Collective Tactile Cueing*

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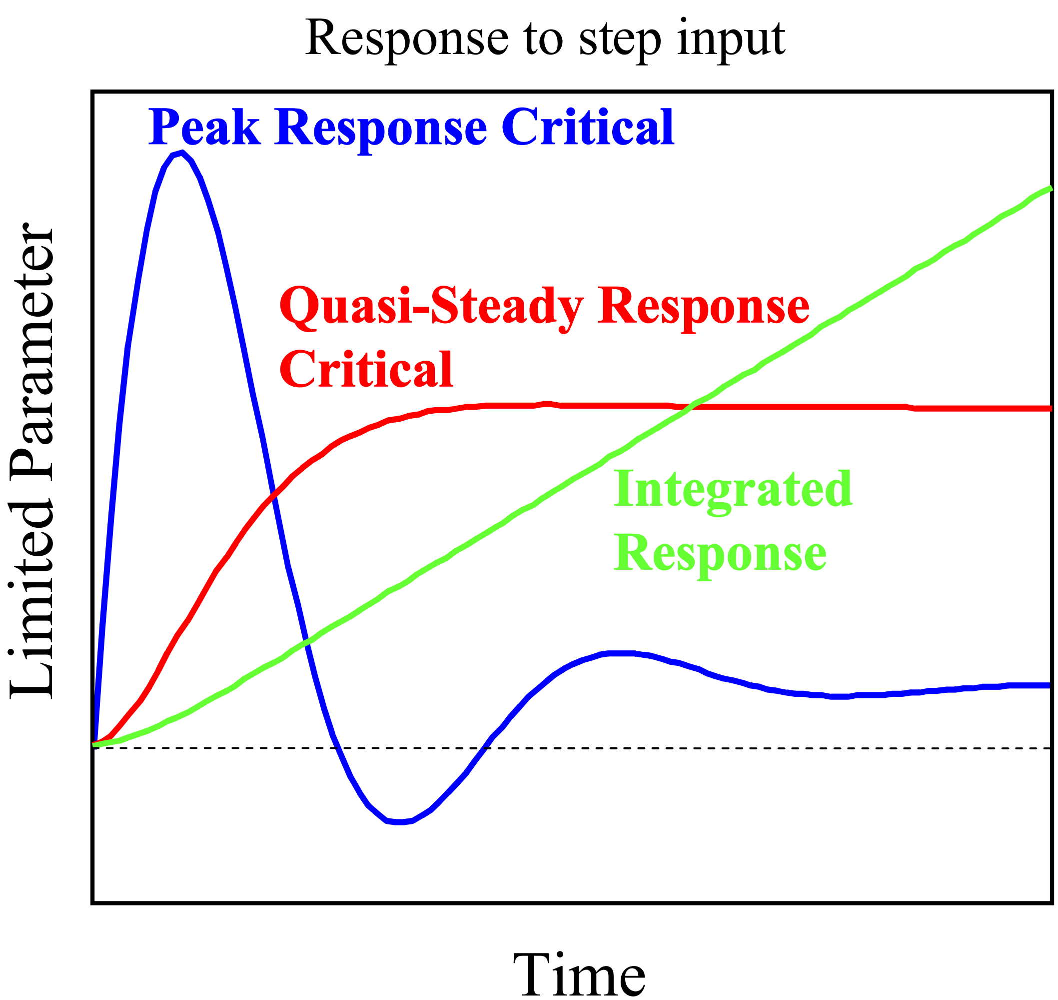
Comprehensive Collective-Axis Cueing Algorithms

Cues	**Limits**	**Results**
1. Continuous Torque Limit	100% Transmission Torque	Successfully tested in piloted simulation
2. OEI Recovery	Torque Corresponding to 95% Rotor RPM with One Engine	Successfully tested in piloted simulation
3. Transient Torque Limit	110% Transmission Torque	Rarely encountered in piloted simulation
4. Transient Rotor RPM Limit	103% Upper RPM Limit 97% Lower RPM Limit	Rarely encountered in piloted simulation
5. Engine Limit	Max Turbine Temperature, function of ambient conditions	Tested in non-real-time simulation only

Limit Response Types



- Limits can be classified in terms of the response to a step input to the primary control
- Prediction algorithms can depend on the response type
- Prediction algorithms look forward in time to detect if a parameter is going to exceed a limit in
    - The transient peak (RPM)
    - The quasi-steady response (Torque)
    - The long term response (Altitude)
- For tactile cueing, algorithm must ultimately calculate the maximum allowable control motion that stays within envelope limits (the inverse solution)

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Prediction Algorithms

Dynamic Trim Estimation (Horn, Calise, Prasad) ⬅ Used in the study
Use neural net or other function approximation tool to predict the quasi-steady response of a limited parameter based on current aircraft flight condition and control positions. Used for quasi-steady response types.

