NEAR EARTH AUTONOMY

Lessons Learned in Implementing Autonomy

NASA workshop on
Enabling Autonomous Flight & Operations in the NAS

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What is Autonomy?

- Sense/Plan/Act/Interact
- Outer loop layered on top of flight control
- Dealing with Contingencies

Fly safe, Land Safe, Do it Without GPS,

Even when things go wrong

Progression of Autonomy on the Ground

1986: 1 m/s

1995: 5 m/s

2007: 10 m/s

2014: 30 m/s

2018: 15 m/s

Key Problems

- **Localization**: Where am I?
- **Classification**: What kinds of objects are around me?
- **Prediction**: How are these objects likely to move?
- **Planning**: How do I get to goal given hazards?

Extension to the Air

2014: 50 m/s

2016: 15 m/s

Key Problems

- **Localization**: Where am I?
- ~~**Classification**: What kinds of objects are around me?~~
- ~~**Prediction**: How are these objects likely to move?~~
- **Planning**: How do I get to goal given hazards?
- **Contingency Management**: How do I deal with failure

Scalable Autonomy

2006

RMAX (20 kn)

2010

AH-6 (40 kn)

2014

AH-6 (100 kn)

2017

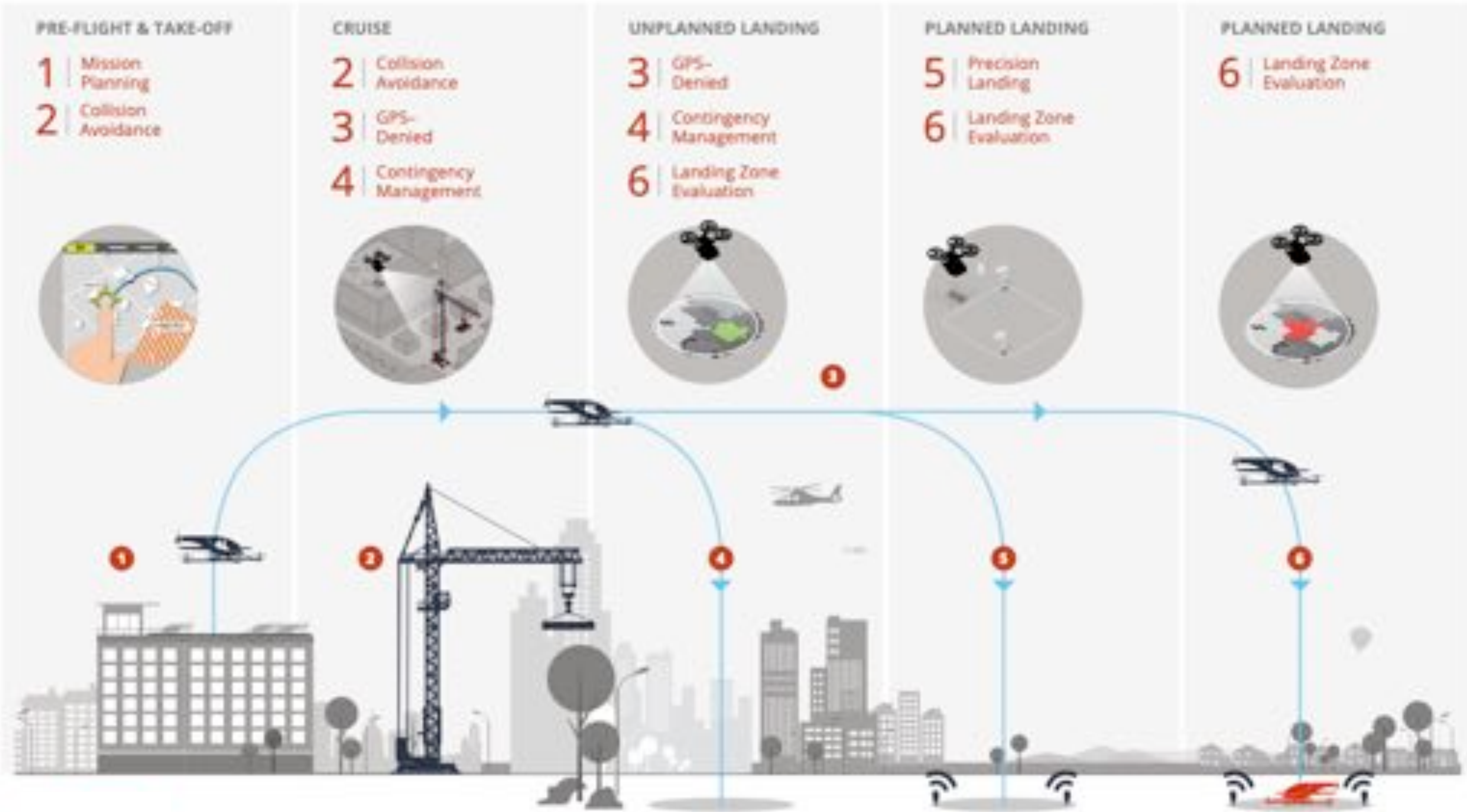
UH-1 (100 kn)

