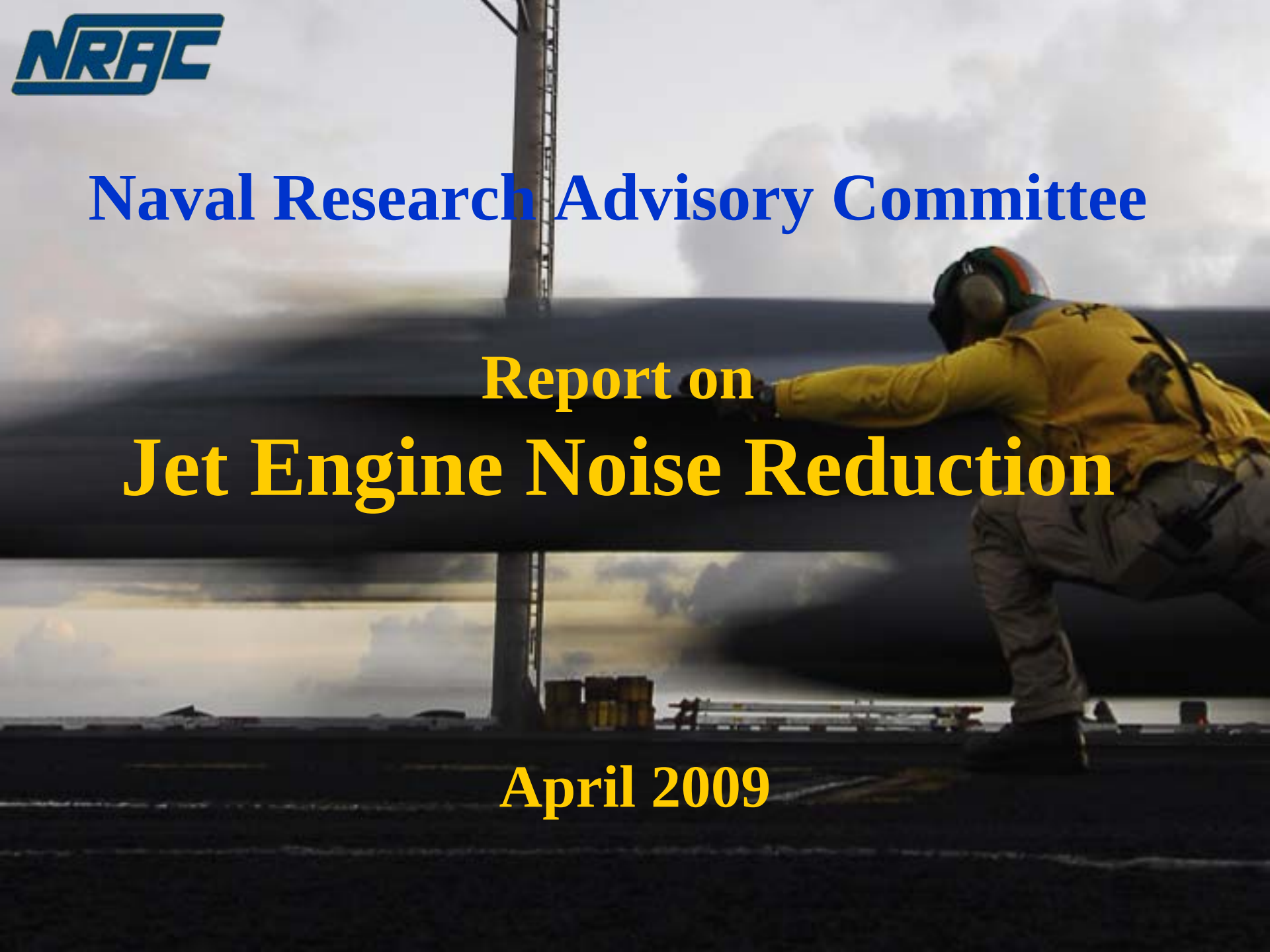


Naval Research Advisory Committee

Report on

Jet Engine Noise Reduction

April 2009

STUDY OBJECTIVE

To Understand Naval Aviation's Jet Engine Noise Problem

and Propose an Approach to Solve It…

Study Sponsors & Panel Membership

Sponsors

VADM Thomas J. Kilcline, Jr. USN
Commander, Naval Air Forces

VADM David Architzel, USN
Principal Deputy Assistant Secretary of the Navy (Research, Development and Acquisition)

Panel

VADM William C. Bowes, USN (Ret) – Chair
NRAC Member, Private Consultant

Mr. Dick Rumpf – Vice Chair
President and CEO, Rumpf Associates

RADM Daniel R. Bowler, USN (Ret)
NRAC Member, VP, Naval Systems & Advanced Technology Solutions, Lockheed Martin

