Technology Considerations for Advanced Formation Flight Systems

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How Can Technologies Impact System Concept

- **Need (Technology Pull)**
  - Technologies can fulfill need or requirement
  - Technologies can overcome barriers (limitations, constraints, etc.)

- **Opportunity (Technology Push)**
  - Technologies can Create Opportunities
  - New Capabilities
  - Competitive advantage
    - Cost
    - Performance
    - Maintenance
    - Other

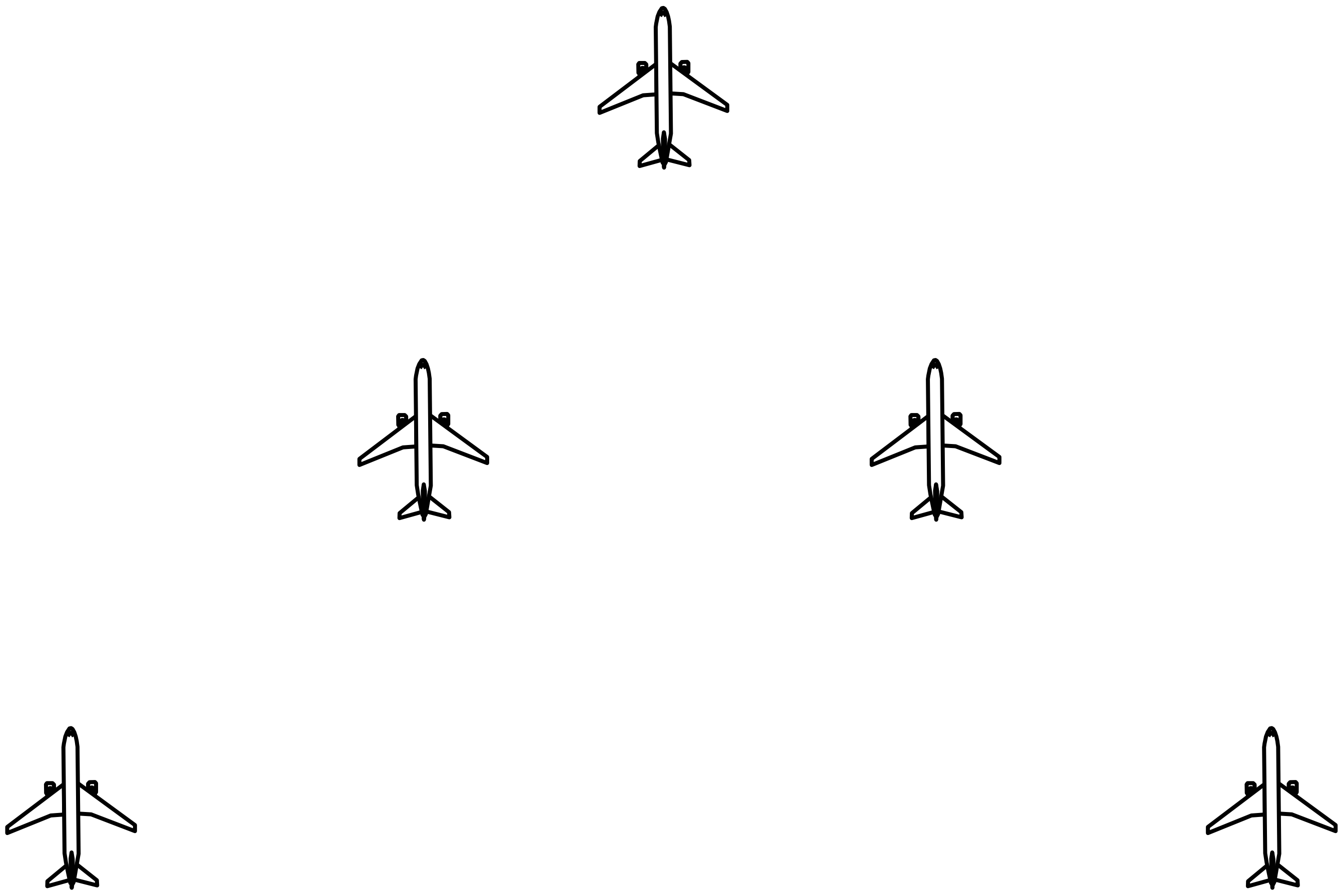
Formation System Concept is Itself a Technology

