Contract Number: 692M15-19-R-00020-02

Federal Aviation Administration (FAA)
UAS Integration Office
Program & Data Management Branch
(AUS-410)

Project Title: Development of non-system specific technology to integrate uncrewed aircraft systems (UAS) into the National Airspace System (NAS)

Company Name: Merlin, Inc.
Report Date: 18AUG23
Contract Period of Performance: 19AUG22 - 18AUG23

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1 Introduction

1.1 Executive Summary

This is the final report for a completed research contract under BAA Call 003 by the Federal Aviation Administration (FAA) Unmanned Aircraft Systems Integration Office, UAS Program and Data Management Branch (AUS-410) for a commercial entity (CE) to demonstrate or validate technologies the FAA considers essential to the safe integration of UAS in the National Airspace System (NAS) at one of seven (7) FAA designated test sites.

The research contract for the *development of non-system specific technology to integrate uncrewed aircraft systems (UAS) into the National Airspace System (NAS)* supported a demonstration project for Merlin's experimental, highly automated onboard system in a relevant environment. The project had four focus areas: automated system reliability, natural language processing (NLP), beyond visual line of sight (BVLOS) links, and automated systems operational data.

The project's goal was to gather quantitative and qualitative data on the feasibility and challenges of operating an advanced aviation system in the national airspace, specifically along established cargo routes in Alaska's interior. The project showcased:

- 18 test flights conducted to six airports.
- Over 66 flight hours using Merlin's integrated system in a wide variety of airspace, runway, and weather conditions.
- Sufficient situational awareness of the airborne crew's status to the ground crew using the BVLOS link.
- Reduced pilot workload via pilot voice commands using Merlin's NLP system based on video analysis and post-flight surveys.
- Several opportunities to assess and improve NLP system accuracy.
- Identification of several feature improvements to Merlin's integrated system that will reduce pilot workload and improve system autonomy, providing key insights for future advanced autonomy roadmaps.
- Public engagement efforts by Merlin with community members in Alaska.
- Strong partnership with the University of Alaska Fairbanks' ACUASI test site.

1.2 Background

Merlin

Merlin is an institutionally-backed startup that has received significant funding from private sector venture capital firms including Snowpoint Ventures, GV, and First Round Capital. Headquartered in Boston with a test flight facility in Mojave, CA, the company aims to improve the safety, efficiency, and cost of flight operations by leveraging advanced aviation systems.

Merlin is developing an entirely onboard, integrated software system that would enable reduced-crewed and uncrewed operations by replicating the existing pilot functions on traditional aircraft, without the need for remote operations. Since 2018, the company has successfully designed, integrated, and tested advanced aviation systems on a variety of aircraft

platforms, ranging from single engine piston aircraft to twin engine turboprops. Merlin is currently in the process of certifying its technology via an STC on a Part 23 aircraft, and is also exploring opportunities to integrate autonomy into large transport category platforms.

Demonstration in Alaska

This project in Alaska was an opportunity for both the FAA and Merlin to focus on the development and deployment of highly automated onboard systems on aircraft, with an initial focus on providing safe, reliable transport of cargo.

Alaska's interior is a unique environment for air cargo due to its weather, terrain, and significance in providing remote communities access to critical goods. According to the Alaska Department of Transportation, only 18% of the state's communities are accessible by road (reference 1). For the 82% of Alaskan communities without road access, air freight provides all the necessities of daily life including food, mail, medicine, and fuel. Without air freight, these communities wouldn't be able to stock grocery shelves or provide electricity. The Alaska Department of Transportation and Public Facilities identifies the state's rural airports as "Alaska's Lifeline" (reference 2).

In order to sufficiently serve the remote communities of Alaska's interior, the state deploys the highest number of aircraft and pilots per capita in the country (reference 3). With this substantial reliance on Alaska's air infrastructure comes a high air accident rate. Between 2008 and 2017, the National Transportation Safety Board found that Alaska had an overall aviation accident rate that was 2.35 times higher than the rest of the United States (reference 4). Contributing to this accident rate is the high number of critical flights (food, medicine, etc.) into hazardous terrain with dynamic weather.

1.3 Project Objective

The Statement of Work sought to test Merlin's experimental system along established cargo routes and six airports near Fairbanks, AK for data collection. Merlin proposed four focus areas in response to BAA call 003:

1. System Reliability in various environmental conditions, specifically unimproved (dirt/gravel) runways and varied weather conditions
2. Natural Language Processing (NLP), with focus on radio data collection, Air Traffic Control (ATC) command interpretation and compliance, and situational awareness enhancement
3. Beyond Visual Line of Sight (BVLOS) link, for use with a ground monitoring station
4. Operational Data, including quantitative and qualitative information on the challenges and lessons learned of operating a highly automated aircraft on established cargo routes

Merlin selected Fairbanks because it is the home to one of seven FAA-designated UAS Test Sites, managed in partnership with the University of Alaska Fairbanks' Alaska Center for Unmanned Aircraft System Integration (ACUASI, pronounced "ah-kwah-zi") (Reference 5). The remaining five destination airports were selected due to their distance from Fairbanks for BVLOS testing, existing operational cargo routes, and familiarity with Caravan operations.

The FAA accepted this Statement of Work and awarded Merlin Labs contract #692M15-19-R-00020-02, officially titled “Development of non-system specific technology to integrate uncrewed aircraft systems (UAS) into the National Airspace System (NAS)”.

Merlin’s project team identified specific targets for testing, aiming to perform at a minimum two flights conducted to each destination, with a goal of six flights. The onsite team consisted of one project manager, 5 rotating test pilots (2 onsite at any one given time), 1 aircraft maintainer, 1 flight test engineer, and 2 software engineers as well as IT and other support crew.

1.4 Acronyms & Abbreviations

The following acronyms and abbreviations are used throughout this document:

Table 1: *Acronyms & Abbreviations*

Acronym/ Abbreviation	Definition	Acronym/ Abbreviation	Definition
ACUASI	Alaska Center for Unmanned Aircraft System Integration	INS	Inertial Navigation System
AGL	Above Ground Level	IP	Internet Protocol
API	Application Programming Interface	IT	Information Technology
ASR	Automatic Speech Recognition	KMHV	Mojave Air and Space Port
ATC	Air Traffic Control	LEO	Low Earth Orbit
ATIS	Automated Terminal Information Service	LG	Low Gain
AUS	UAS Integration Office	LRU	Line-replaceable unit
AWOS	Automated Weather Observing System	MVP	Minimum Viable Product
AWS	Amazon Web Services	NAS	National Airspace
BAA	Broad Agency Announcement	NLP	Natural Language Processing
BERT	Bidirectional Encoder Representations from Transformers	PLM	Product Lifecycle Management
BIS	Bureau of Industry and Security	PTT	Push to talk
		RNAV	Area navigation
BVLOS	Beyond Visual Line of Sight	SA	Situational Awareness
CE	Commercial Entity	SBU	SwiftBroadband Unit
CNES	Global Monitoring for Environment and Security	SCTP	Stream Control Transmission Protocol
COM	Communication	SID	Speaker Identification
DLS	Direct Link Service	SOW	Statement of Work
DR	Deficiency Report	SSH	Secure shell
EAR	Export Administration Regulations	STO	Specific Test Objective
ETA	Estimated Time of Arrival	TCP	Transmission Control Protocol
FAA	Federal Aviation Administration	UAS	Unmanned Aircraft System
FOD	Foreign Object Debris	UDP	User Datagram Protocol
GPS	Global Positioning System	US	United States
HF	Human Factors	USB	Universal Serial Bus
HFO	Human Factors Observation	USD	United States Dollar
HLD	High Power Amplifier/Low Noise Amplifier/Diplexer	VFR	Visual Flight Rules
ICS	Intercom System	VMC	Visual Meteorological Conditions

Acronym/ Abbreviation	Definition	Acronym/ Abbreviation	Definition
ID	Identification	VPN	Virtual Private Network
IFR	Instrument Flight Rules	WAAS	Wide Area Augmentation System
IMC	Instrument Meteorological Conditions	WER	Word Error Rate

1.5 Definitions

The following terms are used throughout this document:

Table 2: *Term Definitions*

Term	Definition
Mission	Series of waypoints created by the pilot for the system to fly
Assignment	In-flight change to the mission (revision to altitude or airspeed, skip ahead or fly back to a waypoint, or vector off the mission to fly a specific heading)
Waypoint	Latitude, longitude, and altitude coordinate with other metadata
N713CB	The tail number of Merlin's Cessna Grand Caravan 208B used for this project
S###CB	Refers to a sortie number. The sorties in Alaska were sorties 61-78.

1.6 References

The following documents are listed for reference only. Each document is applicable to this document only to the extent specified herein.

Table 3: *Reference Documents*

Reference Number	Title	Link
1	National Transportation Board Safety Recommendation Report: Revise Processes to Implement Safety Enhancements for Alaska Aviation Operations	https://www.ntsb.gov/investigations/AccidentReports/Reports/ASR2002.pdf
2	Alaska Department of Transportation & Public Facilities Department Fast Facts Prepared for Legislative Session 2023	https://dot.alaska.gov/comm/legislative/docs/Fact-Sheet.pdf
3	Alaska Department of Transportation and Public Facilities Division of Statewide Aviation Homepage	https://dot.alaska.gov/stwdav/
4	Aviation - Alaska's Lifeline	https://dot.alaska.gov/documents/aviation/Lifeline_FactSheet-Talking_Points.pdf
5	FAA UAS Test Site Locations	https://www.faa.gov/uas/programs_partnerships/test_sites/locations
6	Satellite Orbit Types	https://www.satellitephonereview.com/networks/
7	iPerf - The ultimate speed test tool for TCP, UDP and SCTP	https://iperf.fr/

2 Approach: Engineering Implementation

2.1 Merlin Autonomy System and Aircraft

For this project, Merlin's second generation research and development highly automated system was integrated onto a Cessna Grand Caravan 208B (tail number N713CB) to provide a baseline aircraft configuration for other projects. The target feature set initially consisted of automated takeoff, enroute flight with manual and NLP-directed assignments, and automated landing. This section provides some additional detail on the implementation of the system under test in this project.

2.2 Features

The main components and features of the system tested during this project were:

1. Takeoff and landing performance
2. BVLOS link
3. Ground monitoring station
4. NLP for ingestion of voice commands
5. ATC Screen for displaying a constant stream of NLP-interpreted radio comms
6. Mission planning using a standard third party tool (ForeFlight)

2.3 Takeoff and Landing Performance

Runway 03/21 at Huslia Airport was the smallest runway used by Merlin, measuring 4000 ft x 75 ft (see Figure 1 for comparison to Merlin's home runway, KMHV runway 12/30). Testing in Mojave prior to transfer to the Alaska test area verified that takeoff and landing performance were sufficient for operating out of the short, narrow, and unimproved runways in the Alaska test area.

Figure 1: *Size comparison of Mojave Runway 12/30 (background) to Huslia Runway 03/21 (overlaid)*

2.4 Beyond Visual Line of Sight Link

2.4.1 Background

The Merlin experimental system includes a ground monitoring station that ground-based engineers can use to monitor the flight status via a line of sight radio link.

The ground monitoring station uses a similar user interface to what the crew sees onboard, but with the control interface removed and only monitoring allowed. No data is transmitted from the ground to the aircraft to control the aircraft in any manner.

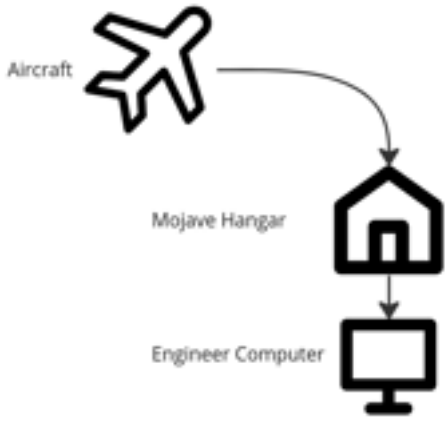


Figure 2: *Ground monitoring station network in Mojave*

The line of sight radios have a line of sight range of at most 40 miles. Given the much larger operating range required in Alaska (the furthest destination was over 400 miles away), a BVLOS link was added to provide telemetry information to the ground monitoring station.

2.4.2 Link Selection Process

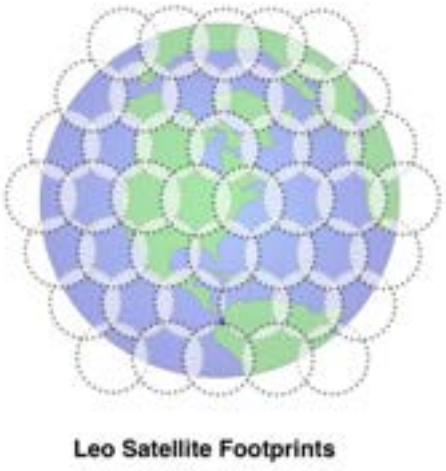
Given the distances covered in the trials, typical line of sight radio communication was not sufficient to meet mission needs. Because of this, the Merlin team entertained various beyond line of sight (BVLOS) options to communicate with and monitor the aircraft during flight. The options considered for BVLOS IP based data link communications are shown in the table below.

