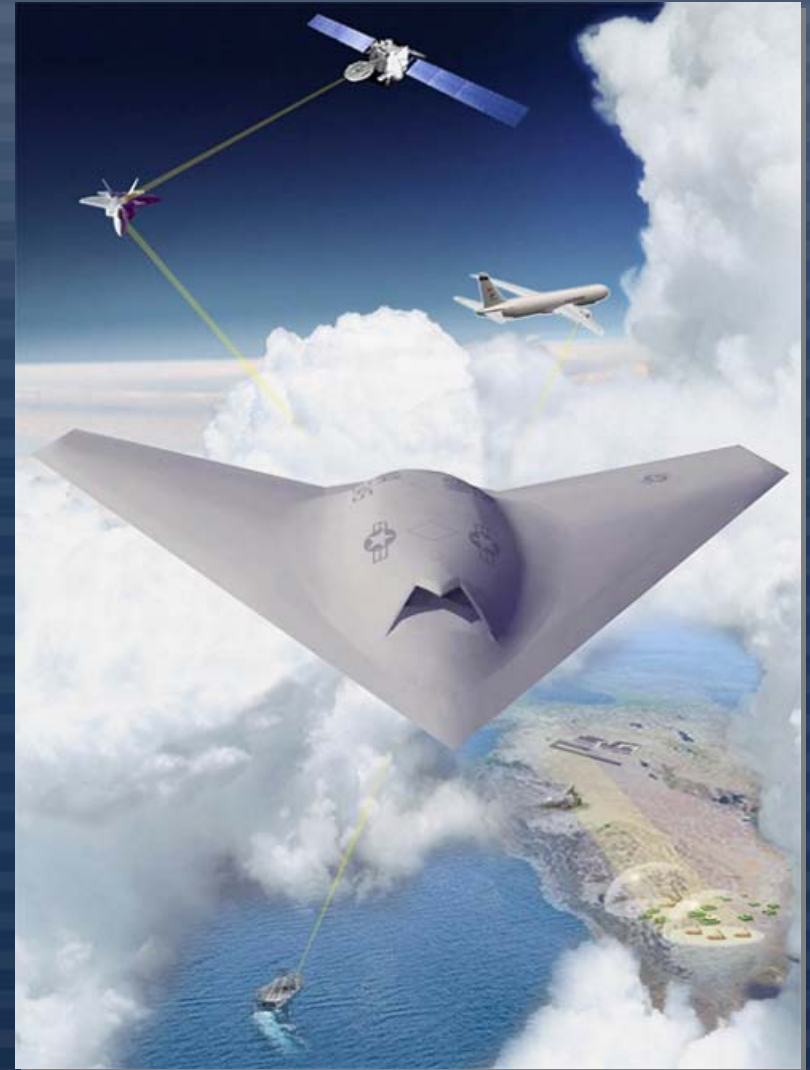




J-UCAS Multi-ship Coordinated Flight Testing at Edwards

Kevin A. Wise, Ph.D.
Senior Technical Fellow
J-UCAS X-45 Program

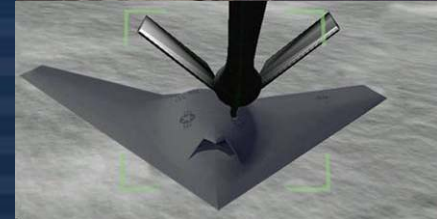
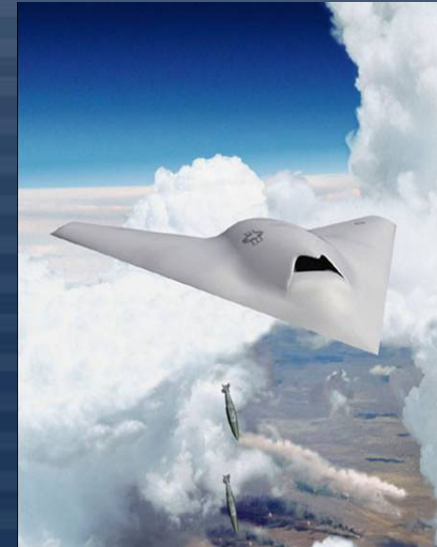


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Outline

- ◆ Program Overview
 - X-45A , X-45C
- ◆ Multiship Formation Control
- ◆ Videos
 - Block 1-2-3
 - Graduation Demo
 - Vignette



VISION

*Become the revolutionary force enabler for affordable
21st century airpower*



MISSION

*Rapidly field a weapon system that integrates distributed
adaptive control technology and robust communications
with a next generation unmanned stealth platform*

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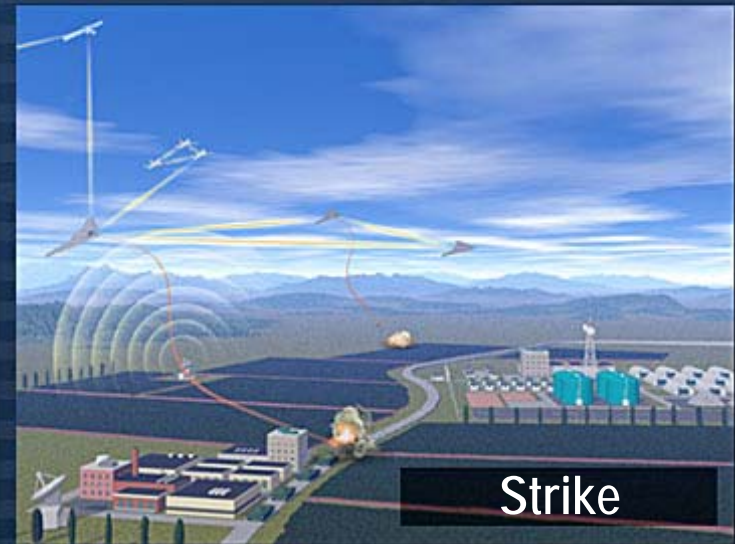
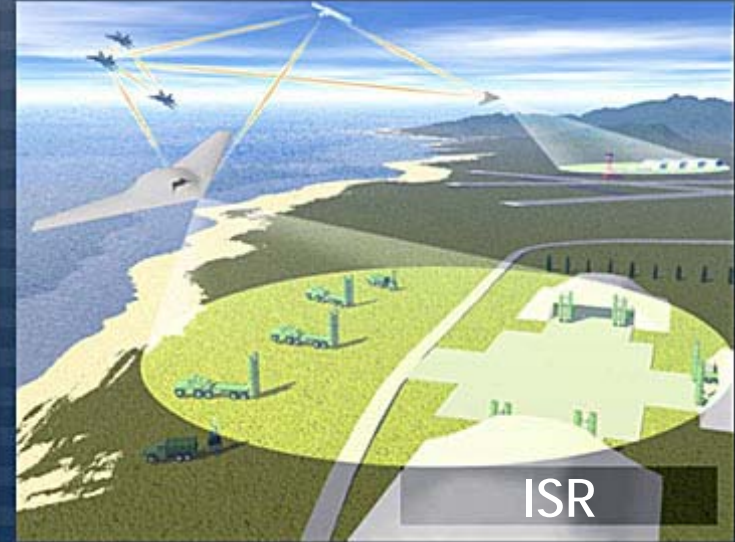
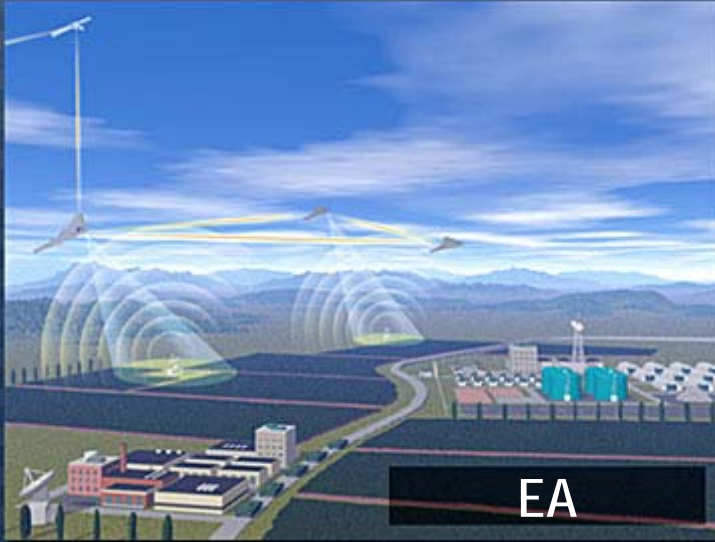
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J-UCAS X-45 System Characteristics

