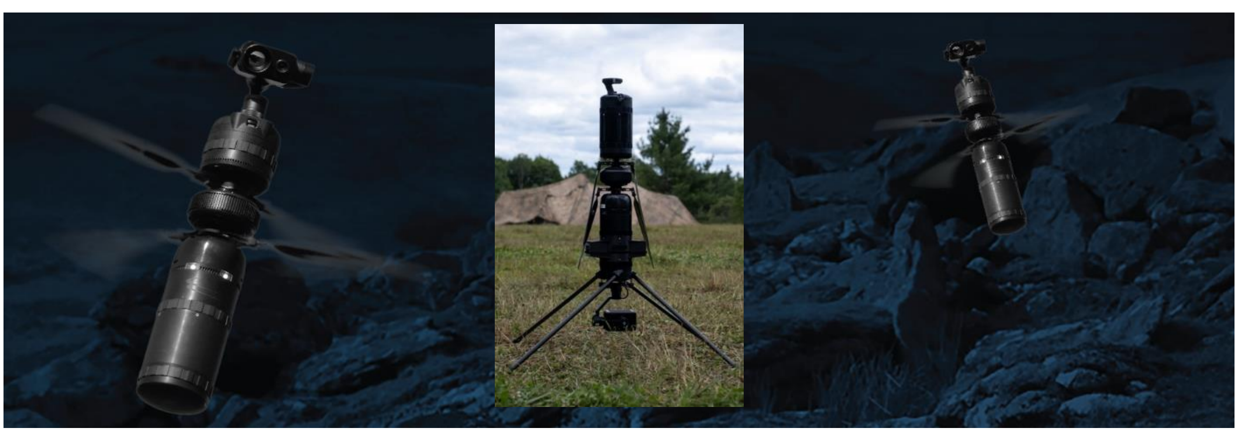
The Advantages of Coaxial Unmanned Aerial Vehicles (UAVs)

A cylindrical form factor with coaxial propulsion delivers a UAV platform that is ideal for mission-critical commercial, military, public safety, and industrial applications

The Ascent AeroSystems Coaxial Advantage

- COMPACT
- QUIET
- RELIABLE
- VERSATILE
- HIGH-PERFORMANCE
- RUGGED, ALL-WEATHER



Executive Summary

Today's unmanned aerial vehicle (UAV) industry is dominated by conventional fixed wing, "H" and "X" quadcopters, as well as larger 6- or even 8-motor multirotor designs[1]. These configurations have demonstrated generally good reliability and are available at low cost, so they are often the ideal platform for prototyping and most routine missions operating in conditions that are well-controlled, and under circumstances where the consequences of an unsuccessful outcome are relatively low.

Coaxials UAVs are radically different. Characterized by two counter-rotating rotor disks, typically stacked in a vertically oriented, cylindrical airframe, they look nothing like quadcopters. The coaxial concept itself is not new; it has been incorporated in full-scale helicopters for decades and is the basis of emerging next generation designs from industry leaders like Sikorsky aircraft. Yet coaxial UAVs operate at a much smaller scale, and the aerodynamics and physics are vastly different from full-scale helicopters. While basic stability and simple forward flight are straightforward, operations at high-speed and with high pitch and bank angles require a completely different coaxial mechanism. Ascent has developed that mechanism.

Today, most UAV manufacturers build UAVs as just one part of a larger system. They are typically focused on delivering end-to-end systems that create a cheaper, faster, better or entirely new capability. Simple and inexpensive, in many cases a quadcopter is a "good enough" solution for the airborne platform.

But the aircraft is a critical part of the product or the service that is enabled by the UAV, and a quadcopter presents many limitations that impact performance and reliability. The coaxial, however, offers significant functional and aerodynamic advantages that provide meaningful benefit to operators. This paper will introduce those advantages and explain how they can be particularly vital in mission-critical applications.

