Breakout Session Accomplishments

- What are minimum viable products to make progress towards increasingly autonomous flight and operations in the NAS
- Where will collaboration be most productive
- Possible collaborative demonstrations
- Steps toward operationalization of increasingly autonomous systems.

A minimum viable product is a product with just enough features to satisfy early customers, and to provide feedback for future product development.

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

BREAKOUT SESSION 1: : Identify needs, minimum viable products, progression towards their autonomous operations, and needed aircraft, ground, and cloud-based capability levels

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

MISSION NEEDS

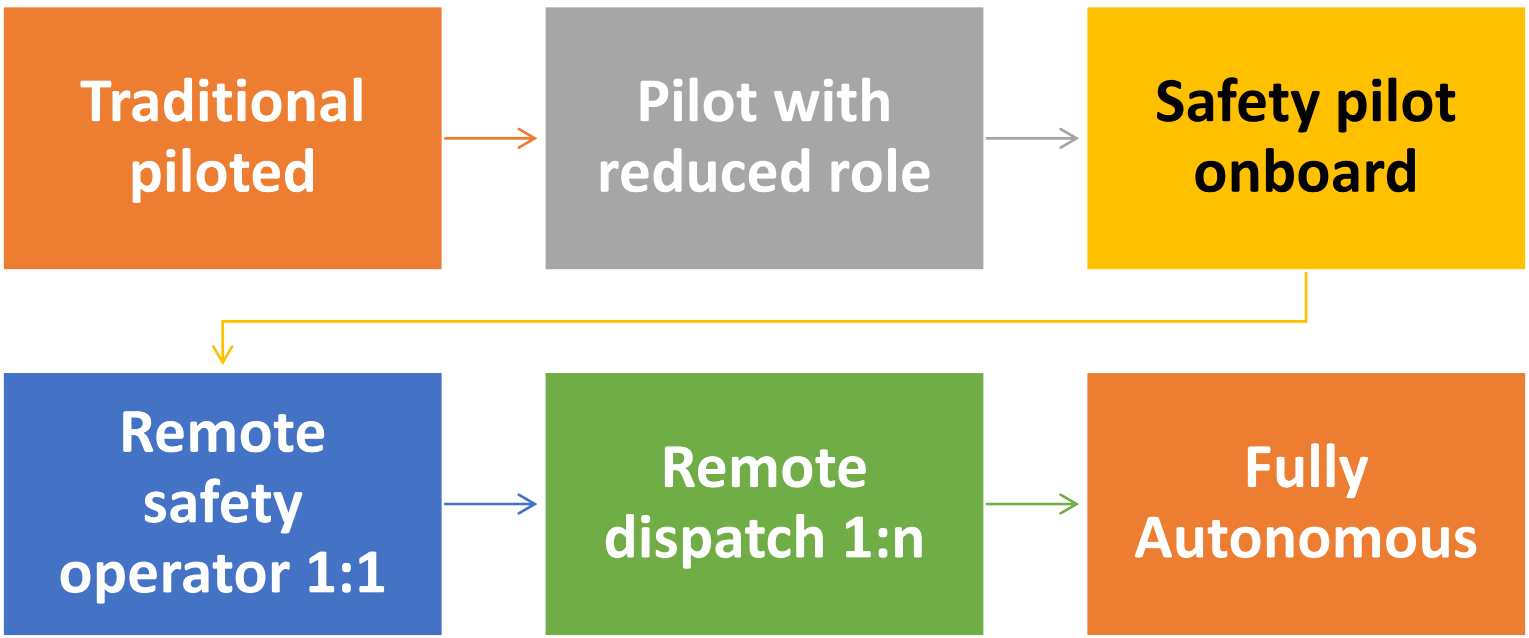
- Save time, save cost
- (1) Inaccessible locations (2) emergencies (particularly firefighting)
- Firefighting & Emergency medical (both have public acceptability)
- Cargo operators - scheduled delivery
- Alaska or over-water, serving remote markets
- Mainland to nearby islands
- When human pilot not practicable

MVPs – General Thoughts

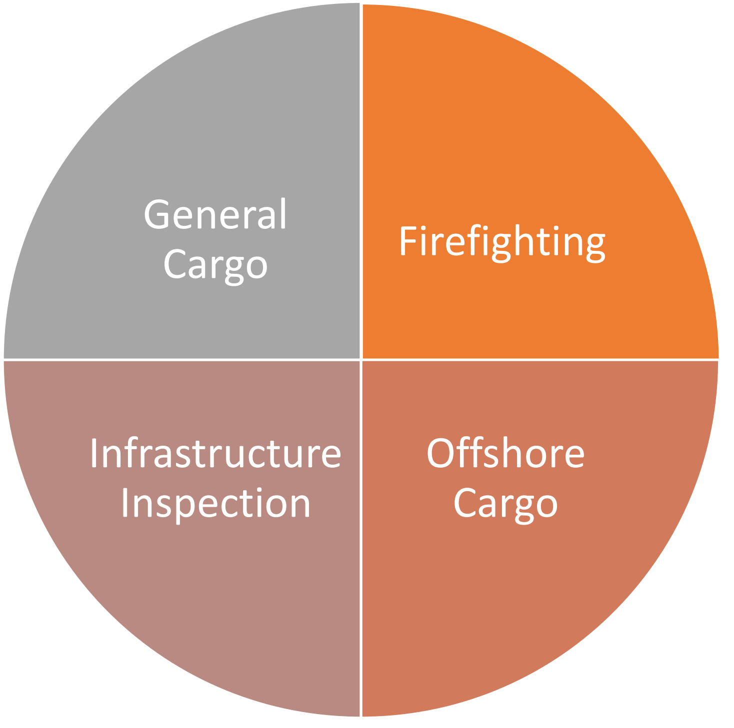
- Robust – Will not die with single crash
- Integration into airspace is essential for most use cases
- MVP as "30% solution"
- Start with simple environment- build up complexity
- MVP is short-term. That sometimes means working within the constraints of the current system.
- MVP is a step towards the long term-product
- As a pie- slowly move the human-autonomy interface
- Autonomy can help with:
    - High-volume
    - Long flights that are difficult for humans
    - Dangerous routes
    - Difficult conditions

