Tuesday, April 18
10:45-11:45

Presented to:

SAE/NASA Autonomy and Next Generation Flight Deck Symposium

Flight Test Results for Mission-Adaptive Autonomy

Distribution Statement A: Approved for public release, pr2031

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

April 18, 2017

Presented by:

Matt Whalley

US Army Aviation Development Directorate – ADD
Aviation & Missile Research, Development & Engineering Center
Moffett Field, CA 94035

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Marc D. Takahashi, Chad L. Goerzen, Gregory J. Schulein, M. Hossein Mansur, LTC Carl R. Ott, MAJ Joseph S. Minor, MAJ Zachariah G. Morford, Ernesto Moralez, Marcos G. Berrios

Outline

- ARP Background
- MAA Introduction
- System Setup
- Experiment Overview
- Results
- Conclusions

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- **ARP Background**
- MAA Introduction
- System Setup
- Experiment Overview
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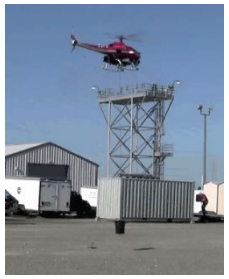
ARP Background
Autonomous Research Project (ARP)

AMRDEC

AFCS 3D spline-based trajectory-command

PALACE ATO: vision-based SLAD, GPS-denied



AOS HERMES FUSE: sling load pick-up and delivery

* 20 lb, 5m sling *

US/IS SLAD Benchmarking

OFN-2D Voronoi

OFN-3D Quadtree

OFN BM

RiskMinOFN

APEX w/NASA

2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010

RMAX delivery to AFDD

Linear ID

Auto takeoff and landing

Change detection w/Stanford

Forward-Flight AFCS

DSMAC w/Raytheon

DelCon 1

DelCon 2

ARP Background
Autonomous Research Project (ARP)

Full Codebase

RASCAL JUH-60A

Autonomous Level 1 ADS-33 MTEs

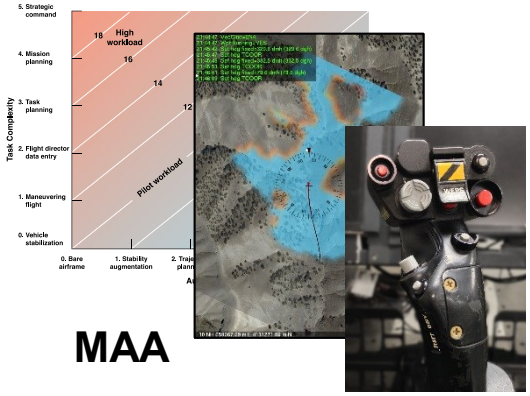
HNBEC MFL
110 kt OFN

Dual Lift

2011 | **2012** | **2013** | **2014** | **2015** | **2016**

First UH-60 OFN/SLAD

AOS Hermes+



MAA

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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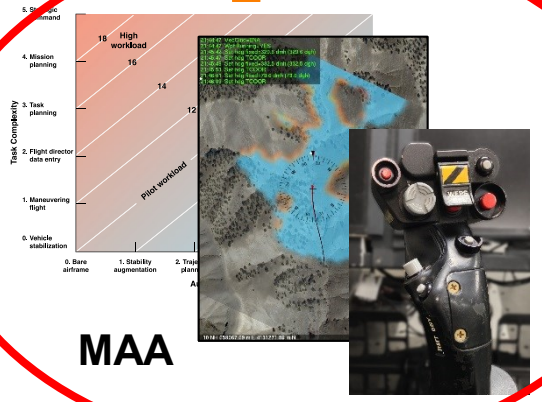

MAA

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Outline

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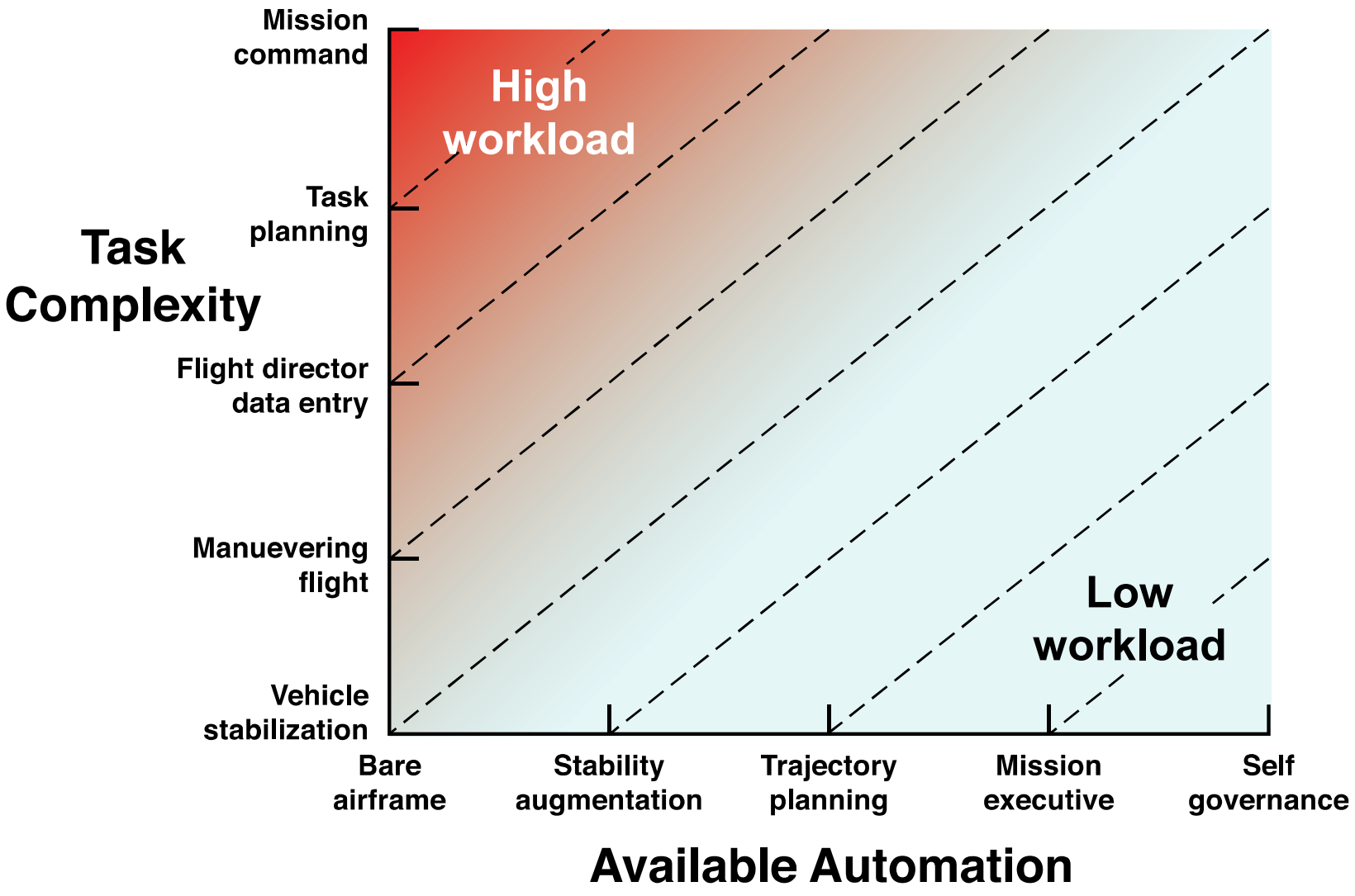
- **MAA Introduction**
- System Setup
- Experiment Overview
- Results
- Conclusions

Introduction
Mission Adaptive Autonomy (MAA)



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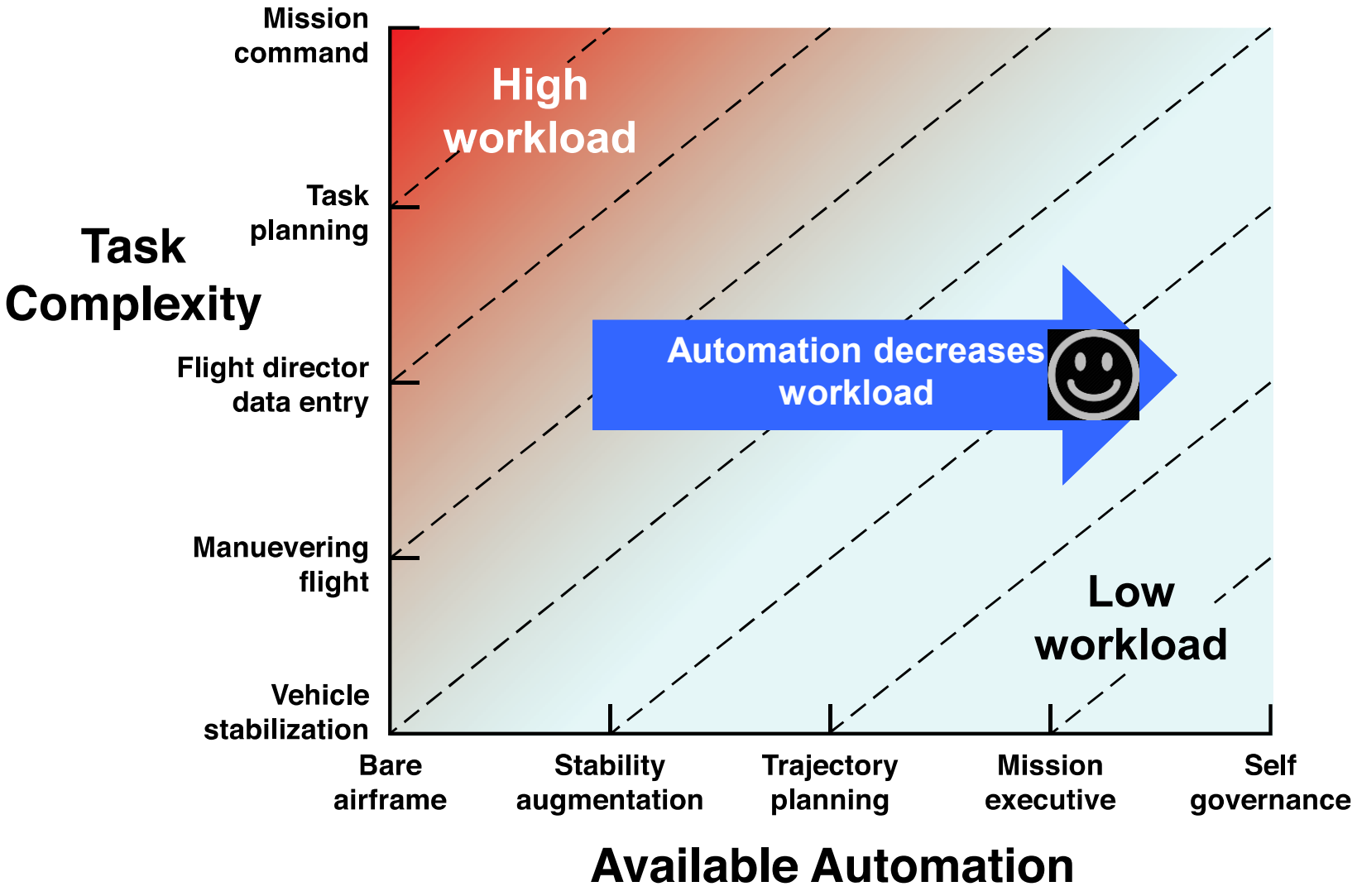
Mission Adaptive Autonomy (MAA)



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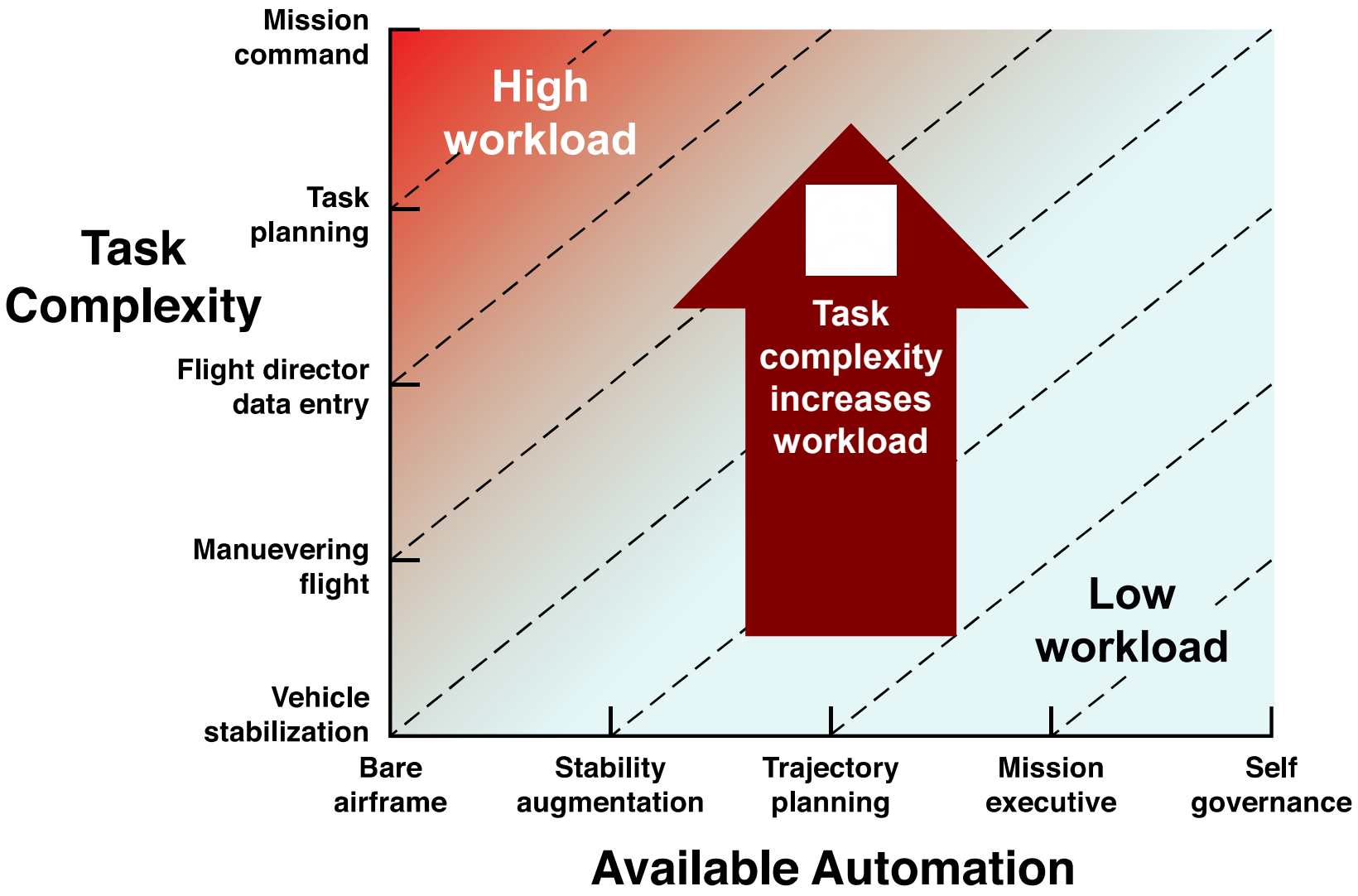
Mission Adaptive Autonomy (MAA)