[1] The terms "conventional multirotor" and "quadcopter" will be used interchangeably in this paper to denote any unmanned aerial vehicle with a series of rotors arranged around a central hub. The term "coaxial UAVs" does not include X- and H- multirotors that have two motors mounted on each hub (X6, X8, etc.); these are also considered to be "conventional multirotors".

I. Functional Benefits of the Coaxial Design

1. COAXIALS UAVs ARE MORE COMPACT. A conventional multirotor arranges a series of electric motors around a central hub. Attached to arms in an "H" or "X" configuration, these motors spin propellers that provide lift and directional control. Pitch, roll and yaw are controlled by precise adjustments in the speed of each motor.

With an airframe shaped like a cylinder, the coaxial design reduces airframe parts to an absolute minimum. It eliminates all major airframe components, and with no need for long booms to support each motor and rotor disc, a coaxial is a fraction of the size of a comparable conventional multirotor. Removal of those major structures also saves significant weight, making a coaxial much lighter.

Benefits of the compact form factor: Contained in a compact, lightweight package a coaxial provides significant benefits to operators:

- Coaxials are easier to transport where needed, especially in austere environments
- Coaxials are easier to store in smaller spaces or in larger numbers
- Coaxials can carry more while weighing less
- Coaxials are more adaptable to ground infrastructure, requiring less complex automation for launch, recovery and reset operations

2. COAXIALS ARE MORE RUGGED. When manufacturers seek to reduce the weight of quadcopter, they begin with lighter, thinner materials that invariably reduce strength. But even when constructed with composites, lightweight metals and high-strength plastics, the complex arrangement of structural components cannot easily disperse stresses from hard landings and rough ground handling. Conventional multirotors are not inherently strong and making them more rugged carries a significant weight penalty[2].

With a cylindrical design, coaxials are fundamentally different. Cylinders are a "primitive" geometric shape, combining the simplicity of a sphere with the utility of a cube. For this reason, they are used extensively where structural strength and low weight are critical. Examples include gas and liquid storage containers, rockets, missiles and submarines.

Cylinders are also an ideal form for UAVs, providing strength without the need for reinforcing structures or heavy materials. They are able to disperse stress and impact forces throughout the entire airframe, so the coaxial can also absorb rough handling that would damage conventional UAVs. With few structural joints, a cylindrical coaxial is also far easier to seal against environmental contaminants, protecting sensitive electronic components inside.

Benefits of a rugged design: This inherent strength make the coaxial the ideal form factor for mission-critical operations:

- Coaxials can absorb impacts that would damage conventional multirotors
- Coaxials can operate in austere, contaminated environments, including rain, snow, dust and sand
- Coaxials require fewer spares and support equipment, decreasing the equipment footprint

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[2] Just like in fixed wing aircraft, root bending moment Is the leading variable driving the weight of the arm and the wing-box. No arm means no need for extra weight to hold It.

II. Aerodynamic Benefits of the Coaxial Design

1. COAXIALS GENERATE LESS DRAG. Quadcopters generate relatively high form drag as they travel through the air. Their many angular faces, joints and rotor arms extend into the airstream, generating significant resistance as oncoming air is forced to split, redirect, separate and recombine in countless turbulent flow patterns. The combination of these forces compound as velocity increases, so a conventional multirotor demands a significant amount of power to sustain high-speed flight. With a smooth, cylindrical form and fewer protrusions into the airstream, coaxials have far less drag. The relative airflow passes more smoothly around the airframe, even as velocity increases. At equivalent airspeeds, a coaxial requires less power to overcome drag.

But the conventional multirotor has two other characteristics that create additional drag as the airframe tilts forward to accelerate. First, the upper surface of the airframe becomes more exposed to the oncoming relative wind. This directly increases drag, so the motors must generate more thrust to compensate. Second, the air impacting the frontal area (in fact, the top of the airframe), imparts a *downforce* on the entire aircraft as the stream is deflected upward. The motors must work harder to overcome that downforce, which requires more power and results in decreased endurance.

