DiskSat: A Large-Aperture Containerized Satellite

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CubeSats and the Small-Satellite Revolution

The power of "containerization"

Containerization of terrestrial shipping

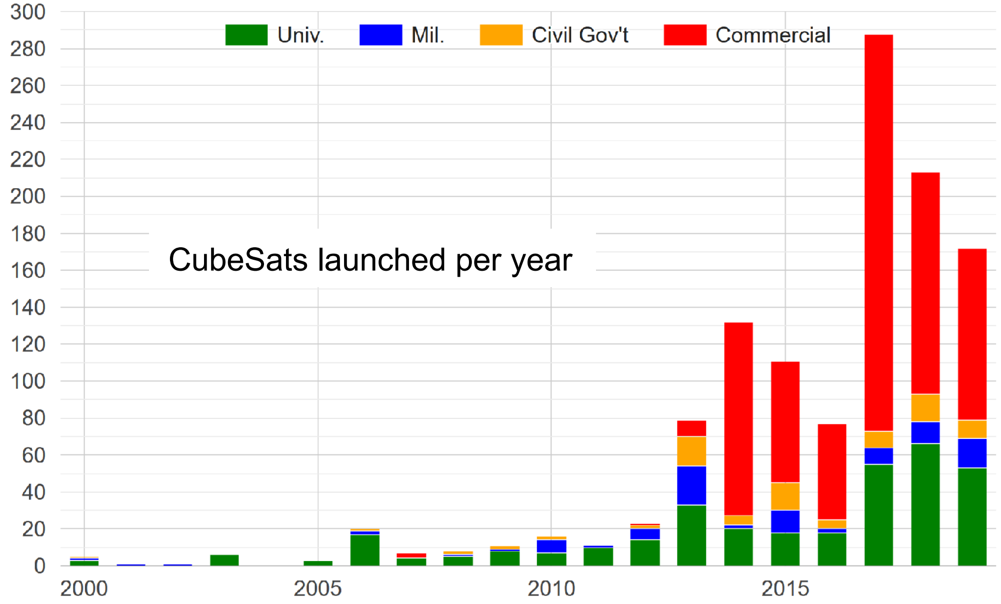
Images courtesy U.S. DOT

- CubeSats revolutionized the small satellite industry through containerization, just as containerization revolutionized terrestrial shipping
  - *Containerization simplifies the interface and protects the host, enabling inexpensive rideshare*
  - *In 20 years, over 1100 CubeSats have been launched worldwide*
  - *CubeSats have flown on at least 20 different launch vehicle types*
- CubeSats are rigidly constrained by the volume of the container
  - Limits on power and aperture, even with complex deployables

Containerization
→ Reduced launch risk and simplified interface
→ Inexpensive rideshare
→ Frequent and flexible launch
→ Commercial expansion
→ Mass production

PSSCT-2 leaving dispenser on STS-135

Image courtesy NASA



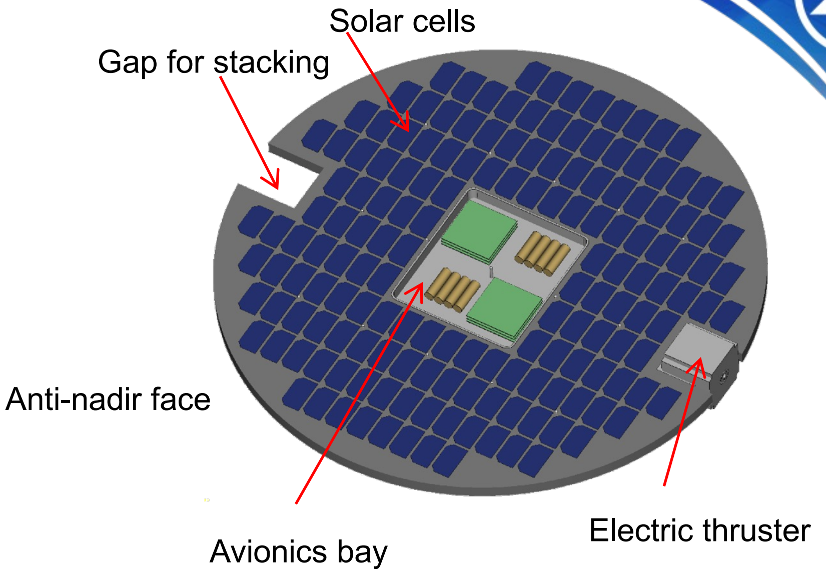
Data from M. Swartwout

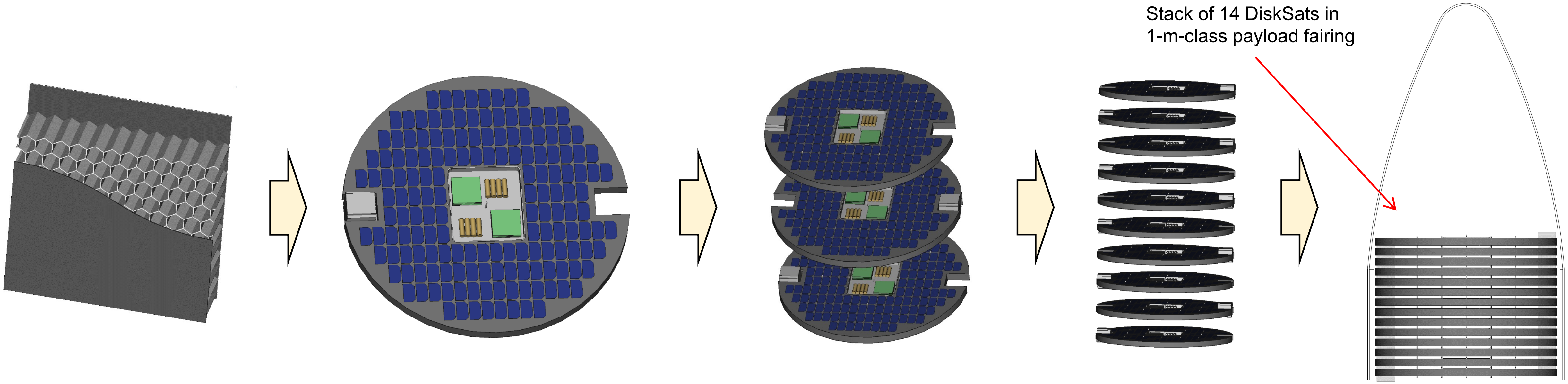
How to get the benefits of containerization without the limitations of CubeSats?

Out-of-the-(CubeSat)-Box

DiskSat – Containerization in an Alternate Form

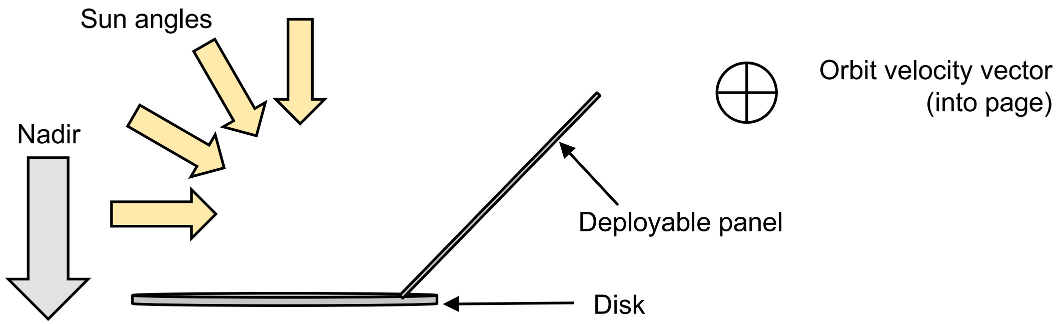
- Efficient shape: thin disk 1 meter diameter, 2.5 cm thick
  - *Large surface area for power and aperture without deployables*
  - *Volume equal to ~20U CubeSat*
- Stackable for containerization
  - *Sized to stack in 1-m-class payload fairing*
- Simple, low-mass construction
  - *Graphite/epoxy composite sandwich – mass < 3 kg/m²*
  - *Satellite components distributed throughout internal volume, or in a central avionics bay*

