quoted traffic and modify the UA's speed to allow an aircraft to pass. Finally, after landing and exiting the runway, CARGO12 experiences a LC2L and executes the previously uplinked contingency plan to automatically taxi to the gate (Scenario S3).

Figure 8. Surface operations overview graphic depicting CARGO3, CARGO9, and CARGO12 at a Class B airport.

2.5.4. Preflight Scenario

The single preflight scenario (Table 1, Scenario P1 not pictured) described likely preflight tasks required of the dispatcher, the ground crew, and the RP(s) from before push-back to the request for taxi.

2.5.5. Departure Scenarios

The two scenarios for the departure phase of flight included RP-to-RP handoffs from the Ground RP to the Terminal RP as both CARGO3 and CARGO9 transit from the gate to the runway (Figure 9). In Scenario D1, there is a ground delay program in place for CARGO9's departure and an estimated departure clearance (EDC) time is issued. After the RP completes CARGO3's takeoff checklist and begins to accelerate, the RP receives a warning for an engine anomaly and elects to reject the takeoff and return to the gate (Scenario D2).

Figure 9. Departure overview graphic depicting CARGO3 and CARGO9 at a Class B airport.

3. Results

During the tabletop workshop, researchers solicited participants for recommended solutions to overcome operational challenges that might be encountered when integrating UA cargo flights into the NAS. The first part of the following results section explores seven operational challenges while the second part of the section explores six solution approaches. Operational challenges have been grouped into the following categories:

- Flight route planning
- Separation and flow management
- Traffic pattern integration
- Contingency planning
- Taxi, takeoff, and landing
- Communication
- General m:N issues

Participant solutions have been grouped into the following categories:

- Technology
- Tools and User Interface (UI)
- Best practices and recommended procedures
- Communication
- Roles and responsibilities
- m:N architecture

Recommendations for a notional m:N Operations Center and m:N ratios are also presented. One goal of the current activity was to explore solutions that minimize the potential impacts of autonomous cargo m:N operations on NAS operations and ATC workload. Although most suggestions from the initial session were also addressed by controllers, the pilot participant group accounts for a larger volume of solution ideas presented here due to discussions beginning with the pilot and dispatch SMEs.

It is worth noting that some issues and solutions may seem contradictory, however that is likely due to SMEs' baseline assumptions changing and developing over the duration of their sessions. For instance, attitudes towards the general feasibility of the m:N concept became more positive once participants addressed initial hurdles such as handoff procedures and possible command center configurations. Readers will find that some, but not all, solutions are briefly mentioned in the operational challenges section in order to provide better context to m:N barriers. Likewise, in the solution section, there is some reference to the relevant challenges being addressed. Issues may be solved by a combination of many solutions and those solutions may play a part in solving many different issues. Thus, providing a one-to-one mapping is made difficult by the inherent level of complexity that the m:N concept presents. Also, solutions to issues may highlight technological or procedural gaps to addressing a challenge; only those gaps which were identified by participants are presented in a dedicated gaps section of this report. The issues and solutions presented here are not exhaustive as participants were constrained to the length of the tabletop discussions in which they participated.

3.1. Operational Challenges

The results from the three previous tabletops for the PAAV subproject guided the structure of the fourth. Even though these past activities were focused primarily on ATC impacts, researchers found that pilot-focused feedback from the current tabletop aligned similarly with the issue categories previously identified. The higher-level operational challenges identified by participants and described in this document are about flight route planning, separation and flow management, traffic pattern integration, contingency management, taxi, takeoff and landing, communication, and general m:N challenges. More details on the complimentary solutions to these issues that participants provided can be found in the dedicated Solutions section of this report.

3.1.1.Flight Route Planning

3.1.1.1. Unclear Roles and Responsibilities

One of the biggest challenges for achieving m:N-piloted flights begins before a flight leaves the ground. Determining who signs the release and is legally responsible for the UA is made difficult because there may be multiple RPs (Ground, Terminal, etc.) in control during the duration of a flight. Traditionally, the captain of a flight would review the flight's information and once satisfied, sign the release, therefore assuming legal responsibility. For example, if the first RP for these uncrewed flights were to assume responsibility for the entire flight, then there are questions surrounding what would happen if something went wrong after a handoff to the next RP. Alternatively, if it becomes a requirement that all RPs review a flight's information and sign the release, then some of those RPs may have to do so before the start of their shift. There were many options discussed to remedy this issue, however there were drawbacks to each, and no consensus was reached among participants although they agreed that the rules surrounding responsibility should be clearly defined.

Pilots reported that the number of aircraft they would feel confident remotely piloting at once varied from 1 to 10 depending on the phase of flight, the airspace class, the current conditions of that airspace, as well as environmental factors and UA-specific factors like non-nominal events. In addition to those elements, their estimation was also influenced by the procedures, tools, and technologies available to them. Participants continually asserted that the proper m:N ratio would depend greatly on how their UA were scheduled, how the command center was structured, the presence and roles of support personnel, technological and automation tools to support situation awareness and decision making, as well as external airspace and vehicle conditions. A ratio where two or more RPs work in tandem to control more than two UA simultaneously (e.g., 2:5) could potentially increase the pilot-to-vehicle ratio beyond 1:2 or 1:3.

3.1.1.2. Workload and Technology Limitations

When discussing the preflight scenario, participants indicated that there could be potential impacts to RP workload while retrieving and assessing information for an upcoming flight if they are also monitoring and completing tasks for other aircraft. Whether all of the RP's flights are in the same phase or a different phase, there could be a need to increase the efficiency of RP tasks to accommodate an m:N architecture, even during the preflight planning stage. The checklists that a pilot must complete before a flight also contribute to pilot workload and may be a barrier to maintaining m:N operations, depending on the current state and needs of the RP's other aircraft. Dispatchers could be utilized to alleviate these issues by absorbing some of the tasks that are traditionally taken on by pilots, potentially through advancements in automation or tools available to them. Although automation at the GCS and Dispatcher stations could be developed to assist with RP tasks, participants thought that there may still be some situations that would require a human dispatcher be involved and that automation could not entirely replace that support role.

3.1.2. Separation and Flow Management

3.1.2.1. Workload and Situation Awareness

Controllers often use charted and uncharted holdings to separate and manage the flow of aircraft. During discussion, holding brought up issues surrounding the workload required to choose to accept or reject the hold and, if accepted, the workload required to execute it. Holding times are often accompanied by an expect further clearance (EFC) time, which has implications for fuel constraints, requiring an RP's attention to assess whether they can endure the hold or if they should choose to divert. The pilot participants agreed that accepting and entering the hold would increase RP workload associated with entering the clearance and programming a new contingency plan, possibly making maintaining m:N less feasible at that time if the holding activity is not streamlined.

Like the workload issues surrounding holding, the participants also discussed workload issues regarding metering. Following metering instructions requires more tasks to be executed at a higher frequency for the pilot than a non-metered arrival and approach. Controller instructions may not be predictable and therefore the RP may not be able to enter them in advance, which would be desirable if the RP were also attending to multiple aircraft. Not only does the pilot have more maneuvering instructions to input and execute but metering also requires more frequent communication with the controller. One solution offered to alleviate RP workload while being metered by increasing the use of data link, however, this change may in turn negatively affect both controller workload and RP situation awareness of the surrounding airspace and operations, thus requiring additional solutions to be developed if data link is expanded as a solution.

DAA alerts are designed to attract a pilot's attention so that possible separation events with other aircraft can be avoided. While participants agreed that these alerts are valuable, when viewed through an m:N lens there was some concern about the workload associated with diverting attention to respond to such alerts. If the DAA alerting system is not designed in a way that facilitates quick RP situation awareness, decision making and response, then this could be a barrier to m:N operations, especially if combined with other issues that also might inhibit fast knowledge acquisition and action.

3.1.2.2. Technology Limitations

Although there are benefits to using DAA in an m:N pilot configuration where tools to support situation awareness will be critical, there are also tradeoffs to consider. Pilots recounted experiences when they had been falsely alerted to conflicts and stated that these kinds of false alerts from automation could reduce the ability to maintain control of more than one aircraft, especially if combined with other inefficient processes. Pilots all agreed that DAA is necessary for these kinds of UAS operations and expressed a desire for the capability to be extended further into the towered-airport environment. Automatic maneuvering for Resolution Advisories and warning-level DAA alerts combined with RP-override capabilities for those automatic maneuvers were also discussed. There was some concern about how the RP would be made aware of an automatic maneuver for an RA when assuming that they might be attending to another aircraft at the time of the alert. If important notifications for a certain aircraft are not readily available when an RP is attending to a different aircraft, then it becomes more difficult for a single RP to control more than one aircraft at a time.

3.1.2.3. Unclear Procedures

On the topic of extra spacing, the research team asked the pilot participants about their opinion on UAS capabilities with spacing, between any aircraft, or between other UA. Two of the study remote pilots indicated that, barring any off-nominal events, they could maintain spacing as well as a crewed aircraft if they have access to a comprehensive view and informational support from dispatch to maintain awareness of flight and environmental factors for all their operations. There were no disagreements from the other pilots. While discussing the weather avoidance scenario, pilots implied that there may be a need for extra space from other aircraft in the vicinity if they are given more complex re-routing or vectoring instructions that they must manage along with their other aircrafts' tasks. This aligns with other discussed situations, such as operations in the terminal area, where RP workload may be driven to a threshold. This may cause RP response times to increase beyond an acceptable level, especially if their other aircraft also require significant attention or action.

3.1.3. Traffic Pattern Integration

3.1.3.1. Workload and Situation Awareness

The terminal environment presents a set of unique challenges for m:N operations given its faster pace of tasks than for flights in the en route phase. Pilots must communicate with controllers more frequently in this area and thus have less time to acquire awareness of the situation and enter and execute accurate responses for their UA. Participant pilots indicated that if all of their other aircraft were performing nominally and as predicted (i.e., without vectoring for weather) then maintaining m:N when one of their UA is in the terminal area would be possible. However, if they are actively monitoring or controlling multiple UA in a terminal area, then procedural or technological solutions need to be developed to decrease RP workload. Common, yet workload-intensive operations, happen more frequently in this area, from approach checklists to missed approaches and "visually" following other aircraft, thus solutions must be considered to reduce the associated pilot workload if m:N operations are to be conducted in this airspace. Because discussions were framed around enabling m:N operations, participants suggested that to do so in this environment, technology would need to be incorporated that would facilitate task switching, efficient knowledge acquisition and prompt action.

The airport class that the UA is approaching is also a factor for m:N feasibility. All participants agreed that an approach into a Class D airport would be the easiest to conduct, followed by Class C, Class B and finally Class G. When questioned, both ATC and pilot participants did not foresee any issue arising from integrating IFR (the UA) with surrounding visual flight rules (VFR) traffic around Class D airports as this is frequently done at present with crewed IFR aircraft. Pilots specifically said that normal clearances and terminal area tasks such as detecting traffic and maintaining a position number during approach sequencing in Class D would be possible if they were provided traffic information usually given to crewed flights (i.e., direction of traffic, distance, and position number). Pilot participants noted that the specific cultures of different classes of airports may also contribute to the ease of approaching them. For instance, a Class D airport where high student pilot traffic and limited IFR traffic are present may conduct their operations slightly differently from the operations at a busy Class B hub at peak hours. Airport class, time of day, weather, and RP familiarity with the area are some of the contributing factors to consider when developing solutions to conduct m:N operations in the Terminal area.

3.1.3.2. Unclear Procedures

Pilot and controller participants both identified benefits to conducting VFR-like operations, such as those on an instrument approach in visual meteorological conditions (VMC). Pilots reported experiences where VFR aircraft are sometimes given priority over IFR aircraft in Class D airspace. Controllers supported this when they informed researchers that IFR aircraft require more spacing, thereby reducing the volume that a TRACON airspace can handle, lending to their preference for utilizing VFR procedures for IFR flights when able. Additionally, controllers stressed the importance of avoiding go-arounds at large and busy airports, noting that it is imperative that the UAS can take visual approach clearances once on the final leg, leveraging instruments to maintain equivalent separation and safety. While pilots said that RPs could use current-day technology to “visually” follow an aircraft and call the airport “in sight” with use of tools such as on-board cameras and a DAA system, current-day regulations prohibit issuing visual approach clearances to UA and limiting UA to precision approaches, such as Instrument Landing System (ILS) approaches. Pilots and controllers both agreed that regulation would have to change for controllers to give, and for pilots to accept, visual approach clearances. Although there is a desire for these UAS cargo flights to fly to and from all airport classes, it is yet unclear how each environment can equally support UA operations. In the near-term timeframe, because RPs will not be accepting visual approach clearances for their UA, ATC may need to treat UA slightly differently than crewed IFR aircraft if the weather is clear and the controller is frequently issuing visual approach clearances to IFR flights. When weighing the benefit of lessened workload for always adhering to IFR against the benefit of increased efficiency by “going visual,” pilots agreed that they would prefer not to cancel IFR, that they would feel most comfortable to always fly with active ATC coordination and cooperation.

3.1.3.3. Technology Limitations

Class D airports may lack certain ground infrastructure that is commonly associated with busy Class B or Class C commercial airports. Pilots identified some deficiencies they had encountered at Class D airports, including the physical infrastructure, such as high-speed turnouts and taxiways, and technologies such as radar, ILS, ADS-B (or other technology that allows an RP to monitor traffic). A pilot noted that Class D airports are often converted former military fields and therefore, may lack the space for high-speed turnouts and taxiways, presenting a challenge for faster or heavier aircraft. Additionally, one pilot recounted a personal experience of landing while the radar was out of order, limiting the pattern capacity and increasing delays due to waiting for additional space in the pattern. A dispatcher also reported that sometimes Class D airports lack the technology to enable monitoring the aircraft with the pilots' preferred implementation of a comprehensive view of their operations (e.g., "god's eye view").

3.1.4. Contingency Management

3.1.4.1 Workload and Situation Awareness

Before a pilot encounters an off-nominal situation (e.g., loss of C2 link) or non-nominal situation (e.g., deviation for weather) they must already have planned and uploaded a contingency plan to the UA. Done manually, this is a high workload task, requiring the RP to consider many factors to assure that the safest behavior is pre-programmed after every change to the active plan or route. Communications with ATC also generally will increase at these times, either via radio if still linked or via another means if that link is lost. Controllers stressed that in addition to assuring safety, the UA's behavior needs to be predictable and adapted to the environment. To maintain the safety of all aircraft in their airspace, ATC indicated that they must either receive the contingency plan immediately or be able to reasonably assume the UA's future actions in the event of a contingency event.

Losing C2 link was the most considered off-nominal situation when discussing scenarios with participants. In most cases pilots agreed that losing link would not immediately increase their workload for that aircraft, in fact, they stated that it would potentially reduce their workload because the ability to work towards any tasks for that flight would be interrupted. In the event of a lost C2 link, the primary task for pilots would be to monitor for a notification that link was restored. The workload associated with link restoration is an unpredictable issue with this off-nominal event. Assuming that an RP might be controlling multiple UA in the same geographical areas, it is possible that external factors leading to multiple lost C2 links occur simultaneously, potentially exponentially increasing the workload if all links were restored at the same time. Pilots agreed that if an m:N RP was controlling other aircraft for which they anticipated the need for frequent or quick responses at the time of link restoration, then they may wish to initiate a handoff of one or more of their aircraft, either a nominal UA or the off-nominal one, before link restoration when their workload could reach an unreasonable threshold.

Pilots' choice to hand off their nominal or off-nominal aircraft differed depending on the state of their off-nominal and nominal UA. While handing-off nominal aircraft was agreed to be more efficient as there would be fewer nuances to communicate to the next pilot, the efficiency benefits would always need to be weighed against the environments and states of the other aircraft. For example, if a single pilot was controlling two UA (i.e., m:N = 1:2) where one UA was being vectored into a Class B airport and one was en route, and the en route UA loses link, then it may be preferable to handoff the off-nominal (en route) UA. On the other hand, if the UA on approach loses link, then it may be preferable to handoff the nominal en route UA.

While avoiding weather may not always require contingency management, it necessitates a series of actions that is not always a predicted part of a completely nominal flight; therefore, the authors have categorized this as non-nominal. As expected, participants indicated that workload is a concern in a hypothetical m:N weather avoidance scenario for RP and controllers alike. Moreover, weather is not an instantaneous event, meaning that workload ramps up prior to a weather event, and requires attention and monitoring during avoidance maneuvering and a return to course. On the communication side, weather generally increases frequency congestion in a sector, further adding challenges to m:N operations.

Updating a contingency plan whenever a change to the current routing takes place requires good situation awareness of that aircraft's plan and the surrounding airspace in order to program the safest and most effective plan. Participants indicated that they thought that maintaining adequate situation awareness to continually update contingency plans for multiple vehicles would be difficult without external support, whether by human or automation, and may limit the acceptable m:N ratio.

3.1.4.2. Unclear Procedures

It was unclear during discussion if a nominal or off-nominal aircraft should be handed off in case of a lost C2 link. As this topic was broached throughout the tabletop in different scenarios, pilot participants shared a frequent response of "it depends." As stated above, there is a need to define, either through best practices or formal rules, what an RP should do in various situations that require load-shedding.

While using "canned" contingency plans may reduce RP workload, helping to enable m:N, they lack the flexibility of a manual plan that considers more dynamic airspace factors. To illustrate this, when discussing the "holding" scenario, controllers voiced concern if multiple UA were to lose C2 link while in a holding stack, where multiple aircraft are given the same holding instructions, but are vertically separated. More specifically, they were concerned about those UA having the same contingency plan with the same EFC time uploaded. If measures were not taken to deconflict contingency plans (and actions at the time of link restoration) as they were uploaded, then a high-risk situation may ensue when multiple UA exit the holding stack at the same time, on the same path.

Other specific phases of flight further emphasized the need to investigate appropriate contingency actions for the many scenarios that UA could encounter. Contingency plans while in a common traffic advisory frequency (CTAF) environment may need to differ from those occurring at a towered airport to ensure safety and predictability. Lost C2 links occurring while en route and during taxi, takeoff, approach, and traffic pattern entry were also discussed and participants suggested unique preferred actions for each. A single issue was brought up during a brief discussion of the proper procedures if a UA loses link on a taxiway where the general agreed upon solution was to have the UA be pre-programmed to execute the safest and least disruptive action.

3.1.5. Taxi, Takeoff and Landing

3.1.5.1. Workload and Situation Awareness

Taxi, takeoff and landing require the fastest reactions by pilots and aircraft than during any other phase of flight. The workload associated with maintaining adequate situation awareness, such as airport flow, weather, winds, nearby traffic, and other hazards that help a pilot build a predictive mental picture is more intensive in the airport environment. Monitoring the radio frequency and tracking all this information for multiple airports or airspaces at the same time is a primary barrier to m:N operations, especially if attending to multiple frequencies. The m:N ratio will vary significantly depending on the allocation of aircraft to RPs (e.g., region-based allocation and/or phase of flight-based allocation) and the airports where the UA are operating. Required checklists during taxi, takeoff and landing were also identified as a workload barrier to m:N operations and have situation awareness implications due to drawing an RP's attention away from other operations.

The ground and near-ground environments pose unique challenges associated with an RP's situation awareness that may have a large impact on a pilot's ability to control multiple aircraft simultaneously. These environments change quickly and must be monitored more closely. Maintaining an accurate picture of a single aircraft during this time is already a high workload endeavor, and pilots indicated that doing so for more than one UA at a single airport is possible with procedural and technological assistance. Going further, if one supposes that an RP's aircraft are operating at two or more airports, it becomes clear that tools which facilitate situation awareness acquisition are critical to implement at the GCS and command center. As above, participants illuminated that checklists may cause issues for m:N operations, including confusion between aircraft and corresponding the correct checklist for each of their owned aircraft. An additional issue discussed was how to cope with attention disruption and recovery after a mid-checklist interruption.

3.1.5.2. Technology Limitations

Surface movement currently relies heavily on the human eye and its ability to perceive depth between the ownship and the aircraft they are following during taxi. Alone, RP participants said that currently available on board cameras would not provide sufficient capabilities for enabling an RP to have a clear picture since it lacks the necessary depth perception. However, combined with other or new technologies, it is possible to overcome this limitation in the future.

3.1.5.3. Unclear Procedures

Overall, there was much discussion amongst participants about the feasibility of operating m:N in these environments. Although no single conclusion was reached, it was clear that best practices or defined procedures should be established for how many UA an RP should operate in each phase of flight and when or where handoffs to the next RP should occur.