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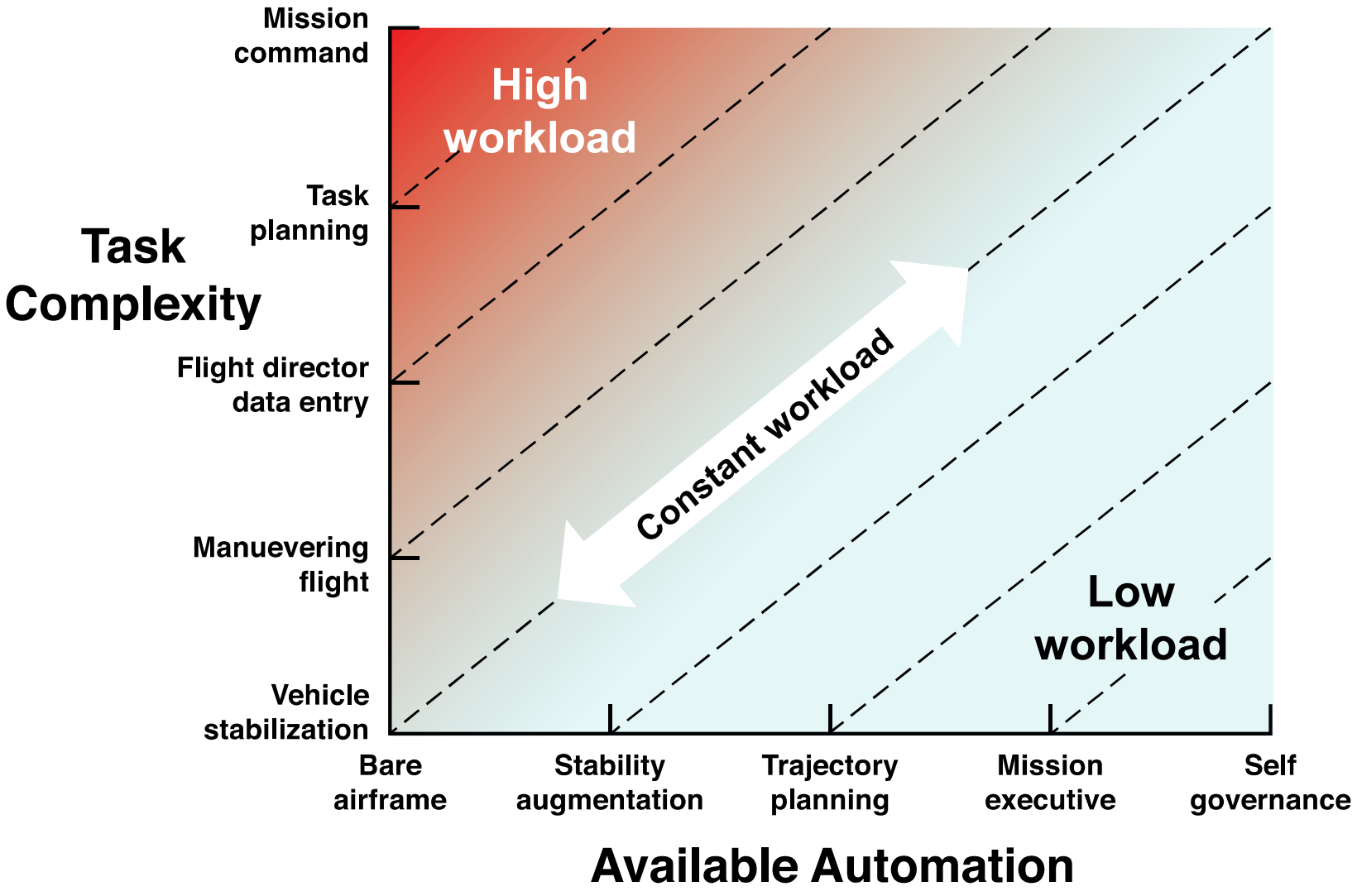

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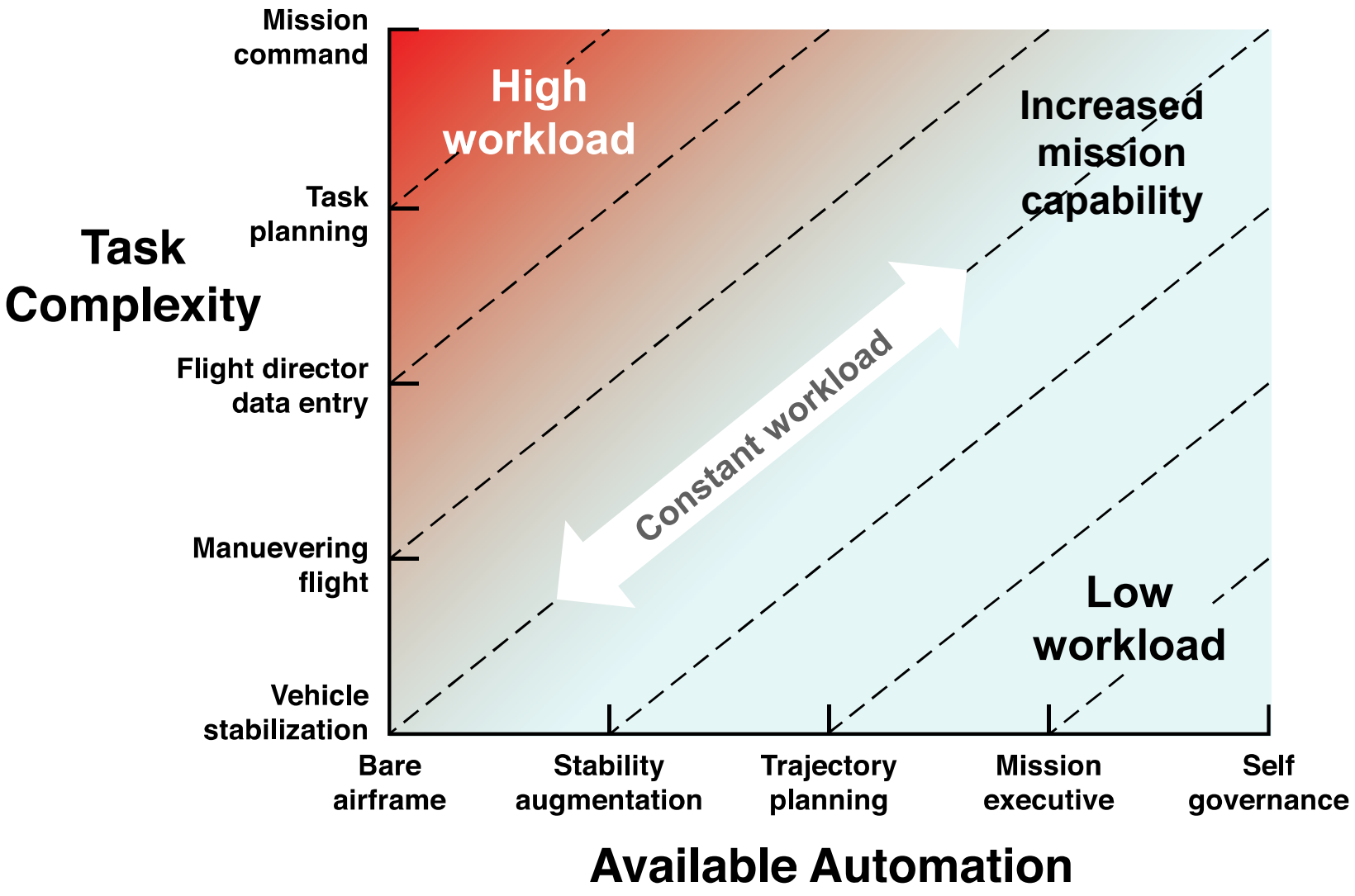

Test Objective:

Evaluate MAA concept – enable pilots to select the automation they need to meet the mission demands.

Outline

- ARP Background
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- **System Setup**
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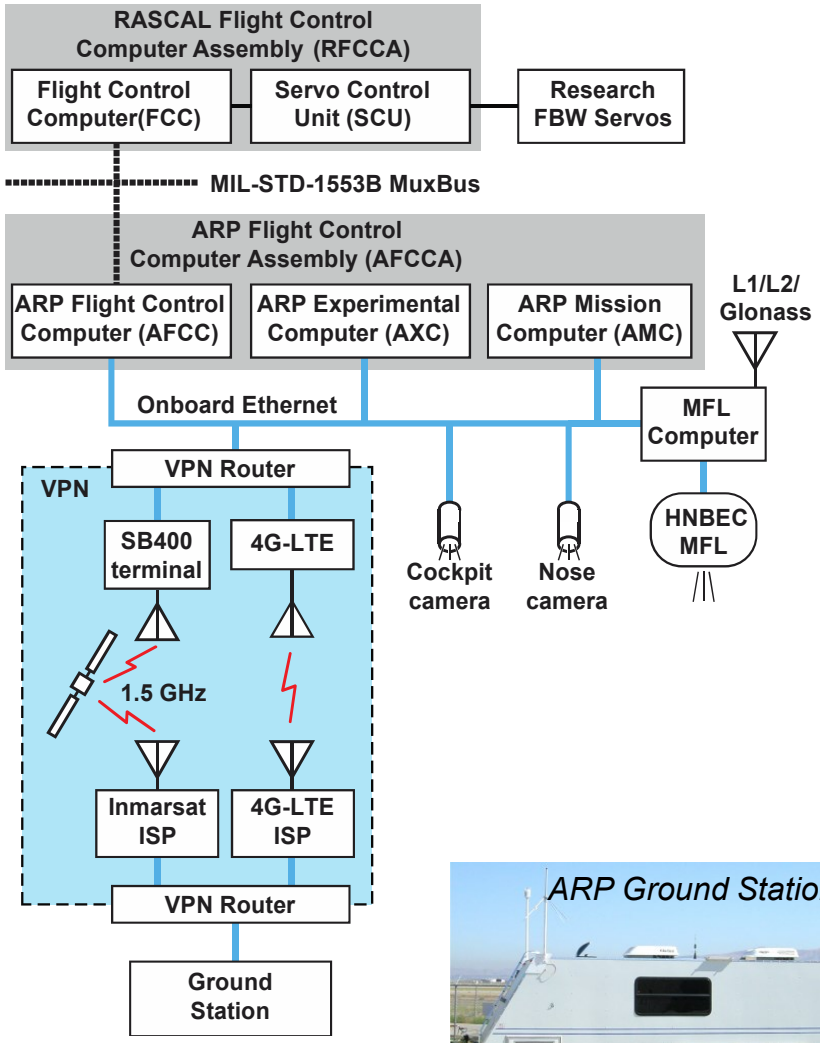
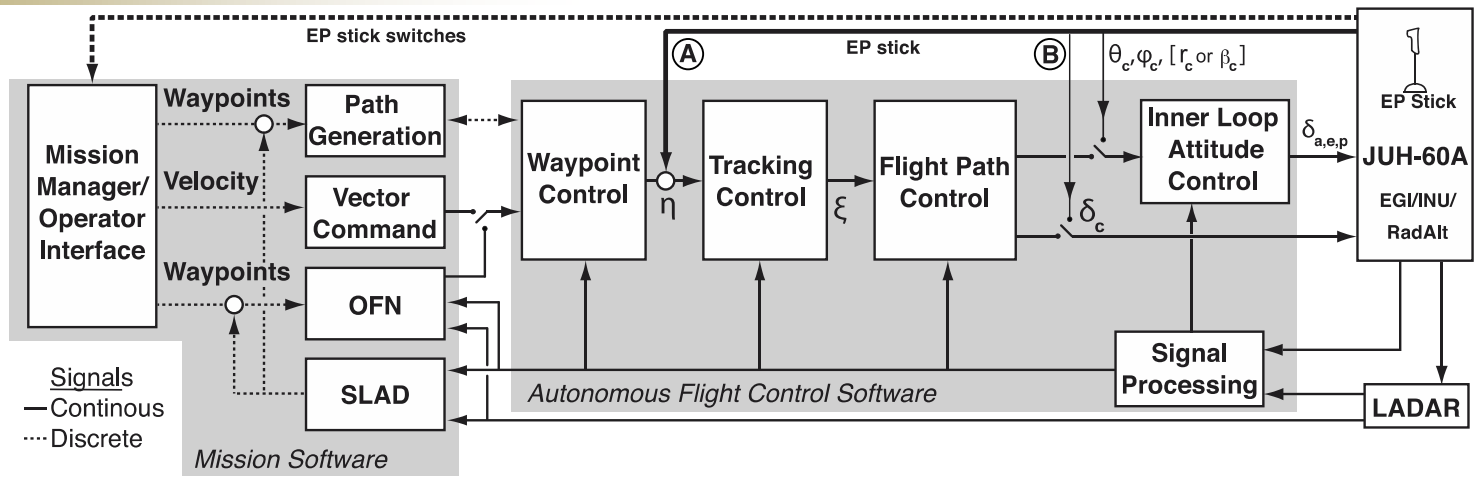
MAA System on RASCAL

ADD RASCAL JUH-60A
(Full-authority fly-by-wire)

3D-LZ Multi-Function LADAR
(AFRL / HNBEC)



Autonomous Flight Control System

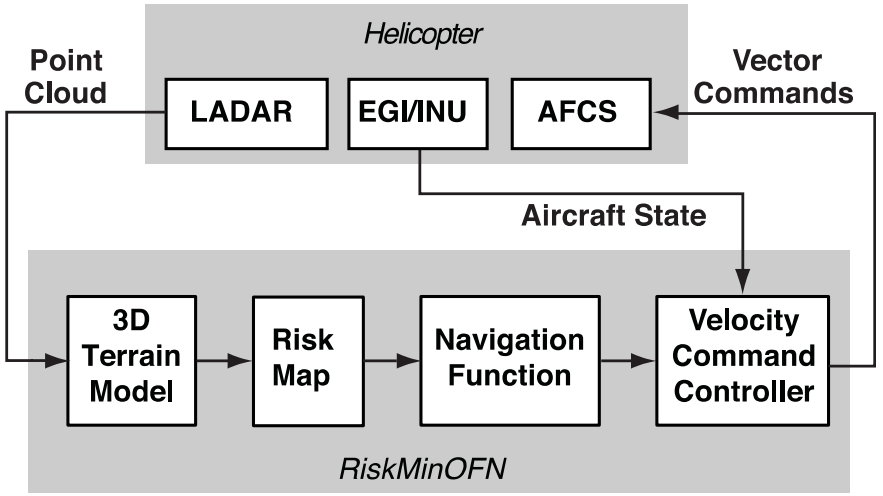


- **Autonomous Flight Control Software**
  - Signal Processing: Filters and estimates states
  - Inner Loop Attitude: ACAH response
  - Flight Path Control: Aircraft oriented velocity command in hover and forward flight modes
  - Tracking Control: Track inertial path with hover and forward flight modes
  - Waypoint Control: Convert commanded trajectories into continuous steam for tracking
- **Additive control at A**
- **Decouple to ACAH at B**
- **Driven by Mission Manager Software**
  - Path Generation: Fixed, pre-defined waypoint paths
  - Vector Command: Velocity vector command
  - OFN: Obstacle Field Navigation
  - SLAD: Safe Landing Area Determination

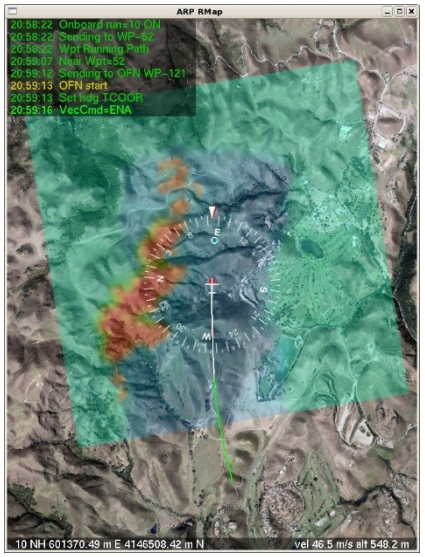
1. **LADAR scans forward region**
2. **Real-time continuous 3D risk map is constructed**
   - Terrain (LADAR), threats, no-fly zones, desired AGL, loss of aircraft
   - 3D space classified as empty, full, or unknown using statistical error model
3. **Navigation function applied to array**
   - Distance transform
   - 3D A* algorithm calculates a navigation function; ~ 5 sec cycle
4. **Velocity command generated at 5Hz**

