Aviation Safety Technical Conference
Integrated Resilient Aircraft Control (IRAC)

“Stability, maneuverability, and safe landing in the presence of adverse conditions”

IIFD - Integrated Intelligent Flight Deck
IVHM - Integrated Vehicle Health Management
AAD - Aircraft Aging and Durability
Example Scenario

1. Aircraft incurs damage/failure(s) resulting in aerodynamic changes
2. Adaptive control recovers from upsets and stabilizes the aircraft
3. Perform assessment of flight and maneuvering envelope
4. Generate robust flyable trajectories that comply with constraints
5. Construct a prioritized list of flight plan options to potential landing sites
6. Provide autopilot & flight director capability to follow trajectory
Challenges

• **Maneuvering Envelope ID**
  - Identifying critical parameters (e.g. airspeed, climb/descent rates, turn rates, normal/lateral acceleration, etc).
  - Performing on-line maneuvering envelope assessment and exploration.
  - Predicting/expanding maneuvering envelope limits for different flight conditions.

• **Trajectory Planning**
  - Addressing constraints on limiting stress on the airframe imposed by maneuvering, meeting flight envelope limits, and airspace/regulatory constraints.
  - Minimizing time-to-land (especially in situations involving smoke and fire).
  - Managing energy (especially in situations where the aircraft can no longer maintain level flight).
  - Handling extreme constraints (such as not being able to maintain wings level flight).
Challenges (continued)

• **Emergency Planning**
  - Determining when and how to provide for interactive and variable autonomy in flight planning functions.
  - Addressing multiple conflicting objectives.
    - Minimizing time-to-land (*which may require more aggressive maneuvers*).
    - Reducing stress on the airframe (*which would require more subtle maneuvers*).
  - Ensuring the plan is robust against uncertain and unpredictable elements of the environment.

• **Adaptive Guidance**
  - Providing autopilot and flight director capabilities under reduced operating conditions (*including when propulsion is used as a control effector*).
  - Handling maneuvering envelope dependent mode transitions (*since some modes may no longer be valid… at least at the current flight condition*).
  - Performing aggressive maneuvering when necessary (*e.g. to intercept the localizer and glideslope when missed approach attempts are not possible*).
Integrated Propulsion Control Challenges

**Concept**
- Collectively increasing or decreasing thrust controls pitch.
- Differential thrust generates sideslip, which through the dihedral effect, results in roll.

**Challenges**
- Engines are slow actuators with weak control moments.
- Non-independent lateral and directional control (yaw-based roll control).
- No airspeed control.
Maneuvering Envelope ID
Potential Approaches

• **Trim-State Expansion**
  - Establish a trim-state database (*based on speed, turn rates, and climb rates at a given altitude*).
  - Seek to identify new feasible trim states in-flight that will be useful for trajectory planning.
  - Use system identification information to compute potential new trim-states.

• **Structural Envelope Assessment and Prediction**
  - Process inputs from sensors, estimation algorithms and vehicle health management systems to assess the current structural state of the aircraft.
  - Perform structural fault detection and identification to provide structural load derivative information.
  - Predict aircraft loading and structural dynamics properties to produce a ‘safe operation’ envelope for the aircraft (*and determine the aircraft’s flexible mode natural frequencies*).
• **Dynamics and Structural Loads Modeling**
  - Use System ID to identify new dynamics of the aircraft.
  - Use structural health monitoring *(with strain gages, load cells, deflection measurement, etc)* to infer the structural load on the aircraft in real-time.
  - Predict loads for a given trajectory to ensure the aircraft will not stray beyond the structural limits.
Modified FMS

- Generate lateral legs that are composed of straight line and (asymmetrically constrained) constant turn radius segments (enabling non-active direct-to and direct-intercept legs).
- Perform (climb/descent rate limited) energy management based trajectory generation (to meet altitude and airspeed constraints).
- Incorporate active lift/drag estimation to adjust for altered aerodynamics during energy management calculations.
Trajectory Planning
Potential Approaches (continued)

• **Segmented Trim-State Trajectories**
  - Compose trajectory from a sequence of trim-state segments, and the corresponding duration of each segment.
  - Use a hybrid discrete-continuous search through the trim-state space to generate trim-state trajectories.

• **Multigrid Temporal Resolution Trajectory Generation**
  - Solve the trajectory optimization/feasibility problem on a non-uniform temporal grid, by iterative refinement/coarsening of the grid using polynomial interpolation to predict missing nodes.
  - Incorporate models of the vehicle dynamics using trajectory primitives within the high-resolution areas of the trajectory.
  - Use wavelet analysis and multiresolution techniques to develop algorithms that blend short-term tactical maneuvering with long-term strategy.
Emergency Planning
Potential Approaches

- **Planning and Scheduling**
  - Combine planning and scheduling algorithms that are discrete in nature (such as landing site selection), with coarse spatial path planning algorithms (taking into account weather, terrain obstacles, and aircraft descent and turning capabilities).
  - Interface with trajectory planning specialists to evaluate detailed trajectory performance, and perform a robustness assessment of each plan with respect to variances in the aircraft’s capabilities and external conditions.
Emergency Planning
Potential Approaches (continued)

• **Heuristic Based Landing Site Search**
  - Determine reachable footprint, evaluate all reachable runways against landing requirements, and then rank the list of feasible runways.

• **Flight Planning using Statistical Optimization**
  - Rank groups of airports according to distance, available facilities, type and orientation of runways.
  - Incorporate additional factors weather, populated areas, and the likelihood of progressive damage (*necessitating backup plans such as an abort to another airfield*).
Adaptive Guidance
Potential Approaches

• **Auto-Gain Scheduled Autopilot and Flight Director**
  - Automatically schedule autopilot and flight director control laws (*by taking advantage the consistent handling qualities provided by the adaptive inner-loop controllers*).

• **Tactical Maneuvering**
  - Replace traditional (*pre-determined*) guidance mode transition logic with motion-based trajectories, represented through autopilot mode and target sequences, that are constructed using mode-dependent prediction models.