System-Wide Safety

Gap Analysis of UAS Manuals and Hazards

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Context

- **Advanced Air Mobility is impacting emergency and disaster response operations**
  - Unmanned Aircraft Vehicles (UAS) Examples:
    - Search and Rescue operations
    - Scene Reconstruction for Disaster Damage Assessment
- **However, the use of UAS introduce <u>safety risks</u> to the National Air Space**

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Goal

- **Find ways to improve UAS mission safety**
  - How to find safety practices ("mitigations")?
    - Operational Manuals
      - City, County, State, cross-county, etc
    - Advisory Circulars (AC 1072A)
    - FAA Orders (Risk Management System Appendix – Waiver Process)
    - Recordings of agencies
    - Waiver Provisions
  - How to find when things went wrong? (Hazards)
    - FAA Accident DB, ASRS, NEISS ("toy" accidents), NTSB – All narratives

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Method

- **Goal: Find ways to improve UAS mission safety**
  - But how do we “group” this large collection of text containing mitigations and hazards so we can compare them?
  - We chose to use Model Based Systems Engineering

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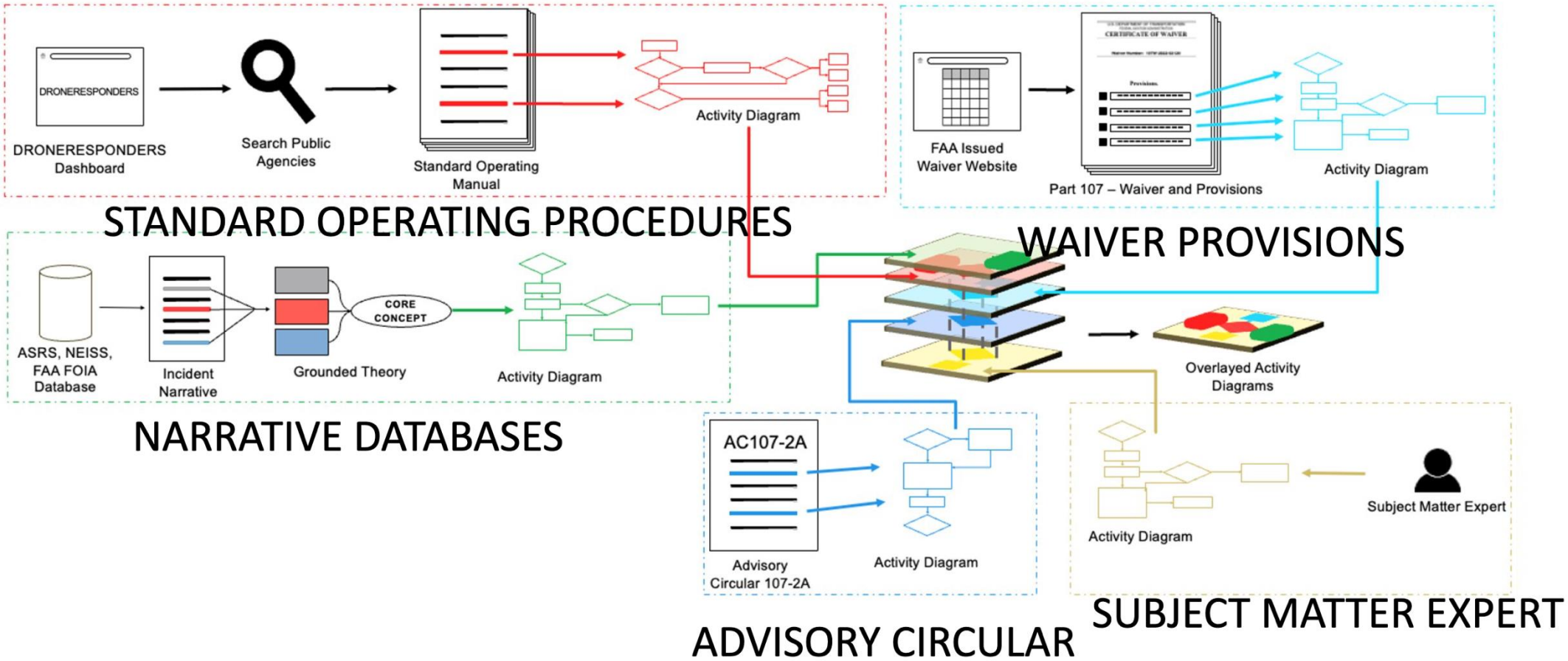
Method



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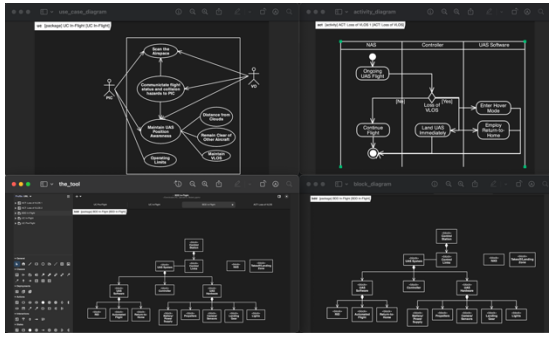
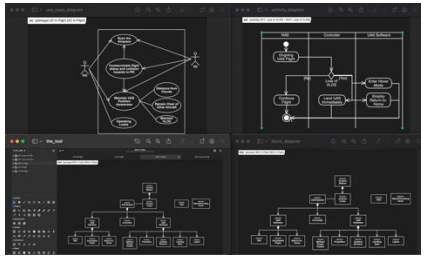
Method

- **The goal is to identify the gaps between mitigations and hazards, validate through agency interviews, and make it operational through a chatbot**



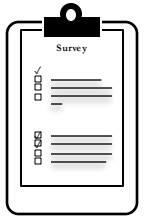
Step 1. Accumulated Mitigations and Hazards

Step 2. Identify where hazards occur in safety procedures

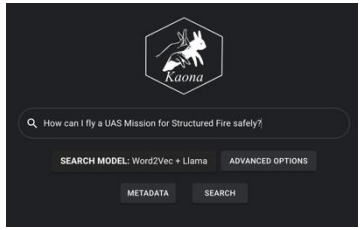


Step 3. Given a manual, compare safety mitigations and hazards for gaps

Step 4. Validated identified gaps through interviews



Step 5. Use findings for larger-scale survey validation



Step 6. Chatbot answering mission questions

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Modeling Example

An intuition on information overlap across different sources and its model representation

Example 1 – Overlapping VLOS from AC1072A and Operational Manuals

- **Different mitigation statements on loss of Visual Line of Sight**

AC 107-2A

5.9 **VLOS Aircraft Operation.** The remote PIC and person manipulating the controls must be able to see the small unmanned aircraft at all times during flight (§ 107.31). The small unmanned aircraft must be operated closely enough to ensure visibility requirements are met during small UAS operations. This requirement also applies to the VO, if used, during the aircraft operation. The person maintaining VLOS may have brief moments in which he or she is not looking directly at or cannot see the small unmanned aircraft, but still retains the capability to see the small unmanned aircraft or quickly maneuver it back to VLOS. These moments may be necessary for the remote PIC to look at the controller to determine remaining battery life or for operational awareness. Should the remote PIC

Fire Operational Manual 1

throughout the entire flight. The FAA recognizes that the person maintaining visual line of sight (VLOS) of the air vehicle may lose sight of the unmanned aircraft for brief moments of the operation. This may be necessary either because the small unmanned aircraft momentarily travels behind an obstruction or to allow the person maintaining VLOS to perform actions such as scanning the airspace or briefly looking down at the UAS control station. However, it is emphasized that even

Fire Operational Manual 2

For operational necessity, the PIC or RPIC may intentionally maneuver theUAS so that they lose sight of it for brief periods of time. In this case, the RPIC must regain VLOS as soon as practicable. For example, a RPIC stationed on the ground utilizing a UAS to inspect a rooftop may lose sight of the aircraft for brief periods while inspecting the farthest point of the roof. As another example, a RPIC conducting a search operation around a fire scene may briefly lose sight of the aircraftwhile it is temporarily behind a dense column of smoke.

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Use Case Diagram

- Loss of VLOS due to Battery life checks and operational awareness
- Loss of VLOS cross-source overlap
- Actors

AC 107-2A

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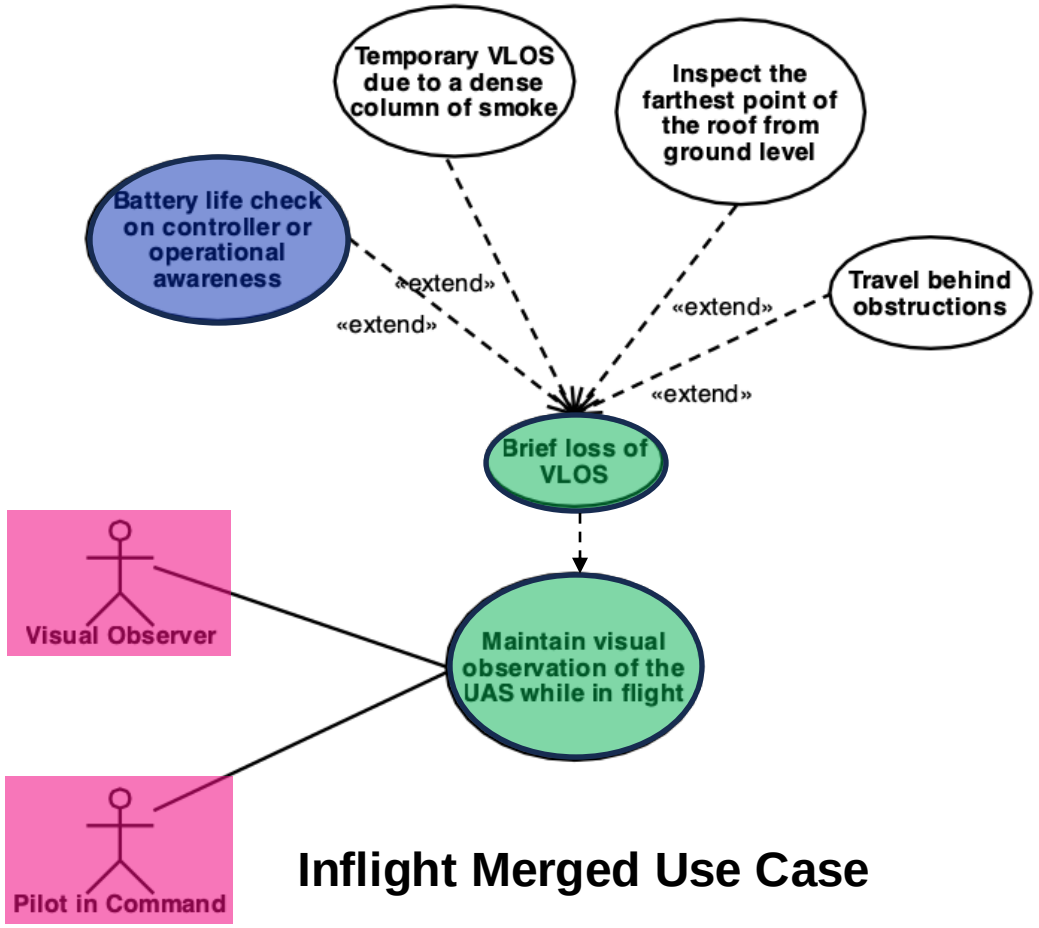

Inflight Merged Use Case

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Use Case Diagram

- Loss of VLOS due to presence of smoke and roof inspection
- Loss of VLOS cross-source overlap
- Actors

Fire Operational Manual 1

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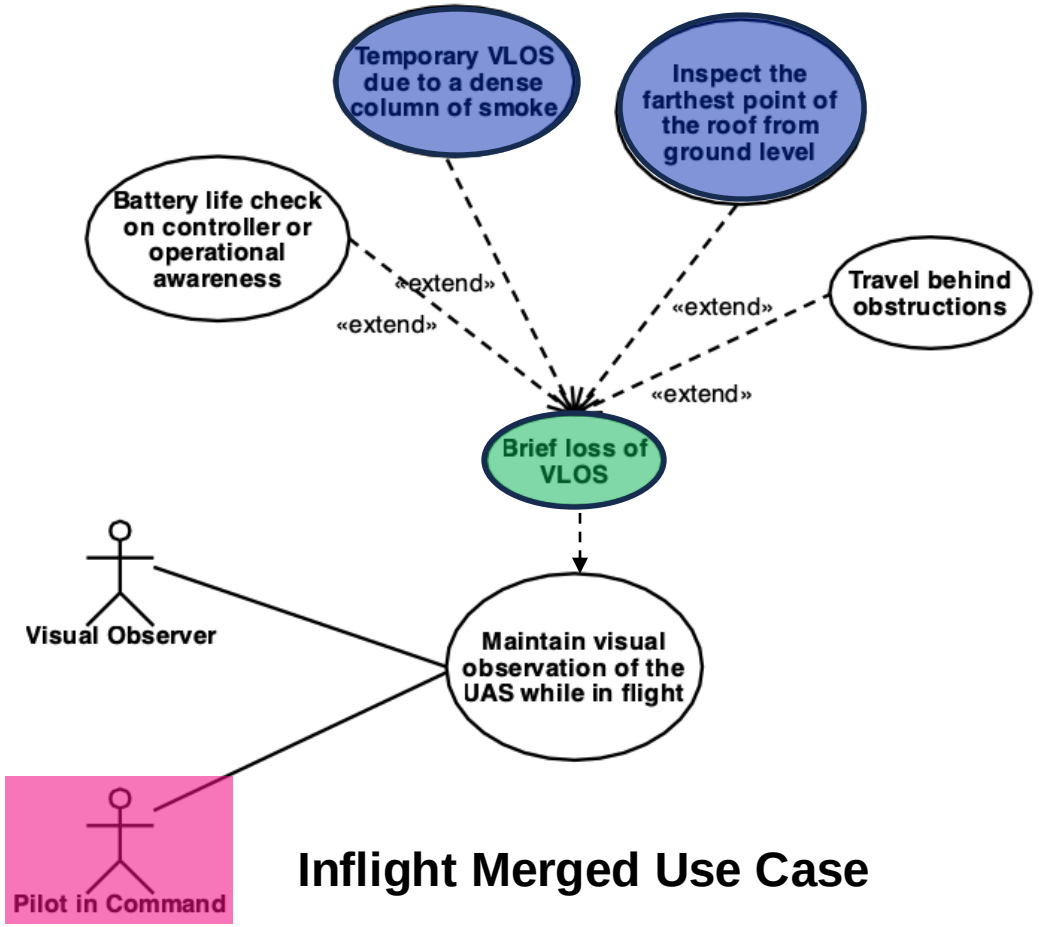


