Academy of Model Aeronautics

AMAEXPO

Presented by: GPC Go Professional Cases

Air Launch to Orbit: Flight Testing the Towed Glider Air Launch Concept using a Sub-Scale Research Model

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NASA Armstrong Flight Research Center
Edwards, CA

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GOAL

Develop an affordable system that truly **enables**

LOD

Launch-on-Demand Access to Space

- So far, Launch-on-Demand has not come to fruition because three key elements are not yet responsive in and of themselves
  - "On the shelf" satellites ready to be deployed
  - "On the shelf" launch vehicles ready to be deployed
  - Flexible launch platform/range with quick turn-around times
- These elements are getting very close to being realizable, but they need a little help to get momentum going in the right direction

An **enabling function** is needed to reach the tipping point…

APPROACH

- Three elements must be combined to provide the enabling function

STAGE 1: PLATFORM

Demonstrate a remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet

STAGE 2: LV STIMULUS

Foster integration of several small LV companies with program to demonstrate launch off the **TOWED GLIDER**

BEHIND THE SCENES: POLICY

Work with FAA to make launch policies for small LVs using **TOWED GLIDER** as the launch platform

LV = Launch Vehicle

Ignite the small satellite launch market and make Operationally Responsive Space (ORS) and Launch On Demand a reality

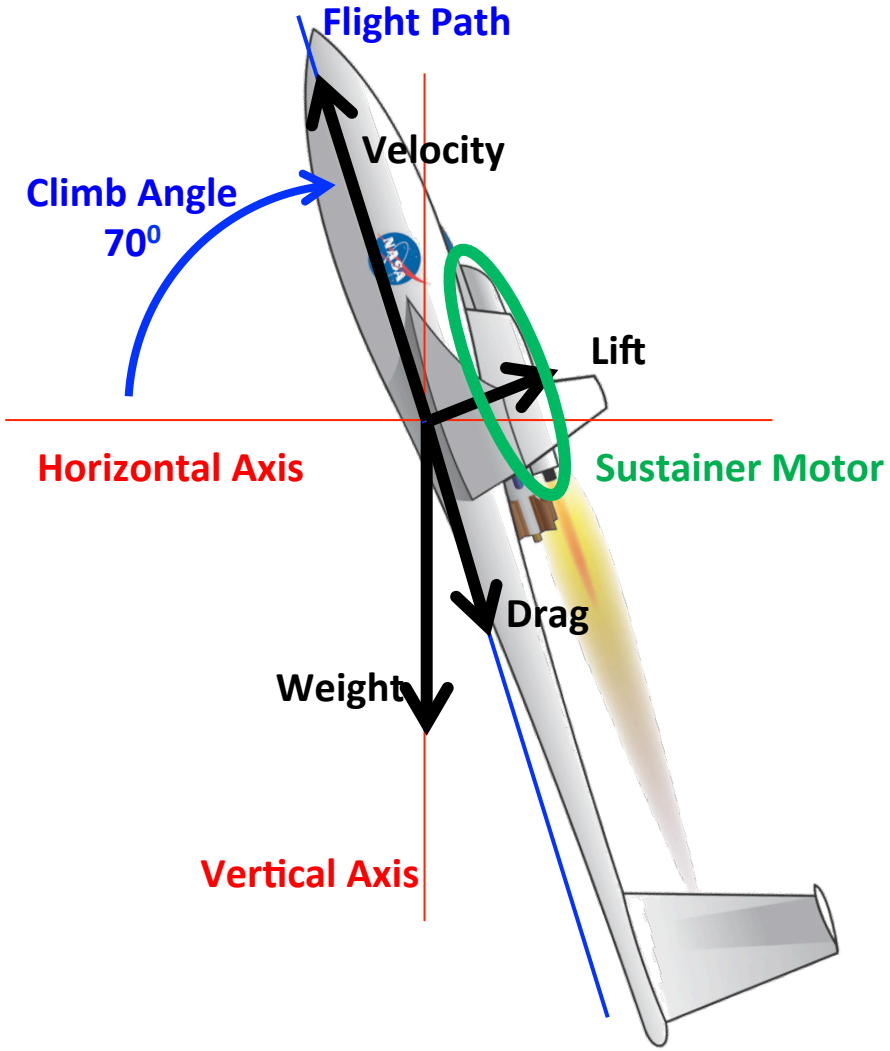
STAGE 1: PLATFORM

3 Year project to build a 100' wingspan remotely-piloted glider, modify an existing business jet for tow, and release 6000 lb LV with 100 lb satellite at 40K', 70^0, M=0.8 safely & effectively.

Towed Glider Air Launch System

Simply put, the Towed Glider concept is the OPTIMIZATION of air launch

Sustainer Motor



Location: Mounted on top of the glider

Purpose: Provides variable thrust on demand to change the Glider and LV orientation from horizontal to nearly vertical

Features:

- Restartable
- Throttleable down to ~15% or less
- Controllable
- Increases Glider fly-back range

Profile: Start horizontal, idle sustainer motor, begin pull-up towards 70^0 climb, use sustainer motor variable thrust to maintain constant airspeed during climb, stabilize at 70^0 then release LV

The sustainer motor provides the energy to go from horizontal to nearly vertical so the LV is optimally oriented for launch

Flight demonstrating the sustainer motor concept at 1/3 scale would increase the TRL from 3 to 5 while simultaneously reducing programmatic and technical risk for the full scale program

PLATFORM: Why Towed Glider?

- High Performance: 50% plus increase in performance to orbit
  - Carry 2+ times mass to altitude as same size direct carry conventional aircraft
  - Pull-up maneuver gives 12-15% performance increase over horizontal release
- Low Cost
  - No new infrastructure costs
  - Relatively inexpensive to build a glider versus a conventional airplane
  - Low maintenance costs compared to a conventional airplane
  - Many existing business jets are candidate tow vehicles with minimal mods
  - Easier for small LV companies to get started without huge capital outlays
  - Commercialize-able as a separate service from LVs
- Safety & Mission Assurance
  - Unmanned glider eliminates human concerns for carrying LV
  - Restartable sustainer motor extends glide home distance following launch or abort
  - Glider capable of landing with LV attached in event of mission abort
- Flexibility
  - Glider plug-n-play center wing allows multiple simultaneous LV build-ups
  - Glider and LV could fit inside C-17 tow plane for transport to desired airfield
  - Inexpensive gliders can be staged at any airfield, ready for immediate launch
  - Tow plane can be existing aircraft that simply adds towed launch to duties
  - Glider concept is scalable from very small LVs

