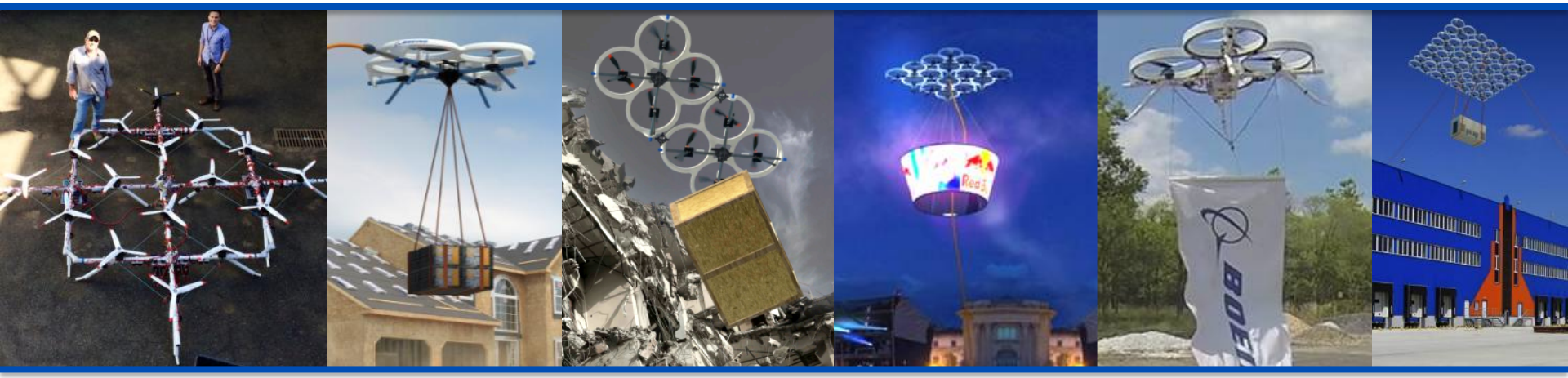


# The LIFT! Project
# Cooperative, Modular Electric Lift

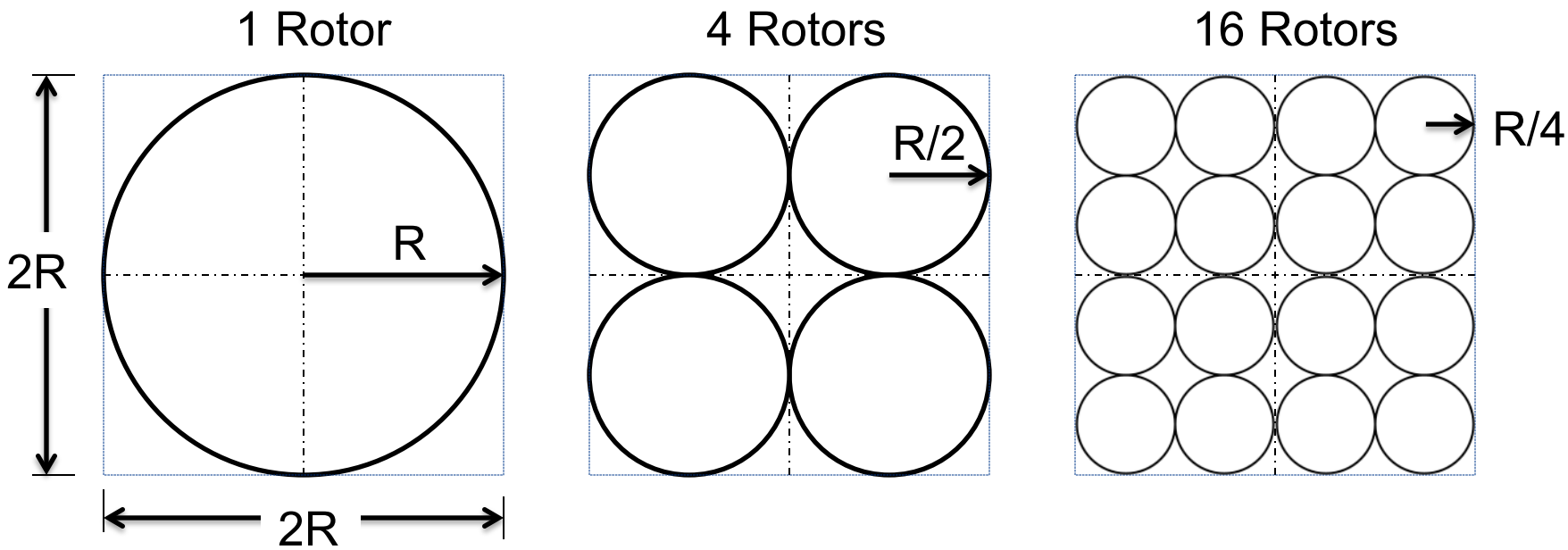
August 2015

Michael Duffy and LIFT! Team
Boeing Advanced Vertical Lift

Video

# DISTRIBUTED ELECTRIC PROPULSION FOR VERTICAL LIFT

# Distributing the Lift




Disc Area = **πR^2**

4π(R/2)^2 = **πR^2**

16π(R/4)^2 = **πR^2**

Same disc loading, many discs

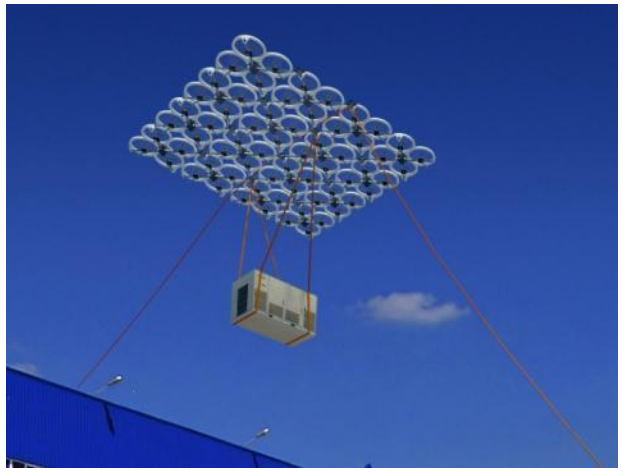
# Scalable – Many Smaller Rotors vs. One Large Rotor

Concept of Modular Vehicles (with Power Tether)

