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Edinburgh, UK

July 18 - 21, 2016

Integration of SE Design Principles in a Capstone Design Course

--The Airborne Birdstrike Countermeasure--

Jeff Newcamp

United States Air Force Academy

Systems Engineering Program

19 July 2016

Overview

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- Motivation
- Framing the Problem
- Course Design
- Designing a Solution
- Test & Evaluation
  - Human Factors Testing
  - Wind Tunnel Testing
  - Field Testing on Live Geese Populations
- Patent Progress
- Tenets for Successful SE Capstone Courses

Real SE Research for Real Customers

Motivation

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- The military now reports about 6,500 birdstrikes per year to its aircraft
- Large birds present the greatest danger
  - Damage to USAF aircraft alone:
    - Average 1.2 destroyed USAF aircraft per year
    - Average $32M per year
  - Loss of life
    - Average > 1 USAF fatality per year
- Operational impact is also significant
  - Elevated USAF Bird Watch Conditions restrict or suspend low-level routes and pattern operations
  - Airdrops impacted

Framing the Problem

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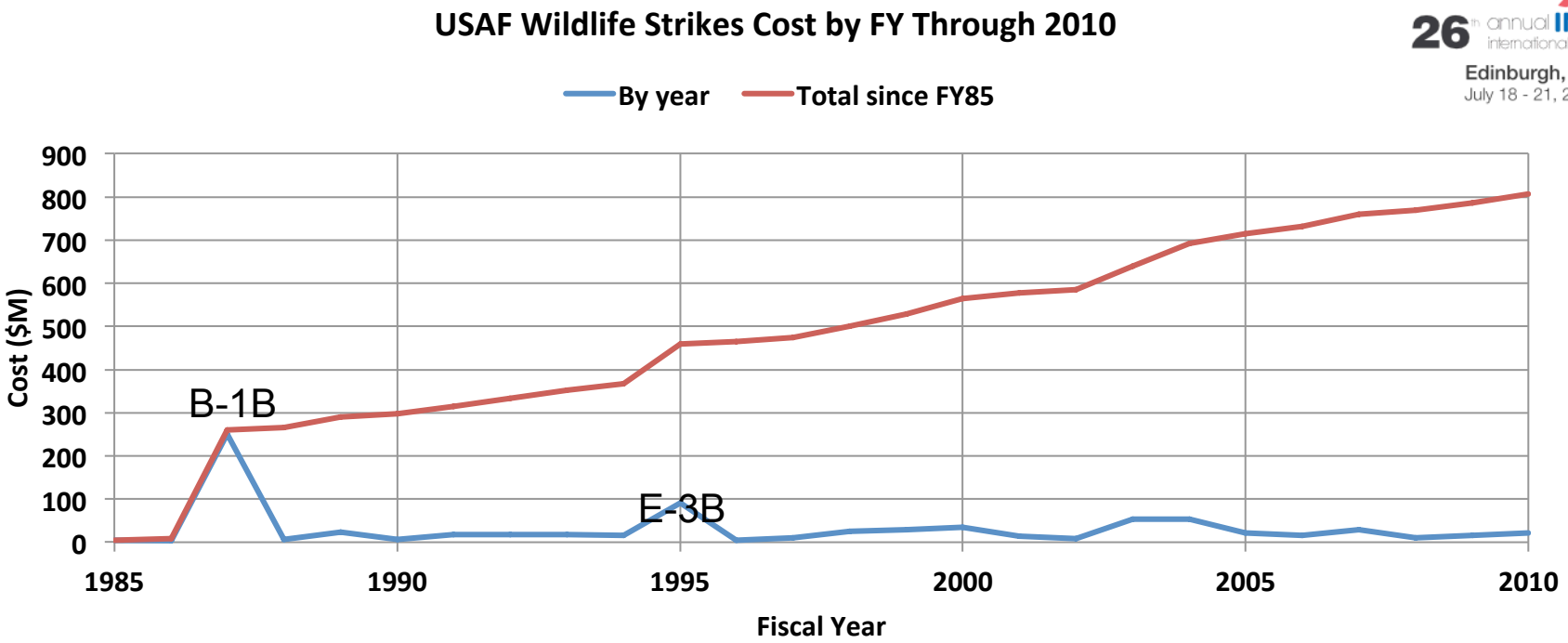

http://www.afsc.af.mil/organizations/bash/statistics.asp

Framing the Problem

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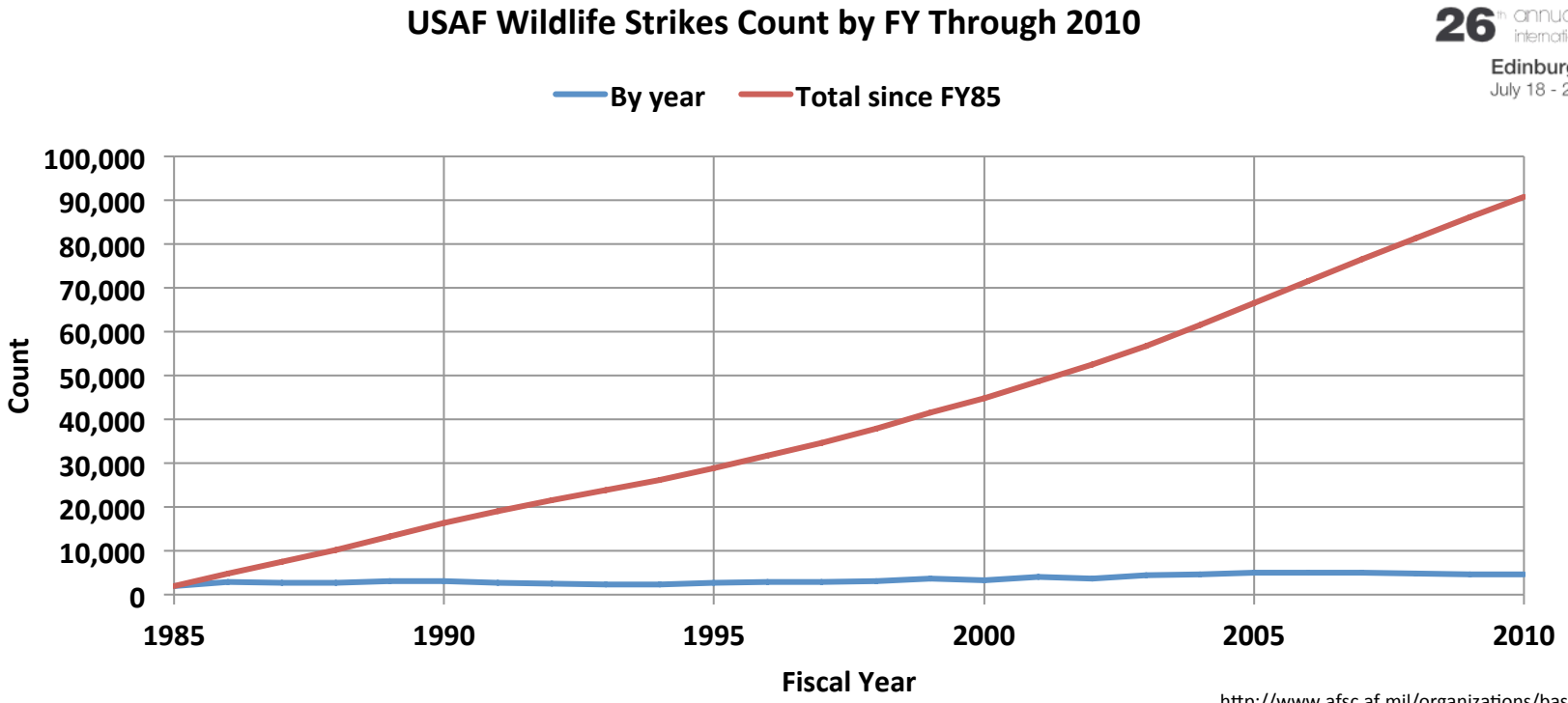

