Chasing Snoopy’s Tail

Roger Twank

January, 2020

Introduction

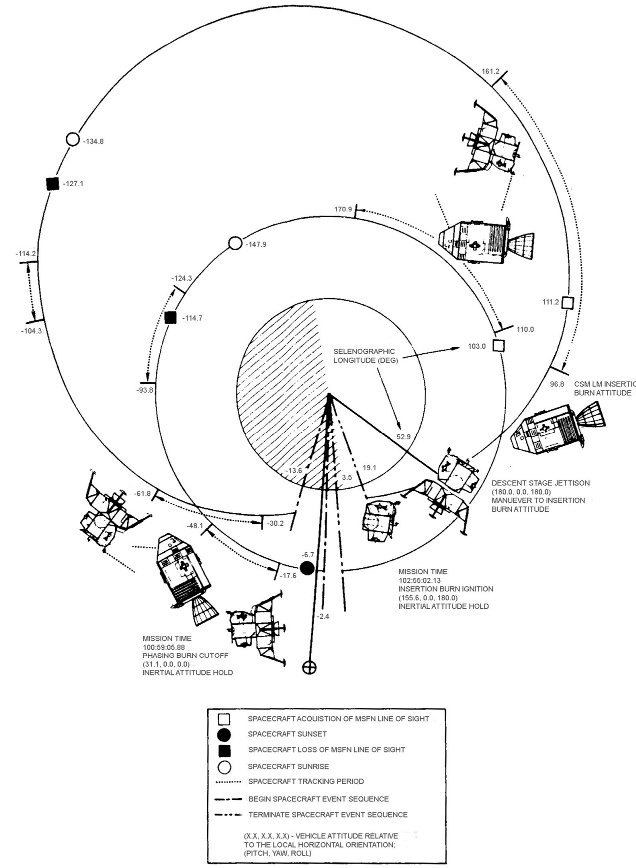
- Apollo 10 jettisoned it’s Lunar Module descent stage into an elliptic, low-inclination lunar orbit in May, 1969
- It is widely assumed that this orbit was unstable, and that the stage impacted the moon soon after it was jettisoned
- Simulations indicate that the orbit is actually quasi-stable, and that the stage might still be in orbit today

July 2021 Update: A paper on this topic has been accepted for publication in the Planetary and Space Science Journal

https://authors.elsevier.com/a/1dOk-7IbIsytQ

About the Phasing Orbit

- In order to run a lunar Descent Orbit Insertion (DOI) followed after one orbit by an Ascent Orbit Insertion (AOI), with no intervening landing, it was necessary to perform a unique (to Apollo missions) "Phasing" maneuver
- The Phasing maneuver raised the LM apolune to 190.1 n.m. (352 km) allowing the CSM to overtake the LM
- The LM Descent Stage was jettisoned into this "Phasing" orbit…12.1 by 190.1 n.m (22.4 by 352 km*)



*See Mission Report Table 6-IV

https://history.nasa.gov/afj/ap10fj/pics/phasing-insertion.jpg

Phasing Orbit State

The Apollo 10 Mission Report list three states representing the phasing orbit

- Cutoff of the Phasing maneuver
- Staging
- Ignition of the Ascent Orbit Insertion maneuver

These are all essentially part of the same arc, with small perturbations during staging

TABLE 6-II.– TRAJECTORY PARAMETERS

Event	Ref. body	Time, hr:min:sec	Latitude, deg	Longitude, deg	Altitude, miles	Space-fixed velocity, ft/sec	Space-fixed flight-path angle, deg	Space-fixed heading angle, deg E of N
Phasing maneuver								
Ignition	Moon	100:58:25.9	0.22S	11.19W	17.7	5 512.4	1.19	-91.09
Cutoff	Moon	100:59:05.9	0.34S	13.67W	19.0	5 672.9	1.88	-91.05
Staging	Moon	102:45:16.9	0.82N	51.23E	31.4	5 605.6	-3.06	-90.75
Ascent orbit insertion								
Ignition	Moon	102:55:02.1	0.30N	19.58E	11.6	5 705.2	-0.78	-91.06
Cutoff	Moon	102:55:17.6	0.29N	18.72E	11.7	5 520.6	0.49	-91.06

