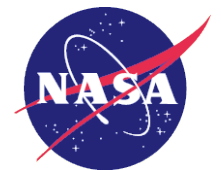


2015 SECOND ANNUAL TRANSFORMATIVE VERTICAL FLIGHT CONCEPTS WORKSHOP AND ROADMAP OVERVIEW

SAE 2016 AEROSPACE SYSTEMS AND TECHNOLOGY AND
AIAA 2016 INTERNATIONAL POWERED LIFT CONFERENCE

SEPTEMBER 29-30, 2016

Michael Dudley, NASA



Second Annual Transformative Vertical Flight (TVF) Workshop Overview



Roadmap Development Process

- Primary elements of an integrated TVF Roadmap
- Transformational Flight Ecosystem

Second Annual TVF Workshop Overview

- Objectives
- Format
- Technical presentations summary
- Breakout Sessions summary
- Outcome

TVF III Breakout Session guidance

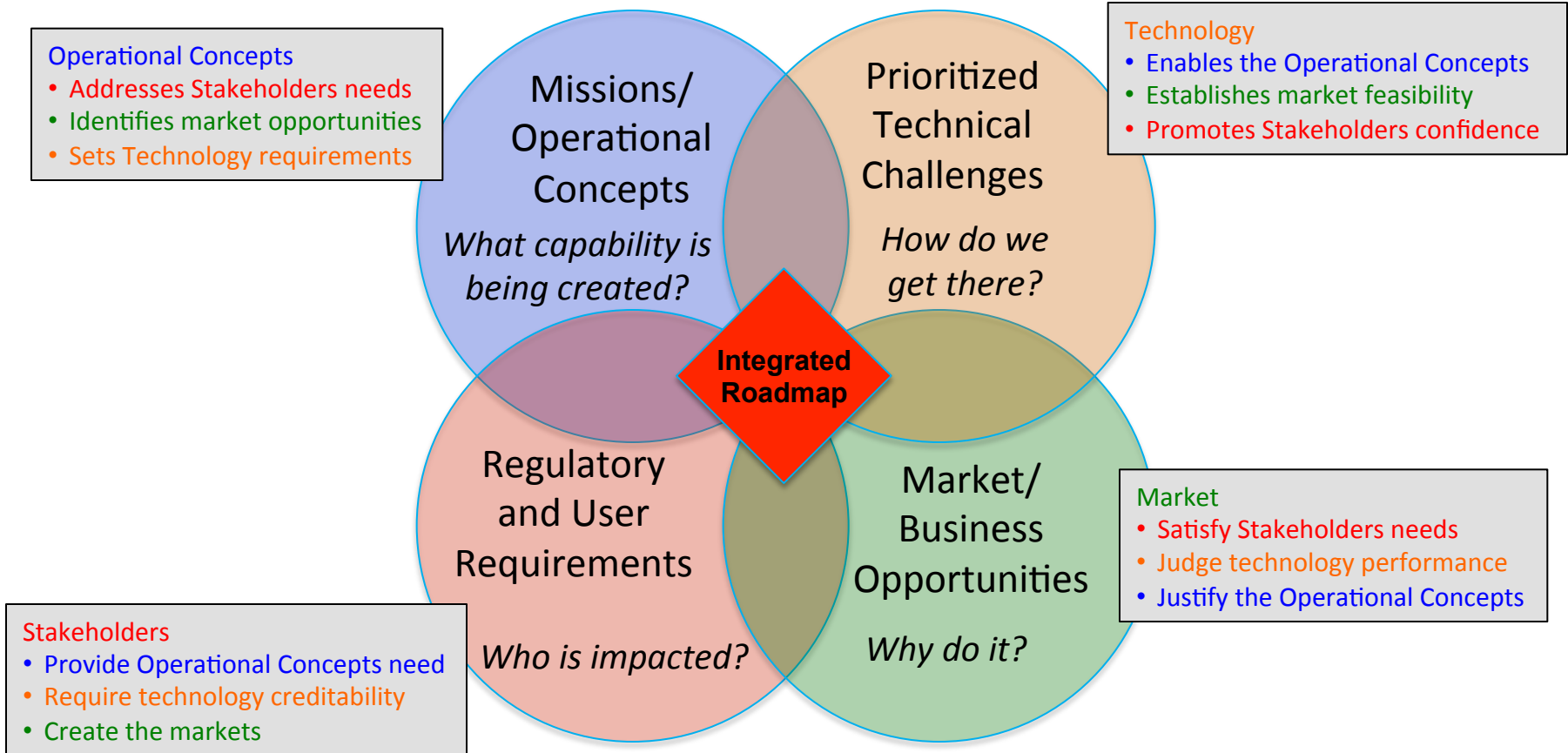
- Process
- Desired Outcomes

Formation of TVF Roadmap Working Groups

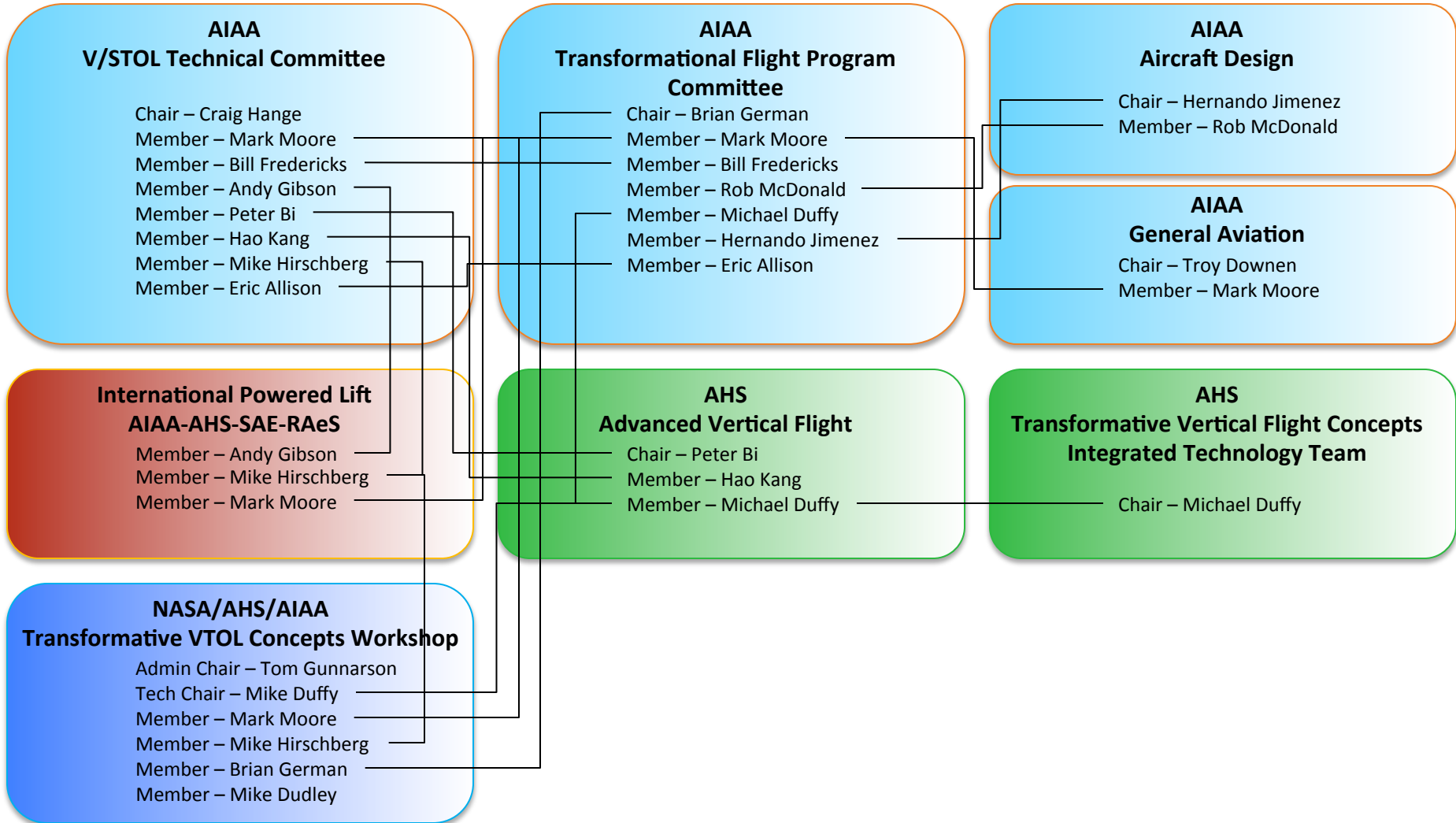


- Identify and agree on the need for a “product” to serve as the roadmap focus and establish participant commitment
 - **Product: A creditable and coordinated advocacy to pursue the development and implementation of “Transformative Vertical Flight” transportation systems**
- Establish primary roadmap elements (swim lanes) to provide an overall framework consistent with the desired level of detail
 - **Operational Concepts**
 - **Technology**
 - **Regulatory and user requirements**
 - **Market opportunities**
- Employ scenario based planning to identify critical barriers
 - **Transform barriers into activity drivers with requirement targets**
