

# Surface Evaluation Network for Tethered Inspection and Nondestructive Evaluation (SENTINEL)

Michigan State University

## Team Members:

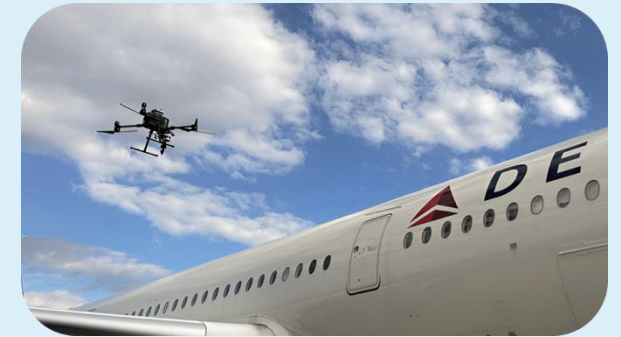
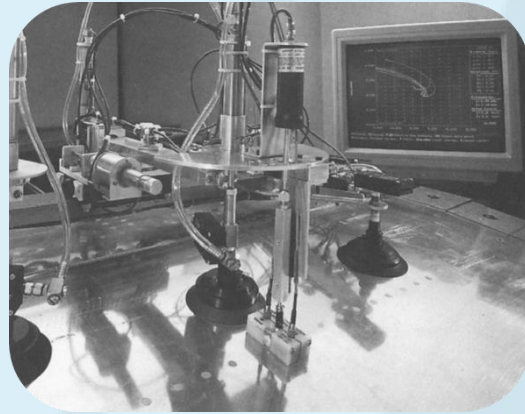
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# Industry Problem: Non-destructive testing (NDT)

- Aircraft maintenance demand is rapidly increasing
- NDT(Non-destructive testing) workforce nearing critical shortage
- Nearly 30% of certified NDT inspectors are over 55 years old
- Manual inspections are labor-intensive and time-consuming
- Future aircraft growth requires scalable inspection automation



# Current Methods & Limitations

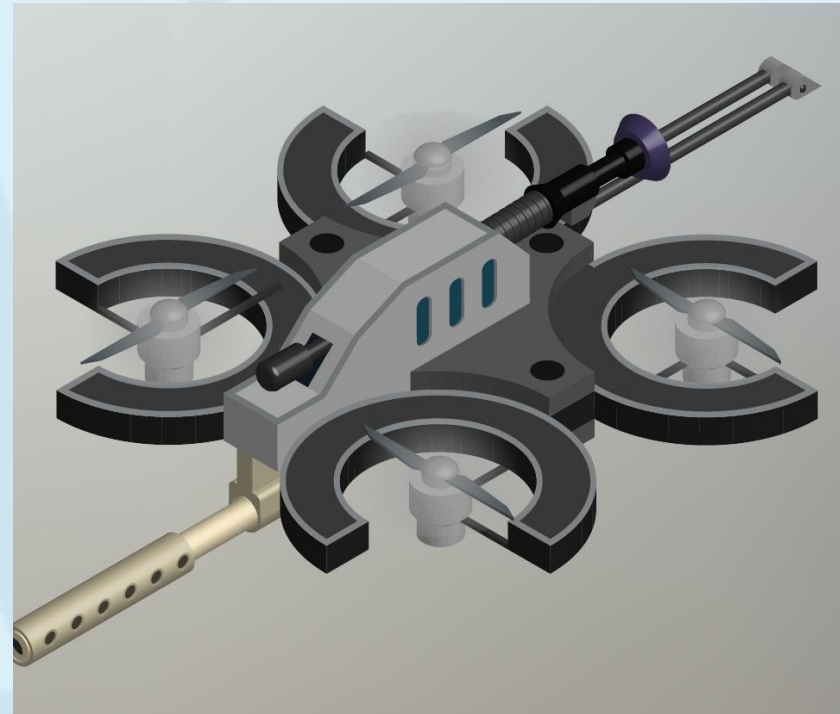


	Robotic Crawlers	Fixed Platform	Free-Flying Drones
Stability	✓	✓	x
Full Airframe coverage	x	x	✓
Continuous Power	x	✓	x
Deployment Flexibility	x	x	✓