- **Needs**
  - ☐ Efficient Transport
    - ◆ Fuel
    - ◆ Cost
      - ➔ Crew, Maintenance…
    - ◆ Operational Access (Noise, Runways)
    - ◆ Flexibility
    - ◆ Others
- **Opportunity**
  - ☐ Different design space if use multiple vehicles
  - ☐ Overcome constraints (eg runway width, single departure point)
  - ☐ Performance
    - ◆ Fuel efficiency, crew
  - ☐ Development of key technologies enable formation flight
  - ☐ Flexibility
  - ☐ Runway Throughput

What are the Key Technologies for Formation Flight

- **Start with Fundamental Abstraction of System or Concept (many ways)**
  - Functional
  - Operational
    - Concept of Operations
  - Physical
  - Component
  - Constraint
  - Information
- **Based on Abstract view, identify**
  - Technology needs
  - Key questions
  - Potential opportunities
- **Useful to sketch elements to visualize system**
  - Multiple views

What are the Key Technologies for Formation Flight



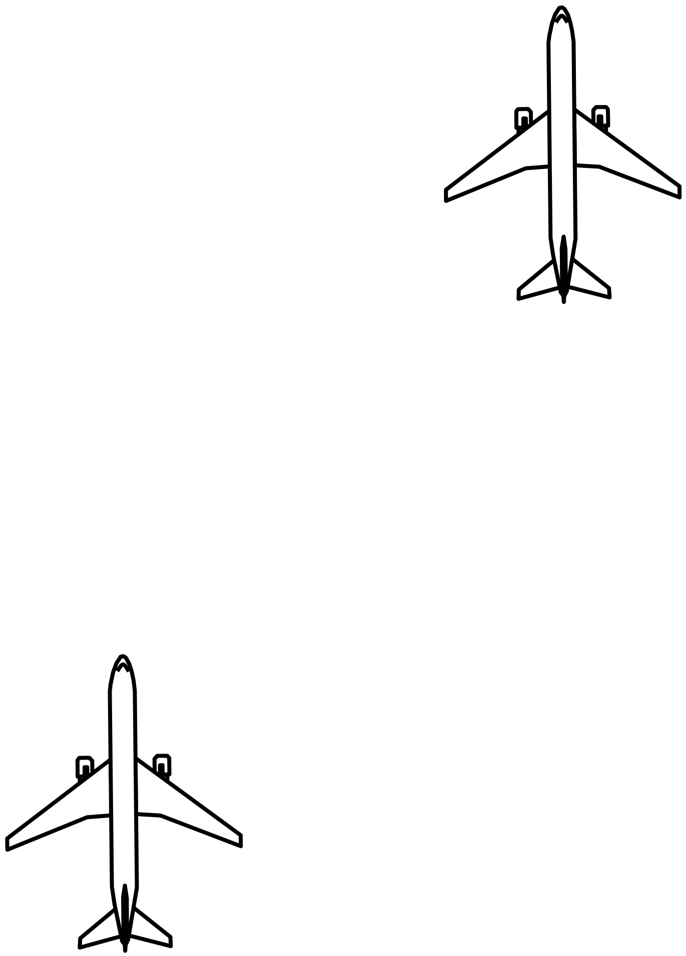
What are the Key Technologies for Formation Flight

- **Overall Concept Questions**
  - ☐ Concept of Operations?
  - ☐ How does form up occur
  - ☐ Station keeping requirements
  - ☐ Failure Modes
  - ☐ Existing elements or New
    - ◆ Vehicles
    - ◆ Control Systems
    - ◆ CNS
    - ◆ Other

- **Concept Scale Opportunities/Costs**
  - ☐ Performance gains estimate
    - ◆ Fuel
    - ◆ Capacity
  - ☐ Costs
    - ◆ Development
    - ◆ Deployment

- **Concept Technologies Reqs**
  - ☐ Formation design
  - ☐ Station Keeping
    - ◆ Com
    - ◆ Nav
    - ◆ Surveillance
    - ◆ Control