Robert S. Carnes, M.D.
NRAC Member, Battelle Memorial Institute

MajGen Paul A. Fratarangelo, USMC (Ret)
NRAC Member, Private Consultant

Representative Members

Dr. William H. Heiser
Professor Emeritus, Department of Aeronautics, USAF Academy

Mr. Dennis L. Huff
Deputy Chief Aeropropulsion Division, NASA Glenn

Professor Parviz Moin, Ph.D.
Director, Center for Turbulence Research, Stanford University

Executive Secretary

Mr. William J. Voorhees
Head, Propulsion and Power Technology Office, NAVAIR

Bottom Line Conclusions

- **Lack of fundamental noise data or hearing damage data**
- **Noise remains a significant health risk on flight decks**
- **There will be no single solution for the jet engine noise problem – it will require a combination of:**
  - Reducing jet engine noise source
    - Which requires a long term research program
  - Developing a requirement for noise in future tactical jet aircraft
  - Continuing to make improvements to hearing protection
  - Finding ways to limit exposure to excessive noise levels
  - Developing better methods to monitor noise exposure and hearing loss of our personnel
- **DOD does not have a "champion" for jet engine noise reduction**

Outline

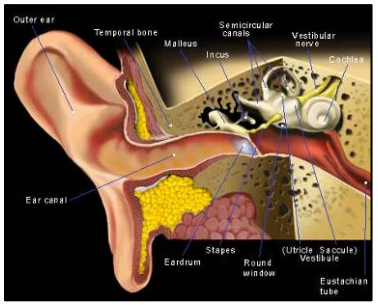
- **The Noise Problem**
- **Understanding Jet Engine Noise**
- **Jet Aircraft Noise Reduction**
- **Physiological Impacts of Noise**
- **Hearing Protection**
- **Conclusions**
- **Recommendations**

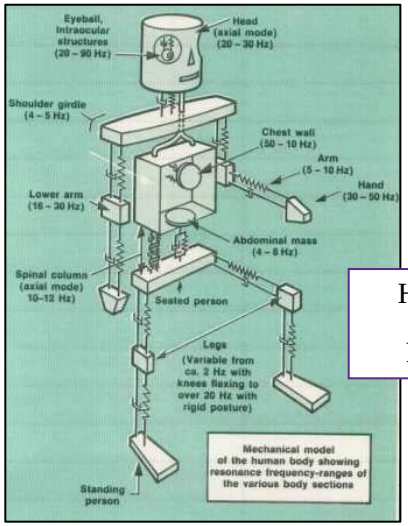
Study Flow

- **NAVAIR Engine Noise Reduction Workshop (10 Dec 2008)**
- **Briefings at ONR provided by government, industry and academia (7-8, 28-29 Jan; 10 Mar 2009)**
- **Visit and working session aboard USS Nimitz (CVN-68) (25-26 Mar 2009)**

The Noise Problem

Reasons to Reduce Jet Engine Noise

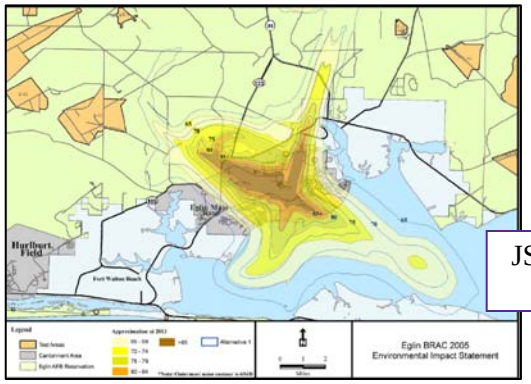




Human Body Resonate Frequencies

- **Near-Field Health Issues**
  - Hearing Loss / Tinnitus
  - Temporary Threshold Shifts
  - Non- auditory

