

# PSCR 2020: THE DIGITAL EXPERIENCE



NIST

#PSCR2020



# INNOVATING ON DRONE TECHNOLOGY TO SUPPORT FIRST RESPONDER MISSIONS

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# Agenda



**Deployables Research  
- UAS and Broadband Communications**



**First Responder Drones Usage Survey Results**



**yet2 Market Research Results**



**Open Innovation UAS Prize Challenges**



**Q&A with UAS First Responder Expert Panel**

# **Deployables Research**

## **UAS and Broadband Communications**

# Deployables Research

## PSCR deployable broadband for public safety

**Goal:** maintain broadband services when the broadband network is not operational or users are outside of the network coverage area

- Maintain Push-to-Talk and Situational Awareness, no matter of the situation
- First responder-centric technology





# Deployables Research

Technical gap: Range of a wireless technology ↔ Solution: Utilizing Unmanned Aircraft Systems

- Hosting radios on UAS provides line of sight to a much larger area
- Lots of information exists on aerial communication systems

## Airborne Base Stations for Emergency and Temporary Events

Alvaro Valcarce<sup>1</sup>, Tinku Rasheed<sup>2</sup>, Karina Gomez<sup>2</sup>, Sithamparanathan S. Ari<sup>5</sup>, Mil

2015 IEEE Wireless Communications and Networking Conference (WCNC) - Workshops - 2nd International Workshop on Device-to-Device and Public Safety Communications

## UAV Assisted Heterogeneous Networks for Public Safety Communications

Arvind Merwady and İsmail Güvenc  
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**Abstract**—Communications play an important role during public safety operations. Since the current communication technologies heavily rely on the backbone network, the failure of base stations (BSs) due to natural disasters or malevolent attacks causes communication difficulties for public safety and emergency communications. Recently, the use of unmanned aerial vehicles (UAVs) such as quadcopters and unmanned gliders have gained attention in public safety communications. They can be used as unmanned aerial base stations (UABSs), which can be deployed rapidly as a part of the heterogeneous network architecture. However, due to their mobile characteristics, interference management in the network becomes very challenging. In this paper, we explore the use of UABSs for public safety communications during natural disasters, where part of the communication infrastructure becomes damaged and dysfunctional (e.g., as in the aftermath of the 2011 earthquake and tsunami in Japan). Through simulations, we analyze the throughput gains that can be obtained by exploiting the mobility feature of the UAVs. Our simulation results show that when there is loss of network infrastructure, the deployment of UABSs at optimized locations can improve the throughput coverage and the 5th percentile spectral efficiency of the network. Furthermore, the improvement is observed to be more significant with higher path-loss exponents.

**Index Terms**—5G, drone, interference coordination, LTE, public safety communications (PSC), quadcopter, unmanned aerial base stations, UAVs.

### 1. INTRODUCTION

Public safety communications (PSCs) carry critical importance to save lives, property, and national infrastructure in case of incidents such as fires, terrorist attacks, or natural disasters. Up until recently, PSC has been handled through narrowband communication technologies such as the land mobile radio (LMR), which can deliver reliable voice communications, but do not support broadband data [1], and are also often limited in terms of coverage and interoperability [2]. The National Broadband Plan by the FCC states that a cutting-edge PSC shall make use of *broadband technologies* “to allow first responders anywhere in the nation to send and receive critical voice, video and data to save lives, reduce

This research was supported in part by the U.S. National Science Foundation under the grant CNS-1406968.

injuries and prevent acts of crime and terror”, while acknowledging that “the U.S. has not yet realized the potential of broadband to enhance public safety” [3].

Broadband wireless technologies such as the 4G Long Term Evolution (LTE), and its foreseen 5G successor have a strong potential for revolutionizing communications during public safety situations. Driven by the need to meet the exponential increase in the demand for the wireless spectrum, research and standardization activities for 5G wireless networks are already underway – with an ambitious goal of 1000× capacity enhancement, 10× cell-edge user rate enhancement, and a 10× (to 1 ms) roundtrip latency reduction over 4G systems [4]. Exploiting such powerful features of 5G systems will be essential for transforming the PSC infrastructures from a capacity-limited platform into a high-speed communication infrastructure [5]. Indeed, the 3GPP standardization group has recently started working on developing public safety capabilities in LTE-Advanced to support the specific requirements of PSC [6]. Studies to develop the first nationwide, high-speed PSC network in the U.S., FirstNet [7], have also begun.

Another important opportunity for revolutionizing the PSC capabilities is to introduce UAVs, such as balloons, quadcopters, or gliders, for delivering pervasive broadband connectivity [8]. Enabled by recent technological advances, miniaturization, and open-source hardware/software initiatives, UAVs have found several key applications recently [9]–[12]. Amazon, for example, claims that seeing its *Prime Air* order delivery UAVs in the sky is expected to be as conventional as seeing mail trucks on the road within the next few years [11]. Google and Facebook have been investigating the use of a network of high-altitude balloons [13] and drones [14] over specific population centers for providing broadband connectivity. Such solar-powered drones are capable of flying several years without refueling. A relatively less explored application of UAVs is to deliver broadband data rates in emergency and public safety situations through low-altitude platforms [15]. UAVs are uniquely suited for such PSC scenarios due to their mobility and

JOURNAL OF COMMUNICATIONS SURVEYS AND TUTORIALS

## Survey on UAV Cellular Communications: Practical Aspects, Standardization Advancements, Regulation, and Security Challenges

Azade Fotouhi, Student Member, IEEE, Haoran Qiang, Student Member, IEEE, Ming Ding, Senior Member, IEEE, Mahbub Hassan, Senior Member, IEEE, Lorenzo Galati Giordano, Member, IEEE, Adrian Garcia-Rodriguez, Member, IEEE, and Jinhong Yuan, Fellow, IEEE

## SkyLiTE: End-to-End Design of Low-altitude UAV Networks for Providing LTE Connectivity

Karthikeyan Sundaresan, Eugene Chai, Ayon Chakraborty, Sampath Rangarajan  
NEC Labs America, Princeton, NJ 08540  
Email: karthiks@nec-labs.com

### ABSTRACT

Un-manned aerial vehicle (UAVs) have the potential to change the landscape of wide-area wireless connectivity by bringing them to areas where connectivity was sparse or non-existent (e.g. rural areas) or has been compromised due to disasters. While Google's Project Loon and Facebook's Project Aquila are examples of high-altitude, long-endurance UAV-based connectivity efforts in this direction, the telecom operators (e.g. AT&T and Verizon) have been exploring low-altitude UAV-based LTE solutions for on-demand deployments. Understandably, these projects are in their early stages and face formidable challenges in their realization and deployment. The goal of this document is to expose the reader to both the challenges as well as the potential offered by these unconventional connectivity solutions. We aim to explore the end-to-end design of such UAV-based connectivity networks particularly in the context of low-altitude UAV networks providing LTE connectivity. Specifically, we aim to highlight the challenges that span across multiple layers (access, core network, backhaul) in an inter-twined manner as well as the richness and complexity of the design space itself. To help interested readers navigate this complex design space towards a solution, we also articulate the overview of one such end-to-end design, namely SkyLiTE—a self-organizing network of low-altitude UAVs that provide optimized LTE connectivity in a desired region.