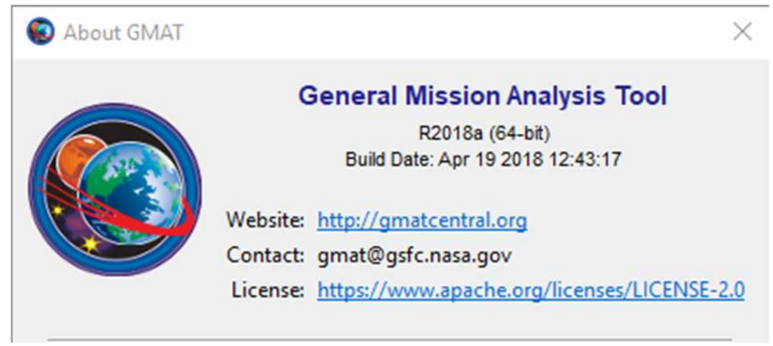
https://www.hq.nasa.gov/alsj/a410/A10_MissionReport.pdf

Time Conversions

- Using a spreadsheet one can convert Mission Elapsed Times to UTC

	Mission Elapsed Time	UTC
Launch	0:00:00.00	5/18/1969 16:49:00.00
Phasing Burn end	100:59:05.90	5/22/1969 21:48:05.90
Staging	102:45:16.90	5/22/1969 23:34:16.90
AOI Burn start	102:55:02.10	5/22/1969 23:44:02.10

Simulation Environment

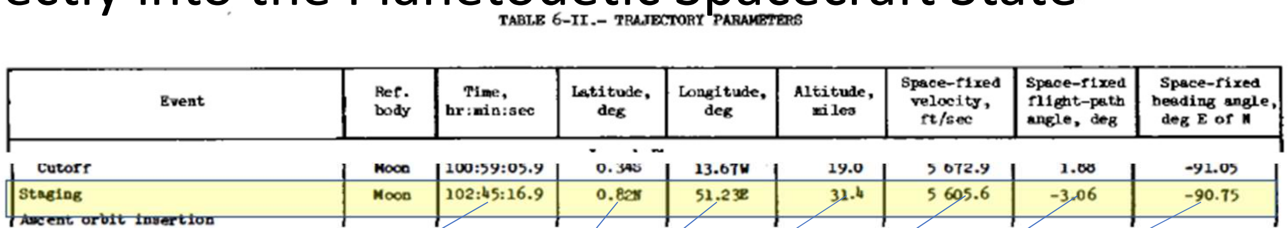


- Using GMAT R2018a
- GRAIL gravity model:
  - jggrx_0420a_sha.tab
- Some customization of output and other paths may be required for your setup

https://pds-geosciences.wustl.edu/grail/grail-l-lgrs-5-rdr-v1/grail_1001/shadr/jggrx_0420a_sha.tab

Entering Mission Report Values into GMAT

- Using LunaFixed Coordinates, one can plug in values from Mission Report table 6-II directly into the Planetodetic Spacecraft State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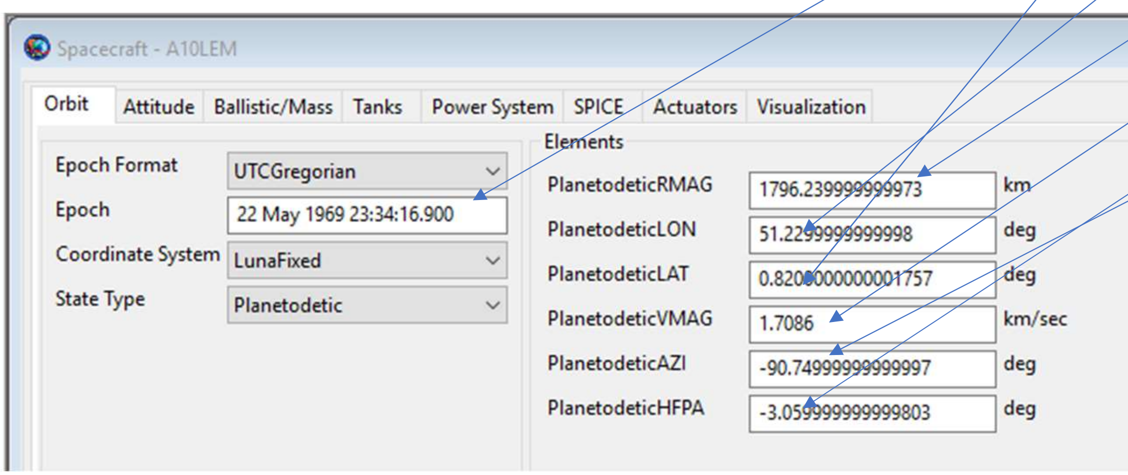
Ascent orbit insertion								



See next page for notes and caveats!!