The Towed Glider concept is the OPTIMIZATION of air launch

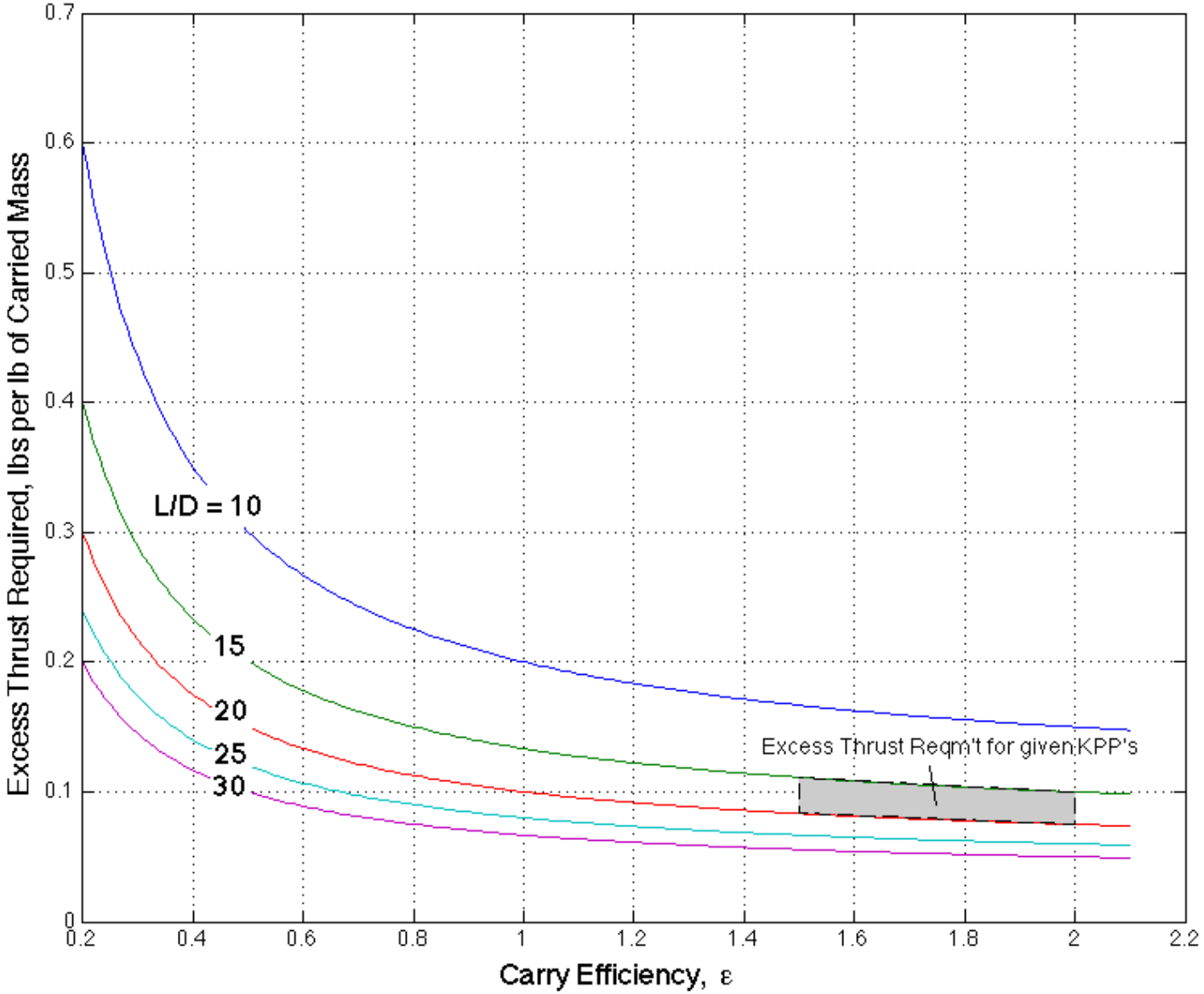
Carry Efficiency for Existing Air-Launch Platforms

Launch Platform	Gross Takeoff Weight (GTOW)	Carried Weight	Carry Efficiency, $\frac{W_{carried}}{(GTOW - W_{carried})}$
WhiteKnightTwo[2]	70×10^3 lb	29×10^3 lb	0.71
Stratolaunch[3]	1.3×10^6 lb	500×10^3 lb	0.63
B-52 Stratofortress[4]	488×10^3 lb	70×10^3 lb	0.17
L-1011 Stargazer	430×10^3 lb[5]	52×10^3 lb[6]	0.14

Key Performance Parameter			
Performance Parameter	*State of the Art*	*Threshold Value*	*Project Goal*
Carry Efficiency	0.71	1.5	2.0

[2] From FAA Draft Environmental Assessment for the Launch and Re-entry of SpaceShipTwo; http://www.faa.gov/about/office_org/headquarters_offices/ast/media/20120309_Mojave_SS2_Draft_EA.pdf. Carried weight represents SS2 maximum launch weight; the maximum carry weight of the WK2 could not be found in the public record.
[3] Stratolaunch Press Kit; http://www.stratolaunch.com/presskit/Stratolaunch_PressKitFull_May2013.pdf.
[4] Air Force Fact Sheet; http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104465/b-52- stratofortress.aspx.
[5] The most favorable (lightest) GTOW of the L-1011 variants; taken from http://en.wikipedia.org/wiki/ Lockheed_L-1011_TriStar
[6] Orbital L-1011 Fact Sheet; http://www.orbital.com/LaunchSystems/Publications/L1011_factsheet.pdf

Excess Thrust Required by Tow Airplane as a function of Carry Efficiency and Tow Glider Max L/D



White Knight II: Direct Carry vs Towing Glider

Real-world example of why Towing is a better business case

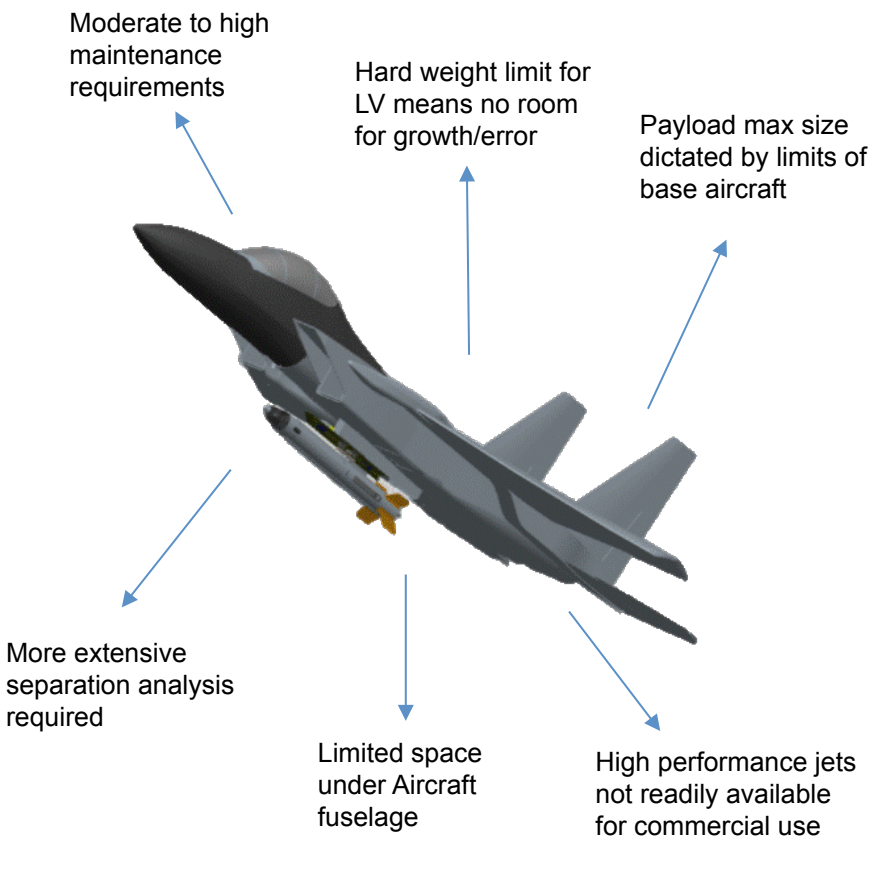
- **Question:** How much more could White Knight II (WK2) bring to altitude if Towing a Glider?
  - WK2 direct lift capability = 30,000 lbs
  - WK2 excess thrust ~ 4900 lbs (assumes 100% tow efficiency)
  - Rocket to glider weight ratio = 2:1 (rocket twice as heavy as glider)
  - Glider (with rocket attached) with 20:1 Lift to Drag ratio (L/D)

- **Math:** WK2 towing 20:1 L/D glider and rocket 2x weight of glider
  - Excess Thrust X L/D X 2/3 = 4900 X 20 X 2/3 = 65,333 lbs
  - 65,333 lbs / 30,000 lbs = **2.18 times direct carry capability**

