Gyro-based maximum-likelihood thruster fault detection and identification

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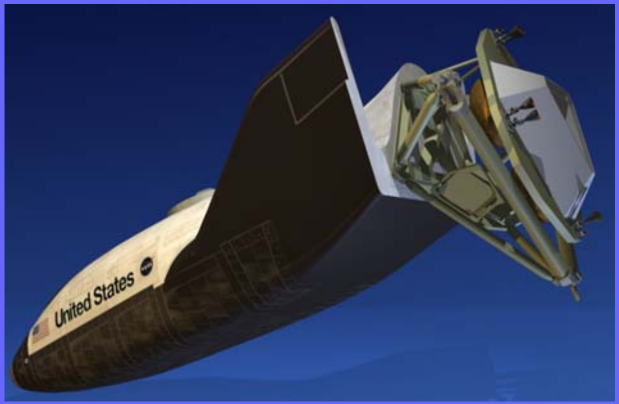
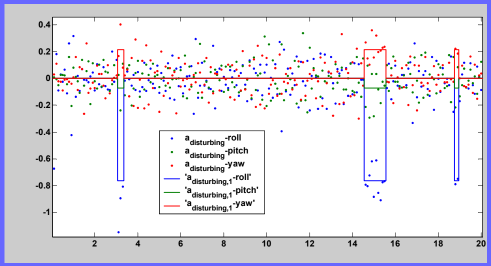
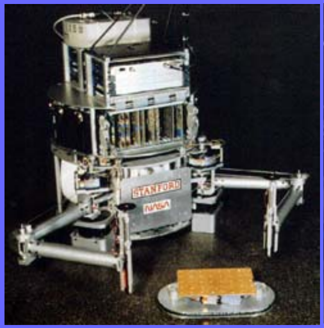
Research objective: For thruster-controlled spacecraft, increase thruster fault tolerance using existing navigation sensors (a software-only solution). Develop and validate through application on realistic simulations and hardware.

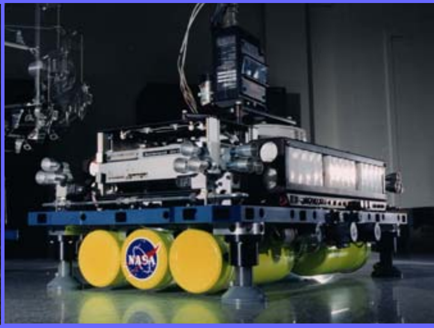


Outline:

- Introduction
- X-38 application
- Maximum-likelihood FDI
- MATLAB Demo
- Conclusions







Introduction

- Spacecraft thrusters – on/off, failure modes
- Sensor-based FDI uses temperature, pressure, electrical sensors – increased mass, cost, complexity
- Motion-based FDI most applicable for small, maneuvering spacecraft (vs. human-rated)
- FDI ➔ R by switching to backup or reconfiguring control
- Compared with existing body of FDI, presence of on/off actuators a problem

- Related research: Deyst and Deckert, 1976, Lee and Brown 1998, Wilson and Rock 1995

X-38 application overview video

X-38 problem definition

- Failure modes:
  - Single- and multiple-jet
  - Abrupt, hard
  - Failed-on or failed-off
  - DPS RCS and Axial
- Sensors: Honeywell ring laser gyros (SIGI)
- Thrusters: Mono-propellant hydrazine, blowdown, RCS (106N), axial (500N)
- FDI:
  - Detect within 5 seconds
  - Limited thruster excitation permitted
- Approach:
  - Test in simulation
  - Generic as possible – applicable to other spacecraft

Thruster FDI approaches taken

- Recursive Least Squares (RLS) – Simultaneously ID all thruster strengths, declare failure when out of spec.
- Targeted RLS – One RLS process running for each thruster.
- Bank of Kalman Filters – One (steady state) KF running for each failure mode, examine residuals.
- Maximum Likelihood – Determine the failure mode whose resulting accelerations most closely match the measured angular accelerations

- Challenge is optimizing response time while maintaining accuracy.
- Difficulties presented by low SNR and biases – exceptionally challenging for X-38, as compared to Mini-AERCam, S4, Stanford Free-Flying Robot

