Working Group Update
MANUFACTURING, INTEGRATED STRUCTURES, & COMMUNITY IMPACT

Transformative Vertical Flight Workshop,
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Michael Patterson, PhD

Aerospace Engineer

NASA Langley Research Center

michael.d.patterson@nasa.gov

Where did Manufacturing, Integrated Structures, & Community Impact come from?

- Electric propulsion and simplified vehicle ops. were identified early as “big hitter” technologies, but what else is required?
- In Kansas City (Oct 2015) held “Other” breakout session
  - The community identified many different areas of interest including airspace, acoustics, safety, public perception, manufacturing, materials, infrastructure, and more
  - Airspace became standalone group
  - Some areas/investments were integrated into the other working groups
  - (Most of) the remaining investments fit into three categories:
    - Manufacturing
    - Integrated Structures
    - Community Impact

Scope

- Manufacturing
  - Reduced costs for both “low” and “high” volume production runs
  - New manufacturing techniques (e.g., additive manufacturing)
- Integrated Structures
  - Improved modeling and analysis capabilities
    - Reduce design cycle / certification time and cost
    - Reduce maintenance costs / increase aircraft availability
  - Advanced structures/materials
    - Can the structure do more than carry loads? (e.g., store energy, self-heal, morph, reduce noise)
    - Can we reduce structural weight?
- Community Impact
  - Increase public acceptance
  - Ensure safety for both occupants and bystanders on ground
  - Acceptable acoustic environment
  - Encourage adoption / increase utilization

ODM Barriers & Figures of Merit

Ease of Certification Metric Time/Cost Required	Affordability Metric Total Operating Cost/Pax Mile	Safety Metric Fatal Accidents per Vehicle Mile	Ease of Use Metric Required Operator Training Time & Cost	Door to Door Trip Speed Metric mph
Average Trip Delay Metric Time	Community Noise Metric Perceived Annoyance @ standoff	Ride Quality Metric Passenger Comfort Index	Efficiency Metric Energy/Pax Mile	Lifecycle Emissions Metric Total Emissions /Pax Mile

Product of Kansas City Workshop, Oct. 2015

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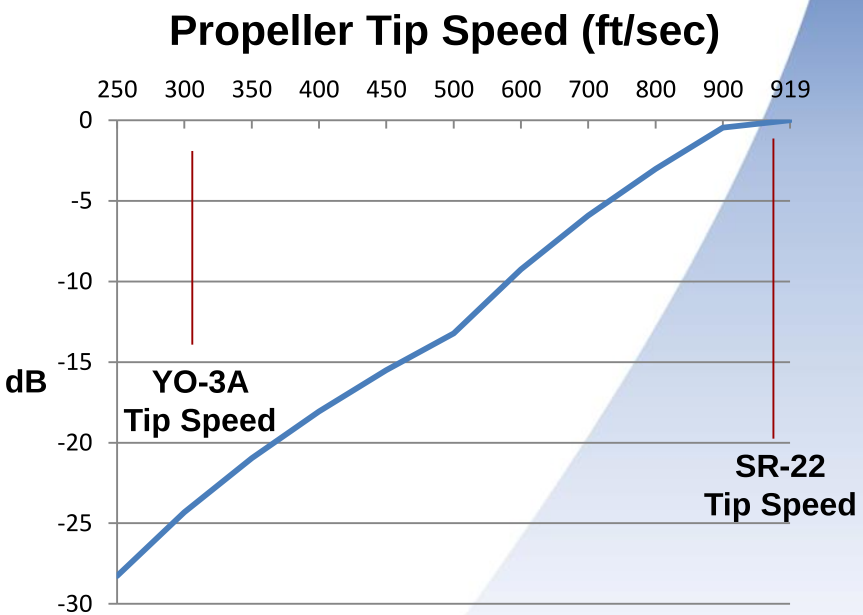
Primary (dark green) **Secondary** (light blue)

COMMUNITY IMPACT: ACOUSTICS

Acoustics Overview

- Noise control technologies
- Metrics: i.e., how to measure annoyance?
- Modeling tools
- Design for low noise
  - Example: YO-3A
    - “Silent” at altitudes of 800-1500 ft
    - Flew in Vietnam and never took a round
    - Used by NASA to measure rotorcraft noise in flight
    - Low prop tip speed
  - New options with DEP



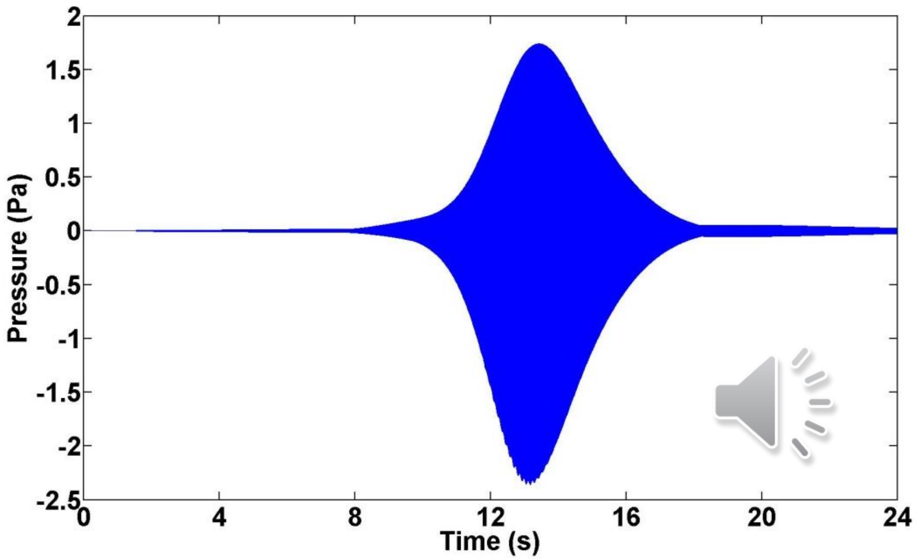
Effect of Propeller Tip Speed on Noise Level
(a 5th order function)

