

## ***Executive Summary***

### ***Introduction to the Twin-Lift Concept: Two is better than one...***

The *Goliath* twin-lift system has been designed in response to the 2010 American Helicopter Society Student Design Competition (sponsored by The Boeing Company). The Request For Proposal (RFP) identified the need for the utilization of a twin-lift system for vertical lift of payloads that exceed the current capacity of individual rotorcraft. Significant technical challenges and high RDT&E costs are associated with developing a single heavy-lift rotorcraft of equivalent payload capacity. A twin-lift concept using certified in-service rotorcraft is highly cost-efficient. Multi-aircraft coordination, elevated pilot workload levels and increased logistical complexity have historically presented challenges towards practical realization of the twin-lift concept.

This design addresses these challenges by developing a load handling system and control architecture which takes advantage of developments in control theory, modern materials and especially the miniaturization of wireless sensing to provide real time information about the twin-lift system. The key operational challenges that have been addressed are namely:

- Multi-aircraft stability.
- Load sharing between aircraft.
- Control coordination, and
- Takeoff and landing techniques.

To meet these challenges and provide a new heavy lift service to the armed forces, the *Goliath* twin-lift system has been designed around:

- Innovative control synchronization techniques.
- Lightweight load sharing structure.
- Robust wireless communication.
- Modularity and streamlined logistics.

The resulting concept is capable of transporting greater payloads, further than any other helicopter available. This is achieved while maintaining operational safety during all stages of the flight. A comprehensive operational procedure has been developed to show the feasibility and suitability of the take-off and landing procedures.

Proven technology has been employed in innovative ways, resulting in a robust concept with a path to production projected to be only 30 months, taking into account the technology readiness levels of the system.





# UNRIVALED VTOL HEAVY LIFT CAPABILITY



## AFFORDABLE

- Uses existing helicopter assets
- Acquisition cost of system is a fraction of an equivalent heavy-lift helicopter

## SAFE

- Innovative control system coordinates helicopter movements to prevent accidents
- Ducted rotor thrusters stabilize load swinging

## SMART-TRUSS

- Relays position of truss and load to helicopter controllers
- Detects and damps load oscillations using ducted rotor thrusters
- Modular and portable

## PORTABLE

- Modular *Smart-Truss* design breaks down into six man-portable sections and fits in the cargo hold of one CH-53E

## LOAD STABILITY

- Vertical fins on attachment frame orient container for least drag

## MISSION CAPABLE

- Fulfills the US Navy Operational Maneuver From The Sea (OMFTS) mission profile
- Delivers 40,000 lb container payloads 100 nm under hot-day conditions



## **Design features**

- Cross-platform adaptability *Minimal hardware modifications to the helicopter.  
Low cost and multi-use.*
- Lightweight materials *High-strength Aluminum alloys used in spreader bar.  
Improved payload capacity to 187% compared to one CH-53E.  
Disassembled sections can be lifted by four personnel.*
- Modular design *Spreader bar disassembled into six sections.  
Transported in the cargo hold of one CH-53E.  
Ease of replacement and repair.*
- Air crew safety *Input synchronization and position regulation control system.*
- Ground crew safety *Stabilizing anti-swing mechanisms for spreader bar.*
- Streamlined logistics *Reduced payload pick-up and alignment time.*
- Payload flexibility *Swivel hook suspension can accommodate various payloads.*
- Payload dynamic stability *Dual vertical fins expand forward speed range to 90 knots.*
- User-friendly interface *Dedicated twin-lift avionics display/control module.*
- Intuitive control *Pilot control inputs automatically synchronized.*
- Real-time measurements *Sensor suite on spreader bar.  
Wireless transmission network.  
Interface with AFCS to utilize onboard helicopter sensors.*
- System redundancy and robustness *Stand-alone doubly redundant twin-lift avionics modules.  
Multiple measurement and transmission/reception paths.  
Resistance to interference/jamming.  
All weather capability.*



