



LUNAR SIM SUPERVISOR

**RUNTIME ASSURANCE FOR A
LUNAR FLIGHT DYNAMICS DRONE**

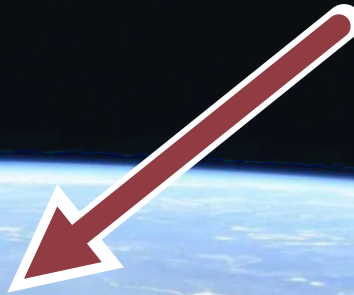
Steven Schierman

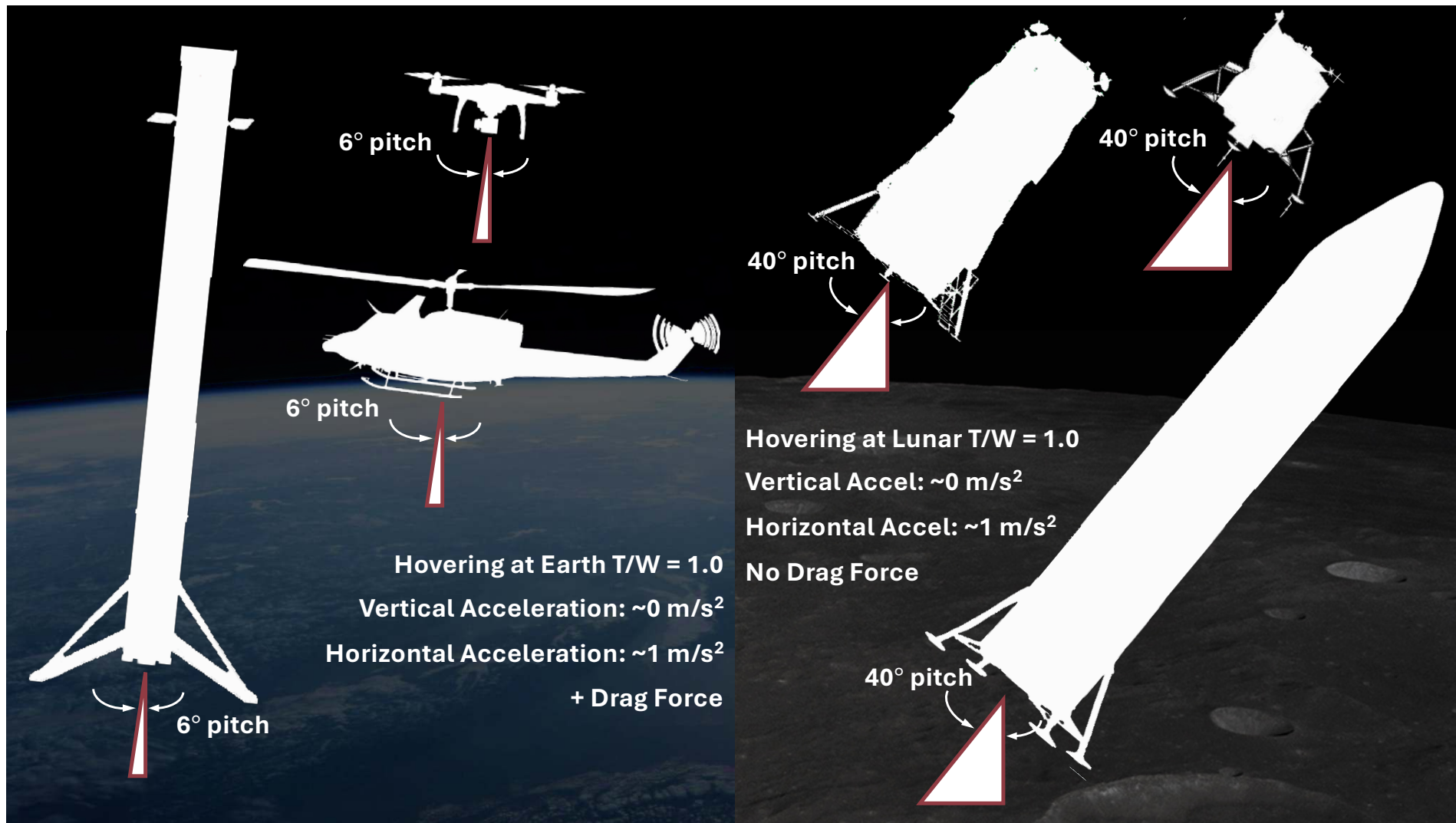
The Challenge:

How to get something to fly
as if it were here...



...when it's actually here.

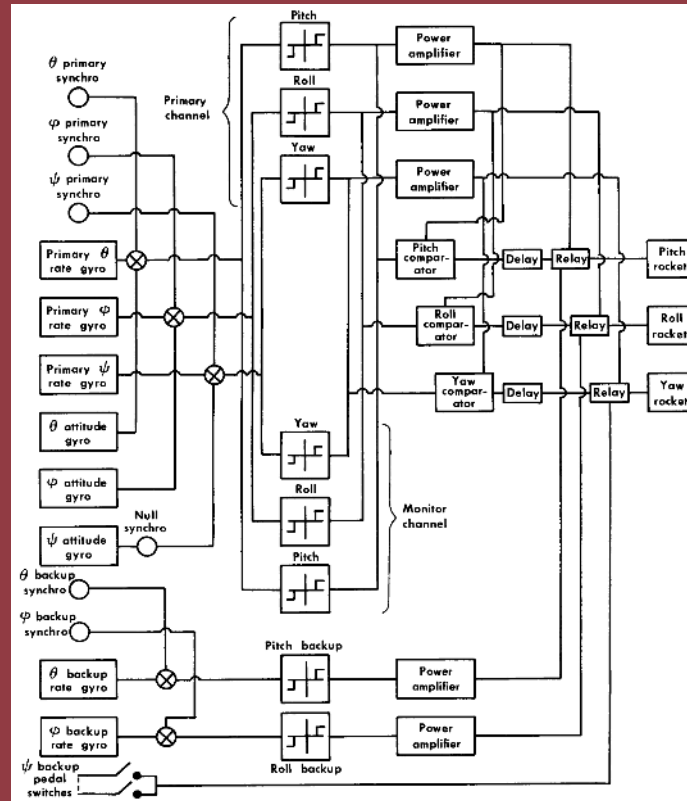




BELL LLRV / LLTV OVERVIEW



- Jet Engine in central 2-axis gimbal offset 5/6 vehicle's weight
- Outer platform: Thrusters for attitude control & simulated lunar lander engines