3.1.6. Communication

3.1.6.1. Workload and Situation Awareness

Monitoring multiple frequencies is prohibitive from a human-factors perspective. To successfully allow m:N operations, this problem needs to be addressed as attending to multiple ATC frequencies approaches the fundamental limit of human perceptive and cognitive abilities. Participants were asked about monitoring multiple UA on a single frequency as well as across multiple frequencies. On a single frequency, pilots underscored how quickly frequency overload can evolve due to weather, emergencies, or simply congestion. This challenge becomes even more compounded when listening to multiple frequencies due to added task switching and task interruption. Pilots indicated that switching between tasks due to interruption would reduce the efficiency of their operations and increase their workload.

Although data link was quoted as a potential solution, it may not be possible to remove verbal radio communication entirely. According to participants, to do so, text-based communication combined with GCS monitoring tools must sufficiently replace the situation awareness gained from listening to a party-line radio frequency.

3.1.6.2. Technology Limitations

Data link could reduce RP workload due to eliminating traditional radio communication, however there are some caveats. Some advantages are that it could mitigate task saturation associated with ATC communication and prevent errors due to messages being stepped on or from partial readbacks. However, while one pilot claimed that data link could enhance their situation awareness if linked to their map, another said that it might reduce their awareness for incoming ATC messages and that there needs to be a balance between communication and streamlining command execution. Other disadvantages mentioned by participants were the possibility for data link input errors and delays stemming from routing messages through the UA's C2 link.

3.1.7. General m:N Challenges

Throughout the days of guided discussion with participants, repeated themes among challenges arose that permeated the concept of m:N in general, rather than being specific to a single scenario. To enable m:N autonomous cargo operations, these overarching human factors, technological and procedural challenges should be addressed.

3.1.7.1. Workload and Situation Awareness

The amount of information a pilot must process will vary with the phase of flight, airspace class, environment, and any off-nominal or unexpected events their UA experiences. However, regardless of the UA's state or the distribution of those aircraft between RPs and airspaces, the workload associated with processing the quantity and quality of information for their aircraft should be improved to increase RP efficiency and therefore their ability to control multiple aircraft. An RP participant estimated that, from their experience, a typical RP controlling a single UA may be monitoring 8 separate screens, a radio with 12 channels, 2 phones, and 3 computers. Although pilots agreed that they can manage the informational volume for one operation, it will become increasingly difficult to do so in an m:N configuration.

It was also suggested that the quality of information may also impact m:N ratios. Information that is received in a more raw form may require an RP to perform additional calculations or time spent to understand the information within the context of their particular operation. Both the quantity and quality of information are areas where technological solutions, either from automation or UI design could be leveraged to reduce pilot workload.

Handoffs, both those that are planned and those initiated for load-shedding purposes were identified as potentially workload-intensive activities that could be mitigated through procedures and automation. Participants discussed the proper timing and location for RP-to-RP handoffs in many different situations and environments, however no single solution fit universally. Optimal timing and location for handoffs should be revisited to ensure that the handoff activity does not overlap with other high workload activities. Additionally, pilots indicated that being physically separated from their RP counterparts could increase the time it took to feel comfortable accepting a new UA if they needed to ramp up their understanding with no prior knowledge of the UA's status. Procedures and technology should also be investigated to facilitate an RP gaining this situation awareness in a timely manner.

Without data link, some pilots indicated that they could manage radio-only communication with ATC, including listening to and responding for a small number of UA under their control on a single frequency, but doing so on multiple frequencies would be much more difficult. They shared that they would not be comfortable with their communication accuracy, their ability to hear all the transmissions meant for them or their ability to always make requests on the correct frequency. Data link was discussed as a solution to this challenge; however, pilots emphasized the benefits to airspace situation awareness gained from monitoring a party-line and indicated that they would prefer to retain the option to do so if possible.

Checklists were discussed by participants as one of many piloting tasks that together, if partially or fully automated, could help reduce the m:N RP's workload to acceptable levels. These tasks should also be investigated for the opportunity to streamline.

3.1.7.2. Unclear Procedures

As the optimal m:N ratio can vary so widely based on both environmental and UA-specific factors, participants discussed the benefits and drawbacks of different options for the characteristics of each pilot's shift. They weighed whether a single RP should be in control of their UA for the duration of the flights, avoiding mid-flight pilot handoffs, or if RPs should have a specialty for their shift, such as ground, terminal or en route operations, transferring control to another RP as the UA transits to the next phase of flight. With the latter UA allocation among multiple RPs, the question of legal responsibility for the flight is accentuated, especially if RP shifts do not begin simultaneously. Pilots expressed that as they sign the release, they are agreeing to accept responsibility for a flight knowing its current condition. Discussions included whether a new release must be signed at every handoff (potentially delaying a handoff), if all RPs must sign prior to the flight, or if only the first RP must sign. Participants stated a similar viewpoint when discussing the procedure when load-shedding is needed.

The point at which m:N becomes difficult depends on many factors such as: RP experience, the state, phase, airspace, and radio frequency of each of their aircraft. If the RP is nearing a point of overload, the pilots agreed that they would want to initiate a handoff of one or more aircraft, preferably before their human performance began to deteriorate. As the handoff process has its own associated workload, this too needs to be considered when deciding whether to keep or hand off aircraft, or even whether to attempt operating m:N at all in certain airspaces. While researchers did not explicitly ask participants how they would measure their performance in relation to task oversaturation, the general takeaway from the tabletop was that pilots are aware of their human performance limits and are conscious to not approach those thresholds. Many different solutions to this were discussed, however, it was clear that best practices be established, either by regulations or by company procedures, to ensure the safety of operations. Additionally, there was no consensus among participants of a single best option for which aircraft to hand off if workload and attention demands reach a point that is not sustainable. As above, they stated that this would depend greatly on many factors beyond the nature of a single event, thus there remains a need to define the proper actions in non- and off-nominal conditions.

3.1.7.3. Technology limitations

Overall, the degree to which m:N operations can scale will be contingent on the technologies in place at that time. Until fully autonomous, the pilots of these flights will need to be in the loop yet supported by technologies that are not currently defined. Although many suggestions were made during the tabletop activity, there is still a need to prioritize which of those solutions to implement first.

3.2. Solutions

The tabletop participants suggested solutions to address the operational challenges outlined above. During analysis, these solutions were organized into the following categories: 1) technology, 2) tools and user interface (UI), 3) best practices and recommended procedures, 4) communication, 5) roles and responsibilities, and 6) m:N architecture. It is worth noting that these participant-generated solutions are sometimes contradictory or imperfect; however, a systemic assessment for the quality, effectiveness, and/or consequences of each solution was outside of the scope of this report.

3.2.1. Technology: Automation

During the tabletop, pilots discussed several near- and far-term automation solutions aimed at reducing the potential increase in RP workload associated with m:N operations. Proposed automation solutions included addressing workload due to maneuvering, communication, and procedural checklists. Among challenges discussed were those that may occur when maneuvering the UA for the purposes of weather, terrain, and traffic avoidance.

3.2.1.1. Maneuvering

While discussing the weather avoidance scenario, pilots proposed that if there are aircraft ahead of the UA in vectoring situations, then automation could assist by retrieving and displaying re-routing information from the aircraft that have recently traversed the same route. This solution would leverage pre-planning and coordinating routes for UA that are traveling along the same flight path.

In the event of a lost link, pilots expressed the desire that automation be capable of handling LC2L logic selection for them. Examples included using forward logic to get the UA to the terminal if ATC has already approved a clearance (a point downstream of the planned flight path). However, if faced with space restrictions such as those found in Class Bravo approach environments and ATC has not yet given a clearance, then use backward logic whereby a UA is programmed to head towards a designated point for turnaround (a point behind a planned flight path). An example of backward logic selection is a UA that is programmed to go into a hold outside of Class B airspace during a LC2L event. Controllers raised a concern with the proposed backwards logic, which will be discussed later in the Gaps discussion. When pilots were asked about their trust in automation during a LC2L event, there was agreement that DAA collision avoidance coupled with autopilot was a key element to obtaining their trust. Controllers had some reservations about the reliance on auto-land at a Class D airport, especially if they have not been made aware of the LC2L status and have not given the RP a clearance to land. Instead, controllers recommend that the best course of action in the case of a LC2L UA approaching a Class D airport would be to execute its published missed approach. This concern was due to the unpredictability associated with Class D environments (i.e., smaller space, unpredictable traffic, and more potential for something to hold up an active runway).

Pilots also considered automation for resequencing, noting that traffic would be the ultimate breaking factor when aiming to increase the m:N ratio. When questioned about what solutions could potentially enable m:N operations in heavily trafficked terminal areas, pilots expressed that future software to automate joining the downwind and integrating into a traffic pattern would help alleviate the increase in workload and attention associated with higher airspace volume. When considering the following scenario—switching attention between resequencing one UA and responding to ATC clearance for another UA—pilots agreed that task switching and maintaining m:N operations is possible in TRACON given the following capabilities:

- a single button-click for executing clearance commands
- well-designed UI that allows for efficiently switching between UA
- systems that allow seamless switching of communication modes (voice and digital)
- alerts incorporated with digital clearances

Notably, pilot participants mentioned that some tools and automation already exist or could be modified and leveraged to make resequencing more efficient in this context.

Maneuvers for terrain avoidance as well as using DAA technology for traffic avoidance was discussed by participants. Pilots agreed that terrain avoidance technology is critical for the success of m:N operations. From past experience, controllers cited the potential for pilot input errors during avoidance maneuvering as a concern to be addressed. Suggestions for reducing such error was for the RP to have good situation awareness about all their owned UA with the help of a well-designed UI, and automation to assist with clearance execution.

There was agreement amongst pilots that DAA alerting be automated so that the UA's intent be communicated with ATC based on priority and alert level. For DAA warning-level alerts, pilots expressed support for software capable of automatically executing the RA maneuver if there were no RP response within a certain time frame. This solution augments the limitation of human performance. Finally, there was agreement amongst pilots that they should have the option to override any automated maneuvering due to a DAA event and have the option to fly manually for as long as they are still adhering to the alerting. When asked if there should be an option for an automated return-to-course function after a maneuver, two pilots preferred that automation display options for the RP to choose from, incorporating logic to not re-engage with the same traffic. Further ideas for improving and leveraging DAA technology that are not directly related to automation will be discussed in the next section.

3.2.1.2. Communication

When considering communication between ATC and RPs, m:N becomes more tenable with the addition of automation for clearance responses. This automation could be realized by "listening" to ATC radio transmissions, identifying the called aircraft, and generating an appropriate confirmation or amended response by comparing against the flight's current characteristics. This would support reducing workload while attending to multiple ATC frequencies at the same time. When automating clearance responses, pilots added that the ability to review their response before automatically sending to a controller is desired, again citing the importance of the RP staying in the loop at all times.

3.2.1.3. Checklists

Pilots also pointed to automation as a solution strategy to reduce the workload associated with preflight, departure, arrival, and handoff checklists. To enable m:N, there is a need to streamline the preflight briefing package. Using automation to go through preflight checklists could address this need, however a dispatcher participant pointed out the limitation in that these checklists will remain a process that requires a human in-the-loop due to variables such as weather and ground delay programs. Checklist automation could also reduce workload associated with handoffs by pre-populating checklist items and then sending the checklists to the relevant RPs via a messenger software.

3.2.2. Technology: DAA

Below are pilots' ideas on how to improve upon and leverage DAA beyond automated resolutions and responses. Some UI solutions included: reducing the number of clicks required to react to a DAA alert and avoiding the need to enter commands for a specific heading or altitude. On the topic of DAA coordination with ATC, there was agreement that it would be useful if the coordination for a DAA alert be similar to those currently done for communicating TCAS II alerts. While it is standard practice that ATC calls the traffic before a pilot sees a DAA alert, controllers may informally ask pilots to visually confirm traffic for them, which adds to pilot workload. Pilots agreed that verifying traffic using DAA is not desirable, especially in the context of m:N operations. An argument for the RP to not call traffic and suggest avoidance maneuvers before the controller does was that it would shift responsibility from ATC onto the RP, blurring that line of responsibility. This shift in task allocation would also add workload for the RP. Overall, pilots agreed that although responding to a DAA alert requires increased attention, m:N operations can be maintained during a DAA event given the solutions discussed for auto maneuvering, including good situation awareness and predictability about auto-maneuvering logic and the ability to verify and override auto-maneuver actions.

3.2.3. Technology: LC2L

During the tabletop we assumed a full loss of C2 link, meaning that in addition to losing communication with ATC and the ability to actively control the UA, the RP would also lose the information about the UA's current state. However, in the approach environment, participants commented that it may be possible to leverage existing technology such as ADS-B and radar to give the RP supplemental situation awareness into the current state of the LC2L UA.

3.2.4. Tools and User Interfaces

The following section focuses on software and UI solutions for environmental situation awareness, pre-flight briefs, and completing checklists. This section's emphasis is on current tools and technologies as well as future tools and technologies that can be leveraged to streamline current UA operations, potentially enabling a greater m:N ratio.

3.2.4.1. Environmental Situation Awareness

The following are tools and UI design suggestions to better anticipate a situation ahead of time, thereby enabling RPs to load-shed earlier and avoid task oversaturation. A key topic in the context of weather avoidance was the weather data itself, both its reliability and the effectiveness of the method by which it is displayed. Pilots desired tools capable of synthesizing finer weather details as well as both on-board and ground-based technologies for gathering weather data. Once a GCS acquires weather data, it would be critical to disseminate it to the RP in a manner that is easily understood. One pilot-suggested a best practice for m:N operations be to leverage pre-departure briefs to allow RPs to start building a picture of the weather with the data available. Another pilot-suggested solution was to have the capability to overlay information that is pertinent to their operations on their displays including, but not limited to, the weather data.

To anticipate task saturation due to environmental conditions, advisory tools that assess factors such as general traffic density, weather, runway changes or closures were suggested. This solution sought to take advantage of predictive software to anticipate non-planned handoffs such as those due to weather avoidance maneuvering. Finally, collocation of the RPs and the dispatcher was a desired and repeated solution to enable m:N operations as evidenced by pilot feedback throughout the week of tabletop discussions. If the RPs could not be collocated, then messaging software and a speed dial function to the dispatcher were suggested as supplemental tools for the RP to gain awareness efficiently.

3.2.4.2. Building a Contingency Plan

Pilots suggested employing a dynamic method to build contingency plans, utilizing drop-down menus to access pre-populated options for maximum efficiency while completing these tasks. In general, the ability to build contingency plans dynamically in response to any event or maneuver while benefiting from some pre-canned options was the most popular method for programming a contingency plan, thereby increasing efficiency and reducing workload. This underscores the participants' desire to stay in the loop and act as a verifier to automation. An additional consideration for contingency events regarded the method to receive clearances, with a solution being to send digital clearances directly to the GCS. One possible drawback to this solution was that digital clearances may require additional RP support personnel to handle these communications for future m:N operations.

3.2.4.3. Pilot Briefings

As part of generally streamlining the user interface for RP briefings, pilots suggested the following solutions to alleviate the workload associated with assembling the brief as well as improving the RP's situation awareness into the UA under their control. Among the solutions was a move from paper to digital briefing packages and flight books to messenger tools to allow an RP to quickly follow up with dispatch, including a remark section for highlighting high level information that dispatch wants the RPs to know (e.g., preferred route). The UA's tail number can be corresponded to a Quick Response code on the briefing package. As stated earlier within automation solutions, software could leverage automation to help assemble these packages on behalf of or in collaboration with the RP.

3.2.4.4. Checklists

The following are pilot and controller suggestions for streamlining the user interface for procedural checklists, including those for departure, mid-flight RP-to-RP handoffs, and GCS position relief briefings. Researchers asked participants for their opinions about the information that should be included to ensure adequate transfer of situation awareness between RPs.

During the departure phase of flight, beyond the preference for checklists to be digitized, pilots wanted the ability to navigate between checklist items with a physical click of a button. ATC participants again pointed to concerns about pilot input error like those discussed during RA and DAA maneuvering. Pilots said this concern could be alleviated by having clear distinction between their owned UA, with one option being to have separate screens for each UA.

While discussing the mid-flight handoff scenario, participants were asked which types of information are necessary to be included on a handoff briefing card. Pilot responses were as follows: flight parameters (such as clearance, altitude, and air speed), any flight anomalies, and airport information (such as taxiway closures or runway changes). As pointed out by one participant, it is possible to miss some information during a verbal handoff, so keeping information at a contextual level and transcribing information if given verbally will be key. Controller handoffs offer a good case study for midflight RP handoffs as they stated that they encounter handoffs and use standard checklists and standard letters of agreement on a regular basis. For controllers, handoffs can entail a verbal relief briefing or can be automated. ATC participants stated that they do not feel they need to know that an RP handoff has occurred.

When asked what information is critical to build a sufficient picture during ground control station position relief briefings, pilots agreed that they would want similar information as would be given during a mid-flight handoff: weather cells, traffic information, and flight parameters. As the UA gets closer to the terminal area, pilots suggested including Automatic Terminal Information Service (ATIS) information and any Notice to Air Missions pertinent to the owned UA in an automatically populated briefing package. Aside from the contents of the briefing package, pilots made additional suggestions to improve situation awareness transfer: have the information displayed and updated regularly and have read-and-reply checklist protocols, where there is affirmative confirmation requirement of each item during a shift change.

3.2.5. Best Practices and Recommended Procedures

3.2.5.1. Handoffs

For planned handoffs such as mid-flight RP-to-RP handoffs and GCS position reliefs, participants recommended the following ideas to make handoffs more efficient and increase safety: handoff at predetermined points, collocate the RPs in the same facility, and use a preferred verbal or visual handoff mode for confirmation. As described previously, an additional solution included using automation to reduce RP workload when completing handoff checklists.

Pilots agreed that standard procedures where handoff points are predetermined would increase predictability while conducting operations in an m:N configuration. Controllers also agreed with this suggestion because they would therefore also be able to anticipate where RP handoffs occur and include that knowledge in their controlling strategies. When determining where or when these predetermined handoffs should occur, pilots suggested selecting expected low-workload times or locations such as before the aircraft is lined up for stabilized approach. Controllers suggested avoiding a handoff when ATC clearances are expected and in congested, time-critical areas. More specifically, both ATC and pilot participants gave the suggestion to plan handoffs at the boundary of a sector or after a frequency change, but before a check-in. For example, when an En route RP is handed off from a center's frequency, they would also hand-off the UA to a Terminal RP, and that new RP would check in on the terminal ATC frequency. When asked about ideal handoff junctures from a Ground RP to a Terminal RP for departure, there was agreement between pilots and controllers that it occur before the UA is in position and waiting on the runway.

Throughout all discussions, pilot participants expressed the importance of being collocated with other RPs in many situations and scenarios. Collocation can aid handoffs by supporting building situation awareness. The receiving RP can start building situation awareness by observing the display "over-the-shoulder" prior to receiving the formal briefing and taking over the UA. When asked if the goal of sufficient transfer of situation awareness and safe handoff can still be achieved if RPs are not collocated, pilots agreed that such goals are still tenable with the right support and technology.

As for the handoff method, pilots proposed verbal and visual modes for handoff confirmation as the preferred standard procedure for improved situation awareness. A specific example used by one pilot was that the incoming RP verbally take control of UA in addition to giving a visual confirmation that there's a transfer of physical control (i.e., push-to-pass, shake-to-take). If a nonverbal handoff is necessary due to an emergency with the RP, a best practice of keeping an updated set of electronic notes with critical flight information such as clearances could aid this process.

When conducting GCS position relief briefings, pilots suggested turning the controls over to the incoming pilot before the transfer of full responsibility. This would allow the incoming RP to build a picture of the operation while being observed by the out-going RP. Next, pilots suggested staggering the pilot who is monitoring and the pilot who is flying, such that RP 1 is flying while the incoming pilot monitors, the roles would then switch where RP 1 is monitoring while RP 2 flies the UA. This overlap could help ensure that there are two pilots actively involved during this critical stage of the operation. Finally, pilots suggested assigning UA that are regionally close to each other to contain all owned UA to a single map and therefore the same environmental conditions. This solution stems from the observation that situation awareness of the environment would take longer to gain if the incoming UA were operating in a different region. One possible drawback of a regional aircraft allocation strategy that the SME's had not discussed is that filing new flight plans for all owned UAs affected by the same weather could be m:N prohibitive.

Consistent with the “it depends” theme of the tabletop results, a planned handoff can be made difficult by varying factors such as type of airspace and particular phase of flight. As such, it then follows that participants prefer to avoid handoffs during high workload times such as when operating in a Class B airspace or during intensive phases of flight (i.e., climb or descend stages). The role that dispatch may play in load-shedding handoffs will be discussed in the roles and responsibilities section.

