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Design of a 98U CubeSat Deployer Optimized for Dedicated Rideshare Missions: Reducing the Costs of Launching a CubeSat by 4x

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Abstract

The advent of dedicated rideshare missions, pioneered by Spaceflight Industries and picked up by SpaceX, Arianespace, and others, has altered the equation of launching a small satellite into orbit. Multiple launch companies have recently announced the sale of fixed-price launch slots directly to customers. However, these launch slots are in the minisatellite range of 100-200 kg, and thus unsuitable for smaller payloads such as CubeSats and PocketQubes. We present a CubeSat deployer, the Skyliner, optimized for 200 kg 15" ESPA-class launch slots. Rather than an aggregation of smaller deployers in tandem, this dispenser is produced as a unified structure, designed to maximize the reduction of marginal cost per CubeSat to orbit. Our architecture allows up to 98Us of CubeSat to be launched together, in a design capable of accommodating multiple extended 12U and 16U CubeSats in a single slot, while maintaining panel access for each satellite. The Skyliner deployer is designed to enable routine, airline-like fixed-price access for CubeSats, as opposed to the current broker model. With the pricing of SpaceX dedicated launch opportunities, Skyliner can reduce marginal costs of launching a CubeSat to under 15,000, opening up potentially revolutionary opportunities in space.

Keywords: Deployer, CubeSat, SmallSat, Rideshare, Picosatellite, Nanosatellite

Acronyms/Abbreviations

J-SSOD – Japanese Small Satellite Orbital Deployer
NRCSD – NanoRacks CubeSat Deployer
HDRM – Hold-down and Release Mechanism
P-POD – Poly Picosatellite Orbital Deployer
NLAS – Nanosatellite Launch Adapter System
SSO – Sun Synchronous Orbit
ESPA – EELV Secondary Payload Adapter
EELV – Evolved Expendable Launch Vehicle
PSLV – Polar Satellite Launch Vehicle
ION – InOrbit NOW
SSMS-PoC – Small Spacecraft Mission Service Proof of Concept

1. Introduction

In the past decade, CubeSats have gone from mere academic toys to a venerable instrument of scientific research, government use, and commercial industry. Constellations comprising hundreds of CubeSats have been launched by private organizations that are now valued at upwards of $1 billion dollars. These facts are well known.

Unfortunately, during this time the cost of launching these CubeSats into space, the final and most crucial step in any successful mission, has more than doubled.

In 2006, launching a 1U CubeSat aboard a Russian Dnepr rocket, a converted R-36 Sarmat ICBM, cost $40,000 USD [1]. At the time, no commercial US-based launched for CubeSats were available.

In 2011, NanoRacks began offering US-based CubeSat launch and deployment from the International Space Station, first from the Japanese Small Satellite Orbital Deployer (J-SSOD), and later from the dedicated NanoRacks CubeSat Deployer (NRCSD). The introductory price for this service was $53,000 USD when first introduced.

Several factors contributed to this price increase. The Dnepr rocket was reliant on a stock of Soviet ICBMs and stopped flying in 2014, heralding the end of the era of Russian dominance in CubeSat launches. American launchers rapidly dominated the market, easing export problems for satellite developers, but also bringing with them more stringent payload restrictions and testing requirements. This entailed a longer, more rigorous, and far more expensive testing and qualification campaign for the CubeSat deployers. That in turn also necessitated the replacement of the most crucial component of the CubeSat deployer, the Hold-down and Release Mechanism (HDRM), which constrains the door of the deployer and contains the payloads until the release signal is given.

For the original iteration of the Poly Picosatellite Orbital Deployer (P-POD), the first standardized CubeSat deployer, a Planetary Systems Vectran Line Cutter, a single-use burnwire mechanism, was used [2]. While custom burnwire mechanisms continue to be used by deployers such as the popular ISIS QuadPack, the Vectran Line Cutter was deemed unacceptable to fly on US launch vehicles. More recent iterations of the P-POD and the subsequent Nanosatellite Launch Adapter System (NLAS) originally developed by NASA Ames and later refined by Tyvak, replaced it with a resettable, non-destructive pin-puller [3].