Table 4: *BVLOS Link Options*

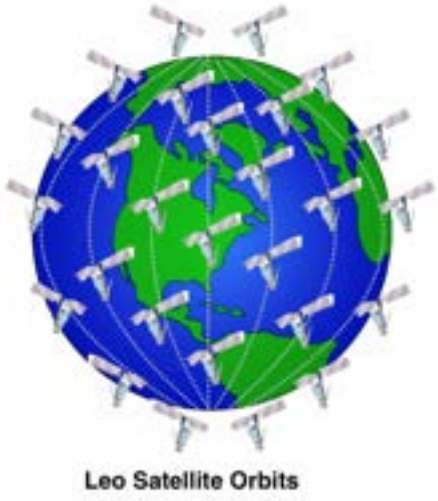
	Iridium Satellite Communications	**Inmarsat Satellite Communications**	**Gogo Biz Aviation**
Model	DLS-100	Aviator 200	Avance L3

	Iridium Satellite Communications	Inmarsat Satellite Communications	Gogo Biz Aviation
Coverage	Low Earth Orbit (LEO) - Global	Geo-Stationary - Strongest at the equator and weaker further north or south towards the poles	Air to Ground - Coverage not available in Alaska due to not having ground stations deployed
Size	DLS-100 - 1.5" x 8.7" x 2.7" Antenna - 3.5" diameter	SwiftBroadband Unit (SBU) Line Replaceable Unit (LRU) - 12.62" x 7.62" x 2.25" High Power Amplifier/Low Noise Amplifier/Diplexer (HLD) LRU - 8.98" x 7.87" x 1.97" Low Gain (LG) Antenna - 11" x 4.58" x 4.25"	4.18" x 8.38" x 16.24"
Weight	DLS-100 - 26.2 oz. Antenna - 5 oz.	SBU LRU - 6.2 lbs HLD LRU - 5.7 lbs LG Antenna - 1.35 lbs	15 lbs
Power Consumption	21 Watts Typical	30 W typical; 83 W Max	115 W @ 20.5 V input

Iridium is the only service that provides strong connectivity over the north and south poles using a mesh network of LEO satellites approximately 485 miles above the earth.



Leo Satellite Footprints



Leo Satellite Orbits

Figure 3: *Iridium coverage area (source: reference 6)*

In contrast, the Inmarsat system coverage is primarily focused on the equatorial region of the Earth due to its geo-stationary orbit keeping the satellite in one place (approximately 22,000 miles away from the Fairbanks test site) and rotating with the Earth. Given the nature of geo-stationary satellite orbits, the closer to The North Pole or to South Pole an aircraft is, the weaker the satellite radio frequency signal, making it unusable.

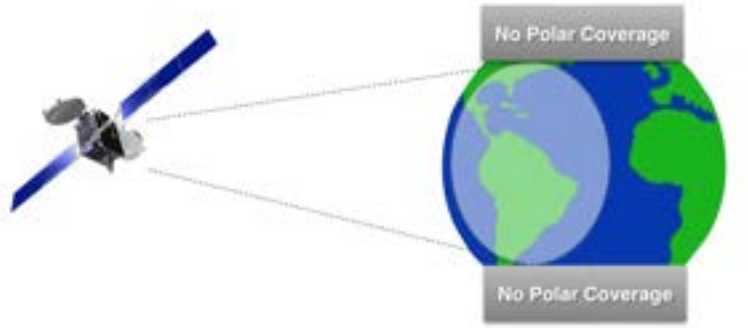


Figure 4: *Inmarsat coverage area (source: reference 6)*

The Inmarsat system would require an additional amplifier to be installed to communicate with a satellite 22,000 miles away. Using the Inmarsat system coverage would also require Merlin to install a steerable antenna on the top of the aircraft. The addition of the amplifier and steerable antenna would significantly increase the overall weight and power requirements of the system.

Gogo Biz Aviation System was not selected because the infrastructure to support air-to-ground communications is not available in the parts of Alaska required for BVLOS operation.

Aside from coverage, additional considerations made Iridium the most viable option:

- Cost: The cost to install and operate the Iridium System is about seven times less than an Inmarsat. The cost savings allowed for a carry-on Iridium Go Hotspot as a second transceiver that was used for the flight crew to communicate with the ground engineers via text and voice during flights in Alaska, freeing up additional bandwidth for the ground monitoring station on the main transceiver.
- Size, Weight and Power: The Iridium system consists of one small transceiver mounted in the aircraft and mounted to a puck antenna on the crown of the aircraft.

The final selection was the Skytrac DLS-100™ Midband Unmanned Aerial Vehicle Datalink and GPS System transceiver with bandwidth of 22 kbit/s from air to ground and 88 kbit/s from ground to air, paired with an Iridium 9770 Sensor Systems Antenna part number S67-1575-414.

Figure 5: *DLS-100 Transceiver and Iridium Antenna*

2.5 Ground Monitoring Station

To meet the BVLOS requirements for this project, Merlin introduced two changes to the existing ground monitoring station and associated infrastructure. The first was optimization of the downlinked telemetry to fit in the reduced bandwidth provided by the BVLOS link as compared with the line of sight link in Mojave. The second change was to the Merlin network infrastructure that secures this link. Both changes were developed and tested prior to transfer to the Alaska test area.

Figure 6: *Example ground monitoring station view*

2.6 Aircraft Radio Connection

Merlin's NLP system is connected to the aircraft audio panel and enables voice commands from both onboard microphones and from ATC over the radio. Both audio inputs were tested with the NLP system over the course of this project.

2.7 ATC Screen

Merlin's system provides a collection of user interfaces that control and monitor flight operations. The system's main onboard interface prompts the pilot with pop up notifications for commands received by the NLP system, as well as a selectable menu that shows all commands (Figure 9).

Figure 7: *Existing NLP features on onboard user interface*

For this project, an additional onboard view was added to Merlin's system interface to show the pilot a rolling transcript of all radio comms (not just commands) being "heard" by the NLP system over the radio. This rolling view was used on a separate tablet that was mounted in the cockpit. The interface can be modified between showing all comms and only showing comms intended for our aircraft.

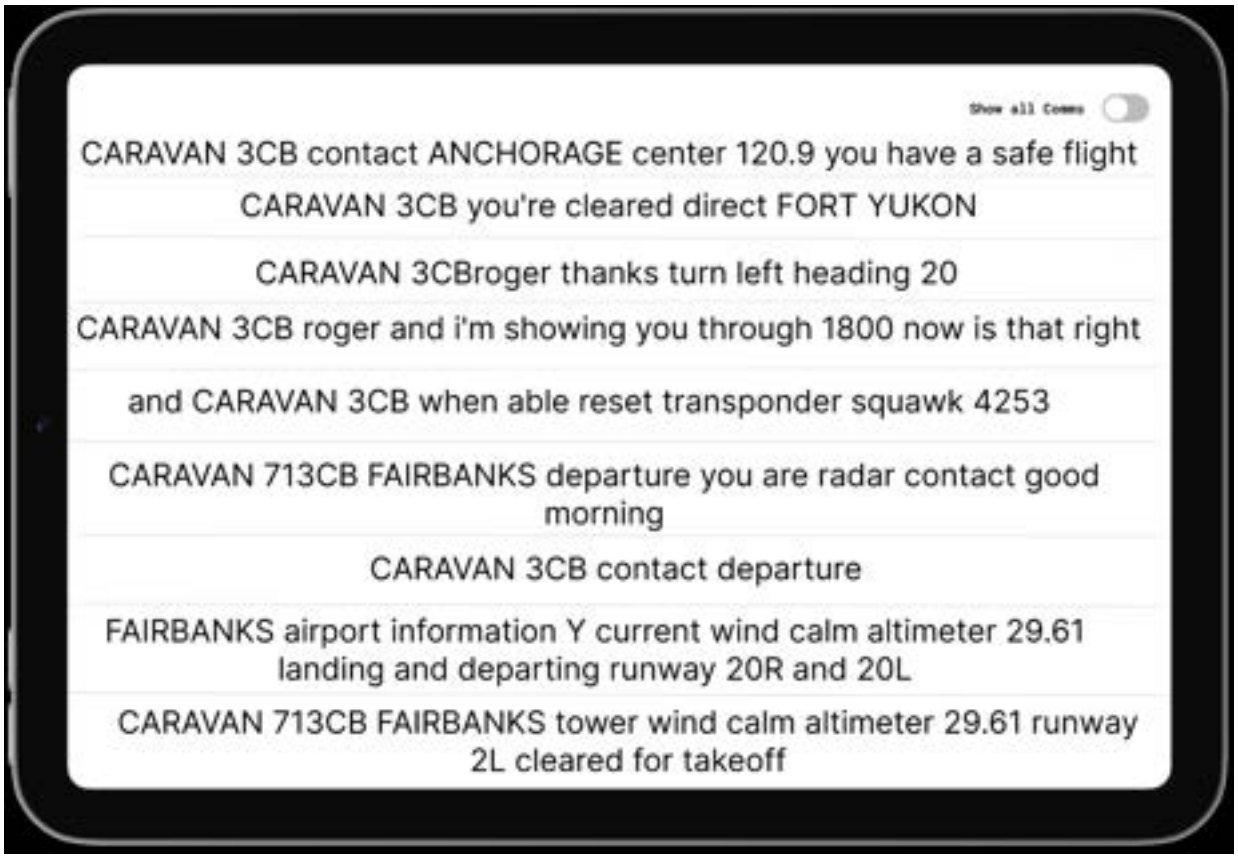


Figure 8: *ATC Screen*

2.9 ForeFlight Mission Planning

The Merlin system includes the ability to ingest flight missions planned using a standard third party tool (ForeFlight).

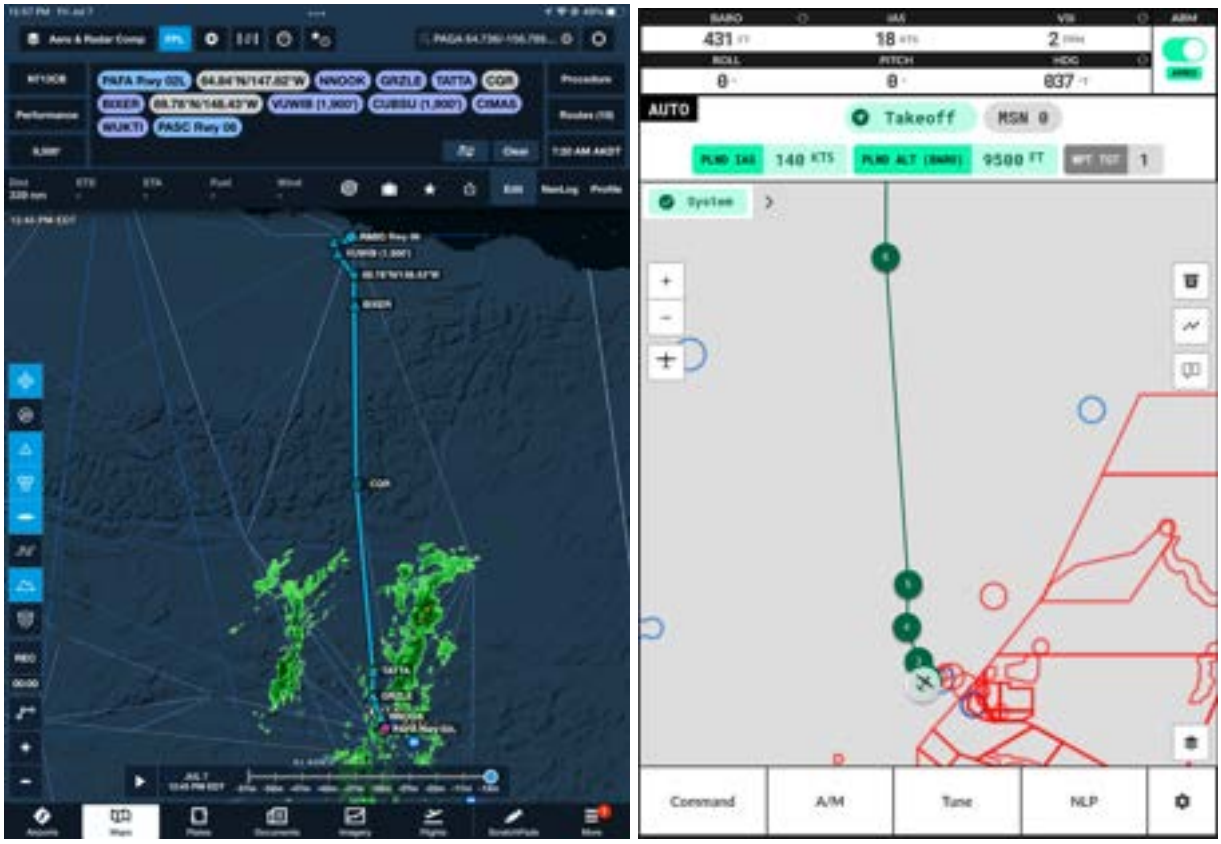


Figure 9: *Example ForeFlight plan (left) and the corresponding mission in the onboard user interface (right)*

3 Flight Testing Overview

The Merlin team was onsite in Alaska from June 5 to June 24, 2023. Over the course of the project, Merlin conducted 18 sorties, including:

- 1 manual sortie with pilot in full control of aircraft operations, gathering baseline pilot workload data and familiarizing with the airspace
- 17 system-on sorties, flying to the five destination airports and gathering data

A typical test crew consisted of one test pilot, one operational pilot, and 1-2 engineers, filling the roles of Test Conductor and/or Discipline Engineer. The final sortie was conducted with only a

single test pilot and Test Conductor, which was a useful exercise in truly evaluating single pilot operations, with the Merlin system acting as the second “pilot.”