2018

2018

2018

Autonomy by Stages of Flight



Lesson: Awareness of Environment is essential

Robust Navigation

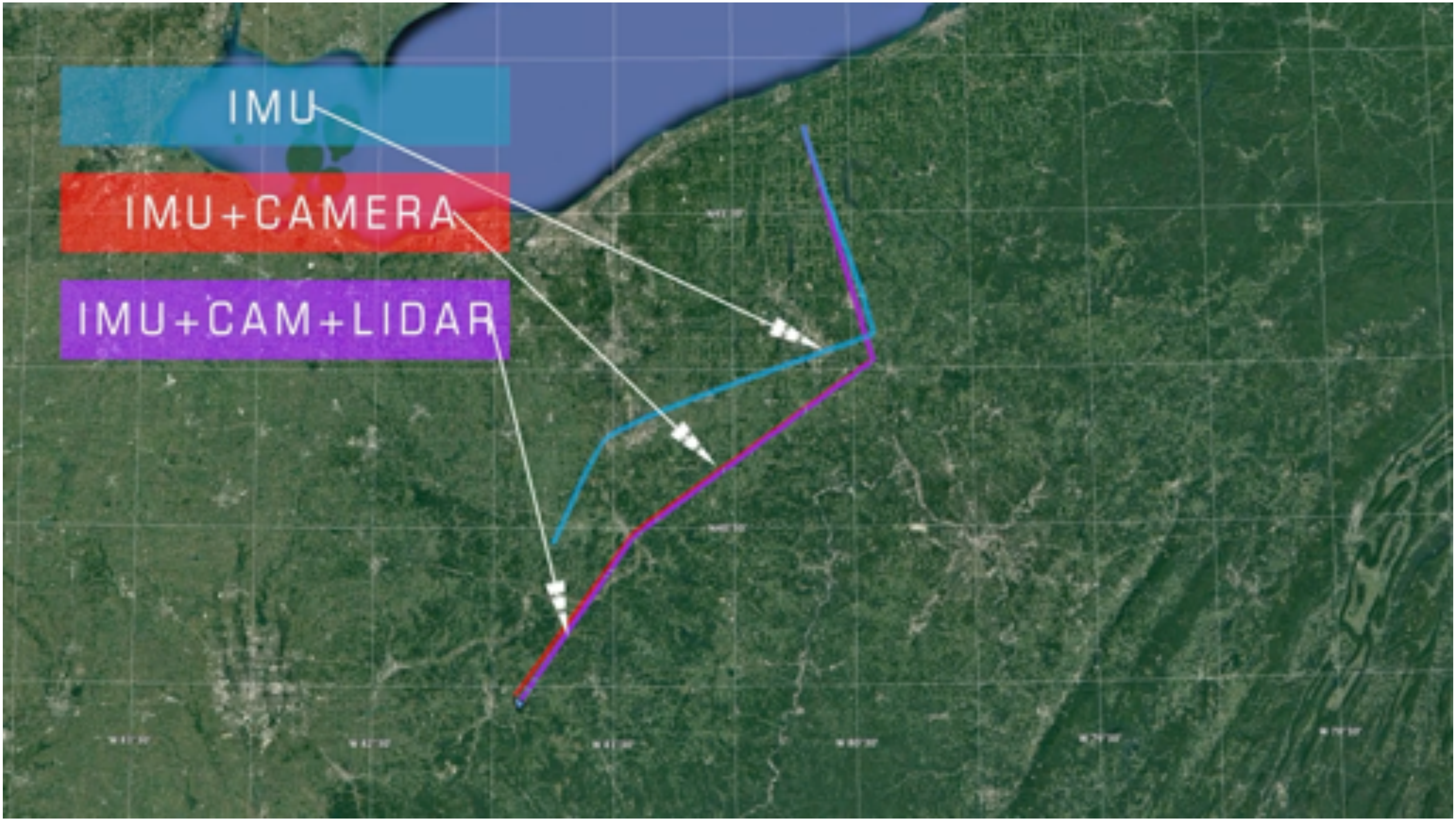
- UAS rely on accurate, high-frequency state (6/12 DOF) for stability and safety
- State is most needed at low elevations when the vehicle is flying close to terrain, vegetation & structures.
- …Exactly when accurate GPS is least assured.

