NASA Vertical Lift Strategic Direction

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Outline

- Context for briefing
- Background for Strategic Plan and Roadmaps
- Definitions and Expectations
- Research Theme Areas
- Roadmap Details
- Dependencies
- Risks
- Opportunities
- Feedback Mechanisms

Three Aviation Mega Drivers

NASA Aeronautics research strategy proactively addressing critical long-term needs

NASA has identified three Aviation Mega Drivers that will impact aviation community future needs

Traditional measures of global demand for mobility - economic development and urbanization - are growing rapidly and creating transportation and competitive opportunities and challenges

Large and growing energy and environmental issues create enormous affordability and sustainability challenges

Revolutions in the integration of automation, information, communication, energy, materials and other technologies enable opportunity for transformative aviation systems

NASA Aeronautics Six Strategic Thrusts

NASA is developing Six Thrusts to focus research in response to mega-drivers. Fixed Wing and Vertical Lift are considered separately.

T1 

Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

T2 

Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard

T3A FW
T3B VL 

Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance

T4 

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

T5 

Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system

T6 

Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

Thrust Relationships

The six Thrusts are not independent. Dependencies exist between operations, vehicles and cross-cutting technologies like autonomy. Supersonic transports, subsonic transports and vertical lift vehicles have different strengths and research needs.

CONVERGENT TECHNOLOGY OPPORTUNITIES

Low-Carbon Propulsion

Real-Time System-Wide Safety

Autonomy

What I Fly

Vehicles

MISSION CAPABILITY

Combination of:
Payload, Range, Speed,
Field-Length, Hover, Endurance

Environmentally Friendly, (e.g. Noise, Emissions)
Safety, Cost/Affordability

How I fly

Operations

365/24/7 OPERATIONS

Rules of the Road:
Safe, Efficient, Flexible, Resilient

Supersonic Transports
Strength: Speed 2X subsonic
Need: efficiency and environmental compatibility similar to subsonic transport

Subsonic Transports
Strength: Backbone of air transportation
Need: Environmental compatibility while reducing cost, increasing range, maintaining safety

Vertical Lift
Strength: Accessibility using Hover/ Field Length
Need: more range, speed, payload, safety, comfort and less noise

NASA Aeronautics Strategic Implementation Plan (SIP) – A Living Document

The SIP contains information on the Thrusts. The SIP documents NASA's view of the community vision and outcomes for a near-, mid- and far-term outlook.

Community Vision

Community Outcomes

Research Themes

Table 6. Outcomes and Research Themes for Strategic Thrust 3 - Vertical Lift

Strategic Thrust 3: Ultra-Efficient Commercial Vehicles – Vertical Lift			
	2015	2025	2035
Outcomes		Technology and Potentially New Configuration Concepts that Achieve N+2 and N+3 Levels of Efficiency and Environmental Performance	Technology and Configuration Concepts, Including Low-carbon Propulsion and Autonomy, that Stretch Beyond N+3 Levels of Efficiency and Environmental Performance
Research Themes	**Clean and Efficient Rotorcraft Propulsion** Demonstration and maturation of propulsion and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalties **Safe and Certifiable Vertical Takeoff and Landing (VTOL) Technologies** Technologies to extend the flight envelope and maximize performance and efficiency of VTOL aircraft **Advanced Component Noise Reduction** Improvements in lift generation, airframe, and other subsystem components to achieve noise reduction		

System-Level Metrics

Table 5. Targeted Improvements in Vertical Lift Vehicle System-level Metrics

Vertical Lift Targeted Performance (Preliminary)		
Technology Benefits	Technology Generations	
	N+2 TRL 4-6: 2020 First Application 2025-2030	N+3 TRL 4-6: 2025 First Application 2030-2035
Noise (Relative to ICAO 8.4.2/ FAA Stage 3 noise limit)	-10 dB Effective Perceived Noise Level (EPNL)	-14 dB Effective Perceived Noise Level (EPNL)
Fuel/Energy Consumption (Relative to 2005 best in class)	-50%	-60%

Link to SIP: http://www.aeronautics.nasa.gov/pdf/armd-strategic-implementation-plan.pdf

NASA Aeronautics Strategic Implementation Plan (SIP) – A Living Document

The SIP contains information about Research Themes and System-Level Metrics for each Thrust. The SIP will be updated as part of developing roadmaps for each of the Thrusts.

