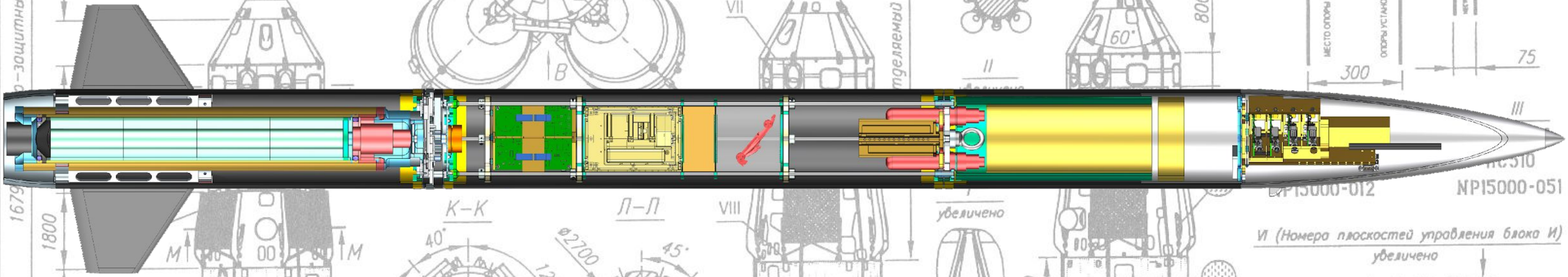
# Subsystem Design



# Control

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Thomas Lew
Anna-Maria Koblenzer
Michael Kurmann

# Control
## Principles

Competition goal:

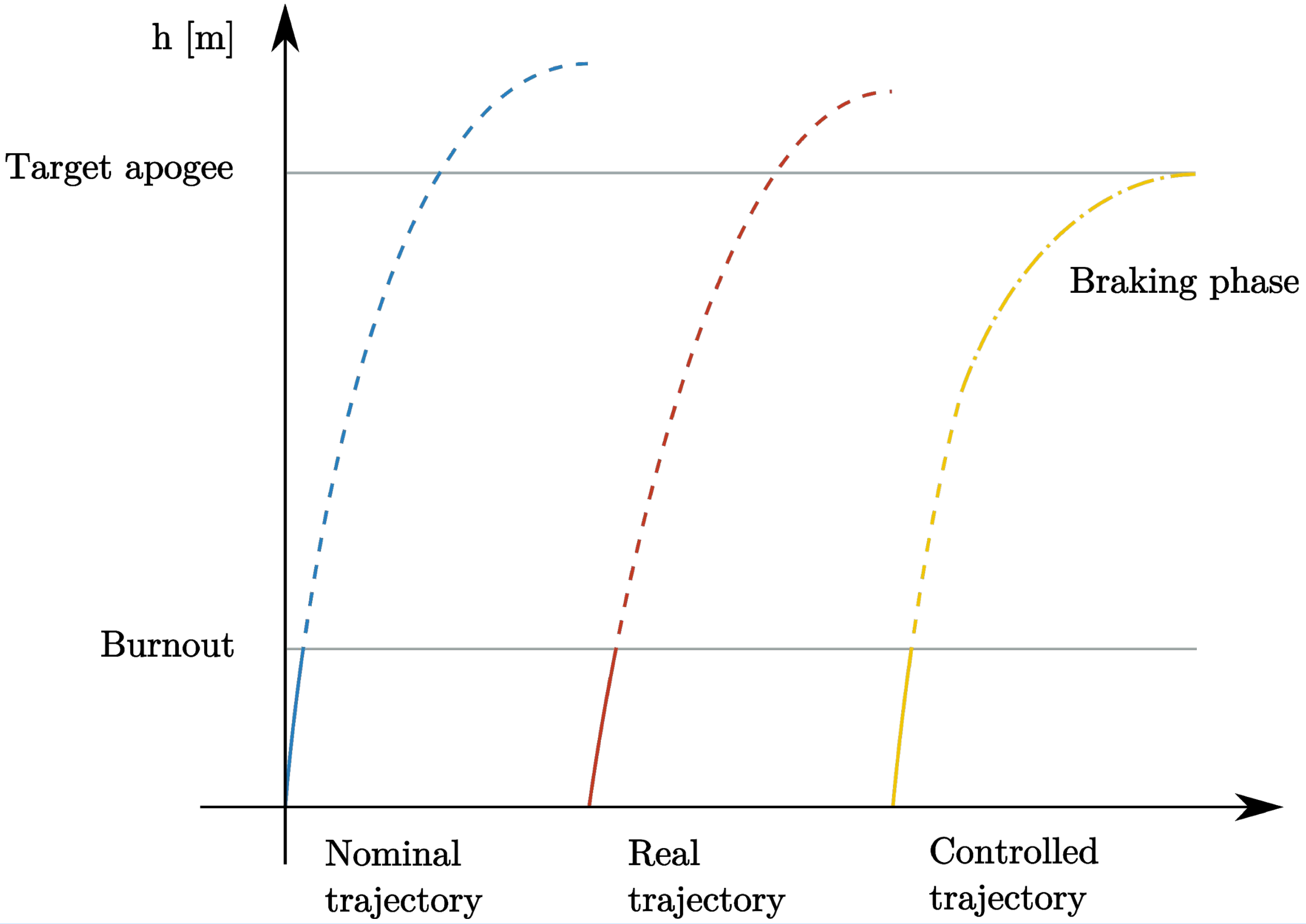
➢ Reach 10’000 feet exactly.

