Human and Automation Integration Considerations for UAV Systems

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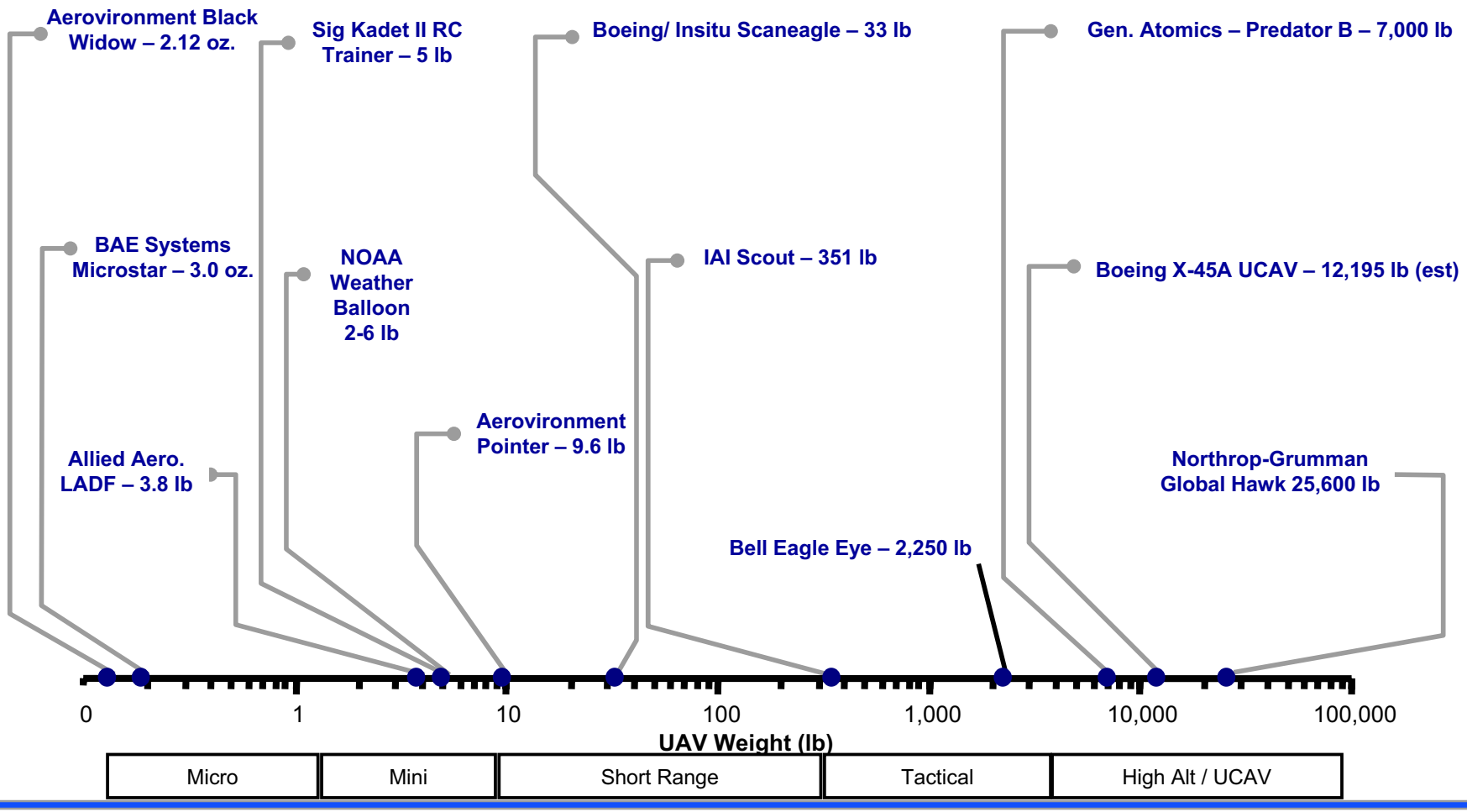
Possible Commercial UAV Applications - Motivation

- **Remote Sensing**
  - ☐ Meteorology
  - ☐ Scientific Research
  - ☐ Aerial Photography/ Mapping
  - ☐ Pipeline Spotting
  - ☐ Disaster Monitoring
  - ☐ Agriculture
- **Surveillance**
  - ☐ Border Patrol
  - ☐ Homeland Security/ Law Enforcement
  - ☐ Traffic Monitoring
  - ☐ Search and Rescue
- **Data Delivery**
  - ☐ Communications Relay
  - ☐ Multimedia Broadcast
- **Cargo Transport**

Possible Military UAV Missions - Motivation

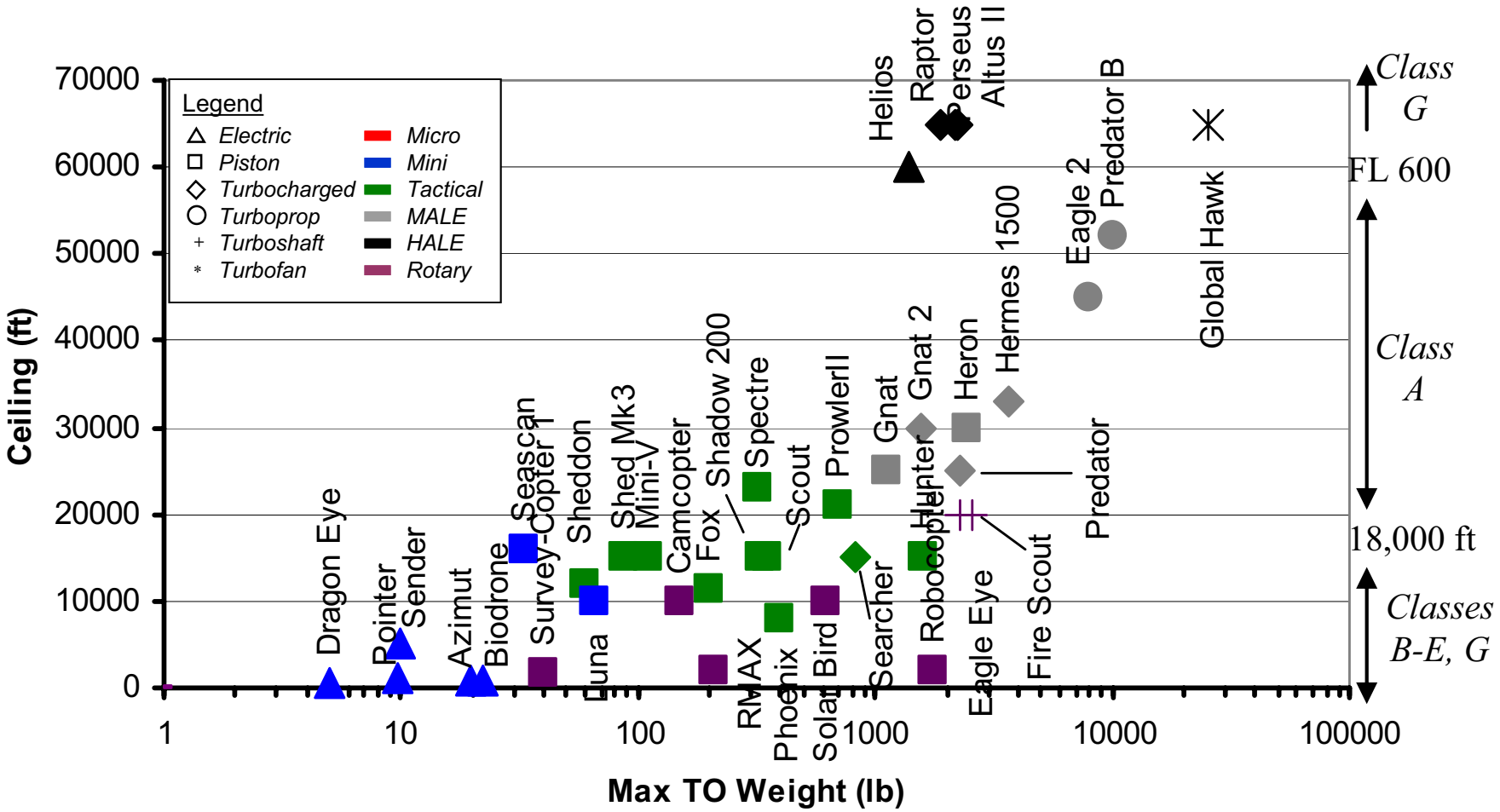
- **Intelligence**
  - ☐ Reconnaissance
  - ☐ Target Monitoring
  - ☐ Forward Air Control
  - ☐ Electronic Warfare
  - ☐ Search and Rescue
  - ☐ Battle Damage Assessment (BDA)
- **Offensive Operation**
  - ☐ Suppression of Enemy Air Defenses (SEAD)
  - ☐ Close Air Support
  - ☐ Deep Strike
- **Cargo Transport**

Current Unmanned Aerial Vehicles



Mass Range
Large range of UAV types as users of NAS
-propulsion, configuration, capabilities, etc

Ceiling


Legend
Electric
Piston
Turbocharged
Turboprop
Turboshaft
Turbofan
Micro
Mini
Tactical
MALE
HALE
Rotary
Ceiling (ft)
70000
60000
50000
40000
30000
20000
10000
0
1
10
100
1000
10000
100000
Max TO Weight (lb)
Dragon Eye
Pointer
Sender
Azimut
Biodrone
Survey-Copter
Seascan
Sheddon
Luna
Shed Mk3
Mini-V
Camcopter
Fox
Shadow 200
RMAX
Spectre
Scout
Phoenix
Solar Bird
ProwlerII
Searcher
Gnat
Gnat 2
Robocopter
Hunter
Heron
Eagle Eye
Hermes 1500
Predator
Fire Scout
Helios
Raptor
Perseus
Altus II
Eagle 2
Predator B
Global Hawk
Class G
FL 600
Class A
18,000 ft
Classes B-E, G

