Human Factors Research Considerations for Terminal Area Urban Air Mobility Operations

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#NASA Retired

Purpose

Review human factors research considerations for urban air mobility (UAM) route replanning in terminal area airspace

Overview

1. What is Urban Air Mobility (UAM)?
2. UAM ecosystem
3. Use cases
4. Route replanning and decision-making strategies
5. Strategies for coordinated decision-making
6. Human factors research considerations

What is UAM?

UAM is an air transportation system for carrying passengers and/or cargo within/to urban areas

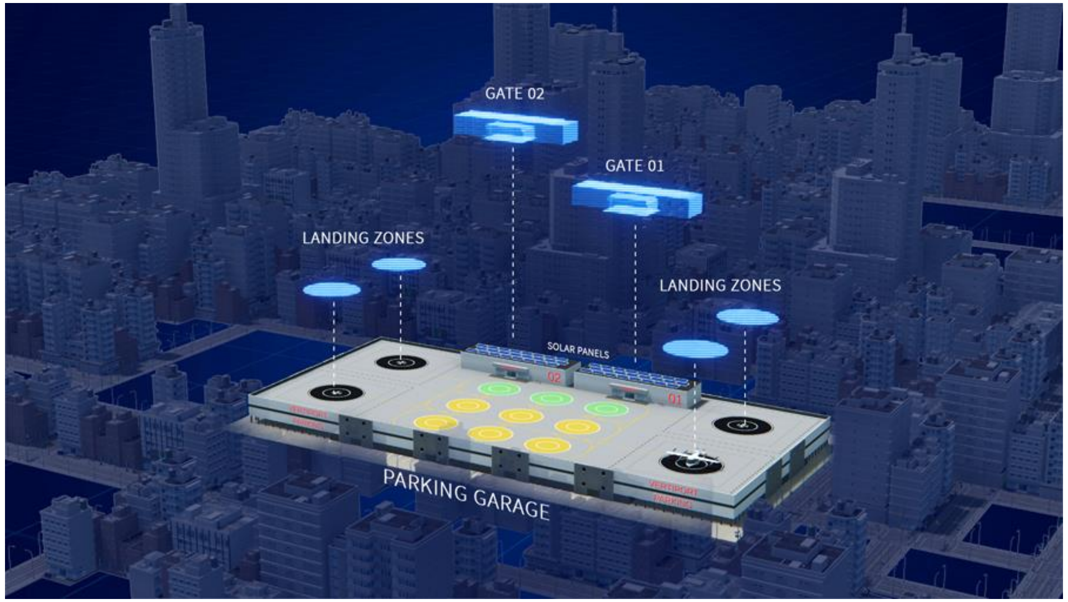
e.g.,

- Air taxi fleet operations
- Connect shipping lines between final delivery destinations and large depots
- Emergency/disaster response

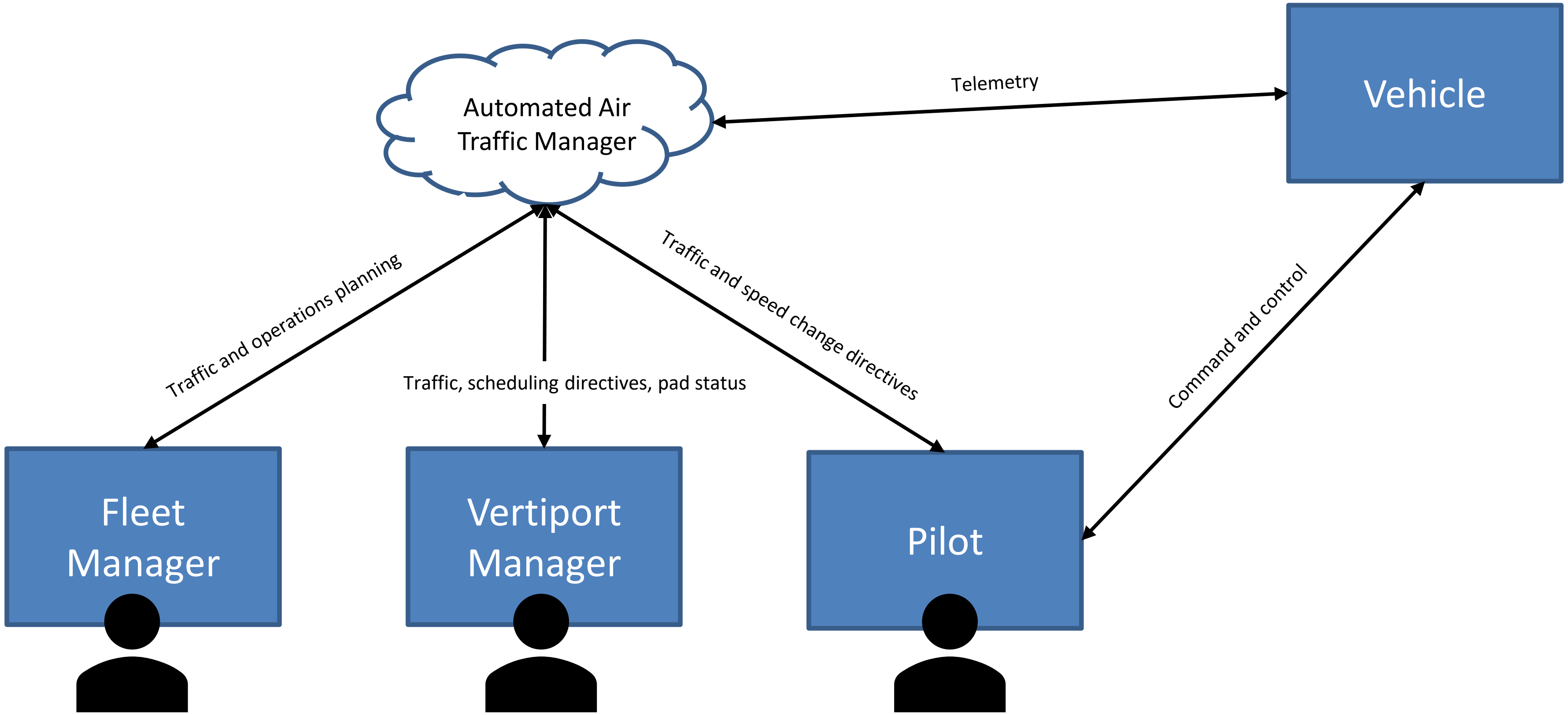
How is UAM different from current day commercial operations?

- New all electric vertical take-off and landing aircraft (evtol)
- Special high-volume heliports, called vertiports
- Higher traffic density
- Distribution of air traffic control tasks to automated services and aircraft operators

Notional vertiport



Simplified UAM Ecosystem: Who are the actors?



Prototype Workstations: Pilot(s)

NASA Langley

*Remote pilots assumed here

Prototype Workstation: Fleet Manager

NASA Ames

Prototype Workstations: Fleet Operations Center

NASA Ames

Prototype Workstations: Vertiport Manager

NASA Ames/Langley

What is UAM?

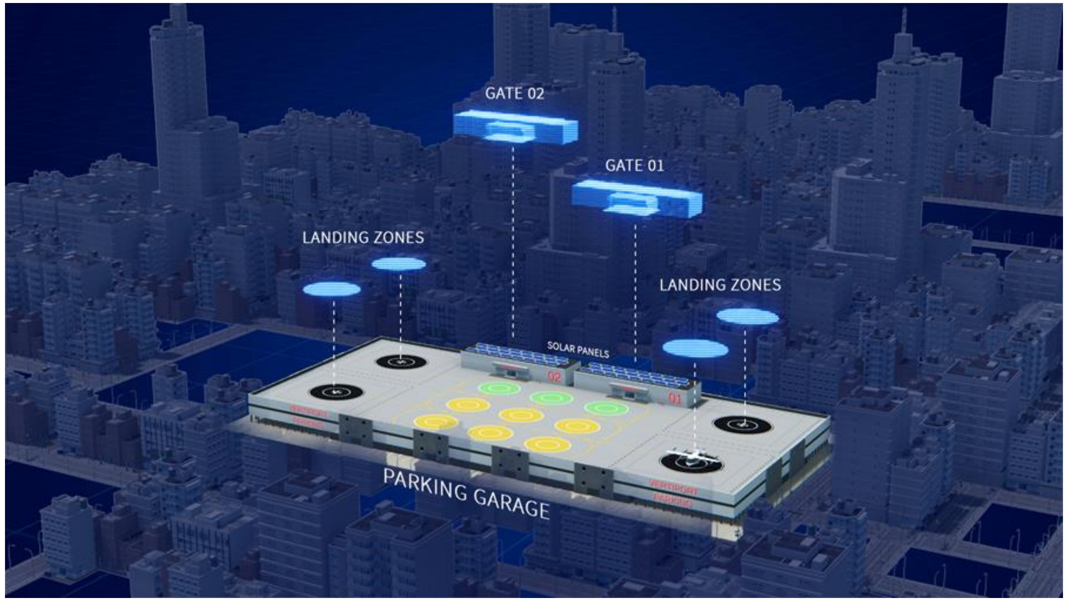
UAM is an air transportation system for carrying passengers and/or cargo within/to urban areas

e.g.,

- Air taxi fleet operations
- Connect shipping lines between final delivery destinations and large depots
- Emergency/disaster response

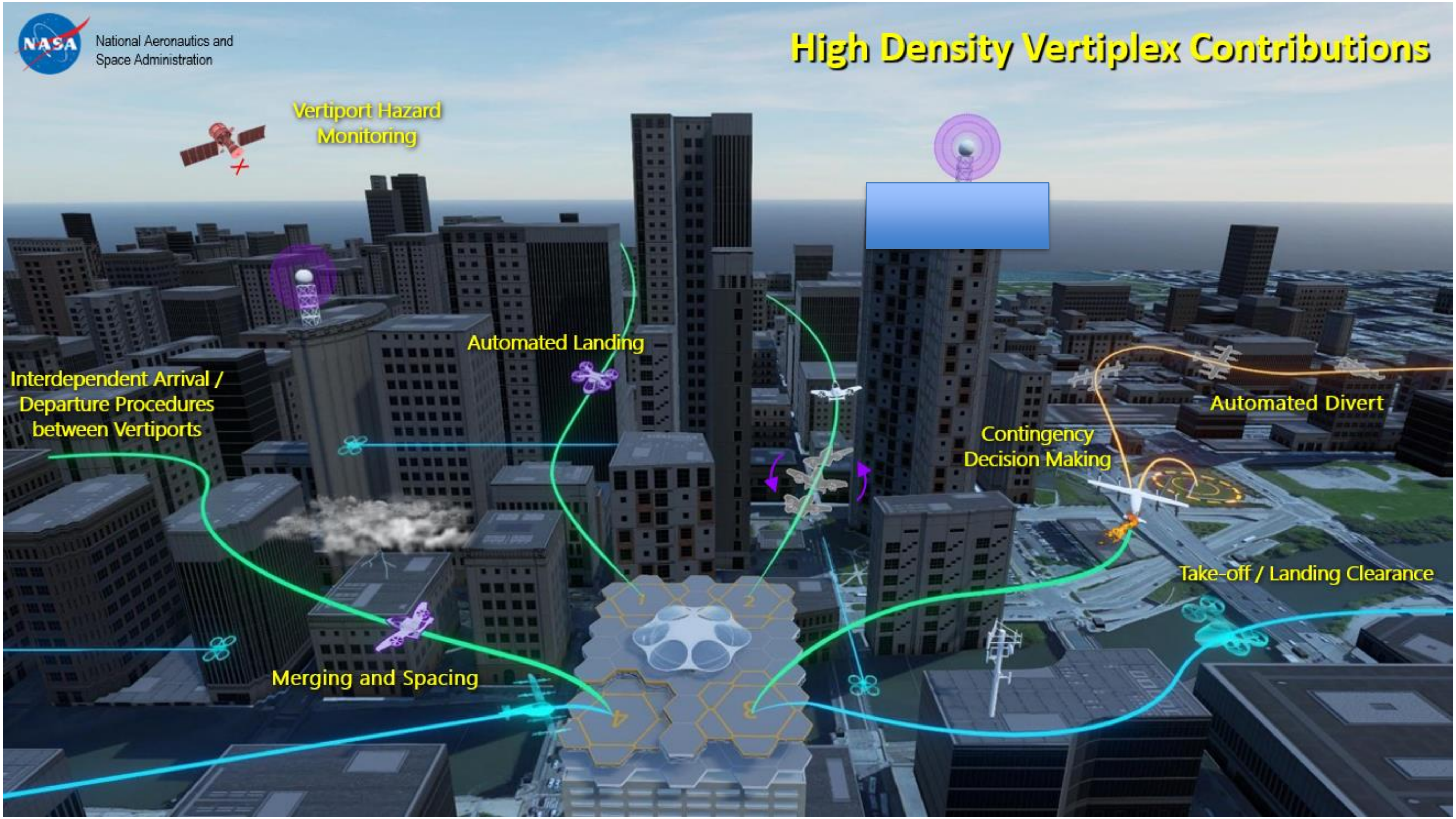
How is UAM different from current day commercial operations?

