



# Air Launch – Low-Cost Small Satellite Launch

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# Armstrong (Dryden) Performed Many Air Launches

*From 1946-2010*

## Summary

- Rocket-propelled flights Bell X-1 through X-43
- Total flight operations – 662
- Total manned flight operations – 654

## Manned Flight – Rocket-powered operations

*(glide flights not included)*

- 135 Bell X-1, 23 Bell X-1A, 25 Bell X-1B, 24 Bell X-1E
- 134 Douglas Skyrocket D-558-2
- 198 North American X-15
- 115 lifting bodies (M2-F2, M2-F3, HL-10, X-24)



## Unmanned – Rocket-powered operations

- 6 B-52/Orbital Sciences Pegasus Launches
- 2 B-52/X-43 Hyper-X (Mach 7 and Mach 10)

# Performance Advantages/Disadvantages of Air Launch

## Performance advantages

- Launch vehicle starts with initial velocity and altitude compared to ground launch (typically Mach 0.8, 40K ft)
- Air launch adds stages to launch vehicle, which lifts rest of launch vehicle to Mach 0.8, 40Kft
  - › two-stage rocket becomes three-stage rocket, three-stage rocket becomes four-stage rocket, etc.
- Launch starts above denser lower atmosphere, decreased drag losses during first stage
- Lower trajectory-averaged atmospheric pressure during first stage, increased rocket thrust and specific impulse
- Lower atmospheric pressure at launch, can use higher expansion ratio nozzles on first stage without flow separation, further increase in rocket thrust and specific impulse

## Performance disadvantages

- Typically a wing needs to be added, with tail control surfaces (aka Pegasus configuration), to provide lift for pull-up maneuver to rotate flight path angle from horizontal air launch to flight path angle needed for ascent to orbit
  - › Wing and tail surfaces add weight and drag, high angle-of-attack during pull-up maneuver increases drag losses
  - › Parachutes or other methods to avoid adding wing typically lose altitude and velocity, first stage ignition altitude can fall to approximately 20K ft, velocity to zero or slightly negative

# Air Launch at AFRC

A number of new commercial companies are attempting very unique air launch operations – AFRC has agreements for support (**bold**) and is negotiating with others

- **Generation Orbit** – Analysis of launch vehicle off a G-III
- **Virgin Galactic** – Analysis of LauncherOne vehicle off a 747
- **Vulcan** – Flight test and technical support of Stratolaunch vehicle
- CubeCab – Satellite launch using an F-104
- **Other companies** – Analysis of launch vehicles

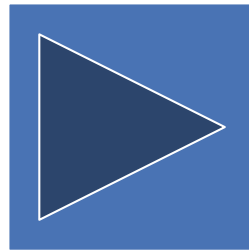
**Strong collaboration with the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) for launch licenses**

- Have had productive meetings discussing air launch



# Towed Glider Small Satellite Launch Concept

A remotely piloted glider, towed by a modified cargo/passenger jet, releasing a launch vehicle with payload at 48K' 45K', non-SBU  $M = 0.75$ , up to a 700 flight path angle, safely and effectively.



<https://www.youtube.com/watch?v=0hEnYyykaL8>

# Why Towed Glider?

## Performance

- Towed Glider Air Launch performance advantages over conventional horizontal air launch
  - › Glider with sustainer motor does pull-up maneuver rotating flight path angle before dropping launch vehicle, no need for wing on launch vehicle, only small fixed fins for aerodynamic stability during 3 to 5-second drop before first stage ignition
  - › Eliminates weight and drag from wing, fixed tail fins have reduced weight compared to moveable fins
  - › Eliminates pull-up maneuver being performed by launch vehicle for decreased first stage drag losses compared to horizontal air launch
- Towed Glider Air Launch performance advantages over ground launch
  - › Has all air launch advantages listed on prior chart, with all air launch disadvantages eliminated
  - › From Towed Glider Air Launch study in progress for DARPA, substantial increases in payload to orbit compared to ground launch for two-stage liquid and multi-stage solid launch vehicles

## Geometry

- Can lift significantly larger payloads to altitude versus modifying a same size, direct carry, “conventional” aircraft for external carriage

## Cost

- Less expensive to build, operate, and maintain than developing and building a one-of-a-kind, custom carry aircraft
- Simple glider, devoid of expensive, complex systems
  - › No hydraulics, fuel system, engines, life support, egress systems
- Leverages the advantages of air-launching
  - › No dependence on critical ground based launch facilities/assets

## Safety

- Unmanned glider eliminates aircrew concerns for carrying launch vehicle (LV)
- LV doesn't have to be human-rated (blast proximity), nor does the glider

## Risk

- A systems level integration of existing, proven technologies

# Towed Glider Air Launch Study for DARPA

## Study tasks

- Assess the viability of operating small (nanosatellite and larger) launch vehicles off the Towed Glider
- Calculate the performance increase for each launch vehicle launching from the Towed Glider compared to ground launch
- Estimate the cost of performing a launch operation from the Towed Glider (excluding the cost of the launch vehicle)
- Multiple (proprietary) launch vehicles

## Performance analysis

- POST trajectories, missile DATCOM aero data, company mass properties data

## **Substantial increases in payload to orbit compared to ground launch for two-stage liquid and multi-stage solid launch vehicles**

## **Towed Glider operating costs \$300K to \$500K per launch**

- Includes amortized cost of Towed Glider depreciated over number of flights
- Includes cost per flight of renting, or owning, the tow plane
- Does not include benefit of potential reduction in range costs
- Cheaper (potentially much cheaper) than adding an additional conventional rocket stage to the launch vehicle
  - › Towed Glider similar to an additional stage that gets rest of launch vehicle to Mach 0.75, 40K ft

# NASA Armstrong Areas to Support Air Launch

Area	Why needed
FAA Launch License	Needed for companies to get paid for launches and operate in FAA airspace.
Separation Analysis	Ensure safe launch vehicle separation. Needed for flight clearance and FAA launch license.
Flight Test Planning	Safe, efficient flight clearance for air launch. Needed for airworthiness process.
Flight Instrumentation	Needed for proper, accurate measurements of pertinent parameters. Used for envelope expansion.
Store Separation Flight Instrumentation	Ensure clean store separation and provide data for mishap investigations and improving store separation analysis tools.

# NASA Armstrong Areas to Support Air Launch

Area	Why needed
Structural Clearance	Ensure that launch vehicle and attached device can withstand the air and dynamic loads for all phases of flight. Needed for flight clearance.
Risk Analysis	Assess risk for both the vehicle and the range. Needed for flight clearance.
Integration of Air-Launch Systems	Properly implement and test air-launch systems for safe and successful operations.
Flight Operations	Perform safe, efficient flight operations for air launch.
Automated Flight Termination	Reduction of operational costs resulting from manual system and range safety operator.

# Summary

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- NASA Armstrong Flight Research Center has a long history of unique air-launch operations
- We believe that air launch represents an opportunity for efficient, low-cost small satellite launch
- We are currently assisting multiple companies using NASA Armstrong air-launch expertise
- We believe that the Towed Glider concept can be the most efficient form of launch for small satellite applications

# Questions?



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