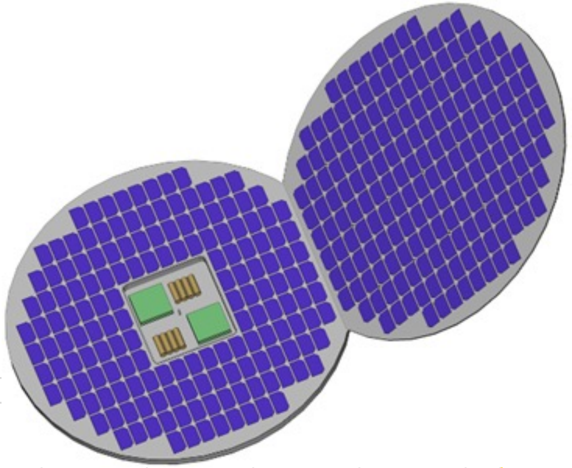


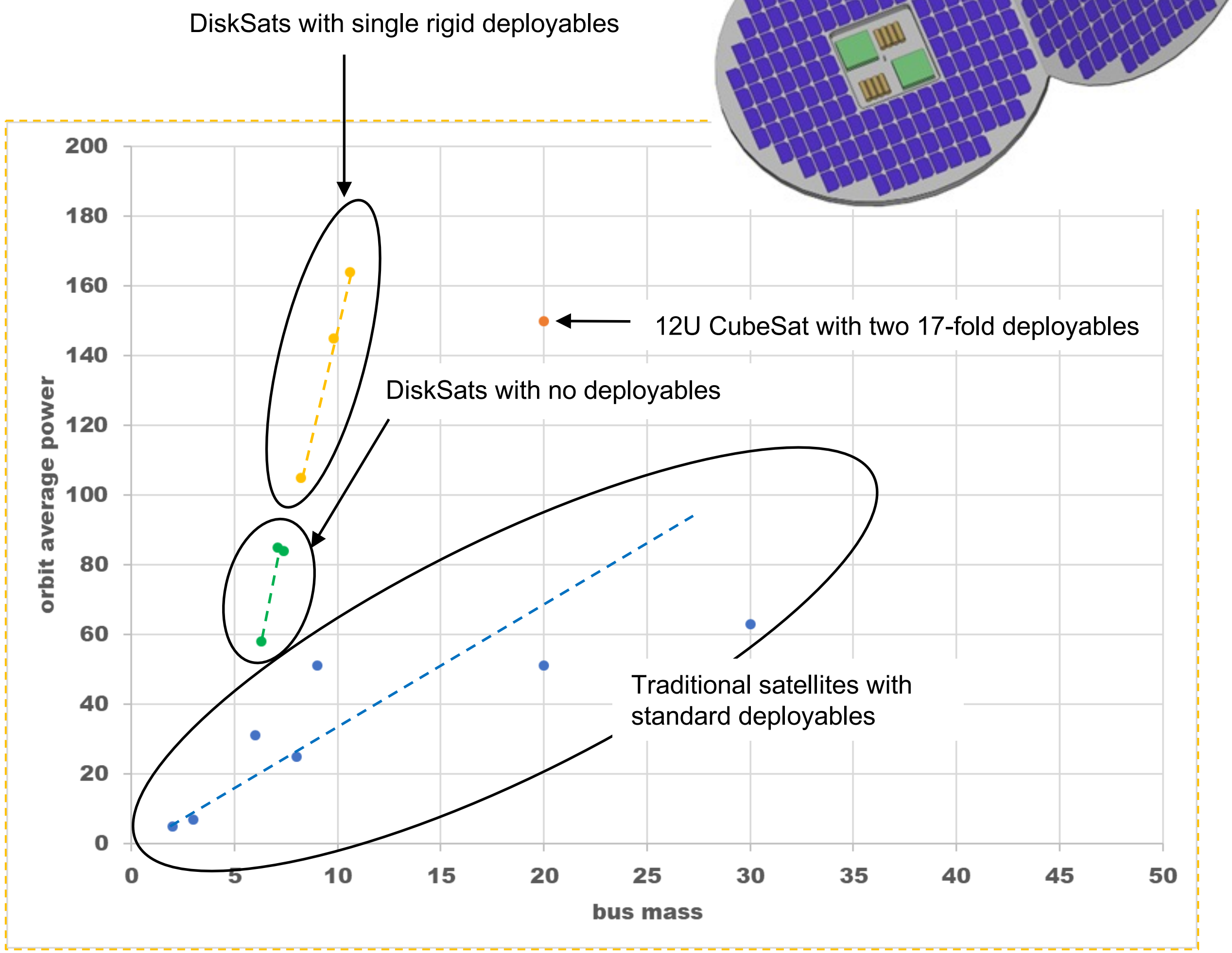


DiskSat Power Budget

- DiskSat achieves high power-to-mass ratio without complex deployable solar panels
  - *1 m diameter has surface area of 0.79 m^2 and can hold 200 W of high-efficiency solar cells*
  - *Alternatively, can host over 120 W of low-cost, moderate-efficiency cells*
- Optional deployed panel
  - *A simple rigid solar panel deployed on a single-hinge doubles surface area for little mass penalty*
  - *At ~30 degrees, the deployed panel ensures steady orbit average power independent of solar beta angle*
- Thermal management is also simplified because the large surface area allows for sufficient area dedicated to heat dissipation without substantially interfering with power collection





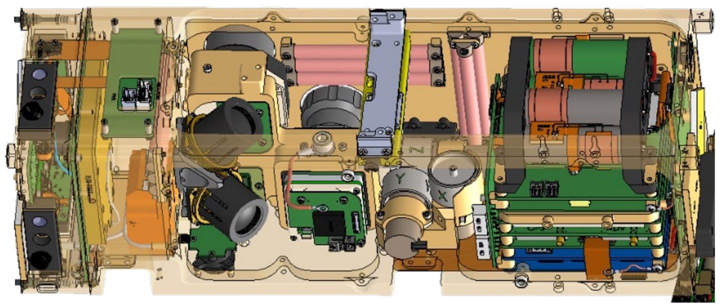


Typical orbit-average power available from various satellite bus designs assuming comparable LEO orbits

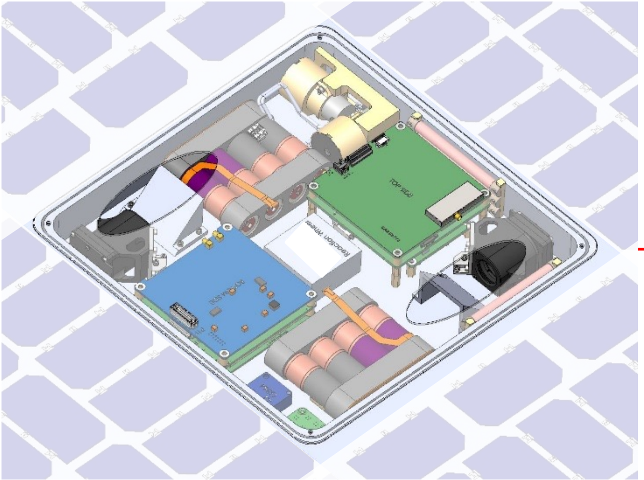
Volume Budget and Manufacturability

DiskSat Compared to a CubeSat

- DiskSats are mass limited, but have large volumes
  - a 2.5 cm thick x 1-m diameter DiskSat has a volume seven times the volume of 3U a CubeSat
- Extended layout and increased volume reduce unit cost compared to a CubeSat
  - *Simplifies mechanical structures*
  - *Eliminates complex harness routing*
  - *Simplifies post-assembly functional testing and component R&R*
  - *Increased surface area simplifies thermal management*