A typical flight test looked like the following:

Setup and Takeoff

1. The test crew arrives at Everts Air Fuel hangar in Fairbanks, Alaska and conducts an air crew brief. This may include using ForeFlight to plan the initial mission.
2. The flight crew boards aircraft.
3. The pilot communicates with ATC and adjusts ForeFlight plan accordingly (e.g., runway change). Pilot downloads the ForeFlight file to the tablet.
4. The pilot taxis the aircraft and lines up on the runway.
5. The pilot uploads the ForeFlight file to the system via the tablet and engages the Merlin system.
6. The pilot releases aircraft brakes.
7. The Merlin system performs takeoff.

Enroute

While airborne:

1. The Merlin system follows the mission.
2. The NLP system “listens” to the aircraft radio to display comms on the ATC Screen and interpret commands from ATC for the system to comply with.
3. The pilot responds to ATC and other radio calls.
4. The pilot uses NLP or the user interface to adjust the mission to vector around weather/traffic, change the arrival runway, or comply with ATC commands that the NLP system did not handle automatically.
5. The test conductor keeps a running log of notes on pilot feedback and system anomalies.
6. The flight crew uses the Iridium Go to communicate with ground engineers about things such as estimated time of arrival (ETA) and fuel needs.

The ground crew monitors the flight progress and location through the ground monitoring station.

Landing and Destination Activities

1. The Merlin system performs an approach.
2. The Merlin system performs landing.
3. The pilot disengages the system at touchdown and taxis the aircraft to a parking location.
4. The flight crew shuts down and deplanes.
5. If any members of the public come to see the aircraft, the test crew provides tours, talks to town members, and answers questions.
6. The pilot plans the next leg of the mission, either to the next destination airport or back to Fairbanks.

Figure 10: *Community engagement with town members at destination airports*

The crew repeats the same procedure for each destination airport in the sortie.

Returning to Fairbanks

Upon arrival in Fairbanks:

1. The test crew debriefs the flight.
2. The pilot writes a quicklook type of report on overall performance of the system and any anomalies or difficulties encountered.
3. The test conductor documents Deficiency Reports (DRs) based on the pilot report and test crew debrief notes to document system issues to the Merlin team.
4. The engineering team offloads logs from the autonomous system.
5. The engineering team uploads the logs from the autonomous system to shared storage for the Merlin team to analyze.
6. The maintenance team preps the aircraft and refuels it.

4 Demonstration/Verification Results

As discussed in Section 1.3, the objective of this project was to gather data that support four research areas:

1. System Reliability on unimproved (dirt/gravel) runways and in varied weather conditions
2. NLP, with focus on radio data collection, ATC command interpretation and compliance, and situational awareness enhancement
3. BVLOS link, for use with a ground monitoring station
4. Operational Data, including quantitative and qualitative information on the challenges and lessons learned of operating a highly automated aircraft on established cargo routes

The team met this objective with 66 hours of both quantitative and qualitative flight data relating to these four focus areas. More specific information about the data gathered for the first three objectives are summarized in this section. Challenges and lessons learned for the fourth objective can be found in Section 5.

The team's goal of two to six flights to each destination airport was also successful. The initial routes identified were:

1. Fairbanks to Fort Yukon to Fairbanks
2. Fairbanks to Deadhorse to Fairbanks
3. Fairbanks to Tanana to Huslia to Galena to Fairbanks

However, the test team ended up combining/changing the order of the routes for various reasons, as detailed below.

Table 5: *Routes used in flight testing*

Route	**Number of occurrences**	**Notes**
Fairbanks to Fort Yukon to Fairbanks	5	Nominal route
Fairbanks to Deadhorse to Fairbanks	3	Nominal route
Fairbanks to Fort Yukon to Deadhorse to Fairbanks	1	The Fort Yukon-Deadhorse route was a combined route due to distance.
Fairbanks to Tanana to Huslia to Galena to Fairbanks	1	Nominal route
Fairbanks to Tanana to Huslia to Fairbanks	1	The sortie that used this route was planned to be to Deadhorse, but weather precluded getting there. The team was able to divert to the Tanana/Huslia/Galena route, but didn't have enough fuel to do the entire route and couldn't get confirmation of fuel availability in Galena. The team opted to skip Galena and fly straight back to Fairbanks.

Route	Number of occurrences	Notes
Fairbanks to Galena to Fairbanks	1	To make up for the route where Galena was missed, the team flew straight to Galena once.
Fairbanks to Galena to Huslia to Tanana to Fairbanks	1	The team found it easier to get the longest leg of the Tanana/Huslia/Galena route out of the way first, so they opted to perform the route in reverse order.
Fairbanks to Galena to Huslia to Fairbanks	4	The gravel and rocks at Tanana caused foreign object debris (FOD) on the aircraft's prop blade, so the team opted to forgo further testing there and substituted this route instead.
Total	**17**	

Table 6: *Number of visits to each destination*

Destination	Number of visits
Fort Yukon	6
Deadhorse	4
Tanana	3
Huslia	7
Galena	7
Total	**27**

4.1 System Reliability

Along with the 27 autonomous landings and takeoffs at each destination airport, there were 14 takeoffs and landings out of Fairbanks, for a total of 41 of each.

Table 7: *Overall System Reliability*

Takeoffs	40 nominal/ 41 attempted
Landings	39 nominal / 41 attempted

4.1.1 Takeoff

The one off-nominal takeoff attempt out of 41 was due to the Merlin system's Inertial Navigation System (INS) not aligning properly before attempting system engagement and takeoff, causing the aircraft heading to be incorrect. After exiting the runway, the INS converged its heading and the team was able to re-attempt the takeoff with no issues.

All other takeoffs were nominal with no adverse pilot comments on system performance. Overall, the system performed takeoffs on dirt/gravel runways successfully, with no noticeable differences compared to taking off on asphalt runways. The demonstrated winds for all takeoffs are shown below.

4.1.2 Landing

The Merlin system was unable to perform two landings due to high crosswinds outside the system design limits. In each instance, the Merlin system has enhanced safety measures in place that allow safety pilots to disengage the system, take control of the aircraft and ensure a proper landing. In the first instance, the crosswinds advertised by the Automated Weather Observing System (AWOS) were less than one knot. However, with 10 ft above ground level (AGL) left to go, the test team felt that system crosstrack error, runway alignment, and drift rate were unacceptable and disengaged the system. Upon landing the team noticed that the windsock looked to be about 15 kts crosswind, which exceeded typical testing conditions experienced at Merlin's test operations at their test facility in Mojave, CA.

In the second instance, a storm was directly over Fairbanks with a crosswind from ATC reported at 23 gusting 33 kts. The test team elected to disengage the system on the approach and manually land.

Table 8: *Demonstrated maximum winds for landings*

Headwind (kts)	Tailwind (kts)	Crosswind (kts)
17.9	7.5	10.8

The vast majority of landings throughout the project were nominal. The system performed landings on dirt/gravel runways successfully, with no noticeable differences compared to landing on asphalt runways. For a few landings there were pilot comments related to:

- Long landings (often as a result of gusting headwinds increasing local performance of the aircraft)
- The touchdown being a bit firm
- Centerline tracking being a bit off (often as a result of crosswinds providing drift at landing)

These were similar to comments received during testing in Mojave. However, the pilots never felt that system performance was unsafe and elected every time to allow the system to touchdown.

One item of interest was the radar altimeter (“radalt”) signal used by the aircraft for flare. Several approaches during the project demonstration were over water and/or other varied terrain, and the test team paid attention to whether this affected the radalt signal, such as if there were longer lasting filtering effects after the aircraft had resumed flying over solid level surfaces.

Figure 11: *The glidepath into Fort Yukon’s runway 04 went over the Yukon River. Imagery © 2023 CNES / Airbus.*

Figure 12: *The glidepath into Deadhorse's runway 24 went over the Sag River. Imagery © 2023 Maxar Technologies.*

Figure 13: *The glidepath into Tanana's runway 07 went over the Yukon River. Imagery © 2023 CNES / Airbus.*

Figure 14: *The glidepaths into Galena's runways 08 and 26 went over the Yukon River (note that although the imagery shows ice there was no ice present during testing). Imagery © 2023 Esri.*

The radalt signal showed that the water did not seem to cause excessive noise in the signal. Aside from the initial jitter as the radalt came into range, the signal was relatively consistent throughout the glideslope. Most importantly, the radalt signal was accurate at 200 ft before the runway threshold, which is the point at which the radalt signal is used by the system for the flare. Lastly, the data confirms the test team's observations that the radalt signal came in at a higher than expected range, around 475 ft, 311 ft higher than the radalt's advertised range of 164 ft.

