Research Progress on an Automation Concept for Surface Operation with Time-Based Trajectories

Victor H. L. Cheng

Optimal Synthesis Inc.

Palo Alto, California

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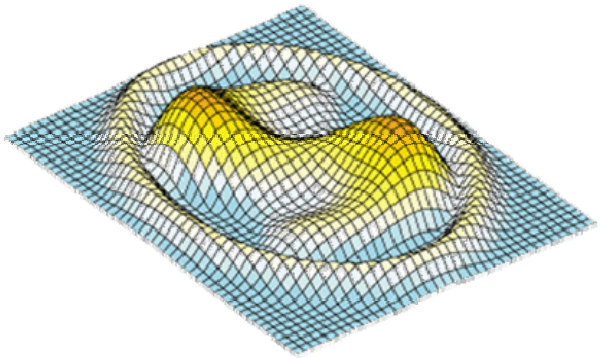
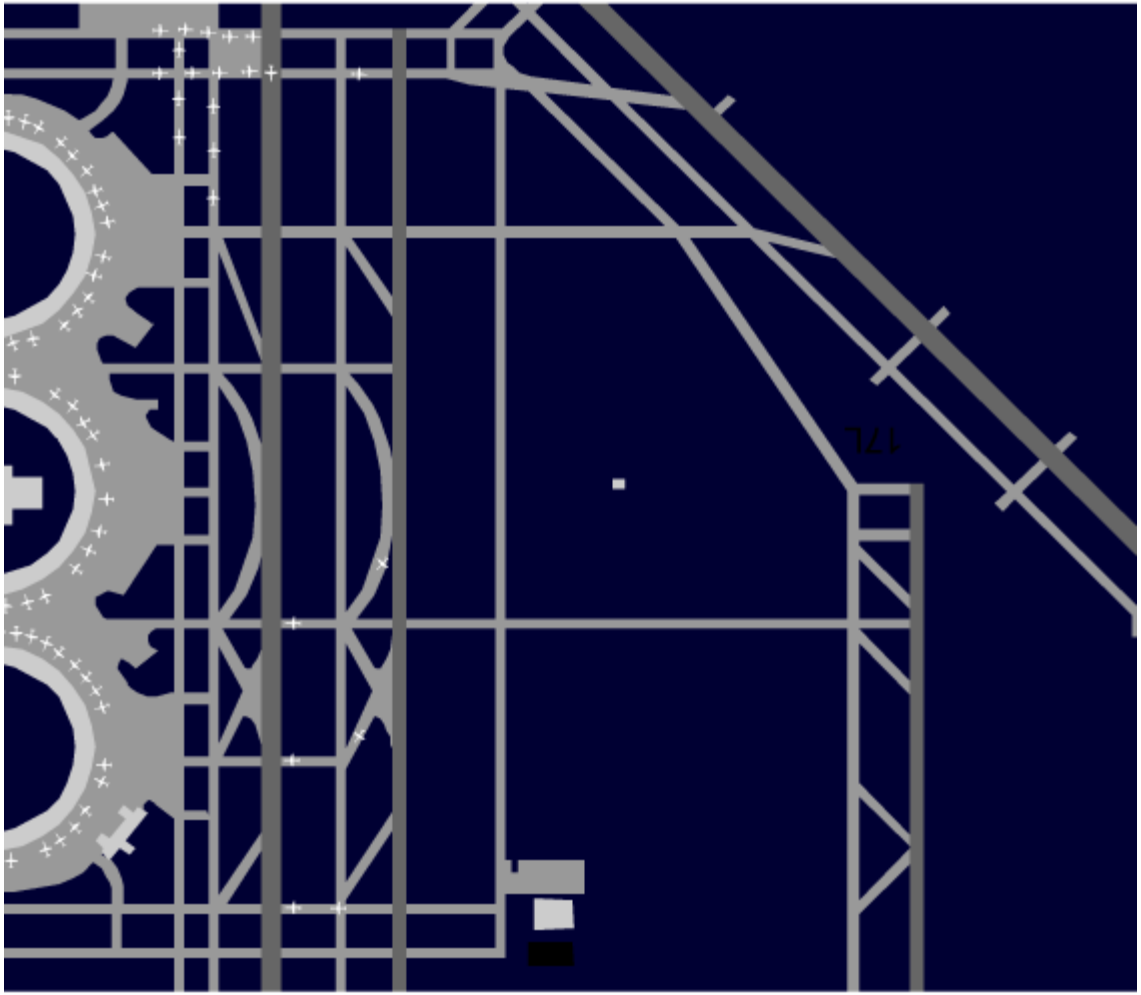