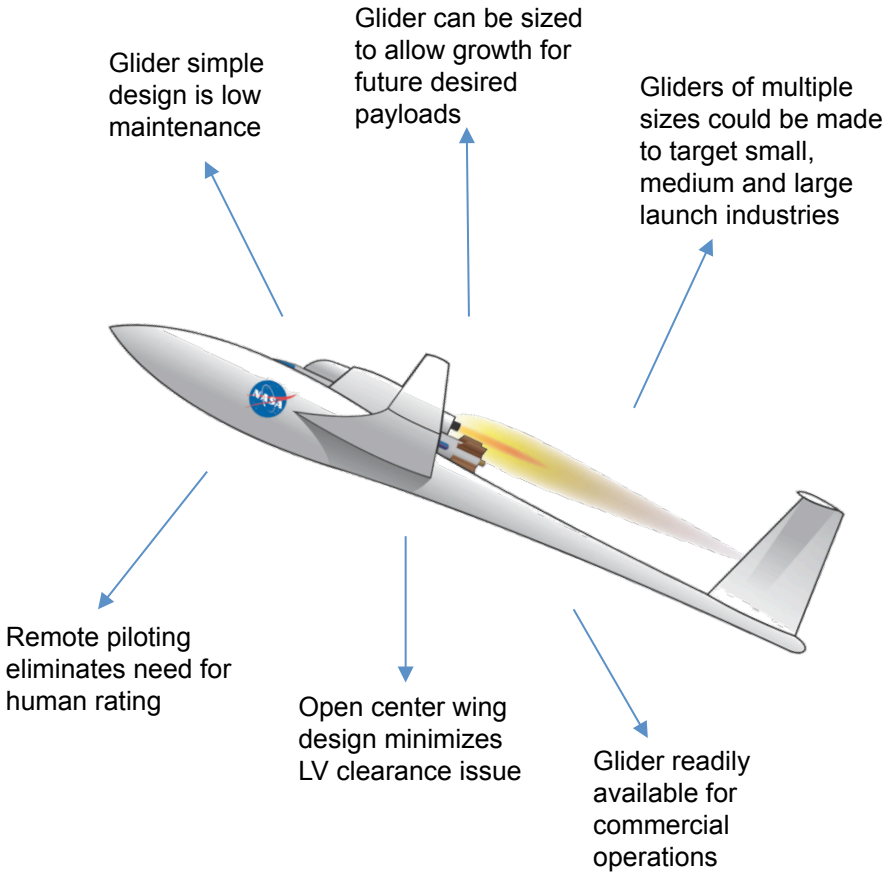
Regardless of system size, using a towed glider allows us to launch 2X as much to orbit for less money than a comparably sized direct carry aircraft

Glider Design Creates Trade Space

Current State of the Art: Direct Carry



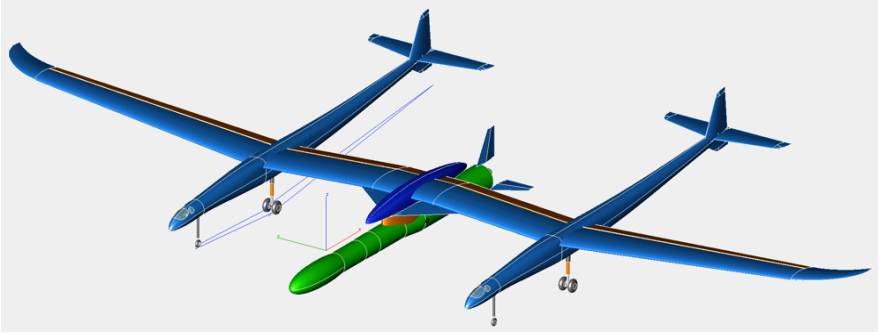
Next Generation: Towed Glider



Glider adds flexibility to ensure design success and commercializability

PLATFORM: SAS-ASI-Burt Rutan Study

- NASA contracted Special Aerospace Services (SAS) to study the viability of the Towed Glider Air Launch Concept
  - SAS teamed with Aerospace Services International and Rutan Designs
  - 120 Day Feasibility Study Conducted in 2012
  - Results presented in January 2013
    - Burt Rutan assessed the concept feasibility and designed a conceptual air-launch towed glider
    - Ken Lindas (SAS) analyzed the improvements in launch vehicle payload performance to orbit



Design Carry Efficiency: 1.5

- Excerpts from the SAS Study Presentation:

> *"This world class design team was surprised in the performance enhancement relative to a Towed Carrier Aircraft leveraging an existing Launch Vehicle System."*

> *"Viability should be considered for demonstration…"*

> ***"This is potentially game changing research with multiple Industry and USG applications."***

The study showed the concept is do-able…next step is the Proof of Concept

1/3 Scale Model Glider

- FY13/14 Center Innovation Funds used to develop single fuselage and twin fuselage gliders for tow behind the DROID unmanned model aircraft
- Remote piloting of glider implemented using the Ground Control Station for DROID
- Whittinghill Aerospace under SBIR contract to build a small sub-orbital LV for launch demo off the twin fuselage glider
- Twin Fuselage Glider towed behind DROID to be used for 1/3 scale sustainer motor risk reduction work in FY15 (requires additional funding)

STAGE 2: LV Stimulus

Enables candidate **small launch vehicle companies** to become **viable commercial launch providers** for putting small satellites into Low Earth Orbit (LEO) **on demand**.

- Stimulate Small Launch Vehicle Market
  - Development companies can enter air launch market without huge capital outlays
  - Successful launch demos could lead to future LSP contracts, as well as contracts with Industry Partners
- Stimulate Small Satellite Development Market
  - Give small satellites an affordable path to orbit without ride sharing
  - Affordable dedicated launch options will encourage new customers for small satellites

The end goal is to produce multiple viable small LV providers for the small launch market…the Glider enables them

POLICY: Tailored for Small Launch

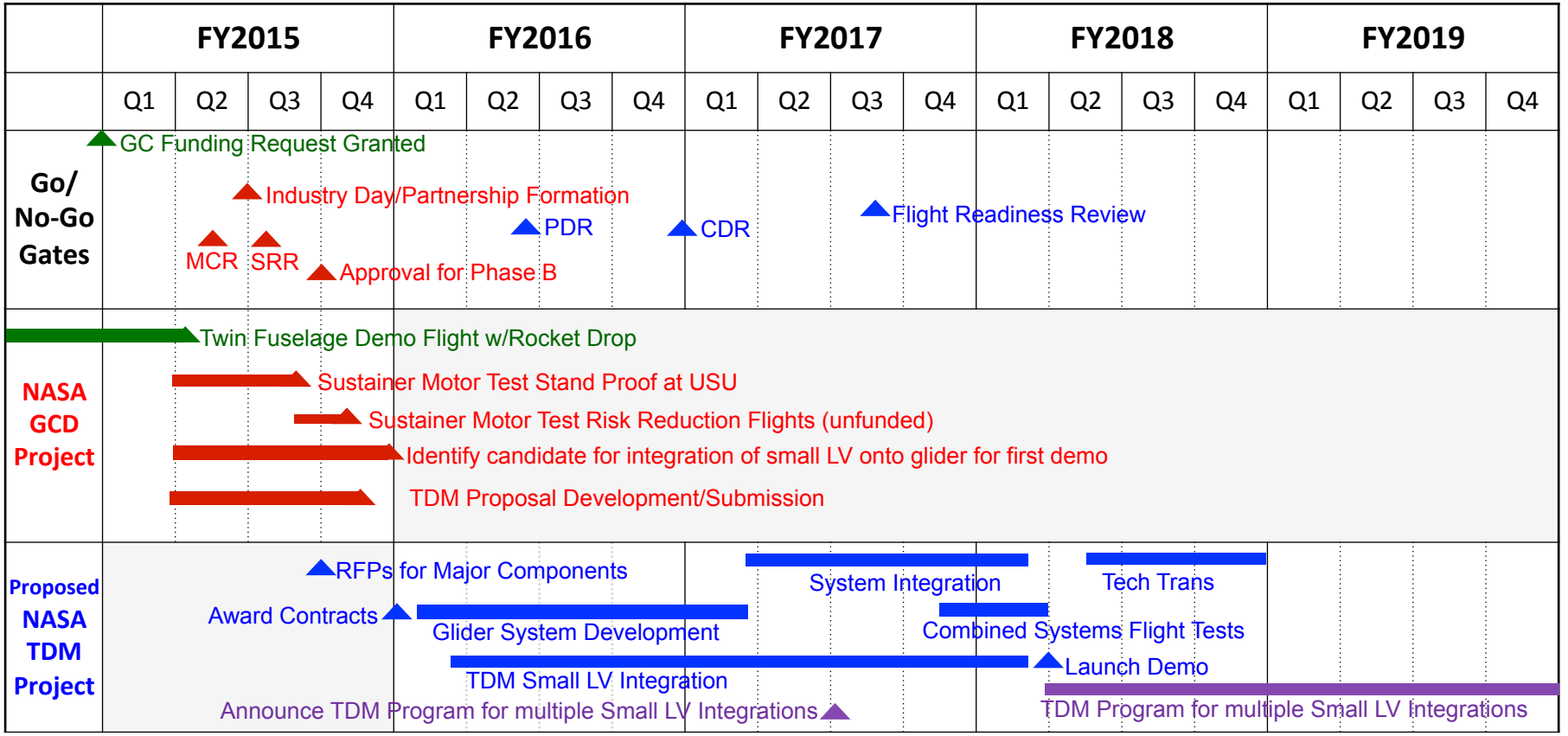
Collaborative partnership between NASA and FAA to coordinate policies and procedures which address the needs and issues associated with small launch