Baseline General Aviation Prop

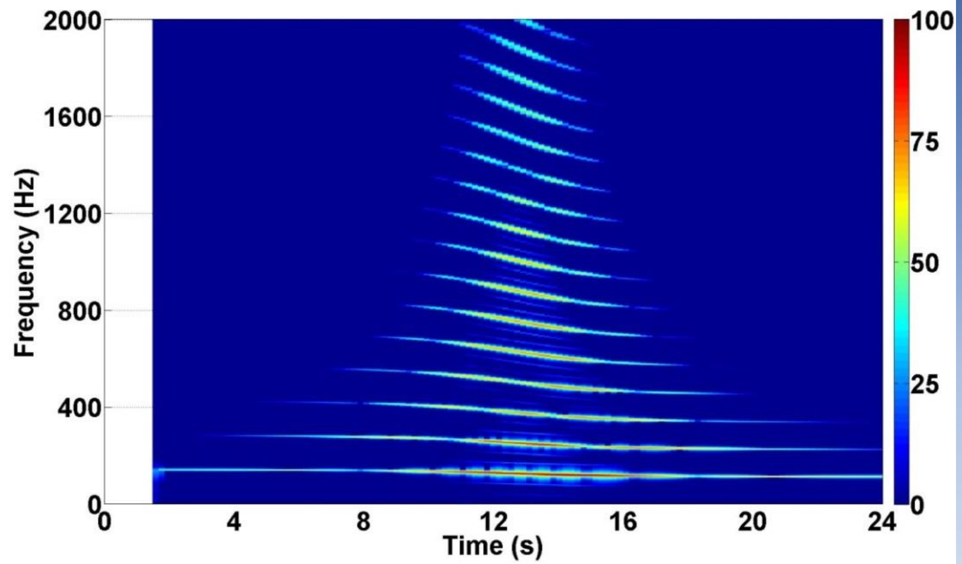
Average Source Power = 101.8 dB

Peak Level at Centerline Receiver = 101.4 dB

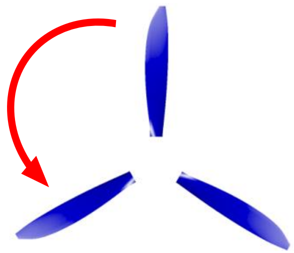
Time History



Spectrogram



135 Hz



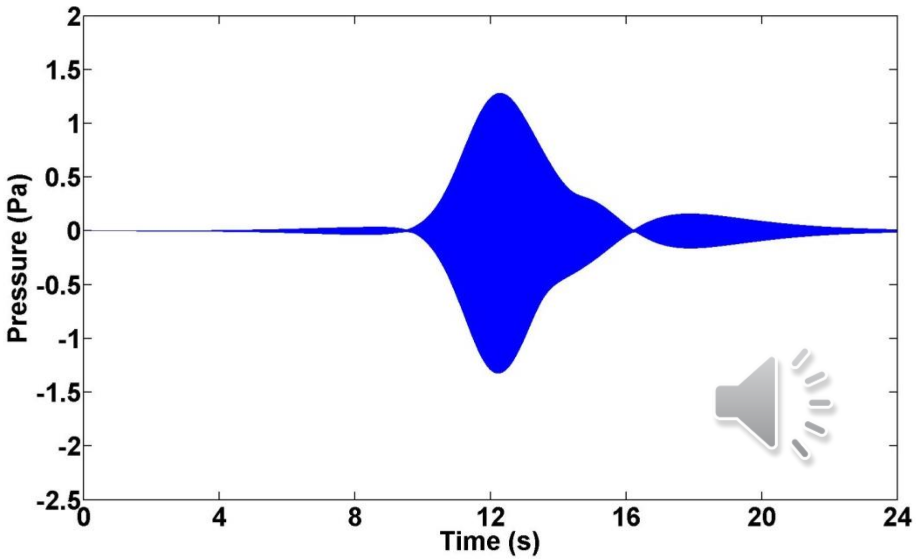
Maximum pressure on centerline

From Palumbo, D.L., Nark, D.M., Burley, C.L., and Rizzi, S.A., "Aural Effects of Distributed Propulsion," 14th AIAA Aviation Technology, Integration, and Operations Conference, (Oral Presentation), Atlanta, GA, 16-20 June 2014. http://stabserv.larc.nasa.gov/flyover/

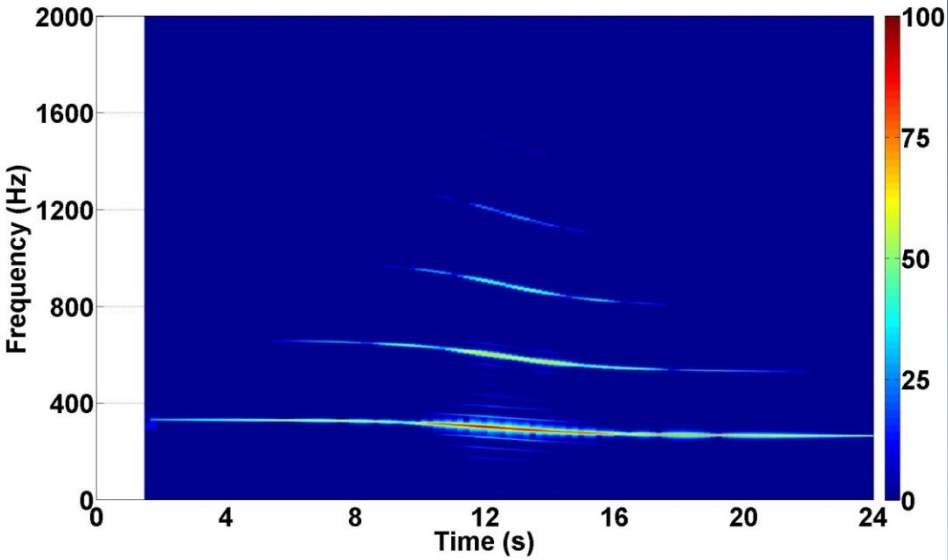
18 LE Props all in phrase

Average Source Power = 89.0 dB (-12.8 dB re: GA Prop)
Peak Level at Centerline Receiver = 96.4 dB (-5 dB re: GA Prop)

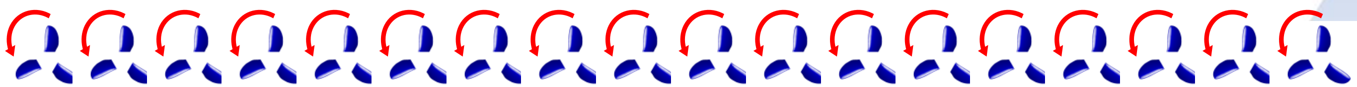
Time History



Spectrogram



All 293.3 Hz and in phase



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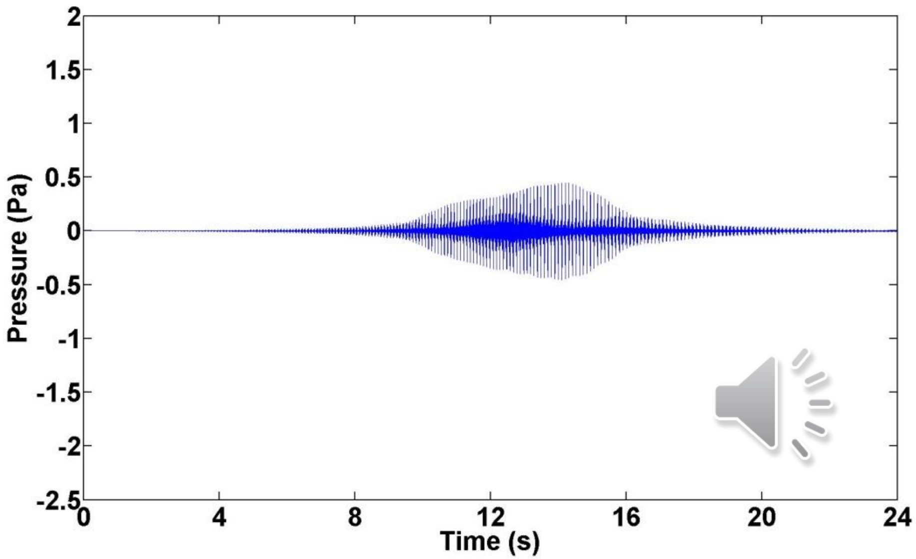
18 LE Props – Spread Spectrum

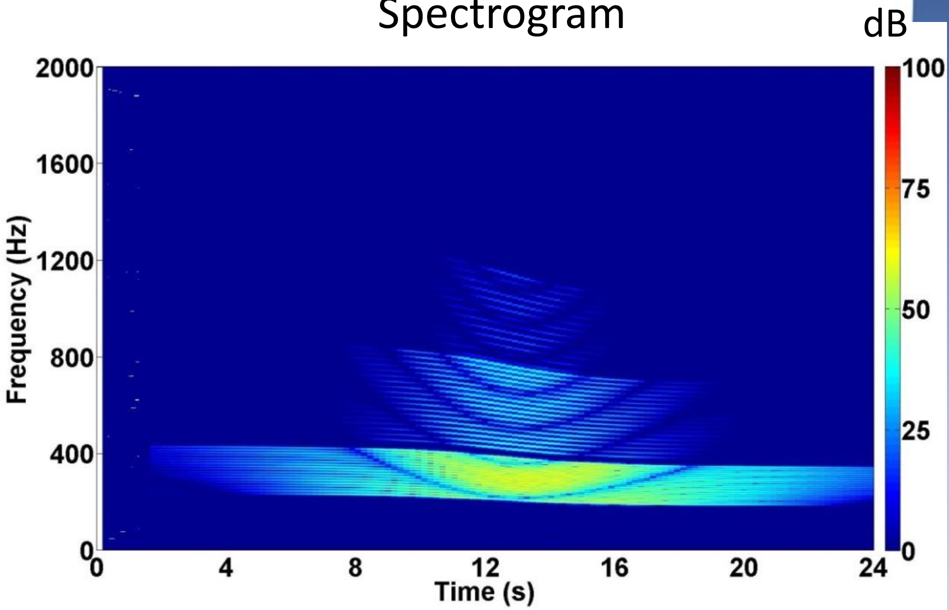
Average Source Power = 89.0 dB (-12.8 dB re: GA Prop)