CONTROL SYSTEM

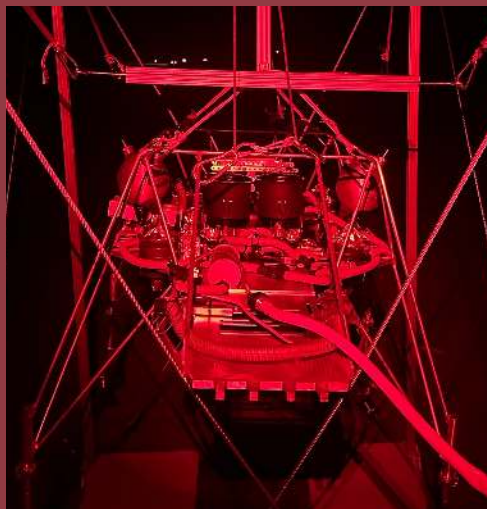
- Analog fly-by-wire stability system mixed pilot input with gyro & accel feedback
- Pilot could select between modes
- A monitor could detect attitude control failures and switch to backup mode



LFED OVERVIEW

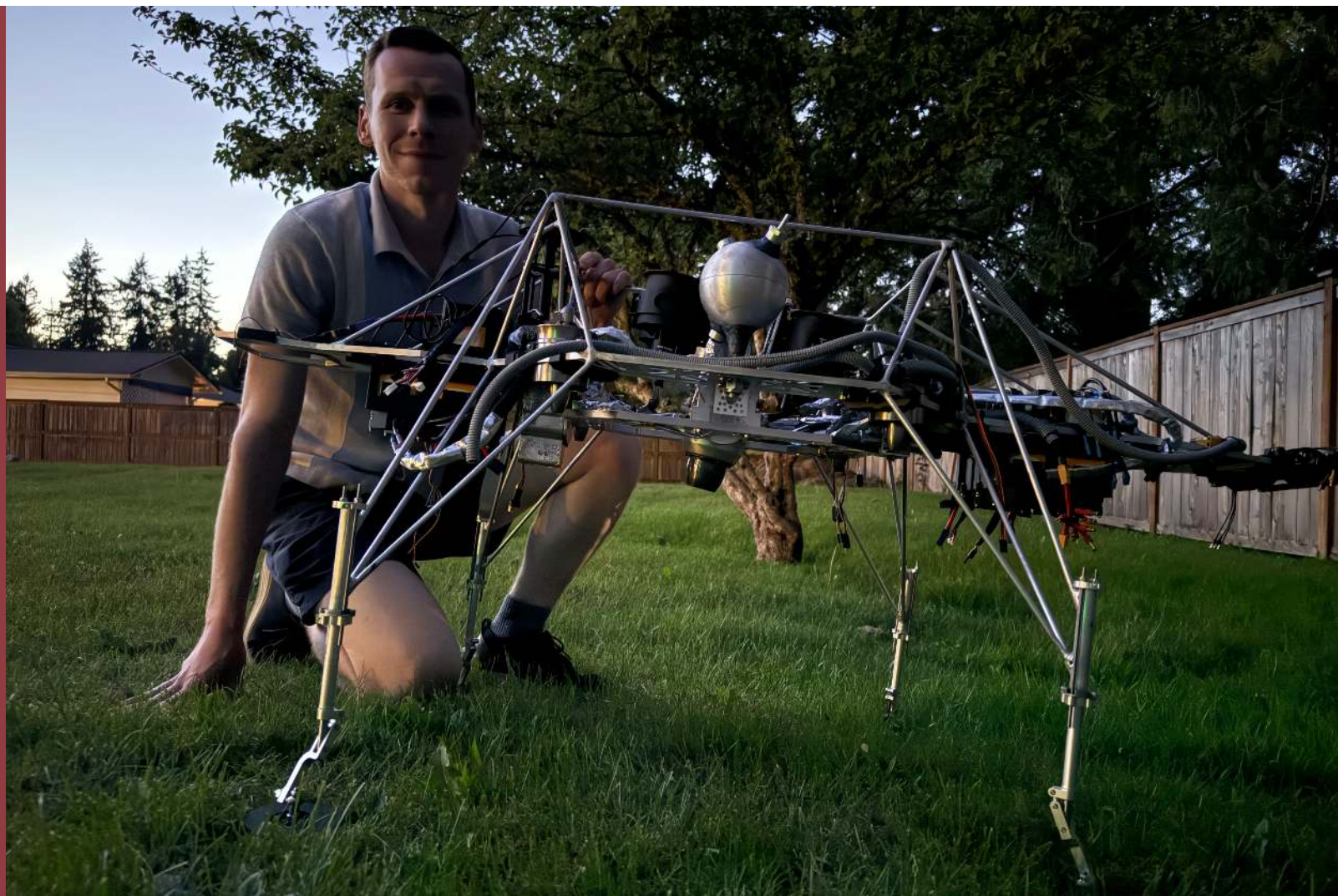
HARDWARE CONFIGURATION

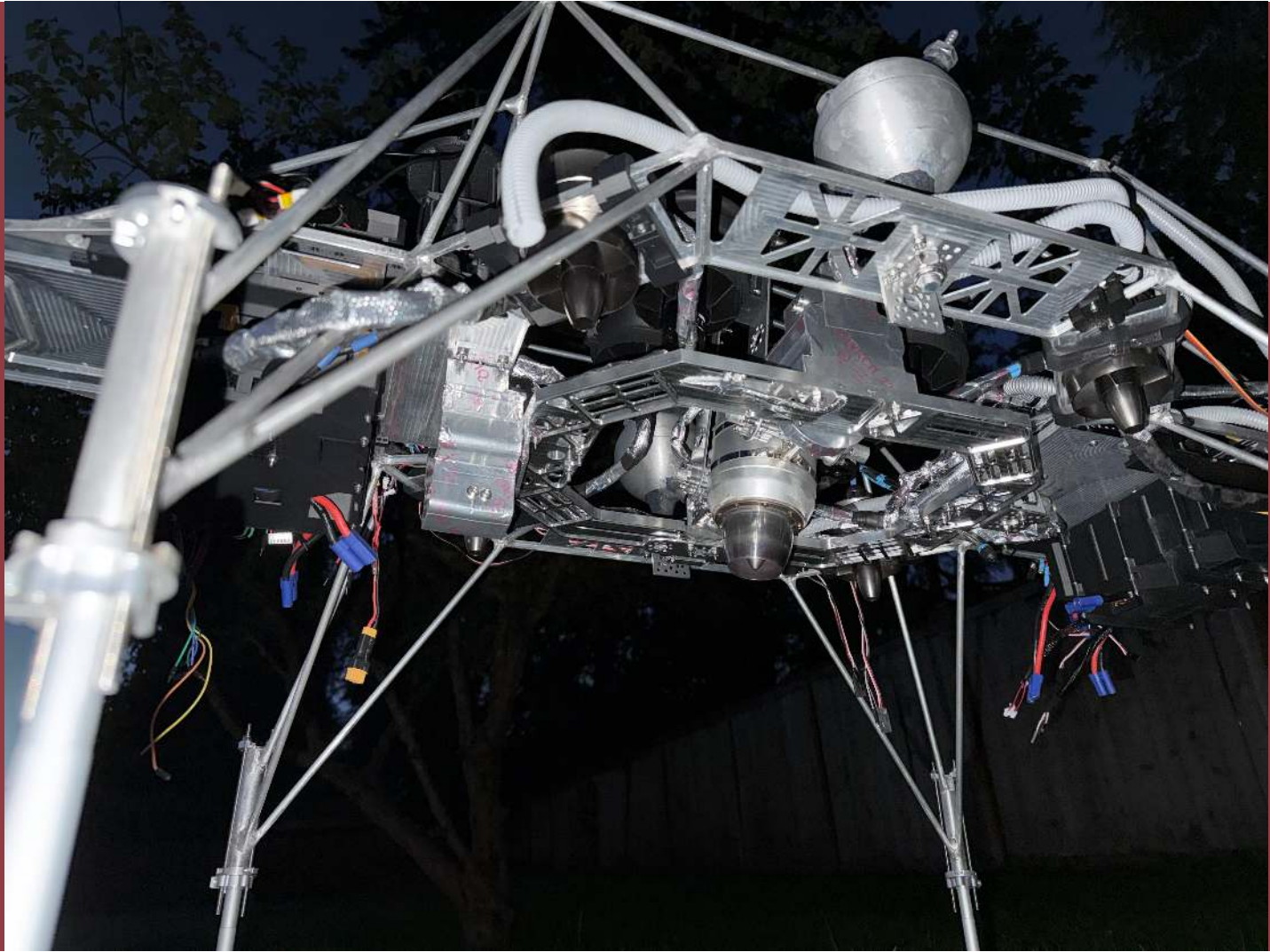
- ~40 lb. drone
- Jet Engine & EDF cluster in central 2-axis gimbal offset 5/6 vehicle's weight
