Overview of Rotorcraft Acoustic Flight Testing

NASA – Michael Watts, Eric Greenwood

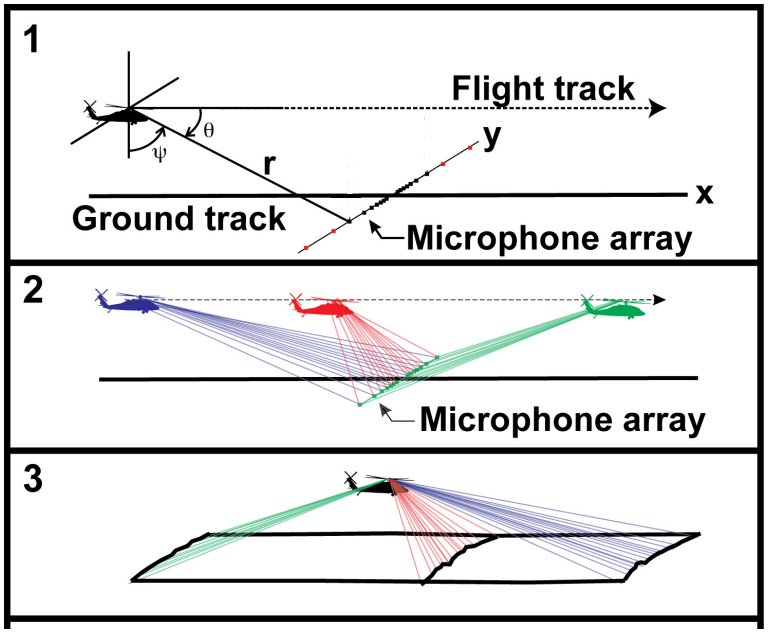
Army – David Conner, James Stephenson

AMA – Charles Smith, Keith Scudder, Andrew McCrea

Why We Flight Test

- Acquire data to
  - Develop semi-sphere data base for use in flight planning software such as RNM, APET and ANOPP2
  - Inform semi-empirical modeling methods (i.e. FRAME)
  - Understand noise generation processes
  - Validation of predictive codes

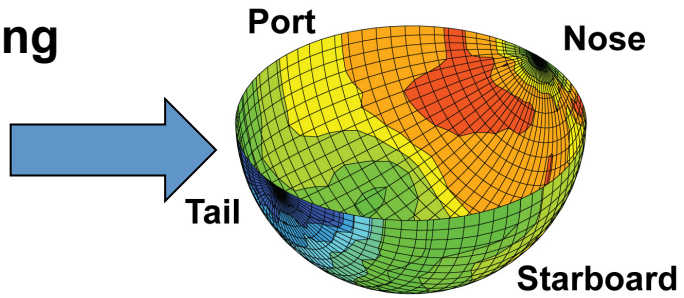
Semi-sphere Development

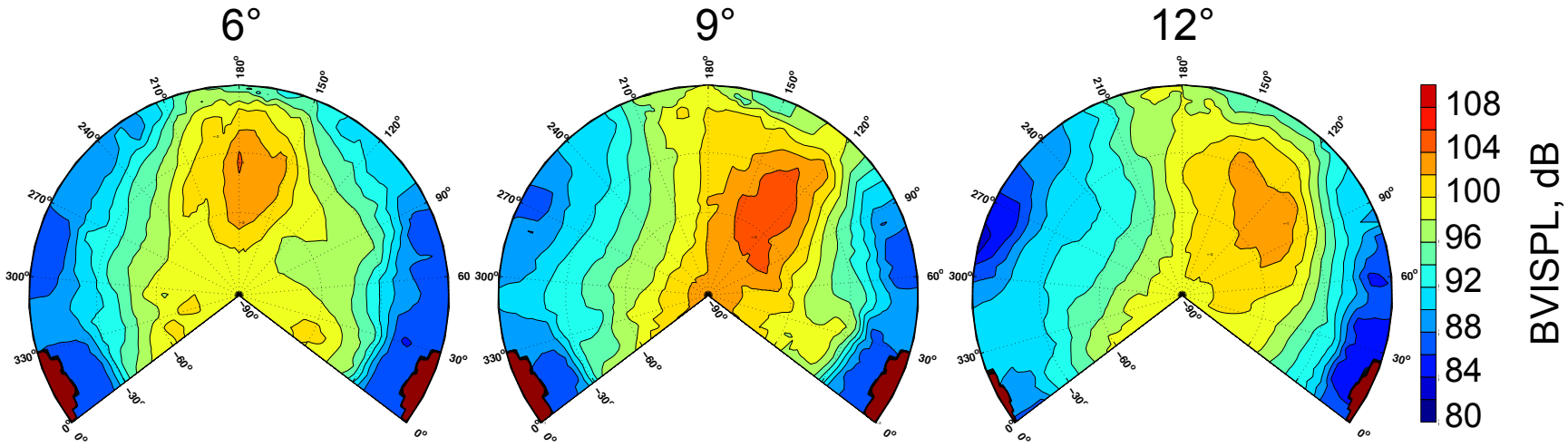


Acoustics measured continuously during flyover

Directivity angles and ranges calculated

Range vectors translated to single point



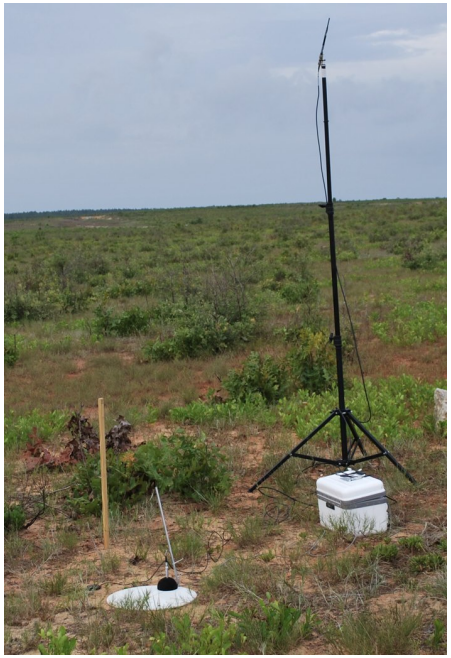


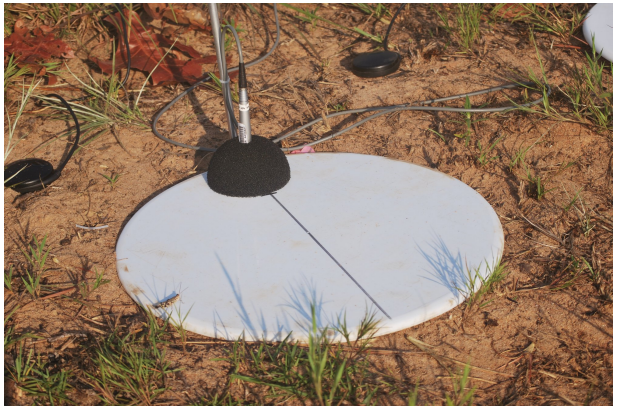
80 KIAS Steady Descent Semi-spheres

Mobile Acoustic Facility

- Command and Control Trailer
- Honda Quiet Generators for power independence
- Portable Satellite System
- Survey System for positioning of microphones to 1 cm accuracy
- Microphone Systems
- Weather Systems
- Aircraft Instrumentation

Wireless Acoustic Measurement Systems (WAMS)