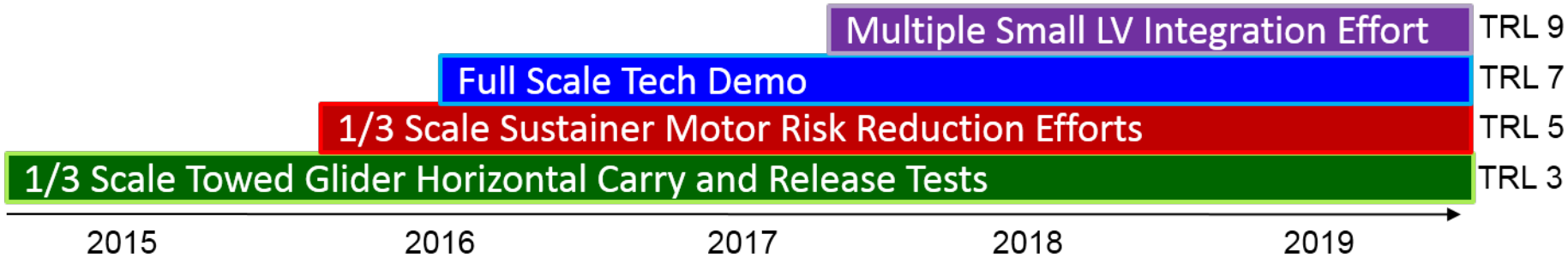
POLICIES & REGULATIONS

- Appropriate safety requirements for small LVs
- Certification of tow modifications to existing aircraft
- Policies and Regulations for servicing small LVs at airfields
- Paperwork and processing time that is conducive to ORS/Launch-On-Demand type CONOPS
- Coordinate streamlined conjunction assessment (CA) process and prepare for increased launch assessment traffic
- Orbital Debris Mitigation policies for the expected increase in small satellite population
- International policy concerns

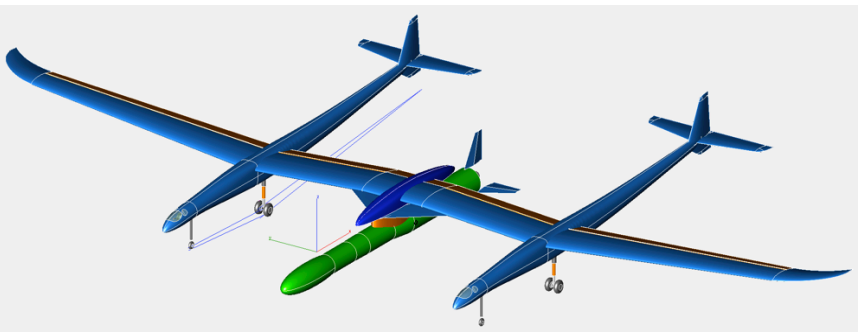
The goal is to ensure NASA, government and military are prepared to accept and support the dedicated small satellite launch industry

Schedule, Deliverables, and Key Milestones





Summary

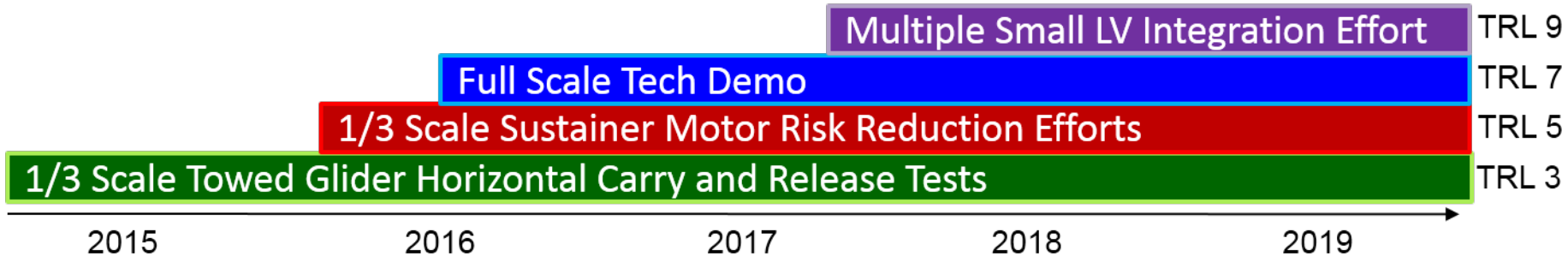


Goal: The goal is to **enable** Operationally Responsive Space.

Approach:
PLATFORM - Remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet
LV STIMULUS - Foster integration of several small LV companies with program to launch off **TOWED GLIDER**
POLICY - Work with FAA to make launch policies for small LVs using **TOWED GLIDER** launch platform

Program:
NASA GCD Project – NASA provides funding and FTEs
Proposed NASA TDM Project – NASA provides FTEs, Partners provide $$, LV Candidates provide innovative new small LV technology

Key: **Glider acts as an enabling function to allow small launch vehicles affordable access to optimized air launch conditions they wouldn't normally be able to afford**



Towed Glider Air Launch Concept (TGALC)

Operational Brief

January 9th – 11th, 2015

Biography

Red Jensen

Operations Engineer (OE) — Associate Engineer 3

Class I & II sUAS Chief Pilot | Master UAS Technician Model Lab

NASA Neil A. Armstrong Flight Research Center

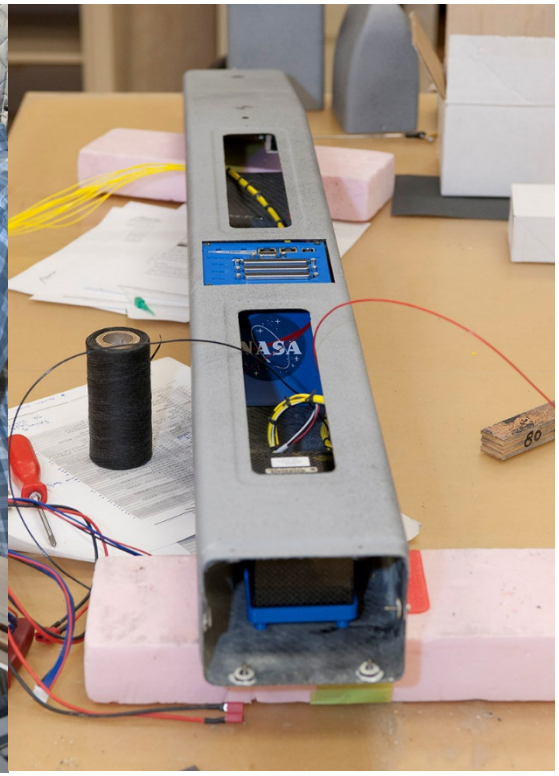
- Responsible for designing, building and piloting sUAS fleet up to 330 lbs.
- Prior Chief Pilot & Program Manager at Arcturus-UAV
- Lifelong R/C Modeler
- AMA Life member

Aircraft Description - Twin-Fuselage Glider

- **Type:** HN Model Ventus 2 AX
- **Wing Span:** 324 in
- **Wing Area:** 3198 in^2
- **Wing Loading:** 2.79 lb/ft^2
- **Empty Weight:** 62 lbs
- **Piccolo II Autopilot System**
- **900 MHz ISM Band C2 link**
- **ADS-b**
- **L-band video link (down only)**
- **JR 2.4 GHz R/C override**