Motivation behind SOAR Concept

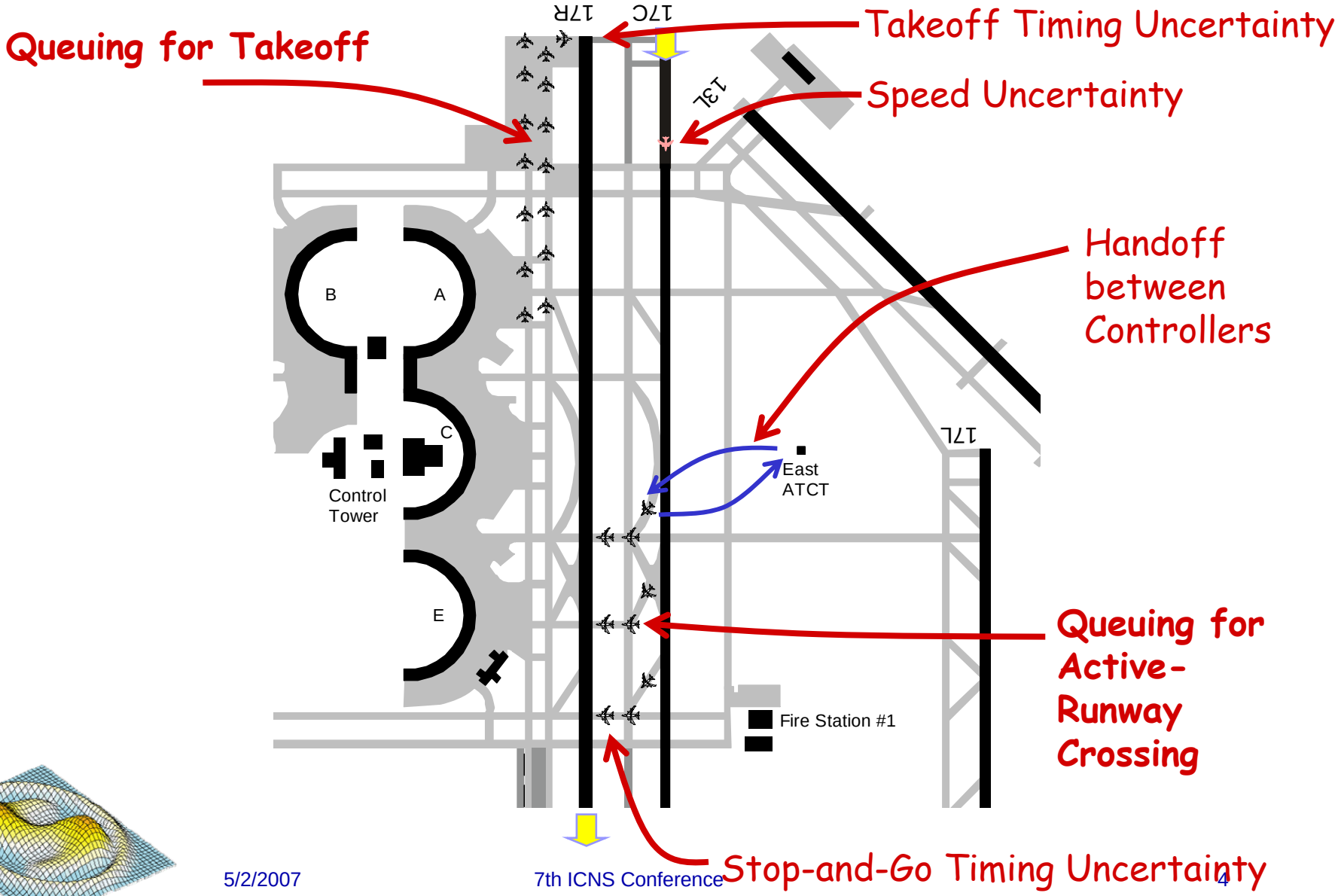


Operational Delay as Metric for Capacity-Related Concepts

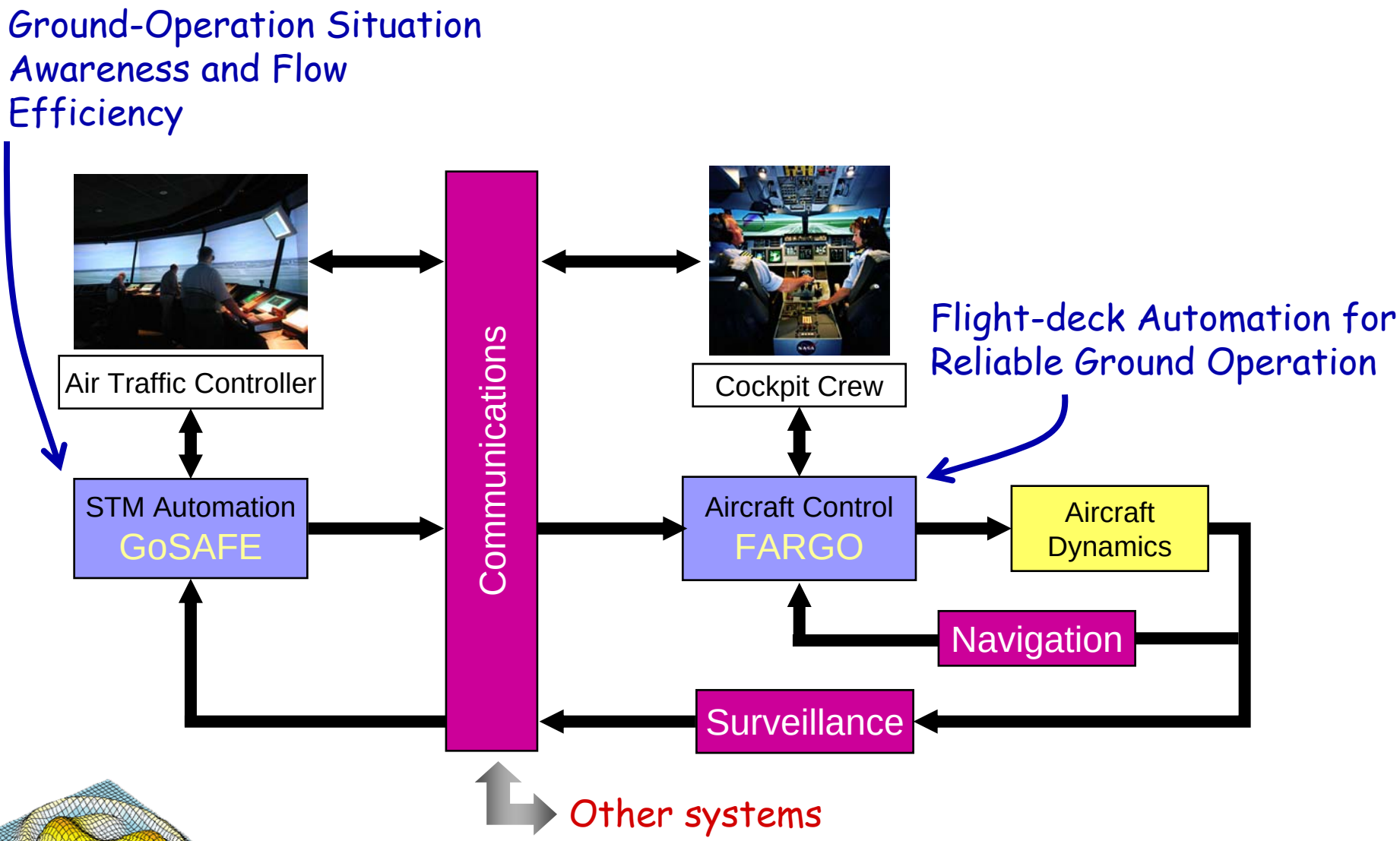
"The benefits that result from capacity-related airport projects and other initiatives will largely consist of cost savings to current and future airport users associated with reduced time spent in the airport system. Reduced time in system may take the form of reduced delay, more efficient processing, or reduced idle time."

— FAA Airport Benefit-Cost Analysis Guidance, December 1999

Examples of Activities Contributing to Taxi Delays



Key Components of SOAR Concept



History of SOAR-Related Projects

Flight-Deck Automation

Precision-Taxi Feasibility

FARGO Experimental Prototype

Surface Traffic Automation

GoSAFE™ Experimental Prototype

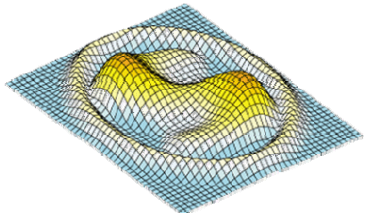
HITL Experiments

SOAR Concept

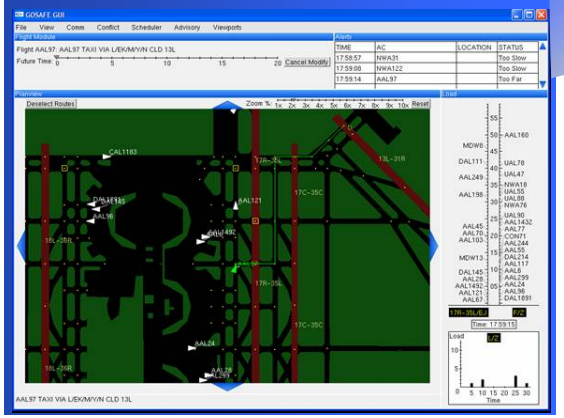
9/06 1/07

Concept Development/Assessment under NASA VAMS & NGATS

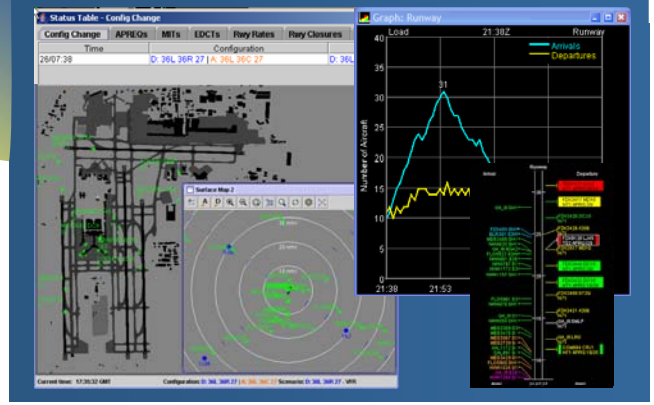
1998	1999	2000	2001	2002	2003	2004	2005	2006	2007