- ◆ Interoperable
 - J-UCAS will be a normal asset/member of the force to be tasked as the Combatant Commander requires
- ◆ Adaptable
 - Flexibility to adjust to the changing combat environment; mission re-planning after launch
- ◆ Autonomous
 - Variable levels to operate efficiently in hostile airspace per ROE
- ◆ Under Human Supervision
 - Operator always in the loop with the ability to trump any system actions
- ◆ Distributed Operations
 - Split operations yields efficient manpower and material asset use
 - Combat employment while minimizing deployment

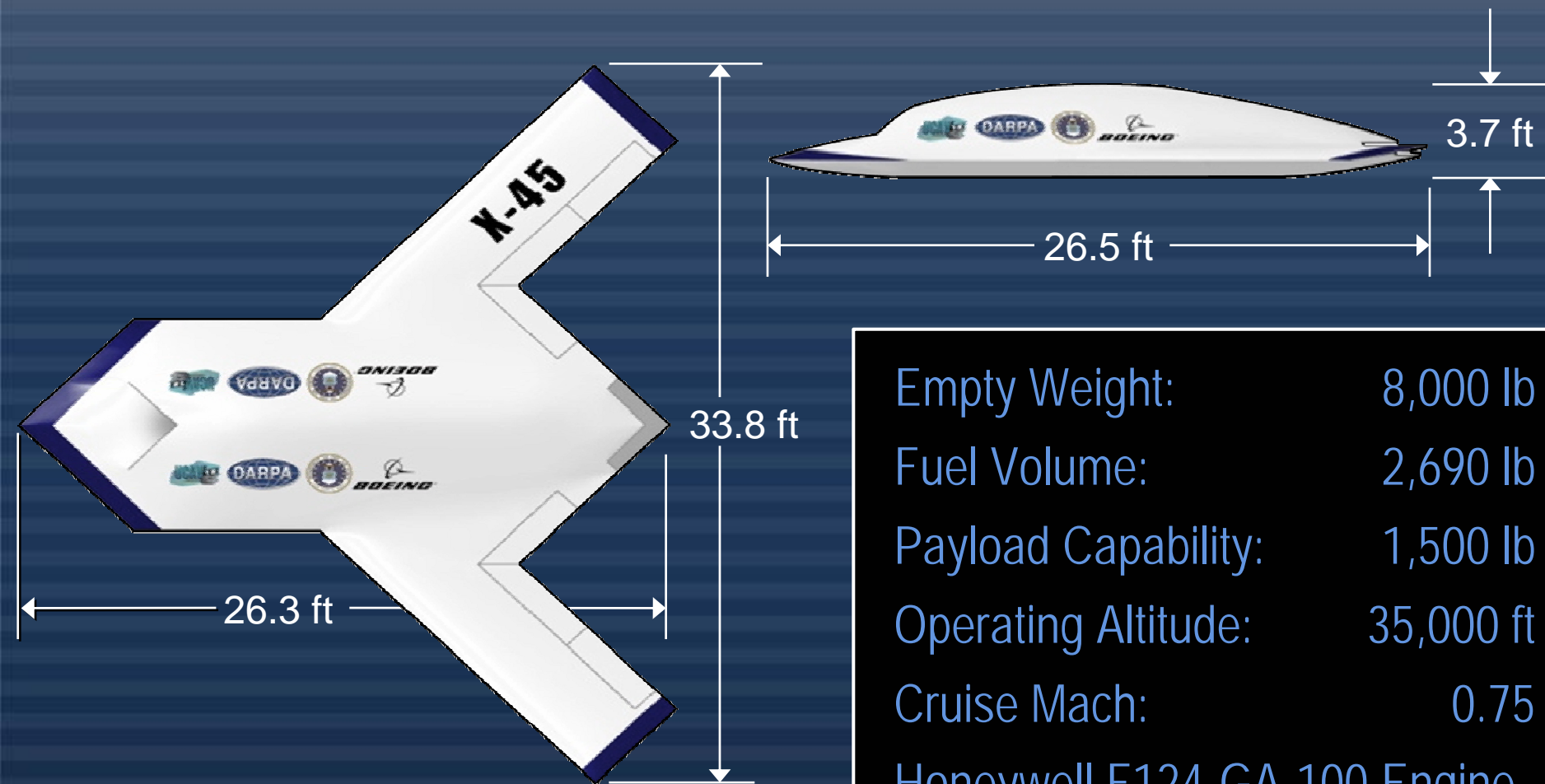
J-UCAS enables legacy systems to engage aggressively in high threat areas – and survive

J-UCAS X-45 Missions



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X-45A Configuration



Empty Weight:	8,000 lb
Fuel Volume:	2,690 lb
Payload Capability:	1,500 lb
Operating Altitude:	35,000 ft
Cruise Mach:	0.75
Honeywell F124-GA-100 Engine	

X-45A System Update



- ✓ X-45A First Flight – May 02
- ✓ Block 1 Complete – Feb 03
- ✓ Block 2 Complete – Aug 04
 - ✓ Guided Weapon Release & First Multi-Ship Flight
- ✓ First X-45C Engine Delivery – Nov 04
- ✓ Block 3 Complete – Feb 05
 - ✓ 3-D/4-D Multi-Ship Demos (Nov 04)
 - ✓ SATCOM Handoff to SEA MCS (Dec 04)
 - ✓ FAO-AOR Handoff (Jan 05)
 - ✓ Peacekeeper Mission Demo (Feb 05)
- ✓ Spiral 0 Complete – Aug 05
 - ✓ PD SEAD Graduation Demo (Aug 05)

X-45A Flight Summary

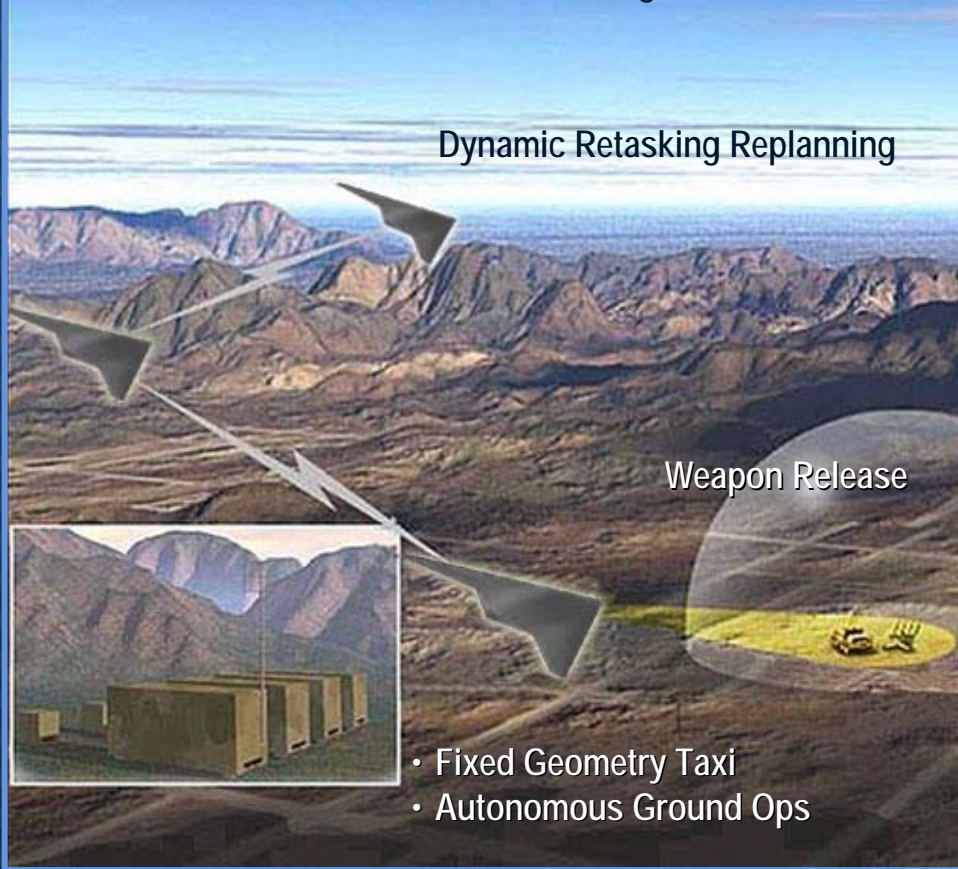
- 64 Flights
- 63 Flight hours
- > 120 T-33 Flights