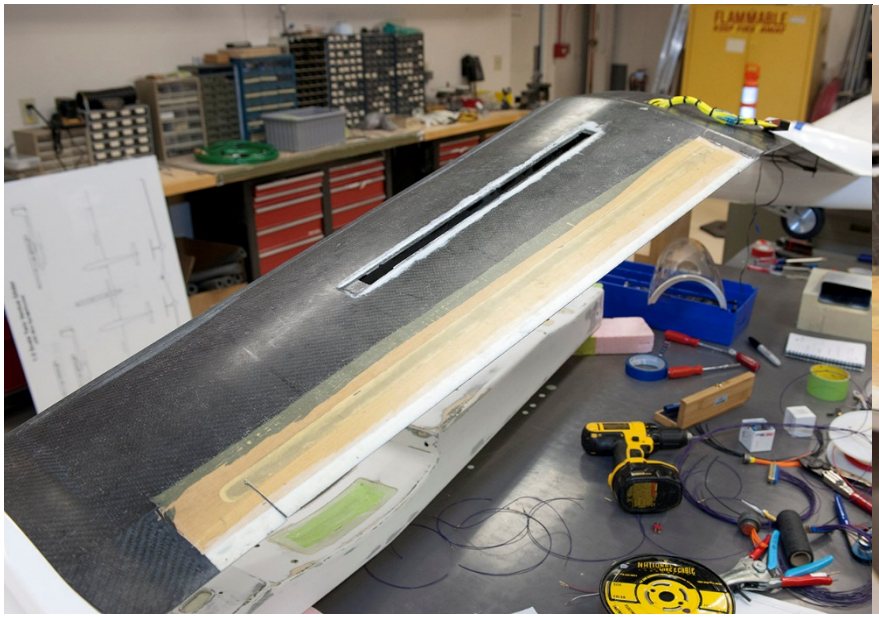
Fabrication

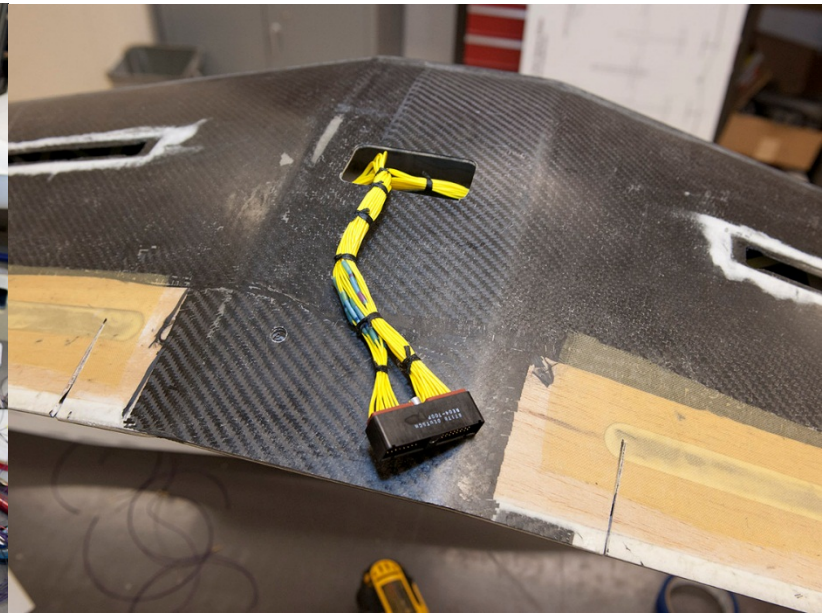
Center Wing & Fuselage Build-up



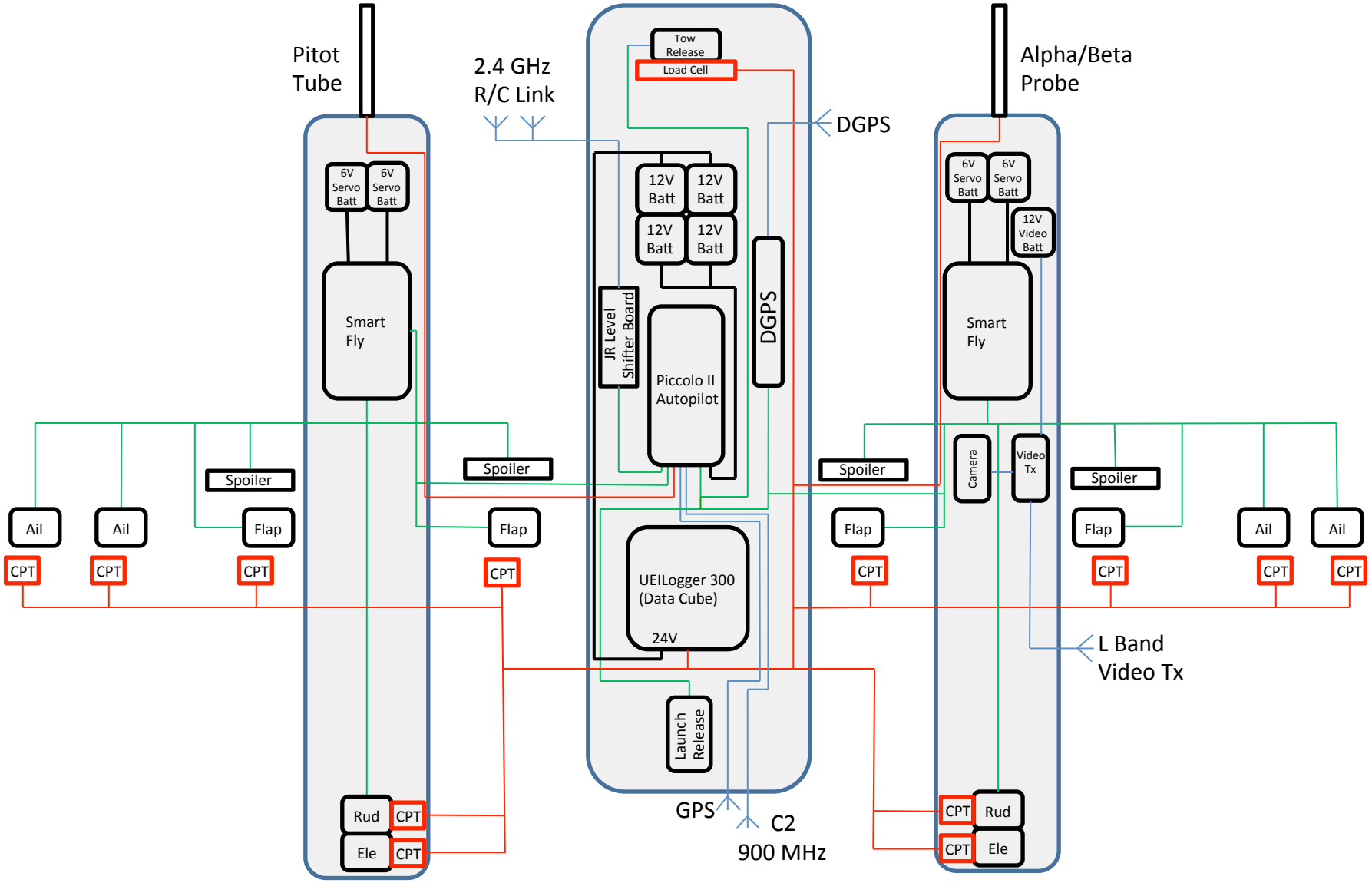
Fabrication (continued)

Center Wing & Fuselage Build-up





Twin Glider Architecture



Aircraft Description – DROID

- Tow Aircraft: DROID
  - Bruce Tharpe Engineering (BTE) Modified Super Flyin' King model aircraft
  - Operated via Radio Control or through GCS
  - Piccolo II autopilot
  - DGPS
  - ADS-b
  - DA 170cc Engine
  - Empty Weight: ~54 lbs
  - GTOW: ~80 lbs
  - V_{NE}: 130 kts
  - Max altitude 10K+
  - Flight Duration: 1 hr

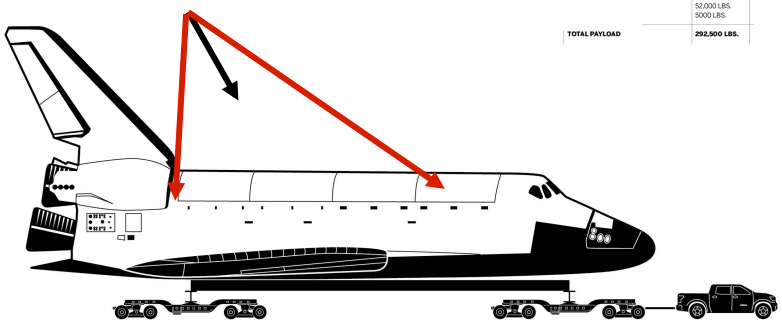
Aircraft Description - DROID Tow/Release Location

Questions?