Converting Table 6-II values to GMAT

RMAG: Apollo-era lunar radius was 1738.09 km

- Convert nautical mile altitude to km, and add to 1738.09
- 31.4 n.m. becomes 1796.24 km

Planetodetic VMAG is not the same as Inertial VMAG

- Table 6-II velocity (ft/sec) does not directly translate to LunaFixed coordinates
- In the GUI change to SphericalAZFPA coordinates, then change to MoonInertial coordinate frame, and enter VMAG…1.7086 km/secs
- Change back to MoonInertial/Planetodetic, and GMAT converts VMAG to the value for that frame…1.7133 km/sec*

HFPA and AZI also differ slightly between fixed and inertial coordinates

- Very small difference at low inclination…I am ignoring it

* There are better ways to do this in a script, but this works to get you started

Perturbations during Staging

- Famously, there were unplanned attitude changes during the staging maneuver.
- The plan was to accelerate 2 ft/sec, jettison the stage, then slow down 2 ft/sec, pushing the stage forward and higher. (The retrograde AOI burn was performed 10 minutes later.)
- Telemetry indicates that the stage was actually pushed ~vertically, but the exact direction is not known.
- A change of 2 ft/sec vertically out of 5600 ft/sec represents a change in the Flight Path Angle of ~0.02 degrees. I am ignoring it.

See Robin Wheeler's excellent Staging Video and graphic:
https://history.nasa.gov/afj/ap10fj/video/staging-with-audio.mp4
https://history.nasa.gov/afj/ap10fj/pics/staging-cartoon-2.png

Automatic GMAT Scripting

- Daniel Estevez has posted python code demonstrating how to run GMAT automatically with sequences of parameters
- I have modified the code for my runs
- For the Monte Carlo run, I generated a large table of orbit state parameters with broad variation…enough to cover any uncertaintly in the values in Table 6-II
  - For each parameter set, I ran a one-orbit simulation to check the apolune and perilune*
  - I eliminated any set that resulted in apo/peri values that differed from table 6-IV by more that +/- 20%
  - Only ~30% of the initial parameter sets passed this apo/peri screen

https://destevez.net/2019/08/trying-to-find-the-dslwp-b-crash-site/

*Dumb way to do it, I know, but when you have a hammer, every problem looks like a nail