### Keywords

UAVs, LTE, RAN, EPC, backhaul, drone, localization, SDN, re-configuration, mmWave, FSO

### 1. VISION

Today, wireless access and connectivity is largely a two-dimensional (terrestrial) problem, where well-planned base stations are statically deployed in economically viable areas. The growing maturity of unmanned aerial vehicle (UAV) technology aims to change that notion by adding a third spatial degree of freedom (aerial), which has the potential to completely change the landscape of wireless connectivity. We now have the technical means

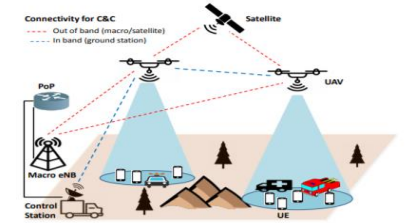


Figure 1: Low-altitude platform/UAV Network.

pre-existing connectivity infrastructure does not exist or exists sparingly (e.g. rural areas) or has been compromised (e.g. man-made or natural disasters). Our overarching vision is to be able to realize such UAV networks that are capable of providing on-demand, wide-area (spanning one or more cities) wireless connectivity using the most popular wireless access technology today, namely LTE. (Fig. 1).

### 2. WHERE ARE WE TODAY?

The tight regulation of the commercial airspace by federal authorities coupled with the scope and longevity of the connectivity solutions envisioned, has given rise to two category of efforts.

- High-altitude Platform (HAP) networks: These UAV networks aim to provide connectivity solutions to the un-connected parts of the world. This requires providing connectivity over large geographical regions over longer periods of time, which can be accomplished by operating at high altitudes (for wider coverage) in a cost and energy efficient (with light-weight, power-efficient UAVs) manner. Google's Project Loon [1] (employs balloons, Fig. 2) and Facebook's Project Aquila [2] (employs custom drone, Fig. 3) are efforts in this direction. These operate above the regulated

# Deployables Research

**Technical gap:** Range of a wireless technology ↔ **Solution:** Utilizing Unmanned Aircraft Systems

- Not as widespread for public safety themselves to deploy
- This is done today, but PSCR looks ahead when drones are untethered and independent of a backhaul connection

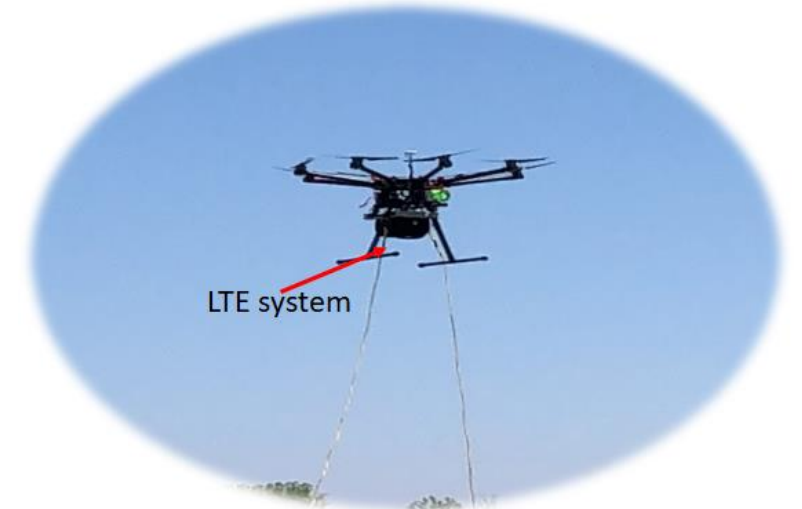




# Deployables Research

- Live aerial tests by PSCR conducted last year showed the complications and opportunities of the concept
- Low cost multi-rotors solutions are limited in duration for heavy deployable equipment, which leads to another technical gap for the deployables use case

**Technical gap: Length of UAS flight times**



# Deployables Research

- Industry continues to deploy tethered solutions while innovating into completely new designs like blimps and fixed wing systems
- The goal of the research is to document the issues and write best practices for public safety stakeholders
- Enabling aerial deployable systems is key in supporting first responders





# **First Responder Drones Usage Survey Results**

# The Reason for the Survey



The survey asked, ‘**would a deployable unit, such as a drone or UAS, enhance their mission if they had wireless communications on the ground with a network communications system in the air?**’

- First Responders are deploying Unmanned Aircraft Systems (UAS) on missions in hard-to-reach areas or otherwise challenging conditions.
- PSCR published a survey to understand the current and potential uses of drones by first responders.

*NIST IR 8305 Publication – Survey of Drone Usage in Public Safety Agencies* <https://doi.org/10.6028/NIST.IR.8305>



# The Focus of the Survey

- The 2019 survey asked America's first responders:
  - How they use drones in their operations
  - The benefits of using drones to support wireless communications during an incident
  - Describe their missions
- The survey was sent to ~900 first responders with a 20% response rate

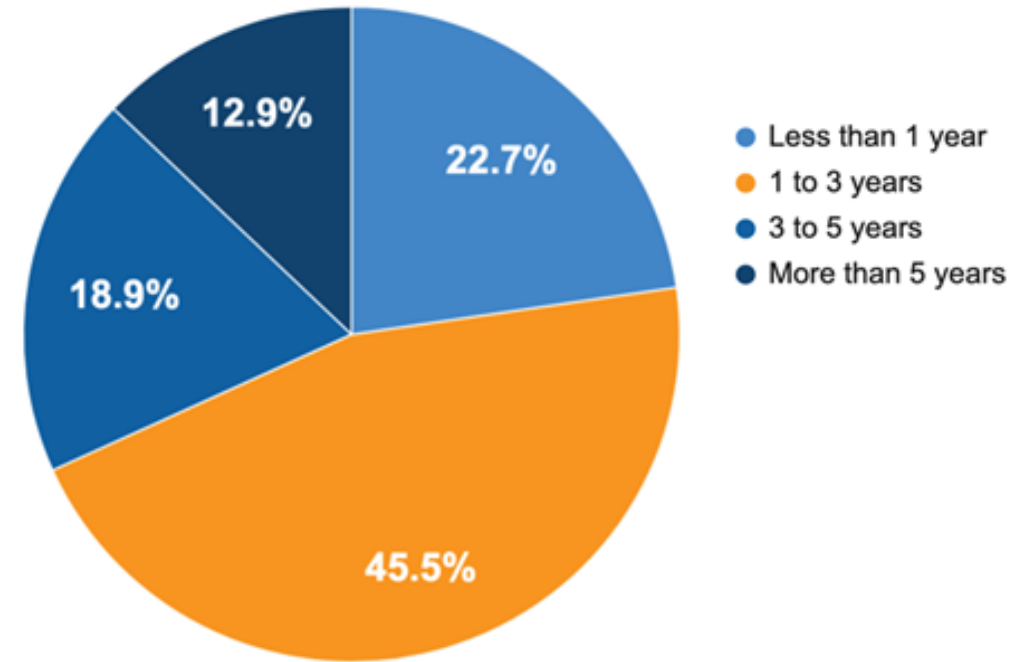


# Demographics & Experience Survey Results

Respondents were first responders in *law enforcement, fire fighting, EMS, rescue services, emergency management*