What are the Key Technologies for Formation Flight



- **Communications**
- **Navigation**
- **Surveillance**
- **Control (Station Keeping)**
  - Intent States
  - String Stability
- **Vehicle Configuration**
  - Aero/Performance
  - Control
- **Propulsion**
- **Degree of Autonomy**
- **Flight Criticality**
  - Hardware
  - Software
- **Low Observability**
- **Others?**

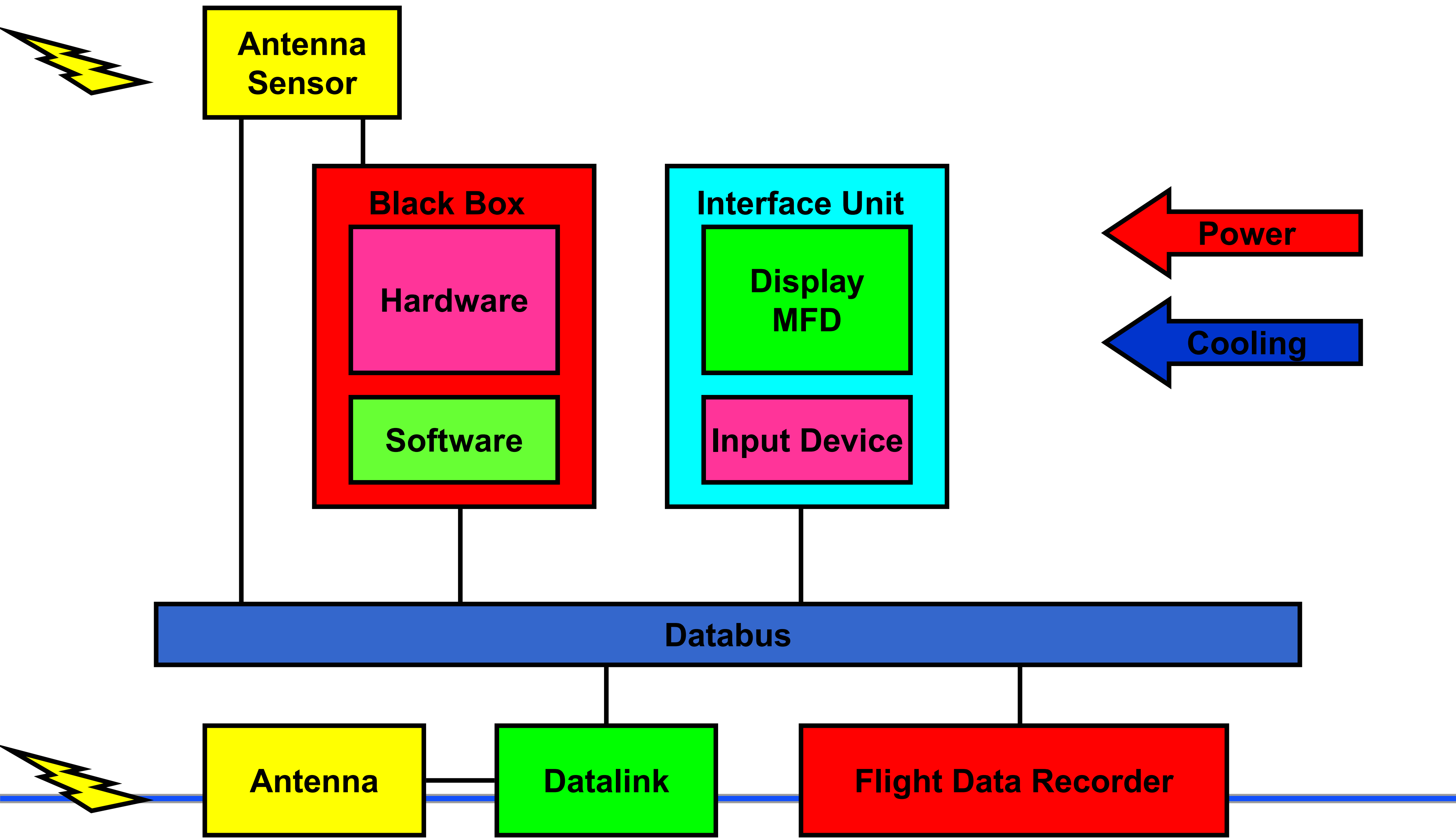
Communications

- **Requirements**
  - Communicate necessary information between formation elements and command node (LAN and Air-Ground)
  - Bandwidth
  - Low-Observable?
  - Synchronous vs asynchronous
- **Constraints**
  - Spectrum
  - Antenna Location
- **Technologies**
  - Radio
    - UHF, VHF, MMW
  - Optical
    - Laser
  - Protocols

COMMUNICATION

- **Voice**
  - VHF (line of sight)
    - 118.0-135.0 Mhz
    - .025 spacing in US, 0.083 spacing in Europe)
  - UHF
    - 230-400 Mhz (guess)
  - HF (over the horizon)
  - Optical (secure)
- **Datalink**
  - ACARS (VHF) - VDL Mode 2
  - VDL Modes 3 and 4 (split voice and data)
  - HF Datalink (China and Selcal)
- **Geosynchronous (Inmarsatt)**
    - Antenna Requirements
- **LEO and MEO Networks**
- **Software Radios**
- **Antenna Requirements**