- *Conventional Wisdom*: use odometry (visual/inertial) as base. Update with global fixes (GPS/landmarks) when available.

A mission

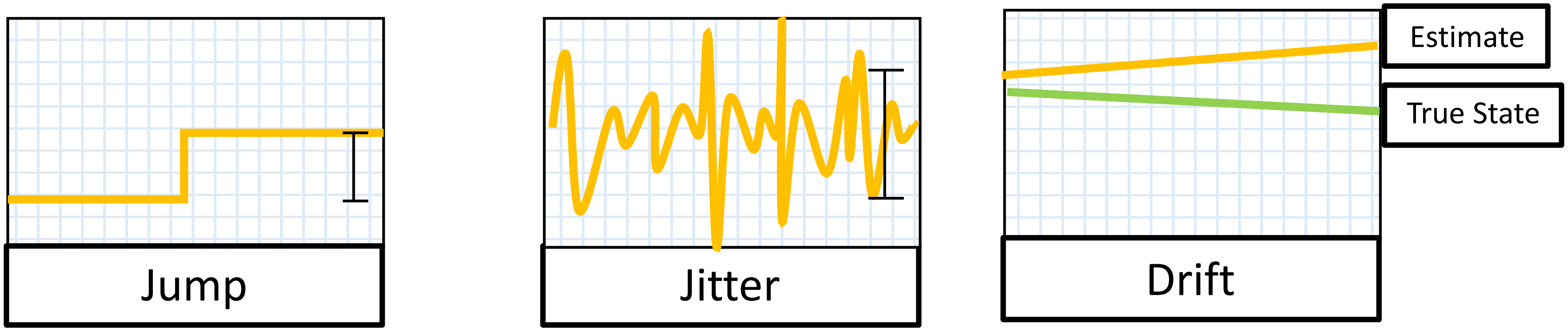
Navigation without GPS

What we can do today with out GPS



Conflicting needs

- CW for affordable sytems results in



	Navigation	Control	Collision Avoidance, Safe Landing
Reference Frame	Inertial	Inertial	Relative
Measurements	Position	Position, Velocity, Attitude	Position, Velocity, Attitude
Corrections	Immediate	Smooth	None