Community Vision

Community Outcomes

Research Themes

System-Level Metrics

Roadmaps for each of the six Thrusts in the SIP are being developed

- **Update the SIP Outcomes, Research Themes and Metrics**
- **Drafts are being vetted for comments internal and external to NASA**

NASA Aeronautics Strategic Implementation Plan (SIP) – Roadmaps

The Roadmaps will be updated with feedback received from internal and external sources.

Roadmaps are

- **A high-level look at what technology is needed to accomplish the community outcomes**
- **A community roadmap; NASA does not expect to accomplish all roadmap goals within NASA programs**
- **Guidance for NASA project and NASA Centers for innovation and planning**
- **Part of the process to determine the strategic contribution of NASA portfolio investments in Technical Challenges in each project**

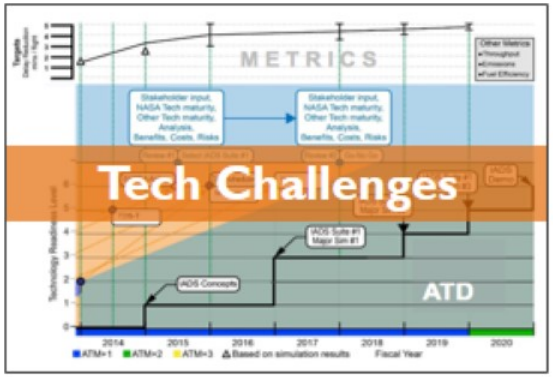
- **Roadmaps ARE NOT**
  - **A funded program or project plan**
  - **A commitment by NASA to accomplish all roadmap objectives**
  - **A determination of specific technology or investment**

ARMD Strategic Portfolio Model

The SIP and the Roadmaps are used to help guide NASA project planning. Feedback from partners and research results informs updates to the Thrusts and Roadmaps.

SIP Outcomes Drive Top-Down Planning

Roadmaps Provide Guidance for NASA Project / Center Innovation and Planning



Partnerships & Performance Create a Feedback Loop

6 Strategic Thrusts

- **Safe, Efficient Growth in Global Operations** — Enable full NextGen and develop technologies to substantially reduce aircraft safety risks
- **Transition to Low-Carbon Propulsion** — Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology
- **Innovation in Commercial Supersonic Aircraft** — Achieve a low-boom standard
- **Real-Time System-Wide Safety Assurance** — Develop an integrated prototype of a real-time safety monitoring and assurance system
- **Ultra-Efficient Commercial Vehicles** — Pioneer technologies for big leaps in efficiency and environmental performance
- **Assured Autonomy for Aviation Transformation** — Develop high impact aviation autonomy applications

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 appear to need improvement in cost, speed, payload, safety and noise

[1]http://www.businessinsider.com/uav-or-commercial-drone-market-forecast-2015-2
[1]The World Rotorcraft Market, Vertiflite, Vol. 61, No. 3, 2015

Envisioned Common Civil Configurations and Missions in 2030 & beyond

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.

	Very Light	Light	Medium	Heavy	UltraHeavy
Missions	•inspection •photography •filming •spraying •mapping •weather •surveillance •delivery	•police •training •traffic/ news •power line service •spraying •personal •cargo	•police •EMS •traffic/news •tourism •executive •charter •oil platforms •SAR •cargo	•oil platforms •disaster relief •cargo •logging •construction •firefighting •commuter (30 pax)	•commercial transport (90-120 pax) •disaster relief •civil reserve aircraft fleet •cargo
	autonomous capability				
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