RiskMinOFN "always on"; updates the on-the-fly; adaptive

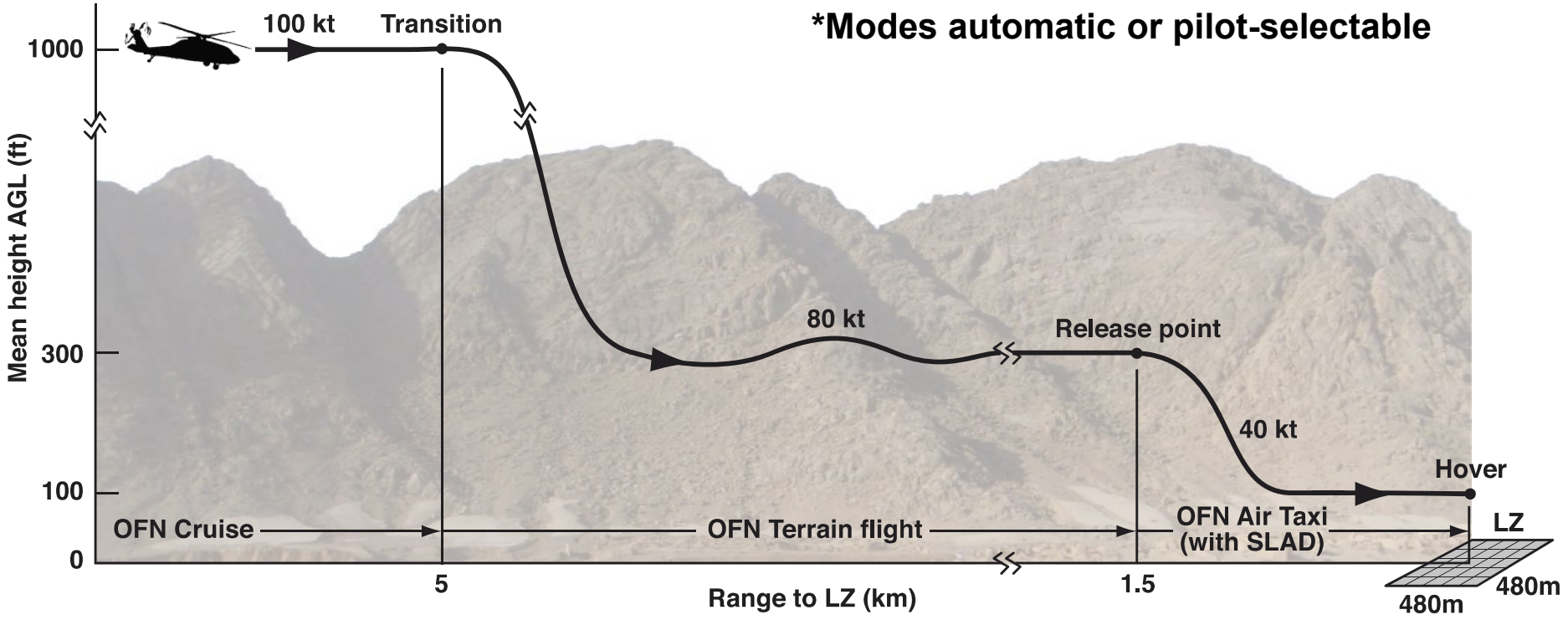
- Destination, speed
- Risk function parameters
- 3D array resizing



HNBEC MFL



System Setup
MAA Enroute and Approach Modes



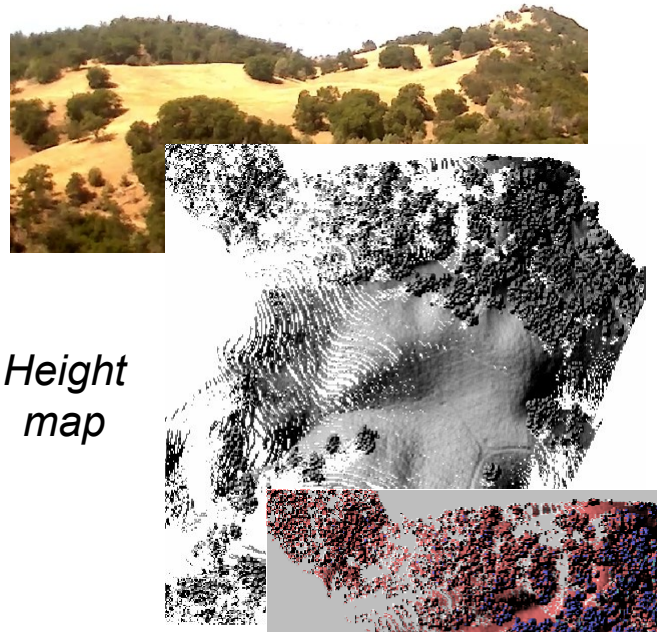
Multi-Layer Surface Map (MLSM)

1. **LADAR scans landing zone**
2. **Real-time continuous height map construction**
   - Scan registration for height/roll bias and time drift

$$J(h,d) = \sum \frac{[(h + dt_i) + H_i - Z_i]^2}{D_i^2}$$

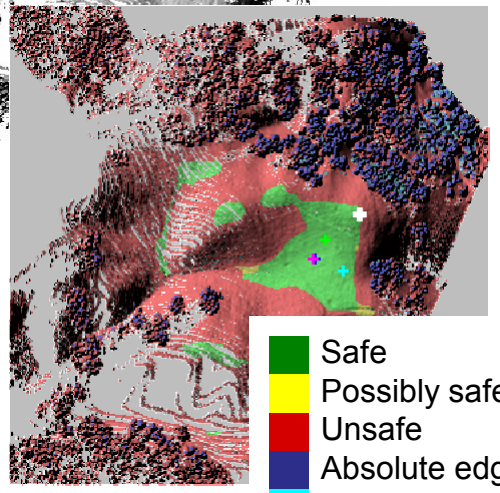
   - Height statistics accumulated using differential and absolute error model
   - Individual Kalman filter for each cell
3. **Map evaluation**
   - Slope and roughness
   - Edge and obstacle detection
   - Landing zone classified safe/unsafe
   - Optimal landing points
4. **Keep data for subsequent solutions**

LZ Black Mountain



Height map

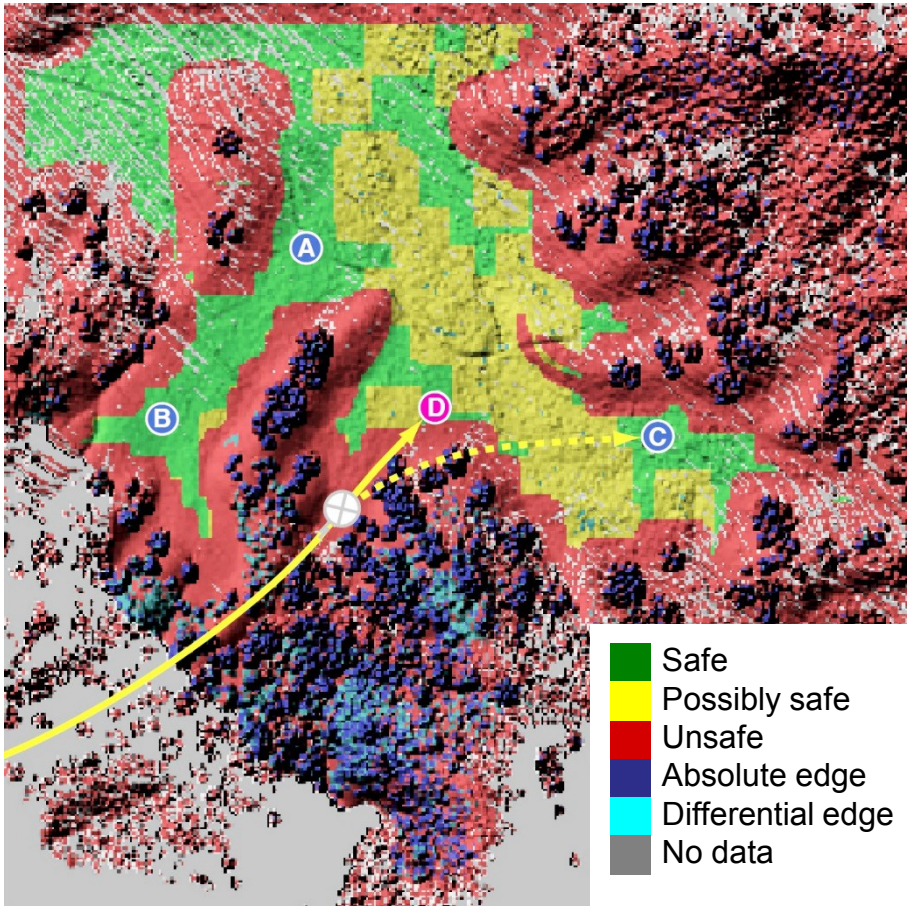
MLSM solution



MAA Approach Sequence

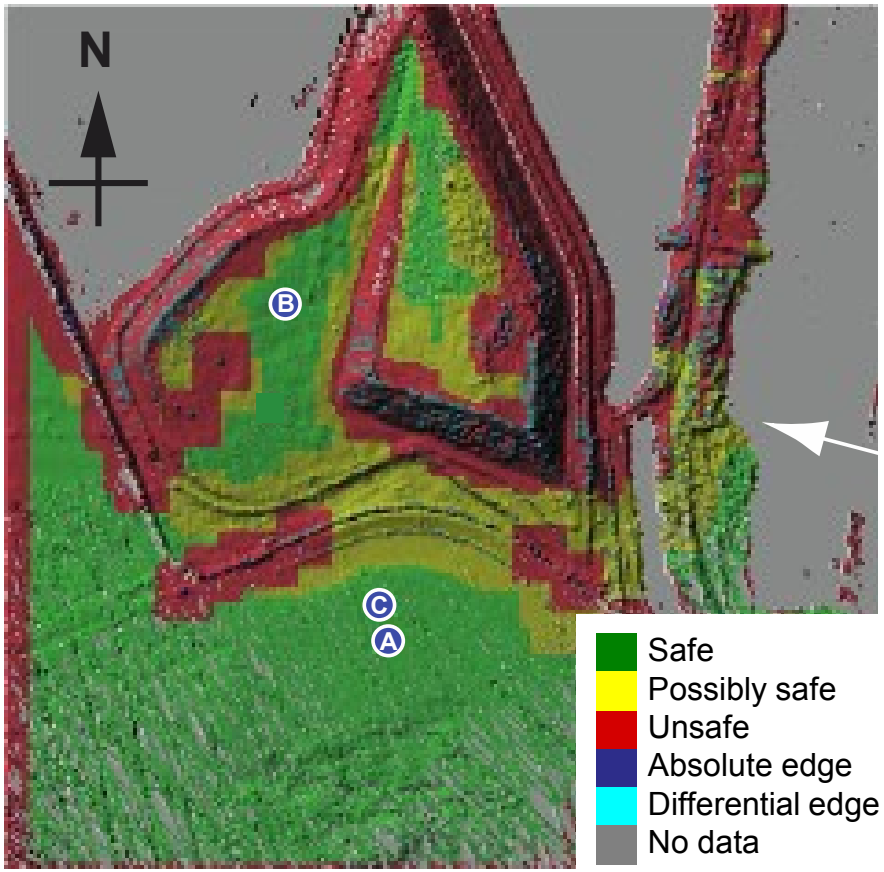
1. Scan landing zone during approach
2. Display MLSM solution
3. Automatically send landing point A to navigation system*
4. Pilot can select alternate landing point if desired
5. Iterate solution every 5 seconds