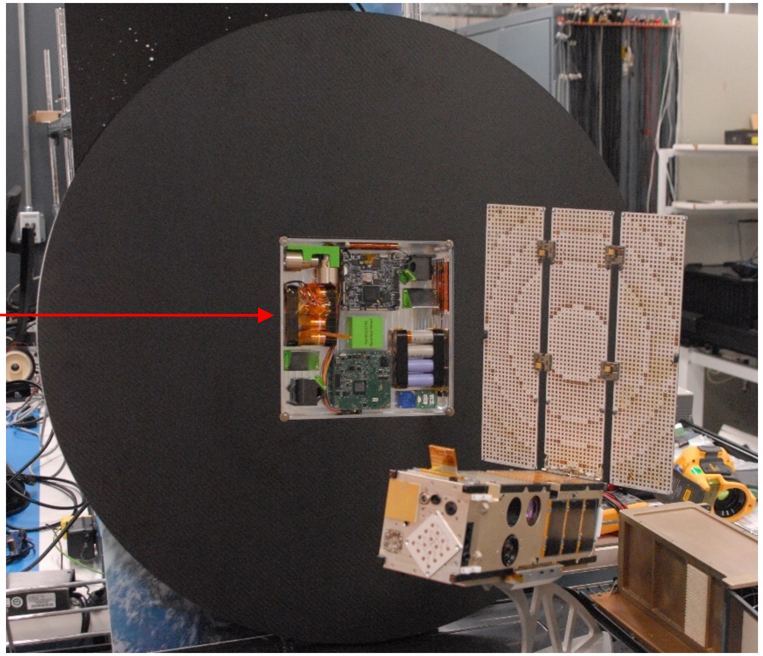


Interior layout of ISARA 3U CubeSat (2017)



ISARA avionics notionally reconfigured into a DiskSat "chassis box"

The ISARA 3U CubeSat (with deployed antenna) next to a notional 3U-equivalent DiskSat



The DiskSat is an efficient approach to building and deploying constellations of very small satellites

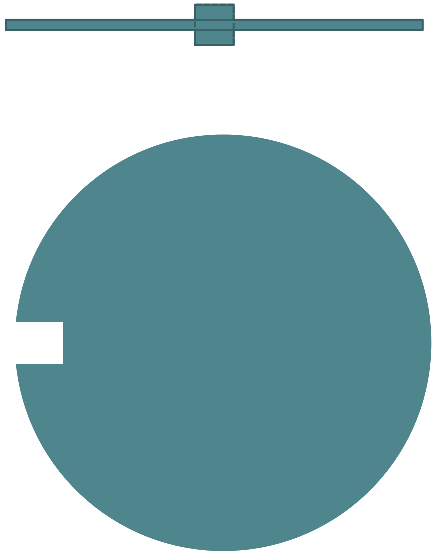
Orbit Raising, Orbit Maintenance, Maneuverability

DiskSat has unparalleled "orbit agility" when coupled with electric propulsion

- Commercially-available flight-proven EP systems can provide over 4000 m/s delta-v for a 10-kg DiskSat
- DiskSat has a uniquely high power/mass ratio without the complexity of deployables
- Applications
  - *Orbit raising*
    - Initial deployment at lower altitude increases launch payload mass
  - *Orbit maintenance*
    - Less than 10 m/s/year delta-v maintains 600 km orbit
    - 800 m/s/year delta-v combined with low drag of DiskSat enables sustained flight in 250 km orbit
  - *Rapid rephasing of constellations*
  - *De-orbit at end of life*
    - Non-functioning satellites will tumble, leading to rapid de-orbit and automatically limiting orbital debris
  - *Cis-Lunar space*
    - <4000 m/s delta-v required for transfer from GEO to lunar orbit
    - Other orbits in cis-Lunar space reachable with comparable delta-v