Maximum Likelihood FDI

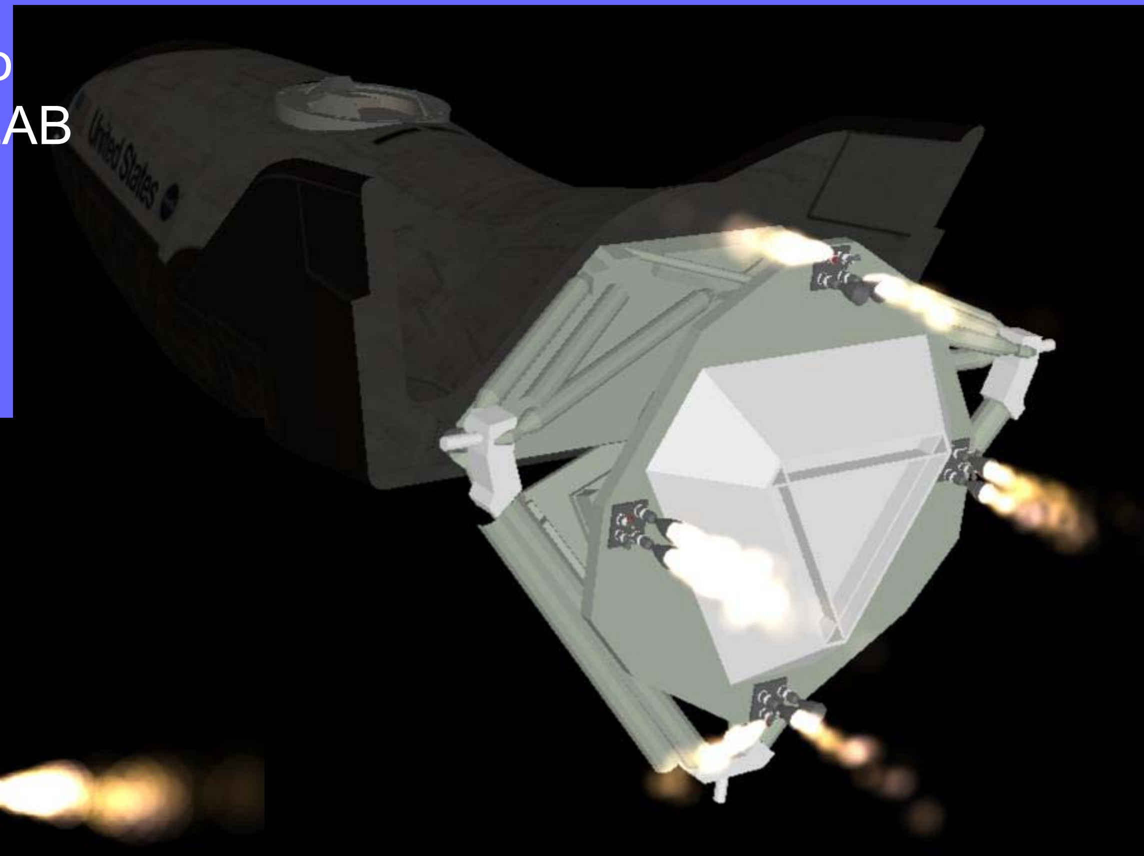
- Algorithm's **core** based on a 1976 paper by Deyst and Deckert on leak detection for the Space Shuttle Orbiter
- Calculates difference between expected and actual angular acceleration
- Compares this "disturbing acceleration" to that corresponding to the possible failure modes
- Due to low SNR and failure modes with similar disturbing accelerations, **filtering and windowing** data required
- Detection based upon generalized likelihood ratio (GLR) test for each failure mode
- Identification based on the likelihood calculation for each failure mode
- Excitation of thrusters required in some cases
- **Logic** to disregard some failures, select correct failure mode

