Engineering Workbook:	DOGE-1 Mission FCC & NOAA Licensing
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Revision History:	V78-1 issued November 27, 2022, all prior versions are considered deprecated
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Application File Number:	0083-EX-CN-2022
Confirmation Number:	EL444793
DOGE-1 Team Members:	GEC, Sam Reid, et al.
	XISP-Inc, Gary Barnhard, et al.
	Exobotics, Ltd., Nadeem Gabbini, et al.
	Maverick Space Systems, Roland Coelho, et al.
	SpaceX, Maria Mathews
DOGE-1 Radio Vendors:	GOMspace, (via Exobotics, Ltd.)
	Endurosat, (via Exobotics, Ltd.)
DOGE-1 Earth Station Vendors:	Goonhilly Earth Station, Matt Cosby, et al.
DOGE-1 Licensing Coordinators:	FCC Experimental License File Manager, David Young, et al.
	NASA JSC Spectrum Analysis - Catherine Sham, et al.
	DoD (via NASA/FCC)
	ITU (via NASA/FCC)
	NOAA License Manager, Frank Rostan, et al. - No license required
DOGE-1 Additional Reviewers:	NASA HQ SCaN Program Cislunar Comm & Nav Architect, Jim Schier, et al.

All parameters osculating at payload separation.
Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame
Date: 2022-05-31
Time (UTC) 707249768.18 days
Apogee alt: 420000.00 km
Perigee alt: 400.40 km
Inclination: 28.50 deg
RAAN: -180.73 deg
AoP: 189.94 deg
True Anomaly: 39.98196228 deg
THIS INFORMATION IS CONSIDERED SPACEX PROPRIETARY

11.2 km/s Earth Escape Velocity

7178 km, Minor Axis 400+6378+400
420000 km, Major Axis
8.80E+05 km, Perimeter of notional eliptical orbit

Notional Elliptical Orbit Period
11 days 17 hours 35 minutes (trial and error).
11d 14:37:55, assuming the earth is the only mass source

From: Maria Matthews
Sent: Tuesday, January 4, 2022 8:51 PM
To: 'Gary Barnhard' <gary@geometricenergy.com>
Subject: RE: DOGE-1 | Bi-weekly Mission Tag Up - 12/30/2021

Hi Gary,

i

Thanks for sending all of this along. We may be a bit confused on what the ask/request is for SpaceX here.

To clarify some points:

1 DOGE-1 will be deployed in a ~400 km x ~420,000 km orbit, specifics to be sent late this week or as available [*sic corrected per above*]

2 SpaceX can deploy DOGE-1 in a variety of desired attitudes, before or after a notional disposal maneuver

3 SpaceX cannot support LOI or a substantial deviation from the IM-1 deploy orbit

4 Because the mission design includes an LOI maneuver and SpaceX has determined an optimal separation state within the LV constraints, the delta-V required will be less than the delta-V required for a Hohmann transfer. Lunar gravity will assist in the LOI maneuver, but SpaceX cannot perform modeling of the DOGE-1 propulsion system.

5 SpaceX will deliver a nominal 3-DOF separation state for each of the notional targets. When available (in a few weeks), SpaceX will provide a nominal 6-DOF separation state, and can incorporate feedback from the DOGE-1 team re: desired separation attitude. These states will include estimates of state covariances. Finally, when SpaceX performs Monte Carlo analysis, we will provide actual covariances for the separation state, which will fully represent SpaceX's preflight predictions.

To summarize, please clarify the request to SpaceX and note that SpaceX cannot model the DOGE-1 propulsion system or orbit after separation from the LV.