- New all electric vertical take-off and landing aircraft (evtol)
- Special high-volume heliports, called vertiports
- Greater support for higher traffic densities
- Distribution of air traffic control tasks to automated services and aircraft operators
- Introduction of vertiports and management systems to support them
- Operations are limited to shorter distances, lower altitudes and routes fixed to vertiports
- Greater landing location (vertiports) densities offer more options for flight replanning
- Closely networked vertiports (called vertiplexes) allow for regular flight replanning and distribution of traffic to relieve congestion

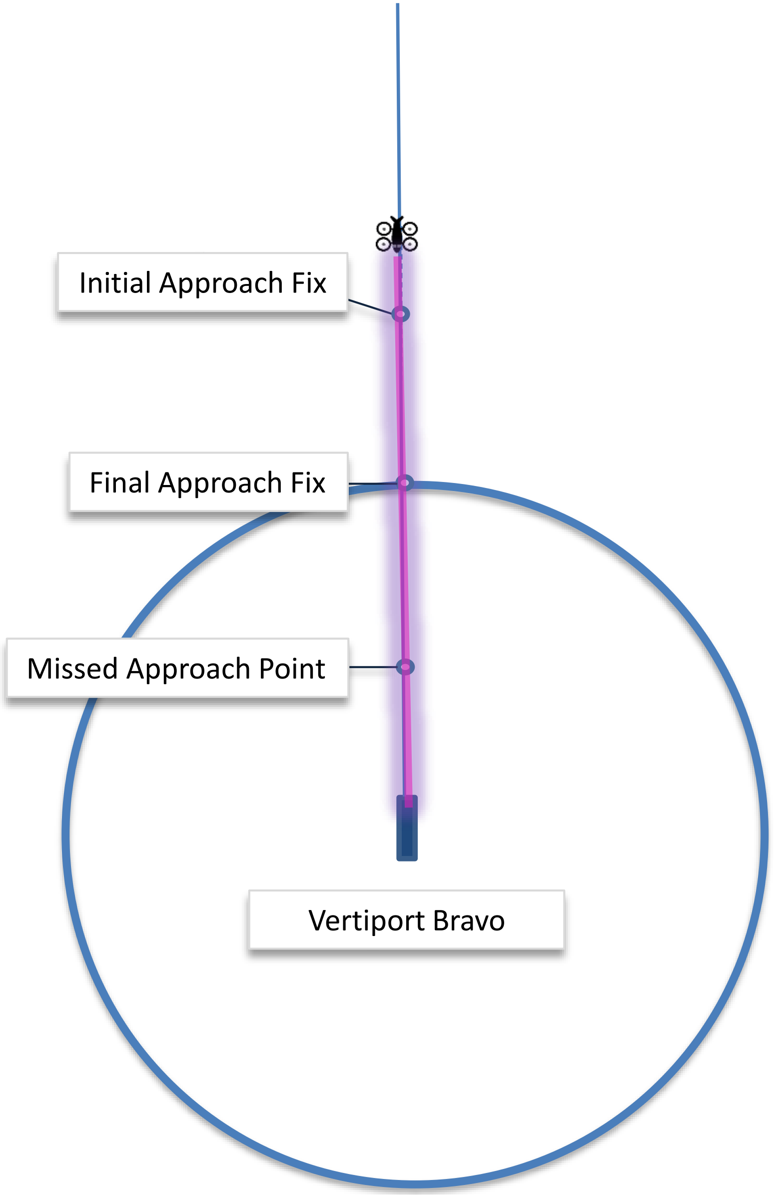


Notional vertiport

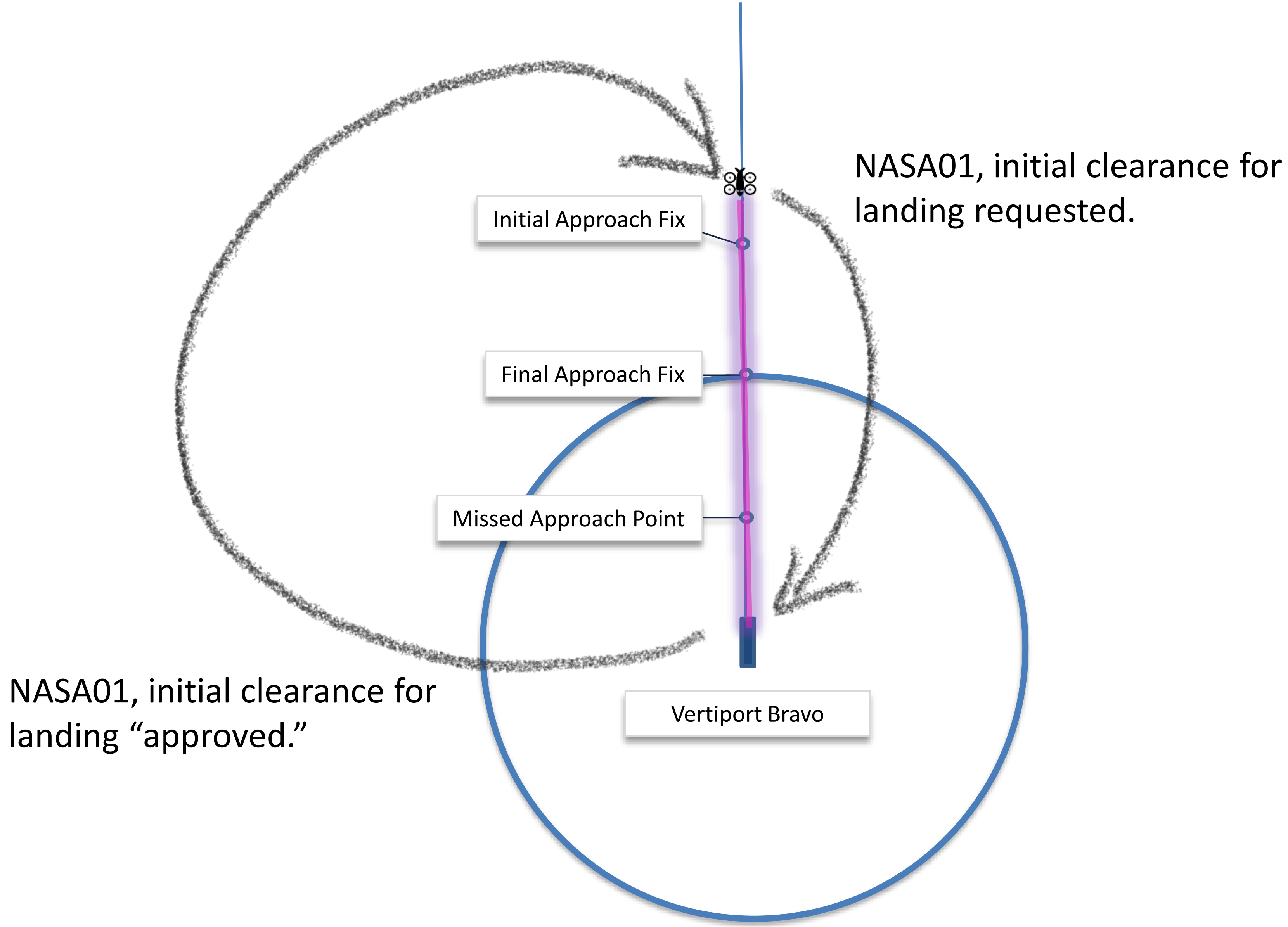
High Density Vertiplex Capabilities



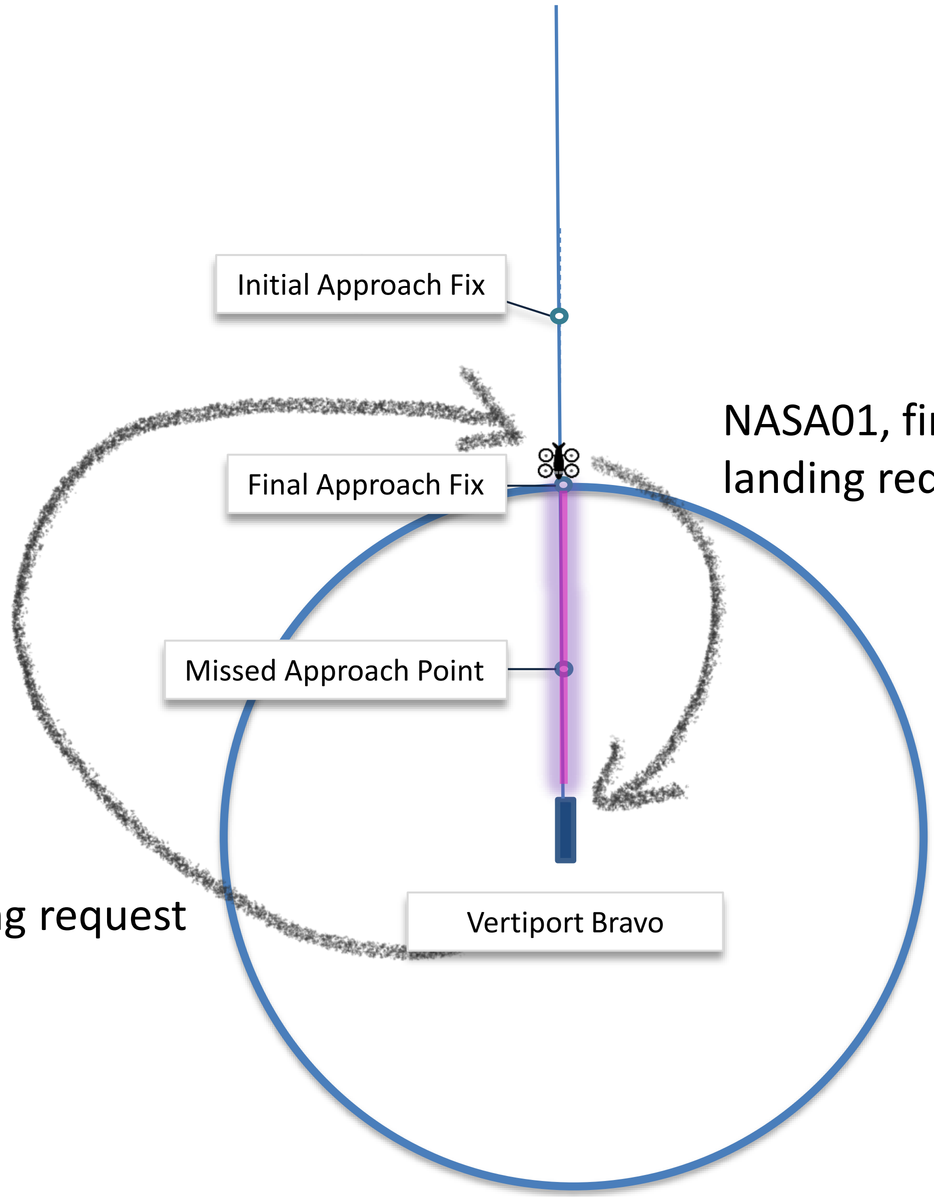
Nominal Approach Procedure



Step 1: Operator requests **initial** clearance for landing with vertiport automation at IAF



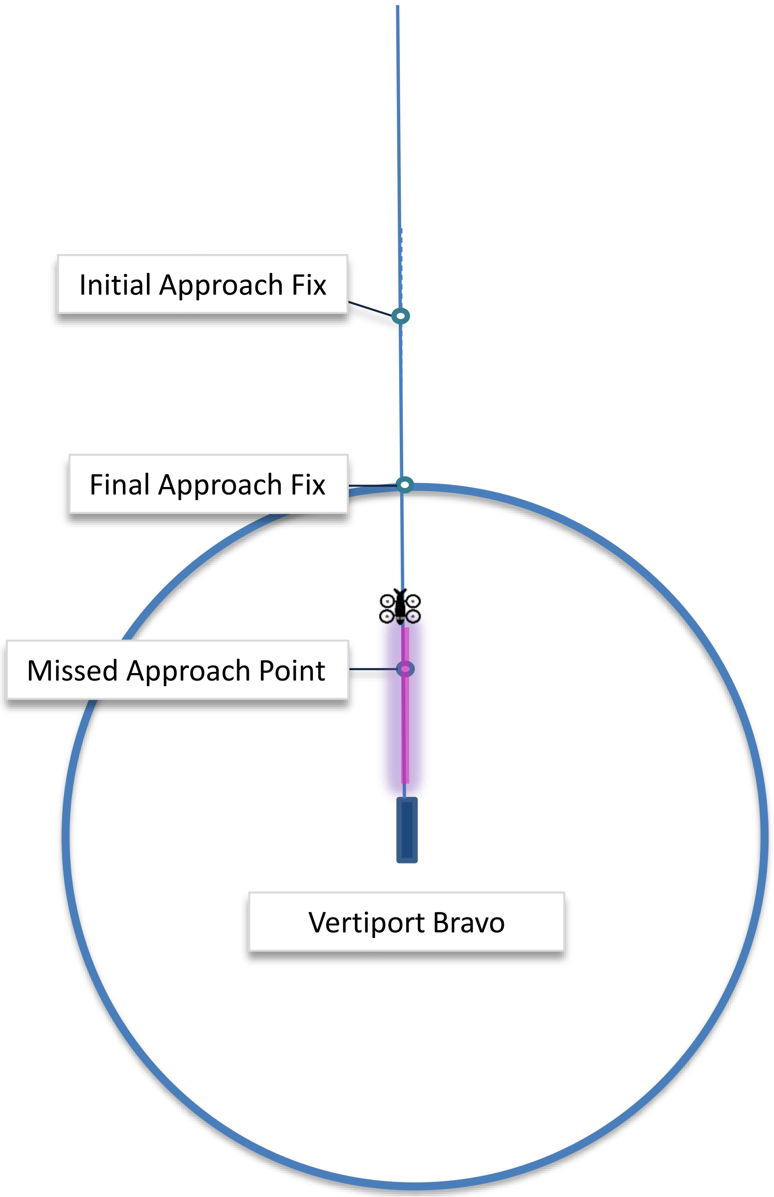
Step 2: Operator requests **final** clearance for landing with vertiport automation at IAF



