National Aeronautics and Space Administration

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SPACE LAUNCH SYSTEM

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Sensor Data Quality for EM-1: Overview

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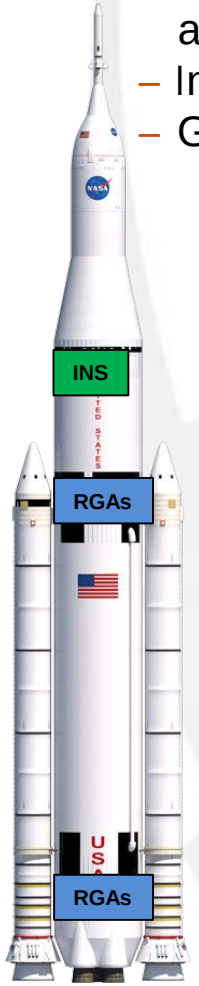
Introduction

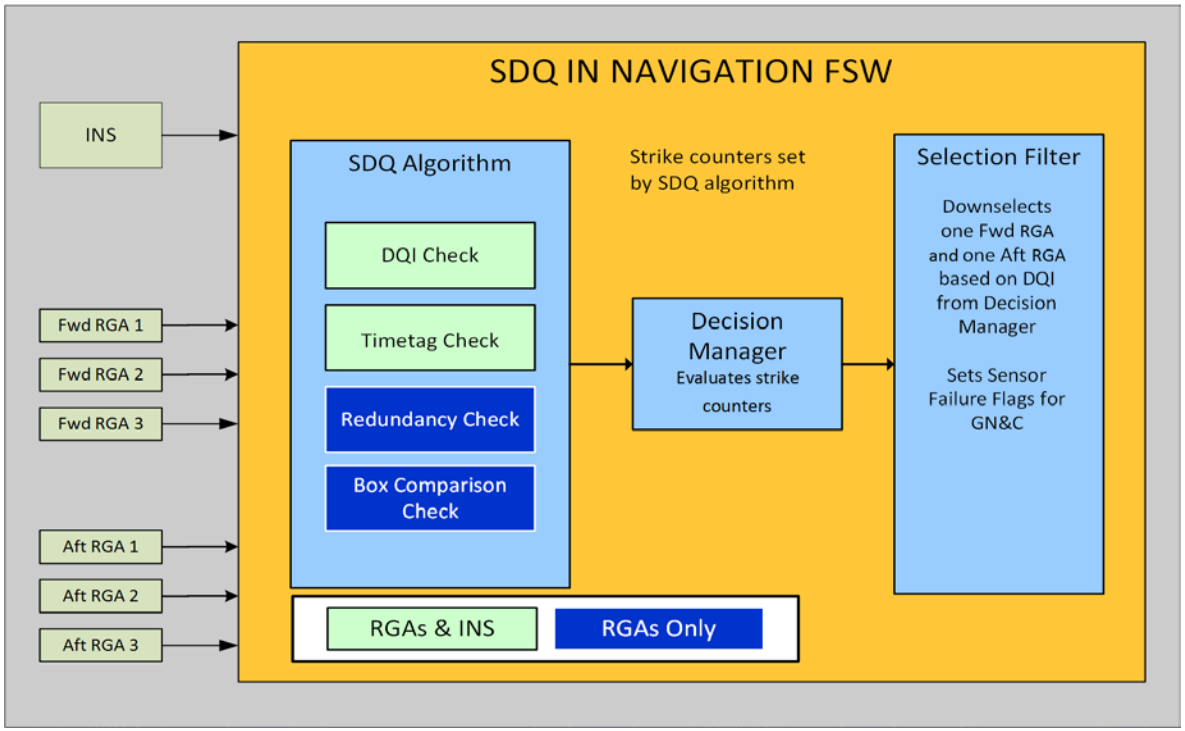
Rate Gyro Assemblies (RGA) provide angular rate data at two (2) locations on the SLS Block-1 vehicle.