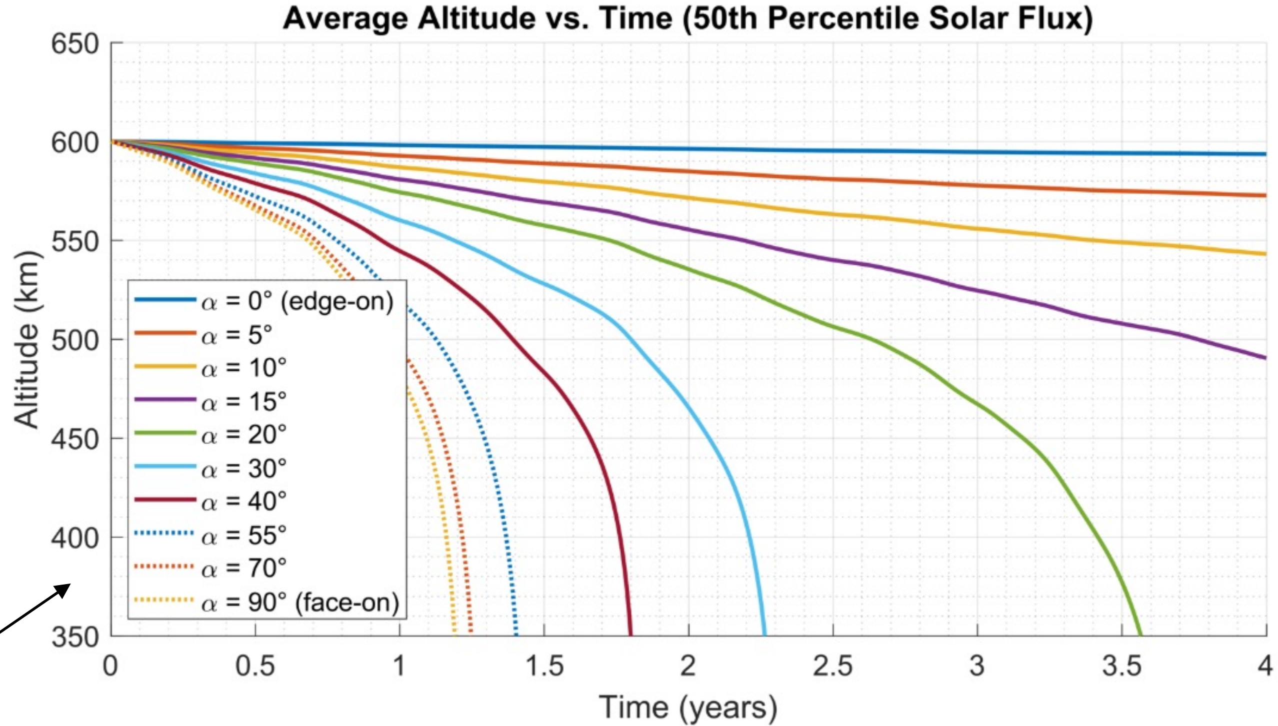
Low drag for VLEO operations

$322\ cm^2$ cross section



High drag for rapid deorbit

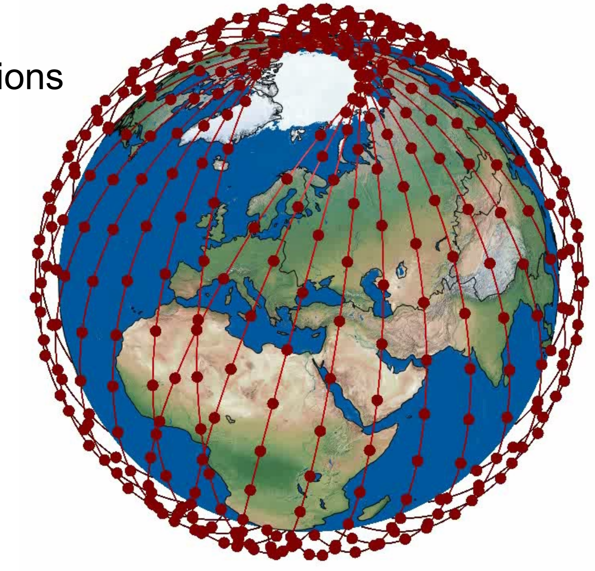
$7700\ cm^2$ cross section

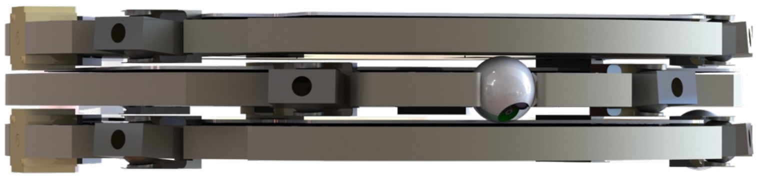


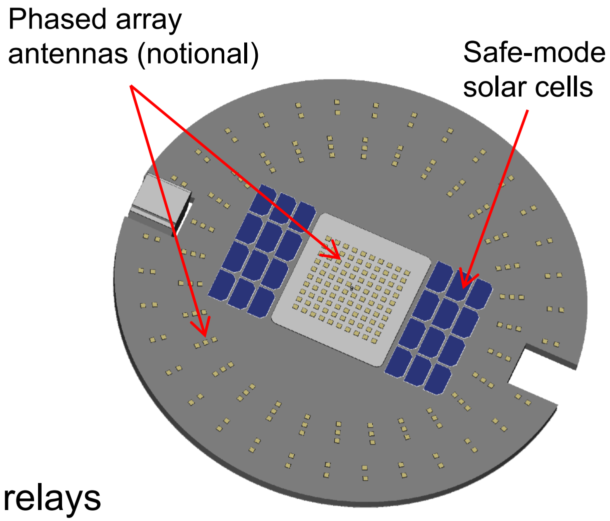
Deorbit with propulsion or enhanced drag

Potential DiskSat Applications

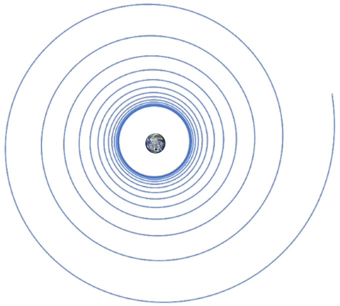
- Constellations
  - *Ideally suited to populating well-structured constellations of large-aperture, low-mass satellites*
  - *Efficient small-launch-vehicle packing*
  - *One orbital plane per launch*
  - *Or two or three planes per launch with low-altitude dispensing and differential precession*
- Missions requiring large apertures
  - *Communications, radar, etc.*
- Missions requiring high power
  - *Radar, high-power EP, etc.*
- Missions requiring large delta-v or continuous thrusting
  - *Low-altitude thermosphere ("Ignorosphere") characterization (160-300 km)*
  - *Low-altitude (high-resolution) imaging*
  - *Orbit raising and orbital agility*
  - *Cis-lunar space – self-propelled from GEO to lunar orbit*
- Low-budget missions with components too large for a CubeSat
  - *In rideshare, a 1-m-class DiskSat should have launch costs comparable to a 3U CubeSat*


Well-structured constellations





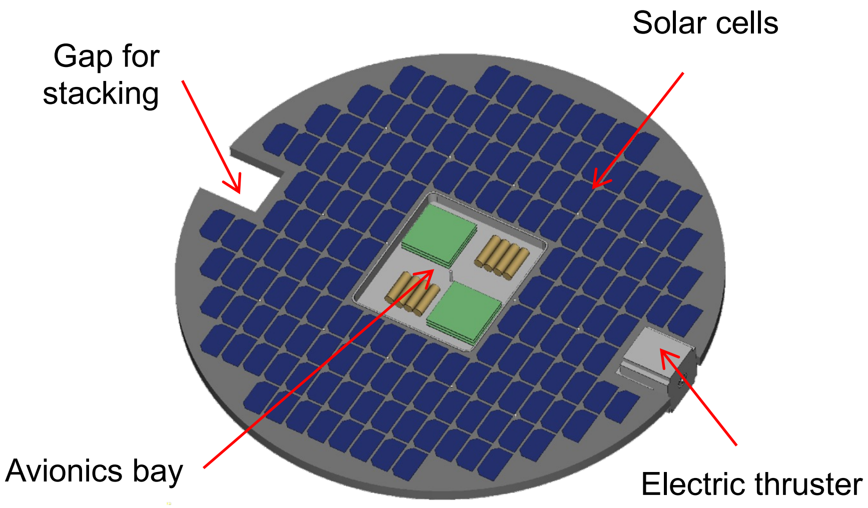
Communications relays


Earth-escape trajectories

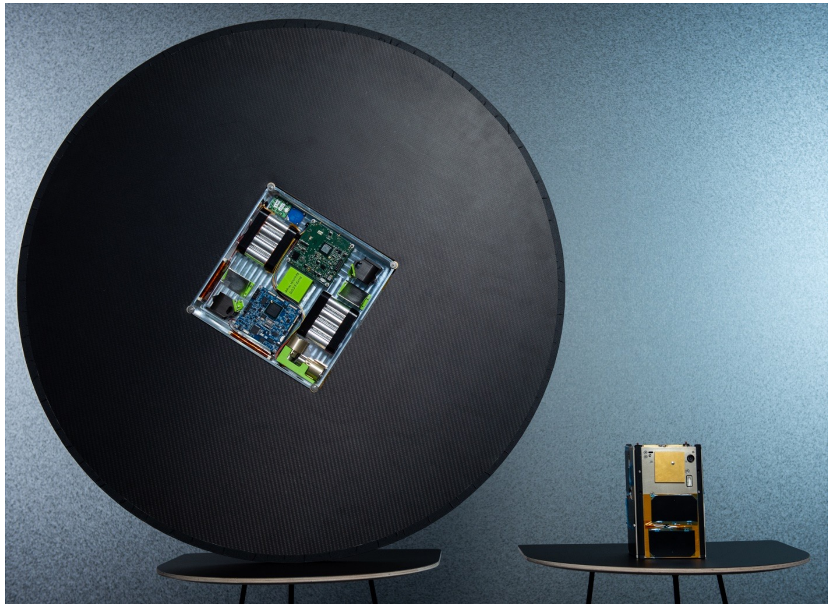
Demonstration Mission

First flight of DiskSat

Notional demonstration mission satellite with propulsion



Mockup of a 1-meter DiskSat next to a 1.5U CubeSat



Description:

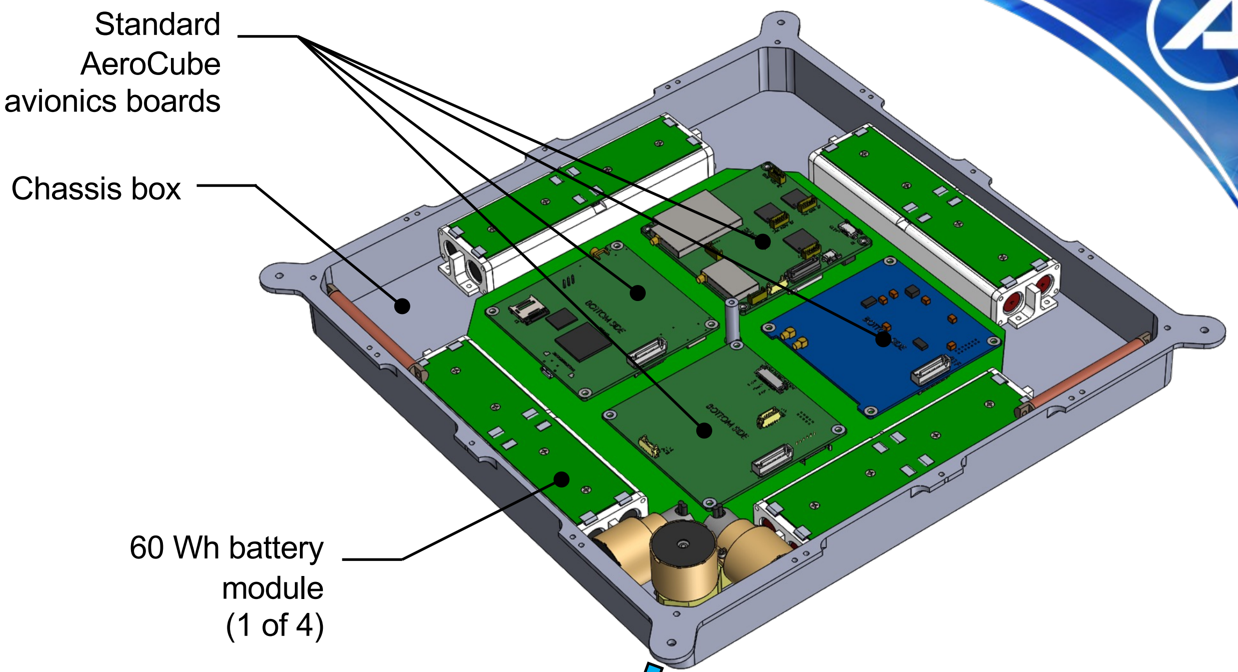
- Fly four first-of-their-kind "DiskSat" satellites at increasingly lower altitudes, equipped with electric propulsion
  - *DiskSat: 1 m diameter, 2-3 cm height*
  - *Fly in edge-on orientation for extremely low drag*
  - *Fly 2 vehicles in circular orbit at ≤250 km altitude*
  - *Fly another 2 vehicles in elliptical orbit with perigee <200 km*
- Two-dimensional form factor provides large surface area for ~200 W peak power in 10 kg package
- Experiment goals:
  - *Demonstrate performance/utility of DiskSat form factor*
  - *Demonstrate multi-satellite deployment with complementary Dispenser*
  - *Demonstrate generation of 200 W peak power*
  - *Demonstrate maneuverability and flight in VLEO*
- Status
  - *DiskSat structure/avionics conceptual design complete*
  - *DiskSat stack vibration testing started*
  - *Dispenser conceptual designs being evaluated*
- Maturity level:
  - *DiskSat: **medium maturity –** heritage avionics and subsystems flown on multiple previous missions, integration into disk form factor is new*
  - *Dispenser: **low maturity –** new development for containerization and deployment of DiskSats*