**1 Vehicle = 100 lbs payload**

**4 Vehicle = 400 lbs payload**

**16 Vehicle = 1,600 lbs payload**



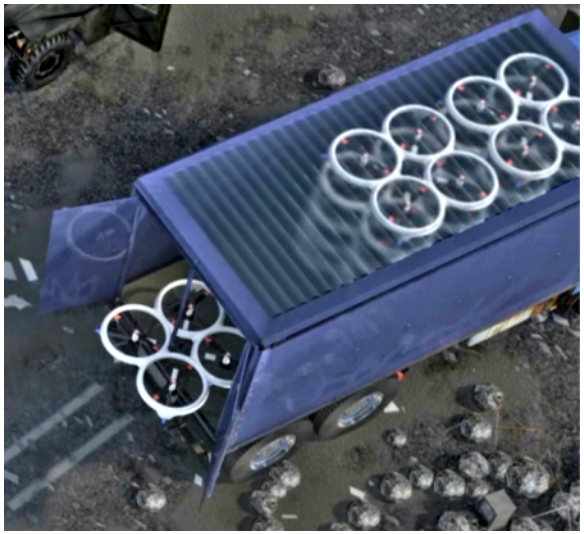
**Un-tethered range = 5 miles**

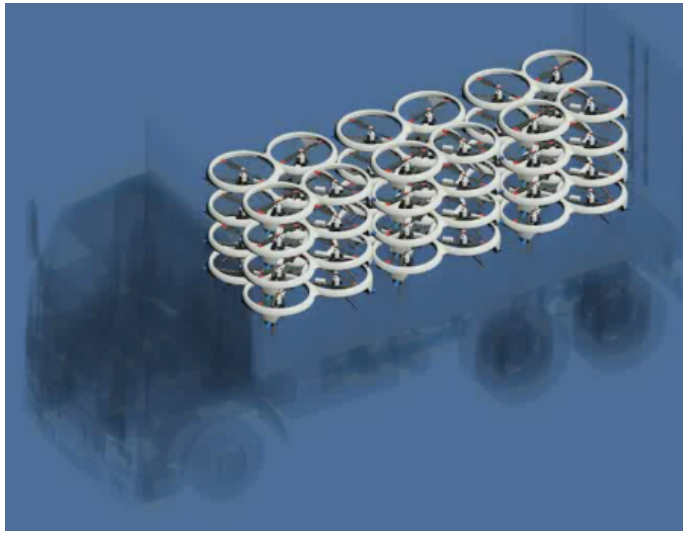
**Powered tether range = 1,000 feet**

'Right sizing' the vehicle to the mission, significant reduces operating cost

# Portable – Can be broken down into smaller units

Portable Vehicles that Fit in Standard Truck



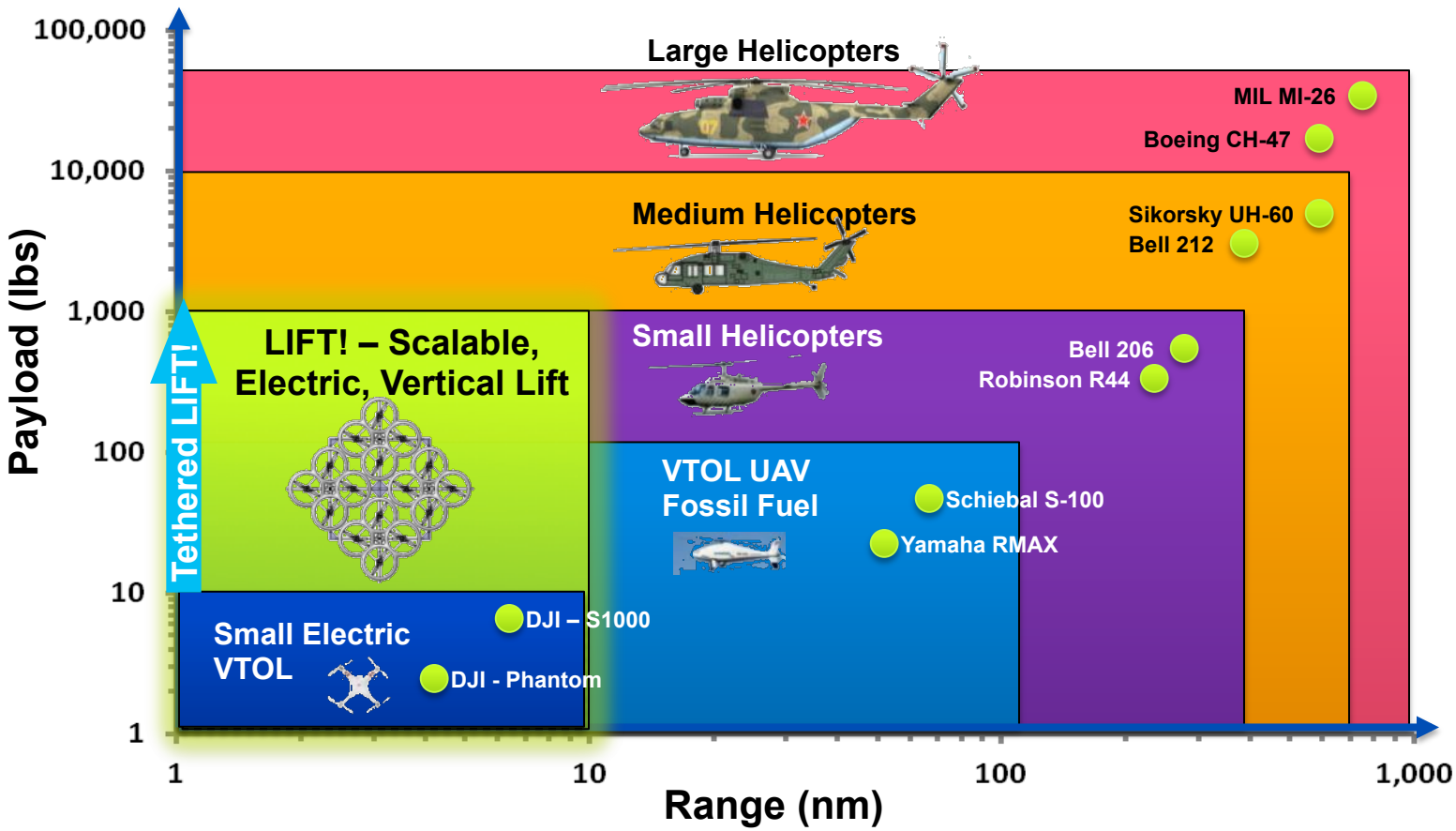


Significantly reduced transportation cost

# COMMERCIAL UTILITY MISSION

# LIFT! Missions

LIFT! focused on short range all electric mission



# Mobile Crane Market
# Reach and Frequency Drives Cost not Payload

**LIFT!**
**~$200 – $1,000**
**Per Job**

**Helicopter:**
**$5,000 – $15,000**
**Per Job**

**Large Mobile Crane:**
**$3,000 – $8,000**
**Per job**

**Small Cranes:**
**$500 – $2,000**
**Per job**

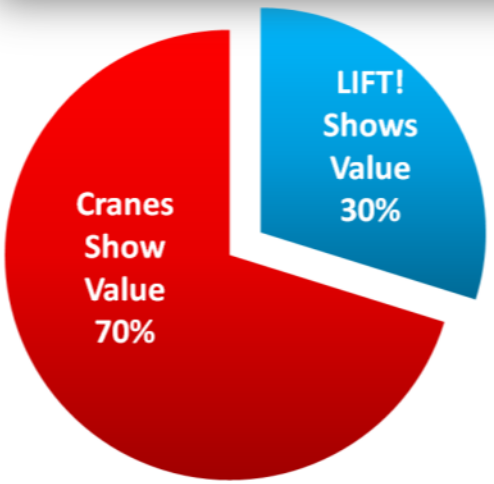
***Payload <2,000 lbs***

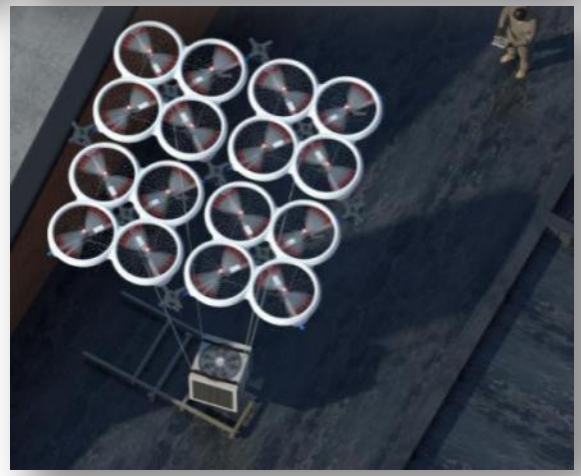
Reach

Building

# LIFT! Service for Industrial Lift

**Jobs under 2,000 lbs**



# Missions

Jobs for Modular LIFT!