While providing reusability and increased reliability, commercial pin-pullers, such as those developed by TINI Aerospace, often cost upwards of $10,000 USD each. This resulted in the increased cost of the deployer, which combined with the greater cost and complexity of qualification, drove up the price of launch. With no competition from obsolete Russian ICBMS, the space industry eventually settled around the $80,0000 USD price point, with no incentive from any player to drive the costs down.

This unchecked cost growth subsequently hindered the grassroots nature of the CubeSat launch community, blocking out the "scrappy" experimentation of the early days in favor of larger-scale government-run missions. It has also limited the number of large-scale constellations that could be launched, limiting it to a handful of companies that have raised hundreds of millions of dollars.

2. Reducing CubeSat Launch Costs

In addition to deployer, testing, and integration costs, the primary factor for the cost of a CubeSat launch is the cost per Kg to orbit of the launch vehicle, as displayed in Table 1.

Table 1. Cost per Kg to LEO of 2020 major launch vehicle families

Rocket	Country	Capacity	Price	Cost/Kg
Falcon 9	USA	22.8t	$50M	$2,192
Atlas V	USA	20.5t	$107M	$5,219
Vega	Europe	1.96t	$37M	$18,848
PSLV	India	3.8t	$18M	$4,736
Soyuz	Russia	8.2t	$35M	$4,268
Electron	USA/NZ	0.3t	$6M	$20,000

The Falcon 9, benefiting from a large payload capacity and a partially reusable architecture, is by far the most cost-efficient launch vehicle, while the Electron is the least. However, the gross cost per kg to orbit does not necessarily translate directly to CubeSat launch cost, since to purchase rideshare slots customers may be required to negotiate through rideshare brokers that may charge their own prices.

3. Falcon 9 Rideshares

In 2019, SpaceX announced the sale of small satellite launches directly to consumers aboard the Falcon 9, without the need to rideshare brokers. This service is transparently priced at $5,000 per kg to SSO, with a minimum order of $1M USD, or 200 kg.

Customers are provided with an EELV Secondary Payload Adapter (ESPA) slot, an industry-standard attachment port for secondary payloads initially pioneered aboard the Atlas V and Delta IV Evolved Expendable Launch Vehicles (EELVs). ESPA is a ring-shaped port available in both a standard 15" (shown in Figure 1) and a larger 24" ESPA Grande size capable of supporting larger masses and payload volumes. The Moog ESPA User's Guide allots 24" x 28" x 38" of volume for a 15" ESPA ring, and 42" x 46" x 56" for a 24" ESPA Grande ring, assuming a 5-meter payload fairing [4].

Figure 1. An ESPA payload adapter with 6 15" mounting rings

SpaceX's announcement slashed costs among the industry and led to several CubeSat launch providers reducing their prices to below even 2006 levels. However, the capability of CubeSat launch providers to utilize this development to reduce prices to the maximum extent is hindered by the fact that none of the current existing deployers have been designed to take advantage of the full volume and mass offered by SpaceX rideshare launches.

4. CubeSat Deployment Systems

Many companies and organizations, mostly based in North America and Europe, develop CubeSat deployers. These range from the original P-POD, which deployed the first CubeSats, to the venerable ISIS QuadPack, which was famously used on the record-breaking PSLV C-37 launch, which deployed 103 small satellites, including 88 Doves built by private company Planet Labs, in addition to the primary payload of PSLV C-37.

The majority of deployers come in only a small amount of sizes, most commonly 3U, 6U, and 12U, but 1U, 2U, and 16U sizes are also available. The major deployers most often used to launch CubeSats today are displayed in Table 2. They represent the systems most commonly used by commercial and government customers to launch their CubeSat payloads into space.

Table 2. Major CubeSat deployers, their manufacturers, and their available capacities

Manufacturer	Deployer	Capacity
Cal Poly	P-POD	3U
ISIS	ISIPOD, DuoPack, QuadPack	1U, 2U, 3U, 6U, 12U, 16U
ExoLaunch	EXOpod	12U. 16U
Tyvak	RailPod, NLAS, etc.	3U, 6U, 12U
Astrofein	PSL, PSL-P	1U, 2U, 3U, 12U
Planetary Systems	CSD	3U, 6U, 12U

Despite the diversity of their manufacturers and designs, from rails to tabs to sheet metal bodies, none of these deployers come close to taking advantage of the full volume and mass limits of the ESPA-class specification. With CubeSats generally having a mass of between 1-2 Kg, even 16 of them will at most take up only 16% of the 200 kg allotted to SpaceX ESPA secondary payloads.