- **Far-Field Community Issues**
  - Takeoff
  - Cruise
  - Approach

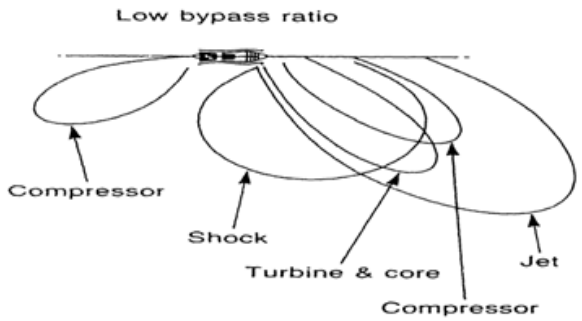


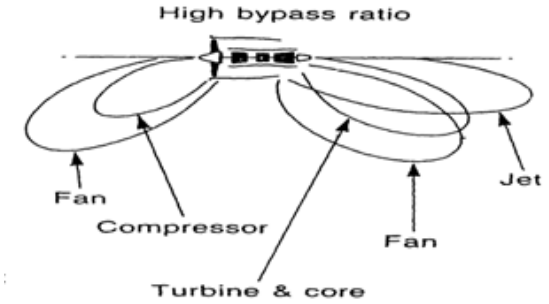
JSF far-field Noise Signature

130-150 dB flight deck noise with only 30 dB ear protection

Jet Engine Noise

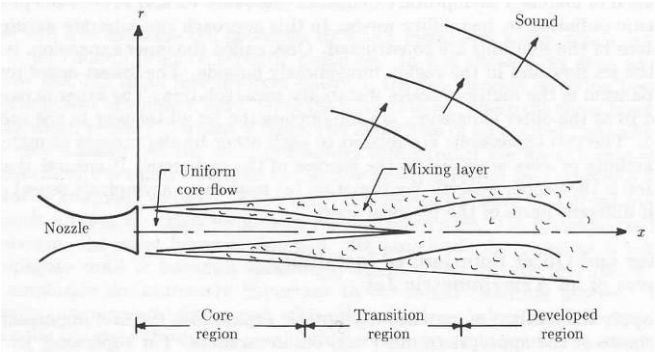
Low Bypass Ratio (Fighter) Engine Noise is Dominated by Jet Effects





Military
Jet noise is a strong function of velocity
Mixing devices to reduce velocity would impact thrust, weight, signature, cost, etc
No noise restriction requirements

Commercial
Velocity reduced as bypass ratio increases
Nacelle treatments targeted towards dominant turbo machinery noise
Noise regulations drive reduction



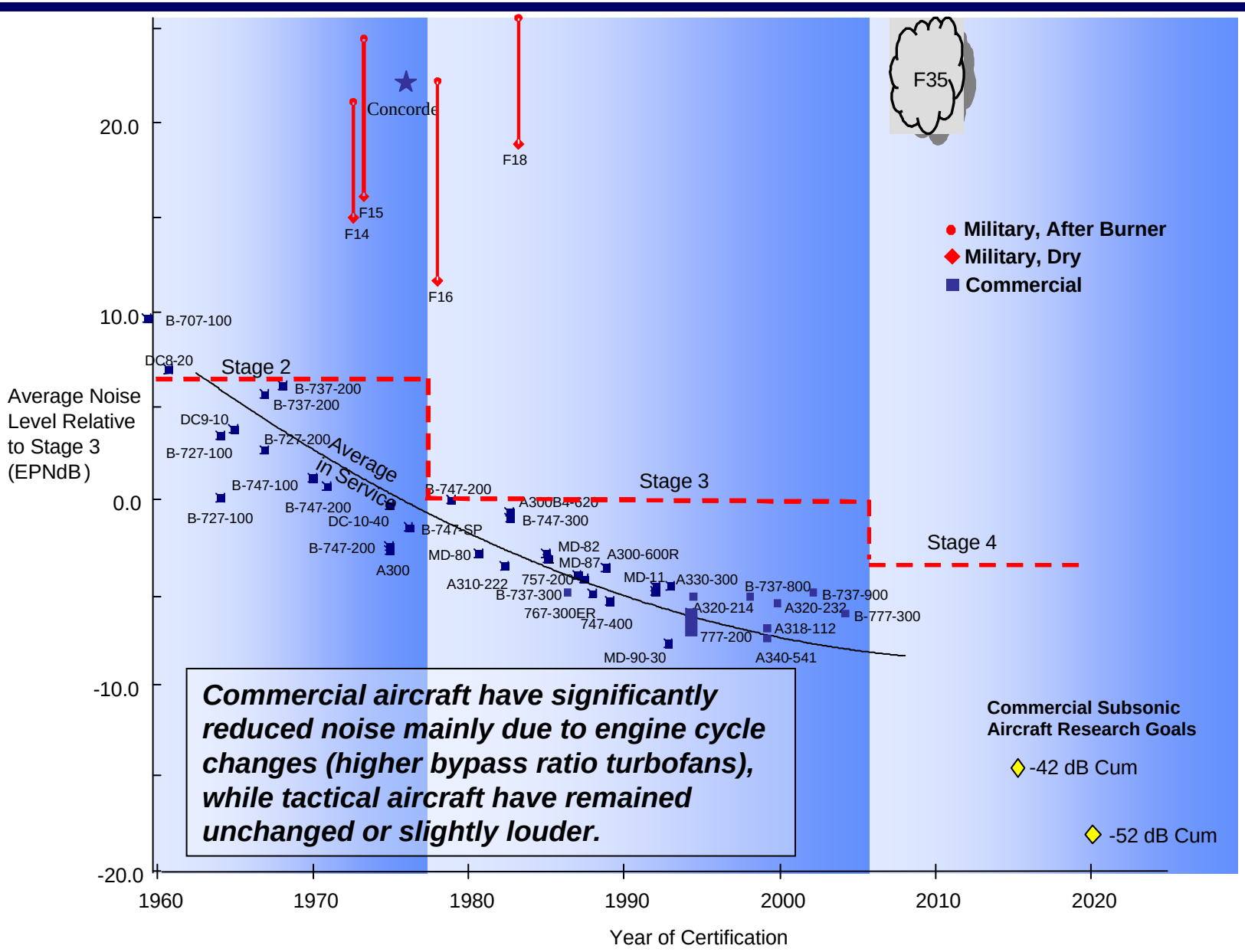
Jet Engine Noise Sources:

Jet exhaust, fan, turbines, combustor, compressor

Jet Exhaust comprised of:

- **Turbulent Jet Mixing**
- **Broadband Shock Noise**
- **Screech (addressed during design)**

Evolution of Jet Noise Reduction



Engine Noise Measurements

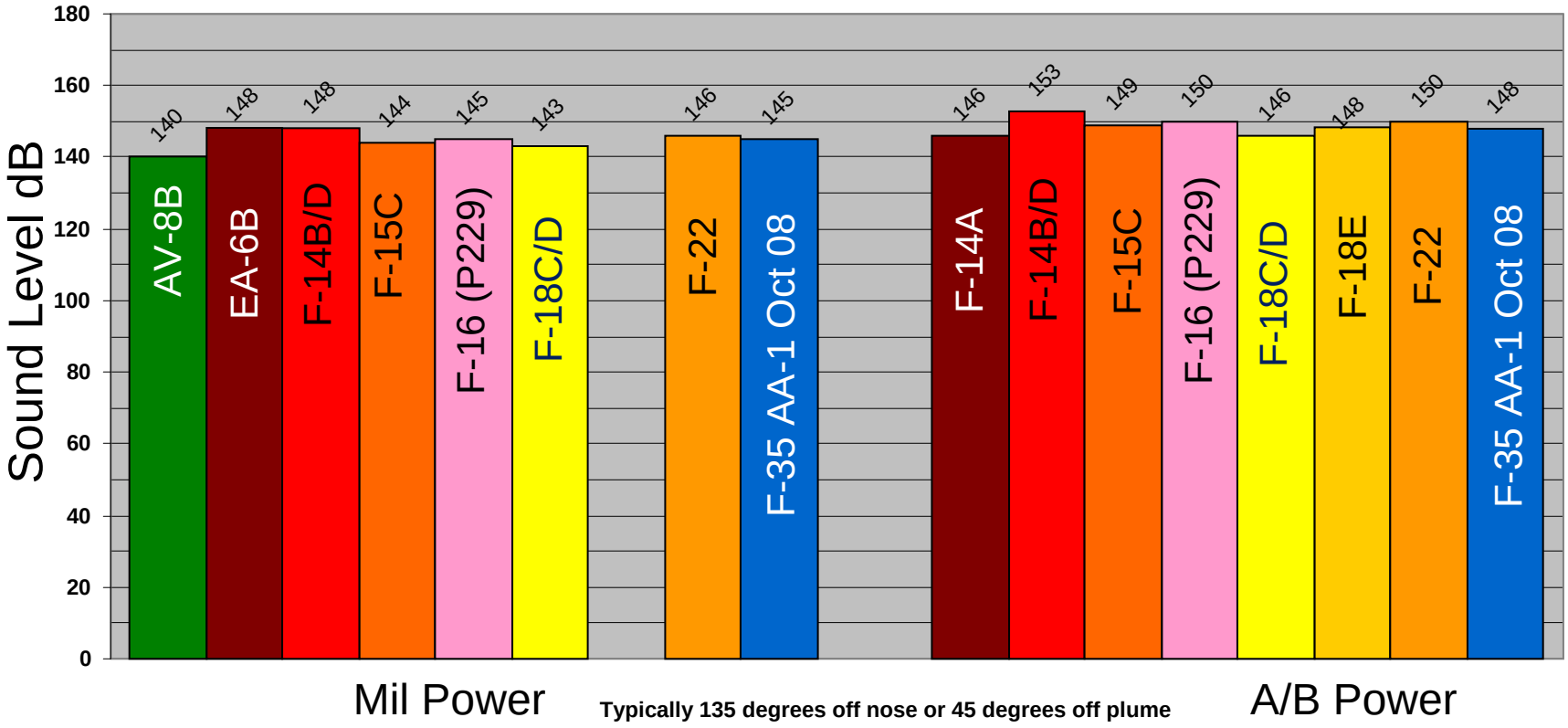
The Navy has not routinely collected engine noise measurement data:

- Engine noise level has never been a requirement or contractual specification
- Only requirement has been completing an environmental impact statement (EIS) for community impacts
- AFRL has measured and retains data on the noise levels of all USAF aircraft and many Navy aircraft
- There are no approved standards for acquiring engine noise for tactical aircraft
- Very limited data exist for flight deck noise

Gathering storm…

Jet Noise Levels

Best Data Available
(Source JSF Vibroacoustics IPT)

