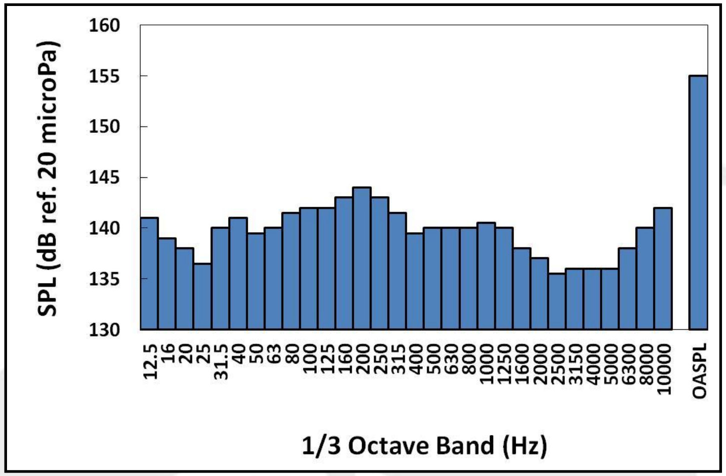
AIAA
GREATER HUNTSVILLE SECTION
American Institute of Aeronautics and Astronautics



Acoustics Overview and Aerospace Test Systems

A. W. Mayne, III

October 14, 2015
Huntsville, AL

INTRODUCTION

What We Will Cover

- Basic Acoustic Concepts
- High-Intensity Acoustic Test Systems for Aerospace Applications
- Underwater Acoustic Systems for Ship and Submarine Applications

A Few Acoustic Projects I Have Worked On

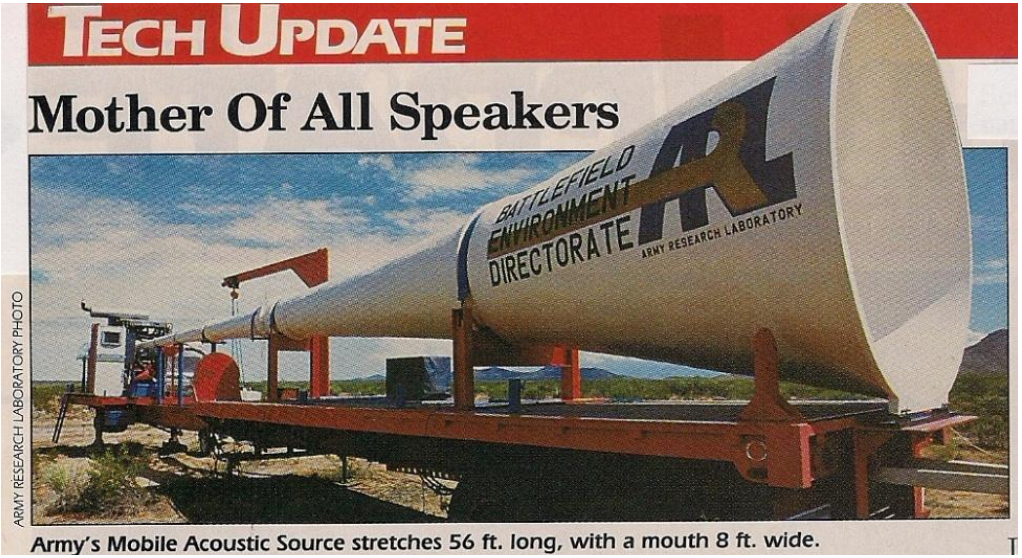
REVERBERATION CHAMBER FOR TESTING SPACECRAFT

(Courtesy of INPE, Brazil)

HIGH-FREQUENCY GAS JET NOISE SOURCE

(Courtesy of NAL, India)

10 HZ HORN AND NOISE SOURCE



("Popular Mechanics", p. 16, Aug 1995)