- Three (3) sets of redundant angular rate measurements in two (2) orthogonal axes.
- Input axes nominally aligned to vehicle pitch/yaw plane.
- Gyros are co-located and commonly isolated (per location).



Sensor Data Quality (SDQ):

- ***Detects*** failures.
- ***Responds*** to failures.
- ***Consolidates*** redundant sensors.



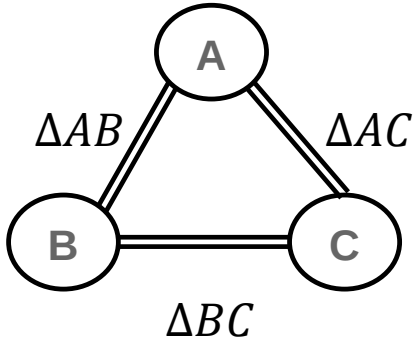
Data Quality & Timetag Checks

- **Data Quality Check (DC):**
  - Input data handlers consolidate:
    - RGA health & status data (vendor ICD)
    - Loss of communications (1553)
    - RGAs labeled VAILD or INVALID.
  - INS uses internal Fault Detection, Isolation, and Recovery (FDIR):
    - (requirement) No performance impacts after failure of a gyro or an accel.
    - Input data handlers set INS INVALID if:
      - Communications bus status (1553)
      - Multiple internal INS failures (loss of INS function)
  - DC check increments strike counter for when INVALID data received from and RGA or the INS.
- **Timetag Check (TC):**
  - Protecting against stale/repeated data in RGAs and INS.
  - Increment strike counters for failed RGA or INS time tags.
  - INS: advance navigation system time (nominally synced to INS time)

Check for hardware-reported errors & time tag errors.

Redundancy Check

- **Co-located & co-aligned & commonly isolated gyros:**
  - Experience same dynamics
  - Differences bounded by error specifications.



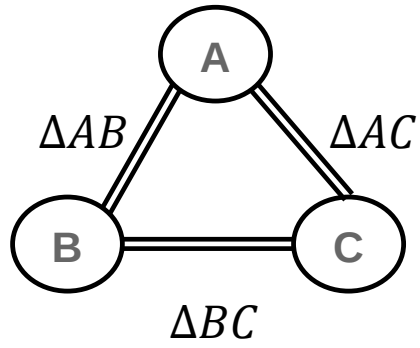
- **Rates are pre-filtered to remove noise content.**

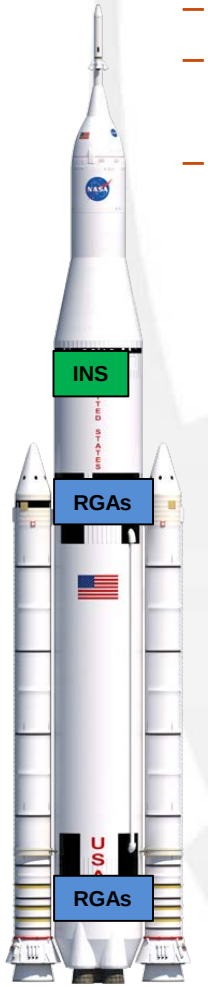
- **Filtered rates *at* each location are differenced (per axis):**
  - Rate deltas are compared to configurable thresholds.
  - If the deltas between a sensor and both neighbors exceed threshold => FAILURE_DETECTED
  - Ex: $\Delta AB > \tau$ AND $\Delta AC > \tau \Rightarrow$ error on sensor A.
  - Strike counters incremented for failed sensor.

Redundant sensors checked for consistency

Box Consistency Check

- **Compare angular rate data from different locations on the vehicle:**
  - INS, Fwd RGAs, Aft RGAs.
  - "Vertical" check supplementing the "horizontal" check in the RC.
  - Uses rates from INS, and the down-selected RGAs rates at each mounting location.