Peak Level at Centerline Receiver = 90.1 dB (-11.3 dB re: GA Prop)

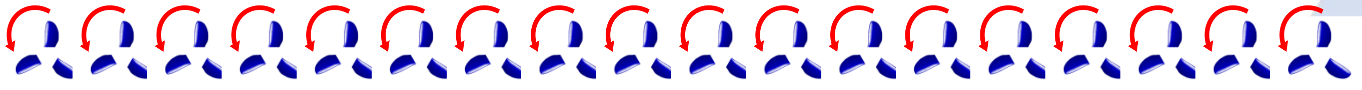
Time History



Spectrogram



Δf = 10 Hz



Maximum pressure not on centerline

From Palumbo, D.L., Nark, D.M., Burley, C.L., and Rizzi, S.A., "Aural Effects of Distributed Propulsion," 14th AIAA Aviation Technology, Integration, and Operations Conference, (Oral Presentation), Atlanta, GA, 16-20 June 2014. http://stabserv.larc.nasa.gov/flyover/

18 LE Props – Spread Spectrum

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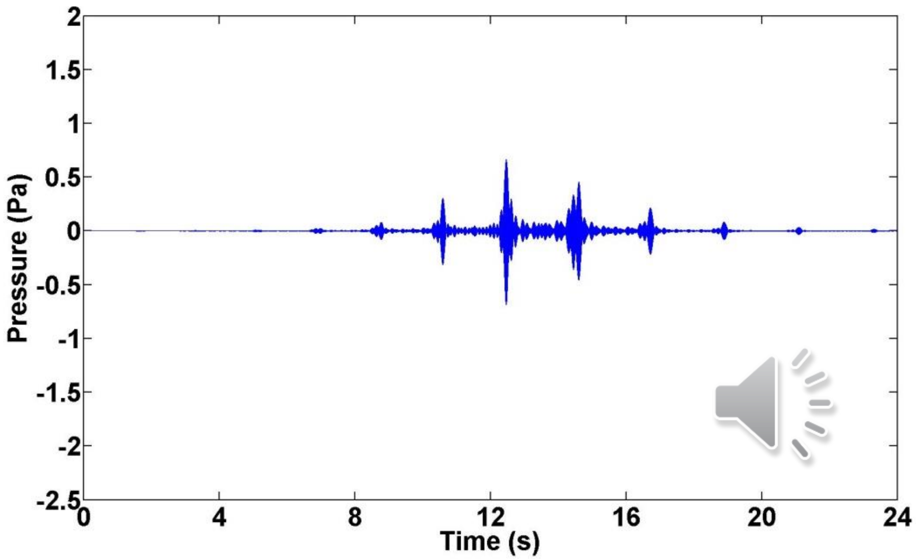
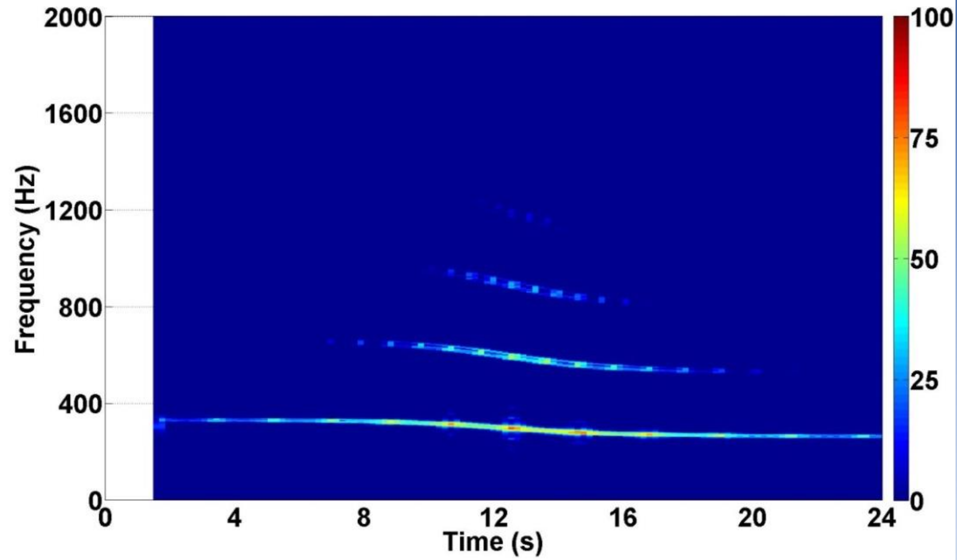
Peak Level at Centerline Receiver = 90.7 dB (-10.7 dB re: GA Prop)

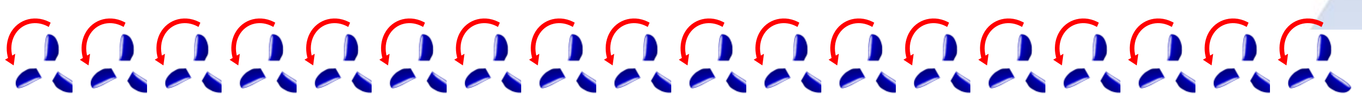
Time History



Spectrogram



Δf = 0.5 Hz



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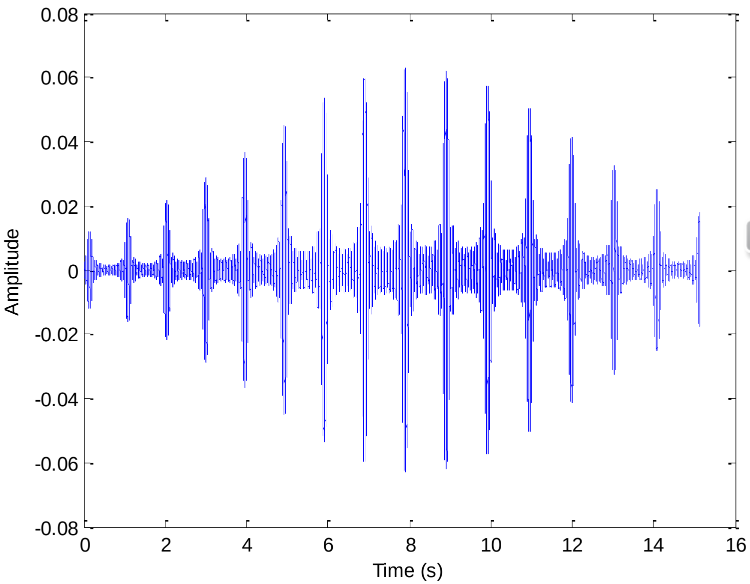
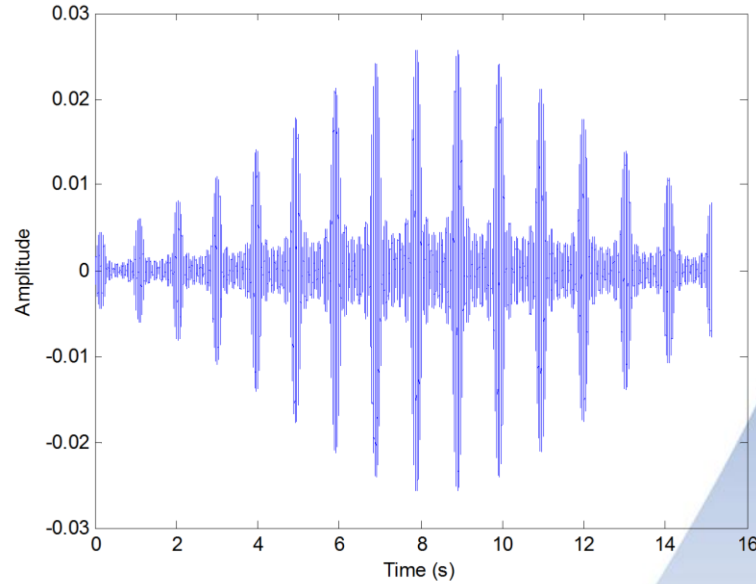
Changing the number of props