Surface Traffic Control/Tactical Automation



Surface Traffic Management/Strategic Automation

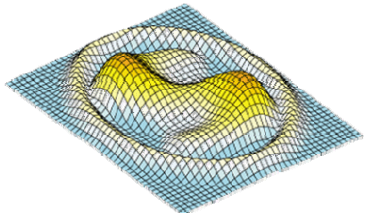


Datalinked Clearances

Flight-Deck Automation

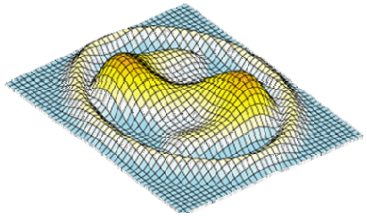
Fundamental Assumptions behind SOAR Concept

- **Flight-deck automation (FARGO) can achieve high-precision taxi to allow the flight to meet any reasonable crossing times at selected points along a pre-specified taxi route on the airport surface.**
- **Tower automation (GoSAFE) can count on the availability of FARGO's precision-taxi capability to plan efficient and safe operations for the surface traffic.**



Tower Automation System – GoSAFE

- **To provide the <u>centralized decision-making</u> functionality**
  - ***Planning*** **functions involving runway usage scheduling and conflict-free route planning to coordinate arrival, departure and taxiing traffics for maximum efficiency**
  - ***Traffic control*** **functions to facilitate issuance of clearances to flight deck for execution of efficient taxi operations**
  - ***Traffic monitor*** **functions to ensure safety of traffic while executing demanding operations**
  - ***Graphic user interface*** **(GUI) to support the abovementioned functions**
- **Preliminary technologies for GoSAFE presented in AIAA GNC Conference, August 2002**

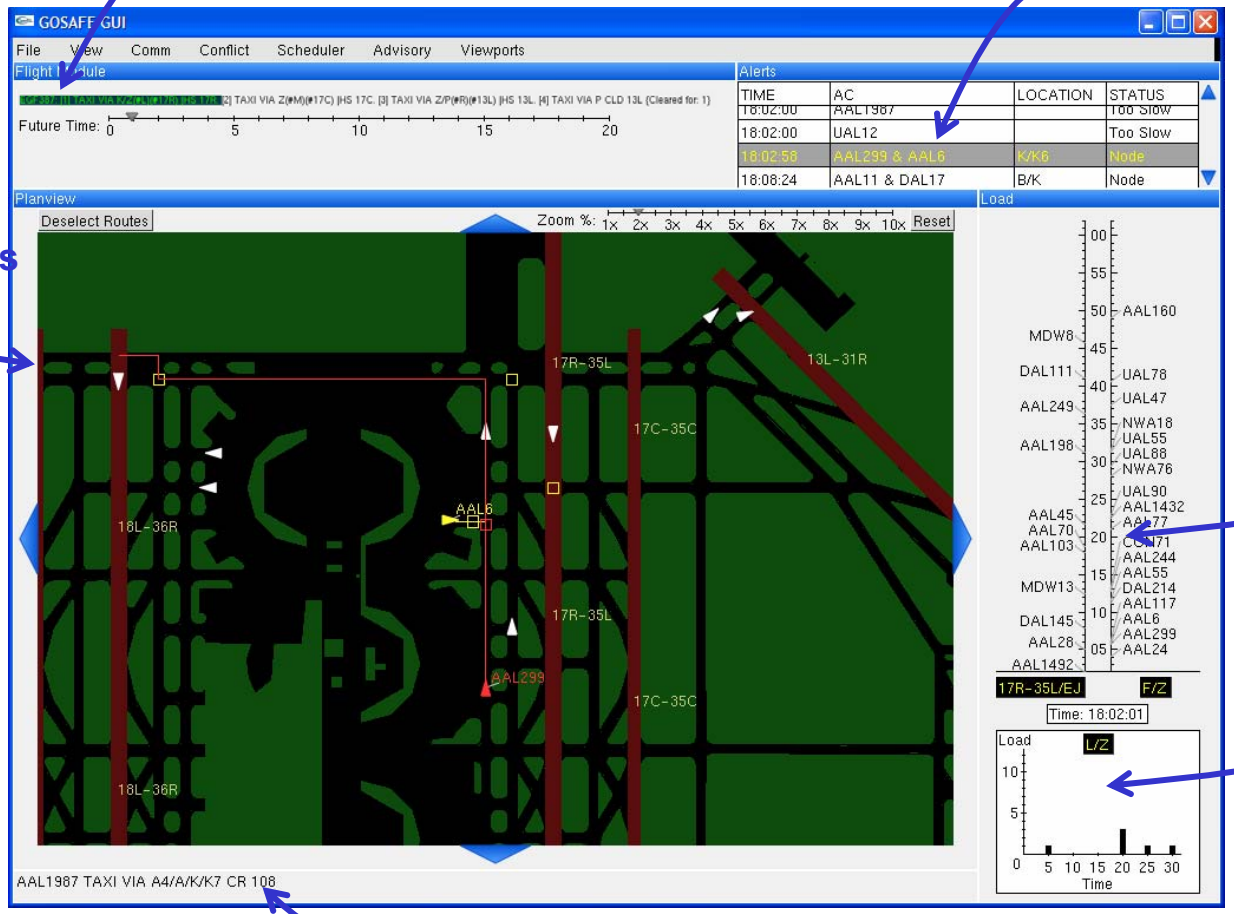


Overview of GoSAFE GUI

Clearance Text – Segmented

Conflict Information
- **Planning**
- **Real-time traffic**

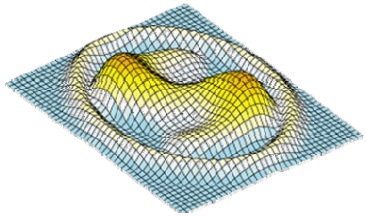
Plan-View Display
- **Surveillance**
- **Route editing**
- **Clearance alerts**
- **Conformance alerts**