Supporting missions in various geographic environments:

- Rural (68%)
- Suburban (68%)
- Urban (61%)
- Wildland (43%)
- Mountains (25%)
- Desert (13%)



Years of experience using drones



# Wireless Communications Survey Results

Most first responders want wireless communications on missions where wireless communications are not available

Some examples of those missions:

- Border Enforcement
- Commercial building fire recon
- Crime scene documentation
- Earthquake/Flood Response
- Fire fighting in rural areas
- Hurricane/Tornado Recovery
- Search & Rescue/Missing person
- National disasters
- Train derailment
- Wildland fire

# Wireless Communications Survey Results

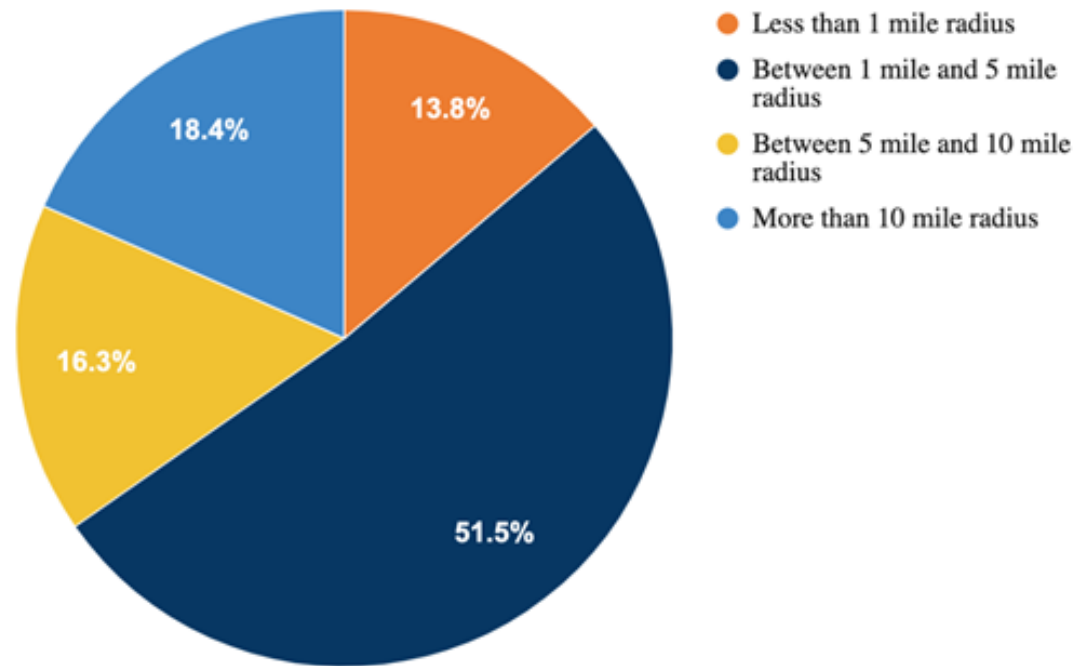
## Benefits using wireless communications on a mission

- Ability to download maps, access online databases
- Ability to transmit back to command
- Ability to transmit video and photos
- Without cellular communications there can be safety issues, time delays, and a lack of mobile data when needed the most
- Increased situational awareness
- Location services
- Live streaming of data and video to command post
- Enhance operations
- Communication is mission critical

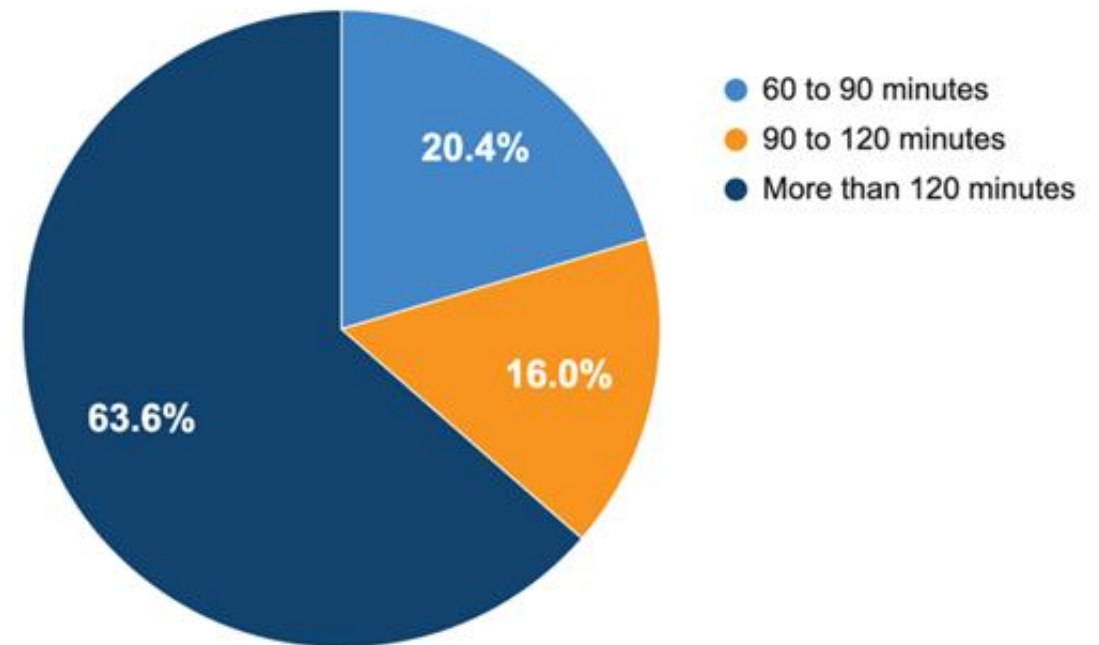


# Wireless Coverage Survey Results

Estimated distance for cellular broadband coverage needed to effectively perform their work

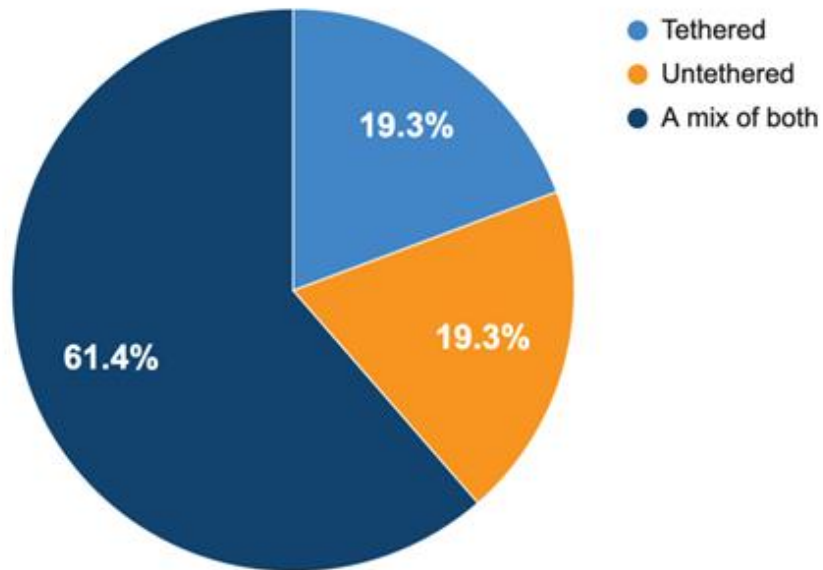


Estimated time a drone is needed in the air for a mission



# Tethered vs Untethered Survey Results

Is there a preference for tethered vs untethered drones?



