

Embry-Riddle Aeronautical University

“Sky Shepherd: Autonomous Aerial Cattle Monitoring”



Conceptual Design of Aerial Cattle Management System

Gus Gatti, Tyler McConnell, Bridget Kenney, Lauren Augusto, Nathaniel Cook



Abstract

The Sky Shepherd proposes innovations and improvements to the current methods of bovine cattle management. Much of modern agriculture is completed with automated processes, however, cattle management is largely done on foot as modern equipment has been found to frighten and cause herd stampeding. Traditional quadcopter Unmanned Aerial Vehicles (UAVs) that are used for small ranch applications operate at a frequency that cattle are most receptive to. Through conversations with cattle ranchers and by searching through scholarly sources, a Vertical Takeoff and Landing (VTOL) UAV design was proposed. The proposed UAV will feature an innovative solid-state battery and an aeroacoustically optimized propeller which reduces the noise emitted by the UAV and shifts the frequency to peak outside ranges cattle are sensitive to. This concept will allow ranchers to have access constant herd position and health data, allowing for quicker veterinary response times and reduced labor.

Problem Identification

Cattle are most receptive to noises in 27 Hz to 37 kHz range, with peak sensitivity in the 8 kHz range.

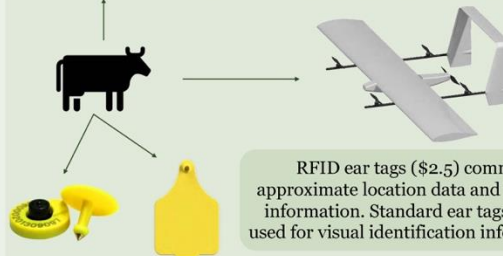
Existing quadcopter technology operates around 4,000-11,000 RPM, where the Blade Passing Frequency (BPF) is in the range of frequencies cattle are most susceptible to.



Location and Health Monitoring



CowTraq Neck Collars (\$120) track health data including signs of heat and rumination which provide indicators of early signs of a decline in health. Collars can also provide location data.

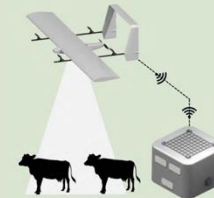


RFID ear tags (\$2.5) communicate approximate location data and identification information. Standard ear tags (\$0.05) are used for visual identification information only.

Conceptual Operations

Autonomous Aerial Cattle Monitoring

Passive & Active RFID Collects Health & Location of Cattle



Radio Transmission for Navigation occurs on 5,030-5,091 MHz Spectrum Band for FCC Compliance

Fixed-Wing UAV used to Increase Monitoring Range and Reduce Noise compared to Quadcopter

SLAM Algorithm interfaces with onboard sensors and fixed base to provide robust navigation in areas of limited connectivity

Aeroacoustically optimized cruise propellers operate with minimal interference with spectrum of frequencies cattle are sensitive to for low-stress cattle management.

Battery Technology

The Sky Shepherd utilizes Solid State Batteries (SSBs) to provide lengthened performance and energy capabilities. SSBs are comprised of a solid electrolyte instead of a liquid electrolyte for ionic conduction between battery electrodes. This new battery technology provides potentially over double the energy density of liquid batteries, leading to greater cycle lifespan and increased flight time.



Less material is required for an SSB

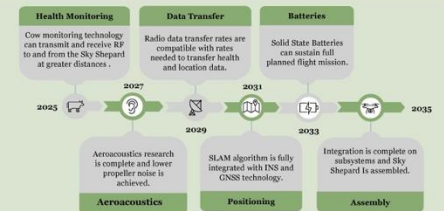
Solid Electrolyte (center) replaces a liquid Electrolyte.

SSB's have yielded high energy density capacity.

High energy density comes with a charging cycle behavior tradeoff, however, research in cycle losses is being conducted.

The location and health monitoring devices used are customizable based on needs of the user, and budget. CowTraq collars do not have to be placed on each animal. It can be decided which animals wear the collars based on the needs of the client. Their purpose is to give the user an overall understanding on the health or breeding cycles of their herds. An ear tag of the user's choice must be placed on all animals for identification purposes.

Timeline for Deployment



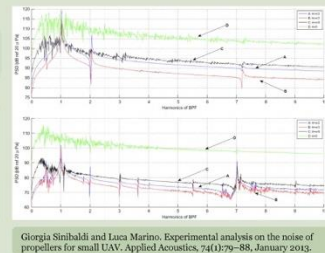
Propeller Acoustics

Existing research on airfoil geometry was used to obtain optimal aerodynamic loading for minimum propeller noise emissions. It was found that decreasing the angle of attack on the inner radius of the propeller, increasing the chord length between the 60% and 80 % span, and adding serrations to the trailing edge.

Overall Reduction in SPL Across Spectrum

Vibrations Occur at Higher Power Settings

Further Effects can be Studied in Anechoic Test Chamber



The Embry-Riddle Aeronautical University Presentation will begin at 8:00 AM Pacific Time.

View the 2025 Finalists' Infographics: <https://blueskies.nianet.org/finalists/>

COLLEGE OF ENGINEERING

SKY SHEPHERD: Unmanned Aerial Cattle Surveillance

EMBRY-RIDDLE
Aeronautical University



Introduction



Tyler McConnell
Team Lead
Sophomore
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Gus Gatti
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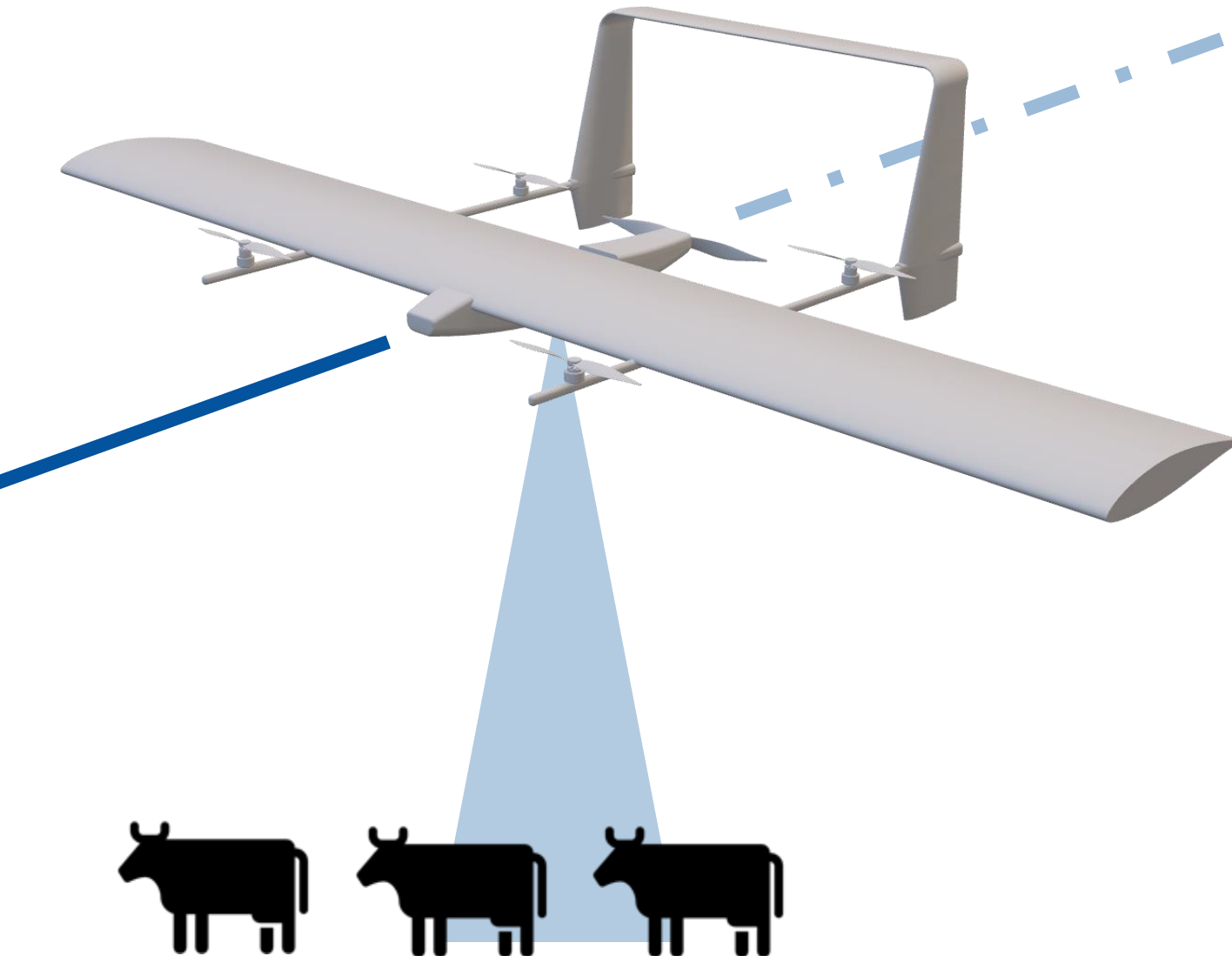


Nathaniel Cook
Member
Sophomore
Aerospace Engineering



Bridget Kenney
Member
Sophomore
Aerospace Engineering

Proposal Overview



Problem Identification

Proposed Solution

Low-Stress Cattle Management

Product Innovations:

- *Aeroacoustically Optimized Propeller*
- *Cattle Monitoring Technology*
- *Navigation Algorithms*
- *Solid-State Battery Technology*

Budget and Timeline

Problem Identification



Increase in Ranch Size Since 1980

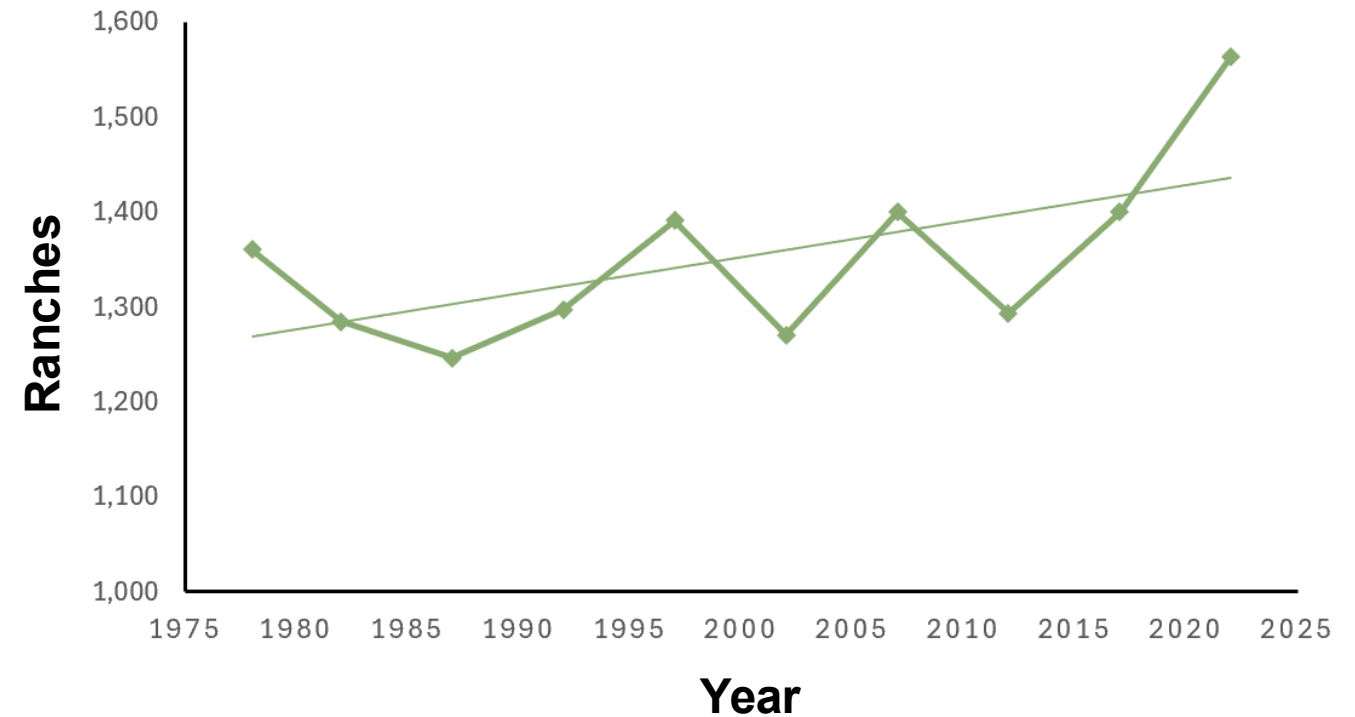
Larger ranch size leads to larger and more expensive cattle management.