- Outer 'sim' platform: EDFs for attitude control & simulated lunar lander engines



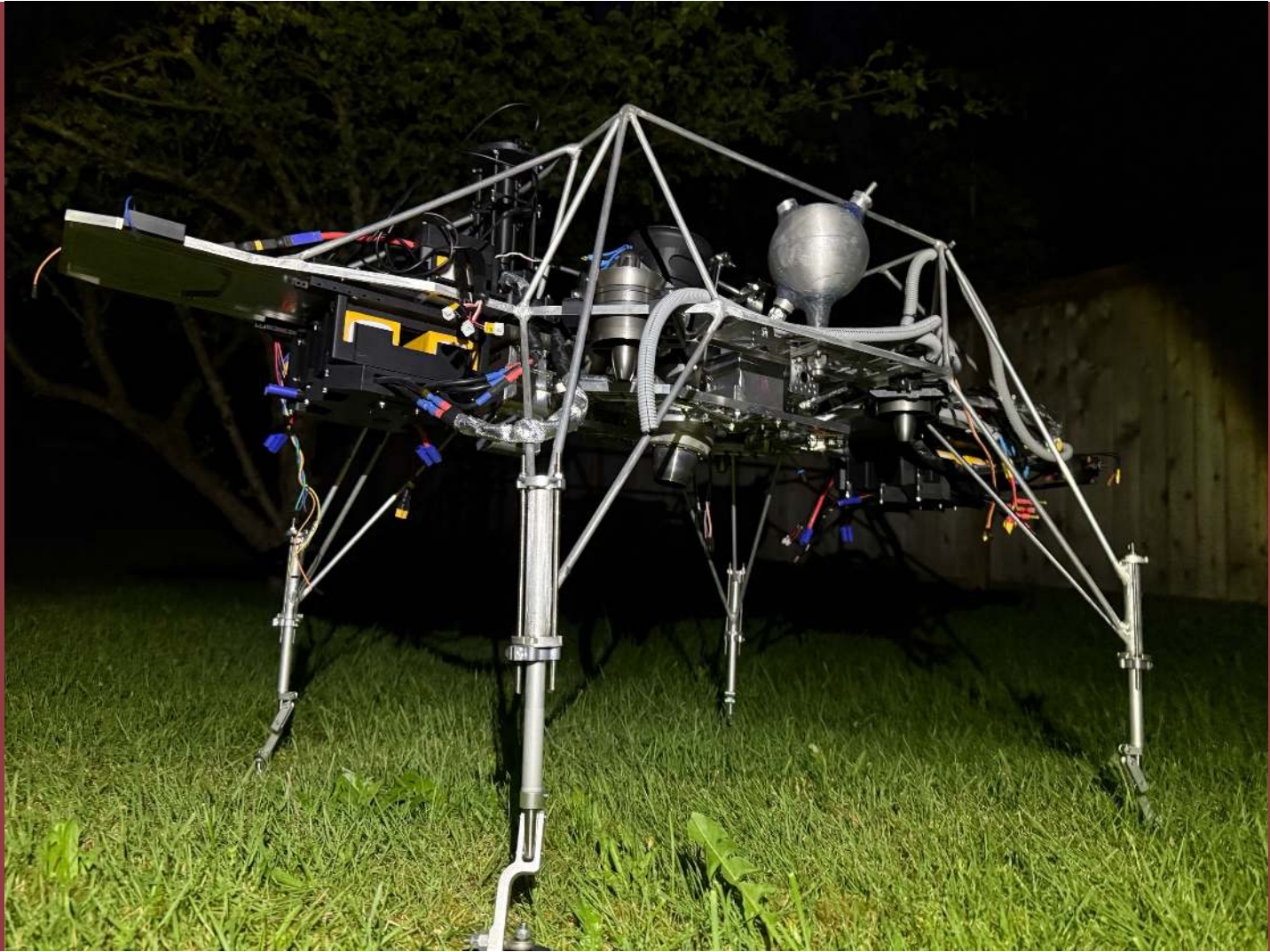
CONTROL SYSTEM

- Autonomous & remote-control modes
- Sim GNC Computer sits in the 'driver's seat'
- Dual-layer RTA monitor
 - Safety Layer: Inner control loop monitor
 - Sim Sup Layer: Dynamic response monitor









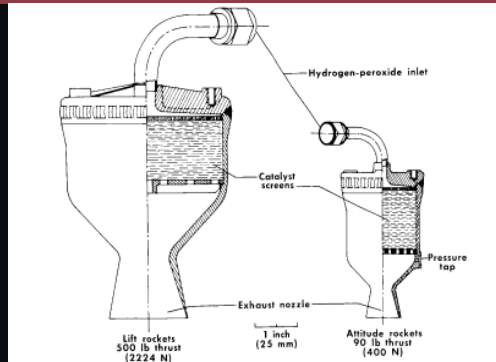
Why use an
RTA Monitor?