Thank you,
Maria Matthews | Mission Manager
(+1 (323) 523 - 3552 | maria.matthews@spacex.com

From: Gary Barnhard <gary@geometricenergy.com>

Sent: Tuesday, January 4, 2022 1:27 PM
To: Maria Matthews <Maria.Matthews@spacex.com>

Cc: sam@geometricenergy.ca; vidur@maverickspace.com; austin@maverickspace.com; aaron@defydevelopmentcorp.com; pointblankcompany@protonmail.com; Erik Susemichel <Erik.Susemichel@spacex.com>; roland@maverickspace.com; shantel@geometricenergy.ca; nela@geometricenergy.ca; Danielle Meisner <Danielle.Meisner@spacex.com>; Timothy@geometricenergy.ca; nela@geometricenergy.com; danielcosic@geometricenergy.com; shantel@geometricenergy.com
Subject: Re: DOGE-1 | Bi-weekly Mission Tag Up - 12/30/2021

Maria -

The DOGE-1 Operations planning urgently requires an understanding of the DOGE-1 deployment sequence.

Pursuant to your request what follows is the best answer we currently have to your question above.

Accordingly, the DOGE-1 team would like to have a discussion of the following with the SpaceX IM-1 GNC team at the earliest opportunity.

Sincerely,

Gary

Givens:

(1) DOGE-1 is assumed to be onboard for the IM-1 Trans Lunar Injection (TLI) burn
(2) DOGE-1 is using a dual Enpulsion electric propulsion system
(3) After launch on a SpaceX Falcon 9 from Cape Canaveral, scheduled for 2022, the Nova-C spacecraft will go into a 185 x 60,000 km Earth orbit, followed by a Trans Lunar Injection (TLI) burn and a Lunar Orbit Insertion (LOI) maneuver to put it in a 100 km circularized Low Lunar Orbit (LLO). [Orbital parameters provided here are deprecated, see note above]

Deployment Objectives:

(4) Minimize DOGE-1 Delta-V requirements to obtain LOI
(5) Minimize DOGE-1 orbital makeup propulsion requirements
(6) Maximize DOGE-1 stable lunar orbital life time (combination of lunar orbit altitude, inclination, and degree of circularization)

Target Orbits:

See Table and Diagram Below for potential stable lunar orbits [circularized LLO, Eliptical Lunar Orbit (ELO), Prograde Circular Orbit (PCO), Frozen Oscillating Orbit (FOO), Lunar Resonance Orbit (LRO), or High Earth Lunar Resonance Orbit (HRLRO)]

Deployment Scenarios:

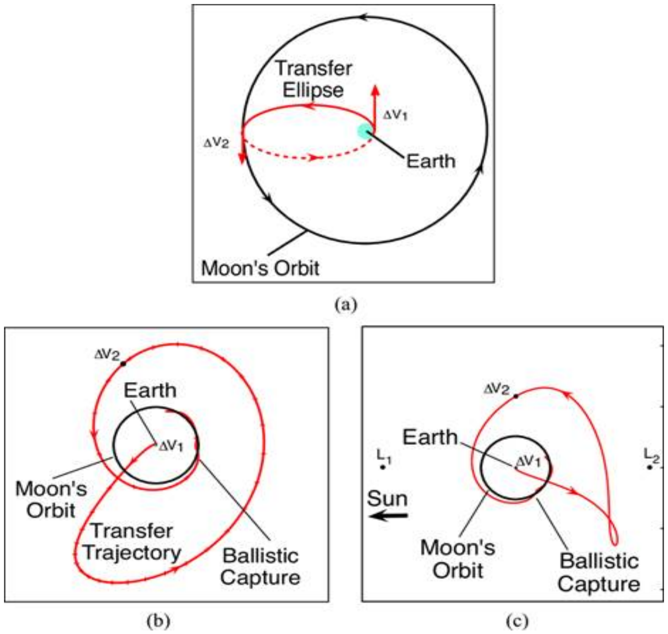
(7) First Choice: DOGE-1 deployed in a stable Lunar orbit [nominal deployment at 100 km circularized LLO with transition to a stable lunar Orbit.

(8) Second Choice: DOGE-1 deployed after the LOI maneuver and transition to a stable Lunar Orbit.

(9) Third Choice: DOGE-1 deployed after the TLI burn and transition to a stable Lunar Orbit.

