Sherpa-FX1 on December SpaceX Rideshare Mission Long-Term Recontact Probability

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1. Introduction

The Sherpa-FX1 Mission (hereinafter "Sherpa-FX1 Mission" or "Mission") on a SpaceX Rideshare launch, currently planned for December 2020 – January 2021, is a commercial rideshare mission with the primary Spaceflight, Inc. objective of hosting 4 customer payloads that will remain attached to the Sherpa FX1 and deploying 14 customer spacecraft into a planned sun-synchronous circular orbit of 525 km ± 25 km. SpaceX's Falcon 9 launch vehicle will deploy a free flyer spacecraft, called Sherpa-FX1, which subsequently deploys the additional 14 customer spacecraft within several hours of liftoff.[1]

The Sherpa-FX1 Mission configuration is variable for the Sherpa-FX free-flyer depending on the number of microsatellites and CubeSats manifested to the mission. CubeSat and Microsatellite separation systems are interchangeable and can be affixed radially on the body of Sherpa-FX. A microsatellite, CubeSat dispenser, or other adapter for separation system mounting can be affixed on the outboard end of Sherpa-FX1. For this Mission, the planned configuration has a microsatellite on the outboard end of Sherpa-FX1, with three other microsatellites, two 6U equivalent CubeSat dispensers, and one 12U equivalent CubeSat dispenser, attached radially on the body of Sherpa-FX1.[2] The Sherpa-FX1 Mission configuration also includes an S-band receive antenna and an L-band transmitter as part of its avionics.

This report presents the probability of recontact for this configuration over two-year time period between the spacecraft on this mission and with resident space objects.

[1] Spaceflight notes that, as with any rideshare mission, there is a possibility that one or more customers will either not be ready, not be able to meet one or more of Spaceflight and/or SpaceX's readiness criteria for flight or, choose to remove their spacecraft from the mission. Removed customers will be replaced by a non-separating mass model to keep the various launch and mission analyses valid. Since the Sherpa-FX1 does not have any attitude control system, the separation dispersion is dependent on the momentum change after each deployment. This momentum change is based on the specific mass of each spacecraft and the spring energy in their separation system. Therefore, replacing a separating customer spacecraft with a non-separating mass model will change the momentum of the Sherpa FX-1, and thus the deployment vector for subsequent spacecraft. In such event, a new recontact analysis will be run to verify that the mission cumulative recontact probability is 1.015×10^{-3} or less. If the probability of recontact would be greater than this threshold, a new sequence will be developed and tested to ensure that this threshold is met.

[2] None of the spacecraft to be deployed will themselves deploy additional spacecraft.

2. Methodology

Spaceflight has performed a high-fidelity analysis set forth below, using the same analytic techniques that Spaceflight described for its previously successful SSO-A mission.[3] As a general matter, spacecraft with propulsion or differential drag capabilities should be able to avoid conjunction with other spacecraft, there is some risk of conjunction in the period immediately following launch which is mitigated through the use of collision avoidance analysis between the launch vehicle and the Combined Space Operations Center (CSpOC). Additionally, the nature of that risk, and more generally of conjunctions involving spacecraft deployed as part of the Sherpa-FX1 Mission, is one better described as recontact rather than collision because of the low speed nature of any possible conjunction. Contact at this low speed may cause minor damage to a spacecraft, but little or no debris.

The high-fidelity approach is based on a Monte Carlo analysis of the full Sherpa-FX1 deployment sequence. This analysis approach considers the mass and separation system properties for all Spaceflight customer spacecraft. Appropriate distributions are applied to these parameters based on customer and vendor inputs, and Monte Carlo simulations of the full Sherpa-FX1 Mission are run using a six degree-of-freedom orbit and attitude dynamics model with relative distances tracked between all spacecraft. Sub-3U spacecraft will be grouped together in the same slot of their separation system, and therefore considered a single aggregate 3U spacecraft in these analyses. These spacecraft would be deployed in the same velocity vector and thus relative velocities between them would be negligible compared to relative velocities between other spacecraft on the mission, or between Resident Space Objects. Ordering of the spacecraft within the dispenser will also help mitigate the chance of recontact by placing the least massive spacecraft with the highest separation velocity, such that it is separated first, thereby minimizing the chance a spacecraft "catches up" to another spacecraft it was deployed with. Moreover, the force of inhibit switches on each spacecraft have a spring effect, contributing in small part to the separation between spacecraft. The probability of recontact for the Sherpa-FX1 Mission is then found by counting the number of recontact events, which are said to occur if an object pair's relative distance falls below that particular object pair's combined hard-body radius, and dividing by the total number of simulations run.