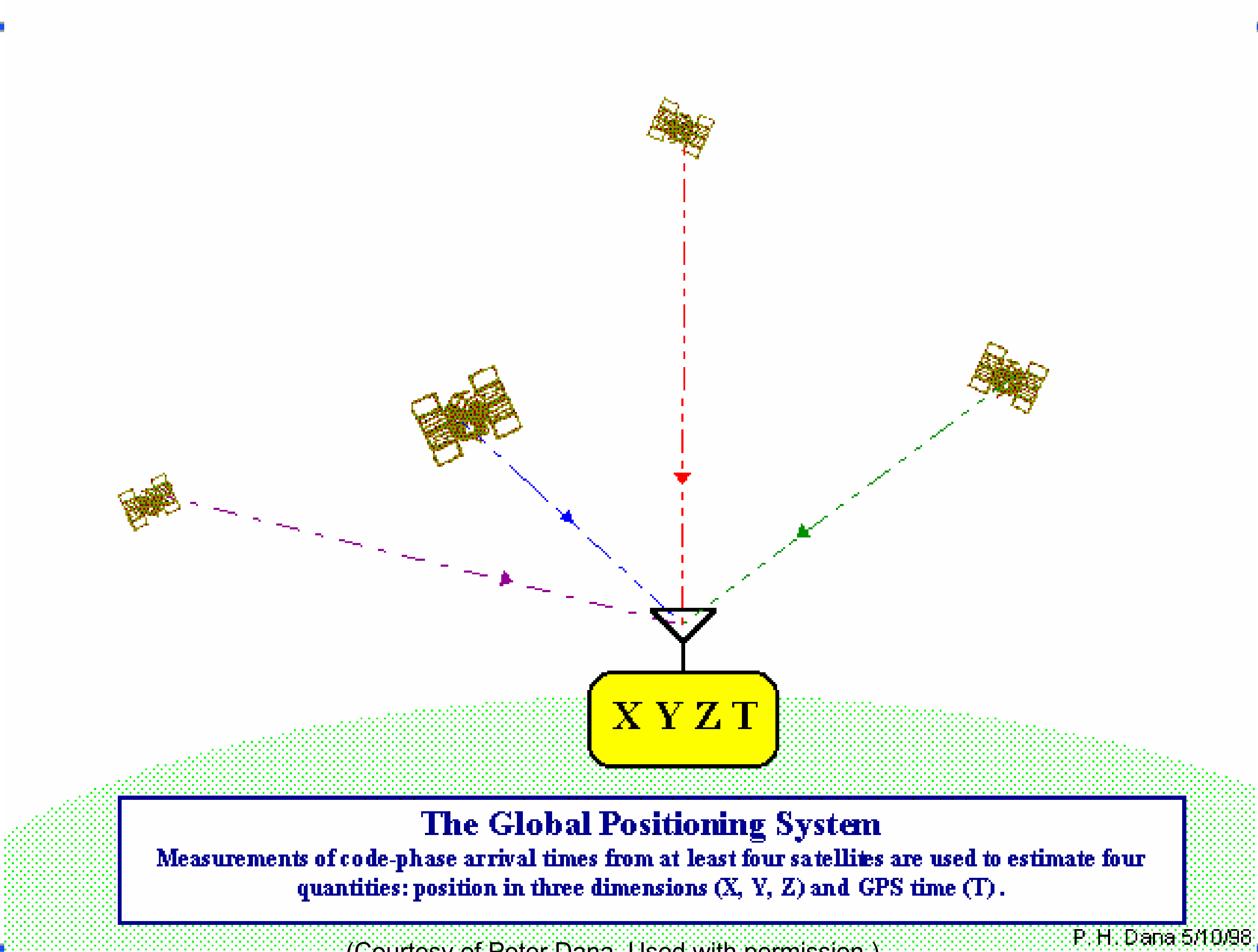
Generic Avionic System



Navigation
(relates to Surveillance)

- **Requirements**
  - ☐ General Navigation (medium precision)
  - ☐ Station Keeping (high precision)
  - ☐ Integrity
  - ☐ Availability
- **Constraints**
  - ☐ Existing nav systems
  - ☐ Loss of signal
- **Technologies**
  - ☐ GPS/Galileo (need Differential)
    - ◆ Code vs Carrier Phase Approaches
  - ☐ IRS/GPS
  - ☐ Sensor Based Approaches for Station Keeping
    - ◆ Image (Visible, IR)
    - ◆ Range Finders (Laser, Ultrasonic)

GPS



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From http://www.colorado.Edu/geography/gcraft/notes/gps/gps_f.html

Inertial Reference Unit

- **Integrate acceleration from known position and velocity**
  - Velocity
  - Position
- **Need Heading**
  - Gyros
    - Mechanical
    - Laser
- **Can get Attitude**
  - Artificial Horizon (PFD. HUD)
- **Drift Errors**
  - IRU unusable in vertical direction (need baro alt)
  - Inflight Correction
    - DME
    - GPS
    - Star Sighting for Space Vehicles
- **Measurement Give Attitude Also**
- **777 Analytical Redundancy**

Surveillance

- **Requirements**
  - ☐ Observed states of lead elements sufficient to form-up and maintain station keeping either manually or by automatic control
  - ☐ Feed forward states (intent)
- **Constraints**
  - ☐ Sight Angles
  - ☐ Installation (weight, cost, power, etc)
  - ☐ Cooperative Targets
- **Technologies**
  - ☐ Automatic Dependant Surveillance Broadcast (ADS-B)
  - ☐ Image Based Systems (Vis, IR)
  - ☐ Radar (X Band, MMW0
  - ☐ Range Finders (Laser)
  - ☐ Sensor Fusion Systems

MIT ICAT

ADS-B

(Image removed due to copyright considerations.)

Bob Hilb

UPS/Cargo Airline Association

RADAR

- **Wavelength λ**
  - ☐ S Band (10 cm)
  - ☐ X Band (3 cm)
  - ☐ Ku Band (1 (cm)
  - ☐ Millimeter Wave (94 Ghz pass band)
- **Radar Range Equation**
- **Beamwidth Θ**
  - ☐ $\Theta = \lambda/D$
  - ☐ D = Diameter of Circular Antenna
  - ☐ Pencil beam vs Fan Beam
- **Mechanically Steered Antennas**
  - ☐ Scan and Tilt

INTENT REPRESENTATION IN ATC

- **Intent formalized in "Surveillance State Vector"**

Surveillance State Vector, ***X(t)*** = {

Position states, P(t)
Velocity states, V(t)
Acceleration states, A(t)