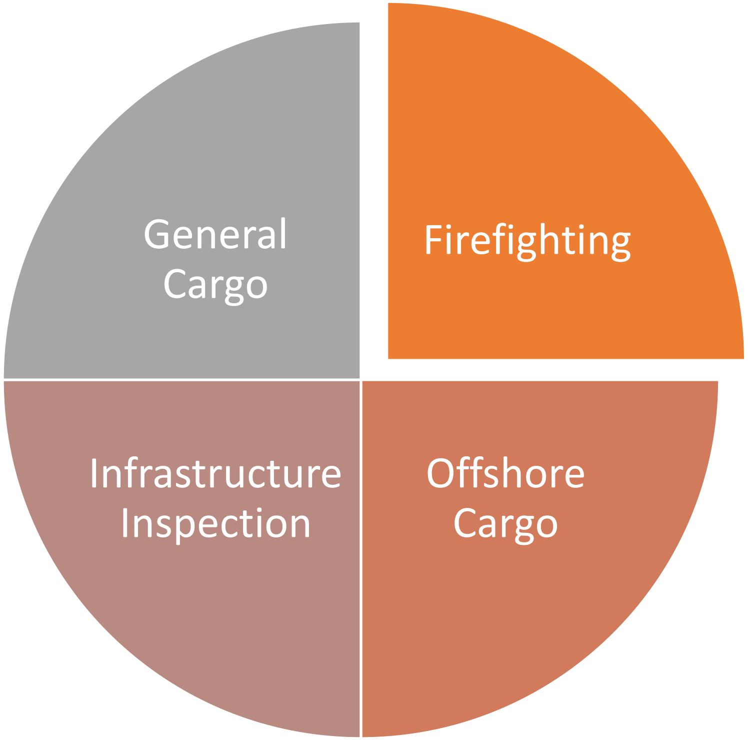
Balance simplicity (as first step- MVP) with significance (demonstrating significant step)

General Discussion – Where is MVP?



MVPs


General Cargo
Firefighting
Infrastructure Inspection
Offshore Cargo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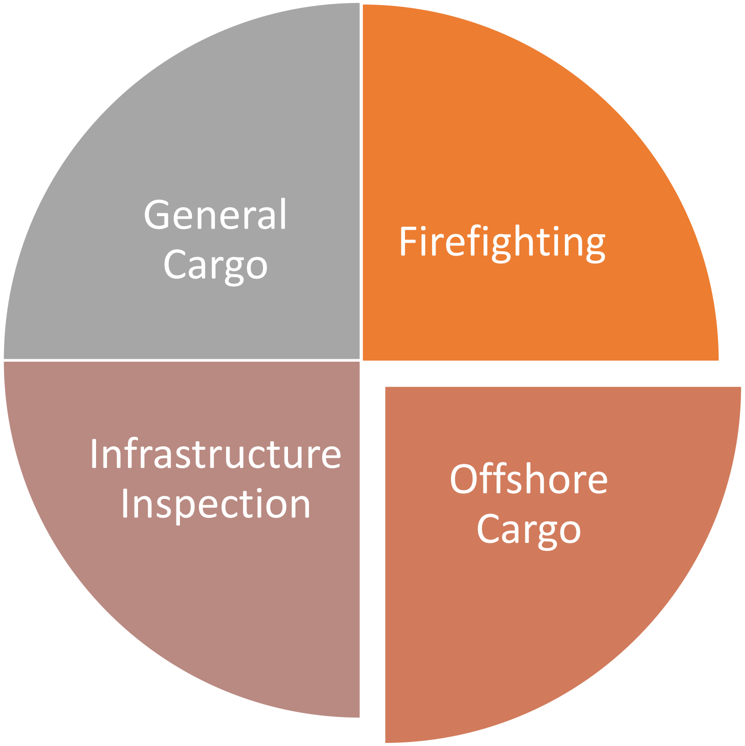
Reasons to automate
1. Reduce risk for humans
2. Performance improvement – perception in obscured environment