Backup Material

Its all about Weight Distribution…

Weight distributed
across 32 tires



Weight distributed
across 2 airframes

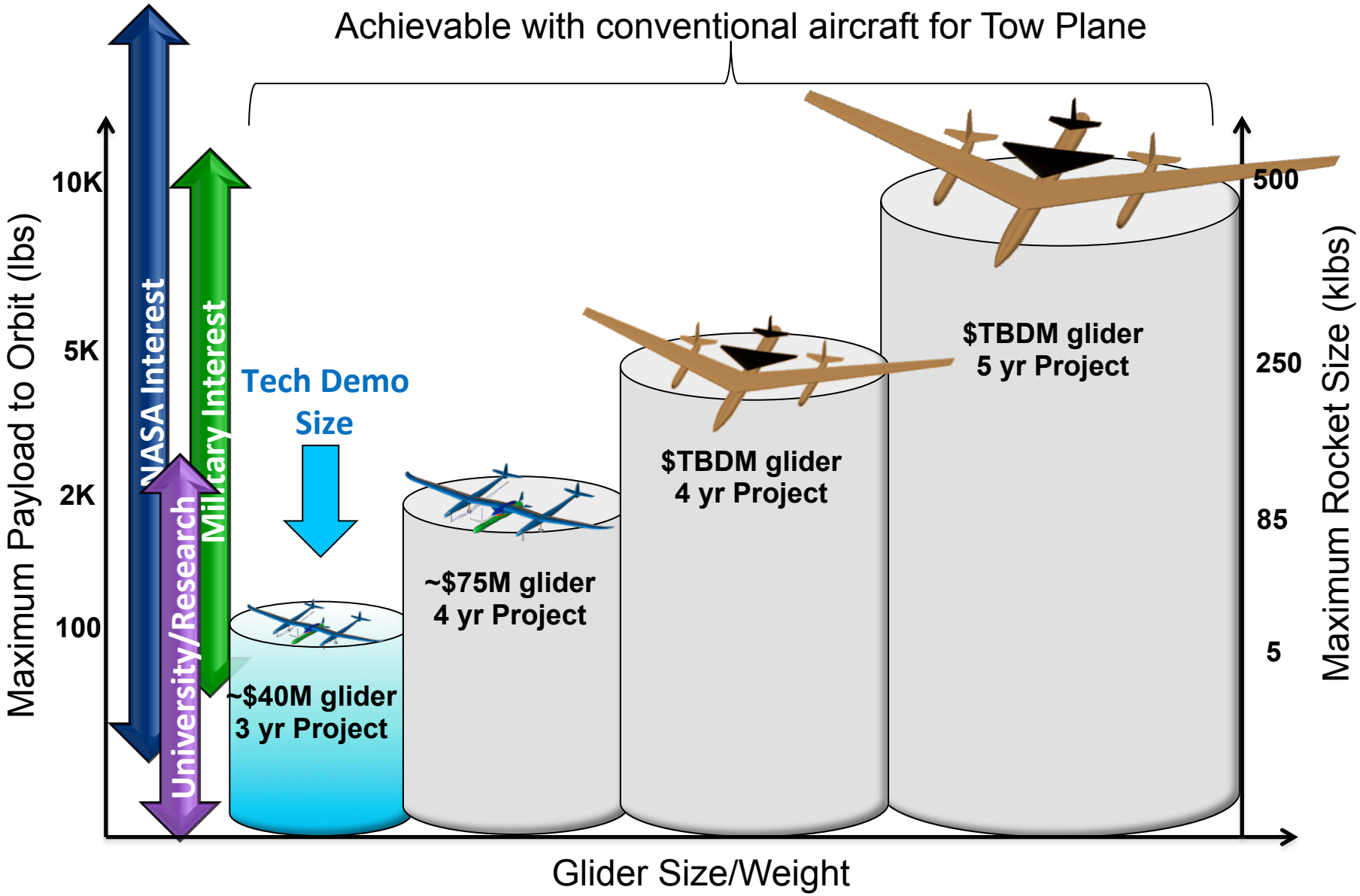
Engines	Fuel
Hydraulics	Crew
Life Support	Avionics

Simplified force vectors

Launch Vehicle
Avionics
Sustainer Motor

Towing provides a dedicated wing to lift the Launch Vehicle to altitude

Towed Glider Technology is Scalable



TGALS – Towed Glider Air Launch System

Launch System Comparison

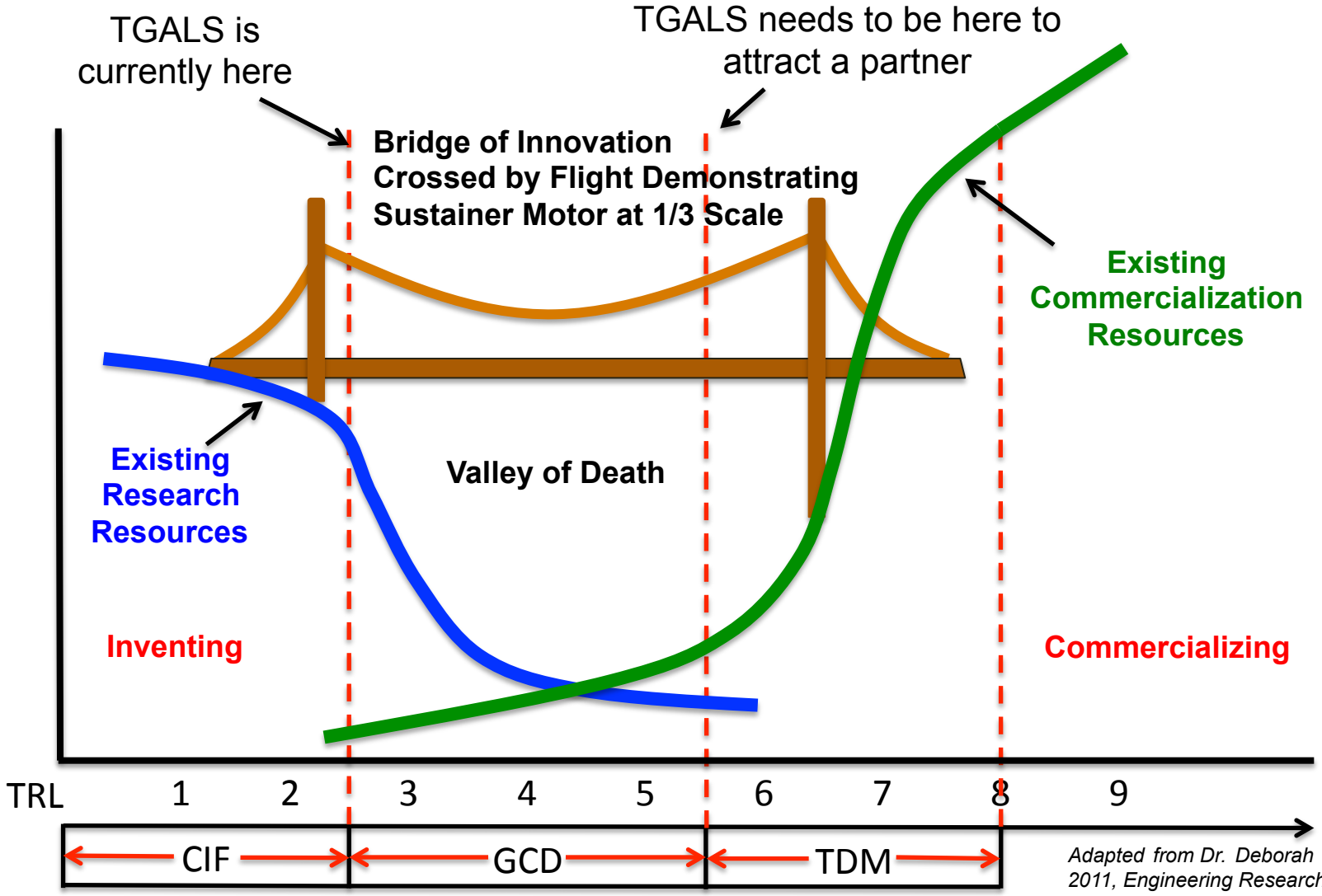
Fixed Infrastructure	Large, expensive complexes	Minimal
Maintenance Hours/Costs	High	Minimal
Scalability (can I make it bigger?)	Not Scalable	Highly Scalable
Launch on Demand	Months	Minutes
Portability/ Survivability	Limited Locations	Locate virtually anywhere
LV Size Limit	6000 lbs or less	> Atlas V
Optimized Launch Coordinates	Fixed Coordinates	Virtually any coordinates
LV Performance (assumes same LV)	Baseline	> 60% Increase