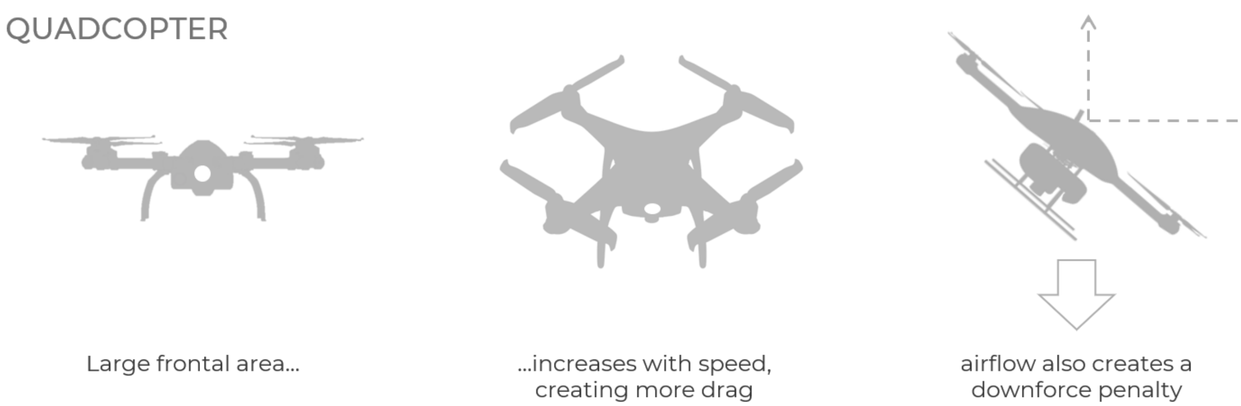

Figure 1 - A quadcopter becomes less efficient as speed increases

On a coaxial, however, these negative effects are reversed. The frontal area exposed to the relative wind *decreases* as the airframe leans forward to accelerate, reducing drag and the thrust required to overcome it. Also, the relative wind strikes the *lower* surface of the airframe in forward flight, providing an *upward* force[3]. These forces decrease the total thrust required to maintain a specific altitude or speed.

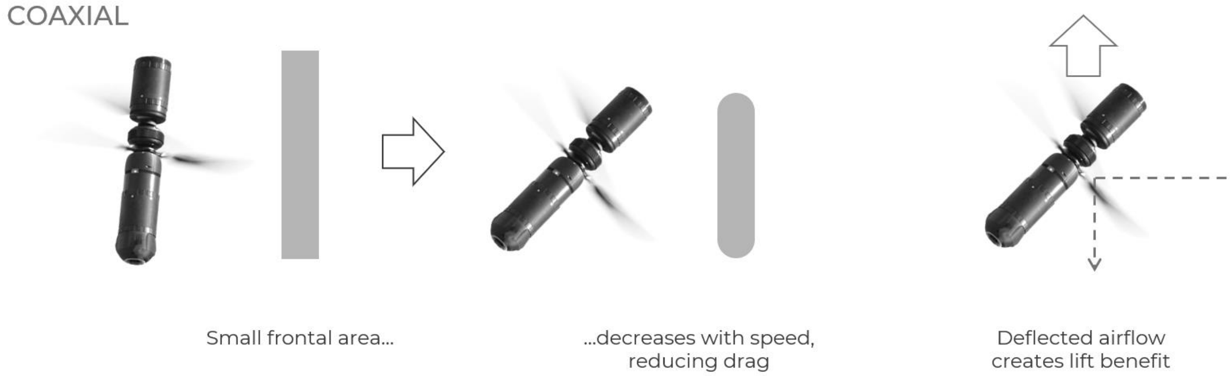

Figure 2 - Compared to a quadcopter, a coaxial airframe is more efficient as speed increases

Each of these examples mean that the basic physical characteristics of a coaxial provide an inherently more efficient platform than conventional multirotors. When plotted on a standard chart illustrating an aircraft's power required against airspeed, the difference is clear.