A 5,000-run Monte Carlo analysis was performed using this approach over a period that lasted five orbits after the last spacecraft is deployed from Sherpa-FX1 (a duration of approximately 8 hours). The analysis was based on a deployment sequence that was chosen to reduce the probability of recontact. Any final modifications to deployment sequence order or timing from that which was used as inputs to the analysis here, shall have an equal or reduced probability of recontact than those presented herein. The five-orbit time period was chosen for detailed analysis because of the divergence of spacecraft that naturally occurs over this period, as further

[3] SAT-STA-20180523-00042. See Spaceflight, Inc. Supplemental filing, SSO-A Long-Term Contact Probability (August 14, 2018) ("SSO-A Recontact Analysis"). SSO-A Recontact Analysis, at 6. For the reasons stated in that Analysis, Spaceflight regards its high-fidelity analysis approach as a far more accurate presentation of risk than the low fidelity model also therein noted. .

analyzed below. Spaceflight notes that customer spacecraft are explicitly forbidden to perform propulsive maneuvers during the first nine hours after final deployment to allow time for spacecraft to be identified on orbit and accurate orbit tracks established to support collision avoidance analysis. During this time (five orbits), only four recontact events were observed over these 5,000 full deployment sequence simulations (Pr(recontact) = $8x10^{-4}$), each with a $\Delta v < 1.0$ m/s. There was a 99.0% probability that all relative miss distances remained above 9.06 m, a 95% probability of all miss distances being greater than 25.98 m, and a 90.0% probability of all miss distances being greater than 40.24 m. Further, this estimate encompasses the period of highest spacecraft density where recontact events are most probable.

2000 further full deployment sequence simulations were run over a longer seven-day duration to substantiate this claim. Figure 2 demonstrates that the probability of a given object pair's relative distance being less than 5m decreases significantly after the first few hours of the mission. In fact, each bin of relative distances decreases significantly after the first few hours, supporting the assertion that the spacecraft continue to diverge over time, with the time period of highest density and therefore highest probability of recontact soon after the last separation.

While the probability of recontact will continue to decrease as spacecraft diverge, we can conservatively assume this simulation's probability of recontact is fixed after the initial five orbit time period, with the additional assumption that the nine spacecraft with propulsive capabilities are able to perform appropriate collision avoidance maneuvers after the initial wait period. Therefore, Spaceflight calculates the probability of recontact between the Spacecraft on the Sherpa-FX1 Mission over a two-year period is $1.0x10^{-3}$.