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Framing the Problem

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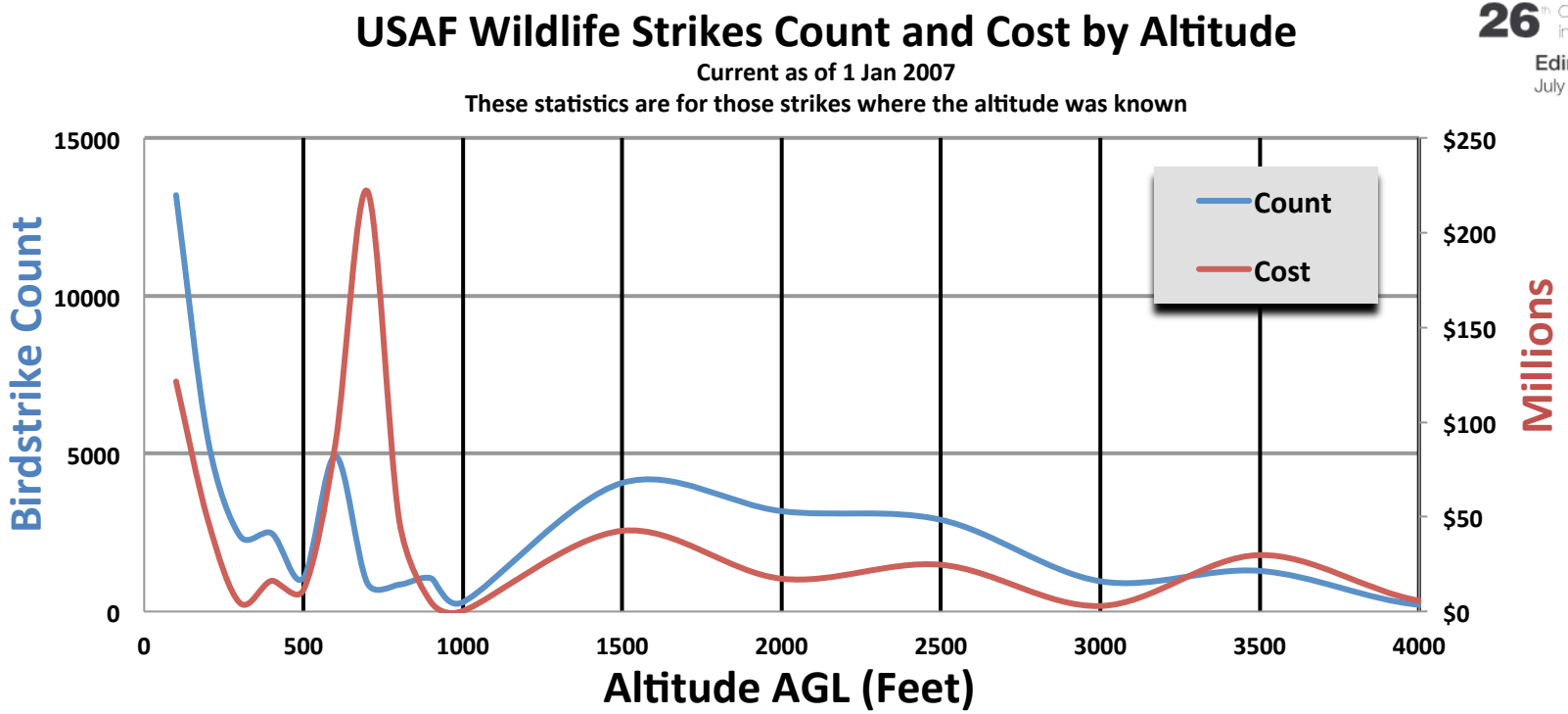
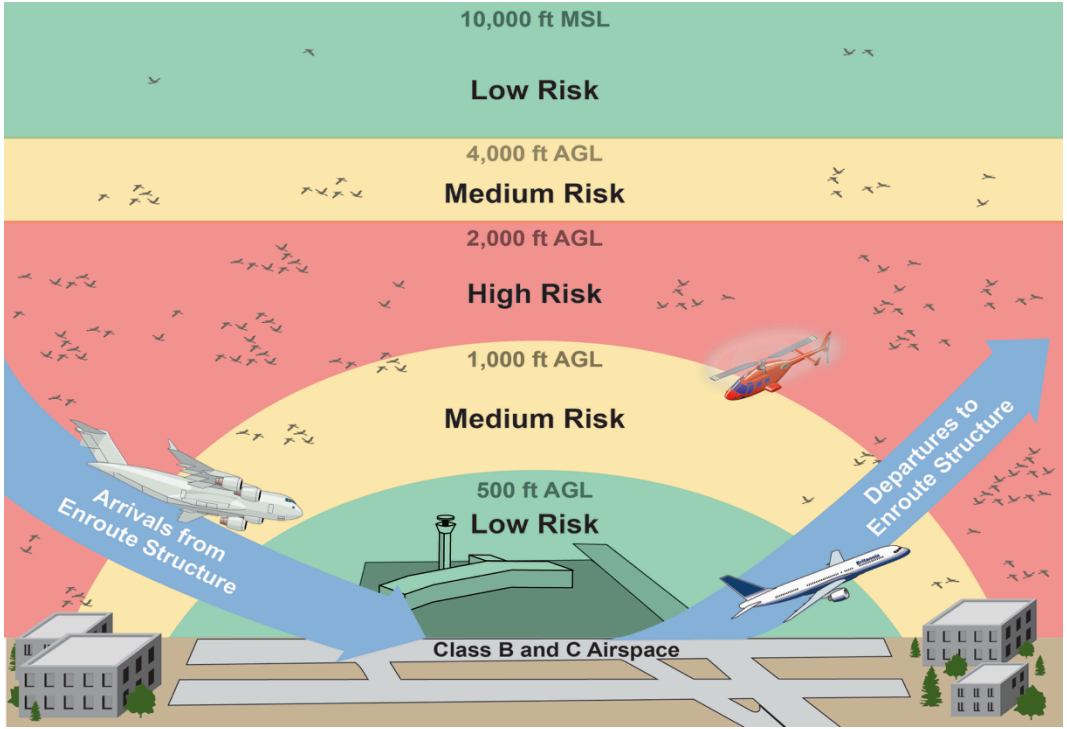