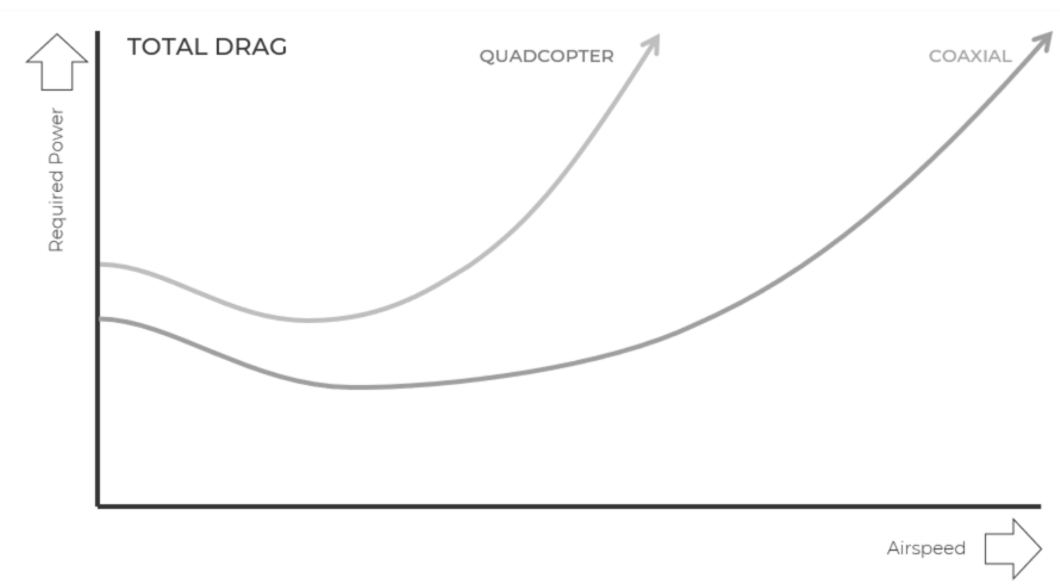

Figure 3 - When carrying an equivalent payload, the lighter coaxial will require less power to hover given the lower weight of the basic airframe. As speed increases, both will benefit from "translational lift", the efficiency gained as a rotor system is free from the disturbances of its own downwash. That benefit eventually reaches a maximum at the lowest point of the curve and drag begins to rise again for both airframe types as airspeed increases.

Lower drag means better performance for operators, including endurance, speed and range. But there's one more feature of the coaxial to describe before all the benefits can be pulled together.

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[3] The induced flow from the rotors might neutralize a big portion of it of the lifting effect, but on a coaxial at the very least It does not produce a performance reducing downforce.

2. COAXIALS HAVE A LARGER LIFTING AREA. As with their basic cylindrical form, coaxials have another advantage over conventional multirotors that is rooted in basic geometry: For an equivalent tip-to-tip rotor span, *a coaxial has more than three times the lifting area*.[4]