18 props



Ideal

12 props



Ideal

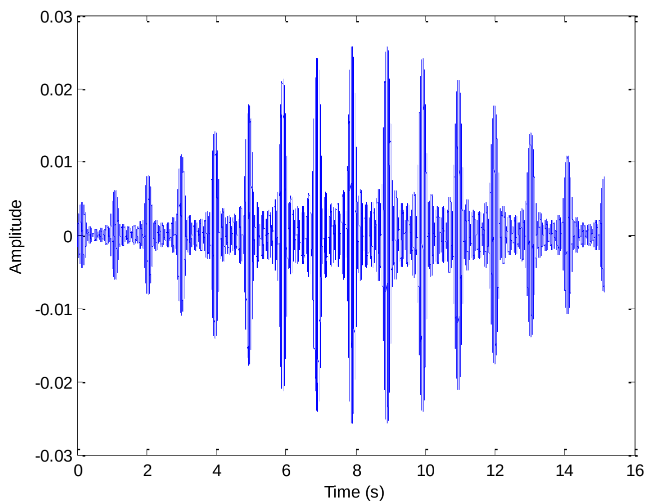
DF=1 Hz

Simulations by Dan Palumbo and Steve Rizzi of NASA Langley. To be published in Rizzi, S.A., “Toward Reduced Aircraft Community Noise Impact via a Perception-Influenced Design Approach,” Inter-Noise 2016, Hamburg, Germany, 21-24 August 2016.

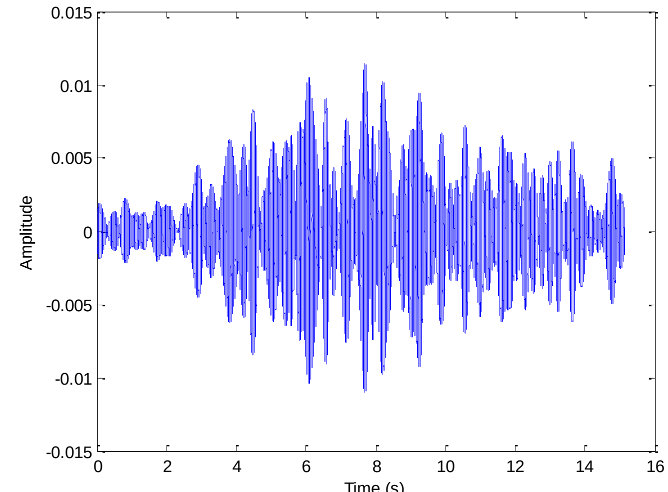
Adding atmospheric & controller impacts

12 props
DF=1 Hz

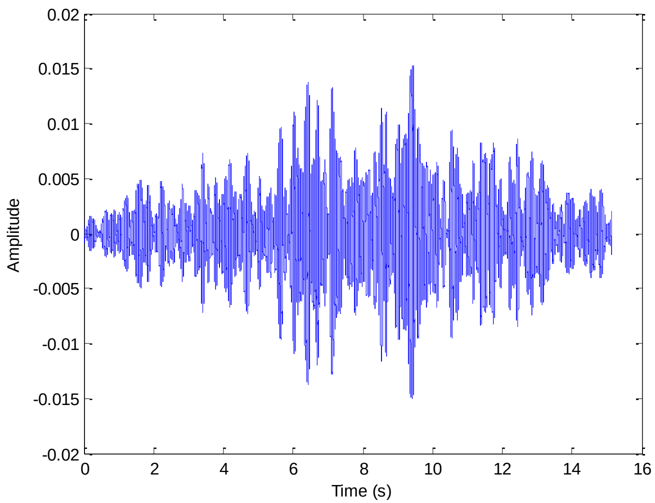
Ideal



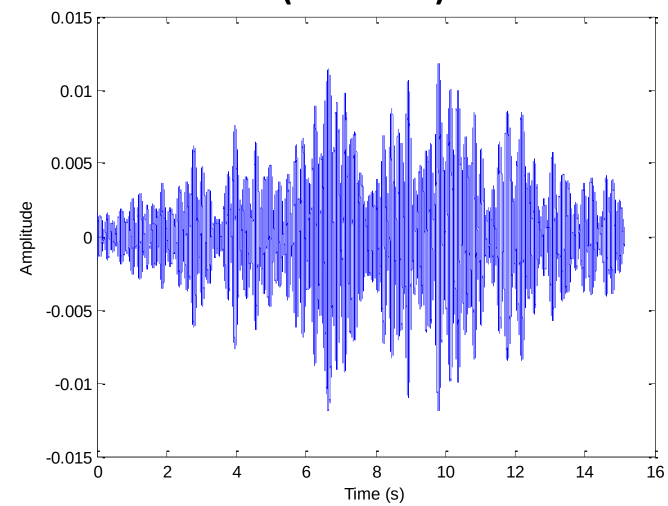
Realistic



Loose Control



Random DF (max=1Hz)



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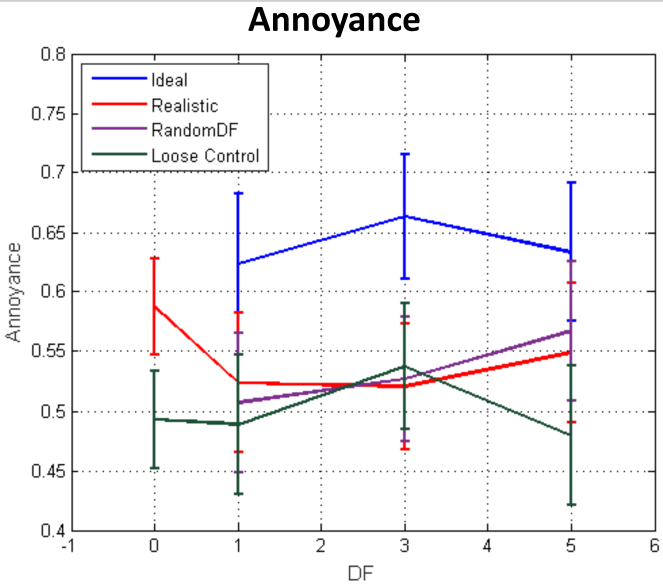
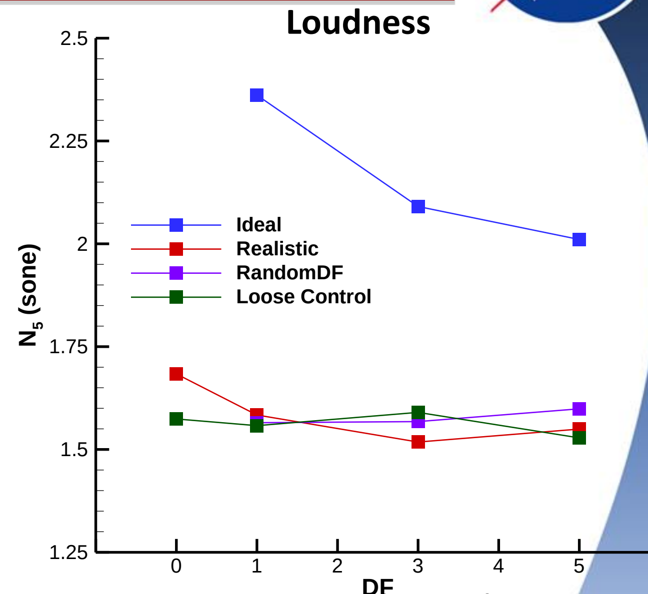
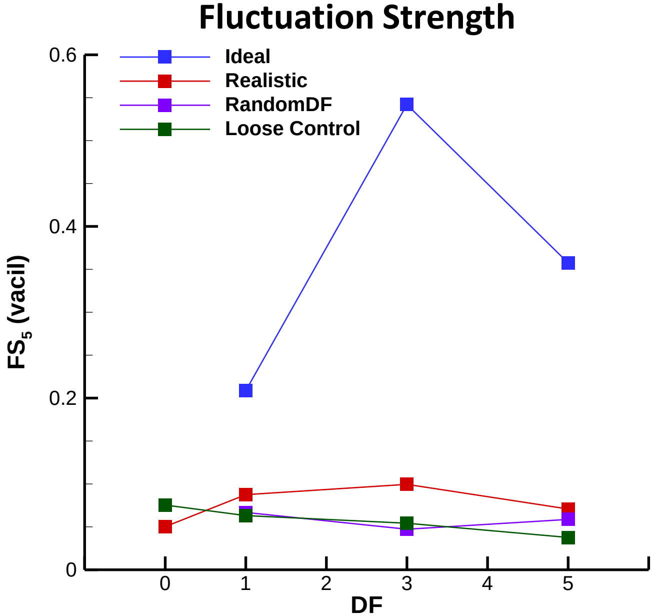
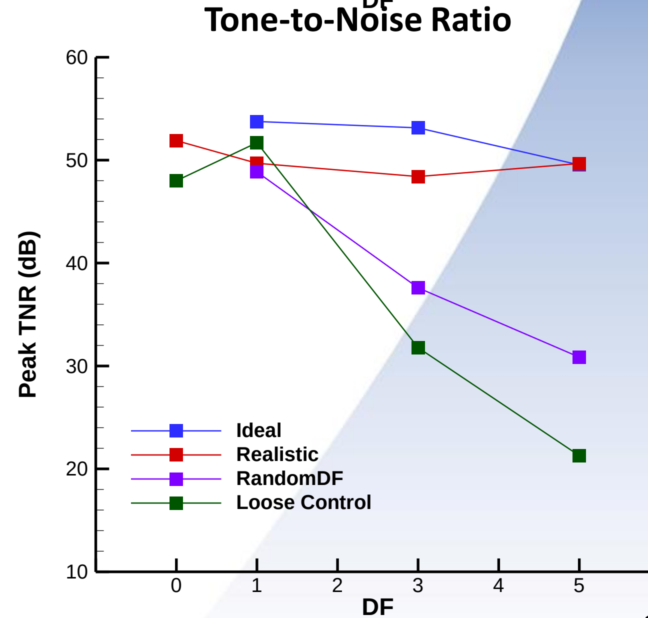
Different metrics show different stories