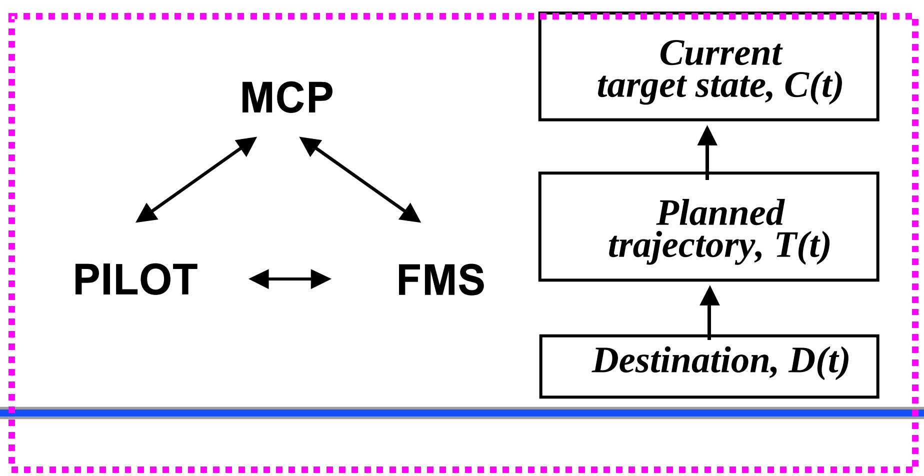
Traditional dynamic states

Current target states, C(t)
Planned trajectory states, T(t)
Destination states, D(t)