- 36 channels available
- Data storage on compact flash card
- System health monitored in real time
- GPS provides time code as well as position
- Simult. sampling on all channels (<8 μsec diff)
- Up to 50 mile range
- Onboard embedded controller
- 80 kHz max. sample rate (25 kHz typical)
- 96 dB dynamic range (16 bit)
- Battery operation w/solar power augmentation

Weather Instrumentation

Tethered Weather Balloon

Ground Weather Stations

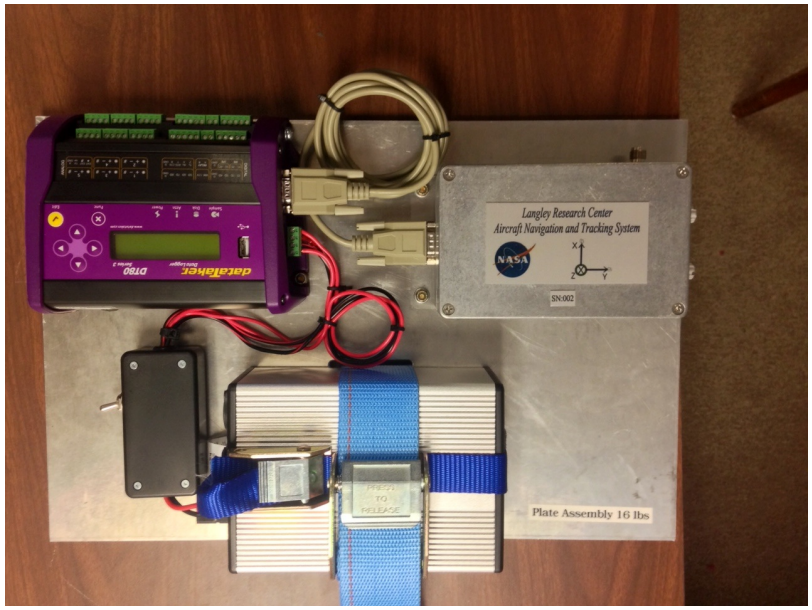
Line Sensors

ZephIR 300 LIDAR

- 11 selectable heights from 30 to 1000 feet AGL
- 1 sample/second/height (11 second full profile)
- IEC 60825-1 Class 1 eye-safe
- Laser Wavelength 1560 - 1565nm
- Peak Power <1W (70mm aperture), battery operated

Aircraft Instrumentation

- Data Logger records analog and digital inputs at 4 Hz



- Aircraft Navigation Tracking System (ANTS)
  - Powered by 4 AA batteries
  - 6 DoF INU measurements
  - GPS
  - Records on SD card
  - 50 Hz sample rate
- Li-Ion battery for airspeed boom

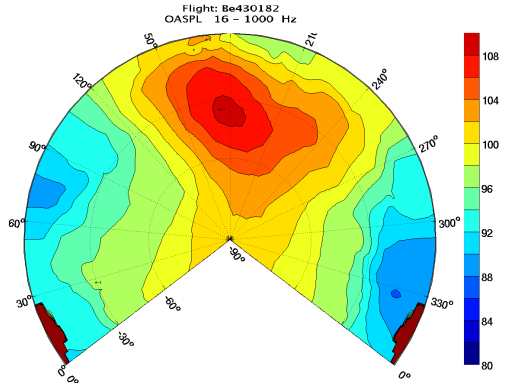
- Airspeed Boom

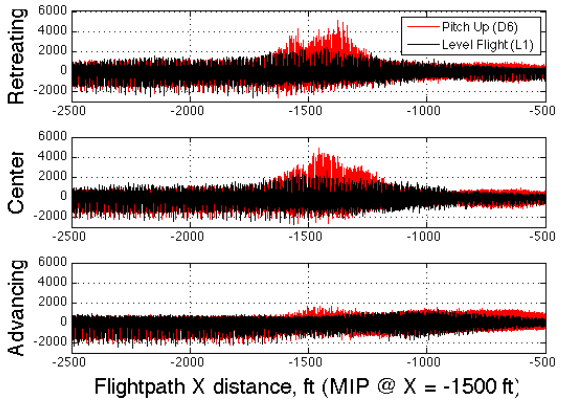
Major Research Tests
Last 5 Years

- 2011 – Maneuver Test, Bell 430, Eglin AFB
- 2013 - Acoustics Week, CV-22, AH-64D, UH-60M, Eglin AFB, FL
- 2014 - 2015 – Three Phase Altitude Variation Test, AS350B, EH-60L, NV/CA
- 2015 – Joint with Navy, AH-1Z, UH-1Y, Yuma, AZ

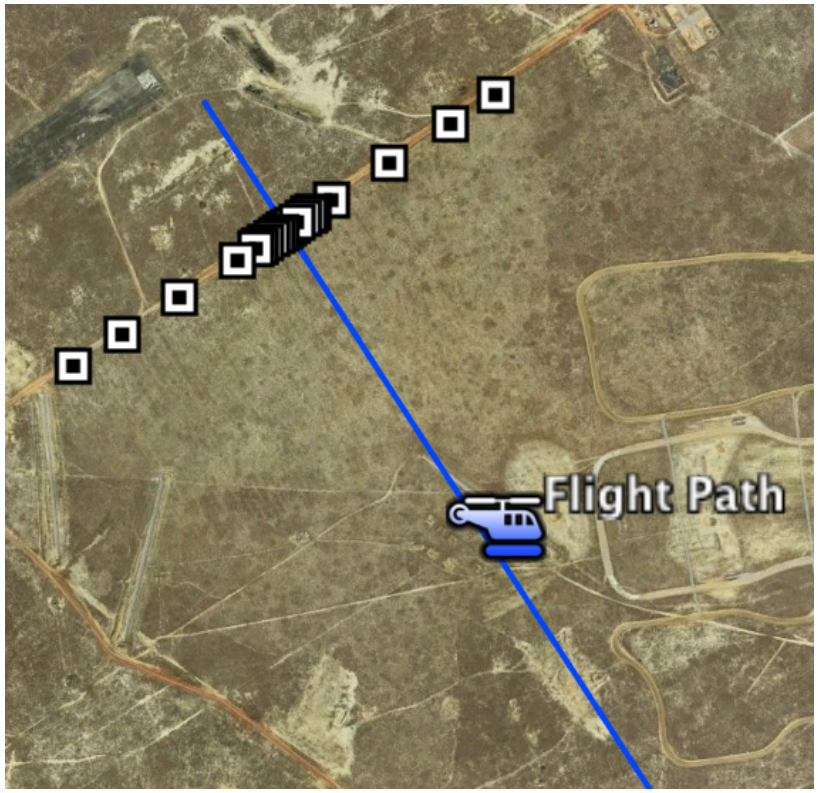
2011 NASA/Bell/Army Maneuver Test

- Acoustic measurement of
  - Source Noise
  - Steady and dynamic maneuvers
  - Optimized approach profiles
- Bell Model 430 Helicopter
  - 8500 pound GW
  - Four bladed semi-rigid main rotor
  - Aircraft attitudes, rates, airspeed and control positions measured
  - Rotor tip path plane measured
- First test of its kind to thoroughly investigate the acoustics of maneuvering helicopters
- 23 person test crew, 7 organizations
- Cost shared by NASA, Bell and Army
- Performed at Eglin AFB, June 2011
- 370 data points total for level, descending, climbing, steady turns, dynamic maneuvers and approaches





Source Noise Mapping



- Acquire detailed hemispheres for use in optimization codes and ground footprint calculations
- Linear array 21 microphone locations