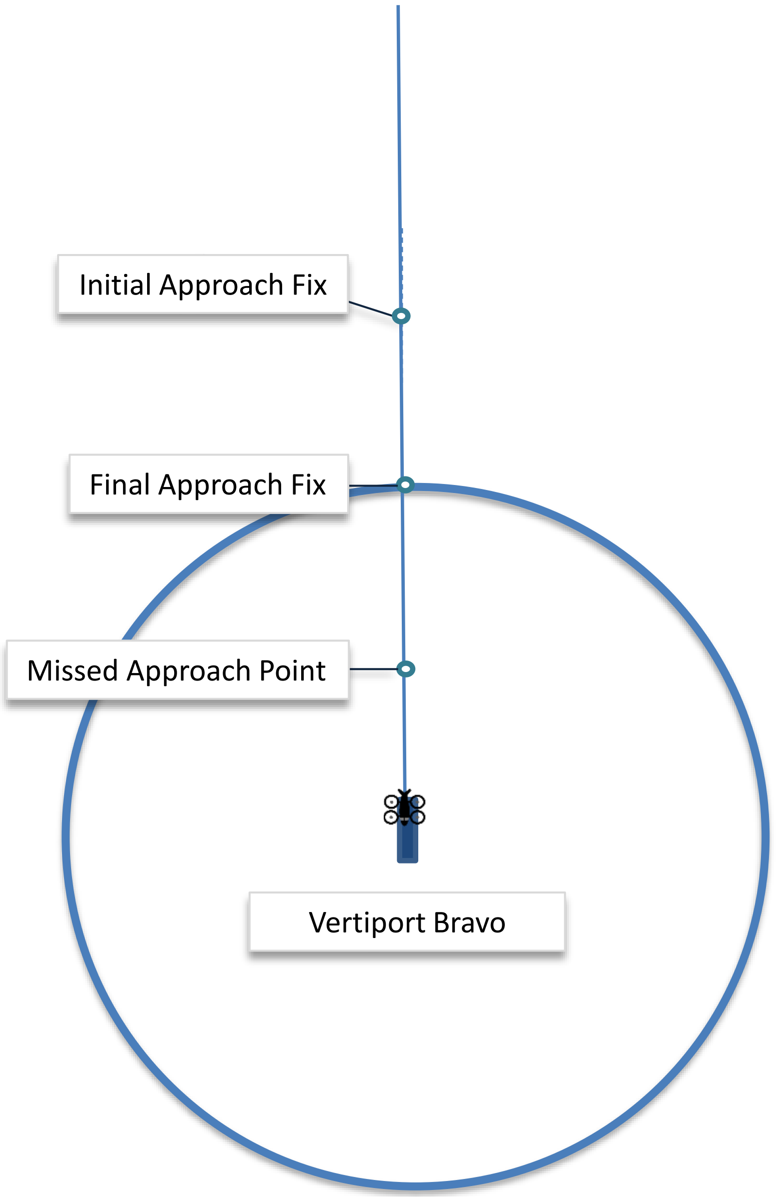
NASA01, final clearance for landing requested.

NASA01, final landing request "**approved**."

Step 3: Operator lands vehicle



Step 3: Operator sends "**closed**" operation notification to PSU



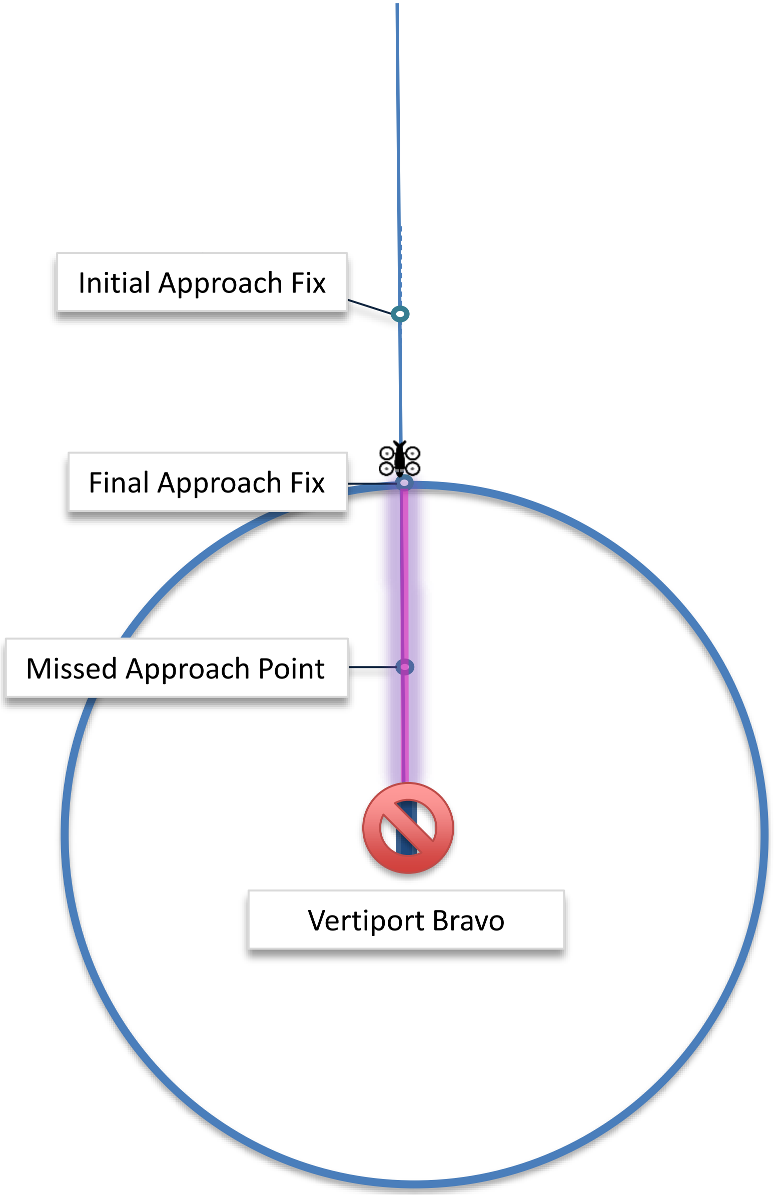
Off-Nominal Operation Procedure

Assumptions:

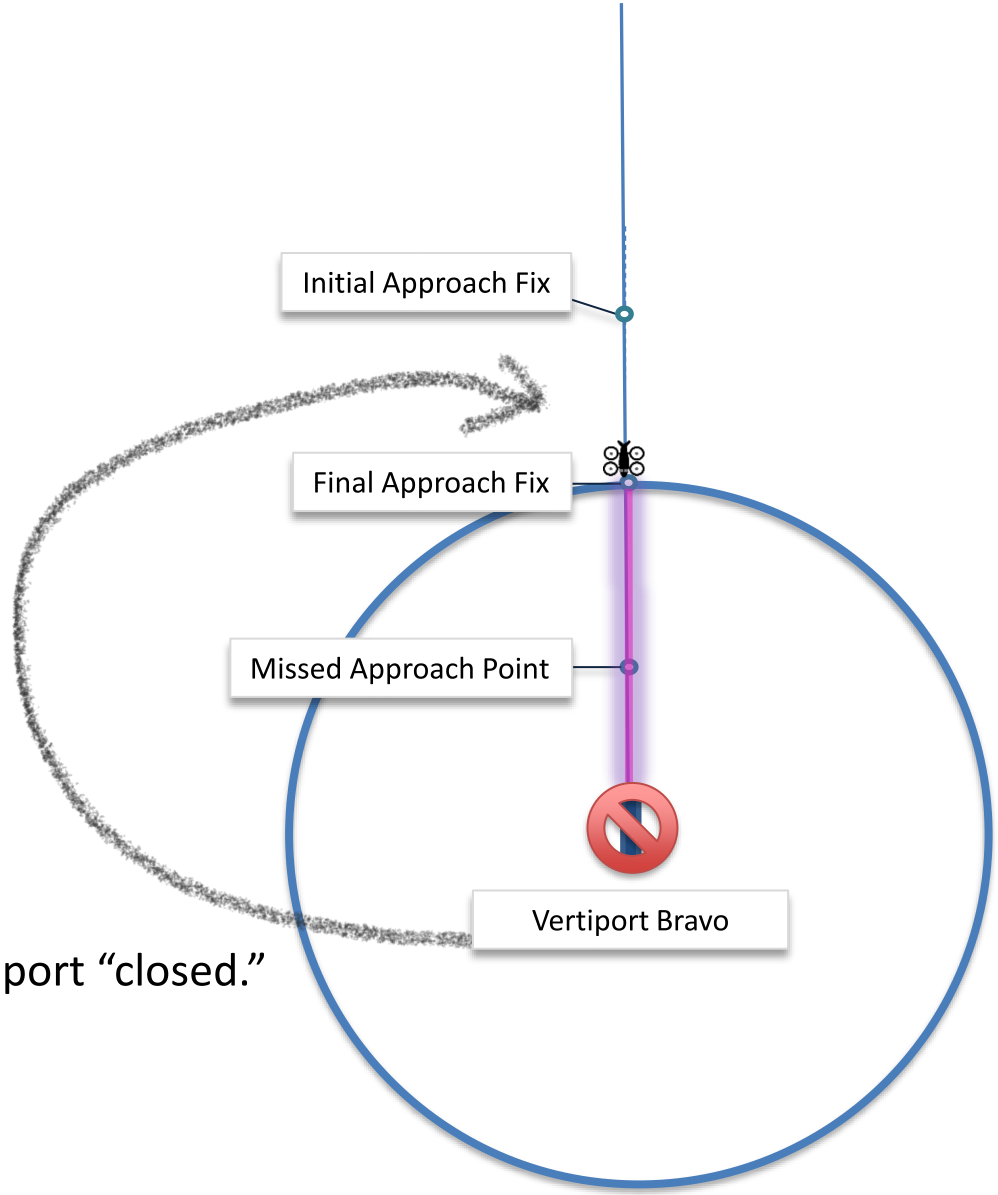
I. Duration of vertiport closure is not yet known