# SENTINEL System Overview



**Mobile GCS**  
Winch, power supply



**TUAV**  
Perching Mechanism, ECT probe, SLAM

# Why Tethered UAVs?

## Problem

- Battery life does not guarantee non-stop missions

## Solution:

- Constant power supply through a tether

## New Problems:

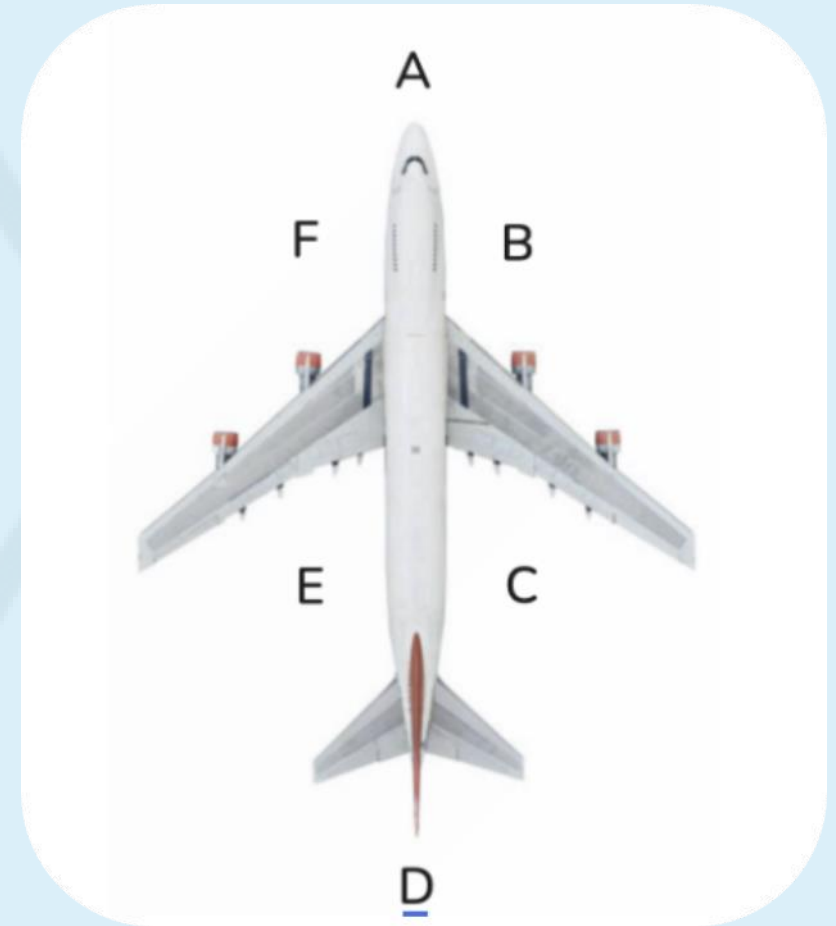
- Entanglement risks
- Stability



# Mobile GCS & tether Management

## Solution: Mobile GCS

- Fixed tether endpoint = eventual entanglement
- Mobile GCS keeps both endpoints variable
- GCS always positioned in the inspection zone
- Winch maintains cable tension in real time