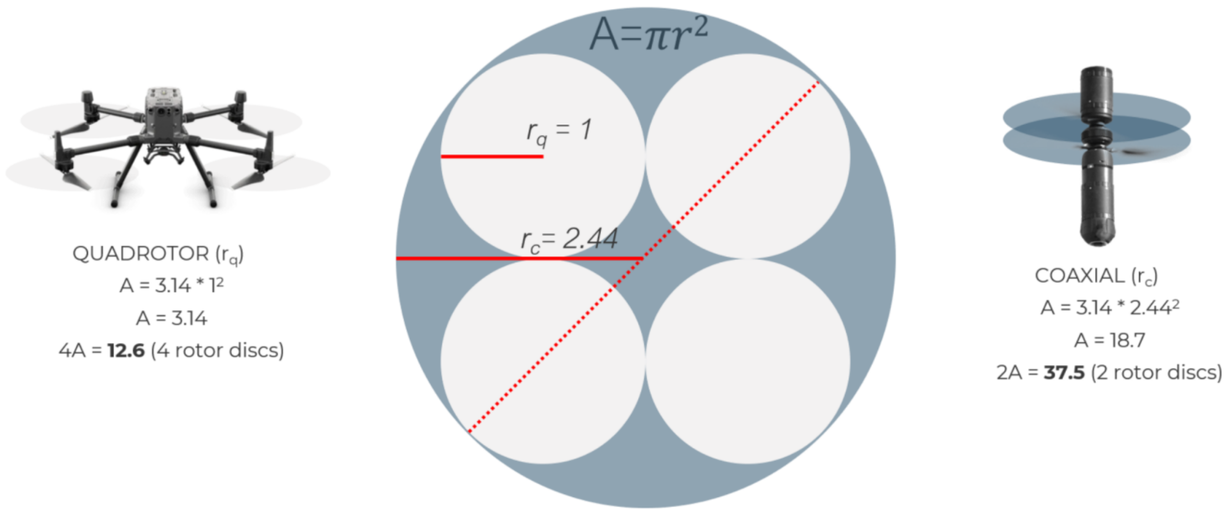

Figure 4 - A coaxial has significantly more lifting area than a multirotor of equivalent rotor span.

Geometry also provides an advantage when comparing *an equivalent rotor area*. For an equal lifting area, a coaxial's rotor span will be nearly half that of a conventional quadcopter.

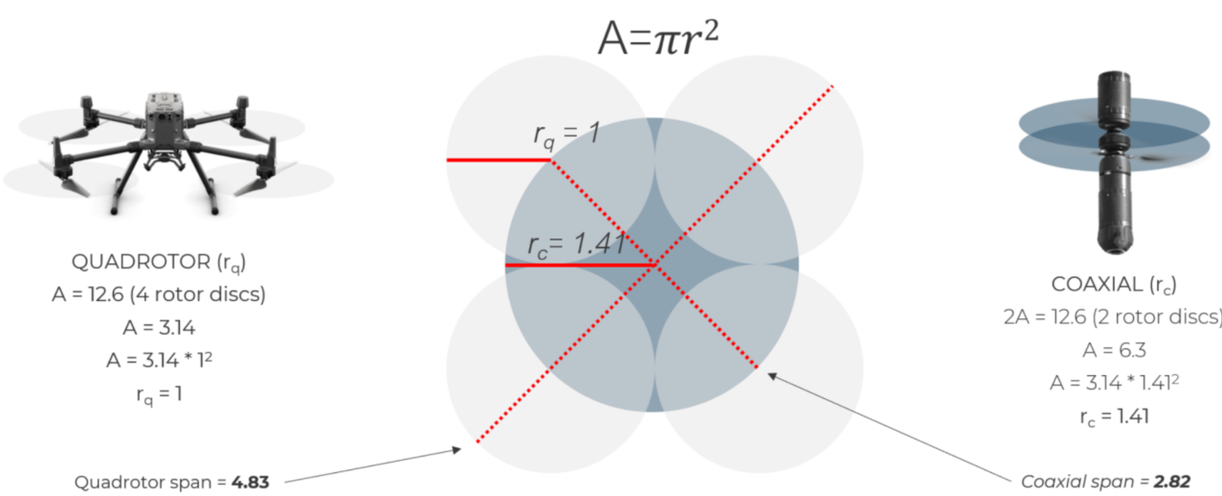

Figure 5 - For an equal lifting surface area a quadcopter requires nearly twice the span

Coaxials also have an advantage as a UAV's size increases, as would be necessary to carry larger, heavier payloads. A conventional multirotor would usually require larger motors, each spinning a large propeller, to create the necessary additional thrust. But propeller blade length is ultimately limited by the distance between propeller blade tips, so longer arms will be required to maintain separation. Those longer arms

[4] The aerodynamics of rotor Interaction are complicated. The top and bottom rotor can interact with each other In good and bad ways. For the sake of simplicity we assume that they behave as independent systems.

mean additional airframe weight from the arms, mounting structures, fasteners and wiring. As a result, only a portion of the additional thrust is available to lift the heavier payload. If one pound of additional payload is desired, *more* than one pound of additional thrust will be required.