...
LLRV
vs
LFED

Key
Differences

LLRV: Rocket Thrusters

1.



LFED: EDFs



2.

LLRV: Pilot



LFED: Computer



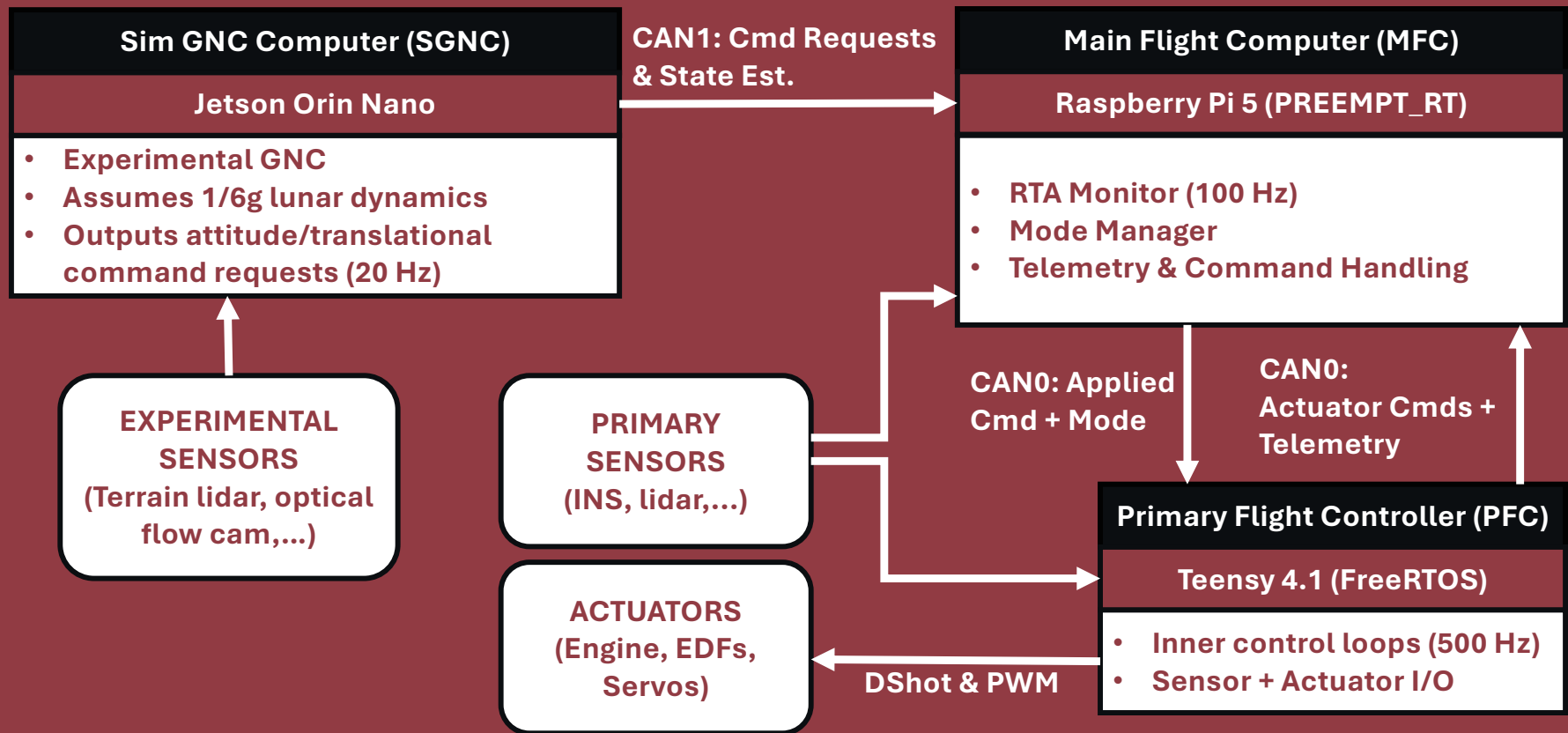
HANDLING COUPLED DYNAMICS

Disturbance	LLRV/LLTV Mitigation	Normality	LFED Mitigation	Normality
Thrust vector / center of mass offset torque	Adjustable weights	Normal	Adjustable weights + ACS	Normal
Jet engine gyroscopic precession	Contra-rotating fan/gas gen	Normal	ACS	Normal
Engine (and EDF) steady torque and spool torque	Yaw-axis bleed-air nozzle	Normal	ACS	Normal
Gimbal reaction torque	ACS: Primary	Normal	ACS	Normal
Aerodynamic moments	ACS: Primary (+ Backup)	Normal	ACS	Normal
Variable actuator authority / effectiveness	ACS: Backup	Abnormal	ACS	Normal
Fuel imbalance	ACS: Primary + Backup	Abnormal	ACS	Normal