 - **From available solution alternatives select performance targets and completion timelines**
 - **Identify key decision points for down-select of alternatives that should be pursued**
- Document and mature the roadmap
 - **Decomposition of the major elements – identify and describe:**
 - + Critical Factors
 - + Unaddressed areas – gaps
 - + Implementation strategies and recommendations

What – How – Who – Why



Transformational Flight Ecosystem





Workshop held at NASA Ames, August of 2015

- Objectives
- Format
- Technical presentations summary
- Breakout Sessions summary
- Outcome



Workshop focused on four desired action-oriented outcomes

- Establish and document common stakeholder needs and potential collaborations including concepts and emerging technologies
- Assemble a community that can collaborate on new conceptual designs/tools for novel configurations with greater multi-disciplinary coupling (e.g. aero-propulsive-control)
- Foster a community to help develop and deploy regulatory guidelines
- Develop and disseminate information to ensure key U.S. Government agencies understand the potential benefits, and industry interest in establishing, new transformative and Vertiport capable flight markets

Primary objectives:

- Inform participants about developments in transformative flight design configurations, operational concepts, technology, market opportunities, and regulatory environment
- Engage the group in developing inputs for a preliminary roadmap that will aid in the advocacy and pursuit of emerging technologies and approaches



Second Workshop co-sponsored by –



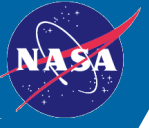
Demographics

- 130 registered attendees plus 15 student intern observers (facility limit)

Format

- Three technical sessions plus four invited talks
 - **Advanced Vertiport Capable Flight Concepts (5 presentations)**
 - **Business and Market Opportunities (3 presentations)**
 - **Electric Propulsion and Electric Energy Storage Technologies (6 presentations)**
- Three simultaneous rotating Breakout sessions (25 min. each) to collect participants' opinions-perspectives-experience to inform roadmap development
 - **Missions/Operational Concepts**
 - **Technical Challenges**
 - **Regulatory Frameworks**
- Breakout session activity summary provided by leads during general panel discussion

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Advanced Vertiport Capable Flight Concepts

Business and Market Opportunities

Electric Propulsion and Electric Energy Storage Technologies

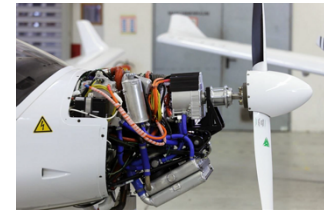
Invited Technical Presentations

Simulation of Electric Aircraft Components

- 261 kW direct drive electric motor with a power density of 5 kW/kg at 95% efficiency
 - Korbinian Petermaier, Siemens Technology