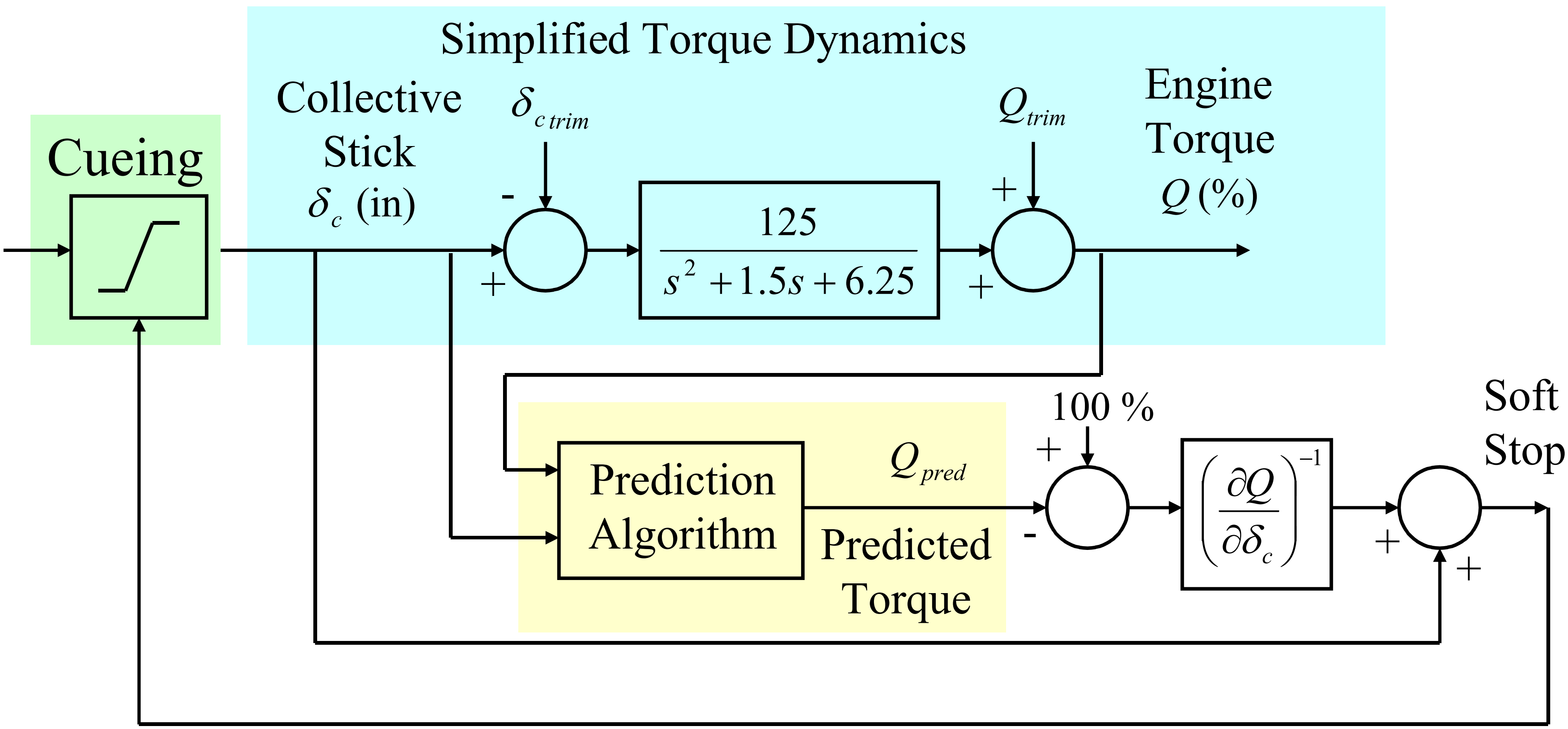
Peak Estimation Algorithm (Horn, Calise, Prasad) ⬅ Used in the study
Use a linear model to estimate the control deflections that will cause limit to be reached in the peak response. Calculation of time to peak is implicit in the method. Used for peak response types.

Fixed Horizon Time (Whalley, Bateman, Ward, Barron)
Use neural net or other function approximation tool to predict the response of a limited parameter at some fixed time in the future based on current aircraft state and controls. Can be used for peak or proportional responses depending on the selection of the horizon time.

Dynamic Shaping (Einthoven, Miller)
Use instantaneous sensor data, but use along with filters and lead shaping.

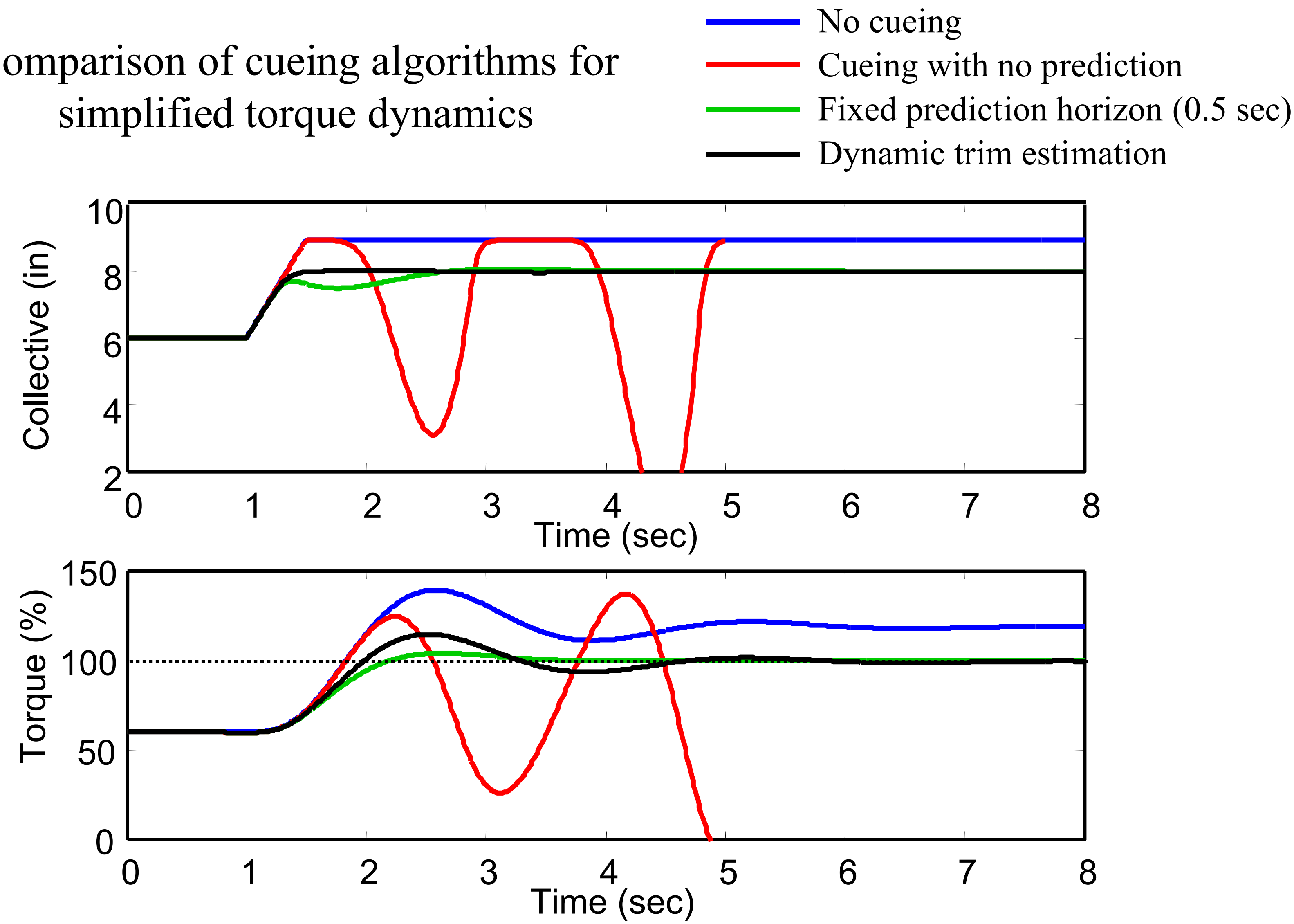
Why Use Prediction Algorithms?
A Simple Example