Awareness of the immediate world

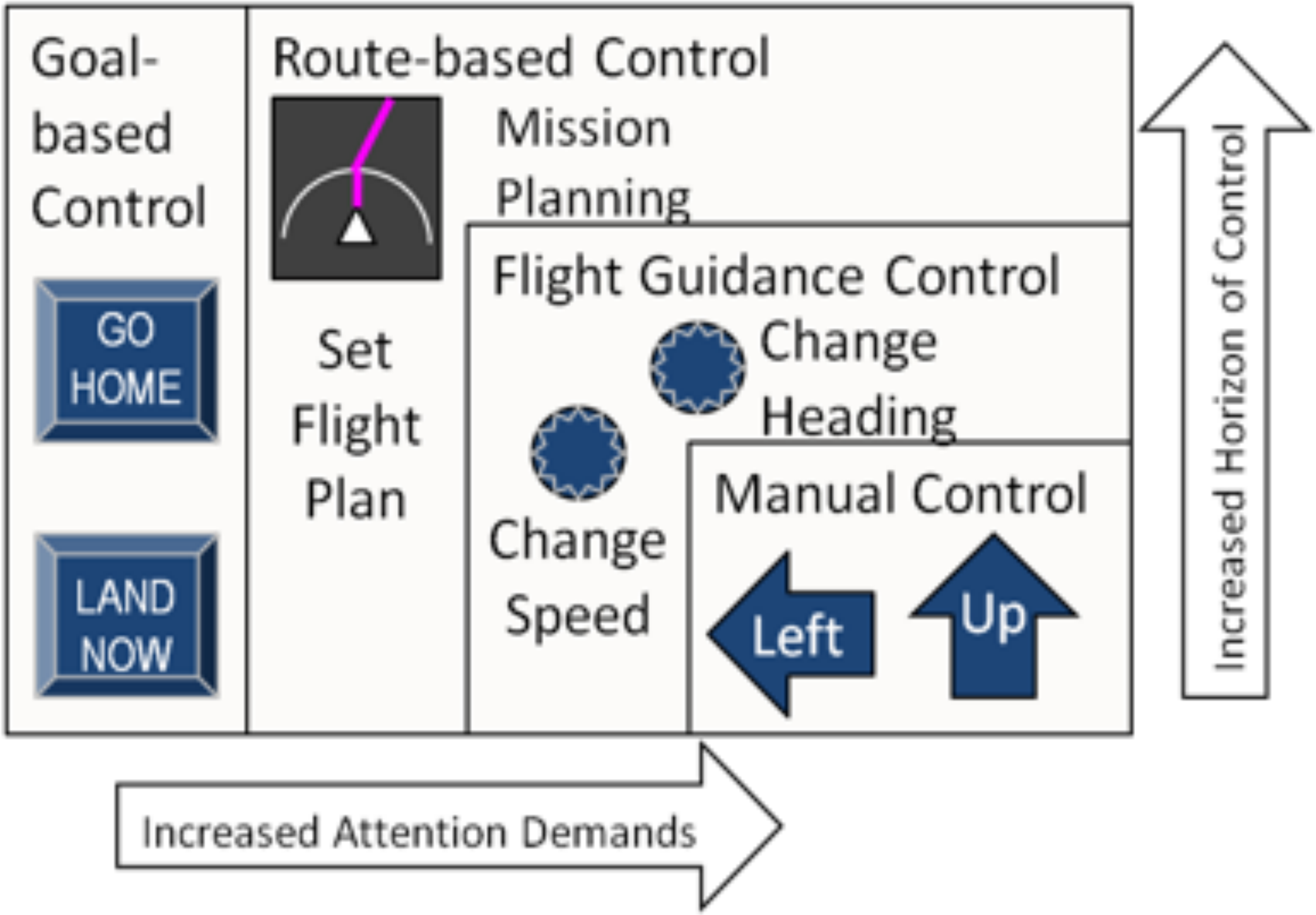
Autonomous Landing in Complex Terrain

Scaling down