Notes:
1. Consequence of crash is not high (already a fire) and risk tolerance is high because it is an emergency
2. Humanitarian aspect – good target for MVP
3. Challenging flight environment – low perception, challenging dynamics, night ops
4. Unmanned- with remote safety operator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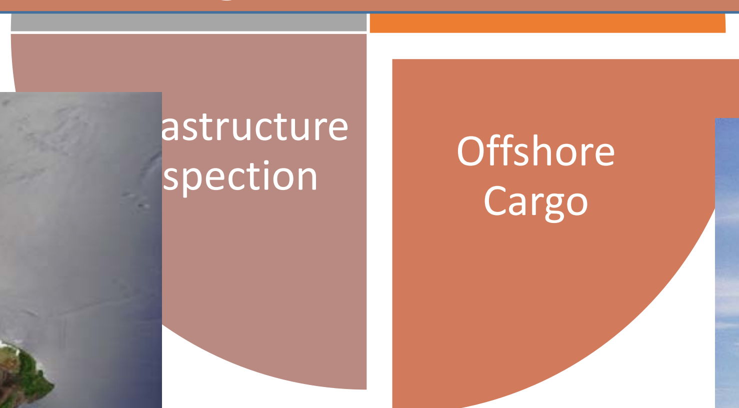
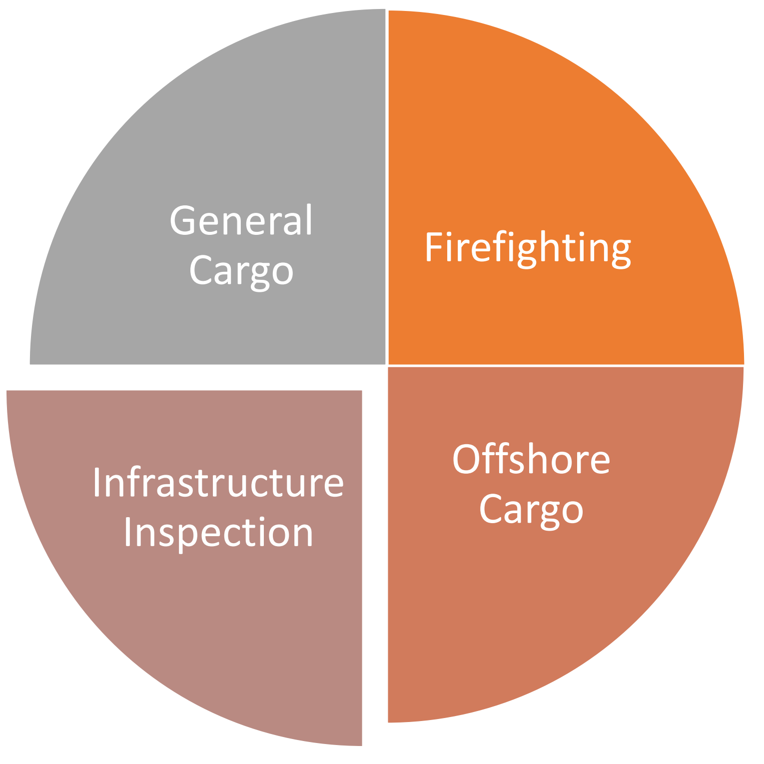
ENABLING AUTONOMOUS FLIGHT & OPERATIONS IN THE NAS

- Flight will be over water- minimizes risk
- The customers have money – Business case exists
  - Faster delivery than shipping
- Wind gusts can create a challenging flight environment
- Could interact with traditional airspace
- Could be fully autonomous vehicle or autonomy assist for pilots in challenging situations.
- Could go to/between islands (e.g., Hawaii), coastal communities with land route challenges (inaccessible or congested), or offshore oil platforms/wind farms

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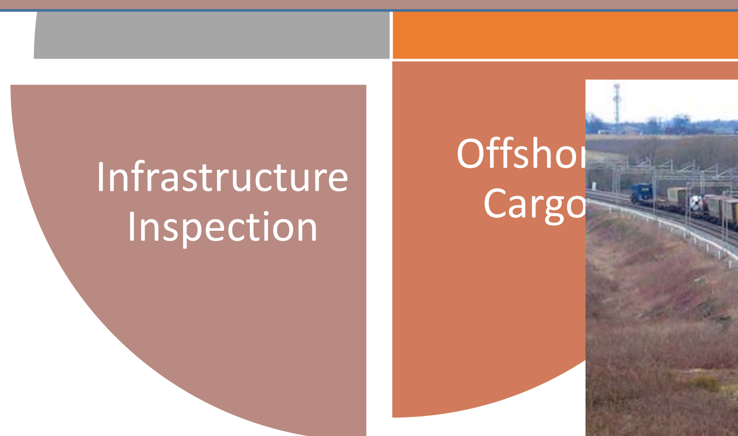
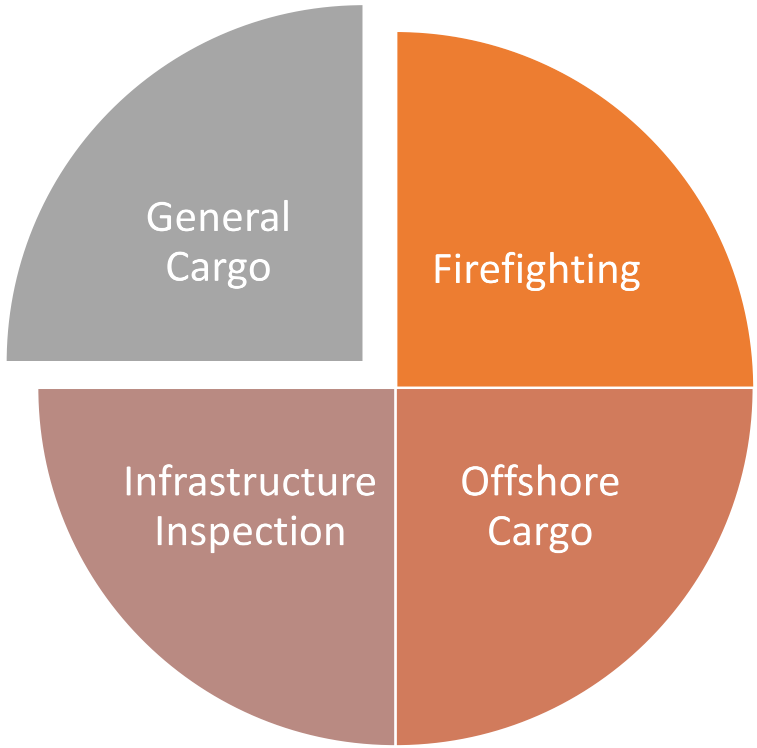
ENABLING AUTONOMOUS FLIGHT & OPERATIONS IN THE NAS