5. Mass Deployment Systems

In order to solve this problem and fully maximize the possible price reduction of CubeSats to orbit, new systems are needed that are designed to accommodate as many CubeSats as possible on a single ESPA port. Several such systems have been proposed, designed, or built for both ESPA and ESPA Grande specifications.

The earliest such system, the Naval Postgraduate School CubeSat Launcher (NPSCuL), was developed beginning in 2007. It was designed to fit on an ESPA port and consisted of a mechanical structure and a sequencer designed to mount 8-10 P-PODs [5]. The largest version of this deployer was designed to contain up to 50Us, but this necessitated the use of 1x5U P-PODs, which were never built. The flown version (Figure 2) carried 8 standard 3U P-PODs and was capable of carrying only 24Us. Part of the decision to fly this smaller version was the choice smaller Aft Bulkhead Carrier (ABC) on the back of the Centaur upper stage, instead of an ESPA adapter inside the primary fairing of the rocket [6].

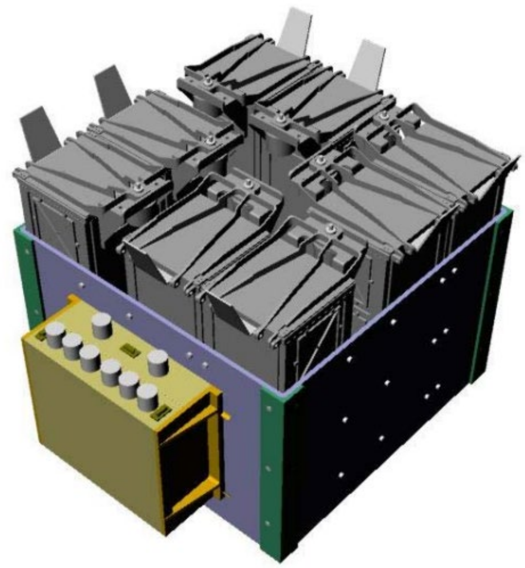


Figure 2. The smaller version of the NPSCuL deployer, flown on the ABC and capable of carrying 24Us

NPSCuL was flown several times and successfully deployed multiple CubeSats. However, the vision of a 50U ESPA-class deployer providing cheap mass access to space was never realized.

More recently, the D-Orbit InOrbit NOW (ION) CubeSat Carrier was flown on board the Vega Small Spacecraft Mission Service Proof of Concept (SSMS-PoC) mission. The ION (Figure 3) is a Freeflyer, detaching from the rocket stage and propulsively carrying its payloads to differing orbits, capable of carrying up to 48Us. CubeSats are deployed from a 4Ux4U array of 1x3U sized D-PODs and deployment can be staggered across orbits and locations due to multiple independent doors.

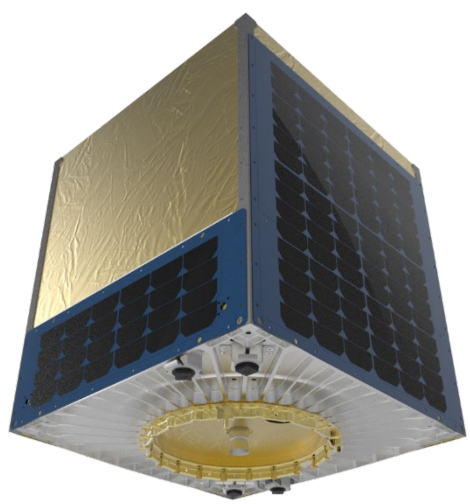


Figure 3. The D-Orbit ION CubeSat carrier and its engines and mounting point

Several systems (Figure 4) have also been proposed for mounting multiple existing 12U deployers on a single ESPA or ESPA Grande port. These include the Spaceflight Industries plate for the ISIS QuadPack [7], the Tyvak 12U [8] mounting system, and the recent ExoLaunch EXOport. Table 3 compares these solutions.

