Design and Dynamical Validation of AI-based Flight Control System

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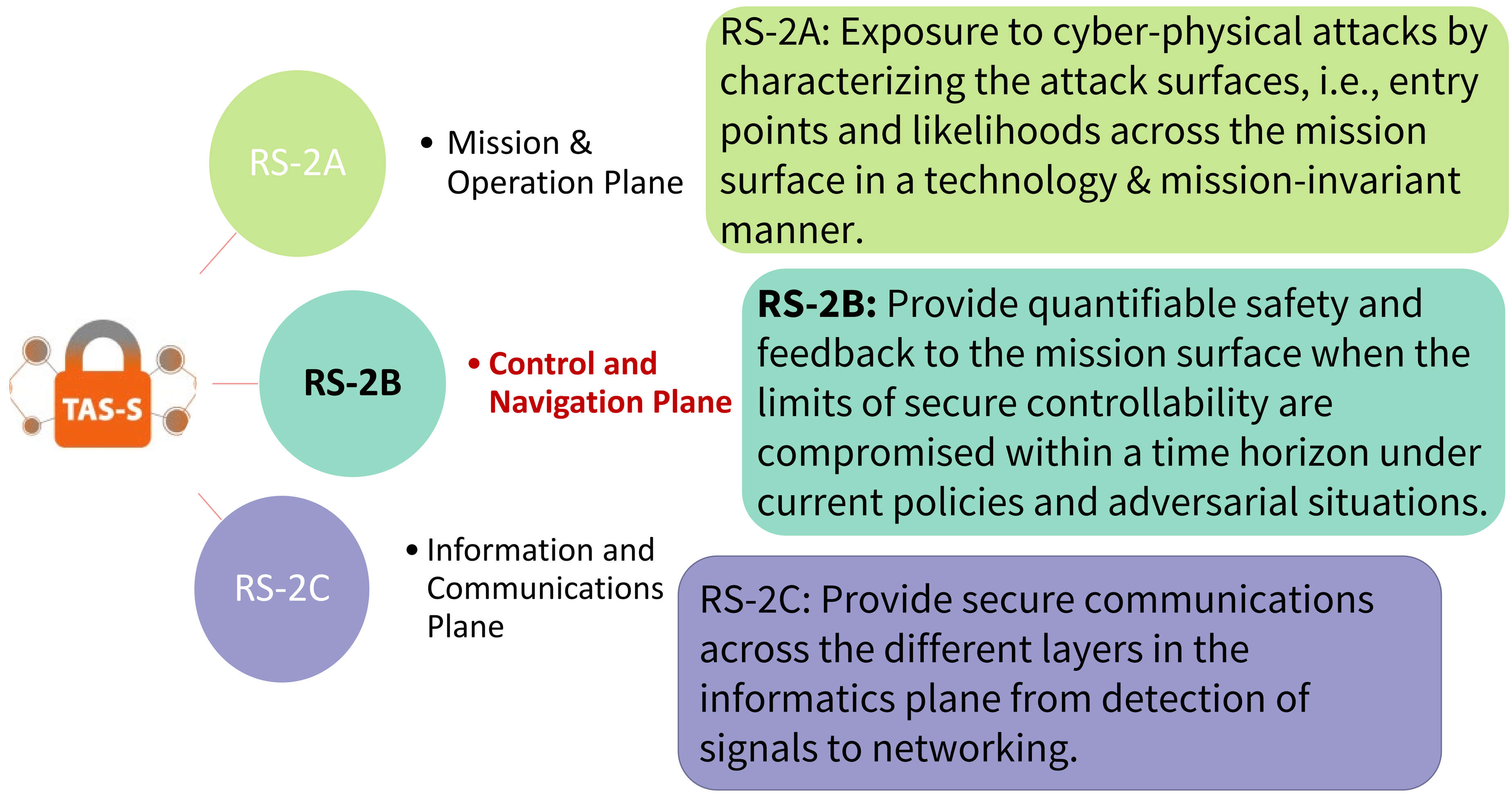
RS-2B: Securing the Control Surface