Level Flight Points		
Airspeed (KIAS)	**Gear Up**	**Gear Down**
50	1	
60	5	
70	2	
80	11	2
90	1	
100	2	
110	1	2
120	3	
130	5	

Descent Points						
	Descent Angle (Degrees)					
Airspeed (KIAS)	**3**	**6**	**7.5**	**9**	**10.5**	**12**
50		3		1		
60	4	4	2	3	3	3
70		3	1	2		2
80	2	4	5	2	3	2
90		2	1	1		

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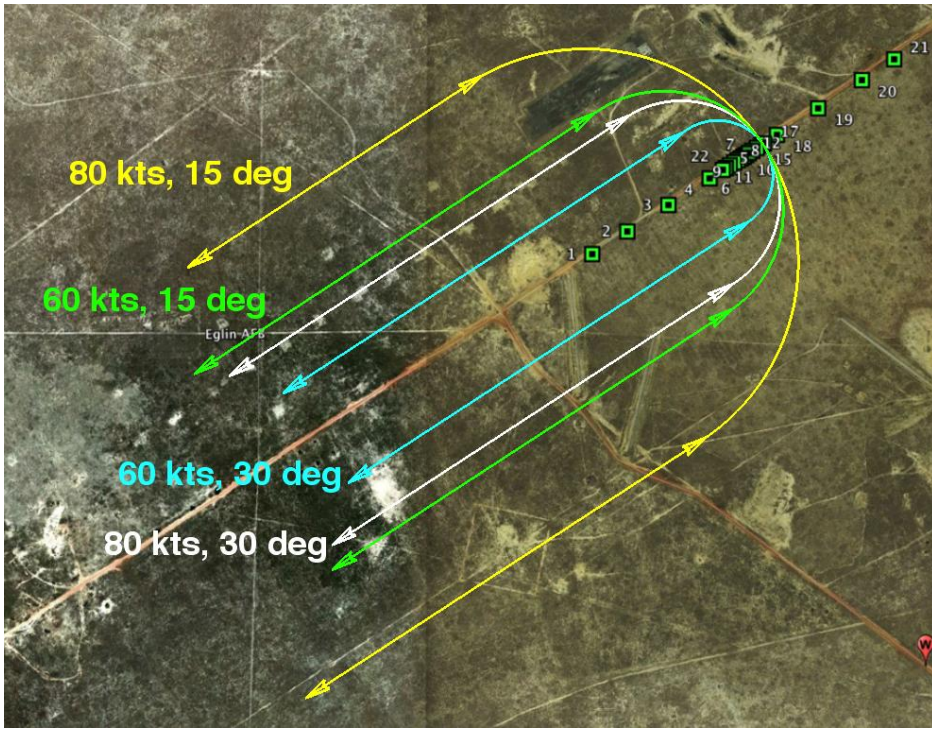
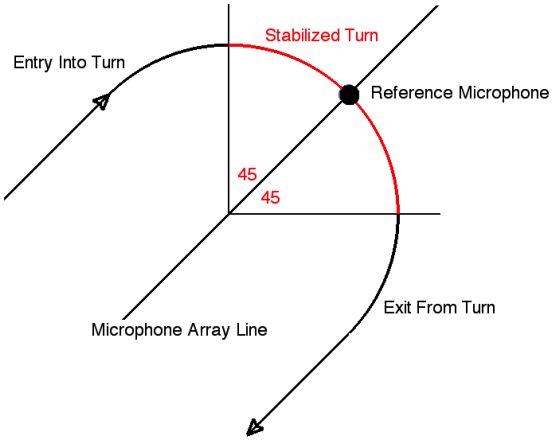
Steady Turns

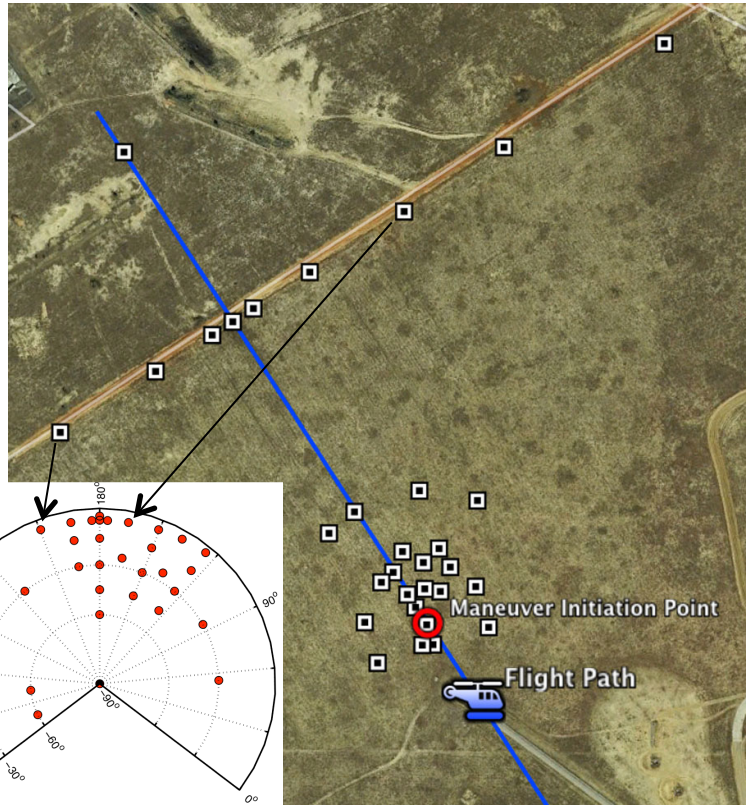
- Acquire data to:
  - Validate acoustic prediction codes
  - Incorporate steady coordinated turns into transition part of terminal area approach predictions
- Source linear array
- Left and right steady bank angles
- 15 and 30 degree banks





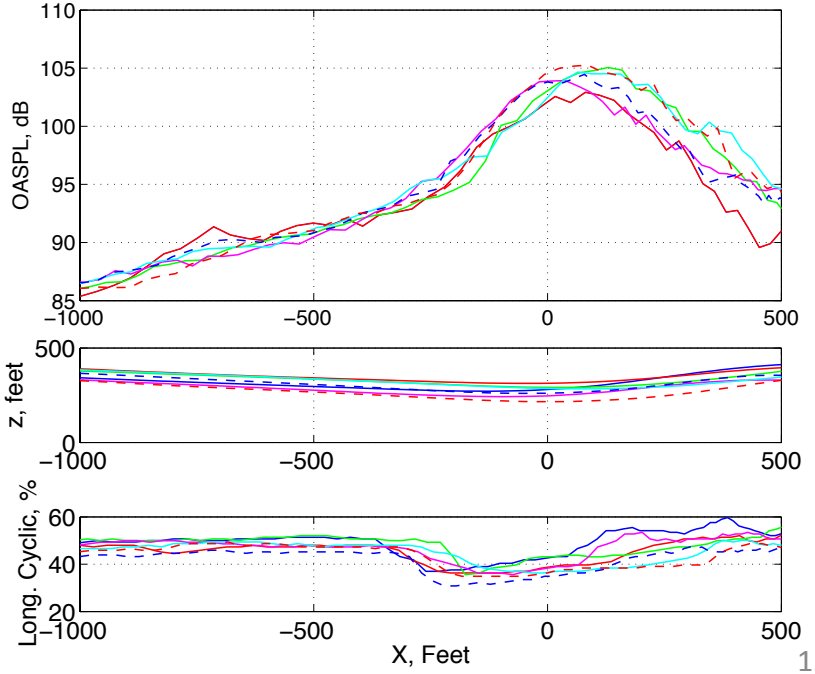
Steady Turn Points				
	Bank Angle (degrees)			
	15		30	
Airspeed	R	L	R	L
60	6	2	7	3
80	2	2	11	7