- Takeoff and land from airport
- Inspect hundreds of miles of rail/pipelines/etc.
- Follow rails- set routes
- Handle contingencies
- Could have remote supervisor
- Medium-size for long distance. Not necessarily cargo

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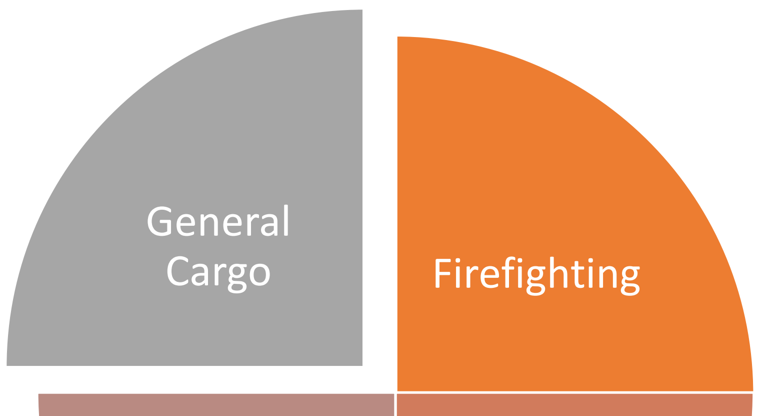
ENABLING AUTONOMOUS FLIGHT & OPERATIONS IN THE NAS



- Fly between airports (controlled or uncontrolled)
- Could have safety pilot onboard or safety operator remotely
  - Likely 1:1 for MVP
- Integrate with existing air traffic
- Over land/water
- Communication with air traffic control
  - Could go through safety pilot/operator, who then sends the instructions to the aircraft
  - More meaningful would be direct communication with aircraft

Other Considered MVPs

- Medical – Blood/Medicine Delivery
  - Public interest
  - Quick delivery is important
- Agriculture – Spraying fields

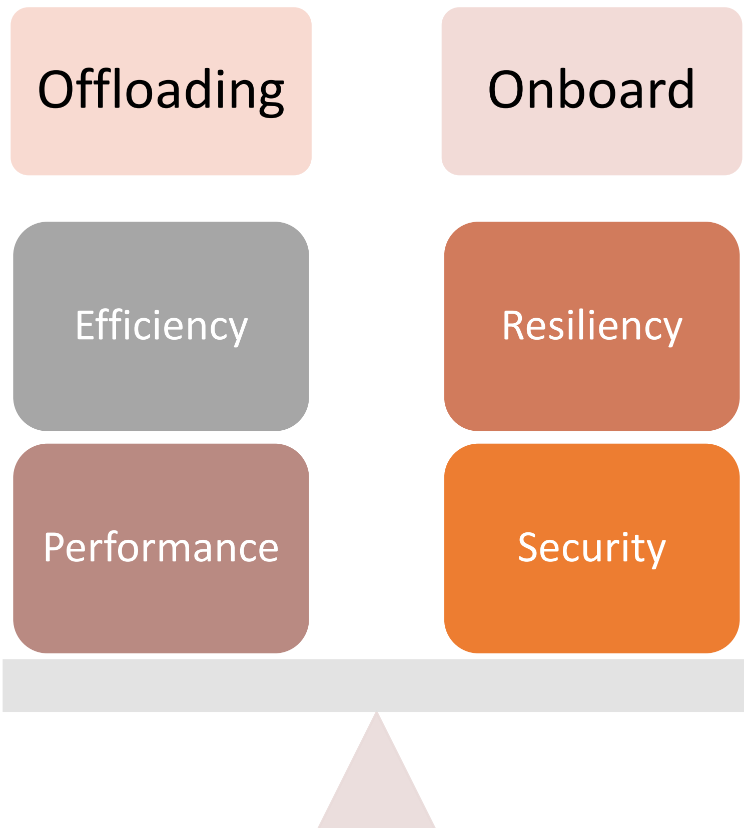
FIREFIGHTING

	TCL 1	TCL 2	TCL 3	TCL 4 (MVP)
Aircraft	Known destination/route told Single vehicle Single trip Pilot-supervised autonomous flight Manual drop DAQ	Known destination/ vehicle plans	Known destination/dynamic re-planning Auto flight planning Missed approach re-planning	Picks drop (sensor based) Closed loop drop control. Flight planning, drop planning, autoflight, drop contingency management.
Ground	Mission defined		Human drop planning	Retardant reload. Fire drop location and dispatch aircraft
Cloud	Fire locations known			Multi-vehicle coordination Surveillance with Firefighters Interaction with other aircraft

OFFSHORE DELIVERY

	TCL 1	TCL 2	TCL 3	TCL 4
Aircraft	Existing airframe (certified) Optionally piloted DO-365 DAA	Unmanned	Dynamic re-routing, planning	Self-separation Machine communication
Ground	Mission planning	Voice comms Command by approval	Command by exception	Dispatch
Cloud	SWIM/AOC Data feeds			UTM (Full) ATM-X

General Notes: Cloud/Ground/Aircraft



- Cloud can provide additional resources and increased efficiency through shared resources
  - Stronger case for UAS/UAM
- Security concern with offloading critical decision making functions to cloud
- Must be able to maintain safety in event of total communication link loss
- Good target for cloud could be information services
- Especially shared services - weather, etc.