Takeoff Method

Hand-launched: Aerovironment Pointer

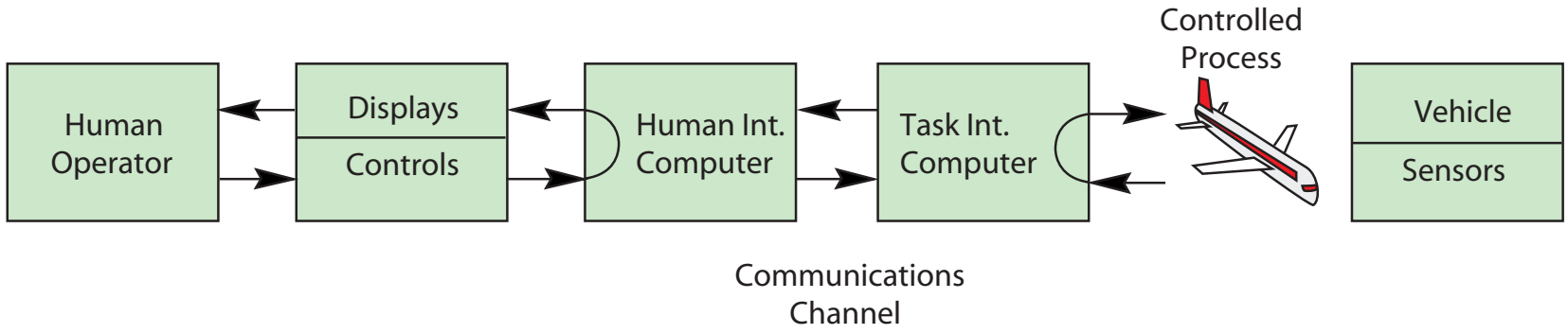
Rocket-Assisted: Hunter UAV

Rail-Launched: Sperwar

Tilt-Rotor: Eagle Eye

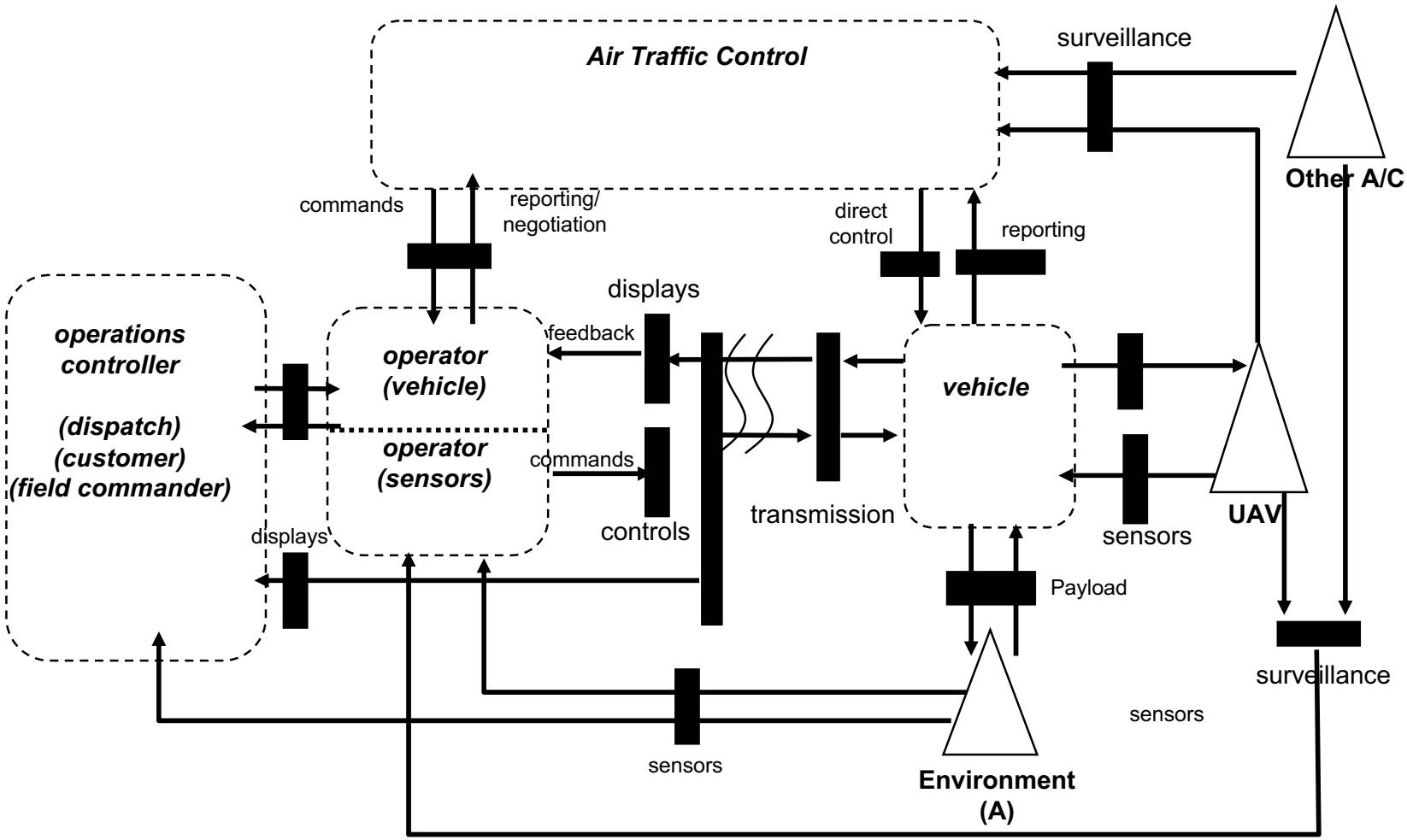
Runway Takeoff: X-45 UCAV

Basic Supervisory Control Architecture



Adapted from Sheridan, Humans and Automation

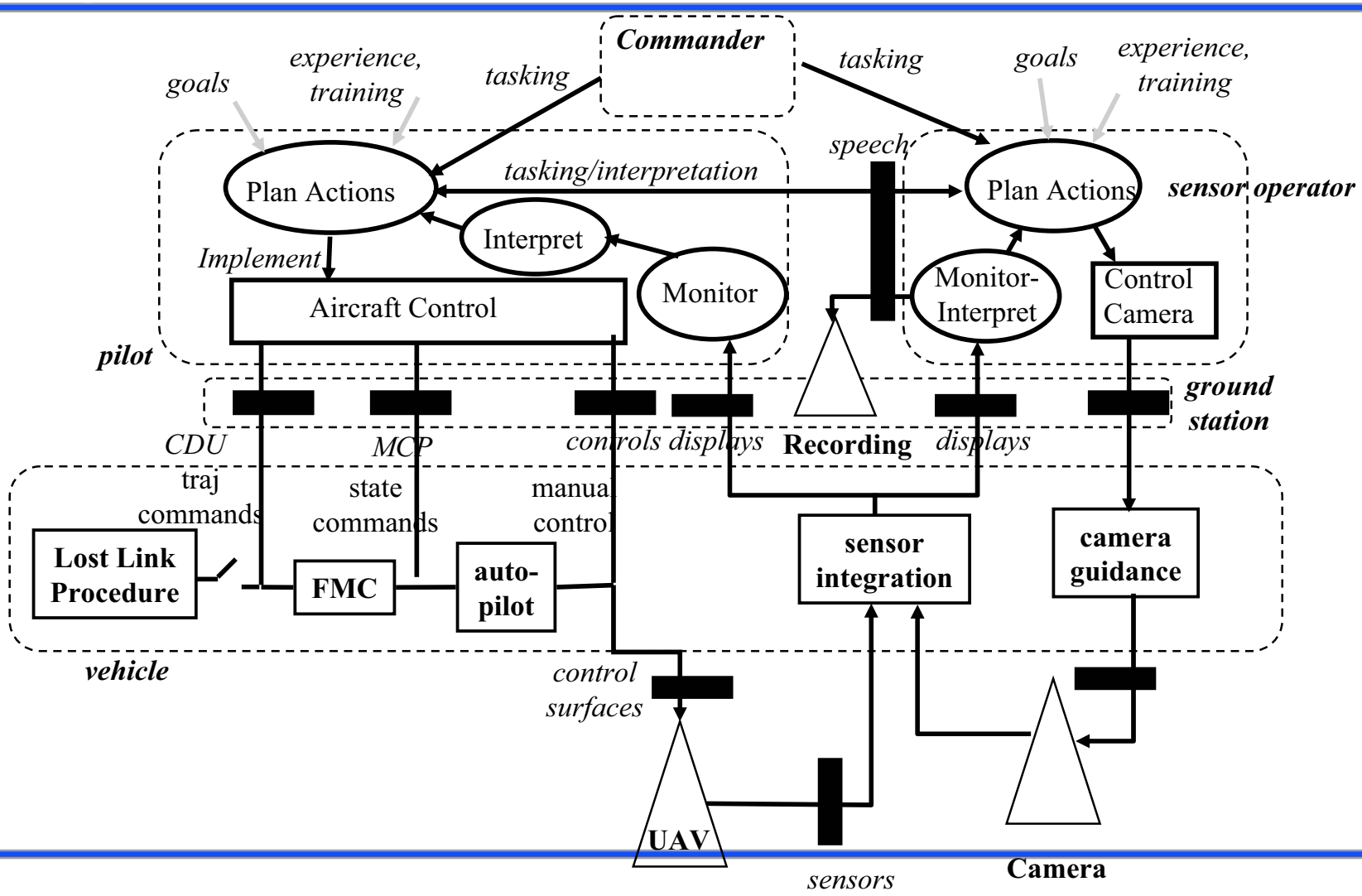
UAV Operation Basic Functional Architecture



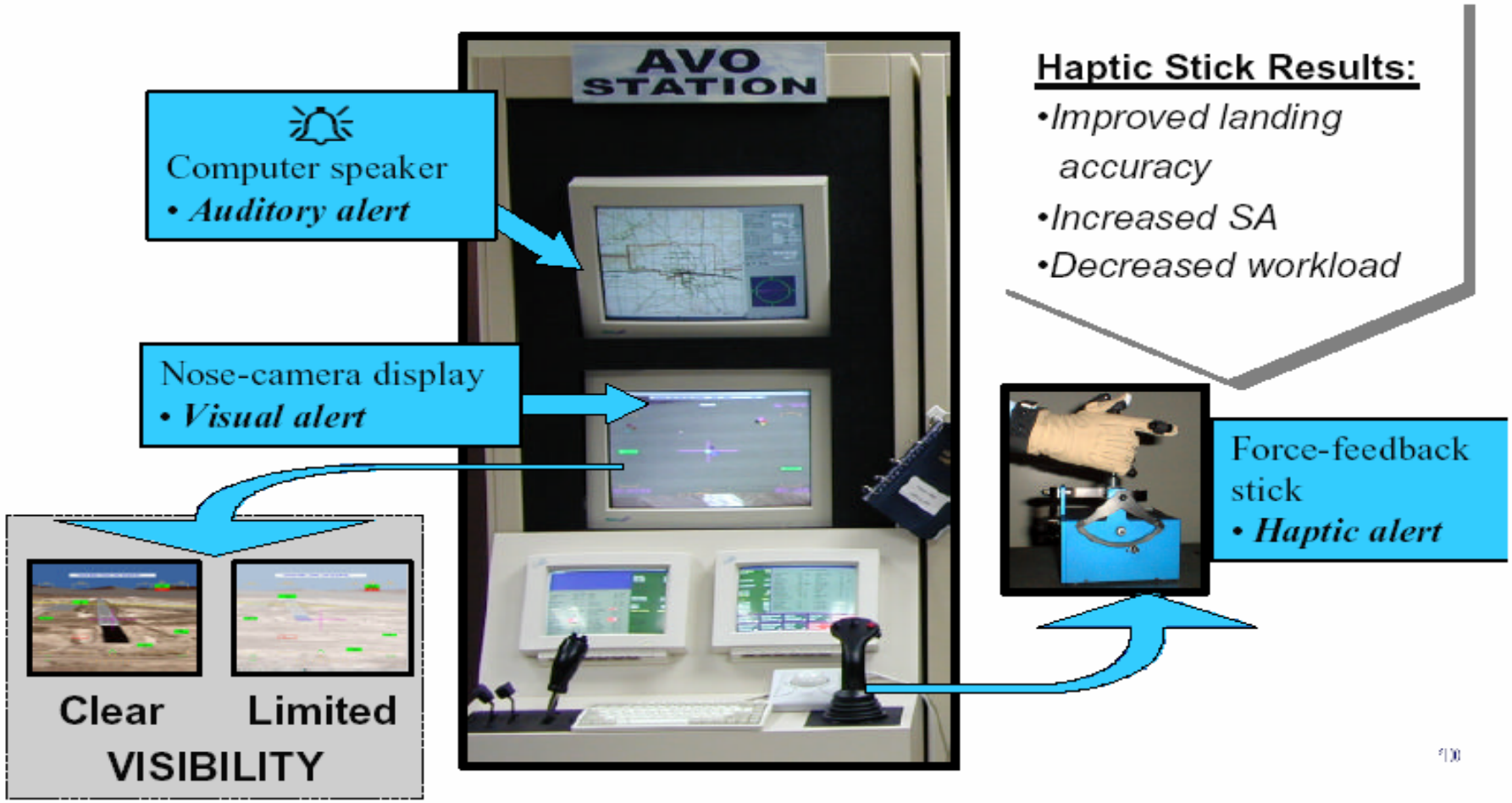
Pointer UAV

- **Used for Short-Range Surveillance**
  - ☐ Battlefield commanders
  - ☐ Law Enforcement
- **Vehicle Capabilities**
  - ☐ Manual Control
  - ☐ Autopilot
  - ☐ Sensor Integration and Display
  - ☐ Loss of Link Return to Base
- **Bandwidth Requirements**
  - ☐ Transmission of Vehicle Commands
  - ☐ Receipt of Sensor Intelligence, Vehicle State

Pointer UAV Tasking & Control



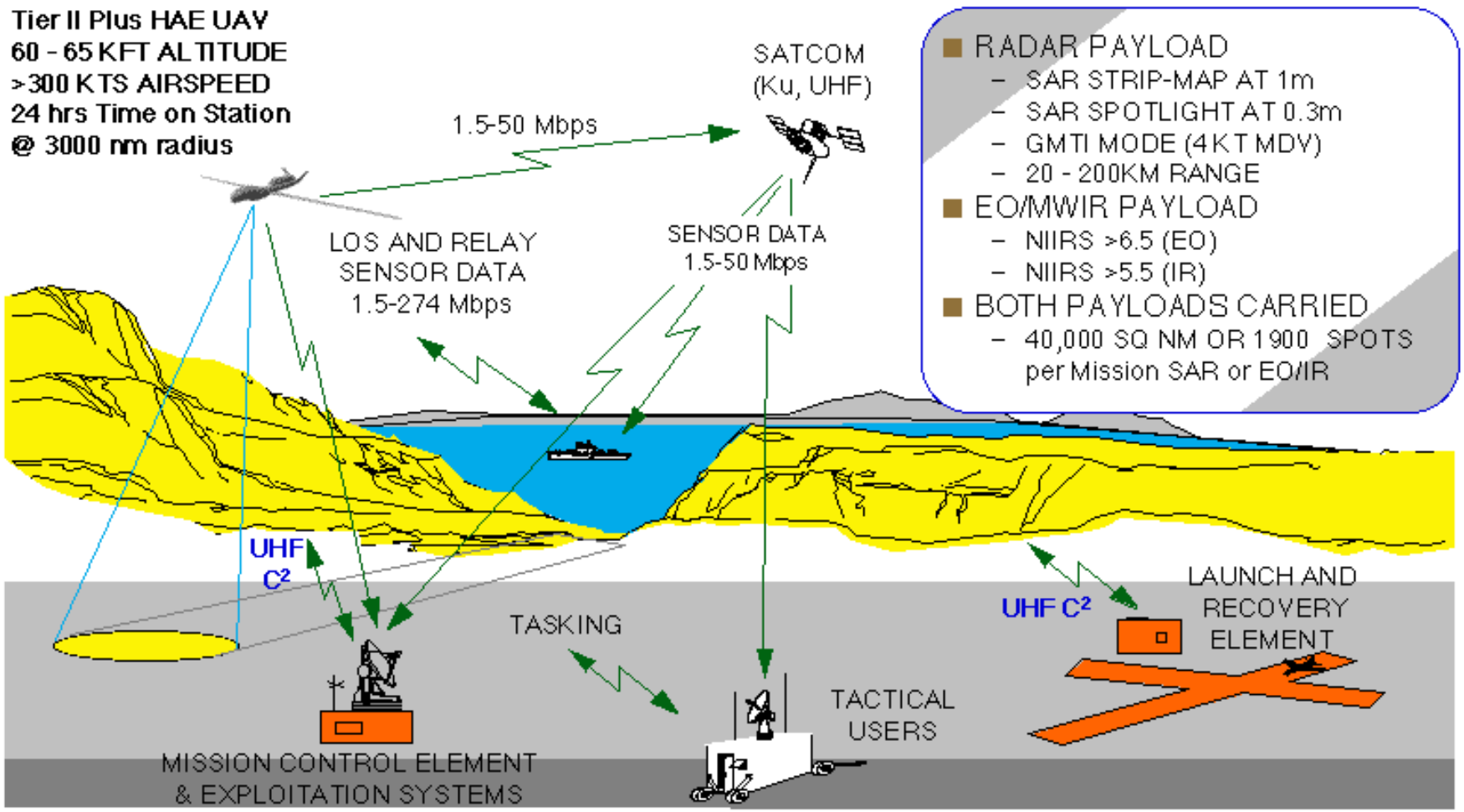
General Atomics Predator
Medium Altitude, Endurance