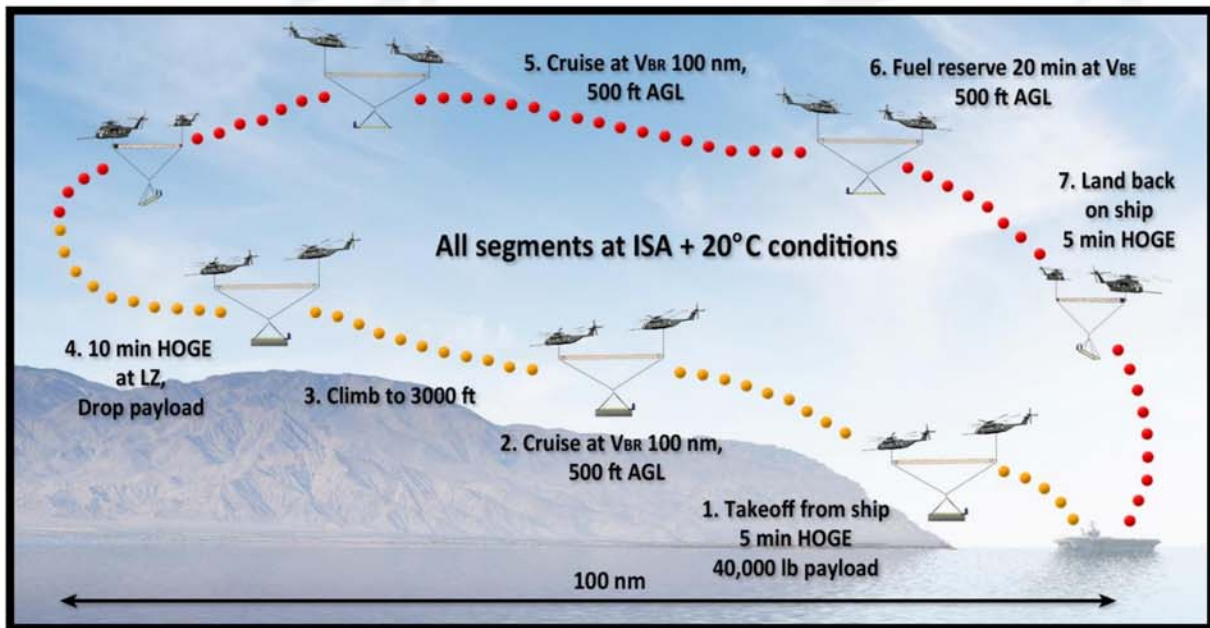
## Mission Capability and Performance

The University of Maryland's *Goliath* twin-lift system utilizes existing assets to provide VTOL heavy-lift capability unrivaled by current or planned rotorcraft systems. While the *Goliath* concept remains versatile in its application, it has been designed specifically to meet the stringent requirements of the U.S. Navy's seabasing and Operational Maneuver from the Sea (OMFTS) missions.

These missions involve rapidly deploying troops, ground vehicles, and logistics equipment from the fleet directly to the inland objective point. This eliminates the reliance on traditional port infrastructure or beach-head staging areas to transport heavy cargo to inland locations.

The mission requirements from the RFP —were met and expanded to match the the OMFTS mission as outlined in the mission profile shown below. In addition the following logistical challenges of shipborne operations have been satisfied.

- Storage within a candidate ship.
- Rapid deployment.
- Transportable without specialized equipment.



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OMFTS primary mission profile using two CH-53E Super Stallions