Challenges

- Secure, reliable communication links
- Sense and avoid (taxi and flight)
- Resilient GNC
- Continuous Safety Assessment
  - Includes Health Monitoring
- Vehicle contingency management
- Certification methods
- Human Autonomy Teaming
- Adequate leveraging of currently available information sources (commercial and public)

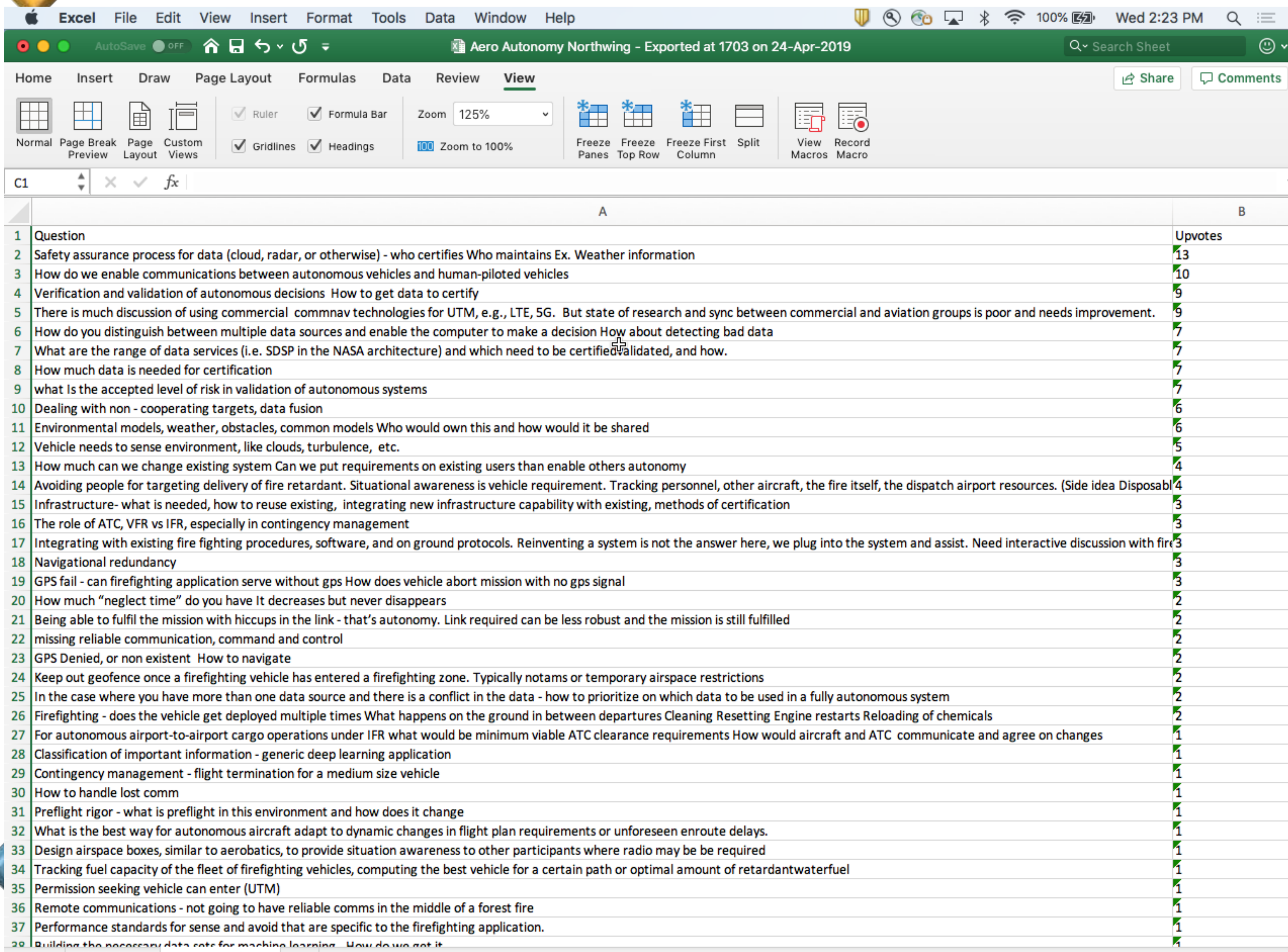
Challenges - Continued

- NAS integration
- Communications protocols – **digital** and voice
- Communication participants
- Operational contingency management
- Scalability
- Controlled/uncontrolled airspace compatibility
  - ATC interaction
  - Traffic rule conformance
  - Minimum equipage
- Economics/ Business Case
- Acceptance

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

BREAKOUT SESSION 2: Identify research gaps, needs, and strategy to implement increasingly autonomous operations in complex airspace and areas