Inflight Merged Use Case

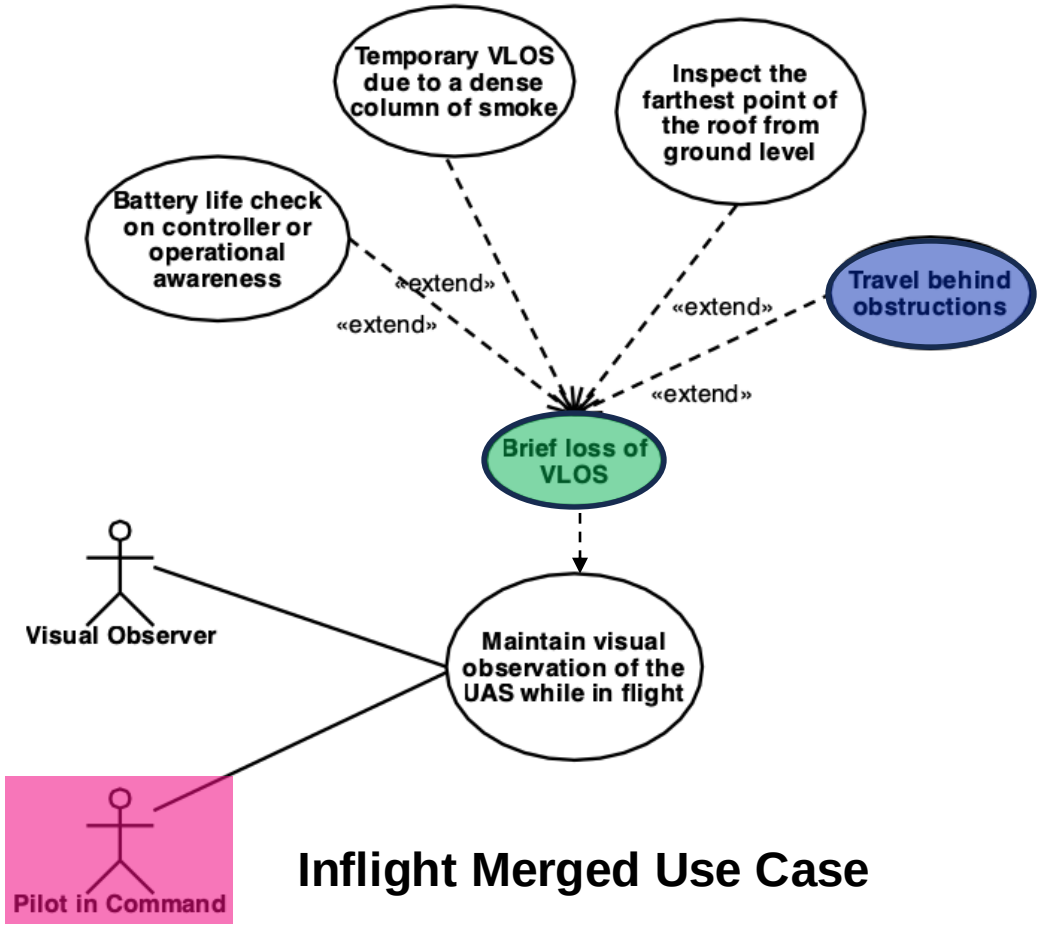
System-Wide Safety

Use Case Diagram

- Loss of VLOS due to travel behind obstruction
- Loss of VLOS cross-source overlap
- Actors

Fire Operational Manual 2

throughout the entire flight. The FAA recognizes that the person maintaining visual line of sight (VLOS) of the air vehicle may lose sight of the unmanned aircraft for brief moments of the operation. This may be necessary either because the small unmanned aircraft momentarily travels behind an obstruction or to allow the person maintaining VLOS to perform actions such as scanning the airspace or briefly looking down at the UAS control station. However, it is emphasized that even



Inflight Merged Use Case

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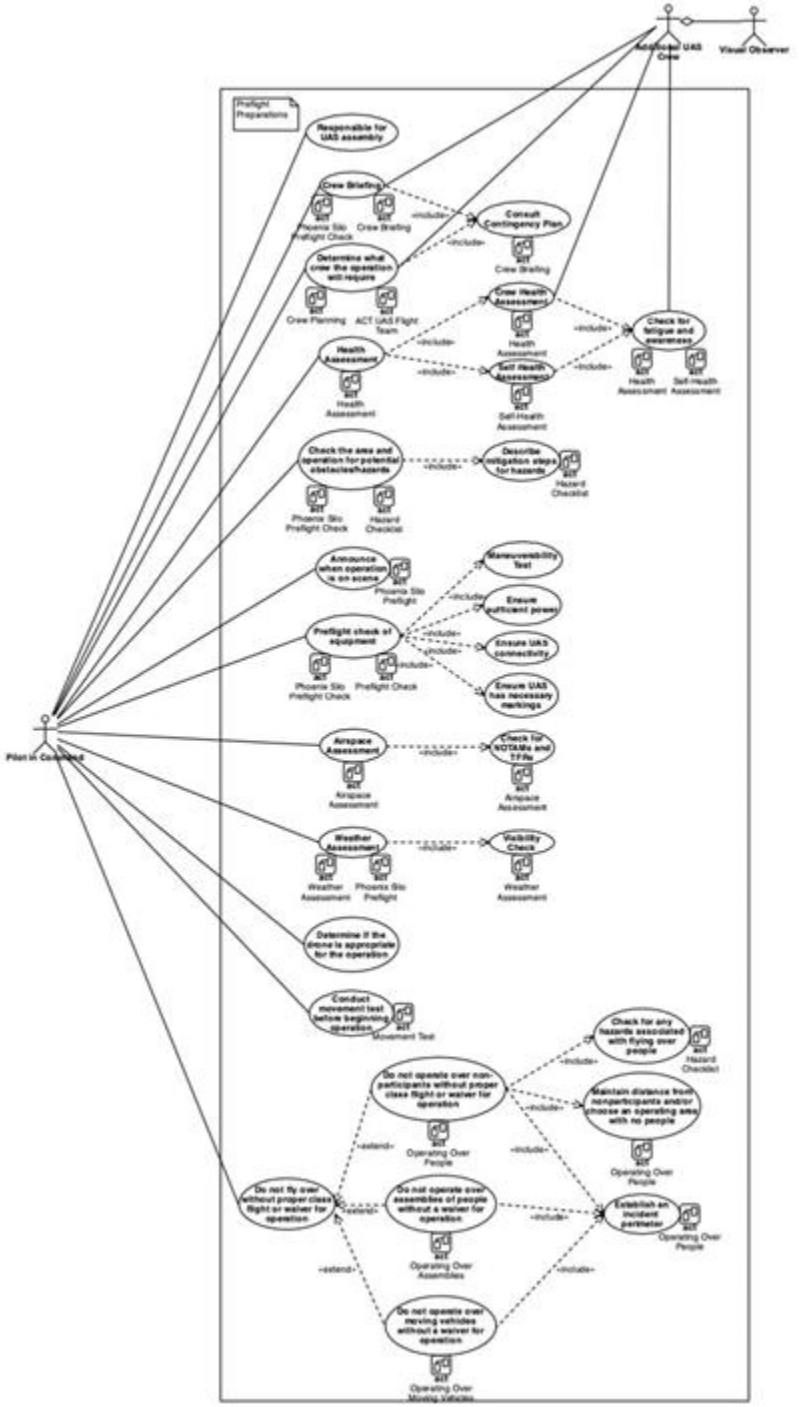
Example - Use Case

- **Preflight Merged Use Case Model**
- **Use Case Model serves to accumulate overlapping information**



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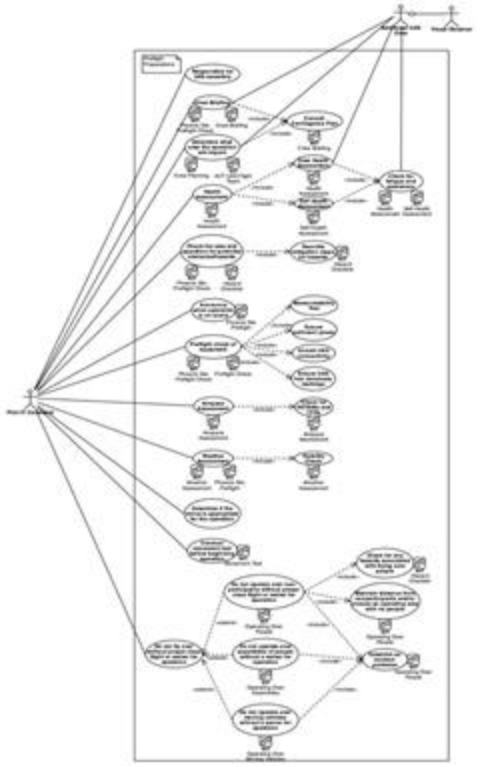
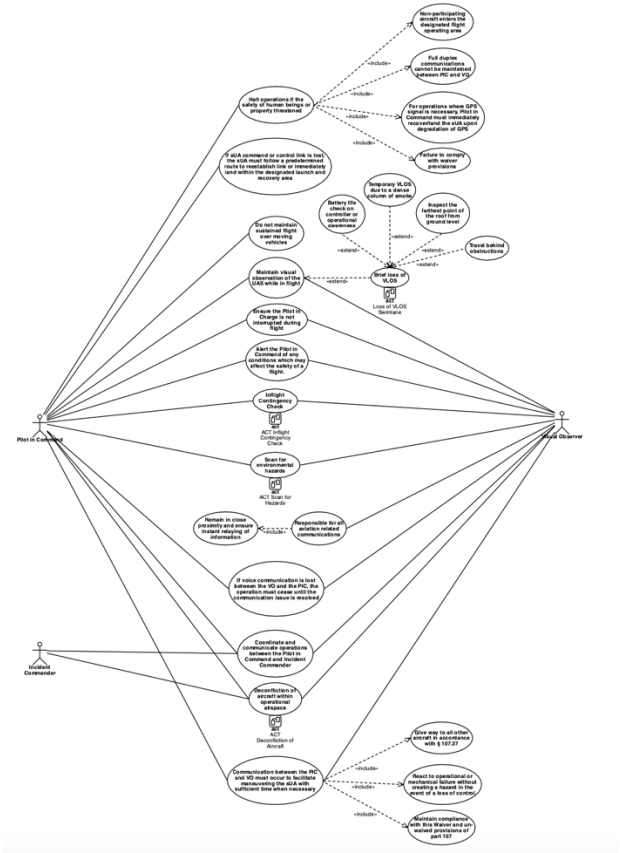
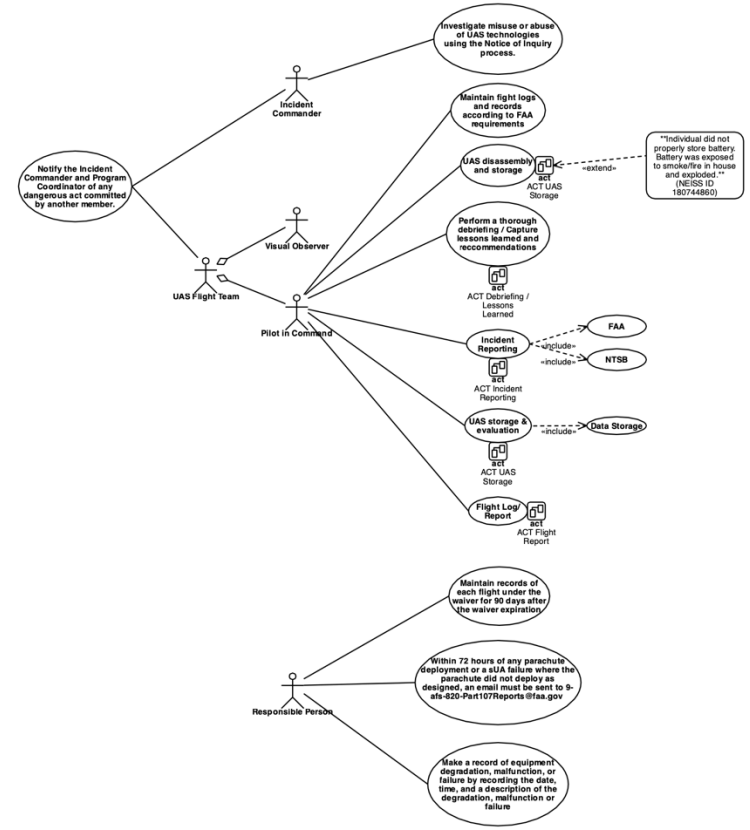
Example – Preflight, Inflight, Postflight Use Cases (Work in Progress)



Pre-Flight



In-Flight



Post-Flight

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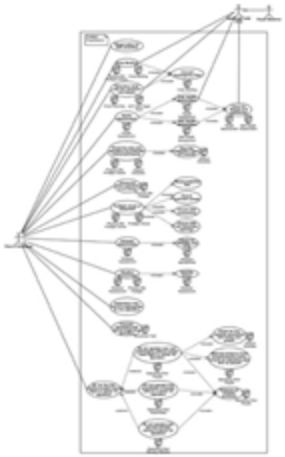
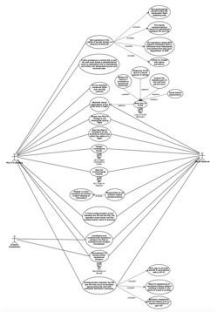
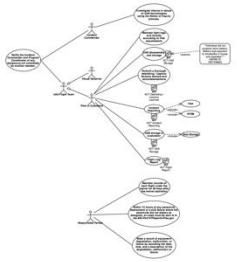
Activity Diagrams