- DEP concept with 12 propellers









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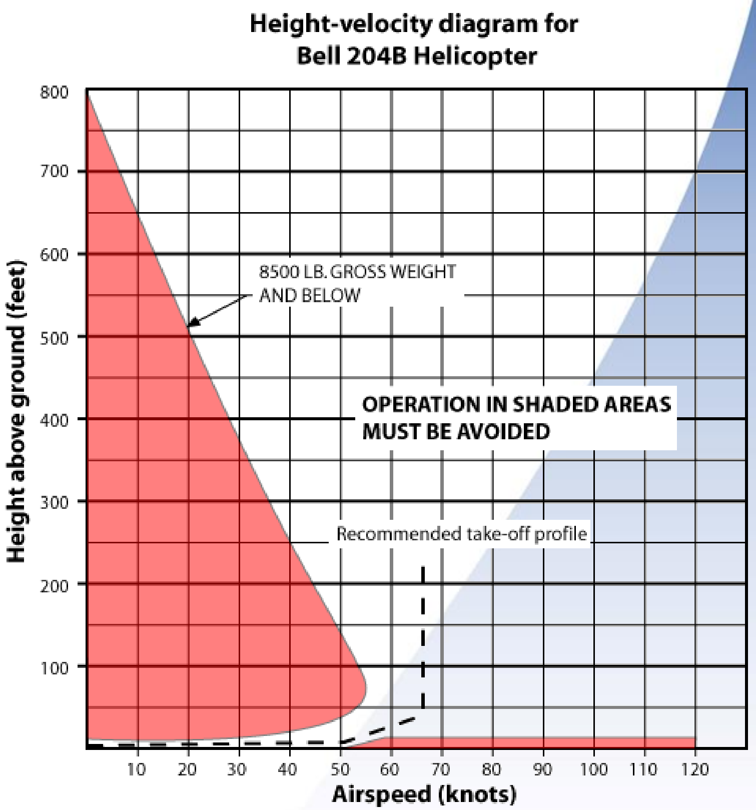
COMMUNITY IMPACT: SAFETY CONSIDERATIONS

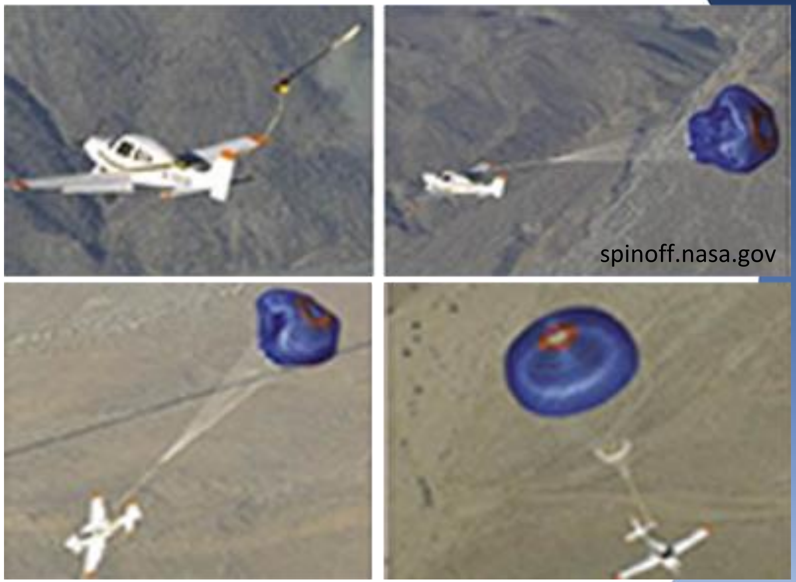
Battling both real and perceived safety

- Legitimate safety issues involved in flying vs driving
  - Must safely land aircraft as opposed to simply pulling car to shoulder
  - Helicopter "dead man's curve"
    - Require sufficient altitude and airspeed to begin autorotation and arrest descent rate in event of engine failure
- New vehicle concepts (e.g., DEP) may avoid certain issues
- Desire "stopgap" safety measures
  - Backup systems to other safety features
  - Provide "peace of mind" to public



Full-Aircraft Parachutes

- Stabilize aircraft in safe attitude and reduce aircraft descent rate
- Current full-aircraft parachutes require ~150-200 ft altitude and more than ~35 knots airspeed to deploy
  - VTOL aircraft may operate at slower speeds and lower altitudes
  - Difficult to deploy with conventional rotorcraft, but possible with new concepts
- Potential future advancements:
  - Lower altitude/airspeed capabilities
  - Steerable parachutes
  - Automatic deployment