ENABLING AUTONOMOUS FLIGHT & OPERATIONS IN THE NAS



Aero Autonomy Northwing - Exported at 1703 on 24-Apr-2019

	A	B
1	Question	Upvotes
2	Safety assurance process for data (cloud, radar, or otherwise) - who certifies Who maintains Ex. Weather information	13
3	How do we enable communications between autonomous vehicles and human-piloted vehicles	10
4	Verification and validation of autonomous decisions How to get data to certify	9
5	There is much discussion of using commercial commnav technologies for UTM, e.g., LTE, 5G. But state of research and sync between commercial and aviation groups is poor and needs improvement.	9
6	How do you distinguish between multiple data sources and enable the computer to make a decision How about detecting bad data	7
7	What are the range of data services (i.e. SDSP in the NASA architecture) and which need to be certified/validated, and how.	7
8	How much data is needed for certification	7
9	what Is the accepted level of risk in validation of autonomous systems	7
10	Dealing with non - cooperating targets, data fusion	6
11	Environmental models, weather, obstacles, common models Who would own this and how would it be shared	6
12	Vehicle needs to sense environment, like clouds, turbulence, etc.	5
13	How much can we change existing system Can we put requirements on existing users than enable others autonomy	4
14	Avoiding people for targeting delivery of fire retardant. Situational awareness is vehicle requirement. Tracking personnel, other aircraft, the fire itself, the dispatch airport resources. (Side idea Disposabl	4
15	Infrastructure- what is needed, how to reuse existing, integrating new infrastructure capability with existing, methods of certification	3
16	The role of ATC, VFR vs IFR, especially in contingency management	3
17	Integrating with existing fire fighting procedures, software, and on ground protocols. Reinventing a system is not the answer here, we plug into the system and assist. Need interactive discussion with fir	3
18	Navigational redundancy	3
19	GPS fail - can firefighting application serve without gps How does vehicle abort mission with no gps signal	3
20	How much "neglect time" do you have It decreases but never disappears	2
21	Being able to fulfil the mission with hiccups in the link - that's autonomy. Link required can be less robust and the mission is still fulfilled	2
22	missing reliable communication, command and control	2
23	GPS Denied, or non existent How to navigate	2
24	Keep out geofence once a firefighting vehicle has entered a firefighting zone. Typically notams or temporary airspace restrictions	2
25	In the case where you have more than one data source and there is a conflict in the data - how to prioritize on which data to be used in a fully autonomous system	2
26	Firefighting - does the vehicle get deployed multiple times What happens on the ground in between departures Cleaning Resetting Engine restarts Reloading of chemicals	2
27	For autonomous airport-to-airport cargo operations under IFR what would be minimum viable ATC clearance requirements How would aircraft and ATC communicate and agree on changes	1
28	Classification of important information - generic deep learning application	1
29	Contingency management - flight termination for a medium size vehicle	1
30	How to handle lost comm	1
31	Preflight rigor - what is preflight in this environment and how does it change	1
32	What is the best way for autonomous aircraft adapt to dynamic changes in flight plan requirements or unforeseen enroute delays.	1
33	Design airspace boxes, similar to aerobatics, to provide situation awareness to other participants where radio may be be required	1
34	Tracking fuel capacity of the fleet of firefighting vehicles, computing the best vehicle for a certain path or optimal amount of retardantwaterfuel	1
35	Permission seeking vehicle can enter (UTM)	1
36	Remote communications - not going to have reliable comms in the middle of a forest fire	1
37	Performance standards for sense and avoid that are specific to the firefighting application.	1
38	Building the necessary data sets for machine learning How do we get it	1

Worksheet | Audience Q&A

Research gaps and needs

1. Communications
2. Health Monitoring/Contingencies
3. Landing
4. Surface Ops
5. Inflight
6. Airspace Integration
7. Certification
8. Human Autonomy Teaming
9. Non-Technical

Research gaps and needs - Comms

- How do we introduce autonomy in voice dominate world?
  - Near-Term (MVP): There will likely still be some sort of voice control. Handle through
    - Natural Language Processing: Gap – has to handle locale differences in speaking/terms, handle poor connection
    - Human transcription
  - Long-term: Fully text-based. Need a robust message set and communication standards
- Handle communication dropout
- Vehicle-to-vehicle communications to improve safety
- How do we enable communications between autonomous vehicles and human-piloted vehicles?
- There is much discussion of using commercial comm/nav technologies for UTM, e.g., LTE, 5G. But state of research and sync between commercial and aviation groups is poor and needs improvement.

Research gaps and needs - Health Monitoring & Contingencies

- Long-term full authority contingency management
- Short-term autonomous mitigation for common contingencies
- Diagnostic technologies
- Assurance of incoming data
- Handle faulty sensors
  - Data-fusion, sensor fault detection, etc.
- Prognostics technologies

Research gaps and needs - Landing

- Short term autonomous all-weather ILS precision landing landing capability
    - Perception technologies or airport infrastructure
    - Longer-term: Inexpensive autonomous landing infrastructure

Research gaps and needs – Surface Operations

- Avoid other aircraft
- Autonomously prepare aircraft
- Pre-flight safety inspection

Research gaps and needs – Inflight

- Low-altitude non-cooperative detect and avoid
- Robust GPS denied localization
- Low-cost GPS denied localization

Research gaps and needs – Airspace Integration

Research gaps and needs – Certification

- Rigorous certification of autonomous systems
- Data required for certification
- Safety assurance process for data (cloud, radar, or otherwise) - who certifies Who maintains Ex. Weather information
- Verification and validation of autonomous decisions How to get data to certify

Research gaps and needs – Human Autonomy Teaming

- Human takeover – contingency situation. Authority handoff
- Clear authority awareness

DATA

- How do you distinguish between multiple data sources and enable the computer to make a decision? How about detecting bad data?
- What are the range of data services (i.e. SDSP in the NASA architecture) and which need to be certified/validated, and how.
- How much data is needed for certification