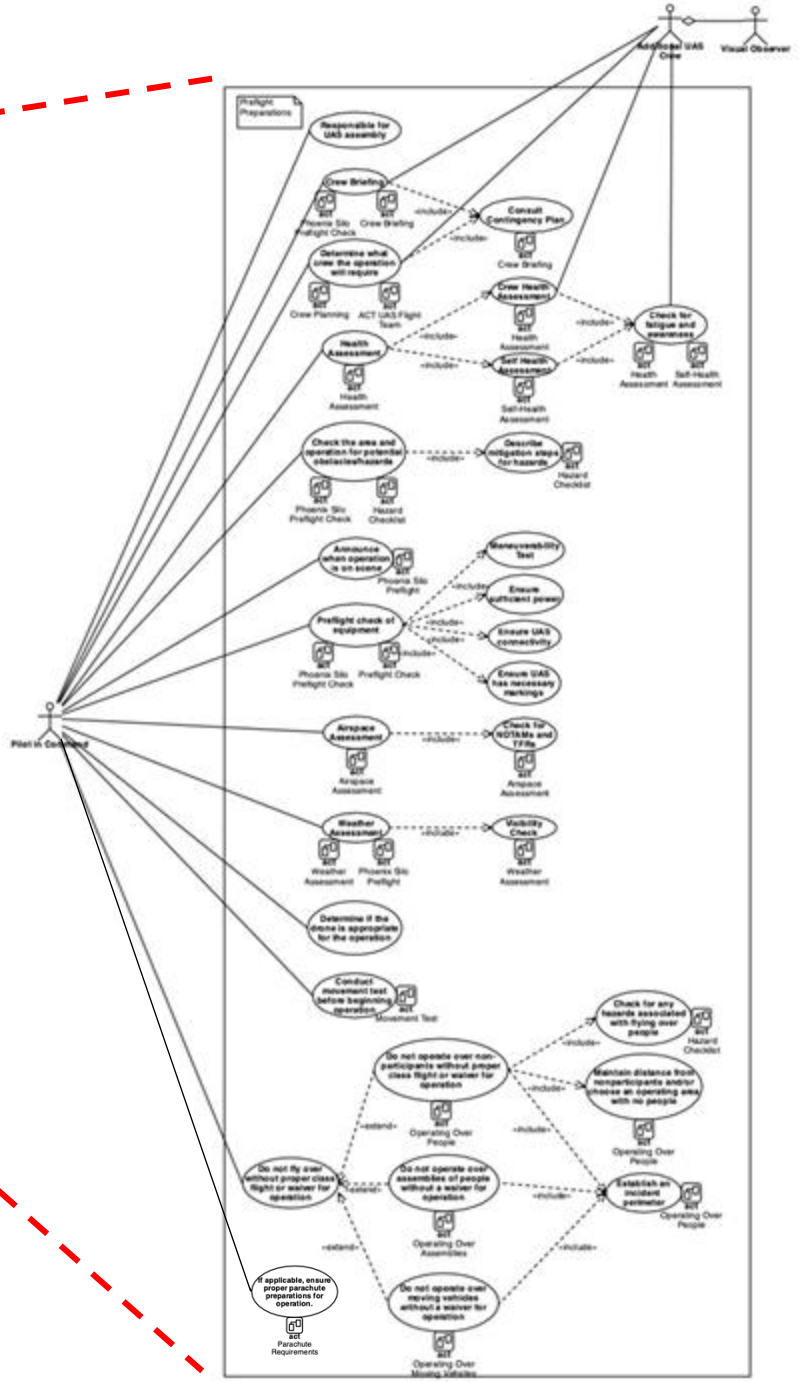
Pre-Flight



In-Flight

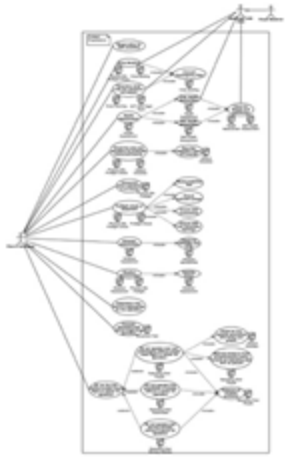


Post-Flight



Pre-Flight

Activity Diagrams



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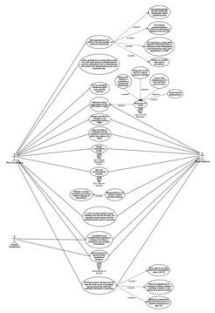
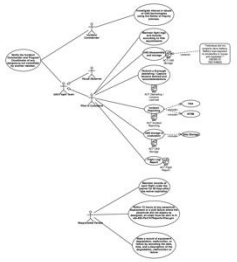
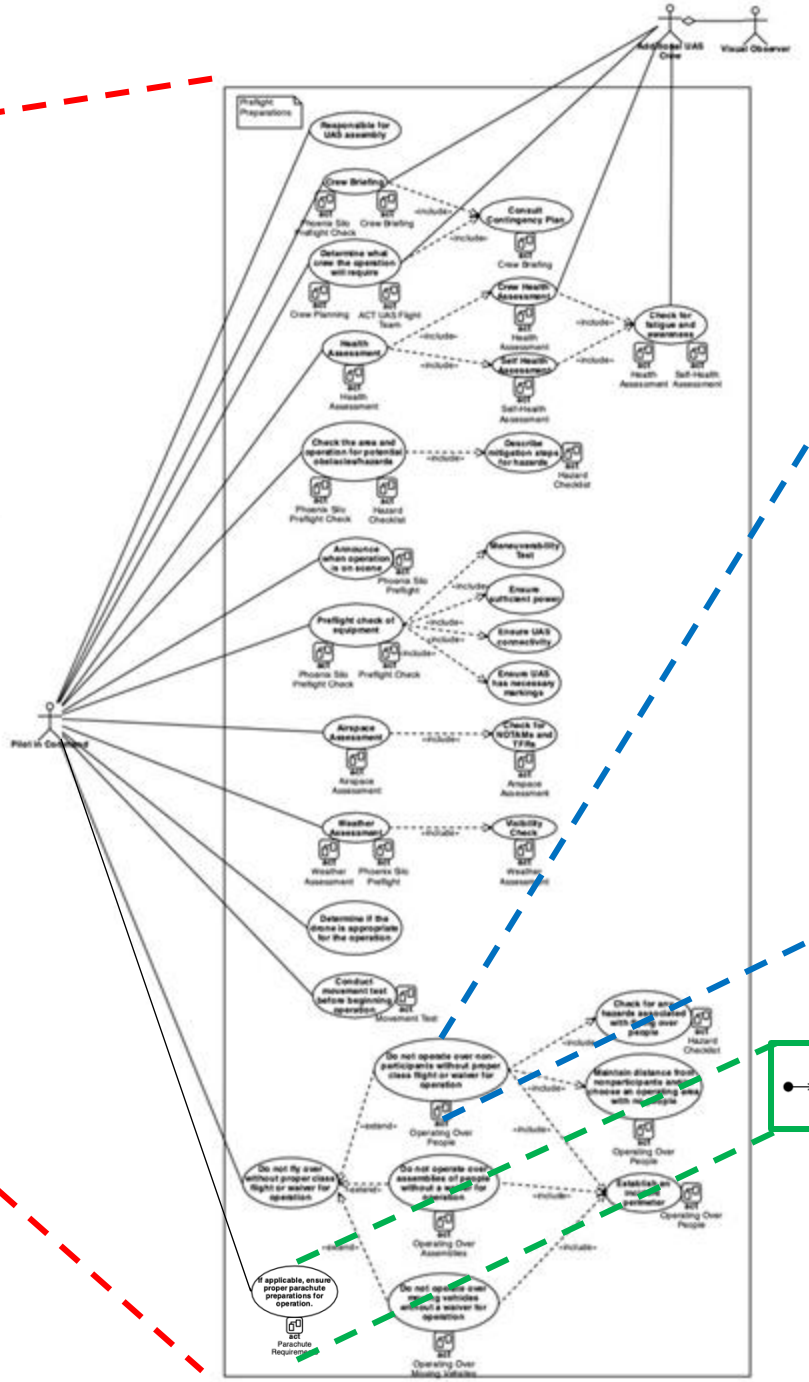


In-Flight

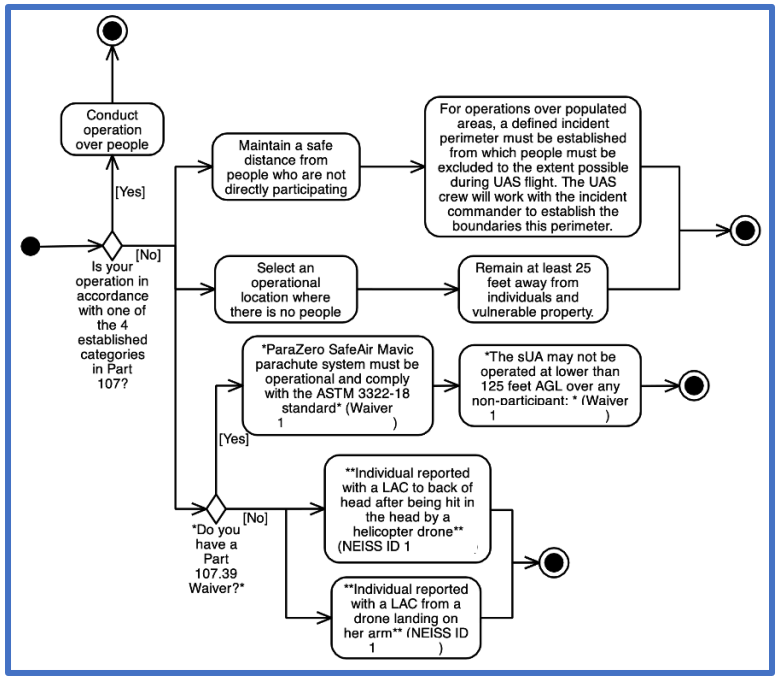


Post-Flight

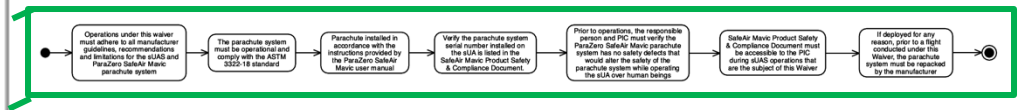
- **Use cases can be further expanded in activity diagrams**



Pre-Flight



Operation Over People Activity Diagram



Parachute Requirements Activity Diagram

System-Wide Safety

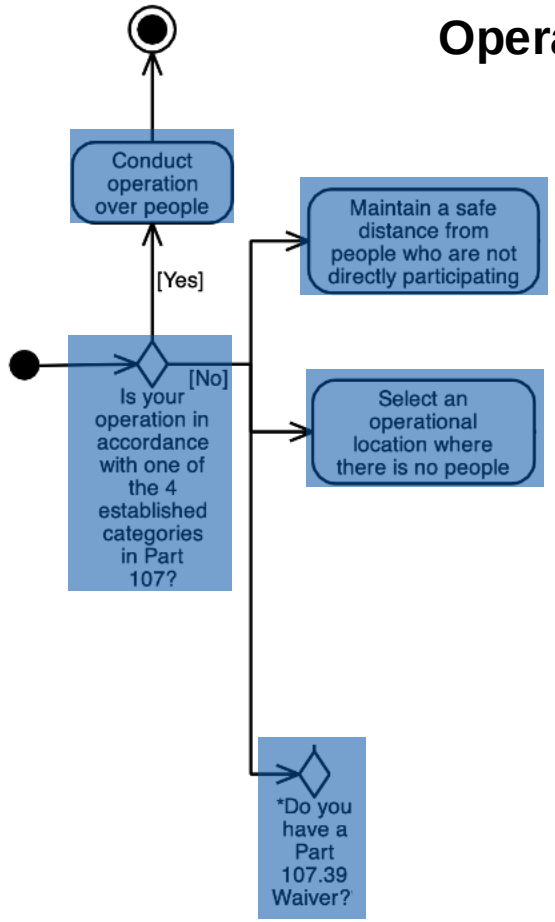
Activity Diagram – Operating Over People

- **The activity diagram aggregates:**
  - **AC107-2A**

8.3 Operations Over People. Section 107.39 prohibits operations of a small unmanned aircraft over a person who is not under a safe cover, such as a protective structure or a stationary vehicle, unless the operation is conducted in accordance with one of the four categories listed in part 107 subpart D. A remote pilot may operate a small unmanned aircraft over a person who is directly participating in the operation of the small unmanned aircraft. Direct participants include the remote pilot in command (PIC), another person who may be manipulating the controls, a visual observer (VO), or crewmembers necessary for the safety of the small unmanned aircraft operation. A direct participant should be directly involved in the small unmanned aircraft flight operation. The remote pilot assigns and briefs the direct participants in preparation for the operation. The remote pilot may comply with the requirements prohibiting operation over people in several ways. For example:

- Selecting an operational location where there are no people and none are expected to be present for the duration of the operation. If the remote pilot selects a location where people are present, the remote pilot should have a plan of action to ensure human beings remain clear of the operating area. The remote pilot may be able to direct people to remain indoors or remain under safe cover until the small unmanned aircraft flight operation has ended. Safe cover is a structure or stationary vehicle that protects a person from harm if the small unmanned aircraft impacts that structure or vehicle.
- Maintaining a safe distance from people who are not directly participating in the operation of the small unmanned aircraft.

Activity Diagram - Operating Over People



System-Wide Safety

Activity Diagram – Operating Over People

- **The activity diagram aggregates:**
  - **AC107-2A**
  - **OP Manual**

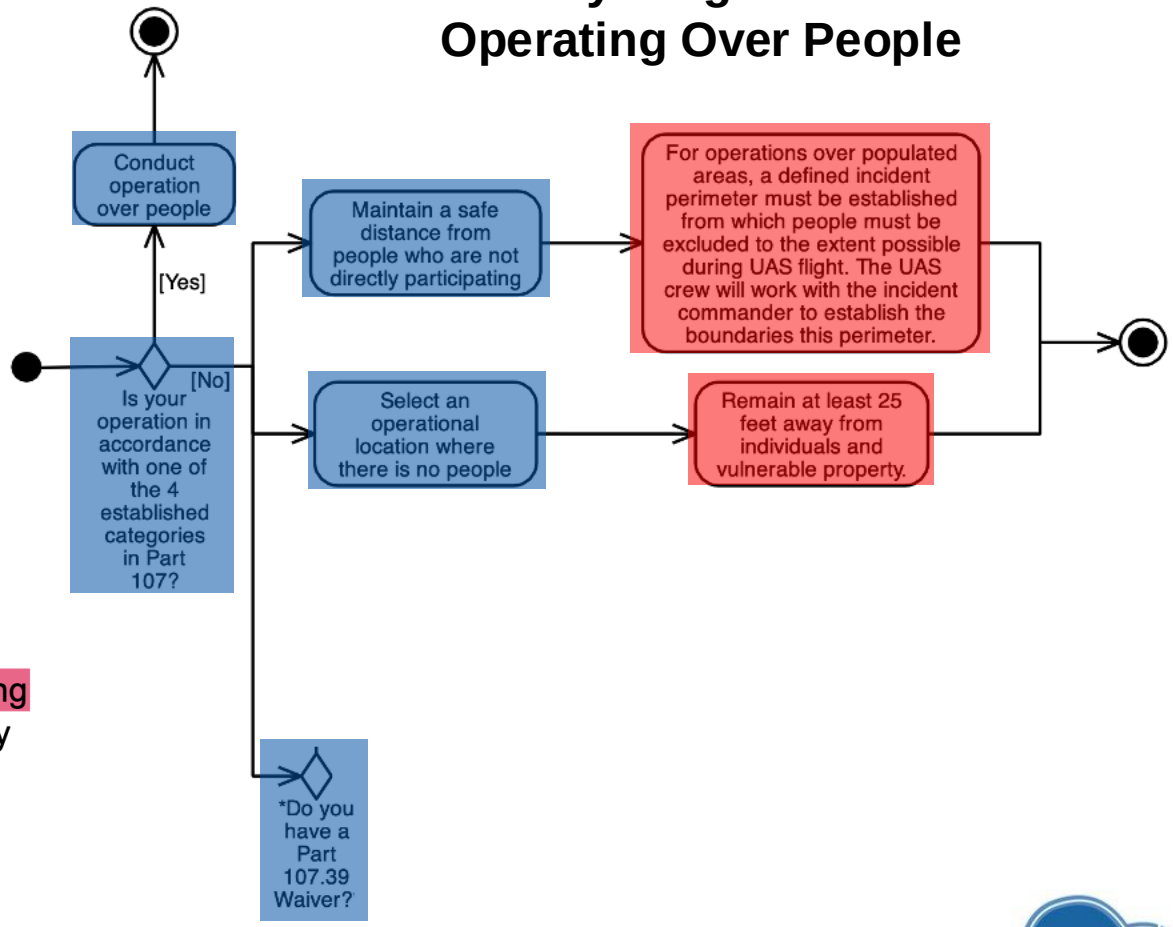
Fire Operational Manual 2

f. If required by the COA, for operations over populated areas, a defined incident perimeter must be established from which people must be excluded to the extent possible during UAS flight. The UAS crew will work with the incident commander to establish the boundaries this perimeter. The use of a "Reverse 911" system or public address system may be used to aid in securing the area.