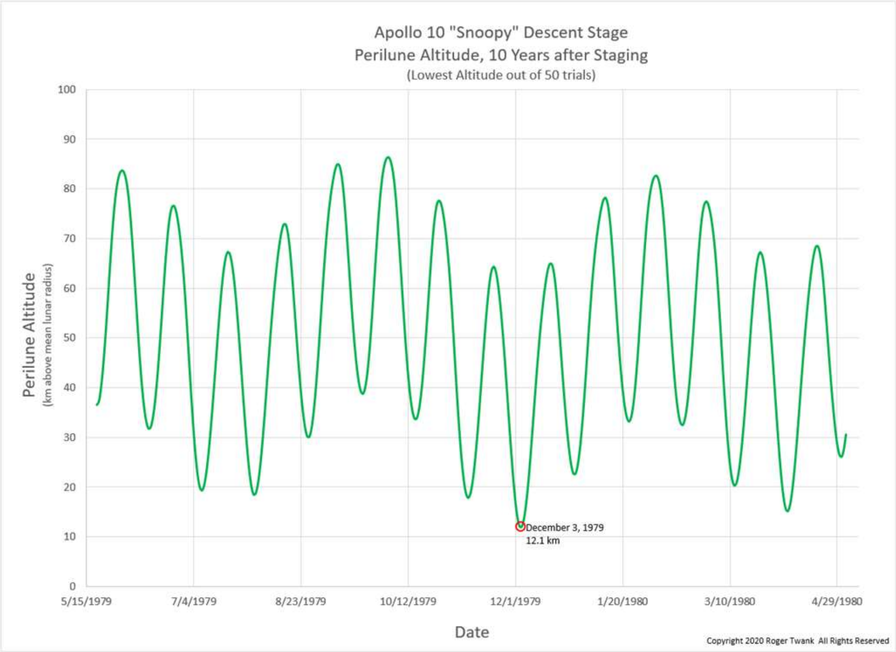
Generating A Monte Carlo Parameter Set

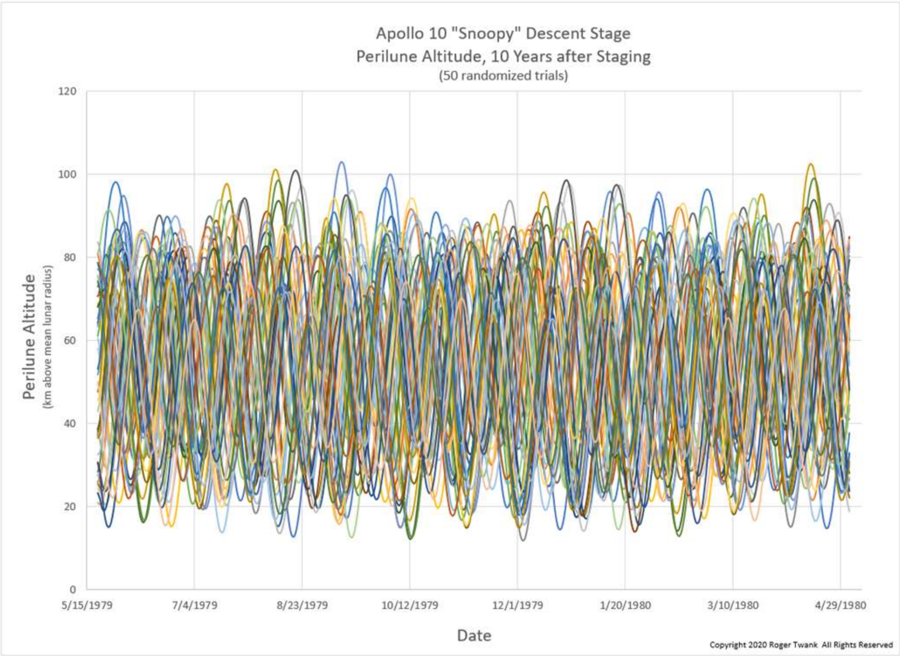
Parameter	Trial	RMAG	Longitude	Latitude	VMAG	AZI	HFPA				
Tweaked		57.68	52.01	0.82	1.7106	-90.73	-3.00				
MAX		65.00	54	0.95	1.7300	-90	-2.50				
Min		50	50	0.69	1.6900	-91.5	-3.50			**Nominal**	**Nominal**
Delta		15.00	4.00	0.26	0.04	1.50	1.00	Apolun	Perilun	**22**	**35**
	2	1790.212	52.01993	0.856048	1.707498	-91.46026	-2.781384	307.86	18.77	0.838	0.874
	4	1799.463	51.42704	0.880245	1.697021	-90.3695	-2.981621	295.72	19.79	0.884	0.840
	5	1797.177	50.35281	0.920862	1.710414	-90.31501	-2.887504	346.61	26.35	1.176	0.984
	6	1788.971	50.85838	0.813243	1.710353	-91.12977	-2.703757	315.10	20.24	0.903	0.895
	7	1797.242	51.86682	0.698828	1.710523	-91.21338	-3.026656	350.24	23.62	1.054	0.995
	8	1792.543	53.56113	0.935391	1.717845	-91.06805	-2.962264	367.76	22.57	1.008	1.044
	9	1791.279	50.43389	0.804623	1.726977	-91.21315	-3.06018	410.01	22.69	1.013	1.164
	10	1802.77	52.53268	0.890792	1.699737	-91.40102	-3.074774	320.37	23.55	1.051	0.910
	13	1801.024	52.51728	0.703791	1.704662	-91.1279	-3.160155	338.73	22.31	0.996	0.962
	19	1790.123	50.73203	0.772892	1.713109	-90.85354	-2.511693	328.13	26.46	1.181	0.932

This shows the first few sets that passed the apo/peri screen

Other Python Code

- There is a script to consolidate all the result csv files and capture one perilune point per day*
- It allows me to consolidate everything into a spreadsheet so I can play with the resulting data and plot it





*It crops the minimum values a bit, I know

Conclusion

- Have fun!
- Let me know if you find major errors!!!!
- If your results agree with mine, please help me to convince NASA that Snoopy may still be out there, and it's worth 8 hours of radar time at Goldstone to try to find this artifact!
- There is more info on my blog: https://snoopy.rogertwank.net/