**Payload Delivery**

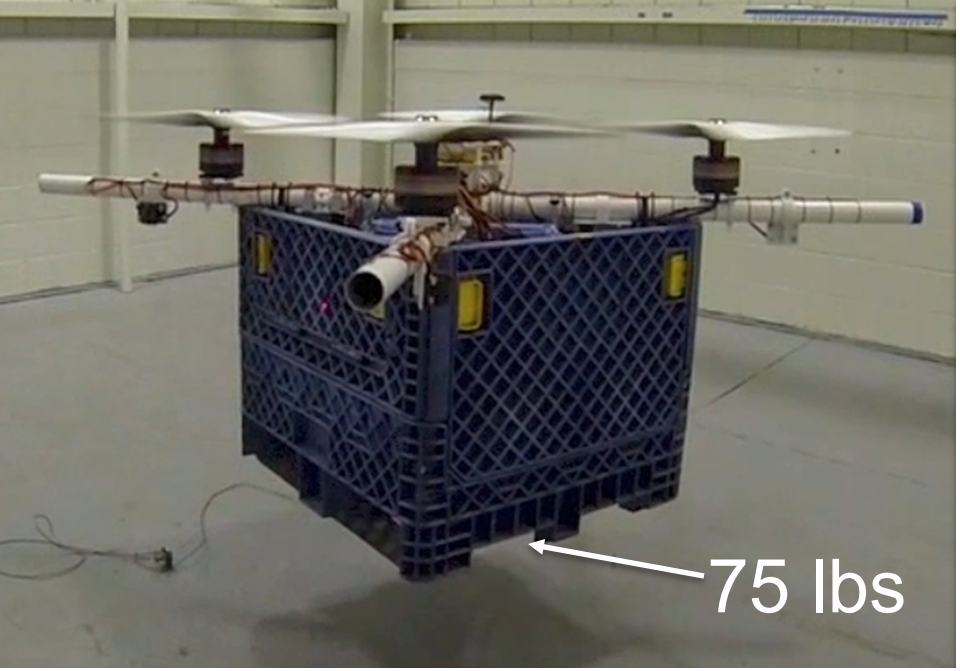
**Line of Sight Lift**

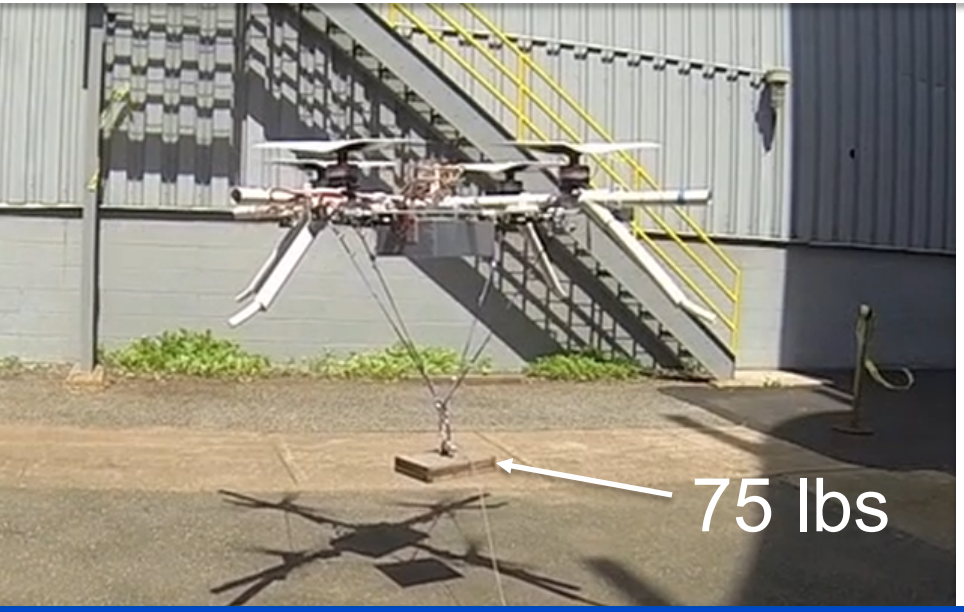
**Mobile Lights**

**Aerial Ads**

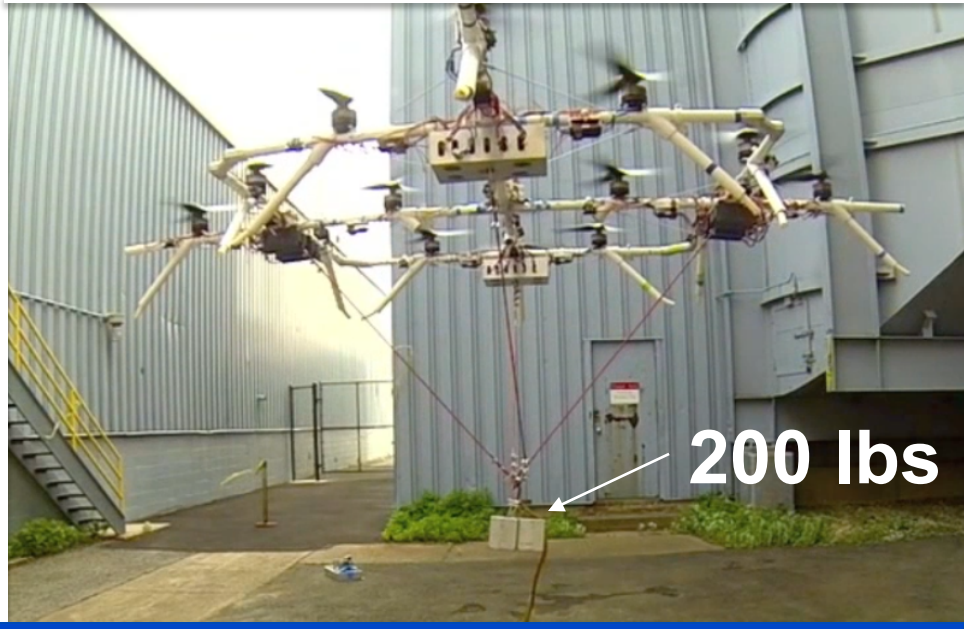
Short range missions

# MULTI-ROTOR VEHICLE TESTING





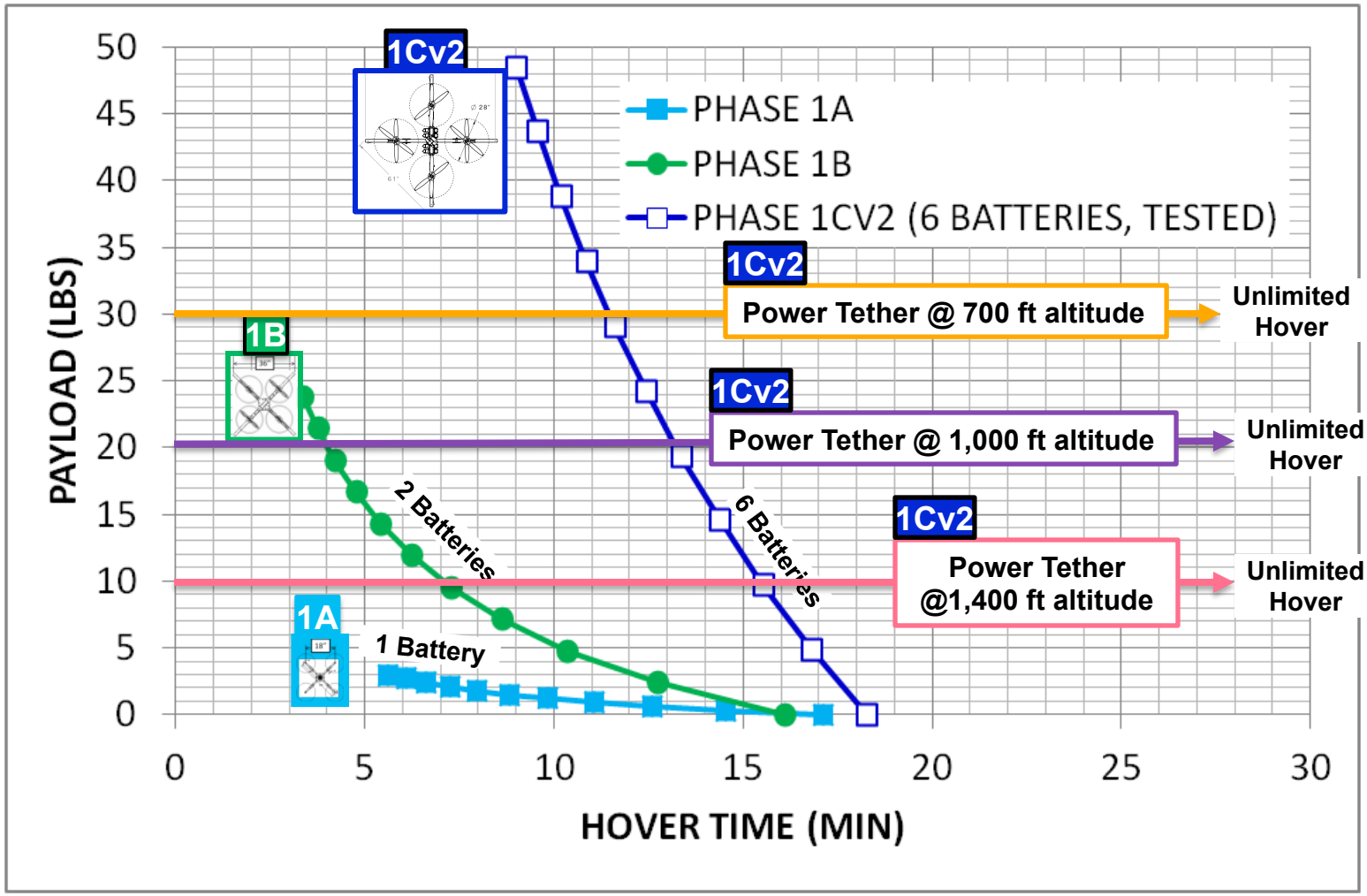
Tested stability for various payload weights and connection types




Max gross weight flown was over 500 lbs

# FLIGHT ENDURANCE

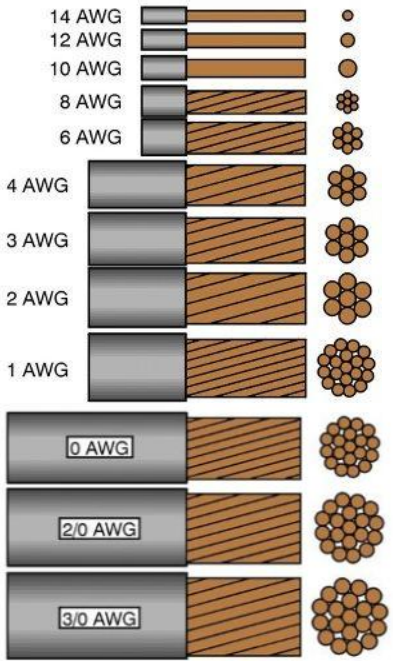
# Hover Flight Endurance w/ Tether




5 – 20 min of endurance for disc loading (2.5-8.5 psf)