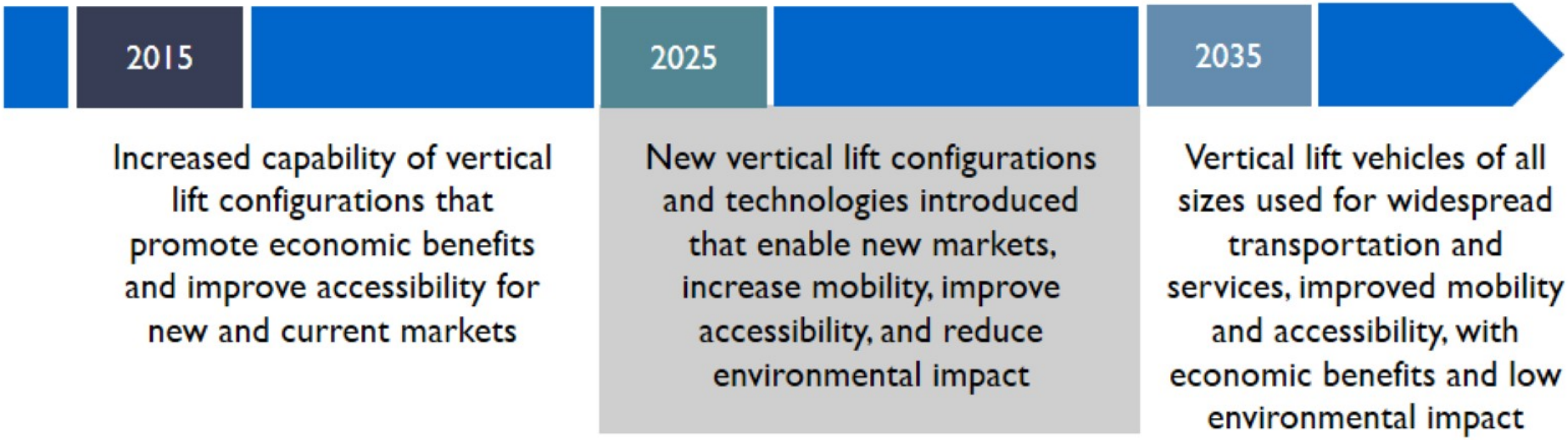
Ultra-Efficient Commercial Vehicles, Vertical Lift (draft)

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):



Benefits Expected

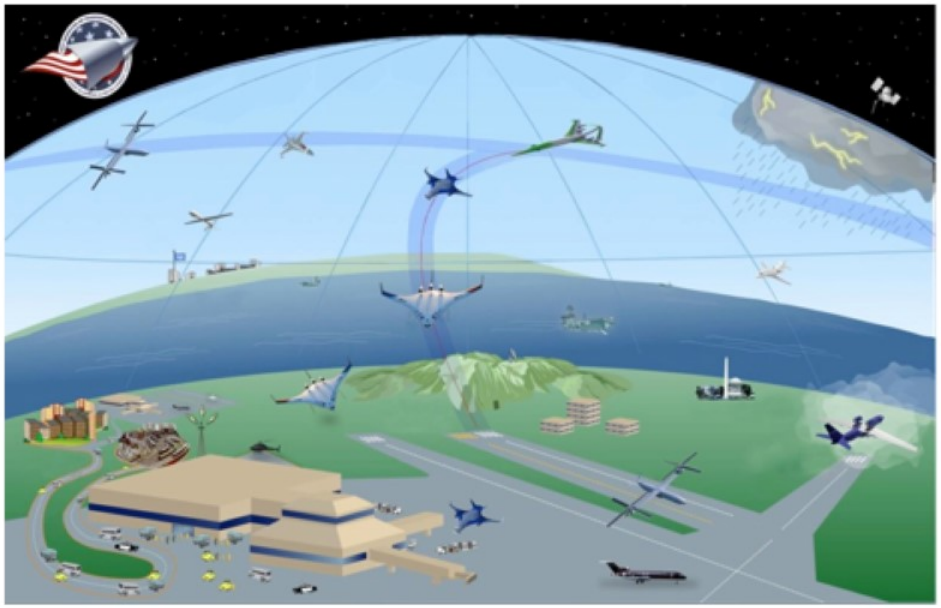
With new technology inserted into the fleet, there will be Benefits realized for each Outcome.

Strategic Thrust 3B: Ultra-Efficient Commercial Vehicles–Vertical Lift			
	2015	2025	2035
Outcomes	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 noise-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
- Aviation will approach overall carbon neutrality



A Vision for the Future of Civil Aviation

Our Roadmap Team proposes that Vertical Lift is required to enable the 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
- Aviation will approach overall carbon neutrality

- *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 Vertical Lift Research Strategy, 2015-2035+

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.