Spiral 0 Demo End-State

PD SEAD CONOPS

Multi-Vehicle Coordinated/Distributed Flight



Dynamic Retasking Replanning

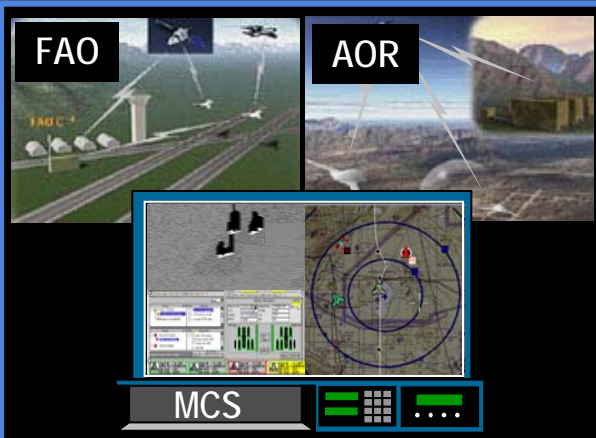
Weapon Release

- Fixed Geometry Taxi
- Autonomous Ground Ops

- ◆ Multi-Vehicle Operations
 - Inter-Vehicle Comm
 - Dynamic/Reactive Taxi
 - Coordinated Flight
 - Rendezvous
 - Tactical Formations
 - CAP/Loiter Patterns
 - Collision Avoidance
 - Contingency Management
 - Distributed Control
 - Dynamic Retasking/Replanning
 - Cooperative targeting
- ◆ End-to-End Demonstrations
 - Single-ship Preemptive Destruction
 - Single-ship Reactive Destruction

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J-UCAS X-45 System Features

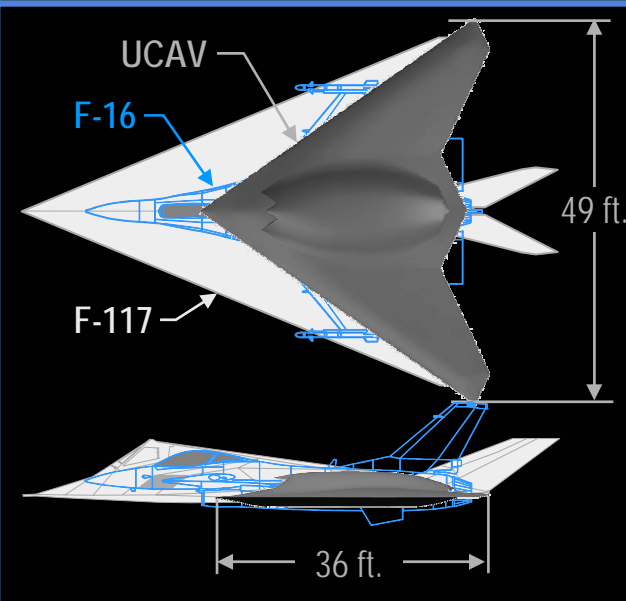


Mission Control Station

- ◆ Task Allocation by Phase of Mission
- ◆ Dynamic Mission Planning and Replanning
- ◆ Single Operator Controls Multiple Vehicles
- ◆ Robust secure LOS, BLOS and intra-flight C2
- ◆ Dynamic Distributed Control
- ◆ Multiple Levels of Autonomy
- ◆ Uses Theater and National Information Sources

Air Vehicle

- ◆ ~36,500 lb Gross Weight
- ◆ ~18,000 lb Empty Weight
- ◆ ~0.8 Mach / 40,000 ft altitude
- ◆ 1100-1300 nm combat radius
- ◆ Current and advanced weapons
- ◆ Electronic Attack (EA) Payloads
- ◆ ESM and On-Board SAR Targeting
- ◆ Affordable Stealth to the Next Level

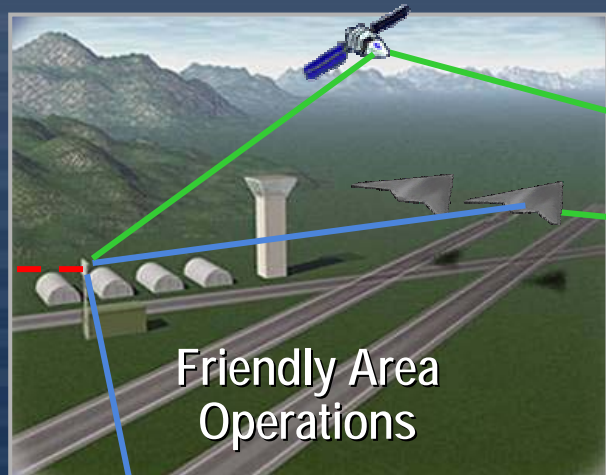


Support System

- ◆ Supportable LO
- ◆ High Sortie Generation Rates
- ◆ No Hydraulics
- ◆ Simulation Based Training
- ◆ Lean Logistics
- ◆ Integrated Vehicle Health Management (IVHM)

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Distributed Adaptive Control Interfaces



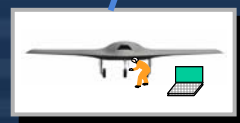
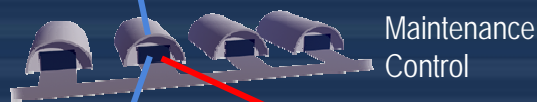
Space Platforms

