ARMD Strategic Thrust 3: NASA Vertical Lift Strategic Direction

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Thrust 3B—Vertical Lift Roadmapping Co-Leads
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Vertical Lift Outlook and Community

The Team for the Vertical Lift Thrust 3B Roadmap realizes that the Vertical Lift Community is a broad community with diverse interests and needs.

- Unique capabilities of vertical lift and hover provides potential for exceptional access and mobility in both commercial and public good applications
  - Specialized missions performed by current configurations
  - Entirely new future missions for advanced conventional and non-conventional configurations
  - Projected market growth\(^1\) of vertical lift (helicopters and civil drones) is >$6B in next 5 years

- Community includes established and emerging manufacturers (large corporations, small businesses, hobbyists) and users

- Community has a wide spectrum of configurations
  - Large- and small-scale vehicles
  - Conventional and unconventional configurations
  - Range of propulsion options from small electric motors to large turbomachinery
  - Crewed and un-crewed configurations

- All configurations need improvement in cost, speed, payload, safety and noise


\(^1\) The World Rotorcraft Market, Vertiflite, Vol. 61, No. 3, 2015
Conventional helicopters perform specific missions today, as shown in the black text. New vehicles will expand the missions of vertical lift vehicles across the size spectrum. Autonomous capability in varying degrees will be applied across the spectrum to enable new missions.

<table>
<thead>
<tr>
<th>Missions</th>
<th>Very Light</th>
<th>Light</th>
<th>Medium</th>
<th>Heavy</th>
<th>UltraHeavy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Inspection</td>
<td>• Police</td>
<td>• Police</td>
<td>• Oil platforms</td>
<td>• Commercial transport (90-120 pax)</td>
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<tr>
<td></td>
<td>• Photography</td>
<td>• Training</td>
<td>• EMS</td>
<td>• Disaster relief</td>
<td>• Disaster relief</td>
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<td>• Filming</td>
<td>• Traffic/news</td>
<td>• Traffic/news</td>
<td>• Cargo</td>
<td>• Civil reserve aircraft fleet</td>
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<td></td>
<td>• Spraying</td>
<td>• Power line service</td>
<td>• Tourism</td>
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<td>• cargo</td>
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<tr>
<td></td>
<td>• Mapping</td>
<td>• Spraying</td>
<td>• Executive</td>
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<td>• Weather</td>
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<td>• Charter</td>
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<td>• Cargo</td>
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<td>• Delivery</td>
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<td>• SAR</td>
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<td></td>
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<td></td>
<td>• Cargo</td>
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**Overarching Vertical Lift Strategy**

Enable a broad expansion of vertical lift applications
- Improve current configuration cost, speed, payload, safety, and noise
- Open new markets with new configurations and capability
- Capitalize on convergence of technology in electric propulsion, autonomy and flight controls

Blue Highlight: New mission and/or new configuration
The Roadmap Team reviewed the current SIP Outcomes and is recommending significant changes to reflect the nature of the Vertical Lift Community and include many types of vertical lift vehicles.

Vertical Lift Community is broad; plan should be inclusive
• Large and small-scale vehicles
• Crewed and un-crewed configurations
• Established and emerging manufacturers and users

New DRAFT Community Outcomes (proposed for the updated SIP):

<table>
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<tr>
<th>2015</th>
<th>2025</th>
<th>2035</th>
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<td>New vertical lift configurations and technologies introduced that enable new markets, increase mobility, improve accessibility, and reduce environmental impact</td>
<td>Vertical lift vehicles of all sizes used for widespread transportation and services, improved mobility and accessibility, with economic benefits and low environmental impact</td>
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With new technology inserted into the fleet, there will be Benefits realized for each Outcome.

| Strategic Thrust 3B: Ultra-Efficient Commercial Vehicles—Vertical Lift |
|---|---|---|
| **Outcomes** | **2015** | **2025** | **2035** |
| Increased capability of vertical lift configurations that promote economic benefits and improve accessibility for new and current markets | New vertical lift configurations and technologies introduced that enable new markets, increase mobility, improve accessibility, and reduce environmental impact | Vertical lift vehicles of all sizes used for widespread transportation and services, improved mobility and accessibility, with economic benefits and low environmental impact |
| **Benefits** | Reduction in direct operating cost, increased accessibility to sensitive areas, and growth in new and current markets enabled by improvements to performance, efficiency and noise. | New markets and applications enabled by unique technologies and configurations. Mobility and accessibility increased through reliable, safe and quieter operation in a wider range of locations and conditions. | Economic, environmental, and public benefits realized through a spectrum of vertical lift vehicle configurations that provide services, transportation, and unique mission capability. |
A Vision for the Future of Civil Aviation

How can vertical flight help realize this Vision?