3.2.5.2. Non-Planned Handoffs

The following are solutions pilots described when it comes to handoffs that are due to unplanned events that cause a need to load-shed one or more flights for weather avoidance maneuvers, lost C2 links, and other off-nominal triggers. Regardless of the event that necessitated a non-planned handoff, pilots began the tabletop by expressing the desire to keep the off-nominal UA and handoff their nominal UA during load-shedding. This was true when considering handoffs due to weather, vectors for traffic avoidance, emergency procedures, increased ATC communication due to an off-nominal event, or an off-nominal event in a CTAF environment. This workload-based decision for handoffs is rooted in the notion that it may require more time to transfer situation awareness of an off-nominal UA versus a nominal UA. As such, it may be more efficient to keep the off-nominal UA and load-shed an “easier” flight to another RP. As the tabletop progressed, the decision making process for non-planned handoffs was further refined as workload-based, keeping the UA that involves tasks for which an RP is already accomplished and skilled, even if that meant keeping the off-nominal UA. Just as familiarity with a task allows for efficiency, so does familiarity with the geographic area; therefore, there was agreement amongst pilots that it would be easier to maintain m:N operations if all owned UA were located in the same areas.

Expanding upon a general rule of thumb to keep off-nominal UA and handoff others, pilots considered some specific events like rejected takeoffs and LC2L during a traffic pattern entry. In the event of a rejected takeoff, pilots considered the pros and cons of having the Terminal RP or the Ground RP to assume control of the UA. The logic behind the idea for the Ground RP to act as the RP in this situation was that the wheels might still be on the ground; however, the Ground RP may already be busy preparing the next UA and may not always be the best choice. This question underscores the potential need for 1:1 ratio at the time of takeoff because surface operations, including taxi, takeoff and landing, are inherently involved phases of flight. Factors such as these for deciding proper m:N configurations in different environments will be discussed further in the section on recommended m:N ratios. Surprisingly, there was agreement amongst pilots that in the event of a LC2L during a traffic pattern entry at a Class D airport a handoff is not necessary because there would not be significant added workload, and that workload may even be reduced. The single suggestion mentioned here was to automate and streamline communication, but there was otherwise no need for a handoff.

A good general practice according to pilots was to have pilots on standby and ready to receive handoffs in order to accommodate a sudden need to load-shed. On the topic of determining whether an individual RP has the capacity for accepting another UA, a bidding or workload scoring scheme was suggested as a future best practice. Specifically, pilots suggested an automated workload assessment tool, whereby flight characteristics and self-reported RP workload levels determine a capacity score for each RP. If the capacity scores have not reached a maximum threshold, then an RP would receive a request to accept or reject a handoff.

3.2.5.3. Building a Contingency Plan

On the topic of contingency planning during a LC2L event, researchers were interested in elucidating expert opinions on several questions, ranging from the best method of building contingency plans to the best time and location to update those plans. Additionally, researchers collected ideas on best practices for contingency planning if pilots experienced a LC2L event during traffic pattern entry in a Class D airport environment, a missed approach in a CTAF environment, in the descent to landing phase in a Class B environment, and finally, while taxiing. Generally, pilots believed that maintaining m:N when one aircraft experiences a LC2L, for example during a weather avoidance scenario, is tenable if: 1) the contingency plan has been approved by ATC; 2) the UA is not in a terminal area; and 3) digital clearances are used in lieu of clearances given by voice.

As to the best method of building contingency plans, pilots agreed that drop-down menus with a selection of pre-populated options would facilitate their ability to dynamically build contingency plans in a holding scenario, as mentioned earlier in the UI section. Outside of holding scenarios, the general consensus among participants was to have uplinked contingency procedures with the flexibility to respond with canned amendments. Controllers supported pre-canned amendments as it would increase predictability, which was cited as more important to them than specificity.

There was a consensus that the safest junction to update contingency plans as part of a standard operating procedure would be before executing deviations to the current plan, although one participant argued that executing deviations and contingency plans at the same time would be efficient and safe. When asked by researchers about their preferred order for updating contingency and operational plans, pilots thought that updating the contingency plan first or at the same time as updating an operational plan were both good options, with the deciding factor being how much time there was left before a change.

If links on multiple LC2L UA are restored at the same time, one potential issue discussed was if those UA attempt to execute the Standard Terminal Arrival (STAR) at the same time. To address this issue, pilots stressed the need to deconflict "expect further clearance" times if more than one UA regains link simultaneously. To that end, controllers stated that they already overestimate their EFC times, which would be helpful in the event of multiple restored links.

Pilots also generated ideas for best practices during LC2L tailored for specific events or maneuvers: traffic pattern entry in a Class D airport environment, executing a missed approach in a CTAF environment, a descent to landing phase in a Class B environment, and taxiing on the ground. In the event of a LC2L during traffic pattern entry at a Class D environment, controllers agreed that contingency plans should be tailored to each individual airport and developed with TRACON and/or tower controllers' involvement. Pilots were divided over best LC2L solutions during traffic pattern entry, specifically between holding, auto-land, or executing a missed approach. On one hand, holding could decompress time and allow for checklist completion, but it could also add workload due to going off the approach course and therefore require additional coordination with nearby traffic by controllers. There was some agreement that once the UA crosses its final approach fix, it may be too late to hold. Controllers agreed that executing the published missed approach would be safer than utilizing auto-land LC2L logic.

Pilots stated that the best course of action for LC2L events while on a missed approach in the CTAF environment would be to go-around and re-enter the traffic pattern as part of a standard operating procedure. This would allow for nearby airborne traffic to clear and allow the RP time to coordinate with dispatch to mobilize a ground crew to expeditiously tow the UA from the runway, especially in the case of a single operational runway. Additionally, pilots suggested a speed dial function to CTAF to notify nearby traffic, or perhaps calling the en route facility so they may advise other traffic of the presence of the LC2L UA, inform about the UA's intentions, and treat it like emergency.

In the case of a LC2L during the descent to landing phase of flight in a Class B environment, the desired programed LC2L logic was one that routes the UA to alternate airports, such as Class D airports, to minimize potential impacts to the safety and efficiency of the other traffic at the Class B airport. Having two sets of approach clearances—normal and contingency clearances—was also stated as a good practice, allowing the UA to execute a contingent approach once the UA passes the Initial Approach Fix (IAF).

Finally, in the case of a LC2L while taxiing, pilots and controllers agreed that the LC2L UA should come to a stop rather than auto-taxi back to the gate. One argument against shutdown logic was that if one were to utilize C-band as a link in this environment, the ground crew, who has the visual of the LC2L UA and could be qualified to control the UA, could taxi the UA back to the gate, relieving the RP, who may be off-site, thus minimizing costs and disruptions.

3.2.5.4. Separation and Flow Management

The following are a set of recommendations for best practices or proposed future standard procedures related to separation and flow management. Among the topics covered are solutions for weather avoidance, operating in CTAF environments, metering, and traffic management initiatives, including holding and sequencing.

While the UA approaches weather cells, the pilot group expressed the need to proceed with caution and give more space around developing weather. Specifically, two pilots were quoted as preferring to give their UA a 25 nautical mile buffer around a weather cell. This is similar to an MQ9 pilot's description of the standard practice when conducting their military operations, which may serve as a good model.

Due to the unique nature of CTAF environments, separation may be challenging for UA operations. Specifically, CTAF has a high student pilot and alternative traffic presence (e.g., gliders, ultralights, drones) which could be problematic due to the increased potential for non-cooperative encounters with said diverse traffic. Using an extended downwind leg could allow more time to state UA intentions with nearby traffic on CTAF and could also account for speed differences with slower aircraft. Another proposed method to ensure shared situation awareness in this airspace was to separate UA by having them enter the downwind from 5,000 feet above the pattern altitude, which is a tactic quoted as presently seen in the military. These solutions address some of the unique challenges of managing the unpredictability of CTAF environment while uncrewed aircraft conducts IFR operations and considers the varying characteristics of nearby traffic.

The pilot group's feedback on metering was that controlling four UA without increased levels of automation or data link, even with modern day metering whereby pilots follow vectors for path stretching, would not be a plausible ratio. However, automation technology with supporting auto-land functionality, specifically for ILS Category III approaches, are already available and could be expanded. Additional general comments regarded data link as a solution for conducting m:N operations in airspace where metering is in effect as neither pilots nor controllers regarded metering via data link as significantly adding to their workload. However, controller participants expressed several other concerns about digitizing metering instructions. As controllers normally provide brief contextual information or an explanation behind their metering instructions, they expressed concerns for the degradation of situation awareness if metering instructions are sent via data link instead of voice. Additionally, metering may need more immediate responses than data link can support. There was consensus amongst pilots that reliable required time of arrival capability is essential for m:N operations. They believed that easily executable pre-planned maneuvers would decrease the workload associated with following metering instructions. They also expressed wanting to know their EFC time, with a preference for slowing down vs "zigzagging," the latter of the maneuvers requiring more workload.

Finally, we come to a set of recommendations from pilots on best practices for holding. General pilot feedback was that UA do not necessarily require extra spacing over what is currently used for crewed flights. Pilots expressed a desire for near-term technology and tools to support decision making for holding and diversions. Specifically, they wanted a tool capable of calculating the minimum required fuel based on EFC time inputs to ease the increased m:N workload challenges caused by focusing attention to those calculations. When discussing sequencing and following aircraft by way of sensor spacing, an agreement amongst pilots was that the RPs should remain responsible for maintaining separation if they are following another aircraft.

3.2.6. Communication

As discussed with operational challenges for m:N autonomous cargo operations, communication is likely the biggest limiting factor for achieving an m:N ratio. With this in mind, researchers tasked pilot and controller groups with providing solutions to the problem of managing and attending to multiple communication streams simultaneously. In this section we discuss data link as a solution to the m:N communication issue, managing multiple ATC frequencies, and additional best practices for communication.

3.2.6.1. Data Link

Data link has immense potential to address the inherent communication workload difficulty when operating in an m:N configuration. In addition to discussing the pros and cons of data link, participants considered improvements to the data link UI and additional technologies that could serve as a complement to data link.

Data link is most useful when attempting to reduce task saturation by initiating non-immediate requests or responding to similar ATC commands. For complying with immediate ATC instructions, such as descend or climb instructions or traffic alerts, pilots regarded voice communication as the preferred method of communication. This also addresses increased delays responding to data link messages. A potential downside of data link is that pilots can become attenuated to the data link messages and therefore could run the risk of missing a voice communication.

Pilots made several recommendations for improving the usability of data link technology. For improving situation awareness, pilots suggested collocating data link messages with a map, having a dedicated data link display, and/or color-coding messages of a particular UA to match a color within a corresponding data link window. Additionally, it was suggested that an audio tone be added to grab attention if it is diverted elsewhere and having a message queue to enable the operator to go back and read past messages. This was something pilots said could easily be coded into a chat software similar to that which is used extensively in military operations. To enable m:N operated flights, pilots suggested using a keyboard and mouse instead of traditional FMS and control inputs and to enable better copy and paste functionality. As a best practice, they wished to have the ability to maintain radio contact but streamline command execution to reduce their workload. Controllers worried about input error by the RP, and recounted possible UI solutions for reducing these errors as discussed previously

Finally, pilots suggested that, where available, to leverage ground-based fiber optic technology to relay messages to and from the GCS rather than through the UA to reduce delay and increase robustness. Also, integrating a customizable messaging software for FMS inputs was a desired solution for pilots.

3.2.6.2. Managing Multiple ATC Frequencies

To manage multiple ATC frequencies, pilots highlighted some key automation capabilities to improve their workload, such as automating clearance readbacks. One caveat was that the RP must have the ability to read the readback response before it is sent to ATC, meeting pilots' preference to stay in the loop. Automating maneuver response for simple ATC clearances, those which usually take 10–15 seconds to execute, was mentioned as another method to reduce an RP's workload. When responding to multiple clearances at the same time, pilots suggested prioritizing responding to maneuvering clearances before advisories as part of a standard operating procedure. Controllers cited experience where pilots have mistakenly answered calls for other aircraft, raising the issue of a m:N pilot's ability to distinguish between their own multiple aircraft. In addition to presently practiced procedures to use call signs and squawk assignments, participants suggested automation at the GCS to markedly distinguish the UA that is being called to reduce the potential for RP confusion errors.

Pilots also considered ways to streamline the UI when managing multiple frequencies. Some ideas included having a single and automatically populated push button for frequency transfers and a UI that differentiates between different owned UA such as a color coded textual-based interface. Having a dedicated dial to switch between different owned UA was thought to be especially useful when managing multiple UA on the same frequency.

3.2.6.3. Other Best Practices for Communication

The following is a summary of the best practices for relaying contingency plans during a LC2L event as well as RP and controller communications during a DAA event.

Controllers noted their preference to have the contingency plan sent directly to them rather than through the Traffic Management Unit (TMU) as they would want that information as quickly as possible. This addresses situation awareness and planning issues stemming from delays in communication when a link is lost. Though pilots may follow up by detailing the UA's contingency plan, this information may not be immediately necessary for ATC—a mere notification of the LC2L event may be initially sufficient to begin their separation strategies. Another solution provided by the controller group was to develop new phraseology to quickly exchange information in the event of a lost link. Controllers suggested to immediately notify ATC of a LC2L as part of a standard operating procedure. This could include automatically squawking 7400, alerting the controller to expect a defined action (e.g., for the UA to continue on a heading until the RP calls), and enabling the controller to begin issuing instructions or alerts to any impacted surrounding traffic.

Controllers and pilots also noted preferences for handling DAA communication. Pilots noted that in the event of a DAA action, they would prefer to inform controllers immediately due to the need for additional coordination. With a DAA warning-level alert, controllers worried that the pilot group's proposal for automatically notifying controllers of maneuvers may cause radio step-ons and suggested that if implemented, logic should be utilized to replicate the flow of radio communications.

3.2.6.4. Ground Control Station Organization

Pilots all supported the notion of working in a geographically collocated RP "cell." All pointed to the benefits of working in this kind of structure, such as an increase in communication efficiency, especially during handoffs. The handoffs have implications for the seating arrangement, such as where the RP commanding a UA is physically located beside the incoming relief RP. More on the physical arrangement of such a cell structure can be found in the later GCS section of this report.

3.2.7. Roles & Responsibilities and m:N Architectures

During training, participants were asked to imagine an m:N architecture configuration that could support the scaling up of aircraft, or the "N." As part of that challenge, participants proposed potential new roles and responsibilities of dispatchers, remote pilots, and in some cases, additional support roles that may arise as part of the proposed new m:N architecture.

3.2.7.1. Dispatch Roles and Responsibilities

Additional responsibilities that the dispatcher participant imagined taking on included the following: being instrumental in pilot load-shed activities during a diversion or weather delays and identifying candidate handoff points prior to an event or when delays become known. As previously discussed, detecting weather and other environmental factors earlier allows more time to prepare for handoffs. A similar concept was quoted for traffic management initiative scenarios (e.g., holding and sequencing), with the idea to leverage dispatchers and their tools to allow more time for contingency planning, potentially increasing feasible m:N ratios.

To support a handoff, the dispatcher suggested that information support personnel (perhaps another dispatcher) be available during RP briefings for the RP to query for updates or general questions before gaining the next UA. This was thought to be especially critical when there are multiple RPs downstream of the initial RP.

3.2.7.2. Remote Pilot Roles and Responsibilities

One of the first challenges m:N operations face begins while the UA is still on the ground, even as the flight plan is created. During a 1:1 operation, there is a single pilot that signs off for the plan that dispatchers provide. In an m:N configuration, the pilot and dispatcher group agreed that every RP assigned to a UA should sign off on their portion of the flight, however, it was not clear at what point in the flight this must happen. Discussions of surface operations complicated this matter further. The pilot group stated that the legal responsibility for signing off on the flight plan on the ground should fall on maintenance, dispatch, and/or the Ground/Terminal RPs. In the case that there are both Ground and Terminal RPs, the consensus was for both to sign off on the preflight brief. Additionally, it was also suggested that RPs' sign off status is clearly displayed on the dispatcher's screen in case one or more RPs rejects a portion of the flight.

In the case of a midflight handoff, one challenge was addressing where legal responsibility for controlling a UA (i.e., the remote pilot-in-command responsibility) begins and ends. Pilots suggested that while all RP's are given a flight plan and briefed at the start of the shift, legal responsibility would begin after the incoming RP verbally takes control in addition to giving a visual confirmation that there is positive control (i.e., push-to-pass or shake-to-take). Seat swaps were also considered acceptable if collocated. Another stated good practice was for the outgoing RP to stay in the room (if collocated) for a few moments to observe and confirm positive takeover has occurred. The implication of seating arrangement, such as where the outgoing and incoming RPs are situated relative to one another, may influence the allocation of RP roles and responsibilities, specifically regarding who is in command. Though the question of legal responsibility was raised, ultimately, no consensus was able to be reached during this tabletop.

While discussing off-nominal scenarios that occur on or near the ground, such as rejected takeoffs, one suggestion was to establish a rule based on the UA's altitude to determine which of the two RPs (RP-Ground or RP-Terminal) would retain or assume control of the UA. Beyond off-nominal situations, researchers also heard general feedback from the pilots that it may be good practice to schedule the most experienced RPs to the more intensive terminal roles.

3.2.7.3. Amended and New Roles

In the case where a Ground- or Terminal-RP is not operating on site at the airfield, there will be a shift in who is legally responsible for performing a proper aircraft pre-flight "walkaround" from the pilot to the ground crew. Although the RP may have access to photos or video of the UA, there is a limit to the level of detail that can be seen remotely. It was also proposed that the ground crew have the ability to take over remote control of the UA for taxiing in the case of a LC2L on the ground. Therefore, training for this ground crew role is critical. There is a need to define this new role in addition to specifying the training and licensing requirements for those who assume this responsibility of performing the preflight aircraft inspection and potentially taxiing tasks. Finally, additional ground crew roles may be necessary in m:N operations, specifically regarding pushback and off-nominal recovery.

Researchers also heard proposals for dedicated staff to monitor communications via radio (if data link is not yet fully integrated or efficient), supporting RPs and increasing m:N ratios. It was noted that a similar practice is already in place in the Airforce and Army's Joint Surveillance and Target Attack Radar System command and control center. Finally, as previously noted, pilots wanted digital clearances sent to the GCS, however, this may require modifications to ATC systems and procedures, possibly introducing supporting roles for both RPs and controllers.

3.2.8. m:N Operations Center

The following section outlines the pilots' and controllers' combined vision for the GCS with m:N operations. All three sessions concluded with a brainstorming activity to notionally "design" a hypothetical UA command center. Participants built upon each other's suggestions and contributed best practices from their own current industries to arrive at the suggestions detailed below.
Figure 10 summarizes key takeaways from participants regarding the organization of a hypothetical command center for autonomous cargo flights. The layout for this command center was created purely abstractly during the tabletop and participants stressed that companies will ultimately construct layouts that best suit their unique operations. The designs proposed by participants considered situation awareness, teamwork, and the overall scalability of the center.

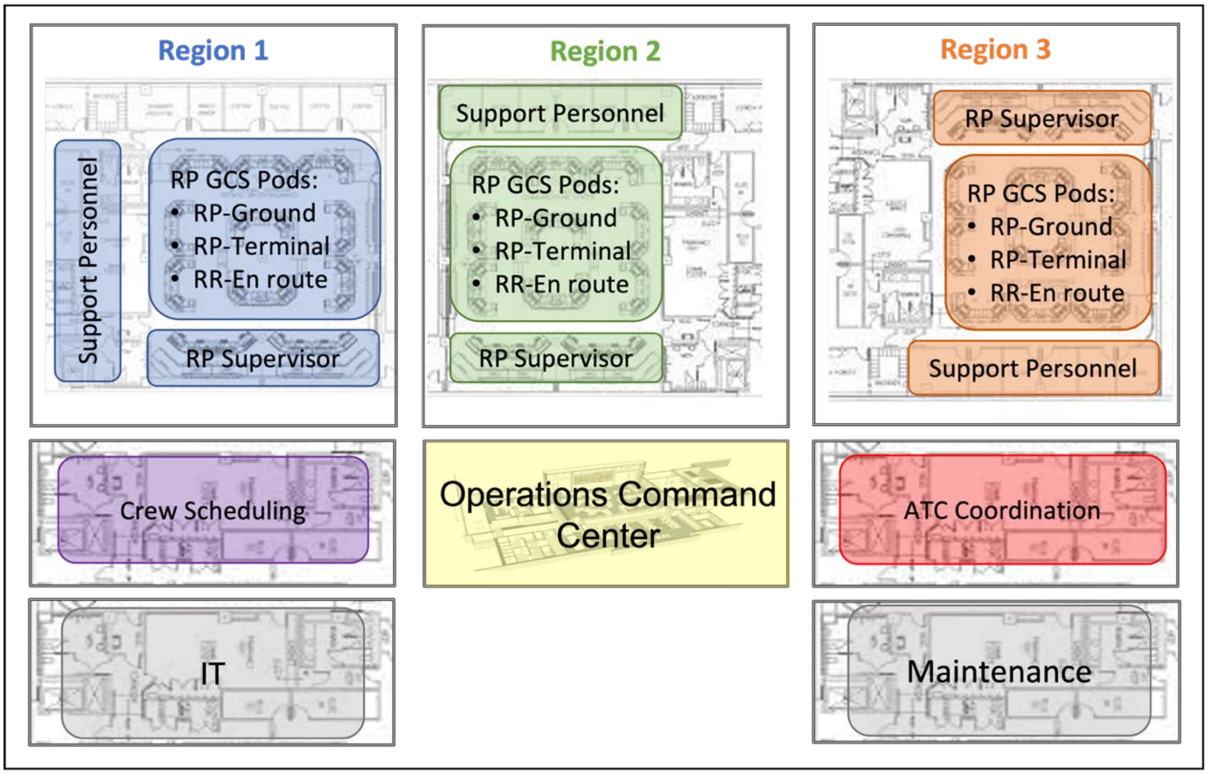

Figure 10. Notional Ground Control Station organization. Note: IT = information technology.