Transient Maneuvers



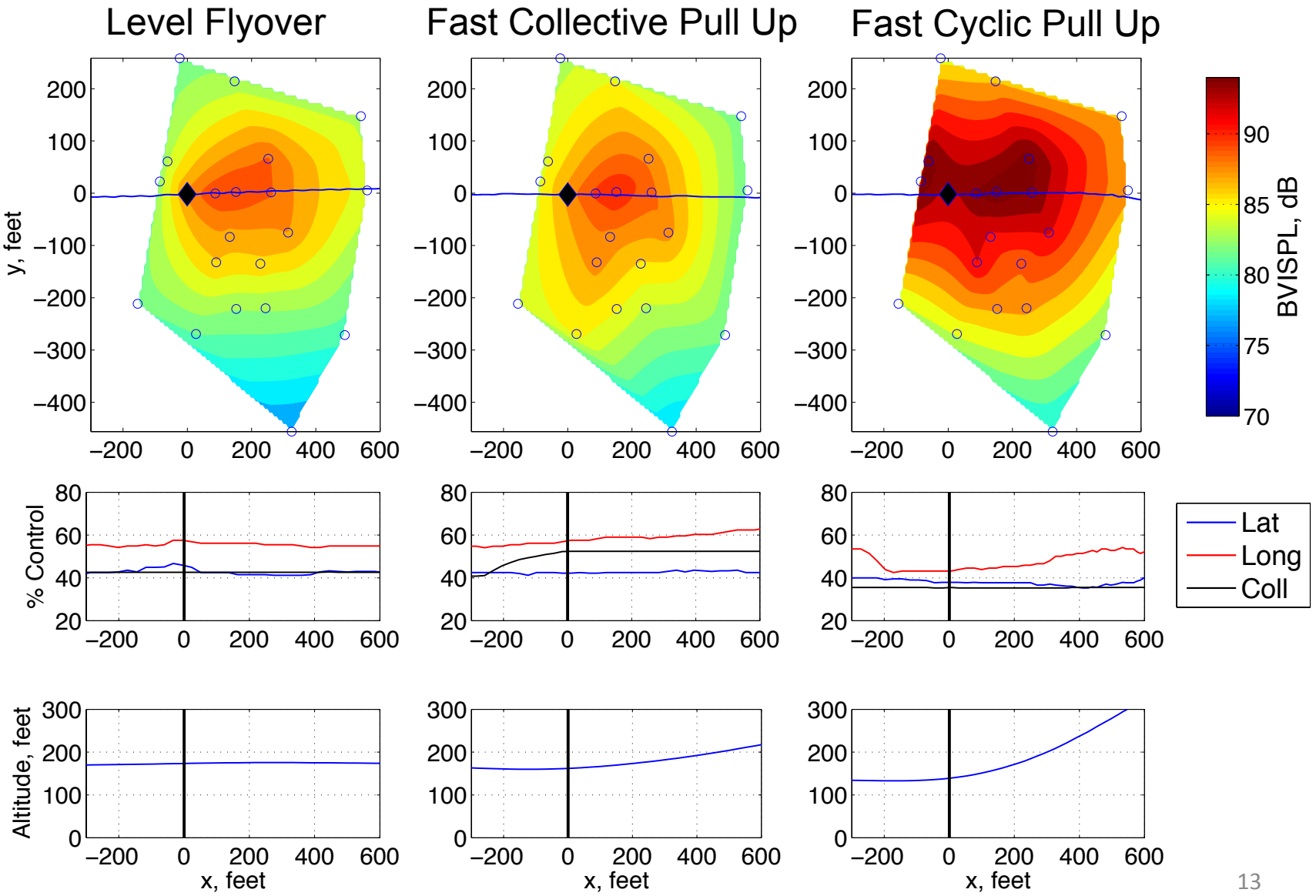
- Acquire data to:
  - Validate acoustic prediction codes
  - Understand the effect of dynamic changes in flight condition on acoustics
- 31 microphones
- Maneuvers initiated from 60/80 kts, level flight and 6°/9° descents
- Slow, medium and fast control inputs

80 KIAS, 6° Fast Cyclic Pitch Up Housekeeping

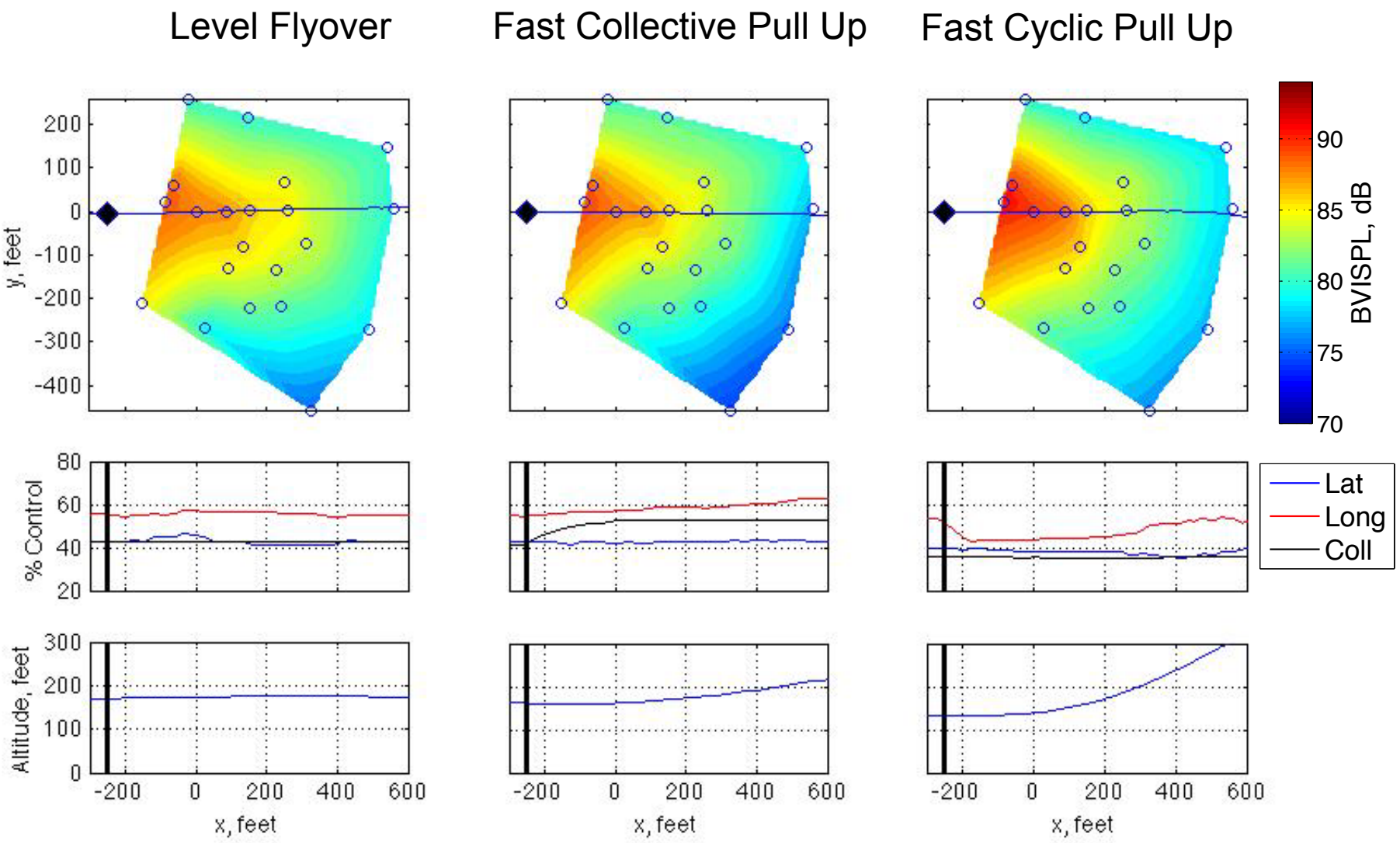


- Single control input
  - Collective pull-up, push over (25)
  - Cyclic pitch-up (55), roll (87)
- Combination maneuvers
  - Quick stop/start (16)
  - Accelerating roll angle change (22)
  - Climbing flight roll angle change (12)