Airspace Risk Assessment



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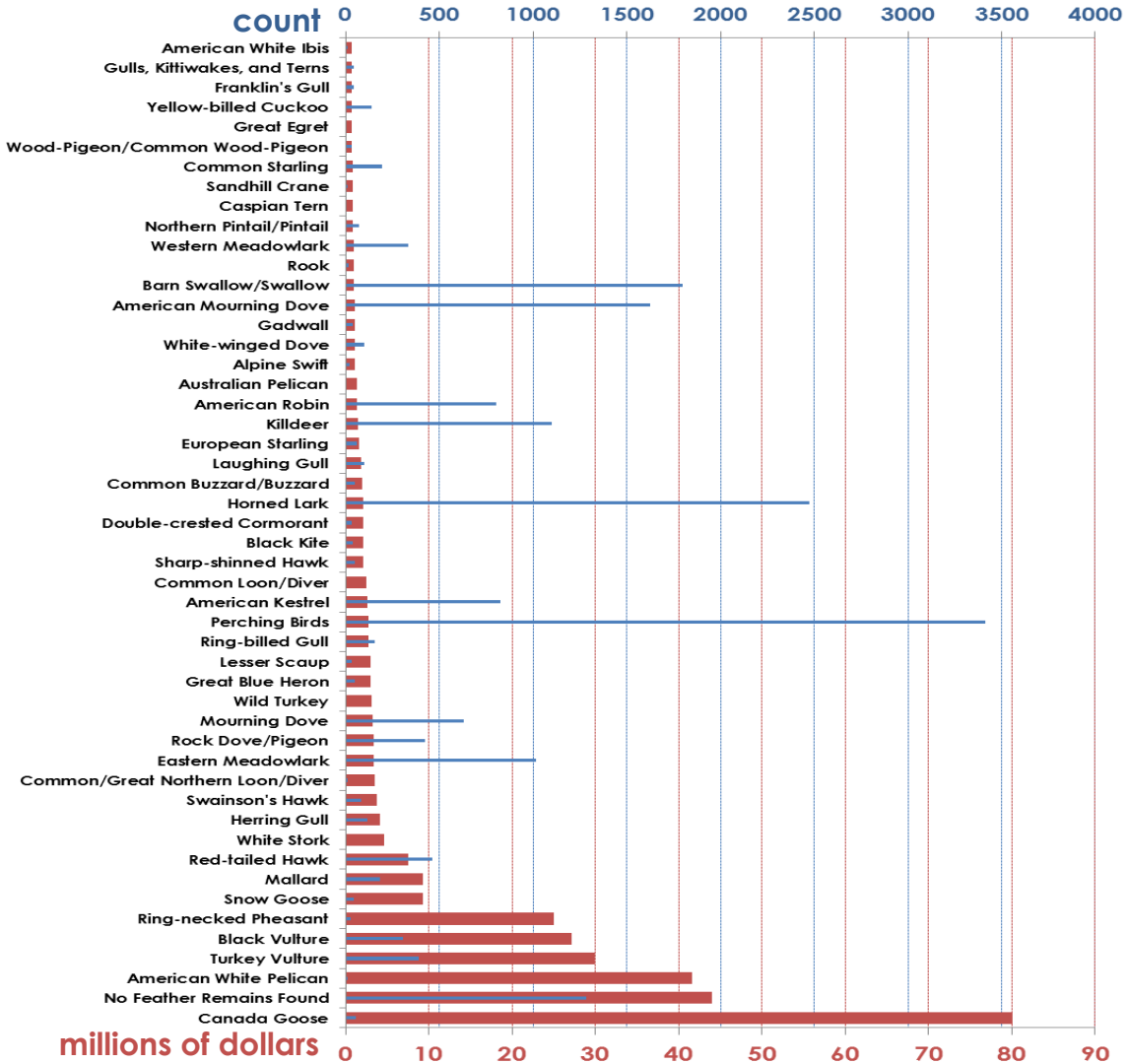
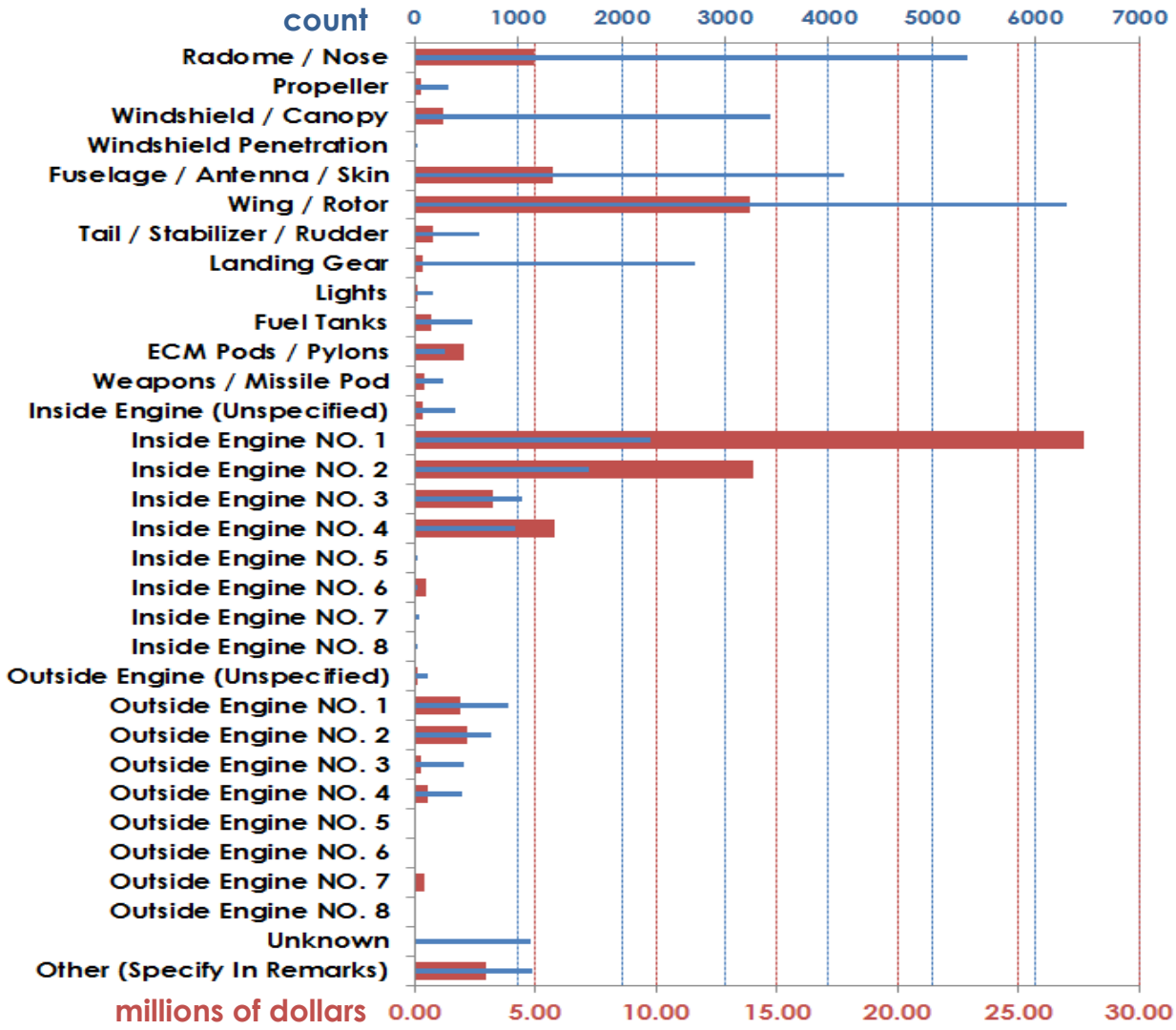
Threat Species by Altitude

Common Name	0-500 ft AGL	501-1,000 ft AGL	1,001-2,000 ft AGL	2,001-4,000 ft AGL	4,001-10,000 AGL
Albatrosses, Petrels, Shearwaters, Fulmars, Diving Petrels, Storm Petrels	1	0	0	0	0
Cranes, Rails, Bustards, etc.	26	34	25	11	5
Ducks, Geese, and Swans	119	90	121	41	11
Grebes	11	4	1	1	1
Hawks, Eagles, Vultures, Falcons, etc.	932	291	210	105	25
Herons, Storks, Ibises, Flamingos, Etc.	120	16	18	9	1
Jacamars, Puffbirds, Toucan, Woodpeckers, etc.	12	7	13	9	2
Kingfishers, Motmots, Hornbills, Bee-eaters, etc.	12	0	1	0	0
Loons/ Divers	3	4	4	2	0
Megapodes, Guans, Quails	40	3	2	2	2
Nightjars, Frogmouths, Potoos, etc.	139	20	28	12	2
Owls, Barn-Owls, Screech-Owls, Scops-Owls, etc.	101	8	5	0	2
Parrots, Parakeets, Macaws, etc.	1	0	0	0	0
Pelicans, Cormorants, Shags, Boobies, Tropicbirds, Frigatebirds, Darters	12	10	13	7	0
Perching Birds	4709	966	942	519	167
Pigeons, Doves, Dodos, and Sandgrouses	1210	74	70	33	15
Shorebirds	1016	145	129	51	26
Swifts, Crested Swifts, and Hummingbirds	362	144	81	48	19
Turacos and Cuckoos	20	13	19	5	1