Current methods of cattle identification rely on ground infrastructure*.

* *ATV, by-foot, horse*

Duration between cattle identification trips can be long leading to delayed veterinary response.

Number of US Ranches with 1000+ Head



Problem Identification



Existing Quadcopter Technology

Not applicable to large ranches.
Short range (under 1hr cruise), small tracking capacity. (less than 40 subjects)

Large noise emissions from 4 powerful motors and propellers.

Does not consider animal response to UAV, no implementation of Low-Stress Cattle Management.

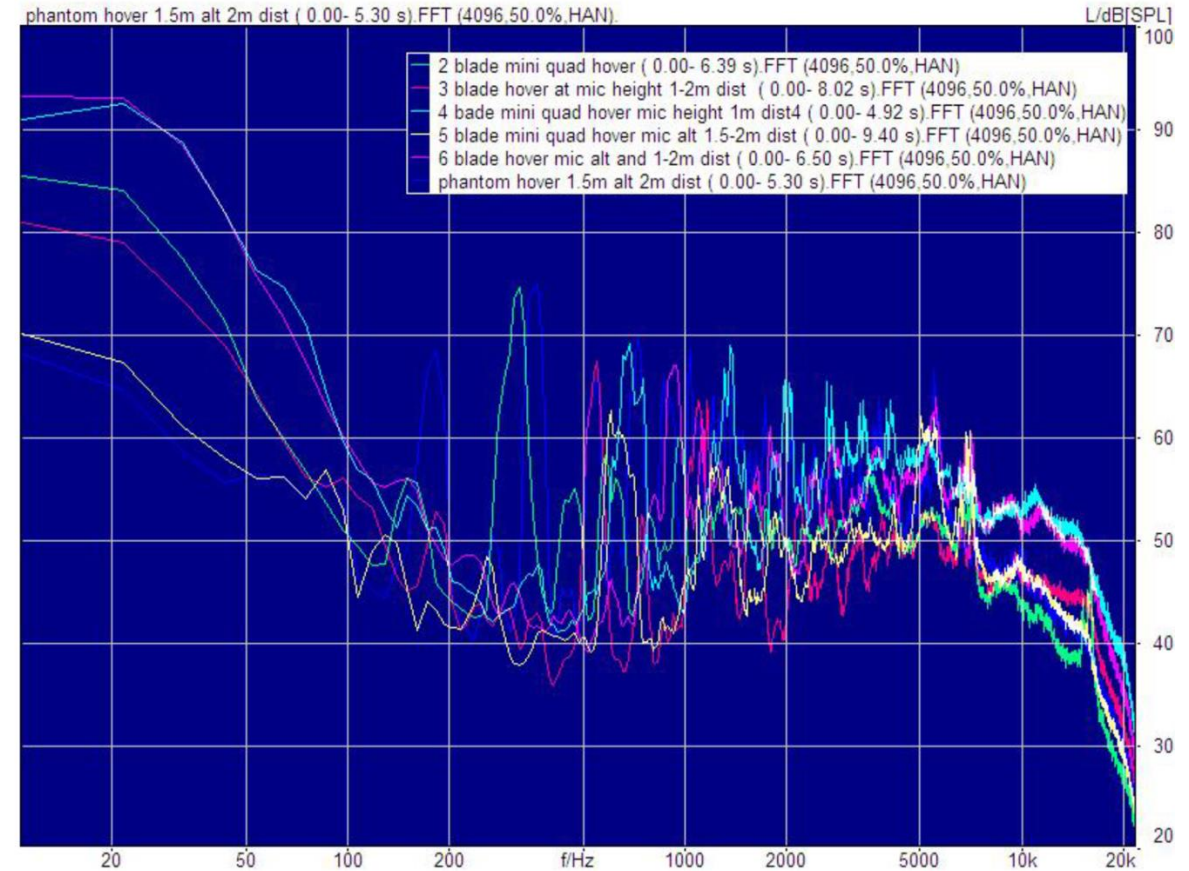
Problem Identification



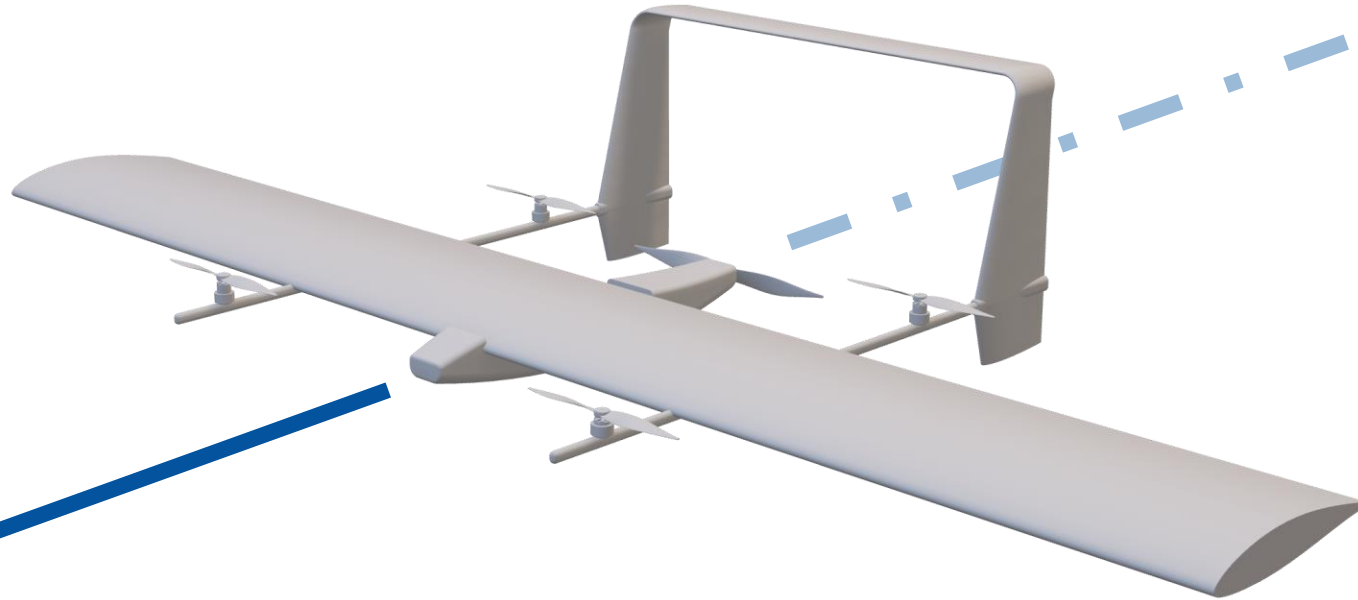
Existing Quadcopter Technology

Cattle are receptive to frequencies between 27 Hz to 37 kHz with peak sensitivity at 8 kHz.

Small Consumer UAVs operate at 4,000-11,000 RPM corresponding to BPF of 400-550 Hz and harmonics in sensitive range.



Proposed Solution



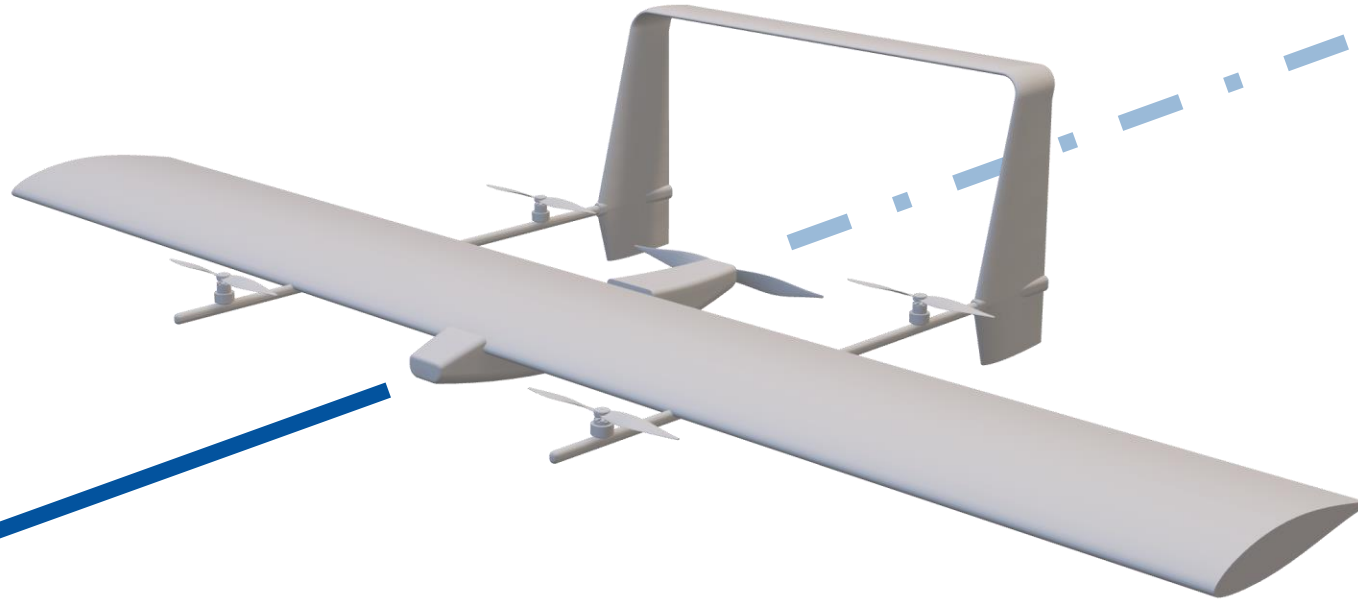
Sky Shepherd: Aerial Cattle Management

Reduce labor costs by eliminating the need for ranch hands to physically travel to locate herd.

Use AI mapping algorithms to identify herd location and report movements.

Monitor herd health in sensitive populations using e-collars to optimize treatment response time.

