USGIF Small Satellite Working Group

Resilient SmallSat
Launch-on-Demand

Microcosm
3111 Lomita Blvd.
Torrance, CA 90505
(310) 539-2306

Dr. James R. Wertz, jwertz@smad.com
Dr. Robert Conger, rconger@smad.com
Dr. Richard Van Allen, rvanallen@smad.com

July, 2016
Who Needs Resilient Launch-on-Demand for SmallSats?

• Answer -- Everybody
  • Commercial: Create a resilient income stream
  • Civil: Protect science data stream and be able to respond to natural or man-made emergencies
  • Military: Respond to rapidly changing needs or adversary attacks

• Microcosm will be presenting a paper at AIAA Space 2016 on “Creating a Resilient Space Mission Architecture”
  • For a preprint or added information on resilient technologies, contact jwertz@smad.com
Avoiding the Space Pearl Harbor

Loss of a capital asset could force National leadership into major decisions due to lack of situational awareness

America has NO capability to rapidly reconstitute or augment on-orbit resources

Dep Sec Def Robert Work, GEOINT Symposium, June 23, 2015:
"The first order of business is to make space systems more resilient. If we fail to do this, the implications for national security will be quite profound."

For every day that the system isn't either on-station or ready to go, it has a reliability of zero. (Hurley and Purdy, "Design to a Reliability of Zero.")

We can mitigate this risk quickly and at low cost if we act now…
Summary of Demi-Sprite Capabilities
Built-to-Inventory for Launch-on-Demand

- 160 kg to LEO for $4 M recurring launch cost
- Launch within 8 hrs of an unanticipated demand
- Minimal infrastructure – flat pad launch with no flame bucket, gantry, or service tower
- LOX & Jet-A propellants are available anywhere
- Launch through 99.9% of winds aloft
- Rapid successive launches provide essentially 100% mission reliability
- Scalable to larger launch vehicles
- Transportable in a single standard cargo container without special requirements (below)

Demi-Sprite can be launched at low cost in response to an immediate need in time to impact the outcome of world events. The technology, cost, and utility have been validated by independent, government-funded reviews.
Scorpius®/Demi-Sprite and Sprite Small Launch Vehicles are Mature Designs Based on Real Hardware

Real hardware, real performance results, real cost

Demi-Sprite model

Aerodynamic Tests at Marshall Space Flight Center (right)

2 Suborbital Flights

Engine testing at EMRTC, NM; Edwards AFB, CA; and Mojave Test Area, CA

Unpressurized tank supports large external load

The SR-M Suborbital (below) is essentially a full-scale Sprite pod that can serve as the first stage of the Nano Launch Vehicle, NLV.

95% of the mass of the Sprite SLV has been built and ground tested. Much of it has flown.
# Microcosm Demi-Sprite Small Launch Vehicle
## Needs vs. Capabilities

<table>
<thead>
<tr>
<th>Property</th>
<th>Broadly Defined Need</th>
<th>SMDC Numeric Goal*</th>
<th>SMDC Numeric Requirement*</th>
<th>Demi-Sprite Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass to LEO (750 km)</td>
<td>SmallSat to any LEO orbit</td>
<td>100+ kg</td>
<td>25 kg</td>
<td>140 kg</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>Launch in time to impact the outcome of world events</td>
<td>&lt;24 hr</td>
<td>&lt;24 hr</td>
<td>8 hr**</td>
</tr>
<tr>
<td>Weather limitations</td>
<td>As above</td>
<td>No requirement</td>
<td>No requirement</td>
<td>Launches in 100 kt ground winds through 99.9% winds aloft</td>
</tr>
<tr>
<td>Operations infrastructure</td>
<td>Low-cost, easily replicated</td>
<td>Minimal beyond dedicated ground system</td>
<td>Minimal beyond dedicated ground system</td>
<td>No flame bucket, no gantry, no service tower, erected by a commercial forklift</td>
</tr>
<tr>
<td>Ops personnel</td>
<td>Small number</td>
<td>Military crew</td>
<td>Military crew</td>
<td>Crew of &lt;12 people</td>
</tr>
<tr>
<td>Propellants</td>
<td>Readily available; easily handled</td>
<td>No requirement</td>
<td>No requirement</td>
<td>LOX and Jet-A, available anywhere</td>
</tr>
<tr>
<td>Transportation</td>
<td>Easy to transport anywhere, any time</td>
<td>Aircraft, overland, or barge</td>
<td>Aircraft, overland, or barge</td>
<td>Transported in a single standard cargo container (goes anywhere, any time, any transportation)</td>
</tr>
<tr>
<td>Recurring Cost (at 10/yr)</td>
<td>Low recurring cost</td>
<td>&lt;$1M</td>
<td>&lt;$10M</td>
<td>$4M</td>
</tr>
<tr>
<td>Time to 1st orbital test</td>
<td>As soon as possible</td>
<td>36 months</td>
<td>36 months</td>
<td>36 months</td>
</tr>
</tbody>
</table>

* SMDC needs from July, 2014, RFI
**Technical capability. Actual time will be limited by launch site regulations & requirements
# Alternative Launch Vehicle Sizes