AFSC BASH Statistics 1995-2010

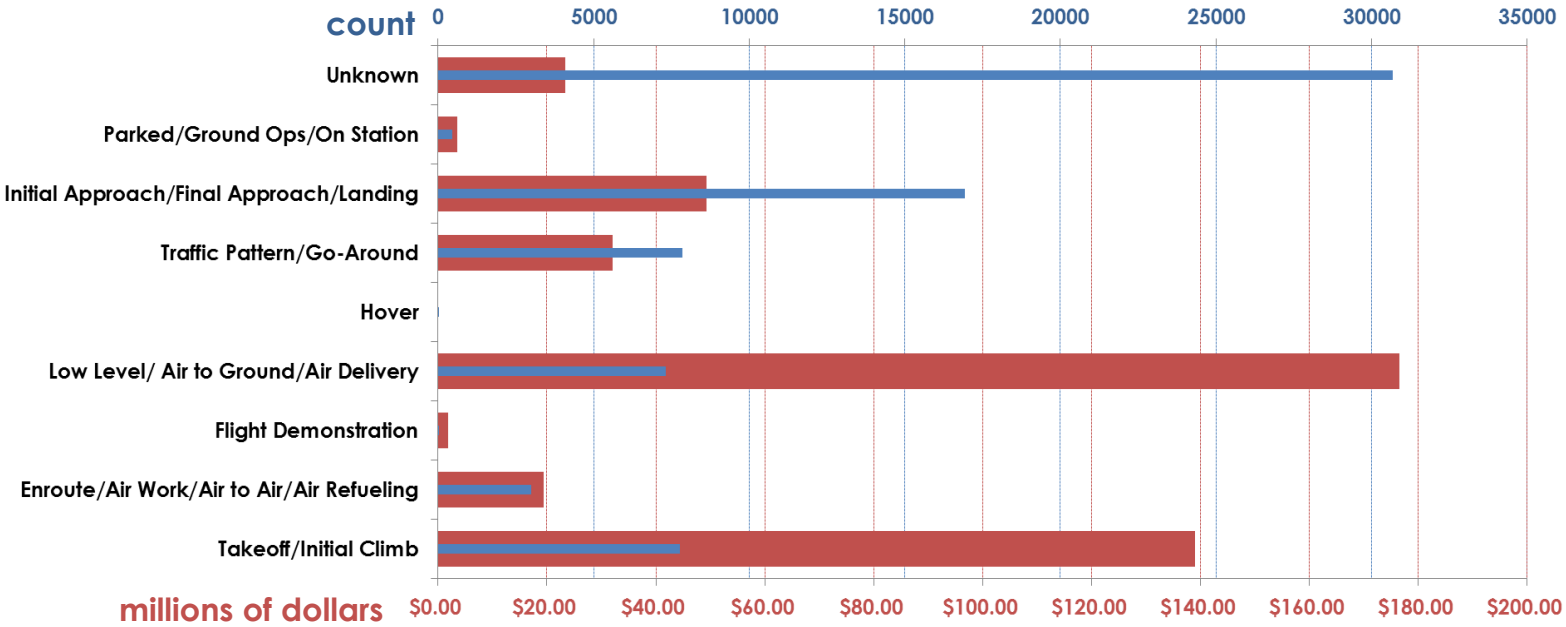


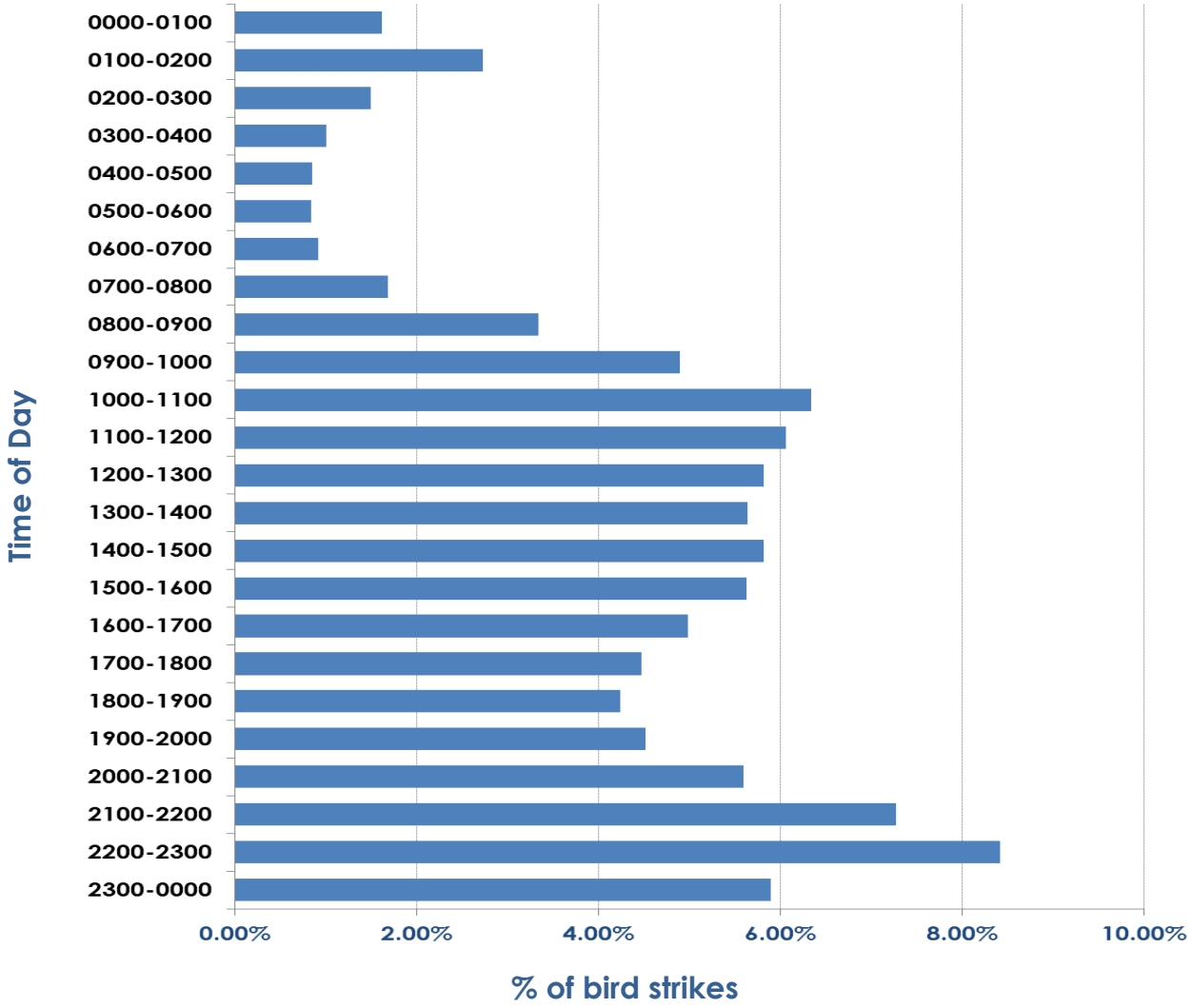
Species by Cost



Impact Point

Aircraft Phase of Flight





By Time of Day

Canada Goose

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- Largest risk to aircraft
- 30-43 in height
- 4.2-5.6 ft wingspan
- 6.6-19.8 lbs
- Yearly increase in numbers a concern