II. Time pressure imposes a missed approach procedure on the operator

III. Due to the time pressure, their options cannot be immediately considered, e.g. divert to alternate vertiport

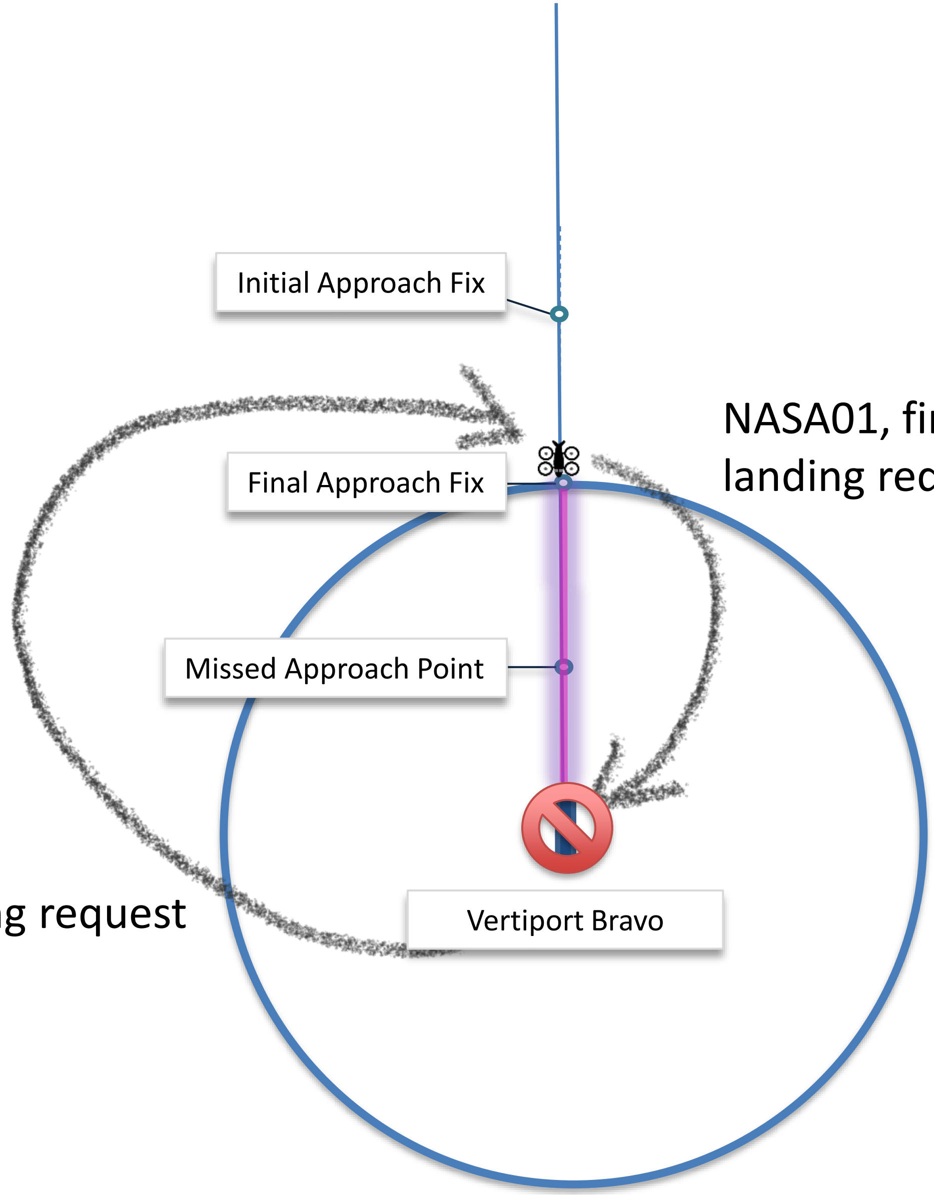


Step 1: VAS broadcasts vertiport closure



Vertiport “closed.”

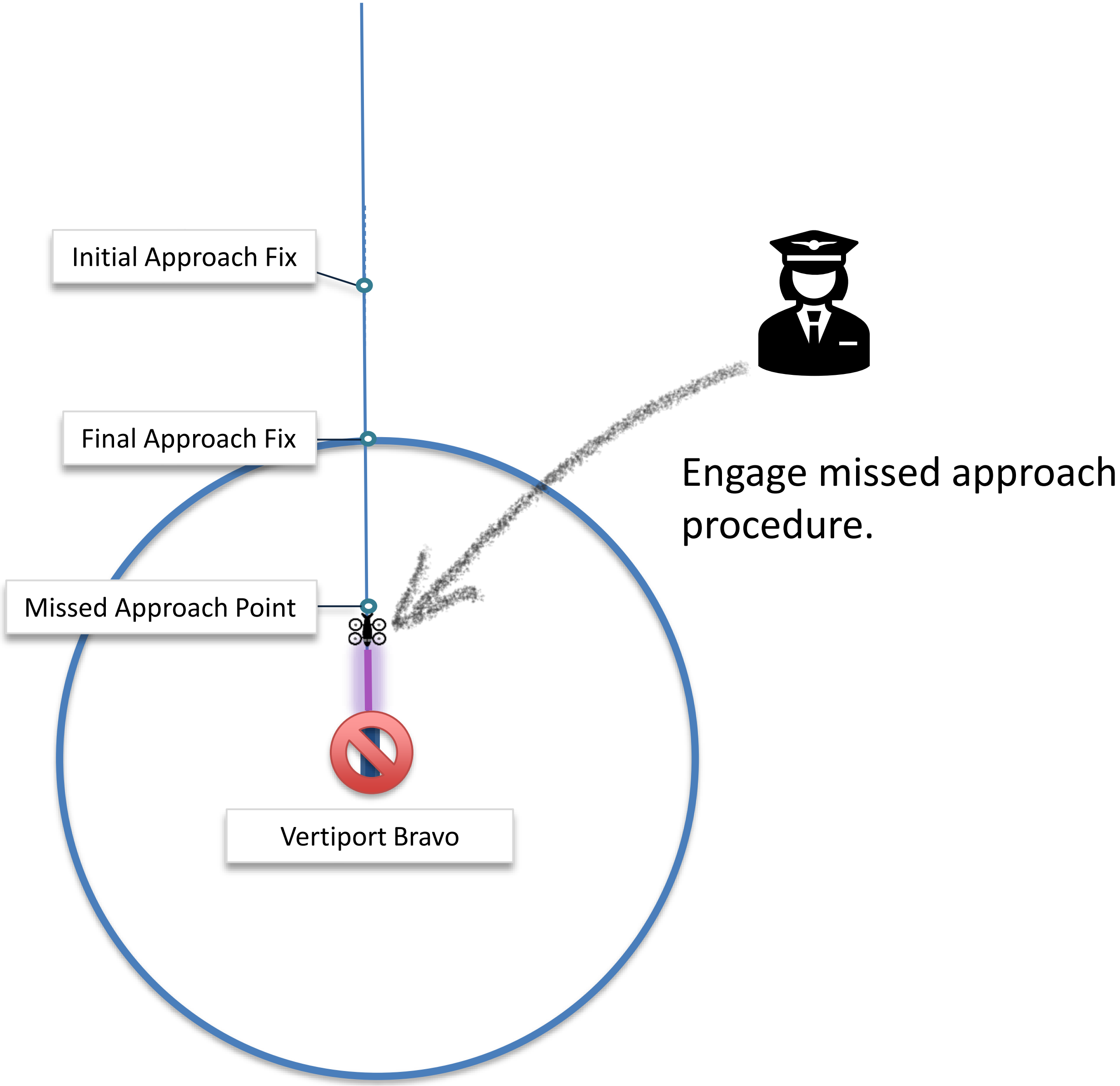
Step 2: Request for final landing clearance is rejected by VAS



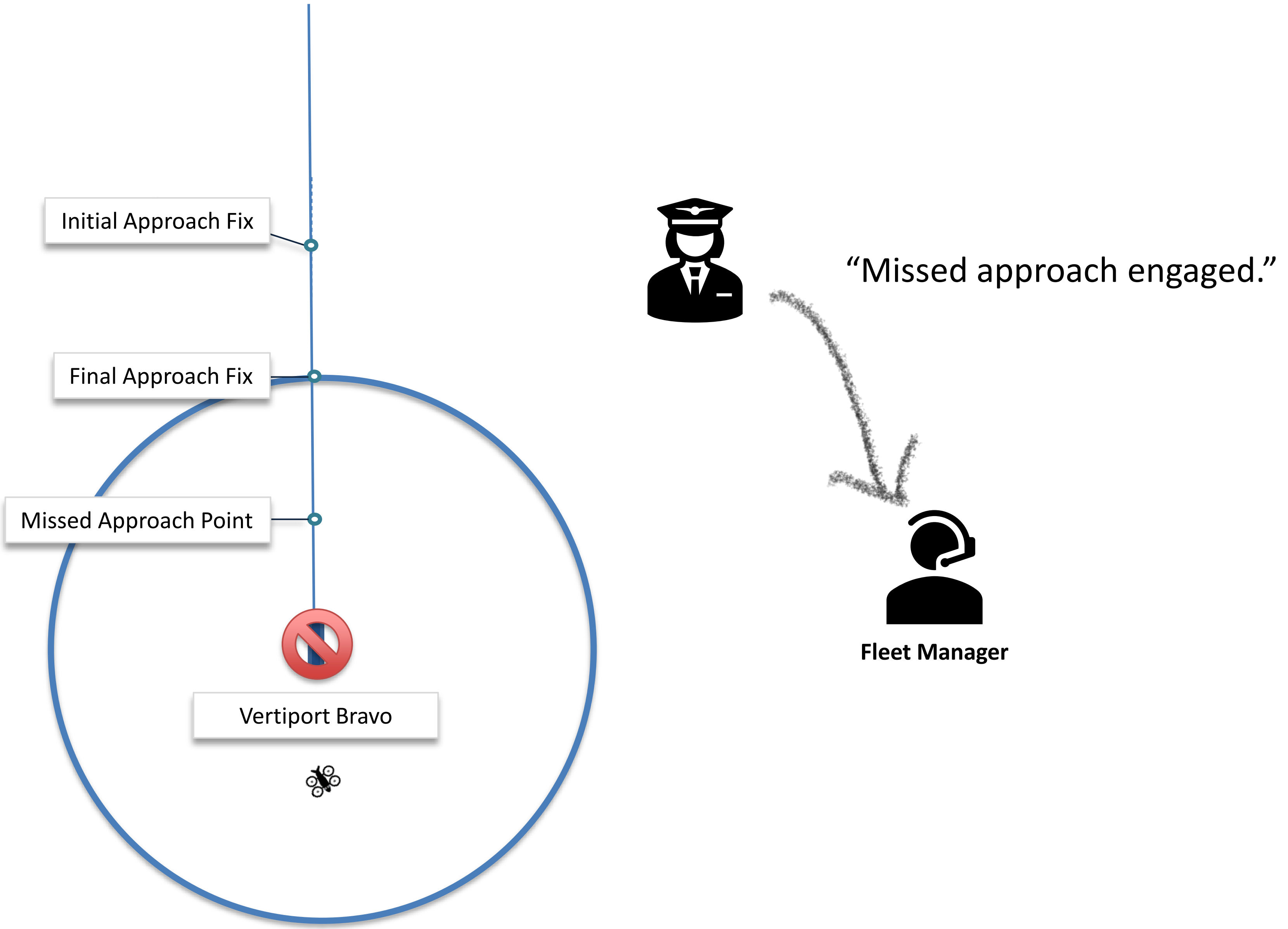
NASA01, final clearance for landing requested.

NASA01, final landing request "**rejected**."

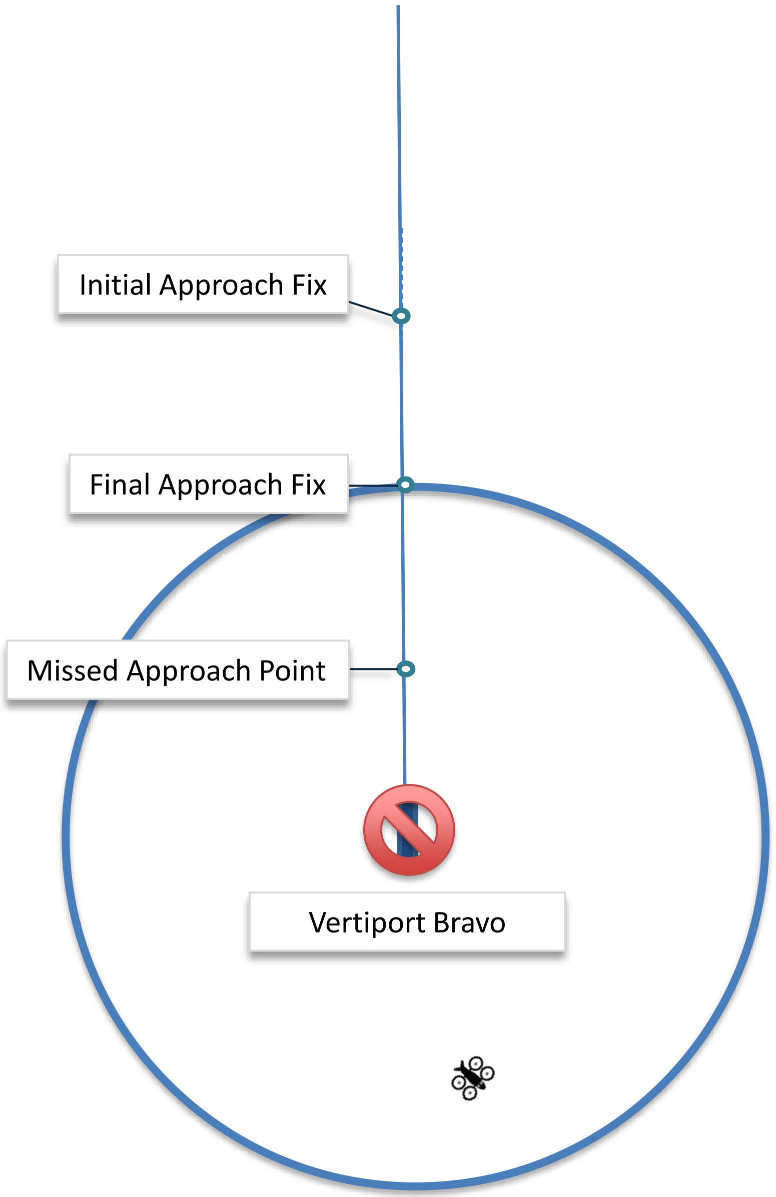
Step 3: Pilot commands vehicle to engage missed approach procedure in response to vertiport closure