ISR Platforms

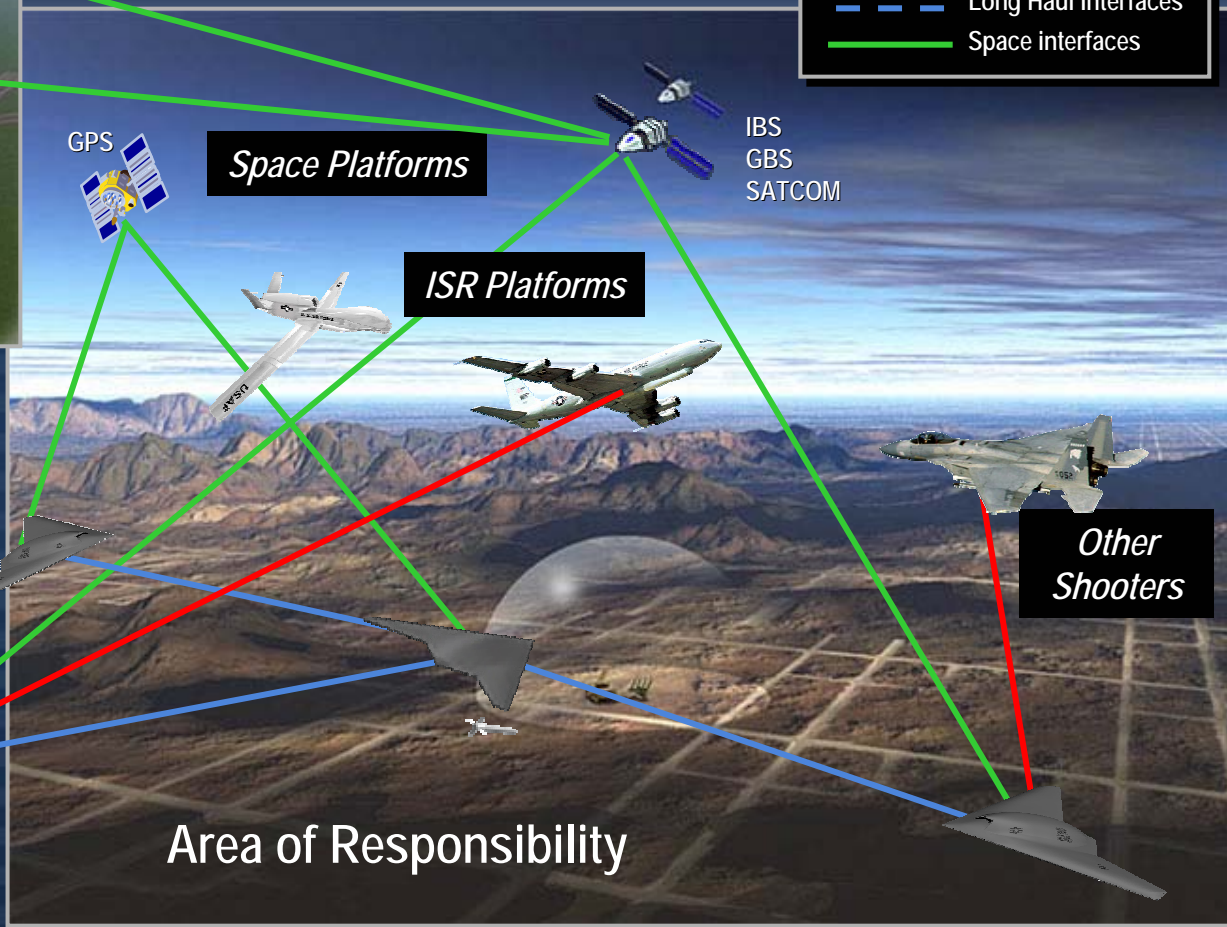
IBS
GBS
SATCOM

Legend for interface types:

- Red line: External Interfaces
- Blue line: Internal Interfaces
- Red dashed line: Long Haul Interfaces
- Green line: Space interfaces

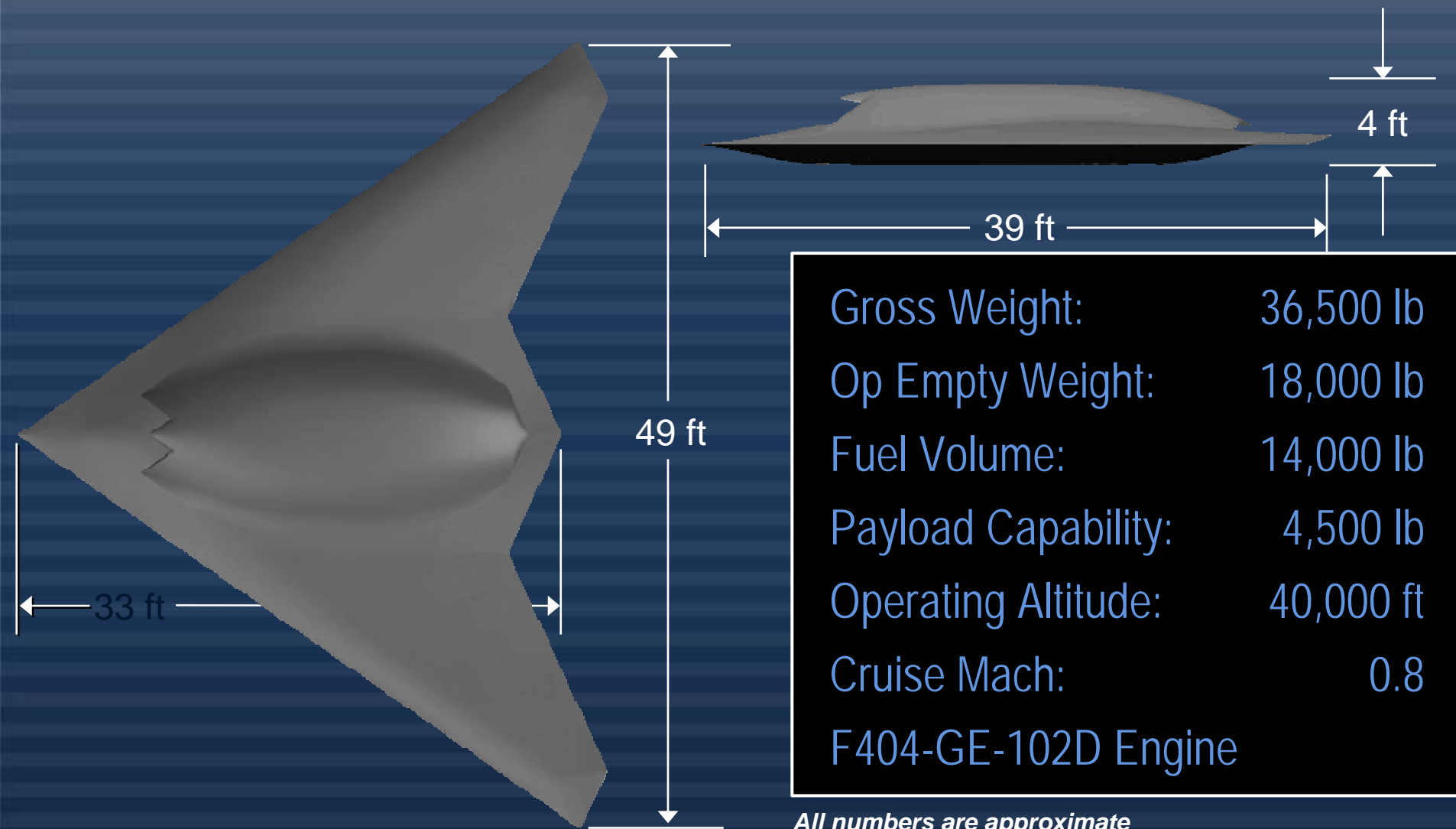


MCS



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X-45C Air Vehicle Configuration



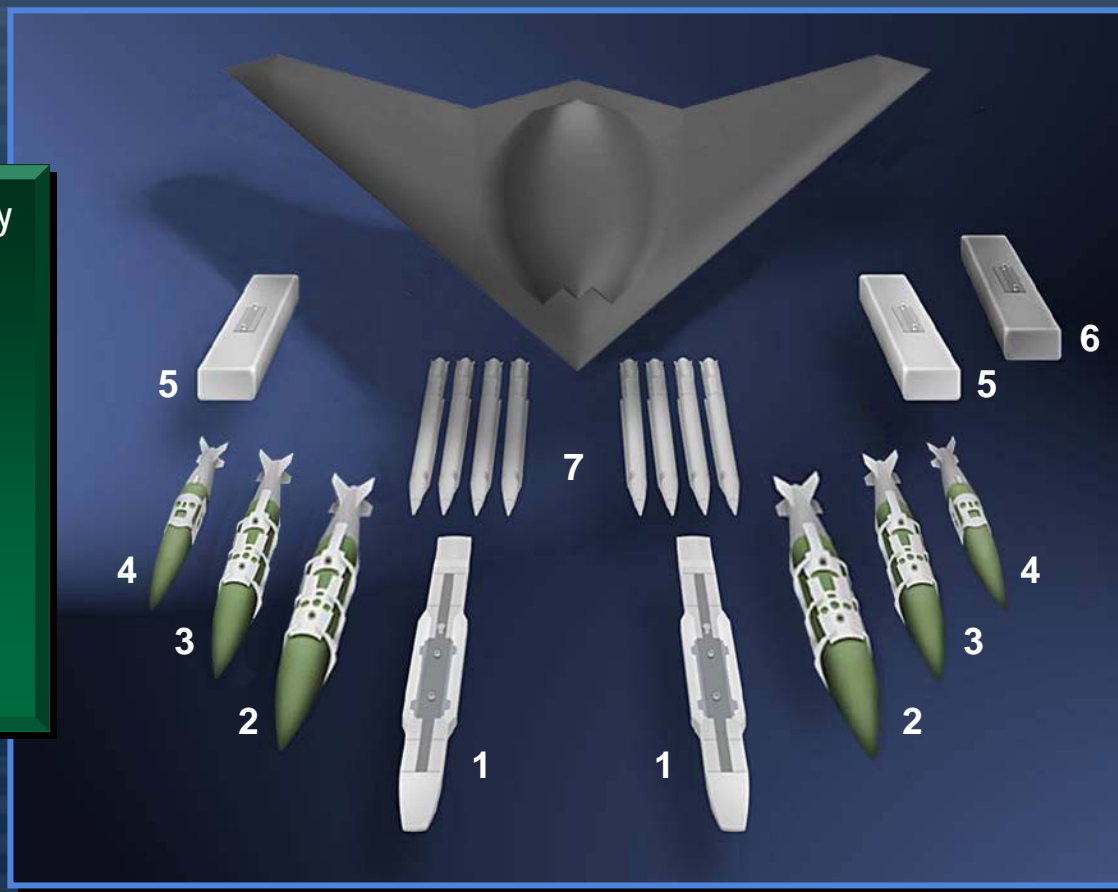
Gross Weight:	36,500 lb
Op Empty Weight:	18,000 lb
Fuel Volume:	14,000 lb
Payload Capability:	4,500 lb
Operating Altitude:	40,000 ft
Cruise Mach:	0.8
F404-GE-102D Engine	