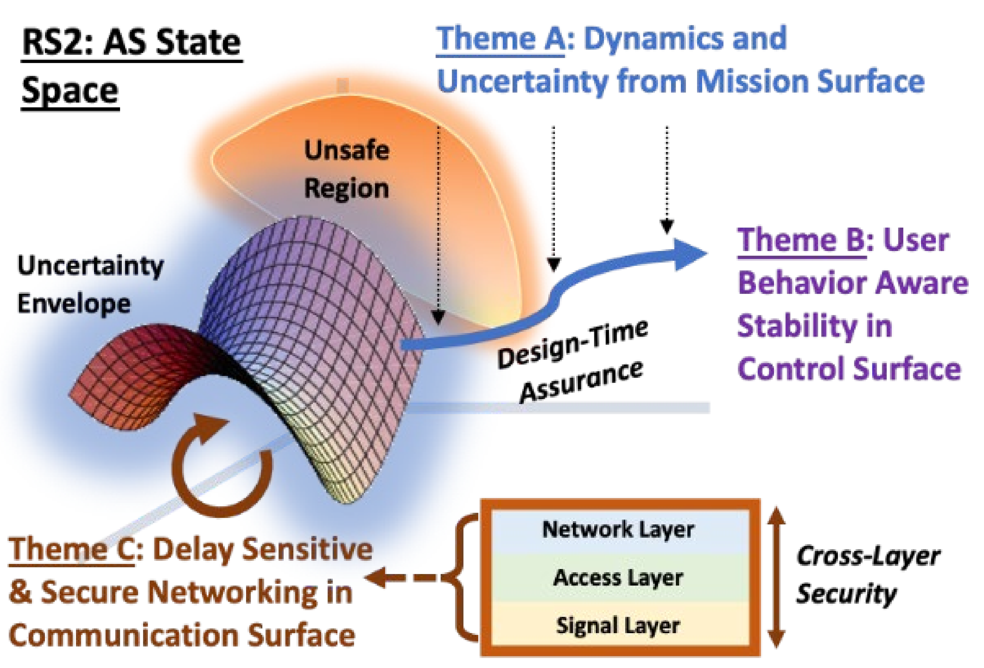


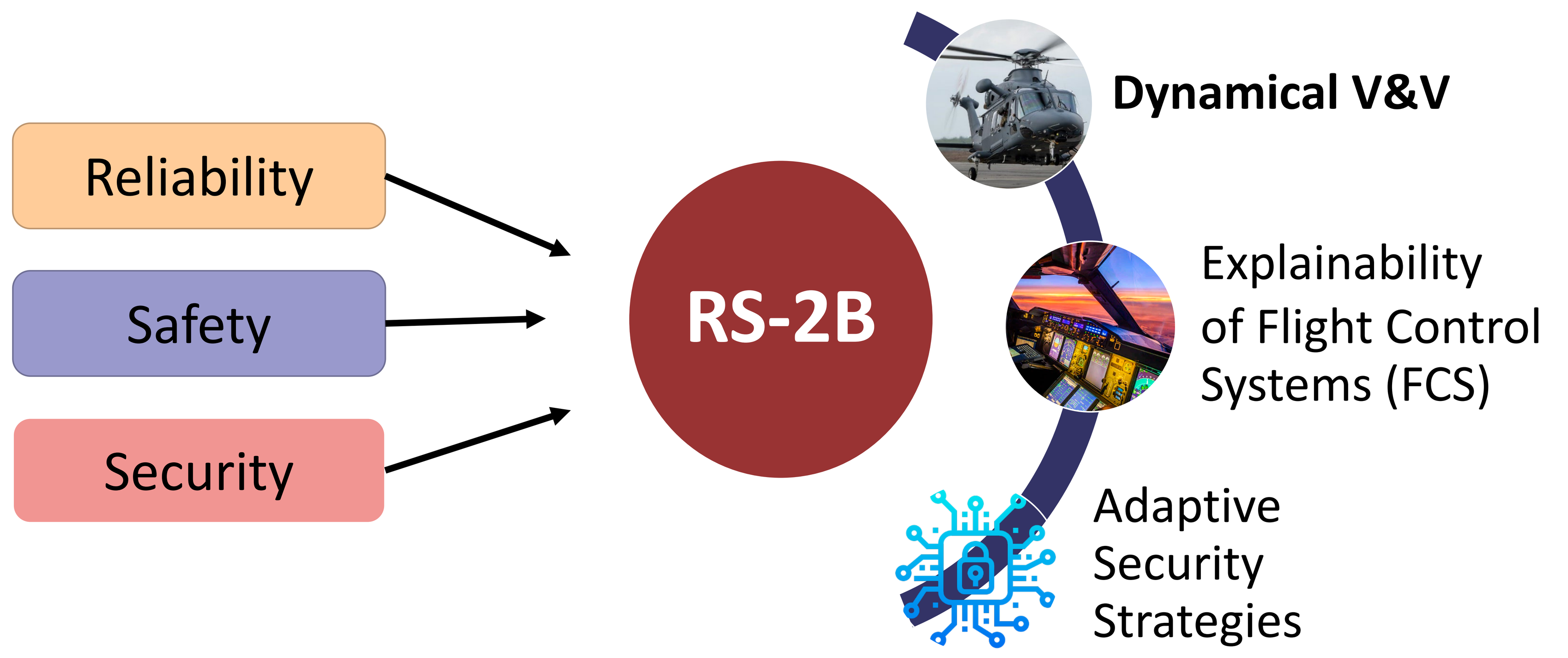
Ability of runtime adaptations of control decisions over attacks or "perceived" attacks:

- Adversaries
- Environment uncertainties
- Degraded performance

How to do this in a "trustworthy" fashion?

- Safe,
- Secure,
- Reliable



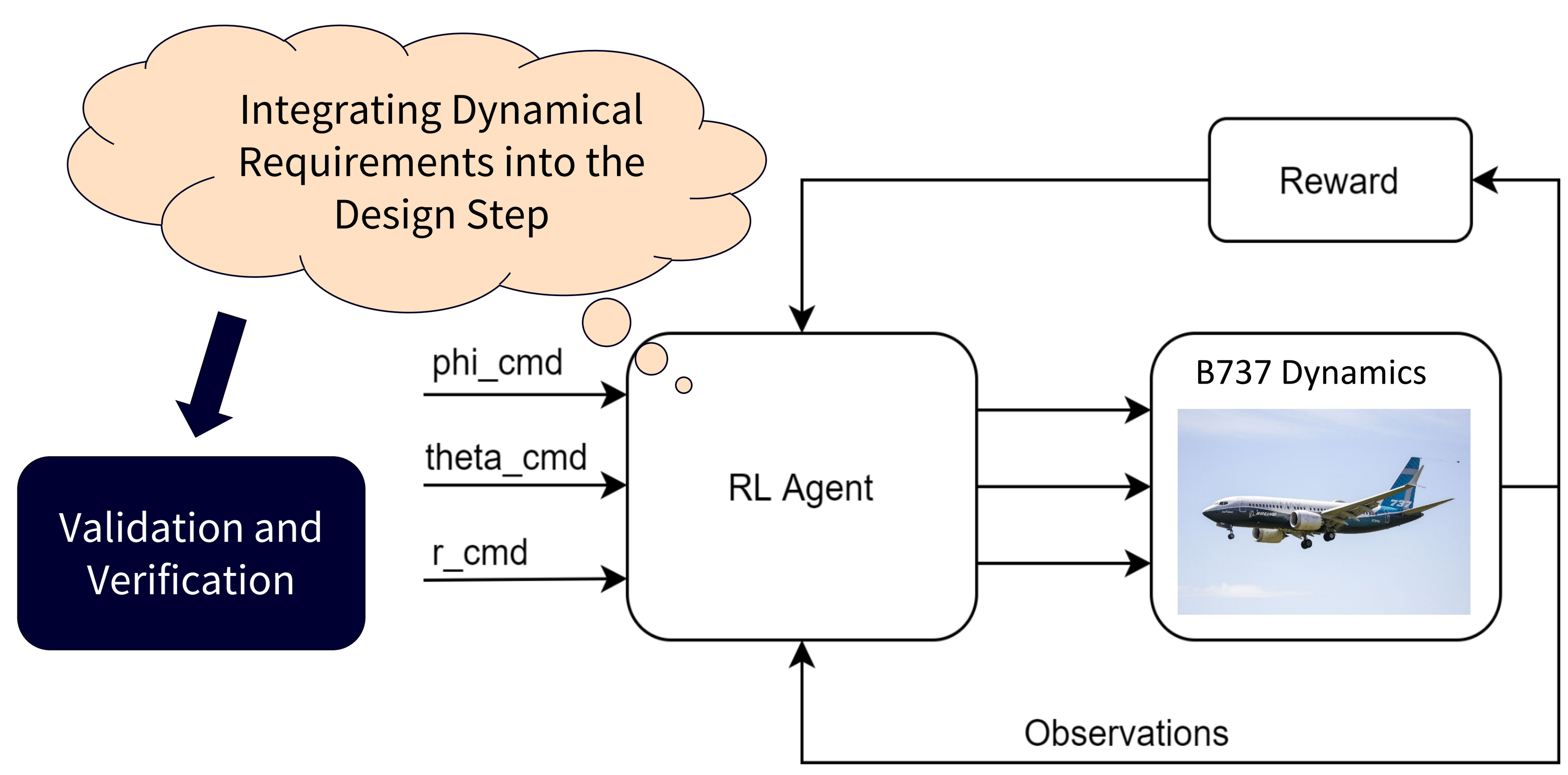


1. AI-Based Flight Control System Design

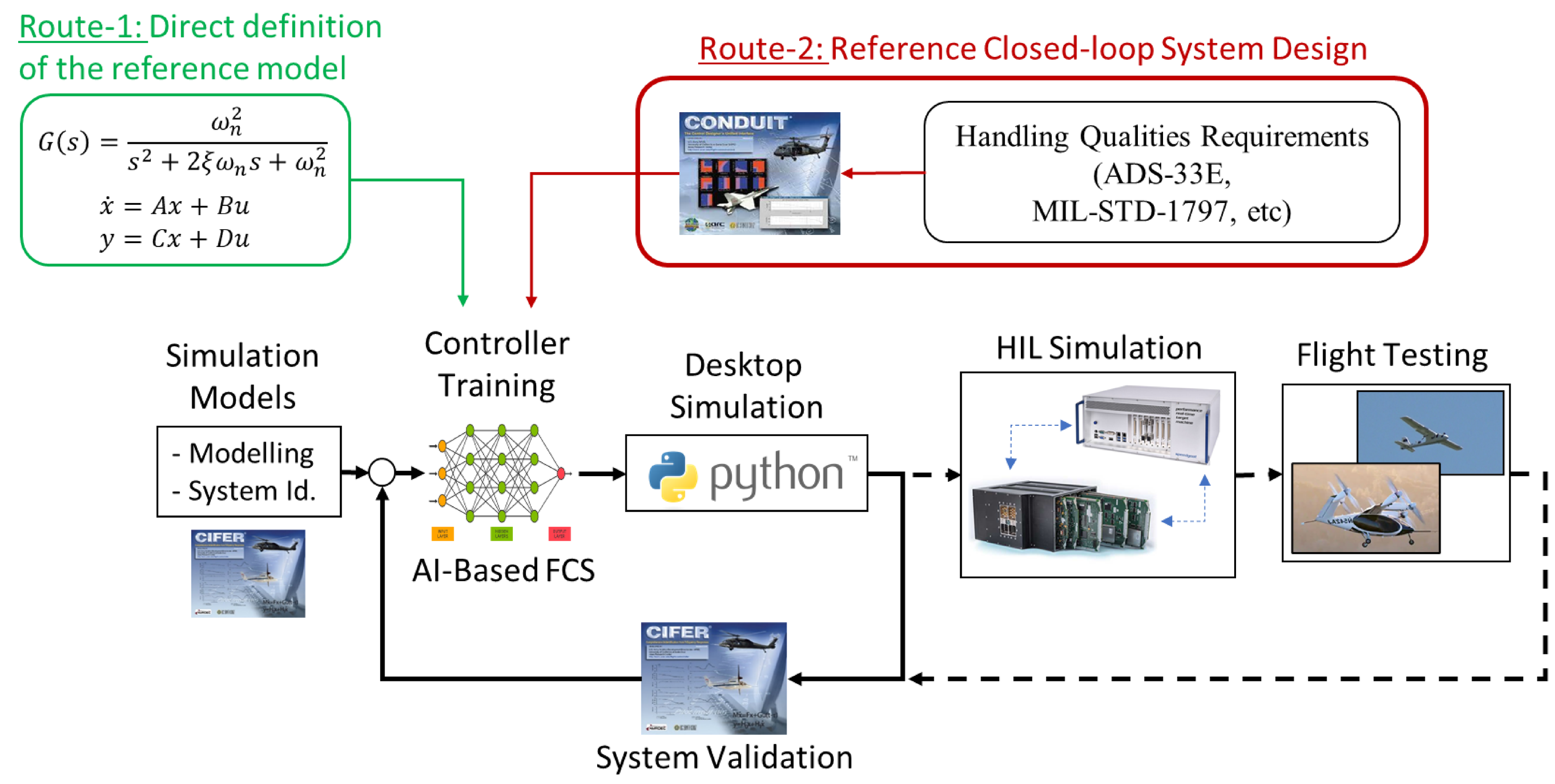
Research Problems:

- Integration of control system specifications into the training phase
- Validation of closed-loop system dynamics of an aircraft that is equipped with AI-based flight control system

Structure of the Attitude Command/Attitude Hold Flight Control System



2. Proposed Workflow for Design and Dynamical Validation of the AI-based Flight Control System

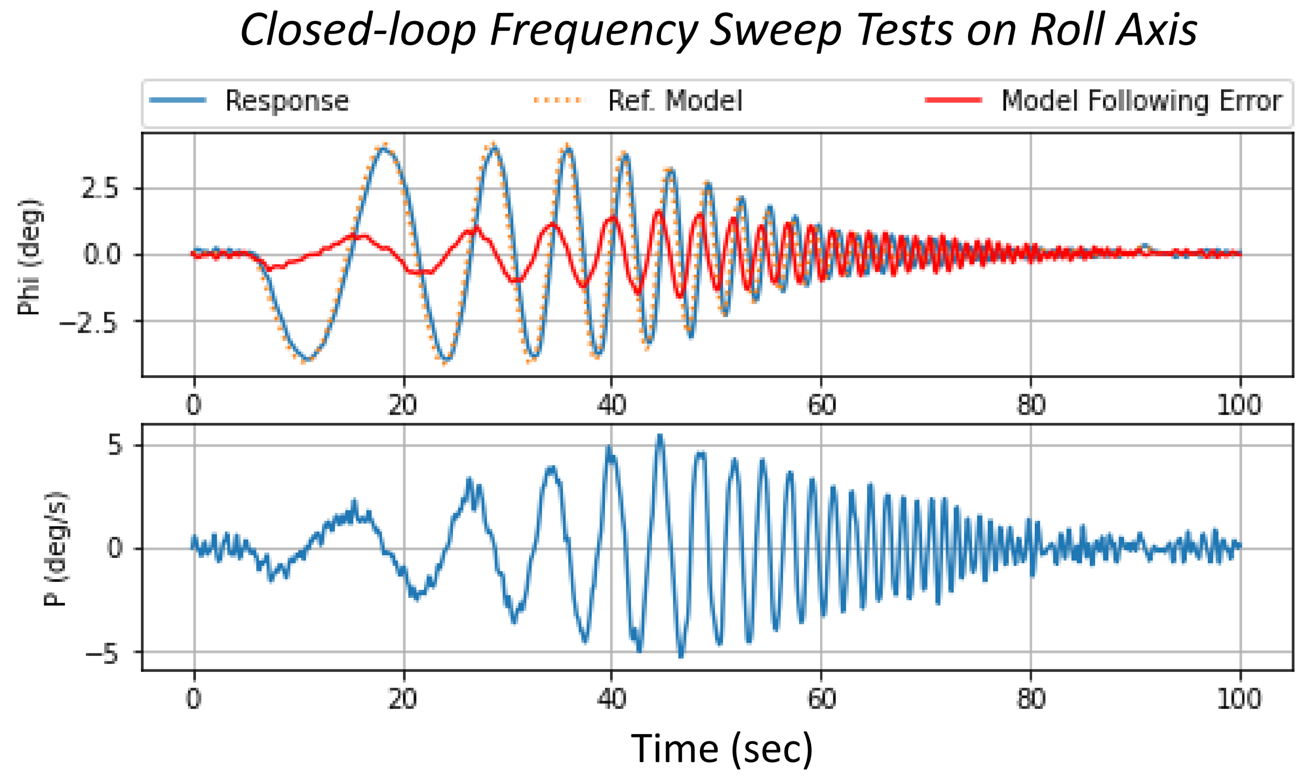


- Reference closed-loop system design is performed by utilizing handling quality requirements (Route-2) in Control Designer's Unified Interface (CONDUIT)
- AI-based controller is a neural network with;
  - 3 layers, 128 neurons in each layer, Tanh activation functions
  - Action signals: control surface commands (i.e. aileron, elevator, rudder commands)
  - Observations: GNSS measurements and auxiliary calculations related to state of the aircraft (i.e. reference model tracking error, etc.)
- Training is performed by utilizing Proximal Policy Optimization (PPO)

3. Validation of the Closed-loop system in Simulation Environment

After the training process of the RL agent, frequency-domain system identification method is utilized to identify the system dynamics with AI-based FCS. Frequency sweep tests are performed on lateral and longitudinal axes separately.

Closed-loop Frequency Sweep Tests on Roll Axis



Performed System Identification Tests:

- **Closed-loop tests** for bandwidth analysis
- **Broken-loop tests** for stability margin and crossover frequency analysis