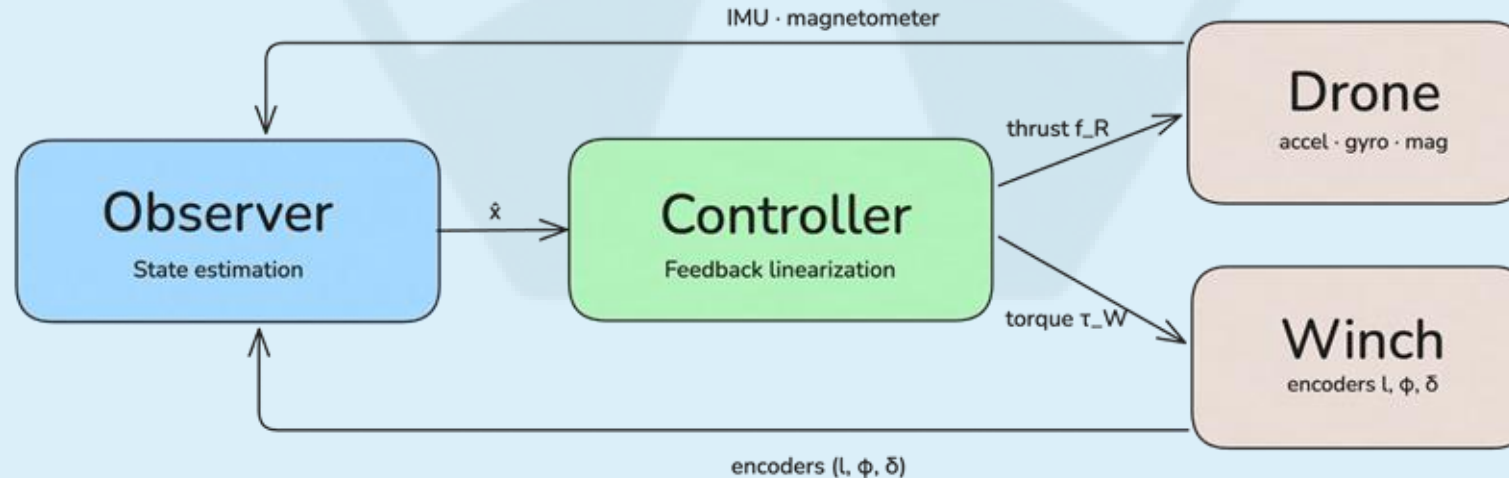
# Stability & Controls

Two operational phases:

- Stationary Inspection
- Zone transition

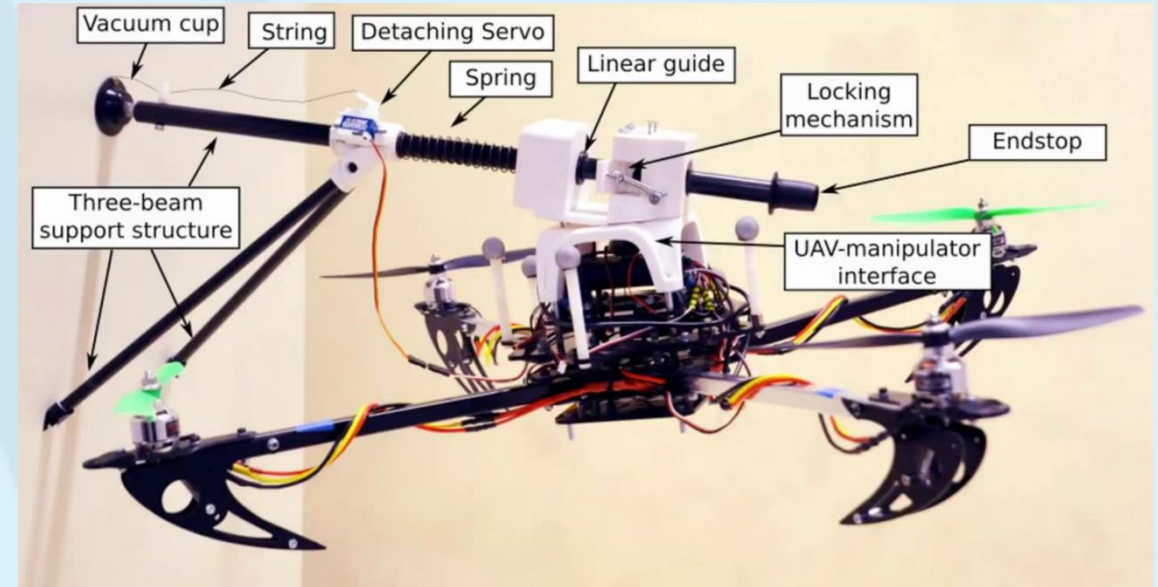
Stability framework:

- Observer-based dynamic feedback linearization
- Proven exponential stability for arbitrary platform trajectories
- Mobile ground vehicle explicitly covered by the model



# Perching Mechanism

- Dual suction-cup docking arms
- UAV attaches directly to aircraft skin
- Removes vibration hover instability
- Enables stable ECT operation
- Stabilization achieved mechanically instead of through flight control



# Mechanical Validation

- Two suction cups generate  $\sim 160$  N holding force
- Total weight estimated at 49-78 N
- Greater than safety factor achieved
- Mechanical deflection remains within ECT tolerance range

# Navigation & SLAM

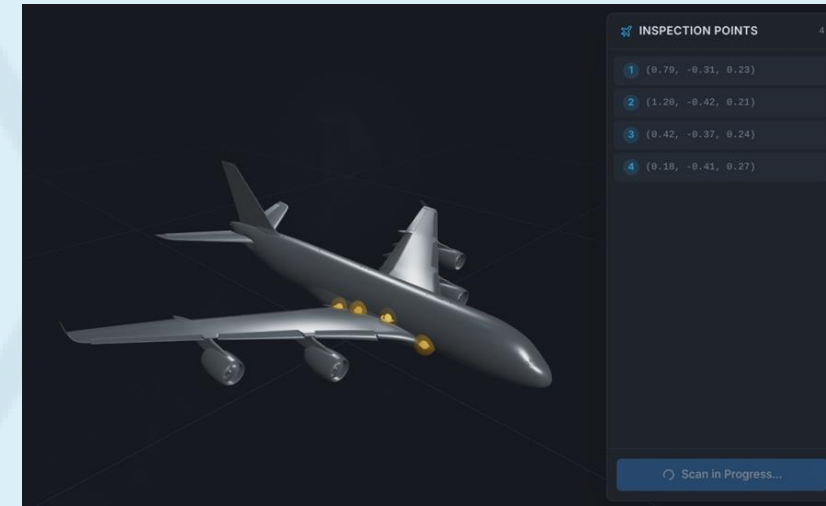
- GPS unreliable inside hangers
- SENTINEL uses LIO-SAM navigation
- LiDAR + IMU based localization
- Enables precise aircraft relative positioning
- Supports collision-free autonomous flight

