Composite VTOL

An improved approach to aircraft design.

Abstract

Heavy lifting tugs will enable aircraft optimized exclusively for mission operation to perform vertical takeoff and landing.

Current aircraft design philosophy requires that all aircraft have continuous capacity for takeoff and landing. Carrying this capacity through the entire flight negatively impacts aircraft performance, and leads to large airfields and increased costs.
By moving the takeoff and landing capability onto a tug, overall fuel efficiency and performance will increase, while reducing demands on ground-based infrastructure and enabling helicopter-like field operation for all classes of aircraft.

Versions
Revision 1.0 on 2016-11-23: Release Version
Revision 0.2 on 2015-10-07: Re-arrange and improved content.
Revision 0.1 on 2015-10-06: First draft completed.

Contents

Drawbacks, Commercial Sector: The State of the Art

Current commercial aircraft design assumes simple (non-composite) aircraft with integrated takeoff and landing capacity. This leads to operation far from hubs of population, commerce, and industry, as well as sub-optimal aircraft design.

Inefficient Cruise Configuration

All mass in an aircraft must be kept aloft by burning fuel. Fuel is the largest operational cost for modern commercial aircraft.

Landing Gear

Landing gear and associated equipment comprise about 5% of maximum takeoff weight. This landing gear is used only for ground operation, takeoff, and landing. It is dead weight and drag in cruise configuration.

High Takeoff Power

In order to take off from reasonably short runways, most aircraft carry capacity for about six times their minimum cruise thrust. Engines and associated structures comprise about 7% of maximum takeoff weight.

Low Speed

In order to take off from a stand-still, aircraft must operate at a low stall speed. Long chord wings are less efficient at high speeds, so flaps are used to temporarily decrease the stall speed and increase drag. Aircraft also carry oversized control surfaces in order to maintain control authority at low speeds, and to produce pitch command during takeoff. Flaps, large control surfaces, and large wings add weight and cost. Wings, flaps, and control systems comprise about 10% of maximum takeoff weight.

Ground Infrastructure

Permitting, building, and maintaining an airfield incurs significant cost. Airport fees are the second largest operating cost for modern commercial aircraft.

Runways

Accommodating horizontal takeoff requires long runways. Even with the relatively high thrust mentioned above, aircraft require significant runway length for takeoff and landing. The runway surface must be specially prepared, maintained, and oriented with concern for local weather, terrain, and presence of manmade structures. A modern runway is approximately two miles long.

Taxiways

Aircraft wingspan is limited by airport taxiway width. Modern airports have a large area devoted solely to aircraft taxi operations. Taxiways must be specially prepared, and maintained clear of debris which might otherwise be ingested into operating aircraft engines. A modern taxiway is approximately 250 feet wide.

Environmental Clearance

Horizontal takeoff requires the absence of tall buildings for miles around. Because tall buildings and structures are a hallmark of population density and capital development, this precludes normal aircraft operation in areas which would otherwise be ideal as hubs for air transport. Height limits are approximately 300 feet tall, but vary with distance from the airport. The intrinsic complexity and unreliability of aircraft leads to a perception of hazard by planners.

Noise Pollution

Horizontal takeoff leaves a long noise footprint, which is exacerbated by the high throttle levels used during takeoff. Quickly changing loud sounds, such as an aircraft taking off overhead, have a much higher annoyance level than that of slowly changing sounds, such as a helicopter taking off in the distance. “Unavoidable” noise pollution means airstrips are normally located as far from (and therefore as inconveniently accessible to) dense population areas as possible.

Design, Fabrication, and Maintenance Cost

Designing and manufacturing aircraft incurs significant cost. Airframe amortization and maintenance is the third largest operating cost for modern commercial aircraft.

Airframe Design

Integrating the complex demands of aerodynamics, weight, balance, strength, rigidity, manufacturability, and dimensional limits is both difficult and time consuming. The broad range of the operating envelope required for an aircraft to take off, cruise, and land more than doubles the difficulty of these challenges. Compare the complexity of a conventional single-seat airplane (designed to operate at a broad range of air speeds) to that of a single-seat glider (designed to operate in a narrow range). This increase in complexity is required to accommodate multi-speed operation, and take-off.

Engine Design

Designing an engine to operate quietly and efficiently from low-speed high-thrust (takeoff) through high-speed low-thrust (cruise) to low-speed reverse-thrust (landing) is non-trivial. Design trade-offs exist between low manufacturing cost, simplicity, reliability, weight, and efficiency, and these trade-offs become more pronounced as the operating envelope widens. Modern commercial engine design must accommodate operation from a dead stand-still at sea level to mach 0.8 at high altitudes. This wide operating range limits both the manufacturing and operating economy available to engine manufacturers.

Manufacturing and Maintenance Cost

More versatile machines are less reliable and cost more to make. More complex machines require more down-time for maintenance, and more skilled technicians to maintain them.

Drawbacks of the State of the Art in the Military Sector

Demands placed on military aircraft are greater in performance, and less stringent in efficiency. Even so, aircraft system procurement and operating cost is a driving factor in military aircraft design. In addition to the above factors common to commercial aircraft, military aircraft present several unique constraints.

