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5.7 SPACECRAFT INDUCED ERROR SOURCES*

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I'm going to say a few words about spacecraft induced error sources, basically attitude errors on the Landsat spacecraft, the 1, 2, 3 and D, and ephemeris errors from various tracking systems.

First, I want to talk about the attitude control system and attitude measurement system on Landsat-2 (actually 1, 2, and 3 as they are basically the same). Table I reviews the kind of attitude information we had to work with on those three spacecraft. The attitude control system uses horizon scanners and gyros to solve for pitch and roll directly, and once those are brought in, there is a gyro in the roll/yaw plane; knowing the roll and the rate from that gyro, you can solve for yaw and bring the yaw error in.

TABLE I

Landsat-2 Attitude Control and Measurement

- Attutude Control System (ACS)
  - Horizon scanners and gyros provide pitch and roll error sensing
  - Rate Measurement Package (RMP) in roll/yaw plane used to determine yaw error
  - Pointing Control = 0.1 deg
  - Pointing Stability = 0.01 deg/s
- Attitude Measurement Sensors (AMS)
  - Independent of ACS
  - Horizon scanners fore and aft determine pitch and roll
  - Yaw assumed proportional to roll
  - Measurement accuracy = 0.1 deg
  - Horizon scanners susceptible to atmospheric effects (e.g., cold clouds)

The specification on the platform is a pointing control of $.1^{\circ}$ and stability of $.01^{\circ}$ per second. Now on that spacecraft the measurement system or what we actually know about the attitude is independent of the control system. We have infrared horizon scanners for pitch and roll. There's nothing though that gives us the yaw error so we assume it's proportional to roll. Basically because of the way the control system solves for yaw, we have the same specification there of $.1^{\circ}$.

What people are really seeing is quite a bit worse because the infrared horizon scanners are susceptible to cold clouds etc. Depending on who you listen to, $.5^{\circ}$ is not unusual -- even possibly 1°. I've heard numbers like that. On the last slide, I'll translate all these numbers into what an image error would be from that type of attitude error.

*Edited oral presentation.

Table II reviews the situation on Landsat-D. It is the same as the previous Landsats for course acquisition and there's a fine sun sensor that's used for transition and the nominal mode is star trackers and gyros. Star trackers and the gyro information are filtered to update quaternians and actually the star trackers are used to update the gyro drift. We have a much improved system here, as we have pointing accuracy advertised as .01° and very good stability. and from talking to different people, that's the specification and it seems to be that it will be achievable. In fact, we may do quite a bit better than that by a factor of 2 or something. On Landsat-D, the attitude measurements come from the control system Kalman filter and the DRIRU.

TABLE II

Landsat-D Attitude Control and Measurement

- Same as Landsat-2 for coarse acquisition
- Fine sun sensor used for transition to fine acquisition
- 2 star trackers and 6 gyros (3-axis redundant) used to update quaternians
- Pointing accuracty = .01 deg
- Pointing stability = 10^{-6} deg/s
- Attitude measurements from control system Kalman filter and DRIRU
    - Quaternians every 4.096 s
    - Gyro measurements every 64 ms

Table IIIa reviews the ephemeris. I'm not contrasting Landsat 1, 2, and 3 against D because basically they're the same class of spacecraft. It depends on what type of data you have to work with for ephemeris error. Now some of these numbers you've already seen from the GE people, in fact some of these numbers come off GE's slides. The altitude variation is due to earth oblateness and variations in eccentricity etc. Along-track variation is not by itself too important because the spacecraft is basically following the same ground path. Dr. Prakash said four kilometers cross-track; I got 5 kilometers from the people who are responsible for the orbit control. That's probably the most important number there. If Mr. Billingsly was talking about relief displacement, that's the kind of number we would be looking at for relief displacement, if you were 5 kilometers off on your look angle there.

With conventional processing, and operational processing of the Goddard network and standard network, we generally can get around 100 meters in ephemeris error. This is definitive, as you get 24 hours of data and do a least squares fit to orbit or doppler data and do a batch fit or sequential filter. You can characterize errors pretty reliably and usually find 100 meters or better. Orbit predicts (a second method) generally represent what is uplinked to the spacecraft. They claim these are 2-day predicts; I would think they would be more like 1-day predict numbers. Five-hundred meters after 2 days is doing pretty good; I would say 1 day or somewhere in there. All of these numbers are 1-sigma numbers and it depends on who you talk to and what your assumptions are.

Table IIIb looks at tracking systems of the future. On Landsat D, using TDRSS data and from simulations and error analysis, we find out we can do about the same that we do now—processing 24 hours of TDRSS data may get you 90 meters,

TABLE IIIa

Landsat-D Orbit Variations and Ephemeris Accuracy

- Variations from nominal
  - Altitude (705.3 km nominal)
    - 696 to 741 km over earth
    - 19 km variation over fixed latitude
  - Along track: $\pm$ 95 km
  - Cross track: $\pm$ 5 km at equator
  - Inclination: 98.21 $\pm$ .045 deg

- Conventional Processing Ephemeris Error (GSTDN Data)

	Operational Post Processing	Orbit Predicts
Along track	100 m	500 m
Cross track	30	100
Radial	20	35
RSS	105	510

you might do slightly better generally, but it's about the same measures as using the ground tracking. The really good news is the GPS, the Global Positioning System, which is a system of DOD satellites and navigational development satellites, which will significantly reduce ephemeris errors. As a result, the combined attitude and ephemeris errors, as shown in Table IV, are expected to experience better than an order of magnitude improvement over the previous Landsats.

TABLE IIIb

Landsat-D Ephemeris Accuracy (cont.)

- Ephemeris Error with TDRSS

	Definitive Orbits
Along track	80 m
Cross track	30
Radial	25
RSS	90

- Ephemeris Error with GPS

	4 nds. Inview	Poor Visibility
Along track	10 m	50 m
Cross track	6	25
Radial	4	20
RSS	12	60

TABLE IV

Attitude/Ephemeris Scene Distortions

Along/Cross-Track Error (MET)

Distortion Source	Landsat-2 AMS GSTDN Tracking	Landsat-D ACS GPS
ATTITUDE		
Pitch	1570/-	123/-
Roll	- /1585	- /125
Yaw	160 / -	124 / 125
EPHEMERIS		
Along Track	100 / -	10 / -
Cross Track	- / 30	- / 6
Radial	- / 3	- / -
RSS	100 / 30	10 / 6