With two larger rotors spinning on a common axis, a coaxial's lifting area is not limited by the distance between the propeller tips. Because the area of a circle grows by the square of its radius, a coaxial's already larger rotor discs can grow dramatically with very small increases of blade length. The only additional airframe weight is that of the incremental rotor blade material.[5]

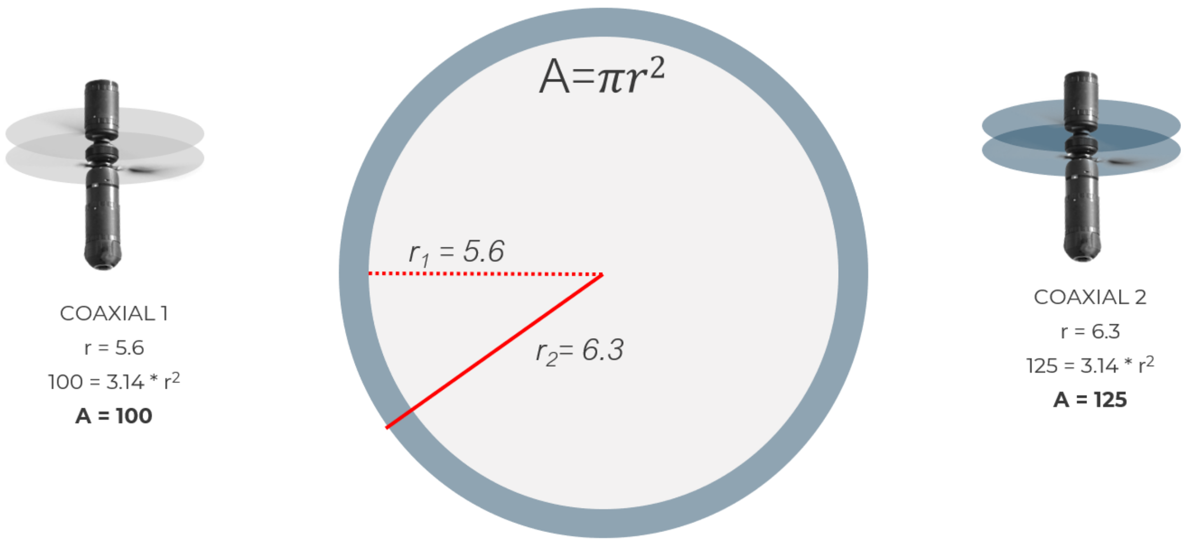

Figure 6 - A small increase in blade length drives a large increase in lifting area

[5] Two more advantages of the coaxial: (1) The non-aerodynamic bodies (fuselage) are placed In the Inner part of the rotor, where not much lift Is produced, so it does not interfere with the rotor wake. (2) For high wing loading configurations, the swirl recovery is an added benefit.

III. The Benefits: Coaxials Fly Longer, Farther, Faster and Carry More

Against a comparable multirotor carrying the same payload, a coaxial will be smaller, lighter, generate less drag and have a larger lifting surface. For operators, this means:

- Longer endurance
- Longer range
- Higher top speed

Returning to the power vs. airspeed chart, these differences can be clearly seen. The lowest point of the vertical axis (power/drag) is the point at which the aircraft requires the minimum amount of power to maintain altitude. The corresponding point on the horizontal axis is the *maximum endurance airspeed*. Flown at this airspeed, the aircraft will offer its maximum flight time. (Note: manufacturers always use this number when making endurance claims, so that's why your endurance in hover never measures up!)