-@RogerTwank

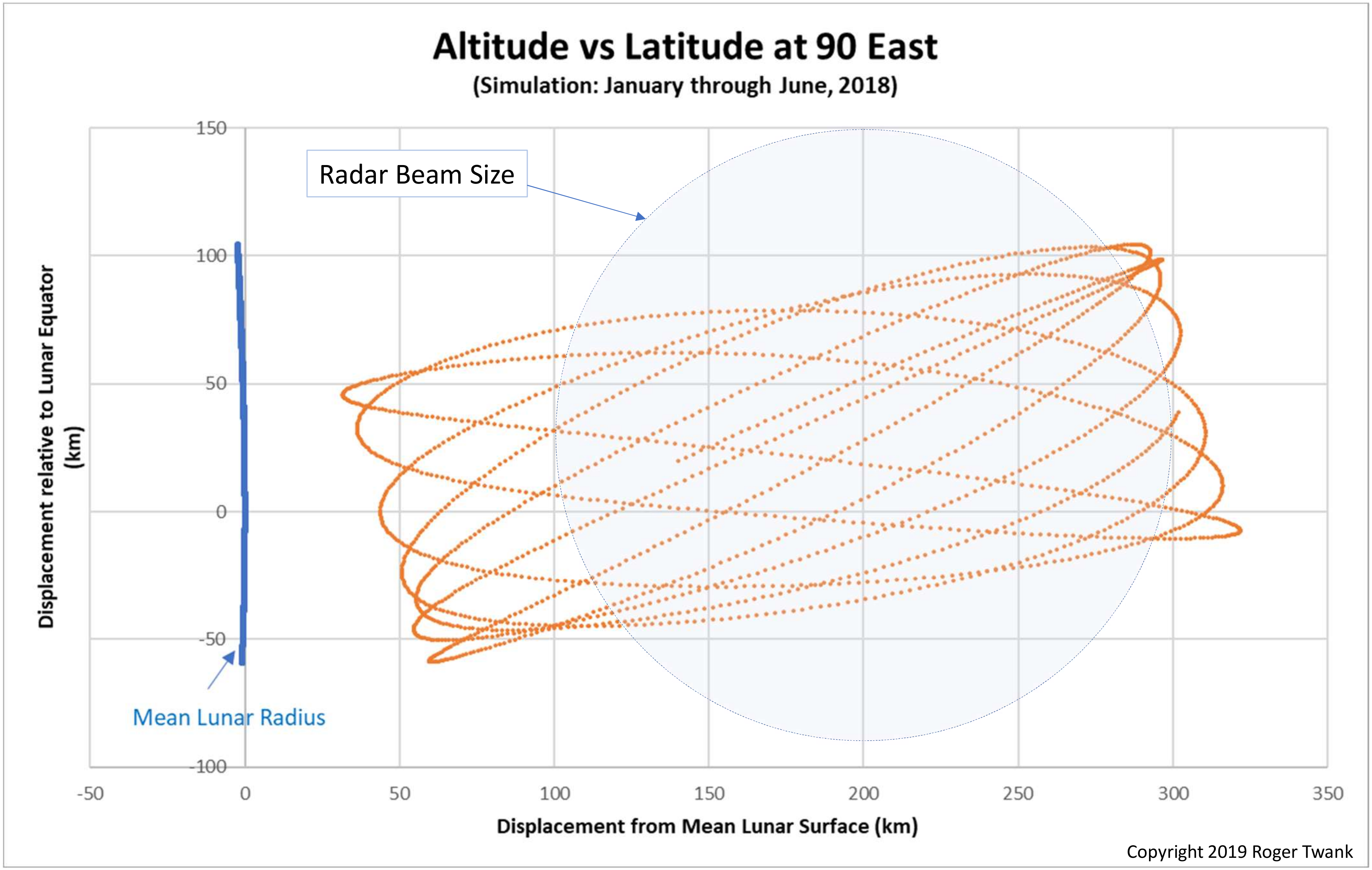
102:45:58 Armstrong (onboard): Engine arm is off. Houston, Tr
Base here. The Eagle has landed.

102:46:06 Duke: Roger, Twank...Tranquility. We copy you on th
You got a bunch of guys about to turn blue. We're breathing aga
lot