- **Rates are pre-filtered to remove high-frequency & flexible-body dynamics.**

- **Filtered rates *from* each location are differenced (per axis):**
  - Rate deltas are compared to configurable thresholds.
  - If the deltas between a sensor and both neighbors exceed threshold => FAILURE_DETECTED
  - Ex: $\Delta AB > \tau$ AND $\Delta AC > \tau \Rightarrow$ error at location A.
  - Strike counters incremented with failed sensor location.

- **BCC *can detect* error with INS rates. HOWEVER:**
  - Internally redundant INS => assumed "truth"
  - Error detection on INS => BC check disabled for that frame.

Check for consistent rigid body measurements

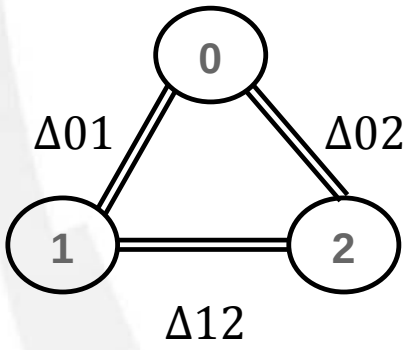
Decision Manager

- **Check for *persistent* errors:**
  - Minimum number of consecutive strikes before reporting failure.
  - Each check has an independent & configurable persistency limit.
- **Check for permanent errors (if enabled):**
  - MAXIMUM number of consecutive strikes before disqualifying a sensor.
  - Each check has an independent & configurable max limit.
- **Recovery Options: Software options allow:**
  - Permanently fail sensor with ANY persistent error.
  - Allow recovery of sensor if no persistent errors for several frames.
- **DM allows for partitioning of fault *detection* and *response*.**

Evaluate strike counters and allow for recovery

Selection Filter

- **Selects ONE RGA per location each computational frame.**
- **Selection logic dependent on number of "healthy" RGAs.**
  - 3 healthy RGAs: Use mean-value selection (MVS) system



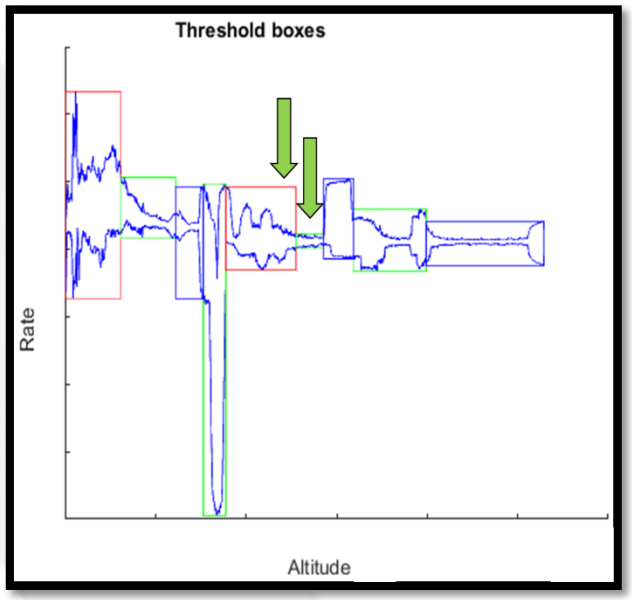
IF	&	IF	SELECT
$\|\Delta_{0,1}\|^2 \leq \|\Delta_{1,2}\|^2$		$\|\Delta_{0,2}\|^2 \leq \|\Delta_{1,2}\|^2$	0
$\|\Delta_{0,1}\|^2 \leq \|\Delta_{0,2}\|^2$		$\|\Delta_{1,2}\|^2 \leq \|\Delta_{0,2}\|^2$	1
$\|\Delta_{0,2}\|^2 \leq \|\Delta_{0,1}\|^2$		$\|\Delta_{1,2}\|^2 \leq \|\Delta_{0,1}\|^2$	2