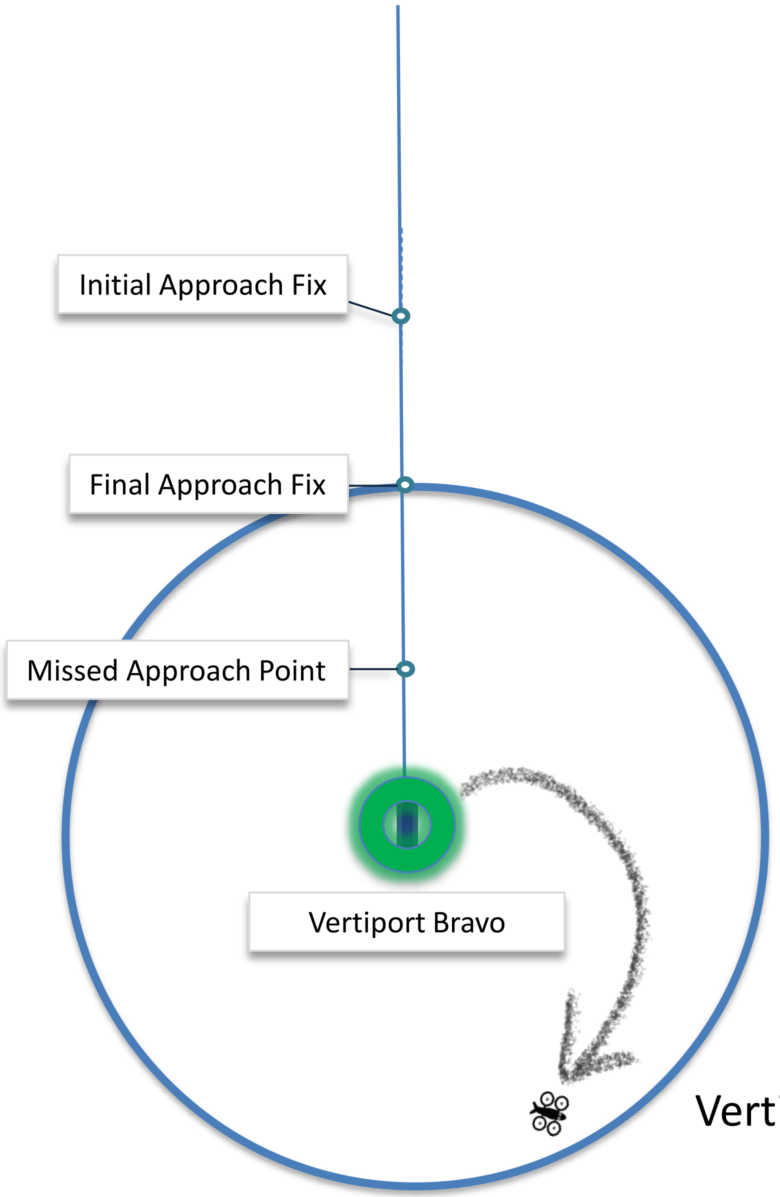
Step 4: Pilot informs fleet manager of the missed approach action



Step 5: Vehicle proceeds to loitering pattern

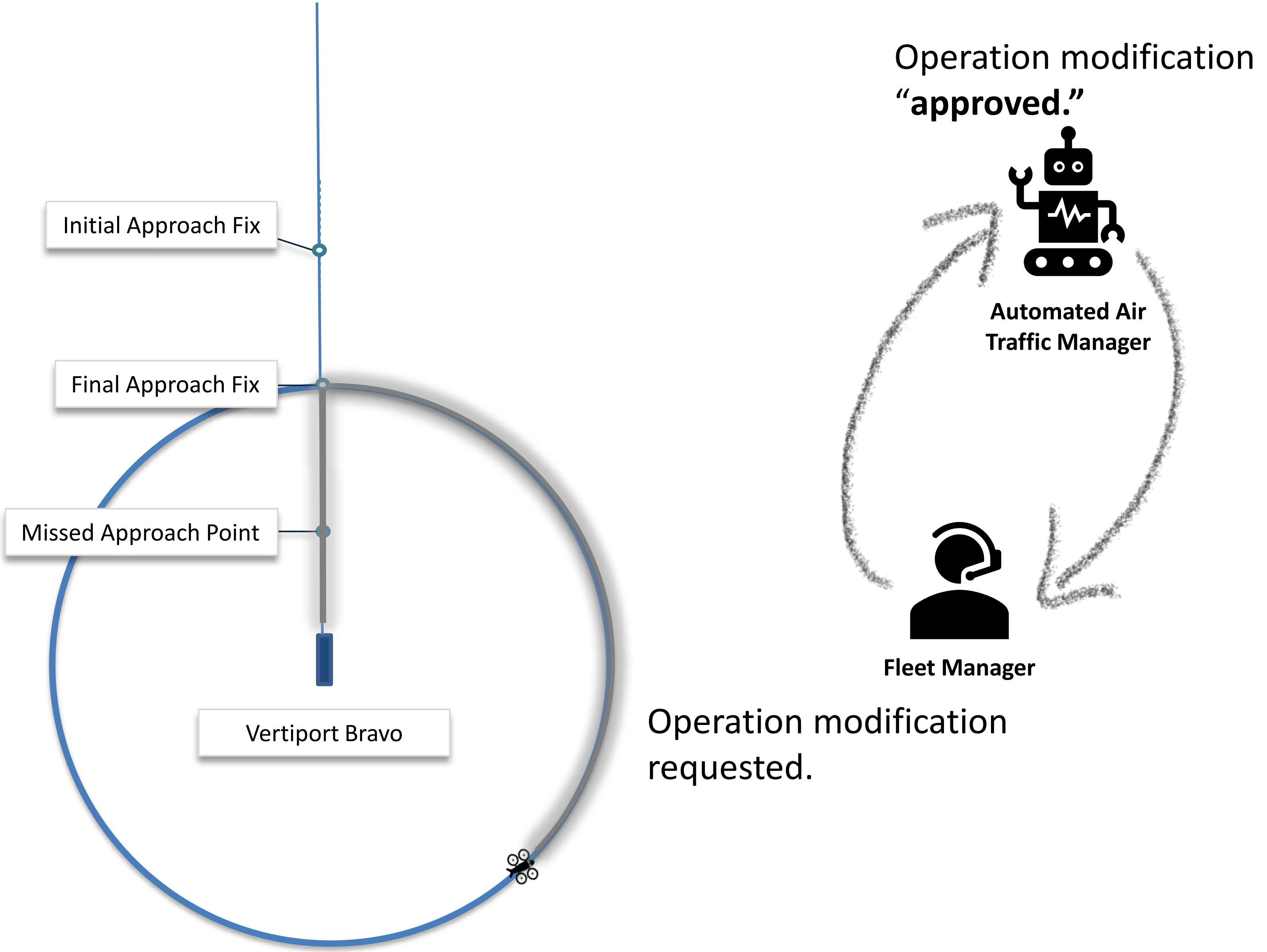


Step 5: Vertiport reopens

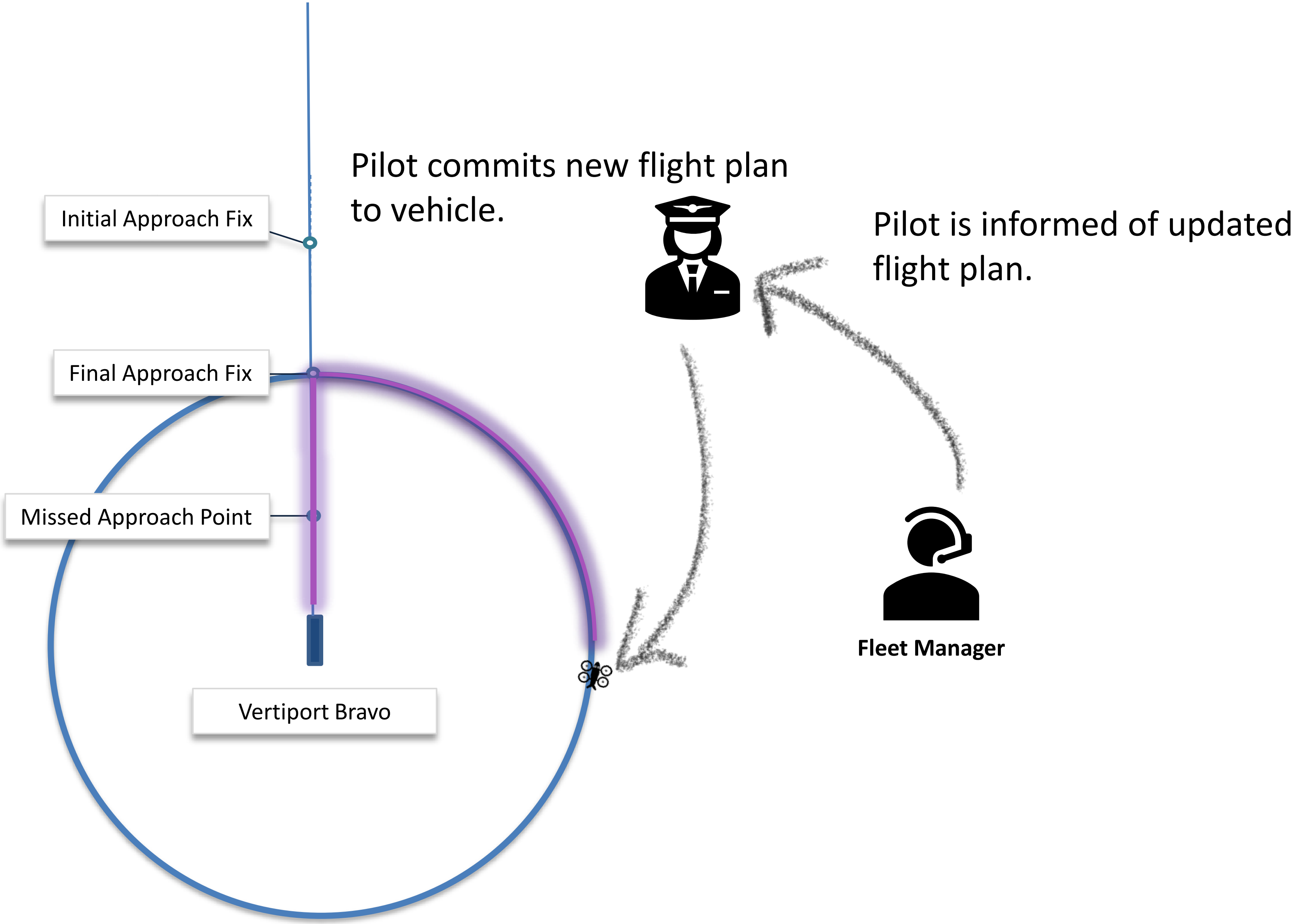


Vertiport status is “**open.**”

Step 7: Fleet manage requests a return route to the approach with the automated air traffic manager, PSU



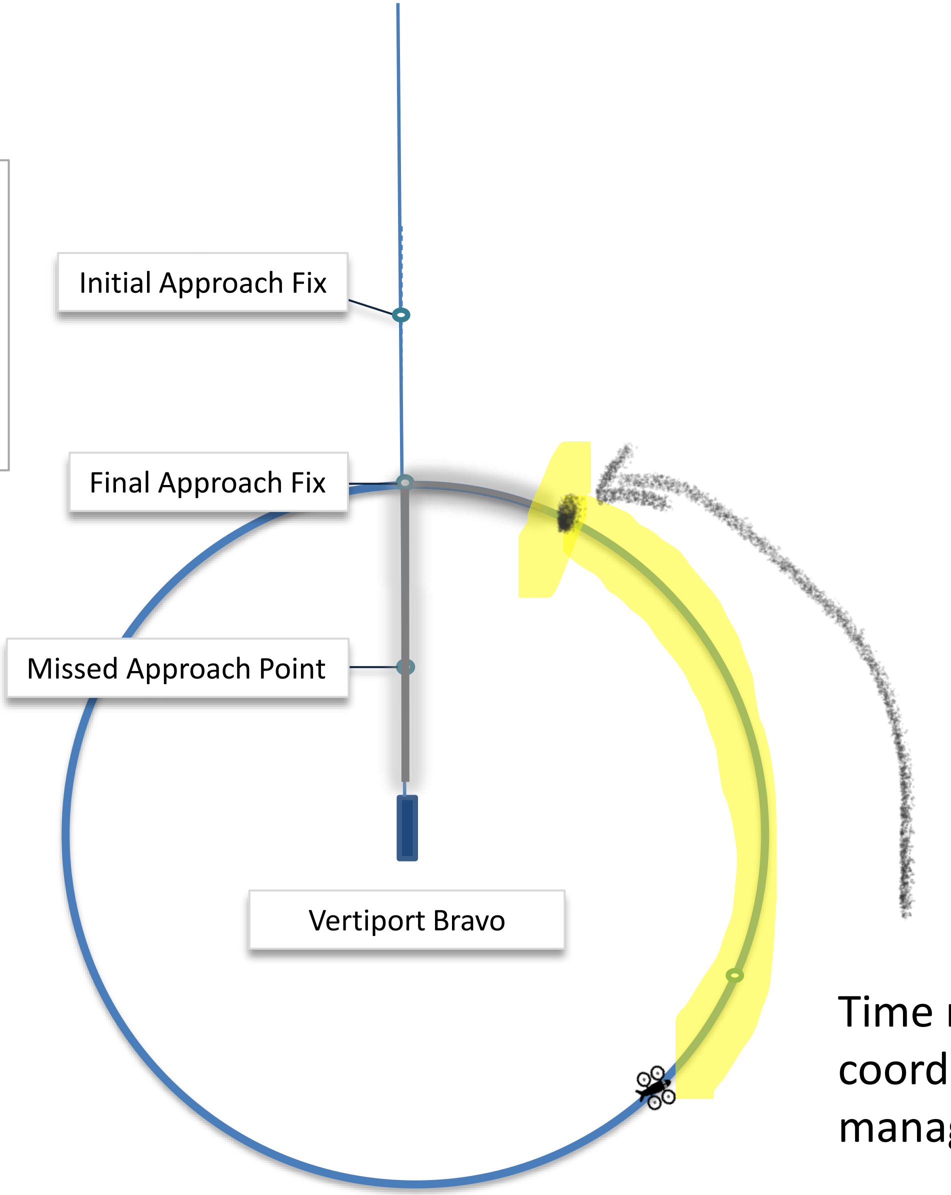
Step 6: Fleet manager informs pilot of updated flight plan



Step 7: Fleet manager negotiates return route to Vertiport A

Research consideration(s):

What is the minimum lead time needed for coordinating route updates between the actors?