BRS chute deployment for SR-20

X-38 (emergency Crew Return Vehicle concept) with steerable parafoil

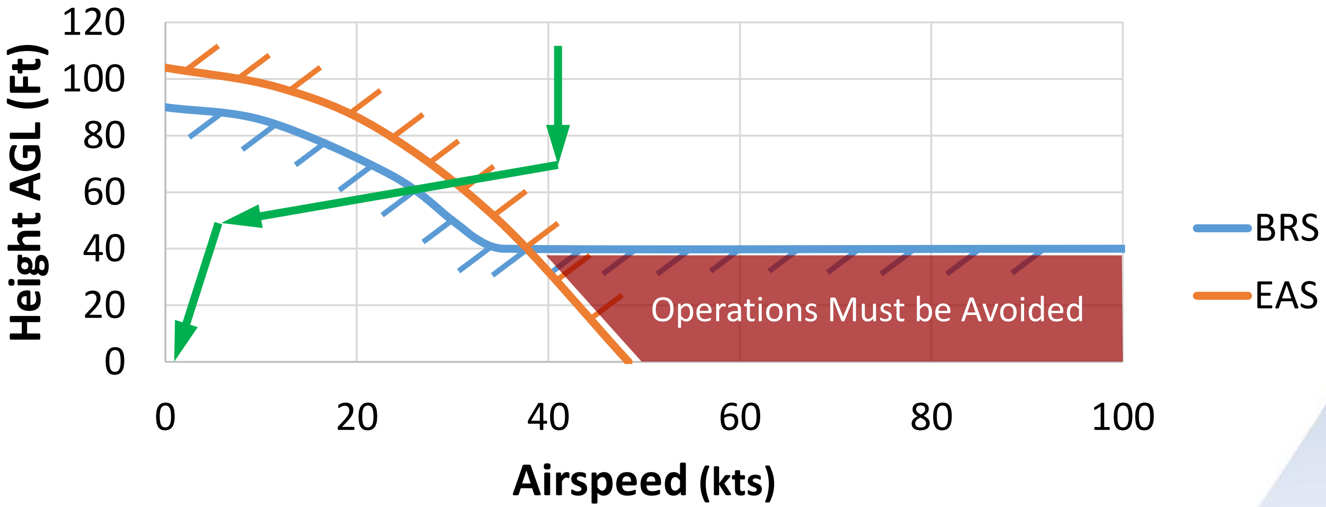
Energy absorbing systems

- Absorb kinetic energy in materials as opposed to transferring to occupants
- Developed to date for spacecraft and military aircraft
- Example systems:
  - Deployable energy absorbing concept
  - Full aircraft airbags
    - Double as floatation devices in case of water landing

Videos of Deployable Energy Absorbing (DEA) concept from Dr. Sotiris Kellas of NASA Langley

Eliminating the "dead man's curve"

- Ballistic recovery system (BRS) for > ~50 ft altitude and ~30 knots
- Energy absorbing systems (EAS) for < ~50 ft and ~30 knots



Calculations from Fredericks, Bill. "Impact of Operational Requirements on Intra-Urban VTOL Conceptual Design." *AIAA Aviation*. June 2016. Oral Presentation. Also see AIAA 2016-3466

MANUFACTURING

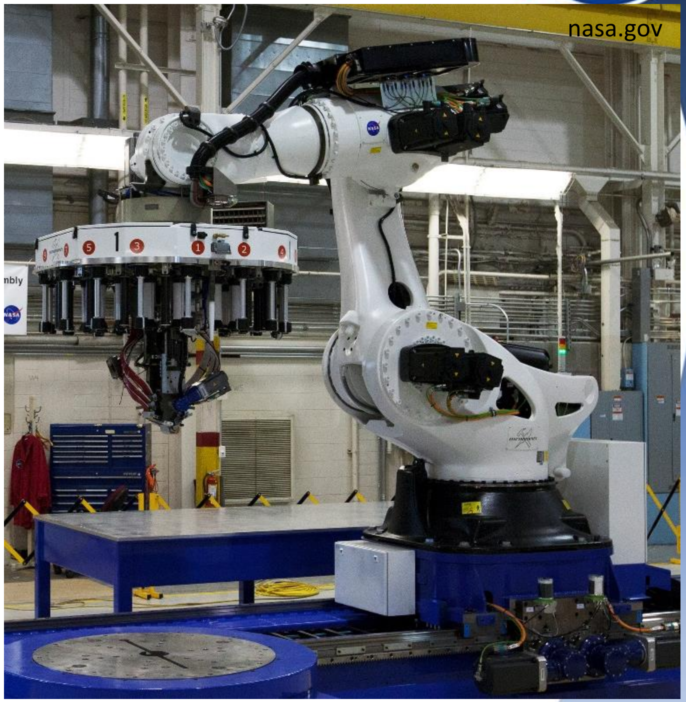
Additive Manufacturing (AM)

- Potential for
  - Reduced weight (i.e., higher efficiency, more range/payload)
  - Reduced cost (less tooling; low-volume production can reutilize same machines)
- AM handbook
- New AM methods
- AM of
  - sub-systems (e.g., electric motors, fuel cells)
  - primary structure
  - entire aircraft

"Guide for Low Cost Design and Manufacturing of Composite General Aviation Aircraft"

Flexible Robotic Manufacturing

- Idea: reduce manual labor required (i.e., recurring cost)
- Robotic stations can be programed to do many tasks
  - Swapping 'end effectors'
- Enables scalable manufacturing
  - Small production runs could employ a small number of robotic stations, each serving multiple functions
  - Large production runs could employ many robotic stations, each serving a small number of functions
- BMW i3 assembly line



INTEGRATED STRUCTURES

Digital Twin / Smart Hangar

Digital twin

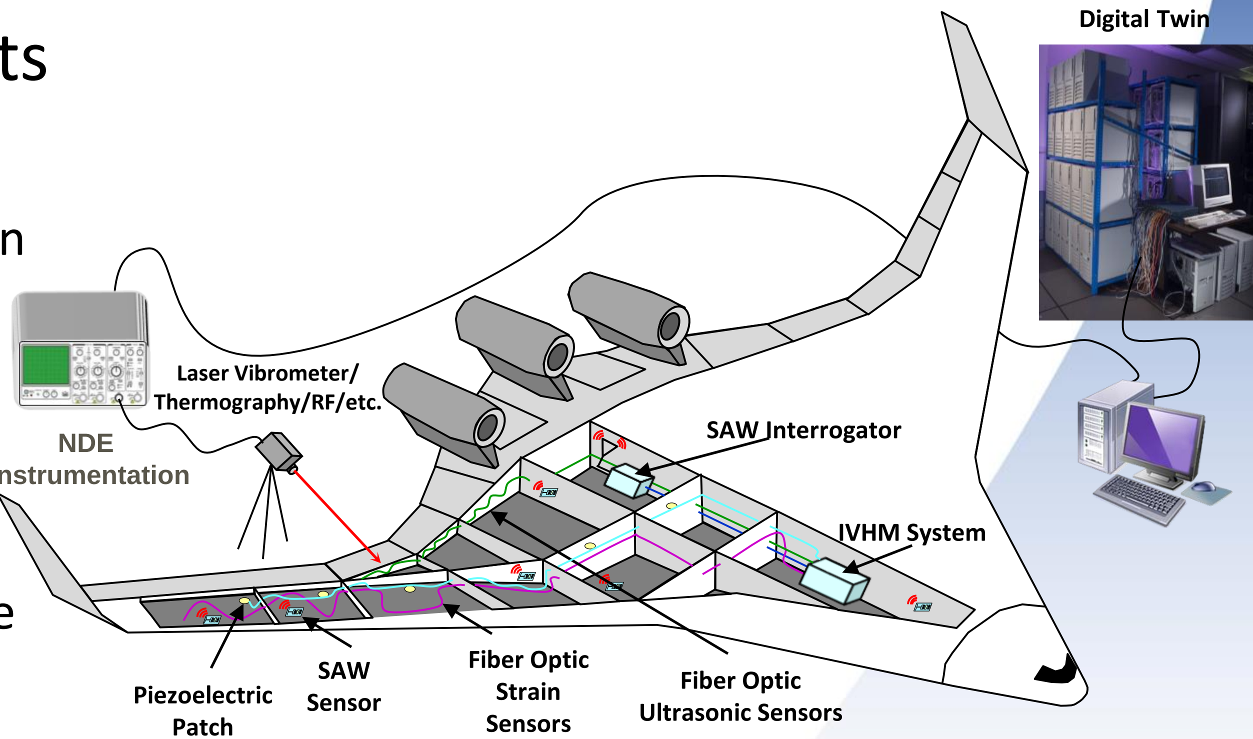
- Use models to predict performance and failures in physical aircraft prior to flight