T TGALS — **F** Fixed Pad — **A** ALASA — **S** SWORDS — **G** Go-Launcher — **L** Stratolaunch

Towed Glider Combines Best Attributes of Current Systems

TGALS – Towed Glider Air Launch System

“TRL Jumping” over the Valley of Death



By taking candidate low TRL concepts to flight we “jump” over the Valley of Death in 1-3 yrs

Game Changing Potential of Towed Glider System

Enable Operationally Responsive Space (ORS)
and **Reduce Reliance on Fixed Ranges**

- Enable the dedicated small launch market to finally emerge
  - Enables ORS and Launch-on-Demand
    - COCOMs can responsively launch small satellites to meet emergent theater needs
    - Launches can originate from almost any airfield making them hard to predict
  - Enables rapid refresh of on-orbit instruments
    - Increased viability of space-based internet bringing service to remote areas
    - Allows optimized Earth Observation of emerging events on Earth
    - Bring incremental improvements in technology to orbit faster
  - Enables the possibility of cost effective dedicated small launch

- Begin to remove the reliance on fixed ground ranges
  - Help reduce future range fixed infrastructure requirements
  - Help ensure NSS launch survivability if a fixed range is rendered inoperable
  - Help optimize launch conditions for each specific orbit

*Potential to **Revolutionize** the Dynamics of **Launch Manifesting** in US*

NSS = National Security Space

Project Snapshot: Towed Glider Air Launch

Goal

- **Affordable System Enabling Operationally Responsive Space**

3 Part Program

- PLATFORM - Remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet
- LV STIMULUS - Foster integration of several small LV companies with program to launch off **TOWED GLIDER**
- POLICY - Work with FAA to make launch policies for small LVs using **TOWED GLIDER** as the launch platform

Notional Partnership

- GCD - NASA provides funding and FTEs
- Tech Demo - NASA provides FTEs, Partners provide $$, LV Candidates provide innovative new small LV technology

Why a Towed Glider?

- **High Performance: 50% plus increase in performance to orbit**
  - Carry 2+ times to alt as same size direct carry piloted aircraft
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- **Low Cost:**
  - No new infrastructure costs
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  - Easier for small LV companies to get started w/o huge outlay
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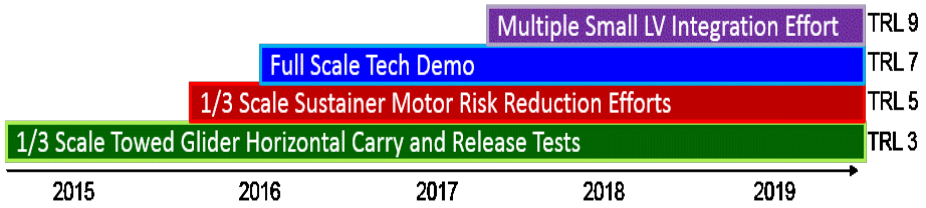
- **Safety:**
  - Remotely piloted glider eliminates human concerns for LV
  - Glider capable of fly home & landing with LV attached
- **Flexibility:**
  - Glider plug-n-play center wing allows simultaneous LV build-ups
  - Glider and LV could fit inside C-17 tow plane for transport
  - Inexpensive gliders can be staged at any airfield
  - Glider concept is scalable from very small LVs

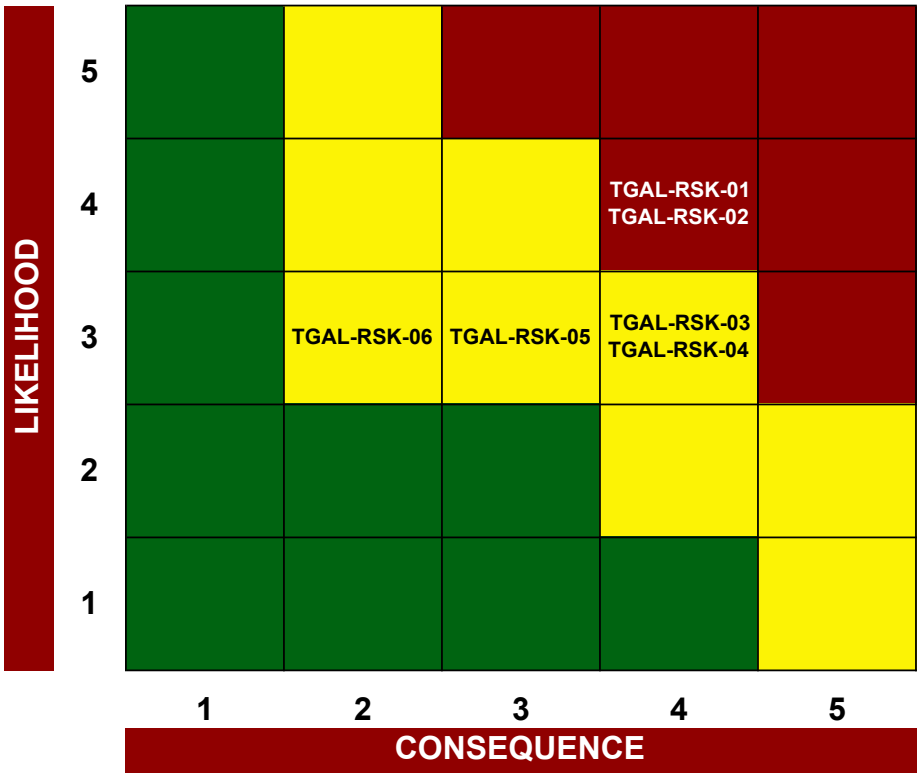
TRL Steps



Tech Demo Deliverables

- *Towed Glider System Development & Build-Up Flights* *FY16-18*
- *Small LV Integration Program* *FY16-18*
- *Policy Development and Coordination* *FY16-18*
- *Small Launch Demo off Glider and Tech Transfer* *FY18*

Risk Management Matrix



Criticality	L x C Trend	Approach
High	▼ Decreasing (Improving)	M - Mitigate
Med	▲ Increasing (Worsening)	W - Watch
Low	▶ Unchanged	A - Accept
	▷ New Since Last Period	R - Research

Risk 1: Performance or operational issues with sustainer motor performance/design

Mitigation 1: Risk-reduction ground tests in FY15 with USU sustainer motor

Mitigation 2: Risk-reduction flight tests in with 1/3 scale glider & USU sustainer motor (currently unfunded)

Risk 2: Problems with effecting new "Policy" for non-traditional launch range ops

Mitigation: Begin investigation in FY15 of the "Core Level" requirements for performing routine launch to orbit operations outside of traditional DoD/NASA Ranges while fully meeting US and Agency requirements

Risk 3: Small Launch Vehicle integration delays/ problems

Mitigation: Find and fund mechanism to assist multiple small launch vehicle providers to develop candidate small LV's for air launch from TGALS