1. There is only one attempt

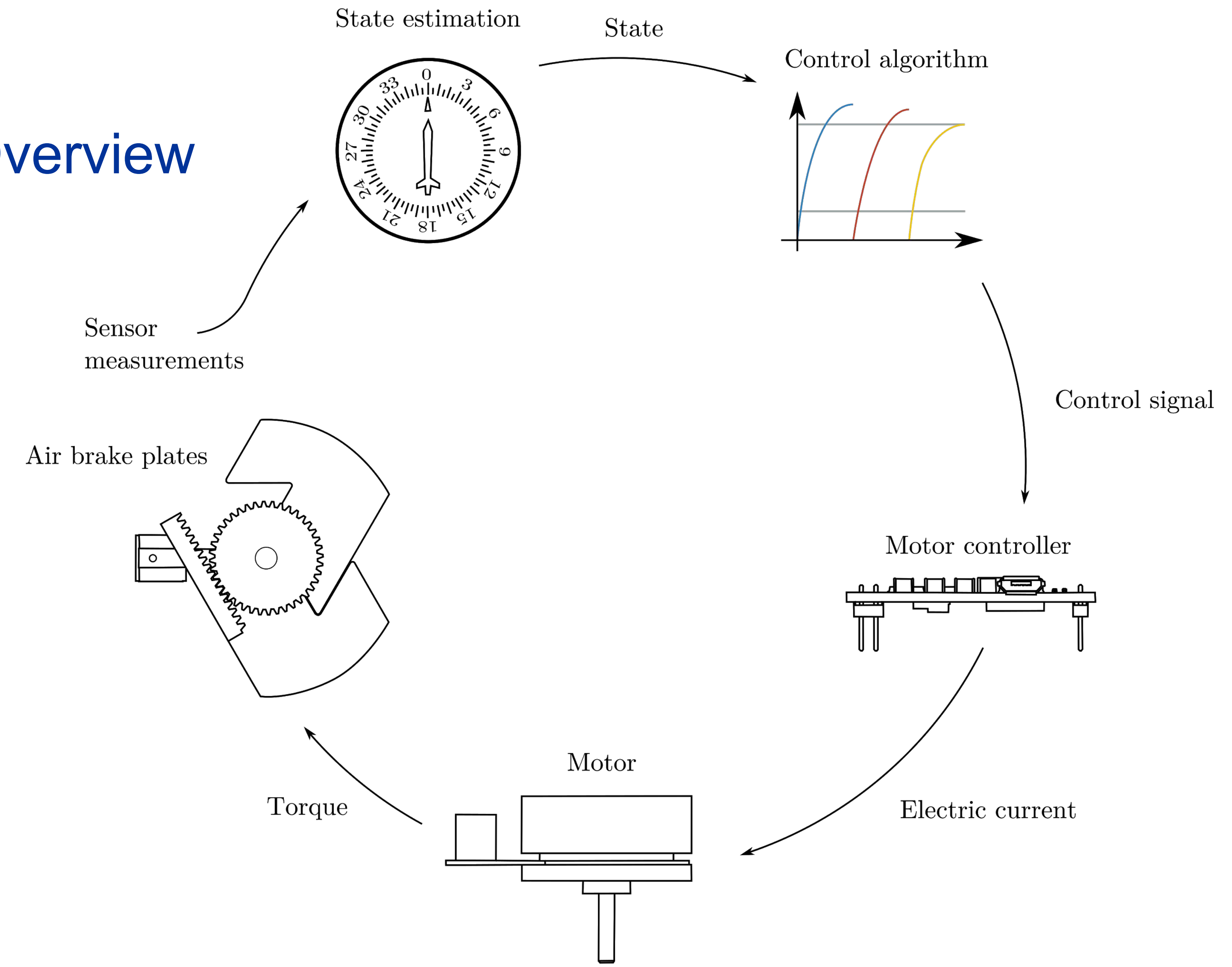
➢ Reliability is key

2. Short development time

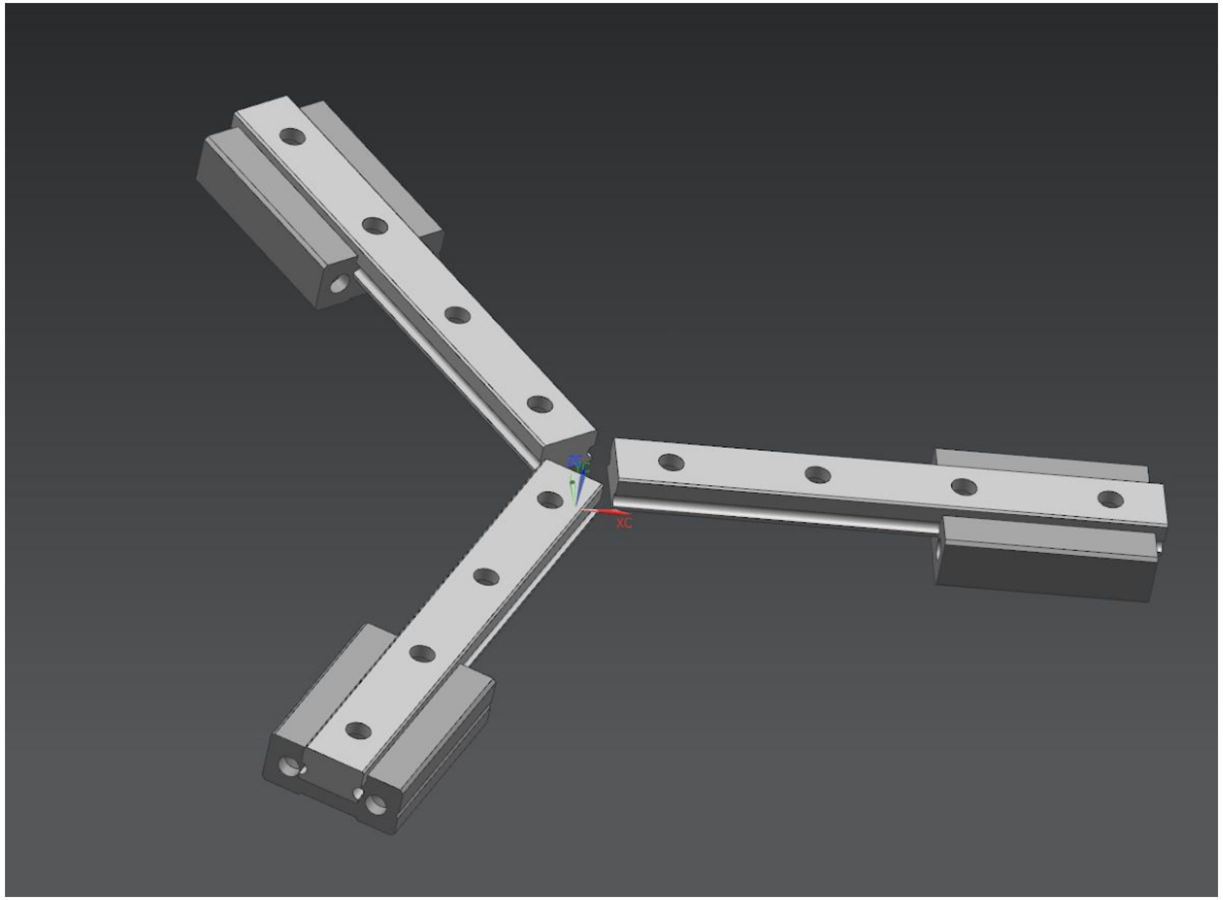
➢ Keep it simple



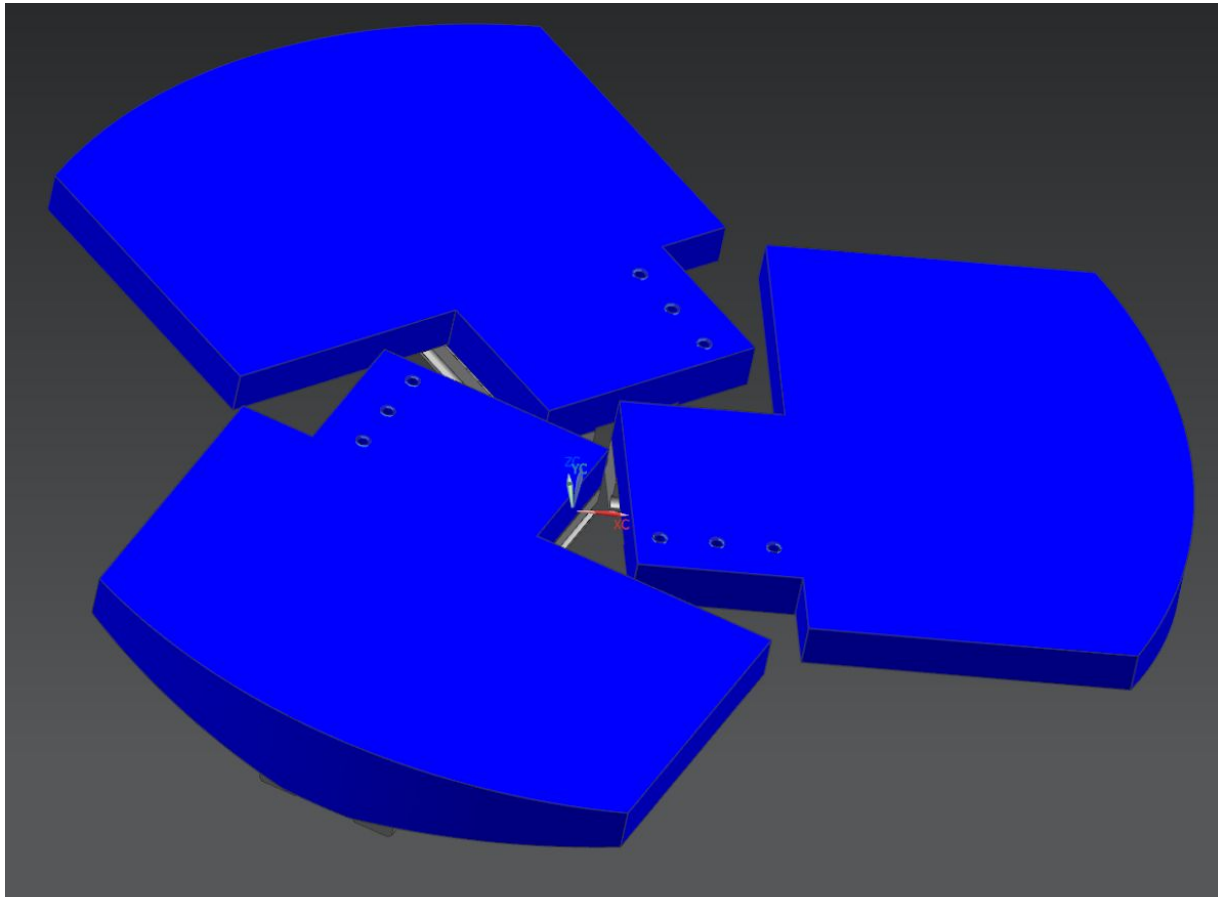
# Control
## System Overview



# Control
## Design