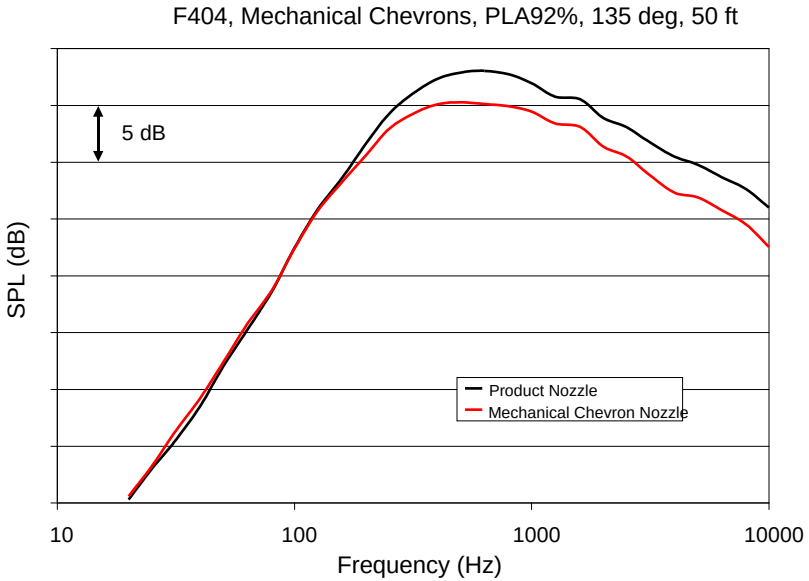


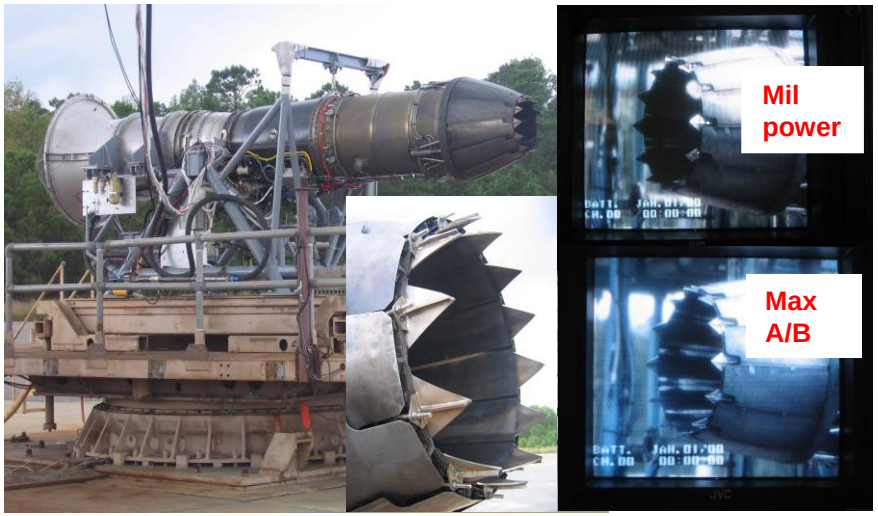
Peak Jet Noise Levels of Modern High Performance Aircraft are Fairly Consistent

Jet Engine Noise Reduction

- **Source**
  - Reduce exhaust velocity
  - Enhance jet mixing (like chevrons)
  - Other methods show promise in laboratories, but need further development
- **Path**
  - Hearing protection
  - Acoustic enclosures/barriers
- **Operations**
  - Minimize exposure time
  - Noise abatement procedures

F-414 Engine Chevrons





Chevron Technology:

- Reduce jet noise at the source: chevrons on engine nozzle
- Minor change in nozzle configuration; not major redesign

Major goals/Schedule by Fiscal year:

- FY09: System Development and Optimization
- FY10: Flight and JBD Demonstration; functionality in AB
- FY10: Manufacture/Production Cost Analysis; System Safety & Long Term Durability Testing

Benefits:

- Up to -3dB reduction in peak jet noise
- Minimal thrust and fuel consumption impact
- Retrofit-able on attrition basis

Sponsors:

- ONR Rapid Technology Transition Program
- F/A-18 E/F Program Office PMA-265

Chevrons are the only demonstrated practical method to achieve noise reduction with current engines

Adaptive Cycle Engine Technology

- **Joint VAATE (Versatile Affordable Advanced Turbine Engines) Program**
  - Includes application of variable cycle engine technology
  - Objective to achieve 10-fold improvement in turbine engine affordable capability
    - Reduction of thrust specific fuel consumption by 25%
- **ADVENT Project under VAATE**
  - Variable cycle engine development
  - Funded primarily by USAF with less USN investment
  - Potential to use the multiple exhaust streams of the variable cycle VAATE configurations to significantly reduce jet noise