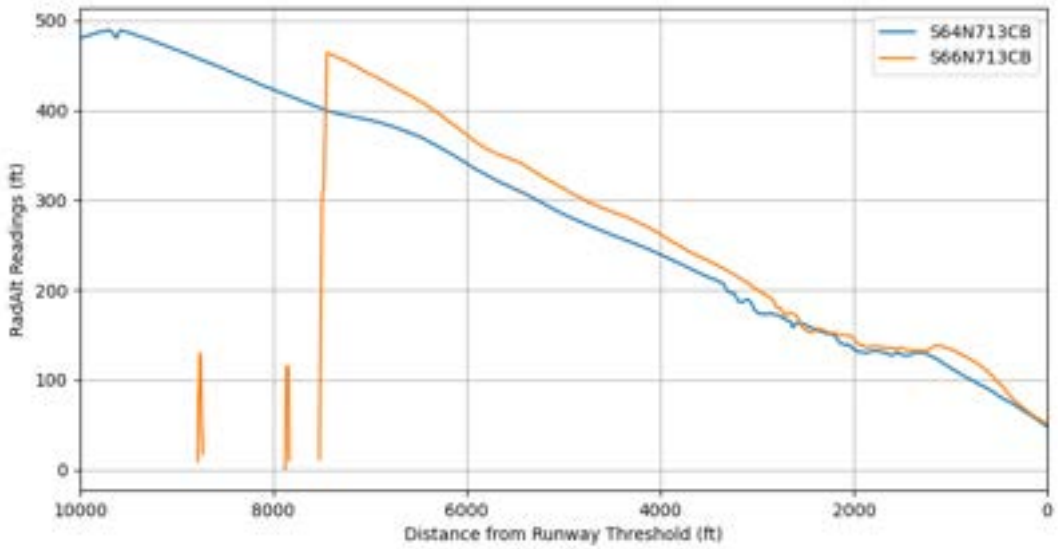


Figure 15: *Fort Yukon runway 04 radalt signal*

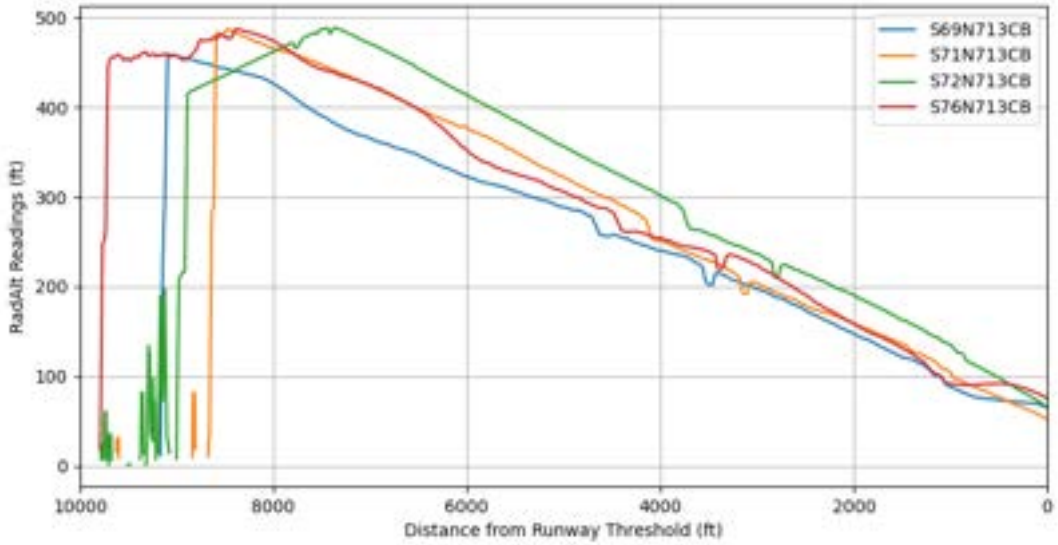


Figure 16: *Deadhorse runway 24 radalt signal*

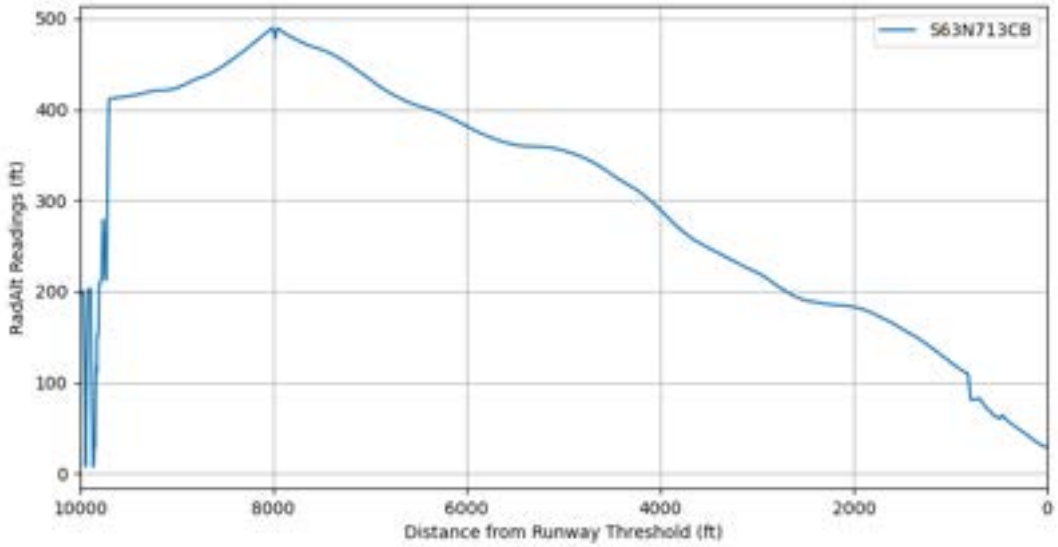


Figure 17: *Tanana runway 07 radalt signal*

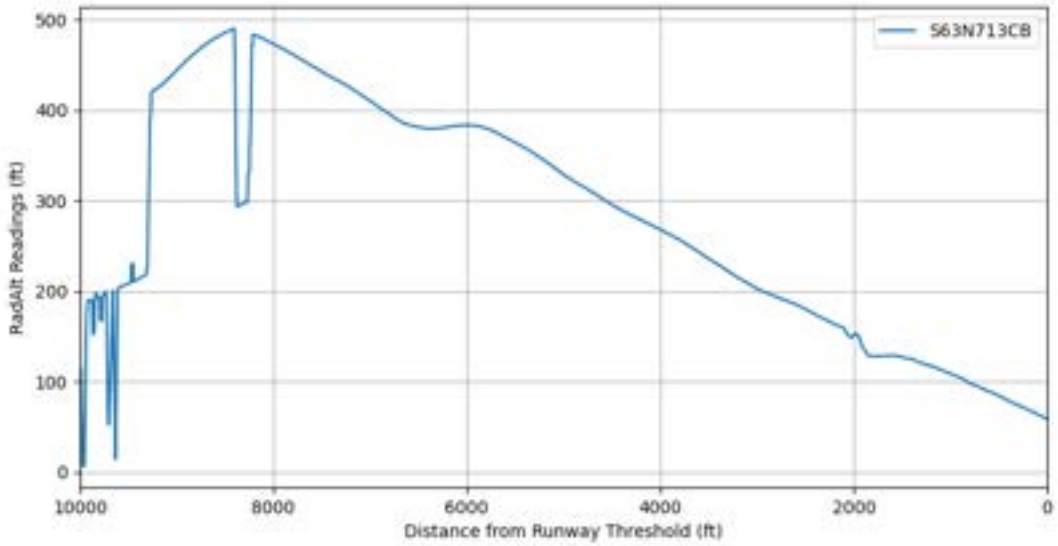


Figure 18: *Galena runway 08 radalt signal*

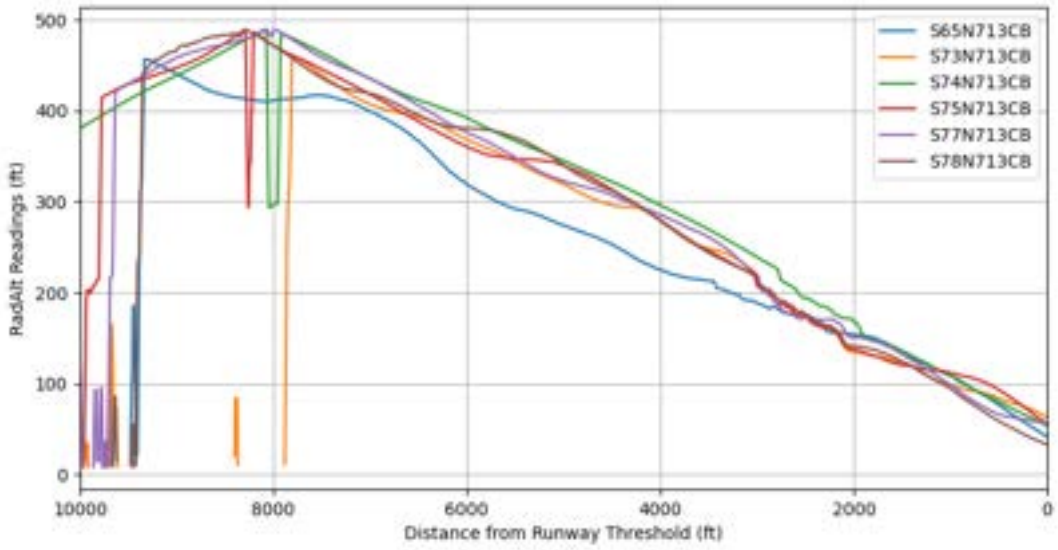


Figure 19: *Galena runway 24 radalt signal*

4.1.3 Weather

Weather patterns in Alaska's interior can be volatile and unpredictable. Throughout the project, weather conditions sometimes precluded flights to certain destinations and required the test team to pivot or cancel sorties. The test team usually set the schedule for the week based on forecasted weather to each destination and, on approximately three occasions, changed the destination the day before or day of the sortie based on latest forecasts. As noted in Section 4, there was one occasion the test team took off with a plan to go to Deadhorse, but encountered weather that precluded going there, and diverted to Tanana and Huslia instead. Ultimately only one sortie (the last one of the trip) to Deadhorse was canceled, since all other destinations had been completed.

Weather was important because Merlin's current operating rules do not allow Instrument Flight Rules (IFR), only Visual Flight Rules (VFR) flight. Therefore, even otherwise benign clouds had to be navigated around. The route up to Deadhorse in particular was frequently cloudy. Weather systems would encounter the Brooks Range and cause lingering instrument meteorological conditions (IMC) at Caravan operating altitudes.

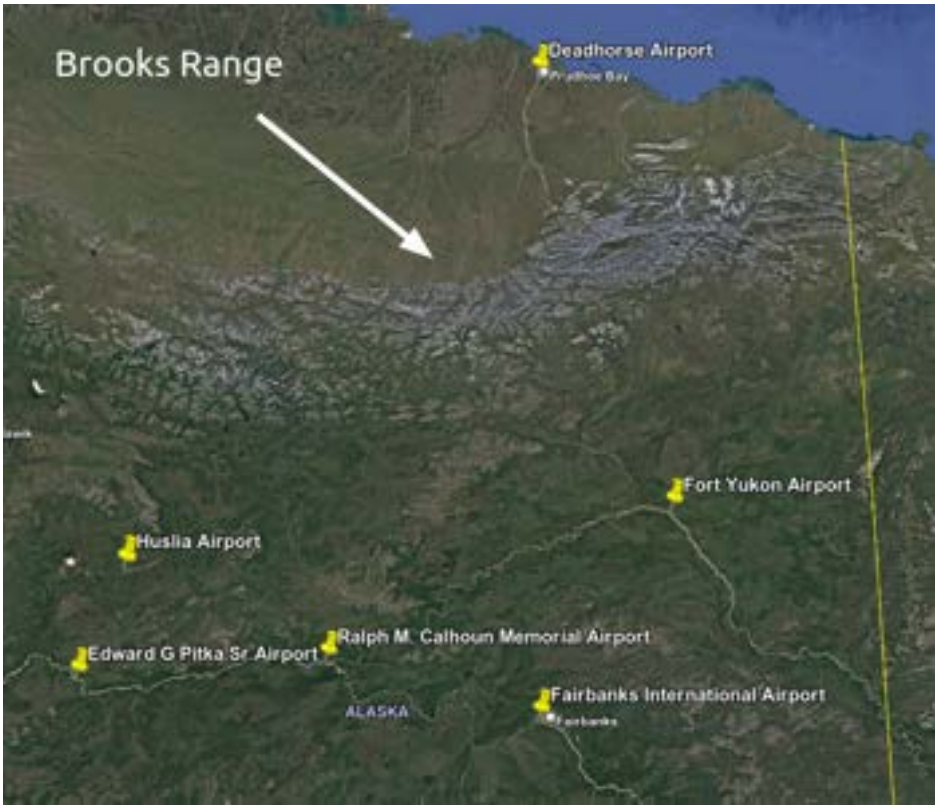


Figure 20: *Brooks Range*

The team used the heading assignments feature frequently to vector off the mission and go around clouds. The heading assignment feature was not available until 5 sorties into the project. Of the remaining twelve sorties, heading assignments were used an average of 14 times per sortie.

The team also used altitude assignments to climb above or below the clouds. Without the use of supplemental oxygen, the crew were limited by Part 91.211, which states that the aircraft is permitted to fly between 12,500 ft and 14,000 ft for up to 30 minutes at a time. The crew used this altitude band during two different sorties, both on the Deadhorse route. In one sortie they used the altitude band once for 10 minutes. In the second sortie they used it three times, for 5, 10, and 21 minutes at a time. The team was creative in finding sufficient VFR holes in the clouds through which to descend when approaching the destination, often performing tight circles using a series of heading assignments paired with an altitude assignment to descend.

When flying below clouds, the Merin system experienced a wide range of weather, including rain, hail, snow, and wind. There were no noticeable changes to report in performance of the system.

4.2 Natural Language Processing

The following NLP sections present data from 12 out of the 18 sorties that were conducted in Alaska.

4.2.1 Radio Data Collection

Over the course of twelve sorties a total of 4102 utterances were detected over the radio. Of those 4102 utterances, 453 or 11% were intended for the Merlin aircraft, and 692 or 17% were from the Merlin aircraft. Table 11 categorizes the utterances intended for the Merlin aircraft. Appendix A: Selected Radio Utterances contains all the utterances for each of these subcategories.

Table 9: *Types of utterances detected over the radio intended for the Merlin aircraft*

Utterances Intended for the aircraft	453
Utterances Requiring Pilot Action (air)	228
Utterances Requiring State Change	37
Utterances Requiring Pilot Action (ground)	42
Utterances Requiring Visual Confirmation	28
Weather Utterances	9
Traffic Utterances	57

4.2.1.1 Air Operations

50% of the ATC commands for the Merlin aircraft required pilot action while in the air. Pilot actions in response to ATC commands were broken down into 13 action categories (Figure 26).