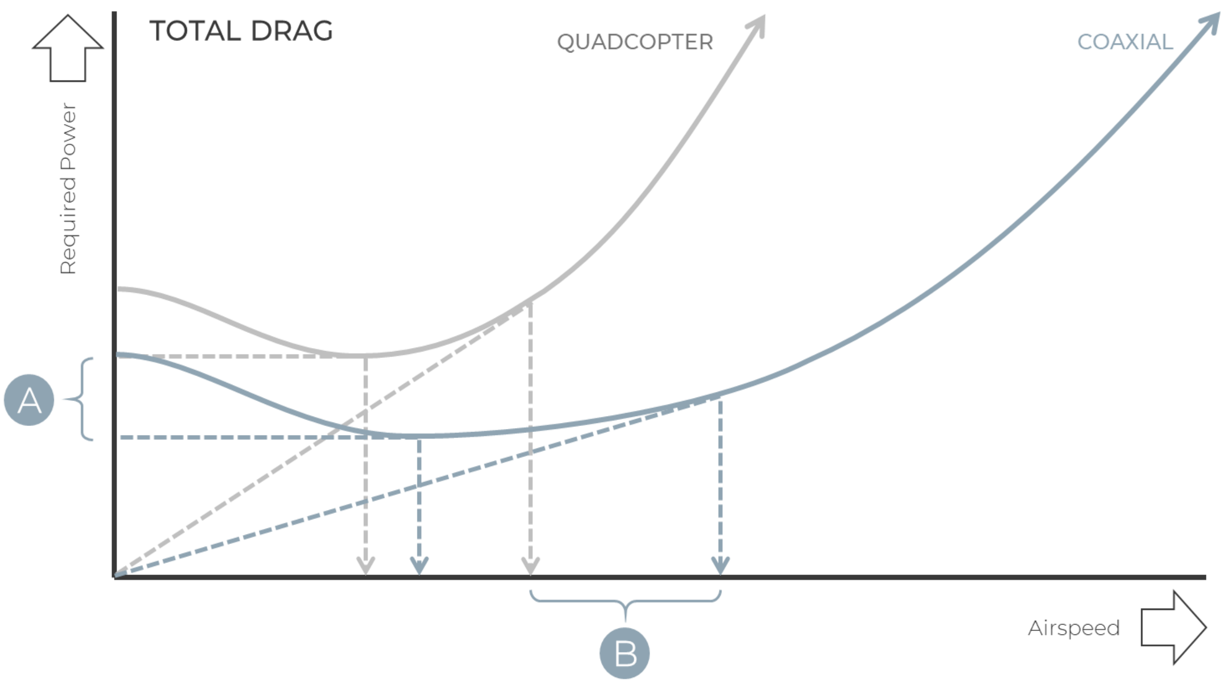

Figure 7 - Drag/Power vs. Airspeed

So, for any given airspeed, a coaxial consumes less power. Conversely, for the same power consumption, a coaxial can fly faster and/or carry a larger payload (A).

The other critical speed identified by the power vs. airspeed chart is the *maximum range speed*, which represents the speed at which the aircraft will cover the most distance for a given amount of power. It is found by extending a line from the origin to the tangential point of the curve. Because a coaxial's drag curve rises much more gradually, the speed at which it achieves its maximum range is *much faster* than a comparable multirotor (B). In fact, to achieve maximum range a coaxial's speed *can approach that of a typical fixed wing UAV* while still maintaining an ability to hover.

When payload capacity is more critical for an operator, a coaxial can trade some of that performance and carry additional weight. With a more compact core airframe the coaxial is lighter than a quadcopter, leaving more available for batteries, sensors and other mission equipment. In fact, the core airframe of Ascent AeroSystems' Spirit™ weighs less than half of a comparable quadcopter, offering more than double the total payload capacity. This flexibility allows the operator to optimize battery and payload on every flight.[6]