Chief amongst the organization suggestions was the desire to centralize operations such that RPs are located close to their support personnel to facilitate quick communication. This could also provide a redundant means of communication, which dispatcher participants noted exists in major centers presently. The support personnel located near the RPs included the following roles:

- RP manager
- Shift supervisor(s)
- Dispatcher(s)
- ATC coordinator(s)
- Maintenance control
- Weather staff

Pilots suggested grouping RPs by operational region (e.g., West Coast, Midwest, and East Coast for a nation-wide operator). This was suggested to facilitate easier midflight handoffs by ensuring pilots are handing off within a common region. For each regional pod, the Ground and Terminal RPs would be positioned nearest one another due to their frequent interactions, with Enroute RPs grouped nearby.

The remaining agents would then be assigned locations based on the level of their "hands on" nature. Thus, the further the role is removed from communication functions, the farther they are located from the RP pods. These agents were identified by participants as the ATC coordinators, the regional operations coordinators, and the crew schedulers. It was stressed that the center be equipped with large displays within view of all agents, and that RPs have a larger scale monitor for all their UA, weather, contingencies, nearby traffic, NAS status, and other useful flight information. Agents which require even less frequent or urgent communications, and thus placed on the perimeter of the center, were identified as Information Technology support and aircraft maintenance coordinators. In addition to the above command center attributes, participants also said that it will be critical to include an onsite backup generator in case of power outages as well as a full secondary backup facility in case the primary facility goes offline. Regarding compatibilities across multiple GCSs, pilots prescribed standardizing GCSs and training to avoid issues arising from incompatible GCS configurations or software.

3.2.9. Recommended m:N Ratios

Pilots reasoned that due to the highly hands-on nature of the terminal environment and the many hazards that surface operations present, including other traffic and obstacles, it may me necessary to minimize the m:N ratio in such areas. More to the point, pilots believed that a dedicated, single-operator control (1:1) of UA would be a viable solution before the flight transitions to an m:N piloting configuration in less complex airspace. Table 2 summarizes the recommended m:N ratios that were generated by the participants during the tabletop discussions. The resulting ratios highlight the recommended maximum “N” (number of aircraft) for a single “m” (number of remote pilots).

Table 2. Recommended m:N Ratios

Operational Context	*Recommended Maximum Ratio*	*Explanation*
Surface operations	1:1	This environment presents hazards in close proximity such as other traffic and obstacles. Sequential (1:1) control of UA on the ground can increase safety.
Terminal area	1:1	Like surface operations, the terminal area requires the UA to operate in close proximity to traffic and obstacles, leading to a recommended ratio of 1:1.
Missed approach or diversion	1:1	The workload associated with these events are prohibitive to multiple operations.
Class B TRACON	1:2 or 1:3	Owning to its typical congestion, the m:N ratio in Class B airspace should not exceed these ratios.
UA operating in different airspaces (managing multiple frequencies)	1:2 or 1:3	Data link, automation, and improving the UI may facilitate managing instruction from multiple controllers, but there is a limit on how many audio streams a human can adequately attend to simultaneously.
Approach	2:5	A 2:5 ratio may be preferrable to 1:3 due to the complexity and frequency of actions in this phase.
En route	1:5, 1:7 or 1:10	Assuming that communications issues are solved, the maximum number of flights pilots thought they could safely control while en route varied from 5 to 10 UA in nominal operations.

Pilots expressed hesitation when asked if it would be tenable to handle four UA if all are operating within the same Class B TRACON environment. Owing to typical congestion factors and availability of the enabling automation, communication, tools, and user interface technologies, including those discussed in the methods section assumptions, pilots felt more confident in their abilities if the m:N ratio in this airspace did not exceed 1:2 or 1:3. When discussing managing multiple frequencies due to owned flights operating in different areas, 1:2 or 1:3 was quoted as the maximum number of UA that pilots felt they could manage simultaneously. Controllers expanded on this by suggesting that a 2:5 ratio may be safer than 1:3, since there would be multiple pilots sharing the task load of five UA versus a single pilot handling three UA. This solution aimed to reduce errors associated with poor situation awareness and high workload of the RP.

The en route phase of flight, unlike the departure and approach phases, was agreed by all to lend itself to higher m:N rations. Specifically, the maximum number of UA that pilots thought they could control was said to be five, seven and ten across three participant responses. The reasoning was that the workload during this phase of flight is typically the lowest with fewer obstacles, lower density of other flights, along with less frequent maneuvers and communications with ATC.

The following are some stated breaking points for enabling m:N operations. Pilots unanimously agreed that it was highly unlikely that m:N could be maintained in the event of maximum task saturation due to situations such as missed approaches or diversions. Furthermore, it was a pilots' opinion that future regulations may be established that require RPs to only operate a single UA while in terminal or ground environments.

4. Gaps

The following sections present gaps between current-day variables and proposed solutions to the operational challenges discussed. These gaps were generated by the participants across all solution sections: automation and technology, communication, tools and UI, and current-day regulations. It should be noted that this is not a formal gap analysis and only includes those gaps which were mentioned by the participants of this tabletop workshop.

4.1. Gaps in Automation Technology

As researchers expected, automation technology that is presently available will not support m:N operations entirely. However, given advancements in technology, specifically automation that is programmed with robust logic and capable of handling many types of maneuvering (weather avoidance, traffic avoidance, resequencing, and auto-land), m:N operations will become more feasible. Controllers addressed several gaps towards the suggested solutions during discussions about automation. Specifically, one point raised by controllers during a LC2L discussion was the potential lack of predictability in UA behavior while a link is lost. Namely, the idea for UA to turnaround before entering a restricted airspace during a LC2L event was found problematic by the ATC group due to their responsibility to manage traffic behind the UA, continuing to ensure separation. When pilots discussed auto-land during LC2L in Class D airspace without a prior landing clearance, controllers disagreed with the proposed idea, citing the unpredictable nature of this particular airspace environment and stated a need to request a landing clearance. Regarding DAA, controllers expressed concern about the proposed idea of canned automated communications for DAA alerts because they were wary that the logic may congest the radio unless automated voice communications can replicate the flow of radio.

Finally, while data link was touted as a key component to solving m:N communications, it is not without drawbacks of its own. Namely, in addition to situation awareness of traffic and the environment that is gleaned through a party-lines, some contextual information that controllers regularly give via voice may be lost if RP communications are conducted only through data link.

4.2. Gaps in Communication

Researchers expected that m:N operations may challenge the limits of human performance and workload when it comes to communication. While data link and other communication related solutions represent promising avenues to increasing the m:N ratio, it is worth noting the limits of what technology and automation offer in the context of this particular challenge. For instance, having a dedicated dial to switch between different owned UA could be especially useful when managing multiple UA on different frequencies. However, this solution may not solve a larger situation awareness issue. What could be at stake is a loss in situation awareness when attention is shifted between different frequencies when using voice to communicate, and loss of a mental picture of the traffic in the surrounding airspace when using data link. Ultimately, future m:N research should aim to address this critical gap in communication technology.

Another gap that emerges due to communication relates to the potential increased workload for controllers in the case of LC2L, specifically brought up during a discussion on metering. Controllers suggested that RPs immediately notify them in the event of a LC2L as part of a standard operating procedure. This may include for example, the UA automatically squawking 7400, and the RPs letting the controller know to expect the UA to perform a known set of actions. Managing this event coupled with managing downstream traffic effects was thought to lead to an increase in ATC workload.

4.3. Gaps in Tools and User Interfaces

As previously stated in the challenges section, pilots may be faced with information overload when controlling multiple UA. The desire for a smart UI display was critical in the general discussion of information overload that pilots reported as likely to occur with m:N. To illustrate this challenge, a dispatcher reported that they now have between 10 and 20 different types of applications they use to gain a full snapshot; however, there are currently some limitations in the ability to process the information in a usable manner. Additionally, two pilots reported that most of their available overlay information is rarely used, colloquially quoting that "99.9% of information is not needed." Therefore, there is a desire for a smart user interface for future m:N operations to overcome information overload.

Considerations must also be made for checklist execution. Additional contextual information that is helpful when considering m:N operations is the time required to complete these checklists, as mentioned for pre-departure and takeoff tasks. Care must be taken to understand how much time it takes to adequately assess individual checklist item. For context, it was reported that the first checklist of the day requires 5-10 mins, while the rest can be performed relatively quickly, in as little as 20 seconds. However, weather, flight restrictions and non-nominal information will take the most time and attention to acquire. These are additional nuances that should be accounted for when designing tools and UIs to support scalable m:N operations.

4.4. Gaps in Best Practices and Procedures

One of the recurring themes during discussions was that eventual solutions will depend on many factors, and it is unlikely that one solution will fit all issues. Particularly mentioned regarding RP handoffs was that it will be important for future research to be directed in a manner which facilitates clear understanding of how standard handoff procedures will differ in different airspace, events and phases of flight.

4.5. Gaps in Regulation

Since m:N operations is a further-term concept, one can assume that current regulations do not support all the solutions participants discussed during this tabletop. As such, we can expect regulatory gaps when solving m:N operational challenges. A systematic review of regulatory gaps was outside the scope of the tabletop; however, this section will summarize those which were specifically identified by participants.

In the case of metering, under the current regulations, the responsibility for separation falls under the role of controllers. However, as mentioned earlier, pilots described a potential shift to self-metering automation technology. For self-metering practices to become a reality, current regulations would have to change and redefine the responsibility of controllers and RPs with the use of such technology.

While discussing traffic pattern entry scenarios, pilots weighed the pros and cons of cancelling IFR on a downwind versus remaining under IFR while being on a visual approach clearance. They voiced their preference to land with positive ATC oversight and not to cancel IFR. Unless regulations change, possibly including requiring a UA to have robust auto-land capabilities with an onboard camera which enables RPs to call an airport, runway, other traffic, and any other potential obstacles "in sight", controllers did not support the idea of UA acting in a VFR-like manner because it would not be compatible with how they presently manage traffic.

4.6. Gaps in Workload Management

When m:N-operated flights are coupled with factors such as weather events, traffic, or LC2L events, the potential to create dynamic shifts in workload at any given moment for both controllers and pilots may increase. Since the m:N operations discussed were predicated on the idea of assigning route portions of multiple UA to a single RP, any factors encountered for one RP could cause workload disruptions for downstream RPs.

Tabletop 4 was designed with the idea that proposed solutions for overcoming m:N challenges were primarily viewed through the lens of pilots with controllers vetting those proposed solutions. However, it was clear that some of these solutions may blur or shift the responsibility from RPs to controllers. Over the course of session two, controllers identified areas where proposed mitigations might impact their own workload, specifically impacting their separation strategies. For instance, if the UA was to experience a deviation during a LC2L, weather avoidance, or any other non-nominal event while in active time-based metering, such deviation could impact ATC workload if controllers must move the other aircraft around the UA.

5. Conclusions

Tabletop 4 demonstrated both the complexity and feasibility of integrating m:N remotely piloted regional cargo operations into the NAS. Researchers successfully leveraged SME knowledge to identify challenges and generate a wealth of solution ideas to address barriers to seamless m:N integration in a scalable way. Although the focus of this activity was on m:N operated flights, it should be noted that many of these solutions may also address challenges present for both uncrewed and crewed flights in configurations beyond m:N.

Data collected from participants identified the following technology, automation, and UI design capabilities and solutions that could contribute to reducing an RP's workload and enhancing their situation awareness:

- Develop or utilize robust automation tools that are programmed with flexible logic and capable of executing maneuvers in a wide array of challenging situations, events, and environments, such as weather, terrain and traffic avoidance, resequencing, and off-nominal situations.
- Keep the RP in the loop during automated events by employing automation-override capabilities coupled with displays that show automation's decision logic so RPs may maintain sufficient awareness of their operations.
- Use reliable and comprehensive data sources (such as for weather and traffic) that are frequently and consistently refreshed or updated.
- Create well thought-out procedures for flight routes and maneuvering to ensure predictability in the behavior of the UA for RPs and controllers alike.
- Streamline the UI to include a view of an operation that encompasses all available flight and environmental information that may affect that operation, information overlay functionality, visibility into all owned UA and features to prevent RP input errors arising from mistaking one of their UA with another.

m:N operations necessitate an accompanying m:N architecture to address the workload limitations of an RP handling multiple UA. A few noteworthy best practice suggestions for the physical structure of the team are described below:

- Collocating RP operators within operational "cells" that are also collocated with other supporting personnel (e.g., dispatchers, ATC coordinators, maintenance staff).
- Clearly assigned RP roles, such as ground, terminal, and en route-specific pilots.
- Define which RP is legally responsible for each stage of a flight (i.e., remote pilot in command), especially before the flight and during RP-to-RP mid-flight handoffs.
- Leverage dispatchers, ground crews, and other personnel for RP support (i.e., using a surrogate to conduct the preflight UA walkaround inspection).
- Establish robust practices for safe and efficient RP-to-RP handoffs (to reduce workload while maintaining situation awareness during the transfer).

Determining exact m:N ratios for future operations was outside the scope of Tabletop 4; however, key factors were identified that may impact the resulting ratios. Listed below are a selection of conditions that participants repeatedly circled back to as variables that would likely impact the viability of m:N operations:

- Airspace complexity (i.e., airspace class, traffic density and flow, types of other nearby operations, others' familiarity with UA operations, weather, arrival and departure routes, and ATC vectoring or holdings).
- The amount of interaction the airspace requires of the UA and attention of the RP.
- Presence or absence of RP support personnel.
- Maturity of RP supporting UI design and technologies, including automation.

- Presence or absence of clear and appropriate procedures for seamless transfer of a UA from one RP to another.
- Level of training for RPs, ATC, ground crews, dispatchers, etc..
- Level of ATC and RP (or carrier) pre-coordination on best practices in the case of non-nominal or off-nominal events.
- Communication architecture: radio-only, data link-only, or a combination of both.
- Presence or absence of best practices to segment flights for RPs (versus a series of end-to-end flights) that operate in similar geographical areas.
- Presence or absence of flight schedules designed to minimize high workload situations for m:N-operated flights.

Variables like the ones above contributed to the emergent "it depends" theme of the tabletop, as that phrase was a consistent response when SMEs discussed m:N viability. This underscores the complexity of this problem space that attempts to balance the expected increase in workload and reduction of situation awareness that may be encountered throughout when implementing these types of remotely piloted operations.

Due to the nature of the subject matter, this tabletop was not designed to investigate the risk associated with each challenge nor the impact of integrating a mitigation. It therefore may seem difficult to know which solutions to prioritize implementing; however, some of the most repeated solution suggestions may be prime candidates for future research. The first of these is to design procedures so that RP workload is minimized by lowering the amount of environmental complexity for which they must maintain awareness. Experts on individual airports and airspaces should be consulted when devising procedures to lessen potential impacts of these operations on controllers and surrounding traffic. A second area for future research is the design of GCS interfaces and UAS control center configurations. These should provide the RP(s) easy access to relevant information that heightens situation awareness and includes automation to ease workload when switching between tasks and/or UA. A third future research recommendation is suggestive automation to assist RPs decision speed and appropriateness while still keeping the RP in the loop. Finally, automation (with RP oversight) could be investigated to facilitate the efficiency of handoffs, checklists, communications, routine flight tasks, and contingency planning. Focusing future research efforts on these most prominent solutions has the potential to address an array of challenges in the pathway towards the seamless integration of m:N remotely piloted cargo flights into the NAS.

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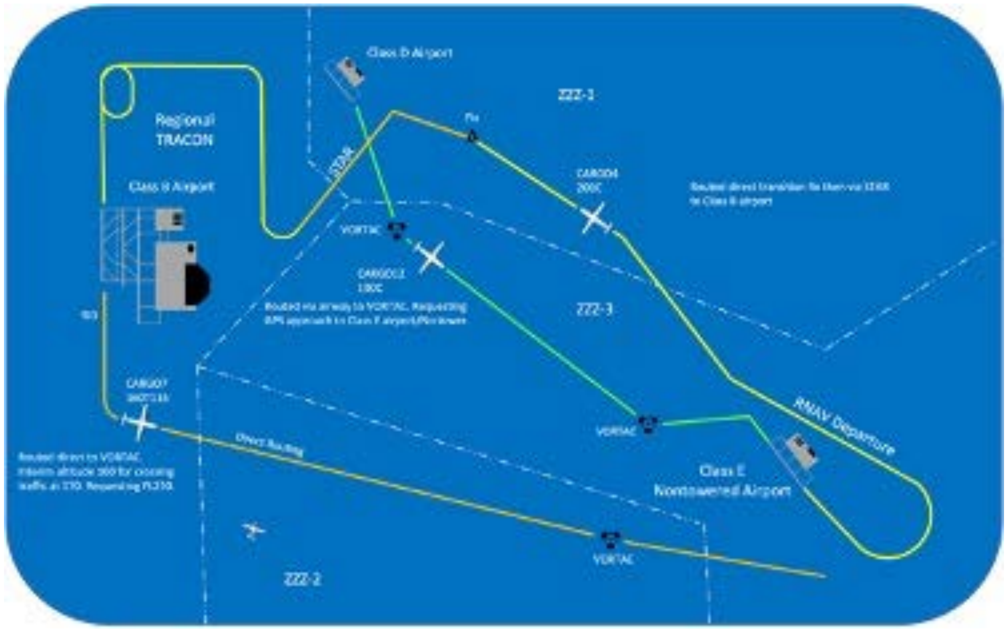
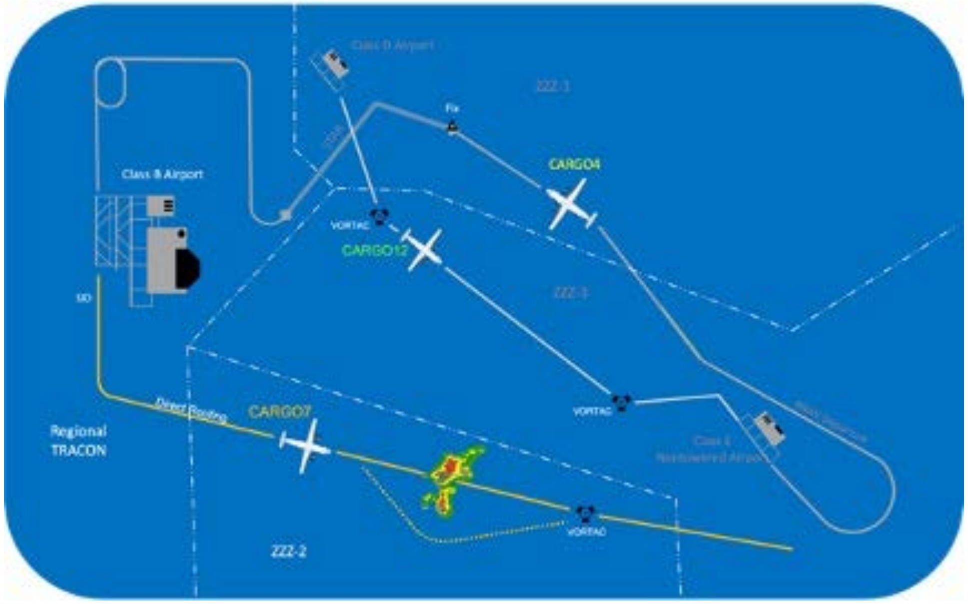
Appendix A. Scenario Narratives and Graphics