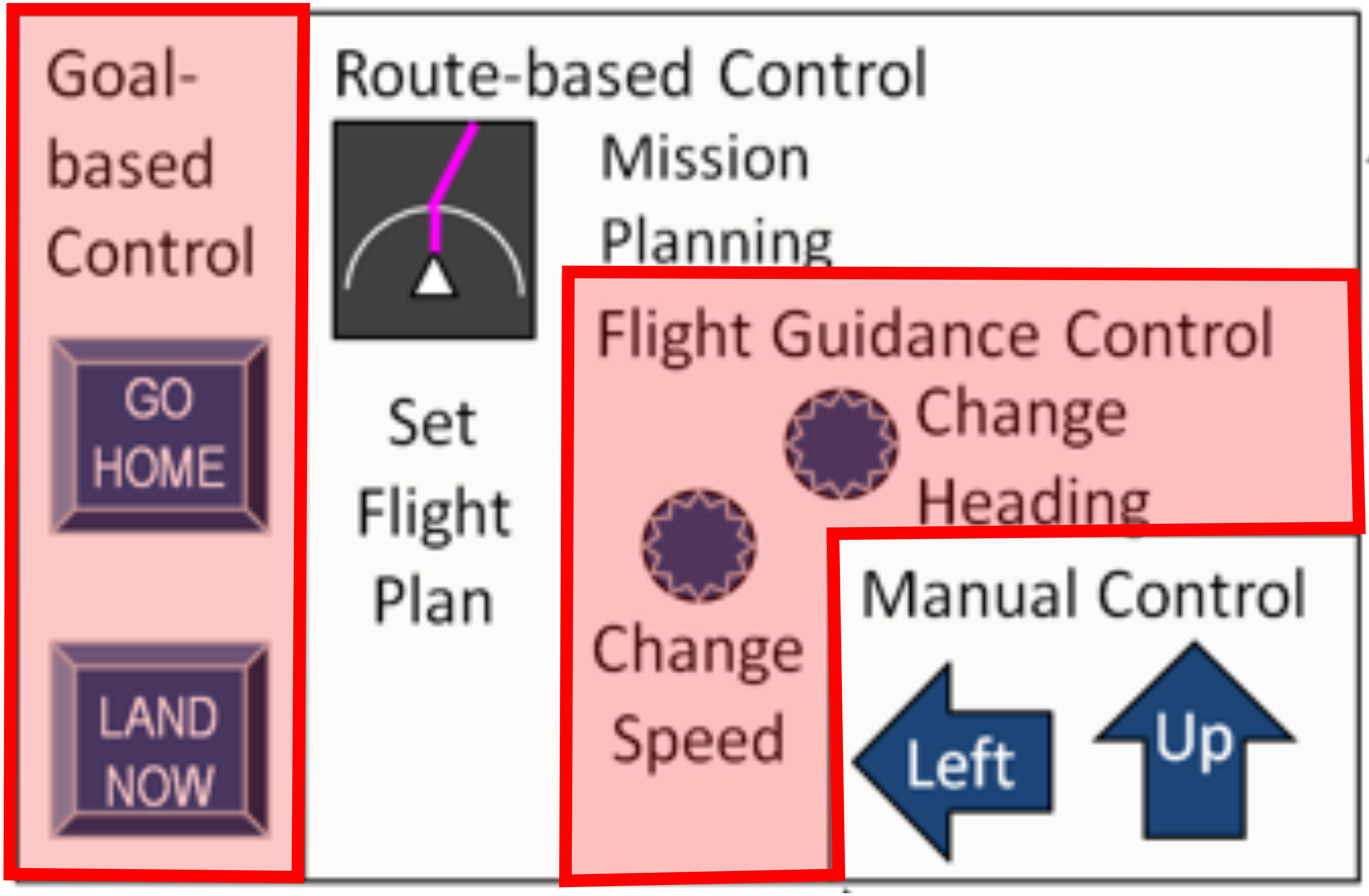
Lesson: Autonomous Operation at scale in NAS needs shared control paradigm

In the not too distant future (circa 2010)