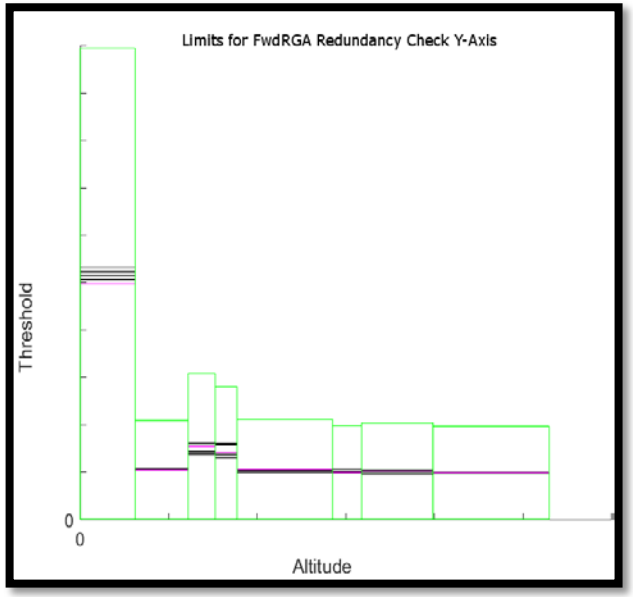
  - 1-2 health RGAs: use pre-determined (software parameter) priority from healthy RGAs.
  - 0 healthy RGAs: use MVS above.
    - Also indicate NO VALID RGA MEASUREMENT flag for Controls (RGA_FAILED).

Consolidate redundant RGA data

Flight Phases and Threshold Determination

- **Capability to use different set of thresholds for various phases of flight**
  - Phases determined using pitch rate as a proxy for predicted dynamics
  - Use navigated altitude as independent variable to chose phase.
- **Zero-margin thresholds: minimum value from Monte-Carlo with NO FAILURES.**
  - Consistent across different vehicle/simulation cases.
  - 0-margin thresholds scaled up to allow for design margin.