- **Disturbance tests** for disturbance rejection capability analysis

Summary of Dynamical Validation Tests in Simulation Environment

		Roll Axis			Pitch Axis		
		AI FCS	Ref Model	Req.	AI FCS	Ref Model	Req.
Closed-loop Analysis	45 deg PM BW (rad/s)	1.2665	1.4558	-	1.255	1.677	-
	dB-gain	-4.2641	-4.705	-	-3.8316	-3.268	-
	6db GM BW (rad/s)	0.6236	1.3773	-	NA	1.5789	-
	Phase Delay	0.542	0.29205	-	0.6864	0.278	-
Broken-loop Analysis	0dB Crossover Freq (rad/s)	4.556	2.165	> 2 rad/s	2.9176	3.0598	> 2rad/s
	PM (deg)	40.634	46.866	> 45 deg	44.1568	45.636	> 45 deg
	GM (dB)	19.675	13.880	≥ 6 dB	23.2805	10.828	≥ 6dB
Disturbance Rejection	DRP (dB)	3.939	4.435	< 5 dB	3.8222	4.631	< 5 dB
	DRB (rad/s)	1.906	0.820	> 1 rad/s	1.4876	0.854	> 1 rad/s

Handling Quality Levels Level 1 Level 2 Level 3

PM: Phase Margin, GM: Gain Margin, BW: Bandwidth, DRP: Disturbance rejection peak, DRB: Disturbance rejection bandwith, Req.: Requirement

4. Conclusions and Future Works

1. It is shown that it is possible to integrate handling quality requirements into reinforcement learning process.
2. Frequency domain system identification method could be utilized to validate the closed-loop system dynamics equipped with an NN-based flight control system.
3. NN will be re-trained with updated reward function weights to improve dynamical specifications that are in Level 2.
4. System level V&V of the proposed AI-based FCS will be performed from operational safety point of view.

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