Proposed Solution



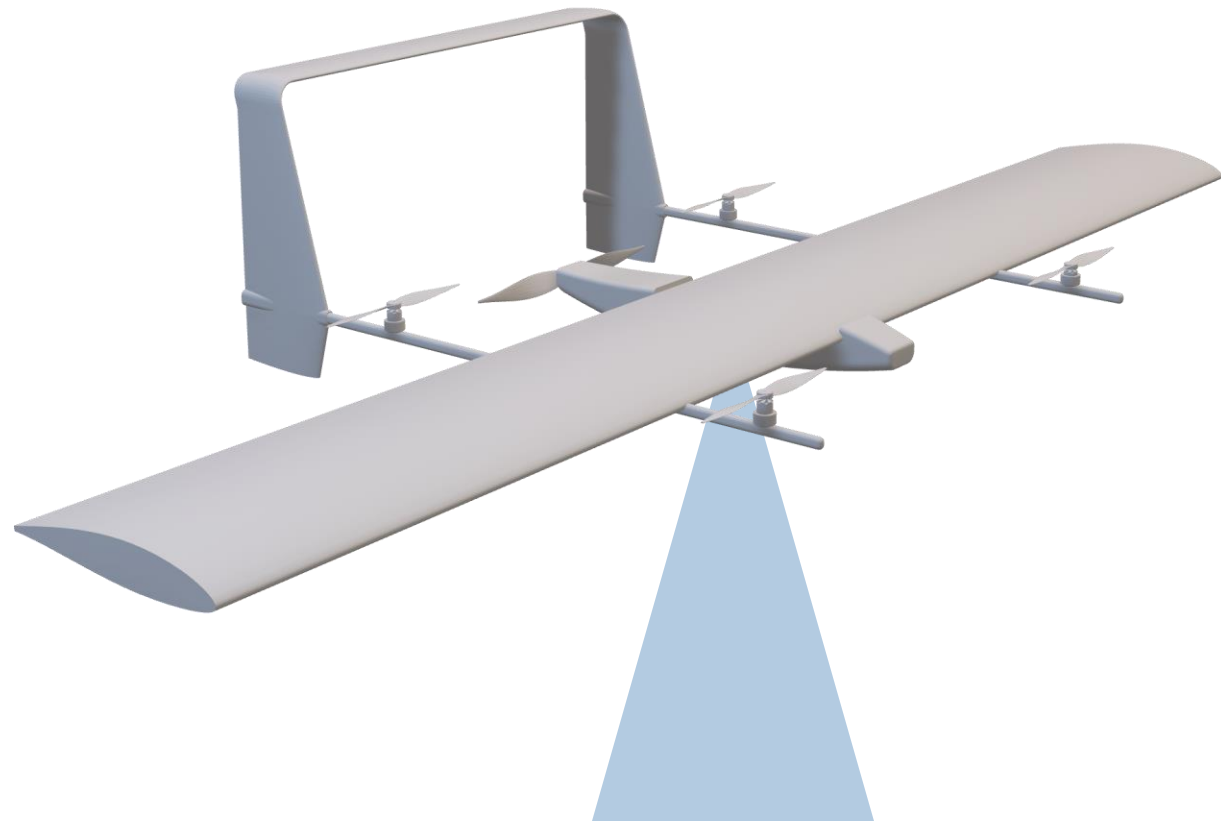
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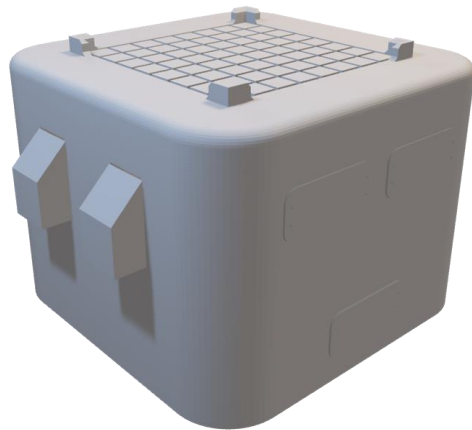
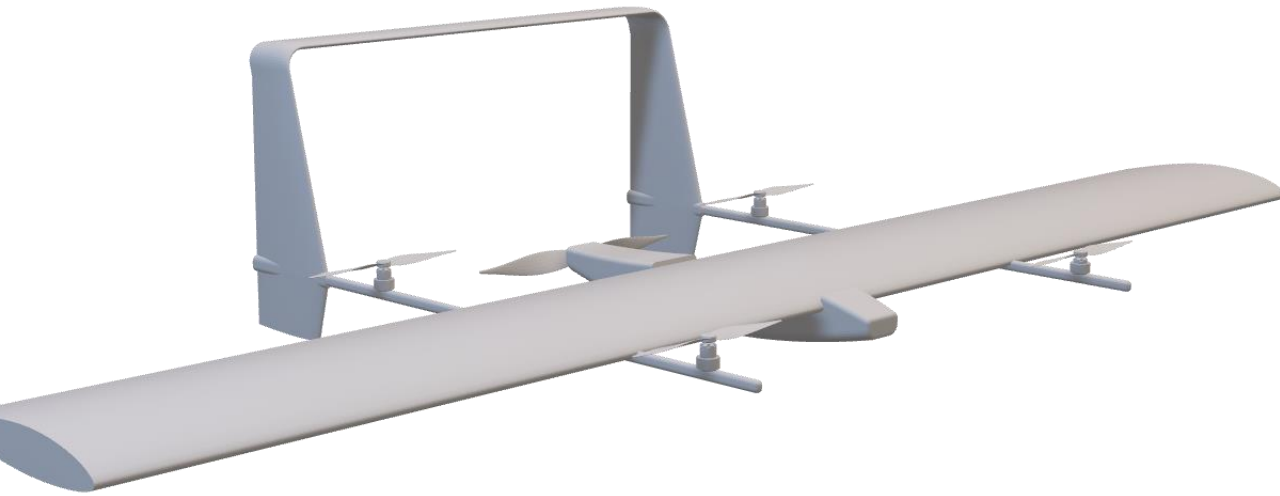
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Sky Shepherd: Aerial Cattle Management

Fixed-Wing Autonomous UAV System

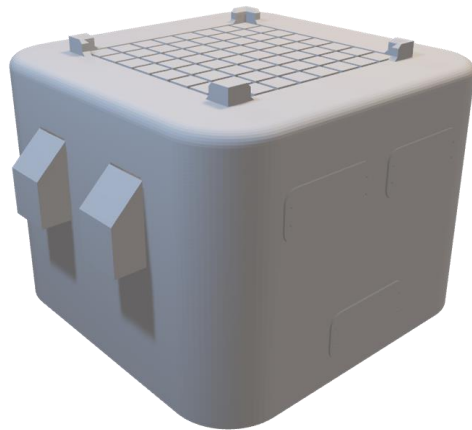
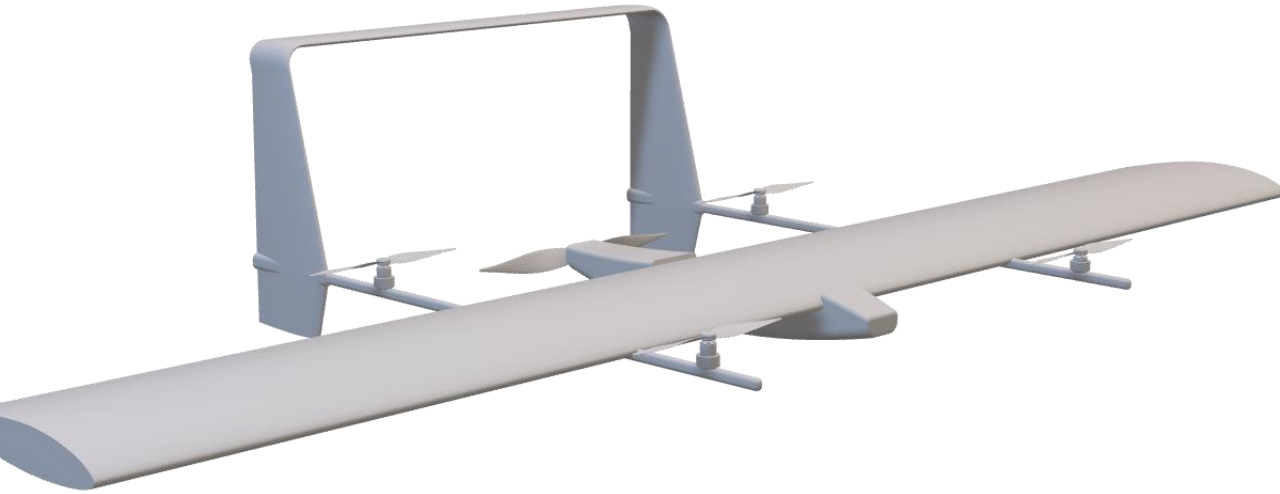
Monitoring capability of 6,000 acres
and 2,500 head

VTOL capability from wireless charging
pad

Sky Shepherd Charging



Logistics

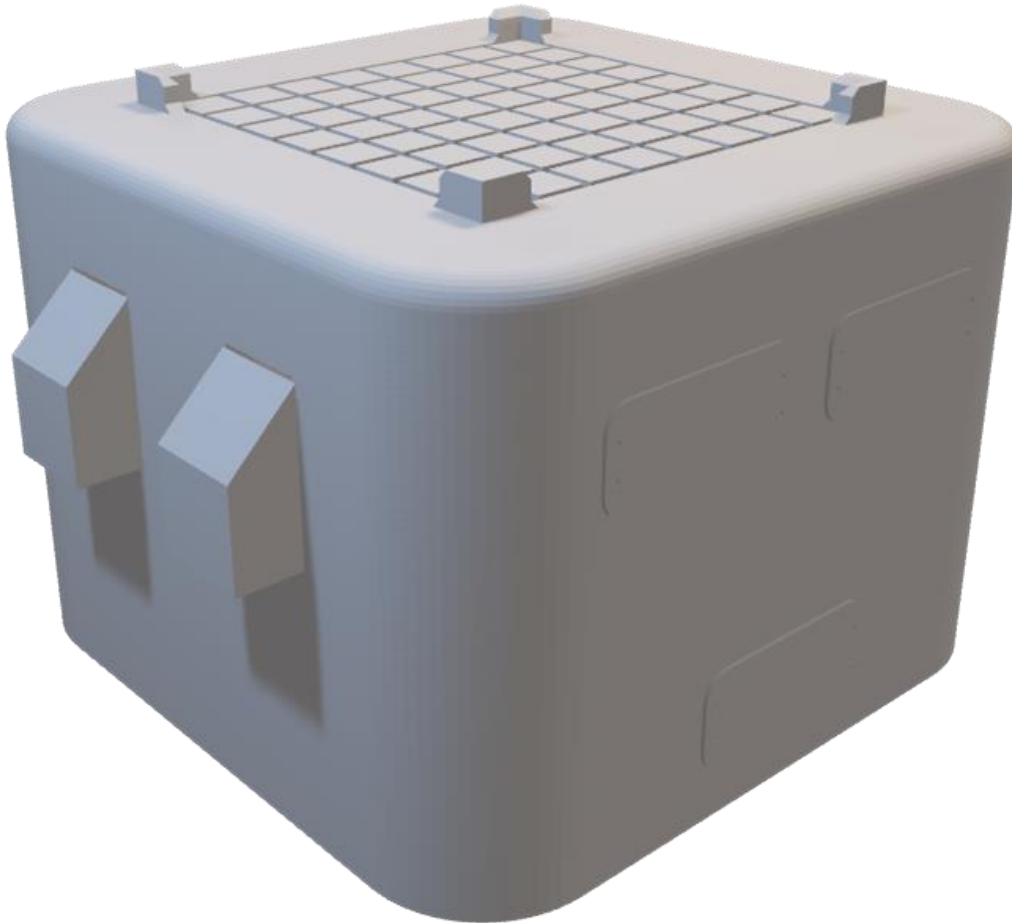


Returns to the charging pad without any input from farmer.