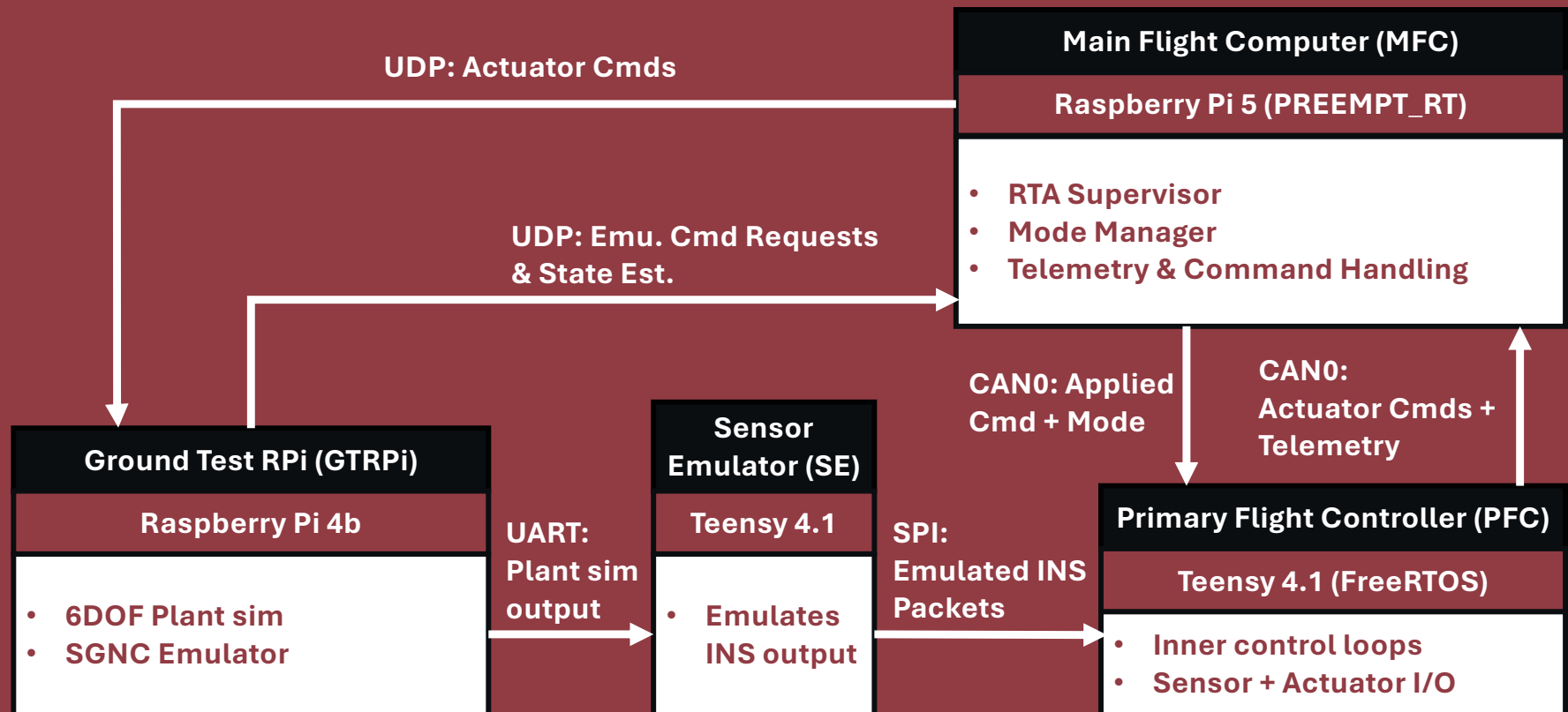
FLIGHT PHASES & MODES

Flight Phase	Central Offset System Mode	Characteristics & Challenges
Ascent	Gimbal Locked	Highest control authority, unique disturbances
Sim Setup	Gimbal Locked - Lunar Sim	Transition phase
Braking	Lunar Sim	Lowest control authority, highest aero moments
Approach	Lunar Sim	Partial authority recovery, undercut by low voltage & high ESC temps
Contingency	Local Vertical or Gimbal Locked	Transition can occur at any phase