Canada Goose in Flight

Phases of Flight - Geese

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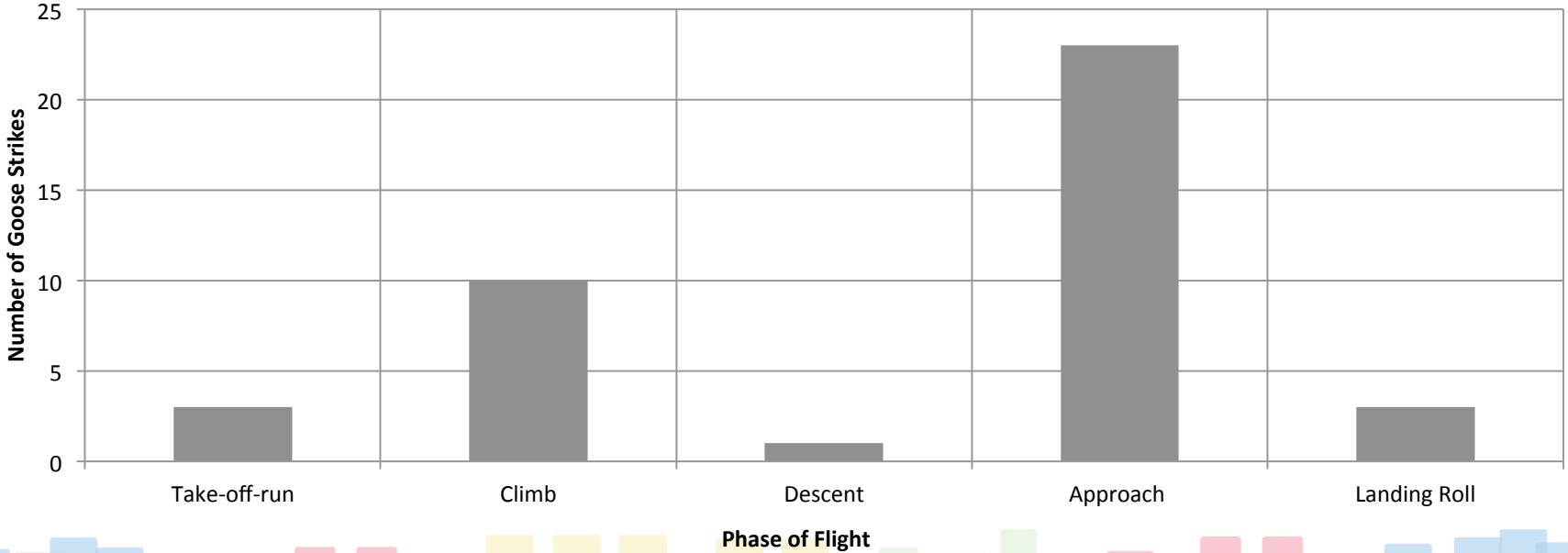
Data Source: FAA
Bird Species: Goose

Airlines: US Airways, UPS, Alaska Airlines
Phase of Flight: All

Dates: 1990-2013



Altitudes for Goose Strikes

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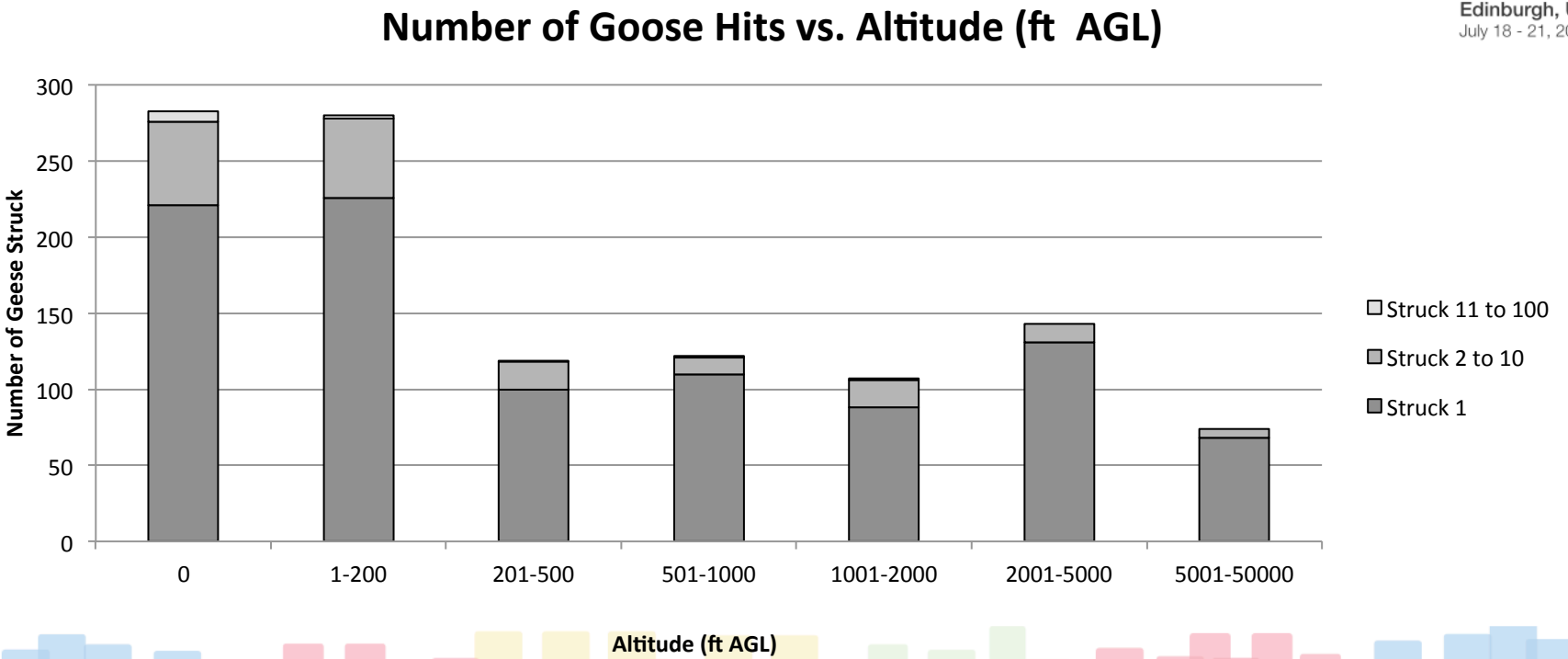

Requirements

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- System must be capable of deterring birdstrikes
- System must be always-on during high-strike probability phases of flight
- System must not endanger ground personnel, the public, other aircraft or occupants of aircraft
- System must be aerodynamically sound & certifiable by FAA
- System must increase net present value for operator
- Project must use cadet researchers

- Seed funding: $20k

Course Design

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- Two academic years (4 semesters). Rough breakdown:
  1. Conceptual/preliminary design
  2. Detail design
  3. Testing & design iteration
  4. Airframe integration & patenting
- Multidisciplinary team, led by Project Manager
- Seed money from FFRDC. Lab support from USAFA Mech & Aero