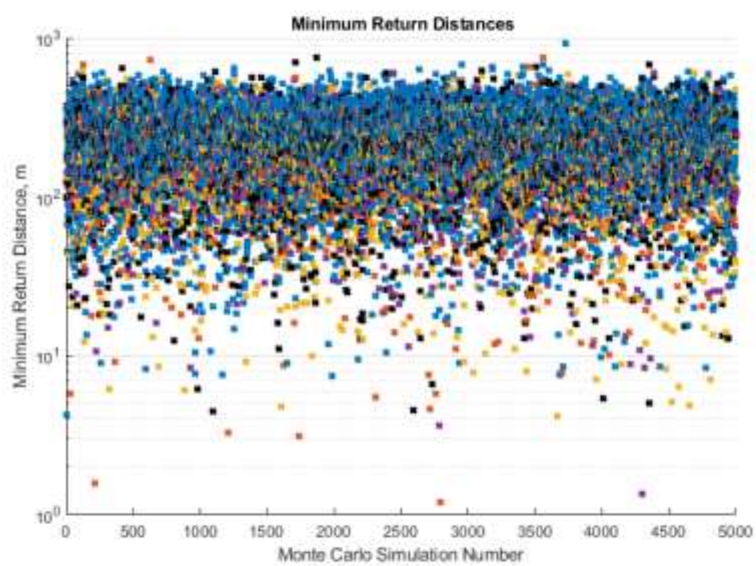

Figure 1: 5,000 simulation Monte Carlo analysis over five orbits. Black data points indicate CubeSat- CubeSat close approach. Yellow data points indicate Microsat-Microsat close approach. Orange data points indicate Sherpa-FX1-Cubesat close approach. Blue data points indicate Cubesat-Microsat close approach. Purple data points indicate Sherpa-FX1-Microsat close approach.

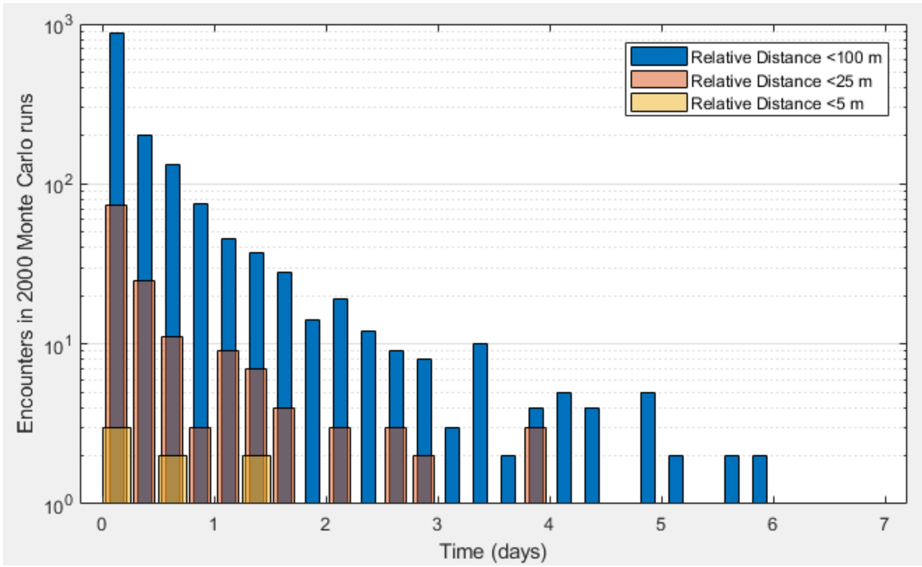

Figure 2: Spacecraft dispersion over time illustrated by decreasing encounters, binned by relative distance, in a 2,000 simulation Monte Carlo analysis over seven days.

2.1 Conjunction with Resident Space Objects

The analyses above addresses recontact between spacecraft on the Sherpa-FX1 Mission, which would be low velocity events. Another concern is the probability of a conjunction with a Resident Space Object (RSO) that is not part of the Sherpa-FX1 Mission. Each spacecraft is responsible for performing this analysis as part of their Orbit Debris Assessment Report (ODAR). Overall probability of conjunction with an RSO for all spacecraft can be estimated based on the individual spacecraft size and mass as an input into the Debris Assessment Software (DAS v3.1.0) RSO collision analysis. It is assumed that spacecraft with propulsion systems will be able to avoid RSO collisions. DAS predicts that Sherpa-FX1 and its deployed spacecraft without the ability to perform collision avoidance, have a probability of recontact with RSOs of 1.45×10^{-5} over the entire orbit lifetime of the spacecraft.

3. Conclusions

Spaceflight estimates that the Sherpa-FX1 Mission has a 1.0×10^{-3} probability of recontact using the approach described in Section 2. Adding the probability of non-propulsive spacecraft and Sherpa-FX1 conjunction with a non-Sherpa-FX1 Resident Space Object increased the probability of any type of conjunction for two years to 1.015×10^{-3}, below the 2.92×10^{-3} recontact probability on Spaceflight's previous SSO-A mission