Control Modes



Crashless vehicle

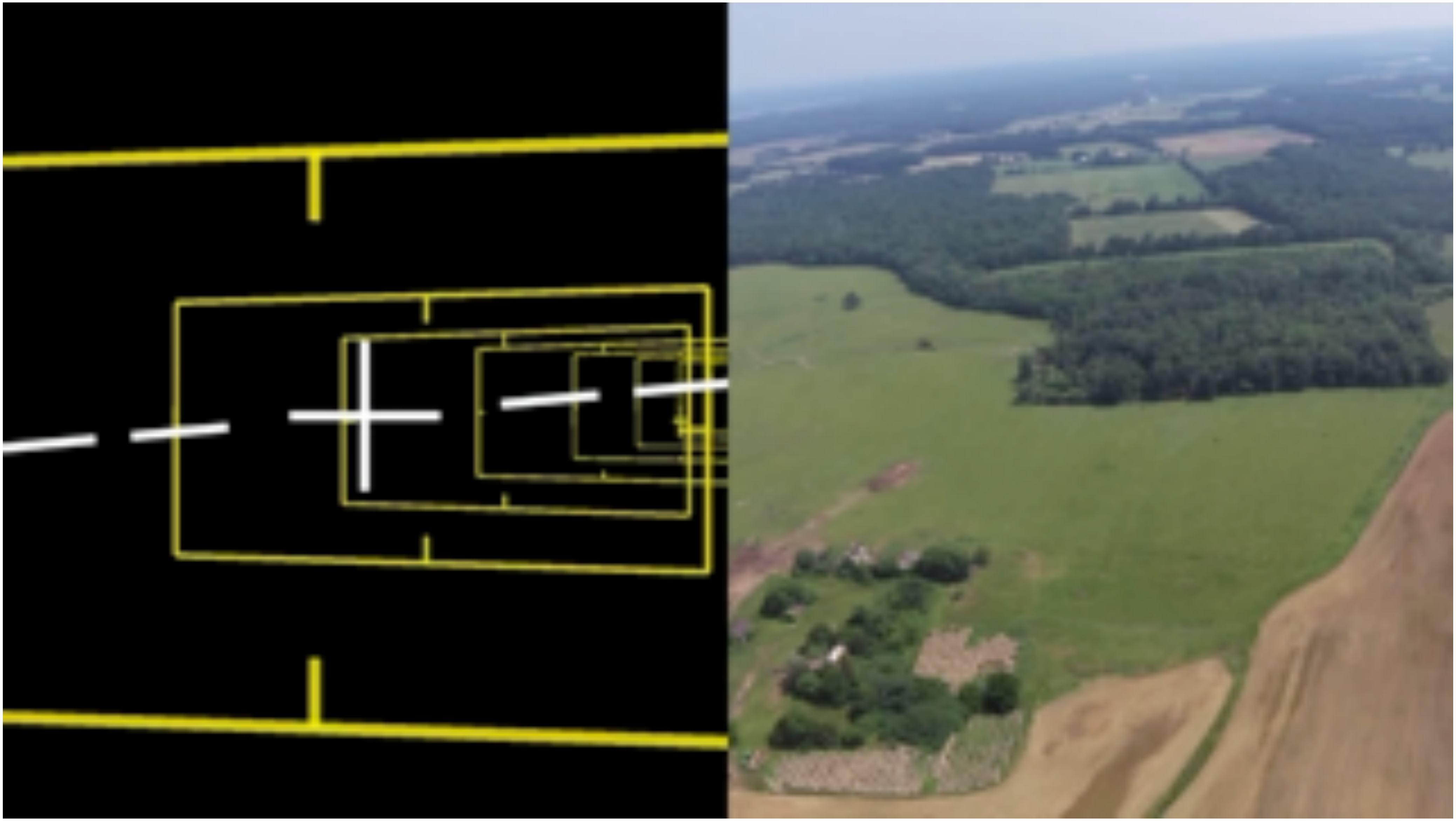


Adjustable autonomy

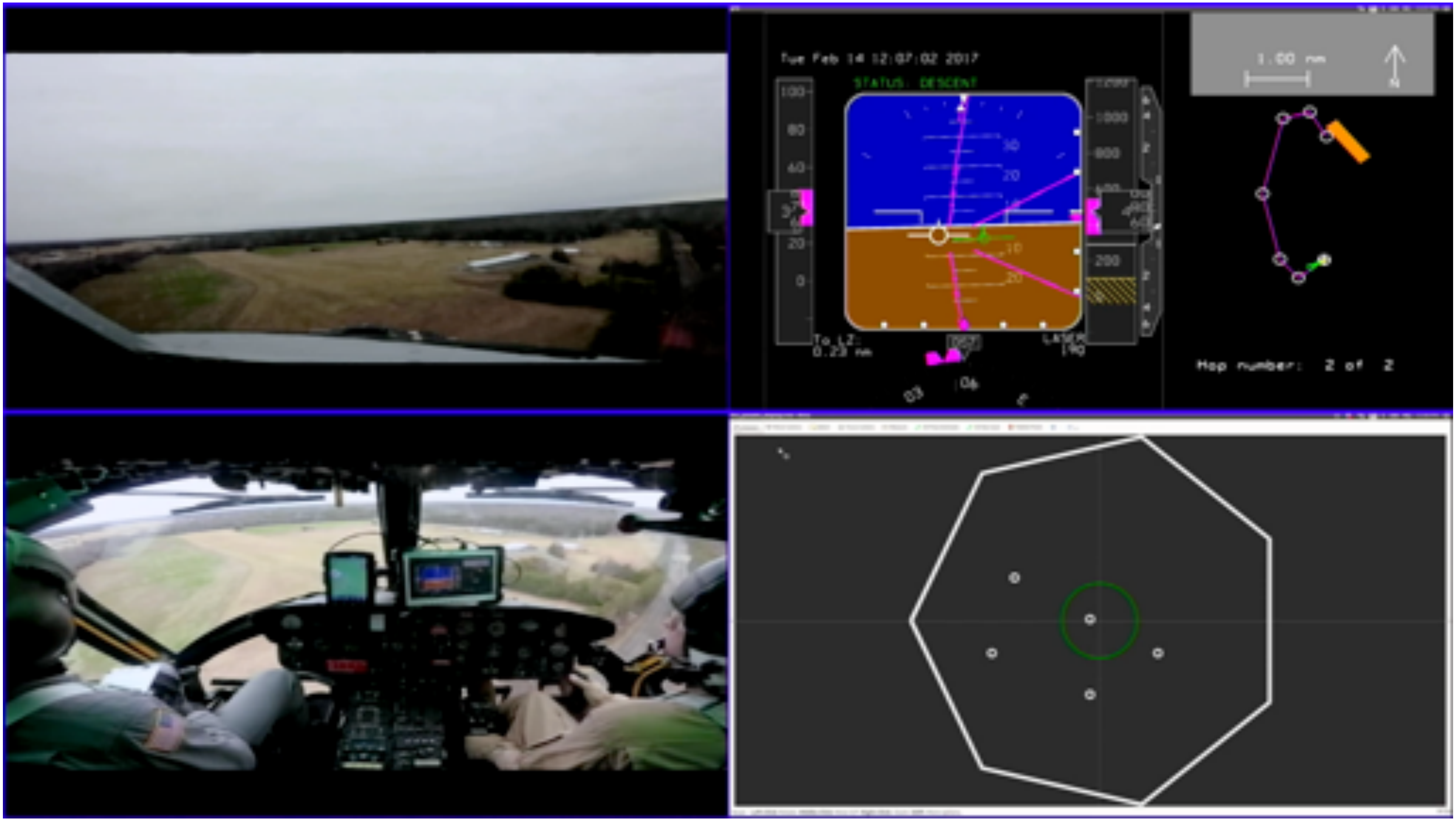
Condition	Workload	Precision	Decision Making	Efficiency
Human	Poor	Poor	Good	Poor
Automation	Good	Good	Poor	Good
Human + Automation	Good	Good	Good	Good

Lesson: Testing Autonomy safely requires human in the loop

Testing autonomy



Testing autonomy



4 Steps to push button autonomy

- Captive carry of sensing/computing
- Pilot closes the loop with good display
- Operator uses Adjustable Autonomy
- Full Autonomous Operation

Difficulty Relative to State of the Art

	Auto Driving	Auto Flying
Navigation		
Detection of hazards in environment		
Classification of Objects		
Prediction of (potentially) moving objects		
Contingencies in case of failure		
Countering willful misuse		

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