	2015	2025	2035
COMMUNITY OUTCOMES	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

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

NASA Vertical Lift Strategy, 2015-2025

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

NASA Vertical Lift Strategy, 2025-2035

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 CONOPS of unconventional configurations

NASA Vertical Lift Strategy, 2035-

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 advancements in configuration design, development and operation.

Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift

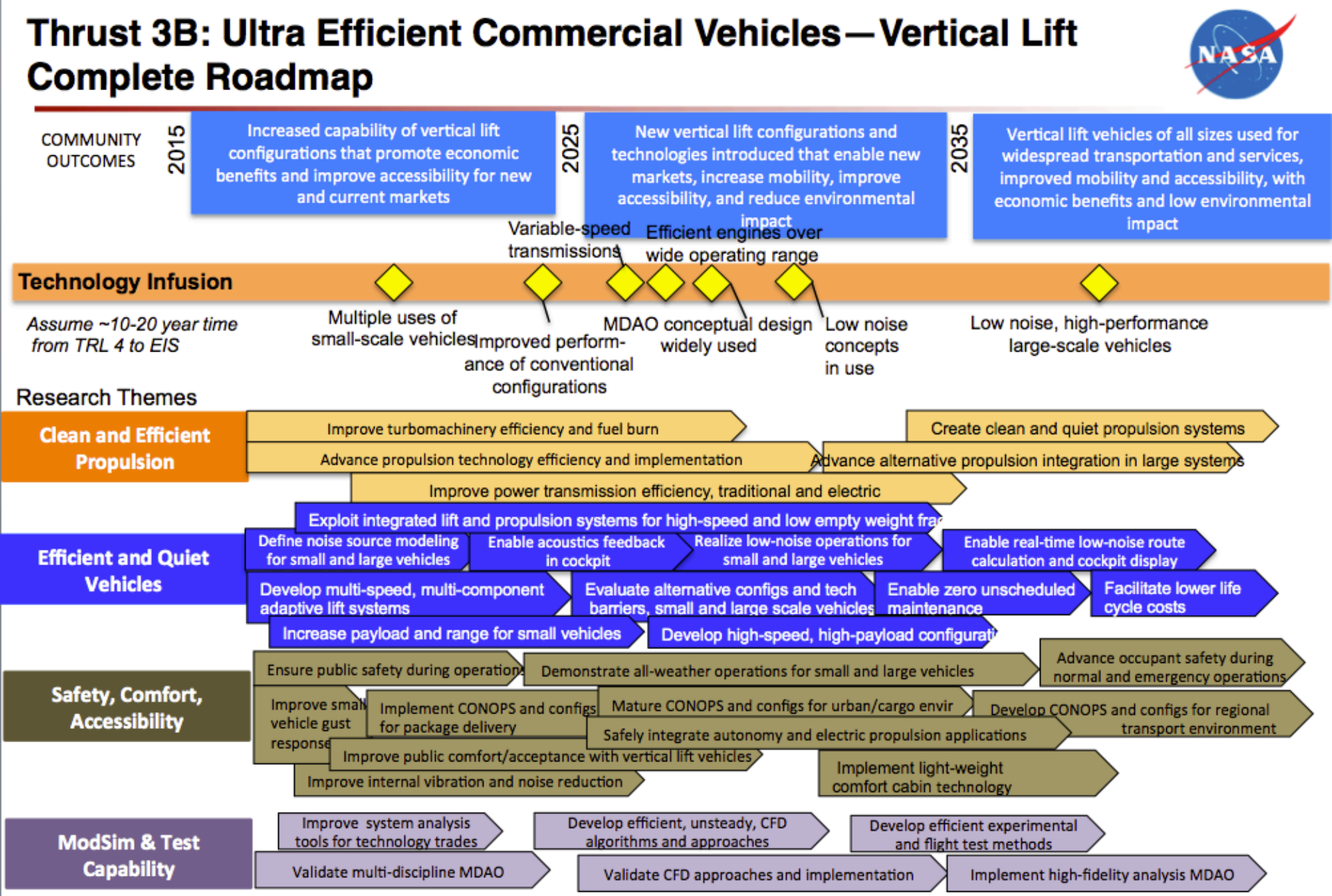
COMMUNITY OUTCOMES	2015	2025	2035
	Increased capability of vertical lift configurations that promote economic benefits and improve accessibility for new and current markets	New vertical lift configurations and technologies introduced that enable new markets, increase mobility, improve accessibility, 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