Charging pad communicates approach and departure instructions to the UAV.

Quadcopter flight when approaching and departing charging pad.

Home Base Functions



Logistics

Charging pad magnetically connects to the Sky Shepherd to ensure UAV safety and charging.

Main computing and communicating unit for the UAV.

Connects to power grid from farm/solar unit, and uses two backup batteries for emergency situations.

Low-Stress Cattle Management

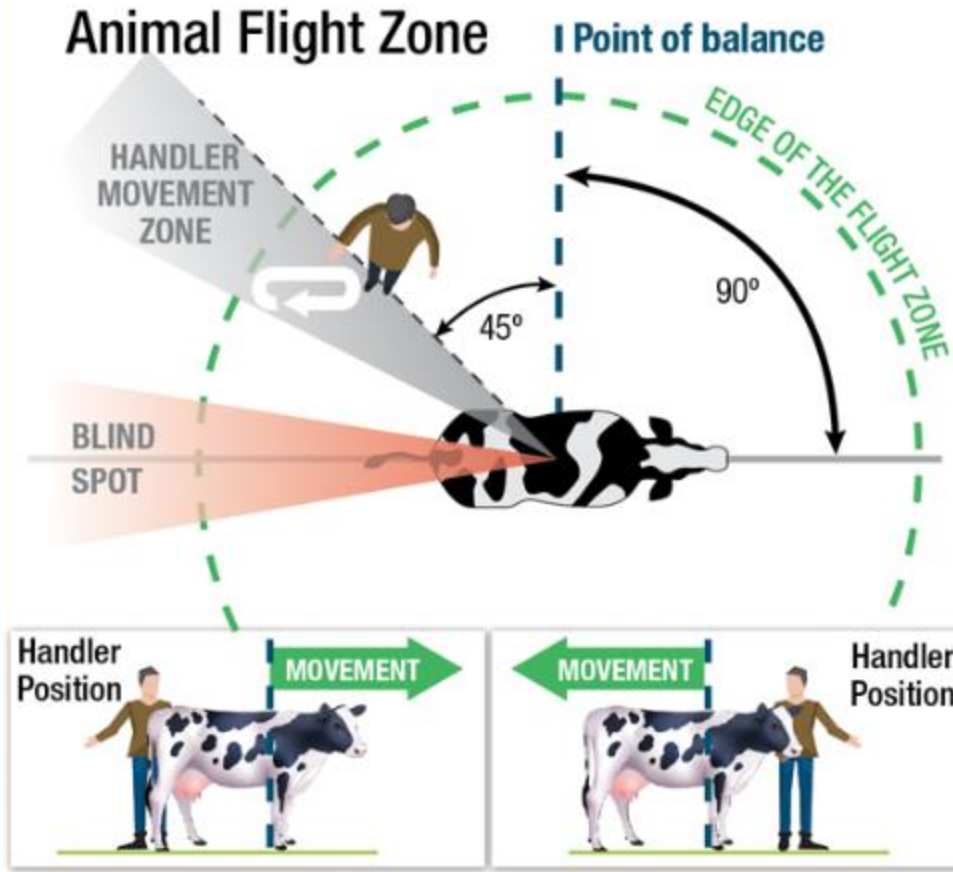


2 – D Cattle Management

Cattle Flight Zone is the reaction cattle has when a person or animal enters their vicinity.

Technique is used in herding to move cattle in a specific direction.

Elevated stress levels increase the radius of flight zone and make it more difficult to control the herds movements. [T. Grandin]





Low-Stress Cattle Management

3 – D Cattle Management

Altitude Less
Than 25 ft



Altitude Greater
Than 25 ft



Research found that UAV's significantly increases the herds stress level when below 25 ft.

Changes with environment, proximity to calves and other animals, and general hormonal changes.

"Others will uncover new ways to utilize the technology to benefit both livestock and farmers."
[M. Beverly]

Aeroacoustic Optimization

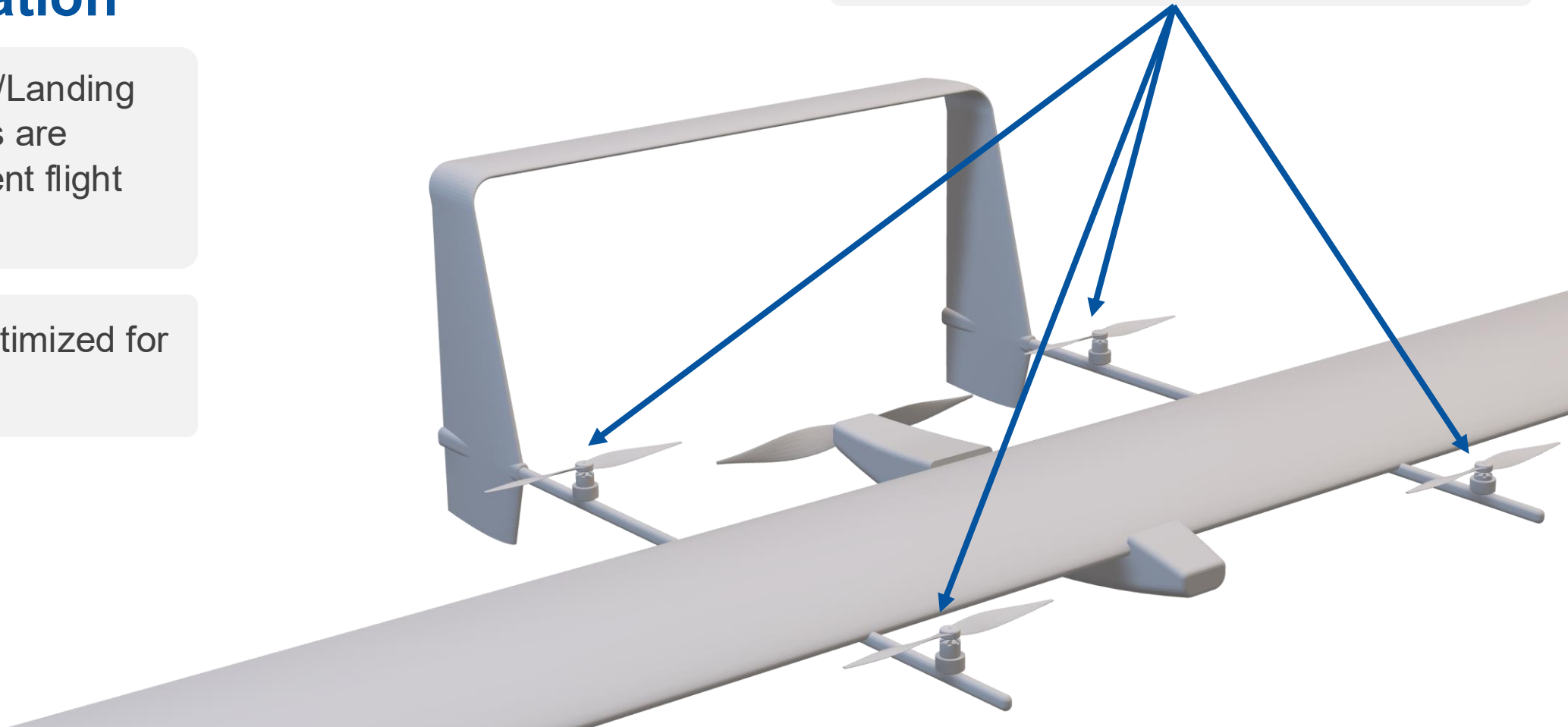


Benefit of VTOL Configuration

Cruise and Takeoff/Landing propulsion systems are designed for different flight conditions.

Takeoff/Landing optimized for high performance.

4x Takeoff/Landing Propulsion System



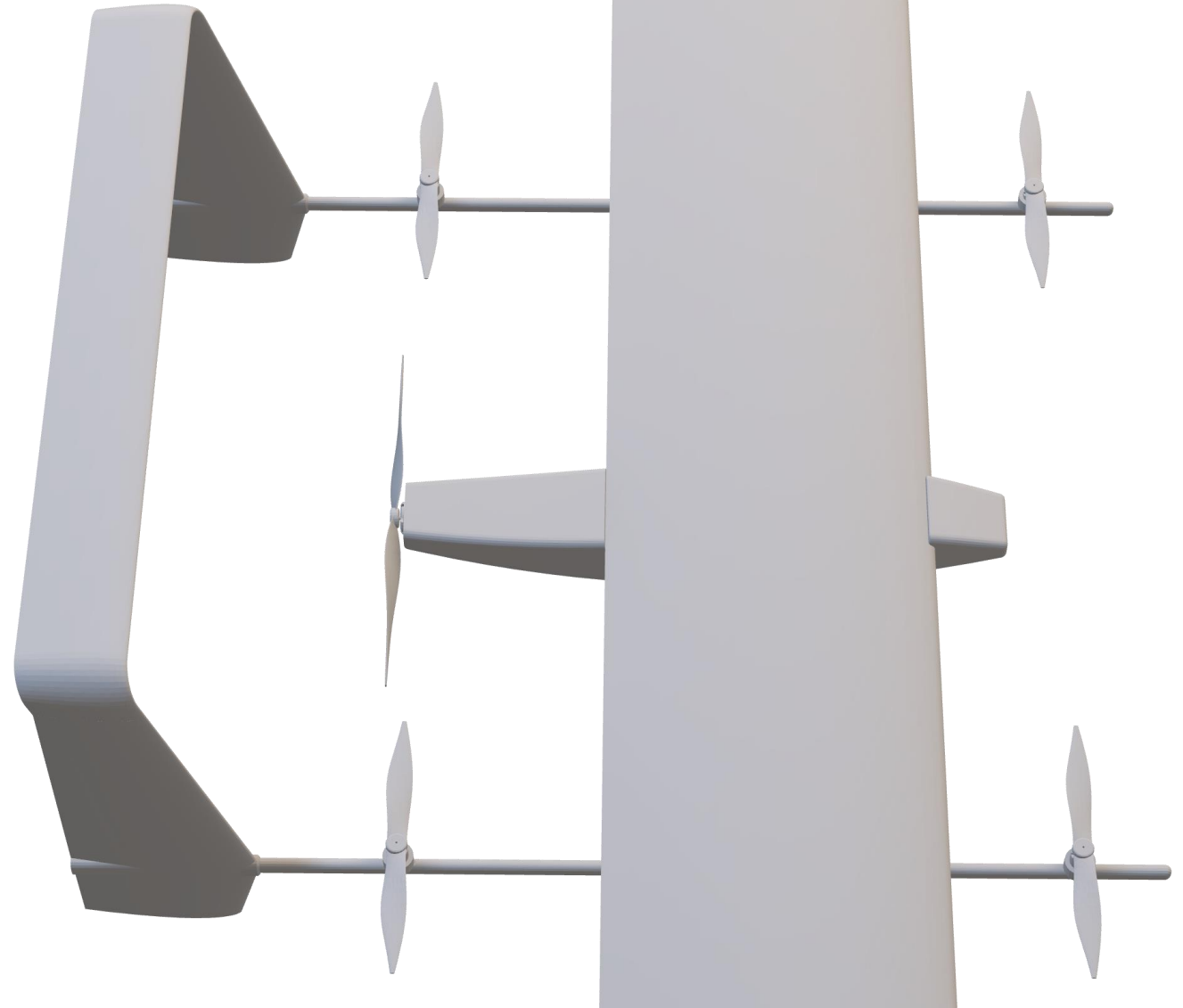
Aeroacoustic Optimization



Benefit of VTOL Configuration

Cruise and Takeoff/Landing propulsion systems are designed for different flight conditions.