- Consider a simplified linear model of torque dynamics
- Prediction algorithm uses sensor data to predict torque at some time in future
- This is used to calculate a constraint on the collective lever (soft stop)
- In this example, cueing is modeled as a saturation function

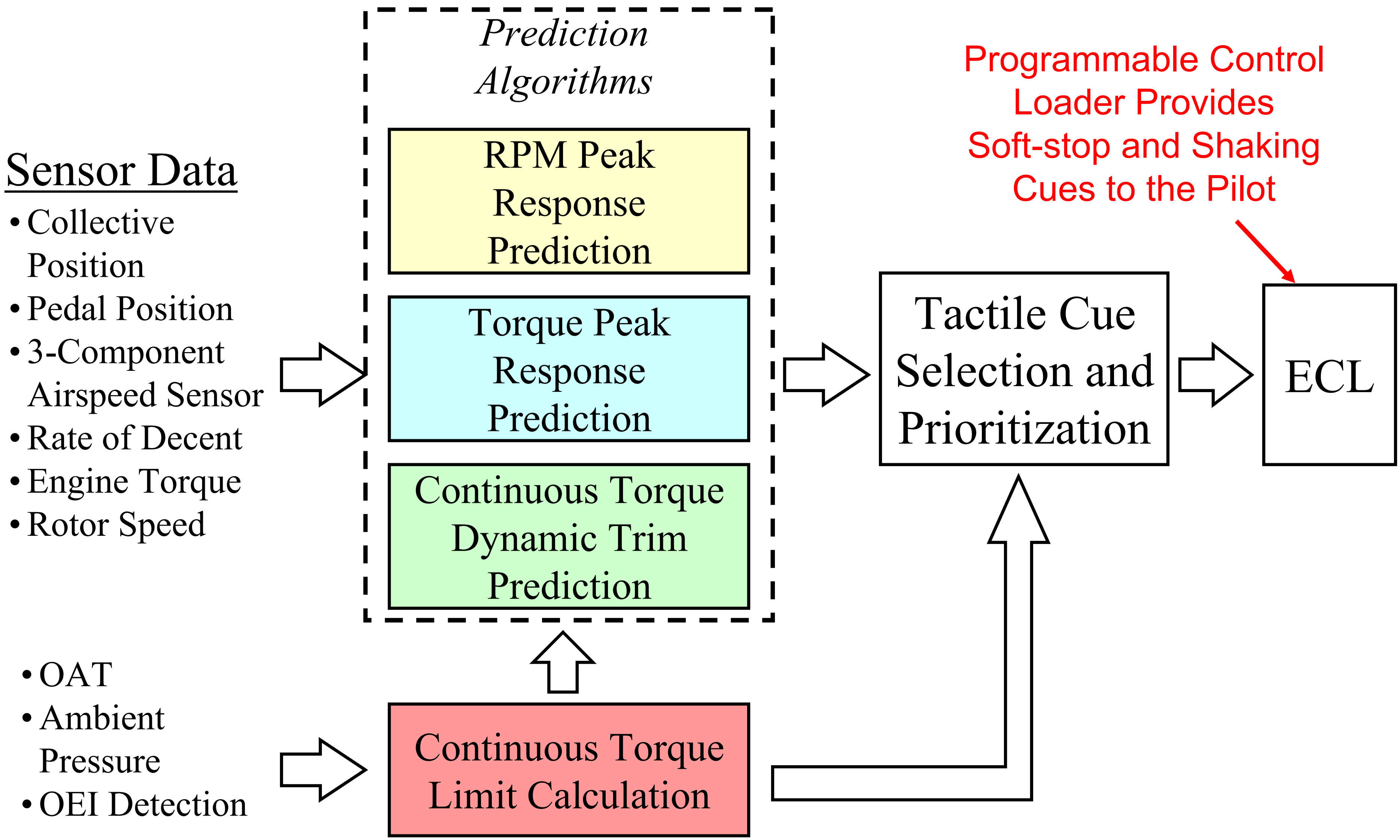


Why Use Prediction Algorithms?
A Simple Example

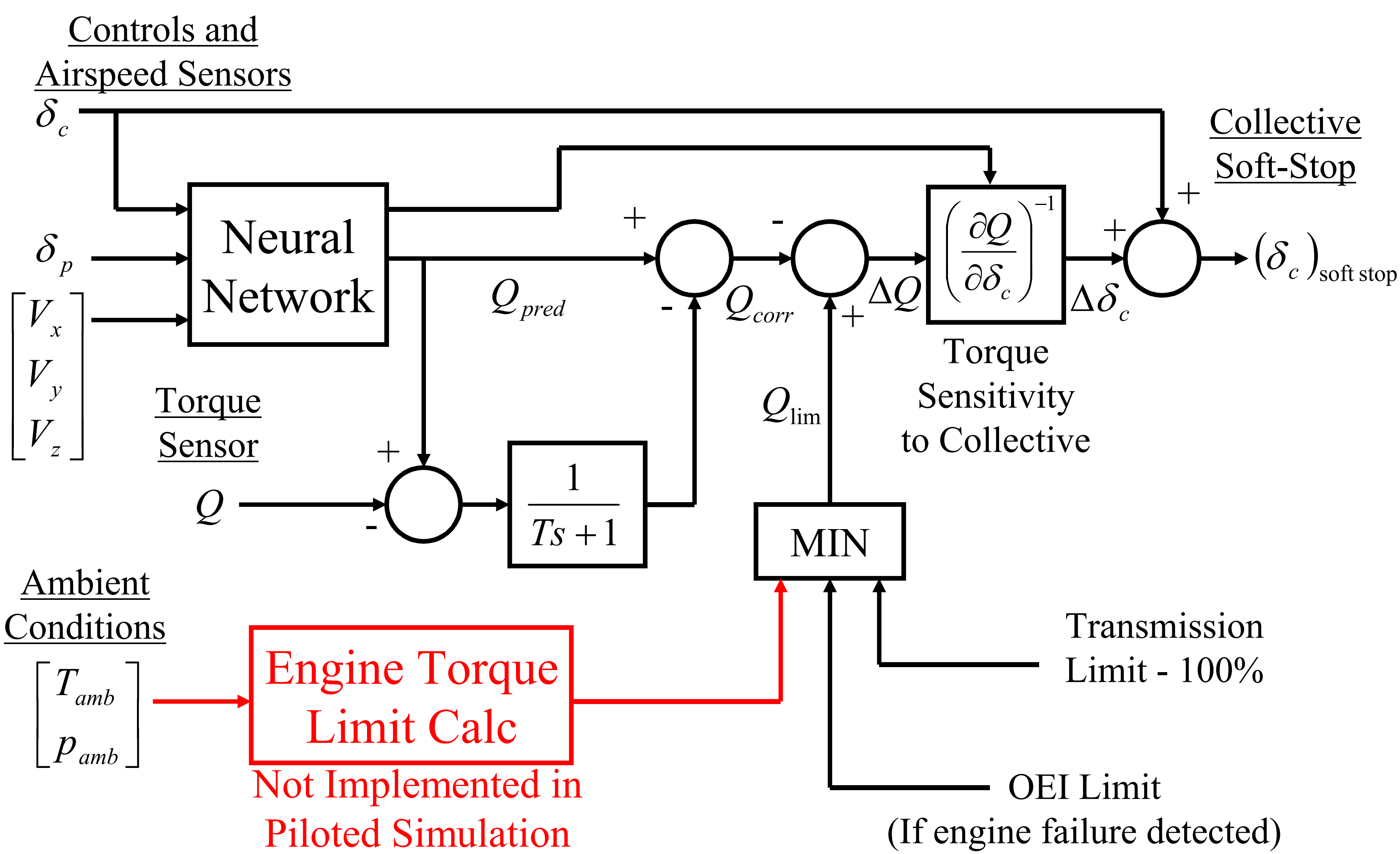
Comparison of cueing algorithms for simplified torque dynamics