Research Themes

- **Clean and Efficient Propulsion**
- **Efficient and Quiet Vehicles**
- **Safety, Comfort, Accessibility**
- **ModSim & Test Capability**

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



* 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

COMMUNITY 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

Application to Small Vehicles

Technology Infusion

Assume ~10-20 year time from TRL 4 to EIS

- Multiple uses of small-scale vehicles
- MDAO conceptual design widely used
- Low noise concepts in use

Research Themes

Clean and Efficient Propulsion

- Improve power transmission efficiency, traditional and electric
- 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
- Realize low-noise operations for small and large vehicles
- Evaluate alternative configs and tech barriers, small and large scale vehicles
- Increase payload and range for small vehicles
- Develop high-speed, high-payload configurations

Safety, Comfort, Accessibility

- Ensure public safety during operation
- Demonstrate all-weather operations for small and large vehicles
- Improve small vehicle gust response
- Implement CONOPS and configs for package delivery
- Mature CONOPS and configs for urban/cargo envir
- Safely integrate autonomy and electric propulsion applications
- Change public comfort/acceptance with vertical lift vehicles

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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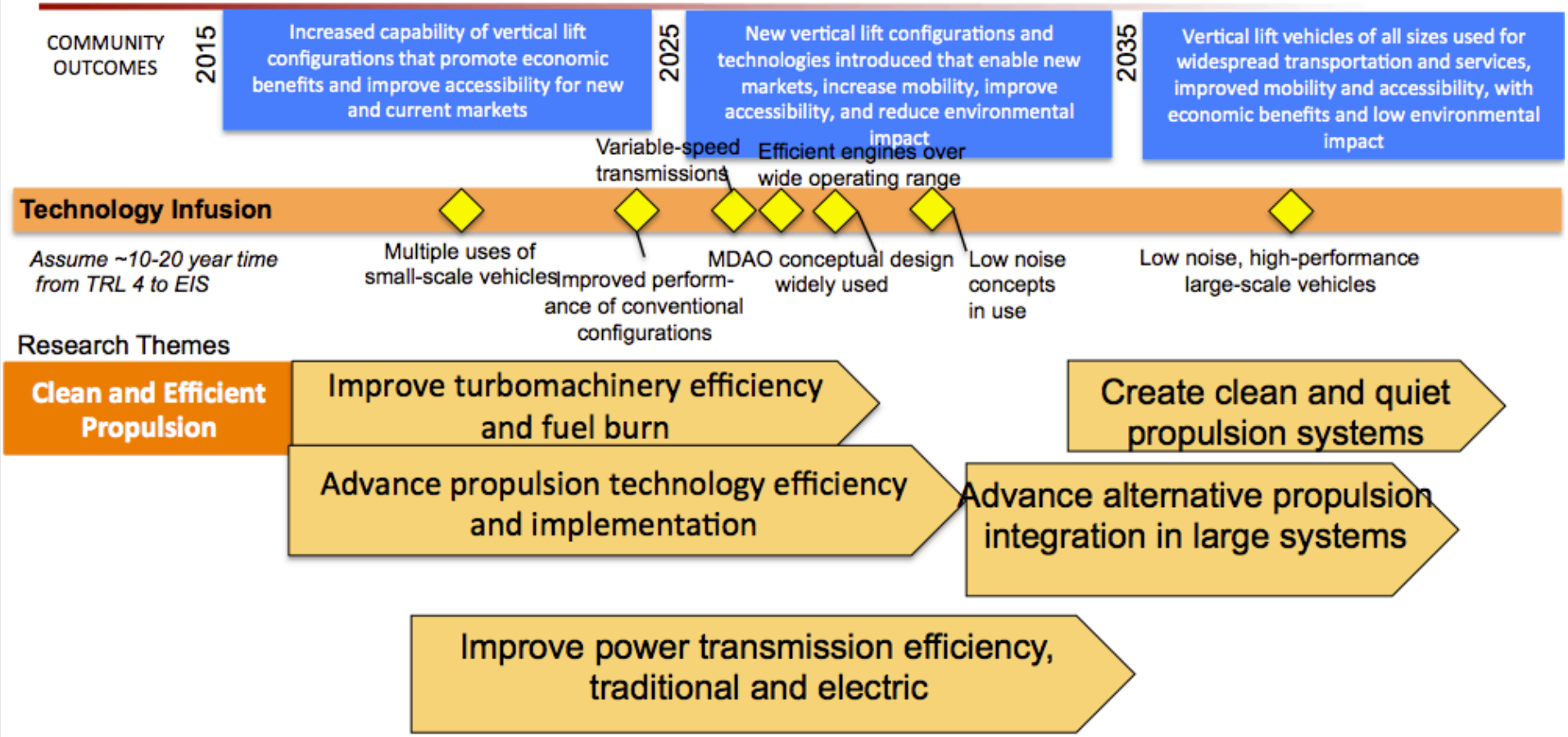
Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift Clean and Efficient Propulsion Research Theme