Defined intent states

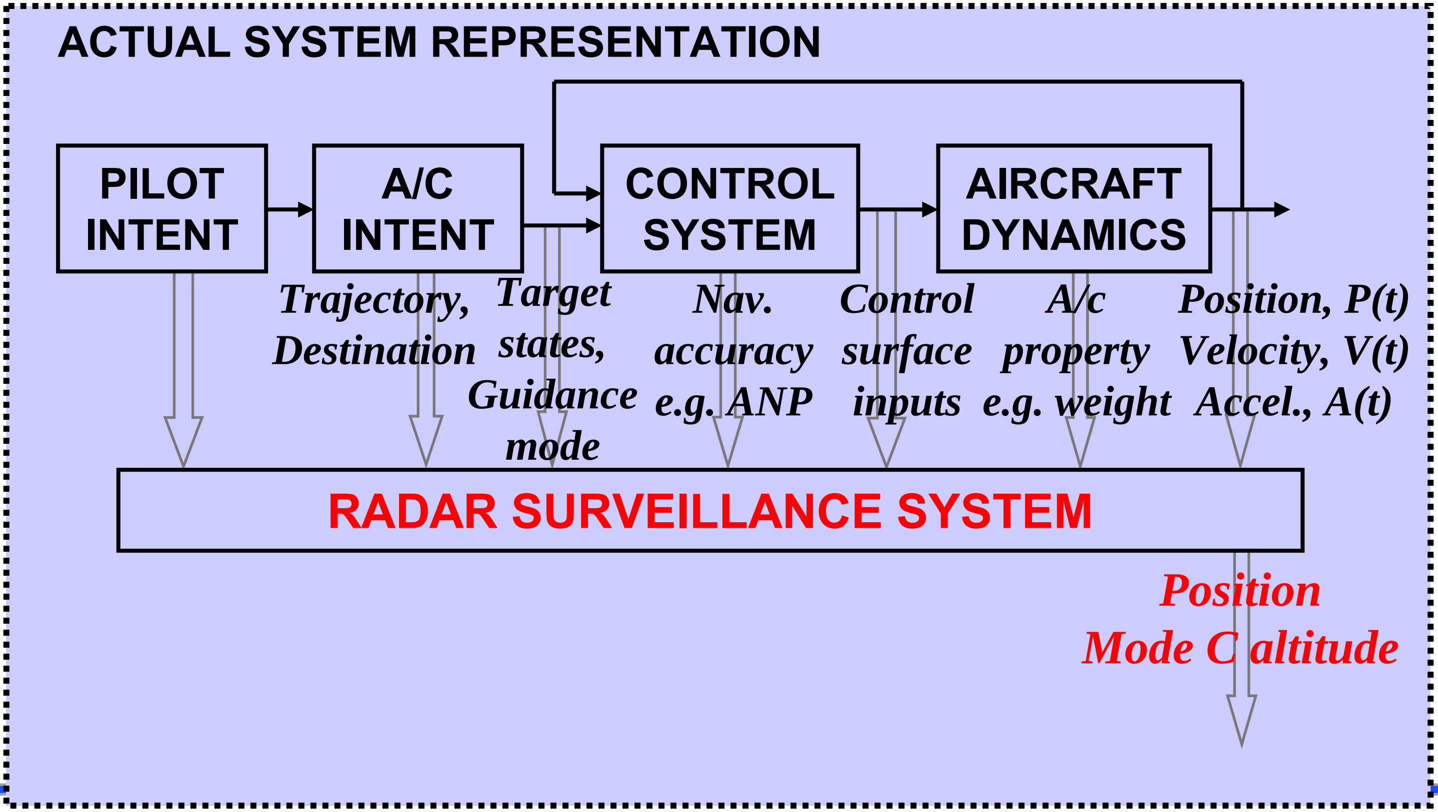
}

- **Accurately mimics intent communication & execution in ATC**



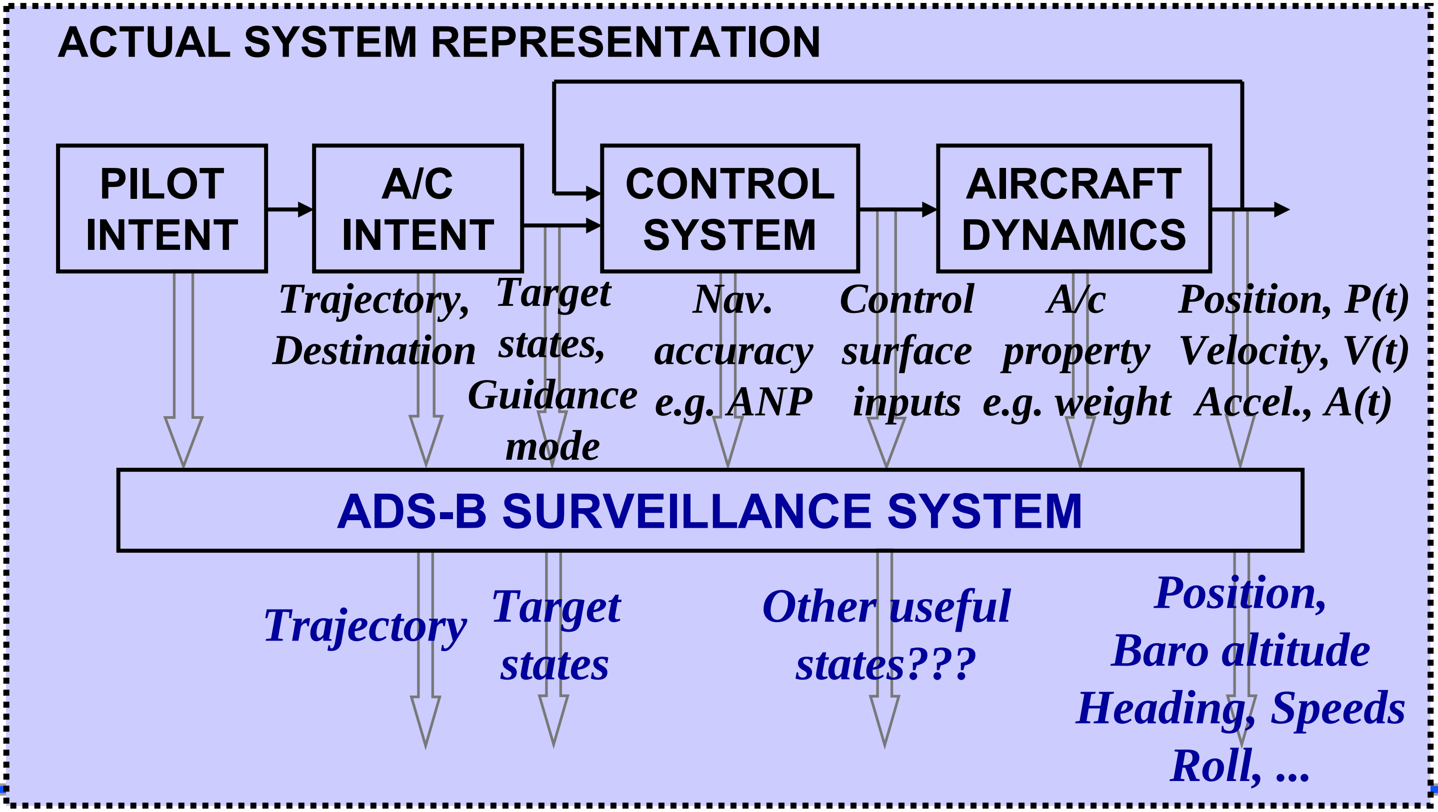
RADAR SURVEILLANCE ENVIRONMENT

- **Allows visualization of different (actual or hypothetical) surveillance environments**
  - ☐ Useful for conformance monitoring analyses of impact of surveillance



ADS-B SURVEILLANCE ENVIRONMENT

- Potential access to more states (e.g. dynamic and intent)
- Need to assess benefits for conformance monitoring



Control

- **Requirements**
  - ☐ Maintain Station Keeping sufficient to achieve formation benefits
  - ☐ Tolerance to Environmental Disturbances
  - ☐ String stability
- **Constraints**
  - ☐ Certification
  - ☐ Failure modes
  - ☐ Available states
- **Technologies**
  - ☐ Performance seeking control
  - ☐ Multi-Agent Control Architectures
  - ☐ Distributed Control Approaches
  - ☐ Leader-Follower Schemes
  - ☐ Fault Tolerant Systems
    - ◆ Redundancy Architectures

Automation

- **Requirements**
  - ☐ Form up and station keeping may need to be automated
- **Constraints**
  - ☐ Reliability, integrity
  - ☐ Certification
  - ☐ Failure Modes
- **Technologies**