Fire Operational Manual 3

3. Small unmanned aircraft may not operate over any persons not directly participating in the operation, not under a covered structure, and not inside a covered stationary vehicle. Remain at least 25 feet away from individuals and vulnerable property.

Activity Diagram - Operating Over People



System-Wide Safety

Activity Diagram – Operating Over People

- **The activity diagram aggregates:**
  - **AC107-2A**
  - **OP Manual**
  - **Waivers**

ENVIRONMENTAL PROVISIONS

29. During sUA operations over non-participants, the ParaZero SafeAir Mavic parachute system must be operational and comply with the ASTM 3322-18 standard as described in the waiver application;

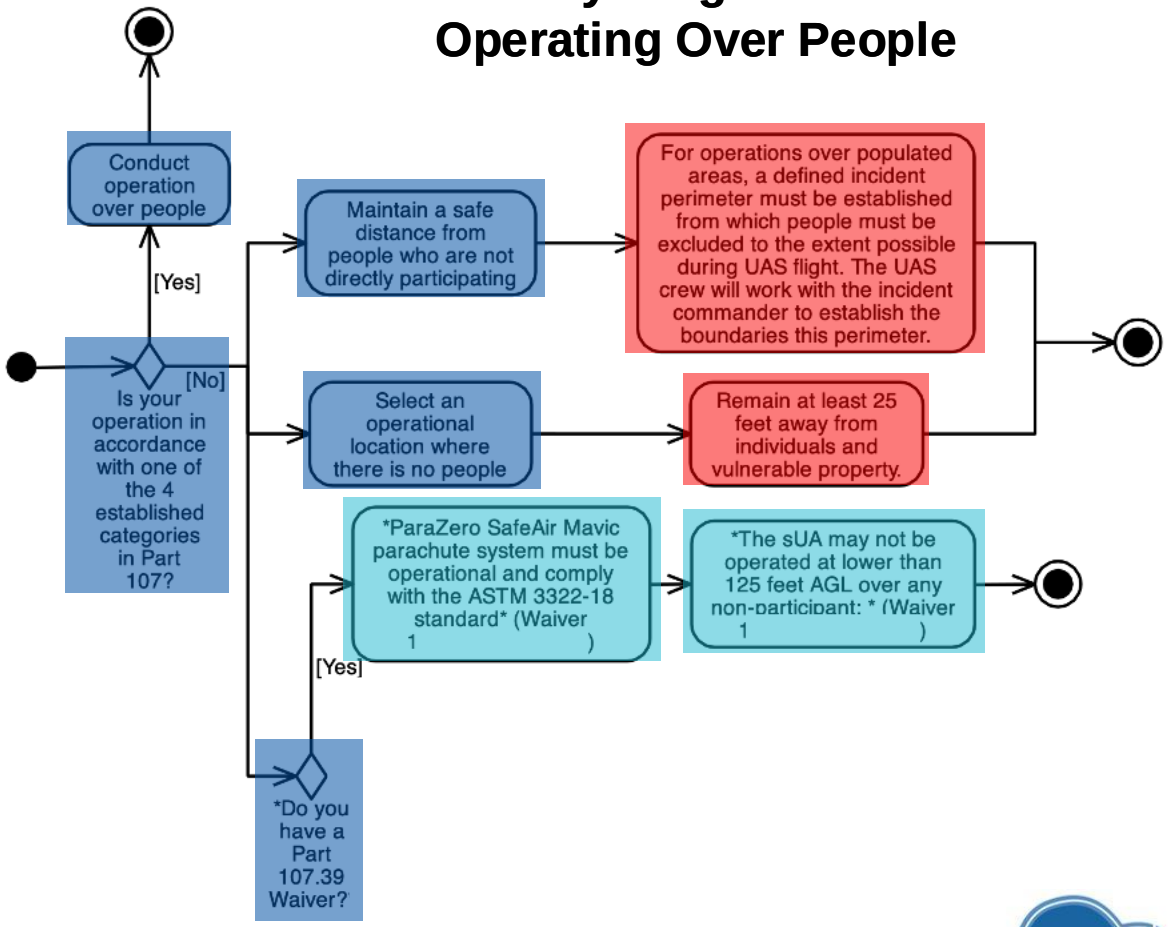
30. The sUA may not be operated lower than 63 feet over any non-participant;

31. sUAS operations over open air assemblies of persons is prohibited. Only transient operations over people are approved;

32. sUAS operations over moving vehicles is prohibited;

33. Operations conducted under this Waiver are limited to the sparsely populated area indicated in the Waiver application.

Activity Diagram - Operating Over People



System-Wide Safety

Activity Diagram – Operating Over People

- **The activity diagram aggregates:**
  - **AC107-2A**
  - **OP Manual**
  - **Waivers**

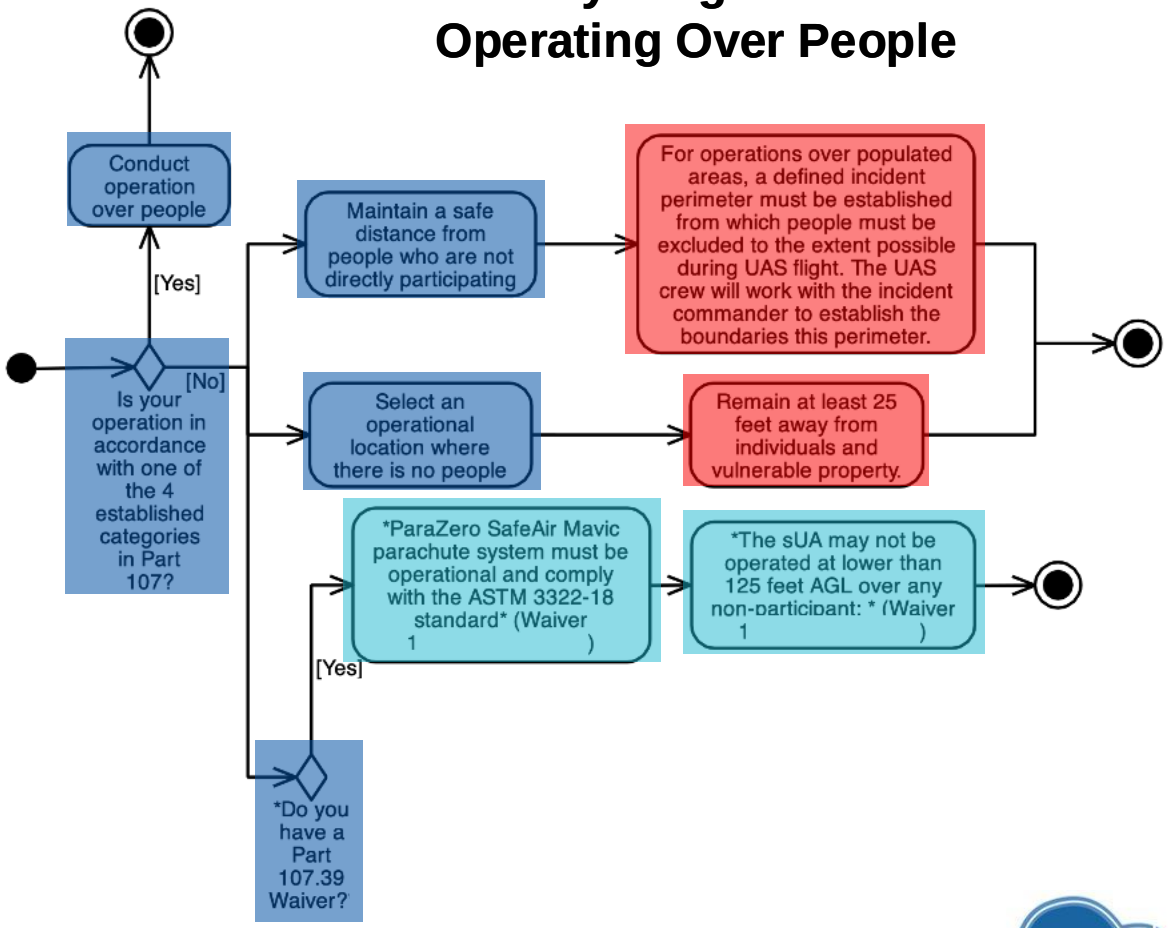
11. Launch or recovery areas must be pre-designated and monitored to keep any human being who is not directly participating in the operation out of the areas prior to, during, and immediately following flight operations;

12. Geofencing must be used to confine the Operational Volume;

13. The sUA must be equipped with high visibility markings and/or lighting to increase the conspicuity of the sUA to 1 statute mile for daytime operations and 3 statute miles for civil twilight and night operations;

14. The sUA may not be operated;
    a. lower than 125 feet AGL over any non-participant;
    b. above 300 feet AGL;
    c. over moving vehicles;
    d. when the wind exceeds 7 m/s (13.6 knots) or gusting 12 m/s (23.3 knots);
    e. at a speed greater than 10m/s over open air assemblies of non-participants;

Activity Diagram - Operating Over People



System-Wide Safety

Activity Diagram – Operating Over People

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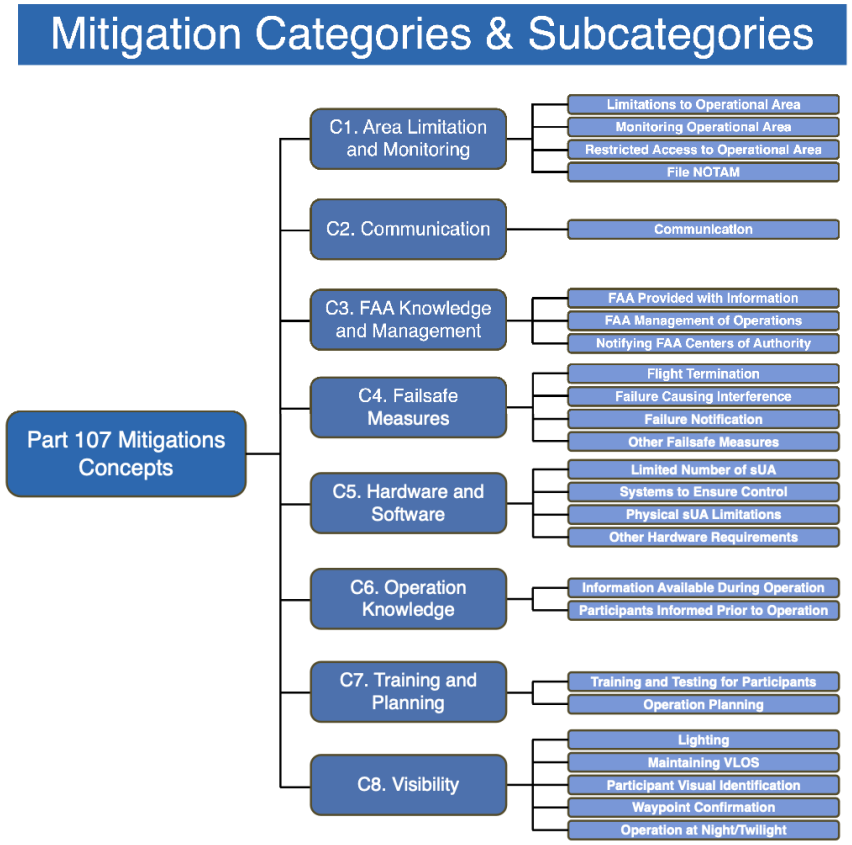
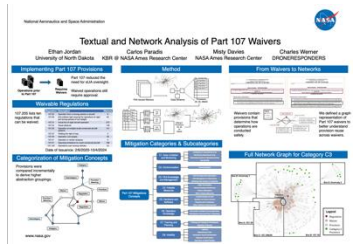
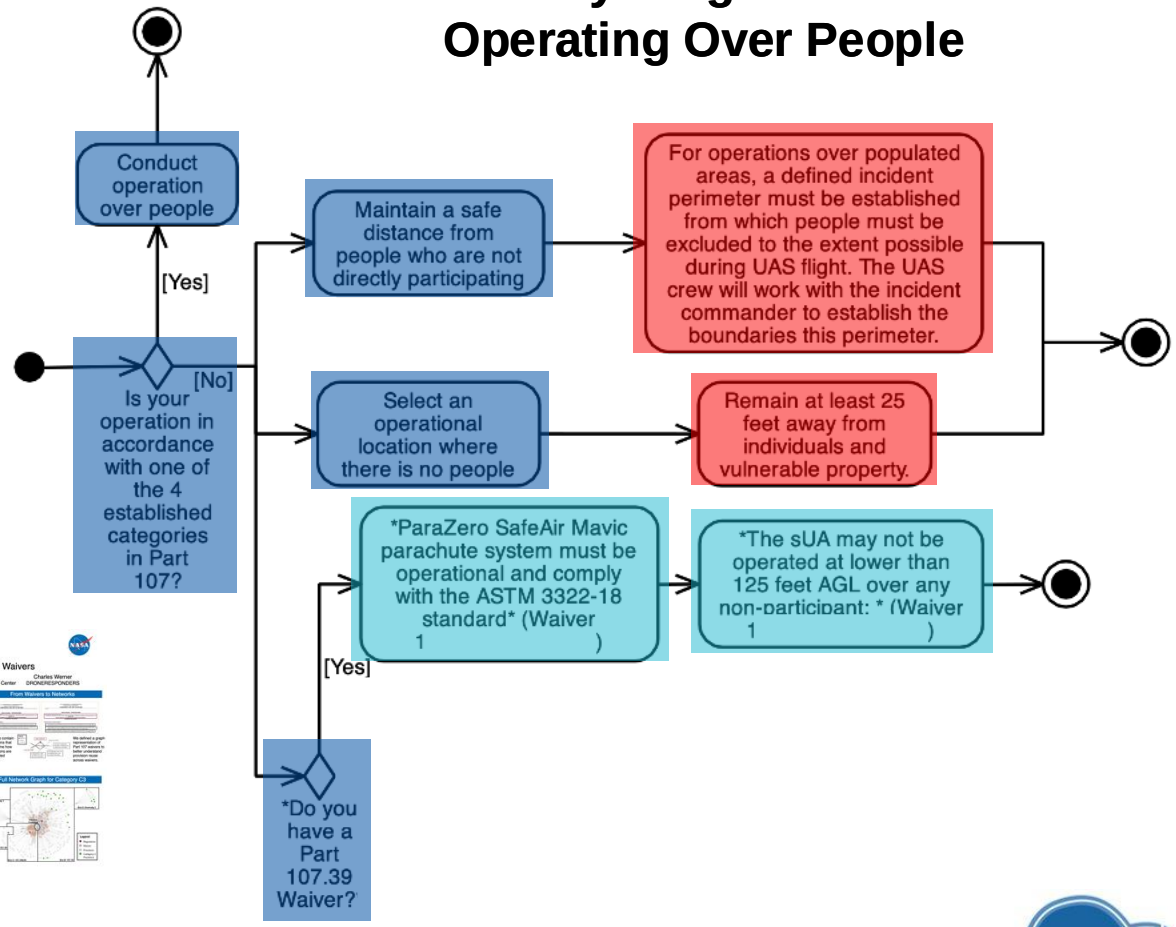