All numbers are approximate

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Payload Flexibility

Key	Quantity
1 – BRU 61 Bomb Rack	2
2 – GBU-31 JDAM	2
3 – GBU-32 JDAM	2
4 – GBU-38 JDAM	2
5 – Internal Aux Fuel Tank	2
6 – Missionized Payload	1
7 – GBU-39 SDB	8-12



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Next Phase Highlights



Cooperative Manned / UCAV Operations



Deployment



Deployed MCS



Mission Planning



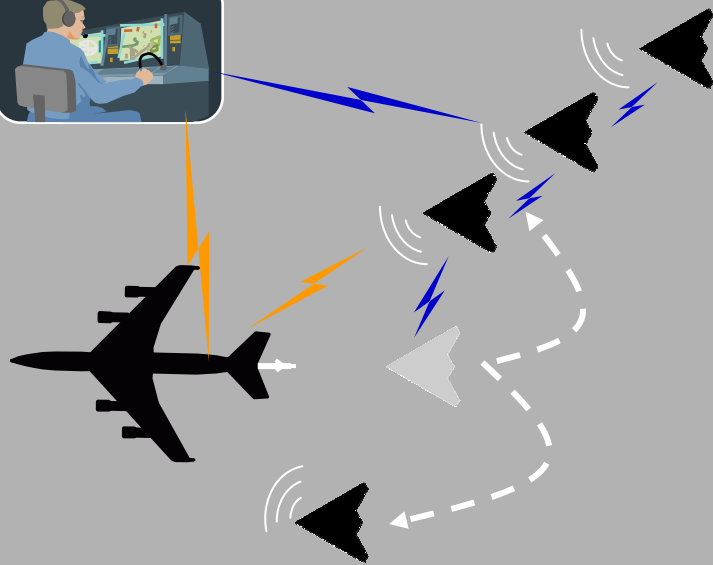
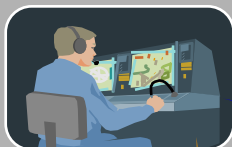
Ground Operations

- ◆ X-45C Performance
 - Flight envelope/weapons drops
 - Survivability/affordability
- ◆ Battlespace Interoperability
 - Safe operation with manned aircraft during ground and flight operations
 - Use off-board targeting info
- ◆ Multi-Vehicle Operations
- ◆ Supportability
 - Deployment/weapon loading/turn time
 - LO maintainability evaluation
 - Simulation based training
 - Integrated Vehicle Health Management (IVHM)

Automated Aerial Refueling

Program Description

- ◆ Automated Aerial Refueling is a joint AFRL/ DARPA/Boeing program to develop AAR capability for UCAVs
- ◆ Flight validate safe control in flow field of manned tanker
- ◆ Demo MCS operator/tanker/UCAV communication, join-up to pre-contact position, connect, disconnect, post-AR procedures, emergency procedures



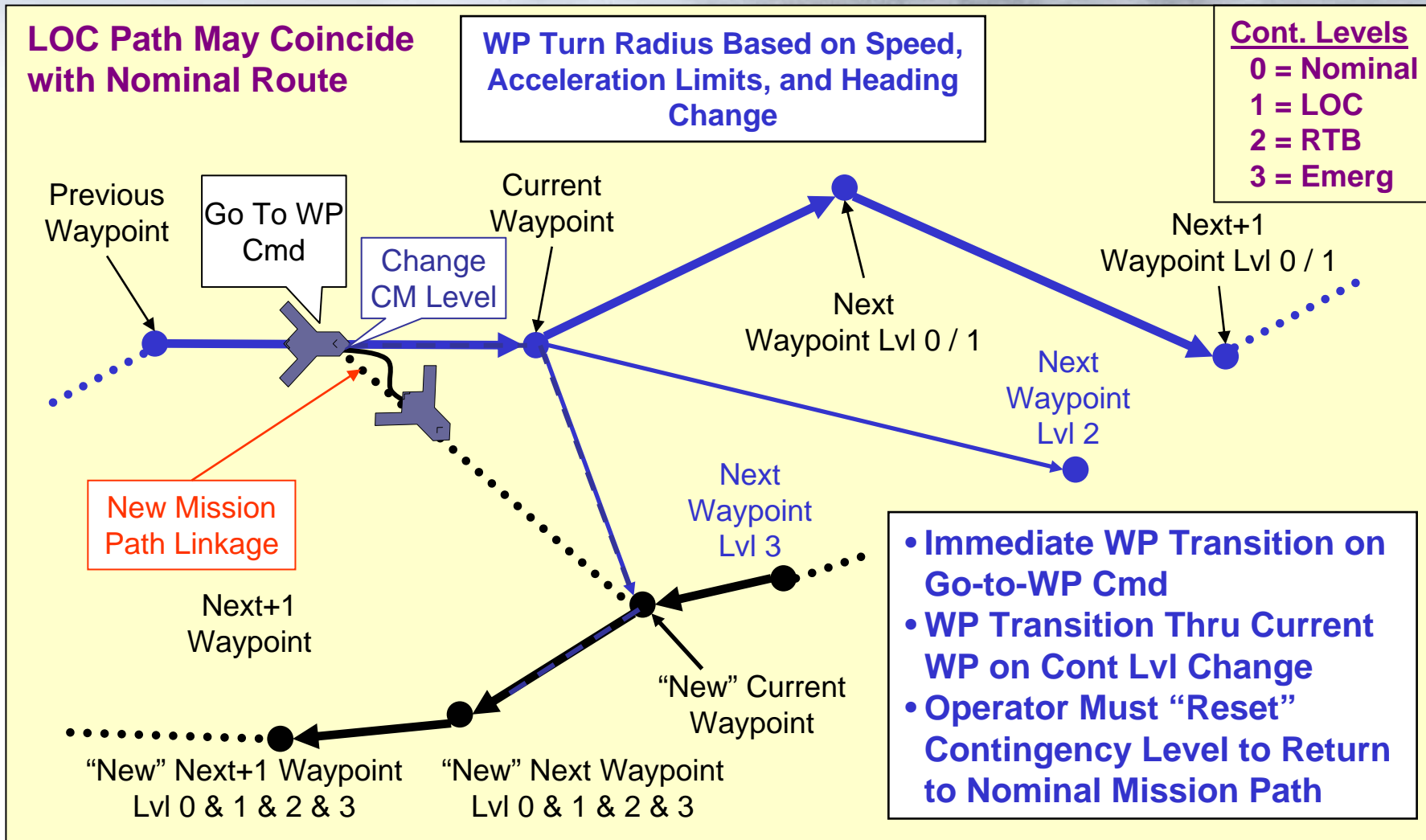
Benefits

- ◆ Enhances J-UCAS utility to the Warfighter
- ◆ Extends range and enables rapid global force projection
- ◆ Shortens response to Time Sensitive Targets (TST) – allows response from forward orbit
- ◆ Maintains in-theater force projection/presence using fewer assets (increased persistence)
- ◆ Enable J-UCAS deployment and attack with manned aircraft without the need for forward staging areas (response to anti-access strategy)

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WP Steering Along Mission Plan Provides Autonomous Mission Execution Capability