Predator Air Vehicle Operator (AVO) Station
from – M. Draper, Air Force Research Lab (2001)

Northrop-Grumman Global Hawk
HALE UAV

Conventional HAE UAV (Tier II Plus) Concept



Global Hawk Mission Control Elements

Command & Control

ATC

Battlefield Intelligence

U.S. Air Force photo

Air Vehicle Operator Station

- Interface with ATC
- Uplink Mission Changes
- Monitor Vehicle Health and Status
- Monitor Threat Warning and Deception

- Navigation Plan
- Communications Plan
- Sensor Plan
- Dissemination Plan
- Dynamic Retasking

Mission Planning Station

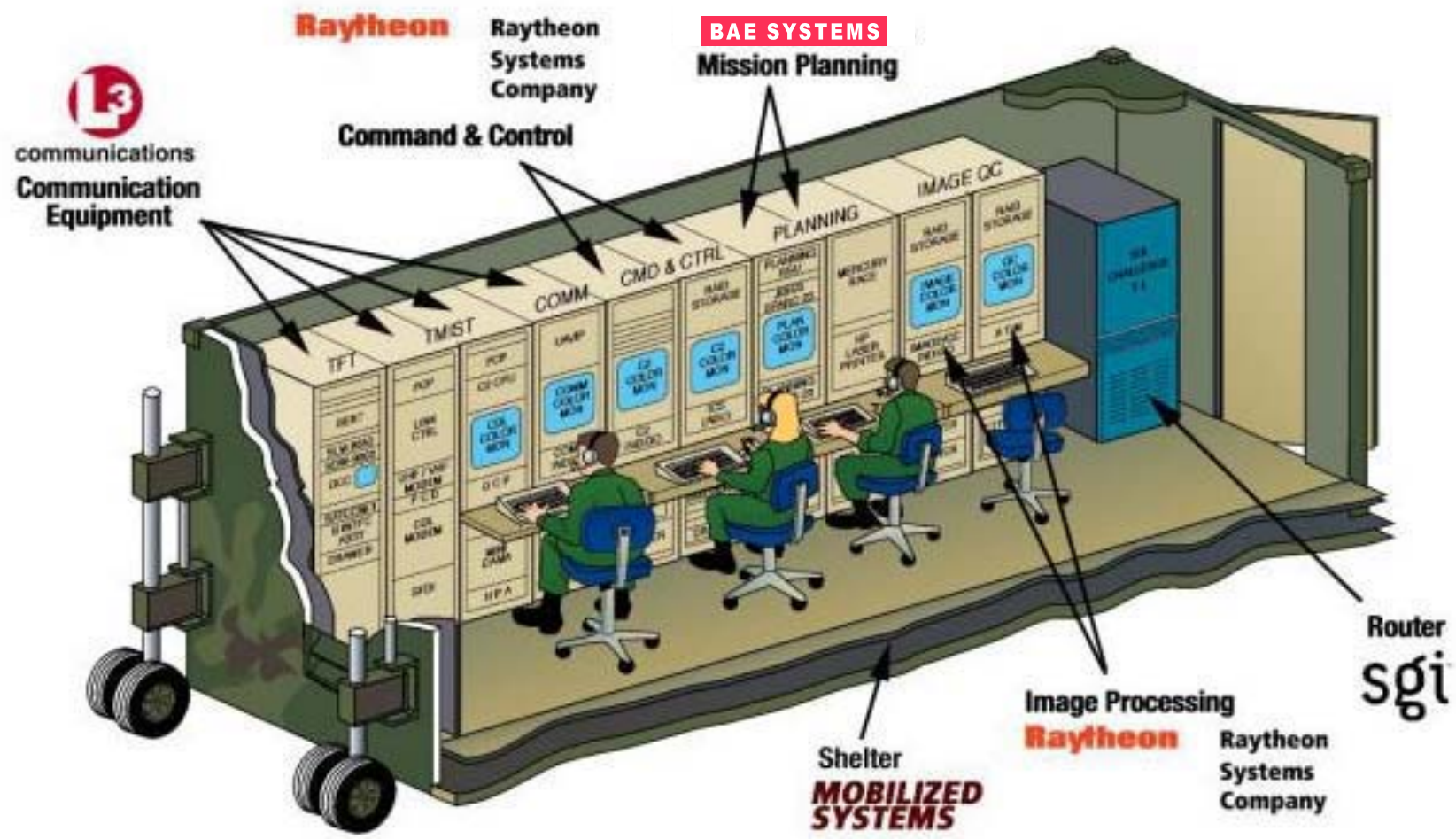
- View Imagery
- Monitor Sensor Status
- Calibrate Sensors
- Process & Disseminate Imagery

Sensor Data and Processing Station

- Maintain Health and Status of Comm. Subsystems
- Construct and Monitor Comm. Plan

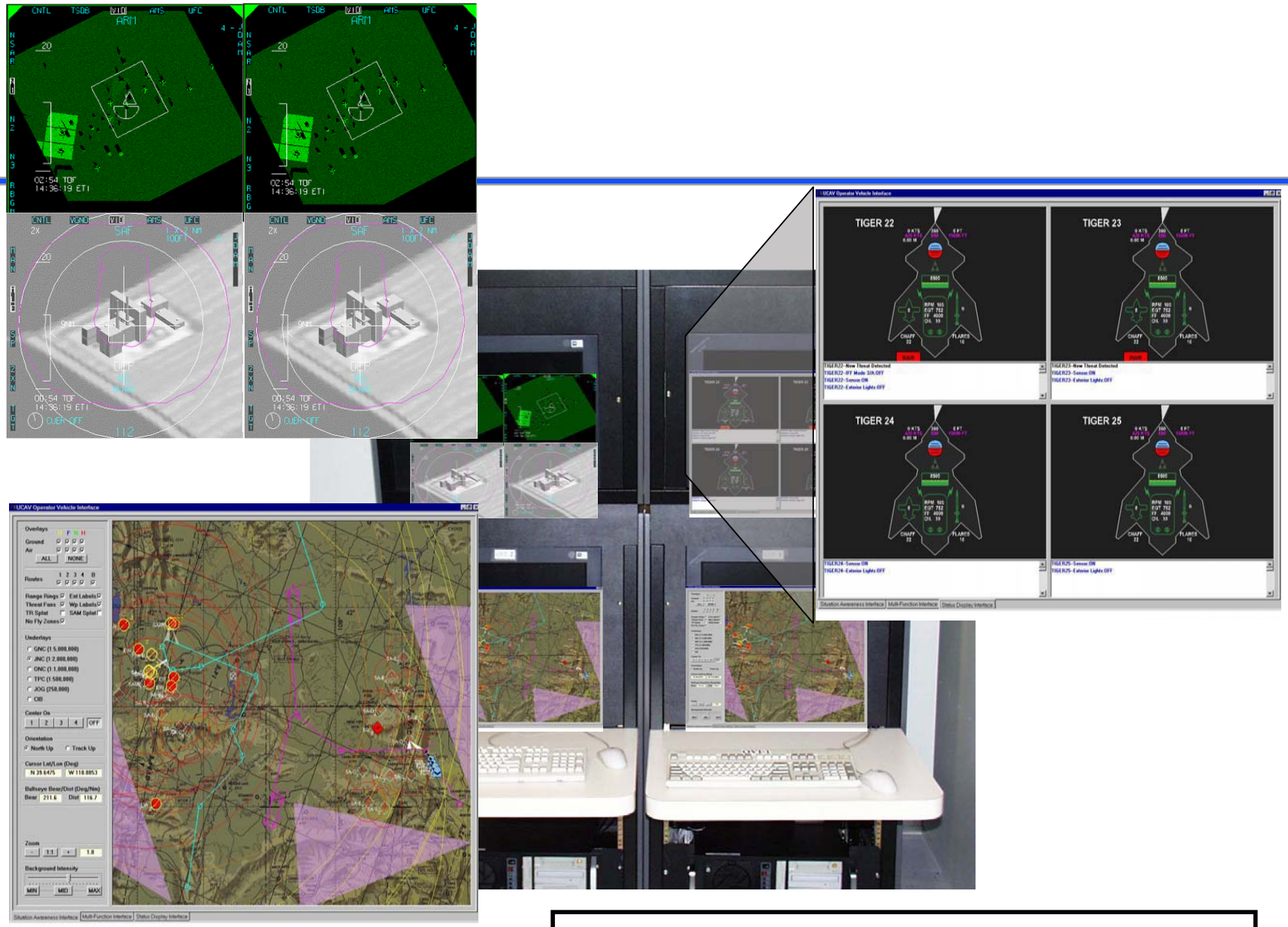
Communication and Control Station

Global Hawk MCE



Boeing X-45 UCAV

Boeing X-45A Control Station
from – DARPA Website (2003)



Multiple UAV Control Station for Simulated Scenario

from – J. Nalepka, Air Force Research Lab (2003)

X-45A Block 1 Flight Demo Summary
Completed 28 Feb 03

- **Air Vehicle 1**
  - Total number of flights: 14
  - Total Flight Time: 11.6 hours
  - Envelope expansion, 4D Nav, loss-of-comm and C2 demos
- **Air Vehicle 2**
  - Total number of flights: 2
  - Total AV2 Flight Time: 1.2 hours

- **48 of 48 ground and flight demonstrations complete**
- **Currently conducting check-out flights/ground tests for Block 2 demonstrations**

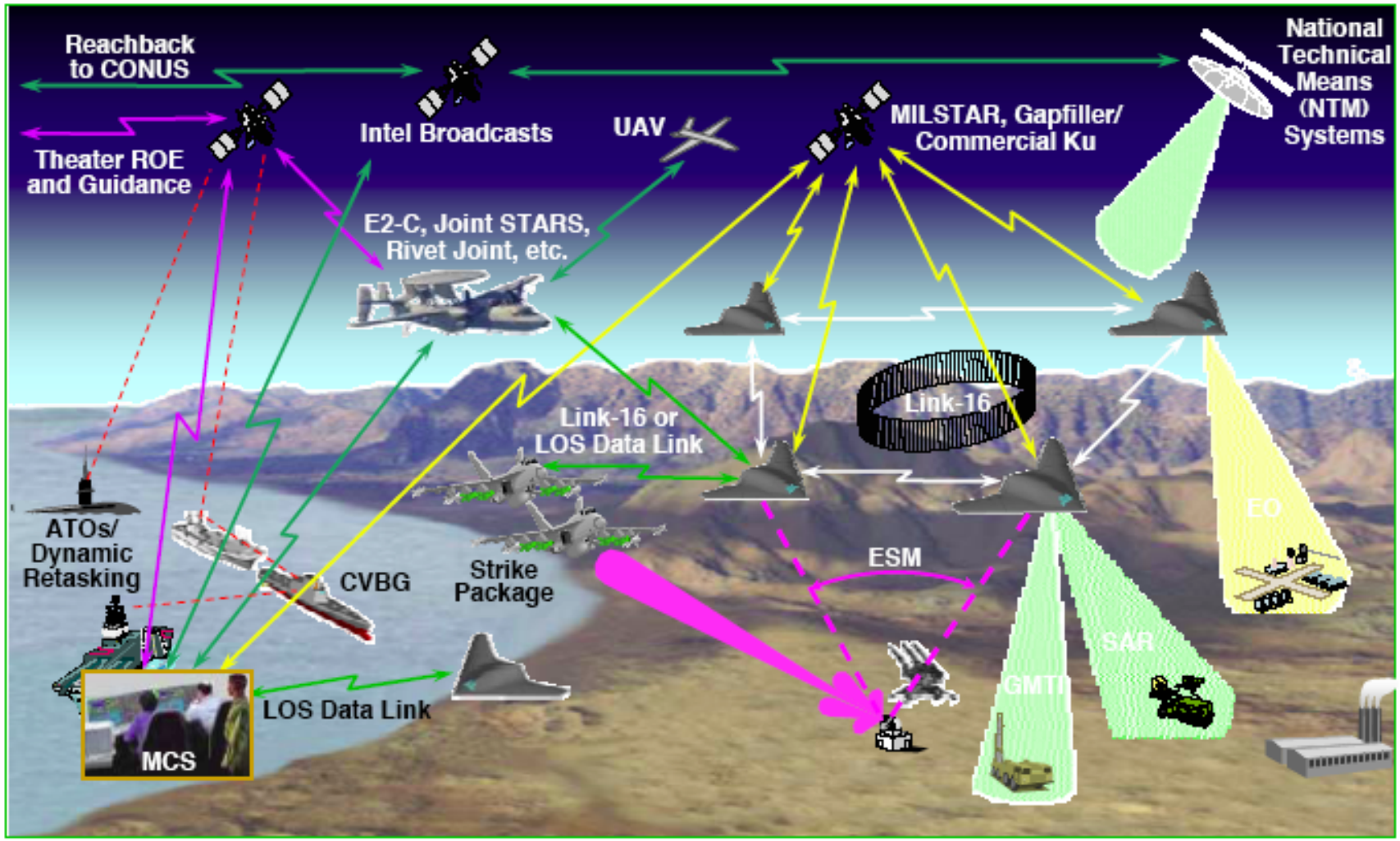
Flight demonstrations successful
Validating technical feasibility of J-UCAS concept

X-47 Pegasus Flight Summary
Conducted 23 Feb 03

- **X-47 First Flight**
  - Flight Time: 12 minutes
  - Simulated a tailhook arrestment point on a carrier flight deck by landing near a predesignated touchdown point
  - Utilized shipboard-relative global positioning satellite (SRGPS) system as the primary navigation source for increased landing precision

Flight demonstration successful

Surveillance
Operational System



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UAV-Related Human Factors Issues - (Partial List)