6.1.1. Phase of Flight: En Route



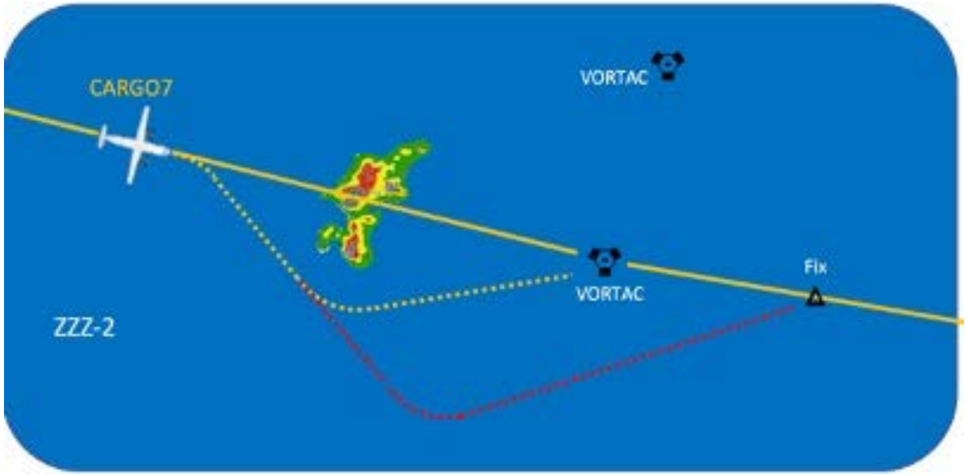
- This scenario involves three fixed-wing twin turboprop uncrewed aircraft on regularly scheduled cargo flights in central Washington state.
- All the flights are routine IFR operations that depart in the afternoon hours in VMC.
- CARGO4
  - — Is at FL200, 20 nm southeast of the first point on the STAR to the destination Class B airport.
  - — It is communicating on Sector 1's frequency.
  - — Sector 1 is currently moderately busy sequencing eight aircraft on the airport's common STAR.
- CARGO12
  - — Is at FL190, 50 nm from a small municipal Class E airport without an operating control tower and has requested the instrument approach.
  - — It is communicating on Sector 3's frequency.
  - — Sector 3 has light traffic with a few VFRs and two IFR aircraft in addition to CARGO12.
- CARBO7
  - — Is departing the Class B airport and on a direct route to the first waypoint.
  - — It is climbing to an interim altitude of 16000 feet for crossing traffic and is requesting FL250 as a final altitude.
  - — TRACON has completed a handoff to Sector 2 and is transferring communications.
  - — Sector 2 has moderate traffic and is working successive departures (including CARGO7) from TRACON along several routes. Sector 2 is also giving advisories to several VFR aircraft.
- All three UAs are under the control of a single RPIC-Enroute that is monitoring all the applicable ATC frequencies for their operations/ownships. The RPIC-Enroute is responsible for flying the UAs within airspace controlled by an Air Route Traffic Control Center (ARTCC), or when their UAs are arriving or departing from Class D airports or Class E airports without an operating control tower.
- C2 links for communication and Command and Control are available for the end-to-end operations of these Auto Cargo flights.

Scenario E1: Weather Avoidance



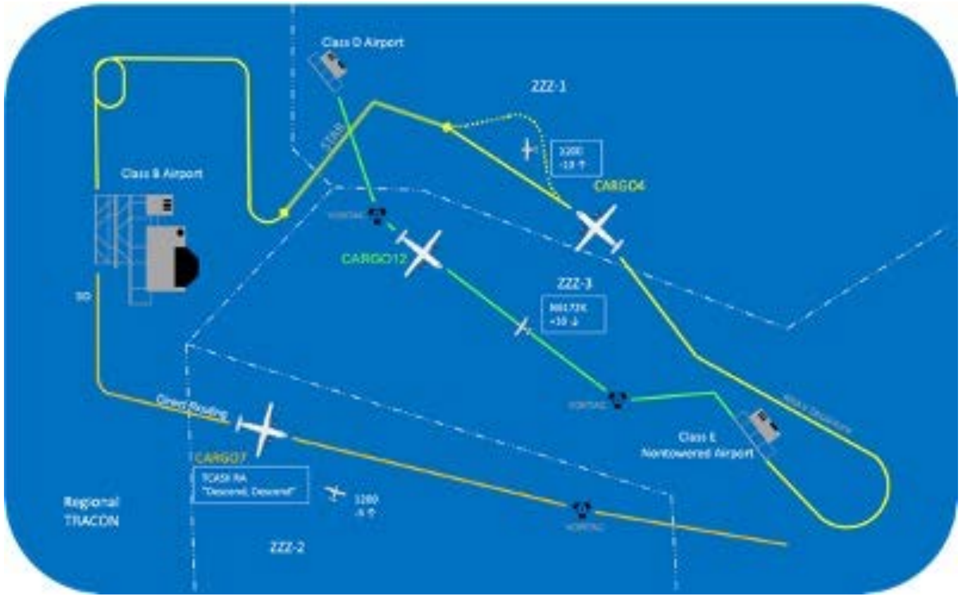
- 40 nm into the CARGO7 flight, the RPIC-Enroute, using information received from the weather radar and visual systems on board, determines that a deviation is required to avoid a line of convective activity building along a ridgeline ahead of the aircraft.
- The RPIC-Enroute contacts the Sector 2 controller and requests a heading that will take the aircraft around the observed weather.
- The controller approves the heading and requests that the RPIC-Enroute advise when clear of the weather.
- The RPIC-Enroute turns CARGO7 right 20 degrees, monitors their weather display, and updates the contingency plan to the next fix in the flight plan.
- The RPIC-Enroute advises the controller when CARGO7 has cleared the line of weather and requests clearance to rejoin the filed route.
- The controller clears CARGO7 direct to the VORTAC on the original flight plan as previously cleared.
- The RPIC-Enroute reads back the clearance and turns CARGO7 to the VORTAC.

Scenario E1a: LC2L During Weather Avoidance



- The RPIC-Enroute turns the aircraft right 20 degrees, monitors the weather display, and updates the contingency plan to the next fix in the flight plan.
- As CARGO7 proceeds around the weather, the RPIC receives a warning that a LC2L has occurred (which begins the LL timer at T0). CARGO7 squawks 7400 and the T1 timer initiates.
- The RPIC-Enroute contacts the enroute facility via landline, declares a LC2L and advises them of the current loaded contingency plan.
- The enroute controller acknowledges the information from the RPIC-Enroute and forwards that information about CARGO7 to future sectors and facilities.
- At T2, CARGO7 turns to the fix specified in the updated contingency plan.
- The enroute controller advises the RPIC-Enroute of the aircraft's position and altitude and that CARGO7 has turned to the next fix in the contingency plan.
- The RPIC-Enroute acknowledges the position report and the maneuver.
- s the aircraft approaches the original route, the RPIC-Enroute reestablishes the link with CARGO7, reestablishes radio communication with the enroute controller, and advises that the LC2L has been resolved.
- The enroute controller acknowledges the resolution, re-clears CARGO7 via its original routing, and forwards the update to future Sectors/facilities.
- The RPIC-Enroute reads back the clearance and configures CARGO7 to proceed according to that clearance.

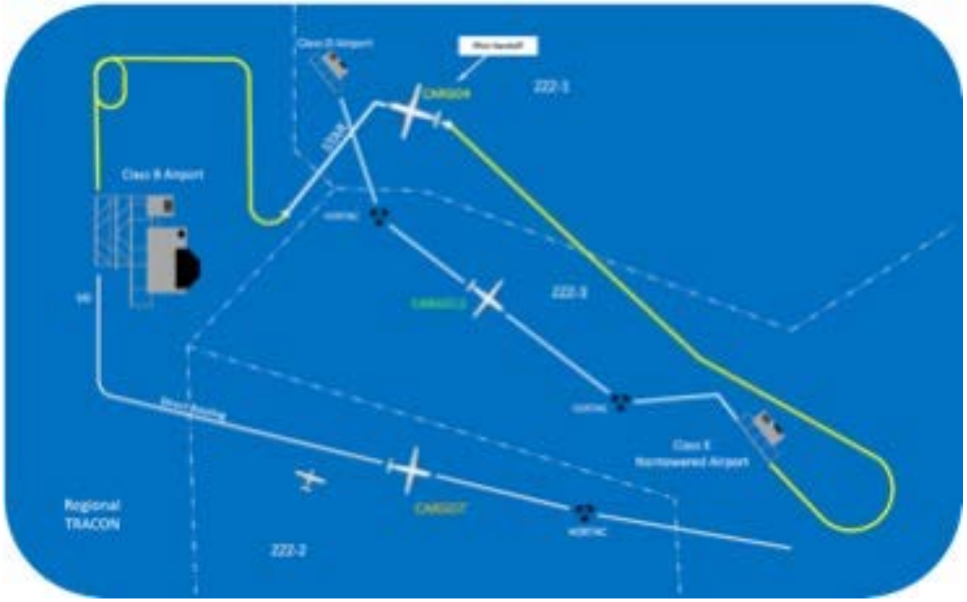
Scenario E2: DAA Alerting and Guidance



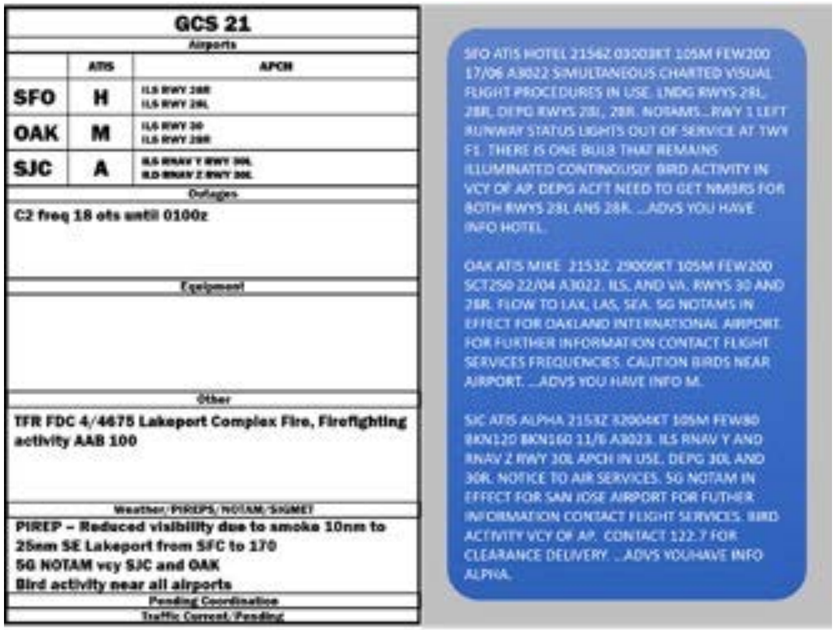
- For each of their three operations the RPIC-Enroute observes separate Corrective alerts for traffic on their DAA display.
- The RPIC contacts the Sector 1 controller and requests a deviation 10 degrees right of course for CARGO4 to avoid traffic.
- The Sector 1 controller approves CARGO4's the request for traffic deviation and requests the RPIC to advise when ready for further clearance.
- As the Sector 1 controller completes their transmission, the RPIC receives a TCASII RA for converging traffic for CARGO7. CARGO7 automatically begins to descend in response to the "Descend, Descend" RA.
  - — The intruding VFR aircraft is not equipped with TCAS II, so any maneuvers it makes will not be explicitly coordinated between TCAS systems.
- The RPIC contacts the Sector 2 controller and advises that CARGO7 is responding to an RA.
- The Sector 2 controller acknowledges the RA for CARGO7.
- The RPIC instructs CARGO4 to turn 10 degrees right to avoid traffic.
- The RPIC observes traffic for CARGO12 on their DAA display and contacts the Sector 3 controller to request an altitude change due to traffic at 12 o'clock.
- The Sector 3 controller denies the request and advises the VFR traffic has CARGO12 in sight, is expediting its descent, and will be no factor.
- The RPIC acknowledges the controller's transmission and withdraws the request.
- The RPIC receives a "Clear of conflict" report for CARGO7 from the TCASII system. The RPIC contacts the Sector 2 controller, advises clear of traffic, and requests to return to CARGO7's original altitude.
- The Sector 2 controller clears CARGO7 to its original altitude.
- The RPIC reads back the clearance and climbs CARGO7 to the assigned altitude.
- The RPIC calls the Sector 1 controller, advises that CARGO4 is clear of traffic, and requests direct to the next fix in their flight plan.
- The Sector 1 controller clears CARGO4 as requested.
- The RPIC-Enroute reads back the clearance for CARGO4 and commands CARGO4 to proceed to the next fix on its route.

Scenario E3: Mid-flight Pilot Handoff

- At a safe and optimal time or location the RPIC-Enroute initiates a transfer of CARGO4 to the RPIC-Terminal to continue the flight.
- The RPIC-Terminal brings the flight status and information up for CARGO4 on their GCS and after reviewing the information, advises the RPIC-Enroute to proceed with the transfer.
- The RPIC-Enroute instructs CARGO4 to continue climb to FL230 as they've been instructed by the Sector 1 controller.
- The RPIC-Enroute briefs the RPIC-Terminal of the current position, altitude, and current ATC clearance for CARGO4. They give a description of CARGO4's current flight status, explain the expectation at the arrival airport, and highlights all applicable traffic that's near CARGO4. The RPIC-Enroute answers the RPIC-Terminal's questions.
- The RPIC-Terminal advises the RPIC-Enroute that they "have the aircraft."
- The RPIC-Enroute acknowledges that the RPIC-Terminal now has control of CARGO4.



Scenario E4: Ground Control Station (GCS) Position Relief Briefing



GCS 21

Airports

	ATIS	APCH
SFO	H	ILS RWY 28R ILS RWY 28L
OAK	M	ILS RWY 30 ILS RWY 28R
SJC	A	ILS RNAV Y RWY 30L ILS RNAV Z RWY 30L

Outages

C2 freq 18 ots until 0100z

Equipment

Other

TFR FDC 4/4675 Lakeport Complex Fire, Firefighting activity AAB 100

Weather/PIREPS/NOTAM/SIGMET

PIREP – Reduced visibility due to smoke 10nm to 25nm SE Lakeport from SFC to 170
5G NOTAM vcy SJC and OAK
Bird activity near all airports

Pending Coordination

Traffic Current/Pending

SFO ATIS HOTEL 2156Z 03003KT 10SM FEW200 17/06 A3022 SIMULTANEOUS CHARTED VISUAL FLIGHT PROCEDURES IN USE. LNDG RWYS 28L, 28R, DEPG RWYS 28L, 28R. NOTAMS...RWY 1 LEFT RUNWAY STATUS LIGHTS OUT OF SERVICE AT TWY F1. THERE IS ONE BULB THAT REMAINS ILLUMINATED CONTINOUSLY. BIRD ACTIVITY IN VCY OF AP. DEPG ACFT NEED TO GET NMBRS FOR BOTH RWYS 28L ANS 28R. ...ADVS YOU HAVE INFO HOTEL.

OAK ATIS MIKE 2153Z. 29005KT 10SM FEW200 SCT250 22/04 A3022. ILS, AND VA. RWYS 30 AND 28R. FLOW TO LAX, LAS, SEA. 5G NOTAMS IN EFFECT FOR OAKLAND INTERNATIONAL AIRPORT. FOR FURTHER INFORMATION CONTACT FLIGHT SERVICES FREQUENCIES. CAUTION BIRDS NEAR AIRPORT. ...ADVS YOU HAVE INFO M.

SJC ATIS ALPHA 2153Z 32004KT 10SM FEW80 BKN120 BKN160 11/6 A3023. ILS RNAV Y AND RNAV Z RWY 30L APCH IN USE. DEPG 30L AND 30R. NOTICE TO AIR SERVICES. 5G NOTAM IN EFFECT FOR SAN JOSE AIRPORT FOR FUTHER INFORMATION CONTACT FLIGHT SERVICES. BIRD ACTIVITY VCY OF AP. CONTACT 122.7 FOR CLEARANCE DELIVERY. ...ADVS YOUHAVE INFO ALPHA.

- The relieving RPIC:
  - — Plugs into the GCS and reviews the Status Information Area.
  - — They observe position equipment, the operational situation, and the work environment.
  - — They listen to voice communications and observe other operational actions.
  - — They observe surrounding aircraft, terrain, and obstructions.
- Once the relieving RPIC has familiarized themself with the work environment, the relieving RPIC indicates to the RPIC being relieved that the position has been previewed and that their verbal briefing may begin.
- The RPIC being relieved:
  - — Briefs the relieving RP on any abnormal status items not listed on the Status Information Area as well as on anything of special interest that might call for additional explanation or discussion. (Example: "The C2 frequency #18 outage may be extended, expect an update fifteen minutes prior to the planned return time.")
  - — They brief on reported weather and other weather-related information.
  - — Any pending coordination that needs to be completed.
  - — On surrounding traffic that might be applicable.
- The relieving RPIC asks questions as necessary to ensure their complete understanding of the operational situation and the RPIC being relieved completely answers any questions that are asked.
- Once the relieving RPIC is satisfied that they have understand of all the activity at the GCS, they make a statement or otherwise indicate to the RP being relieved that position responsibility has been assumed.
- The RPIC being relieved releases the position to the relieving RPIC.
- The relieving RPIC then:
  - — Checks, verifies, and updates the information obtained during the briefing,
  - — And checks their position equipment.
- The RPIC being relieved:
  - — Reviews the Status Information Area, written notes, and other prescribed sources of information and advises the relieving specialist of known omissions, updates, or inaccuracies.
  - — Observes overall position operation to determine if assistance is needed.
  - — If assistance is needed, provides, or summons it as appropriate.

Scenario E5: Management of Multiple ATC Frequencies

- When CARGO12 is 50 nm from the destination airport, the RPIC-Enroute contacts Sector 3 and requests lower altitude and the instrument approach for the Class E destination airport.

9

- The Sector 3 controller clears CARGO12 to 11000 feet and advises that he has received the request for the instrument approach.
- As the RPIC-Enroute reads back the clearance for CARGO12 to Sector 3, the Sector 1 controller also concurrently clears CARGO4 to 10000 feet.

10

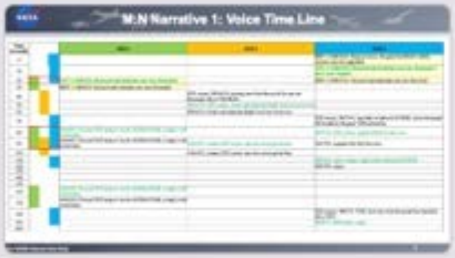
- The RPIC-Enroute reads back to Sector 1 the clearance for CARGO4.
- The RPIC-Enroute commands CARGO12 to descend to 11000 feet and then commands CARGO4 to descend to 10000 feet.
- The TRACON controller working CARGO7 instructs the RPIC-Enroute to contact the Sector 2 controller.
- The RPIC-Enroute acknowledges the frequency change for CARGO7 and checks in on Sector 2's frequency. They advise they are leaving 14000 feet for 16000 feet and request further climb.
- The Sector 2 controller clears CARGO7 to climb to FL180 and to expect further clearance in 3 minutes. The Sector 2 controller quotes crossing IFR traffic at FL190 as the reason for the interim altitudes.
- As the Sector 2 controller is finishing the traffic advisory for CARGO7, the Sector 1 controller clears CARGO4 via the STAR to the destination airport and to comply with restrictions.
- The RPIC-Enroute reads back the clearance for CARGO7 to Sector 2 and acknowledges when to expect further clearance.
- The RPIC-Enroute commands CARGO7 to climb to FL180 and also reads back to Sector 1 the clearance for CARGO4 to proceed via the STAR.

11

- The RPIC-Enroute configures CARGO4 to fly the STAR as assigned and to comply with the restrictions.
- As CARGO7 passes the crossing traffic, the Sector 2 controller clears the UA to FL230.
- The RPIC-Enroute reads back the clearance to Sector 2 for CARGO7.
- The RPIC-Enroute instructs the CARGO7 to continue climb to FL230.
- The Sector 3 controller clears CARGO12 to cross the initial approach fix (IAF) at or above 8000 feet and clears them for the instrument approach.
- The RPIC-Enroute reads back the clearance for CARGO12 and configures the UA to cross the initial approach fix and fly the instrument approach.
- The Sector 2 controller instructs CARGO7 to contact Sector 4 on 127.4 (not pictured).