Modeling Approach:

(10) The First Choice target requires DOGE-1 to provide sufficient Delta-V to transition from the deployment orbit to an orbit that provides an acceptable trade between makeup propulsion requirements and orbital lifetime (i.e., meets deployment objectives). Delta-V capability model initial results indicate that the DOGE-1 propulsion system may not be capable of providing the Delta-V required to achieve the necessary transition using Hohmann transfer (see diagram (a) below).
(11) Delta-V capability model initial results indicate that the DOGE-1 propulsion system is not capable of providing the Delta-V required to achieve the second or third choice Target Orbits using Hohmann transfer (see diagram (a) below).
(12) Accordingly, the use of a Low-energy transfer trajectory is most likely required for any of the Target Orbits.
(13) STK Astrogator will be used to analyze the Delta-V required to reach all Target Orbit candidates for the three Deployment Scenarios using low-energy transfer trajectory manifolds. The combination of Target Orbits and Deployment Scenarios that offer the potential for the lowest Delta-V will then be analyzed for a full 28 day lunar cycle of interest.



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jveq i2$g-$Weq i$xenigxsv}$mrxliWyr1Ievxl$vsxexmrk$jveq i2

Ross, Shane. (2004). Cylindrical manifolds and tube dynamics in the restricted three-body problem.

Introduction | Orbit Types | Earth Access | Lunar Surface | Long Term Ops | Summary

Smaller Cislunar (Lunar Two-body) Orbits

Orbit Type	Orbit Period	Amplitude Range	E-M Orientation
Low Lunar Orbit (LLO)	~2 hrs	100 km	Any inclination
Prograde Circular (PCO)	11 hrs	3,000 to 5,000 km	~ 75 ° inclination
Frozen Lunar Orbit	~13 hrs	880 to 8,800 km	40° inclination
Elliptical Lunar Orbit (ELO)	~14 hrs	100 to 10,000 km	Equatorial

Low Lunar Orbit (LLO): LLO is defined as a circular orbit of an altitude around 100 km. LLOs are favorable for surface access and polar orbit inclinations offer global landing site access.

An Elliptical Lunar Orbit (ELO), such as the 100 x 10,000 km shown, trades insertion costs with transfer cost to lunar surface.

Prograde Circular Orbits (PCOs) are defined as circular orbits of various sizes that rotate in the prograde direction and are highly stable, requiring few to zero corrections to be maintained.

Frozen orbits are similar but need not be circular and have orbital parameters that oscillate around fixed values.

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Reference: Barnhard - SARTC May 17, 2021.pptm, Slide 135

Prospective Target Orbits			Paralune (km)	Apolune (km)	Inclination (degrees)	
Low Lunar Orbit	LLO	Minimum	40	40	90	Lunar Prospector
Low Lunar Orbit	LLO	Maximum	100	100	90	Lunar Prospector
Eliptical Orbit	ELO	Minimum	15	45	90	Lunar Prospector
Eliptical Orbit	ELO		20	60	0	LADEE
Eliptical Orbit	ELO	ACS	100	10000	TBD	Alpha Cube Sat Lunar Derby
Eliptical Orbit	ELO	Maximum	500	10000	TBD	Alpha Cube Sat Lunar Derby
Eliptical Orbit	ELO	Maximum	500	40000	TBD	Alpha Cube Sat Lunar Derby
Prograde Circular Orbit	PCO	Minimum	TBD	TBD	TBD	
Prograde Circular Orbit	PCO	Maximum	TBD	TBD	TBD	
Frozen Oscillating Orbit	FOO	Minimum	TBD	TBD	27,50,76,86	
Frozen Oscillating Orbit	FOO	Maximum	TBD	TBD	27,50,76,86	
Lunar Resonance Orbit		Minimum	TBD	TBD	TBD	Smallest degree 3, Largest degree
Lunar Resonance Orbit		Maximum	TBD	TBD	TBD	
			Perigee (km)	Apogee (km)	Inclination (degrees)	
Trans Lunar Injection Orbit	TLI	Nominal	519	384000	28.5	Earth Orbit
High Earth Lunar Resonant Orbit	HRLRO		TBD	400000	28.5	TESS

Reference: DOGE-1 Mission Workbook V6-0 - GPB - SDPmods.xlsx

On Thu, Dec 30, 2021 at 3:21 PM Maria Matthews <Maria.Matthews@spacex.com> wrote:

Hi Gary,

I spoke to our GNC team, and following up on the request for earlier drop-off in deployment sequence, this is doable but can you please advise on what the target you're currently looking for is, and what your desired direction of improvement would be?