** First solution only – retain previous landing point unless found to be invalid*



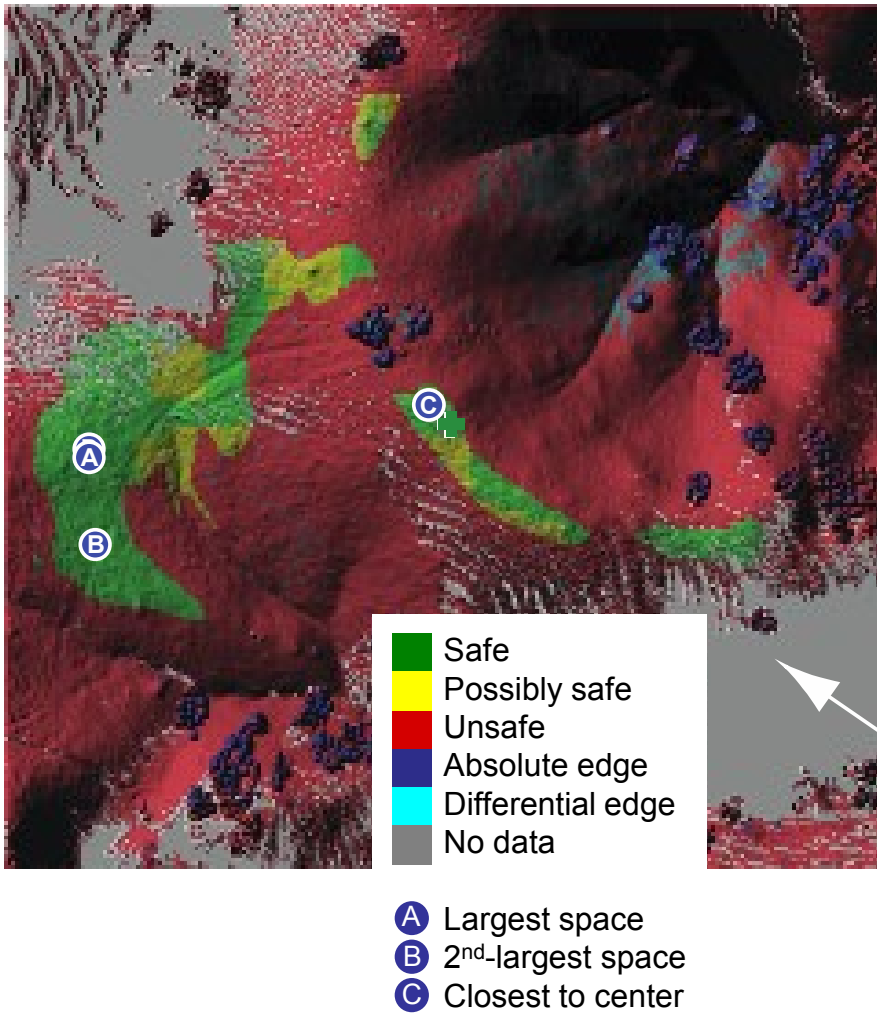
Multi-Layer Surface Map

LZ Moffett NUQ Berm



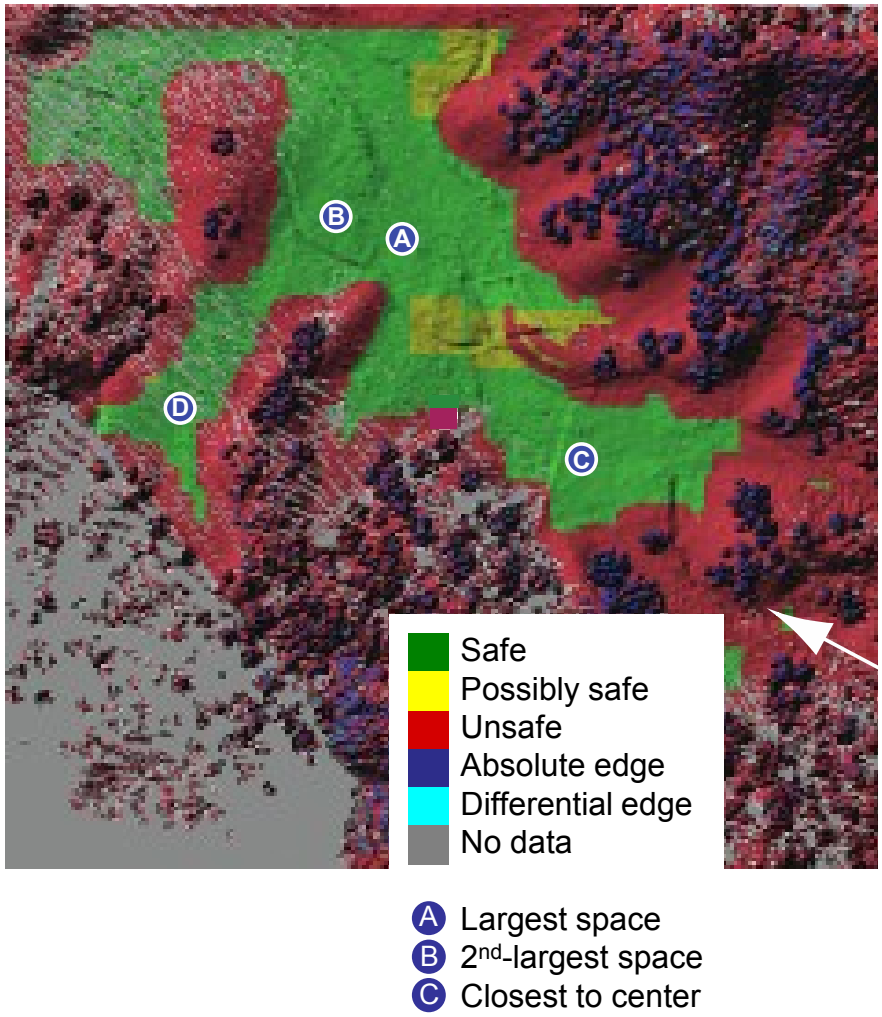
Multi-Layer Surface Map

LZ Packard Ridge



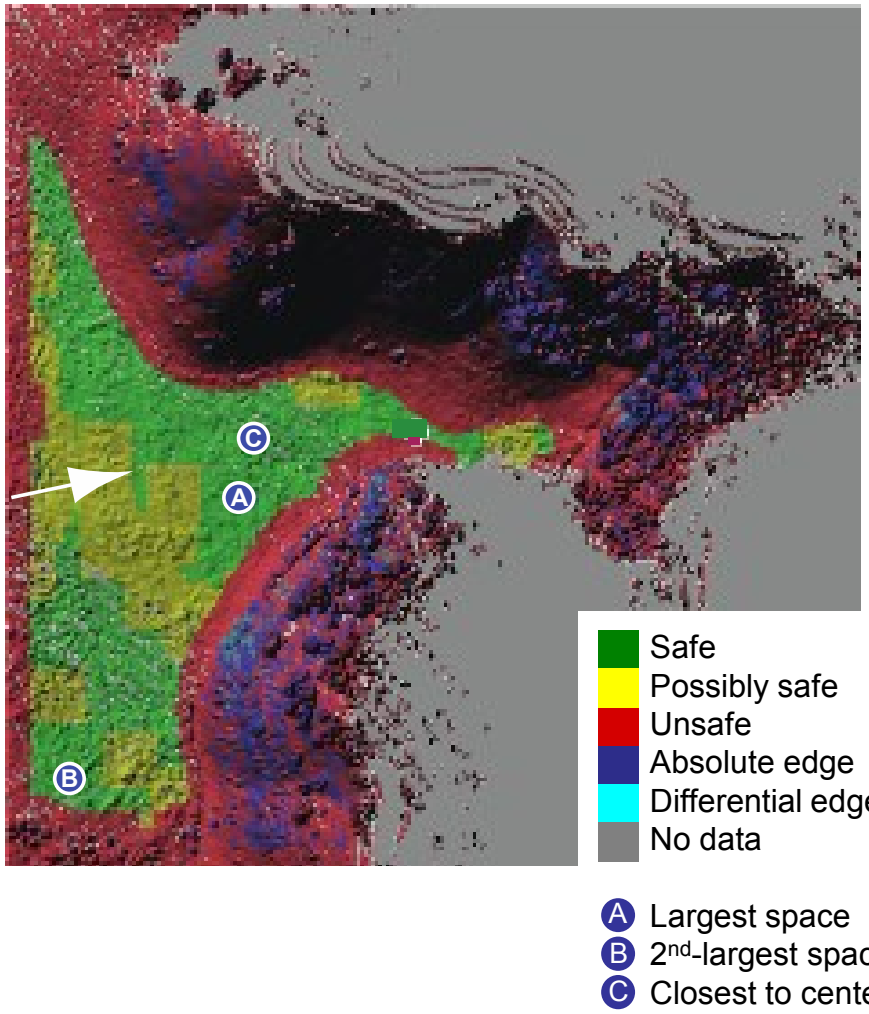
Multi-Layer Surface Map

LZ Isabel Valley



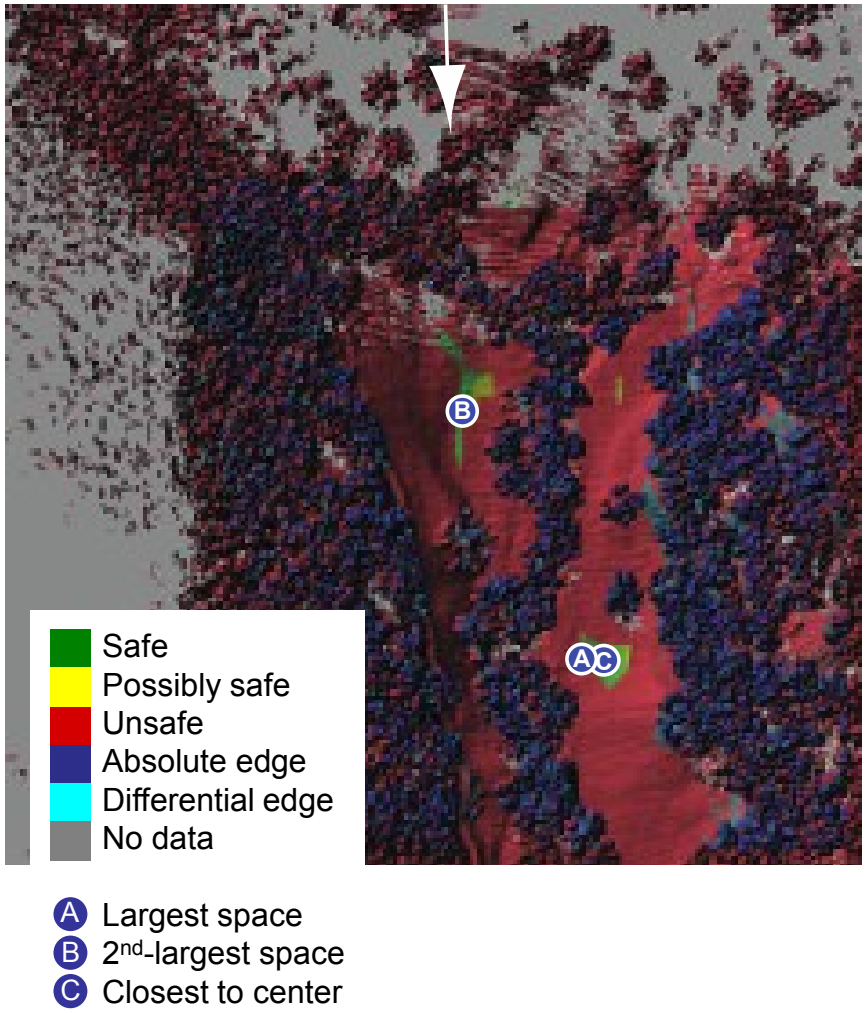
Multi-Layer Surface Map

LZ Calaveras Cove

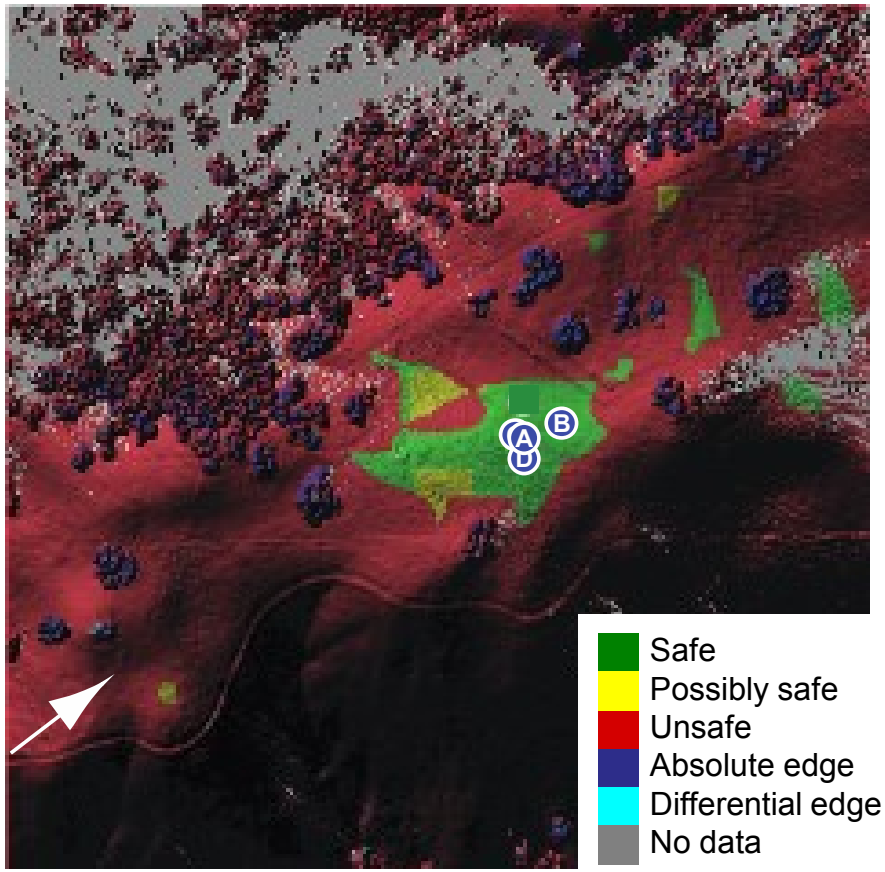


Multi-Layer Surface Map

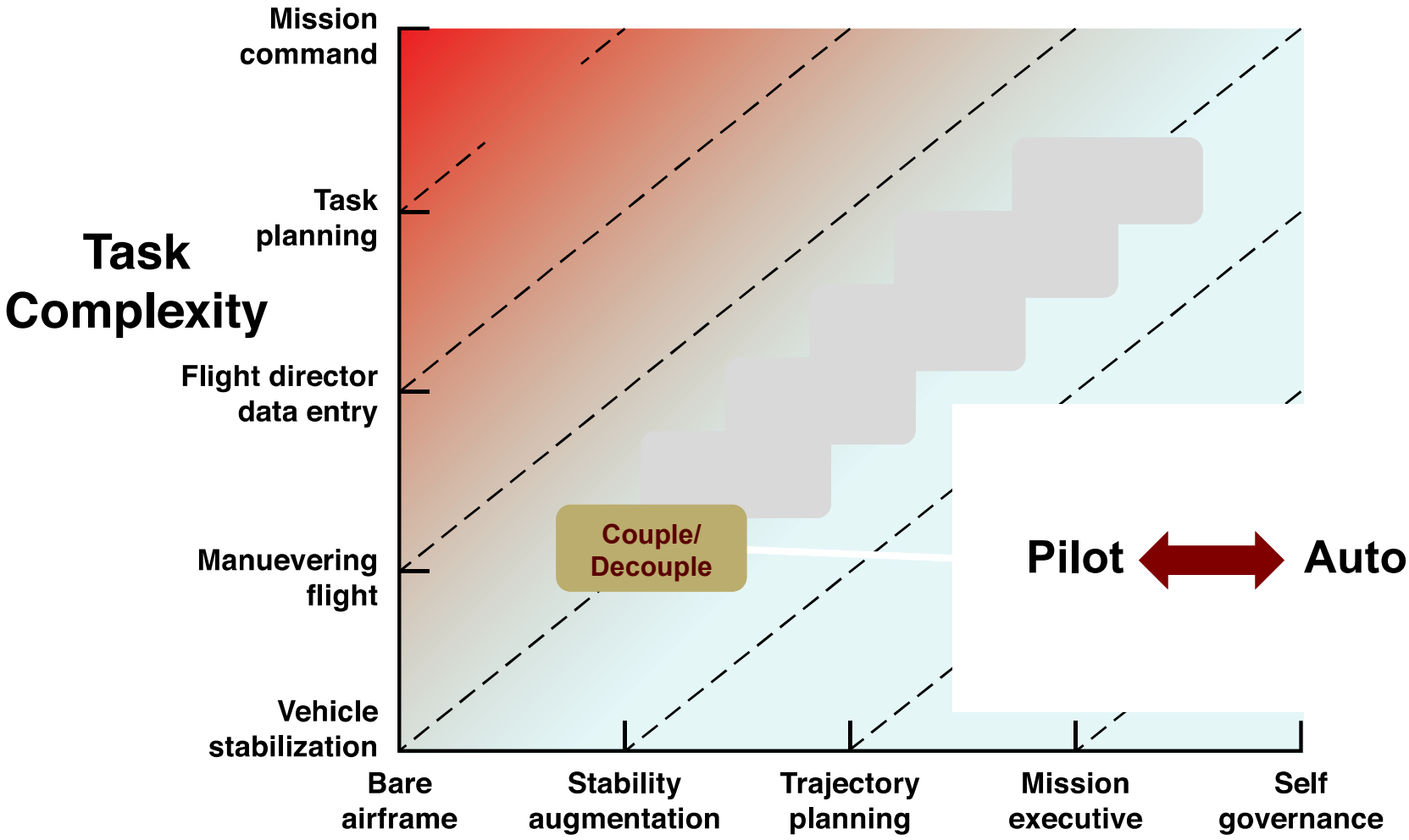