Time required for coordination between fleet manager, pilot, and PSU

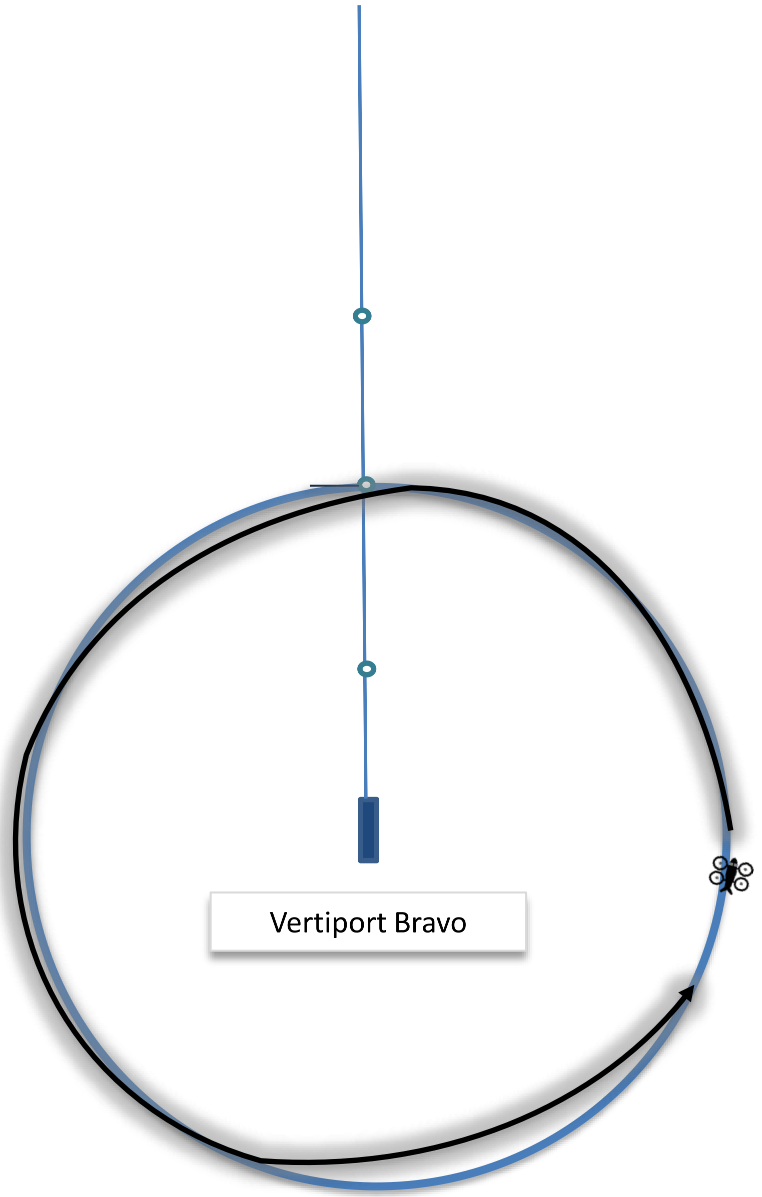
What if an earlier arrival cannot be found?

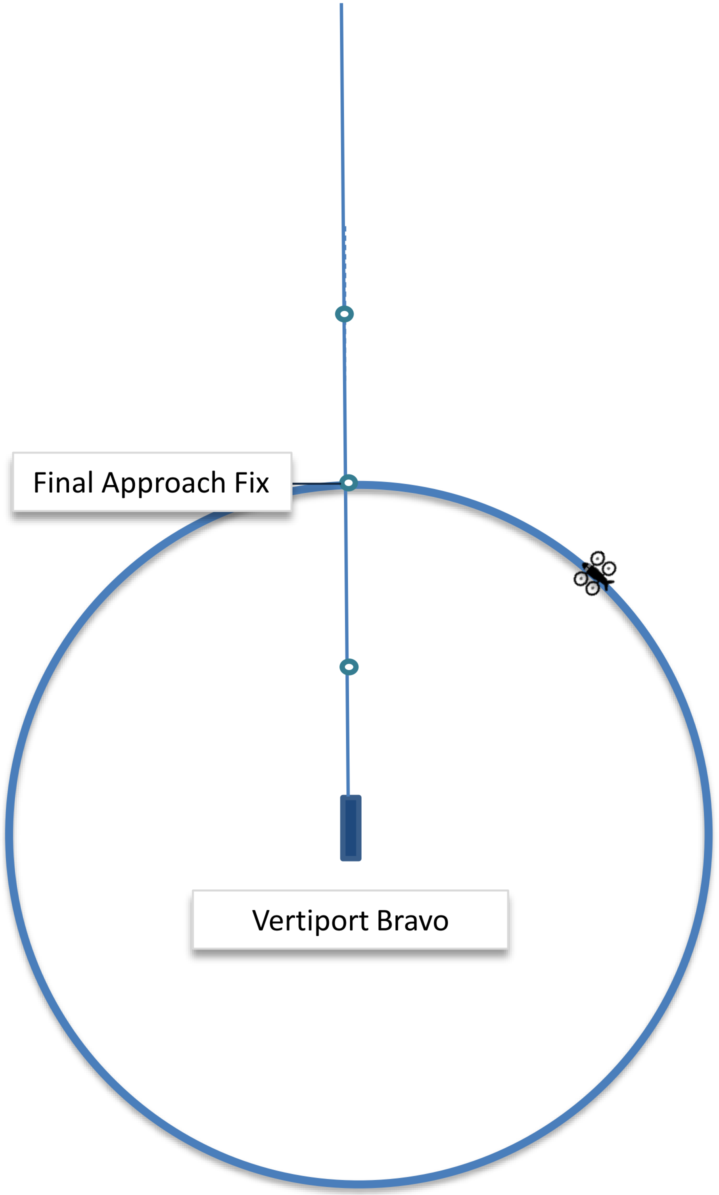
Assumptions

Aircraft must remain on loitering pattern until a vertipad is available

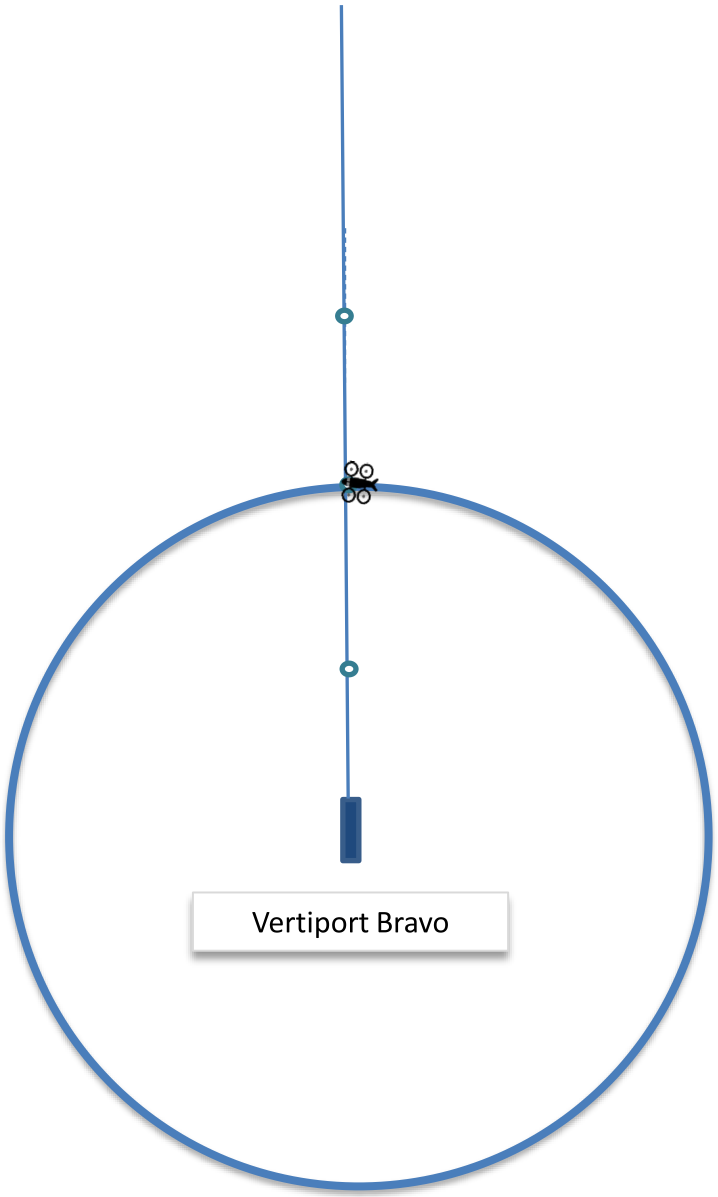
or

diversion to another vertiport can be considered.

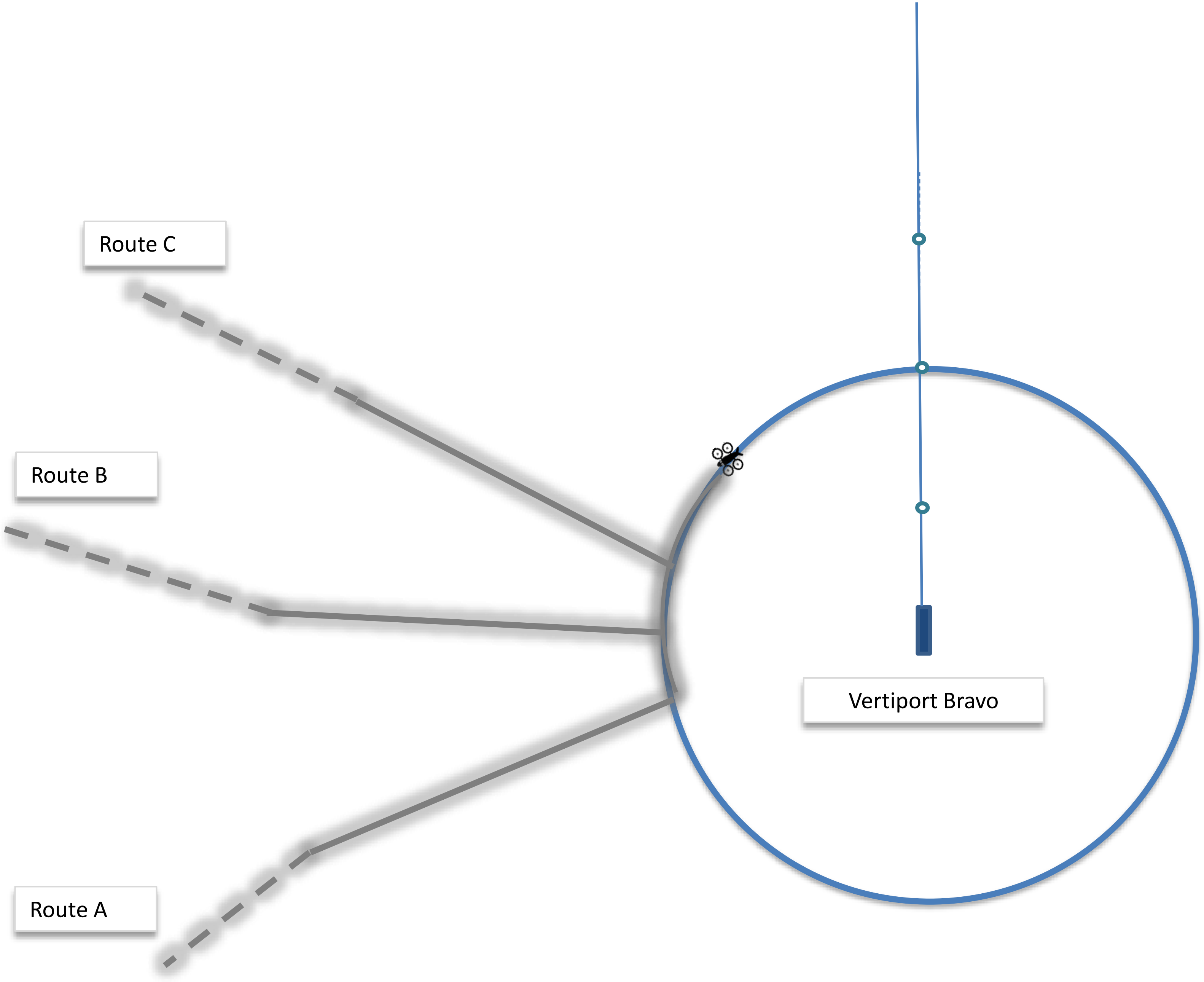




Final Approach Fix
Vertiport Bravo


Vertiport Bravo

Trial Planning Challenges



Research consideration(s):