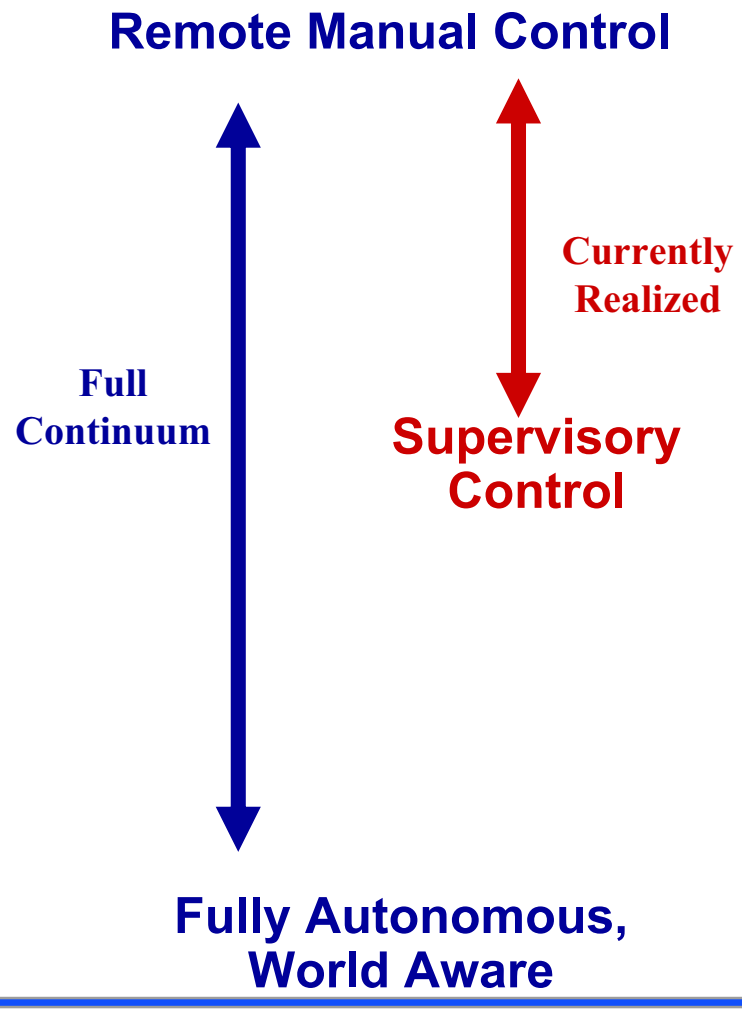
- **Allocation/ Level of Autonomy**
- **Bandwidth/ Latency**
- **Situation Awareness**
- **Cognitive Complexity Limitations**
  - ☐ Single & Multiple UAVs
- **Information Saturation/ Boredom**
- **Simulator Sickness**
- **Operator Orientation Confusion**
- **Culture Resistance**
- **Judgment**
  - ☐ Acceptable Risk
  - ☐ Weapons Release Authorization

UAV Task Analysis

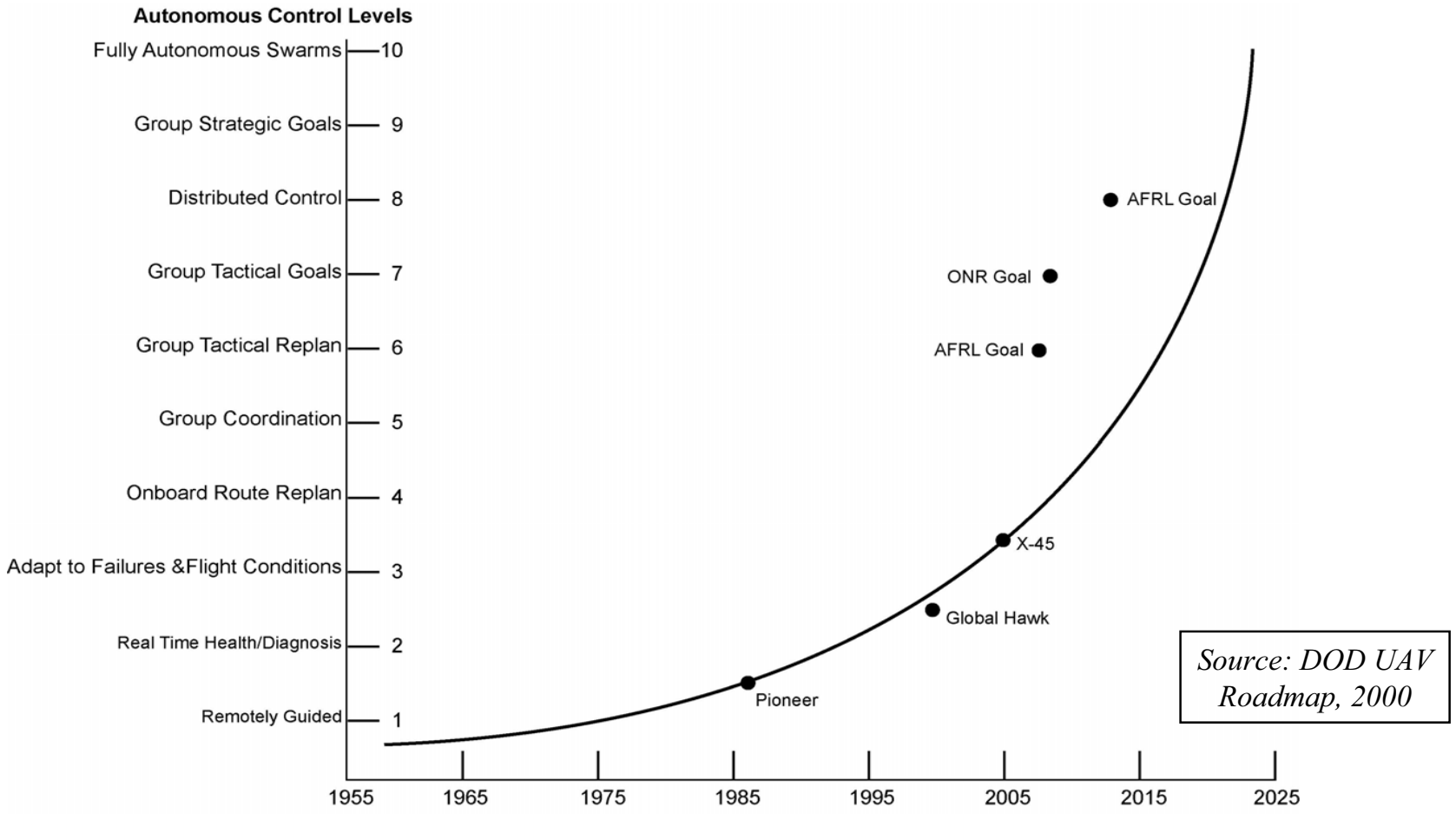
- **Situation (Battlespace) Awareness**
  - ☐ Perception
  - ☐ Comprehension
  - ☐ Projection
- **Diagnosis**
  - ☐ Environment
  - ☐ Threat
  - ☐ Targets
- **Strategic Planning/ Re-planning**
  - ☐ Goal Management
  - ☐ Route planning
- **Tactical Decisions**
  - ☐ Weapons Authorization
  - ☐ Avoidance of Hazards
  - ☐ Systems Management
- **Control**
  - ☐ Navigation
  - ☐ Aircraft Configuration
  - ☐ Sensor Operation
- **Monitoring**
  - ☐ Vehicle Health
  - ☐ External Environment
    - ◆ Threats, Targets, Traffic
  - ☐ Risk Assessment
  - ☐ Communications Link
  - ☐ Sensor Data
- **Communication**
  - ☐ Current State
  - ☐ Intent
  - ☐ Intelligence
  - ☐ Tasking

AFRL Levels of Autonomy

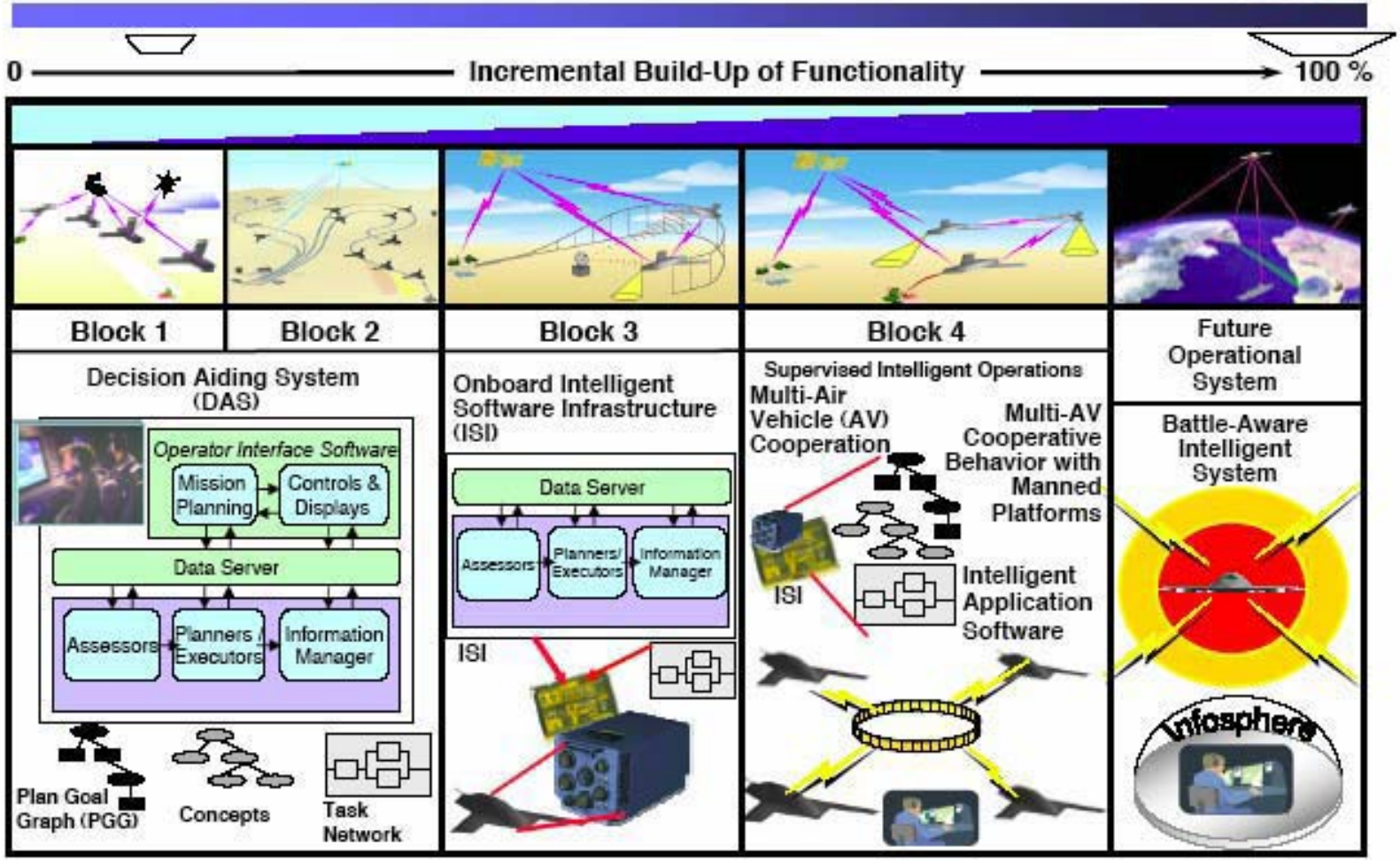
1. Remotely Guided
2. Real Time Health Diagnosis
3. Adapt to Failures & Flight Conditions
4. Onboard Route Replan
5. Group Coordination
6. Group Tactical Replan
7. Group Tactical Goals
8. Distributed Control
9. Group Strategic Goals
10. Fully Autonomous Swarms