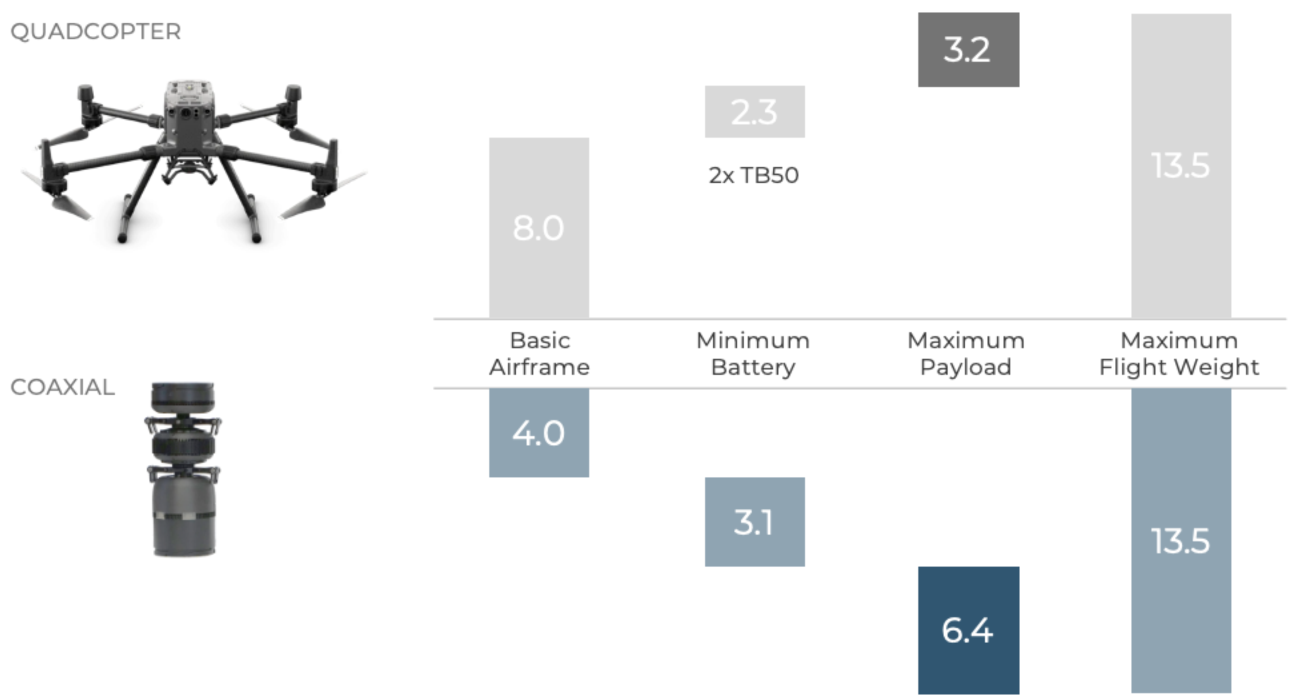

Figure 8 - The coaxial can carry more payload for an equivalent flight weight

Summary

With a unique cylindrical configuration that's more compact and rugged than conventional multirotors, Ascent AeroSystems' coaxial UAVs can fly longer, farther, faster and carry more than other UAVs in their weight class, making them the ideal platform to meet the full range of mission-critical operations. They are:

✦	COMPACT	Easier to transport where needed
✦	RUGGED	Withstands harsh environments and weather
✦	HIGH PERFORMANCE	Flies faster, farther, longer, and carries more

A coaxial is also a far more versatile airframe configuration, making it even more ideal for defense, public safety, and mission-critical industrial applications. This will be the topic of another upcoming white paper from Ascent AeroSystems.

[6] Although details will be provided in a subsequent white paper, it's worth noting that with a larger rotor area, a coaxial can spin larger blades in a smaller area at lower RPMs. This dramatically improves the vehicle's acoustic signature; a coaxial is quieter and less annoying than a comparable multirotor.

About Ascent AeroSystems

Founded in 2014, Massachusetts-based Ascent AeroSystems designs and manufactures rugged, coaxial unmanned aerial vehicle drone systems for commercial, defense, public safety, and industrial markets. The compact, all-weather, high-performance vehicles feature a unique cylindrical configuration that's far more portable and durable than conventional multirotors, ideally suited for mission-critical operations in the toughest environments.

Torrance, CA-based Robinson Helicopter Company (RHC), a premier aerospace OEM with 50 years of manufacturing experience and more than 13,000 type-certificated aircraft delivered to date, acquired Ascent AeroSystems in April 2024. Ascent is now a wholly owned RHC subsidiary. For more information, visit https://ascentaerosystems.com/.