Smart hangar

- Assess vehicle health while in the hangar with on- and off-board sensors

Potential benefits

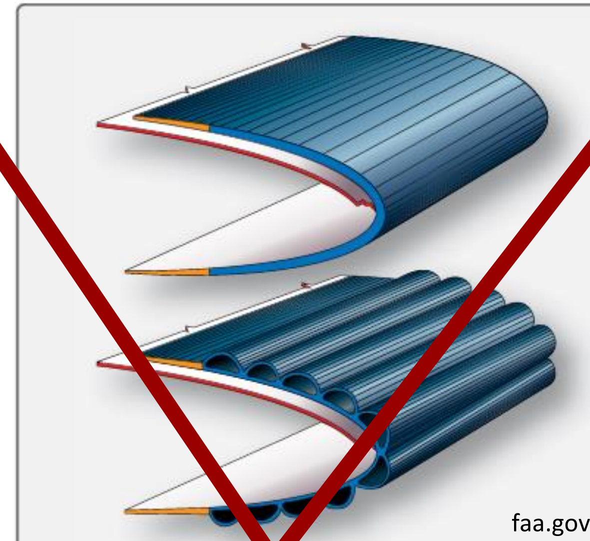
- Increase safety
  - Frequent inspection
  - Help make “no go” decisions
- Reduce costs
  - Enable condition-based maintenance
  - ID problems early

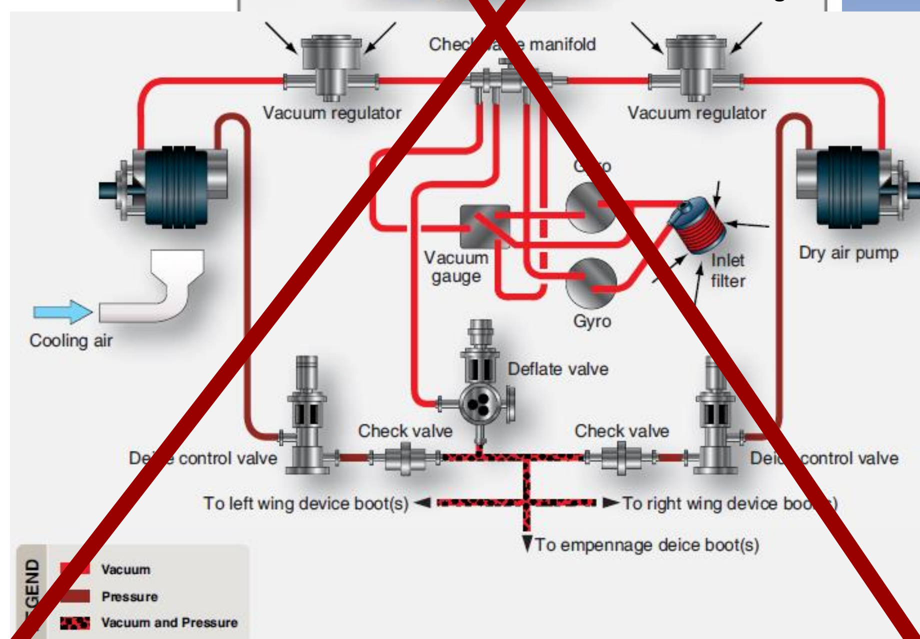


Digital twin POC Paul Leser (NASA Langley); Smart Hangar POC and figure credit: Cy Wilson (NASA Langley)

Anti-ice coatings

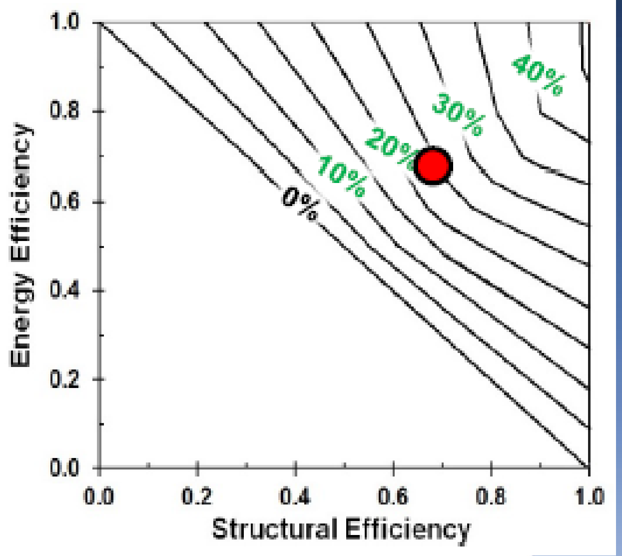
- Many small aircraft cannot afford weight penalty and cost of current de-icing systems
- Coatings based on nano-materials well-matched to lower-than-transonic speeds (i.e., won't wear away)
- Ideally paired with electric propulsion's ability to run at higher powers for short periods of time to climb through potential icing conditions
- Can increase utilization

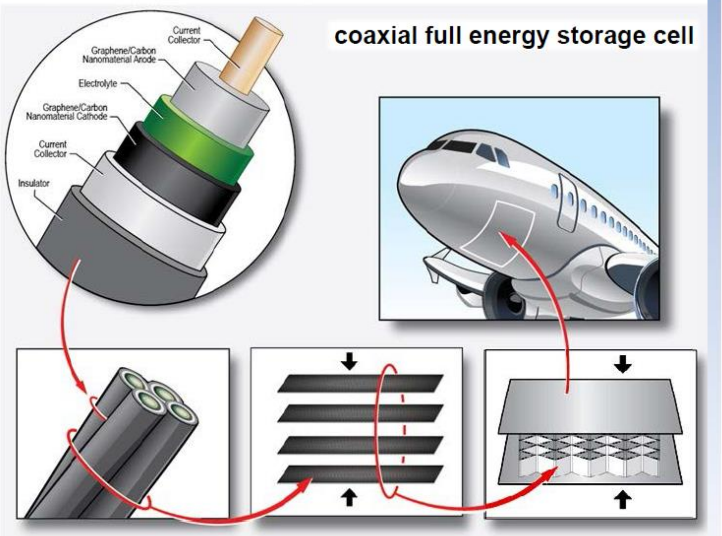




Multi-functional structures

- **Energy storage:**
  - Instead of having separate structure and energy storage systems, combine them to save vehicle weight
  - Poorer structure than conventional structure and poorer energy storage capability compared to conventional means, but net reduction in overall weight
  - Distribution of energy storage may reduce electricity transmission weight/losses and increase reliability through redundancy
- **Other ideas:**
  - Energy transmission
  - Insulating (cryogenics)
  - Self-healing composites





WRAP-UP

Roadmap: Manufacturing, Integrated Structures, & Community Impact

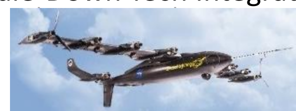
2016	2021	2026
Proof of Feasibility, Concept Exploration, Certification Requirements, Basis	Design, Development, Certification, Validation of Operational Prototypes	Early Operations, Maturation, Redesign, Extension, and Technology Scaling


X-57

Thin-Haul X-Plane


VTOL X-Plane

Scale-Down Tech Integration




Initial Operational Vehicles


Scale-Up Tech Integration

Community Impact
- Extremely low altitude / speed full-aircraft parachute
- Noise/annoyance metric development
- Noise modeling tools with validation data sets
- Crashworthy structural design with energy-absorbing materials
- Noise control technologies
- Energy absorbing systems / external airbags
- High weight / advanced aircraft recovery parachute

Manufac-turing
- Additive manufacturing (AM) ‘handbook’
- AM of subsystems
- Flexible robotic manufacturing
- Advanced additive (AM) manufacturing techniques

Integrated Structures & Materials
- Anti-ice coatings
- Damage tolerant/self-healing composites
- Progressive damage anal. methods for composites
- Smart Hangar
- Morphing structures
- Structural health monitoring techs

Leveraging Existing Investments
- *M-SHELLS (multi-functional structures)*
- *Digital Twin*

Summary

- Many potential technologies
- Impact nearly every ODM goal
- Main goals of investments:
  - Increase safety
  - Reduce community noise/annoyance
  - Reduce structural weight
  - Reduce acquisition costs
- Acoustics and safety technologies likely required
  - Public must accept these vehicles (both to fly in them and to allow them to fly over)
  - Other individual technologies likely not absolutely necessary but some combination of them may be

QUESTIONS?