Comprehensive Collective-Axis Cueing System

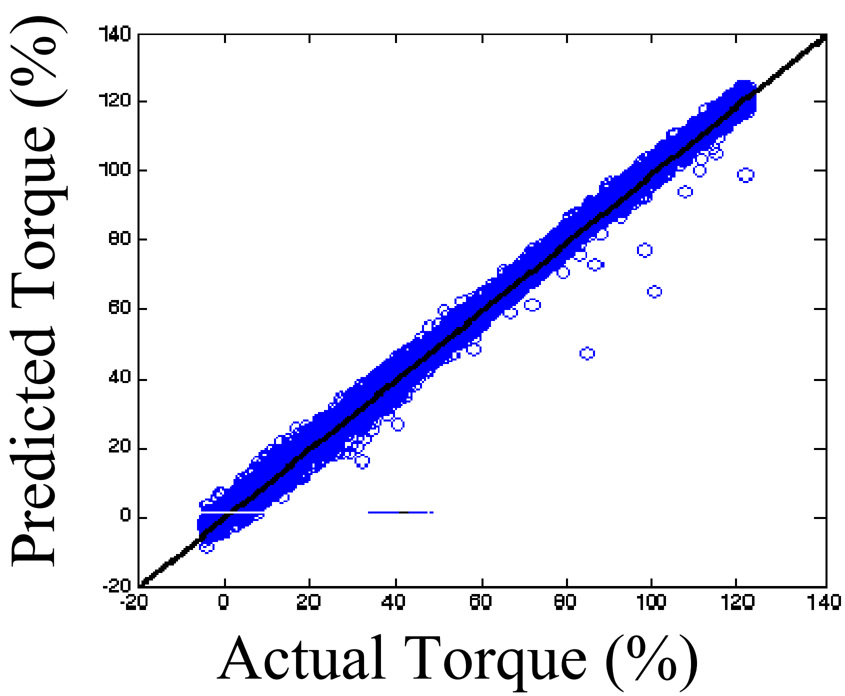


Continuous Torque Cueing Algorithm



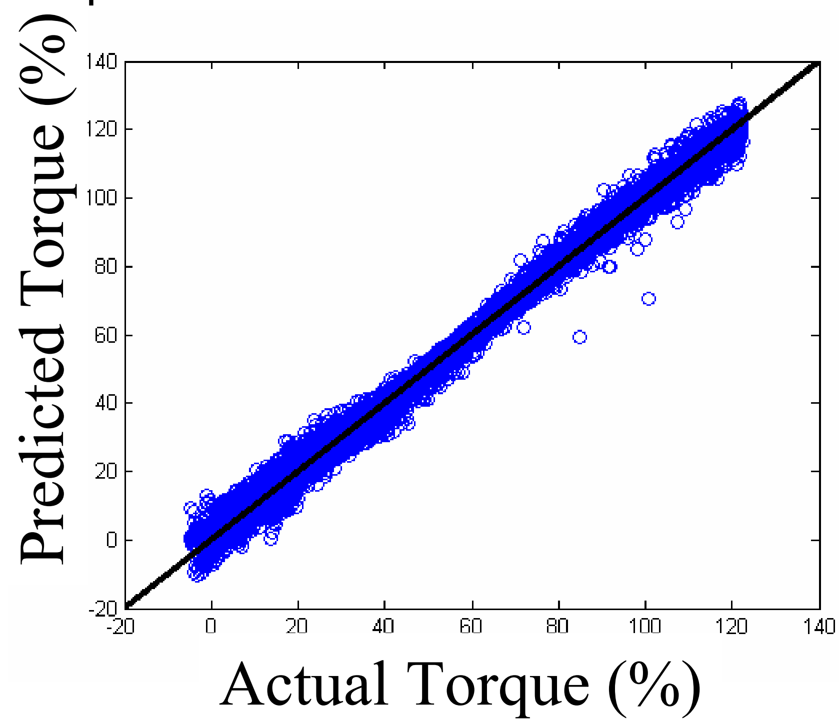
Neural Network Training

- Used GENHEL trim data (includes level flight, climbs, descents, banked turns, yawed turns, sideward flight, and rearward flight)
- Current system uses low airspeed sensor data measured at rotor hub
- Good fit is still possible with standard airspeed and rate of decent data