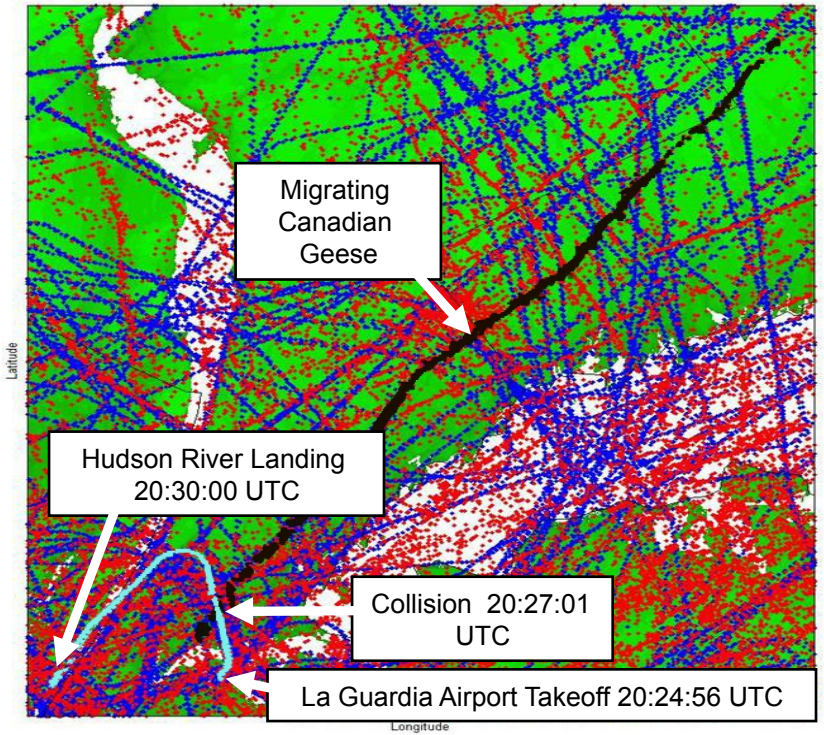
Academic Specialty	Number	Core Responsibility
Systems Engineering (Aeronautics)	6	Aerodynamics of sound system
Systems Engineering (Human Factors)	6	Pilot control of system, pax comfort & threat to other aircraft
Systems Engineering (Mechanical)	3	Integration of system onto aircraft
Biology	2	Field testing on avian species
Systems Engineering (General)	1	Project planning, safety and SE Management Plan
Systems Engineering (Electrical)	1	Wiring and integration of pulsing lights
Systems Engineering (Computer)	1	Software design

Course Design

- Systems + Engineering
  - Purchased COTS hardware
  - Fabricated specialty hardware (circuit boards, test rig)
- Regulatory requirements
  - IACUC (animal testing)
  - IRB (human testing)
- Assessment based on two tenets:
  - Successful application of SE knowledge to a candidate project
  - Solving a real customer's need
- Deliverables:
  - 60% individual (included team ranking of individual)
  - 40% team (primarily assessed by customer)

System Concept

- Case Study: US Airways flight 1549
  - Aircraft vectored into collision
- System architecture should eventually be developed to mirror TCAS advisories and provide resolutions
  - Enhanced bird radars to detect real time bird threats
  - Prediction algorithms
  - On-board resolution advisories
    - To initiate sound and/or light deterrent hardware
    - To change altitude or heading
- This tech is an “always-on” light and sound deterrent



FAA radar data 19:27-20:30 UTC (JFK, EWR)
Beacon tracks
Non-beacon tracks

Designing a Solution

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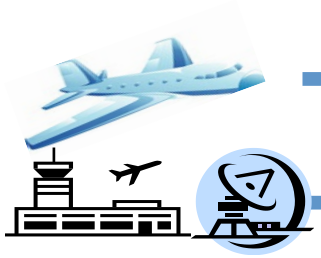


Detect

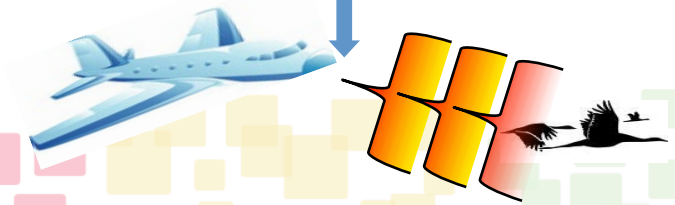
- Tactical Aircraft and Strategic Ground Radar
- ATC and Pilot (Visual)

Track, Prediction, Assessment & Warning

- Prediction Algorithms
- Models (BAM / AHAS)
- Threat Assessment
  - Bird Size/Number
- Targeted Aircraft Warning

Respond

- Tactical Airborne Deterrent
- Evasive Maneuver
- Bird Aircraft Strike Hazard (BASH) Management Techniques (AF Pamphlet 91-212)



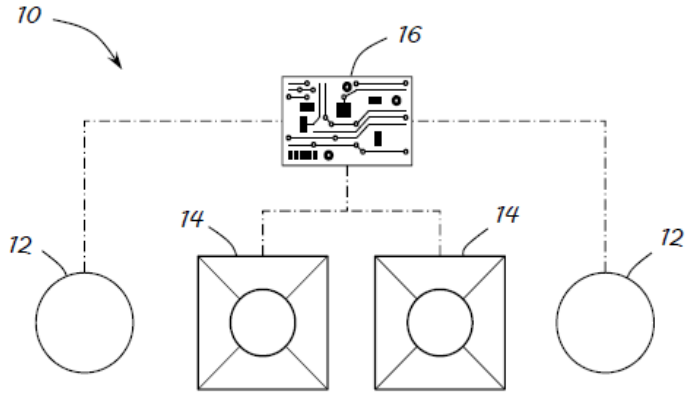
These elements are both strategic and tactical

Designing a Solution

- Design trade space: always-on airborne deterrent for < 10k ft AGL & < 250 KCAS
- Audio & visual countermeasure to provide all-weather solution

Schematic Labels:

- 10 – System
- 12 – Lighting
- 14 – Sound
- 16 – Flashing circuitry



Human Factors Testing

- The combination of light and sound was tested on human subjects flying a Calspan flight simulator
- Cognitive workload tasks were given to pilots flying a tracking task

Human Factors Procedure

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- All subjects given 2-min free flying to flatten learning curve
- Randomized 4 trials (2 w/ stimuli, 2 w/o stimuli)
  - 90-seconds each
  - 15 math/logic questions asked during each trial
  - 30-second breaks between trials
- Sinusoidal tracking task automated by software
  - Error measurements recorded for analysis

- No degradation in primary task (flying) was noted under worst-case scenario conditions (flashing light and sound)

Wind Tunnel Testing at USAFA

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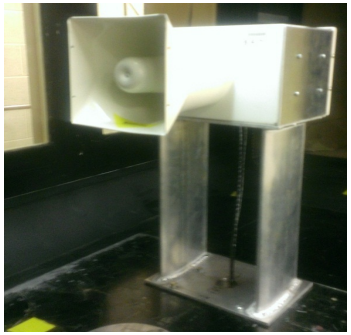
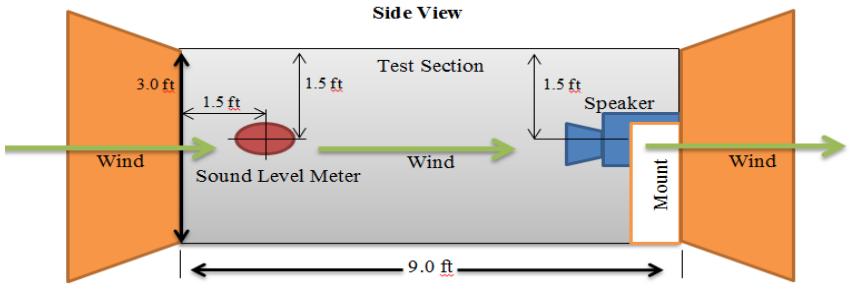
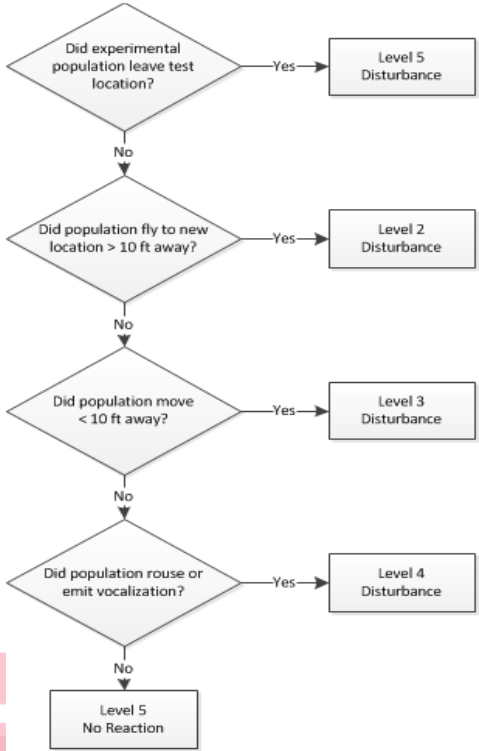
- A PowerSonix speaker was tested at wind speeds up to 250 kts at frequencies of 500 to 2000 Hz
  - It survived physically
  - Monotones at lower frequencies showed no decrease in sound output
  - The 2000 Hz tone decreased 9 dB at highest speed