Research gaps and needs – Non-technical

- Legal/Liability
- Acceptance

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

BREAKOUT SESSION 3: Identify an action plan for collective demonstrations, collaboration topics where research by NASA could help everyone (e.g., certification methods, airspace, requirements/standards for certain systems/capabilities, conops), and operational implementation of increasing autonomous systems in the NAS

Collaboration topics where NASA research could help

- Define safety/performance thresholds for autonomy?
- Define "safe" for various MVPs?
- Develop ATC clearance requirements for airport-to-airport ops. Communicating clearance changes
- What is the complete set of info autonomous system needs to know to be compliant with ATC (including things that human pilots currently have awareness of) ~ TASAR
- Modeling and analysis of impact on airspace
- How to be interoperable in airspace … how much does autonomy need to adapt to NAS vs how much does NAS need to adapt to autonomy?
  - Evaluating the effects of non-cooperative aircraft in the NAS?
  - Contingency management: predicable, communicated, fail safe
- Procedures and communication paradigms tailored to autonomous operations?
  - How does it change airspace? Autonomous-only airports?
- How to use the large volume of available data? How do you certify quality of data?
  - Capturing and integrating sensor data from multiple aircraft (non-approved but valuable). How does industry get access to surveillance data needed for DAA etc?
- Redundancy in navigation sources ~ Explore non-GPS navigation sources, how to monitor integrity of data?
- Does autonomy allow operations in greater range of WX?

Action plan for collective demonstrations

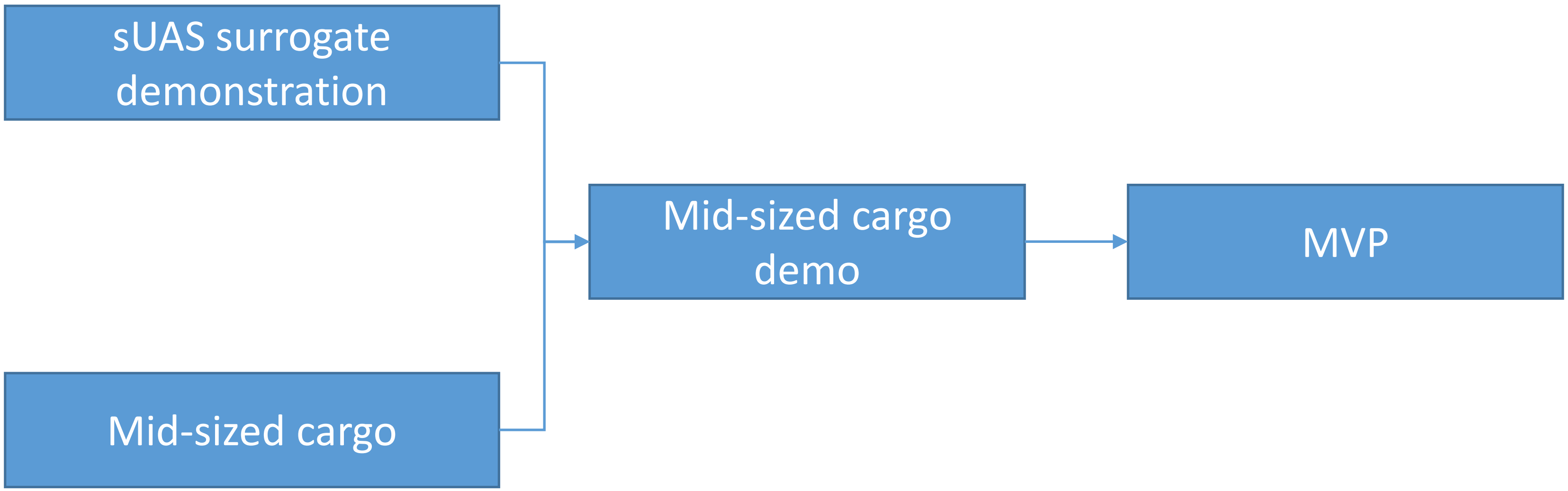
- Demonstration of capability to modify autonomous IFR flight plan to Adapt to dynamic changes in flight plan requirements (strategic and tactical)
- Early flight demonstrations
  - Setup a scenario where you emulate air traffic control environment
  - Cargo class operation into civil airports
  - Early remotely piloted flight operations
  - Demonstrate ability to identify emergency landing site and then execute the reroute
- Work on sequencing and then test vehicle deconfliction
- Investigate vehicle to vehicle communication
- Develop concept for supporting shared SA between aircraft and ground
- Consider starting with a fleet manager that manages communications between aircraft and ground

Action plan for collective demonstrations (cont.)