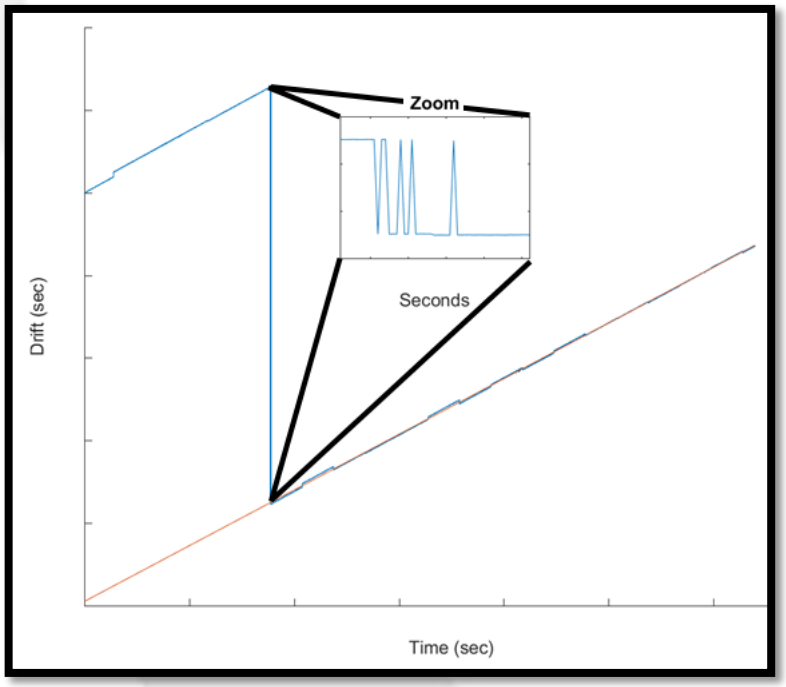


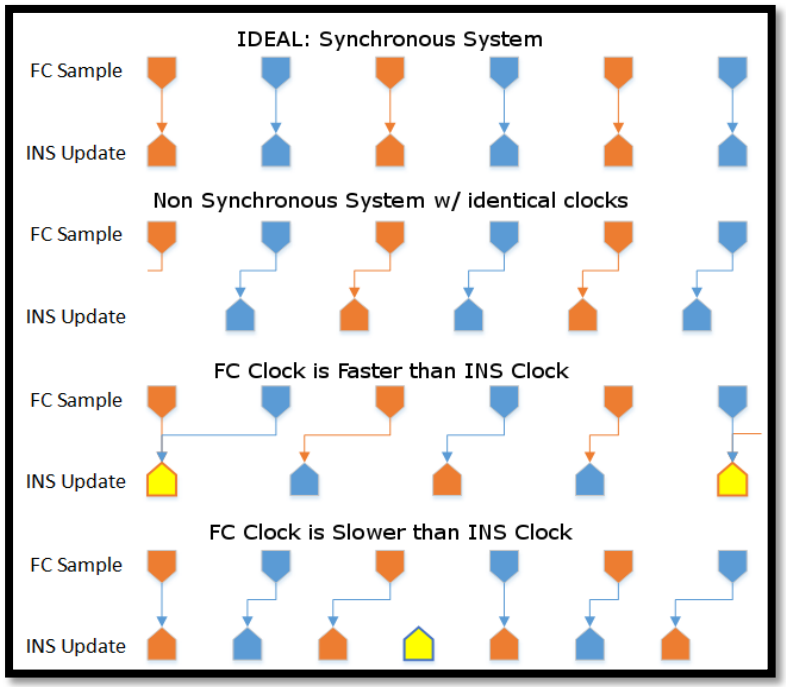


Configurable thresholds in different flight regimes

Lesson Learned: Async. 1553 Timing

- **FCs and INS have independent clocks:**
  - INS received 1553 time broadcast
  - Expect clocks to drift past each other
  - Effects of jitter become apparent as frame boundaries cross
  - *Will* miss or repeat samples.
  - Impacts Timetag Check
    - Large impact for B1B when NAV FSW performs state integration.