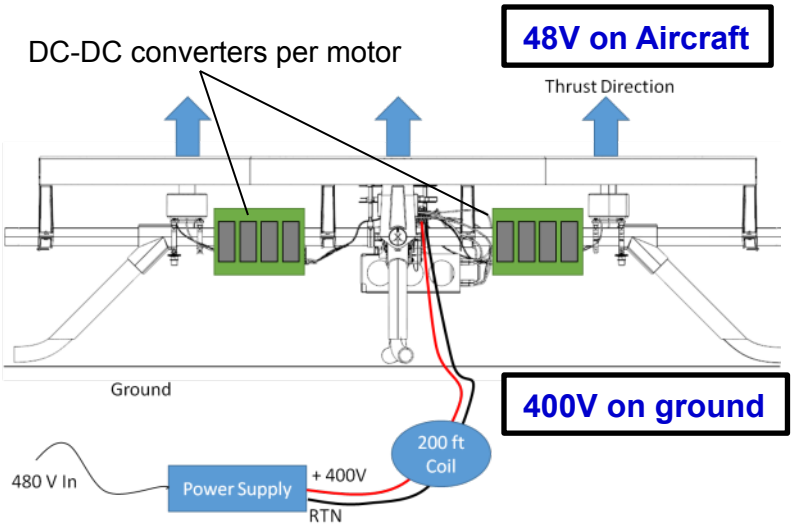
# POWER TETHER TESTING

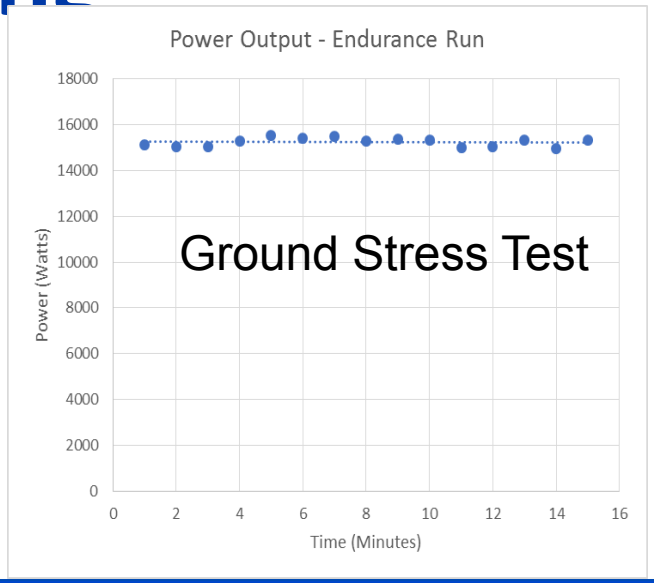
# Wire Gauge vs. Power and Voltage




| Gauge | Max Amps | Power (KW) @ 48 Volts | Power (KW) @ 400 Volts | Weight (lbs) for 100 ft |
|---|---|---|---|---|
| 14 | 15 | 0.7 | 6 | 1.2 |
| 12 | 20 | 1.0 | 8 | 2.0 |
| 10 | 30 | 1.4 | 12 | 3.1 |
| 8 | 40 | 1.9 | 16 | 5.0 |
| 6 | 55 | 2.6 | 22 | 8.0 |
| 3 | 100 | 4.8 | 40 | 15.9 |
| 1/0 | 150 | 7.2 | 60 | 31.9 |
| 3/0 | 200 | 9.6 | 80 | 50.8 |