Thank you,

Maria Matthews | Mission Manager
i (+1 (323) 523 - 3552 | maria.matthews@spacex.com

From: Maria Matthews
Sent: Thursday, December 30, 2021 12:15 PM

To: Maria Matthews <Maria.Matthews@spacex.com>; sam@geometricenergy.ca; gary@geometricenergy.com; vidur@maverickspace.com; austin@maverickspace.com; aaron@defydevelopmentcorp.com; pointblankcompany@protonmail.com; Erik Susemichel <Erik.Susemichel@spacex.com>; roland@maverickspace.com; shantel@geometricenergy.ca; nela@geometricenergy.ca; Danielle Meisner <Danielle.Meisner@spacex.com>; Timothy@geometricenergy.ca; nela@geometricenergy.com; danielcosic@geometricenergy.com; shantel@geometricenergy.com; gpb8012@gmail.com
Subject: DOGE-1 | Bi-weekly Mission Tag Up - 12/30/2021

Meeting Date: 12/30/2021 12:00 PM
Participants

Notes

General

- Launch date updated to **NET June 03 2022**. [Deprecated]

- Helium potential issues

- Waiting on components to be delivered ETA - targeting end of December; January or early Feb w/ helium test. Waiting on Nadeem for an update.

- Helium ConOps - wait for helium to dissipate

- ICD Draft 1 will be worked with Maverick Space Systems (ITAR)

- Timothy as signatory

- Sam as signatory

- **TAA is now active!**

- Request (per Gary): drop off DOGE-1 as early as possible after TLI burn.

- DOGE-1 concerned about orbit being too close to a landing orbit instead of a lunar orbit.

SpaceX Actions

- Details on orbit dropoff and sequence

- Tx turn-on time and exclusions

Customer Actions

- Complete Mission Analysis Inputs Deliverables

- Inputs to ICD - ETA aim for mid-Feb.

- Separation analysis - ETA aim for mid-Feb.
- Ground Operating Plan (GOP) - due at L-4M (February 2022)
- Verification Reports - due at L-3M (March 2022)
- Revised spacecraft schedule - ETA early Jan.