Node-Traffic Time Lines

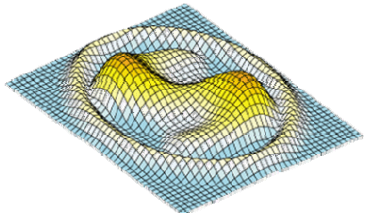
Node-Traffic Load Graphs

Clearance Status

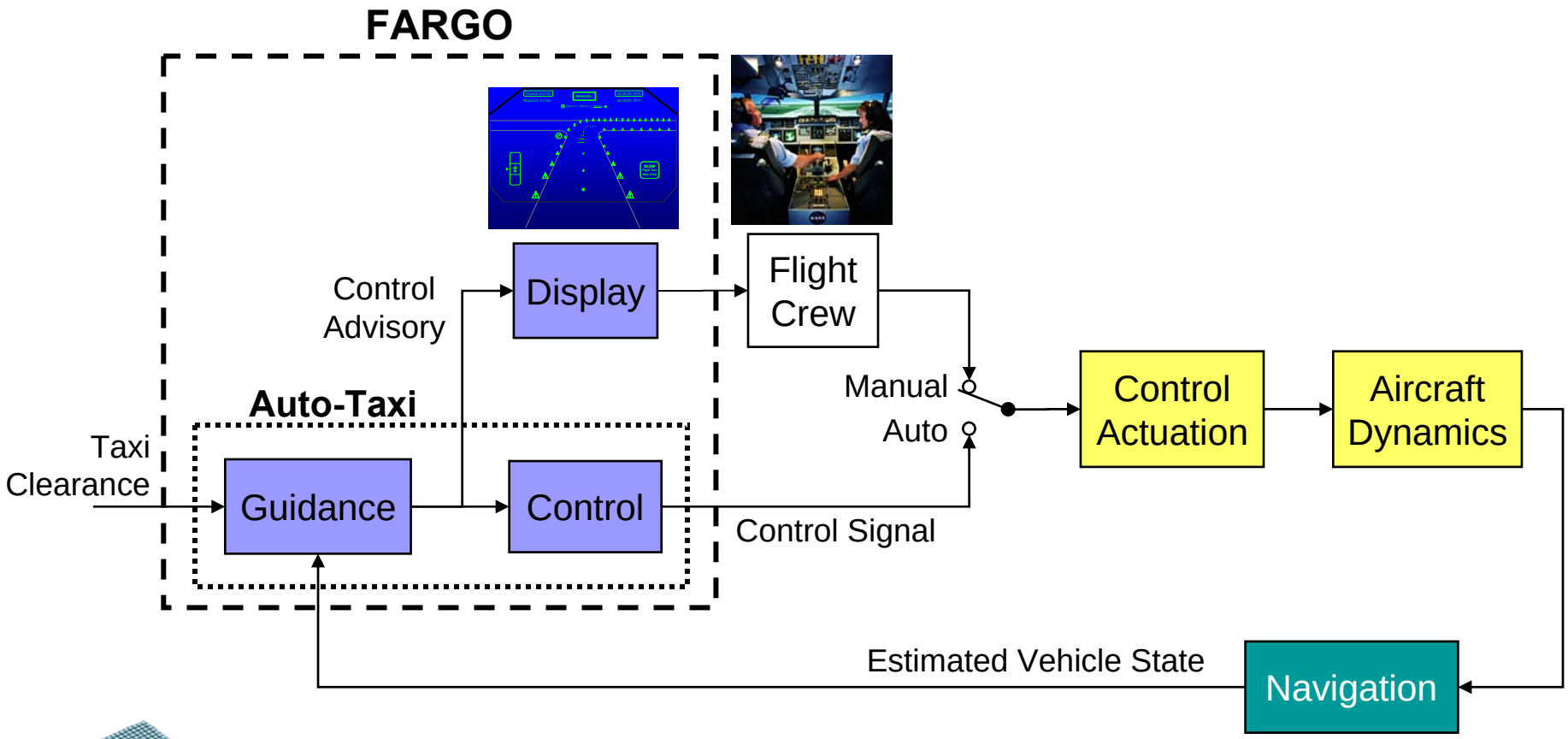


Flight-Deck Automation Systems – FARGO

- **Collectively provide <u>distributed control</u> of overall traffic**
  - ***Auto-taxi*** **function to generate aircraft taxi control commands for achieving precision taxi requirements demanded by GoSAFE-generated clearances**
  - ***Pilot interface*** **to enable pilots to execute precision taxi operations either in fully automatic mode or automation-assisted mode**
  - ***Traffic monitor*** **functions provided through pilot interface to alert pilots of deviation from cleared taxi routes or impending incursion by other vehicles**
- **Feasibility of high-precision taxi control demonstrated in previous research study**
  - **Paper published in IEEE ITS Transactions, June 2001**

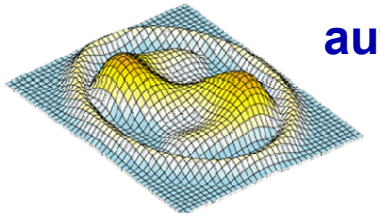


FARGO Concept



Considerations for Operational Procedures

- **SOAR concept promotes traffic efficiency through use of time-based route clearances**
  - **Clearances can be accomplished only with FD automation.**
  - **Use of voice clearances to send the timing details is considered impractical.**
  - **Use of digital data link is considered necessary.**
- **"4D trajectory" information needs to be embedded in the clearances**
  - **Use <u>pre-clearances</u> to initially send the complete route information for pre-visualization of taxi operations.**
  - **Divide taxi route into <u>segments</u> ending at locations where safety may be a concern (e.g., active-runway crossings).**
  - **Insert "<u>contingency holds</u>" at end of segments to require active clearance control for continuing.**
  - **Clear each segment as a separate clearance, which automatically removes contingency hold.**



4D Trajectory Clearances

Complete route broken into segments

Timing constraints

"Contingency hold"

EFG381: [1] TAXI VIA K/Z (#L@ . . .)(#17R@ . . .) |HS 17R.

[2] TAXI VIA Z (#M@ . . .)(#17C@ . . .) |HS 17C.

[3] TAXI VIA Z/P (#R@ . . .)(#13L@ . . .) |HS 13L.

[4] TAXI VIA P CLD 13L.

Operational Procedure: Clearances in Segments

Clearance by voice:
say segment number

Acknowledgement

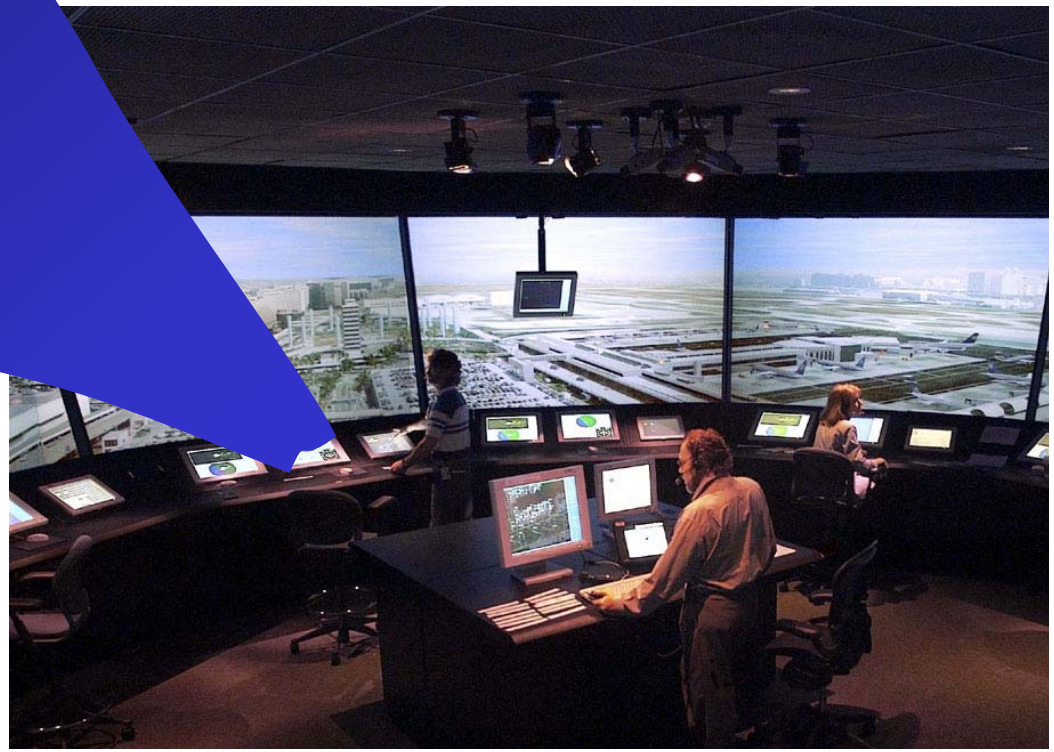
Clearance via
data link

Acknowledgement

GoSAFE

FARGO

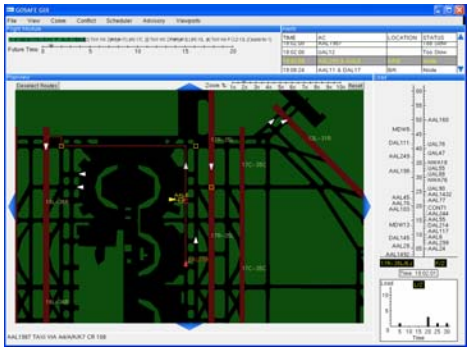
GoSAFE Station



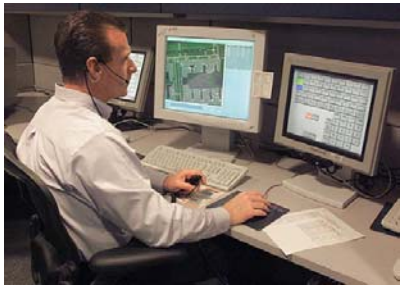
Real-Time Simulation Architecture

FutureFlight Central Tower Simulator

GoSAFE

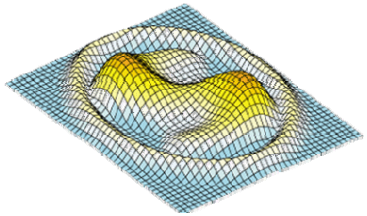


DoD High-Level Architecture (HLA)