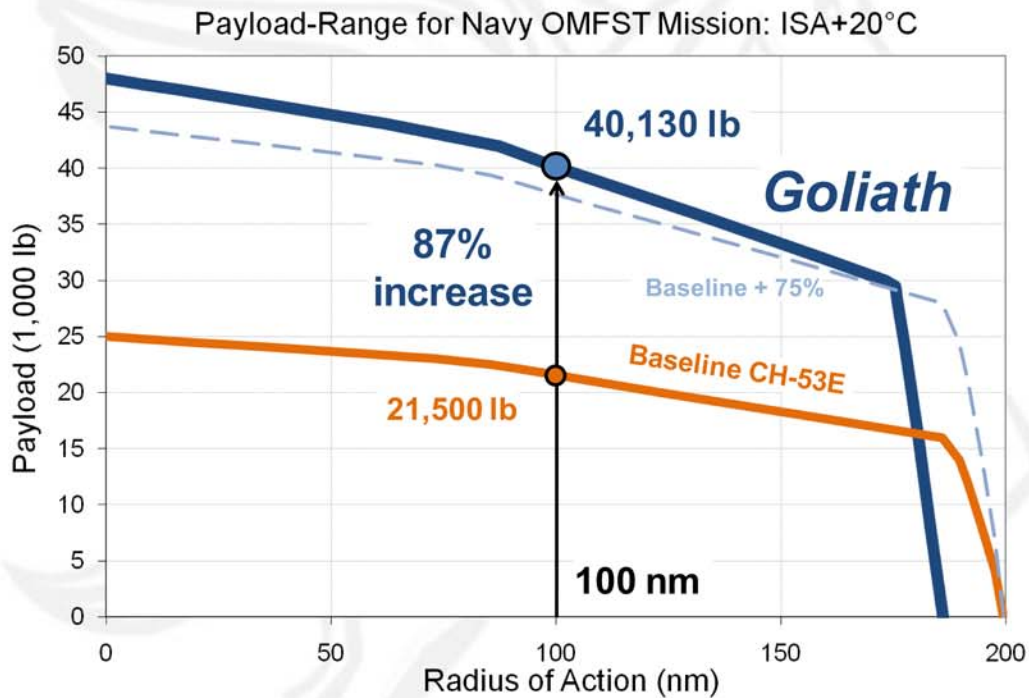




## Goliath Twin-Lift Performance

The *Goliath* twin-lift system uses two U.S. Marine Corps CH-53E helicopters to cooperatively lift and safely deliver a single external payload at best-range cruise speeds. Performing the primary Navy OMFTS mission, the *Goliath* capabilities are:

- Hot-day: Deliver a 40,000 lb ISO container to a distance of 100 nautical miles in 65 minutes and return without refueling.
- Standard-day: Deliver 51,500 lb the specified 100 nm delivery distance.



This represents an **87% payload increase** compared to a single CH-53E, the Navy's current option for lifting heavy cargo. This meets and exceeds the RFP requirement of a 75% increase in payload capability over the baseline.

The increased payload capability greatly widens the operational flexibility of military units. For example, commanders using the *Goliath* system could deploy armored tactical vehicles such as the LAV-25, Stryker, and the Buffalo MRAP, as well as heavy logistics and construction vehicles.

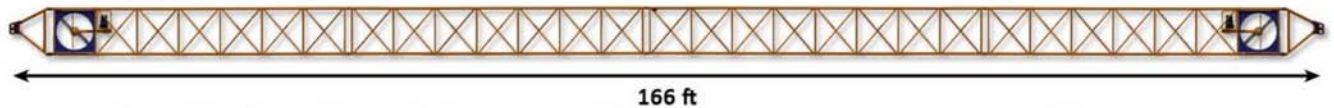


## ***Spreader Bar – Designed for Logistics***

The key focus of the *Goliath* Smart Truss was to make the logistics of the twin-lift concept a manageable reality. The operation of the twin-lift resource in a theater of war would be crippled if the logistical realities—transportation, ground handling, and storage—are not integral in its design. The *Goliath* Smart Truss has been designed from the bottom up with these in mind. The result is a twin-lift concept that:

- Can be rapidly and economically deployed on strategic missions that deliver more payload at less cost.
- Minimizes dependence on specialized aircraft.
- Demands the least possible ground support.
- Ready to be deployed at a moment's notice.

The *Goliath* Smart Truss achieves this without sacrificing payload capability. The control and stability of a twin-lift system demands a robust, accurate, and safe sensing network. This system is seamlessly designed into the *Goliath* Smart Truss, taking advantage of the unique geometry of the spreader bar to leverage state of the art, but proven, technology to provide real-time and dependable positional awareness.



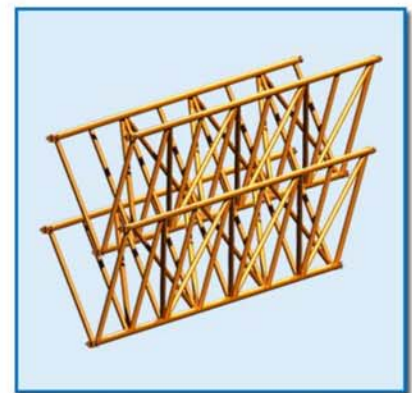
The spreader bar truss is essential for:

- Reacting lateral payload cable tensions.
- Maintaining safe helicopter separation.
- Load sharing.
- Relaying payload dynamics to the control system.

To maximize payload efficiency the spreader bar is designed from lightweight aluminum alloys.

### **Ground handling:**

- Every element of the spreader bar is optimized around modularity and handling.
- The spreader bar consists of six identical truss elements, routinely moved by a team of four men.