DASC'24
Textual and Network Analysis of Title 14 CFR Part 107 Waivers

Activity Diagram - Operating Over People



System-Wide Safety

Activity Diagram – Operating Over People

- **The activity diagram aggregates:**
  - **AC107-2A**
  - **OP Manual**
  - **Waivers**
  - **Hazards**

1 05/02/2015

DX LAC SCALP 27YOF

PATIENT WITH LAC TO BACK OF HEAD & LT UPPER FH

SHE WAS HIT IN HEAD ACCIDENTALLY BY A HELICOPTER DRONE FLOWN ANOTHER PERSON

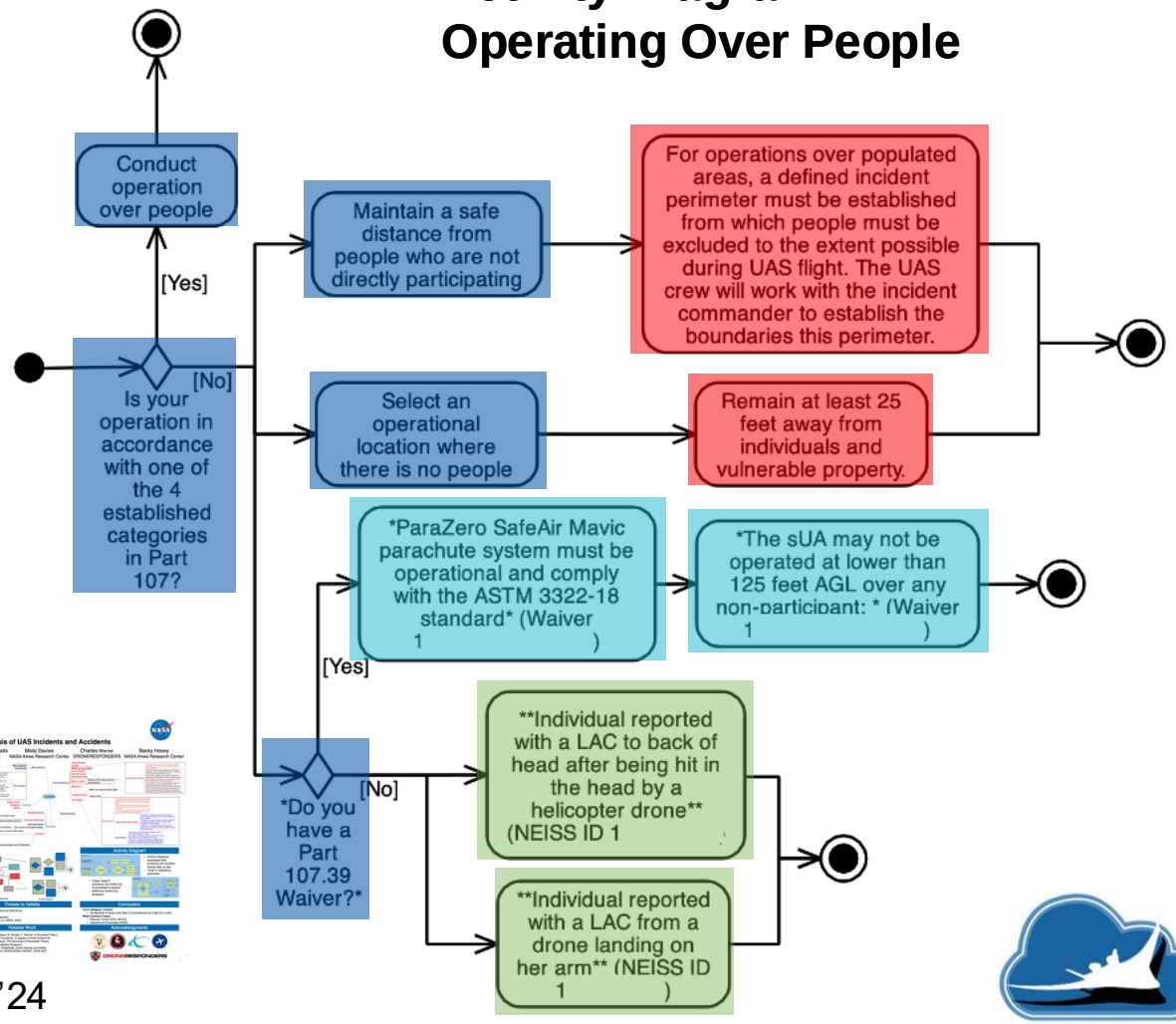
1 08/26/2018

12 YOF C/O

FOREARM LACERATION S/P A

FREIND'S DRONE LANDED ON HER ARM WHILE THEY WERE BOATING DX LACERATION OF LEFT FOREARM

Activity Diagram - Operating Over People



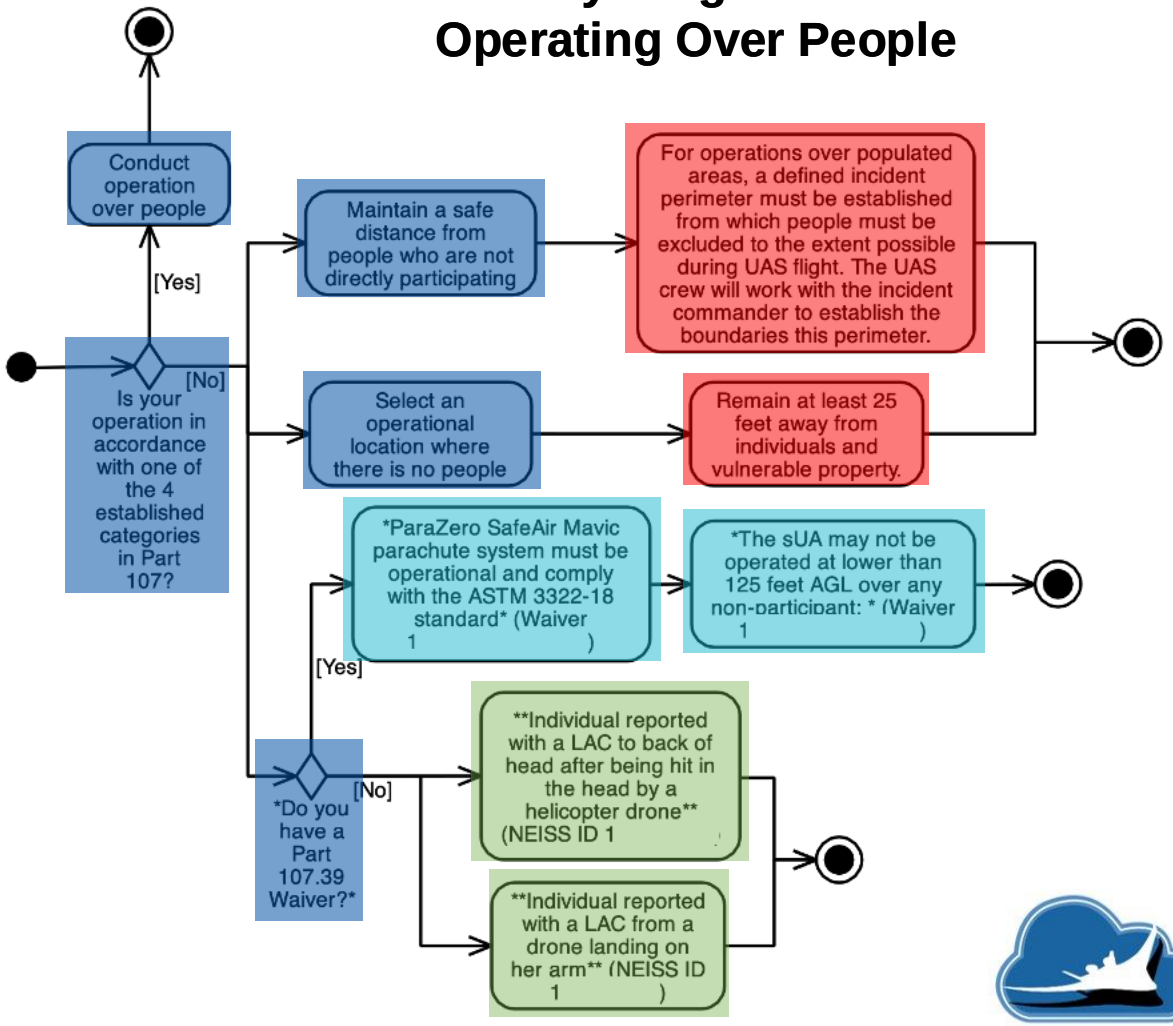
Aviation'24
Grounded Theory of UAS Reported Accidents

System-Wide Safety

Activity Diagram – Operating Over People

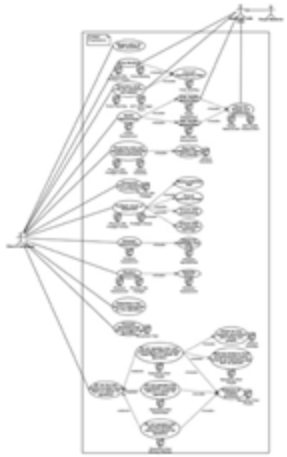
- **Hazards are included in the diagram so we can see where they occur**