80 KIAS Maneuvers



80 KIAS Maneuvers



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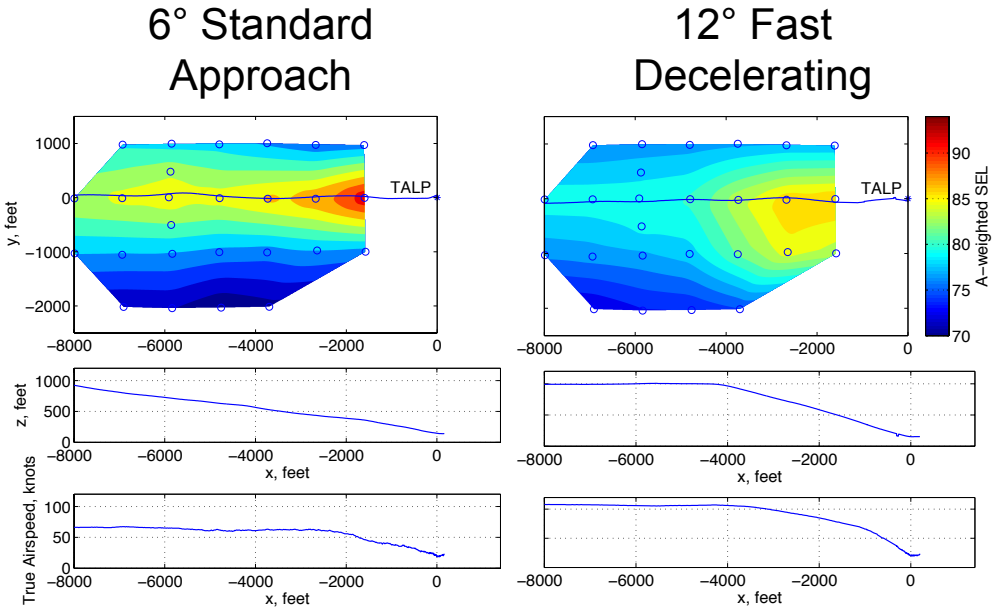
Terminal Area Approaches



- Purpose is to gather data for validation of ground footprint prediction and flight path optimization codes
- 27 Microphones deployed in grid
- 26 Approaches Acquired

- Approaches
  - Constant glide slope
  - Multi-segmented linear
  - Three dimensional
  - Pilot's discretion

Acoustic Week 2013, Eglin AFB

PROBLEM
Rotary wing noise is a barrier for increased use of vehicles and expanded missions

OBJECTIVE
NASA, in collaboration with DoD, is developing acoustic prediction tools to assess community noise impact and improve design capability for low noise rotor systems. Acquiring data to validate the prediction tools is an integral part of the effort.

ACCOMPLISHMENTS
Flight test was conducted from July 22-Aug 16, 2013. The testing successfully acquired 108 test points for the AH-64D, 118 for the UH-60M, and 83 for the CV-22. Flight conditions tested included level, descending, maneuver and hover. The purpose of the test was to acquire a benchmark acoustic database of detailed acoustic source noise characteristics for a range of typical operating conditions.

SIGNIFICANCE
Acquiring validation data for highly loaded rotors performing descents, landings, hover and maneuvers expands the capability and accuracy of the prediction tools such as the Rotorcraft Noise Model (RNM) and the Acoustics Propagation and Emulation Toolset (APET). This was the first time that the acoustic signature of these aircraft were measured with the NASA microphone array technique.