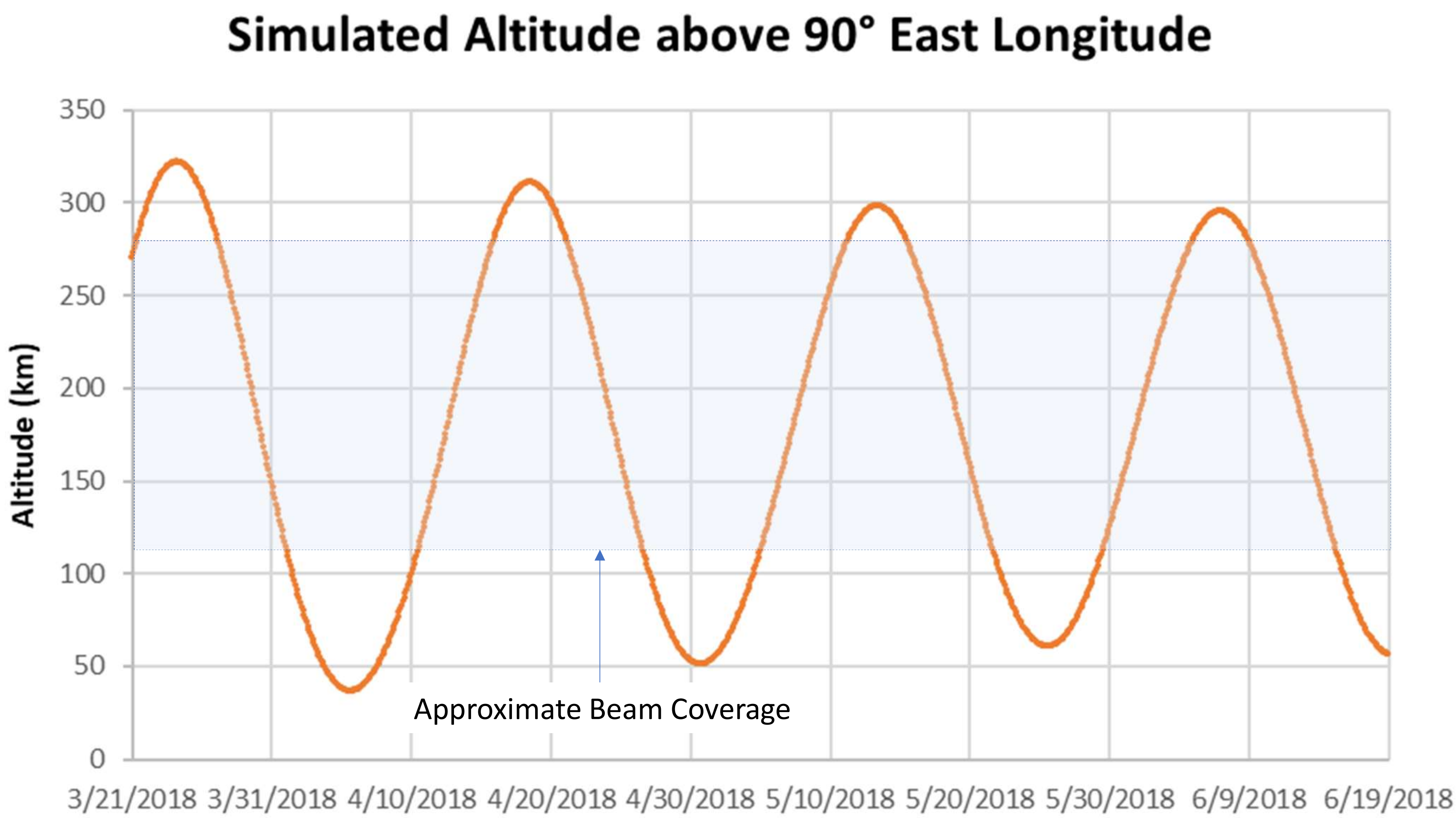
Backup

Radar Tracking

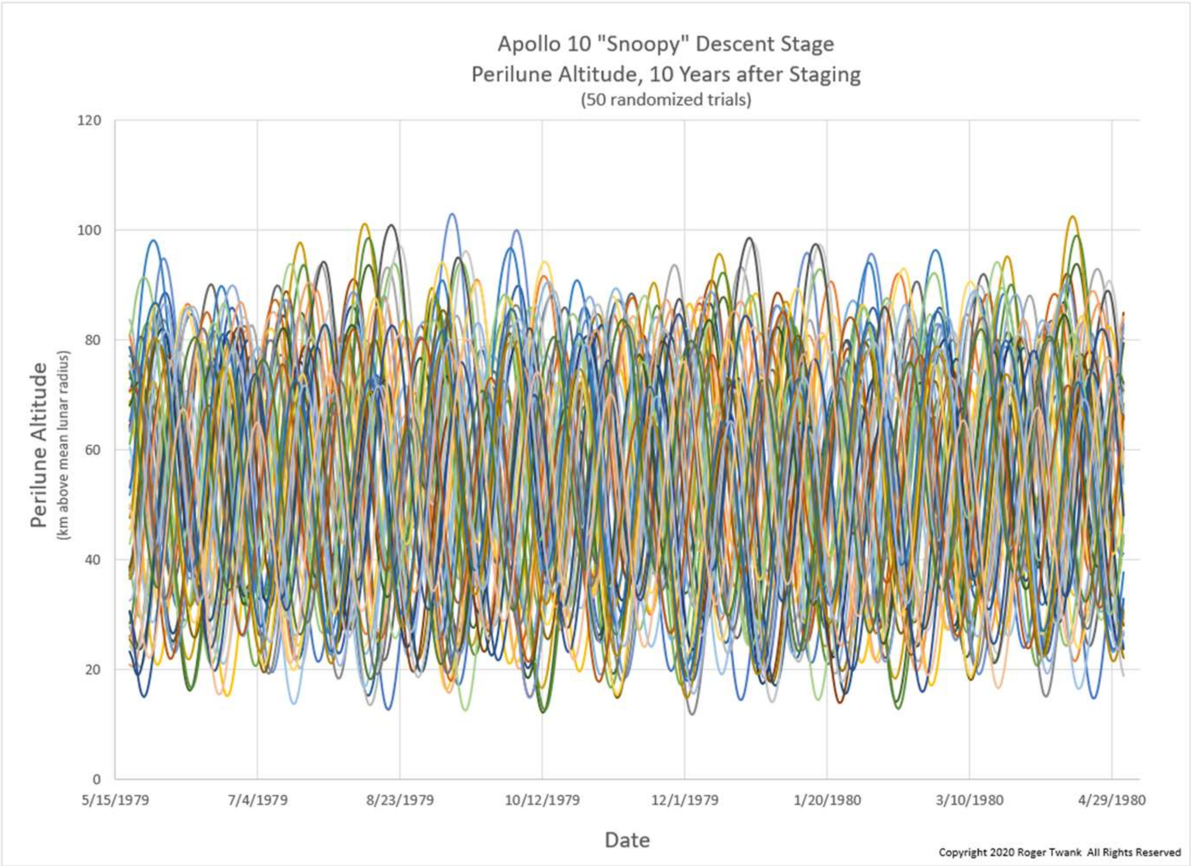
- NASA has successfully located “lost” lunar satellites using Radar
- Following two slides match up the orbit against the radar beam width at lunar distance
- More about it in this blog post:
  https://snoopy.rogertwank.net/2020/01/how-could-snoopy-be-found.html