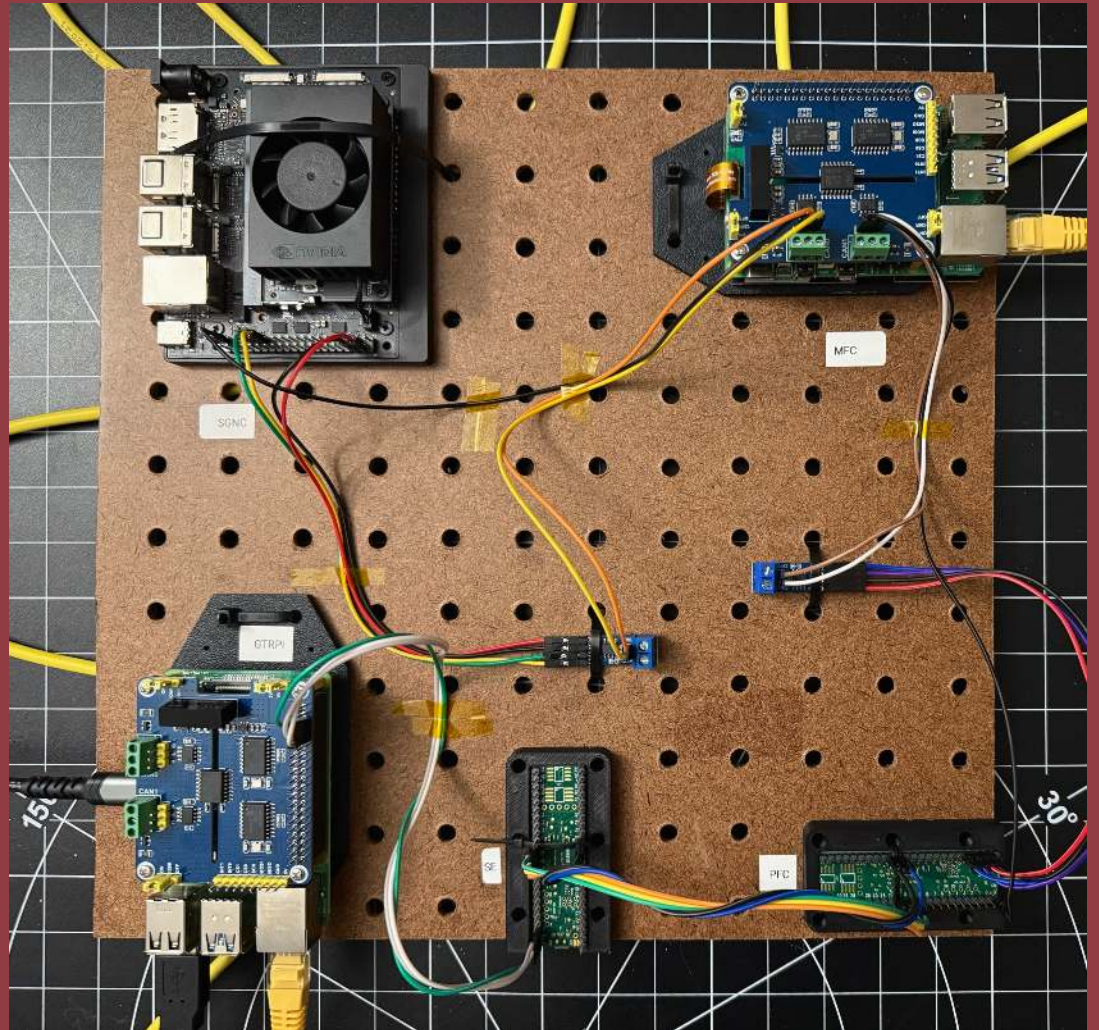
FLIGHT HARDWARE



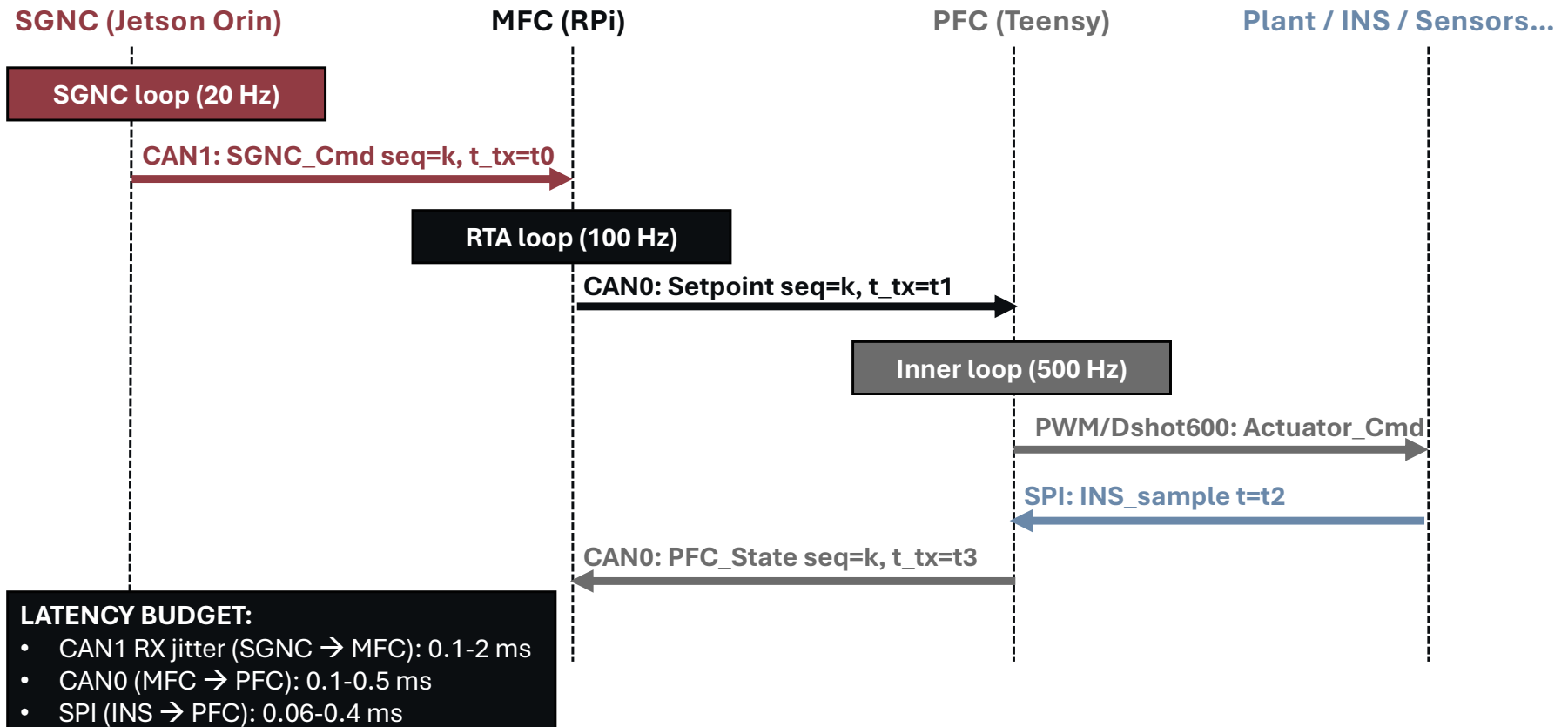
HIL TEST SETUP



HIL TEST SETUP



COMMAND FLOW



RTA MONITOR MODULES

What is the RTA Monitor?

Not a controller. A supervisor that: 1. Filters SGNC (and RC) command requests for the controller.
2. Compares vehicle dynamics to control intentions to ensure: a. vehicle safety b. lunar sim fidelity

INPUTS	RTA CORE	OUTPUTS
SGNC_Cmd (or RC_Cmd) (CAN1) - Cmd: Attitude/Rate - Cmd: Thrust - Cmd: Target landing point	Envelope Monitors (Safety Supervisor) - Enforces hard attitude & translational limits - Detects actuator saturation, battery / thermal limits - Outputs: Allow/limit flags → Mode Manager	PFC_Cmd - Attitude/Rate Setpoints - Thrust vector
PFC_State CAN(0) - Meas: Attitude/Rate - Meas: Accel - Meas: Actuator Status	INDI Monitor (Sim Supervisor) - Predicts incremental response bounds, computes residuals - Uncertain control effectiveness / bandwidth - Outputs: Response score, fidelity flags → Mode Manager	Telemetry / Logs - Current State - Current Mode - Response / Residuals - Setpoints - Flags
	Setpoint Shaper - Clamp SGNC (or RC) command requests - Mix with lunar sim offsets, rate limiting, and smoothing - Output: Applied setpoint → PFC	
	Mode Manager - Determines current mode state, command source - Latching behavior, timeouts, etc.	