Overview

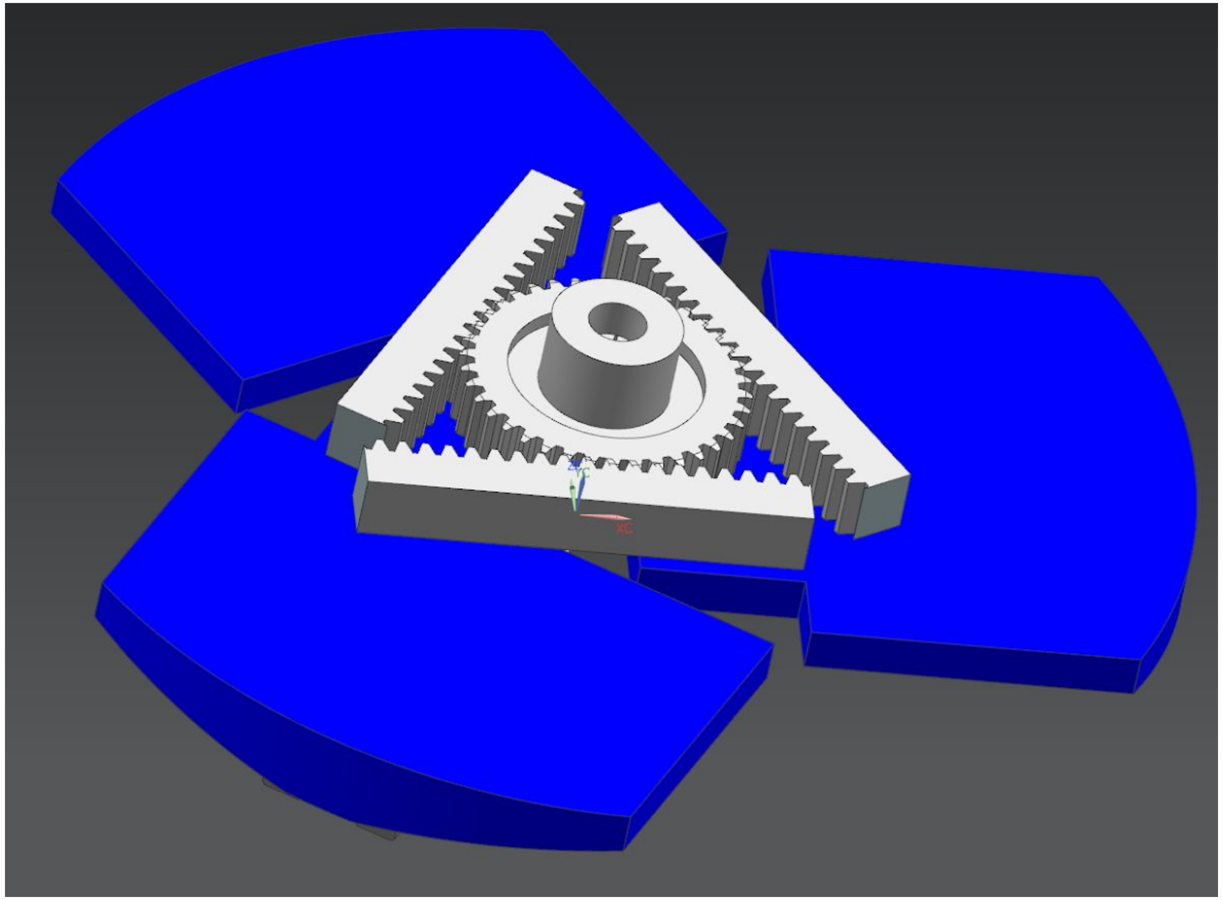


# Control
## Design Overview



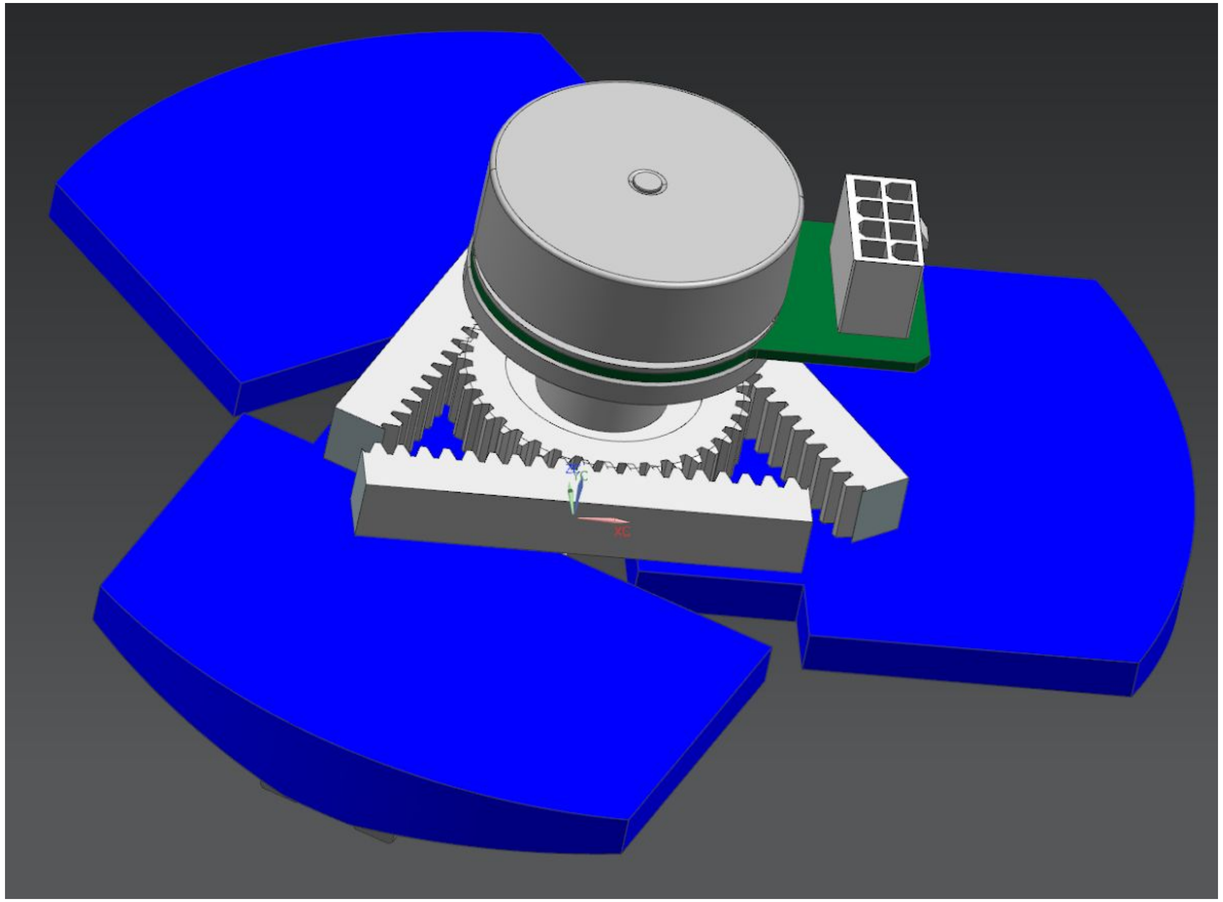
# Control

## Design Overview

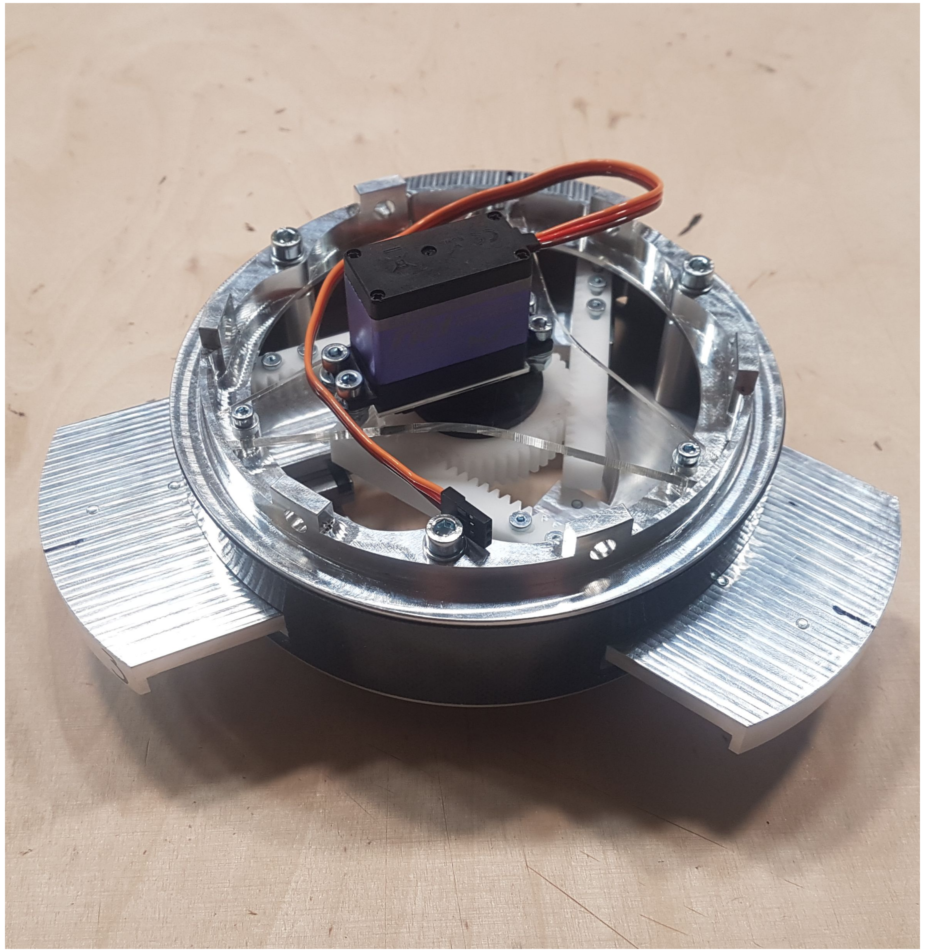


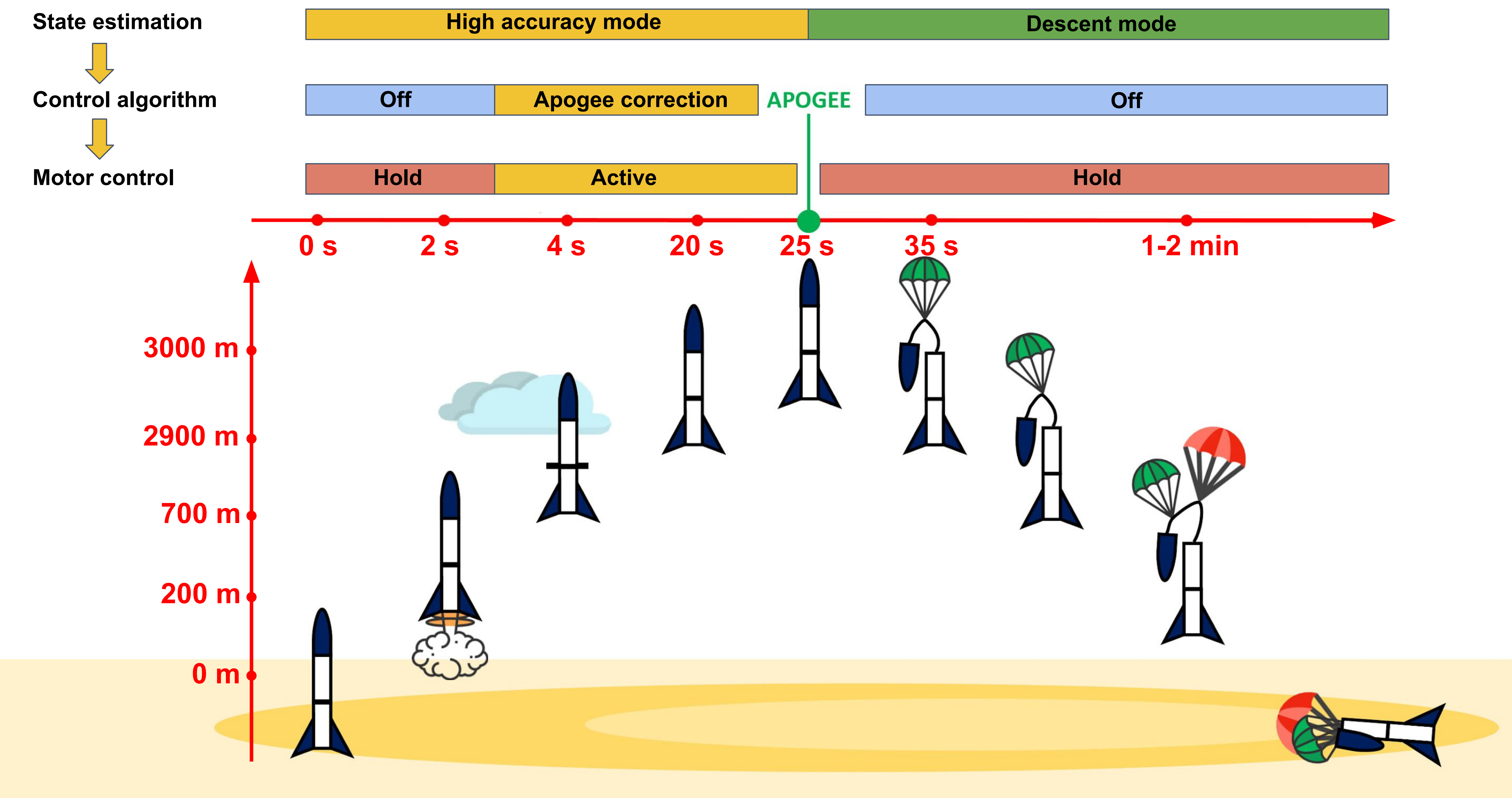