Altitude vs Latitude at 90 East
(Simulation: January through June, 2018)
Radar Beam Size
Mean Lunar Radius
Displacement relative to Lunar Equator (km)
Displacement from Mean Lunar Surface (km)
150
100
50
0
-50
-100
-50
0
50
100
150
200
250
300
350
Copyright 2019 Roger Twank


Simulated Altitude above 90° East Longitude
Altitude (km)
350
300
250
200
150
100
50
0
3/21/2018
3/31/2018
4/10/2018
4/20/2018
4/30/2018
5/10/2018
5/20/2018
5/30/2018
6/9/2018
6/19/2018
Approximate Beam Coverage

Monte Carlo Simulation of Orbit Variations

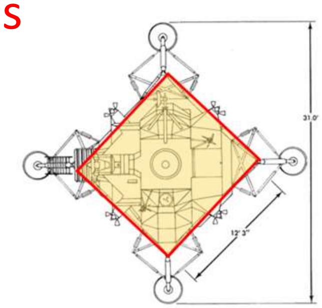


More about this in my blog…

https://snoopy.rogertwank.net/2020/02/simulating-uncertainty.html

Lunar Exosphere Effects

- Estimate density of Lunar Exosphere: 4e-18 grams/cm^3
- Estimate (worst case) LM cross section: 1.4e5 cm^2
- Estimate Volume swept out by stage during 50 years 3.5e19 cm^3
  - Total mass of exosphere that has collided with the stage…145 grams
  - Negligible compared to 2138 kg (dry) weight of stage



https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html					
		#/cubic cm	Atomic weight	Total atomic weight	
Helium4	(4He)	40000	4	160000	
Neon 20	(20Ne)	40000	20	800000	
Hydrogen	(H2)	35000	2	70000	
Argon40	(40Ar)	30000	40	1200000	
Neon22	(22Ne)	5000	22	110000	
Argon36	(36Ar)	2000	36	72000	
Methane		1000	16	16000	
Ammonia		1000	17	17000	
Carbon Di	(CO2)	1000	44	44000	
				2489000	Atomic Units per cc
				4.13E-18	grams/cc

Cross Section	
373	cm per side
1.39E+05	cm squared

160000	cm/sec	Velocity
1.58E+09	Seconds in orbit	
2.53E+14	Total cm travelled in 50 years	
3.52E+19	Total volume (cc) swept out	
4.13E-18	grams/cc	
145.53	grams impacted in 50 years	
2.14E+06	dry weight of stage (grams)	
0.0068%	mass ratio exosphere/stage	

