2 SOPS Anomaly Resolution on an Aging Constellation

30 November 2000
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Introduction

• GPS Constellation Status
  – 19 satellites past contractual mean mission duration (6 years)
  – 15 satellites past design life (7.5 years)
  – 5 satellites past updated mean mission duration
    – 9 1/4 years for Block II
    – 10 3/4 years for Block IIA
    – 7 1/2 years for Block IIR
  – 16 satellites one component away from navigation mission failure
Introduction

- Air Force has no precise methodology for predicting when satellites will fail
- Satellites past their design life are causing anomalies that impact users
- Illustrate difficulties of operating such a constellation
- Highlight the drawbacks of maintaining “launch when failures occur” approach
• Five satellites with only 3 reaction wheels
• Satellites operated in a different mode
• Creates possibility for glint firing during eclipse season
  – Satellite’s Earth sensor misinterprets the sun’s reflection off the Earth’s surface as an attitude error
  – Leads to thruster firings which can perturb the satellite’s orbit
  – Can cause significant ranging errors
SVN 15 and 18 Glint Firings
• Ranging errors
  – Exceeded 6 meters during 48 fifteen minute intervals and 10 meters during 8 fifteen minute intervals
  – Resulting in three dimensional errors of up to 23 meters

• Solution to this problem is modified Jet Control Logic (JCL) cycling
  – Turn off thrusters during eclipse to prevent thruster firing
  – Must maintain contact with the satellite during full eclipse - manning intensive operation
• Problem with its attitude subsystem that requires a different operational mode
  – Requires manual momentum dumps
• Last summer, 2 SOPS found the satellite with both yaw and pitch momentum saturated
  – Caused clock panel to yaw into the sun
  – Rubidium frequency standard heating caused change in frequency drift from negative to positive
  – Difficult for the Kalman filter to model change from positive back to negative
• Modeling problems led to ranging errors
SVN 29 Clock Heating due to Yaw Saturation

Date/Time

Estimate Range Deviations (m)
Satellite was on its last unused frequency standard (a Rubidium) in the summer of 1999

- It had been very stable
- Errors in GPS time transfer performance indicated that something was destabilizing the GPS time scale
- 2 SOPS noticed that SVN 19’s frequency standard had become significantly less stable
- SVN 19 was removed from an estimating partition
- Large number of contingency uploads and frequency steps indicated the problem was getting worse
- Vehicle was set unhealthy because we could not keep errors below tolerance
SVN 19 Rubidium Frequency
Standard End of Life

Date 1999

Estimate Range Deviations (m)

0 20 40 60 80 100 120 140 160 180
8/23 8/24 8/25 8/26 8/27 8/28 8/29 8/30 8/31 9/1
• Rubidium frequency standard never stabilized
• 2 SOPS was forced to resort to a Cesium frequency standard
  – Cs had been turned off in the past for poor service
  – Beam current of 1.8 nanoamps when 2 SOPS operational limit is 2.0 nanoamps
  – Since swapping to this frequency standard, it has been the worst performer in 7 out of 7 months
  – Its beam current is down to 1.39 nanoamps
  – Only a short matter of time before this last frequency standard fails
In late Feb, failure of its Cs frequency standard
- Running off its VCXO, ranging error of 450 meters in 1 1/2 hours
- Satellite taken off the air before errors grew too large
- Cs recovered and satellite monitored for two days before being set healthy to users
- Two weeks later: same failure, except ranging errors grew to 1300 meters within 1 1/2 hours
- Cs recovered again, but judged an integrity-monitoring problem

Satellite had an unused Rb frequency standard
- FS was never stable enough to set operational
• Satellite now in the same situation as SVN 19
  – All frequency standards had been operated and selected as unfit for operational service
  – Only options: Unstable Rb or Cs with a beam current of 0.8 nanoamps
  – Unstable Rb chosen as less risky option
  – Rb operated poorly, but within tolerances for 3 1/2 months
  – Became unstable and satellite was set unhealthy
  – Swapped to Cs FS on August 14, 2000
  – 2 SOPS assessing its performance
• Two days before 2 SOPS switched to SVN 16’s last Rubidium, SVN 14 experienced its second reaction wheel failure
  – SVN 14 could no longer point at Earth
  – Anomaly occurred when Ascension monitor station was unavailable due to a comm failure
    – Situation was not recognized until hours later
  – SVN 14 never recovered attitude pointing capability
Simultaneous Anomalies

- Both SVN 14 and 16 off the air and in view at the same time
  - Caused coverage problems and Dilution of Precision (DOP) spikes over the US and Kashmir
  - Coverage loss (lack of 4 satellites in view)
    - Oklahoma, Kansas, Nebraska and northern Texas lasting up to 18 minutes
  - DOP spikes as high at 888 (lasting < 1 minute)
    - Over the areas mentioned above and Nevada, Utah, Arizona, New Mexico and Colorado
• Solution: get 14 and 16 on the air or move another satellite to fill the gap
  – SVN 14 never usable, spun-up and boosted
  – 16’s Rubidium still warming up
  – Aerospace Corporation analysis concluded SVN 19 could most quickly fill the gap without negatively impacting other users
  – SVN 19 on borrowed time
  – SVN 44 launched to fill this gap (healthy Aug 00)
Conclusion

• Anomalies caused by aging are creating large ranging errors, impacting users
• 2 SOPS was able to prevent most of these anomalies from severely impacting users
  – Depends on the availability of Ground Antennas (92% vis) and Monitor Stations (88% vis)
• Errors combined with poorly performing satellites, increased ground and satellite outages, and poor geometry can cause large navigation and time transfer errors
Conclusion

- The Air Force is addressing GPS sustainment policy
  - Consider replacing satellites before they fail and become an operational risk to users
  - The world’s increasing dependence on GPS should increase our aversion to risk
- 60 day call-up may not be enough
- Risk may seem small, but it is important to address even a low level of risk