NN Input Data:

Three velocity components measured at rotor hub and control inputs



NN Input Data:

Total airspeed (minimum 30 kts), yaw rate, rate of descent, and control inputs

Rotor RPM and Transient Torque Cueing Algorithm

- Use linear model of heave / yaw / rotor RPM dynamics to predict short term response of torque and rotor RPM. Identify model using CIFER®
- Peak response algorithm used to calculate upper constraint on collective to ensure torque does not peak above 110%
- Calculate upper and lower constraints on collective to ensure rotor RPM does not peak above 103% or below 97%
- Details of algorithm in paper and Horn, Sahani, AIAA AFM Conference, 2001

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 & N_r & N_w & & N_Q & & \\
Z_\Omega & Z_r & Z_w & -Z_w & & & \\
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\end{bmatrix}
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\Delta\Omega \\ \Delta r \\ \Delta w \\ \Delta v \\ \Delta Q \\ \Delta w_f \\ \Delta\Psi
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R_{col} \\ N_{col} \\ Z_{col} \\ I_{col} \\ T_{col} \\ \\ \\
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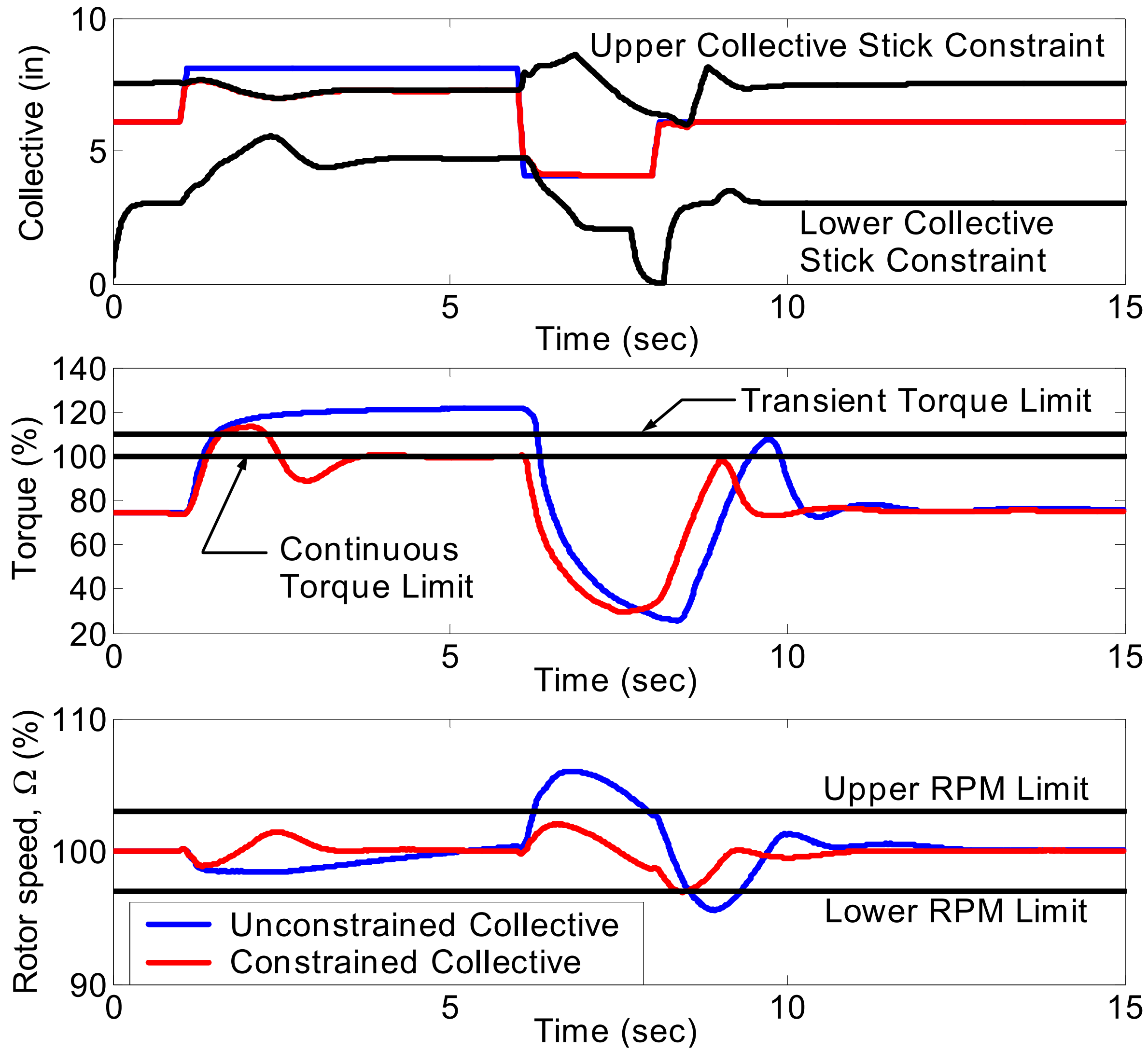
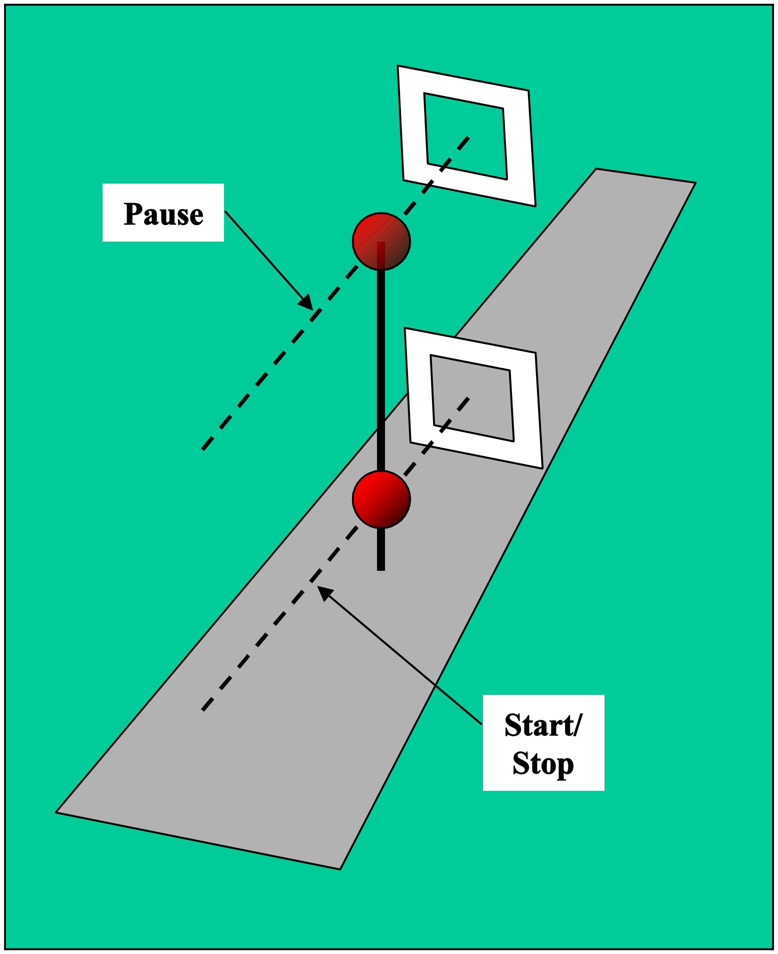
CIFER identified heave / yaw / rotor RPM Model. Model Structure from Fletcher, 1995.