Pseudo-Aircraft Station

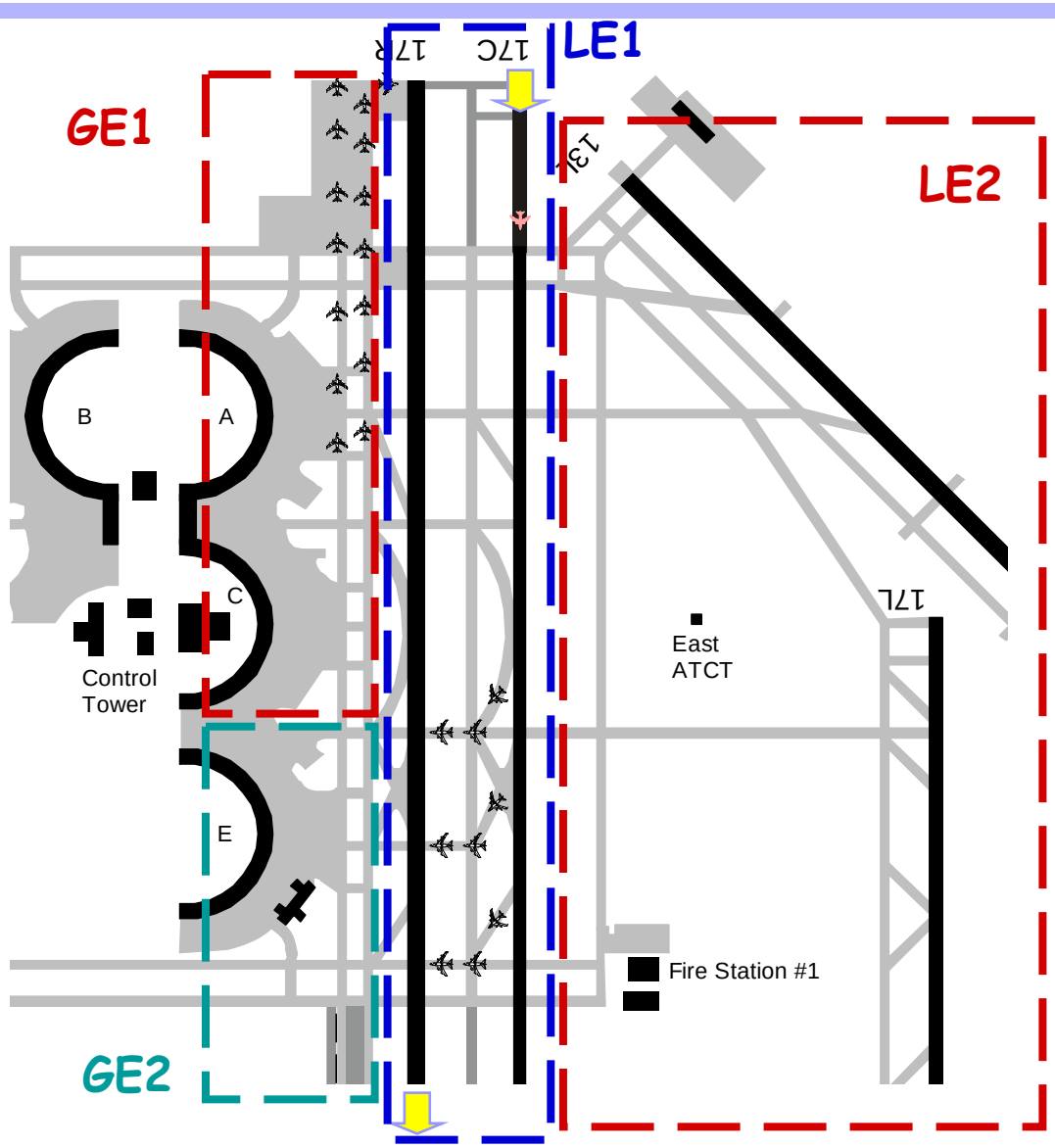
ATG



Scenarios for Human-in-the-Loop Experiments

- **DFW East ATC Tower, South Flow airport configuration**
  - **Typically 17R and 13L for departure, 17C and 17L for arrivals**
  - **Heavy arrival demand: 17R for mixed arrival/departure traffic**
- **Traffic demand set at about 150% of current-day levels**
  - **arrival flights starte at about 12 nmi out**
  - **departure flights end at about 5 nmi after takeoff**