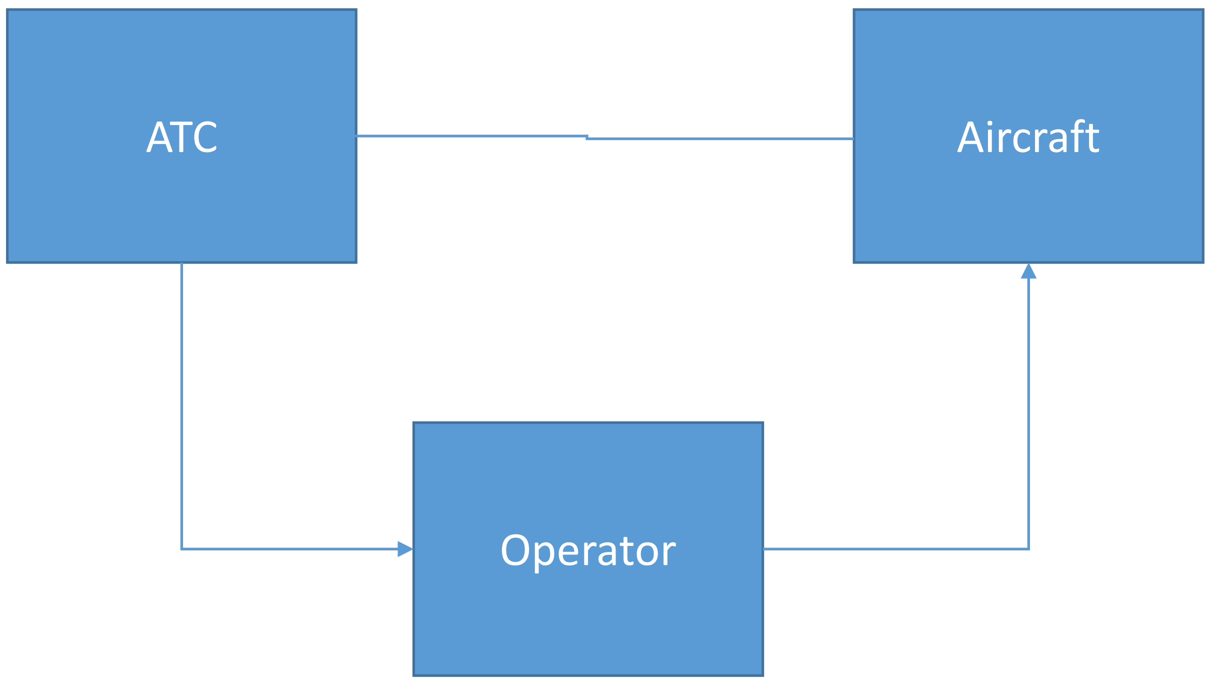
- Determine workable number of aircraft a human can manage at a given time.
- Begin examining communications issues from digital and voice mode incongruences
  - Run machine learning algorithms in shadow of actual operations to acquire training data for natural language processing
  - Standardize language/commands for conducting entire flight
  - Examine how a human (be the natural language processor) can do the job as intermediary between digital comm from aircraft and voice comm with ATC
  - Leverage work from major data product providers, e.g., Google
  - Test and develop neural network system for communication
  - Standardize and augment CPDLC

- Demonstrate intent communication capabilities so that surrounding operators can respond to the off-nominal event
- Identify data/information requirements, e.g., for an aircraft to execute its mission
- Need to pursue MOPS for safety requirements
- Identify existing system that could serve an analogy to target system and reconcile that system’s capabilities against the needs of the concept.
- Reconcile differences between information we have on our maps and what we need to facilitate safe navigation

Potential Demonstration Routes



Demonstration – Communications at ATC



Potential Demonstration Routes

Steps:

1. Demonstrate ground operations
2. [Simulated/emulated flight]
3. Demonstrate nominal flight
4. Demonstrate contingency- Especially loss of comms
5. Full integration

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

ACTION PLAN FOR COLLECTIVE DEMONSTRATIONS

- 9 CATS for gaps: comm, health monitor, contingency, landing, surface ops, airspace integration, certification, human autonomy teaming, non technical challenges.
- Start with remotely piloted flight demonstrations
- Start with demonstration of cargo class operation into civil aiports
- Setup a scenario where you emulate air traffic control environment
- Work on sequencing and then test vehicle deconfliction
- Vehcile to vehicle communication
- Test and develop neural network system for communication
- Need to standardize and augment CPDLC
- Examine how a human (be the natural language processor) can do the job as intermediary between digital comm from aircraft and voice comm with ATC
- Start with developing a shared common picture between aircraft and ground
- Consider starting with a fleet manager that manages communications between aircraft and ground.

Breakout Session 3

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

ACTION PLAN FOR COLLECTIVE DEMONSTRATIONS

- Need to determine workable number of aircraft a human can manage at a given time.
- Prepare in shadow mode language processing capabilities to test in actual operations.
- Run machine learning algorithms in shadow of actual operations to acquire training data for natural language processing
- Standardize language/commands for conducting entire flight
- Leverage work from major data product providers, e.g., Google

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

ACTION PLAN FOR COLLECTIVE DEMONSTRATIONS

- Contingency management

- Demonstrate ability to identify emergency landing site and then execute
- Demonstrate intent communication capabilities so that surrounding operators can respond to the off-nominal event
- Identify data/information requirements, e.g., for an aircraft to execute its mission
- Need to pursue MOPS for safety requirements
- Identify existing system that could serve an analogy to target system and reconciling that system's capabilities against the needs of the concept.
- What is the delta between information we have on our maps and what we need to facilitate safe navigation

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

ACTION PLAN FOR COLLECTIVE DEMONSTRATIONS

- Demonstrate autonomous ground operation
- Demonstrate nominal flight case
- Demonstrate contingency case, e.g., loss of comm
- Demonstrate a complete mission

- Test scenario with multiple vehicles, inject loss of comm and loss of gps

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

COLLABORATION TOPICS WHERE NASA RESEARCH COULD HELP

- Standardize ATC communication
- Facilitate discussion about whether we have a capable infrastructure
- Provide procedures and methods for testing
- Can use access to data about military unmanned aircraft operations
- Host a repository for data that can be shared with the community for learning

ACTION PLAN FOR COLLECTIVE DEMONSTRATIONS

Collaboration topics where NASA research could help

- Certification
- Coordination
- Airspace integration
- Data

AUTONOMOUS MEDIUM-SIZE CARGO/FREIGHTERS

OPERATIONAL IMPLEMENTATION