Level of Autonomy Trend

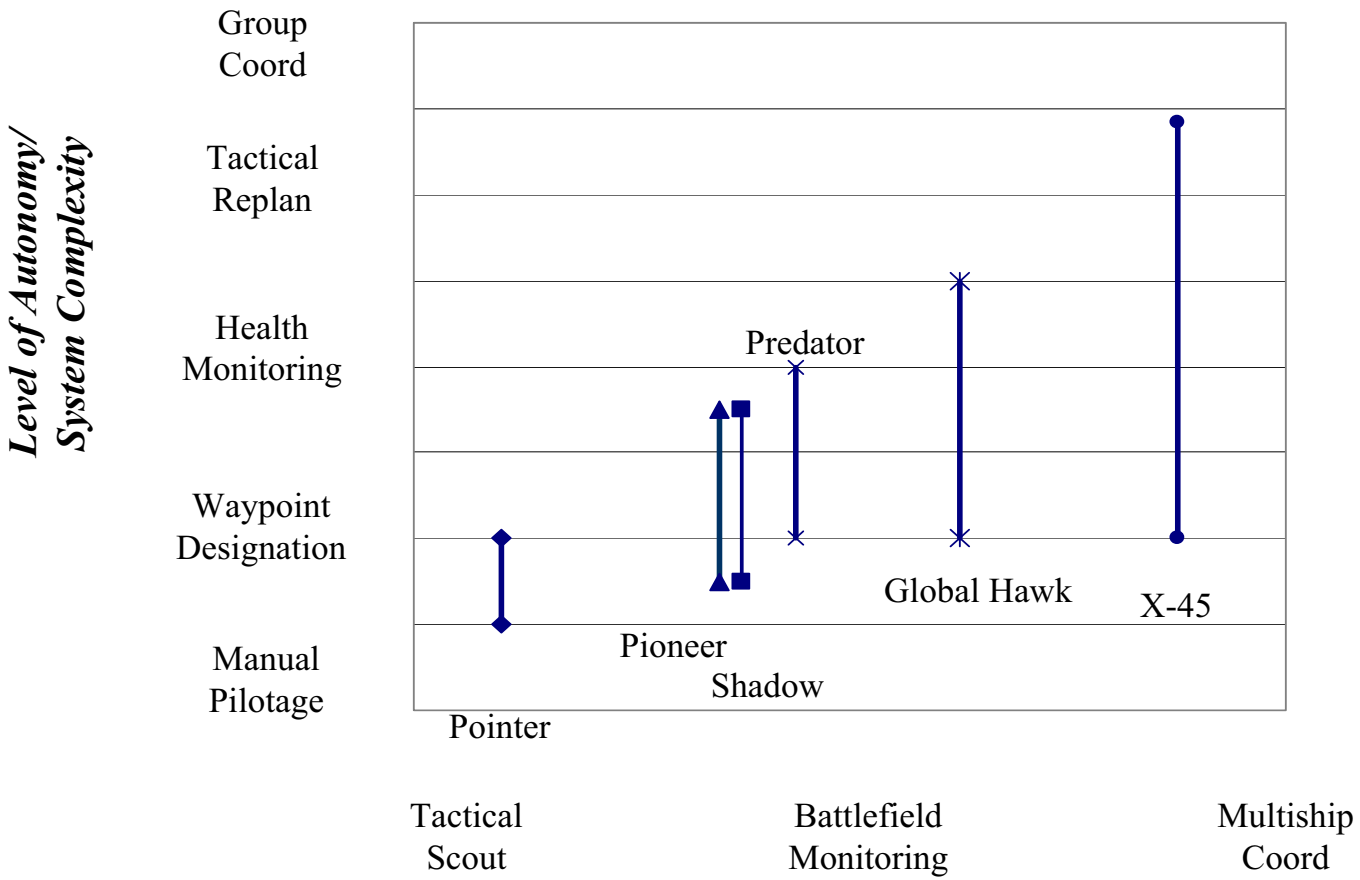


Intelligent System Capability Development

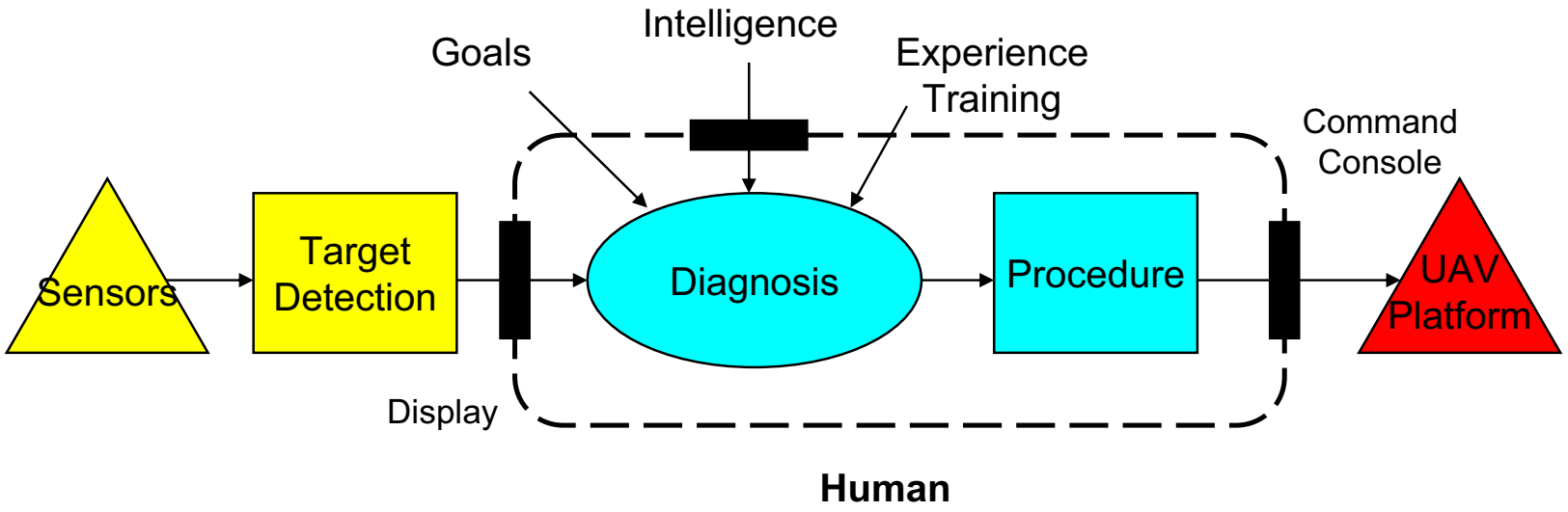


UAV Design Space - Military

@add pictures@



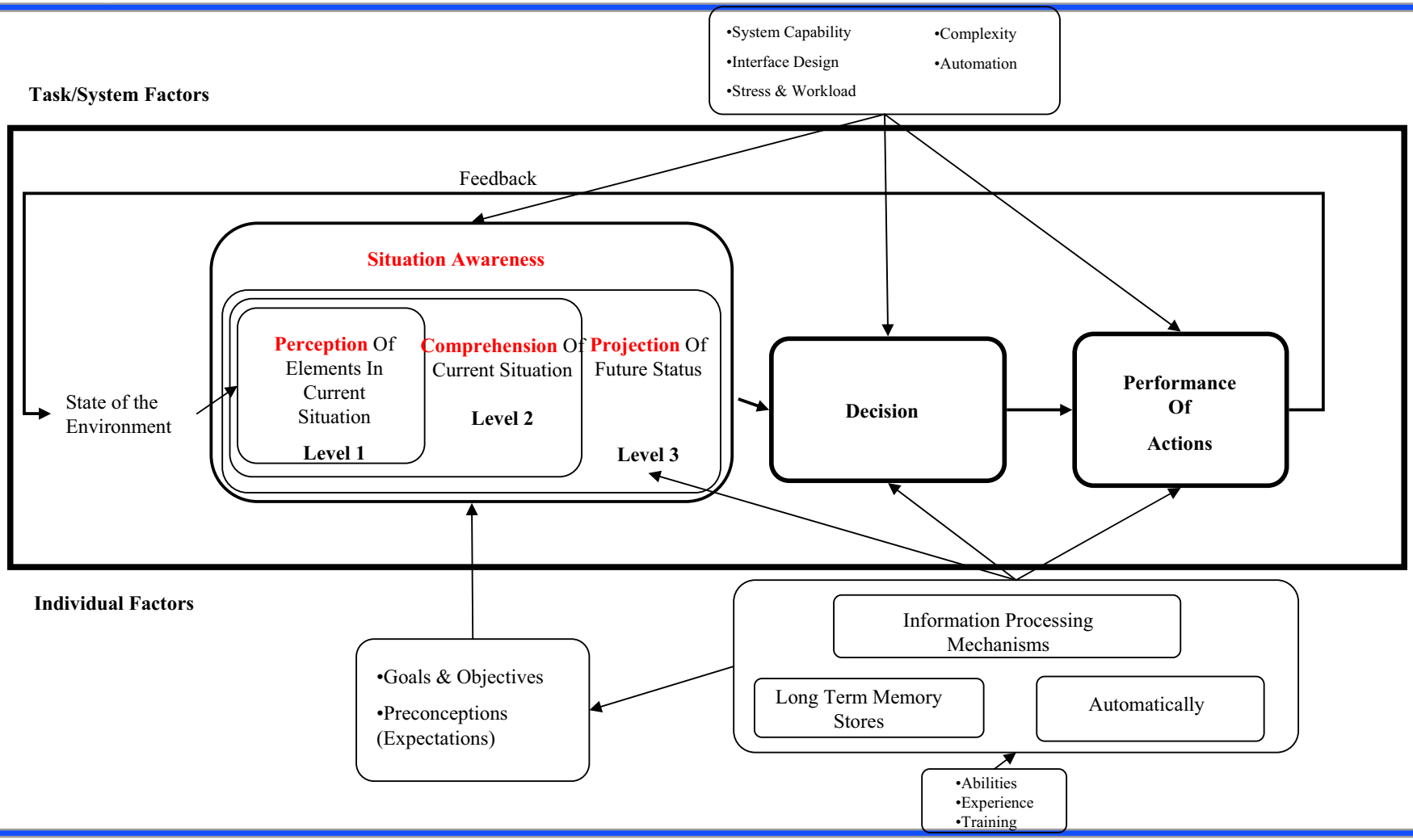
Diagnosis Procedure Role



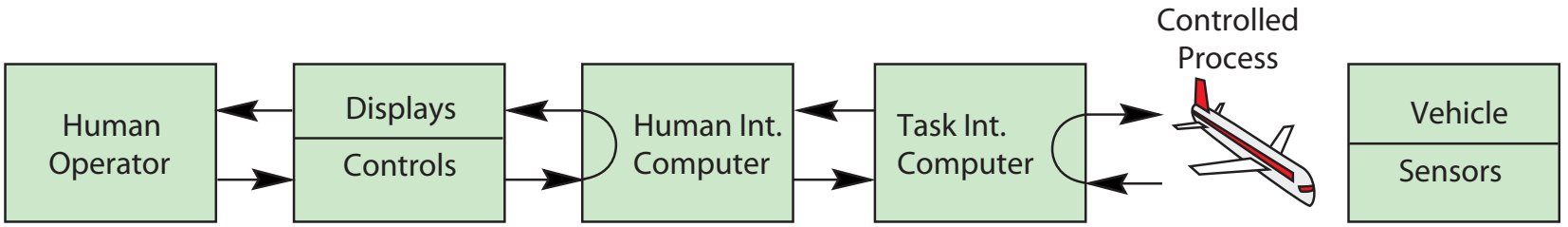
Lethal Force Authorization

Importance of Situation Awareness

Endsley Situation Awareness Model



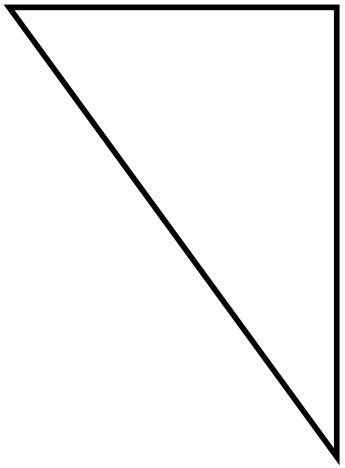
Bandwidth Limits



Adapted from Sheridan, Humans and Automation

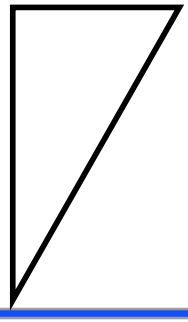
Bandwidth Limit

Downlink



- **Video**
  - Forward View, Surveillance
- **Imagery**
  - Reconnaissance, Target Selection
- **Voice**
  - ATC Comm, Intelligence
- **Schematic Data**
  - System Health, Location

Uplink



- **Voice**
  - ATC Comm, Comm to Ground
- **Manual Control**
- **Commands**
  - Waypoint/ Tasking Commands