Combat Factors

Military aircraft are expected to avoid scrutiny and continue to operate after sustaining damage.

Stealth

Military aircraft can not be effectively engaged unless they are first perceived either visually, through electronic means, or by environmental means (thermal or acoustic). Aircraft size is the defining feature of visual perceptibility, radar cross-section, and sound signature (especially for super-sonic flight) The systems mentioned in the commercial section above also contributes to reduce aircraft stealth.

Survivability

Military aircraft design incorporates some level of resilience to intentional damage. Redundant systems, load paths, and excess performance are all common methods of increasing combat survivability. The complexity outlined in the commercial section above also contributes to reduced survivability.

Ground Infrastructure Vulnerability

The greater the takeoff, landing, and ground support requirement of a design, the more vulnerable that design is to indirect attack.

Runway Requirements

Conventional aircraft require a significant runway to both takeoff and land. Runways are notoriously vulnerable to attack, difficult to set up, and easy to convert to enemy purposes if they are captured.

Carrier

Aircraft carriers employ various means to shorten takeoff length. All of these methods are expensive to both produce and maintain. Despite these measures, aircraft carriers still require ample deck area, and are among the largest class of naval vessel.

VTOL

Vertical takeoff and landing bypasses much of the ground infrastructure problems, but exacerbates the inefficiencies in cruise configuration. VTOL thrust is approximately four times the standard aircraft thrust capability, or twenty-four times the minimum cruise thrust.
Current vertical takeoff and landing capable aircraft carry the VTOL equipment through the entire mission. For this reason they are expensive to purchase and maintain, are inefficient to operate, and have reduced performance.

Composite VTOL

In order to alleviate the above-mentioned drawbacks, a composite aircraft design philosophy is proposed. This consists of at least two craft, a tug and a core mission craft (or core). The tug and mission core form a composite craft for takeoff and landing, while the core operates solo during the mission phase.

Tug

A tug is a heavy lifting VTOL craft capable of operating either alone or as part of a composite craft. Its primary purpose is to enable cores to perform vertical takeoff and landing. It may also operate solo in similar fashion to a heavy lifting helicopter.
A tug is optimized for low-speed high-thrust operation. One possible design is a multi-rotor craft. The specific design and construction is outside the scope of this paper.

Core

A core is an aircraft dependent on assistance from a tug for takeoff and landing. Its primary purpose is inexpensive, fuel efficient, high performance operations in the field or from helipad-style ground facilities.
As a core does not need to be designed to operate in the low-speed regime for takeoff and landing, it can be very light, simple, and highly optimized for mission performance.

Example Operations

There are four basic phases of aircraft operation. Ground, takeoff, mission, and landing. All four are affected by the composite VTOL model.

Ground

Ground operations include cargo and munition load and unload, taxi, and maintenance. The tug performs ground operations in a similar fashion to a helicopter. The core rests in a cradle for normal ground operations. If necessary, the core may be transported in a mobile cradle, but this is not ideal, as it requires taxiways. The core may also be moved by crane, or by a tug.

Takeoff

A tug flies solo from a waiting area or storage to the core. It docks atop the core, forming the composite craft. The composite then lifts off to clear obstacles. Once at a safe height, the composite transfers to forward motion. When sufficient altitude and airspeed is reached, the composite separates. The tug then flies solo back to a waiting area at the airfield.

Mission

After separating from the tug, the core continues flight under its own power. It possesses sufficient thrust and fuel to maintain cruise velocity and altitude, and perform mission objectives. If core recovery on mission completion is desired, it is met in the air by a tug.

Landing

As the core prepares to land, a tug flies solo from a waiting area to a rendezvous location. The core and tug match speed and position in-flight, and dock, forming a composite craft. The composite reduces altitude and airspeed. As the composite nears the ground, it transfers to vertical flight. The composite comes to rest with the core resting in a cradle. The composite separates, and the tug flies solo to a waiting area, or returns to storage.

Mid-air Docking

The critical element in the Composite VTOL concept is mid-air docking of a tug and core to form a composite craft for landing. This will require a standardized docking interface, so that any tug may reliably and quickly perform mid-air docking with any core.
The development of a combined hardware and software solution to the problem of configurable, light, reliable, inexpensive, secure, and robust mid-air docking is crucial to the success of the Composite VTOL system, but specifics fall outside the scope of this paper.

Advantages

The Composite VTOL model results in smaller, better placed air fields, lower operating costs, and more optimal aircraft design resulting in improved performance.

Airfield and Ground Support

VTOL capability essentially reduces airfield requirements to that of an appropriately sized helipad. This in turn will result in smaller less expensive carriers and improved capacity at airbases.

Smaller

Runways and taxiways compose approximately 90% of the land area of an airbase. The Composite VTOL model eliminates the need for these features, allowing an order of magnitude reduction in airfield size, with a corresponding reduction in construction and maintenance costs. The reduction of airbase runway area also allows for vast runway redundancy, or construction of landing zones out of more durable materials.