BACKUPS

MISC Contributions to ODM Goals

Ease of Certification

<u>Metric</u>
Time/Cost Required

- Potential to reduce certification requirements for other technologies with improved “stopgap” safety systems
- Improved modeling may reduce need for extensive physical testing
- “Handbooks” to help enable certification of new manufacturing processes

MISC Contributions to ODM Goals

Safety
<u>Metric</u> Fatal Accidents per Vehicle Mile

- Improved “stopgap” safety systems to complement other technologies (e.g., SVO-related technologies)
- Reduced risk of flying with unsound structure
  - Structural health monitoring/modeling
  - Improved material damage tolerance

MISC Contributions to ODM Goals

Affordability

Metric
Total Operating Cost/Pax Mile

- Reduced system weights can lead to reduced acquisition costs
- Improved modeling and monitoring of structures can reduce costs
  - Acquisition costs (i.e., design, certification)
  - Operating costs (i.e., reduced maintenance)
- Improved safety and reduced damage in crashes reduces depreciation costs

MISC Contributions to ODM Goals

Ease of Use
Metric
Required Operator Training Time & Cost

- Only minor impacts
  - Safety technologies could reduce required pilot certification requirements (e.g., less off-nominal training required)
  - Structural monitoring/modeling reduces required operator knowledge/time for inspections

MISC Contributions to ODM Goals

Door to Door Trip Speed
<u>Metric</u>
mph

- Potential for more direct routes / desirable altitudes
  - Anti-ice coatings to fly through instead of around known icing conditions
  - Improved safety systems (i.e., parachutes, airbags) to reduce concerns of low flight over populated areas
- Multi-mode vehicles
  - Reduced mode change time
  - May be enabled with morphing structures

MISC Contributions to ODM Goals

Average Trip Delay

<u>Metric</u>
Time

- Weather penetration
  - e.g., anti-icing
- Improved aircraft availability
  - Better scheduling of maintenance downtime
    - e.g., monitoring or modeling indicates repair/replacement in advance
  - Reduced maintenance downtime
    - e.g., damage tolerant structures

MISC Contributions to ODM Goals

Community
Noise

Metric
Perceived
Relative
Annoyance
@
Community
Stand-off
Distance

- Metrics to quantify the perception of noise
- Noise reduction technologies
- New tools to enable design for low perceived noise
- Reduced vehicle weights can lead to lower noise

MISC Contributions to ODM Goals

Ride Quality

<u>Metric</u>
Passenger Comfort Index

- Decreased cabin noise
- Indirect impacts possible through
  - morphing structures
  - improved actuators that may help enable gust load alleviation systems

MISC Contributions to ODM Goals

Efficiency

Metric

Energy/Pax Mile

Lifecycle Emissions

Metric

Total Emissions /Pax Mile

- Reduced structural weight
- Increased electrical transmission efficiency

Investment List: Example Subset

- Manufacturing
  - Flexible robotic manufacturing
    - Replace many manual labor tasks with robotic stations
    - Robotic stations can be programed to do many different tasks
    - Small production runs could employ a small number of robotic stations, each serving multiple functions
    - Large production runs could employ many robotic stations, each serving a small number of functions
  - Additive manufacturing handbook
    - Define “best practices” for design and inspection
    - Determine sufficient factors of safety for different processes
  - Additive manufacturing of subsystems (e.g., fuel cells, electric motors)
  - New additive manufacturing methods (e.g., liquidjet printing, robotic direct fiber placement)

Investment List: Example Subset

- Integrated Structures
  - Multi-functional structures with energy storage (e.g., M-SHELLS)
    - Instead of having separate structure and energy storage systems, combine them to save vehicle weight
    - Poorer structure than conventional structure and poorer energy storage capability compared to conventional means, but net reduction in overall weight
    - Distribution of energy storage may reduce electricity transmission weight/losses and increase reliability through redundancy
  - Improved modeling of composite structures
    - Develop improved, high-fidelity progressive damage analysis methods for composite materials to predict onset and propagation of damage
    - Utilize tools to develop more structurally efficient designs and/or reduce design/certification time with less physical testing than currently required
  - Morphing structures / advanced actuators
    - Change vehicle characteristics (e.g., wing camber) throughout mission to be more advantageous for different phases of flight
    - May help enable multi-mode vehicles that can safely fly and drive on roads
  - Damage-tolerant / "self-healing" composites
    - Damage from accidental damage (e.g., dropping tools), high voltage electrical shortages, projectiles, etc. can be automatically mitigated

Investment List: Example Subset

- Community Impact: Safety enhancements
  - Extremely low altitude aircraft parachute
    - Aircraft parachutes serve as safety backup in case of off-nominal situation, decreasing aircraft acceleration to safe levels prior to ground impact
    - Current aircraft parachutes require altitude/airspeed to successfully deploy and are not applicable to VTOL aircraft operating close to people at low altitudes
    - Low altitude parachute systems can eliminate “coffin corner”/“dead man’s curve” for VTOL operations and reduce risk of damage to objects on ground
  - External aircraft airbag
    - Provides absorption of energy during crash while reducing structural deformation to enable safe egress post-crash
    - Reduction in damage to objects on ground upon landing
    - Can be utilized as a “life jacket” to keep aircraft afloat in water, reducing chances of drowning if aircraft crashes over water
  - Energy absorbing composites
    - Crash loads are absorbed by the structure while enabling safe egress post-crash

Investment List: Example Subset

- Community Impact: Acoustics
  - Noise metrics for ODM vehicles
    - Current certification metrics assume conventional aircraft and operations, but ODM aircraft and missions may differ significantly
    - Need to assess the human perception of noise to make practical ODM vehicles that can operate in close proximity to people with minimal annoyance
    - Metrics could be used in vehicle design and certification as well as assessment of airspace models
  - Noise modeling tools
    - Novel vehicle configurations or airspace usage will require new tools to effectively predict noise for both occupants and those on ground
    - New metrics will require new tools to predict perceived noise to enable effective vehicle and airspace design
  - Noise control technologies
    - For operations near humans, noise levels must be reduced from current SOA aircraft/rotorcraft levels
    - Many possible ways to reduce noise including rotor design/operation, acoustic liners, and active control

Investment List: Example Subset

- Community Impact: increased utilization
  - Anti-ice coatings based on nano-materials
    - Small aircraft (particularly those with low utilization) cannot afford weight penalty, cost of current de-icing systems
    - Coatings well-matched to lower-than-transonic speeds (i.e., won't wear away)
    - Ideally paired with electric propulsion's ability to run at higher powers for short periods of time to climb through potential icing conditions
  - Digital twin
    - Multi-physics, probabilistic simulation of aircraft used to predict performance and failures in physical aircraft prior to flight
    - Predictions can be used to make "no go" decisions, enable condition-based maintenance, and inform risk management
  - Smart hangar
    - Couple onboard sensors and external non-destructive evaluation techniques to assess vehicle health while in the hangar
    - Provides frequent, automatic inspections to identify problems early when repairs may be less costly and reduce manual inspection time

Investment List (1 of 3)

- Manufacturing
  - Flexible robotic manufacturing
  - Additive manufacturing handbook
  - New additive manufacturing methods (e.g., liquidjet printing, robotic direct fiber placement)
  - Additive manufacturing of subsystems (e.g., fuel cells, electric motors)

Investment List (2 of 3)

- Integrated Structures
  - Multi-functional structures with energy storage
  - Improved modeling of composite structures
  - Damage-tolerant / “self-healing” materials
  - Morphing structures / advanced actuators
  - Polyimide aerogels for primary wing structures
  - Multi-functional structures with cryogenically cooled electricity transmission
  - Modular structures and design methods for these structures
  - New nano-structure materials or other “superstructures” with improved material properties

Investment List (3 of 3)

- Community Impact
  - Safety enhancements
    - Extremely low altitude aircraft parachute
    - External aircraft airbag for improved survivability and flotation
    - Crashworthy structural design using energy absorbing composites
    - Advanced aircraft recovery parachute technologies (e.g., steerable parachutes, autonomous activation, extractor motor control, etc)
  - Acoustics
    - Noise metrics for ODM vehicles (to determine perceived noise)
    - Noise modeling tools
    - Noise control technologies (e.g., liners, active control)
  - Increased utilization
    - Anti-ice coatings
    - Digital twin
    - Smart hangar