Activity Diagram - Operating Over People

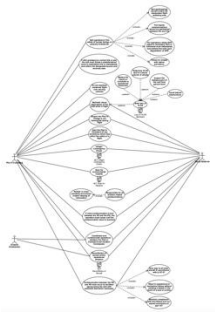


System-Wide Safety

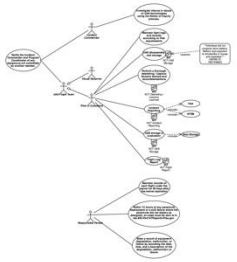
Activity Diagrams



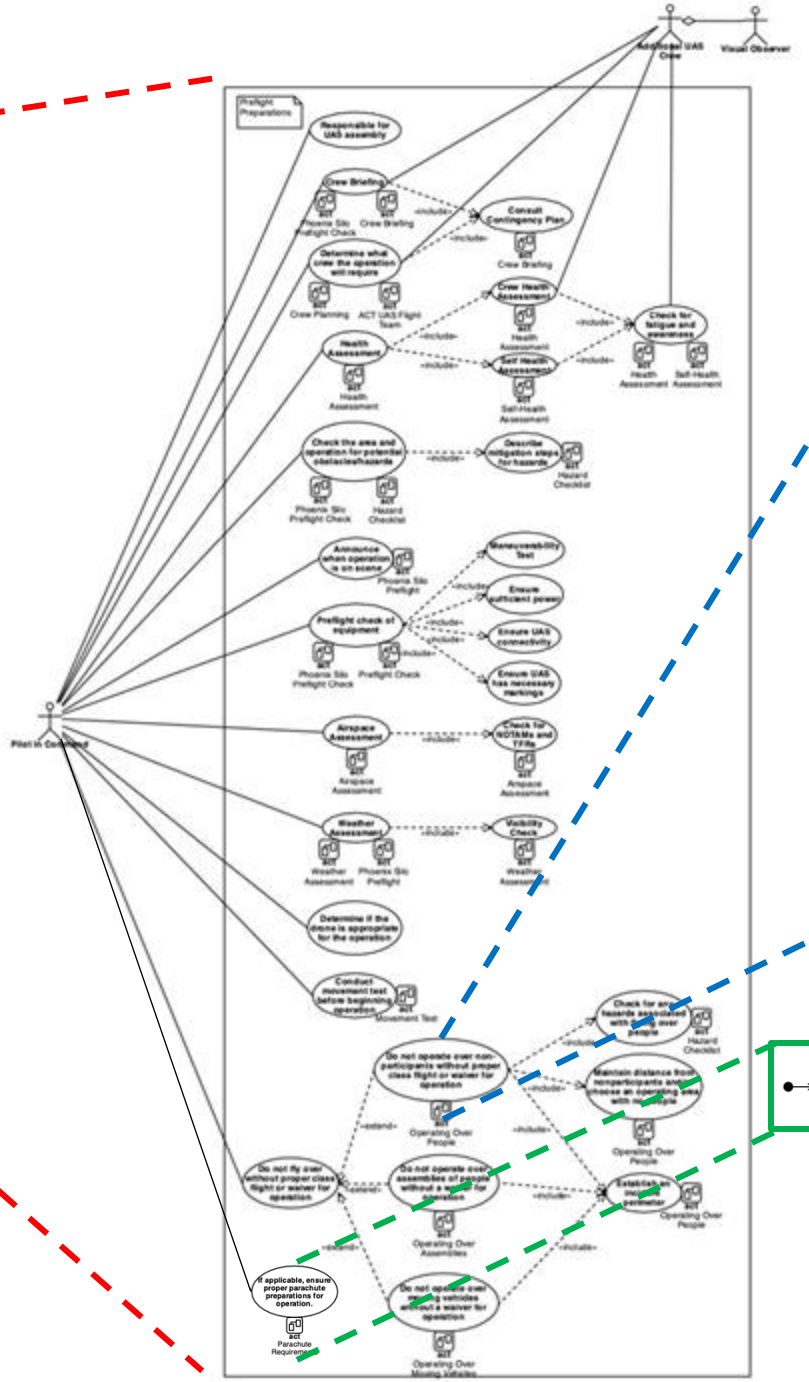
Pre-Flight



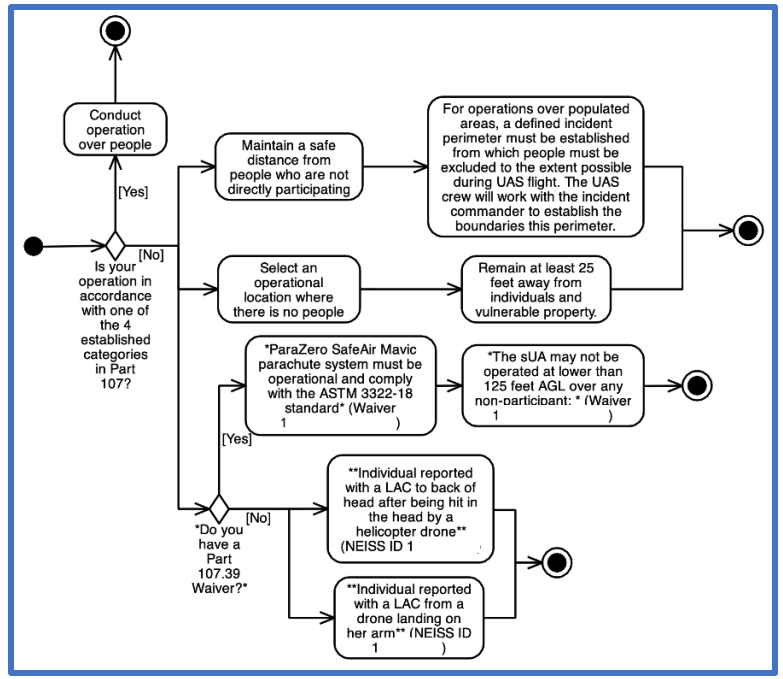
In-Flight



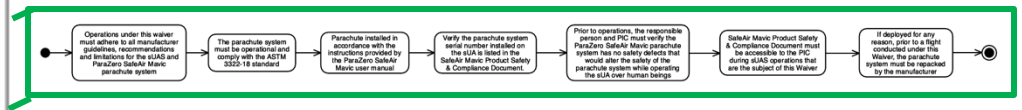
Post-Flight



Pre-Flight



Operation Over People Activity Diagram

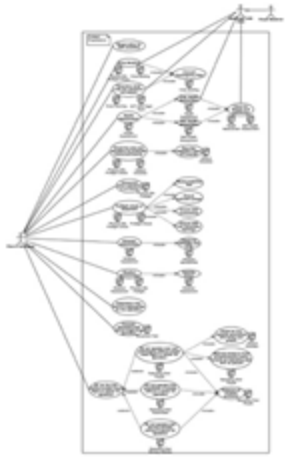


Parachute Requirements Activity Diagram

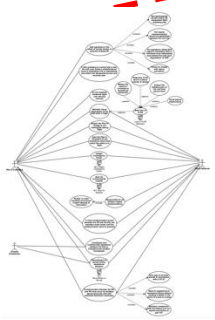
- **Constructed Activity Diagrams can be used to identify Operational Manual Gaps**

System-Wide Safety

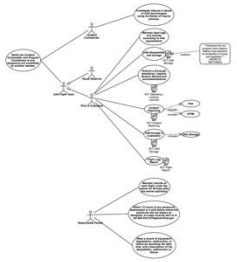
Manual Evaluation



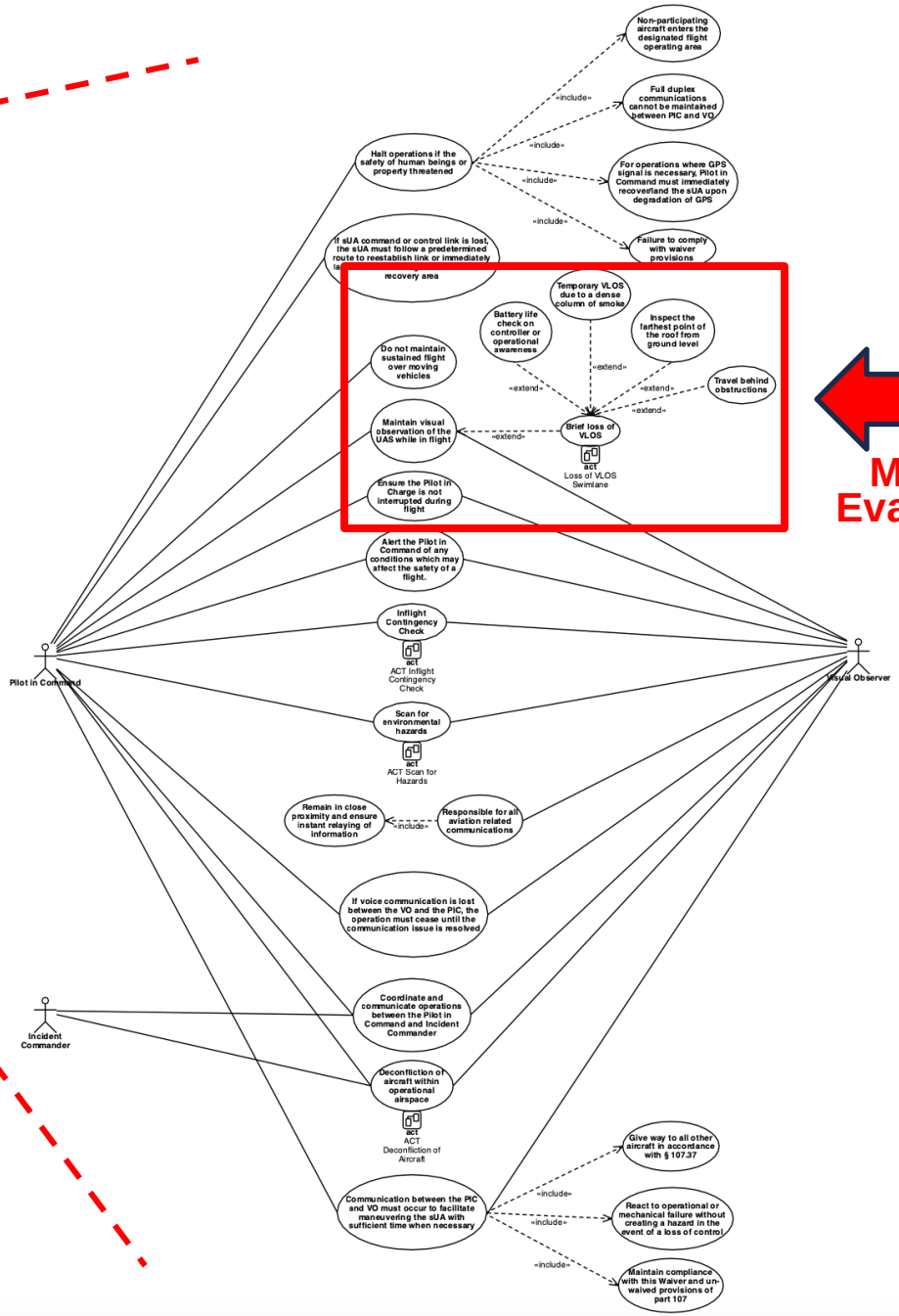
Pre-Flight



In-Flight

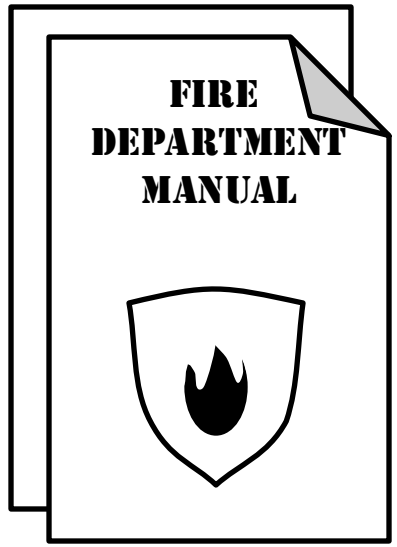


Post-Flight



In-Flight

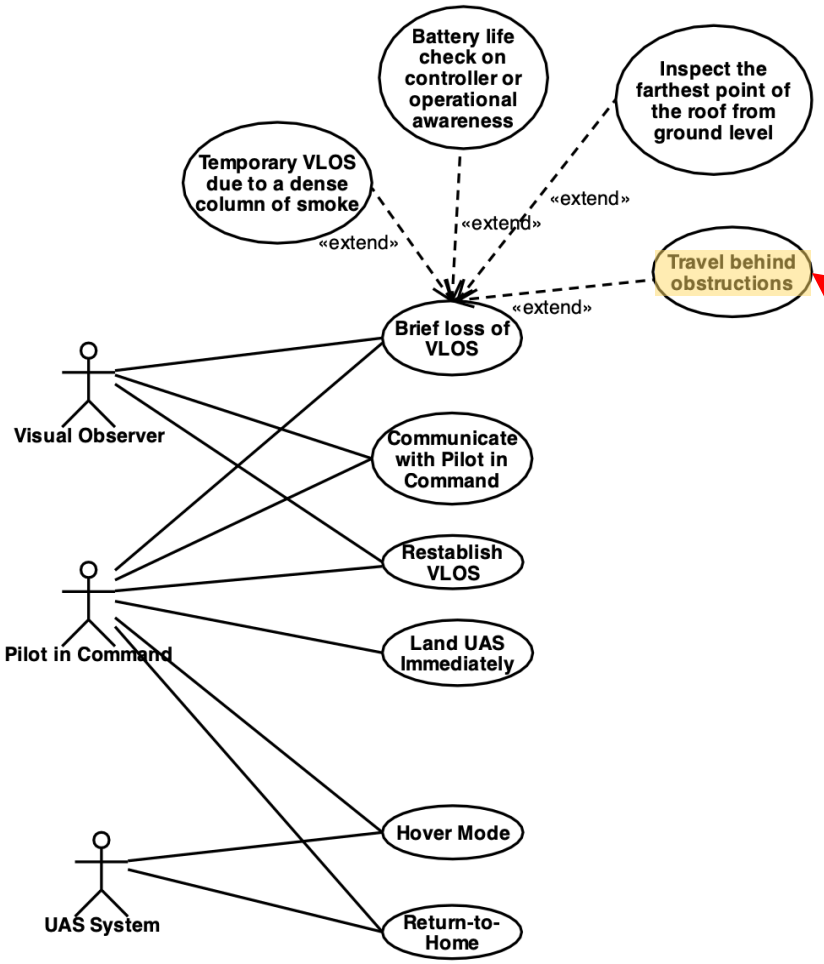
Manual Evaluation

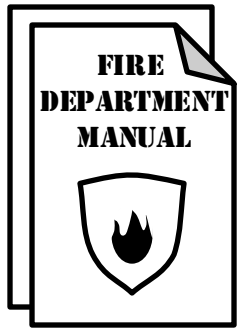


Operational Manual

System-Wide Safety

Example – Operational Manual – New information added to the model

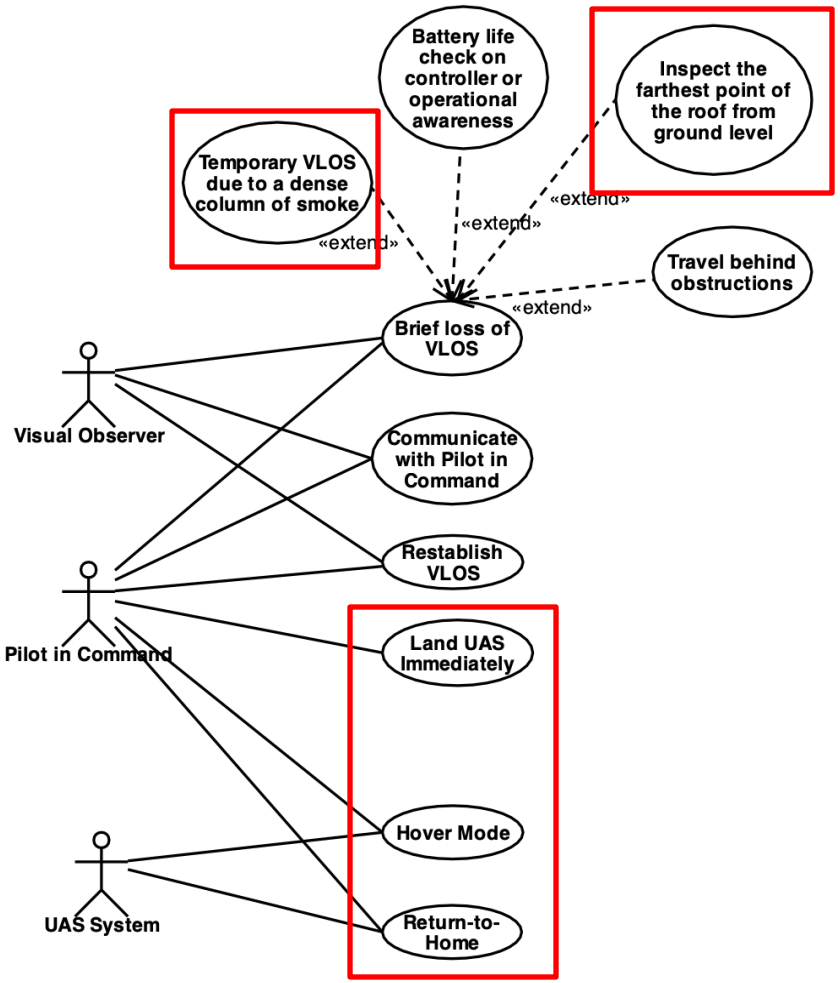


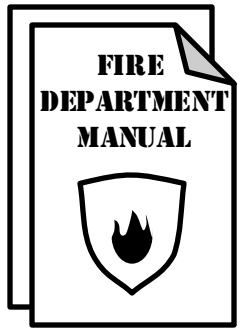


The number of personnel assigned to the UAS operation affects the ability to successfully complete the mission and the ability to comply with the requirement to be able to see the unmanned aircraft throughout the entire flight. The FAA recognizes that the person maintaining visual line of sight (VLOS) of the air vehicle may lose sight of the unmanned aircraft for brief moments of the operation. This may be necessary either because the small unmanned aircraft momentarily travels behind an obstruction or to allow the person maintaining VLOS to perform actions such as scanning the airspace or briefly looking down at the UAS control station. However, it is emphasized that even though the RPIC may briefly lose sight of the unmanned aircraft, he or she is responsible for the see-and-avoid provisions set out in Federal Aviation Regulations (FAR) Part 107.