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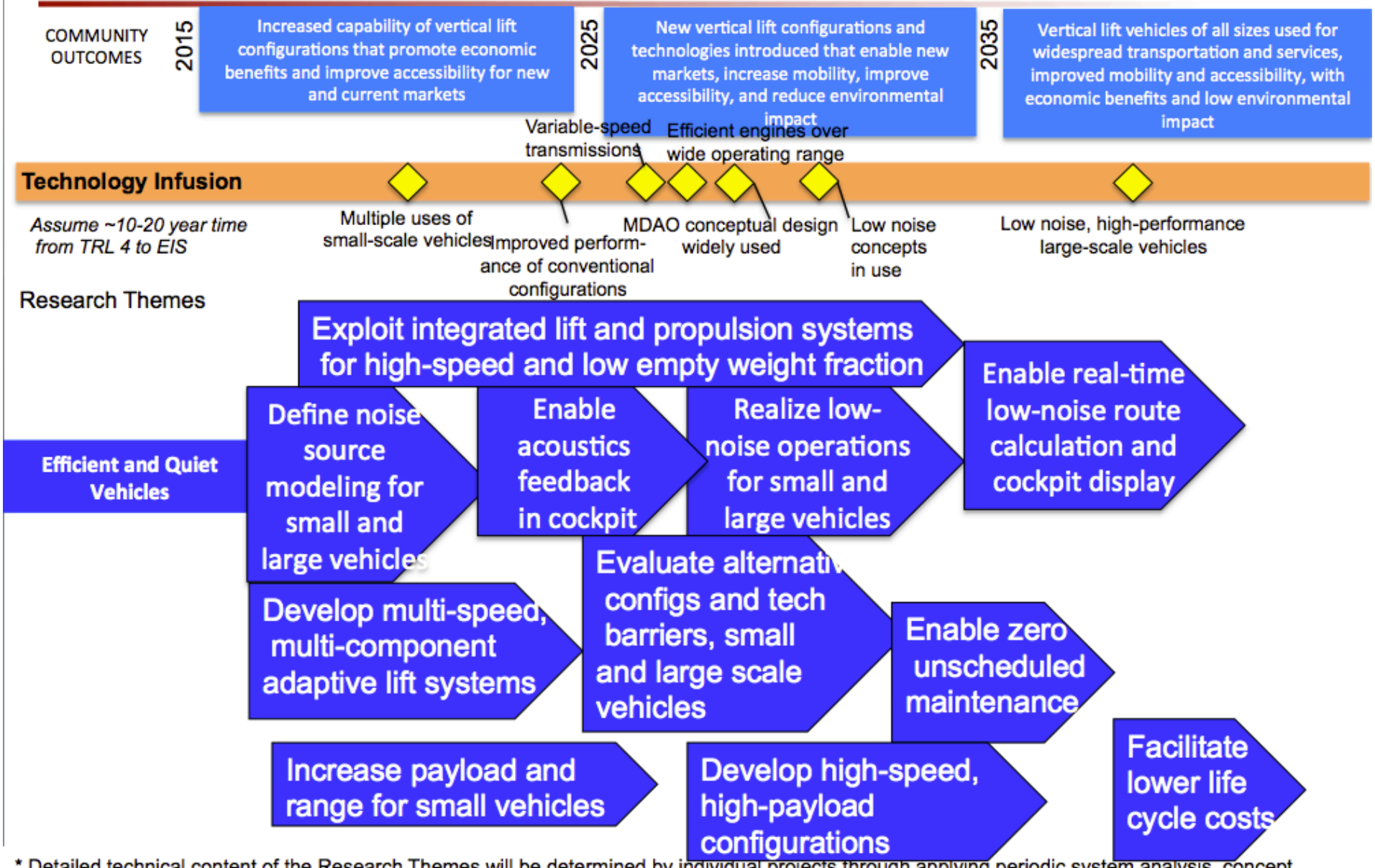
Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift Efficient and Quiet Vehicles Research Theme