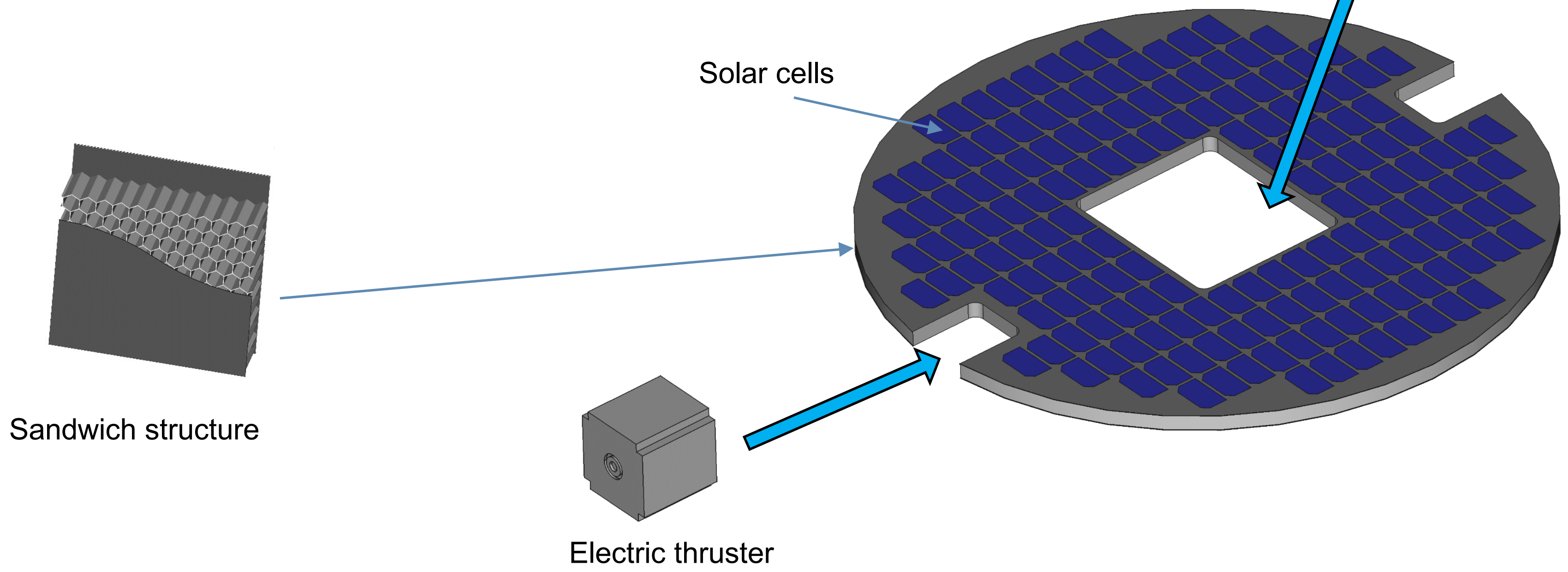
- First flight anticipated in FY 2024

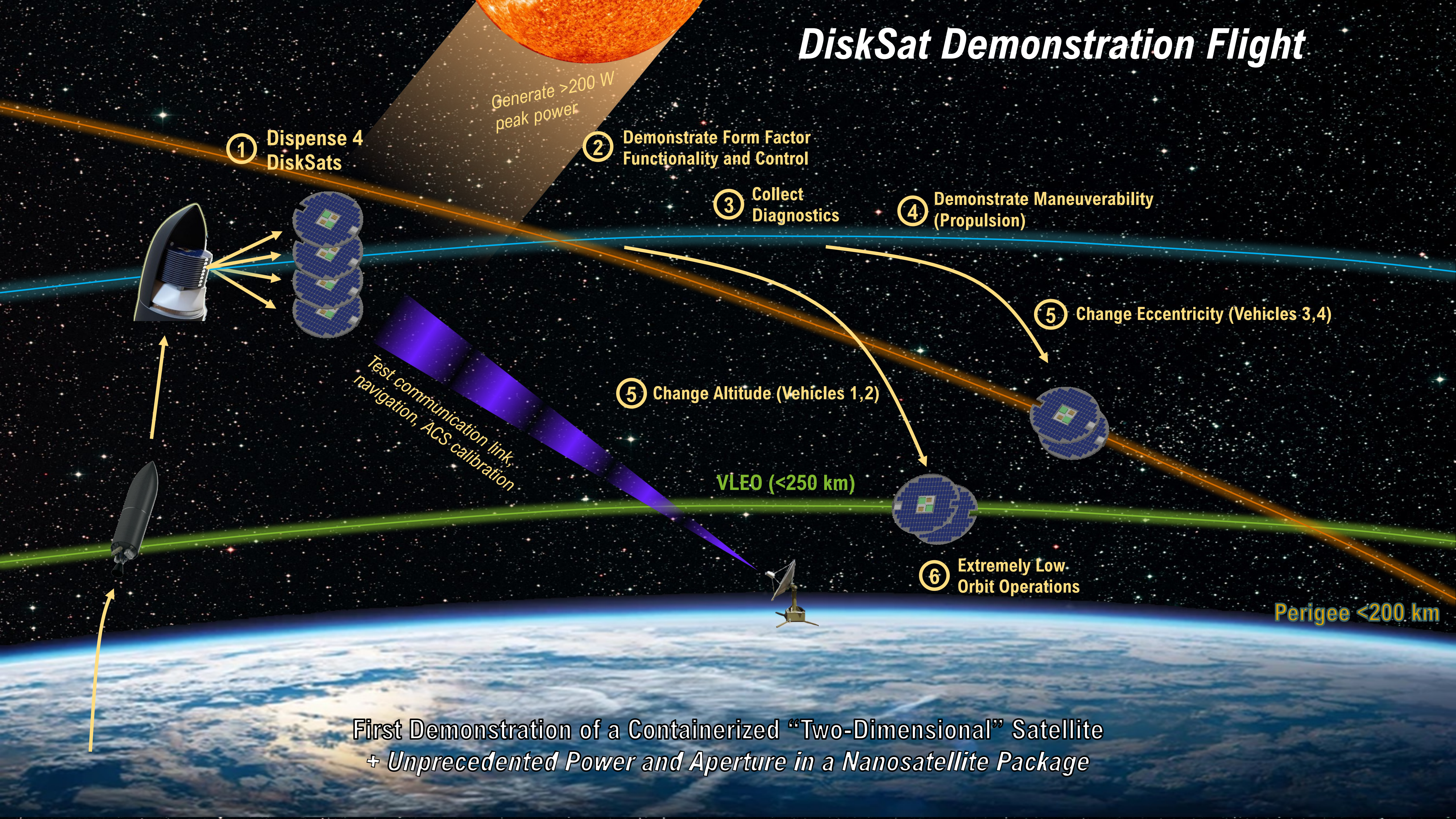
Mission Overview

Spacecraft

- Structure: composite sandwich with aluminum honeycomb core and graphite/epoxy face sheets
- Avionics in central chassis box derived from AeroCube avionics suite
- Electric propulsion
- Power: >150 W solar cells on one face
- Three-axis attitude control using reaction wheels and magnetic torque rods



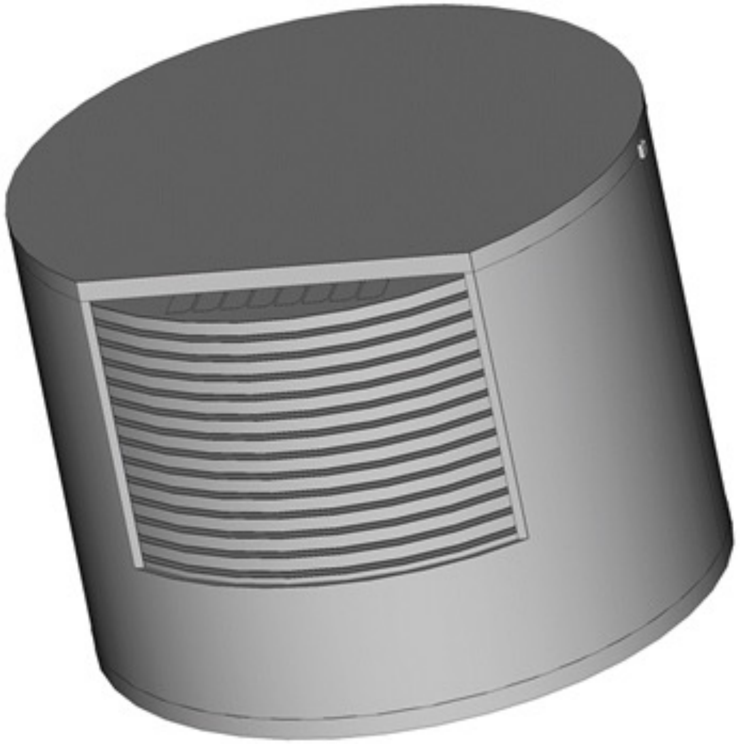



DiskSat Demonstration Flight
Generate >200 W peak power
1 Dispense 4 DiskSats
2 Demonstrate Form Factor Functionality and Control
3 Collect Diagnostics
4 Demonstrate Maneuverability (Propulsion)
5 Change Eccentricity (Vehicles 3,4)
Test communication link, navigation, ACS calibration
5 Change Altitude (Vehicles 1,2)
VLEO (<250 km)
6 Extremely Low Orbit Operations
Perigee <200 km
First Demonstration of a Containerized "Two-Dimensional" Satellite
+ Unprecedented Power and Aperture in a Nanosatellite Package

DiskSat Dispenser

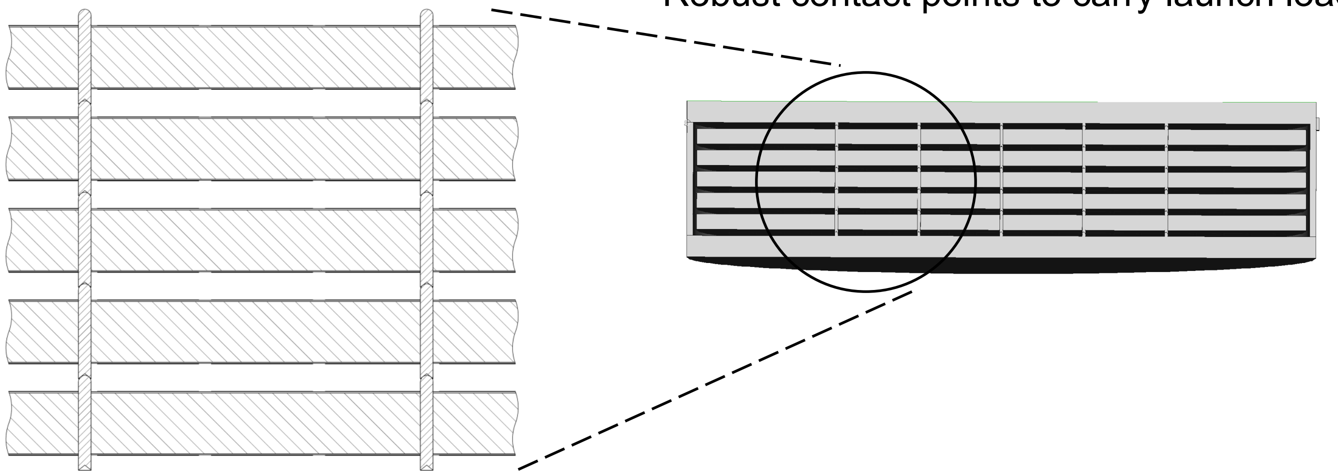
Conceptually Modeled on CubeSat Dispenser