Analysis and Full Scale Testing of Joby S4 Propulsion System

- Electric four-seat VTOL six tilt-rotor aircraft that only uses two in cruise
 - Alex Stoll, Joby Aviation



Flight Test of NASA GL-10 Distributed Electric Propulsion UAV

- Experimental validation of DEP and closed loop control laws for an unstable aircraft
 - Bill Fredericks, NASA Langley

Full-Scale Test of LEAPTech Wing

- Investigation of aerodynamic and acoustic advantages of DEP on the wing leading edge
 - Andy Gibson, ES Aero

LIFT! – Modular, Electric Vertical Lift

- Electric ground-powered tethered propulsion for cooperative large multi-rotor VTOL aircraft
 - Michael Duffy, The Boeing Company

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Existing VTOL Operators Needs Perspective

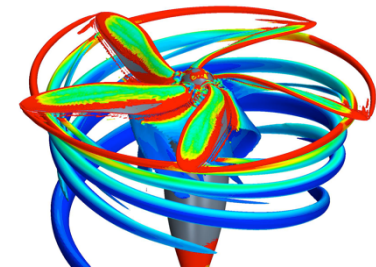
- Successful regional VTOL transport enterprises using available technology
 - Mark Moore, NASA Langley

Market Drivers for Civil Vertical Lift

- Explores urban growth driven paradigm shift from hub-n-spoke to point-2-point
 - Rich Ouellette, The Boeing Company

Silicon Valley Early Adopter CONOPs and Market Study

- Market feasibility study for electric VTOL distributed regional transportation system
 - Kevin Antcliff, NASA Langley



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Advanced High Energy Density Lithium Batteries

- A 350 Wh/kg lithium battery for UAVs utilizing silicon anodes and high capacity cathodes
 - Michael Sinkula, Envia Systems

Solid State Batteries

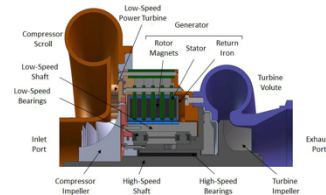
- Solid-state liquid electrolyte lithium high energy/power density battery development
 - Josh Buettner-Garrett, Solid Power

Launchpoint 1 kW and 40 kW Hybrid-Electric Range Extender

- Reciprocating engine gen-sets for long endurance reliable electric flight
 - Mike Ricci, LaunchPoint Technologies

Metis 30 kW Turbine-Alternator Hybrid-Electric Range Extender

- Lightweight compact gas turbine/permanent-magnet gen-sets scalable to >100s kW
 - Rory Keogh, Metis Design



SwissTurbine 7 & 75 kW Hybrid-Elect Turbine-Alt Range Extender

- Small-scale engines for UAV & lightweight aircraft with SFC of 0.4 kg/kWh and P/Wt = 3
 - Tim Moser, SwissTurbin

Heavy-Fuel SOFC Fuel Cell

- Demonstrator platform using solid oxide fuel cells & mature elect components
 - Nick Borer, NASA Langley

<http://nari.arc.nasa.gov/tvl>

Advanced Batteries Progress

- Overview of ARPA-E electric propulsion research goals and funding focus areas
 - Aron Newman, Advanced Research Projects Agency – Energy, ARPA-E

Advances in Distributed Propulsor Acoustic Modeling

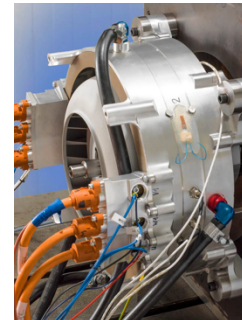
- Noise simulations neglecting unsteadiness are not suitable human annoyance studies
 - Steve Rizzi, NASA Langley

Road Mapping Example for On-Demand Mobility

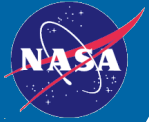
- Technical strategy roadmap for improved safety and on demand use of small aircraft
 - Ken Goodrich, NASA Langley