Cruise optimized for minimal SPL in cattle sensitive frequency range.



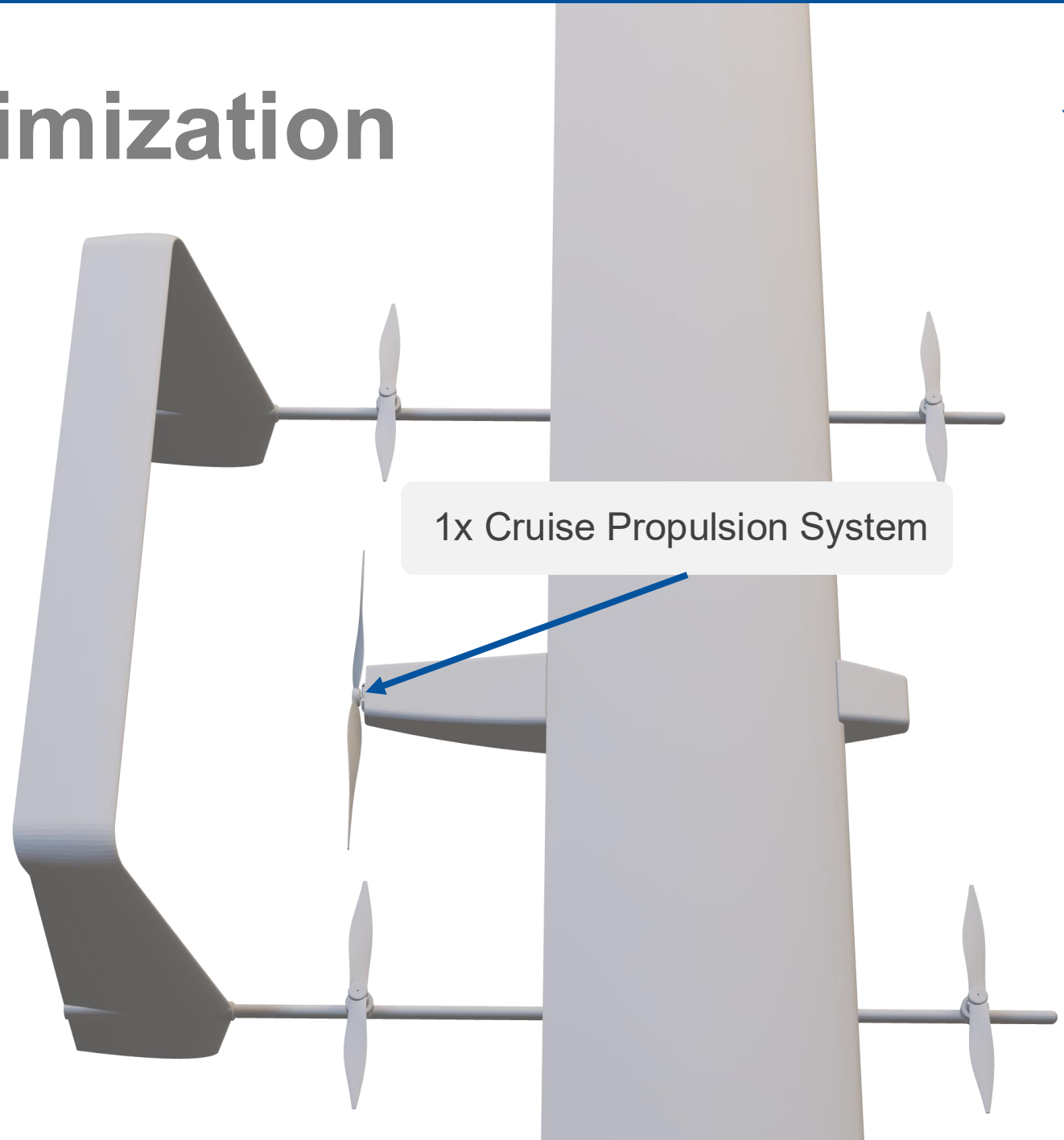
Aeroacoustic Optimization



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Aeroacoustic Optimization

Identified and Down-Selected Solutions

Electric Ducted Fan (EDF)

- Higher BPF and lower SPL in broadband/tonal noise.
- Heavy, higher manufacturing complexity.



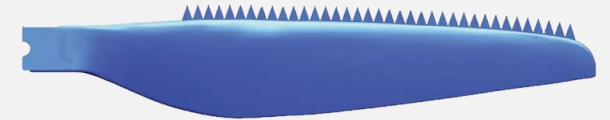
Traditional Propeller

- Slightly elevated BPF SPL magnitude, can be decreased by lowering RPM.
- Weight efficient.



Bio-Mimetic Propeller

- Increased acoustic reduction and thrust.
- Increased manufacturing complexity and cost.





Aeroacoustic Optimization

Methods of Propeller Sound Reduction

Increasing span and reducing RPM.



Decreases magnitude and frequency of BPF.

Decreasing local angle of attack across spanwise portion of blade.



Decreases magnitude of tonal/broadband noise, lower pressure gradient, lower thrust.

Increasing chord length toward tip of propeller.



Larger area allows for decreased loading on propeller.



Conventional Propeller Geometry

Aeroacoustic Optimization



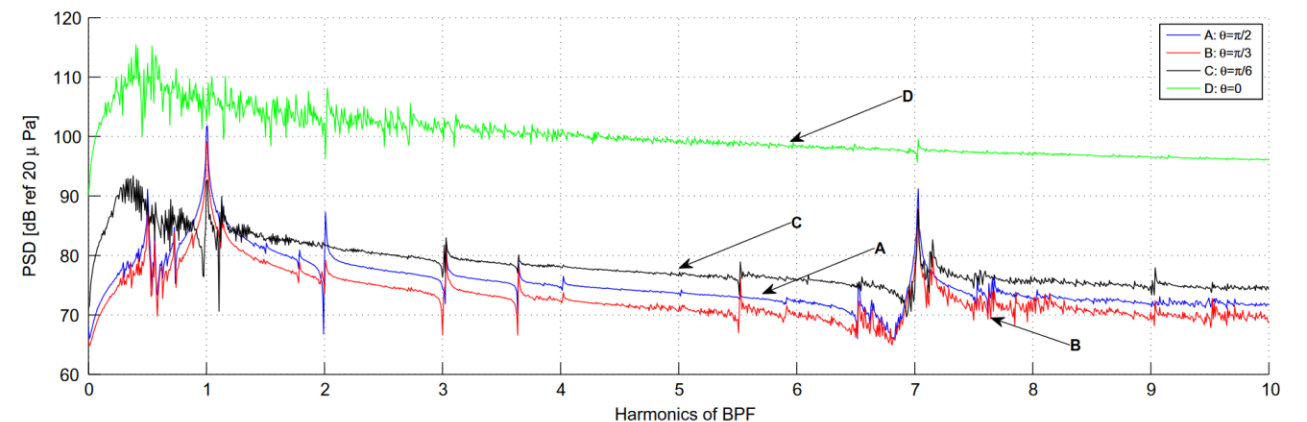
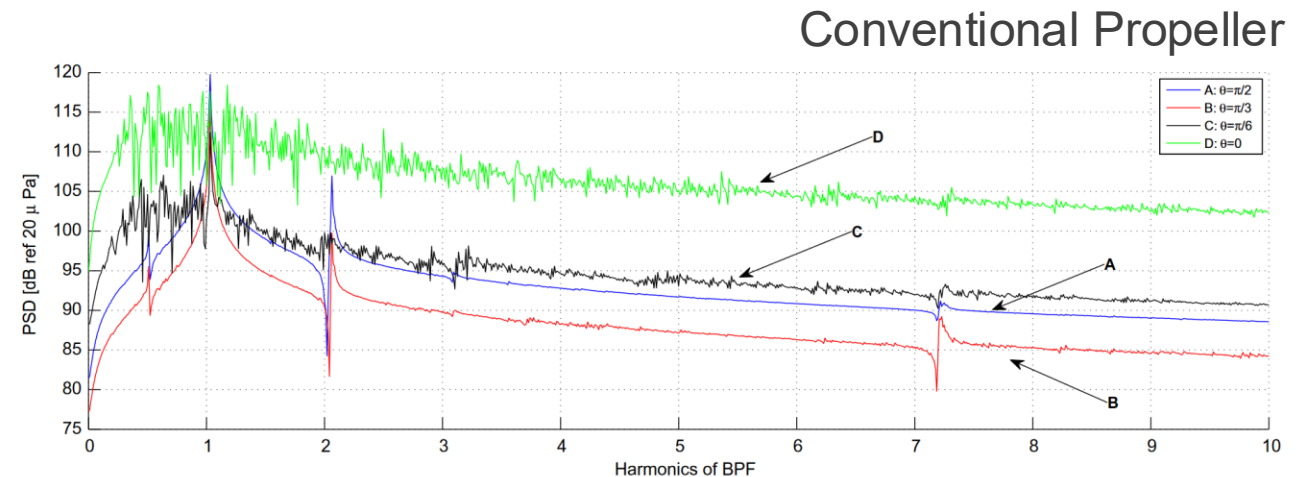
Existing Research Results and Application

Chord Length increased between 60% and 80% spanwise radii.

Angle of attack decreased overall, particularly at inner spanwise locations.

Geometry changes decrease SPL across most BPF harmonics by 5 dB.

Additional decreases in tonal/broadband noise by up to 12 dB in 8 kHz range.