LZ San Felipe



System Setup
Multi-Layer Surface Map



MAA Selectable Features



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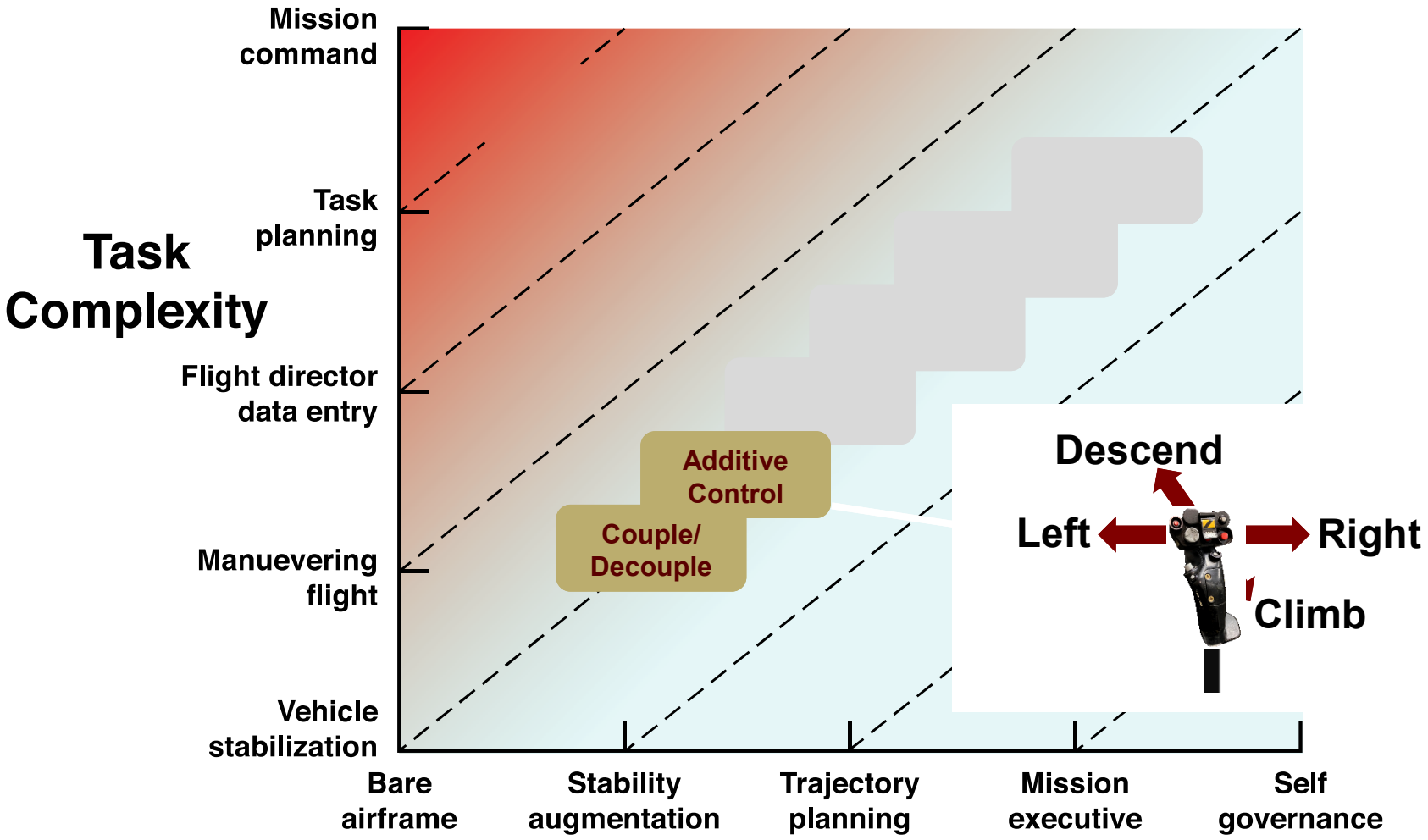
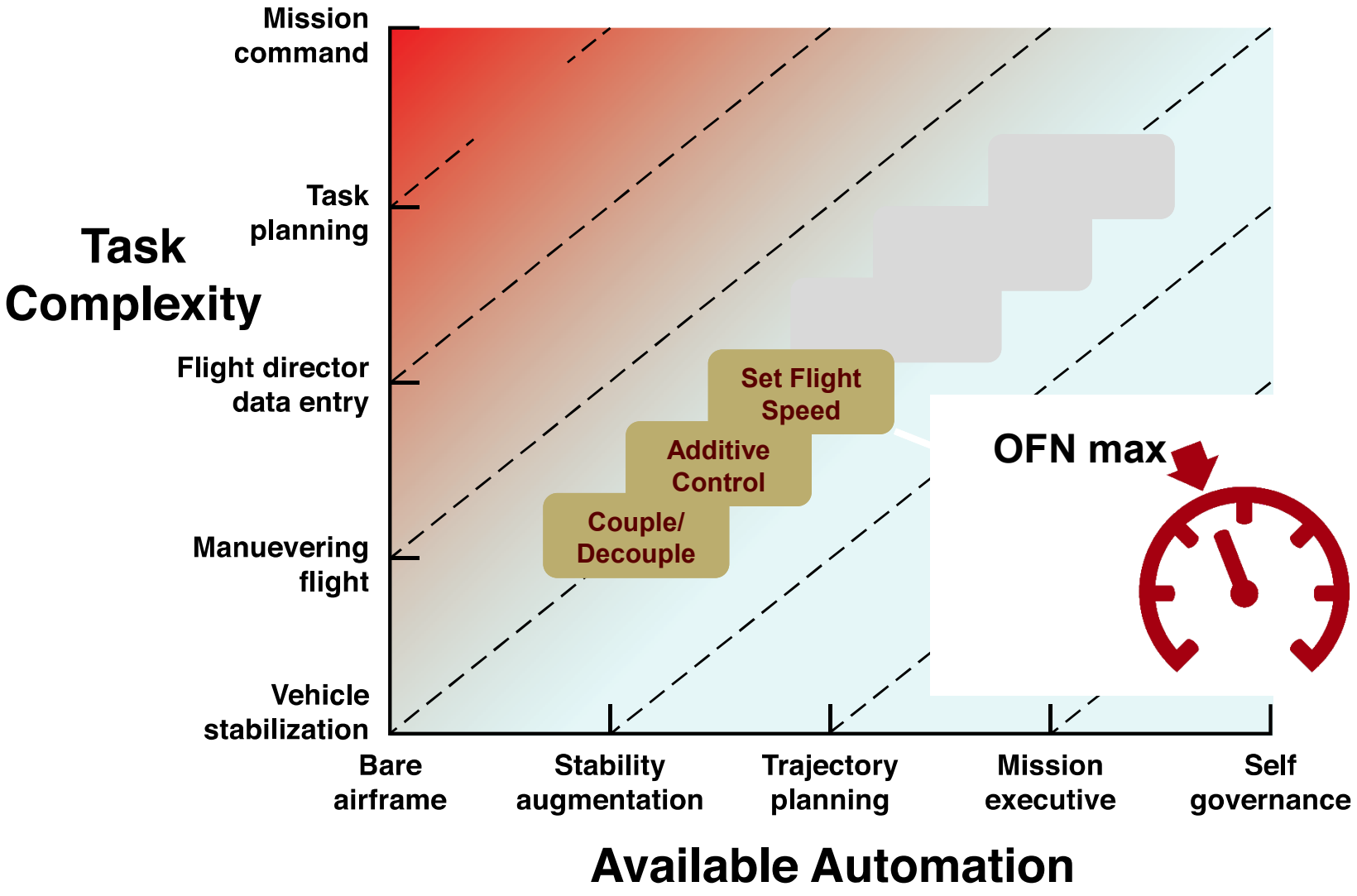
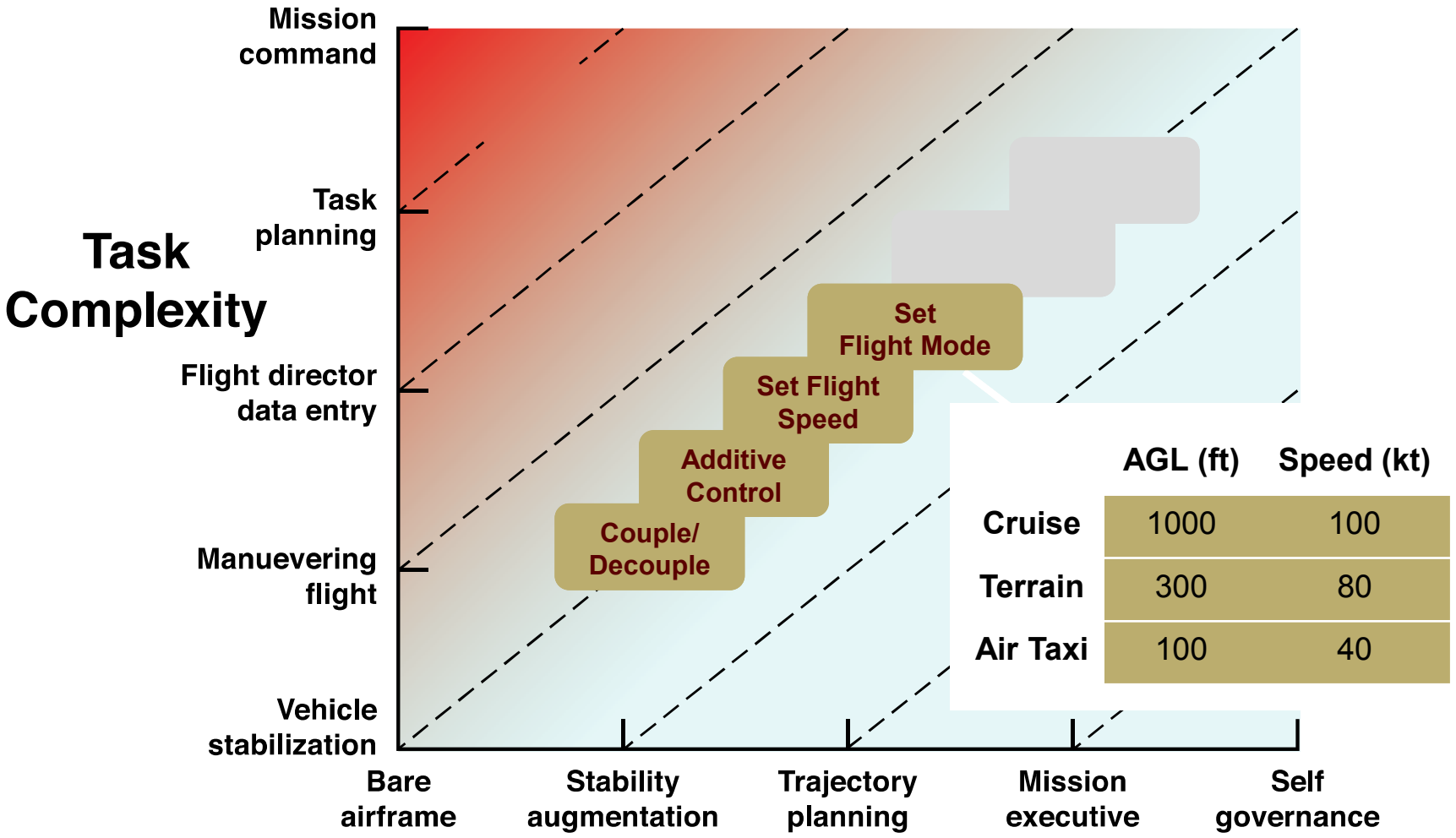


MAA Selectable Features

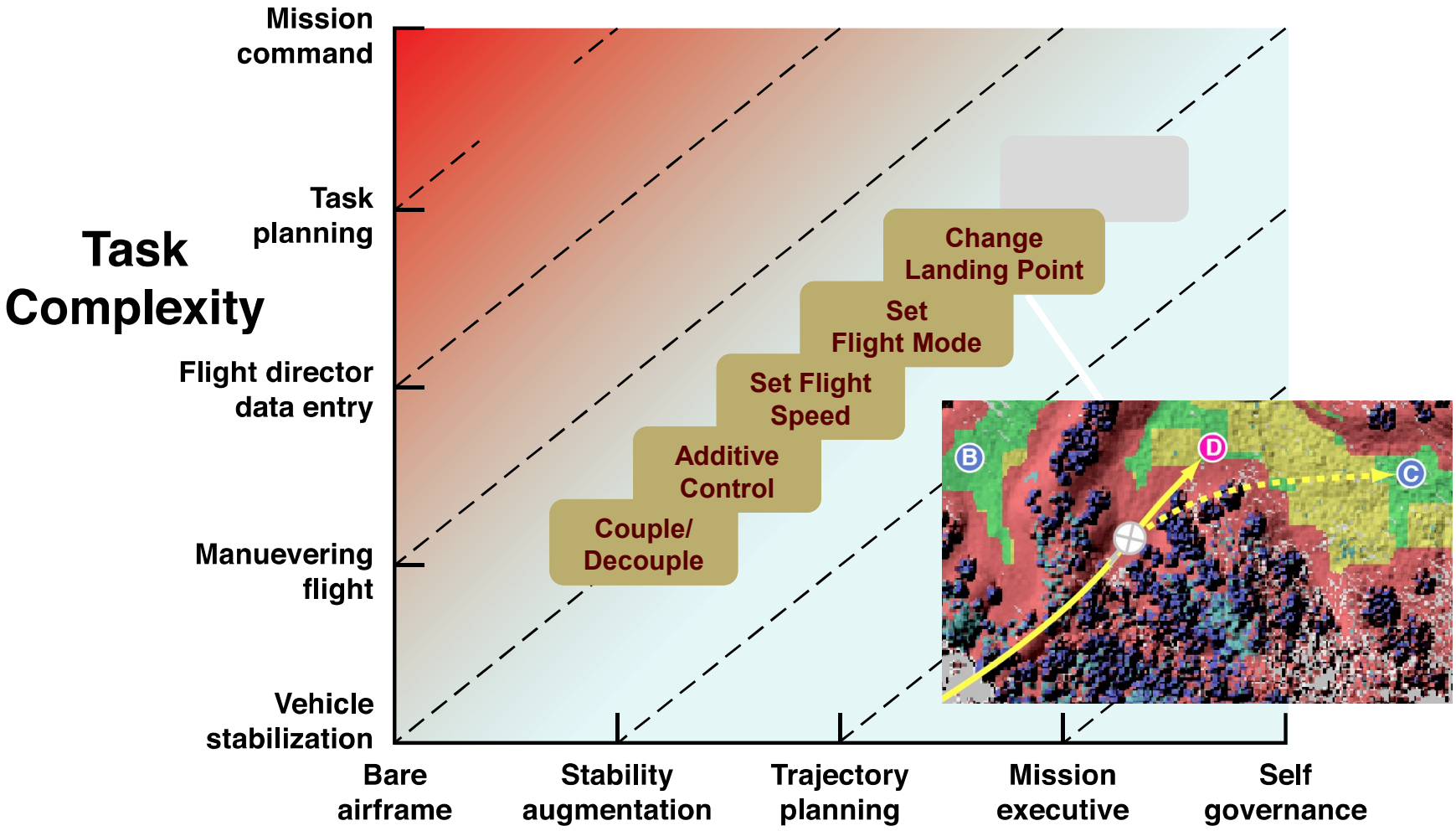


MAA Selectable Features



	AGL (ft)	Speed (kt)
Cruise	1000	100
Terrain	300	80
Air Taxi	100	40

MAA Selectable Features



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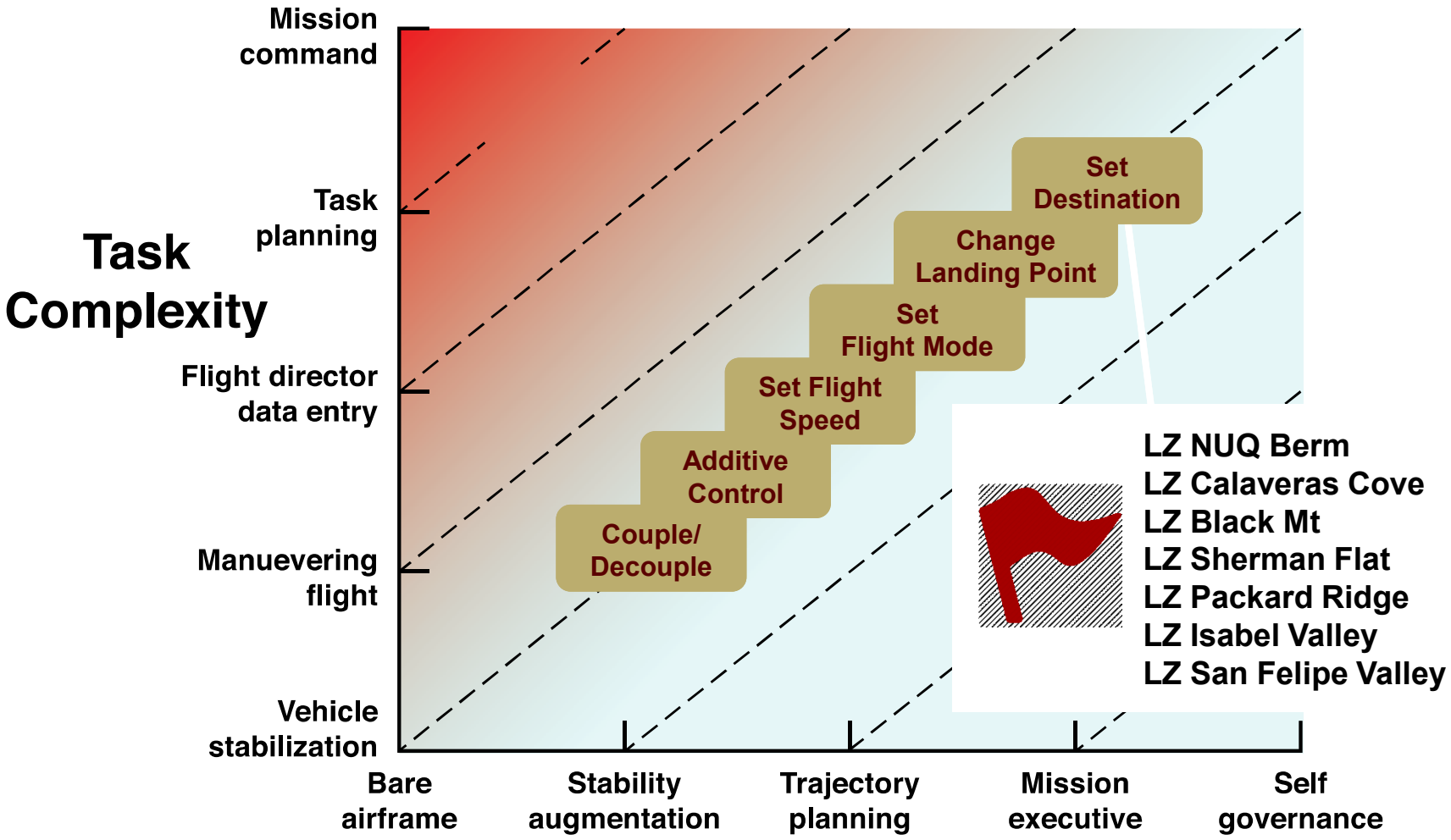