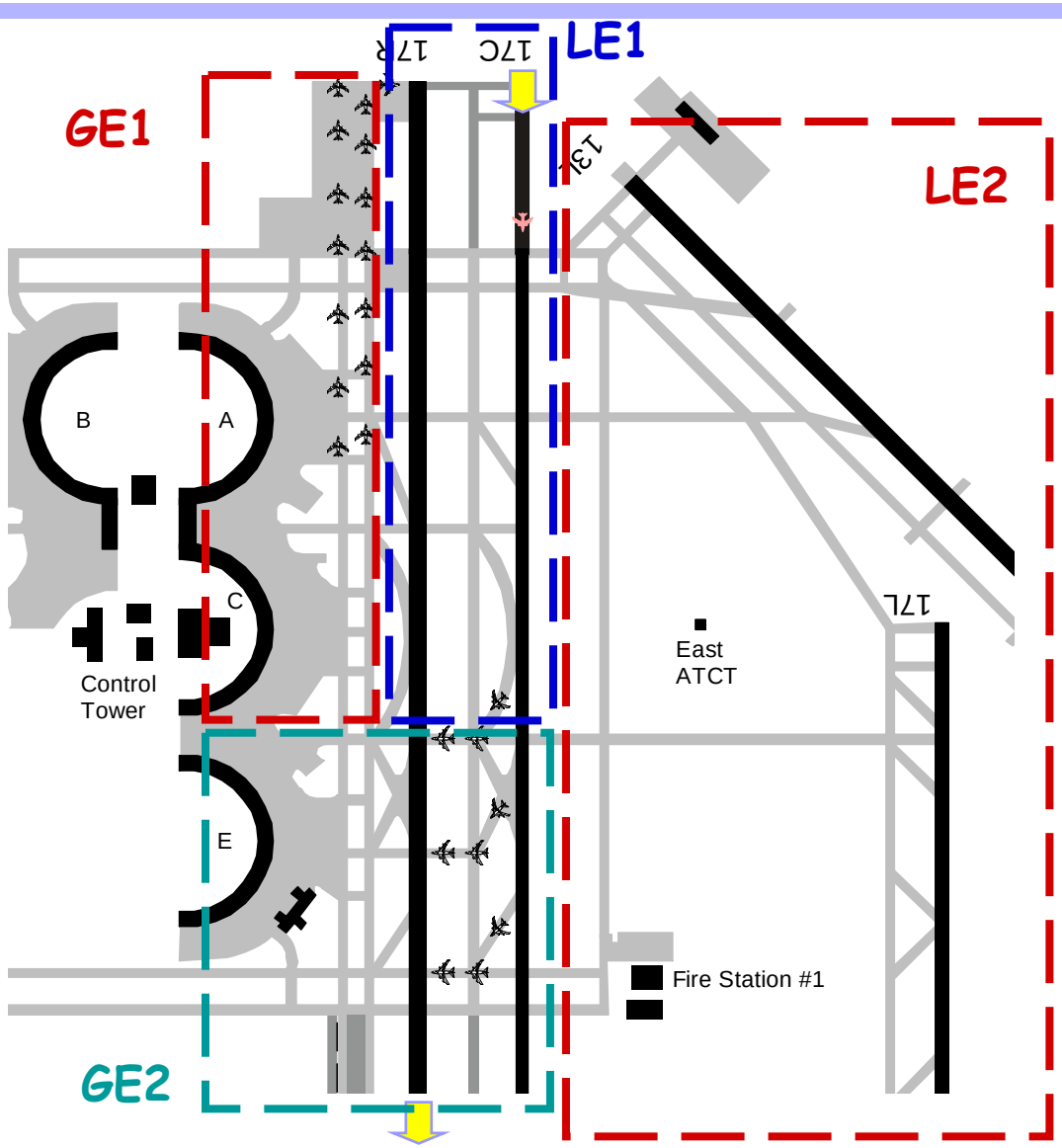
Four Controller Positions



Options on Procedures, Roles, and Responsibilities

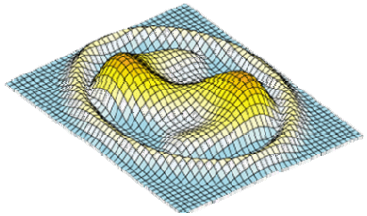
- Voice vs. Data-Link Clearances
- Handoffs: Voice, Data Link, Published/Automatic
- Replanning for New Clearances
  - Graphical route editing
  - Replanning crossing constraints
- Controller Roles and Responsibilities
  - Option of sharing runway responsibility/jurisdiction
  - GE2 responsible for south-end running crossing

Optional Controller Positions



Sample Results

- **Voice vs. Data-Link Clearances**
  - **Data-link clearances easier to handle**
  - **Possibly artificial effect on voice clearances due to pseudo-pilots: take longer than needed to respond when controlling multiple flights**
- **Handoffs: Voice, Data Link, Published/Automatic**
  - **Preferred published/automatic handoffs**
- **Replanning for New Clearances**
  - **Graphical route editing: too time-consuming**
  - **Replanning timing constraints: needed to keep traffic moving when controllers missed issuing timed clearance**
- **Controller Roles and Responsibilities**
  - **Option of sharing runway responsibility/jurisdiction**
  - **Acceptable, but only with automation**

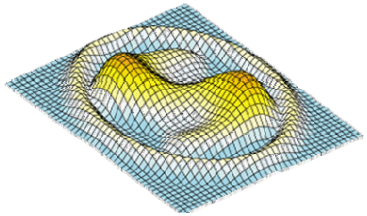


Sample Results (contd.)

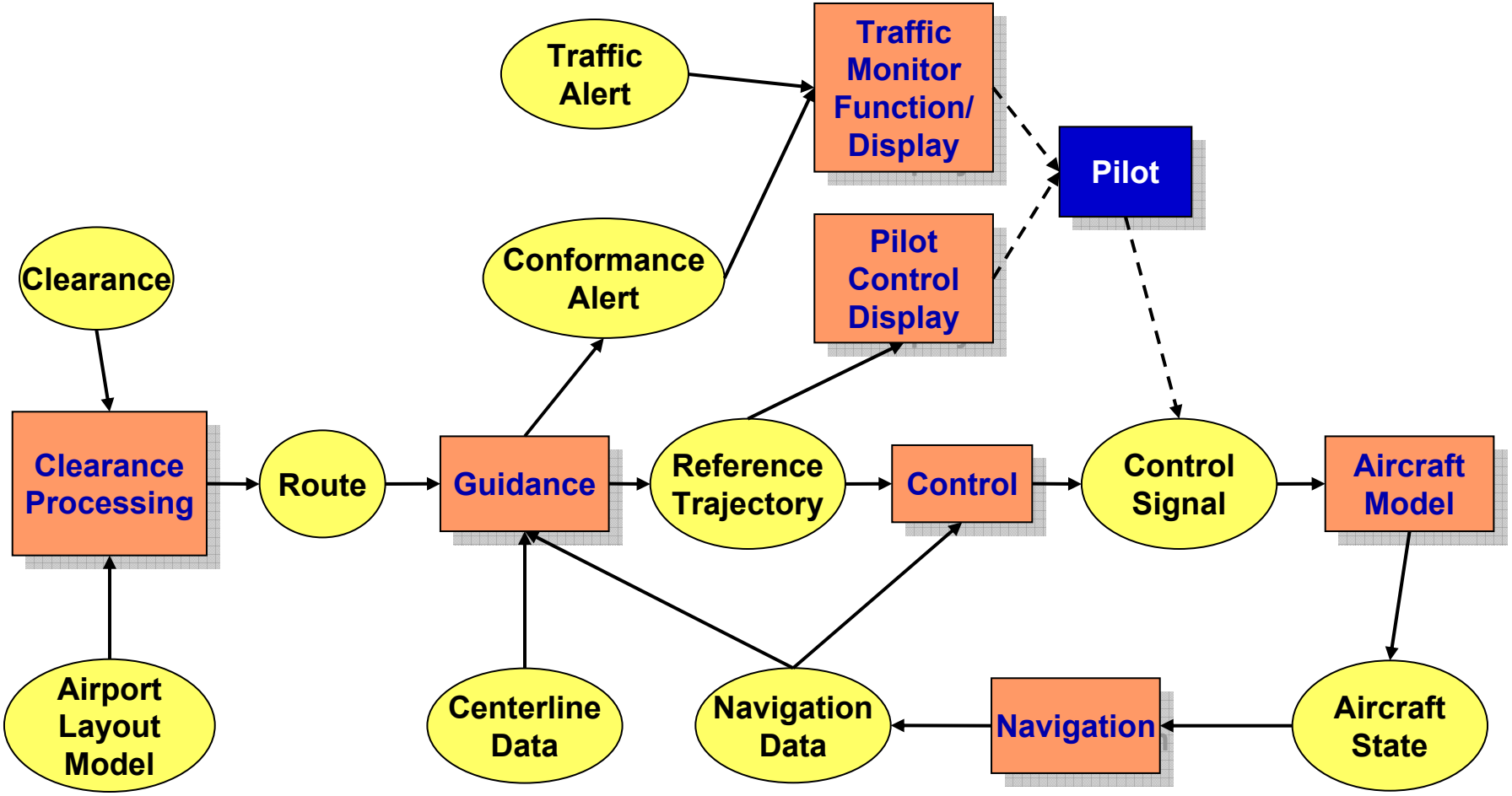
- **Impact on Controller Workload**
  - Periodically report perceived workload using a workload assessment keypad
  - NASA Task Load Index (TLX) at end of runs
  - Perceived workload significantly reduced under advanced automation conditions
- **Information Requirements and Presentation: Research Issues**
  - What type of information would benefit the controllers' understanding of the intent of the automation system
  - How to present the information to the controllers so that the controllers can act on the GoSAFE events in a timely manner.
- **Results to be Presented:**
  - AIAA Modeling and Simulation Technologies Conference and Exhibit (MST), Hilton Head, SC, August 20-23, 2007.
  - Human Factors and Ergonomics Society's 51st Annual Meeting (HFES), Baltimore, MD, October 1-5, 2007.