# Control

## Design Overview



# Control
## Design Overview



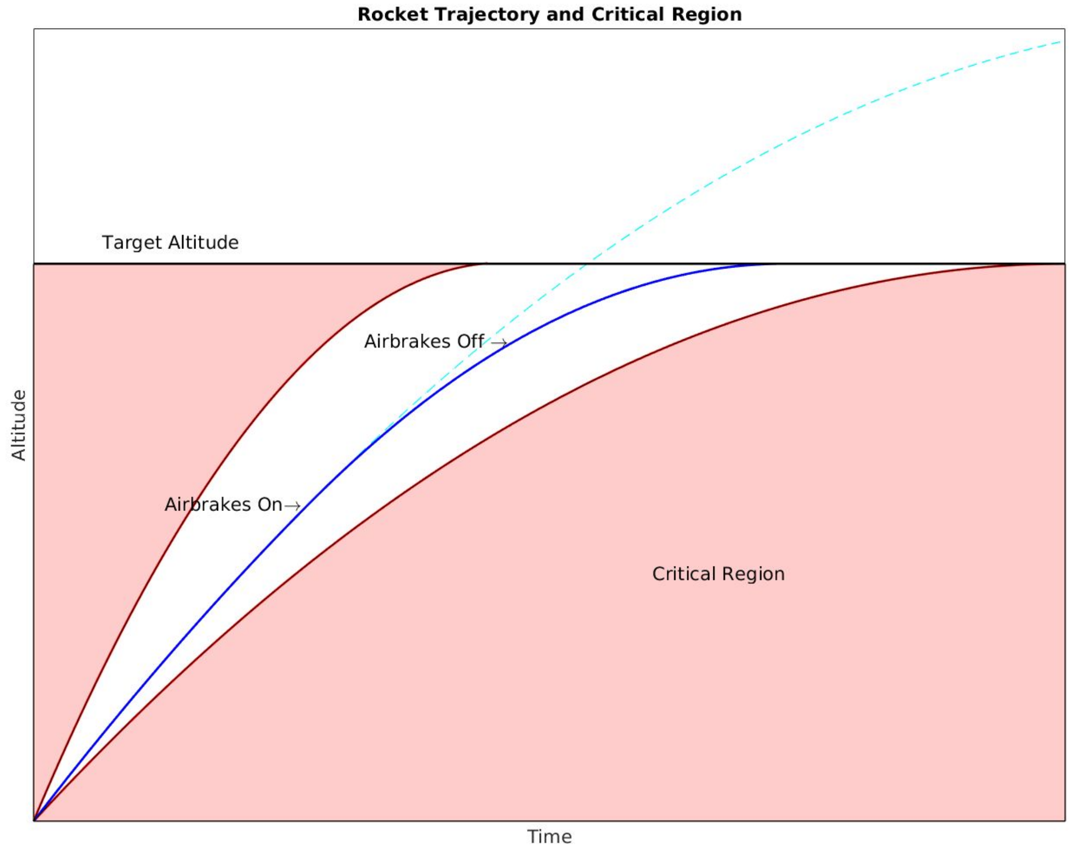


State estimation
Control algorithm
Motor control
High accuracy mode
Descent mode
Off
Apogee correction
APOGEE
Off
Hold
Active
Hold
0 s
2 s
4 s
20 s
25 s
35 s
1-2 min
3000 m
2900 m
700 m
200 m
0 m