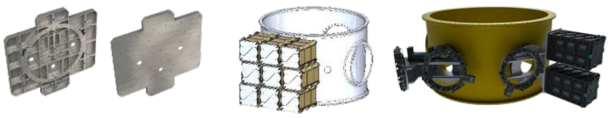


Figure 4. The Spaceflight ISIS QuadPack Plate, Tyvak 12U mounting plate, and ExoLaunch EXOport.

Table 3. Comparison of the deployer mounting systems

System	QuadPack Plate	Tyvak Plate	EXOport
Number of Deployers	7	9	4
Capacity	72U	108U	48U
Mount	24”	24”	15”
Estimated Cost	>$500K	$864K	>$200K

Two of the three solutions require the use of a larger, oftentimes more expensive 24” ESPA Grande port. The only 15” ESPA solution can carry 48Us, which assuming maximum 2 Kg mass per U still means the total CubeSat mass is 96 kg, less than half of the total ESPA capacity. In addition, the use of discrete individual deployers not greatly increases cost, but also mass. To maximize the payload carried on a 15” ESPA port, a new, efficiently designed deployer is needed.

6. New Shapes

In 2013, Lucy Berthoud and Jason Phillip tackled the problem of creating new deployer layouts to maximize available space on rockets for CubeSats (Figure 5). They created 3 concept designs, the “Cube”, the “Tower”, and the “H” [9]. Table 4 compares these designs.

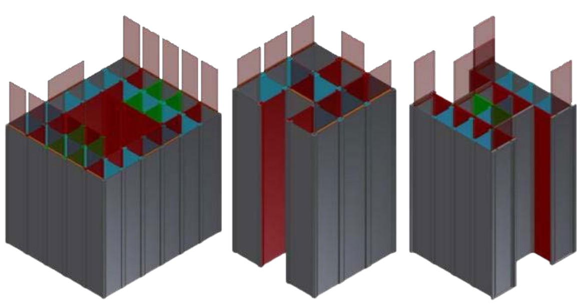


Figure 5. The 2013 Berthoud/Phillip deployer designs

Table 4. Comparison of the deployer designs.

	“Cube”	“Tower”	“H”
Capacity	144U	48U	72U
Loaded Mass	320 Kg	110 Kg	200 Kg

The “H” design was eventually chosen for further development. We concurred with this decision because the 200 Kg total mass of the system when loaded fit the SpaceX Rideshare ESPA capacity.

Berthoud and Phillip’s final design, the New Deployment System (NDS) presented a system capable of carrying 72Us in an Aluminum-7075-T3 55 Kg deployer measuring 506 mm x 500 mm x 819 mm. CubeSat deployment tubes were double heigh, capable of carrying 1x6U CubeSats, and the interior could be split to accommodate different form factors with removable panels. As with all their designs, every CubeSat in the deployer had an access port. The deployment mechanism was baselined as a Moog size 8 permanent magnet DC motor.

Unfortunately, the NDS was never built.

7. Skyliner Design Philosophy

We wanted to revive the shape of the NDS while creating something newer, specifically optimized for SpaceX rideshares on ESPA rings and taking advantage of new technologies developed in the intervening years. We set out the following goals:

- **Maximize ESPA-class volume usage**
  Every additional CubeSat decreases launch cost
- **Low-cost production**
  Deployer cost should not be a major launch pricing factor.
- **Focus on Falcon 9 Rideshare launches**
  Optimize for the lowest-cost launch option.
- **Go big or go home**
  Largest size, protrusions, and tuna can volume.

8. The Skyliner Deployer

Based on these guiding principles, we designed the Skyliner (Figure 6), the largest CubeSat deployer ever engineered, measuring 640 mm x 523.7 mm x 945 mm. Compared to the original “H” design, Skyliner has greatly increased height and two added tubes in the center, increasing CubeSat carrying capacity significantly (Figure 7).