Development of Flight-Deck Automation

- **Guidance Function for Trajectory Generation**
- **Nonlinear Controller for Aircraft Taxi Control**
- **Interface for Piloting**
- **Paper to be published:**
  - **26th Digital Avionics Systems Conference (DASC): *4-Dimensional Trajectory-Based Operations*, Dallas, TX, Oct. 21–25, 2007.**

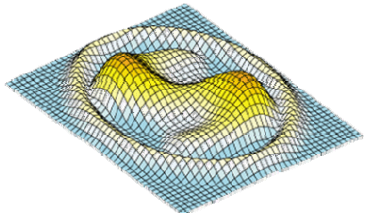


Data Flow Diagram of FARGO Processes



Guidance Trajectory Generation

- Convert clearance into time history
  - Clearance Processing function converts clearance to route of nodes & arcs
  - Construct trajectory from nodes, etc.—as a complete function of time
- Requirements
  - Airport geometry: Observes conventions in “Airport Design,” FAA Advisory Circular AC 150/5300-13
  - Physical constraints:
    - Performance characteristics per aircraft type
    - Surface conditions
  - Operational procedures



Nonlinear Controller Design

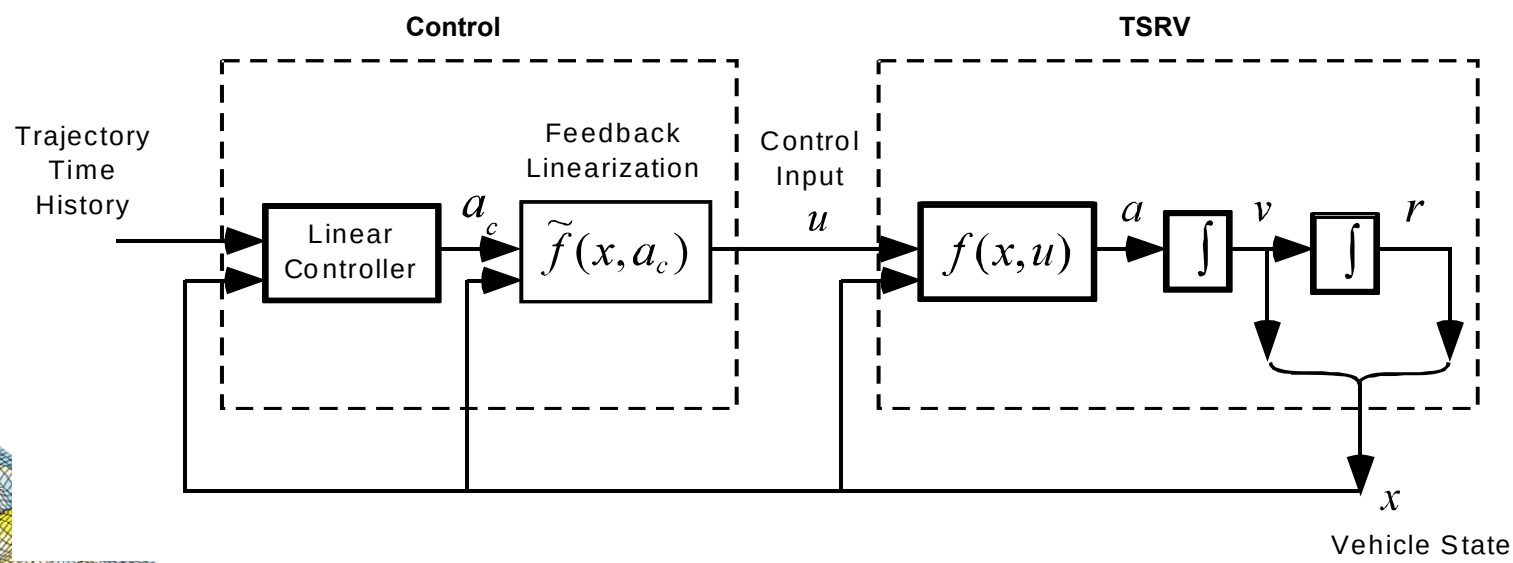
Feedback Linearization Control

- **Also known as "dynamic inversion"**
- **Main idea: cancel nonlinearities; effectively linear system**

$$\dot{x} = f(x) + g(x)u$$

$$u = -g^{-1}(x)\left[f(x) - v\right] \quad \textbf{simplest case!}$$

$$\Rightarrow \dot{x} = v = -Kx \quad \textbf{use linear techniques for K}$$



User Interface to Support FARGO Operations

Head-Up Display
- Taxi Control
- Conflict Avoidance

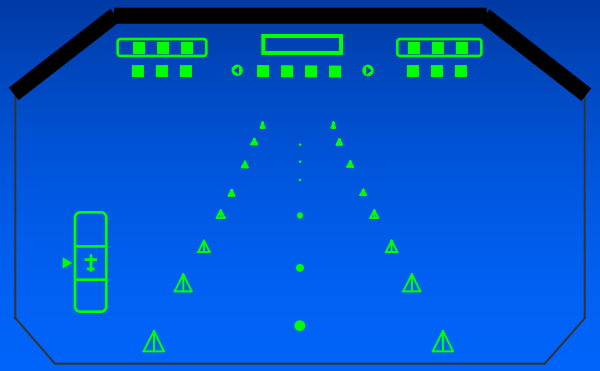
Upper EICAS
- Clearance Alert

Electronic Moving Map
- Taxi Route Preview
- Navigation
- Traffic Monitoring

Lower EICAS
- Textual Clearance

Captain

First Officer

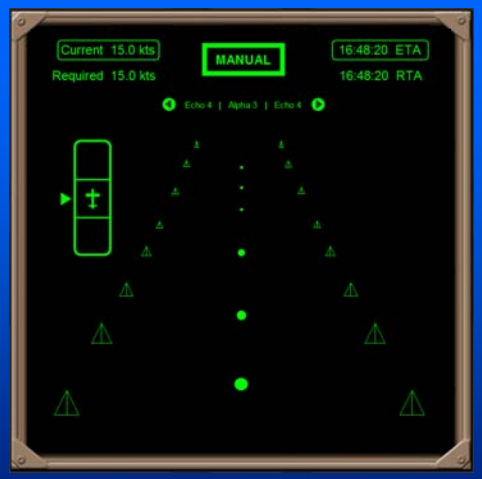


DATALINK
Departure Clearance

#2 16:46:50 ✓
Alpha 1 to Alpha 4
Hold for Seg 4.