- Requirements
  - *Support satellites against launch loads*
  - *Containment to protect primary*
  - *Eject satellites one at a time after launch*
    - Simultaneous release as used in CubeSats could be problematic with large stacks of disks
- Approach
  - *Separate launch loads from the ejection process*
  - *Transfer launch loads through disk stack directly to cannister*
  - *Dispenser mechanism is loosely coupled to disks during launch and does not carry launch loads*
  - *Single mechanism to lift stack and deploy top disk one at a time*

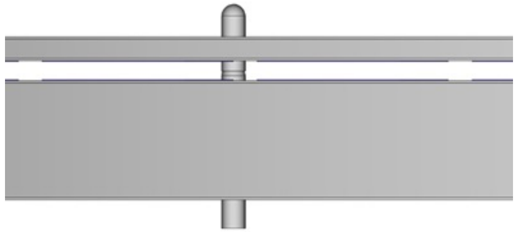


Launch container (cutaway)

Robust contact points to carry launch loads

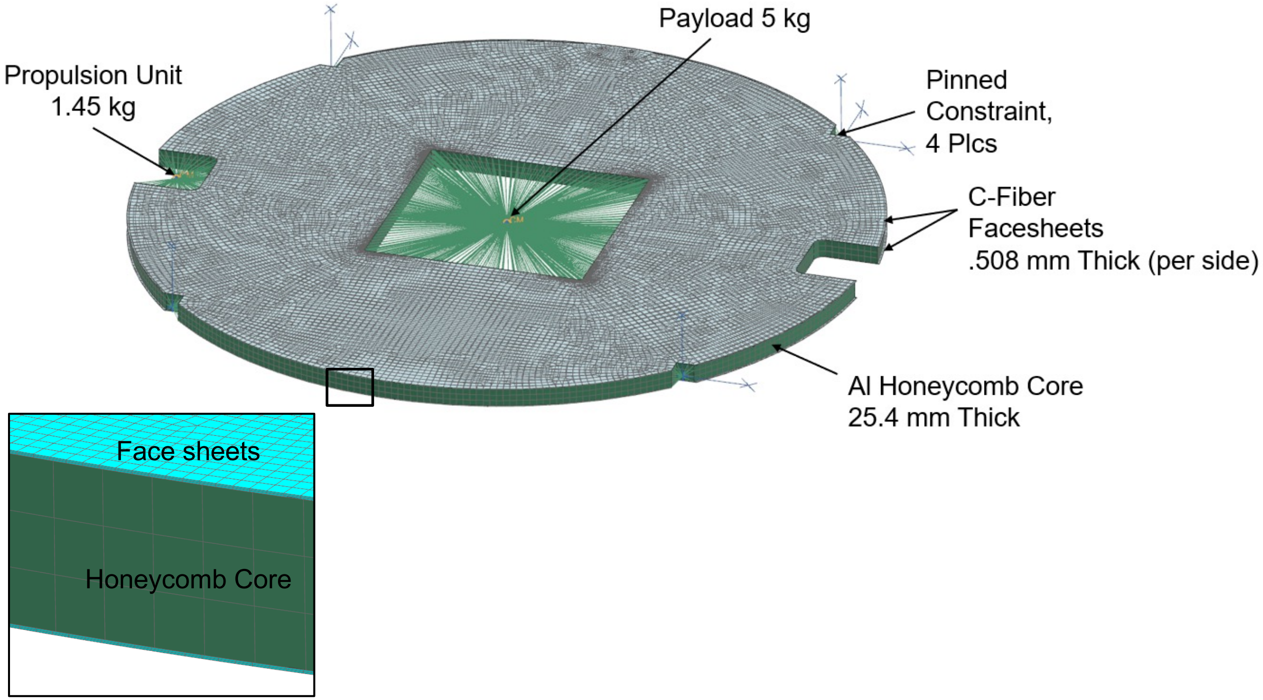


Secondary load pins in deployable panels

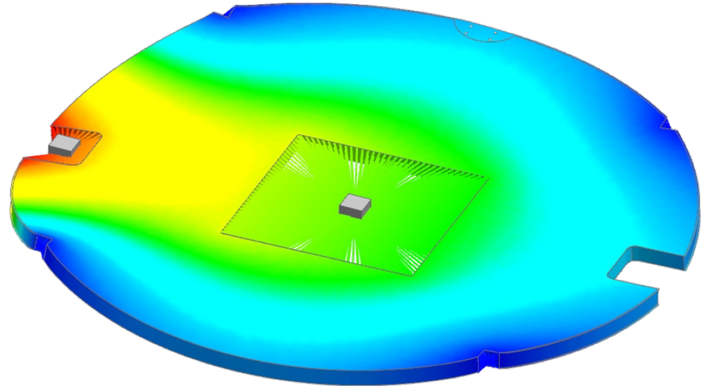


Structural Analysis

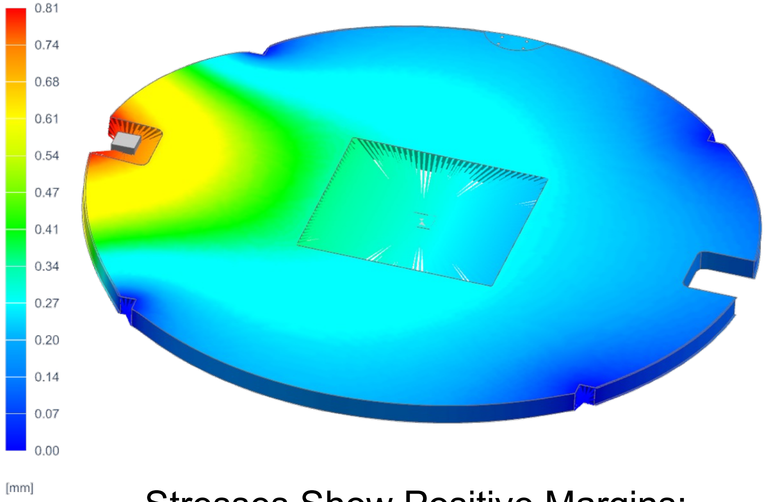
Trades on Materials, Thickness, Edge Support



1st Mode 121 Hz



Maximum deflection < 1 mm under 42.3g load



Stresses Show Positive Margins:
Face-sheet Stress < 69 MPa, Max Core Shear Stress ~ 0.69 MPa

Sandwich Panel Materials Can be “Tuned” to Control Stiffness

Main Parameters:
- Face-sheet Material: Carbon-Fiber vs. Aluminum
- Carbon-Fiber Modulus
- Face-sheet Thickness
- Honeycomb Density, Cell Size, Thickness

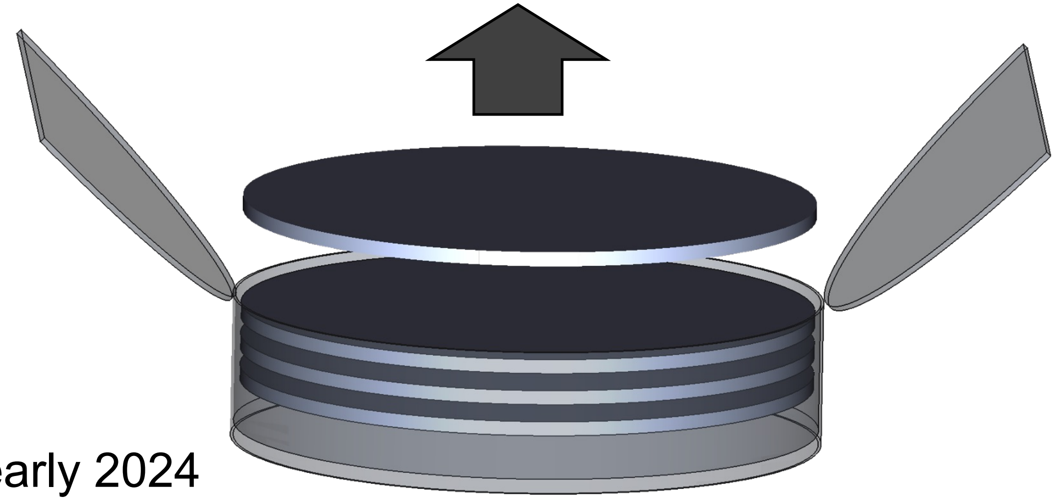
DiskSat is very stiff, can be supported along edges without internal support