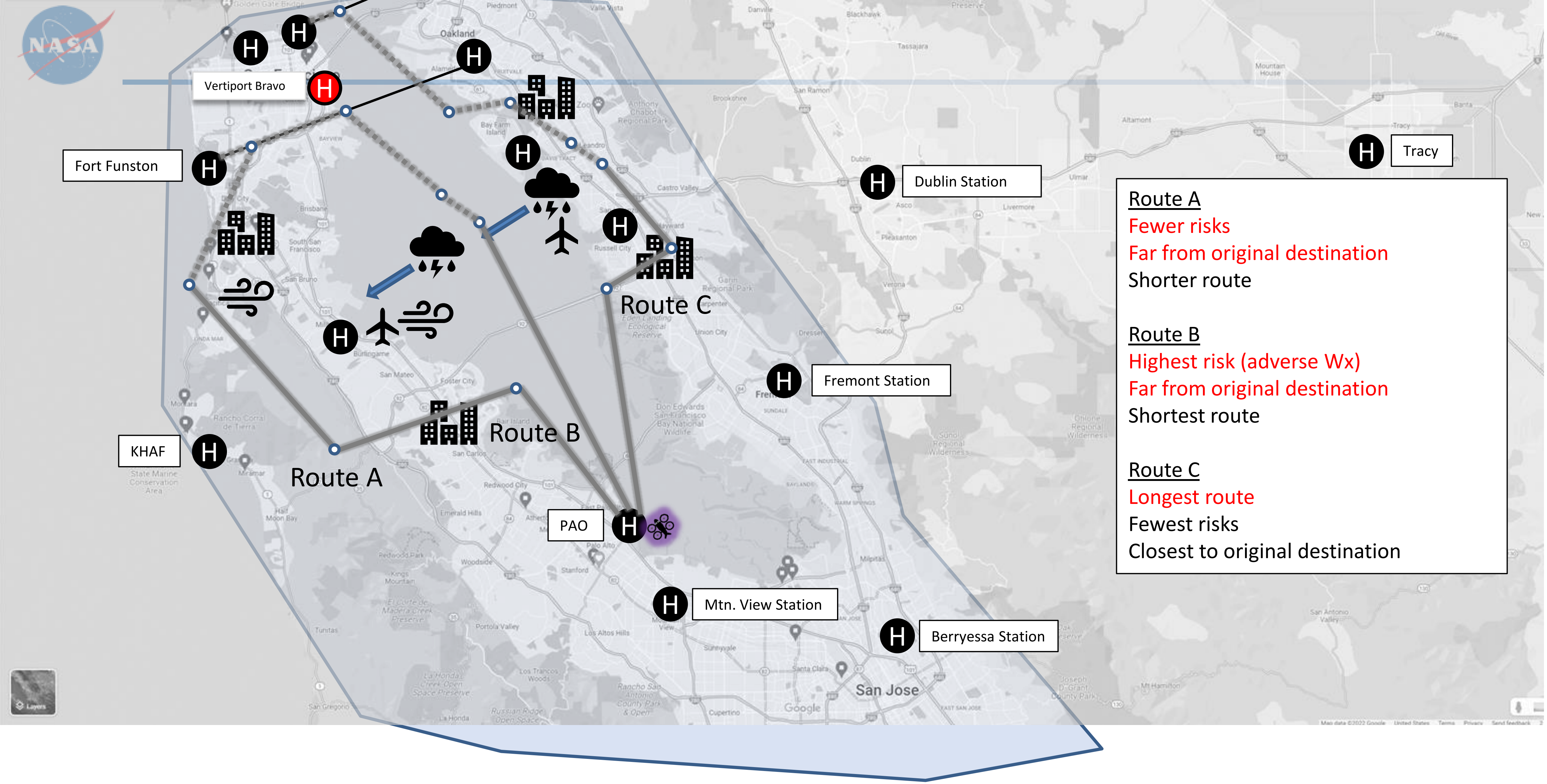
I. What factors should be considered when selecting between multiple route options, e.g., weather, ground risk, distance?

II. How can understanding of the route solutions be supported through interaction design of the tool and presentation of the solutions?

III. Where should responsibility for selecting new routes lie, e.g., automation, pilot, fleet manager?

IV. How should submitting the new routes be coordinated?

V. What is the lead time required for decision-making and coordination of execution of the new route?



Notional San Francisco Bay Vertiplex

Route Decision-Making Structure: Normative

	Weather Risk	Terrain Risk	Population Risk	Score
Route A	0	5	95	100
Route B	60	5	40	105
Route C	50	10	50	110

*Rule: The lower the score, the better

Automation can decide when a best route can be computed normatively.

Ref. Ho, N., Johnson, W., Wakeland, K., Keyser, K., Panesar, K., Sadler, G., & Wilson, N. (2022). *Coordination of remote vehicles using automation level assignments* (Patent No. PCT/US2019/050797).

Route Decision-Making Structure: Information Integration Problem

	Weather Risk	Terrain Risk	Population Risk	Score
Route A	0	5	95	100
Route B	60	5	40	105
Route C	50	10	50	110

*Rule: The lower the score, the better

Even though option A is acceptable from the score, it is not acceptable as the population risk is too high. A simple summation will not work.

Ref. Ho, N., Johnson, W., Wakeland, K., Keyser, K., Panesar, K., Sadler, G., & Wilson, N. (2022). *Coordination of remote vehicles using automation level assignments* (Patent No. PCT/US2019/050797).

Route Decision-Making Structure: Information Integration Problem

	Weather Risk	Terrain Risk	Population Risk	Score
Route A	0	5	95	100
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Route C	50	10	50	110

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Humans must be involved when a best route cannot be computed normatively and trade-offs need to be made. However, this is difficult to do as the number of factors to consider grow and the factors need to be weighted to reflect the operators priorities.

Ref. Ho, N., Johnson, W., Wakeland, K., Keyser, K., Panesar, K., Sadler, G., & Wilson, N. (2022). *Coordination of remote vehicles using automation level assignments* (Patent No. PCT/US2019/050797). **Submitted**

Route Decision-Making Structure: Best Rating and Score

Priority	Rating	Weather Risk	Terrain Risk	Population Risk
1	Good (G)	Risk < 20	Risk < 5	Risk <10
2	Acceptable (A)	20 < Risk < 60	5 < Risk < 8	10 < Risk < 60
3	Unacceptable (U)	Risk > 60	Risk > 15	Risk > 60

With advanced weighting, the decision structure can be simplified. A normative decision can be achieved, but human input is still required to create the prioritization above.

	Weather Risk	Terrain Risk	Population Risk	Overall Rating
Route A	0 (G)	4 (G)	95 (U)	(U)
Route B	60 (U)	5 (A)	40 (A)	(U)
Route C	50 (A)	10 (A)	50 (A)	(A)

*Rules
The lower the score, the better
Any route option with an unacceptable rating is eliminated

Ref. Ho, N., Johnson, W., Wakeland, K., Keyser, K., Panesar, K., Sadler, G., & Wilson, N. (2022). *Coordination of remote vehicles using automation level assignments* (Patent No. PCT/US2019/050797). **Submitted**

Route Decision-Making Structure: Equal Options

Priority	Rating	Weather Risk	Terrain Risk	Population Risk
1	Good (G)	Risk < 20	Risk < 5	Risk <10
2	Acceptable (A)	20 < Risk < 60	5 < Risk < 8	10 < Risk < 60
3	Unacceptable (U)	Risk > 60	Risk > 8	Risk > 60

With advanced weighting, the decision structure can be simplified. A normative decision can be achieved, but human input is still required to create the prioritization above.

	Weather Risk	Terrain Risk	Population Risk	Score
Route A	40 (A)	5 (A)	60 (U)	(U)
Route B	25 (A)	5 (A)	55 (A)	(A)
Route C	55 (A)	5 (A)	25 (A)	(A)

*Rules
The lower the score, the better
Any route option with an unacceptable rating is eliminated
If rating is equal, then select at random or decide by score using predetermined primary factor (e.g., population risk); both equally valid options for tie breaking

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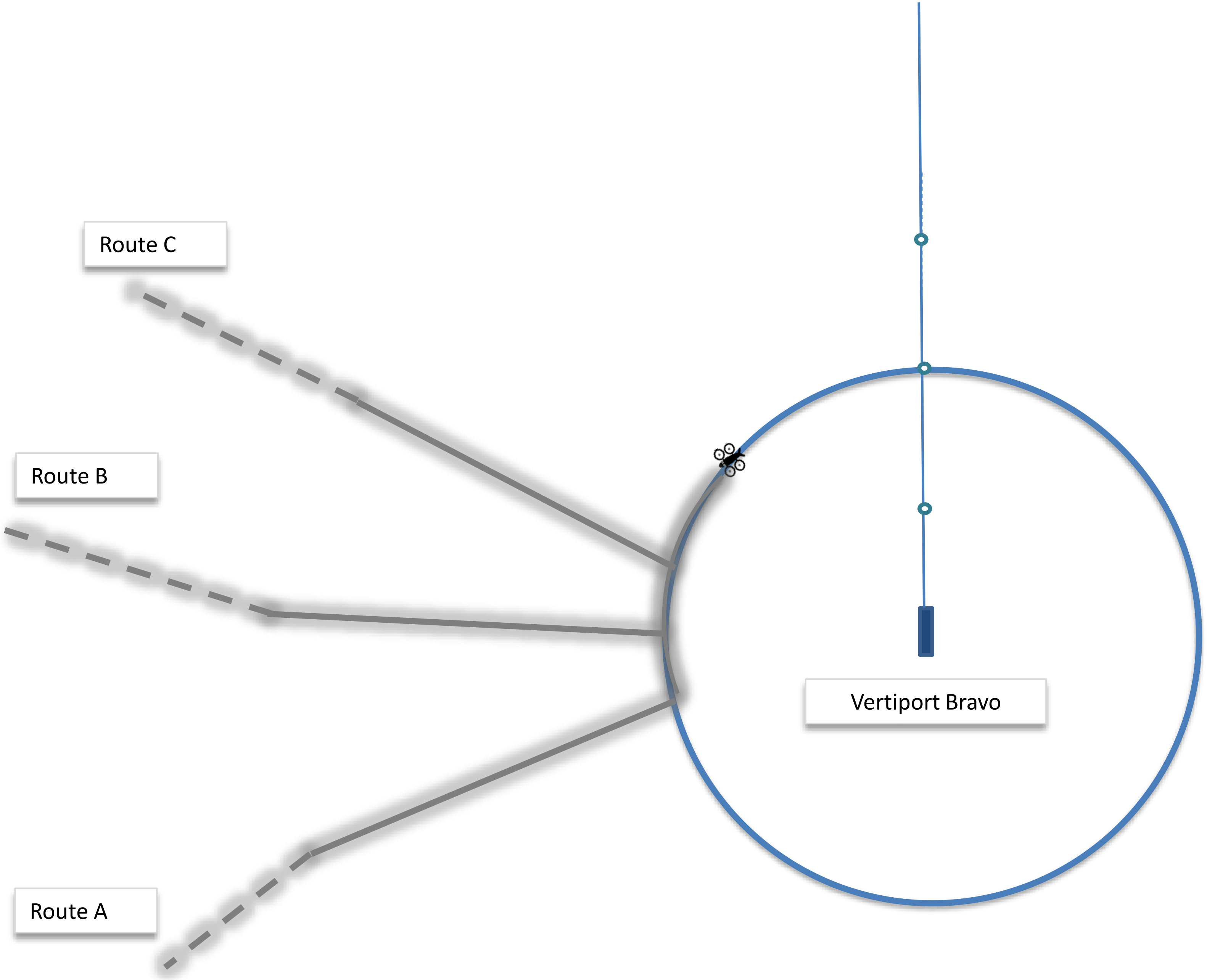
Trial Planning Challenges



Research consideration(s):

I. What factors should be considered when selecting between multiple route options, e.g., weather, ground risk, distance?

II. How can understanding of the route solutions be supported through interaction design of the tool and presentation of the solutions?