## Reasons

### Tethered

- Additional flying time
- Provides long term communications support
- Another operator and observer is not needed
- Increase flying time and payload capacity

### Untethered

- More flexibility
- Area wide observation
- Concern about flying a drone in areas with trees
- Power is always an issue
- A more versatile platform

# Frame Options Survey Results

First Responders preference for multi-rotor, fixed wing or hybrid

- 29% multi-rotor
- 14% hybrid
- 1% fixed wing
- 46% no preference
- 11% indicated VTOL was critical

Reasons for their answer

- Flight time
- Multiple missions & longer flight time
- Total manpower
- Cost and reliability
- Distance to cover & length of time aloft
- Battery consumption
- Operating endurance
- Amount of space for launch & recovery
- Ease of use and implementation
- High quality and efficient
- Skill of the flight pilot



# Power Sources Survey Results

First responders would consider alternatives to traditional power sources  
- These are preferred for a drone providing cellular communications -

- Electric (50%)
- Hybrid (24%)
- No preference or not relevant (17%)
- Mission dependent (5%)
- Liquid fuel (2%)
- Whatever power source is most available (2%)

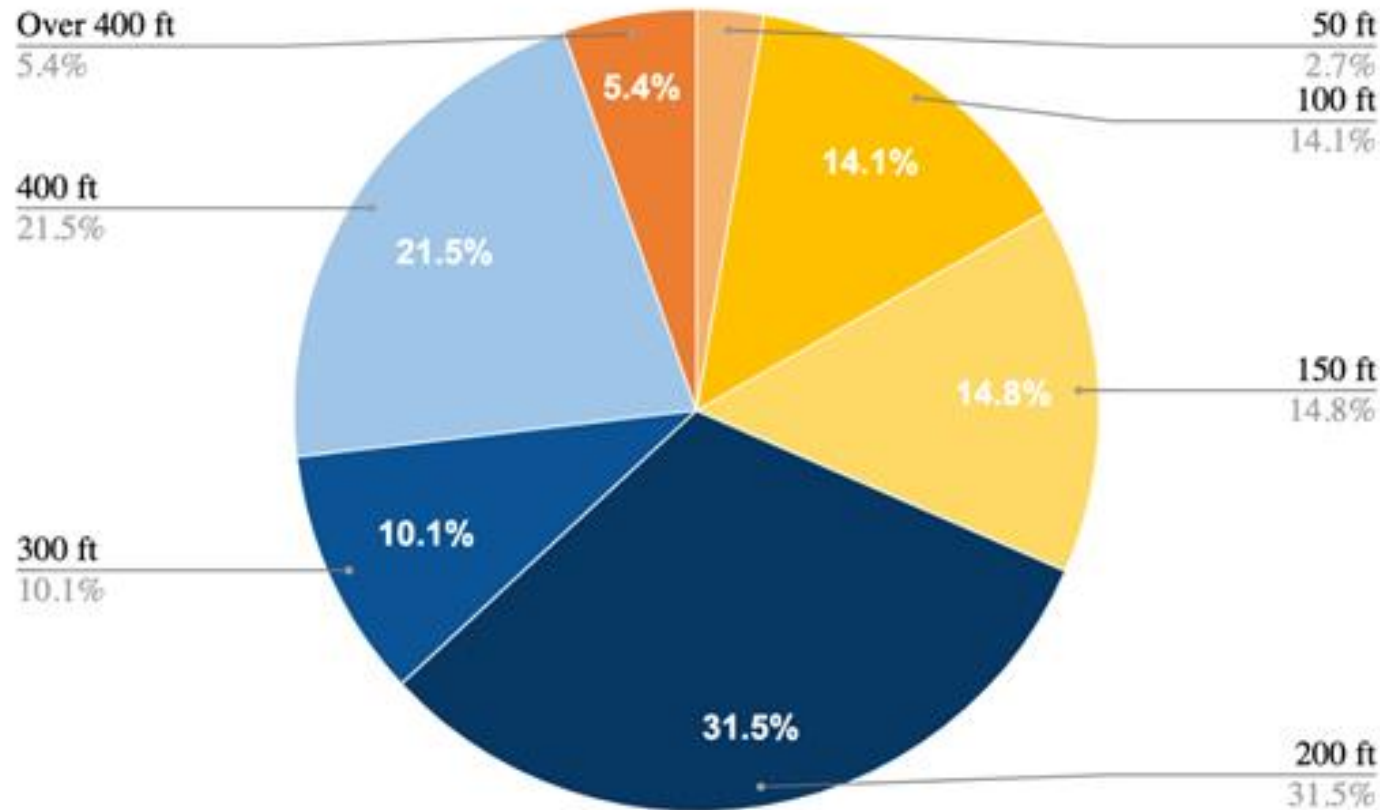
# Flight Time & Payload Survey Results

Considering the trade-off between flight time and payload capacity  
- Larger drones >55 lbs can carry more energy and stay in the air longer -

- More paperwork/special permit required
- Only if “Time in the Air” provided a benefit
- Additional cost may be an issue
- Too big and heavy
- Would consider if it provides better coverage for an operation
- A larger drone makes it difficult to coordinate in FAA airspace
- Too big and heavy for fast deployment
- More training and upkeep is required

# Other Considerations **Survey Results**

When asked for a safe minimum flight elevation above ground (AGL)  
- 90% of the respondents would want to fly between 100-400 feet -