# Control

## Algorithm - Flight phases

1. Motor burn
    - High acceleration
    - Unpredictable chemical reaction
    - Maximum dynamic pressure
2. Near Apogee
    - Low velocities
    - Rotations (Pitch/Yaw)

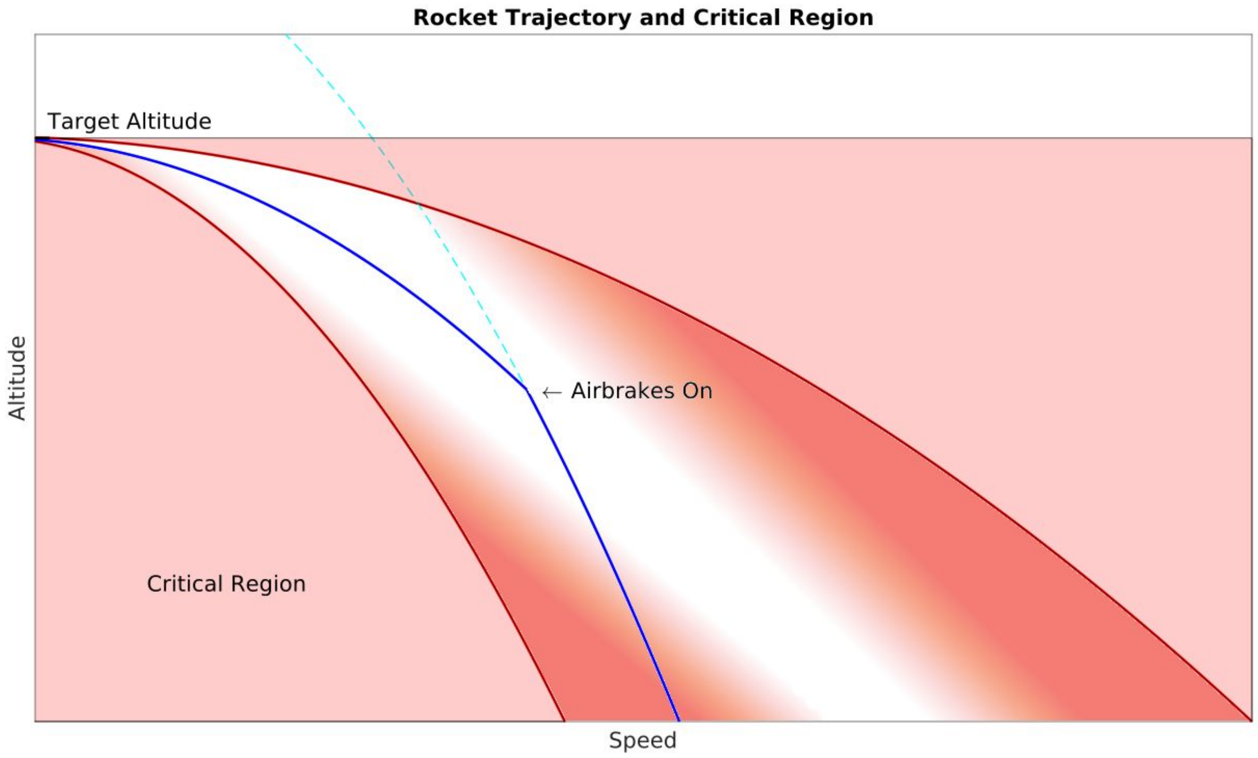



➢ Control during coasting phase directly after burnout

# Control
## Algorithm - Implementation

➢ Control during coasting phase after burnout

1. Parameters
   - Rate of climb
   - Altitude
2. Minimum Risk Optimal Controller
   - Based on simulations
   - Robust to disturbances
   - Simple implementation