Modified Geometry

Aeroacoustic Optimization



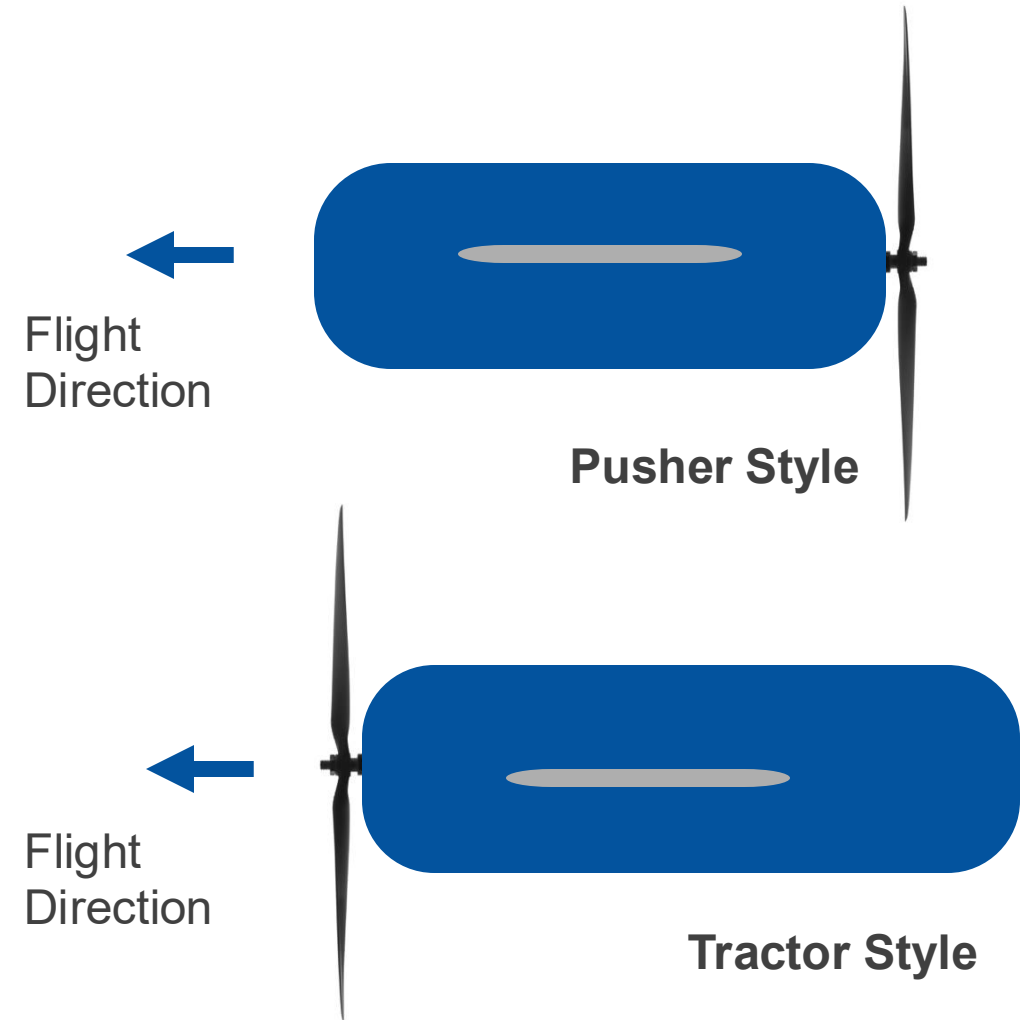
Tractor vs Pusher UAV Design

Tractor style propeller placement used due to heavier sensor payload in fuselage.

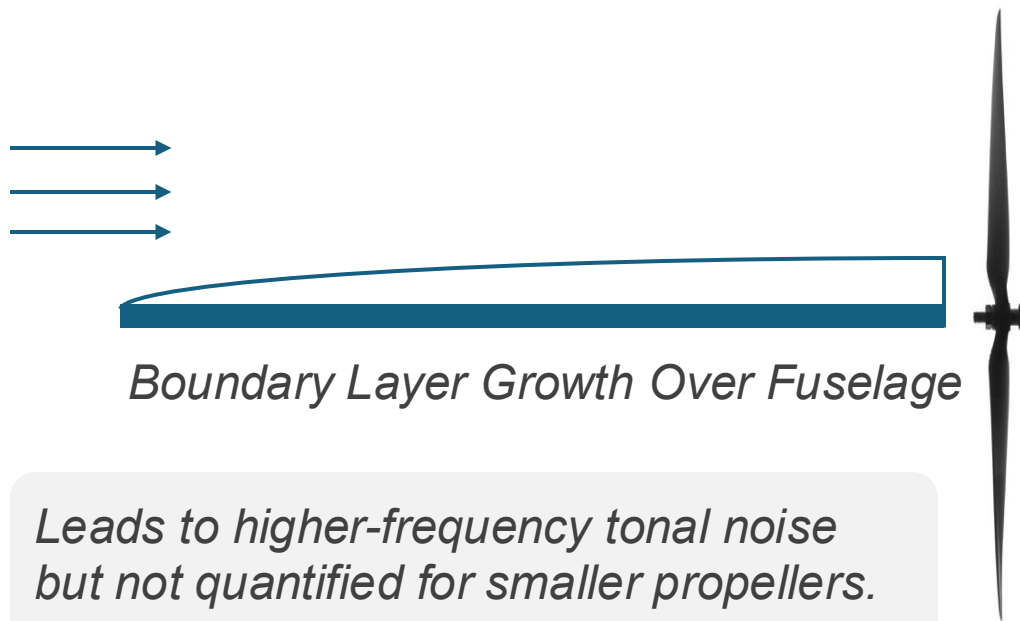
Balancing CG (Center of Gravity) is essential for aircraft stability.

Further aft CG allows for a smaller vertical stabilizer decreasing weight.

Turbulent wing wake and fuselage boundary layers cause inflow turbulence.



Aeroacoustic Optimization



UAV Scale Propellers with Turbulent Inflow

Gap in research for small-scale turbulent inflow aeroacoustic research.

Limited research into viscous effects from fuselage and wing interaction.

High-resolution studies (simulation and experimental tests) only performed on larger propellers; scaling effects and effects on pusher-style propulsion systems not extensively studied.

Aeroacoustic Optimization

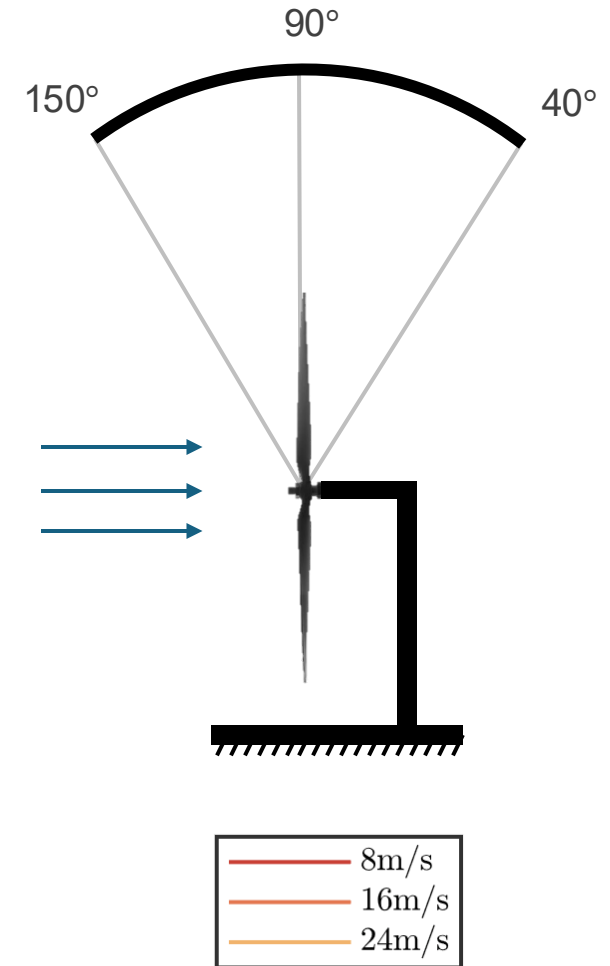
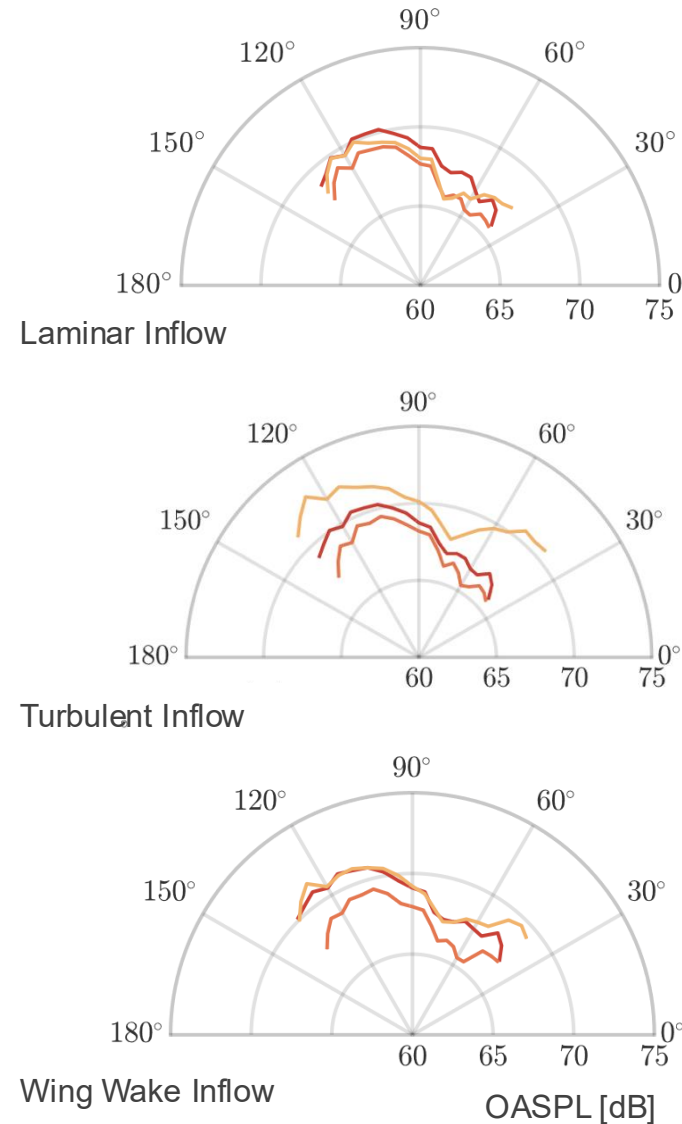


UAV Scale Propellers with Turbulent Inflow

Turbulent Inflow and wing wake interactions increase SPL.

Limited research into viscous effects from fuselage and wing interaction.

Frequency increases with turbulent and wing wake inflow, higher SPL in frequencies cattle are sensitive to.



Data via Jamaluddin et al. 2021

Aeroacoustic Optimization

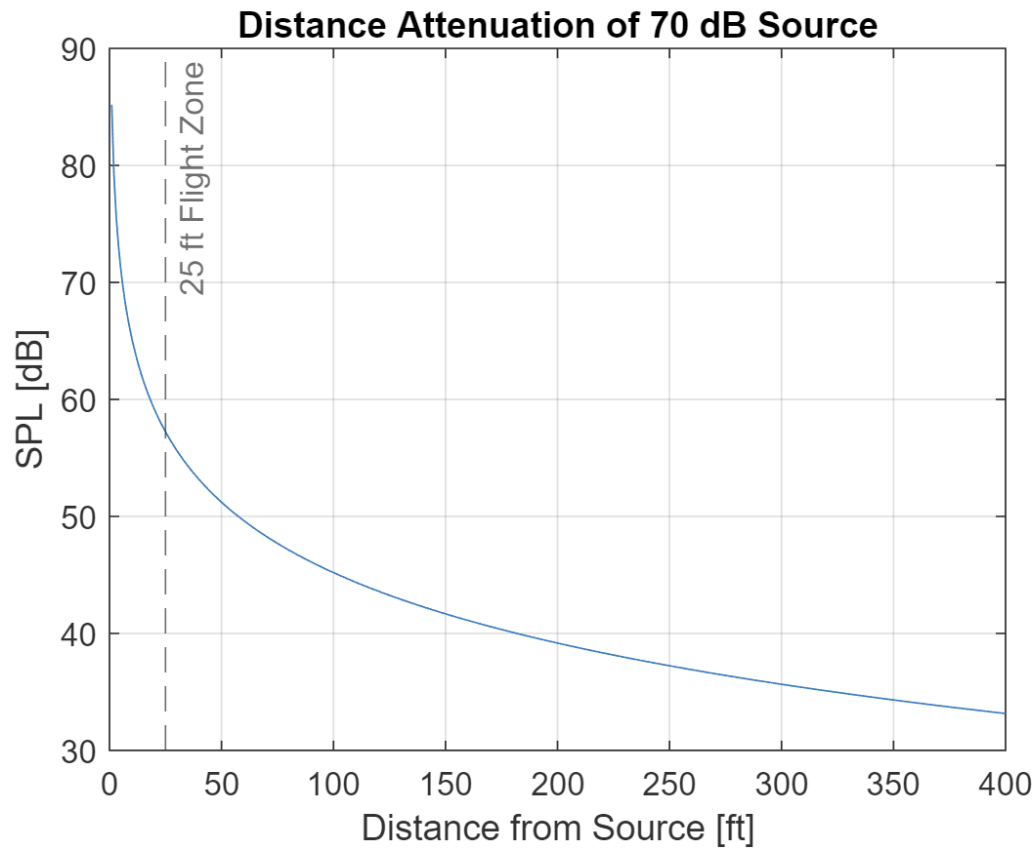


Distance Attenuation of Turbulent Case

SPL decreases as distance from source increases.