Risk 4: Glider load carrying capability significantly lower than predicted/expected

Mitigation: Risk-reduction aerodynamic performance flight tests in FY14 with 1/3-scale glider

Risk 5: Glider performance under tow significantly lower than predicted/expected

Mitigation: Risk-reduction dynamic tow characterization flight tests in FY15 with 1/3-scale glider

Risk 6: Glider aerodynamic performance significantly lower than predicted/expected

Mitigation: Risk-reduction aerodynamic performance flight tests in FY14 with 1/3-scale glider

Socialization

Name	Position	Date
Robert Lightfoot Jr. & Lesa Roe	NASA Associate Administrator & Deputy Associate Administrator	11/25/14
Tom King	SORDAC Space – Special Operations Command	11/5/14
Dr. James Reuther & STMD DPMC	Deputy AA for Programs, Space Technology Mission Directorate	9/4/14
Dr. John Grunsfeld	Associate Administrator for the Science Mission Directorate	7/31/14
Michael Lopez-Alegria	President of the Commercial Spaceflight Federation	7/31/14
Dr. George Nield	Associate Administrator for FAA Commercial Space Transportation	7/31/14
Frank DiBello	President and Chief Executive Officer of Space Florida	7/29/14
Jay Dryer and Barbara Esker	Director and Deputy Director of the Fundamental Aeronautics Program, ARMD	6/25/14
Dr. Ellen Stofan	NASA Chief Scientist	6/23/14
Dr. James Reuther	Deputy AA for Programs, Space Technology Mission Directorate	6/20/14
DoD Joint Space Team	Executive forum advising DoD on Space issues	6/19/14
Dr. Alexander MacDonald	Assistant to David Miller, NASA Chief Technologist	6/4/14
Eric Poole	KSC Launch Services Program System Integration Engineer	6/2/14
Charles Bolden & Dr. David Miller	NASA Administrator & NASA Chief Technologist	5/13/14
Stuart Witt	Chief Executive Officer, Mojave Air and Space Port	4/17/14
Robert Lightfoot, Jr.	NASA Associate Administrator	4/15/14
Dr. Michael Freilich	Director, Science Mission Directorate, Earth Science Division	1/24/14
Steve Isakowitz	President, Virgin Galactic	10/23/13
James Wood	KSC Launch Services Program Chief Engineer	9/12/13

Socialization (cont.)

Name	Position	Date
Dr. Mike Ryschkewitsch	NASA Chief Engineer (at the time)	5/21/13
Dr. Walker, Dr. Tousley, Pam Melroy	DARPA Deputy Director and DARPA Tactical Technology Office	4/29/13
Dr. Antonio Elias	Executive Vice President and Chief Technical Officer, Orbital Sciences Corp.	2/26/13
Doug Shane	President, Scaled Composites (at the time)	1/4/12

Endorsements

SPACE FLORIDA

April 11, 2014

Gerald D. Budd, Project Manager
Advanced Planning and Partnerships Office, Code Z
Neil A. Armstrong Flight Research Center
P.O. Box 273, M/S-2701
Edwards, CA 93523-0273

Re: Towed Glider Air-Launch Concept Project

Dear Mr. Budd,

Space Florida is please to express a genuine interest in facilitating the development of the Towed Glider dedicated cubesat launcher concept. We have long believed the small sat market to be as exciting a business opportunity as anything associated with technology. That future is exciting and our job is to assure that future happens here in Florida.

A partnership between Armstrong Flight Research Center and the Kennedy Space Center (KSC), as a part of the Game Changing Division of NASA's Space Technology Mission Directorate, this technology's development is encouraging. That it would then be handed off to industry to operate is what makes it so intriguing. It is the business opportunity for Florida which so aligns with our charter and our mission.

Space Florida is prepared to sponsor the development of an independent business case for the Towed Glider as a commercially-operated, dedicated cubesat launcher based at Shuttle Landing Facility (SLF). This modest investment will then be used to attract interested industry partners. Additionally, with the existing workforce, resources and facilities already maturing here on the Space Coast to support cubsat development, processing, integration, as well as the potential to process the downlinked data, this concept clearly supports the future we are trying to create here in Florida.

Also, Space Florida can readily facilitate 1) the development of a NASA-funded lease for required shop and office space at SLF for the developmental project; 2) participate in Range coordination for the developmental project; and 3) to participate in securing an industry partner.

Finally, the potential pace of work at the SLF, the further evolution of the cubsat processing and launch capability, as well as the opportunities to engage local university students in this new industry, represent exactly what it is Space Florida was created to support.

We look forward to working with you in the future on this innovative concept.

Sincerely,

Frank A. DiBello
President & CEO
Space Florida

sf 14-309-dk-fad

SPACE FLORIDA
505 Odyssey Way • Suite 300 • Exploration Park • FL 32953
www.SpaceFlorida.gov • f: 321.730.5307 • p: 321.730.5301

Space Florida is prepared to sponsor the development of an independent business case for the Towed Glider as a commercially-operated, dedicated cubesat launcher based at Shuttle Landing Facility (SLF). This modest investment will then be used to attract interested industry partners.

Also, Space Florida can readily facilitate 1) the development of a NASA-funded lease for required shop and office space at SLF for the developmental project; 2) participate in Range coordination for the developmental project; and 3) to participate in securing an industry partner.

Endorsements

MOJAVE
AIR & SPACE PORT

April 22, 2014

Gerald D. Budd, Project Manager
Advanced Planning and Partnerships Office, Code 2
Neil A. Armstrong Flight Research Center
P.O. Box 273, M/S-2701
Edwards, CA 93523-0273

Re: Towed Glider Air-Launch Concept Project

Dear Mr. Budd,

Mojave Air and Space Port (MA&SP) is pleased and excited at the opportunity to facilitate the development of the Towed Glider dedicated cubesat launcher concept. We have direct access to special use airspace, a supersonic corridor and a letter on file from FAA authorizing access to space.

MA&SP has engaged in towed aircraft activity for nearly 70 years. Multiple commercial space companies now call Mojave home and more rocket motors have been tested here in Mojave this century than any other location on earth.

MA&SP would be very pleased to further this initiative in any way possible. At least three destinations or original points will be required in North America to reach desired space inclinations. Mojave is a natural for one of these three.

We look forward to working with you in the future on this innovative concept.

Sincerely,

MOJAVE AIR AND SPACE PORT

Stuart C. Witt
Chief Executive Officer

SOW/dar

East Kern Airport District • 1434 Flightline • Mojave, CA 93501 • 661. 824.2433

Mojave Air and Space Port (MA&SP) is pleased and excited at the opportunity to facilitate the development of the Towed Glider dedicated cubesat launcher concept.

MA&SP would be very pleased to further this initiative in any way possible.

AFRC Historic Capabilities

- AFRC Tow Experience
  - F-106 tow from C-141A
  - M2-F1 Lifting Body
  - 1/3 Scale Towed Glider


- AFRC Remote Pilot Experience
  - F-15 RPRV
  - HiMAT
  - IKHANA
  - DROID




- AFRC Air Launch Experience
  - Pegasus
  - X-43
  - X-15
  - HL-10
  - M2-F2



TGALS is an Integration of Proven Capabilities

TGALS CIF Activity Photos

DROID towing Twin Fuselage Glider

Team photo with Twin Fuselage Glider and MiniSprite Launch Vehicle during fit-check activities

Flexible Partnering Options

Military Partner

- Build glider system to augment existing launch capabilities
- Military sizes system to meet their tactical needs

Big Commercial Partner

- Build glider system to be first to market with dedicated small launch capability
- Size glider to cater to projected near-term small launch market

Hybrid Solutions

- Any 2 or more combine to pay for development of all major parts (glider, tow plane, LVs)

NASA Demonstration

- Tech Demo of minimum cost proof of concept system (likely sub-scale)
- Tech Transfer to industry to commercialize as they see fit

Multiple Small Partners

- Each contributes part of the glider system to open small launch market
- Enjoy first to market status without huge capital outlays

Excess Thrust Required by Tow Airplane as a function of Carry Efficiency and Tow Glider Max L/D