BASIC ACOUSTIC CONCEPTS

Acoustics in General

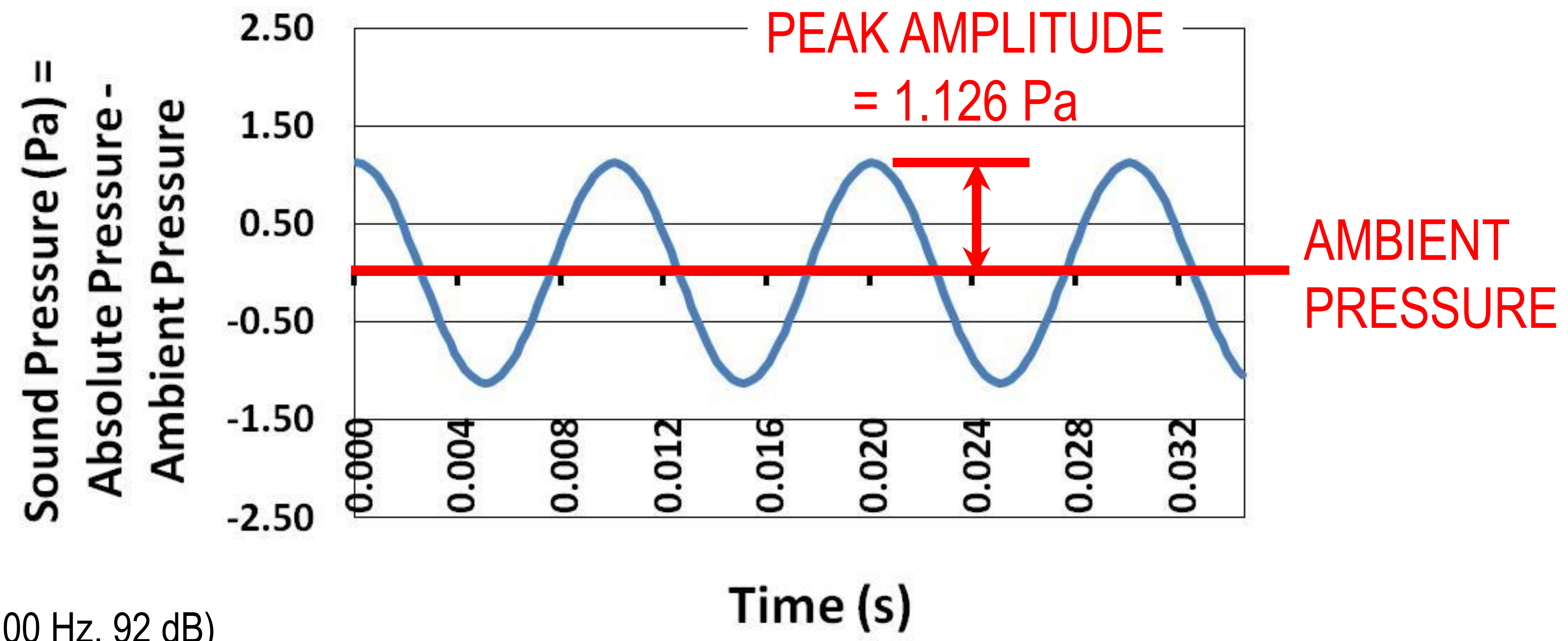
- An oscillating pressure disturbance that moves through a medium.
- Requires a medium: gas, liquid, solid, plasma. Here, we will discuss small amplitude (linear), ideal gas acoustics.
- The disturbance travels in waves through the medium at a speed characteristic of the medium (speed of sound).
- Like all waves, acoustic waves have amplitude, frequency, and wavelength.
- Some acoustic disturbances can be perceived as sound, and some cannot.

Speed of Sound

- The speed at which an acoustic disturbance travels through a medium (ft/s, m/s, etc.)
- Typically given the symbol “c”
- In an ideal gas, the speed of sound is proportional to the square root of the absolute temperature of the gas.
- Convenient formulas for the speed of sound in ***air:***
  - $c = 49 * T^{1/2}$ T in degrees R, c in ft/s
  - $c = 20 * T^{1/2}$ T in degrees K, c in m/s

Sound Pressure

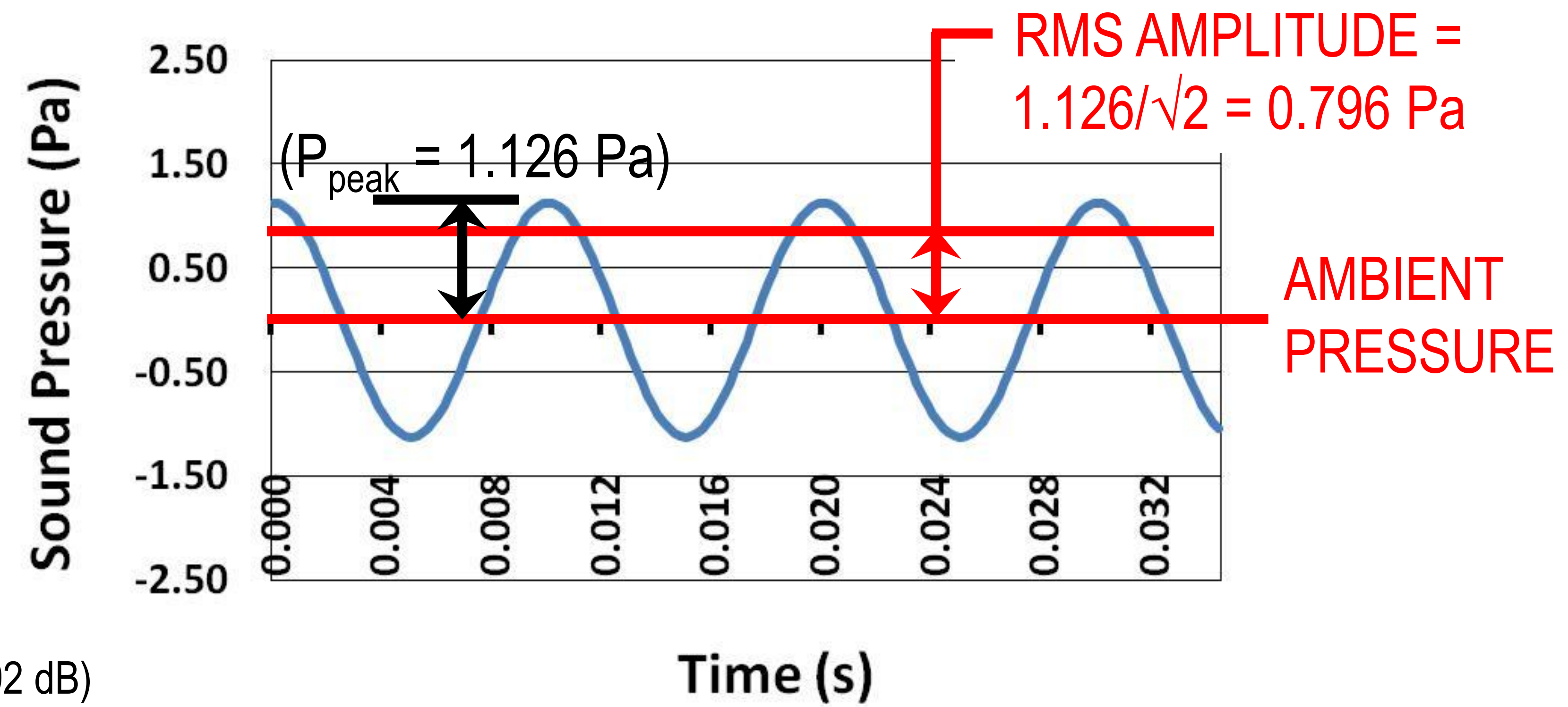
- The varying pressure in an acoustic wave, measured from the ambient, undisturbed pressure
- Measured as pressure (psi, Pa, etc.)