# Other Considerations **Survey Results**

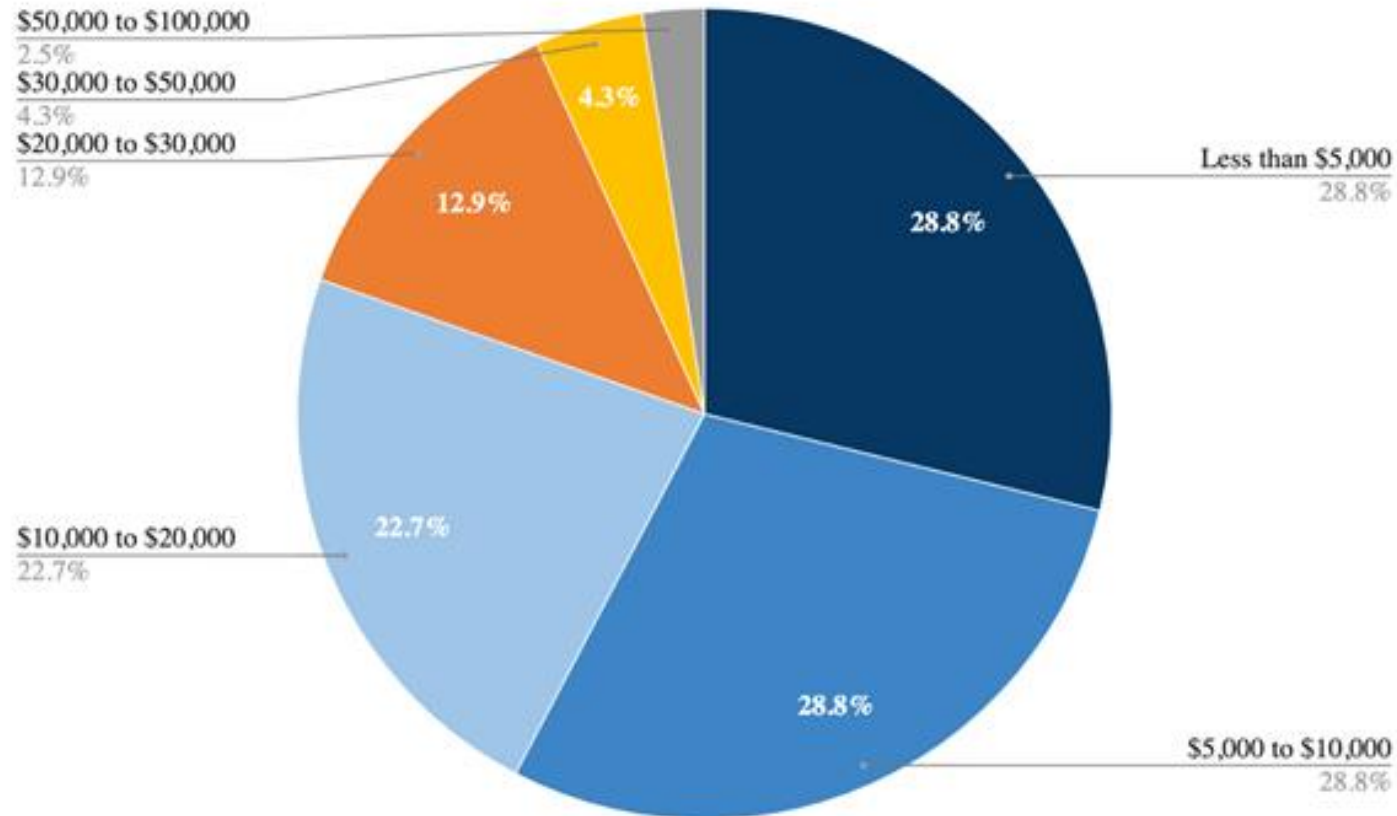
When asked the environmental conditions that a drone would operate in, the following examples were given:

A word cloud of environmental conditions for drone operation. The words are arranged in a roughly circular shape, with some words appearing larger and more prominent than others. The colors of the words are primarily blue and orange. The words include: WEATHER-PROOF, HIGH HUMIDITY, ALL OF THE ABOVE, DARK, EXTREME WEATHER, DUSTY ENVIRONMENT, SAND, FREEZING TEMPERATURES, RAIN, EXTREME HEAT, HEAVY DEW, VERY RUGGED, LIGHT RAIN, SMOKE, HIGH WIND, SNOW, DRIVING RAIN, HUMIDITY, AS RUGGED AS POSSIBLE, DUST, MODERATE WIND, MODERATE RAIN, WIND, and EXTREME COLD.

WEATHER-PROOF HIGH HUMIDITY  
ALL OF THE ABOVE DARK  
EXTREME WEATHER  
DUSTY ENVIRONMENT  
SAND  
FREEZING TEMPERATURES  
RAIN  
EXTREME HEAT  
HEAVY DEW  
VERY RUGGED  
LIGHT RAIN  
SMOKE HIGH WIND  
SNOW  
DRIVING RAIN  
HUMIDITY  
AS RUGGED AS POSSIBLE  
DUST  
MODERATE WIND  
MODERATE RAIN  
WIND  
EXTREME COLD

# Other Considerations **Survey Results**

Based on the value that a public safety agency would give to a drone used to carry a communications device  
- 81% said they would consider spending \$20k or less -



# yet2 Market Research Results

# Objective of Market Research

- Identify existing UAS technologies that meet NIST's minimum requirements:

**payload  $\geq 15$  lb**

**weight  $< 55$  lbs**

**endurance  $\geq 30$  minute**

**volume  $\leq 6' \times 4' \times 3'$**



- Identified drones *close to meeting* or *could already meet* the requirements
- Other considerations:
  - hovering precision
  - cost
  - maximum altitude
  - optional tether
  - fixed-wing flight radius
  - innovative solutions



# Heavier Aircraft Market Research

NIST also considered heavier UAS between 55 lbs and 100 lbs

- Aircraft > 55 lbs require additional FAA approval
- Although heavier aircraft are designed to carry large loads, little noticeable increases in endurance were observed



Source: yet2

One exception was a drone that could carry 15 lbs for 60 minutes at slightly > 55 lbs (or 12 lbs for 63 minutes at < 55 lbs)

# Industries Market Research

Identified 41 Companies with UAS designed for:

- Industrial applications (wind turbine inspection, agriculture, mapping, surveying, cleaning)
- Government (law enforcement, fire, security)
- Photography/cinematography
- Commercial payload delivery



*Source: yet2*

In addition to the minimum core requirements, NIST focused on innovative drone designs and energy sources

# Most Promising Market Research

- 13 companies showed the most promise in meeting NIST requirements
- Additional factors considered:
  - Cutting edge technologies that will move the field forward
  - Technology solutions (such as energy harvesting) designed to allow longer UAS flight endurance



Source: yet2



Source: yet2

# Power Sources Market Research

Different power sources offer different advantages, depending on the use case of the drone. yet2 explored seven (7) different power source categories at varying stages of development

## 1. Battery

- the most common in consumer drones; charged anywhere; transported with ease; lower cost

## 2. Gasoline

- longer flight times; high energy density; UAVs lose weight over time; refueling is typically quick; gas is easy to obtain
- combustion engines are noisy, may have efficiency/fuel-injection issues at higher altitudes, and tend to be heavier and bigger



Source: yet2



# Power Sources Market Research

## 3. Hybrid Electric-Gas

- allows a gasoline engine to charge the battery or provide power to the electric motors directly; can be more efficient than direct power-train; onboard batteries don't need to be re-charged

## 4. Hydrogen Fuel Cell

- clean energy source with high energy density; potential instability near heat and lack of infrastructure for refueling; early stage technology, currently available for smaller drones with less capacity to carry heavier payloads



Source: yet2



Source: yet2

## 5. Solar-Powered

- solar cells are evolving with increase in efficiency; harvests energy from the sun, even in cloudy or smoky conditions; night missions require energy storage; most commonly seen on fixed-wing drones

# Power Sources Market Research

## 6. Tethered/Untethered

- an option to keep drones in the air longer with a continuous power supply; use in areas with no power outlets, an external battery source must also be carried along with the tether

## 7. Wireless charging

- could allow untethered drones to stay in the air indefinitely; becoming more technically feasible and commercially viable; this area of technology is likely to continue to grow and be of high interest in coming years