MAA Input

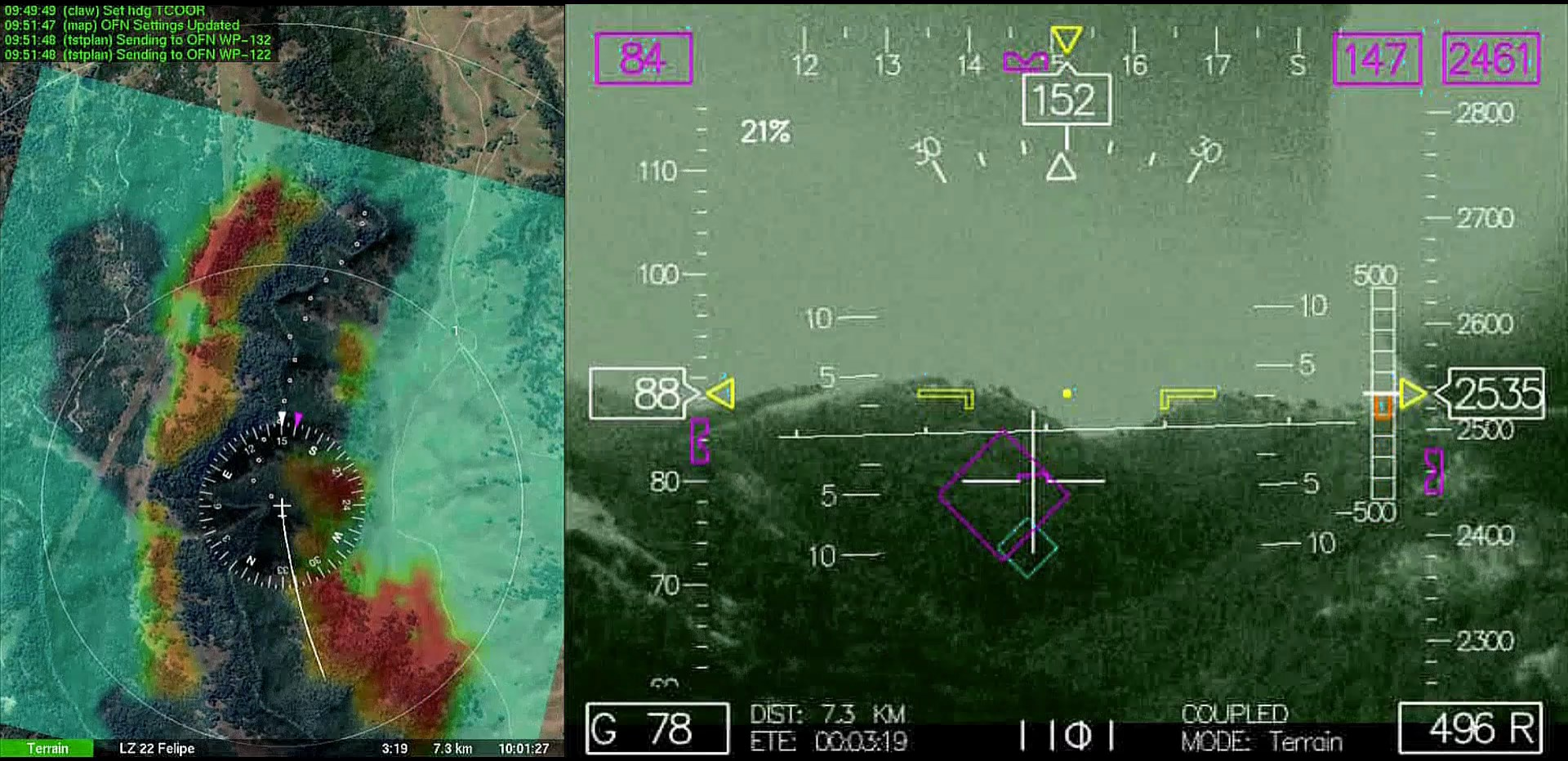
Set destination and flight mode

Push to couple/decouple
Set flight speed *(coupled)*
Stick trim *(ACAH)*

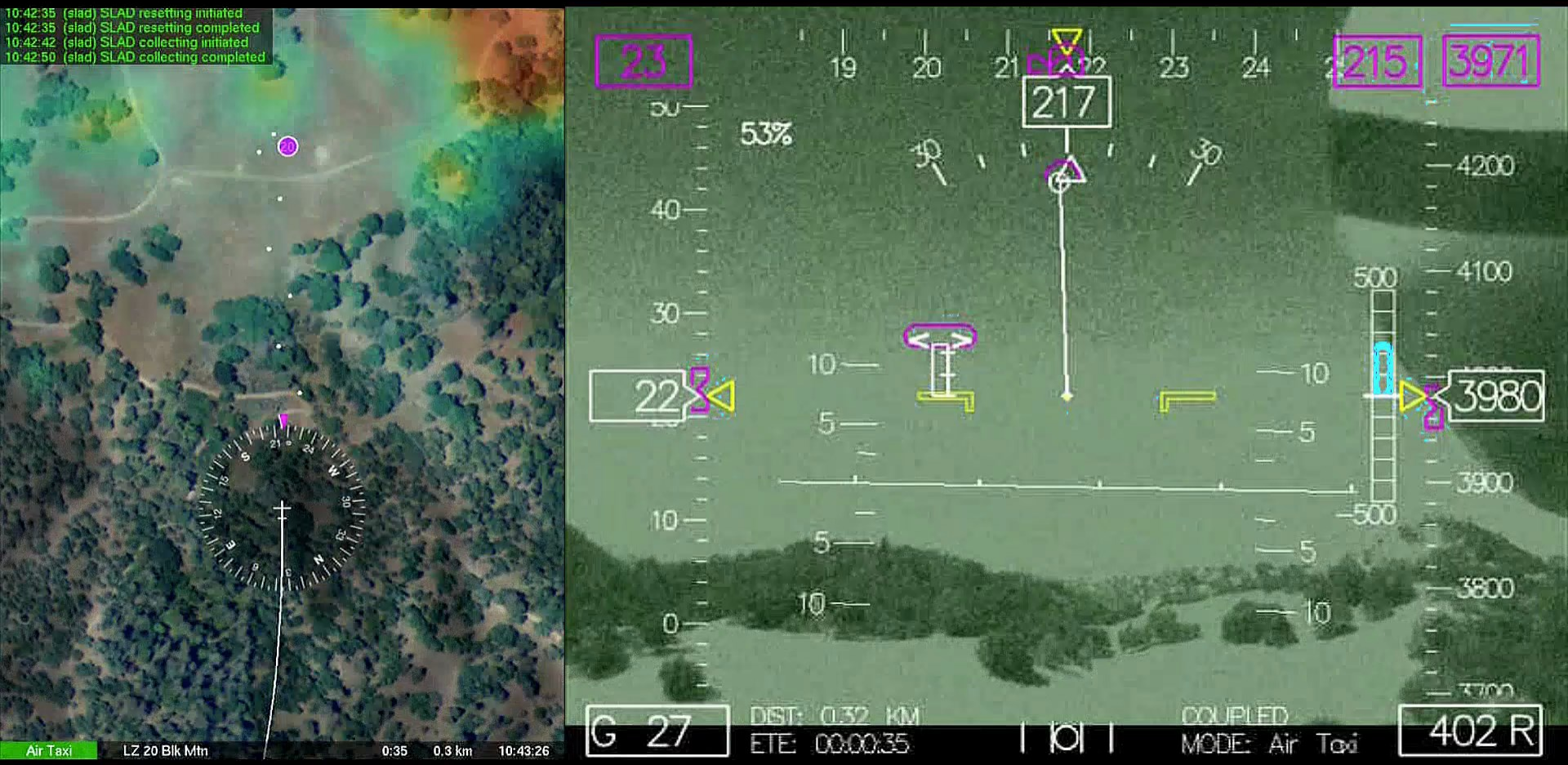
Change landing point

System Setup
MAA Displays

System Setup
Enroute Guidance Symbology



System Setup
Approach Guidance Symbology



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Experiment Overview

- Leverage prior ADD autonomy work
- Add MAA selectable features
- Add display guidance
- Fly utility mission scenarios
- Use filtered NVGs + mask to achieve degraded visual environment (DVE)
- Collect pilot opinion, performance data, workload ratings

RASCAL JUH-60A

Simulated DVE

Three Test Configurations

Configurations

Baseline

Control	ADS-33 Level 1 ACAH	**X**
Display	Primary flight display	**X**
	MAA guidance	
Selectable Features	Set Flight Mode/Speed	
	Change Landing Point	
	Set Destination	
	Control Coupling (autopilot)	
	Additive Control	

Three Test Configurations

Configurations

		Baseline	Display-Only MAA
Control	ADS-33 Level 1 ACAH	X	X
Display	Primary flight display	X	X
	MAA guidance		X
Selectable Features	Set Flight Mode/Speed		X
	Change Landing Point		X
	Set Destination		X
	Control Coupling (autopilot)		
	Additive Control		

Three Test Configurations

Configurations

		Baseline	Display-Only MAA	Full MAA
Control	ADS-33 Level 1 ACAH	X	X	X
Display	Primary flight display	X	X	X
	MAA guidance		X	X
Selectable Features	Set Flight Mode/Speed		X	
	Change Landing Point		X	
	Set Destination		X	
	Control Coupling (autopilot)			
	Additive Control			

Experiment Overview
Mission Scenarios

- **Depart Moffett NUQ to the east**
- **Base radios mission description**
  - Pick up troops, materials
- **Proceed to first destination**
- **Base introduces secondary tasks**
  - SITREP
  - Site RECON
  - Time-on-station estimate
  - Radio relay
  - Copy popup threat coordinates
  - Workload ratings
- **Multiple mission segments**
- **Return to Moffett NUQ**

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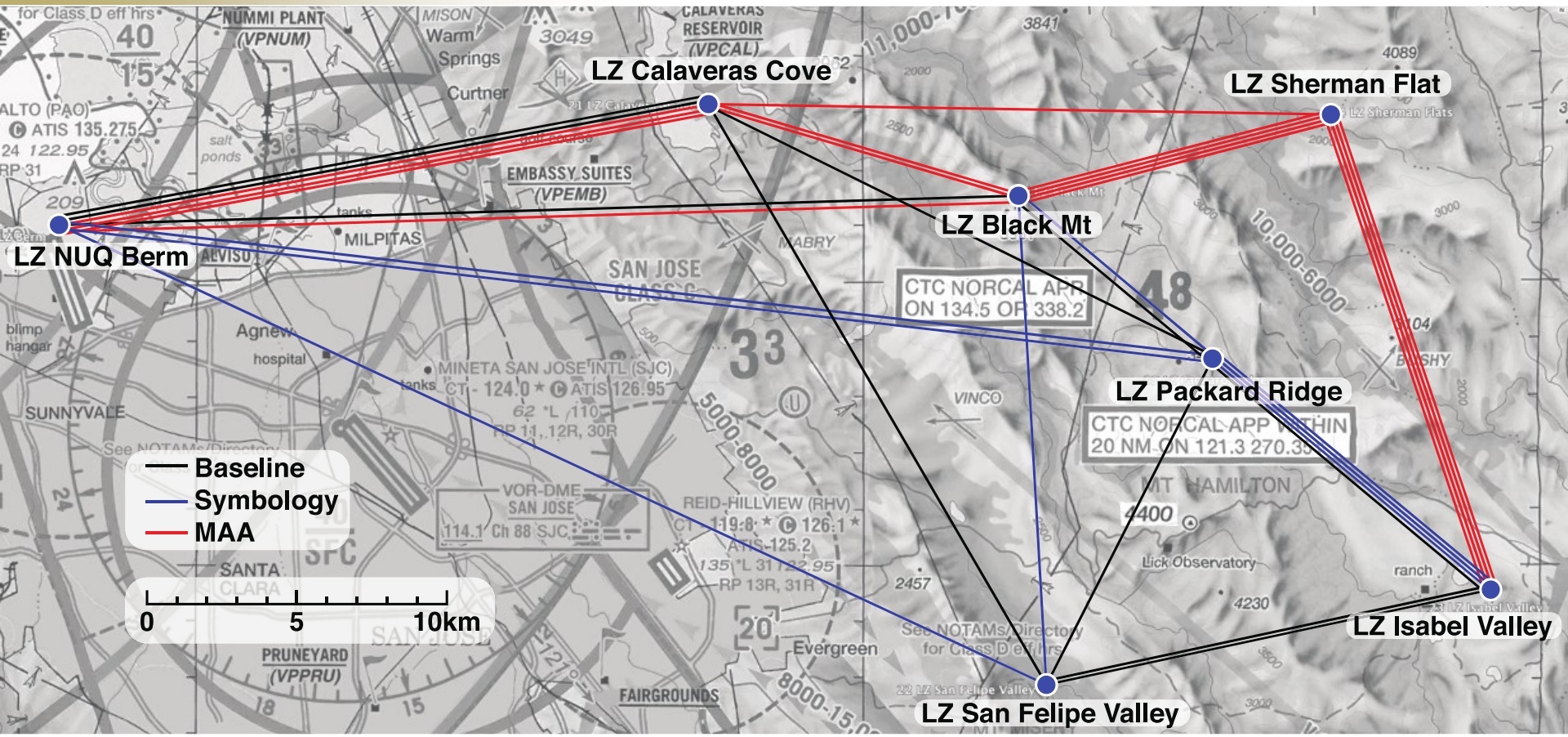
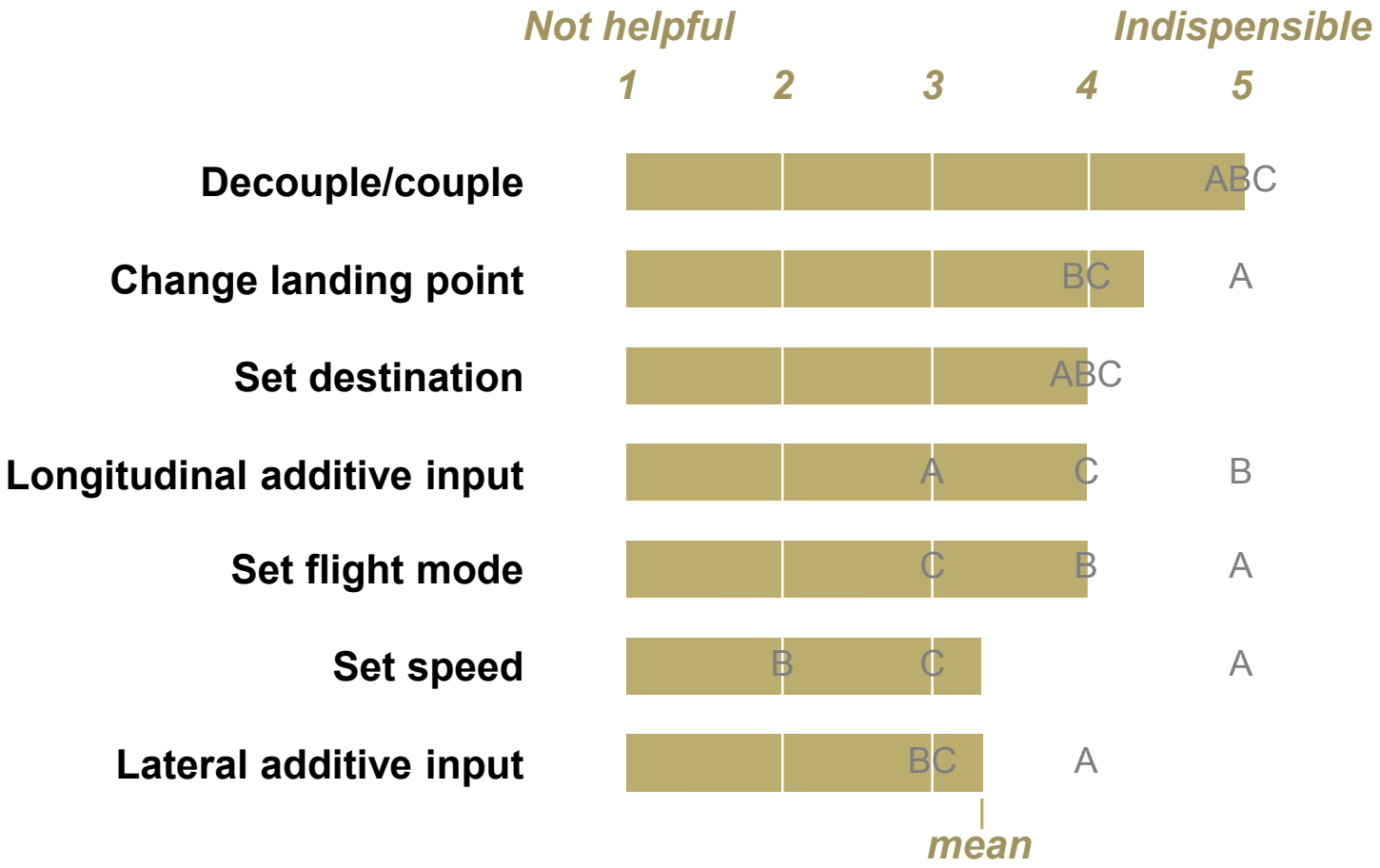
Routes Flown



- 1000+ km flown during development & test
- 90 approaches at 7 locations
- 3 Army XPs (data) + Army XP + Air National Guard pilot

Feature Desirability



*ABC = post-experiment ratings given by three pilots

Display/Guidance Results

Input

- Destination/flight mode input easy
- Pilots suggested a freeform destination input

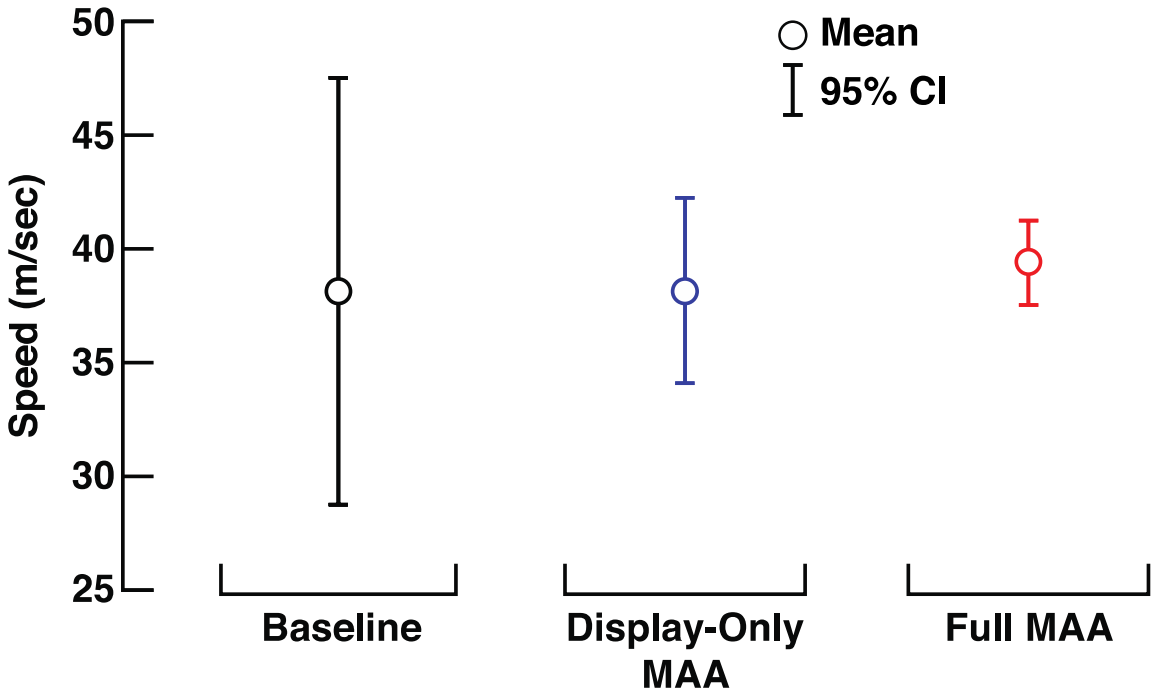
Enroute Guidance

- SPI and blue diamond significantly enhanced predictability and trust
- Manually piloting Display-Only possible but high workload; implied more precision than really required
- Speed guidance for Display-Only should distinguish between too slow and too fast – too fast is a safety concern