  - ☐ Flight Directors
  - ☐ Autopilots
  - ☐ Intercept systems

Software

- **Requirements**
  - High Integrity Implementation for Formation
  - Formation requirement exceeds specs for current vehicles (eg 777)
- **Constraints**
  - Failure Modes
- **Technologies**
  - DO 178B
  - ??

Aero-Configuration

- **Requirements**
  - ☐ Mission based requirements (you will define)
  - ☐ Formation based requirements
  - ☐ Special Control Requirements
- **Constraints**
  - ☐ Stability and Control (CG)
  - ☐ Formation and non-Formation operation
- **Technologies**
  - ☐ Conventional approaches modified by formation considerations
    - ◆ Asymmetric
    - ◆ Formation optimal vs single optimal
      - ➜ Lead - High WL, Low AR >> high vortex
      - ➜ Trail - Low WS, High AR >> Low drag
  - ☐ Vortex Tailoring
  - ☐ Unique configurations or control systems

Configuration

- **Symmetric vs Asymmetric**
- **Variable**
  - Formation vs Free Configurations
- **Formation Specific Considerations**
  - What is the optimal aspect ratio for overall performance
- **Are there special, non-classical control needs?**
- **What are takeoff and landing considerations**
- **In-flight physical hookups**

Propulsion

- **Requirements**
  - Take-off, balanced field length >> drives thrust
  - Cruise efficiency
  - Response time
- **Constraints**
  - Operational in formation and non formation configuration
- **Technologies**
  - Unmatched multi engines (shut down in cruise, eg Voyager)
  - Broad operating envelope engines (SFC hit)
  - Tow Schemes

Propulsion

Voyager aircraft return from non-stop trip around the world

Voyager

Formation Transport Example: C-47 (DC-3) towing CG-4 Cargo Gliders

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http://www.atterburybakalarairmuseum.org/CG4A_C47_color_photo.jpg

What are the risk considerations for technology incorporation

- **Readiness**
  - ☐ NASA Technology Readiness Levels (TRL)
- **Vulnerability**
  - ☐ High (Key Element on Which Concept Based)
  - ☐ Medium (Performance or Capability Enhancing, Competitive Factor)
  - ☐ Low (alternatives available)
- **Competitive Risk**
  - ☐ Goes both ways
- **Certification Risk**
- **Operational Considerations**
  - ☐ Issues are discovered in field operations
    - ◆ Tracking Programs
  - ☐ Unanticipated uses of technology

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