GoFlyUp HeroX \$2 Million Personal VTOL Prize

- Motivation behind and prize challenge rules for a revolutionary personal VTOL aircraft
 - Gwen Lighter, Lighter Group



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Mission/Operational Concepts

Technology

Regulatory Roadmap



Transformative VTOL business case must consider trends, market needs, operations, user, and market constraints

- Question breakout looked to answer included:
 - **What is different that justifies investment in transformative VTOL products?**
 - **How can we better understand whether technology is leading to real market opportunities?**
 - **Are emerging technologies aligning with user and market needs?**
 - **How can we decompose market opportunity space to predict evolution and strategies?**
- Perspectives reported
 - **Technology Trends** – Potential for 200 mph \$1.5/mi Civil VTOL Transport
 - **Market Needs** – On demand air mobility for congested urban and regional transportation
 - **Operations** – Safe low noise/emissions operations in close proximity to communities
 - **User Acceptance** – Comfort, affordability, reliability and safety
 - **Market Constraints** – Existing FAA regulations, helipad infrastructure, community noise, zoning
- Convergence of Perspectives
 - **Essential that stakeholder appreciate and reconcile the convergence of all perspectives – market, operations, regulatory, technical – while pursuing their objectives**
- Business Case Feasibility
 - **Desirable to leverage military needs for certification of initial products, but mission alignment is an issue – difficult to reach consensus in allotted time**

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Enabling the transformative VTOL markets, operations, and vehicles will require a broad range of technological advances

- Session brainstormed needed technologies and related engineering knowledge
 - Fundamental science and modeling tools
 - + Modeling and designing high-power aircraft electrical systems
 - + Interactional aerodynamics of distributed propeller/rotor propulsion and acoustics
 - + Science of “Hybridization” and “Distribution” optimizations approaches
 - Standards and design rules
 - + Power transfer/distribution
 - + Fault-tolerant data protocol
 - + Design handbook data, e.g., reference configuration wind tunnel databases and empirical rules
 - Vehicle technologies
 - + Energy storage technologies to advance the specific energy of battery and fuel cell systems
 - + Power transmission and conversion
 - + Adaptive thrust and acoustics control
 - Operations and controls technologies
 - + Fully automated IFR and envelope protection
 - + Digital communications, EMI, lightning, and cyber protections
 - Wish list technologies

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Technical innovation leading to new transportation options can necessitate amending older regulations that don't cover the scope or impact of new methods, materials, and operations

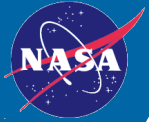
- Session grouped 22 relevant topics in 6 general areas of interest:
 - **Aircraft**
 - + Level of Safety, ASTM Standards, Maintenance, Telemetry/Black Box, Unique Configurations
 - **Pilot**
 - + Certification, Allocation of Decision Authority
 - **Operations**
 - + Communications/Spectrum Management, Zoning/Land Use, Infrastructure
 - **Environmental**
 - + Noise/Quiet, Privacy, Emissions
 - **Regulatory System/Government**
 - + Local vs. National vs. International, Trusted Autonomy: Procedural vs. Automation, Taxes , User Fees, Funding Models, Vehicle Classification, CFR Part 103 and LSA Regulatory Systems, Regulation Adoption Process, Outreach to FAA, Work with Other Groups – UAS, GA, ODM, Automotive
 - **Airspace**
 - + Traffic management

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Outcome

- A community of interest was assembled that is strengthening cross-discipline technical professional networks and collaborations
- Participants were informed of developments in transformative flight design configurations, operational concepts, technology, market opportunities, and regulatory environments
- Attendees were engaged in developing inputs for a notional roadmap that will aid in the advocacy and pursuit of emerging technologies and approaches
 - **Interactive breakout sessions augmented the identification and documentation of stakeholder needs**
 - **Data to develop a notional TVF roadmap was collected**
 - **Increased community awareness of the need to develop and deploy regulatory guidelines**
- The workshop proceedings were documented to disseminate information to potential sponsoring organizations of the potential benefits, and industry interest, in establishing new transformative and Vertiport capable flight markets