CV-22 Osprey

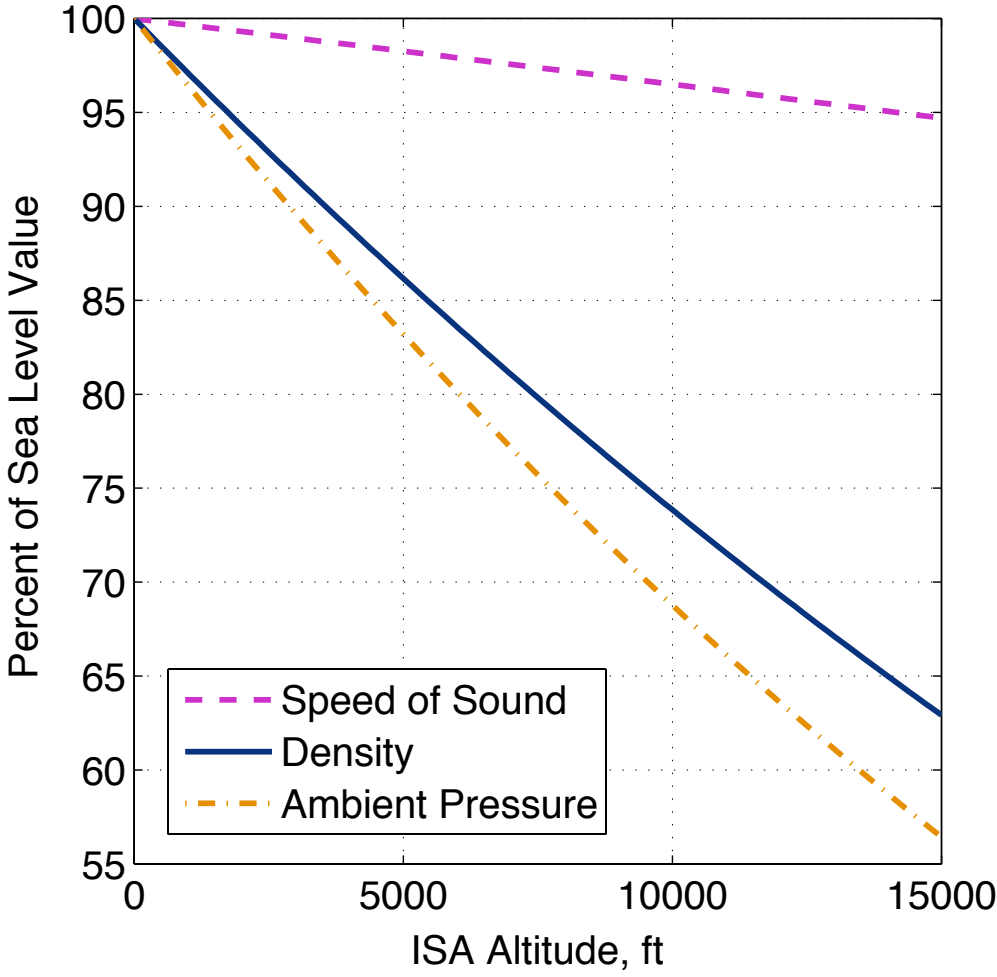
AH-64D Apache

UH-60M Blackhawk

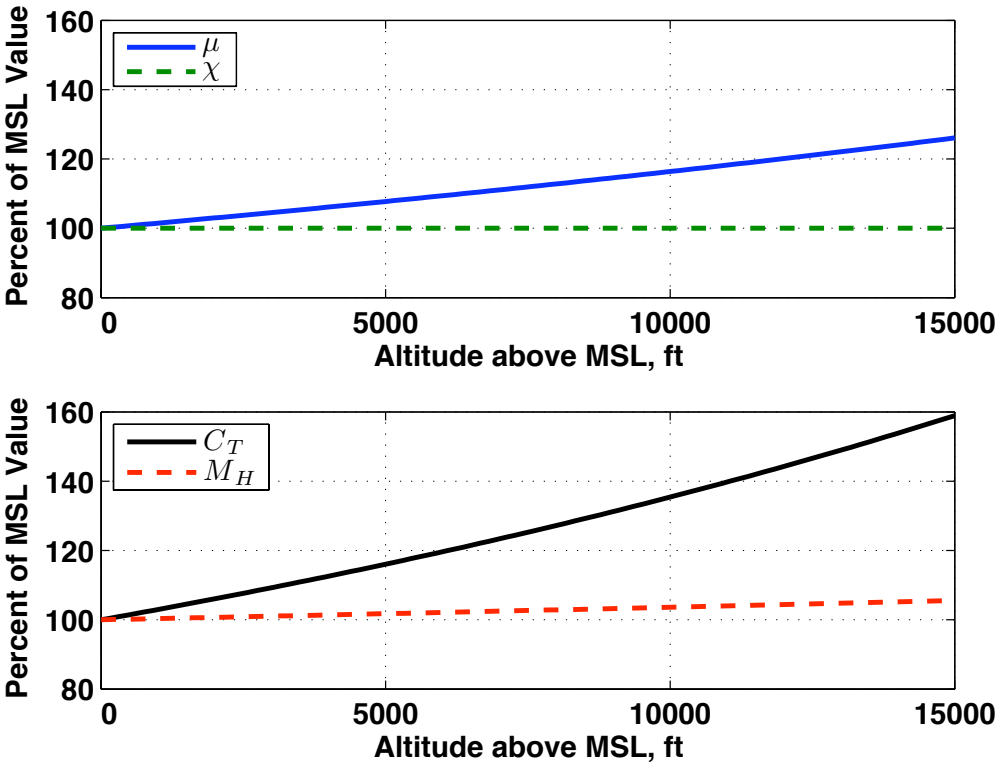
Partners: Army AMRDEC, Apache PM, Blackhawk PM, Chicken Little Joint Project Office, Naval Air Surface Warfare Center

Helicopter Operations at Altitude

- Decreased air density results in higher blade lift coefficients, reducing performance
- Decreased air temperature results in higher section Mach numbers, increasing noise



Flight Conditions Defined by Indicated Airspeed (IAS)



Constant 60 kts IAS, -6 degree FPA
Bell 206B3 main rotor

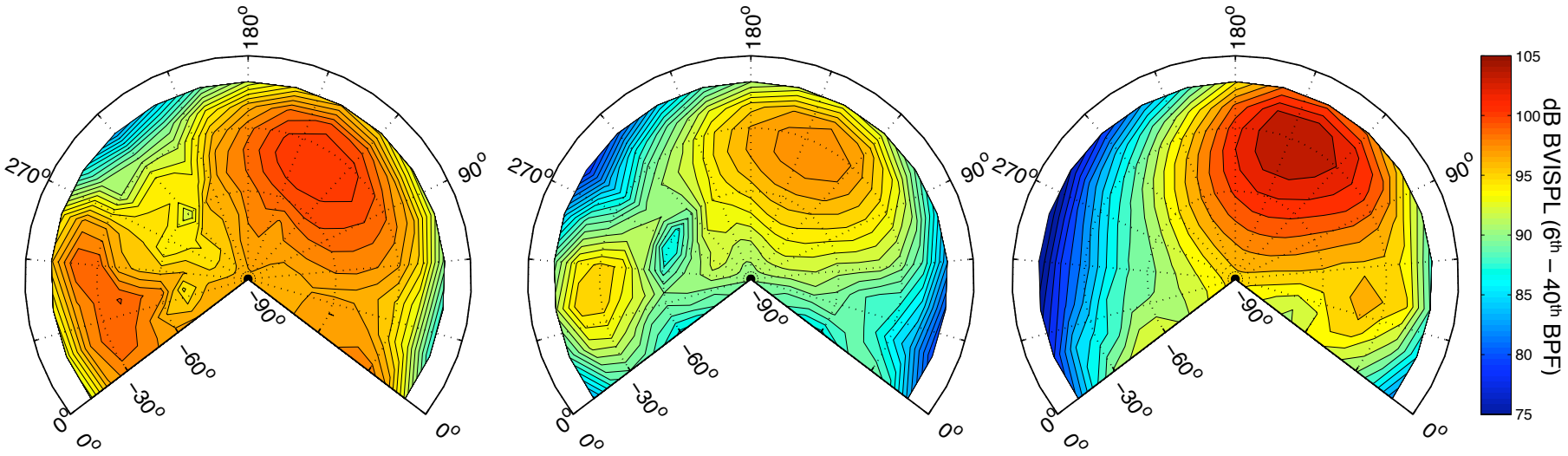
- True Airspeed (advance ratio) increases for same IAS due to decreased ambient density

$$V_{IAS} = V_{TAS}\sqrt{\rho_0 / \rho_{SL}}$$

- Wake skew ratio stays constant, due to increased induced inflow
- Thrust coefficient increases for decreased density
- Increase in hover tip Mach number with decrease in temperature

Noise Variation with Altitude

Bell 206B, 60 KIAS, -6° Descent



ISA Sea Level Conditions

ISA 7,500ft Conditions

ISA 15,000ft Conditions

- Non-linear variation in noise levels with altitude
- Directionality changes as well as noise levels
- Trends are different for different noise sources *(not shown here)*

NASA/Army Altitude Variation Test

1. Investigate changes in acoustics caused by ambient condition changes
2. Acquire validation data for the prediction of maneuvers in FRAME

AS350

EH-60L

4000 feet

6800 feet

Sea Level

Altitude Variation Test Conditions

Table 1. AS350B Test Conditions: Altitude Variation

Priority	Condition Code	KIAS	Angle	Description
	V1	80	0	Commanded
	V2	80[1]	0	Match Madv and Cw [2]
	V3	120	0	Commanded
	V4	120[1]	0	Match Madv and Cw[3]
	V5	80	6°	Commanded
	V6	80[1]	6°	Match Madv and Cw [2]