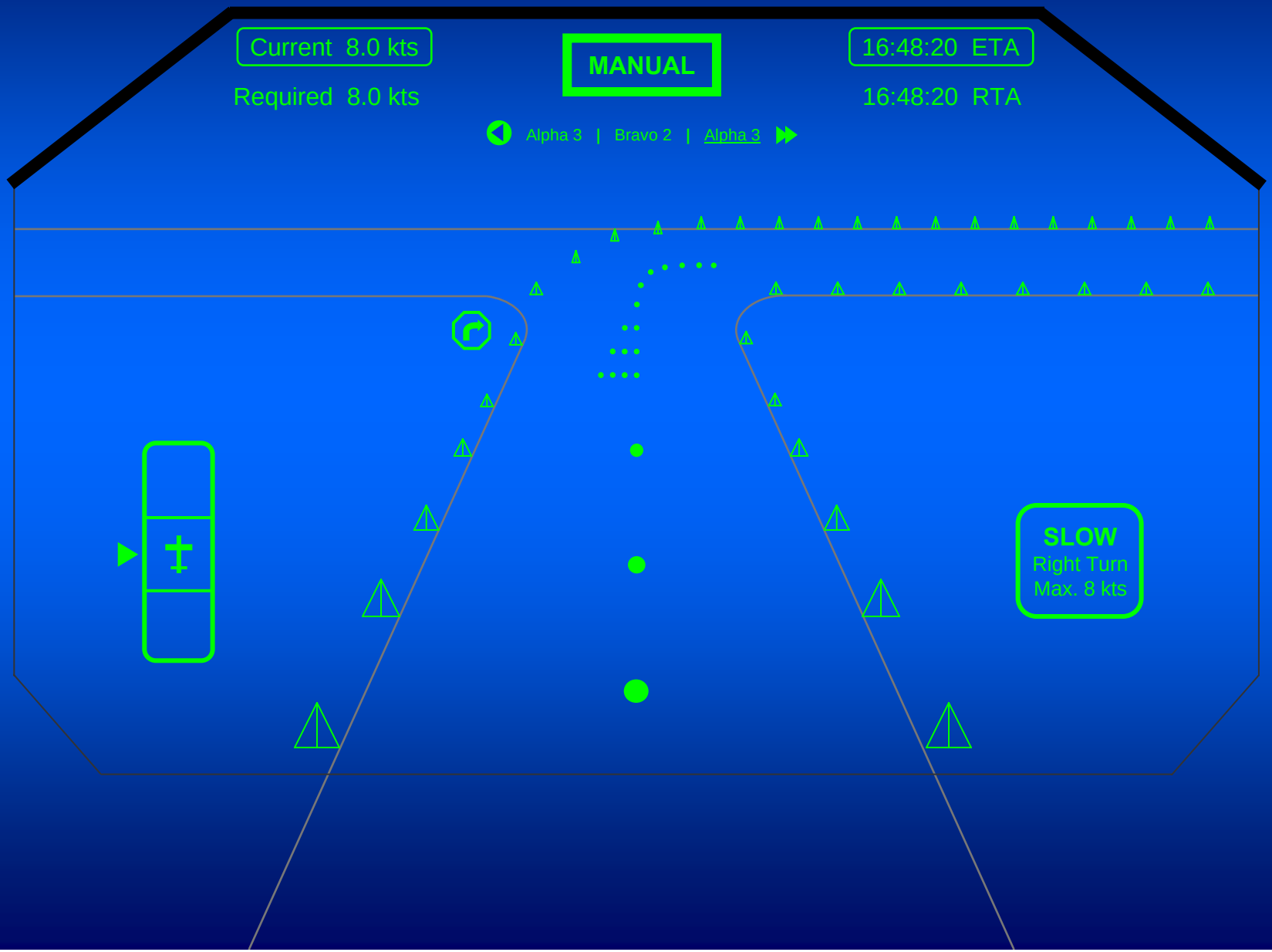
#3 16:48:20
Alpha 4 to Rwy 4L
Hold for Seg 4.

#4 16:50:00
Enter Rwy 4L
Hold for Depart

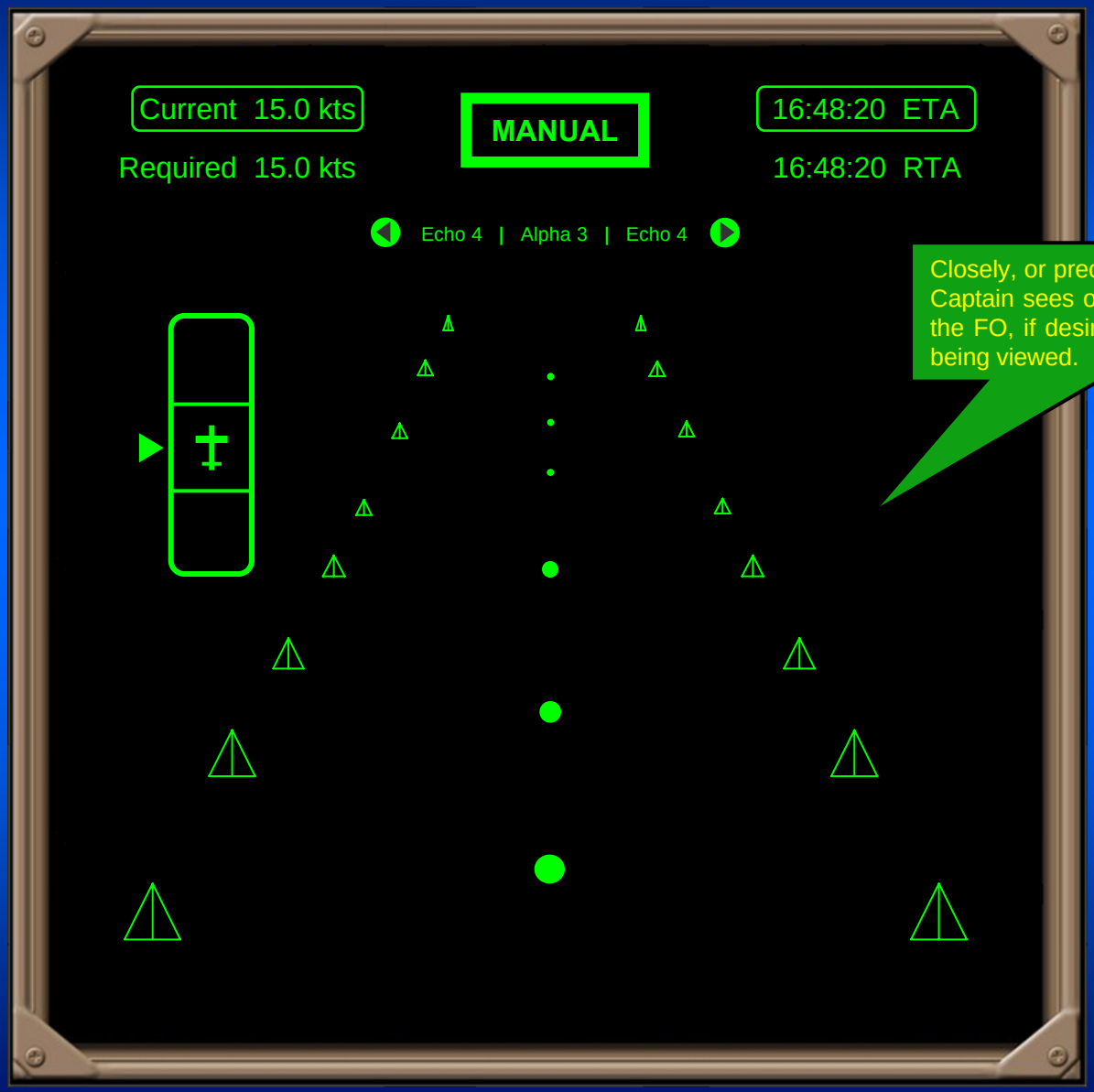


EMM Taxi Preview…

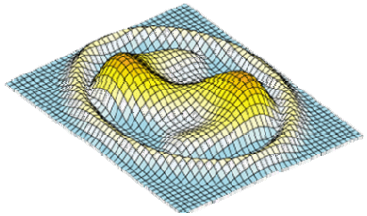
Ownship has throttled up to the required speed…



EMM HUD view…



Closely, or precisely, mirrors what the Captain sees on his/her HUD. Allows the FO, if desired, to monitor what is being viewed.

Suggestions for Future Research

- **Transition into the next phase of development:**
  - **full-feature functions, operational procedures, roles and responsibilities**
  - **experiments covering operators and automation**
- **Optimal route planning to design 4D trajectories for <u>complete</u> surface traffic**
  - **trade some optimality for inter-flight separation margins to alleviate potential impact of non-conformance events**
- **Design of procedures and user interfaces that promotes synergy from operator/automation interaction**
- **Integration with strategic automation functions for airport/airspace configurations and traffic flow management**
- **Human-in-the-loop experimentation of FD automation technologies**