- There will be a radical increase in new and cost-effective uses of aviation
- The skies will accommodate thousands of times the number of vehicles flying today
- Travelers will have the flexibility to fly when and where they want in a fraction of the time that it takes today
- All forms of air travel will be as safe as commercial air transport is today
- Significantly reduced carbon footprint from aviation
Our Roadmap Team proposes that Vertical Lift is required to enable the Vision!

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- Vertical lift vehicles will encompass a wide spectrum of configurations that operate safely and reliably
- Vertical lift vehicles will provide unmatched access to transportation and services
- Vertical lift vehicles will create economic benefit for unique missions and services
- Vertical lift vehicles will be operated in various states of automation and autonomy to enable unique mission capability
- Vertical lift vehicles will have low environmental impact and minimal intrusion when in close proximity to people and property
NASA has a strategy that supports each of the three Community Outcomes (2015-2025 2025-2035, 2035+) of the SIP. The strategy for vertical lift research, with examples of recommended NASA technology investments, is described on the next few slides.

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**NASA Strategy**

- **Deliver key capabilities and technologies that directly benefit our partners in industry and government**

- **Focus on key technologies that enable US industry to expand the global vertical lift market while setting new standards in noise, performance and reliability**

- **Focus on capabilities and technologies that eliminate barriers for clean, efficient, quiet autonomous vehicles operating in urban and isolated environments**
For the near term, emphasis is on improvement and development of tools.

- **Deliver key capabilities and technologies that directly benefit our partners in industry and government**
  - Validated tool for modeling noise from entire vehicle
  - Validated tools for multi-discipline vehicle design, analysis and optimization
  - Tools for mission analysis and configuration trade studies
  - Technologies for pilot workload reduction
  - Design for improved turbomachinery efficiency
  - Approach for high power-transmission efficiency established
  - Lower drag for increased speed, range, payload and lower fuel burn
While the Strategy targets a timeframe for the realization of benefits, the research work must begin well before the expected technology infusion date. For example, the strategy and technology for the 2025-2035 timeframe will be worked in parallel with the near- and far-term strategy to ensure the technology is developed in time to be deployed.

• **Focus on key technologies that enable US industry to expand the global vertical lift market while setting new standards in noise, performance and reliability**
  – Process to characterize and predict human response to noise
  – Validated tool to calculate acoustic footprint in real-time
  – Efficient alternative propulsion options
  – On-board systems to enhance safe operations in icing conditions, degraded visual environments and confined or urban areas
  – Validated, high-fidelity computational algorithms for full configuration simulations
  – Tools for mission analysis and concept of operations (CONOPS) for unconventional configurations
Defining specific far-term technology advances is not possible. Instead, general descriptions are used to show direction of the research. The expectations will be updated as technology progresses.

- **Focus on capabilities and technologies that eliminate barriers for clean, efficient, quiet, autonomous vehicles operating in urban and isolated environments**
  - Best practices for integration of lift and propulsion systems
  - Methods for real-time low-noise operations
  - Active and prognostic condition-based maintenance systems to reduce life-cycle costs
  - Methodology to analytically certify composite primary structure for loads and impact response
  - Advanced experimental methods for ground and flight test validation of configurations
NASA Vertical Lift Research Themes

These are the proposed new Research Themes for the Vertical Lift Thrust. Research Themes are long-term research areas that will enable the SIP Community Outcomes.

• **Clean and Efficient Propulsion**
  – Research and development advancing the efficiency of turbomachinery and power transmission.
  – Expanded integration and development of alternative propulsion systems for vertical lift configurations.