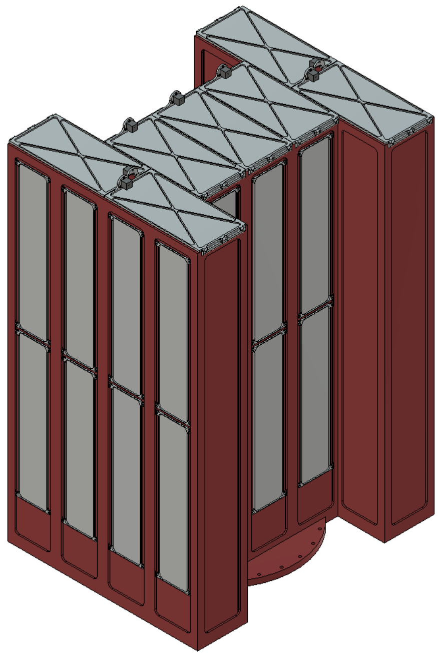


Figure 6. The Skyliner CubeSat deployer

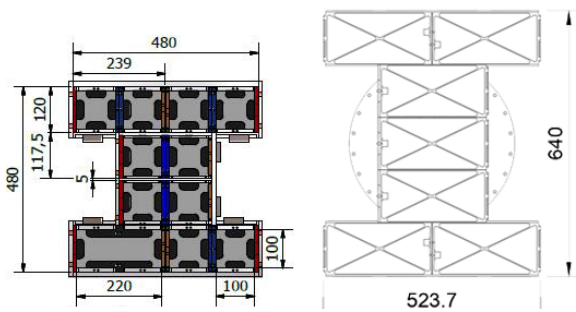


Figure 7. Size comparison of the NDS and Skyliner

The deployer in total consists of 14 double-height tubes with two access panels per tube and one deployment door for every two tubes. Internal panels are reconfigurable so that multiple sizes of CubeSat, from 3U to 6U to 16U, can be launched. Spring pusher mechanisms at the bottom of each tube deploy the CubeSats when the doors are released. The base of the deployer is machined into a circular 15" ESPA ring-compatible mounting point.

9. Structure

Skyliner is made of a machined panel structure of thin Aluminum-7075, the same material used in many commercial CubeSat structures as well as the NDS. To reduce the mass of the deployer to roughly 49.5 kg, the panels comprising the deployer are 5 mm thick at their strongest points, but most of the panel is only 1 mm thick. In addition, 28 access panels, between 4mm and 1 mm in thickness, attach to the outer faces of the deployer to allow easy removal access to the CubeSats within. To reduce complexity and increase reliability, each deployment door (5mm – 2 mm thick) contains two tubes, thus allowing for a reduced amount of HDRMs.

10. A New Release Mechanism

The HDRM has long been the most complex and expensive part of any CubeSat deployer. With a double-height deployer such as Skyliner, the HDRM must be capable of withstanding far greater forces from the spring pusher and stack of CubeSats. While some deployers continue to use burnwire mechanisms, most rely upon either Frangibolt or pin-puller HDRMs. These are primarily made by TINI Aerospace and can cost upward of $10,000 USD. As Skyliner requires 7 HDRMs, these mechanisms alone would have raised its cost by $70,000 USD.

Fortunately, the patent on the Frangibolt has expired, and nowadays other companies are producing their own, more inexpensive version. Deployables Cubed offers both pin-pullers (Figure 8) and Frangibolts for under $3,000 USD, while retaining the high quality and resilience necessary for aerospace applications. Using 7 Deployables Cubed Frangibolts, the total HDRM cost for Skyliner can be reduced to under $20,000 USD.

Figure 8. A pin-puller produced by Deployables Cubed

11. CubeSat Accommodations

A standard 3U CubeSat, as defined in the CubeSat standard, has dimensions of 100 mm x 100 mm x 340.5 mm [10]. In contrast, a 6U CubeSat is specified as having a length of 366 mm [11] (Figure 9). This means that a deployer capable of accommodating a 6U CubeSat or two must be long enough to accommodate this height increase.

