SPACEX

MISHAP INVESTIGATION REPORT

STARSHIP ORBITAL FLIGHT 1

EXECUTIVE SUMMARY

SEPTEMBER 8, 2023

[redacted]

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1 ORBITAL TEST FLIGHT 1 MISHAP OVERVIEW

Space Exploration Technologies Corp. (SpaceX) launched Starship Orbital Test Flight 1 (OTF-1) under Federal Aviation Administration (FAA) Commercial Space Transportation License VOL 23-129 on April 20, 2023, at 8:33 AM CST. The vehicle proceeded through a nominal propellant load and terminal countdown to engine startup. After liftoff, the vehicle suffered several engine and vehicle system failures resulting in a mission rules violation at 8:36 AM CST, triggering the automated flight termination system. The vehicle and was lost. Section 4 of this document provides an overview of anomalous behavior experienced during OTF-1. OTF-1 was an experimental test flight—the first ever of a space launch vehicle of this size and complexity—to gain learnings on Starship Super Heavy in flight. This test flight was conducted safely with no risk to public safety and no impact to third-party property.

After the mishap, SpaceX initiated an investigation as described by the SpaceX Boca Chica Emergency Response and Mishap Investigation Plan and pursuant to FAA regulations and the Starship OTF-1 license. The SpaceX Boca Chica Emergency Response and Mishap Investigation Plan prescribes procedures for responding to, reporting, and investigating Launch Accidents, Launch Incidents, and Mishaps related to licensed activities in accordance with 14 CFR §450.173. This plan covers SpaceX activities at the SpaceX launch and landing facility in Boca Chica, TX. SpaceX led this investigation with FAA oversight and participation from the National Aeronautics and Space Administration (NASA), the National Transportation Safety Board (NTSB), and the Aerospace Corporation consistent with FAA regulatory requirements and well-understood, proven processes in place for commercial space launch mishap investigations.

2 STARSHIP AND SUPER HEAVY VEHICLE OVERVIEW

SpaceX built the OTF-1 Starship and Super Heavy vehicles at the Starbase production facility in Boca Chica, TX. The Starship-Super Heavy orbital launch system is comprised of two stages: the Super Heavy Booster and Starship. For OTF-1, the vehicles were Super Heavy Booster 7 (known also as simply “Booster 7” or “B7”) and Starship 24 (known as “Ship 24” or “S24”). Booster is designed with a main liquid oxygen (LOx) tank, a main liquid methane (LCH4) tank, a liquid oxygen landing tank, thirty-three Raptor sea-level engines, grid fins, sub-assemblies, and a flight termination system. Ship is comprised of a LOx tank and header tank, a LCH4 tank and header tank, an aft skirt, three Raptor sea-level engines, three Raptor vacuum engines, a nosecone, flaps, sub-assemblies, and a flight termination system. An overview diagram is shown in Figure 1.

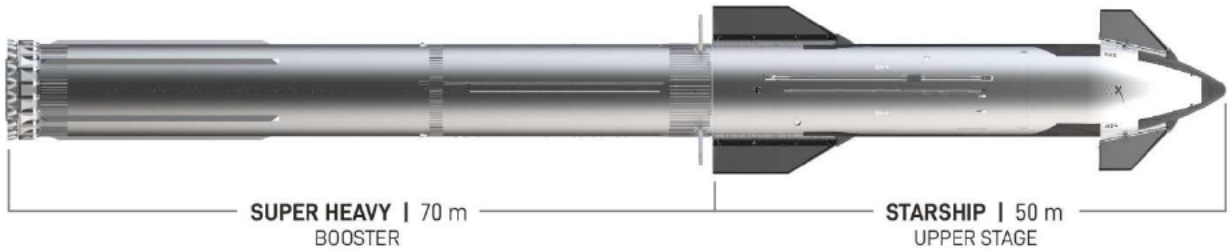

Figure 1: Starship-Super Heavy vehicle overview

3 MISHAP SUMMARY

SpaceX Starship-Super Heavy vehicle system (Booster 7 and Ship 24) was launched from SpaceX's launch site in Boca Chica, Texas at 8:33 AM CST on April 20, 2023. [redacted]

(b) (4)

[redacted]

- (b) (4) [redacted]

The Starship OTF-1 Mishap Investigation Team has fully reviewed the mishap, determined root causes, (b) (4) [redacted]

4 CRITICAL KEY EVENTS

Events that contributed to the failure will be outlined in this section in more detail. [redacted]

(b) (4) [redacted]

(b) (4) [redacted]

[redacted]

5 CONCLUSION

The Mishap Investigation Team for the Starship Orbital Test Flight 1 has fully reviewed the mishap, determined root causes, and have implemented (b) (4) [redacted] corrective actions, which will be monitored closely prior to subsequent flights. At this time, SpaceX has completed all corrective actions required for Flight 2, which are identified in Attachment A. [redacted]

(b) (4) [redacted]

It should also be noted that the Starship and Super Heavy vehicles are still in the early stages of development by SpaceX. SpaceX takes no risk with respect to public safety.