• **Efficient and Quiet Vehicles**
  – Research and development of technologies and configurations that optimize performance and speed and minimize noise and cost.

• **Safety, Comfort, Accessibility**
  – Research and development of technologies and capabilities that improve passenger and public safety during operations.
  – Research and development of technologies that improve vehicle response
  – Research and development of technologies, configurations and operational concepts that improve access to transportation and services.

• **ModSim & Test Capability**
  – Research and development of modeling tools and experimental methods that support achievements in configuration design, development, certification and operation.
## Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift

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In this chart, the new Community Outcomes are located across the top and the new Research Themes are located to the left.
Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift

## Complete Roadmap

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### Technology Infusion

- **Assume ~10-20 year time from TRL 4 to Entry Into Service**
- **New config fit demo**
- **Variable-speed transmissions**
- **Efficient engines over wide operating range**
- **New config fit demo**
- **New config fit demo**

#### Clean and Efficient Propulsion

- Improve turbomachinery efficiency and fuel burn
- Advance propulsion technology efficiency and implementation
- **Exploit integrated lift and propulsion systems for high-speed and low empty weight fraction**

#### Efficient and Quiet Vehicles

- Define noise source modeling for small and large vehicles
- Enable acoustics feedback in cockpit
- Enable real-time low-noise route calculation and cockpit display
- Develop multi-speed, multi-component adaptive life and low drag systems
- Evaluate alternative configurations and tech barriers, small and large scale vehicles
- Enable zero unscheduled maintenance
- Facilitate lower life cycle costs
- Increase payload and range for small vehicles
- Develop high-speed, high-payload configurations
- **Advance occupant safety during normal and emergency operations**

#### Safety, Comfort, Accessability

- Ensure public safety during operations
- Demonstrate all-weather operations for small and large vehicles
- Improve small vehicle gust response
- Implement CONOPS and configurations for package delivery
- Safely integrate autonomy and electric propulsion applications
- Improve public comfort/acceptance with vertical lift vehicles
- Improve internal vibration and noise reductions
- **Implement light-weight comfort cabin technology**

#### ModSim & Test Capability

- Improve system analysis tools for technology trades
- Develop efficient, unsteady, CFD algorithms and approaches
- Develop efficient experimental and flight test methods
- Validate multi-discipline MDAO
- Validate CFD approaches and implementation
- Implement high-fidelity analysis MDAO

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* Detailed technical content of the Research Themes will be determined by individual projects through applying periodic system analysis, concept evaluation, technology assessments, subject matter expert evaluation, and community interest. Specific Technical Challenges will be proposed to address the roadmap objectives.*
## Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift

Subset of Roadmap that is Applicable to Small Vehicles

<table>
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<tr>
<th>Community Outcomes</th>
<th>Thematic Focus</th>
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<th>2025</th>
<th>2035</th>
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### Application to Small Vehicles

<table>
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<th>Technology Infusion</th>
<th>2015</th>
<th>2025</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assume ~10-20 year time from TRL 4 to Entry into Service</td>
<td>Multiple uses of small-scale vehicles</td>
<td>MDAO conceptual design widely used</td>
<td>Low noise concepts in use</td>
</tr>
</tbody>
</table>

- Improve power transmission efficiency, traditional and electric
- Exploit integrated lift and propulsion systems for high-speed and low empty weight fraction

### Key Challenges

- **Clean and Efficient Propulsion**
  - Define noise source modeling for small and large vehicles
  - Realize low-noise operations for small and large vehicles
  - Evaluate alternative config and tech barriers, small and large scale vehicles
  - Increase payload and range for small vehicles
  - Develop high-speed, high-payload configurations

- **Efficient and Quiet Vehicles**
  - Ensure public safety during operations
  - Implement CONOPS and configurations
  - Mature CONOPS and configs for urban/cargo envir for package delivery
  - Safely integrate autonomy and electric propulsion applications
  - Improve public comfort / acceptance with vertical lift vehicles

- **Safety, Comfort, Accessibility**
  - Improve small vehicle gust response
  - Develop efficient, unsteady, CFD algorithms and approaches
  - Implement efficient experimental and flight test methods

- **Modeling, Simulation, and Test Capability**
  - Improve system analysis tools for technology trades
  - Develop efficient experimental and flight test methods
  - Validate multi-discipline MDAO

- *** Detailed technical content of the Research Themes will be determined by individual projects through applying periodic system analysis, concept evaluation, technology assessments, subject matter expert evaluation, and community interest. Specific Technical Challenges will be proposed to address the roadmap objectives

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*www.nasa.gov*
Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift

The Vertical Lift Roadmap is dependent on other Thrust roadmaps, other agencies, industry and operators to complete the work.