RTA MONITOR PROCESS & THREADS

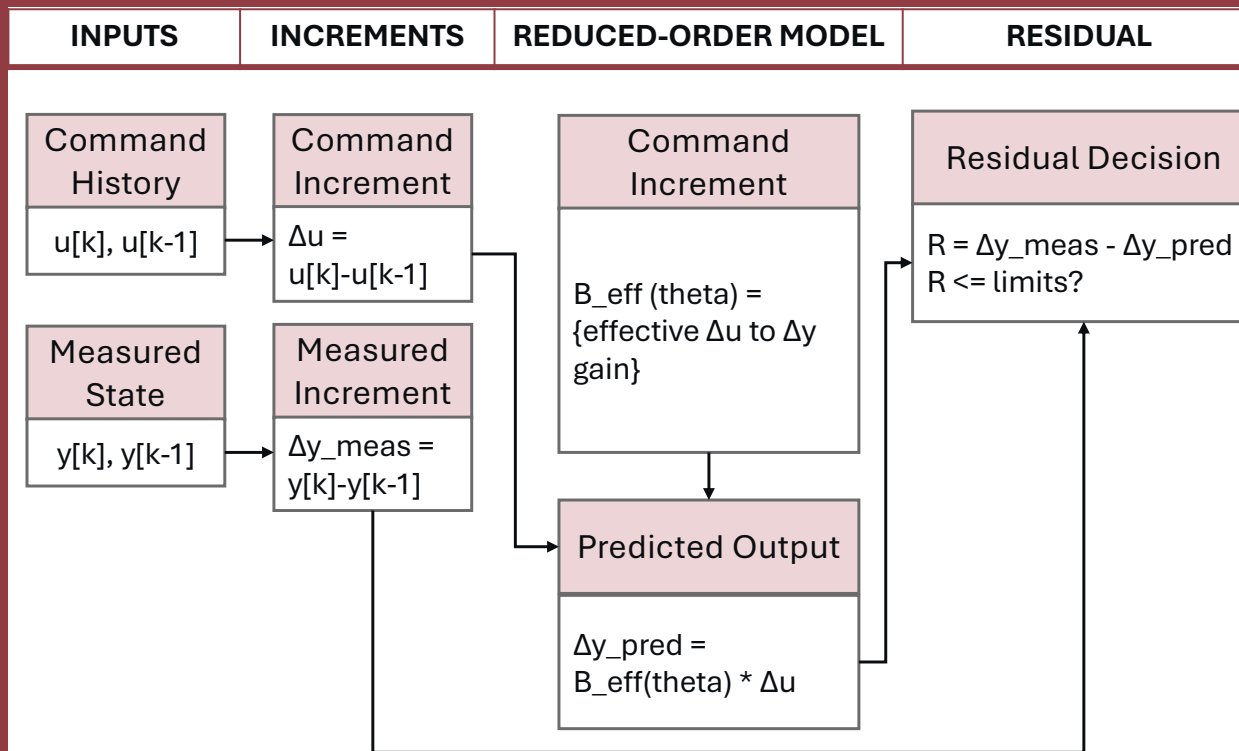
Thread	Priority	Trigger	Writes	Reads	Interface	SHARED STRUCTS (NON-LOCKED): -pfc_meas {seq,t,rates,accel...} -pfc_act {seq,t,actuator_cmd ...} -sgnc_cmd {seq,t,cmd_type,vals ...} -pfc_setpt {seq,t,mode, stpt_outer, setpt_offset...} -rta_status {resid, score...} -mode_state {mode_id, substate, transit_ctr...}	PSEUDO-CODE: RTA_LOOP() <pre> while(running){ wait(next_tick); // 1. New input reads pfc = pfc_state.load(); cmd = sgnc_cmd.load(); // 2. Envelope monitor env = check_env(pfc,cmd); //3. INDI monitor drm = drm.update(cmd, setpt_prev, pfc); //4. Setpoint shaper setpt = clamp(cmd, env, drm, mode); //5. Mode manager mode = update_mode(env, drm, health); //6. To PFC & log can0_tx.push(setpt, mode); log.push(rta_telem); } </pre>
Rta_loop	Highest	Periodic, timer (200 Hz)	setpt rta_status mode r (residual)	pfc_meas pfc_act pfc_health			
Can0_rx_pfc	High	Event, socketCAN RX	pfc_meas pfc_act pfc_health		can0 → PFC		
Can0_tx_pfc	High	Event, rta_loop, new setpt		setpt mode rta_status	can0 → PFC		
Can1_rx_sgnc	High	Event, socketCAN RX	sgnc_cmd sgnc_state sgnc_health		can1 → SGNC		
Telem	Mod	Periodic, timer (10-50 Hz)		telem_fields	UDP		
Logger	Low	Periodic, timer (1-20 Hz)		lock-free log ring	NVMe		
Health	Mod	Periodic, timer (5-20 Hz)	health_flags	healths, t			

INCREMENTAL NONLINEAR DYNAMIC INVERSION

Accounts for actuator dynamics: lag between control input + vehicle response

Separates residuals (measured output vs model-predicted output) from control inputs

State derivatives (e.g., angular acceleration) + est. control effectiveness $\rightarrow$ desired control input



PSEUDO-CODE: INDI RTA update()