III. Where should responsibility for selecting new routes lie, e.g., automation, pilot, fleet manager?

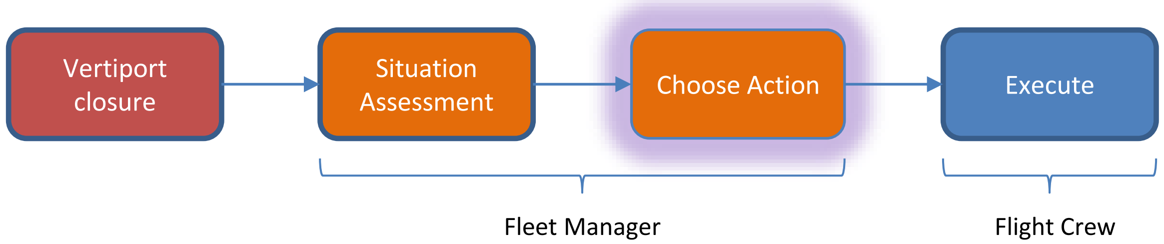
IV. How should submitting the new routes be coordinated?

V. What is the lead time required for decision-making and coordination of execution of the new route?

Fleet Manager Responsible

Task: Deviate to secondary vertiport

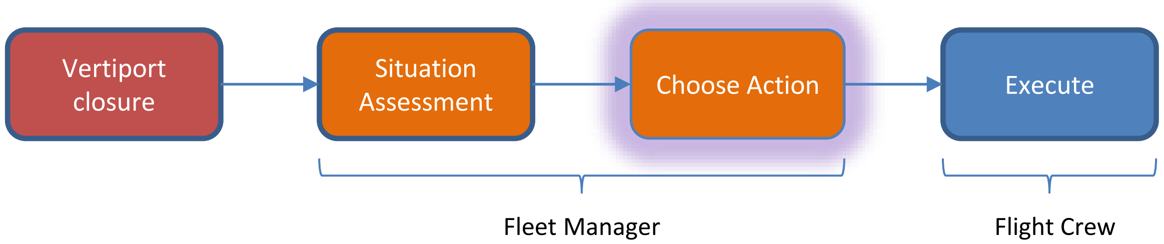
Fleet manager responsible for choosing action



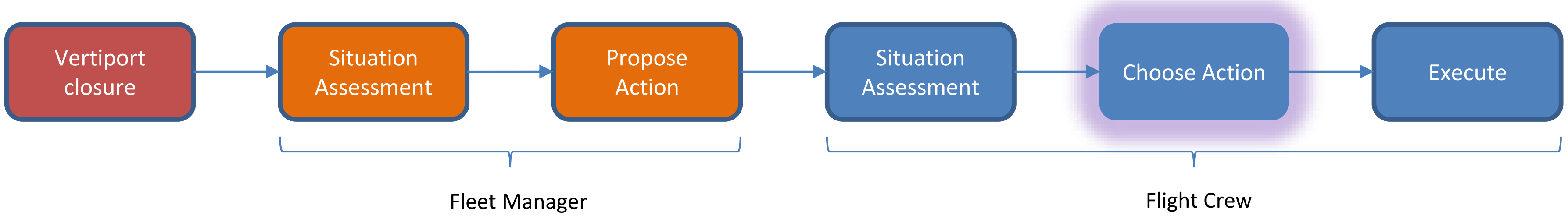
Fleet Manager or Pilot Responsible

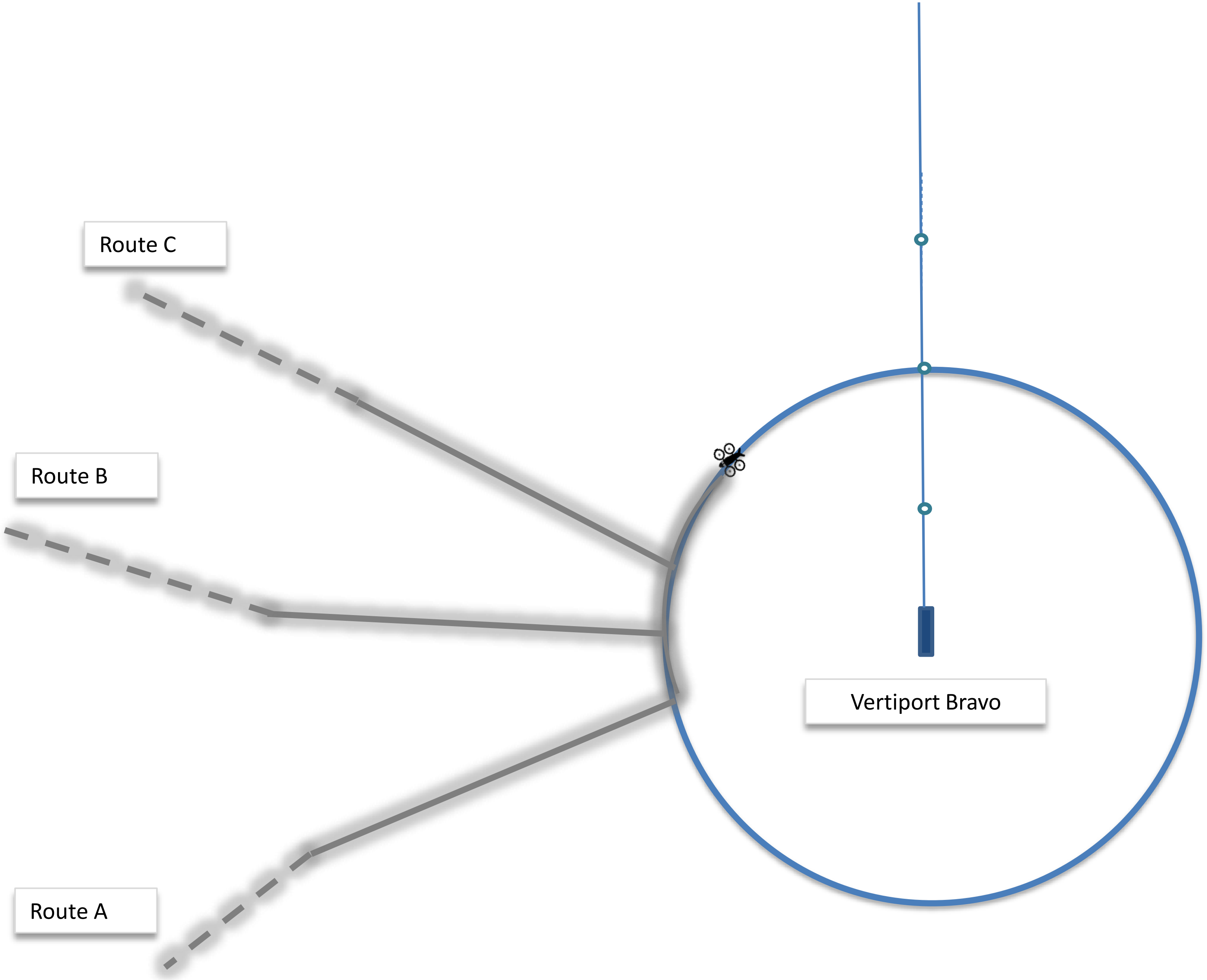
Task: Deviate to secondary vertiport

Fleet manager responsible for choosing action



Flight crew responsible for choosing action





Research consideration(s):

I. What factors should be considered when selecting between multiple route options, e.g., weather, ground risk, distance?

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IV. How should submitting the new routes be coordinated?

V. What is the lead time required for decision-making and coordination of execution of the new route?

Experiment Design

I.V.s: Responsibility Allocation x Delay

Responsibility Allocation

Level 1: Fleet Manager

Fleet manager reviews and selects new route

Level 2: GCSO

GCSO and Fleet manager review new route; GCSO selects new route

Traffic Density

Level 1: Low

Arrival/Departure rate at vertiport (2 pads): ~20* - ~80/hr

Level 2: High

Arrival/Departure rate at vertiport (2 pads): ~60* to ~120/hr

Responsibility Allocation

Traffic Density	Human: Fleet Manager	Human: GCSO
Low		
High		

Task: See use cases.
Ref: HDV.Research.Design.pptx

Experiment Design

Research consideration(s):

I. What factors should be considered when selecting between multiple route options, e.g., weather, ground risk, distance?

II. How can understanding of the route solutions be supported through interaction design of the tool and presentation of the solutions?

III. Where should final responsibility for selecting new routes lie, e.g., automation, pilot, fleet manager?

IV. How should submitting the new routes be coordinated?

V. What is the lead time required for decision-making and coordination of execution of the new route? Human actions + time for system to implement

Responsibility Allocation

Traffic Density	Human: Fleet Manager	Human: GCSO
Low		
High		

Metrics

I. Flight delay (measure how many revolutions taken by aircraft before pilots decides)

II. Rated situation awareness

II. Rated workload

III. Rated acceptability of route options

IV. Rated trust and transparency of route options

V. Open feedback on:

   a) Relevant factors for filtering route options

   b) Procedures for coordinating selection and execution of new routes

VI. Assess quality of decision-making

BACKUP

Assessment of Decision-Making

	Ref.	Decision Process for Choice Decision	Trial Planner (UI Evaluation)	Fleet Manager/Flight Crew (Evaluate Coordinated Decision Making)
Situation Assessment	1	Identified the problem?	Did the user invoke the trial planner after detecting the vertiport closure notification?	Did the team have a common understanding of the problem?
	2	Determined available time to solve?	Can the user identify expiration time for recommendations?	Did the team identify remaining distance to the vertiport? *impacts decision to go to rule-based or choice actions?
	3	Determine acceptable risk	Did the user promptly invoke the trial planner?	Did the fleet manager promptly engage the flight crew to engage in coordinated decision-making?
Choose Action	4	What are relevant options?	Can user identify prompts to consider routes prior to modifying an operation?	Did the fleet manager forward route options to the flight crew and express preference?
	5	What are the relevant decision factors?	Are the goals and constraints applied to routes transparent to the user?	Was the team able to identify and mitigate conflicting goals and objectives?
	6	What are the trade-offs?	Can the user entertain what-if scenarios, e.g., what happens if I pick route A vs. route B?	Was the team able to identify and mitigate conflicting goals and objectives?
	7	Was an action taken within the time available to solve problem?	Was the user able to submit a route to PSU before the solutions expired, e.g., 90s?	Was the team able to select a route before the solutions expired?

Overview

- Goal: Review human factors research considerations for UAM
  1. Context: Describe the terminal area urban air mobility research and development effort
  2. Research gap: What are main approaches for allocating functions flight replanning

- What is Urban Air Mobility (UAM)?
  - Scalable
  - Autonomous
  - Vertiport relative
  - Below 10k feet
  - eVTOL
  - Managed by automation and human
  - UAM is a complex combination of human and automation to manage eVTOL operations in an airspace surrounding a vertiport. This is contrast to current day where human roles are predominant where automation are used as tools, while in UAM will employ automation for proactively making decisions and executing them.
  - UAM airspace penetrates and exists within airspace that is traditionally managed.
  - This is a redistribution of roles and responsibility of the air traffic controller to flight dispatchers and automation with secondary role for vertiport managers to establish acceptable flow right.
  - There will be differential roles and responsibilities for humans and automation; from traditional most things are same except in UAM you can have autonomous vehicles
  - Government will be involved in ensuring route separation
  - Aircraft that cannot conform to UAM requirements, will need to employ ATC services and conform to less optimal routes.
- Characterize UAM terminal area operations
  - Ecosystem
  - Airspace (routes, vertiports, VPV, VOA, safety and traffic ring)
  - Actors (FM, VM, GCSO, Vehicle Systems, PSU, VAS, SDSPs)
- Roles and Responsibilities
  - What are functions?
  - What are the roles?
  - What are the responsibilities?
  - Layout all possibilities for autonomous aircraft, fleet managers etc.
- Use Cases: How will roles be exercised?
  - Task
  - Use Case 6: Divert or stay on track?
- Research challenges
  - decision-making
  - allocation of responsibility for route decision-making
  - How do we coordinate flight replanning?
  - What is the potential impact on airspace performance

Route Decision-Making Structure: Equal Ratings, Different Scores

Priority	Rating	Weather Risk	Terrain Risk	Population Risk
1	Good (G)	Risk < 20	Risk < 5	Risk <10
2	Acceptable (A)	20 < Risk < 60	5 < Risk < 8	10 < Risk < 60
3	Unacceptable (U)	Risk > 60	Risk > 8	Risk > 60

With advanced weighting, the decision structure can be simplified. A normative decision can be achieved, but human input is still required to create the prioritization above.

	Weather Risk	Terrain Risk	Population Risk	Score
Route A	40 (A)	5 (A)	60 (U)	105 (U)
Route B	25 (A)	5 (A)	40 (A)	70 (A)
Route C	50 (A)	5 (A)	50 (A)	105 (A)

*Rules

The lower the score, the better

Any route option with an unacceptable rating is eliminated

Scenario Timeline

Task: Return to planned destination

Fleet manager responsible for choosing action