**Stackable truss sections**





### Assembly:

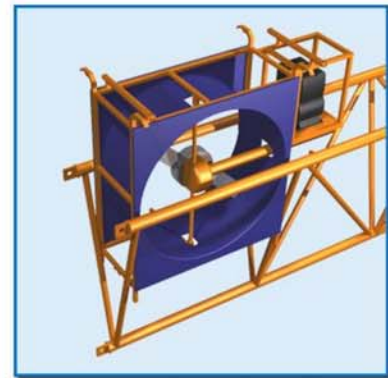
- Pin joints allow for rapid assembly of the spreader bar and minimum logistical downtime.
- Minimum unique parts provide for fast and economic repairs.
- Disassembled spreader bar elements can be stacked to reduce storage requirements and allow for greater logistical flexibility.



*Easy disassembly*

### Modularity:

- Thrusters, sensors and spreader bar elements have been developed in coordination to maximize dual functionality, minimize weight, expedite assembly and minimize footprint.
- The vertical fin is simply bolted to the container attachment frame.
- Spreader bar elements are each identical for efficient manufacture, maintenance and repair with minimal training.



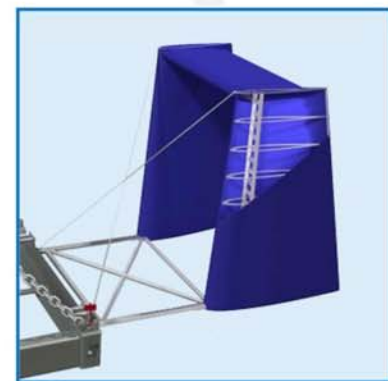
*Removable ducted rotors*

### Transportability

- The disassembled spreader bar and all auxiliary components can be stored in the cargo hold of a single CH-53E.



*Entire truss and ducted rotors fit in cargo hold of a CH-53E*



*Stabilizing Vertical Fins*



## Control of the twin-lift system

Previous attempts at utilizing a twin-lift system were thwarted by high pilot workloads at speeds as low as 20 knots. The need for control augmentation has been well-recognized, and stabilization is considered crucial to overcoming operational restrictions imposed by the system dynamics. The Goliath twin-lift design incorporates an automatic controller that features the following functions.

### Multi-function twin-lift avionics module:

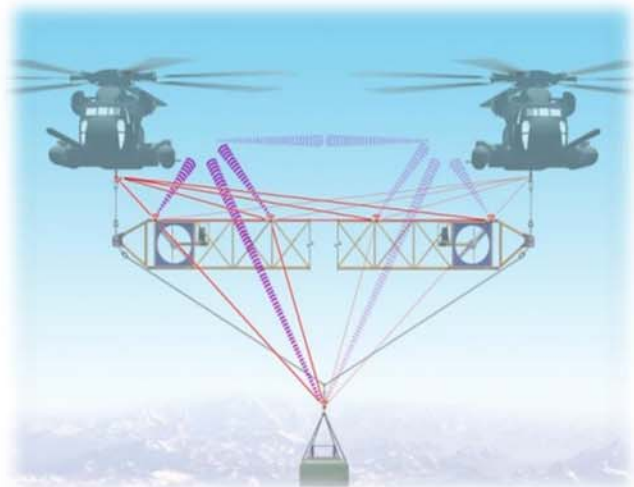
The Goliath twin-lift controller features an all-in-one pilot interface that provides real-time display and control, featuring:

- Visual cues for ease of hook-up
- Spreader bar sensor diagnostics
- Helicopter avionics monitoring
- Twin-lift control processing
- System heading dial
- Emergency jettison and synchronization disengage switch
- Immediate control transfer during emergency



### Real-time measurement and separation regulation:

A sophisticated sensor suite is utilized in conjunction with the existing AFCS sensors to measure and then transmit the system states using a wireless network to two twin-lift avionics modules, one in each helicopter. These processors generate analog signals that are fed to the AFCS outer loop servos to produce the desired helicopter control changes, maintaining system stability and complete operational safety.





## Instant conversion to twin-lift mode

The CH-53E helicopters are operable as fully functional independent aircraft.

- Transition to the twin-lift configuration is actuated through a simple pilot interface.
- The Goliath twin-lift system is commanded by a single Master pilot.
- The slave pilot is hands-off, the controller interprets Master pilot commands for both helicopters.
- The twin-lift system can be disengaged at anytime in case of emergency. Both pilot input and failure sensors are monitored for disengagement and/or jettison commands.
- The simple electrical interface requires no structural modifications.