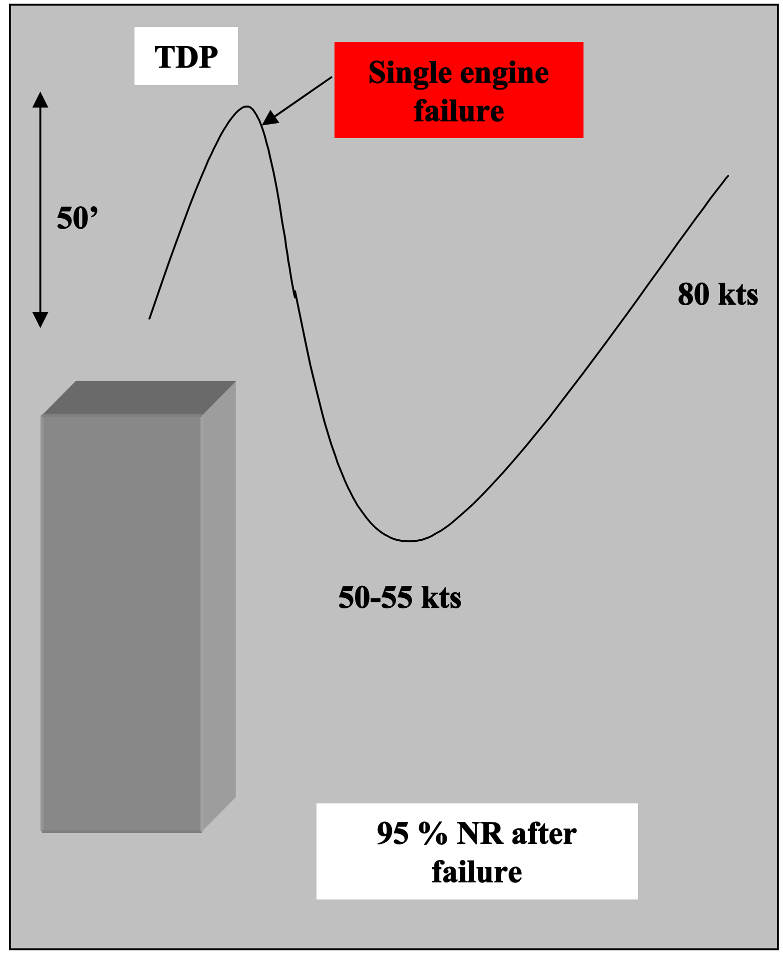
Non-Real-Time Simulation Results



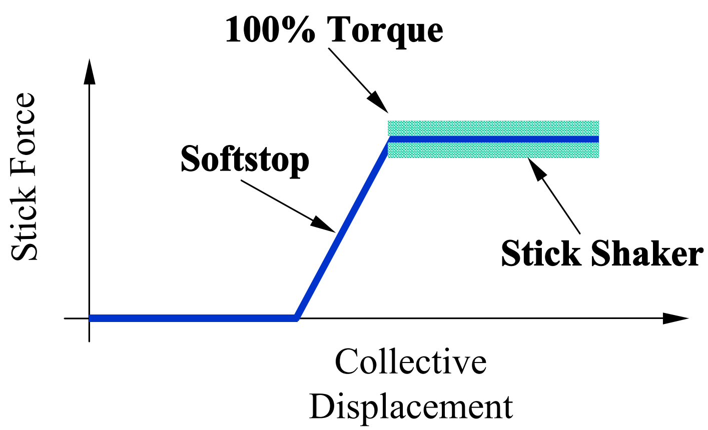
Sikorsky Reconfigurable Cockpit Simulator