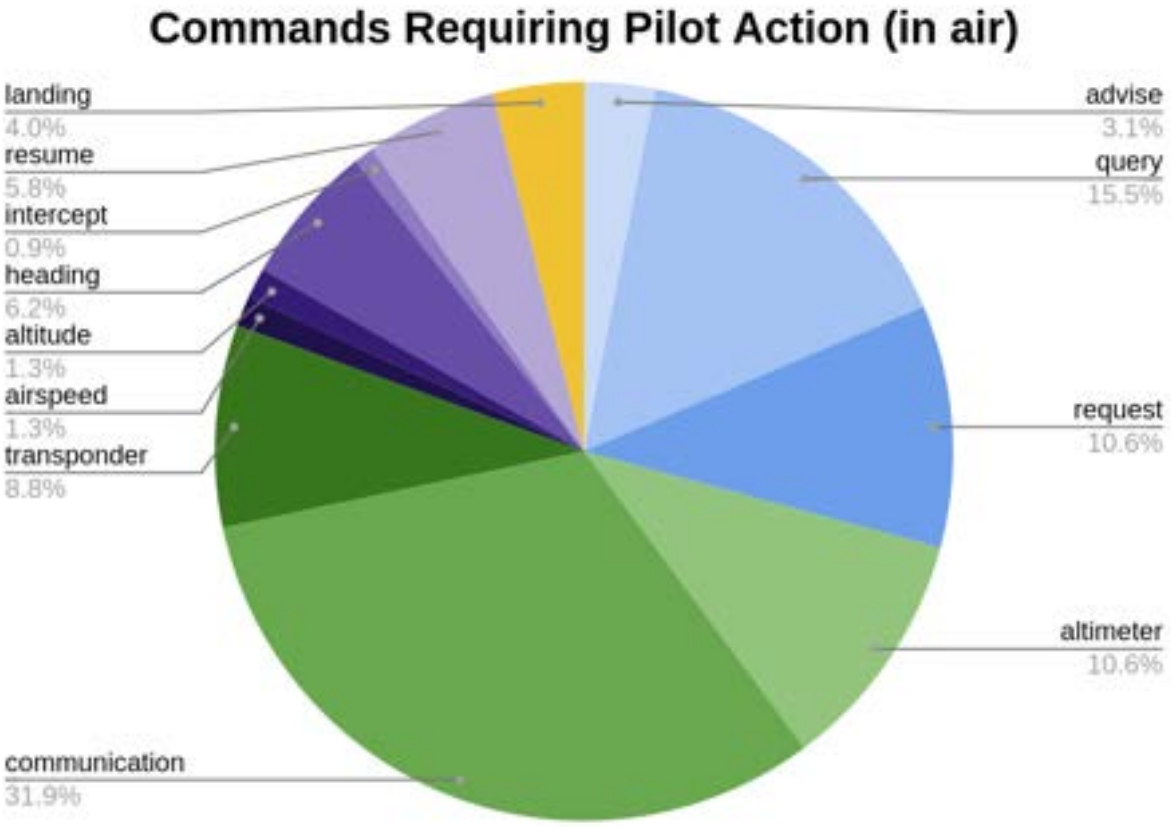


Figure 21: *Commands that required a pilot action while in the air*

The advise, request, and query categories (Figure 26, blue) contain commands where ATC was asking for information from the aircraft. These categories made up 15% of the 453 commands spoken to the aircraft.

Example commands for each topic are:

Advise

- "*caravan november three charlie bravo roger just* ***advise when you start your turn*** *but you are approved to resume own navigation*".

Request

- "*fairbanks three charlie bravo* ***say altitude***"
- "*november seven one three charlie bravo fairbanks ground* ***say again type aircraft***"
- "*november seven one three charlie bravo squawk four six seven one* ***say request****"*

Query

- "*november three charlie bravo roger proceed as requested and* ***was that for uh two zero right or two zero left***"
- "*november three charlie bravo uh runway two zero right taxi via correction runway two zero right at papa taxi via alpha and* ***verify you said you have kilo***".

The altimeter, communication, and transponder categories (Figure 26, green) required the pilot to set the altimeter, radio frequency, and transponder respectively. There were a total of 116 of these commands.

The airspeed, altitude, heading, intercept, and resume categories (Figure 26, purple) required a state change of the aircraft. These made up 8% of commands spoken to the aircraft. Appendix A.1.7-A.1.11 list all state change commands received during testing. The last category is landing which contains clearance to land. An example is "*caravan seven one three charlie bravo fairbanks tower wind two two zero at one two **runway two zero right cleared to land** traffic will cross right to left for the parallel caravan*". There were only 9 landing clearances since only one of the 6 airports we landed at was towered.

Over the course of the 12 sorties there were 7 utterances reporting weather and 57 utterances reporting on traffic. There were 28 commands that required a pilot visual confirmation, the majority of which were related to traffic. Some examples include:

1. "*caravan three charlie bravo **maintain visual separation from the c one thirty as well***"
2. "*caravan three charlie bravo y**ou're following a caravan eleven o'clock one two miles four thousand one hundred uh joining final for two zero right***"
3. "*experimental seven one three charlie bravo fairbanks tower **you'll be following a skyhawk at left close for runway two left** continue inbound*"
4. "*caravan three charlie bravo **number two behind the skyhawk runway two left cleared to land***"

4.2.1.2 Ground Operations

While on the ground the majority of commands received were taxi commands, such as "*caravan seven one three charlie bravo runway two zero **right taxi via alpha***". Taxi commands made up 6% of the 453 commands spoken to the aircraft and 59% of ground commands requiring pilot action. T**wo** commands were line-up commands such as "*experimental seven one three charlie bravo **runway two zero right line up and wait traffic in your departure corridor***". The rest of the commands received were takeoff/departure clearances such as "*caravan seven one three charlie bravo runway two zero right at papa **clear for takeoff** wind two zero zero at five*". Takeoff/departure clearances made up 3% of the 453 commands spoken to the aircraft. Figure 27 below shows a summary of the number of commands received for each category.

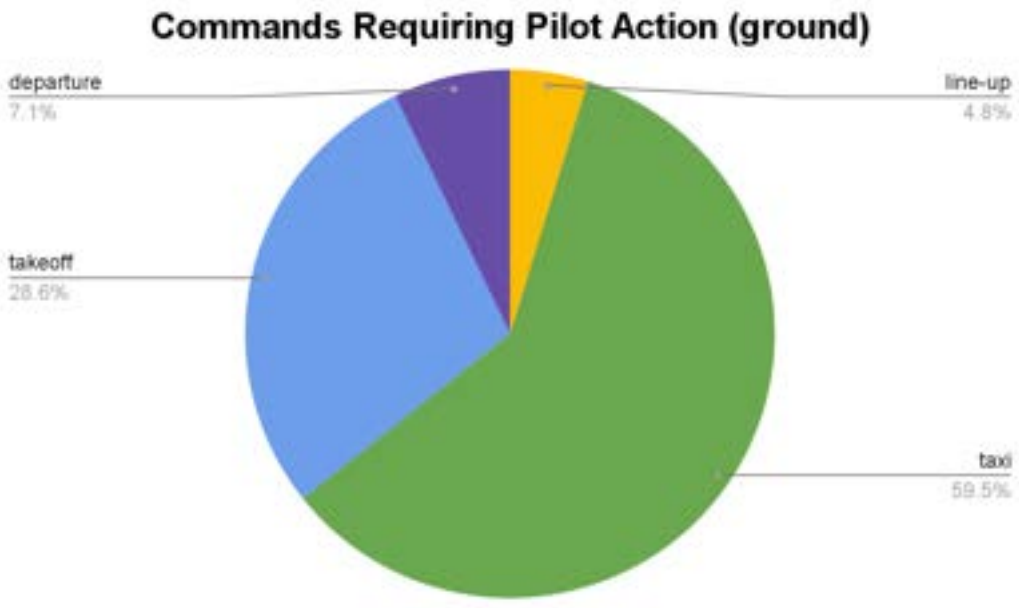


***Figure 22**: Commands that required pilot action on the ground*

4.2.1.3 Radio Data Collection Per Route

To understand how often pilots change radio frequencies the number of frequencies listened to each route was recorded. Figure 28 shows the number of frequencies per route. The number of frequencies ranged from 7 for longer routes, to 2 for shorter routes.Not all of these frequency changes were called out over the radio, and some of the changes were issued minutes before a change was required; Ex. "*caravan three charlie bravo **in case you lose me this frequency one two four point six will be your next frequency in about ten minutes***".

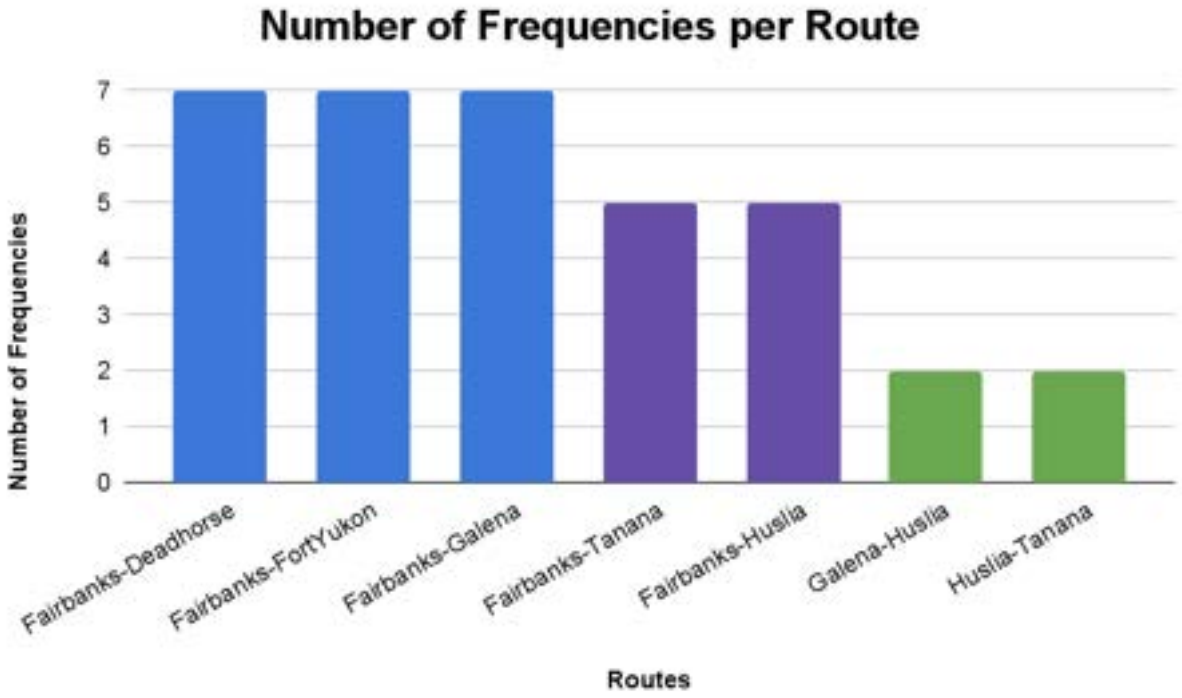


***Figure 23**: Number of radio frequencies tuned to each route*

Statistics on the average number of utterances per route were calculated to understand how communication differed amongst the different routes. Figure 29 shows the full results.

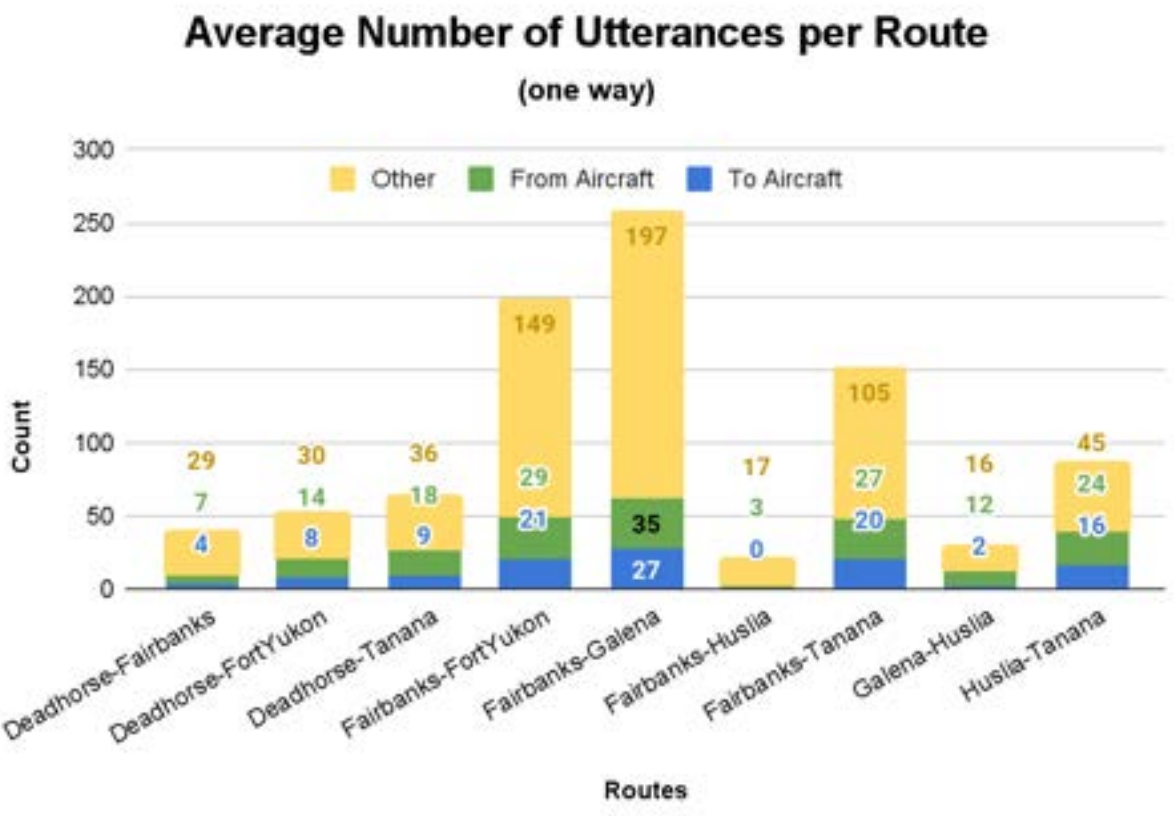


***Figure 24**: Average number of utterances per route*

4.3 Human Factors Analysis

The statement of work included a section to measure situational awareness (SA) related to the use of the NLP system that interpreted ATC communications and displayed them to the pilot, referred to as the ATC Screen. The Merlin human factors (HF) team developed a series of questionnaires to deliver to the pilots to obtain subjective measures of their SA. The Merlin HF team augmented their approach to analyze the system as a whole as it related to pilot workload and SA, using semi-structured interviews with the pilots (after completion of all flight activities in Alaska) and observational methods applied to audio and video recordings. The objectives of these methods were to obtain pilot subjective opinions on as many combinations as possible of:

- pilot states (including workload, trust in the automation, scan patterns, and SA)
- novel functions (including auto takeoff, auto land, and automated communication)
- various implementations of the system (including flying with the Alaska implementation of the system vs. flying with the envisioned "final" product vs. flying the baseline Caravan 208B)

Cameras were installed in the test aircraft to capture video footage. Three camera viewpoints were captured: from the glareshield looking back at the pilots, from the ceiling between and

behind the pilots looking forward at the instrument panel and controls, and from the ceiling looking down at the ATC Screen. Audio was separately recorded, and captured incoming and outgoing aircraft transmissions, ATIS radio, and internal crew communications. The audio and videos were later synced and reviewed as a single combined recording, per leg of each flight (Figure 30).

Figure 25: *Screenshot of the three camera views time-synced and stitched together*

The main findings derived from the human factors processes included:

- Pilots experienced reduced overall workload when flying with the Merlin system relative to flying with the baseline 208B.
- Identification of aspects of the system (including human-machine interfaces) that are designed well and aspects with potential areas of improvement.
- Identification of flying tasks that may be good candidates for automating in future versions of the Merlin system.

4.4 Beyond Visual Line of Sight Link

4.4.1 DLS-100 Transceiver and Ground Monitoring Station

The BVLOS link ended up being crucial for comms between the ground and airborne crew, as the crew was unable to get cell service in three of the five destinations. The ground monitoring station provided situational awareness for the ground team regarding the airborne teams precise location. For instance, it was easy to see when the airborne team was vectoring off the mission for weather, meaning the ground team could anticipate a late arrival or even possible destination change.

4.4.2 Iridium Go Hotspot Voice and Text Communications

The airborne test crew used the Iridium Go to communicate:

- Estimated time of arrival to next destination
- Fuel needs (e.g.,, asking to call ahead to the next destination and confirm fuel availability)
- Plan updates or delays (e.g., “Eating lunch in Deadhorse, expected departure in 30 mins”)

The crew sent anywhere between 1-10 texts per sortie and received a similar number. The crew rarely used voice calls, since:

- Text messages were sufficient, andreal-time comms were not typically needed
- Signal strength was sometimes insufficient to support a phone call
- The 1-3 second lag on the call made communication difficult

The team encountered some issues with the Iridium Go app:

- Issues logging into the app
- Issues sending texts — texts would say “Sending” for a long time, and sometimes would never send even when a higher signal area was reached
- Issues receiving texts — the team frequently did not receive the response from the person on the ground
- When first logging in, the app would suddenly receive multiple messages as once. These were any messages received since the last time the person logged in (potentially multiple sorties ago if they hadn’t been on the last flight)
- When logging in, any messages sent during the last sortie still showed as “Sending” even though they had already been sent.
- There didn’t seem to be a way to add contacts, so you had to sync the contacts from your phone to the app. This meant that if you didn’t have a ground based crew member’s phone number stored on your own personal phone, you would have to guess what their number was based on past sent messages on the app.

These comments are qualitative; detailed quantitative analysis of the texts sent and received were not gathered.

5 Challenges and Lessons Learned

5.1 Beyond Visual Line of Sight Link (BVLOS)

The team took a minimum viable product (MVP) approach to the BVLOS link and associated infrastructure used for this project. Specific lessons learned from the experience will be used to inform future Merlin product requirements where a BVLOS link is needed.

5.2 NLP

The operational learning in Alaska, both in terms of NLP performance and its impact of HF considerations, will be used to enhance the NLP performance and identify any operation limitations required to satisfy the certification HF requirements for Merlin's products.

As a result of this project's data collection, Merlin was able to collect data (including for types of operations and scenarios not previously in our training data set) that will be used to improve our natural language processing technology.

5.3 Flight Test Operations in Alaska

Merlin's flight testing in Alaska successfully met all project objectives. Due to dynamic weather conditions, the team remained flexible with regards to the flight test schedule and route selection. The team kept detailed documentation of each flight test.

6 Recommendations and Next Steps

The demonstration in Alaska's interior, in partnership with ACUASI, presented many meaningful opportunities for R&D of Merlin's product — from technology improvements, to significant data collection, to end-user design, and even engagement with local community members.

While future Merlin operations in Alaska are still being scoped, the following next steps are being explored:

1. Seek opportunities with Federal agencies, such as the FAA, to research highly automated, onboard aviation systems that require minimal changes to existing infrastructure and procedures.
2. Partner with ACUASI to identify additional contract and funding opportunities for continued research and development of system capabilities and design.
3. Identify aircraft integration opportunities with Everts Air Cargo.
4. Develop an engagement strategy to seek feedback from demonstration partners and community members to further refine system capabilities and operations, as well as provide opportunities for transparency and education on advanced aviation systems.

7 Appendix A: Selected Radio Utterances

A.1 Utterances Requiring Pilot Action (Air)

A.1.1 Advise

caravan three charlie bravo just let me know when you get that other caravan in sight twelve o'clock seven miles three thousand four hundred
caravan three charlie bravo ready to copy your clearance sorry correction your v f r departure
caravan three charlie bravo advise when you're ready to taxi
experimental three charlie bravo roger report established maintain v f r and verify you have information papa
experimental three charlie bravo roger thank you and contact tower one one eight point three advise when ready for departure
caravan uh november three charlie bravo roger just advise when you start your turn but you are approved to resume own navigation
caravan three charlie bravo roger i don't have anything uh any weather radar in that area uh once you're heading back for deadhorse uh advise

A.1.2 Request

november seven one three charlie bravo radar contact two zero miles south fort yukon v o r say altitude
november seven one three charlie bravo radar contact two five miles south fort yukon v o r say altitude
november seven one three charlie bravo cleared to the fairbanks airport or actually were you looking for v f r or i f r
fairbanks three charlie bravo say altitude
caravan three charlie bravo say altitude climbing to
caravan three charlie bravo roger uh how slow you uh how slow are you slowing up to
november seven one three charlie bravo squawk four six seven one say request
november seven one three charlie bravo radar contact five miles south fort yukon airport say altitude
where are you coming from
november seven one three charlie bravo fairbanks ground say again type aircraft
november three charlie bravo say again type aircraft and uh you said you're westbound
calling center say again
experimental caravan seven one three charlie bravo deadhorse radio roger no traffic reported say direction outbound please
three charlie bravo radar contact one zero miles east of galena say altitude
caravan three charlie bravo altitude and you said to tanana
caravan three charlie bravo say position

caravan seven one three charlie bravo fairbanks tower wind zero five zero at eight for runway two left cleared to land and say parking
november seven one three charlie bravo radar contact uh nine miles south of the fort yukon v o r say altitude
+unintelligible+ approach say again
caravan seven one three charlie bravo fairbanks approach say again altitude leaving
experimental seven one three charlie bravo fairbanks tower runway two zero right at papa taxi via alpha uh TRSA departure and can you confirm the equipment suffix for you
last calling fairbanks tower say again
caravan seven one three charlie bravo radar contact four eight miles northeast bettles v o r say again altitude
november seven one three charlie bravo fairbanks departure radar contact say again altitude leaving

A.1.3 Query

three charlie bravo i stepped on you if you stay at fifty five we're gonna have to vector you but you did say you had them in sight
caravan seven one three charlie bravo fairbanks approach i missed the last of your transmission verify you had juliet make straight in runway two zero right
fairbanks three charlie bravo i just wanna understand you're flying the r nav yankee two zero right approach
this is tanana weather do you need a uh an an agent called
november seven one three charlie bravo fairbanks approach good evening and did you want a pattern entry or you're going to be o nav for a long straight in
november three charlie bravo roger proceed as requested and was that for uh two zero right or two zero left
caravan seven one three charlie bravo fairbanks approach you're following a caravan twenty miles north of fairbanks do you want a vector to follow or would you like to slow down twenty knots
november three charlie bravo say again type aircraft and uh you said you're westbound
november three charlie bravo uh runway two zero right taxi via correction runway two zero right at papa taxi via alpha and verify you said you have kilo
caravan seven one three charlie bravo fairbanks tower runway two zero right clear to land wind two zero zero at niner say parking
november three charlie bravo you said you're going to everts south
experimental caravan are you the seven one three charlie bravo
experimental uh caravan seven one three charlie bravo deadhorse radio traffic's a pilatus he's inbound from the east he'll be turning final here shortly for runway two four and confirm you have information juliet
experimental caravan deadhorse radio roger thanks confirm your call sign is november seven

one three charlie bravo
caravan seven one three charlie bravo deadhorse radio roger hey what's your direction uh southeast bound
november seven one three charlie bravo radar contact maintain v f r and say aircraft type
november three charlie bravo say destination
caravan three charlie bravo you keep deviating a little bit you experiencing you experiencing any icing or turbulence
caravan three charlie bravo say parking
three charlie bravo you're gonna want flight following with the center
okay uh how many minutes out
caravan three charlie bravo altitude and you said to tanana
experimental seven one three charlie bravo fairbanks approach just verify you're gonna intercept the r nav yankee for two left
experimental three charlie bravo roger report established maintain v f r and verify you have information papa
i had two calls at once there caravan seven one three charlie bravo fairbanks departure you're radar contact i'm still a little unfamiliar with your normal operation i understand you want to go to fort yukon but uh about how far out are you planning on flying with your current heading
november seven one three charlie bravo thanks you're going to fairbanks correct
what's your estimated time
seven one three charlie bravo deadhorse radio roger no reported traffic verify your information golf
you're landing six or two four
seven one three charlie bravo when able say parking
and just verify the full call sign and aircraft type
november seven three charlie bravo is that the uh highest you'll be climbing
caravan three charlie bravo anchorage center loud and clear the anaktuvuk pass altimeter two niner five six uh it's way ahead and it's pretty far southwest uh if you need any assistance on the way north
november seven one three charlie bravo are you canceling i f r this time
yep are uh are you clear

A.1.4 Altimeter

november seven one three charlie bravo the de- actually fort yukon altimeter two niner six five
caravan seven one three charlie bravo anchorage center the fairbanks altimeter two niner six seven
fairbanks atis information juliet now current wind two two zero at four altimeter two niner seven one
november seven one three charlie bravo cleared to fairbanks airport via direct maintain v f r the fort yukon altimeter two nine seven eight

caravan three charlie bravo fairbanks atis bravo is current wind calm altimeter two niner seven four contact fairbanks tower
november seven one three charlie bravo anchorage center galena altimeter two niner six four +unintelligible+
november seven one three charlie bravo squawk one three three five the tanana altimeter two niner six niner
november three charlie bravo the tanana altimeter two niner six seven
november seven one three charlie bravo anchorage center roger fairbanks altimeter two niner niner four
caravan seven one three charlie bravo deadhorse radio roger again deadhorse altimeter two niner eight one
november three charlie bravo the deadhorse altimeter two niner eight one
november three charlie bravo roger the anaktuvuk pass altimeter two niner seven six
caravan three charlie bravo loud and clear the bettles altimeter two niner seven three
caravan seven one three charlie bravo the tanana altimeter two niner five niner no observed traffic between you tanana airport radar service terminated frequency change approved
november seven one three charlie bravo anchorage center good evening radar contact a hundred and twelve miles west of fairbanks v o r fairbanks altimeter two niner five seven
caravan three charlie bravo new atis will be out shortly in about uh five minutes or so wind calm altimeter two niner six three
seven one three charlie bravo thank you fort yukon altimeter two niner niner seven
november seven one three charlie bravo thank you maintain v f r fort yukon altimeter is two niner six eight
seven one three charlie bravo roger fort yukon altimeter two niner six niner eight +unintelligible+ feet one three five point zero
caravan seven one three charlie bravo anchorage center radar contact seven eight miles northwest fairbanks v o r the fairbanks altimeter two niner niner six
caravan seven one three charlie bravo anchorage center the bettles altimeter is two niner niner six more than one hour old
caravan three charlie bravo anchorage center loud and clear the anaktuvuk pass altimeter two niner five six uh it's way ahead and it's pretty far southwest uh if you need any assistance on the way north
navajo three charlie bravo understood and maintain v f r the bettles altimeter two niner six one more than one hour old i'll try and get you something a bit closer
november seven one three charlie bravo anchorage center roger the fort yukon altimeter two niner eight seven