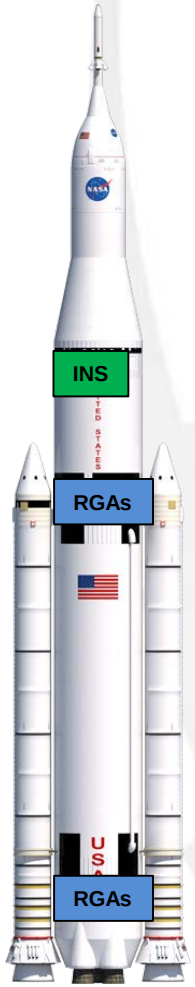


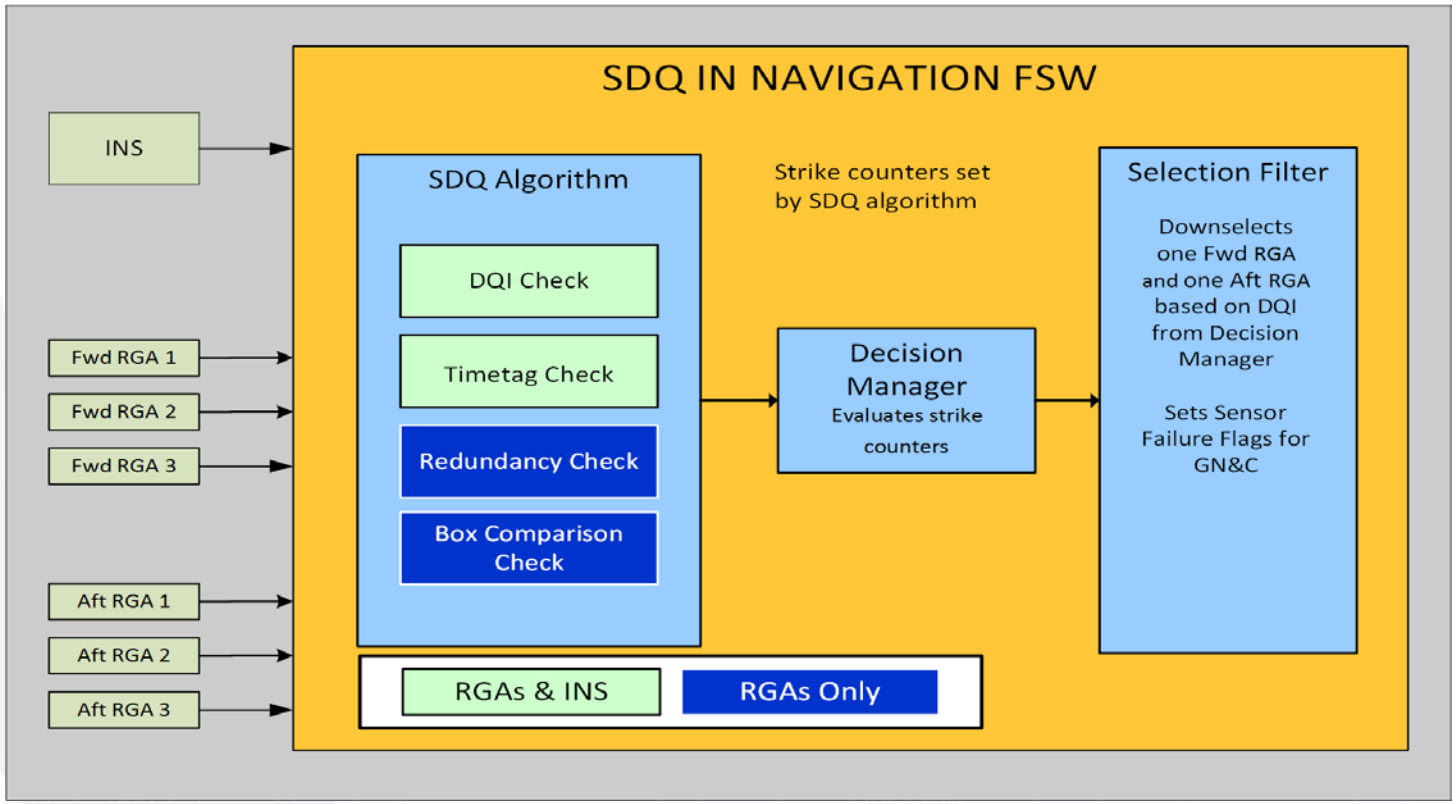


Conclusions

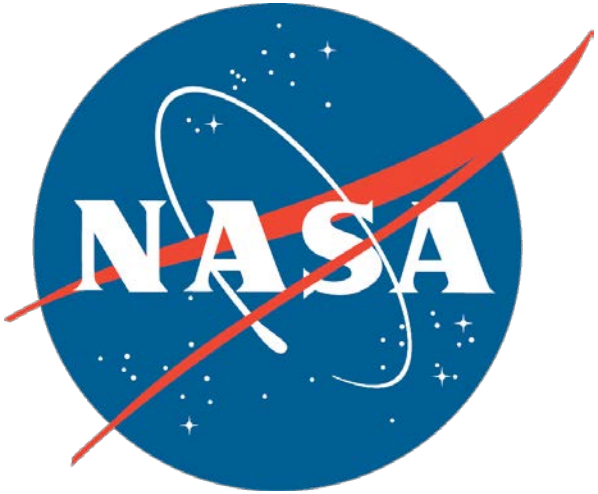
- **For redundant angular rate sensors, SDQ provides the capability to:**
  - ***Detect*** failures.
  - ***Respond*** to failures.
  - ***Consolidate*** redundant sensor data.

  - Configurable parameters usable across varying dynamic regimes.





Thank you!



Any questions?