Bob-Up and Category A Takeoff





Collective Tactile Cueing



100% Torque cueing

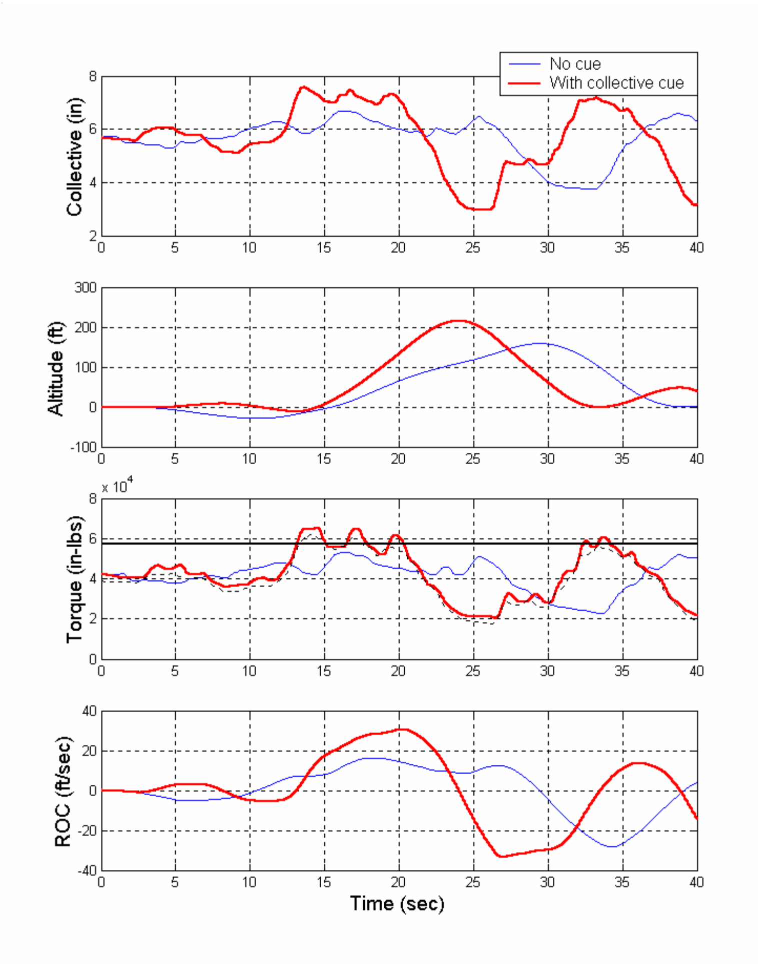
- Softstop (increasing force) as limit approached
- Shaker at 100% limit
- Beyond limit, force levels off, shaker stays on