*Source: yet2*

# Airframe Types Market Research

- **Multi-rotor**

- most common design in consumer drones; greater maneuverability such as vertical takeoff and landing (VTOL); can hover in mid-air; usually lower priced than fixed wing; more compact; can carry a variety of payload sizes; shorter ranges and typically less stable in the wind

- **Fixed Wing**

- very long ranges; great stability in high winds; longer flight durations due to gliding capability; require runways or a catapult to launch, less compact than multi-rotors, can't hover in place

- **Hybrid Fixed Wing/Multi-rotor**

- uses rotors for VTOL and wings for optimizing flight times; designs aren't prolific in the marketplace



Source: yet2

# Frame Types Market Research

- **Intermeshing Rotors**

- used on helicopters with two rotors at a slight angle; intermesh without colliding; notable for improved payload capacity; eliminates the need for a tail rotor

- **Helicopter**

- better empty weight-to-payload and payload-to-endurance ratios; tend to be large; best fit would include a foldable tail rotor and removable rotor blades

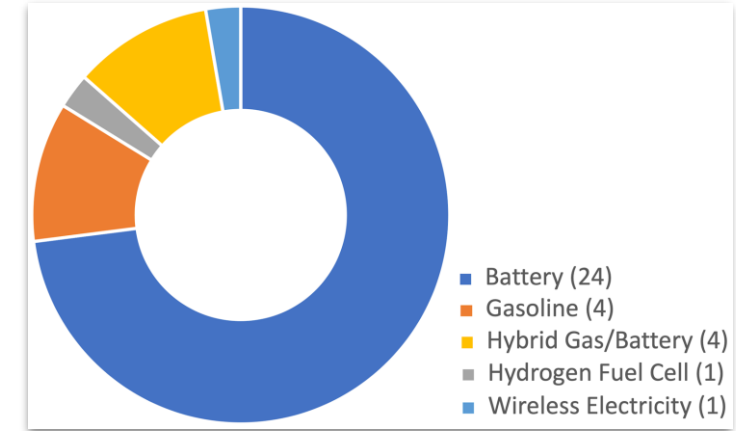
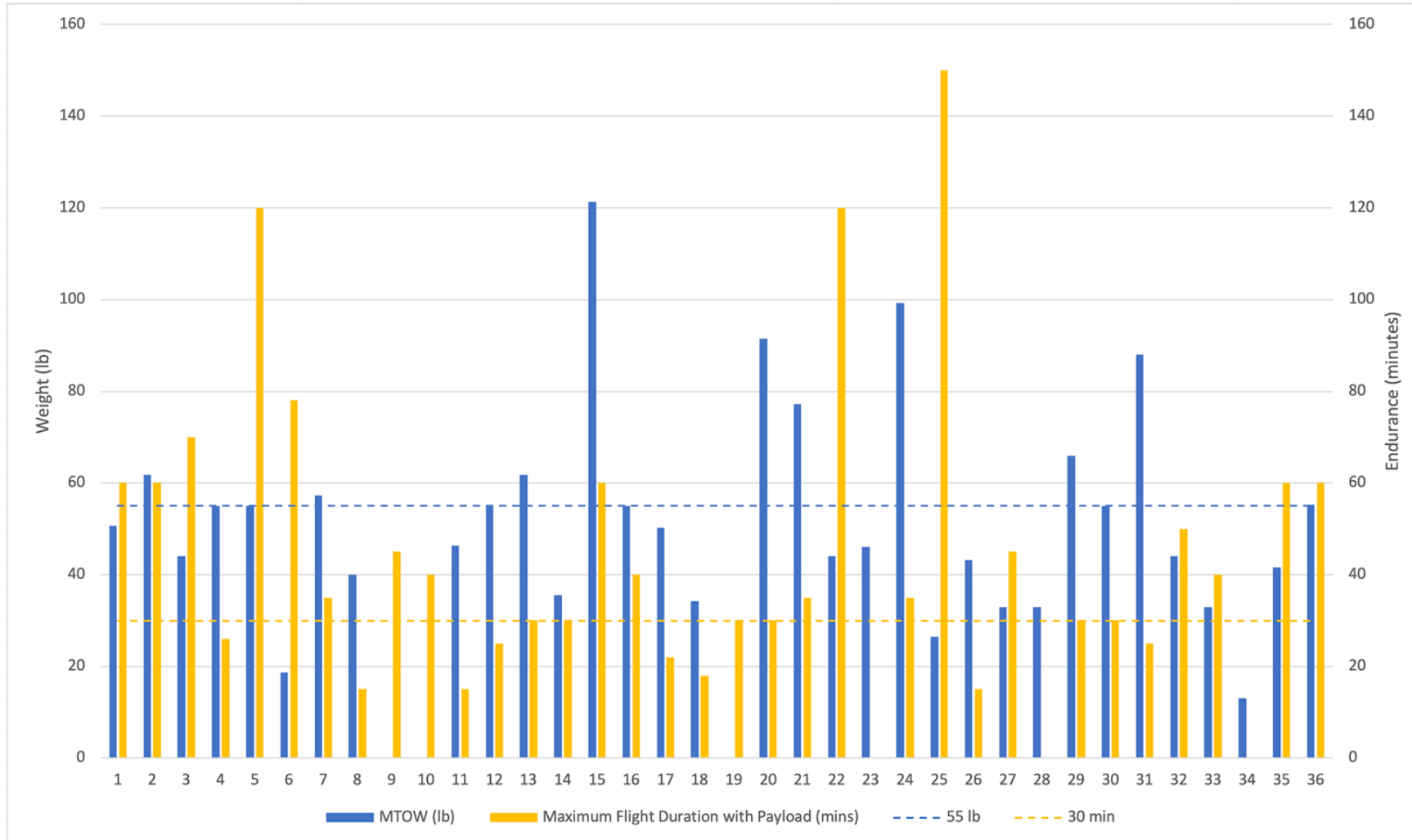
- **Modifying the body of the drone**

- Instead of incremental improvements in payload vs endurance, some companies are making more transformative changes to improve drone performance