Task Performance & Bandwidth

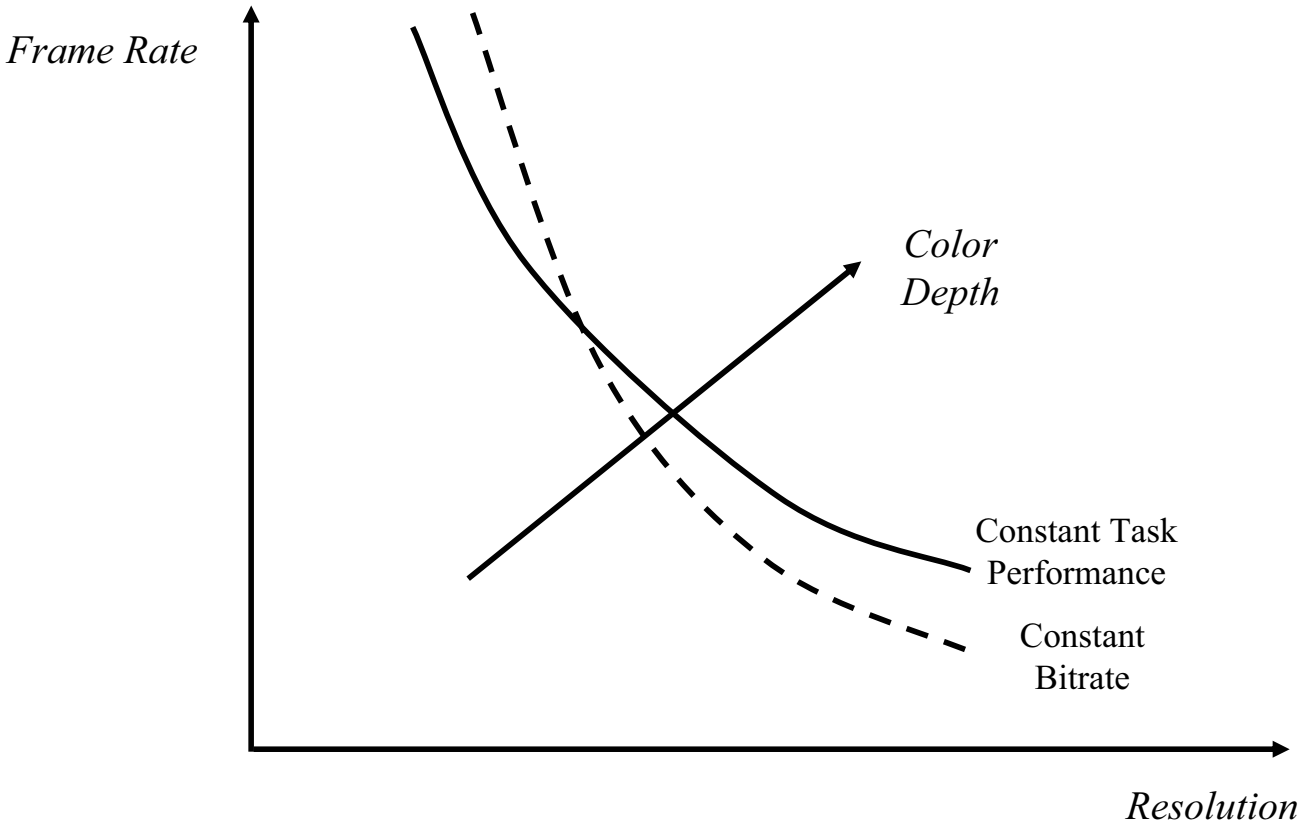
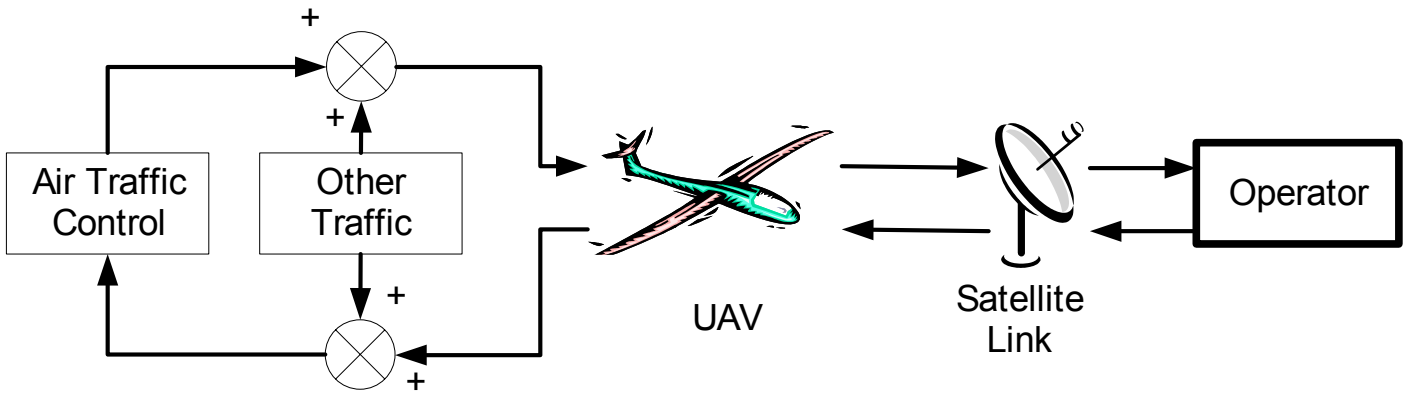
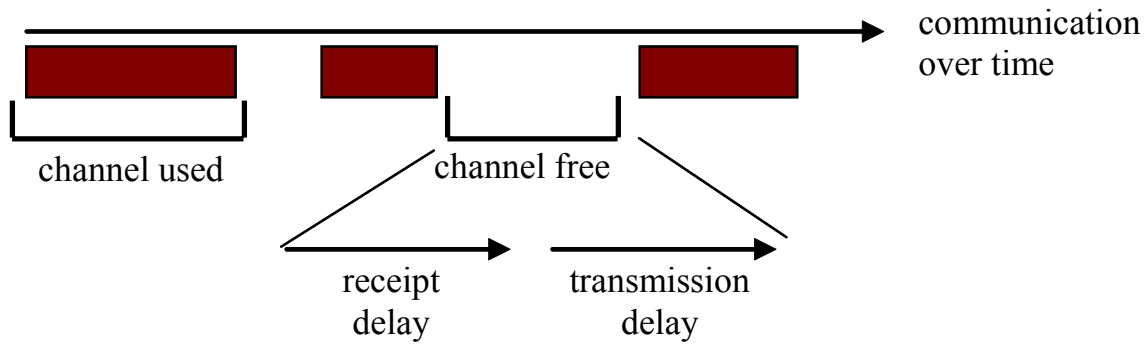


Diagram from Sheridan, Teleoperation

Communications Latency Problems



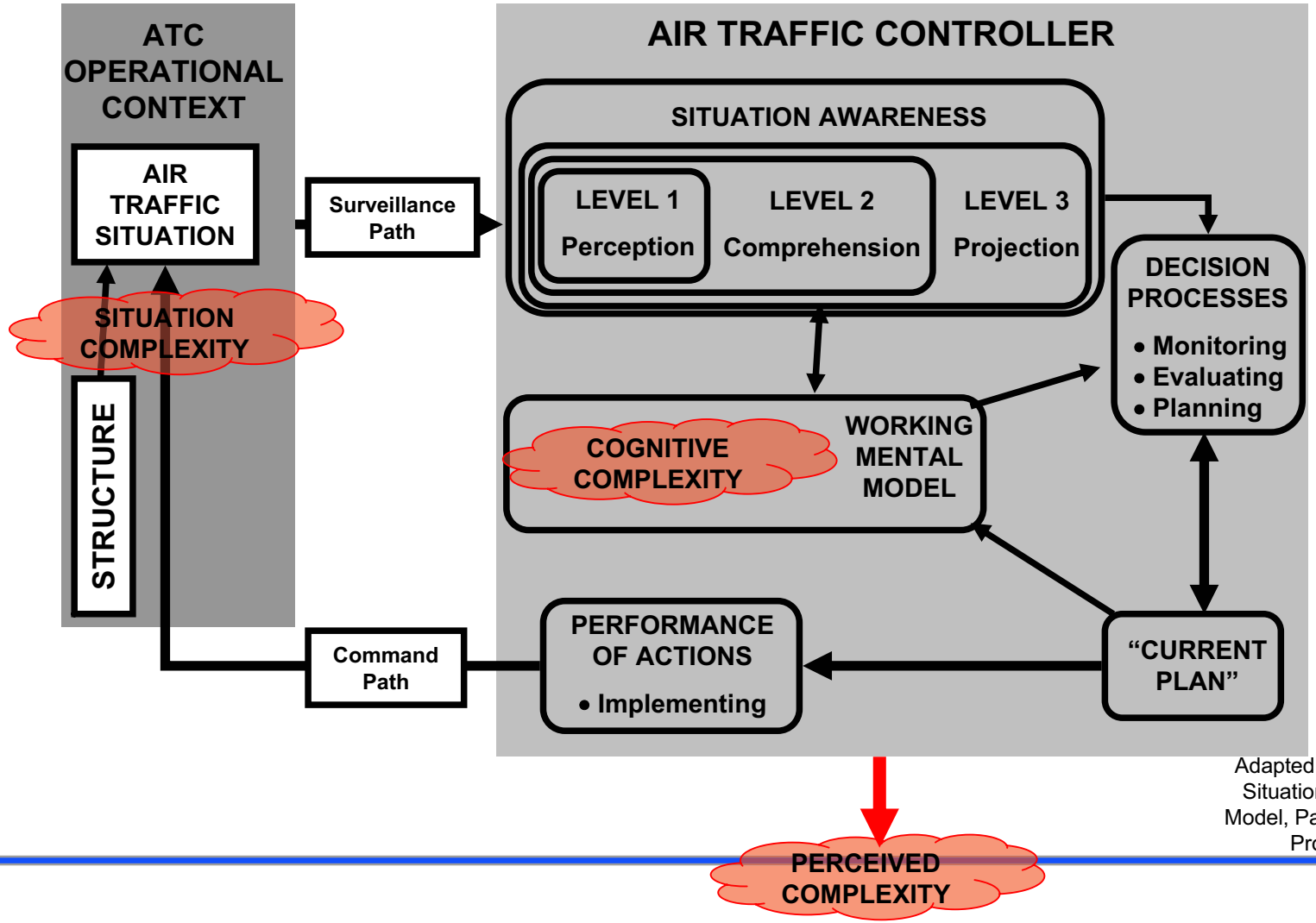


Satellite Latency Cycle Times : 2-5 sec
PIO Issues due to lags.

Multiple Vehicle Control

- **Situation Awareness**
  - ☐ “Big Picture” Overview of Battlefield
  - ☐ Orientation Confusion Multiple Reference Frames
  - ☐ N Vehicle states
  - ☐ N Vehicle status
  - ☐ Kindergarten Model
- **Human/ Machine Allocation**
  - ☐ Level of Vehicle Autonomy
  - ☐ Need for Higher Level of Abstraction (Macro vs Micro Management)
  - ☐ Organizational vs Operator Model
  - ☐ Directed vs Behavioral Automation
  - ☐ Dynamic re-allocation
- **Cognitive Workload - Taskload**
  - ☐ How many vehicles can be reliably managed
  - ☐ Cognitive Complexity Limitations
  - ☐ ATC Analogy (Acceptable Level of Traffic)

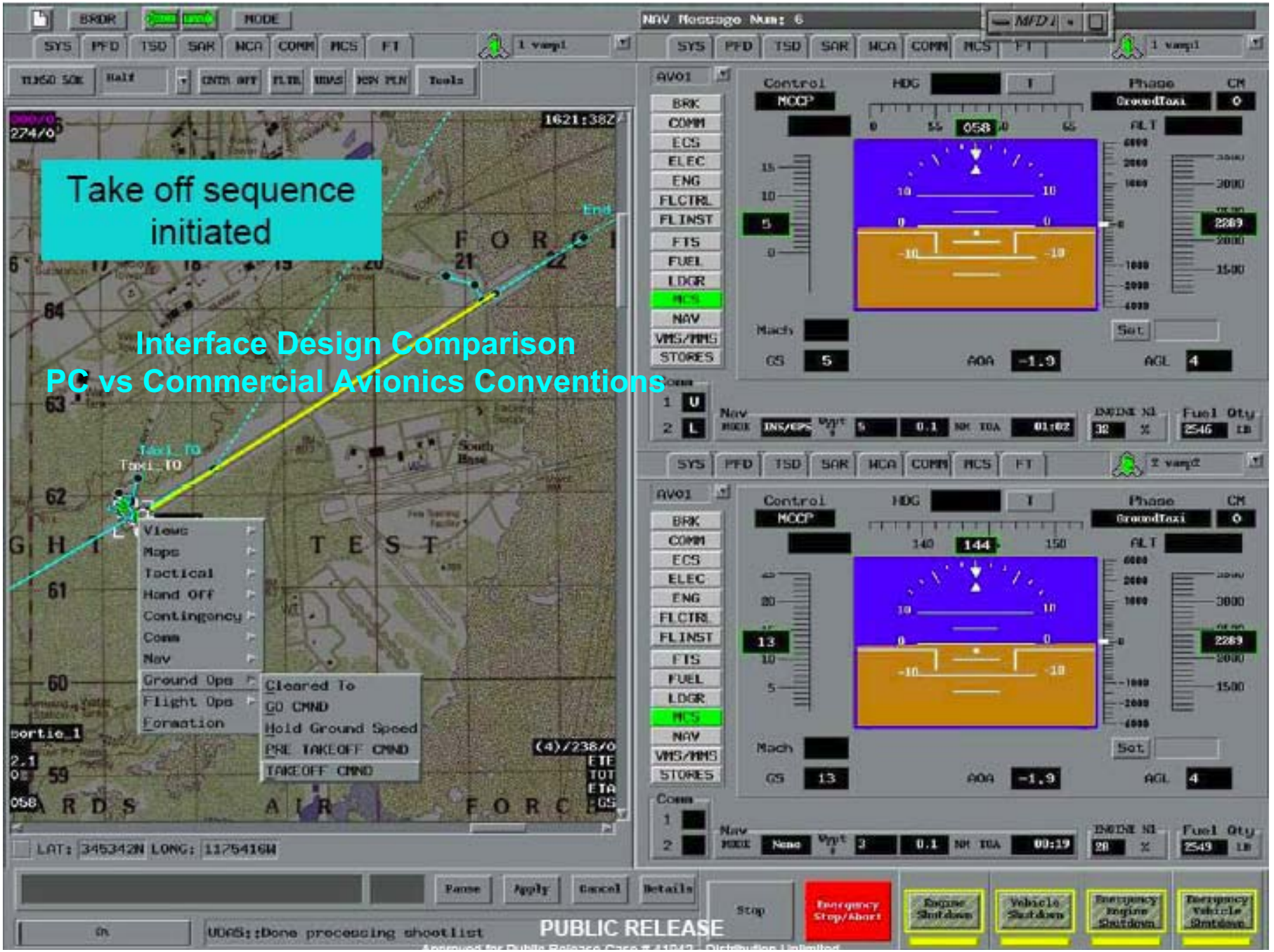
Complexity Concepts & Controller Process Model



Adapted from Endsley Situation Awareness Model, Pawlak Key ATC Processes

Human-System Interface Issues

- **Interface Comparison - UAV vs Commercial**
  - DARPA USAF Boeing X-45 Example
  - Boeing B-777
- **Source: Build 2 Operational Simulation Overview Briefing**
  - Caveats:
    - Prototype not operational system
    - Briefing may not reflect actual system
    - PC based interface


Take off sequence initiated
Interface Design Comparison
PC vs Commercial Avionics Conventions
PUBLIC RELEASE