## Motion synchronization for single pilot control

When twin-lift synchronization is engaged:

- The master pilot's control inputs are modified by the controller
- Modified commands are transmitted wirelessly to both helicopters.
- The avionics module installed on both helicopters interprets the commands before actuating the helicopter controls.

## Twin-lift specific control inputs for pilot intuition

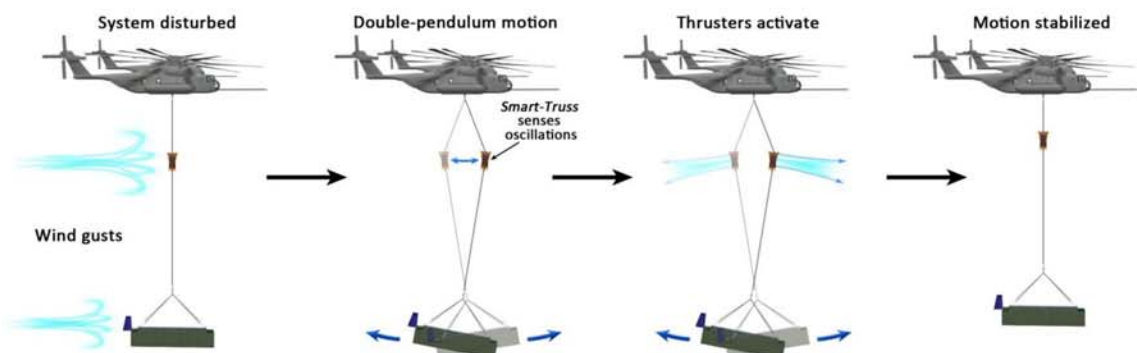
Coordinated turns require unique control architecture:

- The avionics module has a dial interface for heading commands.
- This interface preserves pilot yaw flexibility.



## Active ducted rotors for stabilization

- Active thrusters damp spreader bar oscillations from helicopter motions or wind gusts.
- Wireless signals from the controller variably actuate the thrusters.
- Active damping eliminates oscillations that delay hook-up time of payload and endangers life.



## Equal helicopter workload enforced

- Cargo hook load sensors provide dynamic updates to the controller for load sharing

## ***Sequence of Operations: Carrier-Based Mission***

The logistics of ground and air operations at every stage of the mission have been incorporated into the design of the *Goliath*. The following sequence of operations gives a step-by-step overview of the carrier-based mission profile.

To succeed in Seabasing operations the *Goliath* twin-lift system has been tailored to excel in the most demanding shipboard environment. Key features are:

- **Compact storage:** the *Goliath* Smart truss can be stored compactly and within the limitations of an aircraft carrier and within the cargo hold of a single CH-53E
- **Requires no specialized equipment:** Each component of the disassembled spreader bar can be carried just four people.
- **Rapid assembly:** Simple assembly and fast set up times are imperative for time critical shipboard operations.

## **Spreader bar hook-up**

- The spreader bar is assembled, straddling the ship deck.
- Each helicopter is piloted to the ends of the spreader bar.
- Immediately after the attachment of the spreader bar cables to the helicopters the pilots initiate twin-lift control synchronization.
- The master pilot takes command of the *Goliath* Twin-Lift system.