Source: yet2

# Results Market Research



## Out of 36 VTOL drones:

- 19 drones < 55 lbs
- 19 drones > 30 min

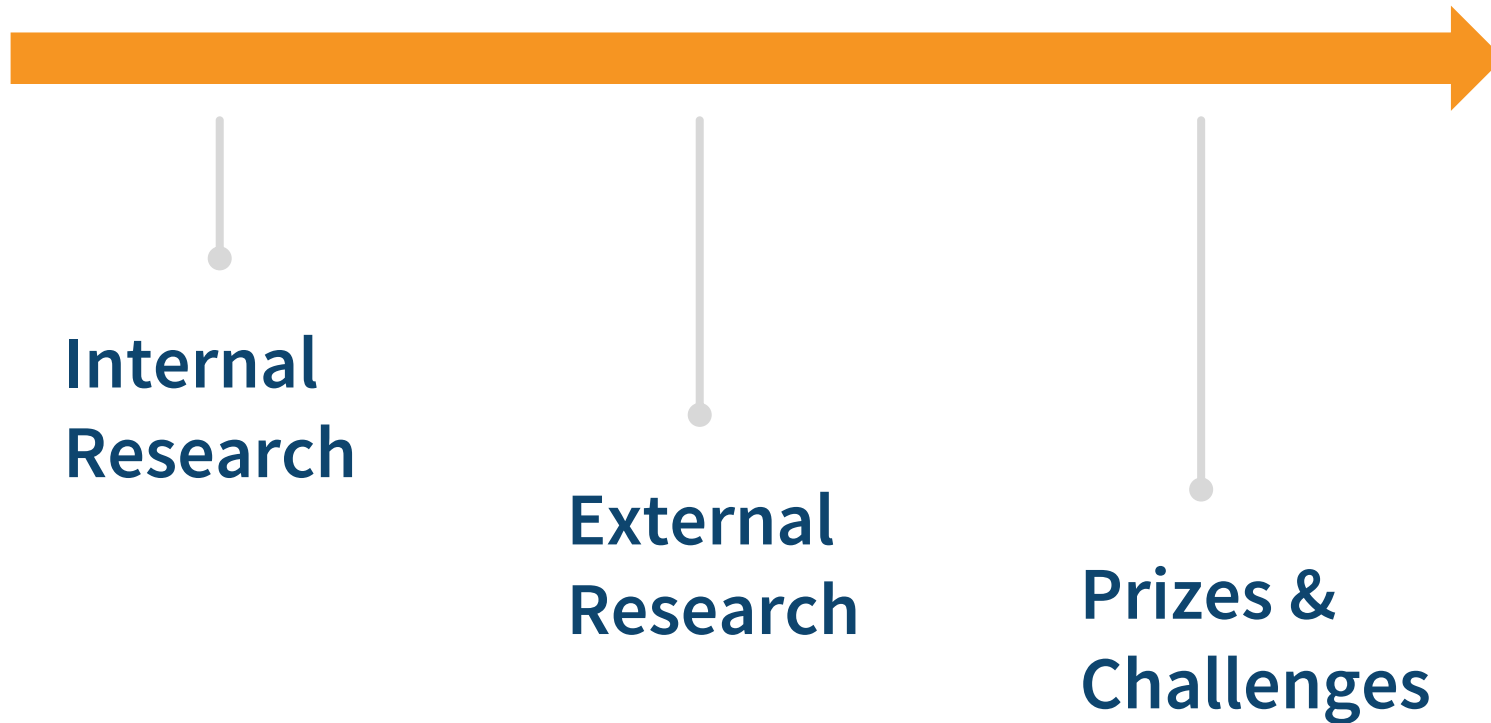
MTOW = maximum takeoff weight



# Open Innovation UAS Prize Challenges



# How does **PSCR** achieve their mission?



# Overview Challenge 1.0



- Up to \$432k in Prize awards
- Ten (10) teams & designs
- Three (3) stages: concept, prototype, live event
- Test & evaluation included:
  - 10lbs, 15lbs, 20lbs payloads
  - Vertical take-off and landing with ability to hover in place
  - Autonomous and human controlled flight capability
  - In flight accuracy to within +/-5 ft
- UAV Design Parameters
  - Weight < 55lbs
  - Transport Size < 6ft x 4ft x 3ft
  - Hardware Cost < \$20k

# Lessons Learned Challenge 1.0

- **Flight Time**

Hybrid design explored practical solutions

- **Payload**

Tradeoffs were made to support various payload weights

- **Accuracy/Versatility**

Maintaining accurate location in flight was a significant challenge

- **Cost**

More funds spent on hardware vs software; advanced software may add stability, accuracy and autonomous functions

1<sup>st</sup> Place



Finalists

As these approaches are refined and improved, in-flight battery charging has the potential to expand the possibilities for use by First Responders

# Overview Challenge 2.0



## Goal

Advance UAS technologies by **designing, building and flying drone prototypes** that are safe and stable to support first responders.



## Context

The Public safety community requires enhanced drone features and capabilities to **fly for 90+ minutes** while carrying a heavy payload to support the mission.



## Scenario

A 'lost person in a desert area' initiates a search & rescue operation; An aerial vehicle/**UAS carrying a 10 pound network device is deployed to provide broadband network coverage.**



## Objective

To **fly a UAS and its payload airborne for the longest time possible** to support first responders' communication technology.



# Requirements & Objectives Challenge 2.0

Requirement	Objective
Endurance	> 60 minutes
All Up Weight	< 100 lbs
Vertical Take-off and Landing	Demonstrate ability
Loiter	+Points for a defined airspace
Level of Autonomy	Achieve Levels 0,1, 2
Total System Weight	< 120 lbs
System Volume	6'x4'x3'
Payload	10 lbs (provided by NIST)
Payload Mount	Equipped (provided by NIST)
Component Weight	< 50 lbs

Refer to the official challenge rules, Table B: Drone Design Specification  
(<https://firstresponderuaschallenge.org/rules.php>)

# Requirements & Objectives Challenge 2.0

Requirement	Objective
Set Up Time	< 20 minutes
Video, Camera, GPS, RTK-GPS	Equipped
No Tethers	No tethers
Radio Controller (FHSS)	Use FHSS
System Cost	< \$30k
FAA	Comply with FAA regulations/laws
Pilot (Part 107 certified)	One (1) FAA certified pilot
Drone Insurance	Minimum coverage \$1M
FCC Compliance	Comply with FCC regulations/laws

Refer to the official challenge rules, Table B: Drone Design Specification  
(<https://firstresponderuaschallenge.org/rules.php>)