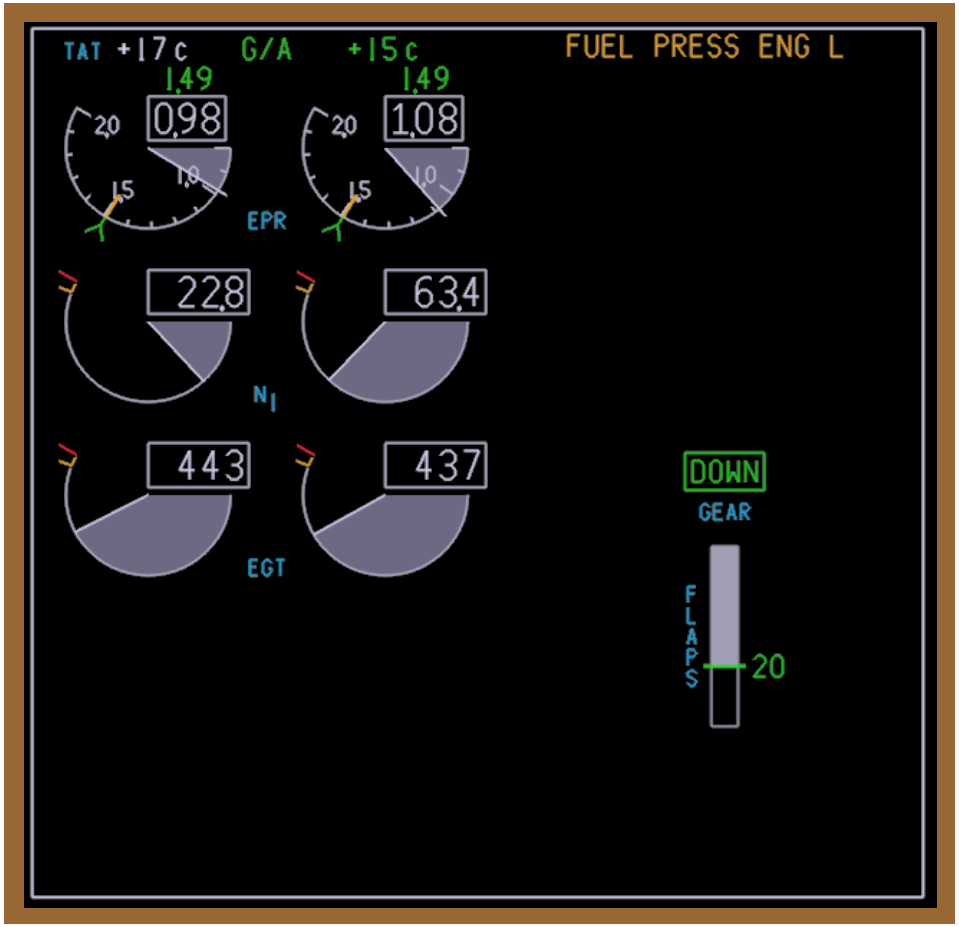
X-45
Primary Flight Display (PFD)

Analogue vs Digital Indications
Color Conventions
Readability
Hidden Info

Commercial B-777
Primary Flight Display (PFD)

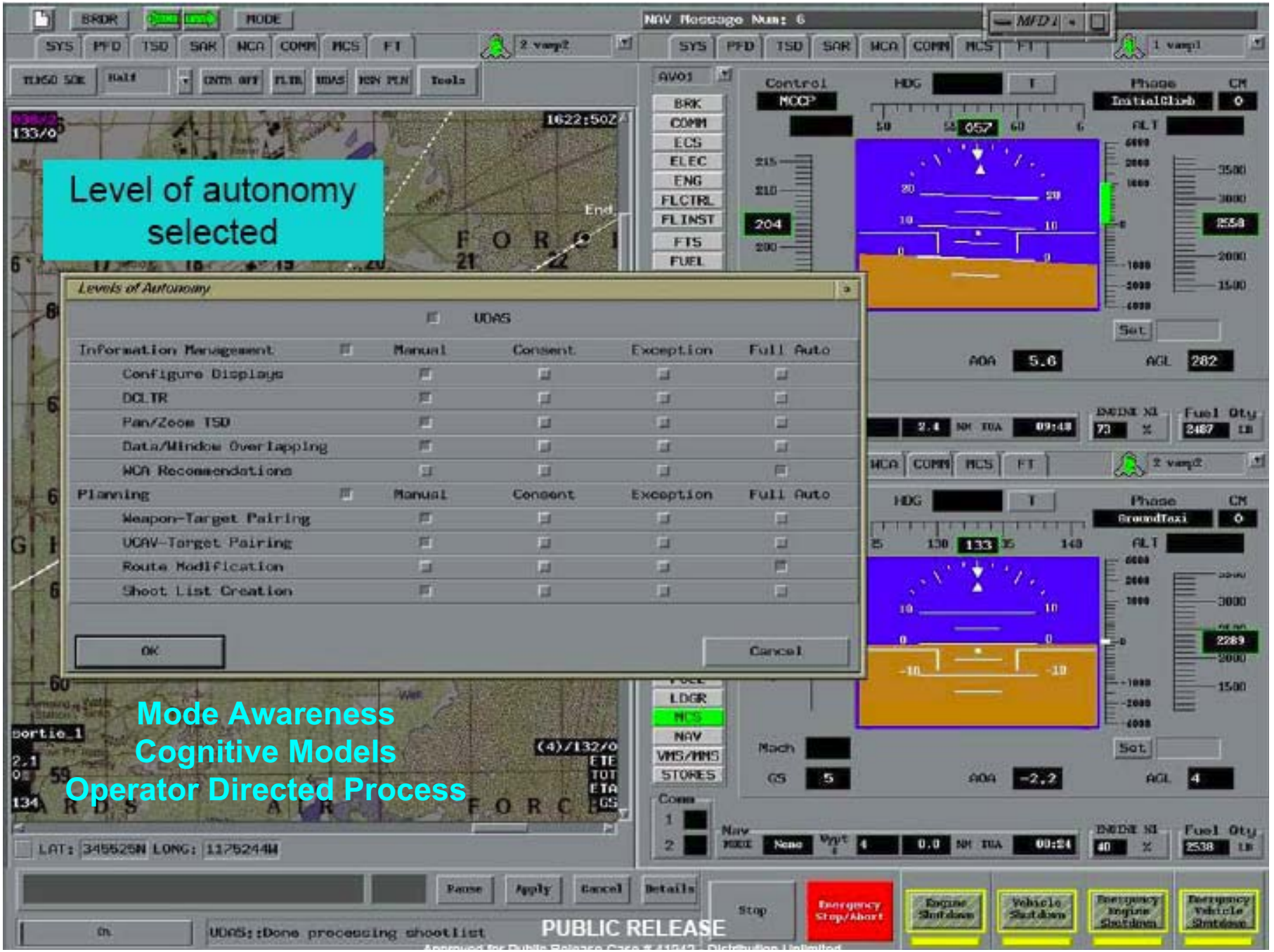
Quiet Dark Philosophy

- Reduction of Clutter
- No indications for “normal”
- No “ON” indicators
- No indications for “do nothing”
- Indicate limits, not normal range



Elements of quiet dark …
So once the procedure for this failure is taken care of ….
When the gear is safely up and locked …

When the flaps are up …
Only the engine indications remain. Maybe in the future we can eliminate most of them as well.


Level of autonomy selected
Levels of Autonomy
UDAS
Information Management
Manual
Consent
Exception
Full Auto
Configure Displays
DCLTR
Pan/Zoom TSD
Data/Window Overlapping
WCA Recommendations
Planning
Manual
Consent
Exception
Full Auto
Weapon-Target Pairing
UCAV-Target Pairing
Route Modification
Shoot List Creation
OK
Cancel
Mode Awareness
Cognitive Models
Operator Directed Process
UDAS: Done processing shootlist
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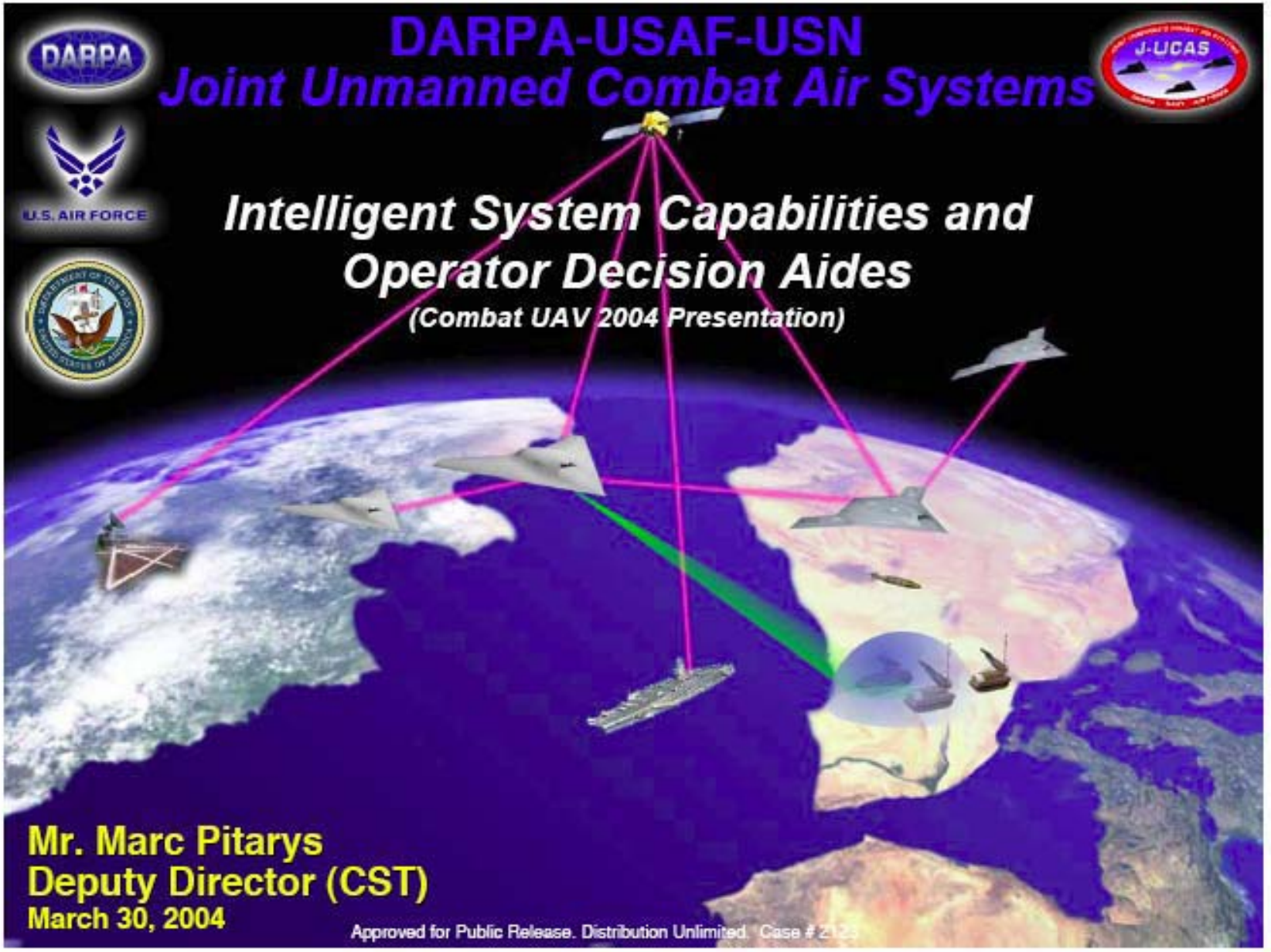
Example: Flight Automation

- ***Mode Awareness* is becoming a serious issues in Complex Automation Systems**
  - ☐ automation executes an unexpected action (commission), or fails to execute an action (omission) that is anticipated or expected by one or more of the pilots
- **Multiple accidents and incidents**
  - ☐ Strasbourg A320 crash: incorrect vertical mode selection
  - ☐ Orly A310 violent pitchup: flap overspeed
  - ☐ B757 speed violations: early leveloff conditions
- **Pilot needs to**
  - ☐ Identify current state of automation
  - ☐ Understand implications of current state
  - ☐ Predict future states of automation

Reference: *Aviation Week & Space Technology*. McGraw-Hill, January 30, 1995.


DARPA-USAF-USN
Joint Unmanned Combat Air Systems
J-UCAS
U.S. AIR FORCE
Intelligent System Capabilities and
Operator Decision Aides
(Combat UAV 2004 Presentation)
Mr. Marc Pitarys
Deputy Director (CST)
March 30, 2004
Approved for Public Release. Distribution Unlimited. Case # 2123