# Control
## Risk Assessment: Data processing

| Module | Risk | Solution |
|---|---|---|
| Sensor Fusion | Sensor errors during ascent | Filter can handle IMU/Altimeter dropouts |
| | | 2x IMU from avionics |
| | | Backup from barometers |
| Control | Sensor errors<br>Wrong state estimate | Control disabled in critical cases |
| | | Focus on reliability |

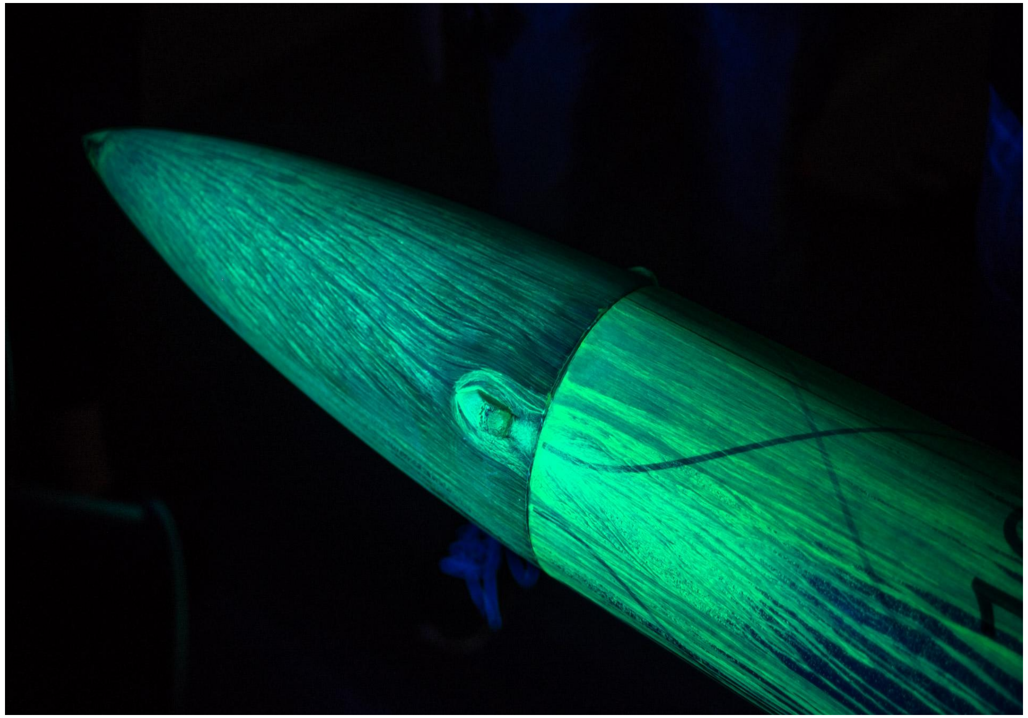
# Control
## Risk Assessment: Hardware

| Module | Risk | Solution |
|---|---|---|
| Control | Overload | Slightly oversized parts to ensure stability |
| | | Finite Element Analysis (FEM) of critical parts |
| | | Load tests on ground |
| | Vibrations (motor, aeroelasticity, …) | Loosening of screws prevented with loctite |
| | | Vibrations tests |

# Control
## Testing

1. Ground tests
   - Motor controller and motor, power supply
   - Mechanics (check smooth motion, apply expected load)
2. Software
   - Assess controller performance in simulated environment
3. Windtunnel test, Sauber, May 2018
   - Compare final air brake system to simulations
4. Launch TELL, IREC 2018
   - Test full air brake system in practice

# Control
## Testing - Wind tunnel tests (Sauber, May 2018)



# Control
## Conclusion

# Back-Up Slide
## Technical details: Motor and Motor Controller

1. Motor: EC45 flat by maxon motors
    - Stall torque: 0.8Nm, 0.2Nm required
    - Stall power: 36W expected, 225W available
    - Actuation time: max 0.1 sec for full in-out
2. Controller: ESCON Module 50/8 HE by maxon motors
    - Can deliver 6A (0.2Nm) indefinitely at 82°C
    - Can deliver 15A(0.5Nm) for short-term

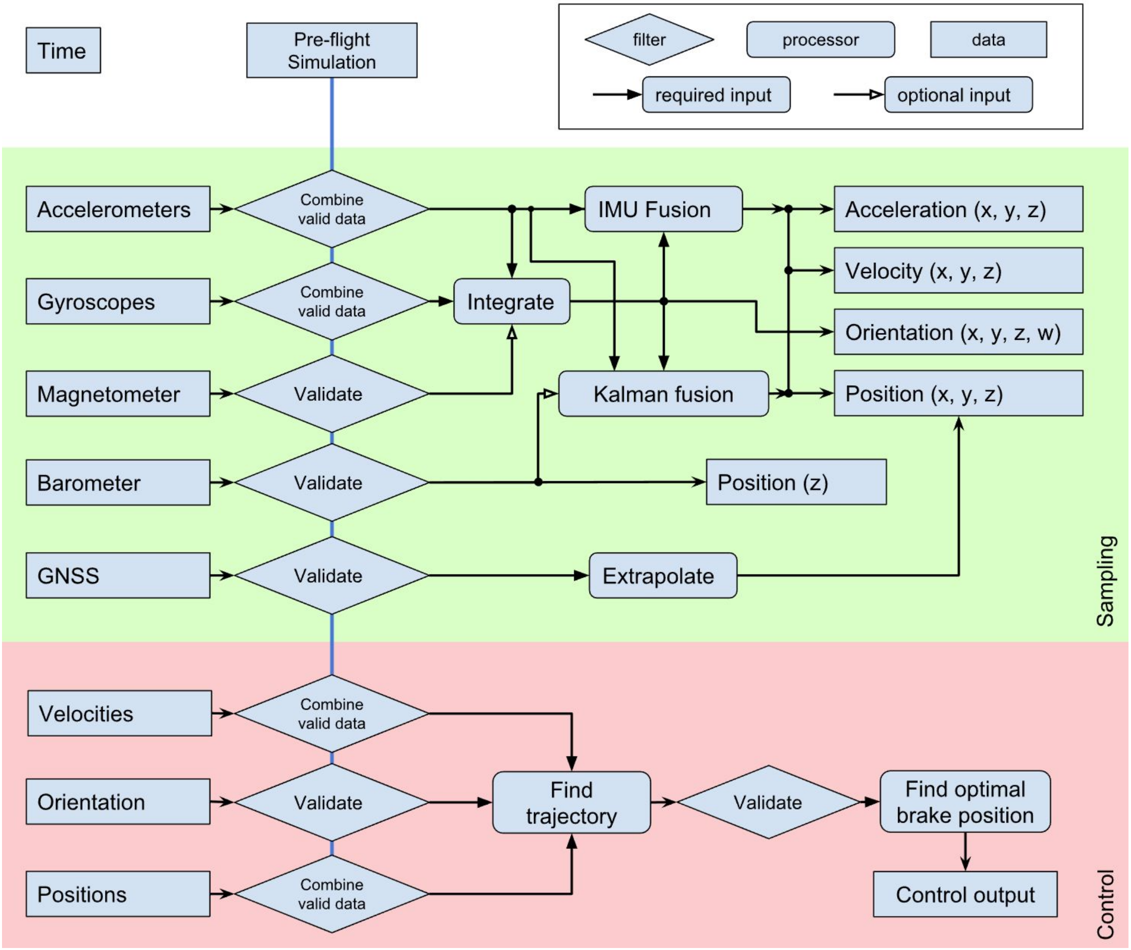
# Back-Up Slide
## Technical details: Linear guides