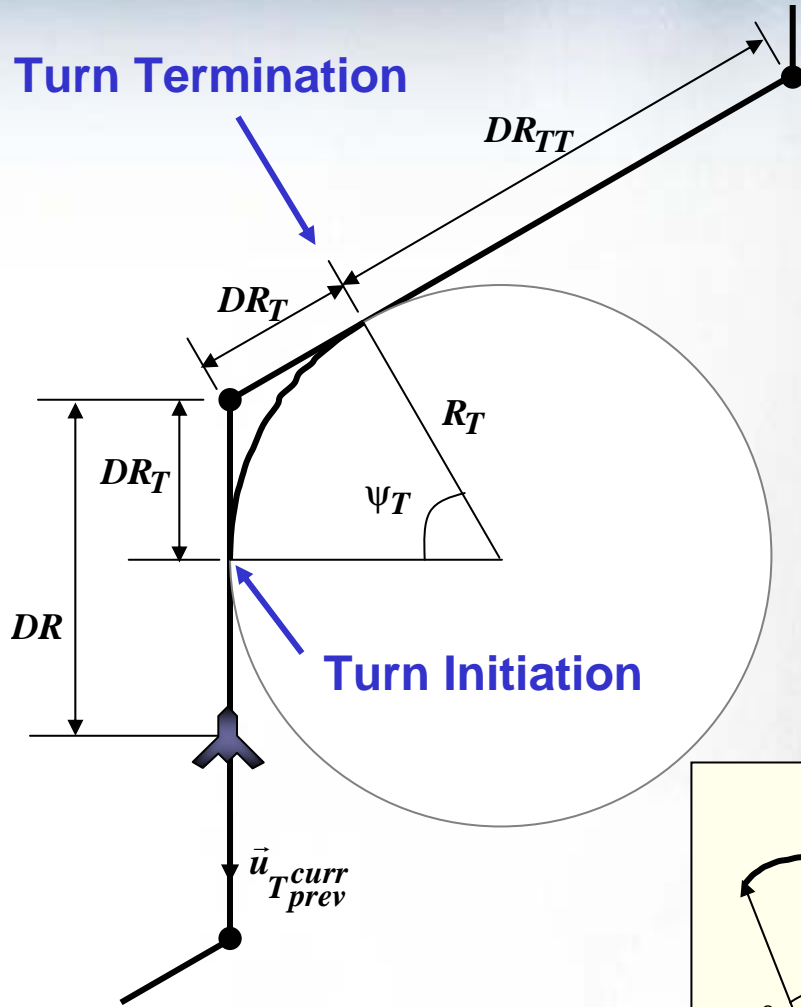


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Waypoint Guidance Turn Geometry



Turn Radius Based on Vehicle Acceleration Capability

$$AY_{nom} = 0.85 * AYC_{lim}$$

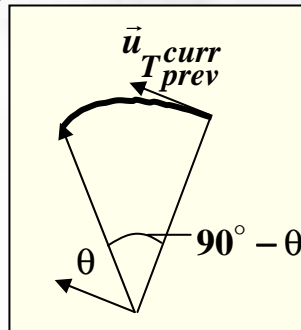
$$R_T = \frac{V_{inertial}^2}{AY_{nom}} \text{ (ft)}$$

Distance from Waypoint to Start Turn Compute from Turn Geometry

$$DR_T = \frac{R_T * \tan(\psi_T / 2)}{R_{earth}} \text{ (rad)}$$

Distance to Waypoint Computed from Radial & Tangential Vectors

$$\left[\vec{u}_R - \left(\vec{u}_R \cdot \vec{u}_{N_{prev}^{curr}} \right) \vec{u}_{N_{prev}^{curr}} \right] \cdot \vec{u}_{T_{prev}^{curr}} = \cos(\theta) = \sin(90^\circ - \theta) \cong DR$$



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X-45A Formation Control Approach



- Virtual Lead Aircraft Propagating Along Mission Plan Provides Common Position & Velocity Reference for Each Aircraft
 - Virtual Lead Can Propagate in 3D (Mission Plan Speed) or 4D (Time of Arrival Control) Mode
- Vehicles Perform Station Keeping by Maintaining Unique Offsets Relative to Virtual Lead
 - Crosstrack, Altitude and Downtrack Offsets Specified for Each AV
 - Offsets Can be Modified While in Formation
- Vehicles Report State & Tracking Error Info Over Inter-vehicle Comm (IVC) Link to Ensure Safe Separation
 - Vehicles Perform Speed Adjustments to Preserve Ellipsoidal Safe Separation Boundary Around Each Vehicle
 - Prioritized Over Station Keeping

Approach Requires Limited Set of IVC Data. Supported by Existing Comm Assets

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Modified Virtual Structure for X-45A Formation Control



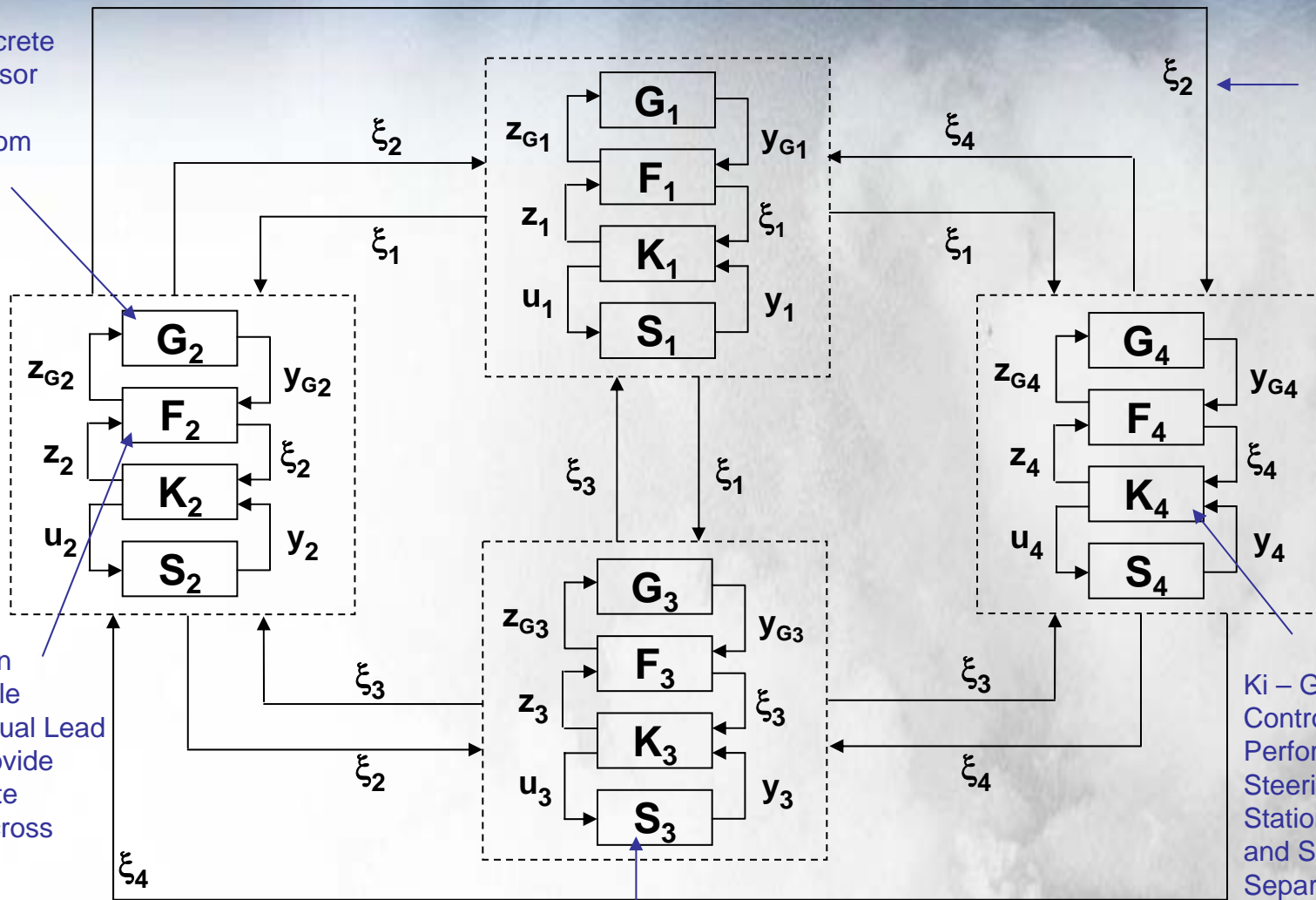
G_i - Local Discrete Event Supervisor Acts on C2 Commands from Operator & Formation Maneuvers Specified by Mission Plan

F_i - Formation Control Module Based on Virtual Lead Aircraft to Provide Common State Reference Across Formation