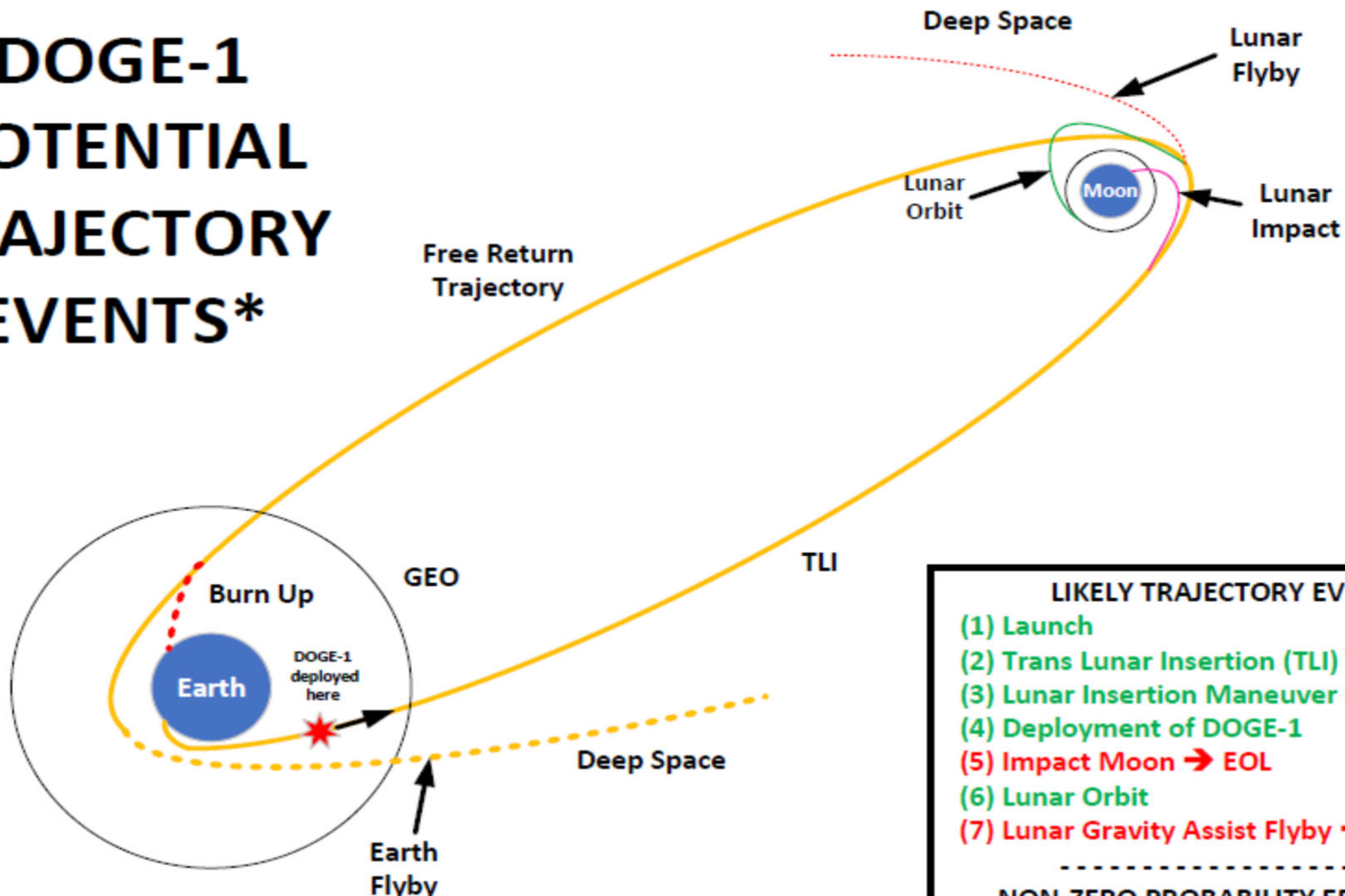
Thank you,

Maria Matthews | Mission Manager

(+1 (323) 523 - 3552 | maria.matthews@spacex.com

Space Exploration Technologies | www.spacex.com
1 Rocket Road, Hawthorne CA, 90250

DOGE-1 POTENTIAL TRAJECTORY EVENTS*



LIKELY TRAJECTORY EVENTS

(1) Launch
(2) Trans Lunar Insertion (TLI) Trajectory
(3) Lunar Insertion Maneuver (LIM)
(4) Deployment of DOGE-1
(5) Impact Moon → EOL
(6) Lunar Orbit
(7) Lunar Gravity Assist Flyby → EOL

NON-ZERO PROBABILITY EDGE CASE

(8) Earth Free Return Trajectory
(9) Burn Up (Earth Reentry) → EOL
(10) Earth Gravity Assist Flyby → EOL
(11) Moon Return Trajectory
(12) Lunar Orbit

*Not to scale

Orbit Type	Minimum Amplitude (m)	Maximum Amplitude (m)
Low Lunar Orbit (LLO)	100000	100000
Prograde Circular (PCO)	3000000	5000000
Frozen Lunar Orbit	880000	8800000
Elliptical Lunar Orbit (ELO)	100000	1000000
		Reference: Barnhard - SARTC May 17, 2021.pptm, Slide 135

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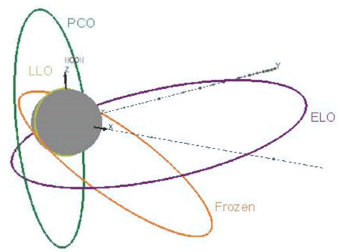

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DOGE-1 Potential Orbital Targets			Paralune (km)	Apolune (km)	Inclination (degrees)	
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