Next Steps

- Dispenser development
  - *Eliminating the need for internal disk-to-disk support opened the trade space for DiskSat dispensing mechanisms*
  - *Alternatives being evaluated, preliminary designs under way*
  - *Detailed design and testing in FY 23*
  - *Flight hardware delivery in late 2023*
- DiskSat development
  - *Detailed design and build*
  - *Four flight units ready in late 2023*
- Launch through Space Test Program, aiming for late 2023 or early 2024

- Development and publication of a DiskSat standard

- Facilitating future shared DiskSat flights



DiskSat Standard

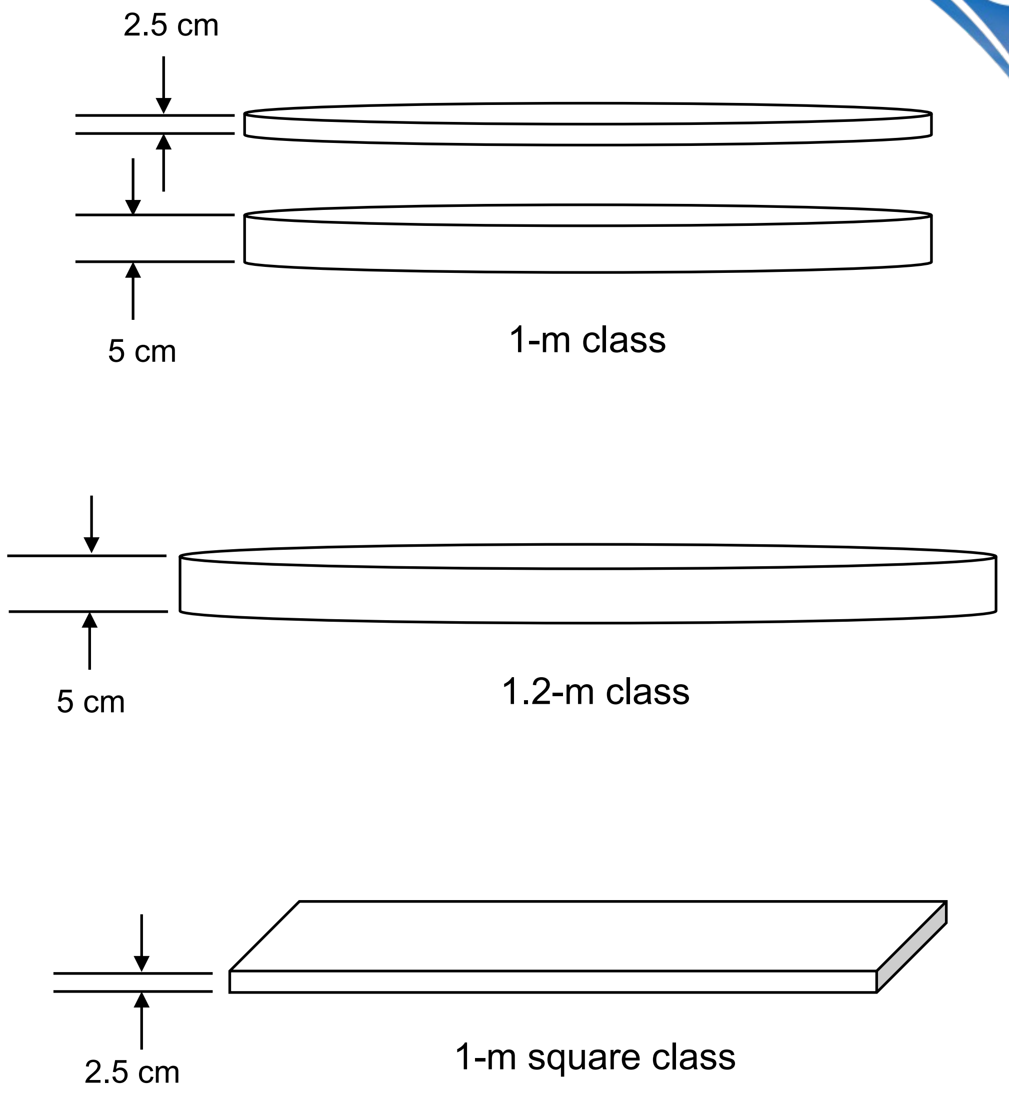
Modeled on CubeSat Standard

- Goals
  - *Standard interface with launch vehicle (containerization)*
  - *Safety of flight (rideshare)*
- Interface definition will incorporate dimensions and loads, but will not necessarily specify materials
- Safety of flight requirements will parallel CubeSat standard
  - *Electrical system powered off until after satellite deployment*
  - *Battery protection*
  - *Hazardous materials limits*
  - *Testing requirements*
  - *Deployable components (solar panels, antennas, etc.) constrained until after satellite deployment*
- Dispenser interface design goals
  - *Simplicity*
  - *Reliability*
  - *Commonality across DiskSat classes*

DiskSat Standard

Degrees of Freedom

- DiskSat classes
  - *Based on diameter or other lateral dimensions*
  - *Sized to make maximum use of available launch volume*
- Multiple DiskSats of the same class can be stacked together for launch
- Each class will have class-specific constraints
  - *Lateral dimensions (and tolerances)*
  - *Minimum thickness (required for dispenser interface)*
  - *Location and design of dispenser interfaces*
  - *Maximum mass per unit thickness*
  - *Center of mass offset limit*
  - *Maximum deflection under launch loads*
- Initial classes:
  - *1-m circular (demonstration flight)*
  - *1.2-m circular*
- Additional classes to be defined as needed



Summary

Containerization outside the CubeSat box

- Aerospace is developing a new paradigm for satellite form factor: DiskSat
  - *"Two-dimensional" bus architecture is low mass and has large aperture without deployables*
- Form factor offers unique capabilities in a 10–20 kg package:
  - *Large surface area for high power and RF apertures*
  - *Large total volume for accommodating payloads*
  - *Large ΔV via electric propulsion for maneuvering, altitude changes, or even cis-lunar missions*
    - Enables very-low-altitude operations (<250 km) via low-drag edge-on flight
- Diverse mission applications:
  - *Large constellations*
  - *RF receivers and transmitters*
  - *Radar*
  - *High power*
- Demonstration mission under development
  - *Fours satellites and dispenser scheduled for delivery in late 2023, flight in 2024*
- DiskSat standard being prepared
  - *Modeled on CubeSat standard*
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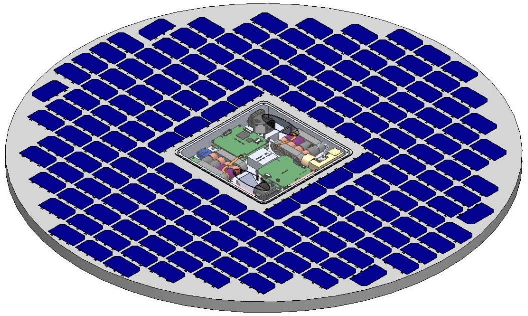

100 cm dia (166 W installed)

Aerospace is soliciting input from potential launch providers and users on defining the DiskSat standard

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