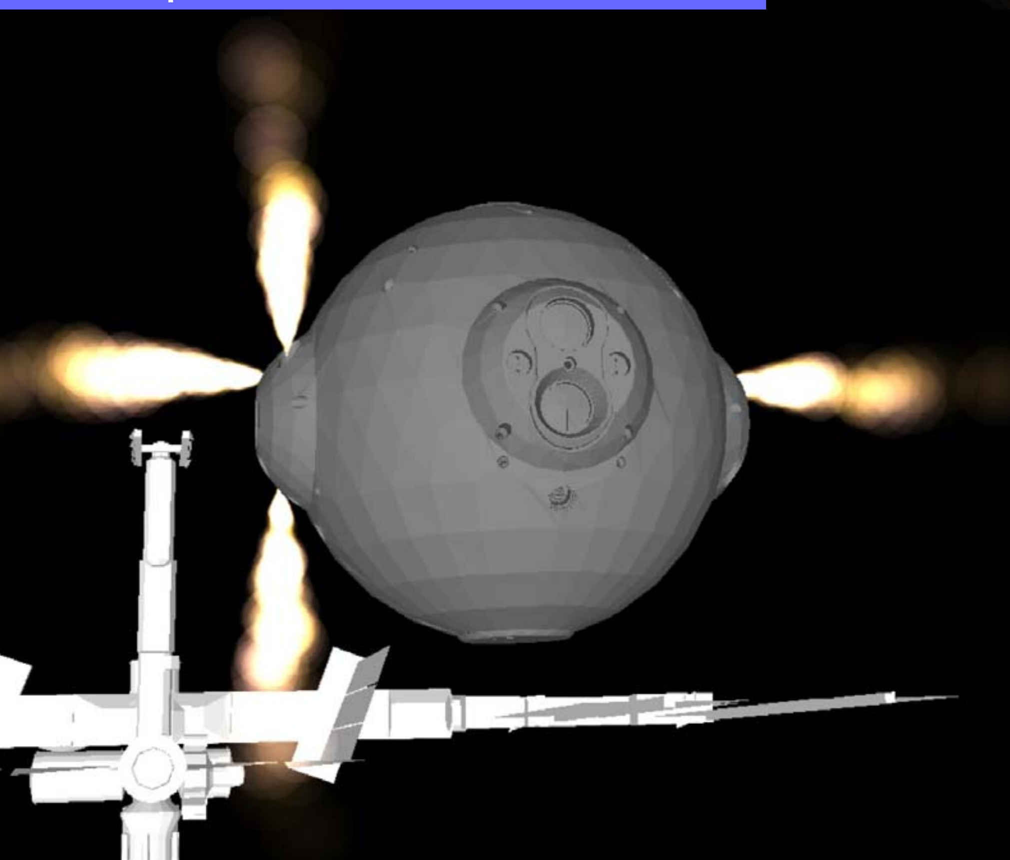
Performance

- Generally detects failure within 1 second (active time) for X-38, faster for Mini-AERCam
- ID follows within 1-5 seconds for X-38 (slower when blowdown multiplier low)
- FDI developed on X-38, then easily “ported” to Mini-AERCam and S4. Significantly easier problem due to better SNR and fewer, less complex failure modes.
- Extended automatic testing run for X-38 – 99.98% accurate FDI (without miss or incorrect ID)
- MATLAB demo

OpenGL visualization linked to MATLAB

- Uses RBNB Data Turbine to communicate between MATLAB and the OpenGL application
- Asynchronous
- Can run on separate computers over network





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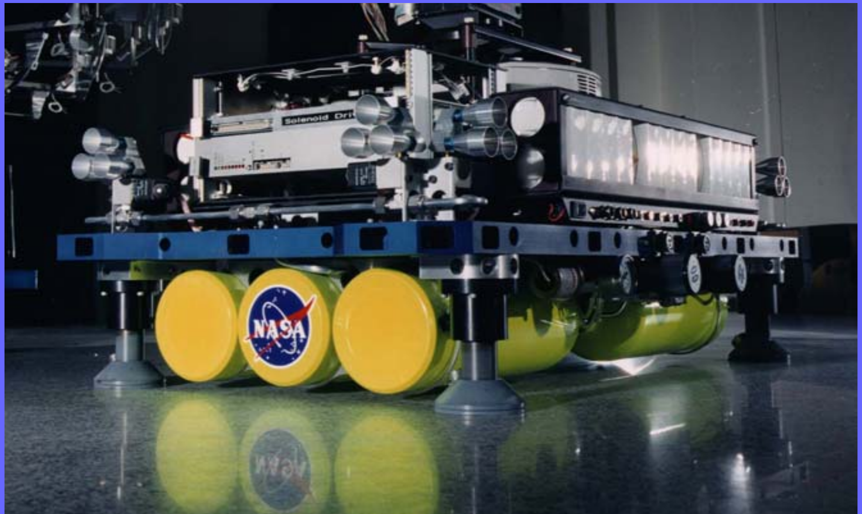
Extensions, continuing work

- Use of translational accelerometers
- On-line mass-property ID
- On-line thruster bias ID
- Integration of on-line ID with FDI
- Implementation on air-bearing vehicle
  - Same MATLAB code runs on X-38 sim, Mini-AERCam sim, S4 sim, S4 hardware
- Standing by for X-38, Mini-AERCam programs



Conclusions

- Maximum-likelihood-based FDI presented for thruster fault detection.
- Allows thruster FDI using (existing) navigational sensors – gyros, accelerometers, etc.
- Generic algorithm applied to 3 vehicles in simulation, 1 in laboratory hardware
- Enables software-only FDI

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