12

- The RPIC-Enroute acknowledges the frequency change for CARGO7, contacts Sector 4 on 127.4 and advises leaving FL210 for FL230.
- The Sector 4 controller clears CARGO7 to climb to FL250.
- The RPIC-Enroute reads back the clearance for CARGO7 to climb to FL250 and instructs the UA to climb to the assigned altitude.
- The Sector 3 controller terminates radar service to CARGO12, requests that the RPIC-Enroute report cancellation of the IFR flight Plan to flight service or on this frequency and instructs the UA to change to the CTAF frequency.
- The RPIC-Enroute acknowledges radar service termination for CARGO12, reads back request for IFR termination, and changes to the CTAF frequency.

9


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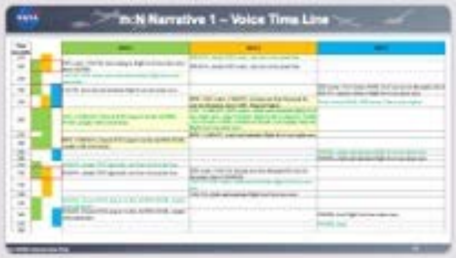

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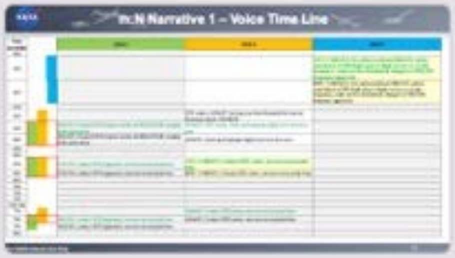
12


Scenario E6: Data Link Management

1
- When CARGO12 is 50 nm from the destination airport, the RPIC-Enroute constructs and sends a data link message to Sector 3 to request lower altitude and the instrument approach for the destination airport.

2
- The Sector 3 controller observes the request in the queue. Using the altitude trial planner they construct a data link message for CARGO12 to descend and maintain 11,000 feet and uplinks the message.
- As the Sector 3 controller sends the message, the altitude in the Full Data Block (FDB) highlights in blue.

3
- Using the trial planner, the Sector 1 controller constructs a message for CARGO4 to descend and maintain 10,000 feet and uplinks the message.
- As the message is sent, CARGO4 altitude in the controller's FDB highlights in blue.

4
- The RPIC-Enroute observes messages in the Data Link Controls display and loads messages for CARGO12 and CARGO4 into the FMS for the respective UAs.
- As they accept and execute the messages for CARGO12 and CARGO4, altitude commands are sent to both UAs and "WILCO" messages are returned to the controllers and the blue highlights are removed from the FDBs.

5
- As the TRACON controller completes the handoff of CARGO7 to Sector 2 at the predesignated distance from the boundary, CARGO7 shifts to Sector 2's frequency and datalink address.

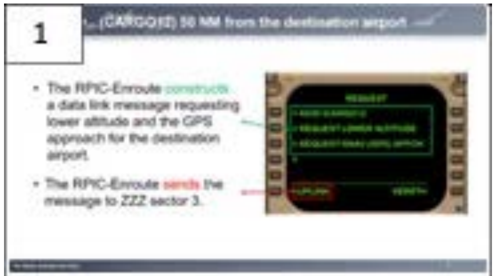
6
- The RPIC-Enroute checks CARGO7 in on the voice frequency for Sector 2 and advises they are leaving 14000 for 16000 and requests further climb.
- The Sector 2 controller observes the check-in report in the datalink queue and clears CARGO7 to climb to FL180 and expect further clearance in 3 minutes.

7
- The Sector 1 controller uses the trial planner to construct a message to clear CARGO4 via the STAR.
- As the message is sent, CARGO4's route block in the Full Data Block (FDB) highlights in blue.

8
- The RPIC-Enroute observes CARGO4 messages in the Data Link Controls display to proceed via the DELTA3 STAR. They load the message into the FMS.
- The RPIC-Enroute accepts and executes the message for CARGO4, and the route command is sent to the UA instructing the aircraft to fly the STAR and comply with restrictions. As the command is issued, CARGO4's "WILCO" message is returned to the controller and the blue highlight is removed from the FDB.

9
- Using the altitude trial planner, the Sector 2 controller constructs a message for CARGO7 to climb and maintain FL230 and uplinks the message to CARGO7.

10
- As the message is sent, CARGO7 altitude in the FDB highlights in blue.
- The RPIC-Enroute observes the CARGO7 message to climb to FL230 and loads the message into the FMS.
- The RPIC-Enroute accepts and executes the message for CARGO7, and the altitude command is sent to the UA instructing the aircraft to climb and maintain FL230. As the command is issued, the "WILCO" message is returned to the controller and the blue highlight is removed from the FDB.

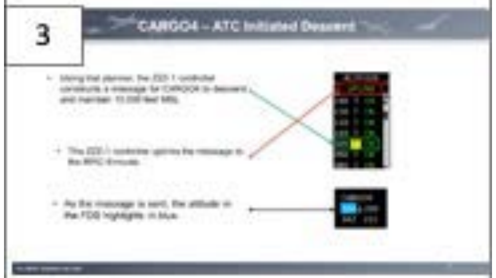

1

(CARGO12) 50 NM from the destination airport

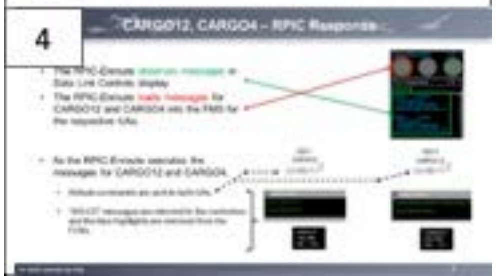
- The RPIC-Enroute constructs a data link message requesting lower altitude and the GPS approach for the destination airport.
- The RPIC-Enroute sends the message to ZZZ sector 3.


2

CARGO12 – ATC Response


3

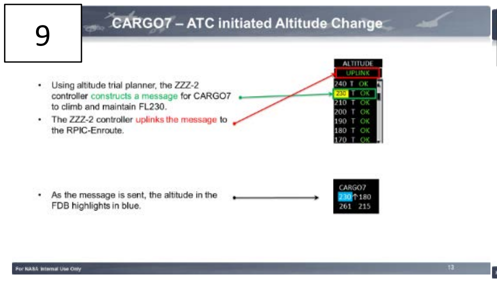
CARGO4 – ATC Initiated Descent


4

CARGO12, CARGO4 – RPIC Response

Scenario E6: Data Link Management (continued)

- 11 Using trial planner, the Sector 3 controller constructs message for CARGO12 to clear the aircraft for the approach at the destination airport and uplinks the message to the RPIC-Enroute.
- 12 As the message is sent to the RPIC Enroute, the r box in CARGO12's FDB highlights in blue.
- 13 The RPIC-Enroute observes CARGO12 message for the approach clearance and loads the message into the FMS.
- The RPIC-Enroute accepts and executes the clearance message for CARGO12, and the approach configuration is sent to the UA. As the clearance is forwarded to the UA, the blue highlight of CARGO12 's route box is removed.
- Using the voice frequency, the Sector 3 controller terminates radar service to CARGO12, and instructs the RPIC-Enroute to change to the CTAF frequency.
- The RPIC-Enroute acknowledges radar service termination for CARGO12 and changes to the CTAF.


9

CARGO7 – ATC initiated Altitude Change

- Using altitude trial planner, the ZZZ-2 controller constructs a message for CARGO7 to climb and maintain FL230.
- The ZZZ-2 controller uplinks the message to the RPIC-Enroute.
- As the message is sent, the altitude in the FDB highlights in blue.

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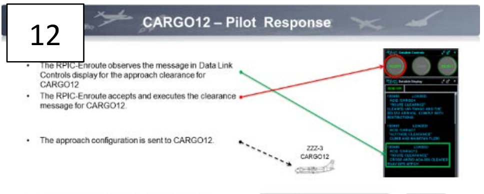
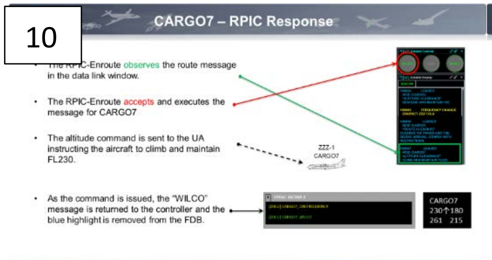

12

CARGO12 – Pilot Response

- The RPIC-Enroute observes the message in Data Link Controls display for the approach clearance for CARGO12
- The RPIC-Enroute accepts and executes the clearance message for CARGO12.
- The approach configuration is sent to CARGO12.
- As the clearance is forwarded to the UA, "Wilco" message is forwarded to the controller's display and the blue highlight of the route box is removed.

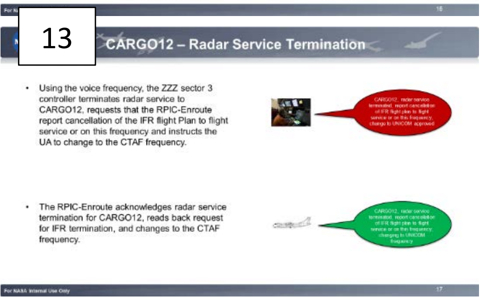
16


10

CARGO7 – RPIC Response

- The RPIC-Enroute observes the route message in the data link window.
- The RPIC-Enroute accepts and executes the message for CARGO7
- The altitude command is sent to the UA instructing the aircraft to climb and maintain FL230.
- As the command is issued, the "WILCO" message is returned to the controller and the blue highlight is removed from the FDB.

14


13

CARGO12 – Radar Service Termination

- Using the voice frequency, the ZZZ sector 3 controller terminates radar service to CARGO12, requests that the RPIC-Enroute report cancellation of the IFR flight Plan to flight service or on this frequency and instructs the UA to change to the CTAF frequency.
- The RPIC-Enroute acknowledges radar service termination for CARGO12, reads back request for IFR termination, and changes to the CTAF frequency.

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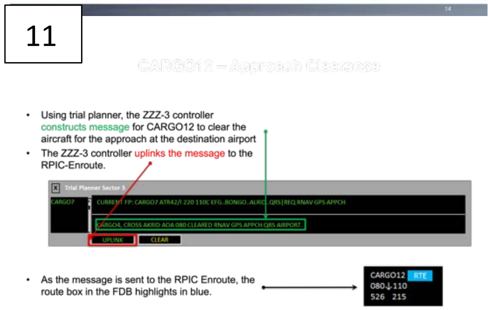

11

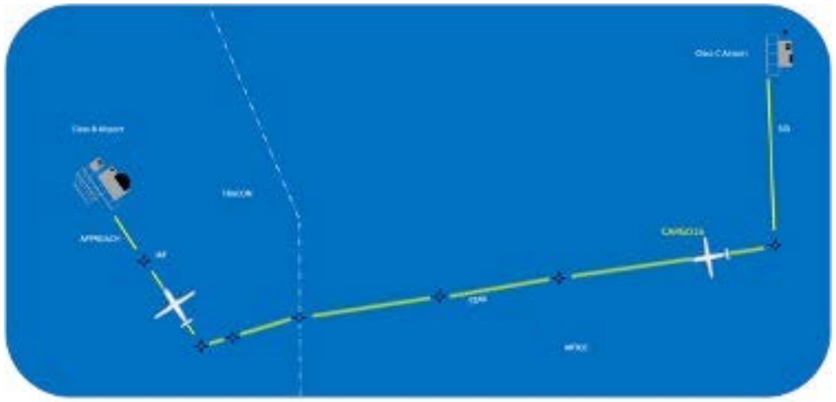
CARGO12 – Approach Clearance

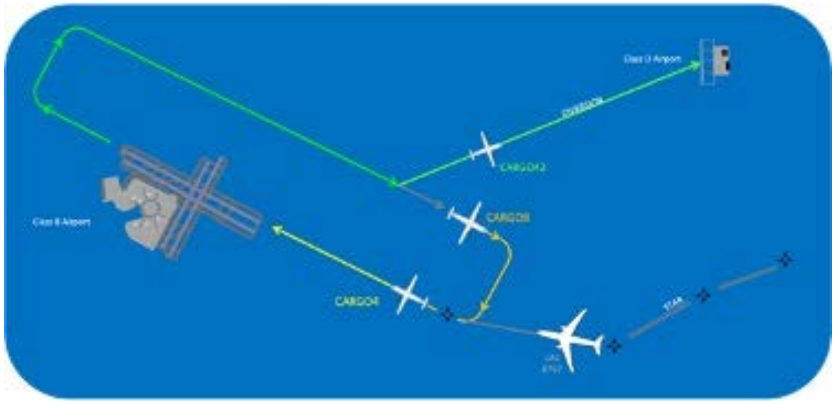
- Using trial planner, the ZZZ-3 controller constructs message for CARGO12 to clear the aircraft for the approach at the destination airport
- The ZZZ-3 controller uplinks the message to the RPIC-Enroute.
- As the message is sent to the RPIC Enroute, the route box in the FDB highlights in blue.

Trial Planner Sector 3
CARGO7
CURRENT FP: CARGO7 ATR42/I 220 110C EFG..BONGO..ALRID..QRS|REQ RNAV GPS APPCH
CARGO4, CROSS AKRID AOA 080 CLEARED RNAV GPS APPCH QRS AIRPORT.

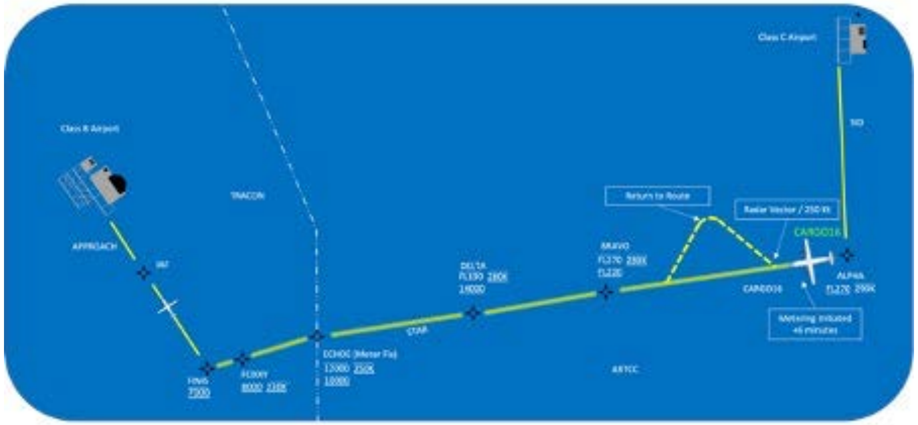
6.1.2. Phase of Flight: Approach

- This scenario involves four fixed wing twin turboprop uncrewed aircraft performing regularly scheduled cargo operations in California.
- These flights are routine IFR operations arriving in the morning hours in marginal VMC.
- Weather at the Class B airport is marginal and variable due to fog.
- The flights are under the control of two RPICs during different phases of flight.
  - An RPIC-Terminal flies the UA within airspace controlled by a regional TRACON or local approach control associated with a Class B or Class C tower.
  - An RPIC-Enroute flies the UA within airspace controlled by an Air Route Traffic Control Center (ARTCC), or a one that is arriving or departing from a Class D airport or Class E airport without an operating control tower.
- Enroute Operations (RPIC-Enroute)
  - — CARGO16
    - The flight departs a Class C airport using an RNAV departure procedure that transitions to the STAR serving the Class B destination airport.
    - The RPIC-Enroute is on Sector 5’s frequency. Sector 5 has a moderate workload, sequencing multiple aircraft.
- TRACON Operations (RPIC-Terminal) (Slide 27)
  - — CARGO4 & CARGO8
    - CARGO4 and CARGO8 have both been given radar vectors for the left downwind and are on final instrument approaches to the Class B destination airport.
    - The RPIC-Terminal is on the approach control frequency.
    - The approach controller is moderately busy sequencing aircraft to the airport.
  - — CARGO42
    - CARGO42 has made serval attempts to land, but their visibility hasn’t been sufficient.
    - In the event of a diversion, CARGO42 will proceed to a nearby Class D airport.
    - That diversion is being considered due to fuel constraints.
    - The RPIC-Terminal is on the local tower control frequency.
- C2 links for communication and Command and Control are available for the end-to-end operations of Auto Cargo flights.



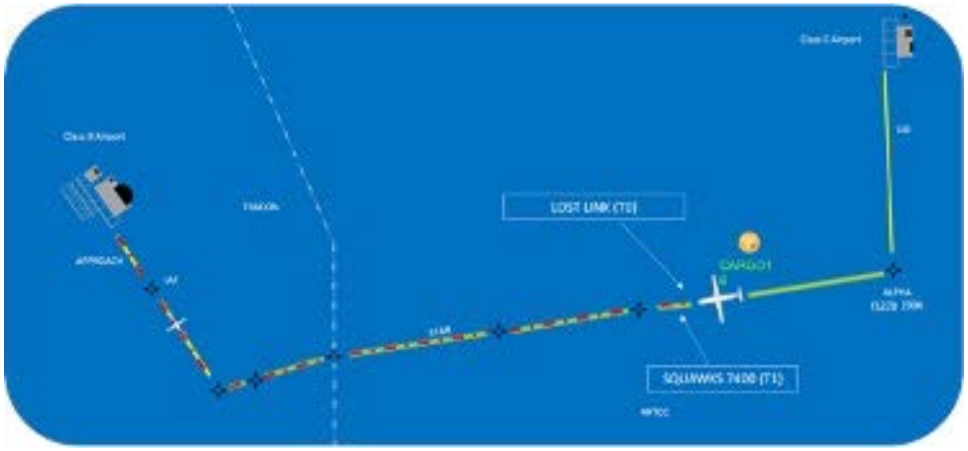


Scenario A1: TMI—Metering



- 20 nm from the transition point for the STAR, the enroute controller clears CARGO16 via the STAR for the destination airport and directs CARGO16 to comply with restrictions.
- The RPIC-Enroute reads back the clearance and configures CARGO16 to fly the STAR as cleared.
- 10 nm past the transition fix for the STAR, the Traffic Management Unit (TMU) determines that, due to deteriorating visibility, metering is required to balance the capacity and demand for the destination airport.
- Upon receiving notification that metering is in progress, the enroute controller turns on metering information on their ATC display and notes that CARGO16 will be required to absorb 6 minutes to meet its time at the meter fix and determines that speed control and vectors will be required.
- The enroute controller advises the RPIC that metering is in progress and issues a speed restriction and a radar vector for spacing.
- The RPIC reads back the clearance, reduces CARGO16's speed, commands it to fly the assigned heading, and updates the contingency plan.
- The enroute controller monitors the progress of CARGO16, judges that CARGO16 is now in conformance with the required time at the meter fix and turns the aircraft to rejoin the STAR.
- The RPIC reads back the clearance and configures CARGO16 to rejoin the STAR.

Scenario A1a: LC2L Descent to Landing

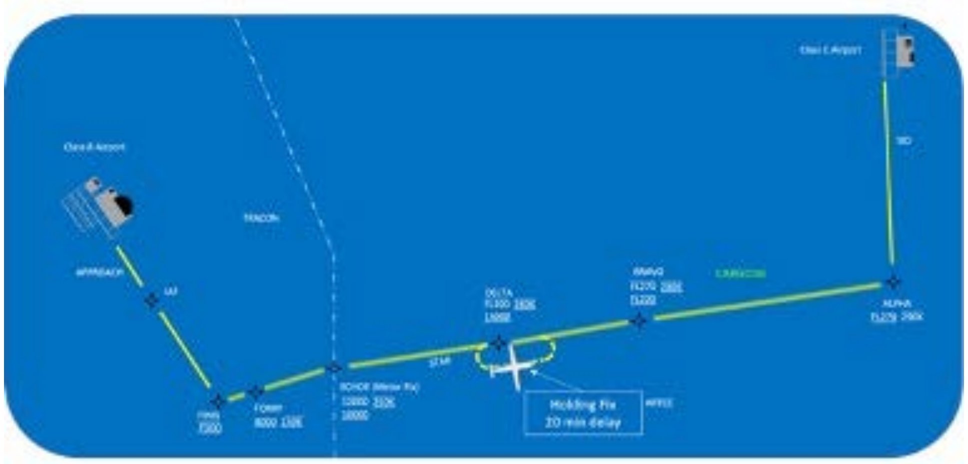


- Following issuing vectors to CARGO16 for spacing, the enroute controller clears CARGO16 via the STAR and instructs the aircraft to comply with restrictions.
- The RPIC-Enroute reads back the clearance and configures CARGO16 to fly the STAR.
- As CARGO16 begins its descent, the RPIC receives a warning that a LC2L has occurred (T0). CARGO16 squawks 7400 and the T1 timer is initiated.
- The RPIC contacts the enroute facility via landline, declares LC2L, and advises that CARGO16 is proceeding automatically on the present routing in accordance with the current contingency plan.
- The enroute controller acknowledges the information from the RPIC-Enroute and coordinates information on CARGO16 to future sectors/facilities.
- At T2, CARGO16 automatically continues the present route in accordance with the current contingency plan • As they approach 100 nm from the destination airport, the enroute controller advises the RPIC of CARGO16’s position and altitude and advises that it will be handed off to the TRACON controller in 20 miles.
- The RPIC acknowledges the information from ATC and initiates transfer of CARGO16 to the RPIC-Terminal, advises that the aircraft is in a LC2L state, and provides the most recent position and altitude information that was received from ATC.
- The RPIC-Terminal receives the transfer and accepts responsibility for the CARGO16, relieving the RPIC-Enroute.