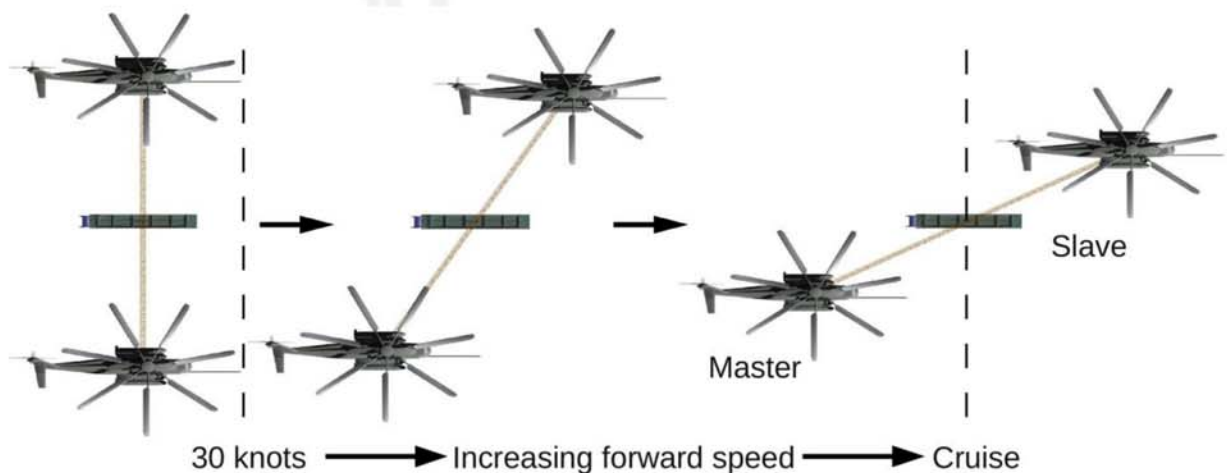
## Payload pick-up

- The master pilot maneuvers the *Goliath* Twin-Lift configuration to the container payload.
- Thrusters on the spreader bar remove any oscillations and allow for precise maneuvering of the container attachment frame.
- A mechanical linkage mechanism automatically locks onto the container.
- The *Goliath* Twin-Lift system is cleared for lift off.



## Transition to cruise

- The avionics module, core to the control architecture of the *Goliath* Twin-Lift system, initiates transition to cruise flight helicopter configuration.
- In cruise the master pilot trails behind and above the slave helicopter
  - This affords pilot visual cues for maneuvering and control.
  - Parasitic drag is reduced on the spreader bar at the acute, 30°, sweep angle.



### Cruise flight

- The master pilot commands maneuvers in flight.
- The avionics module reinterprets the pilot's commands to coordinate both helicopters while maintaining payload stability.
- Robust failure mode analysis ensures crew safety at all times with double redundant jettison procedures.



### Payload drop off

- On approach, the configuration swing back into the hover orientation (airspeed trigger).
- Master pilot engages hover hold and allows controller to stabilize any oscillations.
- On touchdown, mechanical links automatically release container to allow quick egress.



### Configuration return

- Return in swept configuration.
- Lightly loaded spreader bar is more susceptible to oscillations.
- Thrusters on spreader bar maintain load stability.





## ***Ensuring Safety of Flight***

The *Goliath* concept prioritizes the safety of both air and ground crews.

- The *Goliath* is a robust package involving explicit safety procedures and a network of sensors.
- Reliable inner-loop controllers run diagnostics to detect disparities in sensor information in real-time.
- In flight safety is maintained by robust controllers that coordinate helicopter positions during maneuvers.
- Ducted rotors remove potentially unstable oscillation modes from the slung load.
- Emergency hooks, located at the container, and at each helicopter are simultaneously release should a safety threatening fault be detected.
- In the event of emergency load jettison the helicopters default to heading hold to allow recovery time.
- Ground operations assume, where possible, standard slung load procedures. This requires minimum specialized training.
- Spreader bar and auxiliary equipment were designed with ground handling in mind to ensure safe assembly procedures.

## ***The Affordable Heavy Lift Solution***

<b>Heavy lift option</b>	<b>Acquisition cost (mil. US\$)</b>
New build – heavy lift	100
The <i>Goliath</i> twin-lift with 2 CH-53E	45
A single CH-53E	22
The <i>Goliath</i> twin-lift concept	0.2

The economic advantage of the *Goliath* twin-lift concept is amplified by its near zero dependence on any one particular rotorcraft. Without requiring any structural modifications the *Goliath* twin-lift system can be extended and applied to any two rotorcraft after integration to the flight controls and provide lift that is unmatched by any other single platform.

Another critical application of the *Goliath* Smart-Truss technology is in combining two medium-lift helicopters to provide heavy-lift utility on an as-needed basis without expensive procurement of specialized heavy rotorcraft and the associated overhead.



## ***Conclusion***

*Goliath* is a revolutionary scalable twin-lift concept that, when fully implemented, would realize enormous advancements in both civil and military vertical-lift capability. The modular design of system components reduces implementation costs, while minimizing overall system footprint. The innovative use of proven technologies ensures complete operational safety, while robust and redundant sensor suites enable precision position control. Ultimately, it is the scalability of the *Goliath* to both heavy-lift and lighter helicopters, applicability to current and next-generation rotorcraft, and adaptability to a wide variety of payloads, that gives this versatile system an unrivaled edge over most, if not all, other vertical-lift platforms.