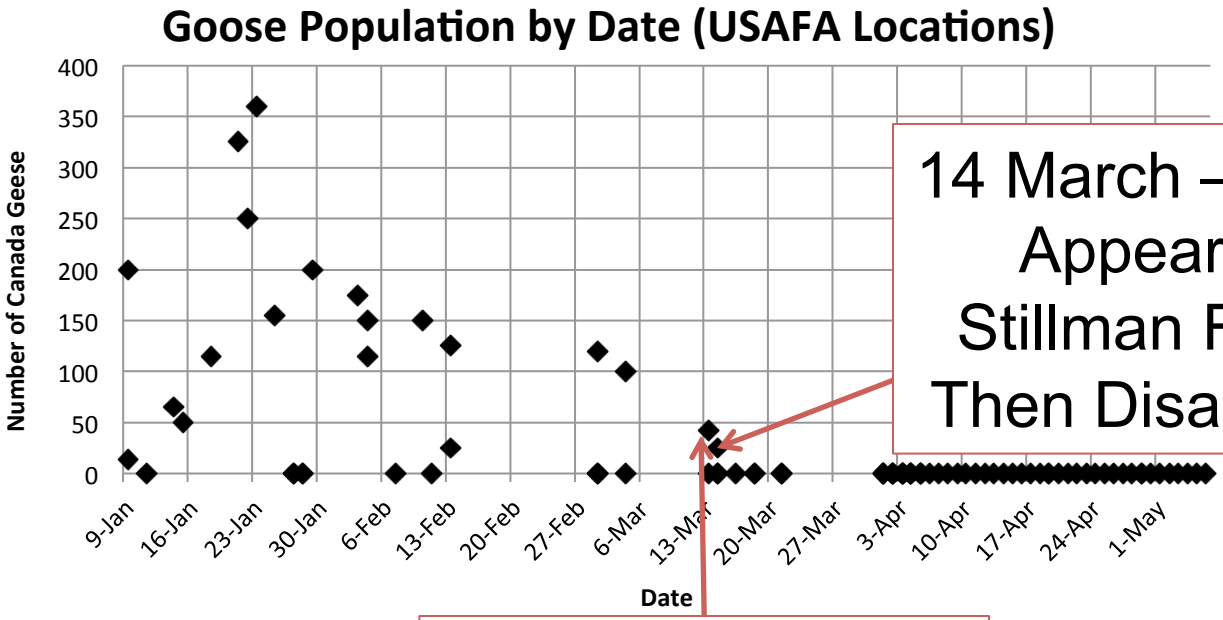


Field Testing

- Field tests of the light and sound system were conducted at three locations in the Colorado Springs area
- Combination of light and sound successfully deterred Canada Geese



Successful Ground Testing

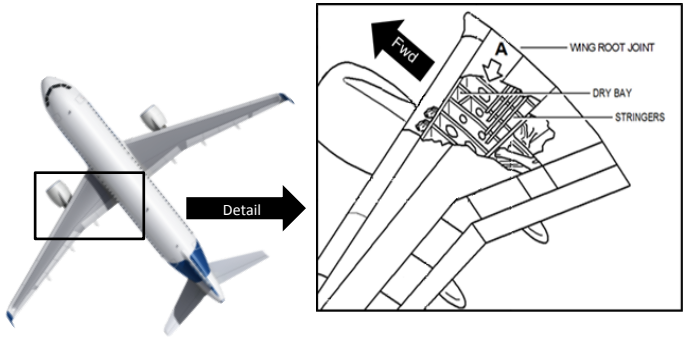


14 March – Birds Appear at Stillman Field, Then Disappear

13 March – Successful Test at Soccer Fields

Future of the Technology

- Proposed integration of ABC onto A320 wing (L & R)
- Placed in dry bay between fuselage and engine
- Capstone course unable to perform integration beyond just the trade study
- Partnered w/ US Airways for on-aircraft investigation



Patent Progress & Licensure

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- The Airborne Birdstrike Countermeasure is the combination of light and sound for in-flight tactical deterrence of avian species. Human factors, wind tunnel and field testing has proven its efficacy.

- Provisional patent awarded: U.S. Serial No. 61/939,377
- Full patent pending: U.S. Serial No. 14/885,623

- Capstone students did patent research study & completed forms for USPTO
- Valuable portion of SE project

Tenets for SE Capstone Success

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- Meaningful project w/ societal impact
- Frequent visits to/from customer
- Populate team w/ diverse academic backgrounds
  - Give each subgroup a different problem to solve
  - Maximize recruitment tools
    - Media, travel, extracurricular testing
- Eliminate resource barriers
- Fair but ruthless peer evaluation (#1 thru #n)
- Be engaged. Allow the professor to learn w/ the students

Give Them a Purpose & Let Them Explore

Disclaimer

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The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

Technology described in this presentation is patent pending.

Application: US 14/885,623
Date of Publication: 4 Feb 2016
Date of Application: 16 Oct 2015

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Backup

Acoustic Solution Space: 300-1200 Hz

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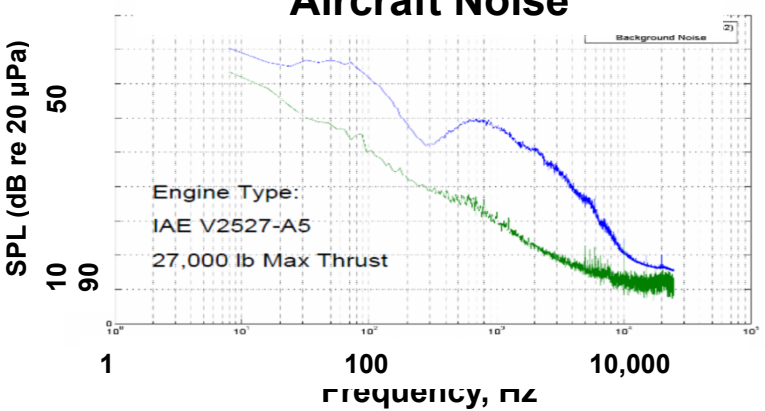
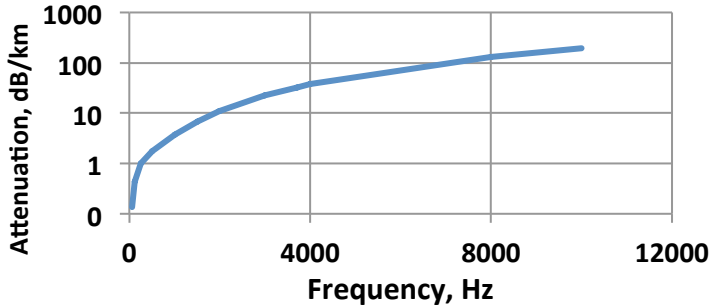
Aircraft Noise