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<tbody>
<tr>
<td>Increased capability of vertical lift configurations that promote economic benefits and improve accessibility for new and current markets</td>
<td>Electric and hybrid-electric propulsion technology: New architecture designs; improved power to weight density—Link from Thrust 4</td>
<td>New vertical lift configurations and technologies introduced that enable new markets, increase mobility, improve accessibility, and reduce environmental impact</td>
<td>Vertical lift vehicles of all sizes used for widespread transportation and services, improved mobility and accessibility, with economic benefits and low environmental impact</td>
</tr>
<tr>
<td>UAS systems: need regulatory rules established for market for safe operations—FAA &amp; Operators</td>
<td>Public perception and acceptability will be manifested through local restrictions and ordinances—Operators, Industry, FAA</td>
<td>Autonomous operations capability assumed for many &gt;2025 missions; operational safety, including cyber threats, sense and avoid, and communications assumed to be linked from Thrust 1 and 6</td>
<td>Electric VTOL and autonomous systems for passenger transport need certification path—FAA and industry</td>
</tr>
</tbody>
</table>

| Improve turbomachinery efficiency and fuel burn | Adoption of new configurations and entry into new markets is dependent on business case.—Operators, Industry | Advance alternative propulsion integration in large systems |
| Improve propulsion technology efficiency and implementation | | |
| Define noise source modeling for small and large vehicles | Enable acoustics feedback in cockpit | Realize low-noise operations for small and large vehicles | Enable real-time low-noise route calculation and cockpit display |
| Develop multi-speed, multi-component adaptive lift systems | Evaluate alternative configurations and tech barriers, small and large scale vehicles | Enable zero unscheduled maintenance | Facilitate lower life cycle costs |
| Increase payload and range for small vehicles | Develop high-speed, high-payload configurations | Advance occupant safety during normal and emergency operations |
| Ensure public safety during operations | Demonstrate all-weather operations for small and large vehicles | Develop CONOPS and configurations for regional transport environment |
| Improve small vehicle gust response | Implement CONOPS and configurations for package delivery | Safely integrate autonomy and electric propulsion applications |
| Improve public comfort/acceptance with vertical lift vehicles | Implement light-weight comfort cabin technology |
| Improve internal vibration and noise reduction | | |
| Improve system analysis tools for technology trades | Develop efficient, unsteady, CFD algorithms and approaches | Develop efficient experimental and flight test methods |
| Validate multi-discipline MDAO | Validate CFD approaches and implementation | Implement high-fidelity analysis MDAO |

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External Risks/Opportunities

There are Risks that may interfere with Roadmap progress and Opportunities that provide potential for high gain.

• **Risks**
  – New concept of operations may be derailed by regulatory restrictions, local ordinance restrictions, and/or public resistance to configurations
  – Supporting infrastructure development does not occur in parallel with vehicle development
  – New certification requirements will be needed for new configurations, new propulsion systems and new flight controls/autonomy
  – Business case needs to close on new markets; industry and operators must decide if new configurations and markets make business sense
  – Atrophy of industrial base and consolidation may limit new configurations
  – Liability and litigation may take a toll on even enthusiastic proponents with deep pockets (similar to General Aviation manufacturer issue)

• **Opportunities**
  – High payoff for domestic and export market if new configurations and markets are enabled
  – Potential to revitalize the industrial base and broaden the base with new participants
  – Creation of entirely new, lightweight, agile ‘infrastructure’ to deliver goods and services
  – Chance to demonstrate expanded utility of VTOL aircraft to public