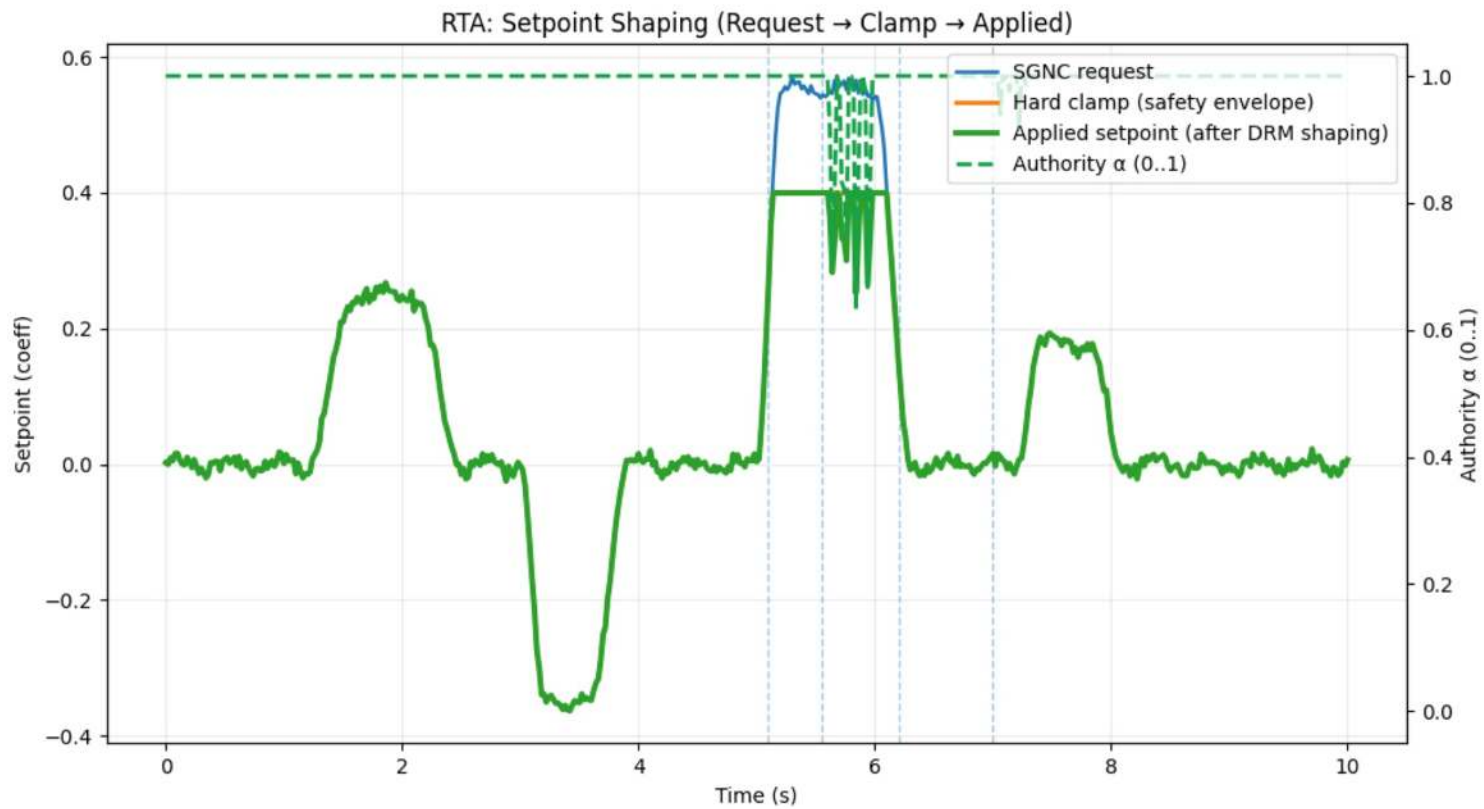
```

DRMUpdate indi_drm.update
(u_k, u_km1, y_k, y_km1){
    du = u_k - u_km1;
    dy = y_k - y_km1; // accel/rate increments

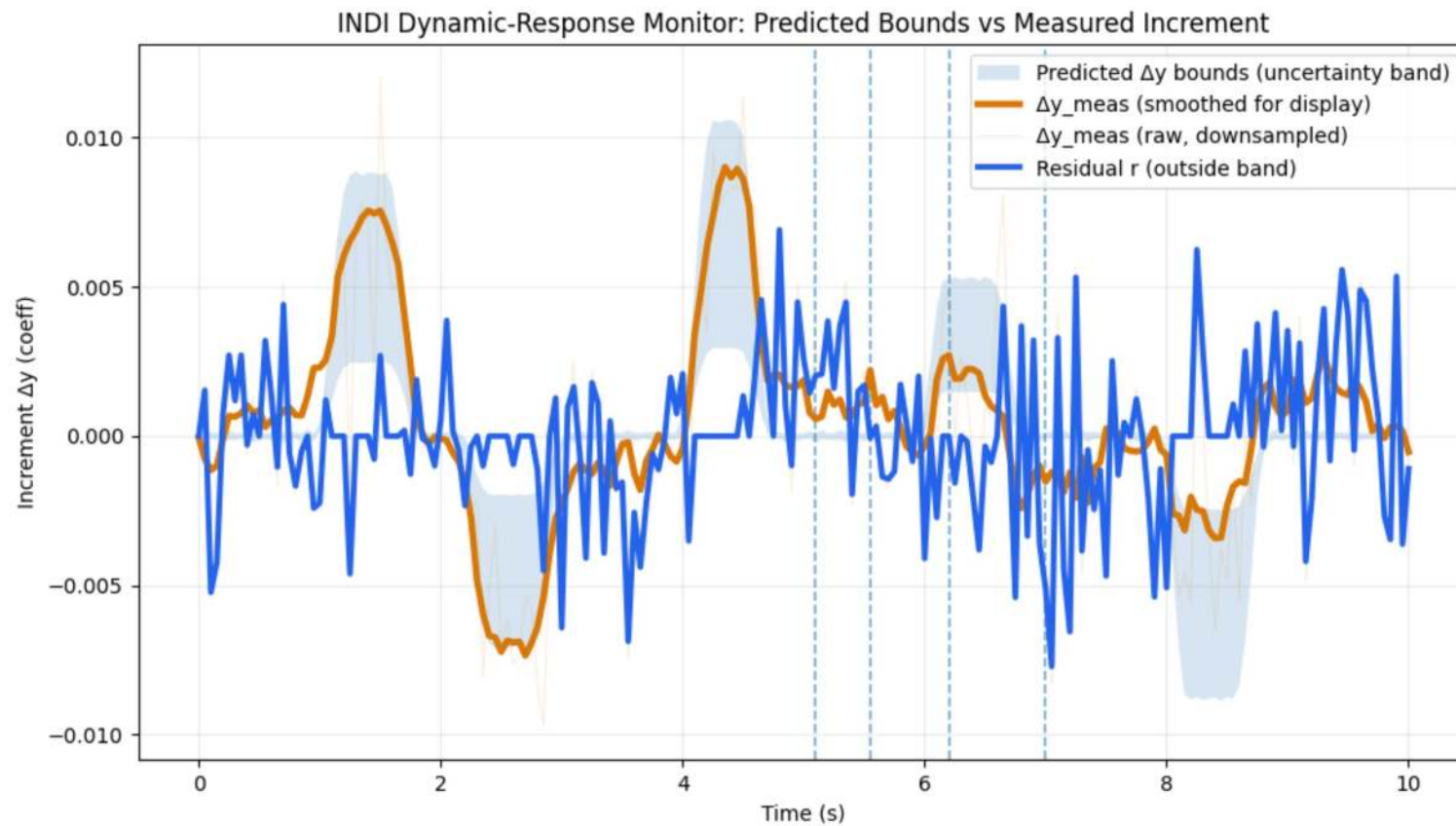
    // Evaluating corner models (k_eff, tau_inner)
    dy_min = +INF; dy_max = -INF;
    for (corner in corners) {
        alpha = (1 - exp(-dt/corner.tau))
        Be = corner.k_eff * * B0;
        dy_c = Be * du;
        dy_min = min(dy_min, dy_c);
        dy_max = max(dy_max, dy_c);
    }

    // Residual vs bounded prediction
    r = clamp(dy - sat(dy_min, dy_max), -rmax, +rmax);
    good_state = norm(r) <= threshold;
    score = update_score(score, good_state, norm(r));
    return {good_state, score, r, dy_min, dy_max};
}
    
```

EXAMPLE RTA OUTPUT GRAPH



EXAMPLE INDI OUTPUT GRAPH



CONTACT

Steven Schierman
(253) 651-7169
stevenschierman@gmail.com
x.com/SvenSchierman
youtube.com/@atlasautonomous
linkedin.com/in/steven-schierman