# Powered Tether Testing



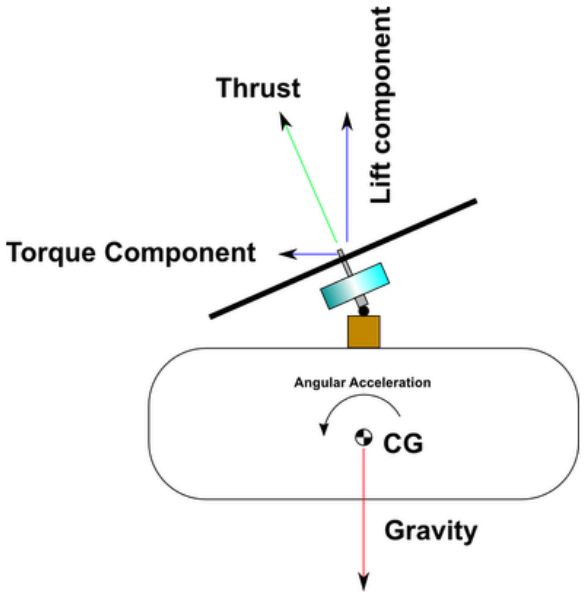




Unlimited endurance with limited range

# CONTROL
# WITH MULTIPLE GROUND TETHERS

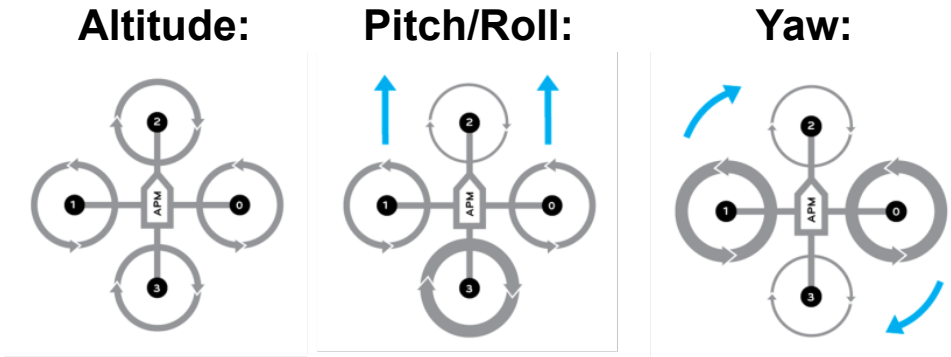
# Multi-rotor Vehicle Control

## Helicopter




Collective and Cyclic Control

## Multi-rotor

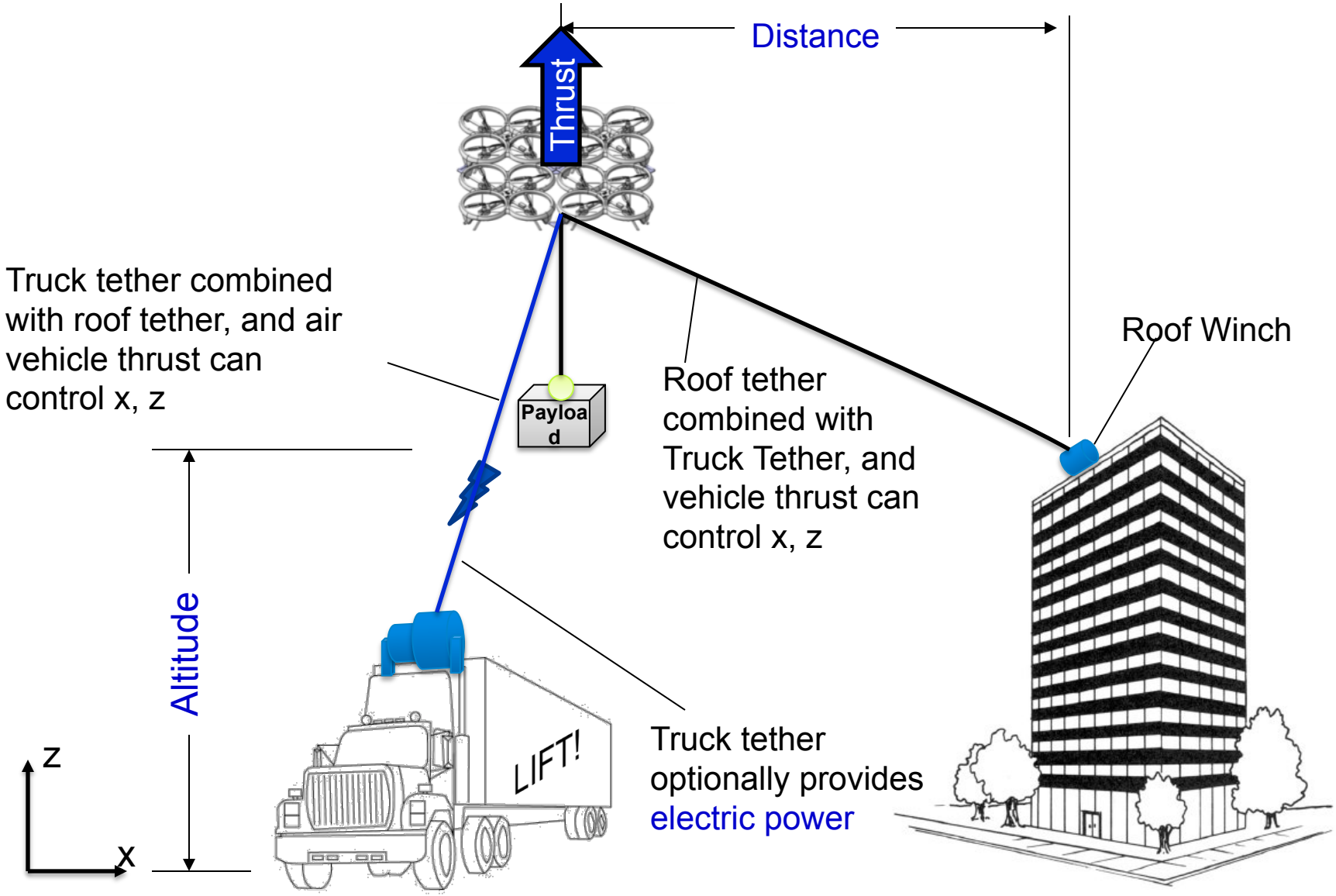