System-Wide Safety

Example – Operational Manual – Information that could be added to Manual





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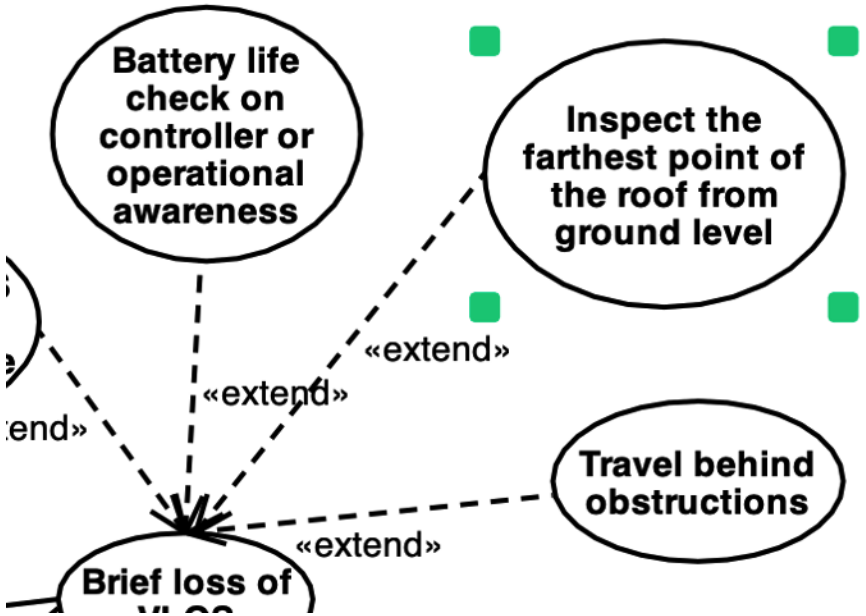
System-Wide Safety

Example – Operational Manual – Document Traceability

- **We preserved the source data references to serve as context for the chatbot model**



Name

Inspect the farthest point of the roof from ground level

Abstract

Note

[fire-sop-city_ , p.17]

Internals of focused item

```
Presentation:
  class: gaphor.UML.diagramitems.UseCaseIt
  id: 4123936c-9646-11ef-838a-6254babcdd39

Model Element:
  qname: Inflight.Merged UC.Inspect the fa
```

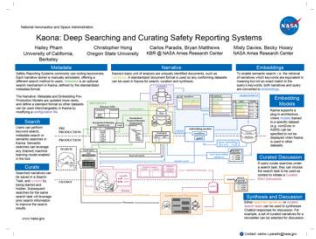
System-Wide Safety

Matching ASRS Results

Text Query: How can I fly a UAS Mission for Structured Fire safely?

Model: Word2Vec + Llama

Based on the given context and ACNs, I can provide the following answer to your question on how to fly a UAS (Unmanned Aircraft System) mission for a structured fire safely. From ACN 359890, it



Scitech'25

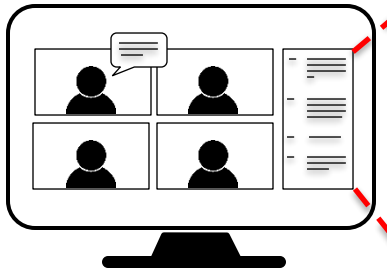
Kaona: Deep Searching and Curating Data from Aviation Safety Reporting Systems

System-Wide Safety

Hurricane Recovery Example

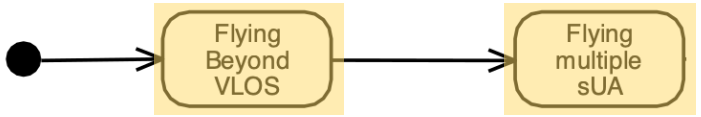
An example using our methodology on a hurricane scenario

Interview



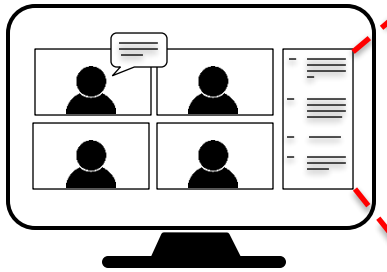
20:47 […]

21:03 […] you had multiple drones and we had beyond visual light of sight […]



System-Wide Safety

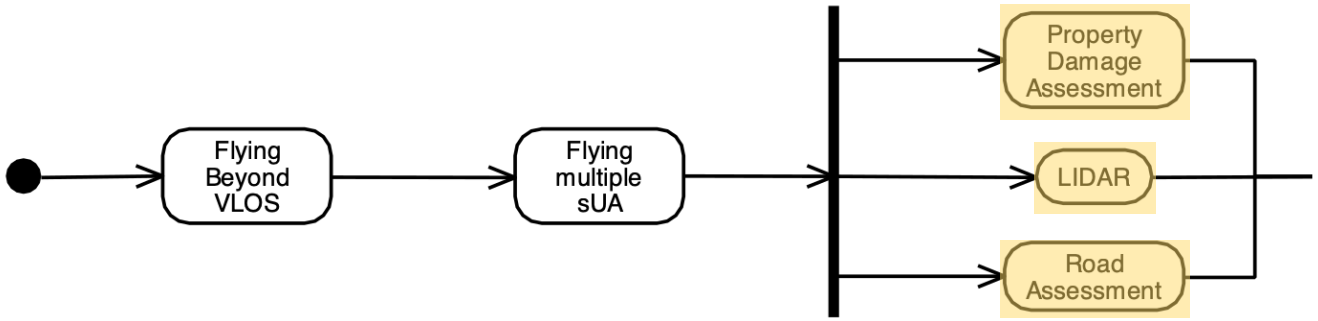
Interview



21:28 […] one drone would fly with LIDAR […]

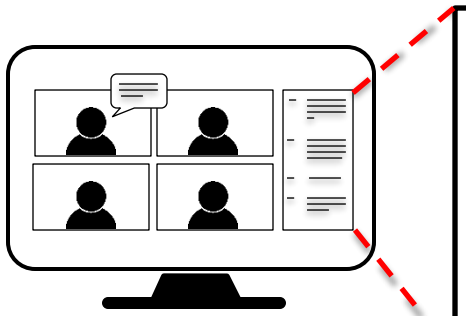
21:42 […] another would perform property damage assessment […]

21:52 […] and another for road assessment […]

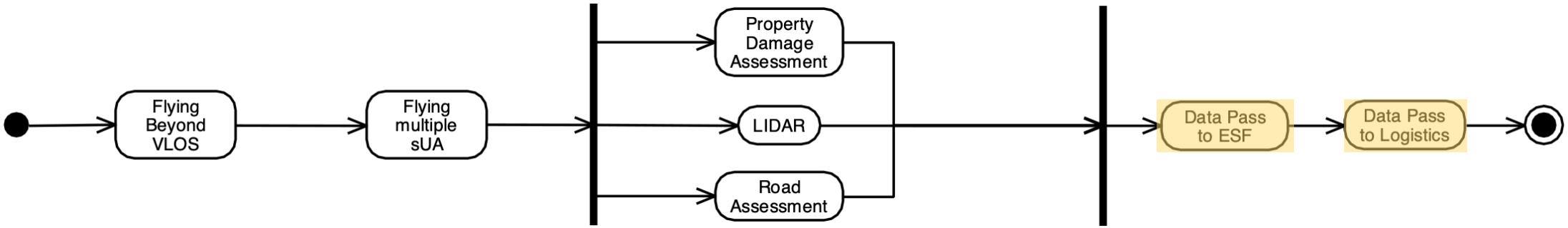


System-Wide Safety

Interview



22:12 […] the data could be passed to ESF […] and then to logistics […]



System-Wide Safety

Hurricane Recovery Example

An example using our methodology on a hurricane scenario

System-Wide Safety

Mitigations - Waiver Provisions – Beyond VLOS and Multiple sUAS

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

14 CFR § 107.31—Visual line of sight aircraft operation

Visual Line of Sight Operations Special Provisions The remote PIC may conduct sUAS operations without the ability to see the unmanned aircraft throughout the entire flight, provided:

14. The remote PIC must ensure:
    a. Prior to conducting operations under this Waiver, the RPIC must perform a documented site survey to:
        1) Identify flight operational area obstacles and boundaries so as to avoid collision with, or damage to property;
        2) Validate C2 signal strength is sufficient for control through the entire route;
        3) Validate suitable launch/recovery site(s); and
        4) Complete and document a Flight Risk Assessment;
    b. Routes are preplanned (using waypoints) prior to flight and aircraft are programmed to automatically follow the route. Manual flights are allowed as necessary;
    c. Geofencing is used to confine the Operational Volume. (defined as the property lines of the assets or perimeter boundaries of the controlled access area or right of way specified in the Waiver application + maximum allowed altitude);
    d. Return to Home/Return to Land feature must not allow the sUA to deviate from the defined operational volume;

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

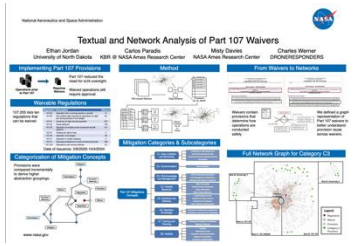
14 CFR § 107.35—Operation of multiple small unmanned aircraft systems

Operation of Multiple sUAS Special Provisions sUAS operations with multiple sUA may be conducted, provided:

12. The remote PIC must ensure that an individual system failure must not interfere with the operation of any other sUA or cause incidents, accidents, or loss of control involving any other sUA that are subject to this Waiver;

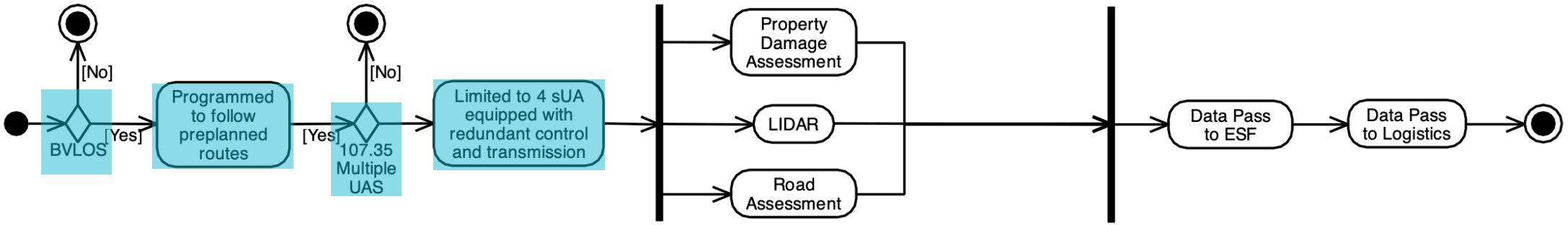
13. The remote PIC may conduct operations of up to 4 sUA, equipped with redundant flight control and transmission systems, and must ensure adequate simultaneous control of the sUA so they remain inside the area of operation, as described in the waiver application;

14. Communication between the remote PIC and VO must allow for the remote PIC to light the sUA and/or ground the sUA with sufficient time to yield right-of-way in accordance with §107.37 as described in the waiver application;



DASC'24

Textual and Network Analysis of Title 14 CFR Part 107 Waivers



System-Wide Safety

Hazards – Lost Signal

Your search returned 0 ACNs

Search Criteria:
Text contains (BVLOS UAS)

Display your results:

Results Online (in HTML)
- View all reports(50 per page)
- View only the 0 most recent reports
- View a list of ACNs

Export Results
- Excel File
- Comma Separated File(CSV)
- Word File

Export Search Criteria
- Text File

Modify Search
- Go back and edit current search
- Start new search

Matching ASRS Results

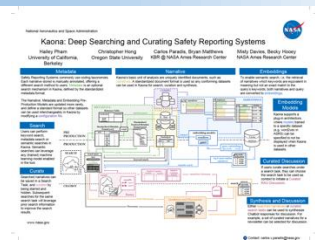
ASRS Report Number.Accession Number: 1840720
Aircraft Operator: Government
Altitude.AGL.Single Value: 35
Configuration (UAS): Multi-Rotor

Control Mode (UAS): Manual Control
Detector: Person UAS Crew

Flight Conditions: VMC
Flight Operated with Visual Observer (UAS): Y
Flight Plan: None
Function: Remote PIC (UAS); Person Manipulating Controls (UAS)
Light: Daylight
Locale Reference: ZZZ.Tower
Make Model Name: Skydio 2
Number of UAS Being Controlled (UAS): Number of UAS 1
Operating Under Waivers / Exemptions / Authorizations (UAS): Y
Problem: Improperly Operated
Relative Position.Distance.Nautical Miles: 4
Result: Aircraft Lost Link (UAS); Flight Crew Overcame Equipment Problem
State Reference: US
Waivers / Exemptions / Authorizations (UAS): 107.31
Weight Category (UAS): Small
Callback: Reporter stated this was a test flight to find limitations of Skydio 2 flying BVLOS underneath a bridge.
Anomaly: Aircraft Equipment Problem Critical; Deviation / Discrepancy - Procedural Published Material / Policy

Aircraft Component: Com Link (C2) (UAS)
Airspace: Class G ZZZ
Ceiling: CLR
Contributing Factors / Situations: Software and Automation; Human Factors; Environment - Non Weather Related; Aircraft
Crew Size: 2
Experience: Flight Crew Last 90 Days (UAS) 5; Flight Crew Total 110; Flight Crew Total (UAS) 15; Flight Crew Type (UAS) 3
Flight Operated As (UAS): BVLOS
Flight Phase: Cruise; Return to Home (UAS)
Flying In / Near / Over (UAS): Critical Infrastructure
Human Factors: Troubleshooting
Local Time Of Day: 1201-1800
Location Of Person: Outdoor / Field Station (UAS)
Mission: Test Flight / Demonstration
Operating Under FAR Part: Part 107
Primary Problem: Ambiguous
Qualification: Flight Crew Private; Flight Crew Remote Pilot (UAS)
Reporter Organization: Government
Route In Use: None
Type (UAS): Purchased
Weather Elements / Visibility: 10
When Detected: In-flight

Narrative 1: 2 Pilots were inspecting their third bridge under a BVLOS waiver from [Goverment agency] when the drone had lost its signal/connection. Eventually during the return to home phase connection was regained. Most likely due to bridge obstruction interference.