Scenario A1a: LC2L Descent to Landing

- The UA flies the STAR automatically, per the contingency plan, meeting the published restrictions.
- As CARGO16 crosses the TRACON boundary, the enroute controller completes a handoff to the TRACON controller and advises the RPIC-Terminal that CARGO16 is now under TRACON control and provides updated position and altitude information.
- The enroute controller instructs the RPIC to call the TRACON facility via landline.
- The RPIC checks in with the TRACON controller, requests CARGO16's position and altitude, and advises the TRACON controller of the approach contained in the contingency plan.
- The TRACON controller provides current position and altitude and acknowledges the approach planned for CARGO16.
- The TRACON controller contacts the Tower and provides the approach information and the ETA of CARGO16.
- The Tower controller acknowledges the advisory from TRACON and takes steps to alert appropriate services.
- The TRACON controller advises the RPIC that CARGO16 is about to begin the approach and to contact the Tower via landline.
- The RPIC advises the ground crew that CARGO16 has experienced a LC2L and will require a tow to remove the aircraft from the runway.
- The RPIC contacts the Tower via landline and advises that a ground crew will be providing a tow for CARGO16 following landing.
- The TRACON controller advises the Tower of the position and altitude of CARGO16 and advises that CARGO16 has started the instrument approach.
- The Tower controller acknowledges the advisory from TRACON and takes steps to assure the runway is clear.
- The ground crew contacts the Ground controller and advises that they are available to tow CARGO16 from the runway.
- The Ground controller acknowledges the transmission and advises the Tower that a tow is available for CARGO16.
- CARGO16 lands and rolls to a stop on the runway.

Scenario A2: TMI—Holding



- As fog continues to degrade the visibility at the destination airport, the acceptance rate is further reduced. TMU determines that 20 minutes of holding will be required to manage the excess airborne inventory for the airport.
- Upon notification from TMU, the enroute controller clears CARGO16 to the holding fix and lets them know to expect a 20-minute delay.
- The RPIC-Enroute reads back the clearance, configures CARGO16 to hold as cleared, and updates the contingency plan.
- The RPIC reports that CARGO16 established in holding.
- The enroute controller acknowledges the RPIC.
- After 15 minutes of holding, the TMU instructs the enroute controller to provide an airport clearance to CARGO16.
- The enroute controller clears CARGO16 to the destination airport via the STAR and to comply with restrictions.
- The RPIC reads back the clearance and configures CARGO16 to fly to the destination as cleared.
- As CARGO16 begins its descent, the RPIC-Enroute contacts the RPIC-Terminal responsible for control of the aircraft operating at and around the primary Class B airport and initiates a transfer of the flight.
- The RPIC-Terminal receives the transfer and accepts responsibility for CARGO16, relieving the RPIC-Enroute.
- As CARGO16 approaches the TRACON boundary, the enroute controller completes a handoff to the TRACON controller and changes the flight to the TRACON's frequency.
- The RPIC-Terminal checks in with the TRACON controller with CARGO16's position, altitude, route, the current ATIS information for the destination airport, and requests an instrument approach to the active runway.
- As CARGO16 descends into TRACON's airspace, the TRACON controller places the flight on a heading to sequence CARGO16 with other aircraft on approach to the same runway.
- The RPIC reads back the clearance, turns CARGO16 to the heading, and updates the contingency plan for a direct route.

Scenario A2a: TMI—LC2L while Holding

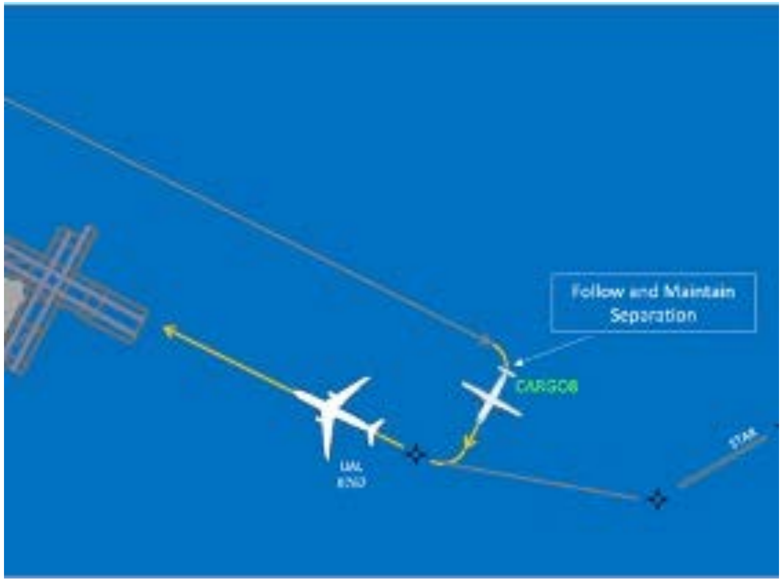
- The enroute controller clears CARGO16 into holding at the holding fix as published with an EFCT of thirty minutes. (CARGO16, cleared to DELTA, hold northeast as published, Expect further clearance one-niner-fife-zero)
- The RPIC-Enroute reads back the holding instructions, configures CARGO16 for holding as directed, updates the contingency plan with the holding and expect further clearance time (EFCT).
- The RPIC-Enroute assesses CARGO16's status based on the holding instruction and expected delay provided by the controller and determines the total amount of holding time that CARGO16 can accept.
- The RPIC-Enroute reports CARGO16 established in the interim holding pattern.

The enroute controller acknowledges the transmission.

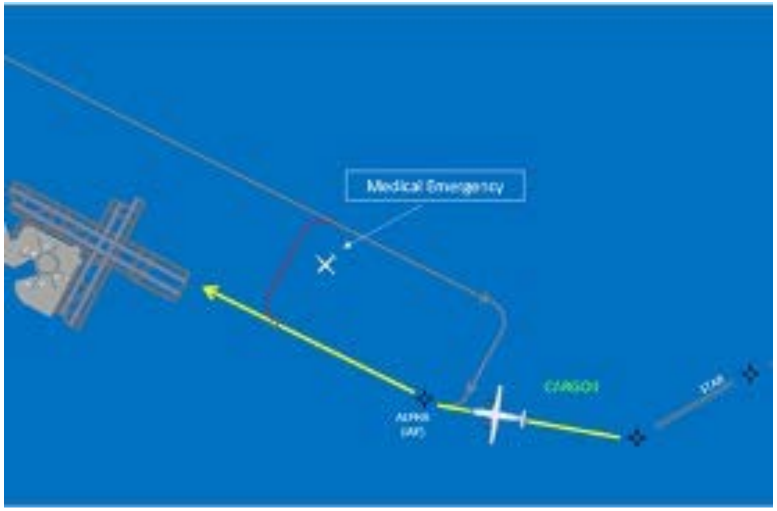
- During the first turn in holding, the RPIC-Enroute receives a warning that a LC2L has occurred (T0). CARGO16 squawks 7400 and the T1 timer initiates.
- The RPIC-Enroute contacts the enroute facility via landline, declares LC2L, and advises CARGO16 will proceed at the EFCT autonomously on the previously cleared routing in accordance with the current contingency plan.
- The enroute controller acknowledges the information from the RPIC-Enroute and coordinates information on CARGO16 to future sectors/facilities and the Traffic Management Unit (TMU).
- At T2, CARGO16 continues to hold at its current altitude until the EFCT in the revised contingency plan.
- The enroute controller clears the two aircraft below CARGO16 to the airport with the approval of the TMU.
- At the EFCT, CARGO16 exits holding and continues to the airport in accordance with the contingency plan.
- The RPIC-Enroute is able to reestablish the C2 link shortly after CARGO16 departs the holding fix. The RPIC-Enroute contacts the enroute controller and advises that the C2 link for CARGO16 has been reestablished.
- The enroute controller acknowledges the transmission and re-clears CARGO16 via the STAR.
- The RPIC-Enroute reads back the clearance and commands CARGO16 to fly the STAR.

Scenario A3: Sequencing—Follow Aircraft (Sensor Spacing)

- The RPIC-Terminal checks in with the TRACON controller with CARGO8's position, altitude, route, the current ATIS information for the destination airport, and requests vectors to final for the instrument approach.
- As CARGO8 descends into TRACON's airspace, the controller places the flight on a downwind heading to sequence CARGO8 with other aircraft on the same approach.
- The RPIC reads back the clearance, turns CARGO8 to the heading, and updates the contingency plan for a direct route to the Initial Approach Fix.
- As CARGO8 passes 7 nm downwind of the airport, the TRACON controller provides a traffic advisory for a Boeing 767 at 1 o'clock, 3 miles on a modified base leg for the active runway and requests the RPIC to advise when the aircraft is detected. ("CARGO8, TRAFFIC, 1 o'clock, 3 miles, westbound, United B767, on a modified base leg for the ILS runway 28R. Report traffic detected.").
- Using the traffic display, the RPIC identifies the traffic and reports "traffic detected" to the controller.
- The controller instructs the RPIC to follow and maintain separation from the 767 and clears the aircraft to intercept the instrument approach.
- The RPIC reads back the clearance and configures the UA to intercept and fly the approach, ensuring proper separation behind the United.

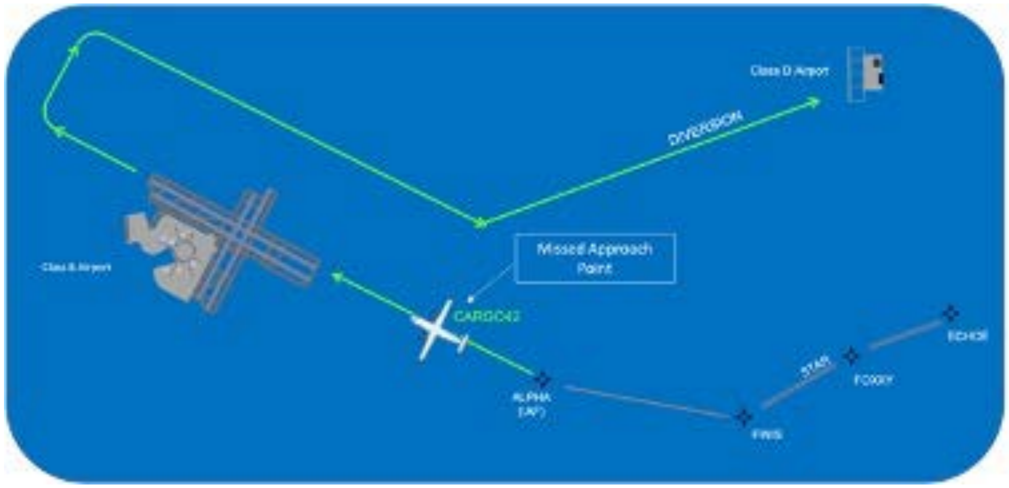


Scenario A4: TRACON Resequencing



- The Approach controller clears CARGO4 direct to the instrument approach fix (IAF) for the approach.
- The RPIC-Terminal reads back the clearance, turns CARGO4 direct to the fix, configures the UA for the approach and updates the contingency plan.
- While the aircraft is on the approach, a downwind aircraft declares an emergency and requests an immediate turn-in for landing.
- The controller instructs CARGO4 to abandon their approach and climbs CARGO4 to pattern altitude.
- The RPIC reads back the clearance and commands CARGO4 to climb to the assigned altitude.
- The controller turns the emergency aircraft to the final approach course (FAC).
- The controller turns CARGO4 into the downwind to be re-sequenced for another approach.
- The RPIC reads back the clearance, turns the UA as directed, and updates the contingency plan.
- 10 nm downwind of the airport, the controller clears CARGO4 direct to the instrument approach fix and clears them for the approach.
- The RPIC reads back the clearance, turns CARGO4 direct to the instrument approach fix, configures the UA for the approach and updates the contingency plan again.

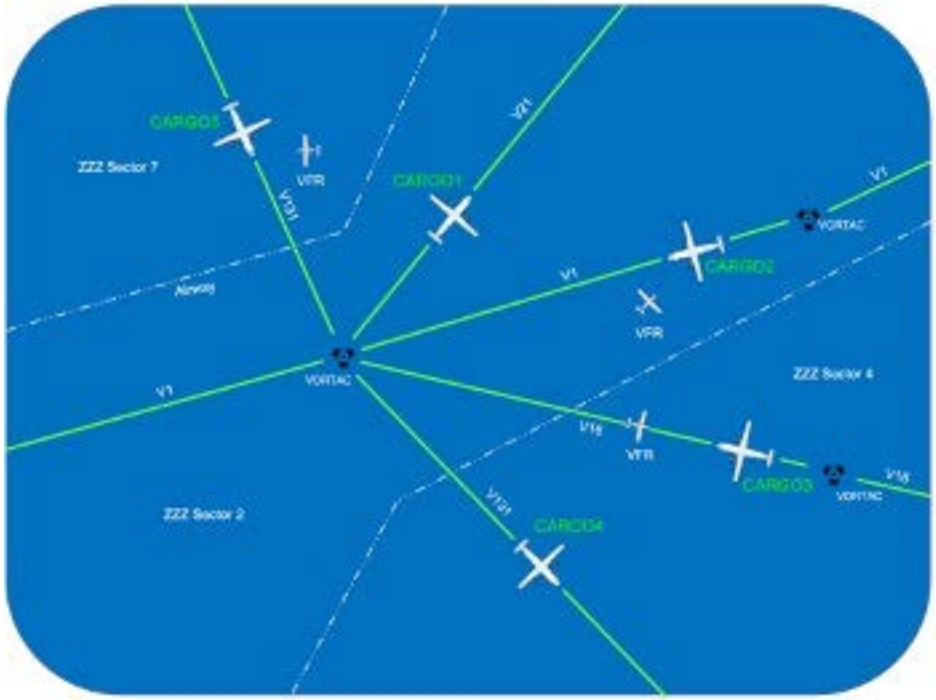
Scenario A5: Missed Approach and Diversion



- As the aircraft passes the final approach fix, the local controller provides winds to the RPIC-Terminal and clears CARGO42 to land.
- The RPIC-Terminal reads back and configures CARGO42 for landing.
- As the aircraft approaches decision height, the RPIC is unable to acquire the runway environment due to fog and low visibility and elects to execute a missed approach.
- The RPIC advises the controller that they are executing a missed approach.
- The local controller acknowledges the report and re-clears CARGO42 into the downwind and changes them to the departure controller's frequency.
- The RPIC reads back the clearance, configures CARGO42 to reenter the downwind and contacts departure.
- The RPIC coordinates with their dispatcher and determines that CARGO42 should instead divert to its alternate airport.
- The dispatcher provides information to the RPIC on the alternate and provides a new flight plan.
- The RPIC advises the departure controller of their intention to divert to the alternate and requests clearance via the new flight plan the dispatcher provided.
- The controller clears CARGO42 as requested and climbs CARGO42 to the top of TRACON's airspace.
- The RPIC reads back the clearance, configures the UA to execute the new route and altitude, and updates the contingency plan.
- Next, the RPIC-Terminal initiates a transfer of CARGO42 to a RPIC-Enroute.
- The RPIC-Enroute brings CARGO42's flight status and information up on their GCS and after reviewing the information, advises the RPIC-Enroute to proceed with the transfer.
- The RPIC-Terminal briefs the RPIC-Enroute of CARGO42's current position, altitude, and ATC clearance. They describe CARGO42's current flight status and explain the expectations at the arrival airport. They highlight all applicable traffic near the UA and the RPIC-Terminal answers the RPIC-Enroute's questions.
- The RPIC-Enroute advises the RPIC-Terminal that they "have the aircraft"
- The RPIC-Terminal acknowledges that the RPIC-Enroute now has control of CARGO42.

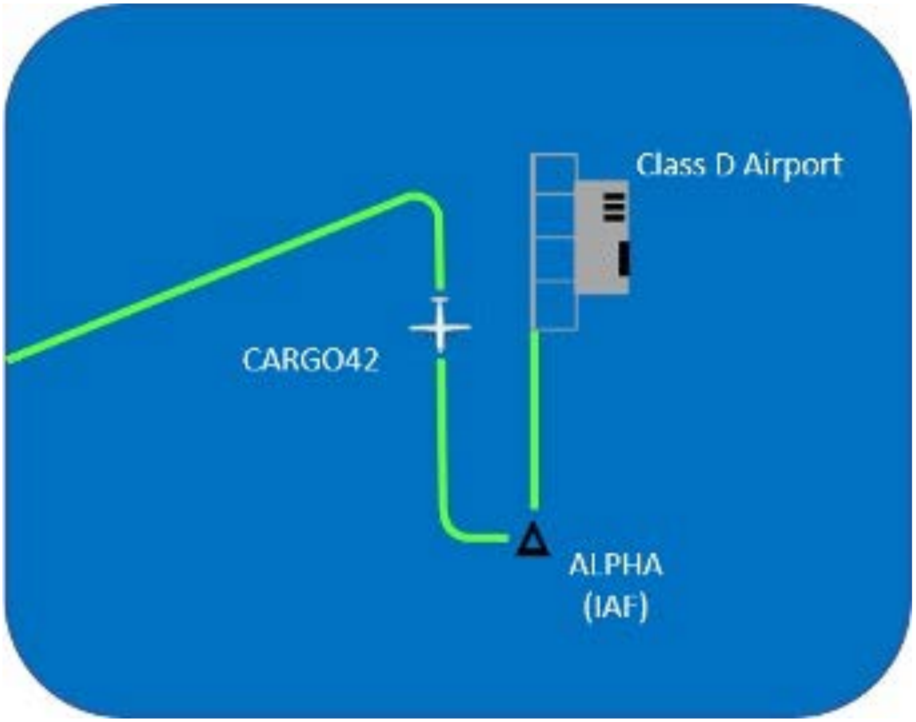
Scenario A6: DAA Alerting and Guidance

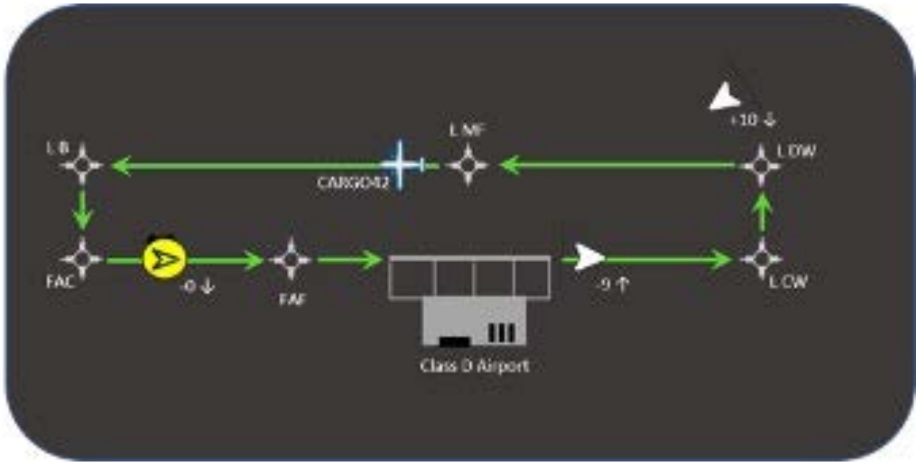
- This scenario involves five fixed wing twin turboprop unmanned aircraft on regularly scheduled cargo operations in California.
- All these flights are routine IFR operations that are arriving at the same destination airport during the afternoon hours in VMC.
- All five flights are operating in class E airspace and are transiting on Victor airways.
- All the UAs are under the control of a single RPIC-Enroute. The RPIC-Enroute is responsible for flying the UA within airspace controlled by an Air Route Traffic Control Center (ARTCC), or a UA arriving or departing from a Class D airport or Class E airport without an operating control tower.
- CARGO1 and CARGO2 are flying in Sector 2, CARGO3 and 4 in Sector 4, and CARGO5 in Sector 7.
- Three of the aircraft, CARGO2, 3 and 5 encounter intruders, which cause Corrective Self-Separation Alerts.
- All aircraft are equipped with a Class 2 (or greater) DAA system which includes a TCAS II (or greater) system and on-board non-cooperative sensors, such as radar.
- C2 links for communication and Command and Control are available for the end-to-end operations of an Auto Cargo flight.