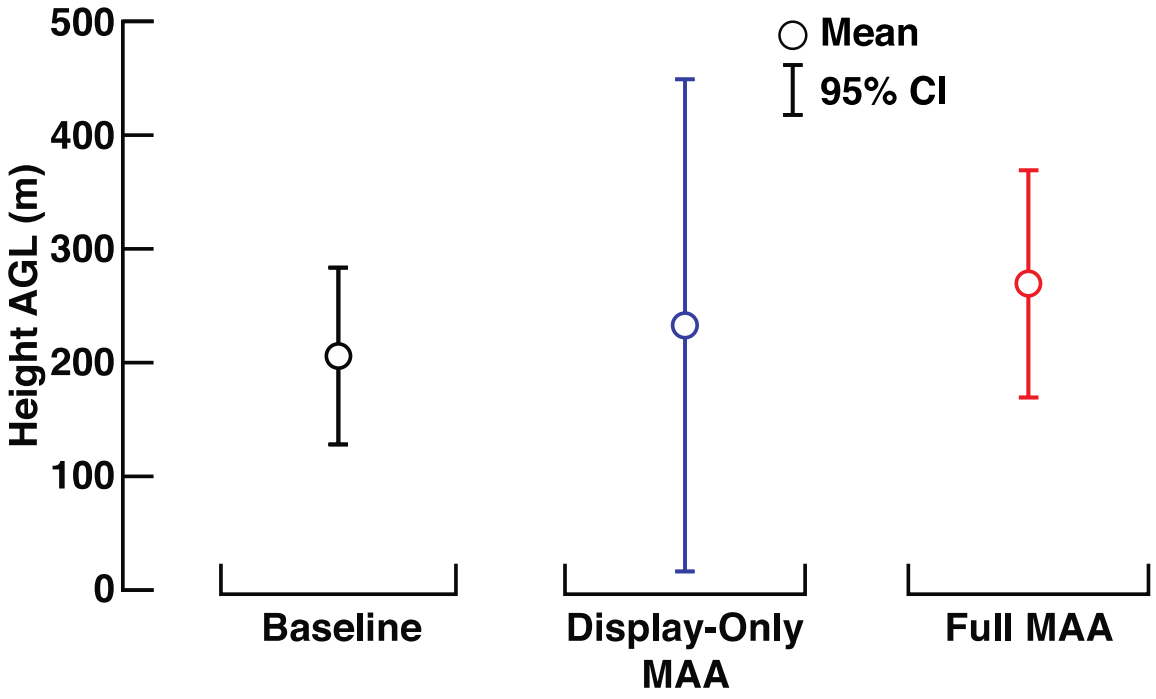
Landing Guidance

- Pilots suggested MLSM results in forward window
- Pilots suggested preselected criteria for LPs to reduce workload on approach

Performance Results
Enroute Speed

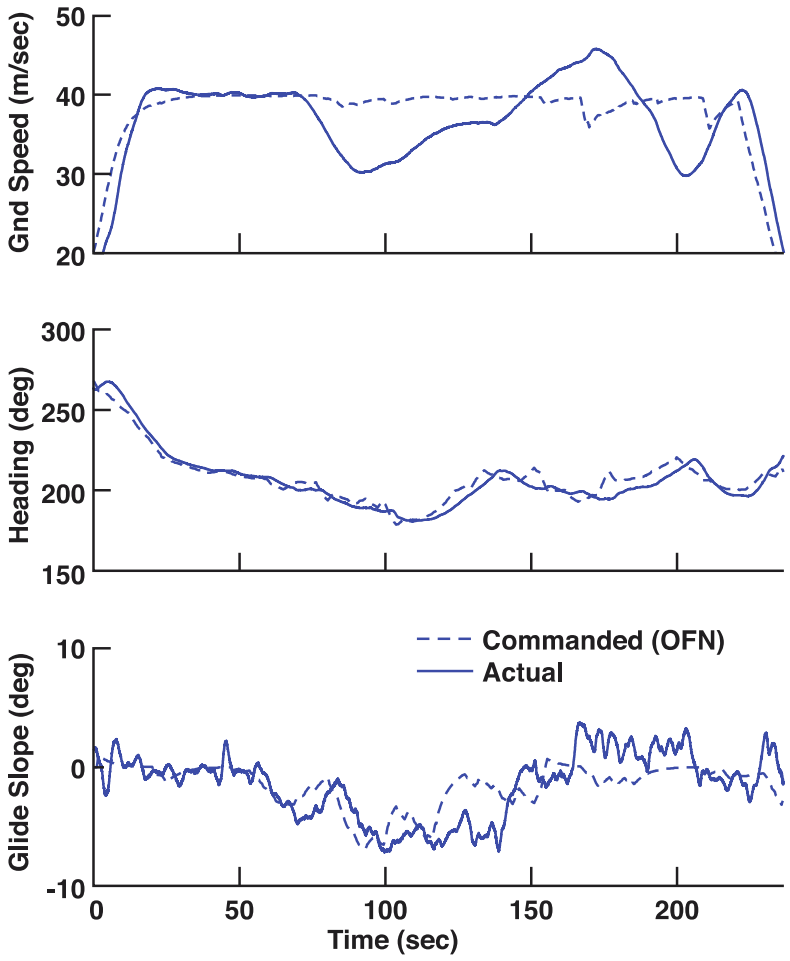


Performance Results
Enroute Altitude

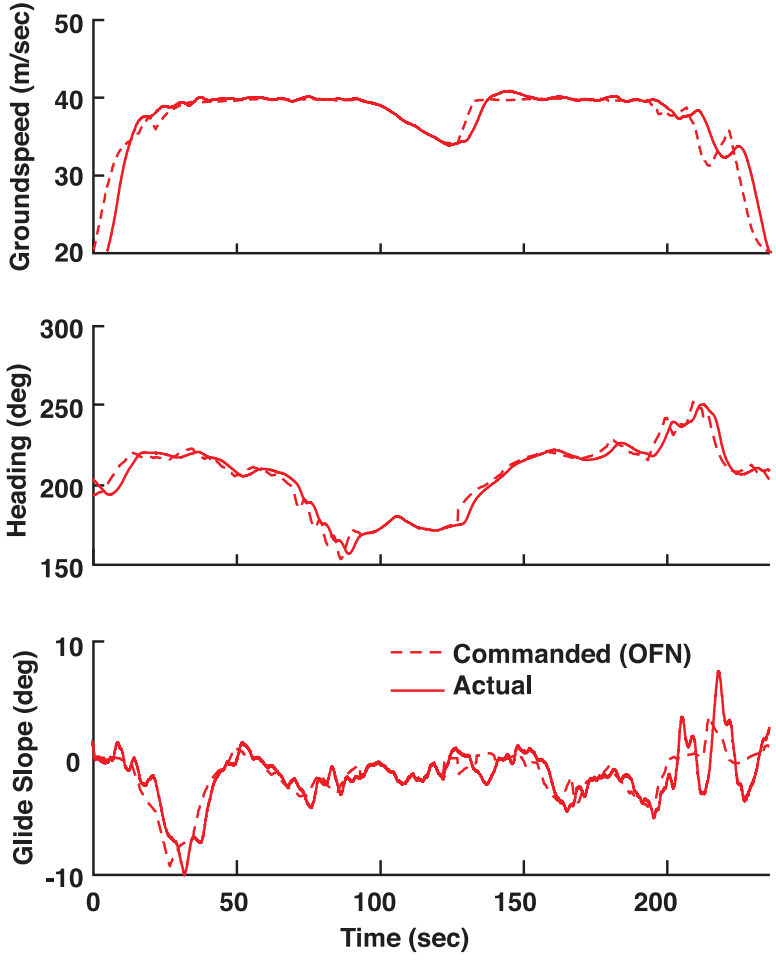


Piloted vs. Auto

Display-Only MAA (pilot following guidance)



Full MAA (coupled AFCS)



Workload
Instantaneous Self-Assessment (ISA)

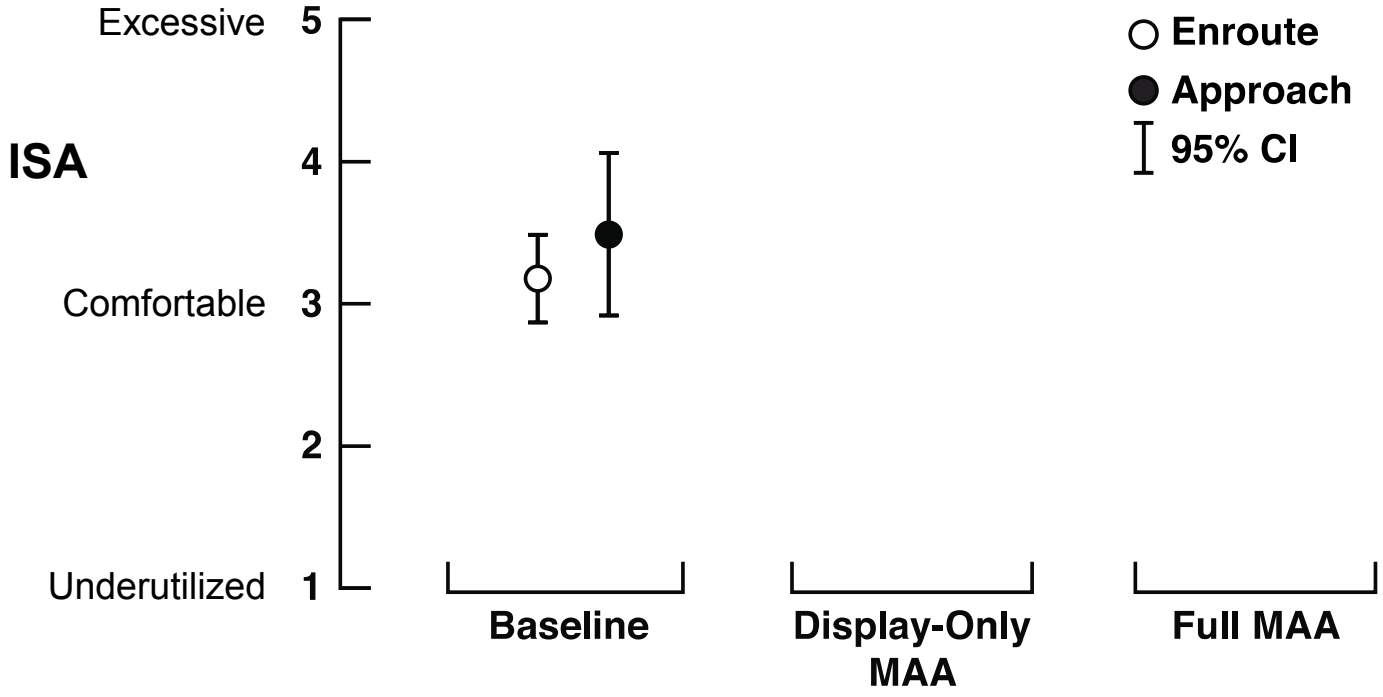
ISA	Workload	Spare Capacity
5	Excessive	None
4	High	Very Little
3	Comfortable	Some
2	Relaxed	Ample
1	Underutilized	Very much

Pro – correlates well with post-test assessment; e.g. TLX*

Con – assigning ISA adds workload; acceptable since we we wanted secondary tasks

**Tattersall, A. J., and Foord, P. S., "An experimental evaluation of instantaneous self- assessment as a measure of workload," Ergonomics, 39(5), 740-748, 1996.*

Workload
Instantaneous Self-Assessment (ISA)



Workload
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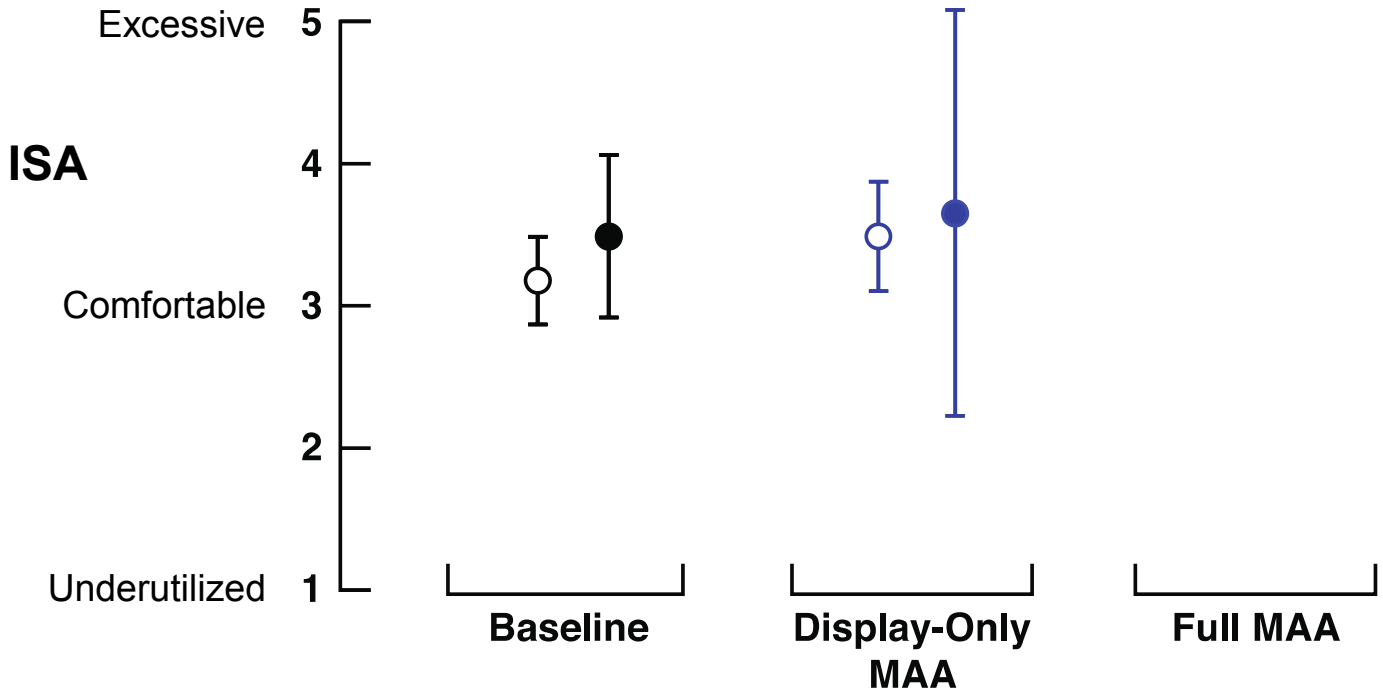