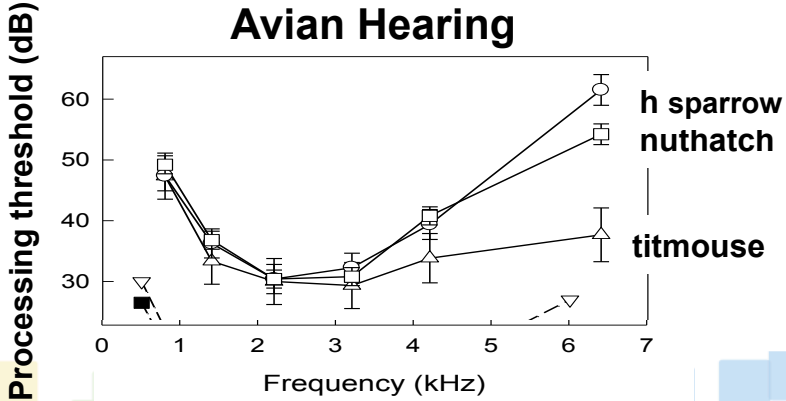


Atmospheric Attenuation



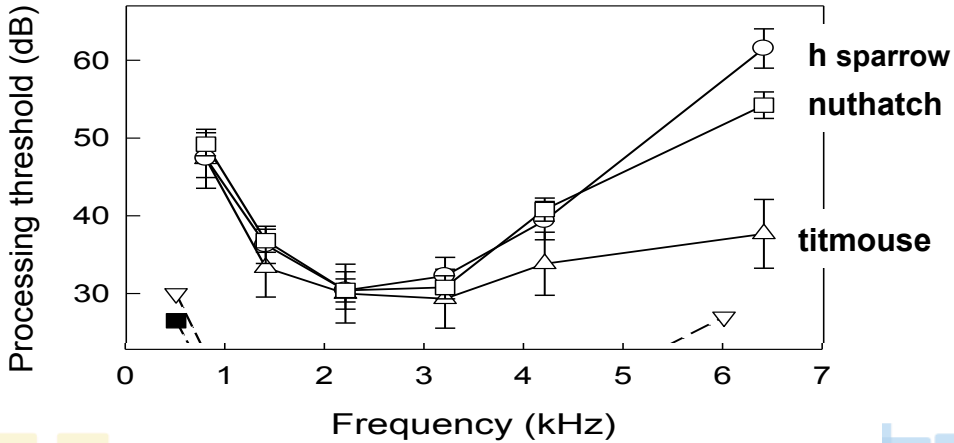
Wind Tunnel tests

Avian Hearing



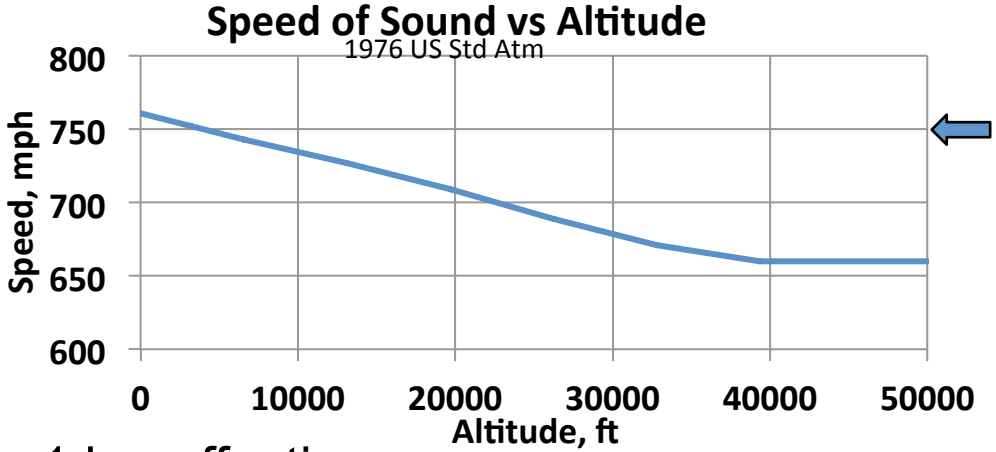
State of the Art Audio Testing

- Purdue University has performed tests to determine avian neurological responsiveness to sounds that could be expanded to threat species
  - Bird frequency responses are different than ours
    - Limited frequency range
    - Able to differentiate tones at 1/200 s
  - Capabilities of threat birds are only grossly understood
  - Tests can vary
    - Frequency
    - Frequency modulation
    - Amplitude
    - Amplitude modulation
    - Temporal spacing



Speed of Sound Limits Reaction Time

- Aircraft speed and speed of sound limit time for bird to react

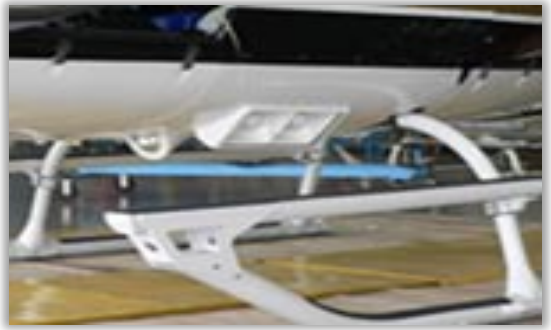


Sound reaches ahead 1 km in 3 sec

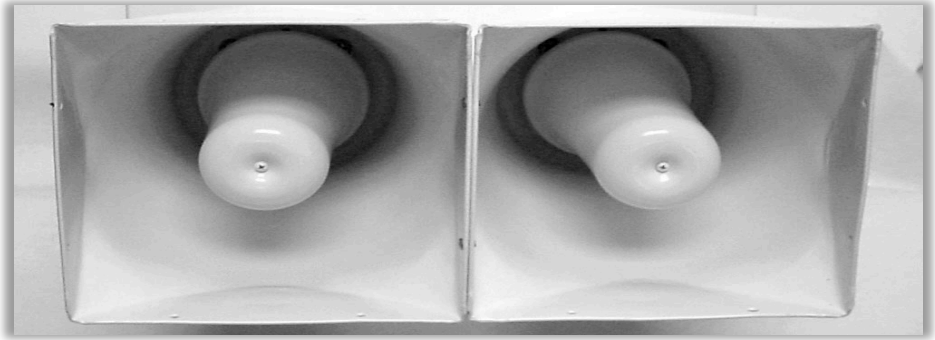
- Example for 1 km effective range
  - Aircraft at 200 mph (174 kts) at 3 kft travels 1 km in 11 sec
    - Reaction time is 8 sec
  - Aircraft at 250 mph (217 kts) travels 1 km in 9 sec, reaction time is 6 sec

Typical Speaker System

- Recent USAFA testing on a candidate speaker
- PowerSonix COTS loud hailer
  - 1200W, 151 dB at 1 meter, loud hailer with range to 2 miles



Installed under helicopter



Close up

Concept

- Recent testing has revealed avian responses to sound that possibly could be used to enhance airborne light systems
- Studies with humans may also provide insight into how to alert birds
- Systems that work on the ground may be able to function on aircraft at the required speeds
  - One example:

LRAD 1000X

Maximum Continuous Output	**153dB SPL at 1 meter, A weighted**
Beam Width	**+/-15° @ 1.0 kHz/-3dB**
Dimensions	**36” W x 40“ H x 13” D**
Weight	**75 lbs**