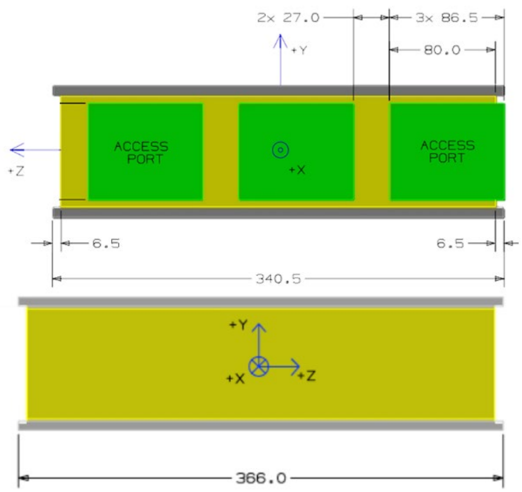


Figure 9. Comparison of 3U and 6U lengths

In addition, while the CubeSat Design Specification sets the maximum size of a CubeSats protrusions as 6.5 mm, the maximum tuna can diameter as 64 mm, and the tuna can length as 36mm, many deployer companies, such as ISIS, NanoRacks [12], and Astrofein [13], have more expansive requirements.

With Skyliner being the largest deployer in the world, it is only fitting that it has the largest protrusions and margins. Skyliner provides CubeSats with 12mm side protrusions and a 92 mm diameter, 62 mm tuna can volume.

Because Skyliner is a double-height deployer, it must be able to accommodate two vertically stacked 6U CubeSats with this extended tuna can volume. While one such volume can fit into the pusher plate, the other must be contained within the height of the deployer tube. As such, the deployer must be lengthened to accommodate this maximal case.

However, when standard 340.5 mm 3U CubeSats are stacked in the tube, and assuming no tuna can volume is contained above the pusher plate, the extra space previously allocated to the extra length of the 6U and its tuna can volume now allows for an extra 1U CubeSat to be placed at the top of the deployer (Figure 10). This increases the capacity of the deployer from 84U in the maximal edge case, to 98U in most regular circumstances. This also theoretically allows for 1x7U CubeSats to be launched.

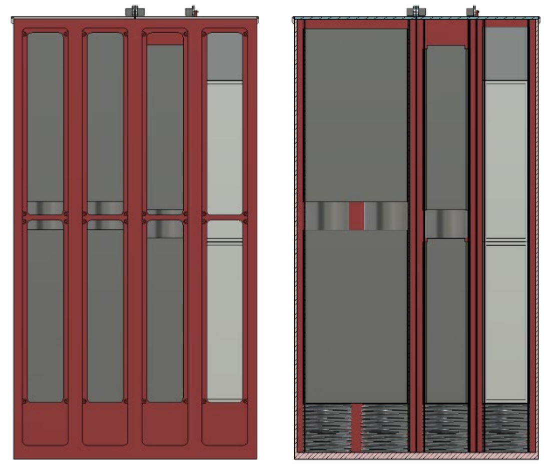


Figure 10. Comparison of 6U + Tuna Can, 3U + Tuna Can, and 3U without Tuna Can inside Skyliner

12. Vibration Analysis

The SpaceX Rideshare Payload User's Guide requires that payloads under 200 kg have a first fundamental frequency of over 40 Hz [14]. Finite element analysis (FEM) was performed in Autodesk Fusion 360 (Figure 11) and computed the following frequencies, displayed in Table 5. As seen, Skyliner's lowest natural frequency is 42.14 Hz, conforming to SpaceX's requirements. Nevertheless, further strengthening and bracing is planned to eliminate the 42.14 Hz and 57.48 Hz vibration modes.