Process

Notional TVF Roadmap Framework

Desired Outcomes

Formation of TVF Roadmap Working Groups



Participants contribute to TVF roadmap content development

- Four 30-minute Breakout Sessions
 - **One for each roadmap primary element (swim lanes)**
 - + Missions/Operational Concepts (Moore/Vascik)
 - + Prioritized Technical Challenges (German/Goodrich)
 - + Regulatory Roadmap (Gunnarson)
 - + Market/Business Opportunities (Duffy, Fredericks)
 - **Two sessions will run concurrently with participants switching after 30-minutes**
 - + Group 1 (A – J), Group 2 (K – Z)
 - **All attendees will have an opportunity to participate in all sessions**
- Participants will assess and suggest roadmap modification in realtime
 - **Notional roadmap posted on wall with adjustable activities (sticky)**
 - + Opinions/perspective expressed by adding-modifying-removing-repositioning activities
 - + Stimulate dialog
 - + Seek consensus
 - + Identify/document disagreements

Notional TVF Roadmap Framework



Missions/Operational Concepts: *What capability is created?*

Address Stakeholder Needs – Set Technology Requirements
– Identifies Market Opportunities

Personal On Demand (OD) VTOL TVF CONOPS

Manned VTOL urban air-taxi CONOPS

Autonomous urban air-taxi CONOPS

Regional OD air-transport networks CONOPS

Prioritized Technical Challenges: *How do we get there?*

Enables the Operational Concepts- Establishes Market Feasibility - Promotes Stakeholder Confidence

Light aircraft energy & propulsion systems

Operational single passenger OD-VTOL

Light transport energy & propulsion systems

Operational multi-passenger OD-VTOL

VTOL regional transport

Operational Hybrid elect. DEP sys.

Demonstrate autonomous air-taxi

Regulatory and User Requirements: *Who is impacted?*

Provide a need for a Operational Concepts – Create the Markets - Require Technology Credibility

Municipal and personal urban air customers needs documented

Personal urban OD-VTOL ops regulations

Autonomous VTOL ops regulations

Secure muni- and business operator commitments

FAR commercial ops updated

Market/Business Opportunities: *Why do it?*

Satisfy Stakeholder Needs - Judge Technology Performance - Justify the Operational Concepts

Metro air-taxi business plan launched

Mega region air-commuter business plan launched

Single passenger OD-VTOL for sale

Metro air-taxi launched

Mega region air-commuter transportation system

Single passenger OD-E-VTOL for sale

Multi-passenger OD-VTOL for sale

What – How – Who – Why

2016	2017	2018	2019	2020	2021	2022	2023	2024
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Version 1.2



Produce a consensus roadmap that is creditable to TVF stakeholders, sponsors, regulators, and investors

- This will be an important advocacy tool to obtain and maintain the support needed to achieve transformative air transportation systems
- This workshop will not produce the final detailed roadmap, but it:
 - **Will be a significant improvement over the current state**
 - **Sets the stage for continued roadmap development and TVF advocacy**

Next steps include

- Formation of focused working groups
 - **To maintain progress and TVF community connectivity**
- Organizing the next annual TVF Workshop
 - **Will evaluate the product of the WG efforts and provide guidance**



Identify the focus areas needed to mature the roadmap

- Recruit Leaders and members
- Establish group charters and regular meeting schedules (monthly / quarterly?)
 - **Virtual meetings will likely be the norm to control costs**
- The working groups are expected to:
 - **Maintain progress by filling gaps and providing finer granularity**
 - **Identify previously unrecognized issues/challenges and propose solutions**
 - **Collaborate across WGs to develop an integrated roadmap that will be available for the next annual face-to-face TVF Workshop**

Actions – please consider:

- Volunteering for, or nominating, working group leaders
- Becoming a member of a working group