A.1.5 Communication

caravan three charlie bravo change to my frequency one three five point zero
caravan seven one three charlie bravo no observed traffic for you in fort yukon airport radar service terminated frequency change approved

number seven one three charlie bravo traffic no factor monitor my frequency one two zero point niner
caravan three charlie bravo contact departure
caravan three charlie bravo contact anchorage center one two zero point niner
november seven one three charlie bravo contact fairbanks approach one two five point three five
caravan three charlie bravo contact fairbanks tower
caravan three charlie bravo roger ground point niner
caravan three charlie bravo roger i have correction radar services terminated squawk v f r frequency change approved have a safe flight
november seven one three charlie bravo change to my frequency one two zero point niner
caravan three charlie bravo roger exit at mike contact ground point niner
november seven one three charlie bravo contact fairbanks approach one two five point three five
caravan three charlie bravo fairbanks atis bravo is current wind calm altimeter two niner seven four contact fairbanks tower
cessna three charlie bravo contact fairbanks approach one two five point three five good day
caravan three charlie bravo follow that caravan there for two zero right as well and contact tower we'll see you
experimental caravan three charlie bravo contact departure see you
experimental three charlie bravo contact anchorage center one two zero point niner
november seven one three charlie bravo in two zero minutes contact anchorage center one two seven point zero
uh three charlie bravo roger turn right at mike and contact ground good day
november seven one three charlie bravo contact fairbanks approach one two five point three five
caravan three charlie bravo contact tower see ya
caravan three charlie bravo right at mike ground point niner
caravan three charlie bravo contact anchorage center one two four point six
caravan three charlie bravo change to my frequency one three four point six
caravan three charlie bravo anchorage center roger ah +unintelligible+ change to my frequency one three four point six three four point six
caravan seven one three charlie bravo change to my frequency one three four point four
november three charlie bravo change to my frequency one three four point six
caravan three charlie bravo in case you lose me this frequency one two four point six will be your next frequency in about ten minutes
november seven one three charlie bravo contact fairbanks approach one two five point three five
caravan three charlie bravo contact tower
caravan three charlie bravo roger turn left on uh caravan three charlie bravo roll out to november left on november contact ground point niner

caravan three charlie bravo make a left on bravo taxiway contact ground point niner
caravan three charlie bravo contact departure
november three charlie bravo contact anchorage center one two zero point niner
correction november seven one three charlie bravo affirmative anchorage center one two zero point niner
caravan three charlie bravo roger radar services terminated squawk v f r frequency change approved have a safe flight
caravan seven one three charlie bravo the tanana altimeter two niner five niner no observed traffic between you tanana airport radar service terminated frequency change approved
seven one three charlie bravo gonna enter an area of little radio communication at ah zero two two zero contact anchorage center one two zero point niner
caravan three charlie bravo contact departure
caravan three charlie bravo contact anchorage center one two zero point niner
november seven one three charlie bravo contact fairbanks approach one two five point three five have a good night
experimental three charlie bravo roger seven miles from CACHE cleared r nav yankee runway two left approach contact fairbanks tower we'll see you
experimental three charlie bravo cancel takeoff clearance exit at november and monitor ground point niner
experimental three charlie bravo correction uh contact ground point niner
experimental three charlie bravo roger thank you and contact tower one one eight point three advise when ready for departure
experimental three charlie bravo contact departure
november seven one three charlie bravo contact anchorage center on one two zero point niner for flight following we'll see ya
november three charlie bravo no other traffic between you and fort yukon airport radar service terminated frequency change approved
caravan three charlie bravo contact fairbanks tower
three charlie bravo +unintelligible+ squawk v f r frequency change approved have a safe flight
november seven one three charlie bravo change to my frequency one two zero point niner
november seven one three charlie bravo contact fairbanks approach one two five point three five good day
caravan three charlie bravo contact departure
three charlie bravo you're five hundered feet above the traffic no factor we will see you in fairbanks tersa radar service is terminated frequency change is approved
uh one two zero point nine er
uh three charlie bravo just stay with me i'll change you off to him
three charlie bravo contact anchorage center one two zero point niner
experimental three charlie bravo contact departure
caravan three charlie bravo contact anchorage center one two zero point niner we'll see ya
+unintelligible+ november seven one three charlie bravo change frequency one three five point

zero
yeah seven one three charlie bravo alaska fifty one relaying for anchorage center they say at that altitude that we'll have no comms and in fifteeen minutes you can switch to one two zero point niner
caravan seven one three charlie bravo contact fairbanks approach one two five point three five good afternoon
caravan three charlie bravo contact tower we'll see you
seven one three charlie bravo roger thanks very much turn right at mike taxi park via alpha monitor ground point niner
caravan three charlie bravo in ten minutes contact center one two zero point niner
alright uh they said to go ahead and squawk v f r uh frequency change approved and we'll catch you later
experimental three charlie bravo contact center one three two point seven
navajo correction caravan three charlie bravo roger and i'm gonna lose you on this frequency within the next five to ten minutes about a hundred and thirty miles south of deadhorse monitor one three four point six and eighty miles south of deadhorse one three four point four
navajo correction caravan three charlie bravo roger and i'm gonna lose you on this frequency within the next five to ten minutes about a hundred and thirty miles south of deadhorse monitor one three four point six and eighty miles south of deadhorse one three four point four
roger that seven one three charlie bravo radar service terminated frequency change approved
caravan three charlie bravo contact departure
november seven one three charlie bravo you've left the fairbanks trsa contact anchorage center one two zero point niner

A.1.6 Transponder

november seven one three charlie bravo anchorage center squawk one one one six
caravan seven one three charlie bravo fairbanks departure radar contact check transponder on squawk five six seven seven
caravan three charlie bravo roger i have correction radar services terminated squawk v f r frequency change approved have a safe flight
november seven one three charlie bravo squawk four six seven one say request
november seven one three charlie bravo squawk one three three five the tanana altimeter two niner six niner
november three charlie bravo radar contact squawk one three seven three
november seven one three charlie bravo squawk one three six five
three charlie bravo squawk five six seven four
caravan three charlie bravo roger radar services terminated squawk v f r frequency change approved have a safe flight
november seven one three charlie bravo squawk one three one one
november seven one three charlie bravo anchorage center squawk one three zero two
three charlie bravo +unintelligible+ squawk v f r frequency change approved have a safe flight

seven one three charlie bravo fairbanks departure squawk five six seven seven
you can go back to the fifty six seventy seven squawk
caravan seven one three charlie bravo on the go squawk five six seven three
november seven one three charlie bravo off our cancellation see you squawk v f r frequency change approved
caravan seven one three charlie bravo squawk one three four four
alright uh they said to go ahead and squawk v f r uh frequency change approved and we'll catch you later
and november three charlie bravo squawk one three zero four
November seven one three Charlie bravo runway two zero right at papa taxi via alpha and uh it'll be a trsa departure we put in there uh fairbanks direct to fort yukon v f r squawk five six seven one

A.1.7 Airspeed (Aircraft State Change Required)

caravan three charlie bravo maintain present speed or greater for the sequence
caravan three charlie bravo you can reduce to a final approach speed now
caravan three charlie bravo maintain present speed or greater 'til five mile final

A.1.8 Altitude (Aircraft State Change Required)

caravan three charlie bravo can you expedite your climb there's a heavy boeing seven thirty seven at your one o'clock and one zero miles southeast bound now holding at six thousand
your current climb rate's fine
caravan seven one three charlie bravo anchorage center ready descend

A.1.9 Heading (Aircraft State Change Required)

november three charlie bravo correction uh turn left left turn heading uh zero niner zero for traffic
caravan three charlie bravo turn ten degrees left for the sequence
november seven one three charlie bravo there is v f r traffic right now they are behind you they're at your six o'clock three and a half miles v f r altitude indicates six thousand five hundred unverified they have a slight overtick on you if you could turn ten degrees right please until uh you're on top of that traffic
caravan seven one three charlie bravo turn ten degrees left traffic twelve to one o'clock in four miles northwest bound is a skywagon four thousand six hundred
caravan three charlie bravo let's make it twenty left
experimental three charlie bravo turn right resume own navigation
seven one three charlie bravo fairbanks departure radar contact turn left on course
caravan three charlie bravo fly runway heading until advised departure frequency one two five point three five squawk five six seven one

caravan seven one three charlie bravo fairbanks departure radar contact turn right resume navigation
experimental seven one three charlie bravo wind two one zero one three runway two zero cleared for take off fly runway heading
caravan seven one three charlie bravo fairbanks departure radar contact and for now continue runway heading for just a moment
caravan three charlie bravo turn right on course
november seven one three charlie bravo fairbanks departure radar contact turn right on course
caravan three charlie bravo turn left on course

A.1.10 Intercept (State Change Required)

november seven one three charlie bravo cleared to the fairbanks airport or actually were you looking for v f r or i f r
november seven one three charlie bravo cleared to fairbanks airport via direct maintain v f r the fort yukon altimeter two nine seven eight

A.1.11 Resume (Aircraft State Change Required)

caravan three charlie bravo turn right resume own navigation
november seven one three charlie bravo fairbanks departure radar contact resume own navigation
experimental three charlie bravo turn right resume own navigation
seven one three charlie bravo fairbanks departure radar contact turn left on course
caravan seven one three charlie bravo fairbanks departure radar contact turn right resume navigation
caravan uh november three charlie bravo roger just advise when you start your turn but you are approved to resume own navigation
caravan seven one three charlie bravo clear on course it looks like that that target behind you is uh still at six thousand five hundred
November three charlie bravo radar contact resume own navigation
caravan three charlie bravo turn right on course
caravan three charlie charlie bravo thank you you can resume own navigation
caravan three charlie charlie bravo if I didn't say it you can resume your own navigation and uh very light precipitation eleven o'clock and five miles about three miles in diameter and twelve o'clock and one zero miles is uh light to heavy precipitation about three miles in diameter
november seven one three charlie bravo fairbanks departure radar contact turn right on course
caravan three charlie bravo turn left on course

A.1.12 Landing

caravan seven one three charlie bravo fairbanks tower wind two two zero at one two runway

two zero right cleared to land traffic will cross right to left for the parallel caravan
november seven one three charlie bravo fairbanks tower runway two zero right clear to land number two flying a station air short final
caravan seven one three charlie bravo fairbanks tower runway two zero right clear to land wind two zero zero at niner say parking
caravan seven one three charlie bravo fairbanks tower runway two zero right cleared to land wind two four zero at seven
caravan three charlie bravo number two behind the skyhawk runway two left cleared to land
caravan seven one three charlie bravo fairbanks tower wind zero five zero at eight for runway two left cleared to land and say parking
caravan three charlie bravo runway two zero right cleared to land number two following the pilatus five miles north of the field +inaudible+
and three charlie bravo runway two zero right cleared to land number two
experimental seven one three charlie bravo fairbanks tower runway two zero right clear to land traffic orbiting the field sky wagon at three thousand

A.2 Utterances Requiring Pilot Action (Ground)