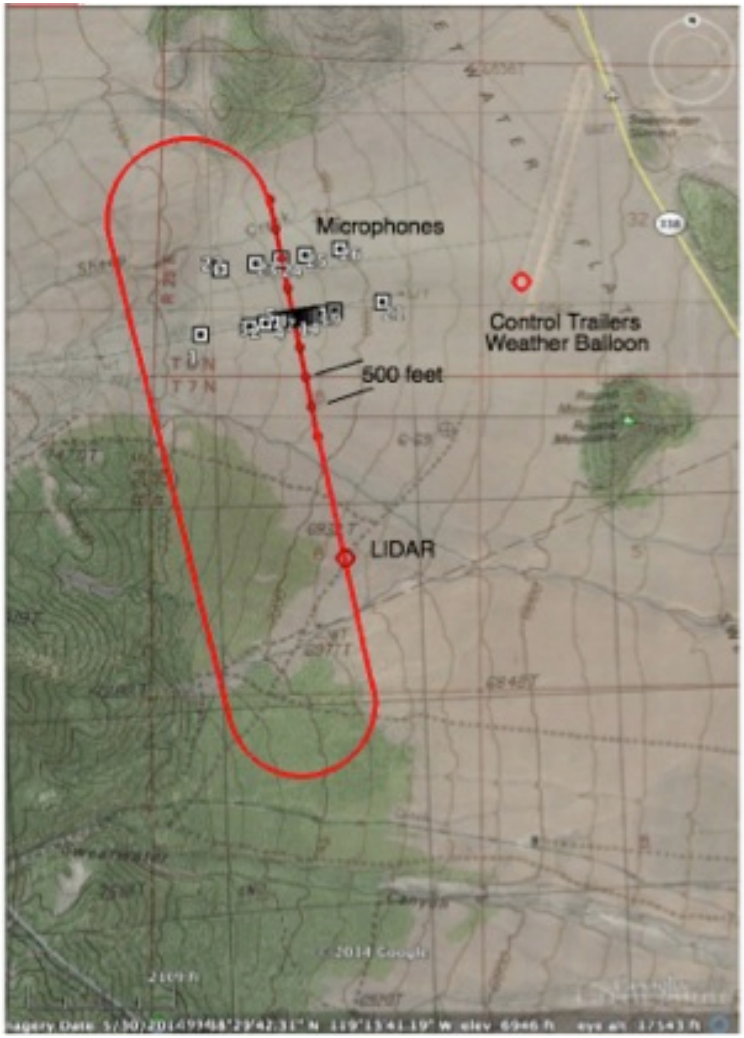
1. Airspeed and RPM determined at time of point acquisition
2. Madv = 0.757, Cw = 0.003677
3. Madv = 0.818, Cw = 0.003677

Table 2. EH-60L Test Conditions: Altitude Variation

Priority	Condition Code	KIAS	Angle	Description
	V7	80	0	Commanded
	V8	80[1]	0	Match mu, Madv and Cw [2]
	V9	125	0	Commanded
	V10	125[1]	0	Match mu, Madv and Cw [3]
	V11	80	6°	Commanded
	V12	80[1]	6°	Match mu, Madv and Cw [2]
	V13	131	0	Match preveiously tested condition of 100.5% NR, Mhov = 0.653, mu = 0.304 Madv = 0.852, Cw = 0.00791, GW = 18500 (only performed at Sweetwater)

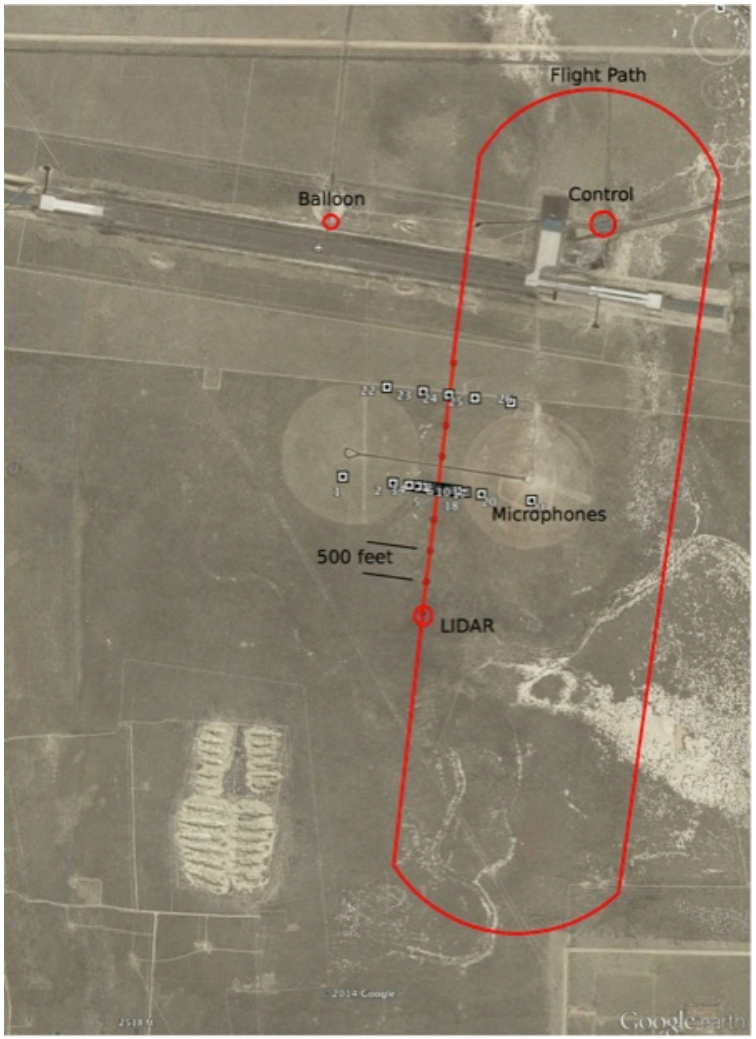
1. Airspeed and RPM determined at time of point acquisition
2. mu = 0.185, Madv = 0.788, Cw = 0.00724
3. mu = 0.283, Madv = 0.852, Cw = 0.00724

Sweetwater USMC Auxiliary Airfield (6800')



- Phase I :
  - Setup: Sept. 22 – 27, 2014
  - AS350B: Sept 30 – Oct 2, 2014
  - EH-60L: Oct 6 – 8, 2014
- Part of the Marine Mountain Warfare Training Center (MWTC)
- 6800 foot altitude
- AS350B based at Bryant Airfield, 17 mile ferry
- EH-60L based at USMC MWTC, 18 mile ferry
- Only Altitude Variation test conditions flown at this site
- AS350B Gross Weights: 3,945 and 3,305 lbs
- EH-60L Gross Weights: 18,500 and 16,500 lbs
- AS350B: 166 data points in 7.45 data collection flight hours
- EH-60L: 138 data points in 6.23 data collection flight hours

Amedee Army Auxiliary Airfield (4000')

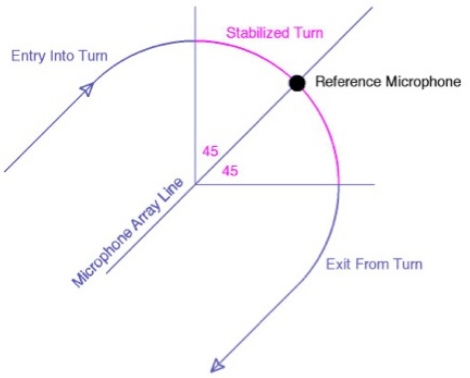


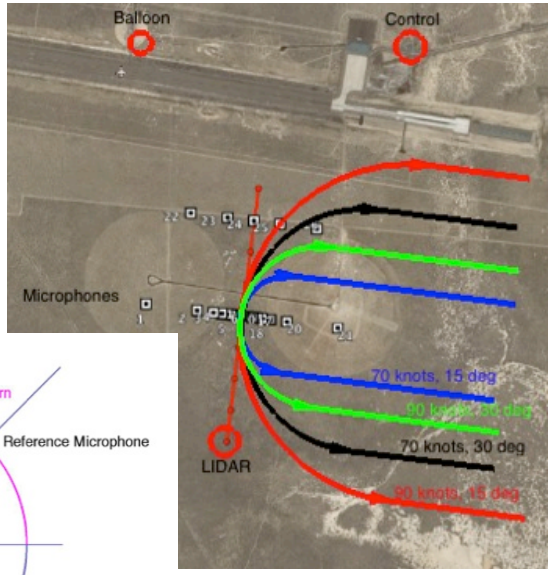
- Phase II :
  - Setup: Oct 20 – 25, 2014
  - AS350B: Oct 28 – Oct 30, 2014
  - EH-60L: Nov 6 – 14, 2014
- Part of the Sierra Army Depot
- 4000 foot altitude
- AS350B based at Amedee, 0 mile ferry
- EH-60L based at Reno-Stead Airport, 45 mile ferry
- AS350B will fly Altitude Variation test conditions only at this site
- EH-60L will fly Altitude Variation, Source and Maneuver conditions at this site
- AS350B Gross Weights: 3,945 and 3,700 lbs
- EH-60L Gross Weights: 18,500 lbs
- AS350B: 257 data points in 10.95 data collection flight hours
- EH-60L: 552 data points in 23.98 data collection flight hours