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Nano Launch Vehicle</th>
<th>Demi-Sprite</th>
<th>Sprite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload to 185 km due east</td>
<td>55 kg</td>
<td>160 kg</td>
<td>480 kg</td>
</tr>
<tr>
<td>Payload to 900 km Sun Sync</td>
<td>30 kg</td>
<td>90 kg</td>
<td>250 kg</td>
</tr>
<tr>
<td>Recurring Launch Cost</td>
<td>$2.1M</td>
<td>$4.0M</td>
<td>$6.2M</td>
</tr>
<tr>
<td>Recurring Launch Cost ($/kg)</td>
<td>$38,200/kg</td>
<td>$25,000/kg</td>
<td>$12,900/kg</td>
</tr>
<tr>
<td>Propellants</td>
<td>LOX, Jet-A</td>
<td>LOX, Jet-A</td>
<td>LOX, Jet-A</td>
</tr>
<tr>
<td>Launch in 8 hours</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Launch through winds aloft</td>
<td>Limited</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Infrastructure needed</td>
<td>Launch Rail</td>
<td>Flat Pad</td>
<td>Flat Pad</td>
</tr>
<tr>
<td>Transportability</td>
<td>Some—long vehicle; needs launch rail</td>
<td>Very—transported in a single standard storage container</td>
<td>Some—transported in 2 or 3 storage containers and then assembled</td>
</tr>
<tr>
<td>Multiple CubeSat Launches</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Orbits</td>
<td>LEO</td>
<td>LEO, MEO, some GTO</td>
<td>LEO, MEO, GTO, GEO</td>
</tr>
</tbody>
</table>
The CubeSat Constellation Launcher (CCL) is a system consisting of a small launch vehicle plus a CubeSat Deployer (CD) that is capable of putting up to 12 3U or 6U CubeSats into 12 separate, individual orbit slots:

- Has up to 1,700 m/s of delta V available for transfer among the various orbit locations
- Does not require any propellant or delta V from the CubeSats themselves

Typical scenario:
- Put 8 CubeSats 45 deg apart in a single orbit plane
- Change the ascending node to a different orbit plane
- Distribute the remaining 4 CubeSats in second orbit plane

Most CubeSat constellations will have multiple orbit planes at the same inclination, with multiple satellites per plane

Deployment sequence:
- Demi-Sprite launch vehicle takes CD to the first orbital slot
- First satellite is dropped off and LV deorbits
- CD goes to 2nd orbital slot, drops off 2nd satellite, and so on
- CD deorbits itself at the end of deployment sequence

The CCL provides low-cost, on-demand, rapid deployment of CubeSat Constellations.
Using a constellation of SmallSats Built to Inventory with Launch-on-Demand in hours provides substantial benefits:

- Major cost reduction
- Mission reliability improved to effectively 100%
- Performance that is difficult to achieve by other means – revisit rates of minutes, rather than hours or days
- 24/7 coverage with an affordable constellation
- Very high flexibility and transportability
- Lower risk – both implementation and operations
- Schedule reduced from years to days or hours – LAUNCH IN TIME TO IMPACT THE OUTCOME OF CURRENT WORLD EVENTS
- Adds asymmetric capability – can add satellites faster and cheaper than an adversary can take them out
- "Resilient Orbits" provide observations of other spacecraft, or points on the ground 5-6 times/day with 1 spacecraft

The Bottom Line – Better Performance, Less Cost, Lower Risk, Higher Reliability, Much Shorter Schedule

Low-cost, responsive smallsat launch can significantly improve space system performance and mission reliability while providing major new capabilities as well.
Back-Up Data
Implementing Real-Time Surveillance-on-Demand

On-orbit performance in a day or less is a capability that has never existed in the US space program – but can exist in the near-term at lower cost than traditional approaches.
For the United States, Launch in a Day Is a VERY Different Concept

Traditional Launch Timeline (Wertz, et al., *Space Mission Engineering*, 2011, Fig. 27-2)

- Note that launch paperwork begins 3 years prior to launch and the Final Mission Analysis (including orbits and flight path) is due 3 months prior to launch.
- In contrast, the Soviet Union launched 29 payloads in 69 days in direct response to the Falklands War in 1982.
Schedules, Reliability, and Risk

• **Schedules** are much shorter for SmallSats and small launch than for traditional large satellites
  
  – Traditional major defense programs take 8.8 years in development (Milestone B) and well over 10 years from Milestone A to implementation [DoD Procurement Study]

• **Reliability** of SmallSats (including single string SmallSats) is essentially similar to that of traditional large satellites according to a Goddard study of over 1,500 spacecraft launched from 1995 to 2007

• **Risk** = the probability of a negative event times the impact/consequences of that event
  
  – Non-recurring cost for SmallSats is 1–2 orders of magnitude less than for traditional satellites
  
  – **Implementation Risk** is low due to low non-recurring cost and short schedule, i.e., the consequences of failing to implement a SmallSat system will not endanger the larger, more traditional system
  
  – **Operational Risk** of SmallSats is also much lower than traditional systems due to shorter operational life and the availability of spares (on orbit or on the ground) or back-up

• SmallSats also support disaggregation

SmallSat missions provide much shorter schedules, comparable reliability, and significantly less risk (both implementation and operational) than traditional large satellite missions.
Performance of Scorpius Small Launch Vehicles

SPRITE, DEMI-SPRITE, AND NANO-LAUNCH VEHICLE

PAYLOAD (KG)

ALTITUDE (KM)