# Human-in-the-Loop Operations

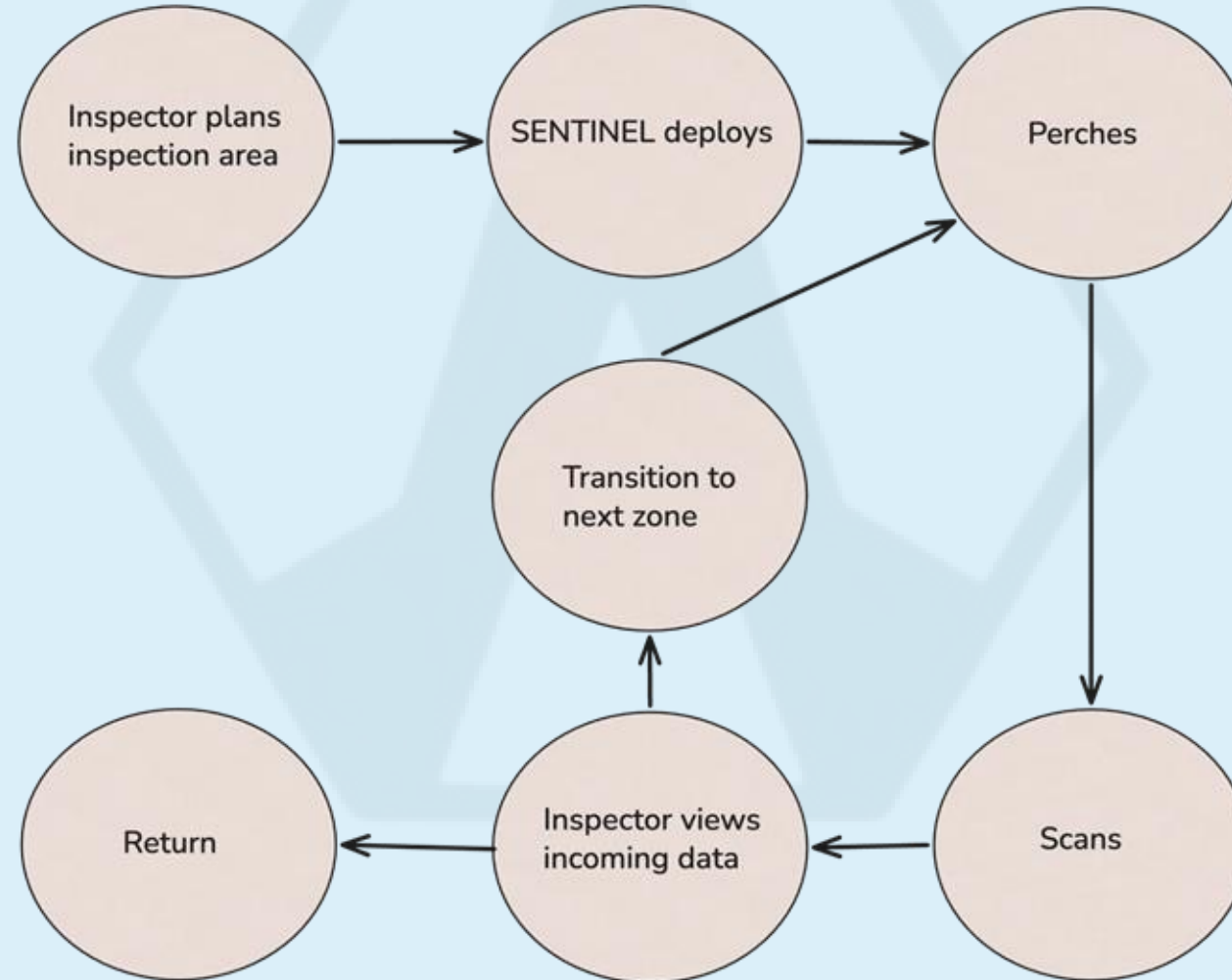
- Inspectors remain responsible for the final validation
- Minimal retraining required
- Compatible with NAS 410 Workflows
- Digital interface for mission planning and review
- SENTINEL augments inspectors instead of replacing them

# Data Pipeline & Digital Twin

- Real-wireless inspection data streaming
- Aircraft digital twin visualization
- Eddy current data linked to aircraft mesh coordinates
- Continuous onboard logging prevents data loss
- Historical inspection tracking supported



# Concept of Operations



# TRL & Technical Readiness

<b>Subsystem</b>	<b>TRL</b>	<b>Status</b>
Eddy Current NDI	8	Industry proven
SLAM Navigation	8	Operational
Perching System	4	Lab validated
Tether Coordination	4	Research validated

# Certification & Regulatory Path

- Indoor operation simplifies approval
- Tether limits operational risk
- NAS 410 data equivalency must be demonstrated
- Similar certification pathways already exist for automated NDI systems

# Time-Motion Analysis

Component	Manual ECT	SENTINEL	Reduction
Access & Setup	20 min	7 min	~65%
Active Scanning	75 min	75 min	0%
Repositioning	20 min	5 min	~75%
Documentation	12 min	0 min	100%
Total per zone	127 min	87 min	~31%

# ROI & Economic Impact

- ~ \$380 labor per C-check
  - \$11,000 annual savings for 50-aircraft fleet
- Estimated system cost: \$ 18k-\$32k
- Projected ROI: 2-3 years
- Reduces inspection backlog caused by labor shortages

# Deployment Timeline

2026-2027:

MVP development

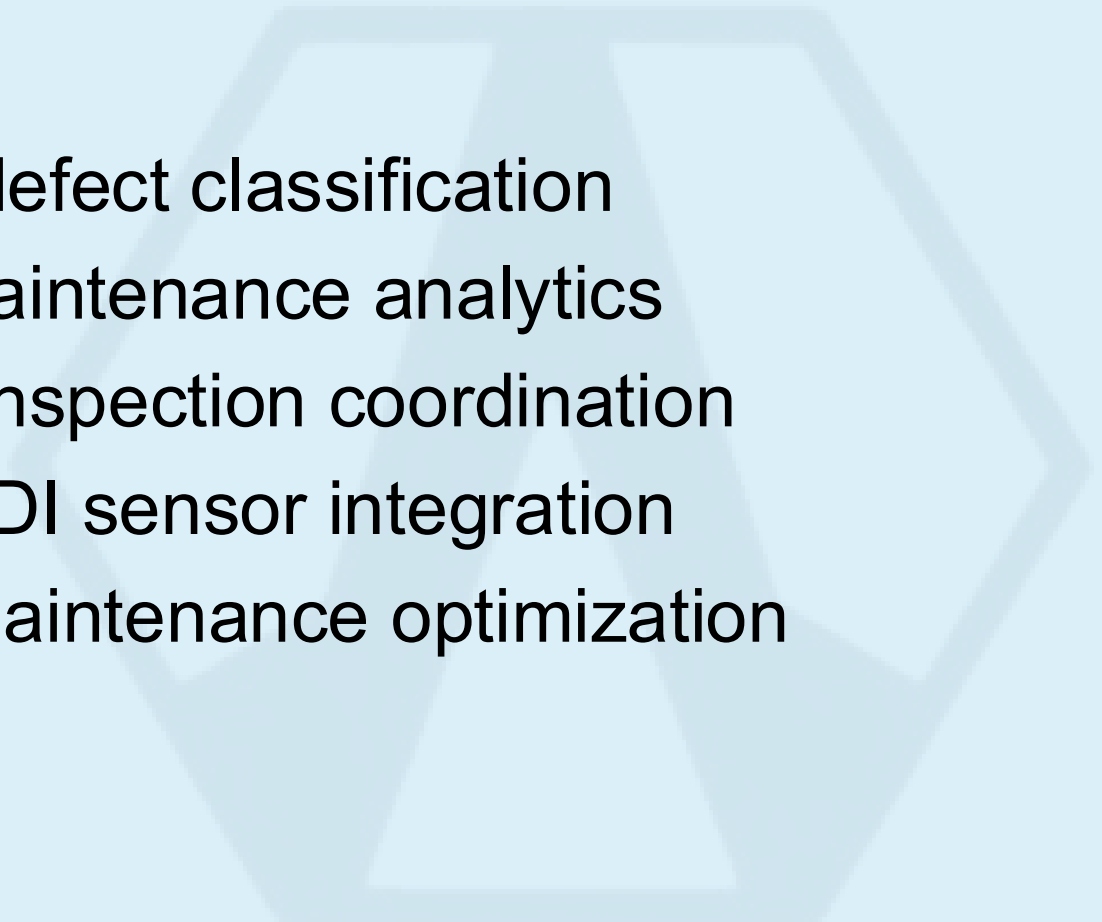
2028-2030:

Certification + manufacturing setup

2031:

projected commercial deployment

# Future Expansion

- AI-assisted defect classification
  - Predictive maintenance analytics
  - Multi-drone inspection coordination
  - Expanded NDI sensor integration
  - Fleet-wide maintenance optimization
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# Conclusion

- The problem:
  - Aerospace NDT is facing a shortage of NDT workers with increasing inspection demand. Current automated NDT methods are either too slow or too unstable.
- SENTINEL addresses this by:
  - Breaking the link between stability and aerial flight control by making use of perching to allow for ECT in the air.
  - Preventing the tangles caused by the tether using coordination between mobile GCS zones and TUAV.
  - Boosting inspection efficiency by up to 60-75% using autonomous operations in parallel.
  - Targeting a ROI in about 2-3 years, coinciding with the anticipated mass launch date of 2031.
- SENTINEL doesn't replace the inspector. It gives them leverage.

Questions?