Faster

VTOL-only operation increases the channel bandwidth of existing carriers and airbases, as an order of magnitude more aircraft can be launched or recovered simultaneously with existing runway or deck area.

Cheaper

Reduction in takeoff and landing system size and complexity will reduce both procurement and operating costs for air bases and carriers alike.

Destination Proximity

Small airfields combined with VTOL allows air transport terminals to locate in close proximity to high density ultimate destinations. This effectively raises the value of air travel, as there will be less distance to the nearest airport from city centers and industrial complexes.

Aircraft

Freed from the necessity of takeoff, landing, and low-speed operations, cores can be optimized solely for efficient single-speed mission performance.

Simpler and Lighter

Aircraft design is much simpler without needing to account for takeoff rotation, ground clearance, noise abatement, and general low-speed and low-altitude operations. Eliminating these complicating factors will result in more elegant aircraft that are easier to design, build, and maintain. In addition, several systems may be removed entirely, including landing gear, flaps, slats, and thrust reversers.

The result of the removal of these systems and airframe optimization is difficult to estimate. Weight savings of about 15% are expected, but accurate estimates will require professional exploration.

Better Performance

A lighter aircraft requires a smaller engine. A smaller engine optimized for cruise burns less fuel than a larger one designed for both takeoff and cruise. Less fuel burn means less fuel carried for the same range, which further reduces weight.

An airframe optimized for mission operations will fly more efficiently than one required to also function during takeoff and landing.

As with weight, estimating efficiency improvements for theoretical aircraft is fraught. Fuel efficiency improvement of about 30% is expected, but accurate estimates will require professional insight.

Compatibility

Both advantages of the Composite VTOL system are compatible with existing airbases and aircraft.

Because the infrastructure requirements are universally lower than those for existing aircraft, the Composite VTOL method can be tested and implemented at existing airbases and carriers. Because all existing aircraft can operate at cruise, and some existing aircraft can operate in VTOL mode, the Composite VTOL method can likely be tested and implemented by refitting existing aircraft. (Note that refitting existing aircraft as cores will only realize the VTOL aspect without significantly improving mission efficiency.)

Challenges

Procurement Costs

While cores may be less expensive to build than existing aircraft, tugs may be significantly more expensive. With a 1:1 tug to core ratio, capital costs will likely be double that of existing aircraft. These costs may be reduced by having a single tug serve multiple cores.

To replace existing VTOL designs, the cost for a tug-core pair are expected to be roughly equivalent.

Increased Danger in Abnormal Operations

The composite system introduces the docking failure mode which remains largely unexplored. Cores should be designed with emergency landing skids for use in case of docking failure, or tug non-availability. Landing with these emergency skids may be more dangerous than a normal aircraft emergency landing.
In addition, the effect of inclement weather on cores, tugs, and core-tug composites is largely unexplored. It is possible that a Composite VTOL craft is more tolerant of inclement weather, but the reverse is also possible. The effect of inclement weather on docking is another unknown.

Unproven Technology

The Composite VTOL system relies on as-yet undeveloped high-end tug and in-flight docking technology. While assisted takeoff is a fairly well explored technology (all munition-bearing helicopters are examples of VTOL tugs carrying single-use cores), no known examples exist of assisted landing.
The aerodynamic interaction of cores and tugs may also prove to result in untenable performance.

Applications

In addition to the advantages outlined above, a few likely applications present themselves. An exhaustive exploration of applications for Composite VTOL is out of scope for this paper.

Point-to-point transport

Numerous small airbases will allow smaller aircraft to perform point-to-point transportation, reducing overall transit time and further increasing total transit network efficiency. Small airbases would likely arise in centers of population and industry, especially since a very small airbases could service relatively large craft. All military bases and craft accessible by helicopter would effectively become an airfield for the purposes of transport. This improvement in transport network responsiveness is difficult to overstate.

High-speed craft

Supersonic flight is much easier to achieve and maintain when the core does not need to operate at low speeds, and can be launched and recovered at a significant altitude and velocity.

Mid-air Refueling

All craft capable of participating in a composite craft mid-flight docking maneuver are also necessarily capable of automated mid-air refueling. This in turn will further increase the fuel efficiency of long-distance aircraft while decrasing the capital cost. This occurs because aircraft will need to carry only enough fuel to reach the next re-fueling tug, and less fuel means less weight, which results in less drag, which means less thrust, which means smaller engines, smaller wings, and a lighter airframe, which further reduces drag.

Fully Recoverable Multi-stage Aerospace Operations

Extrapolation of this model leads to multiple fully recoverable craft for transition to and from various operating velocities and payloads. Multi-stage launch and mid-air recovery of spacecraft seems the ultimate example.

Conclusion

Composite VTOL offers solutions to the most pressing issues of aircraft operating cost and airbase development. If it is within our current technical capacity, it seems prudent to develop it with all expediency.

Thank you for your consideration of these matters. I am neither a professional aircraft designer, nor do I possess any specialized knowledge. All information I used to prepare this report was found in freely available sources. I also release the entirety of this document to the public domain.

Please feel free to contact me if you desire any further elaboration on the content above, as well as its derivation and implications.

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