A.2.1 Taxi

caravan seven one three charlie bravo runway two zero right taxi via alpha
caravan three charlie bravo runway two zero right at papa taxi via alpha
caravan seven one three charlie bravo fairbanks ground taxi parking via alpha
caravan three charlie bravo roger exit at mike contact ground point niner
caravan seven one three charlie bravo fairbanks ground good afternoon taxi to parking via alpha
november three charlie bravo uh runway two zero right taxi via correction runway two zero right at papa taxi via alpha and verify you said you have kilo
uh three charlie bravo roger turn right at mike and contact ground good day
caravan three charlie bravo fairbanks +unintelligible+ park via alpha
caravan three charlie bravo right at mike ground point niner
november seven one three charlie bravo fairbanks ground taxi to parking bay alpha
caravan three charlie bravo roger turn left on uh caravan three charlie bravo roll out to november left on november contact ground point niner
caravan three charlie bravo make a left on bravo taxiway contact ground point niner
caravan three charlie bravo fairbanks ground taxi to park via alpha should be able to get through the barricades on the south side
november three charlie bravo runway two left at golf taxi via alpha
this is ground uh if you could park on the uh south end of the ramp that would be good that's the one past everybody out
caravan three charlie bravo runway two zero right taxi via alpha

caravan three charlie bravo runway two zero right at papa taxi via alpha
november seven one three charlie bravo fairbanks ground runway two zero right at papa taxi via alpha
experimental three charlie bravo cancel takeoff clearance exit at november and monitor ground point niner
november seven one three charlie bravo fairbanks ground roger and uh runway two zero right at papa taxi via alpha
Caravan three charlie bravo runway two left at hotel taxi via alpha
experimental seven one three charlie bravo fairbanks tower runway two zero right at papa taxi via alpha uh TRSA departure and can you confirm the equipment suffix for you
seven one three charlie bravo roger thanks very much turn right at mike taxi park via alpha monitor ground point niner
seven one three charlie bravo roger thanks very much turn right at mike taxi park via alpha monitor ground point niner
November seven one three Charlie bravo runway two zero right at papa taxi via alpha and uh it'll be a trsa departure we put in there uh fairbanks direct to fort yukon v f r squawk five six seven one

A.2.2 Line Up

experimental seven one three charlie bravo runway two zero right line up and wait traffic in your departure corner
experimental caravan seven one three charlie bravo fairbanks tower runway two zero right at papa line up and wait

A.2.3 Takeoff

caravan seven one three charlie bravo runway two zero right at papa clear for takeoff wind two zero zero at five
experimental caravan seven one three charlie bravo fairbanks tower runway two zero right clear for takeoff
caravan seven one three charlie bravo fairbanks tower runway two left at bravo clear for take off winds zero seven zero at six
caravan three charlie bravo runway two left at golf cleared for take off
caravan seven one three charlie bravo fairbanks tower runway two zero right at papa cleared for take off
experimental seven one three charlie bravo fairbanks tower runway two zero right clear to take off wind two three zero at eight
experimental three charlie bravo runway uh clear for takeoff runway two zero right at papa
experimental three charlie bravo cancel takeoff clearance exit at november and monitor ground point niner
experimental three charlie bravo runway two zero right cleared for take off wind two two zero at

eight
caravan seven one three charlie bravo fairbanks tower runway two left at hotel clear for take off wind three six zero five
experimental seven one three charlie bravo wind two one zero one three runway two zero cleared for take off fly runway heading
caravan three charlie bravo runway two zero right at papa cleared for takeoff

A.2.4 Departure

fort yukon traffic caravan on the taxi you're cleared for departure
experimental seven one three charlie bravo fairbanks tower runway two zero right at papa taxi via alpha uh TRSA departure and can you confirm the equipment suffix for you
experimental caravan three charlie bravo deadhorse radio i have your departure

A.3 Utterances Requiring Visual Confirmation

november seven one three charlie bravo traffic twelve o'clock in one five miles opposite direction v f r altitude indicates seven thousand five hundred
caravan three charlie bravo can you expedite your climb there's a heavy boeing seven thirty seven at your one o'clock and one zero miles southeast bound now holding at six thousand
three charlie bravo roger maintain visual separation caution wake turbulence from the boeing seven sixty seven
caravan three charlie bravo just note traffic two o'clock and five miles northwest bound a c one thirty seven thousand
caravan three charlie bravo maintain visual separation from the c one thirty as well
caravan three charlie bravo traffic two o'clock in eight miles eastbound the caravan will base inside of you for the parallel three thousand three hundred
november seven one three charlie bravo fairbanks tower runway two zero right clear to land number two flying a station air short final
just off two six making a left hand turn moving southbound
caravan will stay to the south of the river for a little while longer let you by
caravan seven one three charlie bravo fairbanks approach you're following a caravan twenty miles north of fairbanks do you want a vector to follow or would you like to slow down twenty knots
caravan three charlie bravo you're following a caravan eleven o'clock one two miles four thousand one hundred uh joining final for two zero right
caravan three charlie bravo just let me know when you get that other caravan in sight twelve o'clock seven miles three thousand four hundred
caravan three charlie bravo follow that caravan there for two zero right as well and contact tower we'll see you

experimental three charlie bravo traffic one o'clock in five miles northeast bound cessna one seventy five reported at two thousand
experimental uh caravan seven one three charlie bravo deadhorse radio traffic's a pilatus he's inbound from the east he'll be turning final here shortly for runway two four and confirm you have information juliet
experimental seven one three charlie bravo fairbanks tower you'll be following a skyhawk at left close for runway two left continue inbound
caravan three charlie bravo the traffic's off your eleven o'clock about four miles one thousand four hundred
caravan three charlie bravo number two behind the skyhawk runway two left cleared to land
caravan seven one three charlie bravo deadhorse radio roger traffic state pickup on the runway
november three charlie bravo v f r traffic twelve o'clock twelve miles opposite direction type unknown altitude indicates eight thousand six hundred unverified
november three charlie bravo traffic twelve o'clock five miles looks like they're offsetting to the right just a little bit
caravan three charlie bravo runway two zero right cleared to land number two following the pilatus five miles north of the field +inaudible+
November three Charlie bravo traffic at twelve o'clock two three miles opposite direction altitude six thousand four hundred
November three charlie bravo traffic twelve o'clock five miles same direction climbing out of four thousand three hundred to five thousand
caravan seven one three charlie bravo turn ten degrees left traffic twelve to one o'clock in four miles northwest bound is a skywagon four thousand six hundred
caravan three charlie charlie bravo that traffic's will be one o'clock and a mile and a half northwest bound four thousand six hundred sky wagon
experimental seven one three charlie bravo fairbanks tower runway two zero right clear to land traffic orbiting the field sky wagon at three thousand
caravan three charlie bravo traffic departing prior to your arrival a navajo additional traffic in the pattern for the ski strip stinson the just one mile north of field in the left downwind

A.4 Weather Utterances

Weather Utterances
november seven one three charlie bravo area of moderate precipitation twelve o'clock in two zero miles up to known areas two five miles on your route of flight
heads up it's gonna be a little bit bumpy uh when are you come in
caravan three charlie bravo as you roll out towards tanana the area of light precipitation from your eleven to one o'clock at about twenty miles twenty miles in diameter had multiple aircraft fly through and under and said it appears do not start really up until about ten thousand feet or so

experimental three charlie bravo area of light precipitation between your twelve and two o'clock starting in one zero miles area's one zero miles diameter
caravan three charlie charlie bravo if I didn't say it you can resume your own navigation and uh very light precipitation eleven o'clock and five miles about three miles in diameter and twelve o'clock and one zero miles is uh light to heavy precipitation about three miles in diameter
caravan three charlie bravo area of light to moderate precipitation twelve to twelve thirty in five miles area is about two miles in diameter five miles northwest of fairbanks airport
caravan three charlie bravo roger i don't have anything uh any weather radar in that area uh once you're heading back for deadhorse uh advise

A.5 Traffic Utterances

Traffic Utterances
caravan three charlie bravo traffic no factor
caravan seven one three charlie bravo no observed traffic for you in fort yukon airport radar service terminated frequency change approved
november seven one three charlie bravo traffic twelve o'clock in one five miles opposite direction v f r altitude indicates seven thousand five hundred
number seven one three charlie bravo traffic no factor monitor my frequency one two zero point niner
caravan three charlie bravo can you expedite your climb there's a heavy boeing seven thirty seven at your one o'clock and one zero miles southeast bound now holding at six thousand
three charlie bravo roger maintain visual separation caution wake turbulence from the boeing seven sixty seven
caravan three charlie bravo just note traffic two o'clock and five miles northwest bound a c one thirty seven thousand
caravan three charlie bravo maintain visual separation from the c one thirty as well
caravan three charlie bravo caution wake turbulence for the c one thirty
caravan seven one three charlie bravo traffic twelve to one o'clock in one zero miles opposite direction type unknown altitude indicates six thousand five hundred
caravan three charlie bravo traffic two o'clock in eight miles eastbound the caravan will base inside of you for the parallel three thousand three hundred
caravan seven one three charlie bravo fairbanks tower wind two two zero at one two runway two zero right cleared to land traffic will cross right to left for the parallel caravan
climbing out of two point three for eight +unintelligible+ charlie +unintelligible+ yukon
november seven one three charlie bravo fairbanks tower runway two zero right clear to land number two flying a station air short final
just off two six making a left hand turn moving southbound
caravan will stay to the south of the river for a little while longer let you by

yeah no worries i'm gonna land uh taxiway parallel two six so yeah i'll kinda be behind you
galena traffic helicopter eight seven eight charlie bravo is joining a high right downwind for taxiway parallel two six i got the traffic on two six in sight no factor galena
caravan seven one three charlie bravo fairbanks approach you're following a caravan twenty miles north of fairbanks do you want a vector to follow or would you like to slow down twenty knots
caravan three charlie bravo you're following a caravan eleven o'clock one two miles four thousand one hundred uh joining final for two zero right
caravan three charlie bravo follow that caravan there for two zero right as well and contact tower we'll see you
experimental three charlie bravo traffic one o'clock in five miles northeast bound cessna one seventy five reported at two thousand
experimental caravan seven one three charlie bravo deadhorse radio roger no traffic reported say direction outbound please
experimental uh caravan seven one three charlie bravo deadhorse radio traffic's a pilatus he's inbound from the east he'll be turning final here shortly for runway two four and confirm you have information juliet
transit two three we'll be off at uh charlie here at deadhorse should be out of your way
caravan seven one three charlie bravo roger and no reported traffic
experimental seven one three charlie bravo fairbanks tower you'll be following a skyhawk at left close for runway two left continue inbound
caravan three charlie bravo the traffic's off your eleven o'clock about four miles one thousand four hundred
caravan three charlie bravo number two behind the skyhawk runway two left cleared to land
caravan seven one three charlie bravo deadhorse radio roger traffic state pickup on the runway
caravan seven one three charlie bravo deadhorse radio all personnel and equipment are clear
caravan seven one three charlie bravo the tanana altimeter two niner five niner no observed traffic between you tanana airport radar service terminated frequency change approved
okay i got an everts uh trying to take off in about five minutes it'll be okay
caravan three charlie bravo as you get a little bit closer in you may see a skywagon traffic in the right downwind for the parallel runway
experimental seven one three charlie bravo caution wake turbulence from a d c six departed runway two zero right correction uh disregard hold short runway two zero right at papa hold for wake turbulence
november three charlie bravo v f r traffic twelve o'clock twelve miles opposite direction type unknown altitude indicates eight thousand six hundred unverified
november three charlie bravo traffic twelve o'clock five miles looks like they're offsetting to the right just a little bit
november three charlie bravo no other traffic between you and fort yukon airport radar service terminated frequency change approved

november seven one three charlie bravo there is v f r traffic right now they are behind you they're at your six o'clock three and a half miles v f r altitude indicates six thousand five hundred unverified they have a slight overtick on you if you could turn ten degrees right please until uh you're on top of that traffic
caravan seven one three charlie bravo clear on course it looks like that that target behind you is uh still at six thousand five hundred
three charlie bravo roger they'll be going to the parallel
three charlie bravo there's another caravan about a mile behind you he's got you in sight he's gonna join final for the parallel
caravan three charlie bravo runway two zero right cleared to land number two following the pilatus five miles north of the field +inaudible+
caravan three charlie bravo traffic in the left base for the float pond
November three Charlie bravo traffic at twelve o'clock two three miles opposite direction altitude six thousand four hundred
November three charlie bravo traffic twelve o'clock five miles same direction climbing out of four thousand three hundred to five thousand
three charlie bravo you're five hundered feet above the traffic no factor we will see you in fairbanks tersa radar service is terminated frequency change is approved
caravan three charlie bravo got a caravan that's just six o'clock making the right turn out to the north when he's through your flight path i'll turn you on course
caravan seven one three charlie bravo turn ten degrees left traffic twelve to one o'clock in four miles northwest bound is a skywagon four thousand six hundred
caravan three charlie charlie bravo that traffic's will be one o'clock and a mile and a half northwest bound four thousand six hundred sky wagon
experimental seven one three charlie bravo fairbanks tower runway two zero right clear to land traffic orbiting the field sky wagon at three thousand
caravan three charlie bravo traffic departing prior to your arrival a navajo additional traffic in the pattern for the ski strip stinson the just one mile north of field in the left downwind
caravan three charlie bravo traffic departing prior to your arrival a navajo additional traffic in the pattern for the ski strip stinson the just one mile north of field in the left downwind
experimental caravan seven one three charlie bravo deadhorse radio good afternoon traffic's a wright flyer caravan he will be departing on runway two four and westbound
caravan seven one three charlie bravo deadhorse radio no traffic reported
fat turkey's gonna be departing in a couple minutes i'm gonna be uh back taxiing
number three charlie bravo embraer jet will be exiting the west ramp northbound on alpha give way to them