PRE-DEPLOYMENT OPERATIONS OVERVIEW

As stowed aboard the launch vehicle, the two sections of CubeSail are rigidly coupled by the separation release unit (SRU), and flexibly coupled by the solar sail film. Following a successful launch and orbit insertion of the satellite into near sun-synchronous orbit, communication with mission control will be initiated to verify satellite functionality. Next, a detumbling maneuver utilizing the magnetic torquers will commence. After detumbling, the CubeSail spacecraft will be monitored regularly until its orbit has decayed to an altitude of 350 km. This decay is anticipated to take approximately 2 years during which its instrumentation, communications, and ADCS will be tested extensively in its un-deployed state.

INITIAL DEPLOYMENT OPERATIONS OVERVIEW

Once the orbital altitude has decayed to 350 km or lower, a command is given for CubeSail to orient such that its sail will be perpendicular to Earth's surface in the long dimension, and edge-on to the ram direction, and face-on to the sun direction after deployment. Once the satellite is stable in this attitude and diagnostic data has been reviewed, the ground station will command initiation of the programmed solar sail deployment sequence, with the scheduled time for initiation specified in the command. The ground station at the University of Illinois campus is the only one that will be used to support this mission.

At the scheduled time, the sail deployment initiates and takes place from beginning to end as a programmed sequence, and does not depend on real-time ground control. Each satellite section has a unique sequence of actions which must be executed during deployment. By incorporating appropriate delays in the sequence, sensitivity to clock synchronization has been reduced. On the ground communication pass prior to the intended deployment, both satellite buses will receive clock updates. Following are the main steps in the sequence:

1. The SRU motor spins a leadscrew, to unscrew and rigidly decouple the two sections from each other. The compression springs, mounted on the payload plate, will force the two sections apart.

2. As the sections separate, the slack in the film is reduced. Once the leadscrew has fully cleared its threaded hole, the film is taught and the separation springs remain partially compressed. After an interval, oscillations induced by leadscrew clearing are damped by the springs.

3. The film bobbin motors are activated to pull the sections together using the film, thus compressing the separation springs. The force required by the bobbin motors to compress the separation springs is sensed by the circuit and converted to a rotational bobbin motor film deployment speed.

4. The bobbin motors are then activated and begin deploying film. This deploy velocity matches the separation velocity imparted by the compression springs (5 cm/s), allowing the sections to separate freely as the sail deploys. Cameras on each section of the satellite will capture images of the deployment.

5. As the film nears full deployment, the bobbin motors slow down incrementally to mitigate snapping back when the film becomes taught.

6. Following complete film deployment, the attitude of each of the two CubeSail sections, will be controlled to hold the sail such that its edge is ram-facing (and consequently, the sail will be

approximately facing the Sun). The gravity gradient will hold the sail perpendicular to Earth's surface. This ends the programmed sail deployment sequence.

7. Mission control is notified of sail deploy completion at the next opportunity. During the ensuing phase, data downloads, including health data and images, may be commanded by mission operations.

The deployment sequence has been tested extensively on the ground. Dozens of trials were performed on a four degree of freedom simulator using the flight payload hardware. The sequence was also validated during a micro-gravity parabolic flight experiment.

All flight software undergoes a peer review process. Development occurs on a coding branch, and is only merged into the flight branch after review by another team member.

Below is the timeline for the CubeSail deployment sequence described above. "T" is the pre-scheduled start time, set by a ground command.

T = scheduled deployment start time	**Event**
T + 0 min	Programmed deployment sequence begins: The SRU motor is activated and decouples the two sections from each other. The compression springs force the satellite apart.
T + 3 min	Programmed deployment sequence: The film bobbin motors pull the sections together and compress the separation springs.
T + 4 min	Programmed deployment sequence: The film bobbin motors begin deploying film at 5 cm/s. A camera on each bus captures photos of the sail during this time.
T + 44 min	Programmed deployment sequence: Deployment sequence: As the film reaches full deployment the film bobbin motors slow down.
T + 164 min	Programmed deployment sequence ends: The film is fully deployed. Utilizing their magnetic torquers the satellite sections continue to orient themselves such that the film's edge is ram facing.

MISSION CONCEPT OF OPERATIONS

CubeSail's orbit will be at 85 degrees inclination, which is a near-polar orbit. With the sail edge in the ram direction, the flat face of the sail will approximately face the sun for the entire orbit.

However, CubeSail will not raise orbit under any circumstances – even with the full face of the sail facing the sun, the drag forces from the atmosphere will overpower any forces from solar pressure, and the satellite will continue to deorbit.

After approximately 1 week of operation in the sail edge ram-facing configuration, the CubeSail sections will be commanded by mission operations to be reoriented by 90° utilizing the magnetic torquers. This will hold the sail surface ram-facing (and therefore edge-on to the Sun). The ensuing drag from the increased ram facing surface area, will cause CubeSail to deorbit in less than 0.1 years, as described in the ODAR.

CubeSail's mission success will be determined by successful (1) sail deployment, (2) attitude control of the two individual sections of CubeSail, and (3) deorbit.

CONJUNCTION PREDICTION AND COLLISION AVOIDANCE

CubeSail is registered on Space-Track with 18 SPCS. 18 SPCS screens every satellite at least every 24 hours for potential conjunctions. CubeSail will notify 18 SPCS when sail deployment is scheduled to commence, when sail attitude is scheduled to be modified from edge ram facing to sail face ram facing, and any other configuration changes that may occur.

Should a conjunction be predicted, CubeSail may be commanded to change the sail orientation, thus changing its drag profile and significantly changing its rate of velocity change.

Upon prediction of a potential conjunction between CubeSail and another object, 18 SPCS will send, and the CubeSail team will receive, emergency notifications in accordance with 18 SPCS's practices. Should such a notification occur, the CubeSail team will coordinate with the mission operators of the other spacecraft which is at-risk, if it is a spacecraft. **To contribute to conjunction risk mitigation, the following options are available to CubeSail** and may be coordinated with the other object's operator:

1) If the sail is in a *high-drag configuration*, it can be turned to a low-drag configuration, *reducing the rate of descent, therefore* ***entirely changing CubeSail's forward orbit*** and avoiding the conjunction opportunity, given sufficient time
2) If the sail is in a *low-drag configuration,* it can be turned to a high-drag configuration, *increasing the rate of descent, therefore* ***entirely changing CubeSail's forward orbit*** and avoiding the conjunction opportunity, given sufficient time

By adjusting the drag of CubeSail, the effect of the atmosphere will either increase or decrease, which inturn speeds up or slows down the descent. With the low-drag "edge-on" configuration, CubeSail will maintain its current orbit like a regular satellite; however, while in the "face-on" high drag configuration, it will see a slow descent through the atmosphere.