# Summary Challenge 2.0



# Timeline/Roadmap Challenge 2.0



# Prize Awards Challenge 2.0



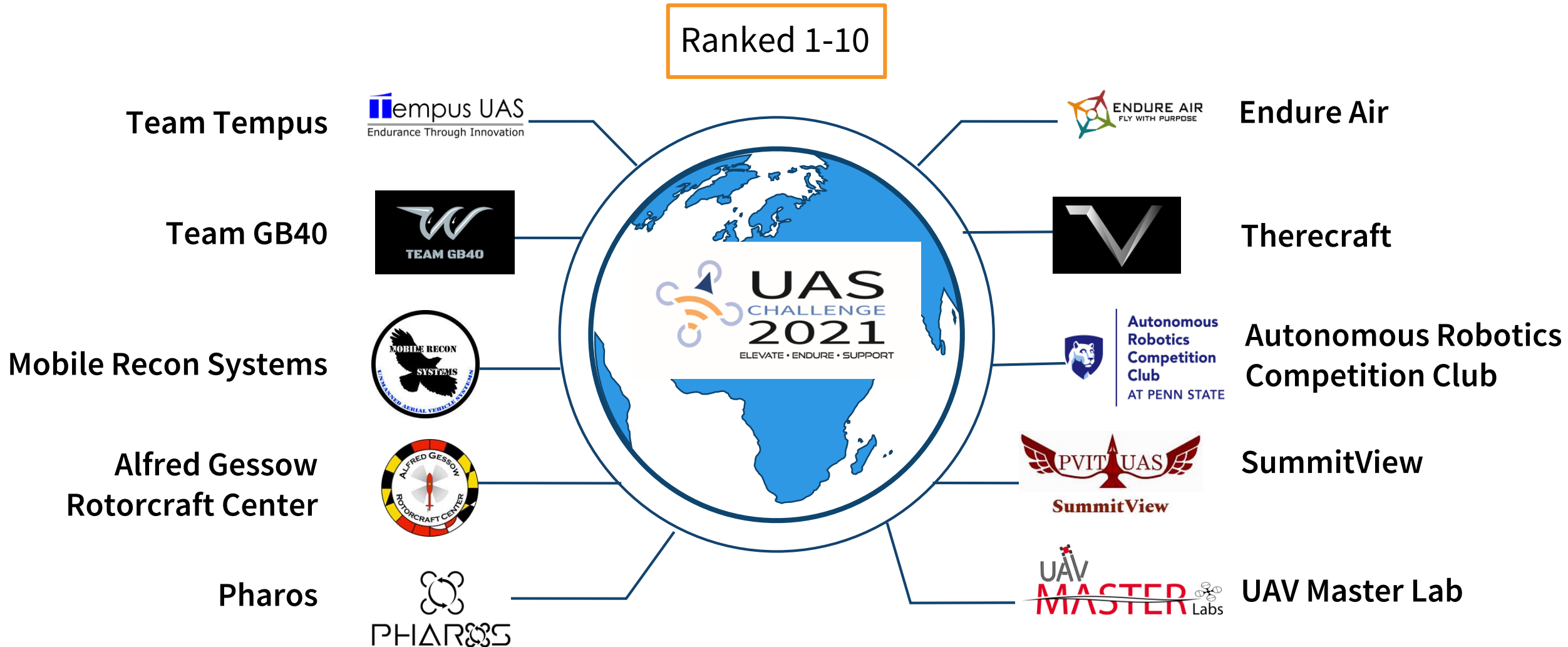


# Stage 1 Winners Challenge 2.0

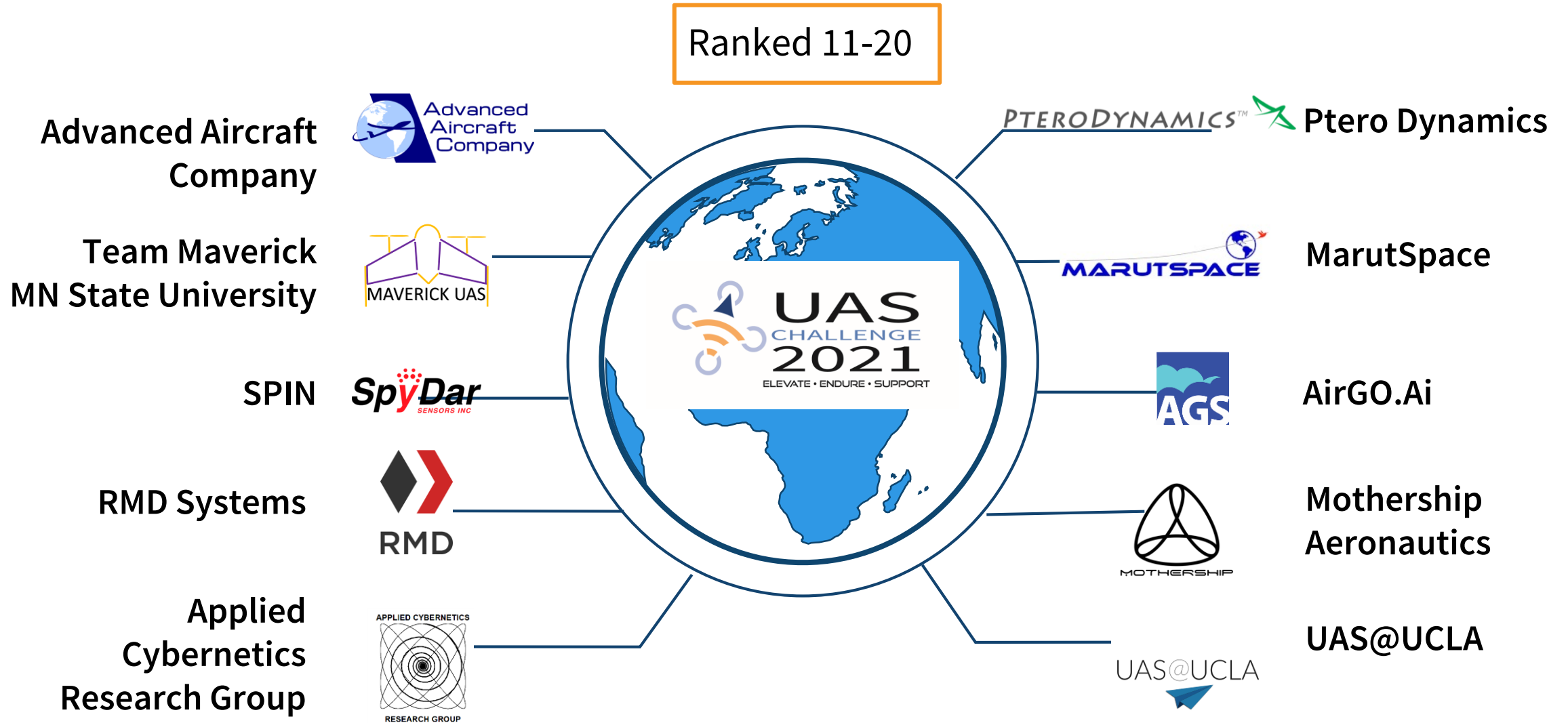
Just Announced!

- Concept Paper Contest
- Teams were evaluated on:
  - Knowledge, Skills, and Team ability to build a UAS prototype
  - Strategic and Technical Ability, including their innovative approach
- The Top 20 teams were invited to compete in Stage 2

# Stage 1 Winners Challenge 2.0



# Stage 1 Finalists Challenge 2.0



# Stage 1 Designs Challenge 2.0

Frame Type	Power Source
Helicopter	Battery
Multi-rotor	Gasoline engine
Fixed-wing (FW) airplane	Hybrid gasoline / battery
Tandem rotor (front / back) helicopter	Hybrid diesel / battery
Tandem rotor (top / bottom) helicopter	Hybrid AvGas / battery
Intermeshing rotor (side by side) helicopter	Hydrogen fuel cell
Hybrid FW/multi-rotor	On-demand hydrogen production
Aerostat	Helium Gas
Tiltrotor	Heavy fuel engine

Cost estimates range from \$8k to \$28k  
Endurance estimates range from 77 minutes to 390 minutes

# Q&A with First Responder Expert Panel



# Panel Speakers



**Captain Philip Hall**

Director, NOAA UAS Program  
National Oceanic and Atmospheric Research



**Christopher Stockhowe**

Master Firefighter, EMT, UAS Team Trainer  
Virginia Beach Fire Department



**Michael O'Shea**

Program Manager, Public Unmanned Aircraft Operations  
Federal Aviation Administration (FAA) Aviation Safety (AVS)



**Raymond Sheh**

Professor, Georgetown University  
& NIST Associate

# THANK YOU

HUD VISUALIZATION

BLOCK - 1

A 001

A 002

A 003

A 004

00015	04580	00125	00896	00014
00028	00169	07895	00145	00332
00074	00085	00120	45697	07074
00112	00123	78952	03694	00110
00089	00045	00569	00070	00972

0035,4

0082,7

0073,8