Variable RPM, Fixed Blade Pitch

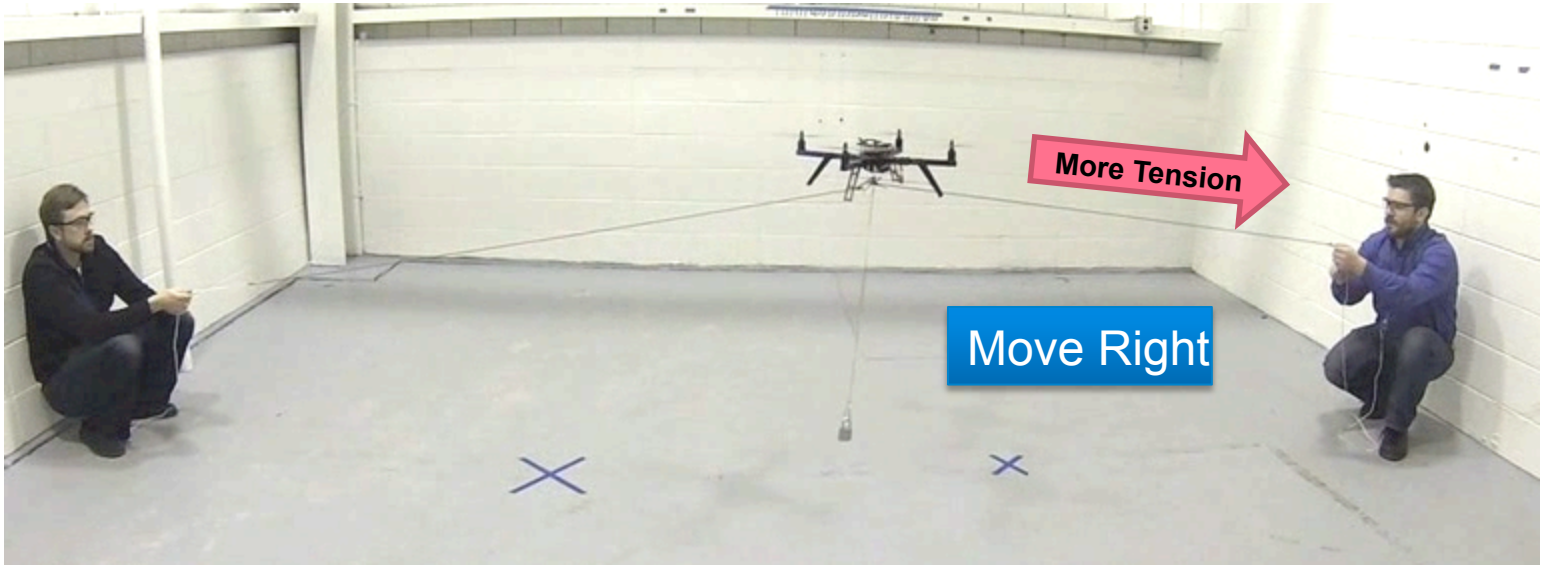
Source:
http://www.manycopter.com/2014/04/quadcopter-control-theory.html

Source:
http://www.socialledge.com/sjsu/images/2/2f/Cmpe240_f13_quadcopter_motion.png

# Precision Delivery with Cable Guide
# Lifting Payload



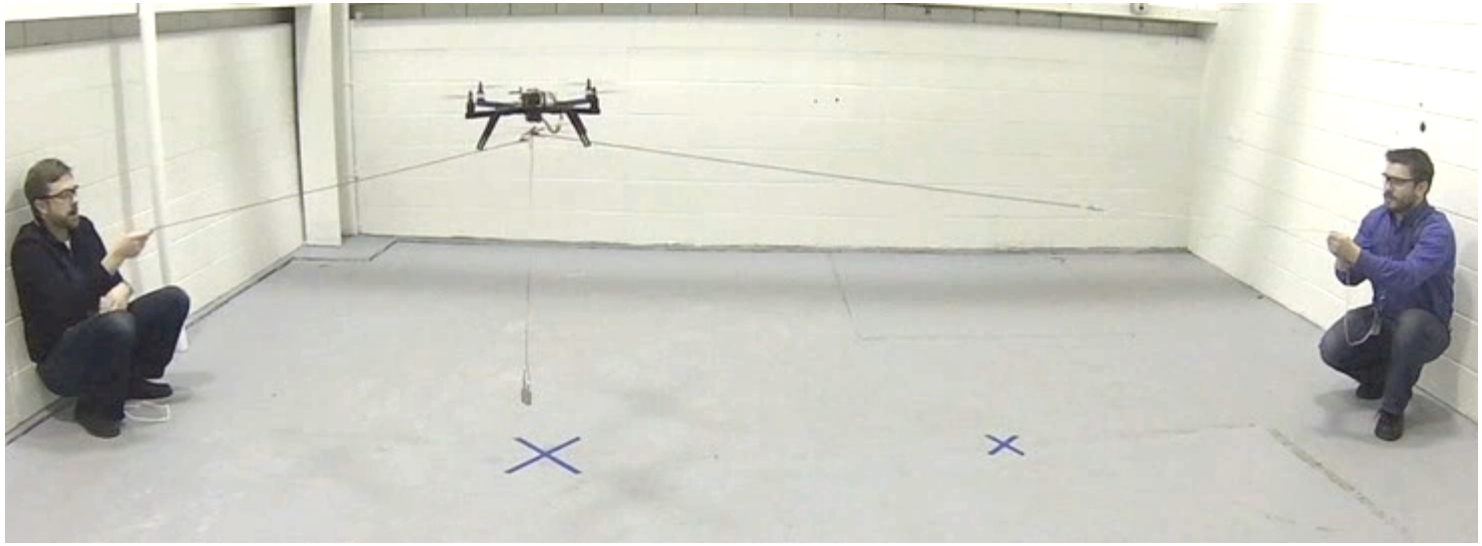
# Flight Test Demo (Phase 1A)