VAATE/ADVENT should be augmented to address noise reduction

Technology Now Enabling Predictions

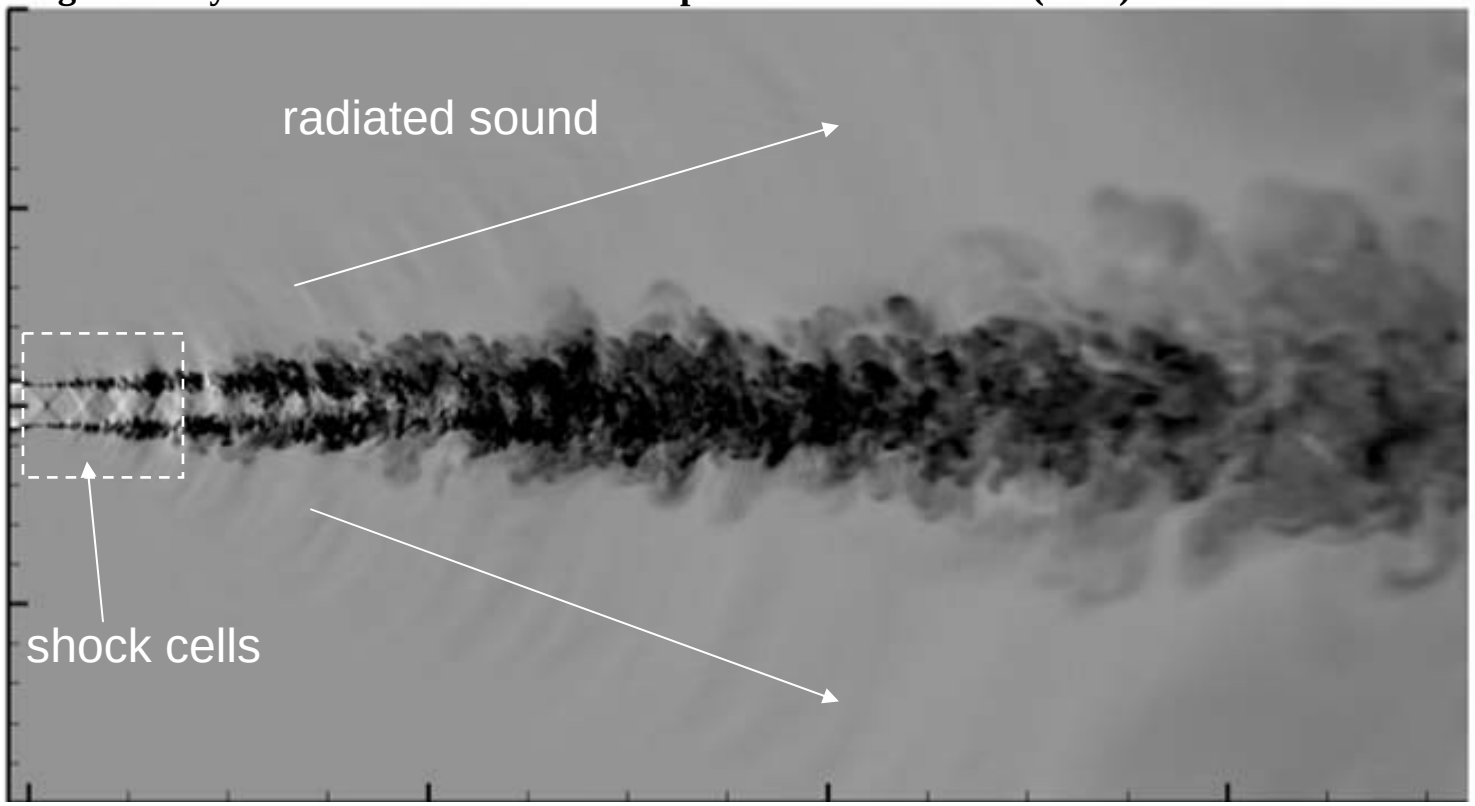
- **Until now, jet noise prediction has relied on empirical methods**
- **Accurate predictive tools just emerging for assessment of jet engine noise reduction approaches from First Principles**
- **Significant increase in computer power through parallel processing (4 orders of magnitude over the past 15 years)**
- **Major developments in algorithms for high fidelity numerical simulations in complex configurations**
- **Better experimental diagnostic capabilities (PIV, microphone phased arrays)**
- **Can conduct experiments of discovery and ask "what if" type questions in the virtual world**
- **Developing predictive tools based on First Principles may lead to insights into jet noise mitigation techniques that are not understood today…**

Essential step for achieving significant reductions in jet engine noise

15

Successful Jet Exhaust Simulation

High Fidelity Numerical Simulation of Supersonic Jet at *M=1.4* (2009)



Breakthrough calculations of flow field and sound have been applied for prediction of noise with some success