For defined 3D flight zone minimum, SPL remains below 58 dB.

$$SPL_2 = SPL_1 - 20 \log_{10} \left[\frac{R_2}{R_1} \right]$$



Cattle Monitoring

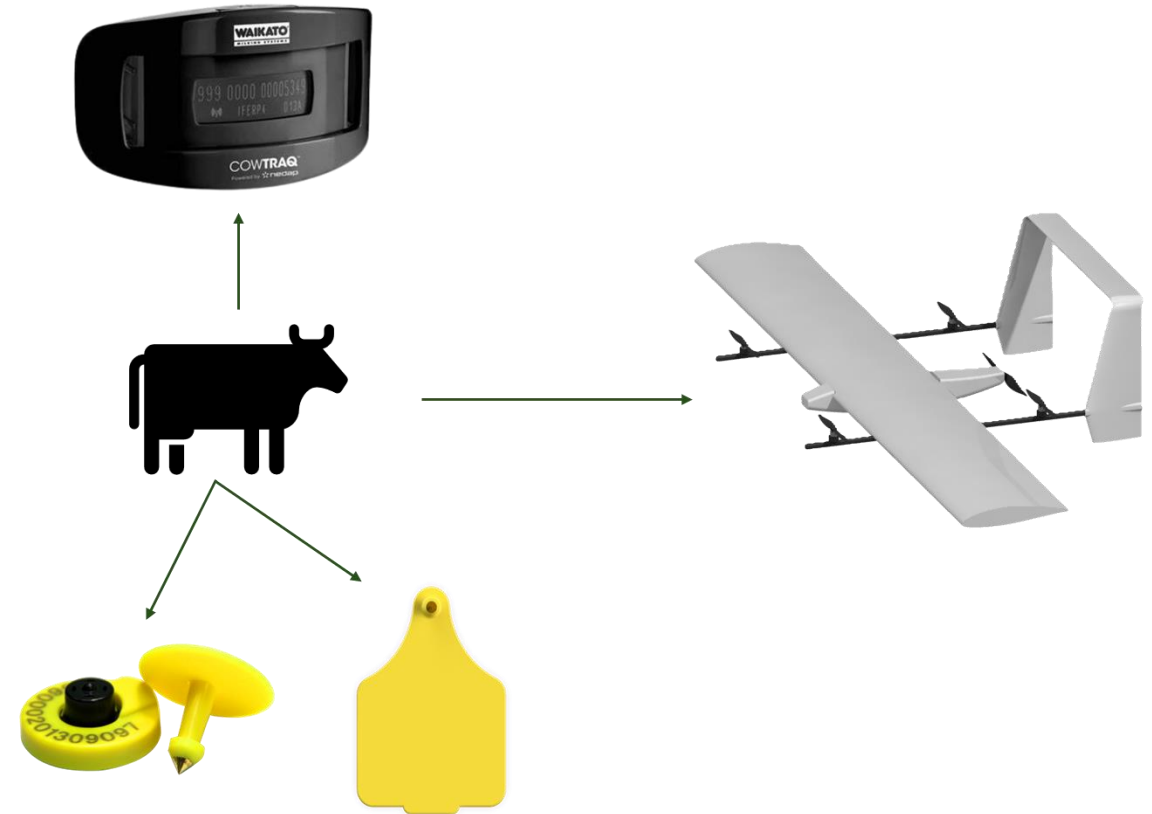


Monitoring and Tracking Capabilities

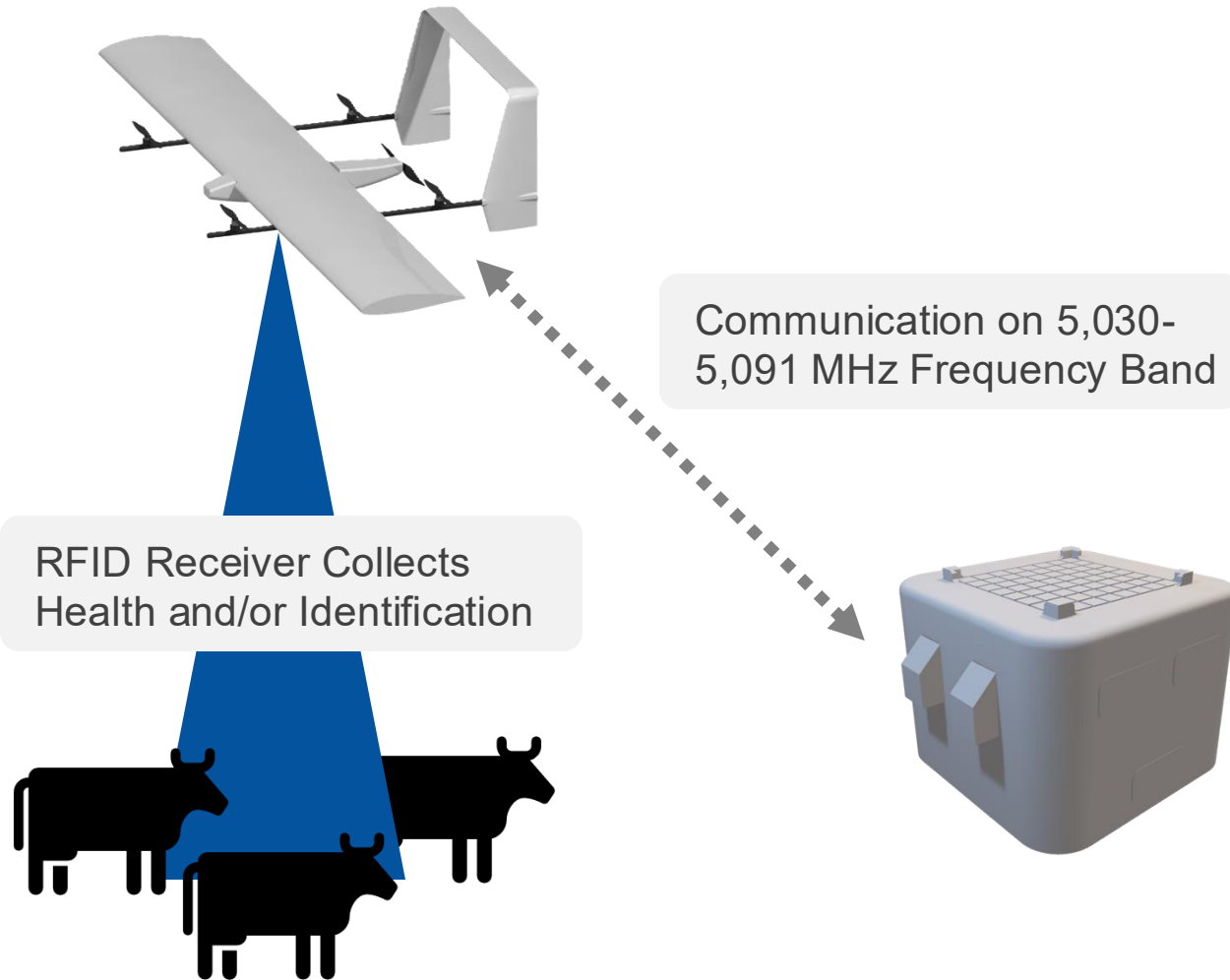
RFID ear tag required for all tracking subjects. Standard ear tag used to reduce cost.

Optional health-monitoring collar (CowTraq) for vulnerable populations.

Both CowTraq and ear tags communicate with UAV via RFID.



Cattle Monitoring



Monitoring and Tracking Capabilities

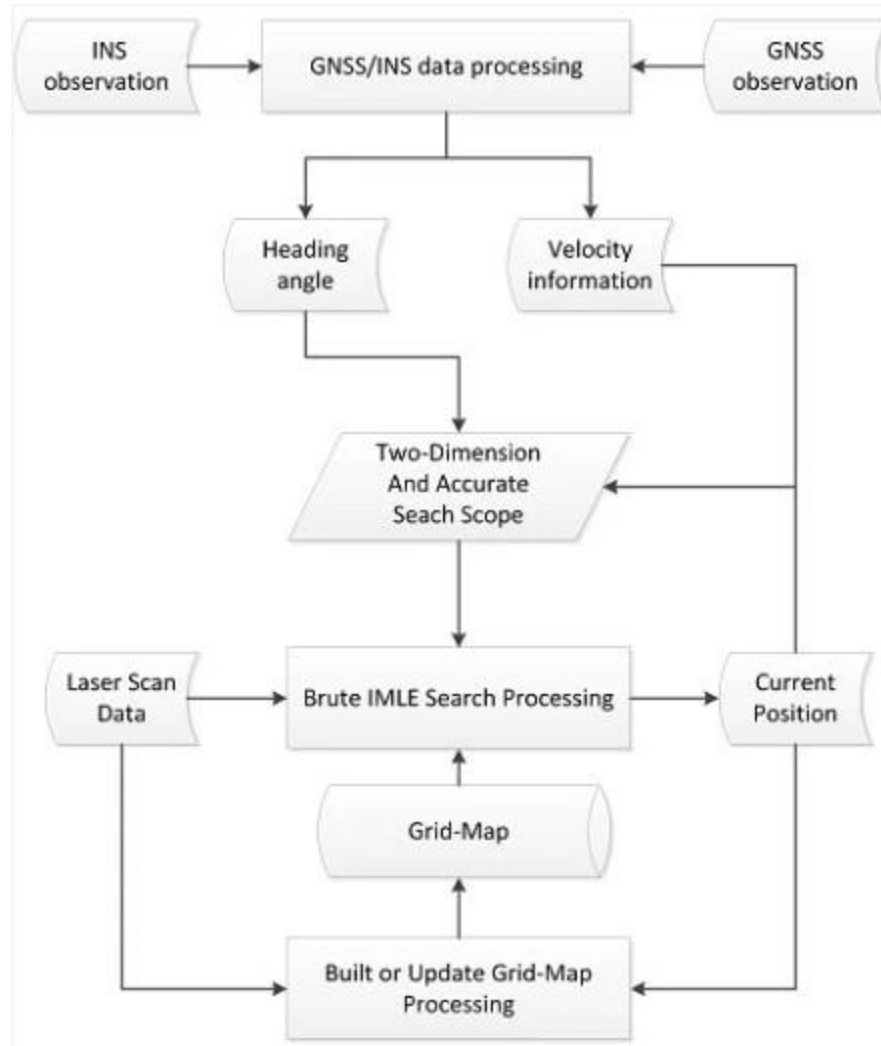
RFID position and health data is collected in the receiver field of view.