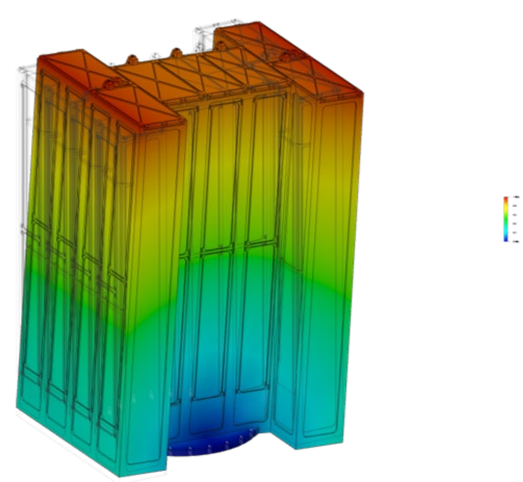


Figure 11. Displacement of Skyliner caused by the 42.14 Hz vibration mode

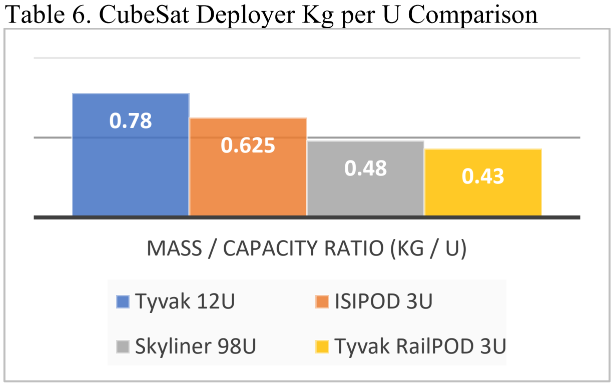
Table 5. First 10 natural vibration modes of Skyliner

Mode Number	Frequency
Mode 1	42.14 Hz
Mode 2	57.48 Hz
Mode 3	195.5 Hz
Mode 4	224.7 Hz
Mode 5	478.9 Hz
Mode 6	515.6 Hz
Mode 7	634.9 Hz
Mode 8	646.7 Hz
Mode 9	761.2 Hz
Mode 10	1013 Hz

13. Skyliner Metrics

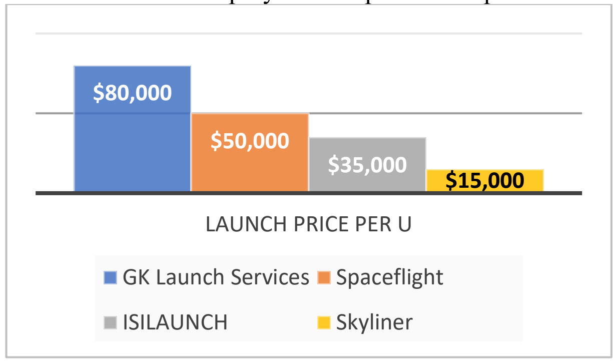
Despite its large size, Skyliner is one of the most mass-efficient CubeSat deployers in the world, as defined in Kg per U – in other words, the mass of deployer adjusted for the number of Units it can carry. Compared to other deployers (Table 6), Skyliner comes in second only to the Tyvak RailPod, an ultra-lightweight 3U deployer constructed out of only rail segments.

Table 6. CubeSat Deployer Kg per U Comparison



Skyliner was designed from the ground up to provide the world's lowest-cost CubeSat deployment. With a minimum launch cost of $1M USD, and an estimated production cost of ~$50,000 USD, Skyliner's marginal cost per U to orbit is $10,714 USD. Adding other costs, such as transport and integration yields an estimated launch cost of $15,000 USD per Unit. This is by far the lowest launch cost that has ever been for CubeSat developers (Table 7).

Table 7. CubeSat Deployer Price per U Comparison



14. Development Plan

We intent to build an engineering model of Skyliner by the end of 2020 and qualify it in Q1 2021, after which the flight model will be constructed. We are working towards a test mission by the end of 2021.

15. Conclusion

Over the past decade and a half, the CubeSat launch market has undergone tumultuous changes. Low-cost launch capabilities have been lost, mass constellation launch has been achieved, and the industry players have changed. A new type of CubeSat launch service is required for this world.

The advent of SpaceX rideshare launches has been a revolutionary force upon the world of small satellites. Skyliner can harness that force to maximize the utility of the ESPA-class specification for CubeSats, deploying 98Us in 49.5 kg while remaining inexpensive.

With launch to space now coming within reach of far more parties, its impact upon them can only be imagined.

16. Acknowledgements

The authors would like to acknowledge Ryan Nugent for sharing his expertise of the early days of CubeSat launch and the design of the initial CubeSat deployers and Patrick Walton and Elad Sagi for their support and advice.

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