Very promising start in predicting Jet Noise

Jet Noise Prediction Olympics

- **Establish a "Jet Noise Prediction Olympics" to establish benchmarks and state-of-the-art prediction methods**
  - Similar to turbulence workshops at Stanford and the NASA Computational Aero-Acoustics series
  - Identify specific objectives for predicting flow field and acoustic spectra
  - Participants compute the benchmark cases without having seen corresponding experimental data (blind test)
- **Form a small government planning group to define requirements and conduct open competition**
  - 3-4 year effort starting with simple nozzle geometries and working toward cases relevant for tactical jet noise
  - Fund participants for these time consuming, difficult problems
- **Some experimental data available from NASA**
  - Need additional data for tactical jets
  - Some model scale nozzle hardware already exists

Fundamental Research Investment

- **Large Noise Reduction (>3-5 db) will require a long term basic research program which includes:**
  - Imaging techniques – e.g., PIV (Particle Image Velocimetry), coherent phased arrays – to identify and quantify distributed sources of sound in well understood supersonic hot jets
  - High fidelity numerical simulations
  - Noise reduction strategies
  - Validation experiments designed to stress the models including uncertainty levels in both flow and noise
  - Development of improved computational design tools

Noise Reduction in Future Aircraft

- **Airframe Primes should have total system responsibility**
  - Desired aircraft performance, signature control and noise levels are only possible through system integration and total system optimization, not individual component optimization
- **Noise must become a KPP**
  - The aircraft system contract must have realistic Key Performance Parameters (KPPs) - including a noise KPP
- **Initiate design competition for a notional tactical aircraft**
  - To help in defining the design space for achieving noise reduction

Community Noise

Differing Approaches to the Jet Noise Reduction Problem

- **Commercial aircraft noise reduction**
  - 1960s: Commercial Airport Authorities institute noise limits
  - 1971: FAA established noise limits (FAR Part 36)
  - Commercial airports establish Noise Abatement Programs
  - Aircraft manufactures respond with quieter aircraft
  - Air Traffic Control makes procedural changes to minimize noise
  - Noise monitors fielded to measure noise impact on community
  - Notification to residential property owners for noise disclosure prior to sale
- **Military aircraft noise reduction**
  - Noise limits waived for military aircraft
  - No requirement for military aircraft/engine manufactures to reduce noise
  - EIS/AICUZ document noise contours
  - Noise abatement procedures adopted
  - Local governments giving voice to citizen noise complaints
  - Anticipate push by military airport communities for restrictions similar to those enjoyed by commercial airport communities

Community noise is becoming a driving issue…

Physiological Impact of Noise

- **Known: humans lose their hearing based on time and intensity of sound between 500 and 6000 Hz**
- **Known: high variability in hearing loss due to genetics, smoking and non-occupational noise (e.g. iPods)**
- **Known: hearing provides information about azimuth and distance to noise source**
- **Not well known:**
  - Impact on humans from low-frequency sound (<500Hz)
  - Impact of sustained exposure to noise on cognition
  - Impact of hearing protection on noise direction (azimuth) sense/situational awareness

Inadequate Measurement of Risk

- **Current pure tone audiometry is dependent on the test subject's cooperation**
- **Inability to correlate aircraft noise exposure to hearing loss**
  - Confounding factors—smoking, recreational noise, other occupational noise (i.e. berthing spaces on CVNs)
- **Hearing Conservation (HC) Program reports do not document increase in hearing loss in aviation classes of ships**
  - No documentation breaking out personnel exposed to flight deck noise
- **CNA study of 2005**
  - Hearing loss highest on surface ships – attributed to less awareness of high noise environment and less discipline in wearing hearing protection
  - No data on NEC or job position with respect to noise exposure
- **No medical correlation of hearing loss to location and exposure for flight deck workers currently exists**
  - Individual in-ear docimetry needed to measure actual noise exposure

Flight Deck Hearing Protection

Flight Deck Cranial Program Production

ADR 2 & 3

2011

2010

MS C

Currently Available for Fleet Purchase

Current Legacy Systems

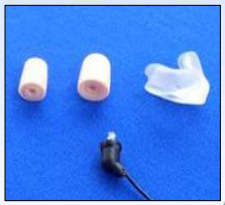
21 dB Mean Attenuation
Legacy Earmuff / Flight Deck Helmet

28 dB Mean Attenuation
Legacy Foam Earplugs

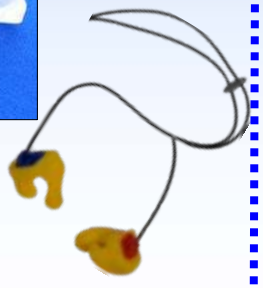
30 dB Mean Attenuation
Legacy Earmuff / Flight Deck Helmet + Legacy Foam Earplugs

25 dB Mean Attenuation
Earmuffs with Improved Earcup Cushions and Inserts

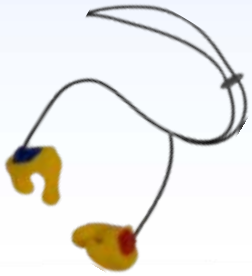
28 dB Mean Attenuation
Communication Earplugs