S_i - Individual Vehicle

Formation Feedback Signals

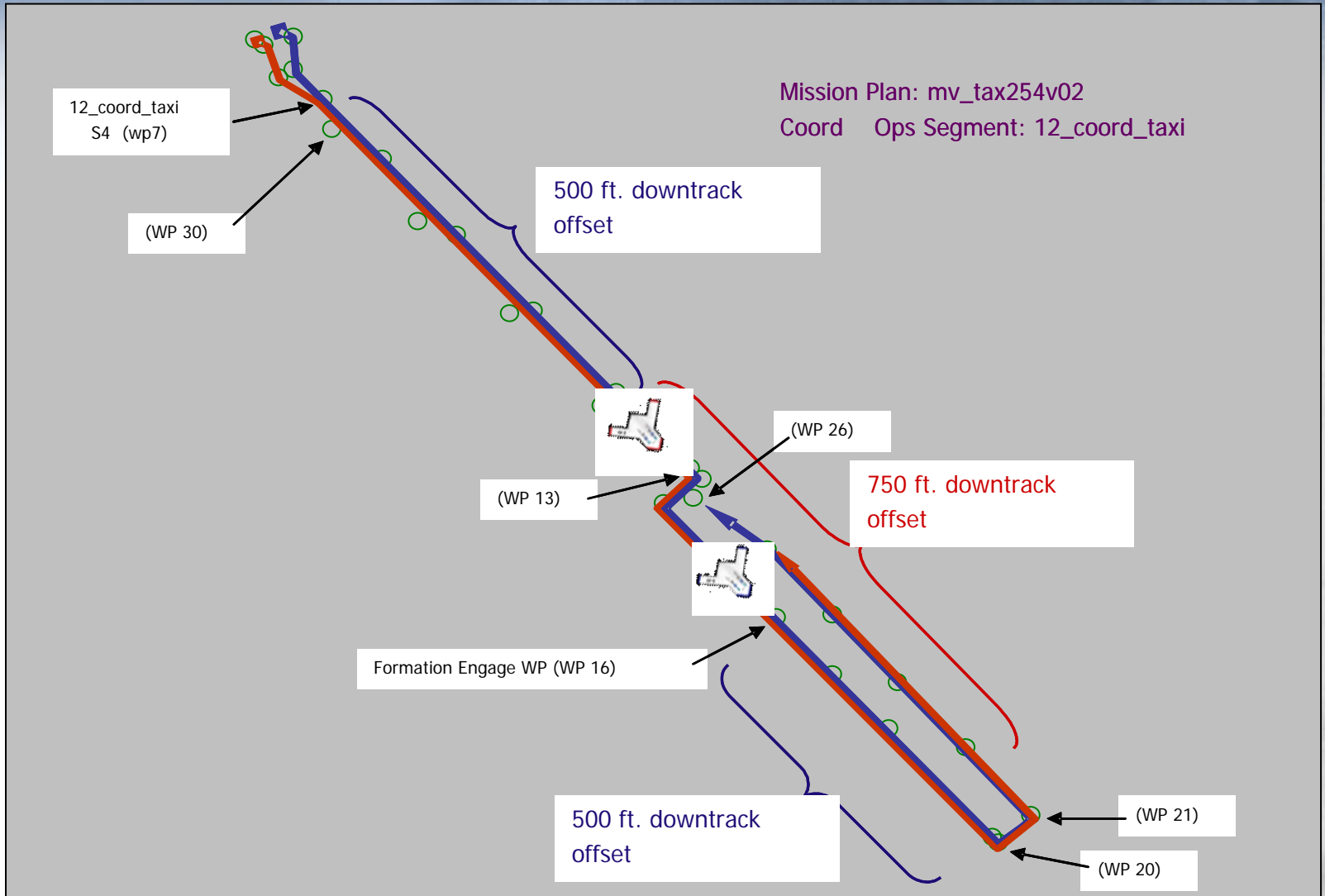
K_i - Guidance & Control Module Performs Steering for Station Keeping and Safe Separation



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Multi-Vehicle Taxi Mission Plan Overview

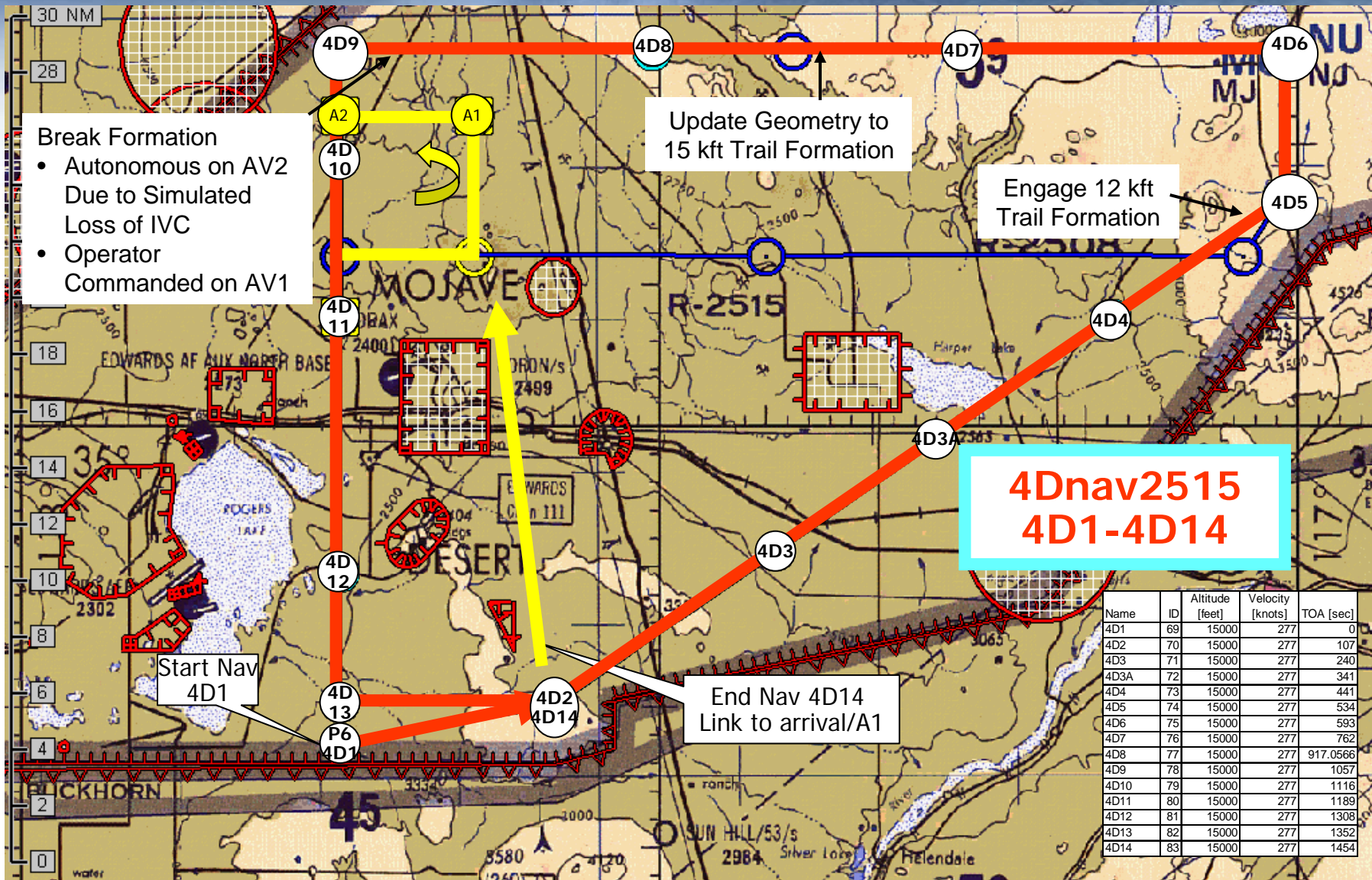


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4Dnav2515 Route Employed for Coordinated Flight Ops