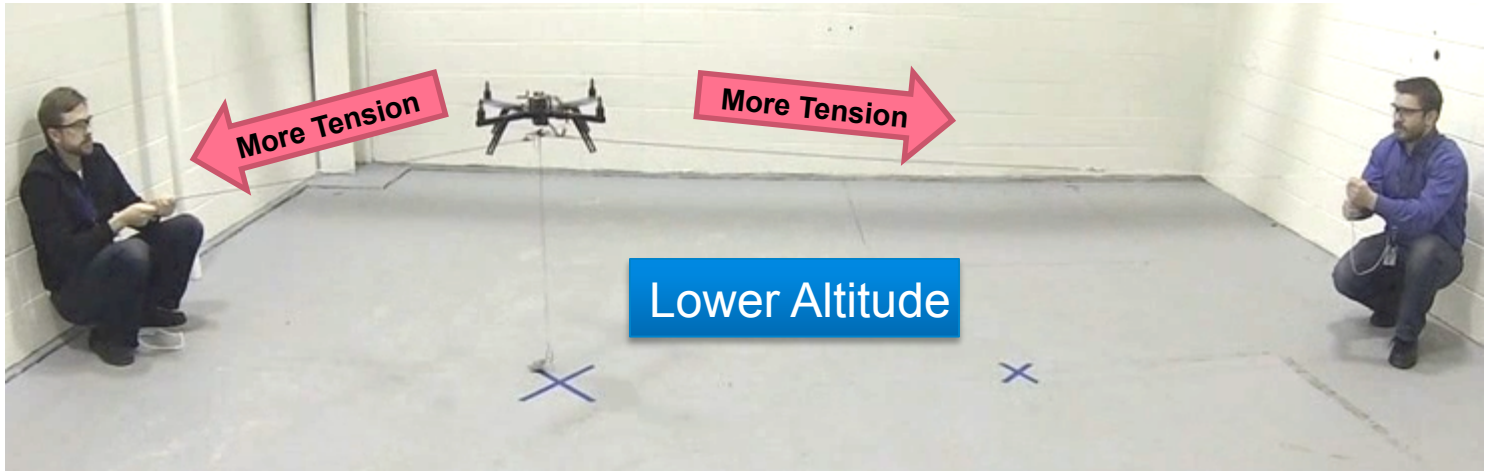


Video:
https://tcc13.web.boeing.com/bds/lift/Shared Documents/VIDEOs/LIFT! Tether Testing - Phase 1A.m4v

BOEING PROPRIETARY

# Flight Test Demo (Phase 1A)






Video:
https://tcc13.web.boeing.com/bds/lift/Shared Documents/VIDEOS/LIFT! Tether Testing - Phase 1A.m4v