29 dB Mean Attenuation
Solid Custom Molded Deep Insert Earplugs



43 dB Mean Attenuation
Custom Molded Deep Insert Earplugs + Improved Earmuff



50+ dB Mean Attenuation
Advanced Passive Protection
Active Noise Reduction (ANR)
Improved Earmuff
Custom Molded Deep Insert Earplug
w/ or w/o Communication

Chart courtesy of NAVAIR PMA-202

More Research for Hearing Protection

Progress made but more needed:

- Improvements for measuring noise environment needed
- Develop ways to measure, and then limit, noise exposure time limits based on type of hearing protection being worn
- Digital methods to measure an individual's ear for deep insertion ear plug
- Better understanding of bone-conducted noise energy and its impact on hearing loss and how to mitigate injury.
- Expand protection beyond just "more hearing protection" (i.e. pharmacological protection)
- Model low-frequency noise impacts on humans

Engine Noise Reduction Investments

NASA/FAA

- 1990- 2009: Civil applications $287M
- $80M Supersonic/$207M Subsonic

Navy

- 2003 – 2009: approx $15M
- Largely S&T for Jet Noise Reduction

Air Force

- 2003 – 2009: approx $5M
- Testing and far-field model focus

JSF Program Office

- Baseline noise measurements supporting Hearing Protection
- Study on potential Noise reduction technology (Netherlands Funded)
  - GE and P&W report on ways to reduce jet engine noise

Investment in tactical Jet Engine noise reduction has been inadequate…

Advocates for Noise Reduction

- **ASN(I&E) and Safety & Survivability Office**
  - Concerned about noise reduction
- **Bureau of Medicine**
  - Growing concern over permanent hearing loss of naval personnel
- **Operational Navy and Marine Corps**
  - Growing concern over flight deck noise environment and community noise

Hearing protection program has greater than $100 million shortfall across the FYDP…and no champion…

Bottom Line Conclusions

- **Lack of fundamental noise data or hearing damage data**
- **Noise remains a significant health risk on flight decks**
- **There will be no single solution for the jet engine noise problem – it will require a combination of:**
  - Reducing jet engine noise source
    - Which requires a long term research program
  - Developing a requirement for noise in future tactical jet aircraft
  - Continuing to make improvements to hearing protection
  - Finding ways to limit exposure to excessive noise levels
  - Developing better methods to monitor noise exposure and hearing loss of our personnel
- **DOD does not have a "champion" for jet engine noise reduction**

Conclusions

>>*Today's Problems*

- **Noise levels on today's flight decks (up to150+ dB) exceed ability to protect hearing**
- **There is a lack of reliable and comparable data on the near-field noise of tactical jet aircraft and the noise environment on aircraft carrier and amphibious ship flight decks**
- **Standards do not exist for acquiring engine noise data for tactical aircraft**
- **There are no requirements for military aircraft noise levels**
- **The Navy does not maintain a data base of the noise generated by its aircraft**
- **There is no senior DOD official who acts as the "champion" for jet noise reduction**
- **Navy hearing loss problems extend beyond the flight deck**
- **Community noise concerns growing and could become the tipping point for requiring jet engine noise reduction**

Conclusions

>>*Human Hearing Protection*

- **Significant progress has been made in hearing protection technology with pilot production hearing protection components which provide up to 43 dB attenuation being tested at sea**
- **There are inadequate data on hearing loss for Sailors/Marines correlated to an individual's noise exposure environment**
- **Individualized sound-level dosimetry is needed to fully match hearing profiles to occupational assignment and noise source exposure.**

>>*Jet Engine Technology*

- **Predictive tools are now emerging with potential for more accurate assessment of jet engine noise reduction approaches**
- **Large reductions (>3-5 dB) in jet engine noise will only be possible if the investments are made in the research and experimentation to reduce jet engine source noise**
- **Should start now with design studies to define realistic noise requirements for the next generation tactical aircraft**

Recommendations

- **Find a senior DOD champion/advocate for jet aircraft noise reduction – USD(AT&L), ASN(RDA)**
- **Initiate a long term research program to obtain the needed understanding of the physics of jet noise – CNR**
- **Conduct a competitive design among the airframe prime contractors to start identifying the design space for noise reduction in tactical aircraft in order to help develop a noise KPP – NAE**
- **Augment the VAATE/ADVENT program to address noise reduction – DDR&E and COMNAVAIR**
- **Support the hearing protection roadmap and fund the procurement of needed improved hearing protection – N8**
- **Develop standards for acquiring engine noise data for tactical aircraft – COMNAVAIR and AFRL**
- **Expand the distribution of improved hearing protection beyond aviation personnel – N86/87**
- **Expand and diversify Navy medical research into physiological effects of noise – Chief, BuMed**