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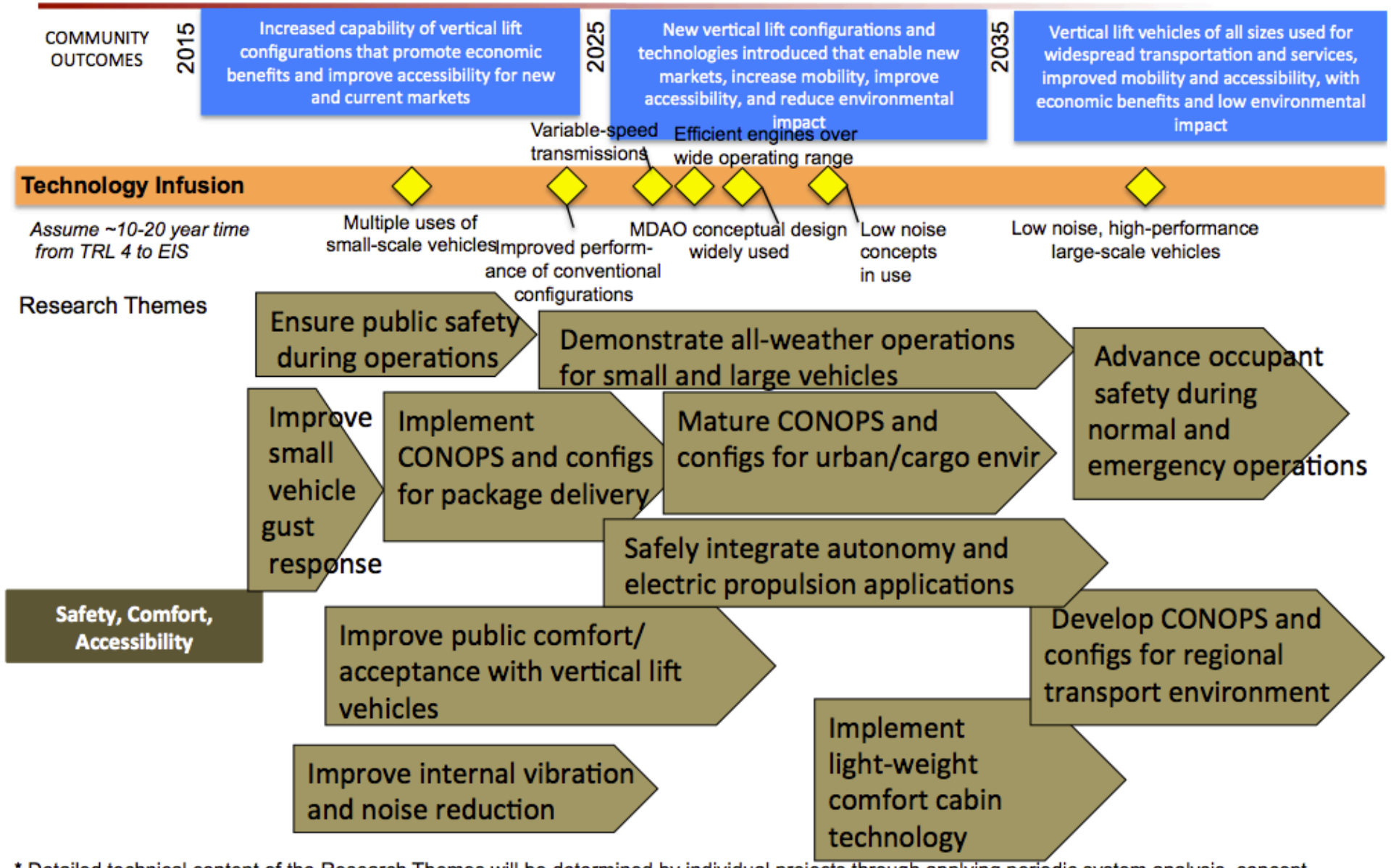
Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift Safety, Comfort, Accessibility Research Theme