BOEING PROPRIETARY

# Technical Challenges of Electric Multi-rotor Aircraft

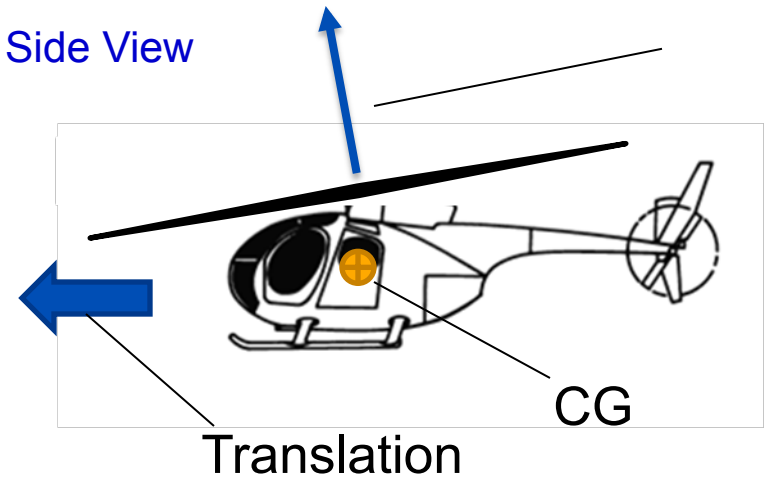
# Attitude Control

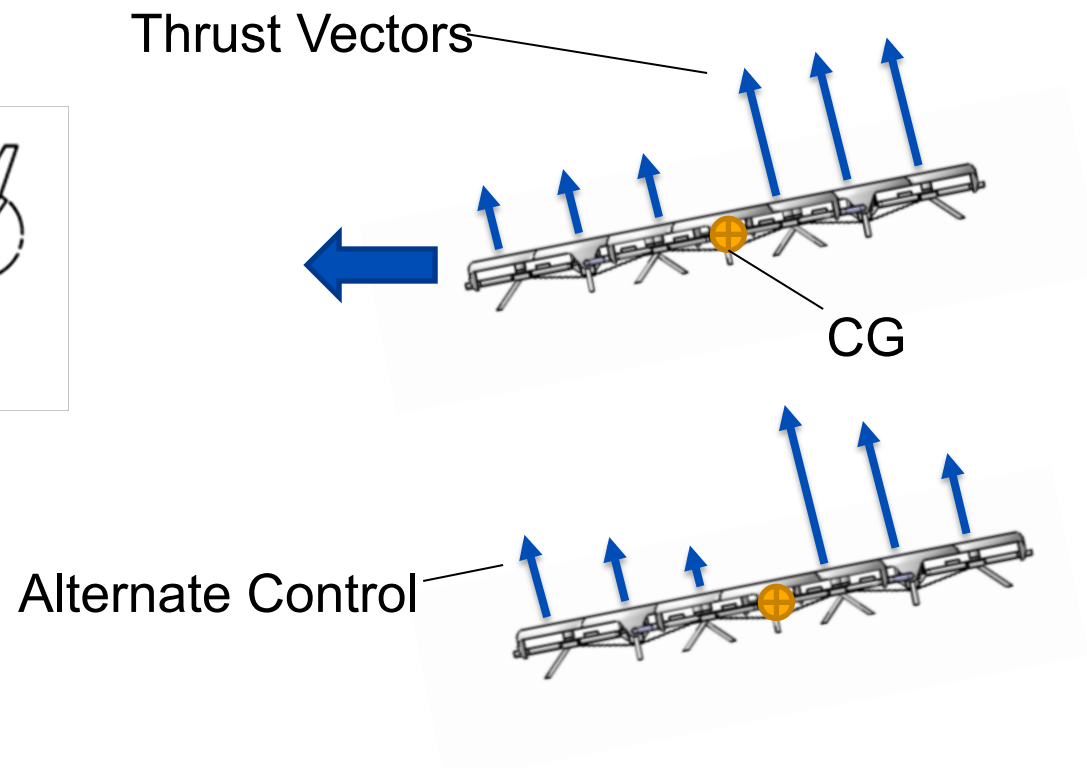
Sample Traditional Rotorcraft

*1x Rotors*

Sample Distributed Electric Propulsion

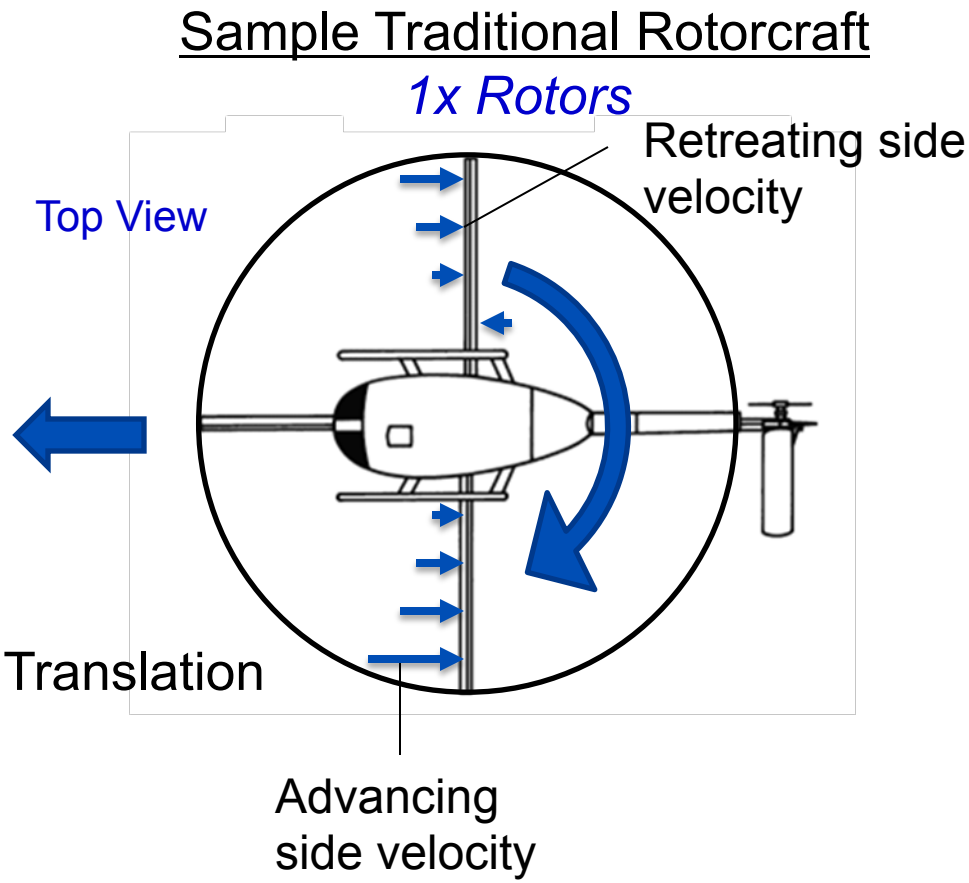
*16x Rotors*

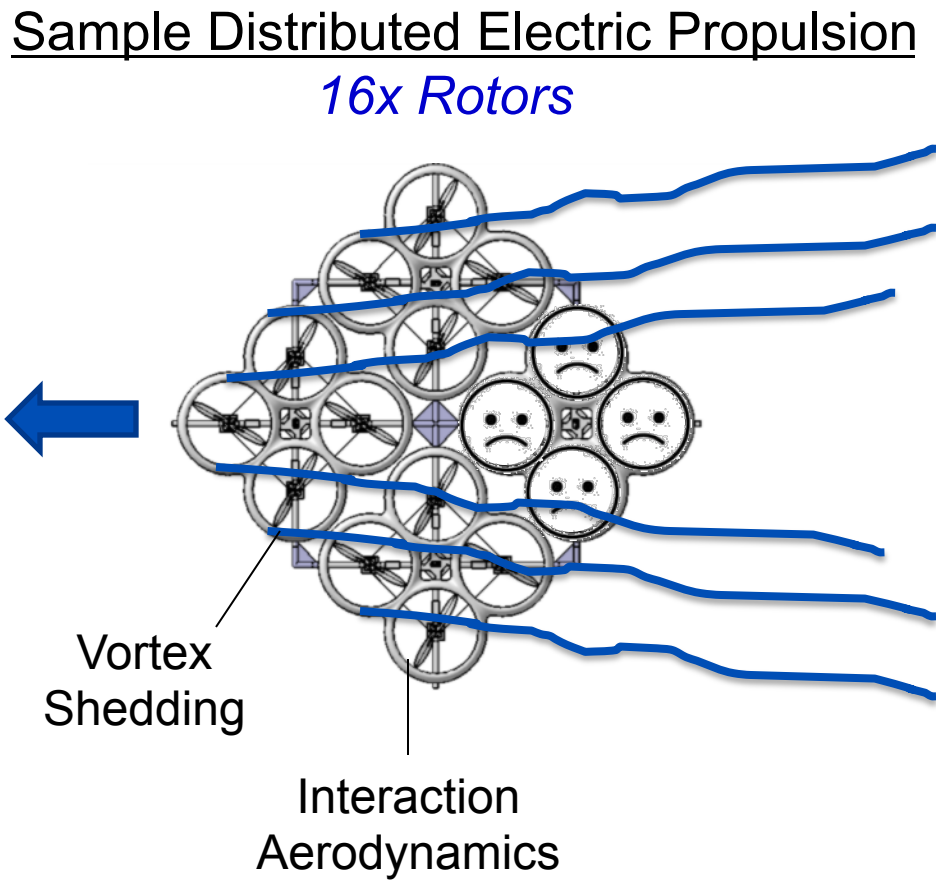



Rotor tilt (articulated blades) vs. vehicle tilt (fixed pitch blades, RPM variation)

# Aerodynamic Interaction



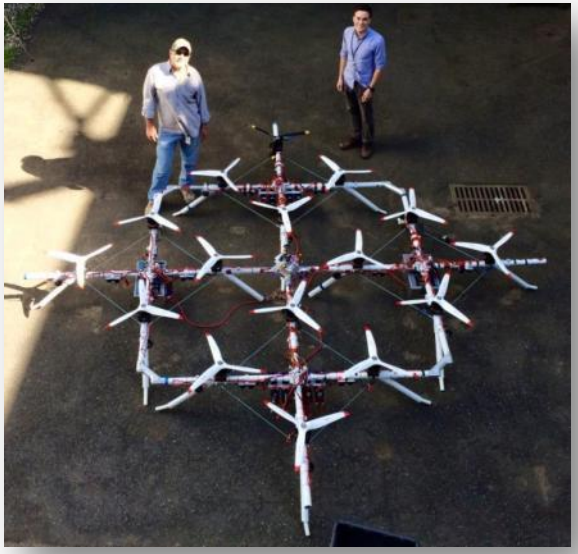



# SUMMARY

# What we learned:

*Electric Multi-rotor:*

- *Mechanically simple*
- *Robust to crashing*
- *Swappable components mean easy repair*
- *Design flexibility*
- *Failure tolerant*



Opportunity:

- New and novel markets for vertical lift aircraft
- Lower barrier to entry for new vehicles concepts

Challenges:

- Mechanical complexity is traded for digital/software complexity
- New aerodynamic and dynamics challenges with multi-rotor
- Line of sight ONLY for tethered
- Tether gets caught on ground obstacles
- New types of controls are required