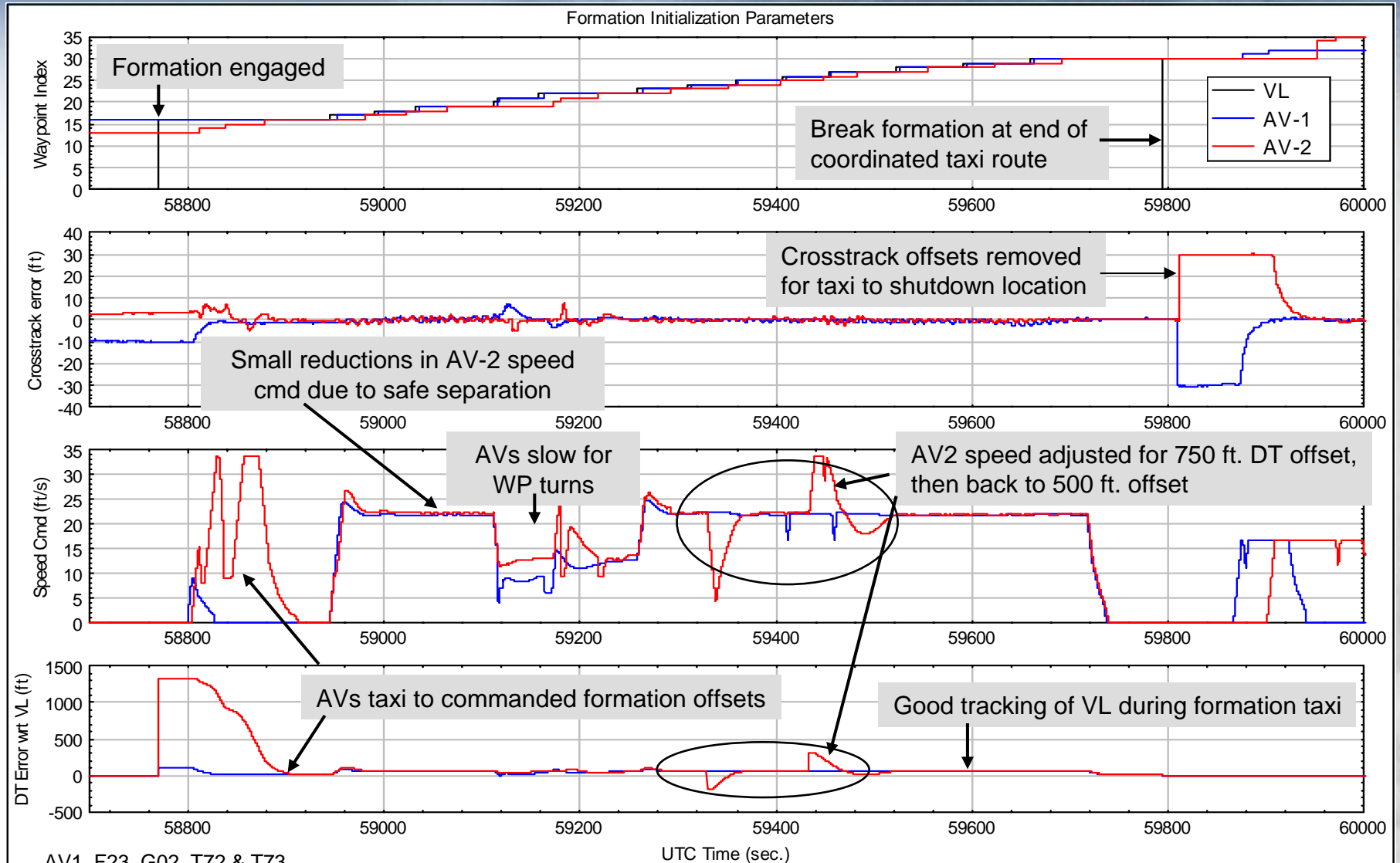


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Formation Initialization: Formation Taxi Scenario



AV1_F23_G02_T72 & T73
AV2_F05_G07_T72 & T73

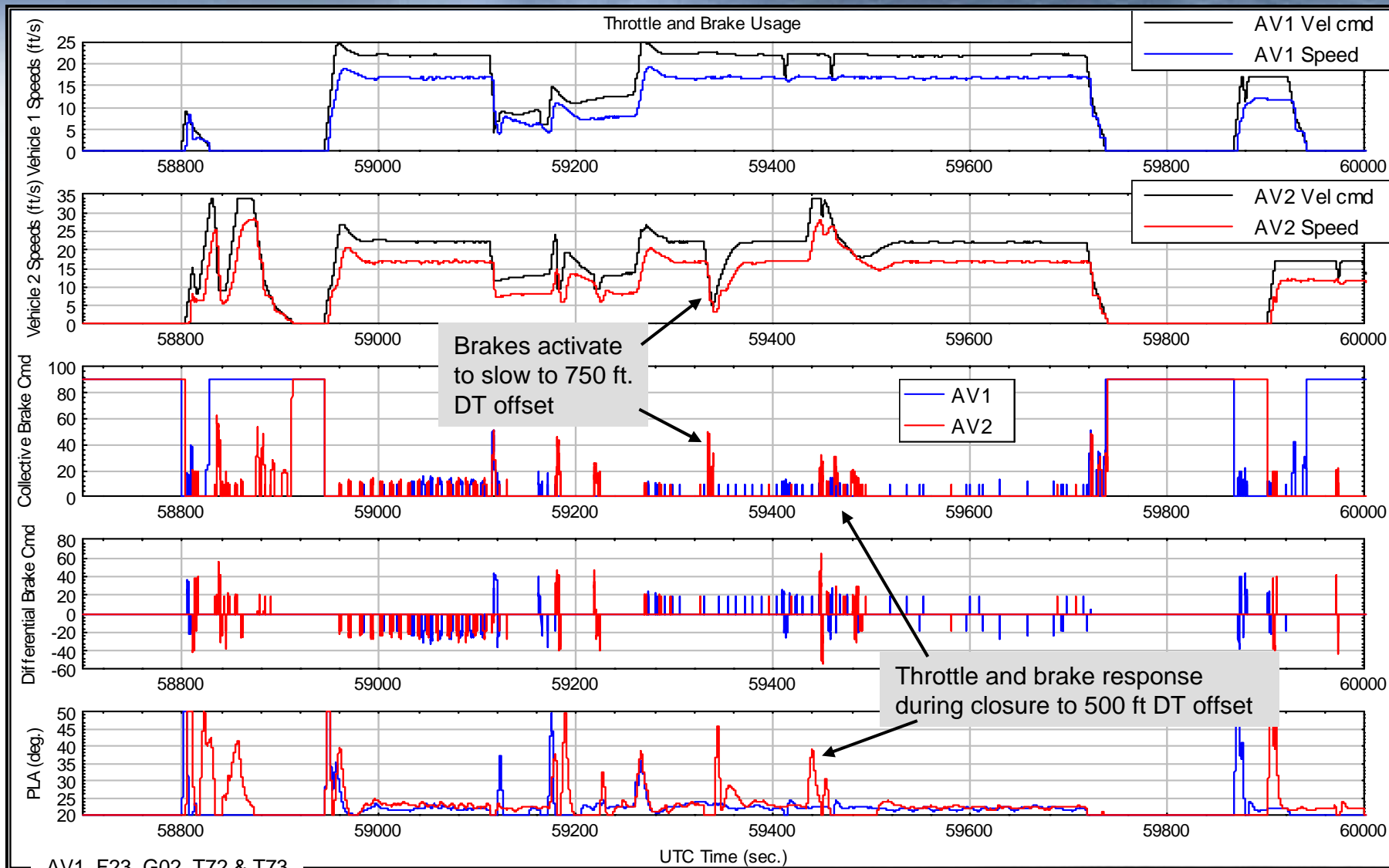
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Throttle and Brake Modulation: Formation Taxi Scenario



AV1_F23_G02_T72 & T73
AV2_F05_G07_T72 & T73

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Summary

- ◆ J-UCAS X-45 is a revolutionary force enabler for affordable 21st Century airpower
 - Rapidly field a weapon system that integrates distributed adaptive control technology and robust communications with a next generation stealth platform
- ◆ Spiral 0 X-45A flight demonstrations proceeding
 - Basic functionality (Flt envelope, Comm, Nav) check-out complete
 - Block 3 flights complete (single operator/multi-vehicle; coordinated flight with two air vehicles)
 - Block 4 flights begin April 05
- ◆ Capability Demonstration Program phase proceeding
 - Significant increase in payload and range/persistence from original concept
 - Addresses gaps in Joint warfighting capabilities