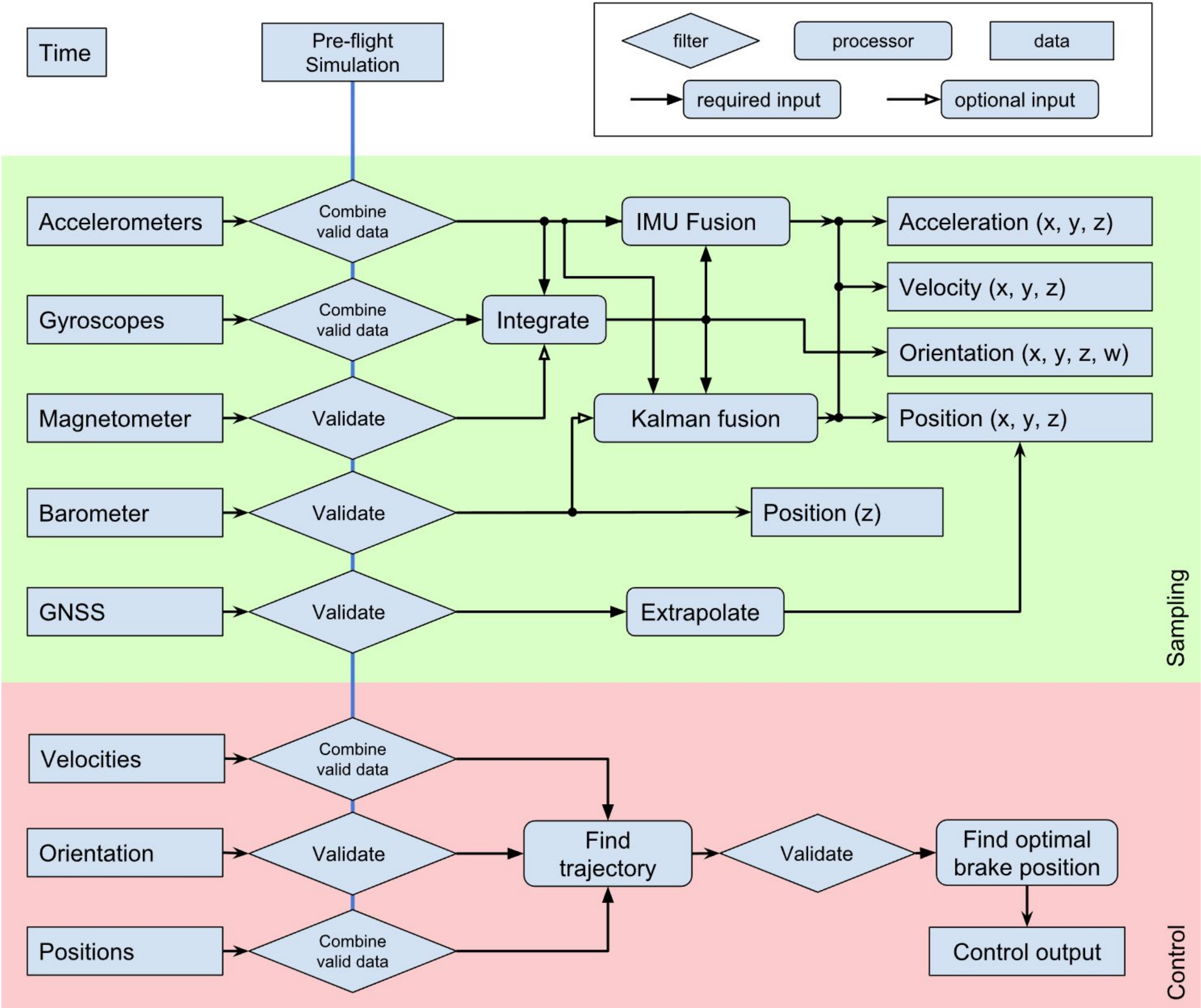
1. Minirail, standard size 9
   - Maximum acceleration: 300 m/s^2
   - Maximum velocity: 5 m/s
   - Friction coefficient $\mu$ = 0.003
   - S_F = 10.1
   - S_M = 2.0

➢ Light, space-saving, extremely robust

# Back-Up Slide
## Technical details: State estimation

1. Ascent
   - Kalman filter (IMU + Pressure)
   - Backup: IMU only
2. Descent
   - GPS




Time
Pre-flight Simulation
filter
processor
data
required input
optional input
Accelerometers
Combine valid data
IMU Fusion
Acceleration (x, y, z)
Velocity (x, y, z)
Gyroscopes
Combine valid data
Integrate
Orientation (x, y, z, w)
Magnetometer
Validate
Kalman fusion
Position (x, y, z)
Barometer
Validate
Position (z)
GNSS
Validate
Extrapolate
Sampling
Velocities
Combine valid data
Orientation
Validate
Find trajectory
Validate
Find optimal brake position
Positions
Combine valid data
Control output
Control

# Back-Up Slide

## Mestral I: Test assembly

1. 2 successful test flights
   - Tested general functionality
   - Tested electronic recovery
2. Now equipped with air brakes
   - Same motor
   - Same motor controller
   - Same linear guides (smaller)
   - Same gears (smaller)