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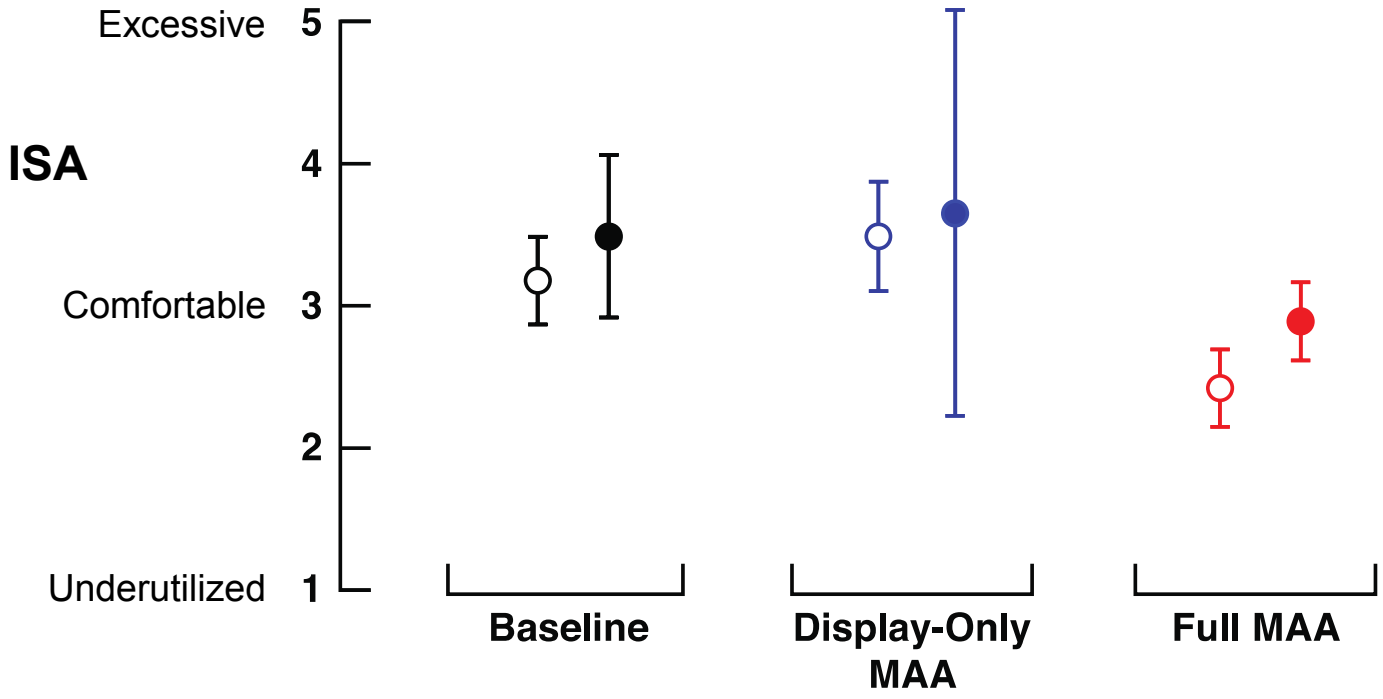
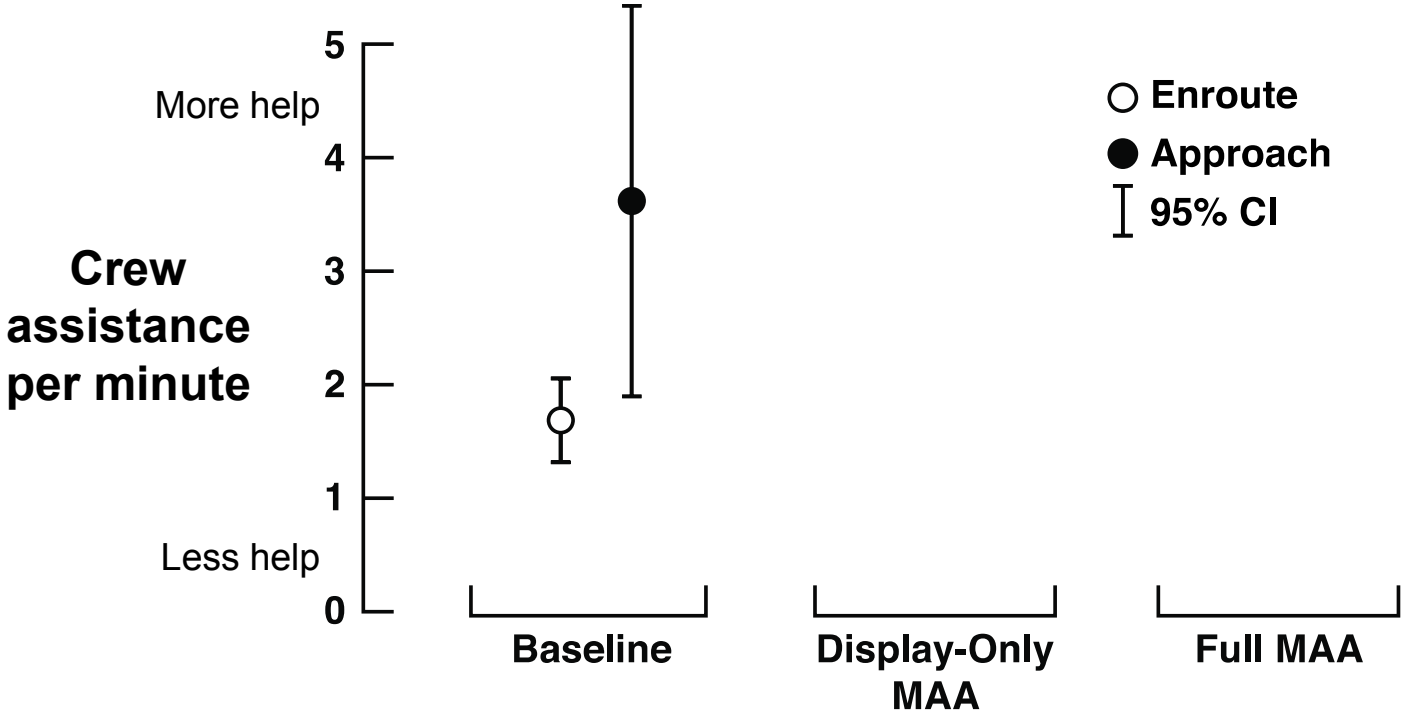
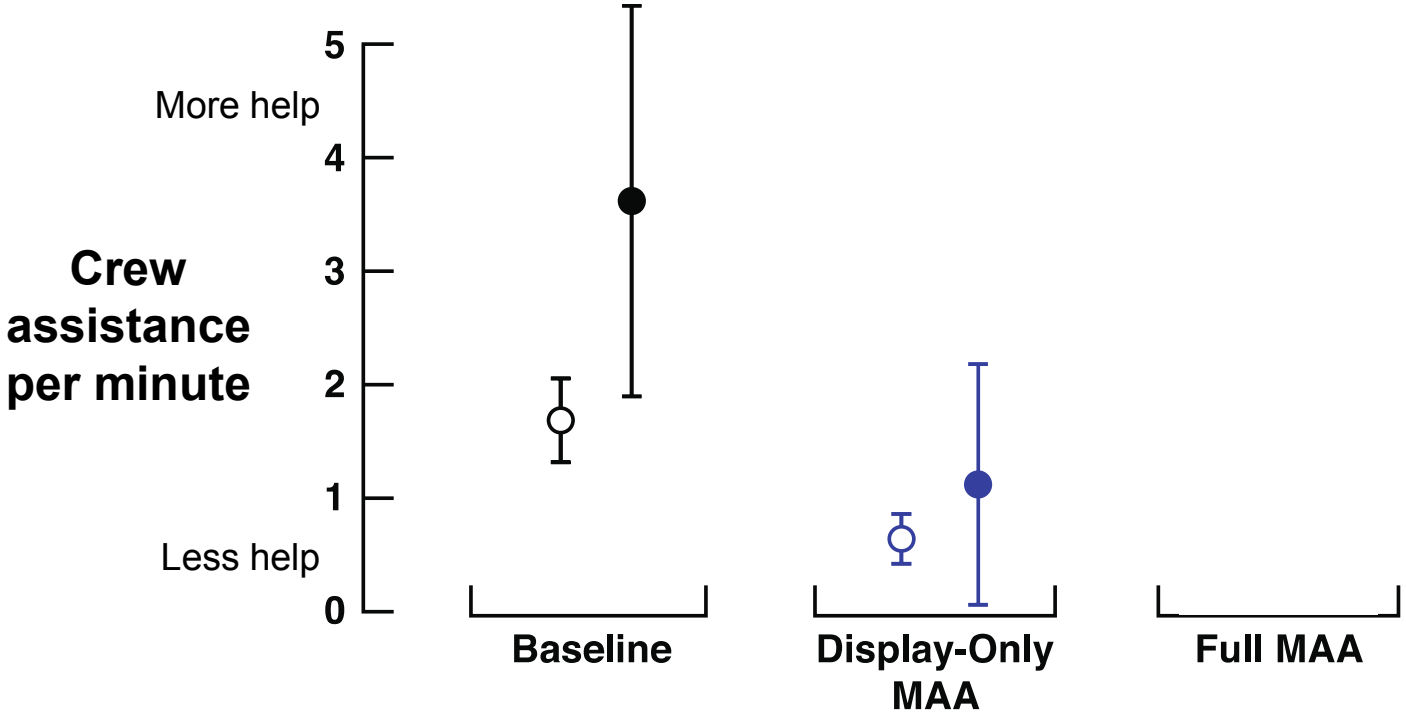


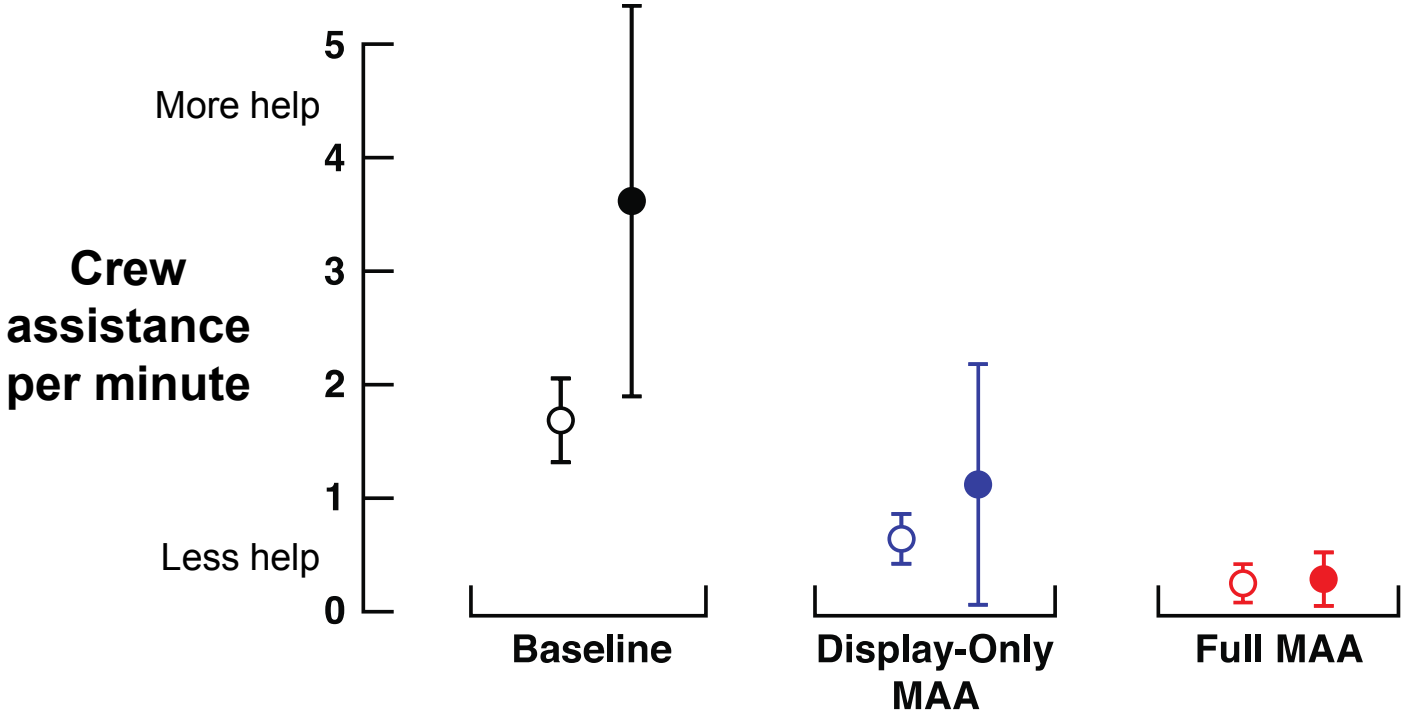
Workload
Crew Assistance



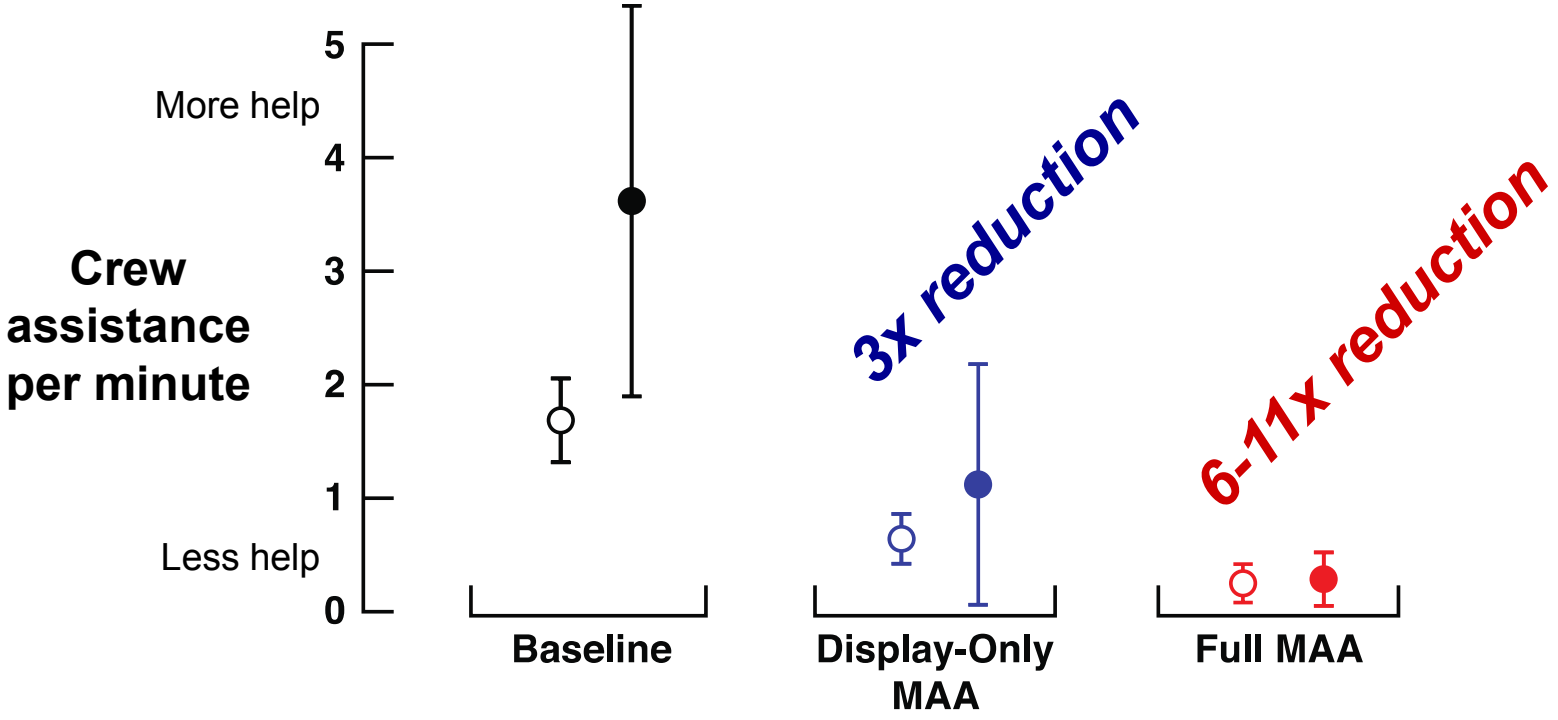
Workload
Crew Assistance



Workload
Crew Assistance



Workload
Crew Assistance



Outline

- ARP Background
- MAA Introduction
- System Setup
- Experiment Overview
- Results
- **Conclusions**

Conclusions

- **MAA system integrated and flown on RASCAL JUH-60A**
- **MAA decreased workload thus increasing spare capacity**
- **MAA feature utility varied:**
  - Good: Decouple/couple, Change landing point
  - Fair: Set destination, Longitudinal additive, Set flight mode/speed
  - Needs work: Lateral additive
- **Display-Only guidance usable but overly precise**
- **Display lead cues critical for increasing trust**
- **Landing point iteration strategy requires careful attention**
- **Strong crew workload effect:**
  - 3x reduction with Display-Only MAA
  - 6x / 11x reduction with Full MAA

Mission Adaptive Autonomy
Aviation Development Directorate Test Team

Vehicle Management and Control TA
Autonomy and Teaming TA
Human Systems Interface TA
Flight Projects Branch, ADD-Moffett

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