EH-60L Steady Turn Noise Characterization

- Only performed at Amedee
- Level Flights at 150 ft AGL, 50 to 140 KIAS
- Steady Descents from 50 to 110 KIAS, 3° to 12° descent angles
  - Descent set up to target between arrays
  - 50 ft AGL hard deck
- Steady Turns at 200 ft AGL

Condition Code	KIAS	Bank Angle (°)	Direction	Radius of Turn (feet)
S1	65	15	Right	1371
S2	65	30	Right	636
S3	65	15	Left	1371
S4	65	30	Left	636
S5	95	15	Right	2928
S6	95	30	Right	1359
S7	95	15	Left	2928
S8	95	30	Left	1359





EH-60L Maneuvers at Amedee

Constant Speed Banks

KIAS	Direction	Bank Angle	
		20	30
65	Left	(2) M9	(1) M12
	Right	(2) M3	(1) M6
95	Left	(2) M8	(1) M11
	Right	(2) M2	(1) M5
110	Left	(2) M7	(1) M10
	Right	(2) M1	(1) M4

Quick Stop

KIAS	Aggression	
95	Moderate	(3) M13
	Aggressive	(2) M14

Constant Speed Climbing Banks

KIAS	Direction	Climb	
		3° Climb	6° Climb
80	Left	(2) M27	(2) M33
	Right	(2) M26	(2) M32
95	Left	(3) M29	(3) M35
	Right	(3) M28	(3) M34
110	Left	(3) M31	(3) M37
	Right	(3) M30	(3) M36

Accel/Decel Banks

Aggression	Bank Direction	80 KIAS Start Accel	120 KIAS Start Decel
Moderate	Left	(3) M20	(3) M24
	Right	(3) M18	(3) M22
Max	Left	(2) M21	(1) M25
	Right	(2) M19	(1) M23

Pull up/Push over

KIAS	
95	(2) M15
110	(2) M16

Bank and Climb at same time

Left	(1) M39
Right	(1) M38

Bank and Decel at same time

Left	(1) M41
Right	(1) M40

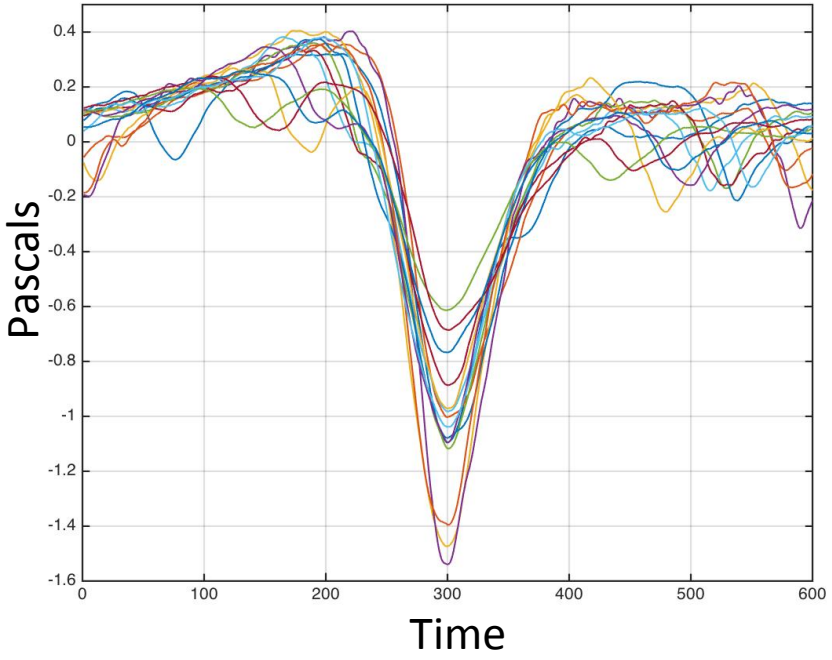
Max Level Acceleration	(1) M17

USNC Salton Sea (Sea Level)

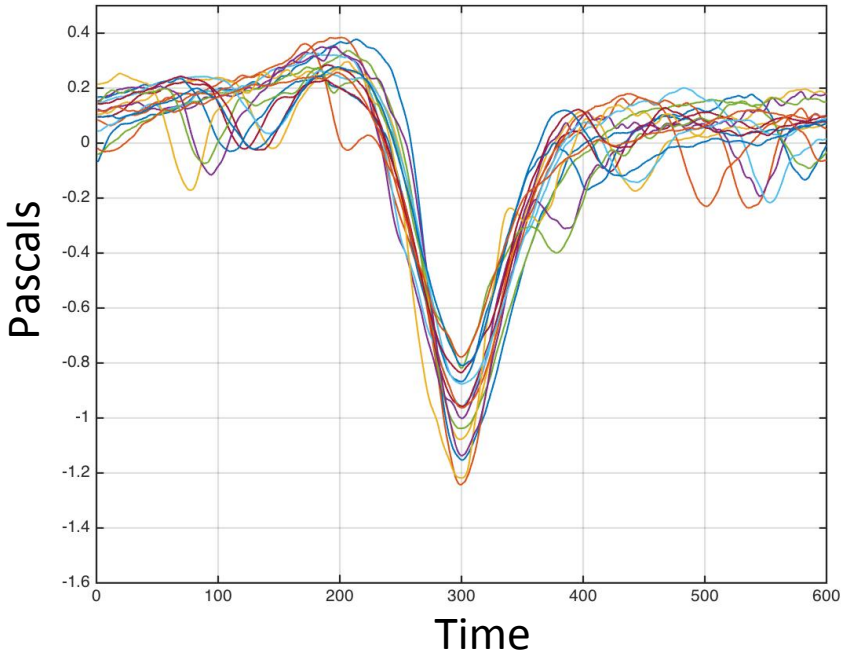
- Phase III :
  - Setup: Feb 2 - 5, 2015
  - AS350B: Feb 13 – 16, 2015
  - EH-60L: Feb 7 – 9, 2015
- Owned by the US Navy
- Test coordinated by Yuma Proving Grounds
- Sea level altitude
- AS350B and EH-60L based at Salton Sea
- Only Altitude Variation test conditions flown at this site
- AS350B Gross Weights: 3,945 and 4,200 lbs
- EH-60L Gross Weights: 18,500 and 21,200 lbs
- AS350B: 210 data points in 9.07 data collection flight hours
- EH-60L: 187 data points in 7.78 data collection flight hours

AS350 Amedee

V3 – 120 knots Indicated Airspeed



V4 – Matched Non-dimensional Condition



Questions?