https://snoopy.rogertwank.net/2020/02/atmospheric-drag.html

Sighting Snoopy on May 24th

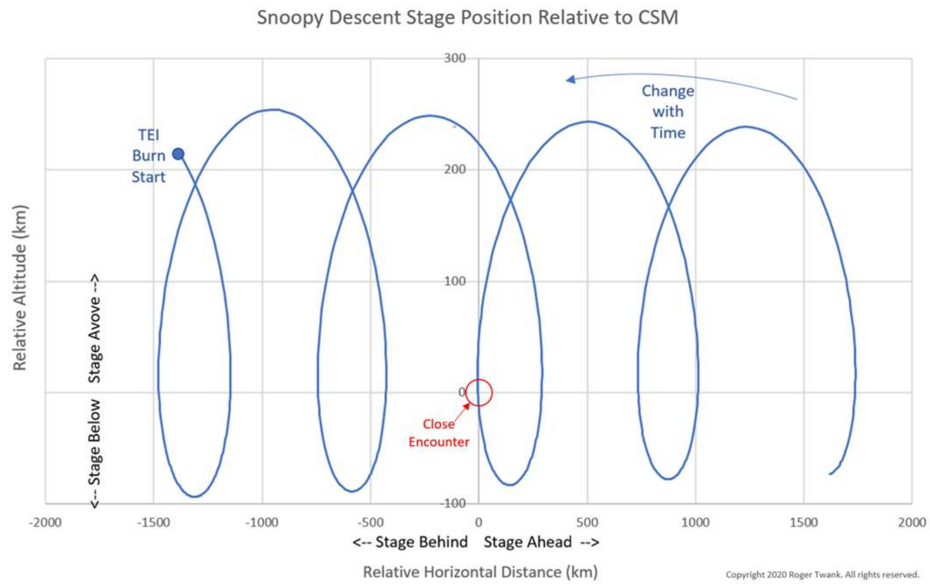
At 132:15:55 CDR Stafford reported seeing the stage:

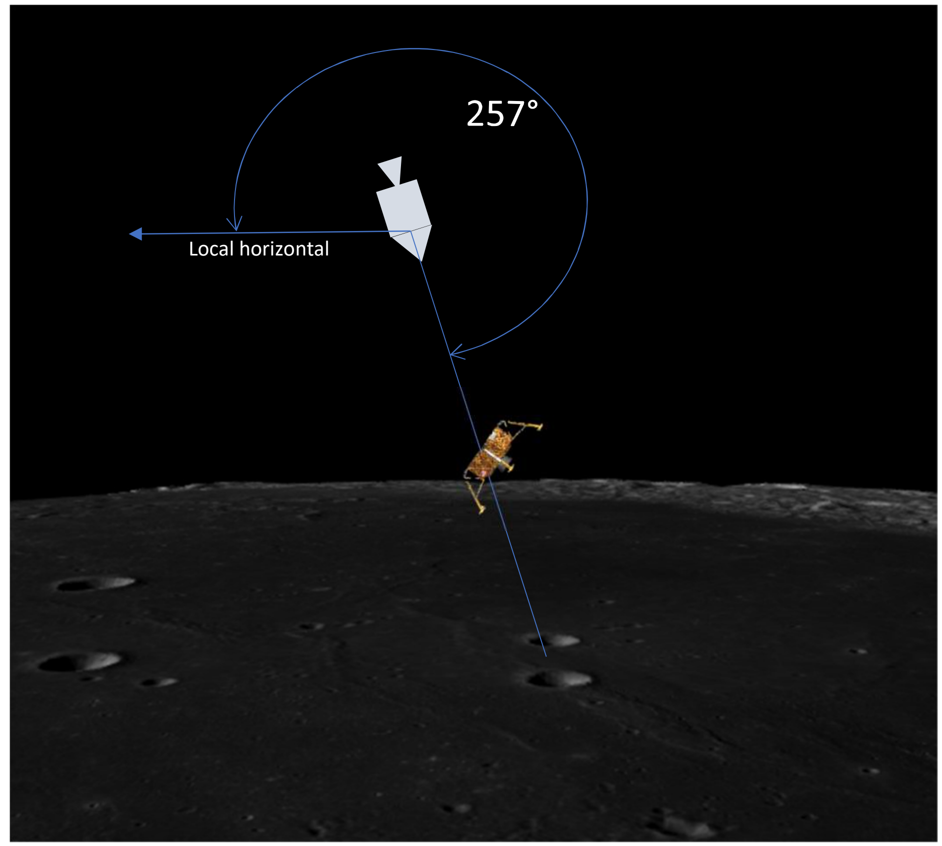
- “There he is right down below us; he's cutting across the Taruntius twins. Yes, between Taruntius P and K. And that rascal is right in-plane with us.”

This narrows down the stage orbital period considerably

https://history.nasa.gov/afj/ap10fj/as10-day6-pt28.html

Stage Sighting on May 24th





https://snoopy.rogertwank.net/2020/04/the-stage-returns.html