Location of UAV is reported to base along with herd data at the reported position.

Defined map area is surveyed and results are summarized for end user.



GNSS/INS/SLAM Integration



Integration Capabilities

Tightly coupled integration offers navigation capabilities in remote areas without consistent satellite coverage.

INS/GNSS sensors used to gather positioning information then passed to the SLAM algorithm.

SLAM algorithm utilizes positioning information to map and continue traveling in designated area.

GNSS/INS/SLAM Integration

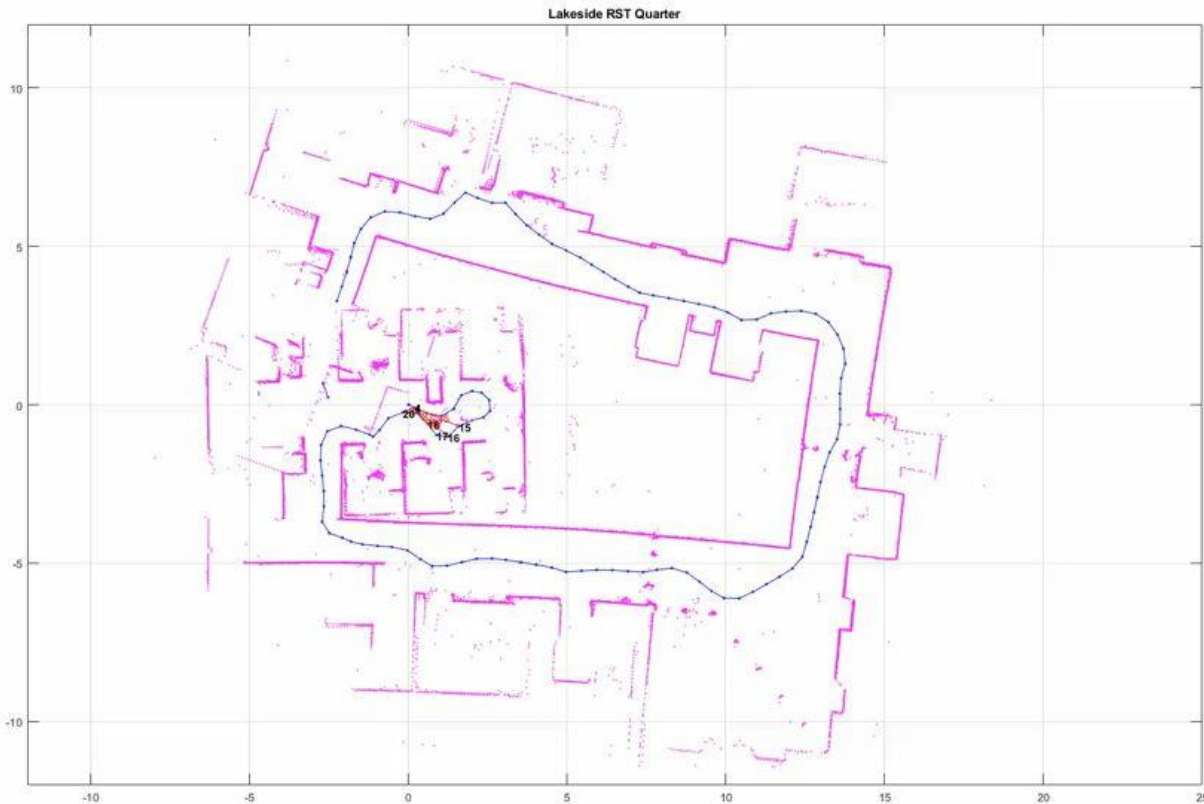


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Battery Technology

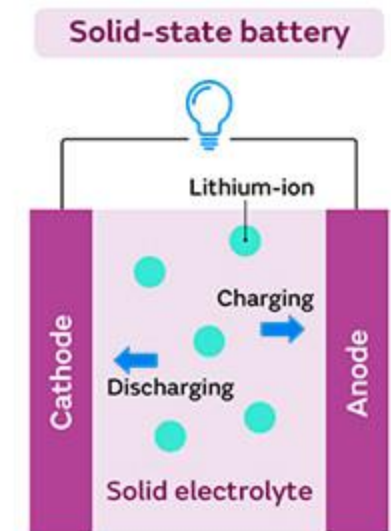
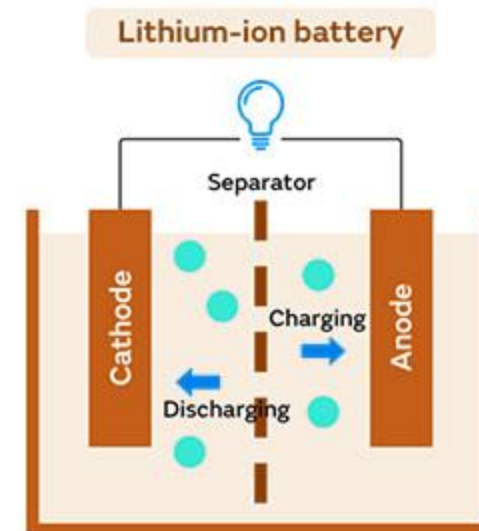
Solid State Battery (SSB) vs. Liquid State Battery (LSB)

SSBs offer increased energy density capabilities.

SSBs utilize less materials than their LSB counterparts.

SSBs charge faster and more efficiently.

SSBs provide a more stable electrolyte composition, increasing safety.



Budgeting for R&D



Software	Estimated Cost
Slam Algorithm Integration	\$10,000
GNSS/INS Sensor Fusion	\$6,000
Communication Protocol	\$5,000
User Interface	\$2,000
Total Cost of Software Development	\$23,000

Testing	Estimated Cost
Wind Tunnel Testing (9 hours)	\$9,900
ANSYS Discovery CFD simulations	\$5,000
Battery Load	\$5,000
Field Testing (Flight Trials)	\$3,000
Testing Equipment	\$1,000
Total Testing Cost	\$23,900

Development of Software System and Experimental Testing

Software development was evaluated with two hours rates. \$100/hour for complex development and \$50/hour for UI development.

Physical testing includes rates from research allocated wind tunnels, software license, and battery testing materials.



Cost and Return on Investment

Internal Systems	Cost
4 Brushless 2,020Kv Motors (VTOL motors)	\$180.00
1 Brushless 1,750Kv Motor (main power motor)	\$43.00
Solid-State Battery	\$720.18
RF Transceiver and Antenna	\$70.00
GNSS module	\$650.00
SONY IMX 415 Camera Sensor	\$69.99
SLAM Application Module	\$250.00
Total Cost	\$1,983.17
Support Systems	Cost
CowTraq Neck Collars	\$48,000.00
Electronic Ear Tags	\$1,000.00
Landing Pad Computer System	\$1,250.00
Skycharge Conductive Charger	\$6,386.25
Internal Electronics of Landing Pad	\$180.00
2 Landing Pad Batteries	\$3,143.50
Total Cost	\$59,959.75

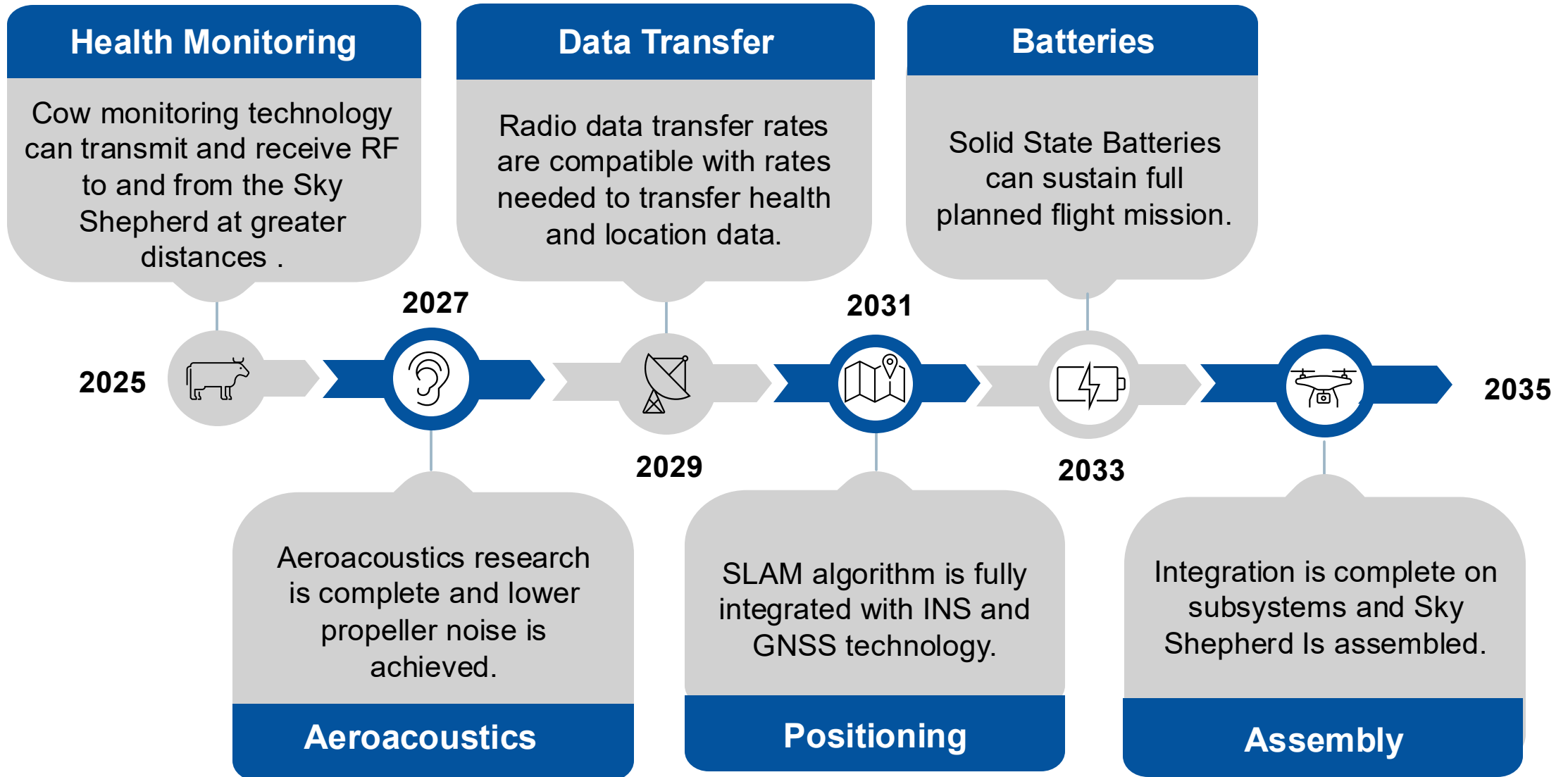
Hardware Costs

Prices of items with a tech readiness level of 9 were evaluated using their current prices.

Increased prices were used for items that still need to be researched. Such as the SSB.

The total cost of Sky Shepherd is \$61,942.92. A rancher saving \$1,200 a week will take roughly one year to have a positive annual ROI of 100%.

Deployment Timeline



QUESTIONS

COLLEGE OF ENGINEERING | DEPARTMENT OF
ENGINEERING FUNDAMENTALS

EMBRY-RIDDLE
Aeronautical University

EMBRY-RIDDLE
Aeronautical University

NASA'S

G A T E W A Y S T O

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