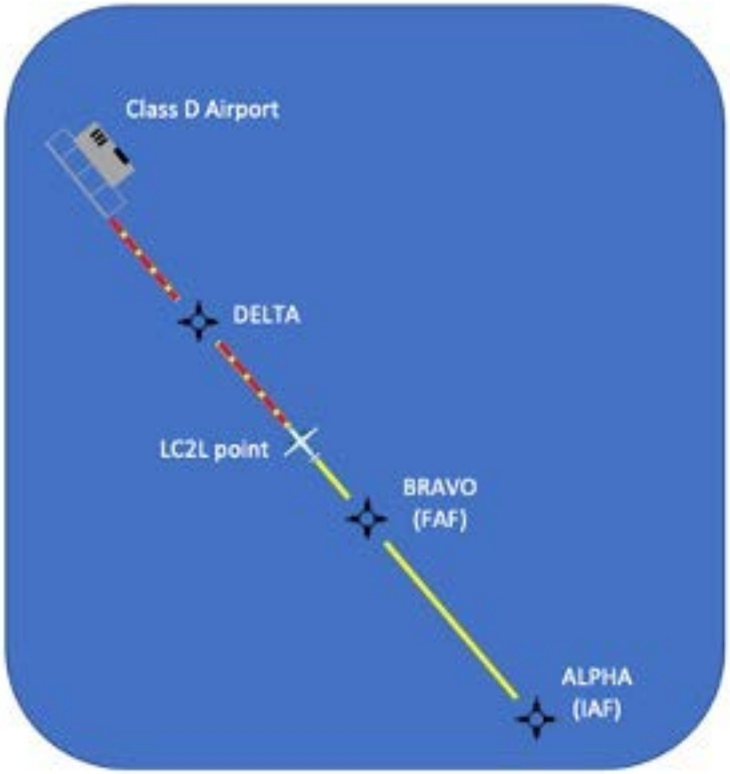
Scenario A7: Pattern Entry (Class D Airport)

- 70 miles from the destination airport, the enroute controller clears CARGO42 direct to the destination airport and to descend to an altitude for entry into Class D airspace.
- The RPIC-Enroute reads back the clearance, configures CARGO42 to fly as cleared, and updates the contingency plan.
- 20 nm from the destination airport, the enroute controller advises the Tower of the inbound flight.
- Prior to 10 nm from the destination airport, the enroute controller terminates radar service with CARGO42 and changes the flight to the Tower frequency.
- The RPIC acknowledges radar service termination and they check in with Tower, giving CARGO42's position, the current ATIS information, and makes a request to fly the final approach portion of the instrument approach to the active runway.
- Tower acknowledges CARGO42 and clears them to enter the downwind for the active, and requests the RPIC to report five miles from the airport.
- The RPIC reads back the clearance, brings up the traffic pattern display for the airport on the nav display, and configures CARGO42 to enter the downwind as cleared.
- At 5 NM, the RPIC advises Tower that CARGO42 is 5 nm from the airport.
- Tower acknowledges the transmission.
- As CARGO42 passes abeam the airport on the downwind, the controller gives a traffic advisory for an aircraft at 11 o'clock on 5 mile final, advises the RPIC that CARGO42 is number 2 behind the aircraft, and extends CARGO42's downwind.
- The RPIC identifies the traffic on their display, reports that the traffic is detected, and reads back the clearance for the extended downwind.
- When CARGO42 is 7 nm downwind, Tower clears them to turn base, clears them via the final approach for the instrument approach, and provides alternate missed approach instructions.
- The RPIC reads back the clearance, commands the UA, and updates the contingency plan with the missed approach information.





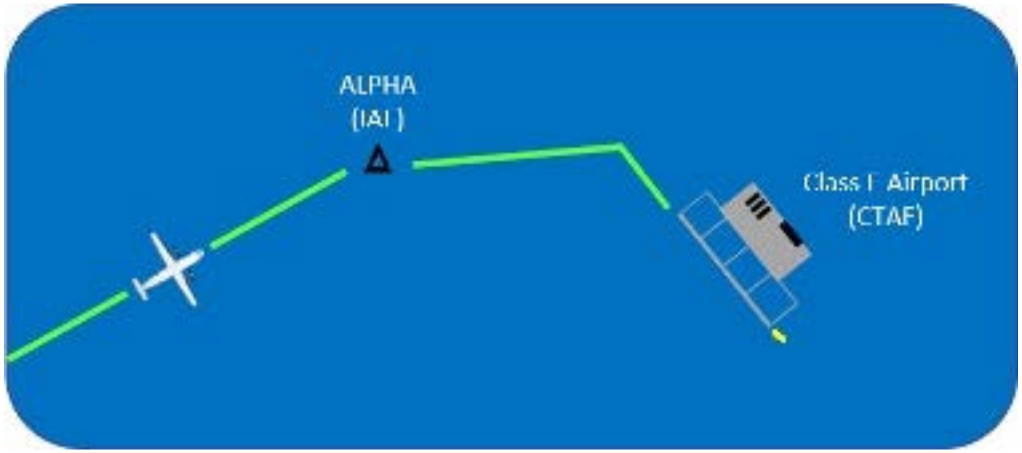
Scenario A7a: L2CL Pattern Entry (Class D Airport)



- The enroute controller clears CARGO42 direct to the instrument approach fix (IAF) and clears the aircraft for the instrument approach to the destination airport.
- The RPIC-Enroute reads back the approach clearance and commands the UA to proceed direct to the fix and execute the approach.
- The enroute controller coordinates CARGO42 with the tower.
- The Tower controller acknowledges the inbound.
- As CARGO42 approaches 13 nm from the airport, the Enroute controller terminates radar service and instructs CARGO42 to contact Tower.
- The RPIC acknowledges radar service termination and contacts Tower prior to entering Class D airspace.
- Tower acknowledges CARGO42 and provides traffic information and airport conditions and requests CARGO42 to report 6 miles from the airport.
- The RPIC receives a warning that a LC2L has occurred (T0) and CARGO42 squawks 7400. Note: The T1 is set to “0” and T2, the contingency plan for landing, is immediately initiated.
- The RPIC contacts the tower via landline, declares LC2L, and advises that CARGO42 will execute an automatic landing.
- The Tower controller acknowledges the information and takes steps to alert support vehicles.
- The RPIC advises the ground crew that they have experienced a LC2L and that a tow will be required to remove CARGO42 from the runway.
- The RPIC advises the Ground controller that the ground crew will be providing a tow for CARGO42 following landing.
- The ground crew also contacts Ground and advises that they are available to tow CARGO42 from the runway.
- Ground acknowledges the ground crew and passes the information to Tower that a tow is available for CARGO42.
- Tower makes a broadcast that a UA is currently LL and takes actions to ensure the runway is clear.
- The UA lands on the active runway and rolls to a stop.
- Tower clears the ground crew to enter the runway and prepare to tow the aircraft to the ramp.
- Members of the ground crew read back the clearance, prepare to hook up and tow the UA from the runway to the ramp, and advises the RPIC that they “have the aircraft.”
- The ground crew advises the RPIC that they have responsibility for the aircraft.
- The Tower instructs the ground crew to contact the Ground controller.
- Upon check in, Ground clears CARGO42 to be towed to the gate.
- The ground crew reads back the clearance and tows the aircraft to the gate

Scenario A8: CTAF Operations

- 70 miles from the destination airport, the Enroute controller clears CARGO42 direct to the instrument approach fix for the destination and descends the aircraft to the crossing altitude for the instrument approach.
- The RPIC-Enroute reads back the clearance, configures the UA to fly as cleared, and updates the contingency plan.
- 20 nm from the destination airport, the Enroute controller clears CARGO42 for the instrument approach.
- The RPIC reads back the clearance and configures CARGO42.
- 15 nm from landing, the Enroute controller terminates radar service, advises the RPIC to report "landing assured" on the frequency with flight service, and changes CARGO42 to the CTAF frequency.



- The RPIC acknowledges the controller's radar service termination, reads back the "landing assured" requirement, and changes CARGO42 to CTAF.
- Approximately 10 miles from airport, the RPIC checks in on CTAF and states the UA's position, approach type and intent to land.
- The RPIC then reports 4 nm on final for the active runway and configures CARGO42 for landing.

Scenario A8a: CTAF Operations—LC2L and Missed Approach

- The Enroute controller clears CARGO42 for an instrument approach at the destination airport.
- The RPIC Enroute reads back the clearance and configures the UA to fly the approach.
- 15 nm from landing, the Enroute controller terminates radar services, advises the RPIC to report “landing assured” on the frequency with flight service, and changes CARGO42 to the CTAF frequency.
- The RPIC acknowledges the controller’s radar service termination, reads back the “landing assured” requirement, and changes CARGO42 to CTAF.
- Approximately 10 nm from the airport, the RPIC checks on CTAF and states the UA’s position, approach type and intent to land.
- Eight miles from the airport, the RPIC receives a warning that a LC2L has occurred (T0). CARGO42 squawks 7400 and initiates the missed approach in accordance with the contingency plan.

  Note: The T1 is set to “0” and T2, the contingency plan for the missed approach, is immediately initiated.
- The RPIC contacts the Enroute facility via landline, declares LC2L, and advises that CARGO42 is proceeding autonomously and executing a missed approach in accordance with the current contingency plan.
- The enroute controller acknowledges the information from the RPIC and coordinates information about CARGO42 to the Flight Service Station (FSS).
- Upon notification, Flight Service makes a broadcast about the LC2L UA on the CTAF frequency.
- As the UA leaves 3000 feet per the contingency plan, the controller establishes radar contact and advises the RPIC of the position and altitude of CARGO42.
- The UA completes its climb to the altitude specified in the contingency plan and proceeds to the instrument approach fix via the planned route.
- CARGO42’s C2 link is reestablished shortly after CARGO42 departs the holding fix. The RPIC reestablishes communication with the Enroute controller and advises that the C2 link has been restored.
- The controller acknowledges the transmission and issues a vector to the instrument approach fix and clears CARGO42 for the instrument approach.
- The RPIC reads back the clearance, commands the to fly the heading and configures it for the approach.

6.1.3. Phase of Flight: Preflight

- This scenario involves two fixed wing twin turboprop aircraft (CARGO3, CARGO9) on regularly scheduled cargo operations in California.
- All flights are routine IFR operations that depart in the morning hours in VMC.
- All flights are under the control of an RPIC-Ground responsible for surface movement of the UA to and from the runway. As examples, an RPIC-Ground can be a dedicated RPIC working from a facility at a large airport or a designated member of a ground crew at a Class D airport or smaller.
- All flights are taxiing to or from gates at a major freight terminal.
- C2 links for communication and Command and Control are available for the end-to-end operations of an Auto Cargo flight.
- All surface movement of CARGO3 and CARGO9 are under the control of a single RPIC, who is monitoring the ground control frequency.

Scenario P1: Preflight

- Prior to pushback and engine start, the dispatcher at the AOC prepares the flight plans for CARGO3 and CARGO9.
  - —The flight plans used for this recurring flight contain standard routings that are used daily.
  - –– Initial contingency planning is also completed prior to pushback and engine start.
- Air Traffic Management automation receives the filed flight plans and includes the flight in its calculations of demand on flight routes and at the destination airports.
- Prior to taxi, the dispatcher briefs the RPIC(s) conducting each flight. (Ground, Terminal & Enroute)
- A certified member of the ground crew for each flight conducts a complete pre-flight inspection of the aircraft and determines that the aircraft is ready for flight.
  - —The results of these inspections are forwarded to the RPIC(s), along with other documents applicable for the flights.
- When the RPIC-Ground is satisfied that CARGO3 is ready for flight, they contact Clearance Delivery and receive an IFR clearance in accordance with the filed flight plan.
- The RPIC also contacts the ground crew and instructs them to push back CARGO3 and start the engines.
- When the RPIC is satisfied that CARGO9 is ready for flight, they contact Clearance Delivery again to receive an IFR clearance in accordance with CARGO9's filed flight plan. However, for CARGO9 there is an estimated departure clearance time for the ground delay program in effect at the destination airport.
- The RPIC then contacts the ground crew and instructs the crew to push back CARGO9 and start engines.
- For both CARGO3 and CARGO9, the ground crew then transfers control of the CARGO3 to the RPIC following push back and engine start.
- After confirming C2 connectivity to each UA, the RPIC-Ground contacts ramp control and requests taxi for 3 and 9, one at a time.

6.1.4. Phase of Flight: Surface Operations

- This scenario involves three fixed wing twin turboprop aircraft (CARGO3, CARGO9, CARGO12) on regularly scheduled cargo operations in California.
- All these flights are routine IFR operations that depart in the morning hours in VMC.
- All flights are under the control of two RPICs during different phases of flight.
  - —An RPIC-Ground that is responsible for the surface movement of the UA to and from the runway. For example, this RPIC may be a dedicated RPIC working from a facility at a large airport, as depicted in these scenarios, or a designated member of a ground crew at a Class D or smaller airport.
  - — An RPIC-Terminal that flies the UA within regional TRACON airspace or local approach control associated with a Class B or Class C tower.
- All flights are taxiing to or from gates at a major freight terminal.
- C2 links for communication and Command and Control are available for the end-to-end operations of an Auto Cargo flight.
- During taxi, a runway change occurs that requires aircraft to be rerouted.
- All surface movement of CARGO3, CARGO9, CARGO12 are under the control of a single RPIC, who is monitoring the ground control frequency.

Scenario S1: Hold Short with Tower

- The ground controller clears CARGO3 to taxi to the departure runway via taxiways BRAVO then FOXTROT, hold short of runway 1L.
- The RPIC-Ground reads back the clearance and begins taxiing CARGO3 in according with the clearance.
- As a departing aircraft clears the intersection, the ground controller clears the aircraft to cross runways 1L and 1R and continue taxi on FOXTROT, hold short runway 28L.
- The RPIC reads back the clearance and begins taxiing CARGO3 in accordance with the clearance.
- As CARGO3 clears runway 1R, the ground controller advises that a runway change is in progress and to expect departures on 10L and 10R. The controller clears CARGO3 to runway 10L via PAPA, CHARLIE, CHARLIE3, cross runway 28L, and hold short runway 28R.
- The RPIC reads back the clearance and begins taxiing CARGO3 in according with the clearance.

Scenario S2: Alternate Detailed Taxi Instructions and Following Traffic with Tower

- The ground controller clears CARGO9 to taxi to the departure runway (1L) via taxiway BRAVO and hold short of runway 1L.
- The RPIC-Ground reads back the clearance and begins taxiing the UA according to the clearance.
- The controller advises that a runway change is in progress and clears CARGO9 to runway 10R via right turn at GOLF then via GOLF, ALPHA, QUEBEC1, BRAVO, ZULU, ZULU1, hold short runway 10R.
- The RPIC reads back the clearance and begins taxiing CARGO9 according to the clearance.
- As CARGO9 approaches GOLF, the ground controller quotes traffic at 1 o’clock on ALPHA, opposite direction, Boeing 737.
- Using visual technology, the RPIC identifies the traffic and advises the ground controller “aircraft in sight”.
- Ground instructs the RPIC to give way to the 737.
- The RPIC reads back the clearance and adjusts their taxi speed to allow the 737 to pass.

Scenario S3: LC2L During Taxi (Taxi Back to the Gate)

- The RPIC-Terminal has received landing clearance from the Tower and configured CARGO12 for landing and rollout on runway 28R.
- As the aircraft lands, the Tower clears CARGO12 to exit the runway at TANGO, hold short runway 28L.
- The RPIC reads back the clearance and configures the UA according to the clearance.
- Tower instructs the CARGO12 to contact ground control.
- As the UA comes to a stop at the hold line for runway 28L, the RPIC receives an alert that the C2 link has been lost (T0). CARGO12 begins to squawk 7400 and stops in position and the T1 timer starts.
- The RPIC contacts Ground via landline and advises that CARGO12 has lost link, that the aircraft is coming to a stop at its current location, and provides the Lost Link Profile (LLP) which describes the route CARGO12 will be using to return to the ramp.
- Ground acknowledges the transmission and begins to clear other aircraft from the route.
- The RPIC contacts their ground crew and advises them of the lost link and provides the Lost Link Profile (the route CARGO12 will be using to return to the ramp).
- The RPIC contacts then the dispatcher and advises them of the lost link and that the aircraft is returning to the gate.
- At T2, CARGO12 taxis back to the gate in accordance with the Lost Link Profile.

6.1.5. Phase of Flight: Departure

- These scenarios involve two fixed wing twin turboprop aircraft (CARGO3, CARGO9) on regularly scheduled cargo operations in California.
- These flights are routine IFR operations that depart in the morning hours in VMC.
- These flights are under the control of two RPICs during different phases of flight.
  - —An RPIC-Ground that is responsible for surface movement of the UA to and from the runway. For example, an RPIC-Ground can be a dedicated RPIC working from a facility at a large airport, as depicted in these scenarios, or a designated member of a ground crew at a Class D airport or smaller.
  - —An RPIC-Terminal that flies the UA within airspace controlled by a regional TRACON or local approach control associated with a Class B or Class C tower.
- All flights are taxiing from gates at a major freight terminal to the assigned runways for departure.
- C2 links for communication and Command and Control are available for the end-to-end operations of an Auto Cargo flight.
- All surface movement of CARGO3 and CARGO9 are under the control of a single RPIC, who is monitoring the ground control frequency.

Scenario D1: Position and Wait and Ground Delay Program (GDP)

- When the RPIC-Ground is satisfied that CARGO9 is ready for flight, they contact Clearance Delivery and receives an IFR clearance in accordance with the filed flight plan. An estimated departure clearance time (EDCT) is issued for the GDP in effect for the destination airport.
- The RPIC-Ground contacts Ground and advises that CARGO9 is ready for push back.
- Ground clears CARGO9 to push back and taxi to the departure runway (10R) via ALPHA, QUEBEC1, BRAVO, ZULU1, hold short runway 10R.
- The RPIC reads back the clearance and contacts the ground crew and instructs the crew to push back CARGO9 and start engines.
- Following pushback and engine start, the ground crew then transfers control of CARGO9 to RPIC-Ground.
- After confirming C2 connectivity to CARGO9, the RPIC begins taxiing CARGO9 in accordance with the clearance.
- As CARGO9 approaches taxi ZULU1, the RPIC-Ground completes a transfer to RPIC-Terminal.
- RPIC-Terminal receives the transfer and accepts responsibility for CARGO9, relieving the RPIC-Ground.
- The ground controller directs CARGO9 to contact the Tower.
- The RPIC-Terminal contacts the tower controller and advises that CARGO9 is ready for takeoff runway 10R with an EDCT.
- The tower controller clears CARGO9 to line up and wait runway 10R.
- The RPIC-Terminal reads back the clearance, taxis CARGO9 into the takeoff position, and completes the takeoff checklist.
- At the EDCT, the tower controller provides the wind and clears CARGO9 for takeoff.
- The RPIC reads back the clearance and commands CARGO9 to takeoff.
- The tower changes CARGO9 to the departure controller's frequency.
- The RPIC monitors the Detect and Avoid traffic display for conflicting traffic as CARGO9 leaves the runway, and checks in with the departure controller.

Scenario D2: Rejected Takeoff

- The RPIC-Terminal contacts the tower controller and advises that CARGO3 is ready for takeoff on runway 10L.
- The tower controller provides winds and clears CARGO3 for takeoff runway 10L.
- The RPIC completes the takeoff checklist, and commands CARGO3 to take off in accordance with the clearance.
- As CARGO3 accelerates to V1, The RPIC receives a warning of an engine 2 anomaly and elects to reject the takeoff.
- The RPIC contacts the tower and advises that CARGO3 is executing a rejected takeoff due to an engine issue.
- Tower acknowledges the RPIC's transmission and requests intentions.
- The RPIC requests taxi to the ramp.
- When CARGO3 comes to a stop and runs appropriate checklist and requests further clearance in accordance with the procedure.
- The tower clears CARGO3 from the runway via the next taxi way and hold short 10R and directs the RPIC to contact Ground control.
- The RPIC reads back the clearance, instructs CARGO3 to exit the runway, hold short 10R and contacts Ground.
- Ground gives CARGO3 clearance back to the gate.
- The RPIC reads back the clearance and instructs CARGO3 to taxi back to the gate.