ATTACHMENT A: CORRECTIVE ACTIONS AND IMPLEMENTATION STATUS

Observation / Description	ID#	Corrective Action Description	Status
Tank sensing	C1	Replace certain fittings with welds inside tank	Complete
Aft end cavity environment failure	C2	Increase fire suppression capacity by 15x	Complete
Booster leak mitigation	C3	Replace certain manifolds with dedicated drain per corresponding valve	Complete
	C4	Replace certain flanges with better seals and improve joint design	Complete
	C5	Replace certain fittings with welds in specific location	Complete
	C6	Replace accessible valves of a certain type with new design	Complete
	C7	Replace certain flange bolts with higher strength bolts and increase torque	Complete
	C8	Disallow certain seal re-use, and add cameras to monitor all engines during ground operations	Complete
	C9	Increased scrutiny on leak checks	Complete
	C10	90+ cameras added to detect leakage during operations	Complete
Raptor leak mitigation	C11	Add leak capture and drain hardware for valves of a certain type	Complete
	C12	Add leak check and screen for porosity on igniter units	Complete
	C13	Improved igniter seal design	Future Action
	C14	Weld certain alignment bolt holes shut	Complete
	C15	Reassess k-factor and torque for engine hot joint #1, add leak capture and route overboard	Complete
	C16	Reassess k-factor and torque for engine hot joint #2	Complete
	C17	Add safety cable to certain fluid lines on high risk locations	Complete
	C18	Add one methane sensor per engine bay	Complete
	C19	Ground test campaign to better characterize typical engine leakage	Complete
	C20	Improve structural FEA/fatigue analysis for all medium to high criticality lines	Complete
Collateral damage from fire	C21	Add insulation to engine lines sensitive to thermally driven loads	Complete
	C22	Add insulation to avionic harnessing	Complete
	C23	Add backup wire to specific harness	Complete
	C24	Improve thermal protection of avionics tray	Complete
	C25	Change routing to flight computers	Complete
Booster reliability improvement	C26	Replace sensor with more reliable units	Complete
	C27	Coat gimbal assembly with lubricant	Complete
	C28	Add pump pressure sensors to certain location	Complete
	C29	Add pump temperature sensors to certain location	Complete
	C30	Replace certain bolts, and increase torque for certain flanges	Complete
	C31	New seal design for certain areas of booster	Complete
	C32	Add electric actuation system	Complete
	C33	Better manage engine bay pressure by increasing fire suppression capacity by	Complete

	C34	Change certain booster valve timing	Future Action
Raptor reliability improvement	C35	Add final leak checks for critical joints	Complete
	C36	Add support bracket for certain sensor	Complete
	C37	Add support bracket for certain sensor	Complete
	C38	Add check valves to certain areas of engine	Complete
	C39	Improve oxygen valve design	Future Action
	C40	Improve oxygen valve seal design	Future Action
	C41	Improve design of hot manifold	Future Action
	C42	Change nitrogen shutdown usage	Complete
	C43	Change engine shutdown logic	Complete
	C44	Increase capability for ground leakage mitigation	Complete
	C45	Redesign fire suppression system	Complete
	C46	Change conditions around bolts	Complete
	C47	Change timing of specific valve actuation	Complete
Avionics reliability improvement	C48	Eliminate certain type of connector	Complete
	C49	Redesign network architecture	Future Action
Risk Process	C50	Improve risk tracking process	Complete
Safety System	C51	Implement improvements to safety system	Complete
	C52	Verify flight safety system design improvements using additional type of test article	Complete
	C53	Verify flight safety system design improvements via analysis	Complete
	C54	Perform component testing	Complete
	C55	Review and improve operations surrounding flight safety system	Complete
Change Control	C56	Improve CAD controls	Complete
	C57	Add engineering walkdown	Complete
	C58	Improve use of change management system	Complete
Pad Design	C59	Redesign of launch pad deck	Complete
	C60	Improve assumptions for new pad deck design	Complete
	C61	Add water cooled pad deck	Complete
Pad Design Process	C62	Improve pad deck design documentation	Complete
	C63	Improve pad design process	Complete