Scitech'25
Kaona: Deep Searching and Curating Data from Aviation Safety Reporting Systems

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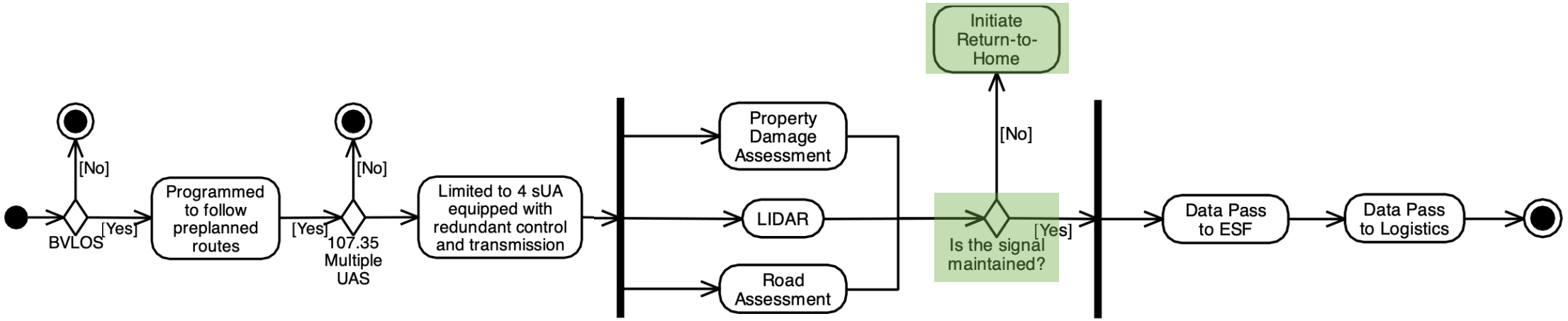
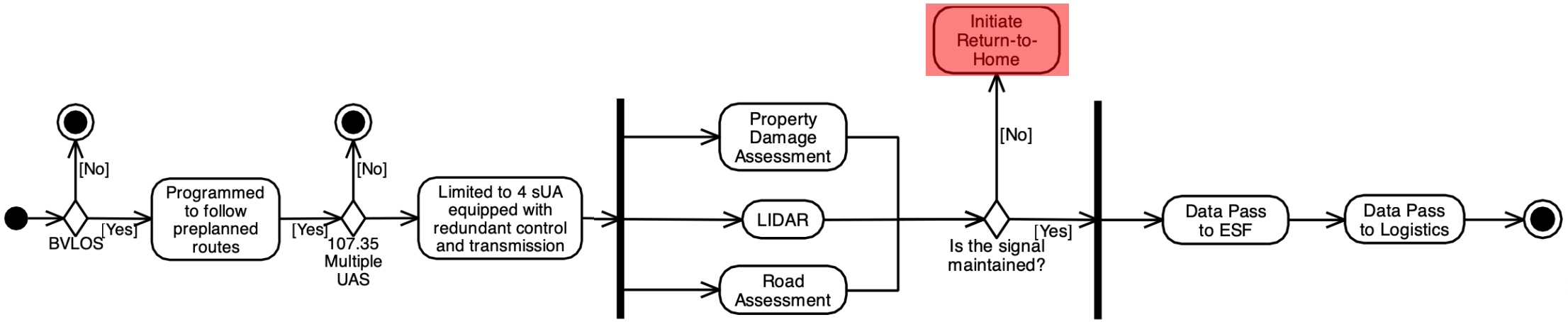


System-Wide Safety

Hazards – Lost Signal

Appendix B: Contingency Plan Checklist

Event	Result	Procedure
Battery depletes	Unmanned aerial system (UAS incapable of continuing flight operations.	UAS return to base (RTB) as soon as practical; cease data collection.
Ditch Procedures	UAS incapable of continuing flight operations.	Identify safe landing area; attempt a controlled landing; if able, land UAS in water (shallow preferred for ease of recovery) away from public.
Fuel Depletes	UAS incapable of continuing flight operations.	UAS RTB as soon as practical; cease data collection.
Hazardous Weather	UAS incapable of continuing flight operations.	UAS RTB as soon as practical; cease data collection.
Hostile Environment	Mission impacted by hazard (for example, air traffic, public activity).	See and avoid; take evasive action as required with safety taking precedence; UAS RTB as soon as practical.
Loss of Communications	Mission impacted by lack of communications hazard.	Maintain visual line of sight (VLOS); take evasive action as required with safety taking precedence; UAS RTB as soon as practical.
Loss of Control Signal	UAS not controllable.	Maintain VLOS; UAS RTB and land without harm to UAS or contacting surrounding objects.



System-Wide Safety

Hazards – Lost Signal and Return-to-Home/Base (RTH/RTB)

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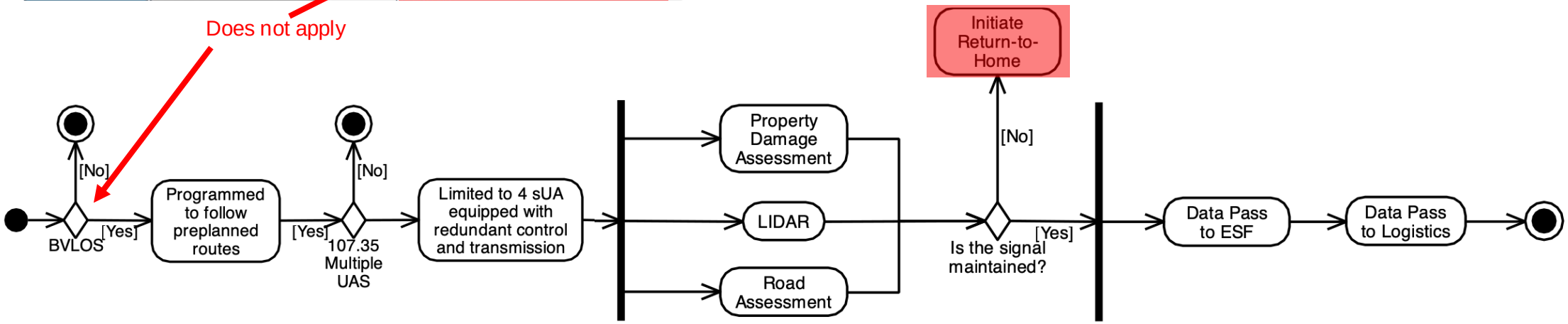
Does not apply



System-Wide Safety

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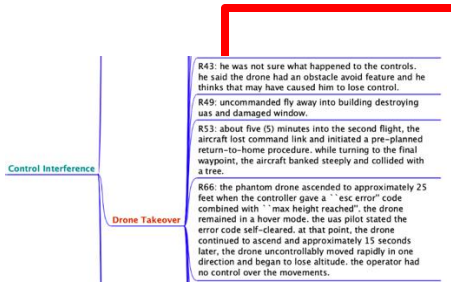
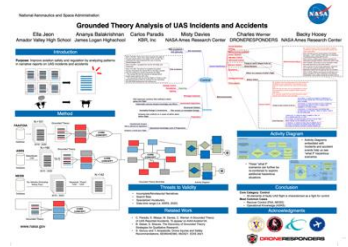


Thematic Synthesis
(Grounded Theory)



Aviation'24
Grounded Theory of UAS Reported Accidents

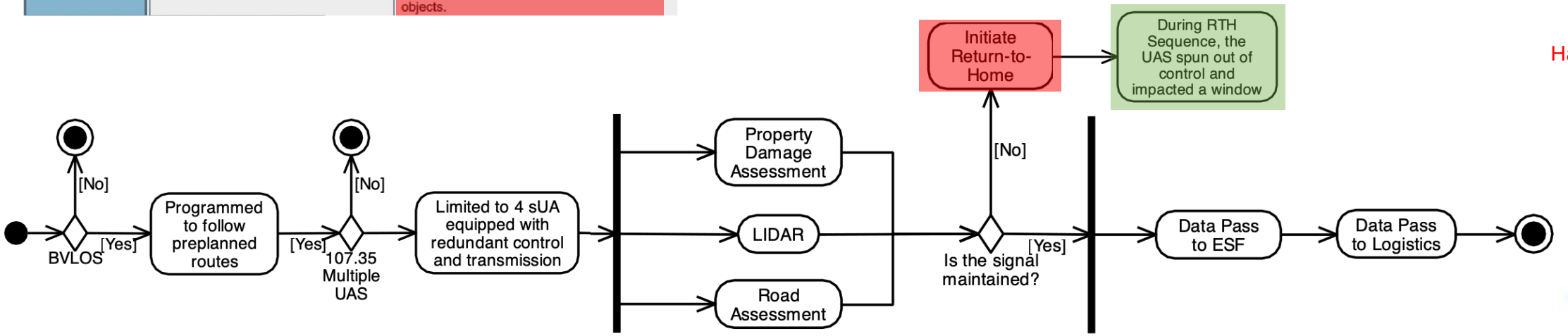
R3: when the UAS lost link to the controller and activated a return to home sequence.

R7: The takeoff was approximately 35 seconds after

3 GL03 20211115022639 7/28/2022 12:00:00 AM I 0 CHICAGO, IL

Remarks: FSDO INCIDENT NUMBER IS: IGL0320220022 ATQA ACCIDENT NUMBER FOR THIS EVENT IS: AGL0322003 SAS ACTIVITY NUMBER(S) ASSOCIATED WITH THE EVENT T-GL03-FY22-0240 AIRCRAFT: DJI MATRICE 300 RTK FA3N7T77RM S/N 1ZNDH9G00C1FH6 WHEN: 11/15/2021 2118Z WHERE: [redacted] ^ INJURIES: NONE DAMAGE FROM EVENT: MAJOR AIRCRAFT DAMAGE POST EVENT FIRE OR DAMAGE: FIRE RESULTED FROM LITHIUM BATTERY IMPACT ON PAVEMENT A REMOTE PILOT WAS OPERATING AN UNMANNED AIRCRAFT SYSTEM (UAS) FOR CITYSCAPE PHOTOGRAPHY WHEN THE UAS LOST LINK TO THE CONTROLLER AND ACTIVATED A RETURN TO HOME SEQUENCE. DURING THE RETURN TO HOME SEQUENCE, THE UAS SPUN OUT OF CONTROL AND IMPACTED A WINDOW ON THE 95TH FLOOR OF A BUILDING. SOME PIECES OF THE UAS REMAINED IN THE BUILDING WHILE THE REST CRASHED ON THE GROUND OUTSIDE THE BUILDING, WITH A RESULTING FIRE.

Additional
Hazard Context



System-Wide Safety

Hazards – Lost Signal and Return-to-Home/Base (RTH/RTB)

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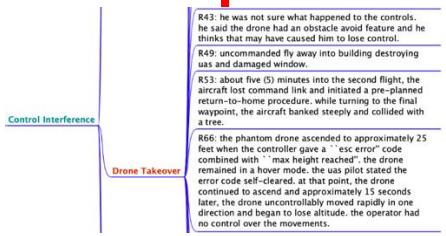

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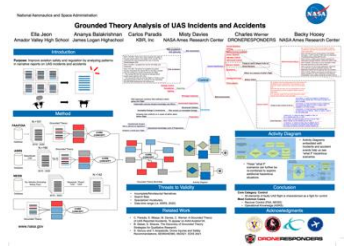

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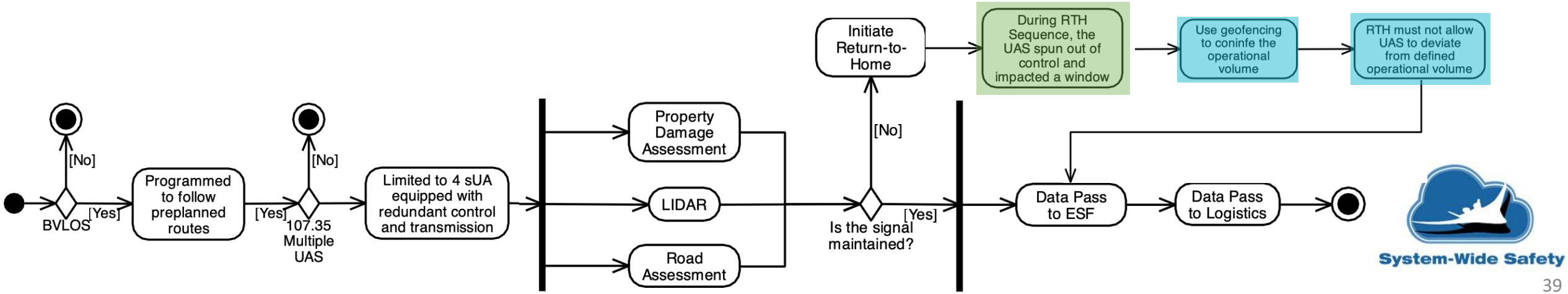
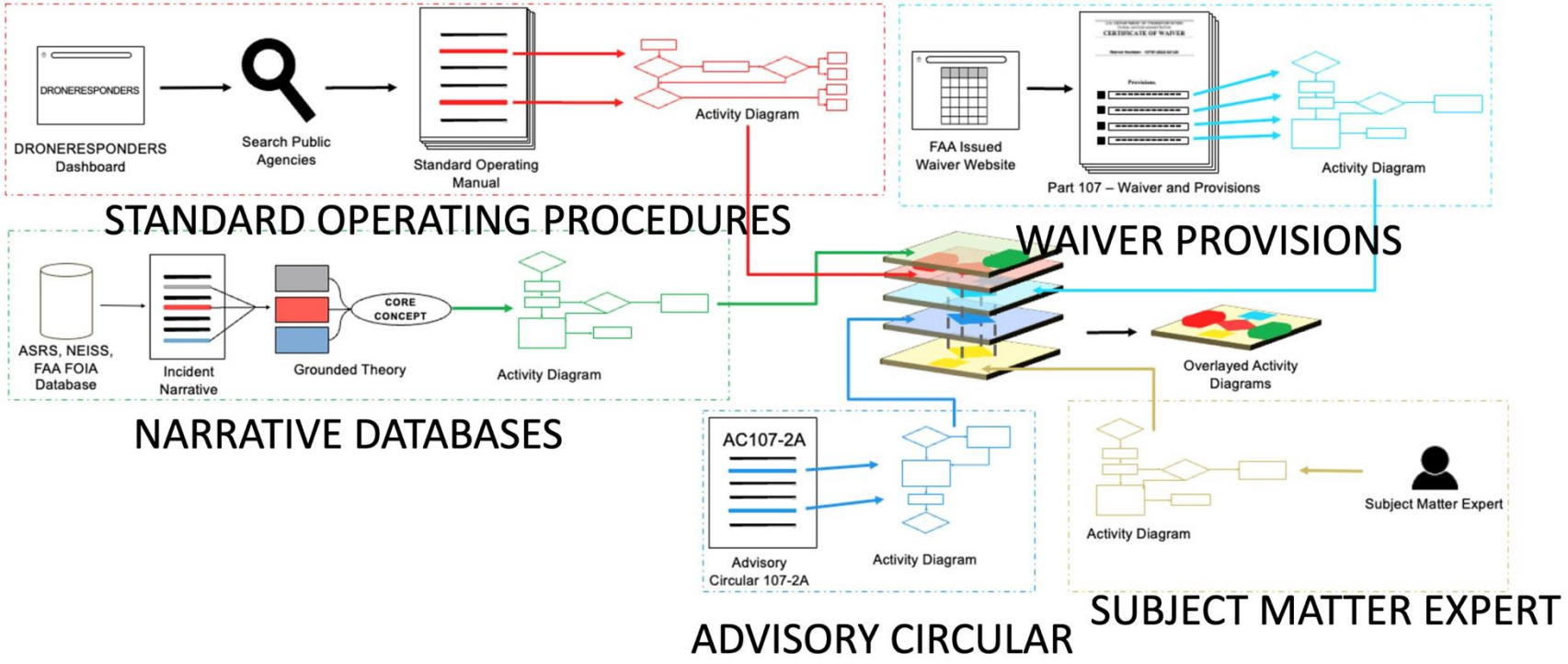


In Conclusion

The three-year partnership aims to:

1. gather safety metrics to identify patterns and common risks, along with proposed solutions to prevent or lessen the impact of the hazards.



carlos.v.paradis@nasa.gov

https://castor.ndc.nasa.gov/intime/home

System-Wide Safety