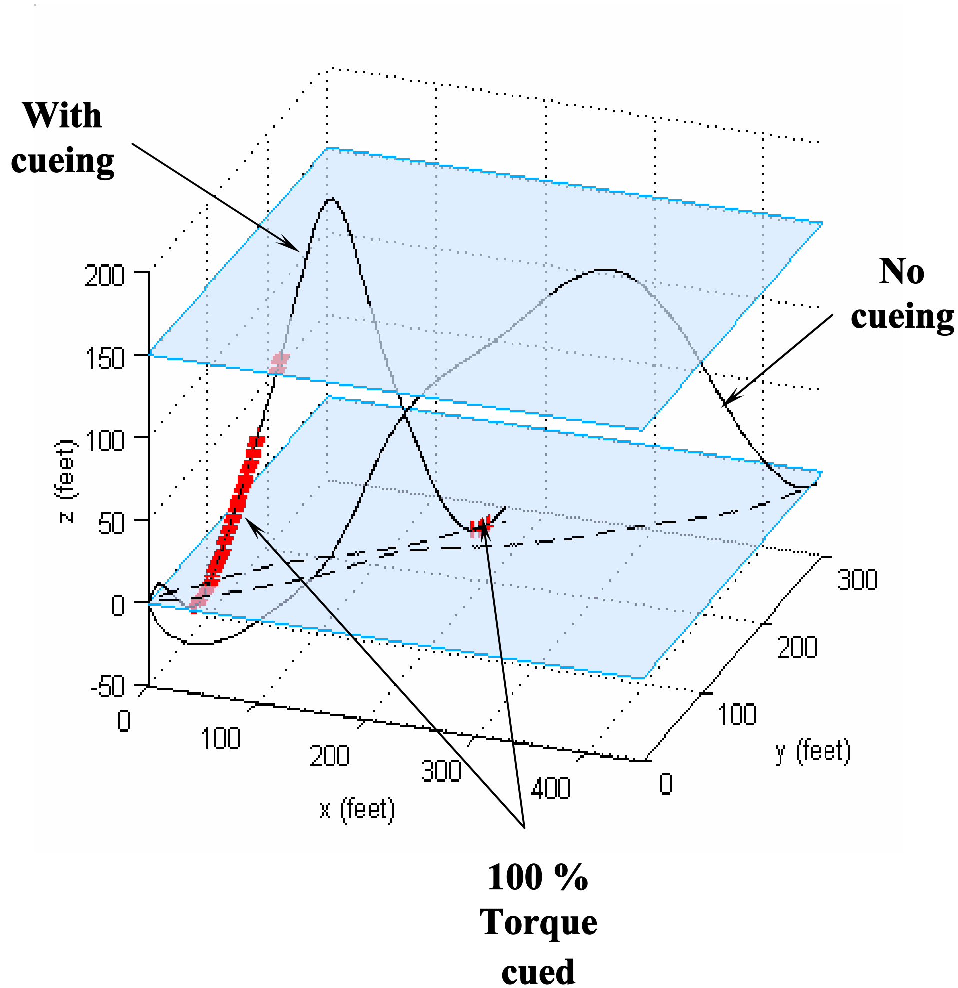
95% Rotor RPM cueing

- Below 95% shaker comes on
- Above 95% shaker is off

Collective Tactile Cueing

Bob-up

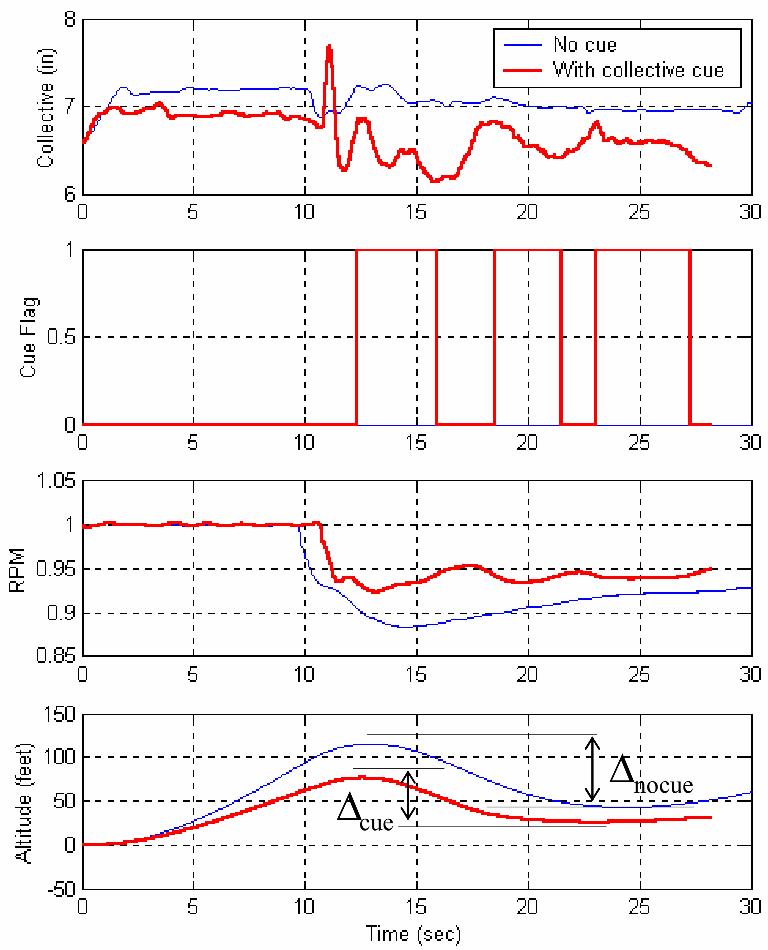




Collective Tactile Cueing

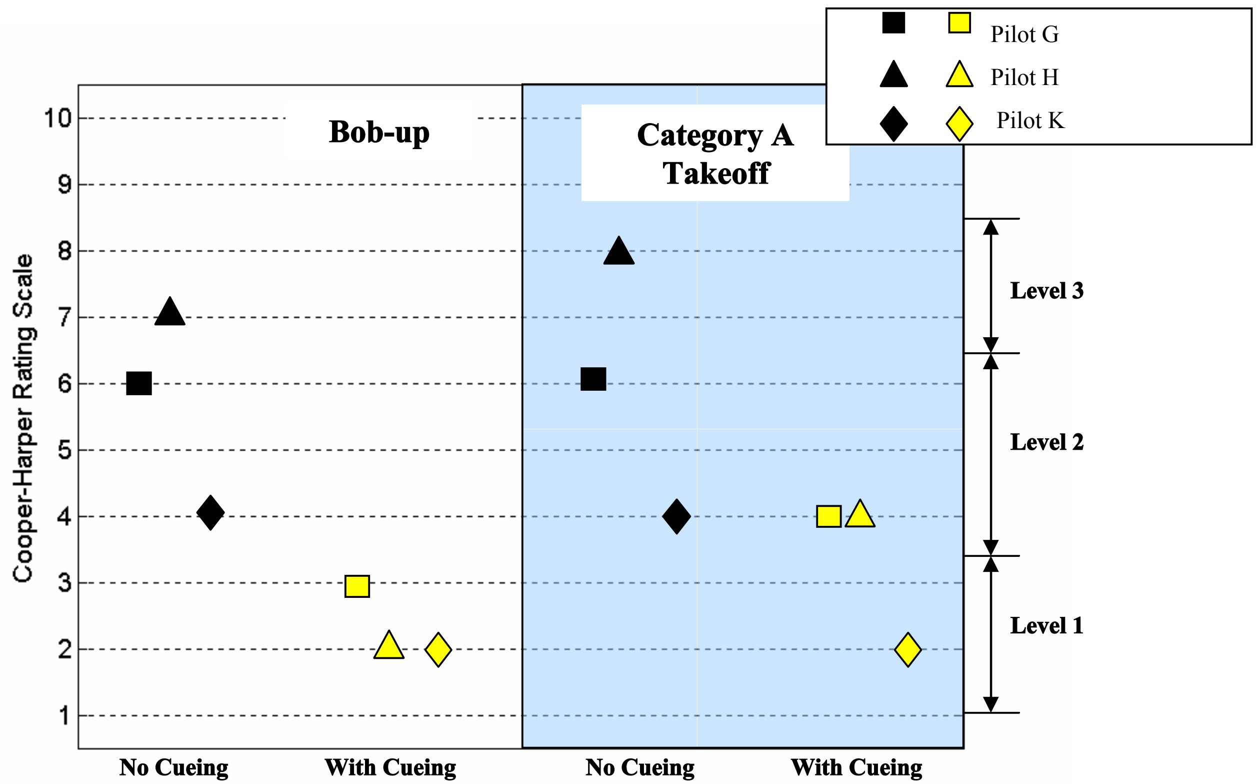
Category A Takeoff

Pilot G



Collective Tactile Cueing

Pilot Ratings



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Summary and Conclusions

- Prediction algorithms are a useful tool for calculating constraints on the collective stick in order to cue the pilot of approaching envelope limits
  - Demonstrated in both batch simulations and piloted simulations
- Collective tactile cueing is a powerful mechanism for the reduction of pilot workload both in emergency and non-emergency situations.
  - Supported by quantitative performance data, subjective pilot ratings and extensive pilot comments gathered during the course of this effort.
- The reduction in workload directly impacts task performance
  - Leads to more aggressive collective inputs
  - Results in lower task completion time and better task accuracy.
- Tactile cueing can be effectively used following a single engine failure
  - Pilot comments and ratings indicate a large reduction in workload
- Multiple limits can be cued through the collective without confusion
  - Through judicious use of different types of cues (soft stops and stick shakers)
  - Intuitively chosen frequencies for the stick shakers.

Acknowledgements

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