Types of Intelligent Systems

Coaches try to make you better at what you do

DAS *Associates* automatically help with tasks

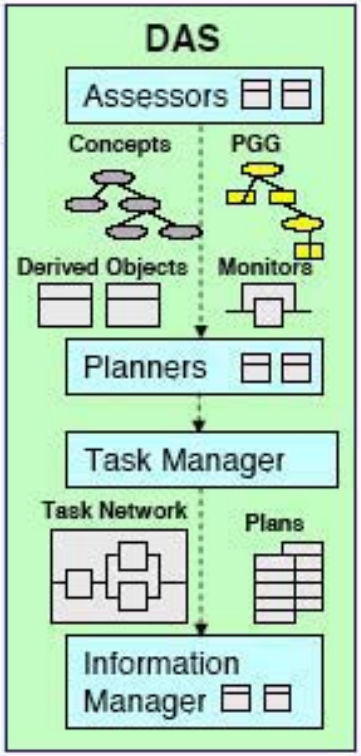
Assistants do what you ask them to do

Experts do what they know how to do

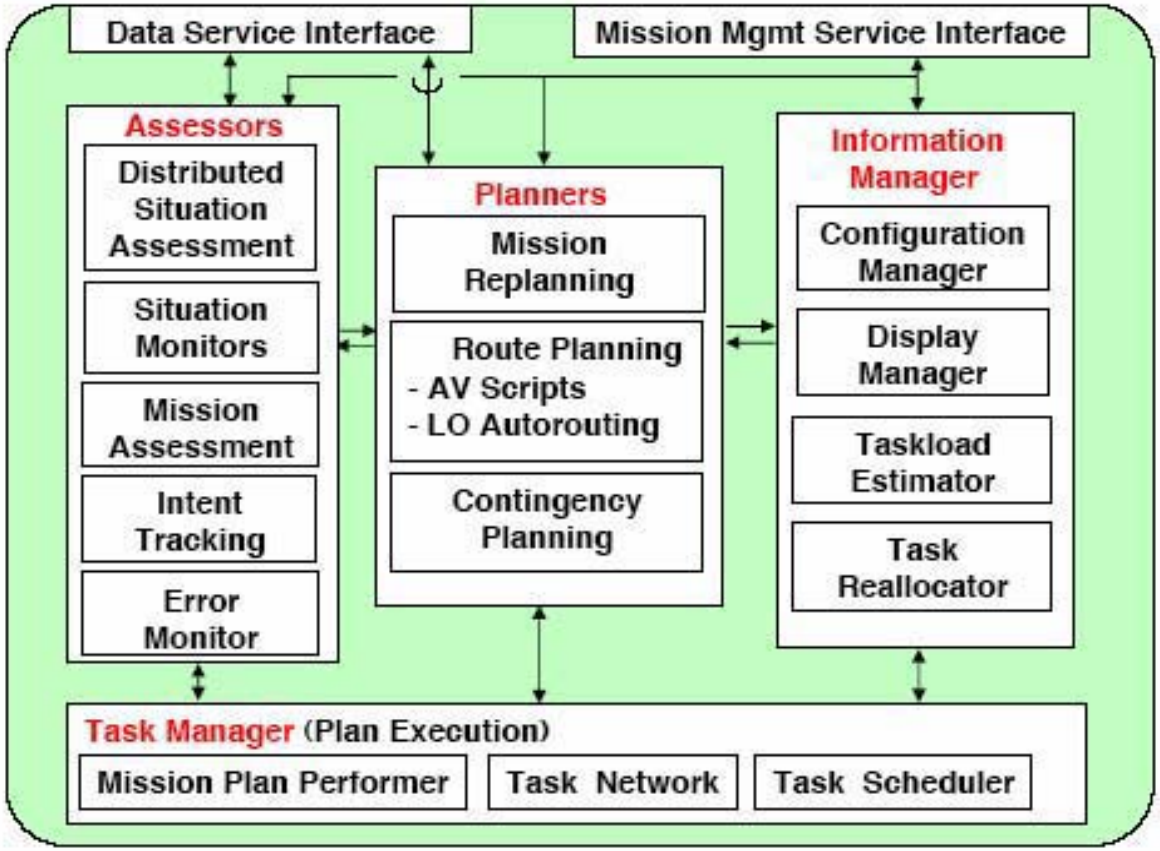
Intelligence

Decision Aiding System (DAS) Functionality Overview

Assessors	Planners	Task Manager	Information Manager
Monitor mission. Detect new threats. Assess route impact. Trigger replanning. Monitor mission plans. Monitor status.	Provide weapon allocation to targets. Evaluates mission plan alternatives with different defining parameters. • Type (ATK, SAR, etc.) • Target • Rejoin point • Weapon type/ number Recommends new mission plan. Operator can apply or cancel recommended plan.	Task Network equivalent to a manager's PERT chart to coordinate activities. Temporal task model of operator and computer tasks. Tasks prioritized by task importance and deadline. Operator task drives displays via information requirements. Computer tasks drive automation.	Bring up displays or specific pages. Pan/zoom about proposed mission plans. Bring up weapon pairing/LAR ymbols. De-clutter unwanted symbols. Locate secondary window text in open corners. Prioritize alerts. Reallocate tasks.



Decision Aiding Notional Software Architecture



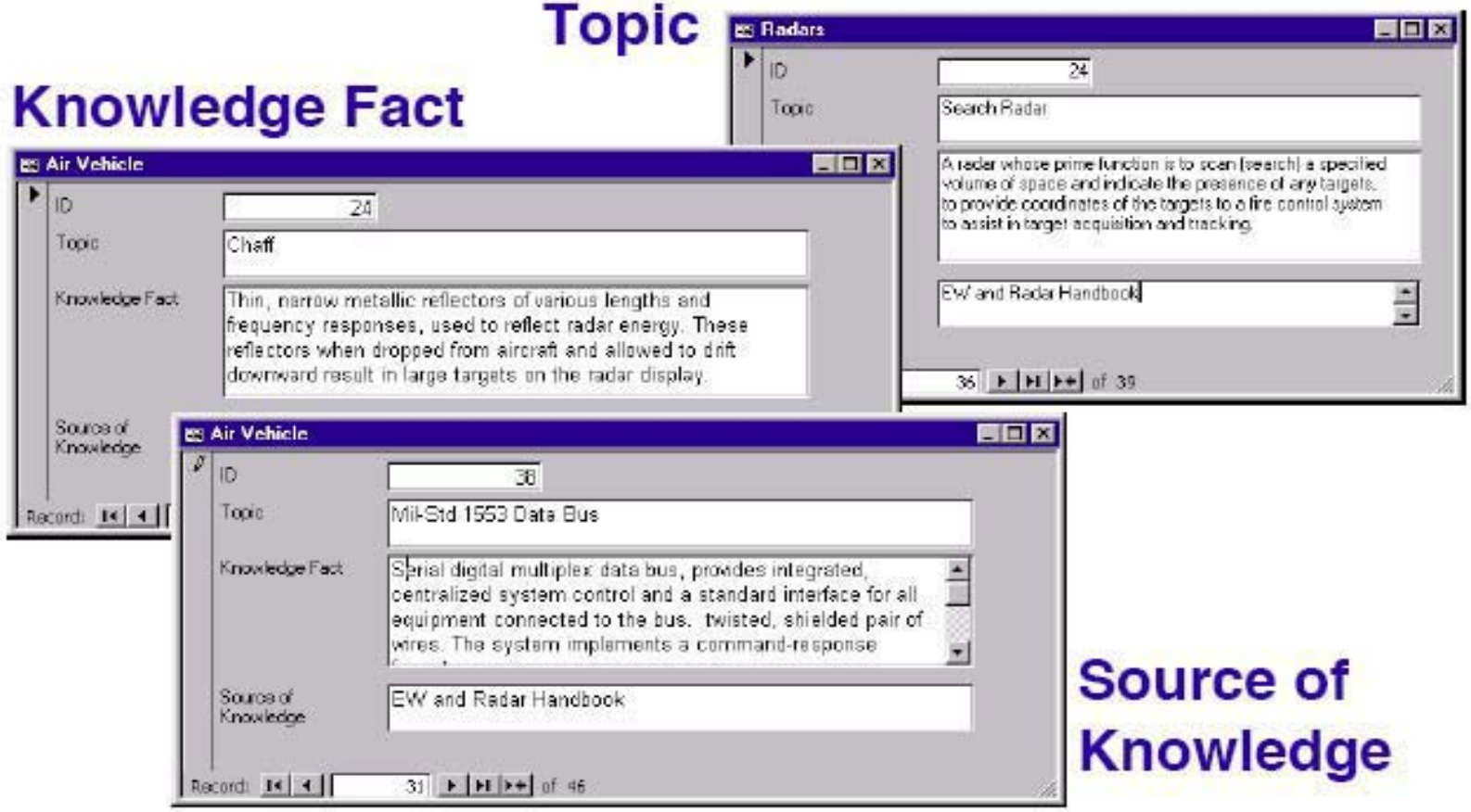
Knowledge Engineering Process

Step	Product	Tool
Identification of knowledge requirements	Requirements Document, Knowledge Engineering Plan	Requirements Engineering tool such as DOORS
Production of the domain ontology for the domain of interest	Domain Ontology	Relational Database
Production of system knowledge at an intermediate level of representation	Intermediate Representation Forms- Contains activities such as Plans, Goals, Graphs, and Tasks	Integrated Knowledge Environment (IKE)
Conversion of this intermediate level representation to operational knowledge	Knowledge Base File containing the Operational Knowledge Representation	IKE
Testing of this knowledge to validate it	Validated Knowledge	Test Plans, Models, and Simulations

Domain Ontology (Knowledge Categories)

Air Vehicle	*Physical Description*
Airspace	*Zones and Areas*
Aviation	*Aircraft Operations and Performance*
Communications	*Radios and IFF*
Formulary	*Mathematical Formulas*
Mapping, Charting, Geodesy and Imagery	*Navigation*
Mission Planning	*Flight Planning plus Target Engagement*
Radar	*ESM and SAR*
Roles and Missions	*Aircraft Roles and Combat Missions*
Weapons	*Air-to-Surface and Surface-to-Air*

Relational Database Organizes Domain Ontology



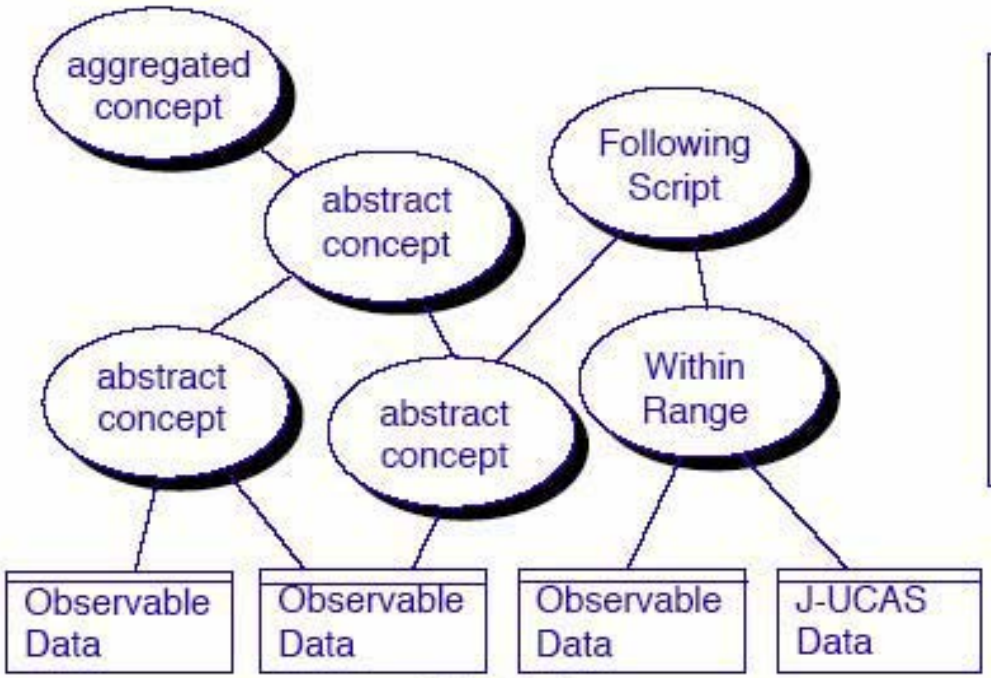
Plan-Goal Graphs Describe System Purposes

INTENT

- **The Plan Goal Graph**
  - Models operator intent

- Plan-Goal Graph (PGG) - a hierarchical decomposition of the mission.
- Rectangles represent plans which indicate "what" the operator is doing.
- Ellipses represent goals or "why" the operator is executing each plan.
- Plan requires all goals to be satisfied (an "and" node); goal requires only one plan to be successful (an "or" node).
- Plan may contain a script: a sequence of simple steps.
- Lowest level of decomposition (actions) represent primitive manipulations.
- Links contain knowledge in the form of constraints (e.g. within weapons range).

Concept Graphs Describe the Situation

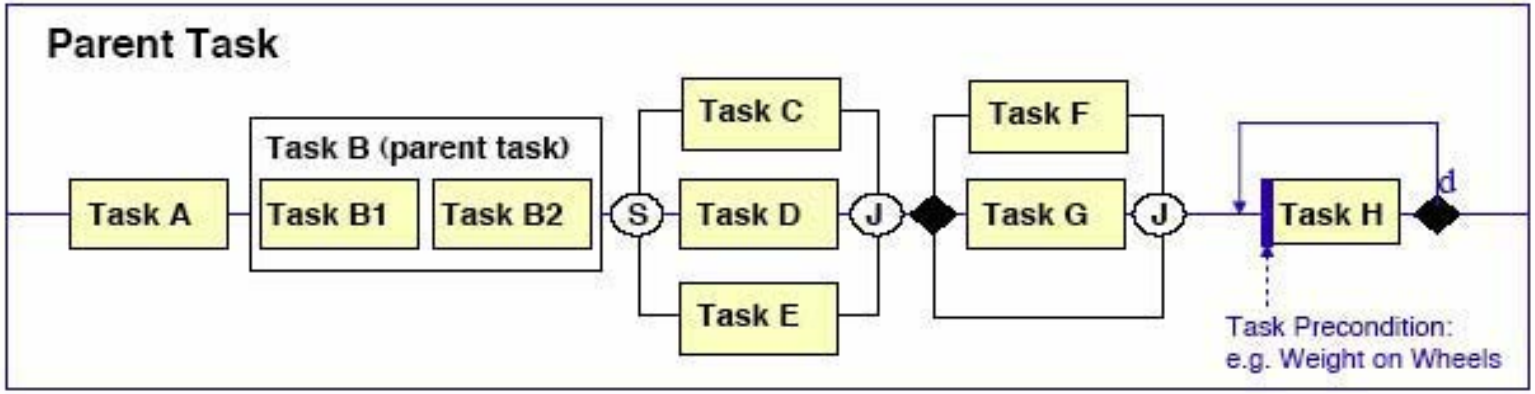


- Directed acyclic graph
- Increasing in abstraction and aggregation
- Links indicate dependencies
- Value propagation is dependency-directed

FACT

- **The Concept Graph**
  - Represents real world state

Task Network Node Types



Task Network Similar to Management PERT Chart

- Represents computer tasks (1 - 100 mseconds)
- Represents operator tasks (1- 60 seconds)
- Network Topology represent task dependencies
- Task parameters include task importance and deadline

Monitors Link the Concept Graph and PGG