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Thrust 3B: Ultra Efficient Commercial Vehicles—Vertical Lift ModSim & Test Capability Theme

COMMUNITY 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

Technology Infusion

Assume ~10-20 year time from TRL 4 to EIS

- Multiple uses of small-scale vehicles
- Variable-speed transmissions
- Improved performance of conventional configurations
- Efficient engines over wide operating range
- MDAO conceptual design widely used
- Low noise concepts in use
- Low noise, high-performance large-scale vehicles

Research Themes

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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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.

OUTCOMES

20 configurations that promote economic benefits and improve accessibility for new and current markets

20 technologies introduced that enable new markets, increase mobility, improve accessibility, and reduce environmental impa

20 vehicles of all sizes used for transportation and services, improved mobility and accessibility, with economic benefits and low environmental impact

Dependencies

Electric and hybrid-electric propulsion technology: New architecture designs; improved power to weight density--Link from Thrust 4

Autonomous operations capability assumed for many >2025 missions; operational safety, including cyber threats, sense and avoid, and communications assumed to be linked from Thrust 1 and 6

UAS systems: need regulatory rules established for market for safe operations—FAA and Operators

Public perception and acceptability will be manifested through local restrictions and ordinances—Operators, Industry, FAA

Electric VTOL and autonomous systems for passenger transport need certification path—FAA and Industry

Adoption of new configurations and entry into new markets is dependent on business case.—Operators, Industry

Research Themes

Clean and Efficient Propulsion

- Improve turbomachinery efficiency and fuel burn
- Advance propulsion technology efficiency and implementation
- Advance alternative propulsion integration in large systems
- Improve power transmission efficiency, traditional and electric
- 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
- 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 configs 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

Safety, Comfort, Accessibility

- Ensure public safety during operations
- Demonstrate all-weather operations for small and large vehicles
- Advance occupant safety during normal and emergency operations
- Improve small vehicle gust response
- Implement CONOPS and configs for package delivery
- Mature CONOPS and configs for urban/cargo envir
- Develop CONOPS and configs for regional transport environment
- Safely integrate autonomy and electric propulsion applications
- Change public comfort/acceptance with vertical lift vehicles
- Improve internal vibration and noise reduction
- 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
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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
  - 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

Give Us Feedback!

- **Download this presentation from the NARI website**
  - Identify gaps or areas that are missing from the roadmap (the roadmap is rolled up to a high level, so we are looking for general categories, not specific technology)
  - Identify additional high level risks or dependencies that are not captured
  - Identify areas that are currently on the roadmap that you believe do not require further investment and should be removed

- **Two ways to provide feedback:**
  1) Email to susan.a.gorton@nasa.gov with subject line FEEDBACK
  2) Give feedback in person to NASA representatives at two upcoming events
     - **Colin Theodore and Mark Moore will be attending the AUVSI Xponential May 2-5, 2016, New Orleans, LA**
     - **Susan Gorton, Paula Dempsey, Colin Theodore and Mark Moore will be attending the AHS International Forum May 17-19, 2016, West Palm Beach, FL**

Concluding Remarks

- NASA Aeronautics has developed a Strategic Implementation Plan (SIP) that contains Community Vision, Community Outcomes, Research Themes, and System Metrics for each of the six Thrusts
- Each Thrust has a roadmap planning exercise underway. Thrust 3 for Ultra Efficient Commercial Vehicles was split into Fixed Wing (3A) and Vertical Lift (3B)
- The NASA Vertical Lift Roadmap team is seeking your comments and input on the draft roadmaps
- Feedback may be through email or in-person communications at upcoming conferences and events

Thank You for Participating!