(100 Hz, 92 dB)

RMS Sound Pressure

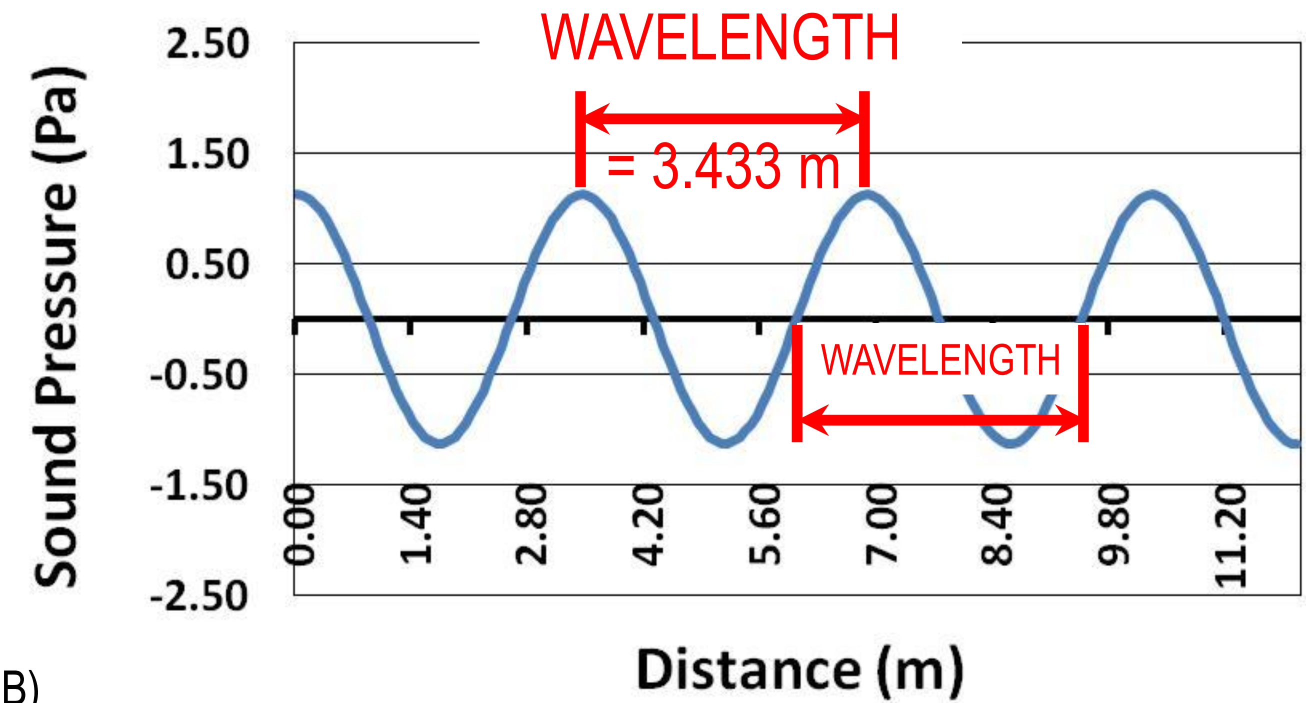
- Root-Mean-Square (RMS) amplitude is a measure of the average sound pressure of the acoustic wave (psi, Pa, etc.)
- For a *sine wave*, $P_{rms} = P_{peak} / \sqrt{2}$



(100 Hz, 92 dB)

Wavelength

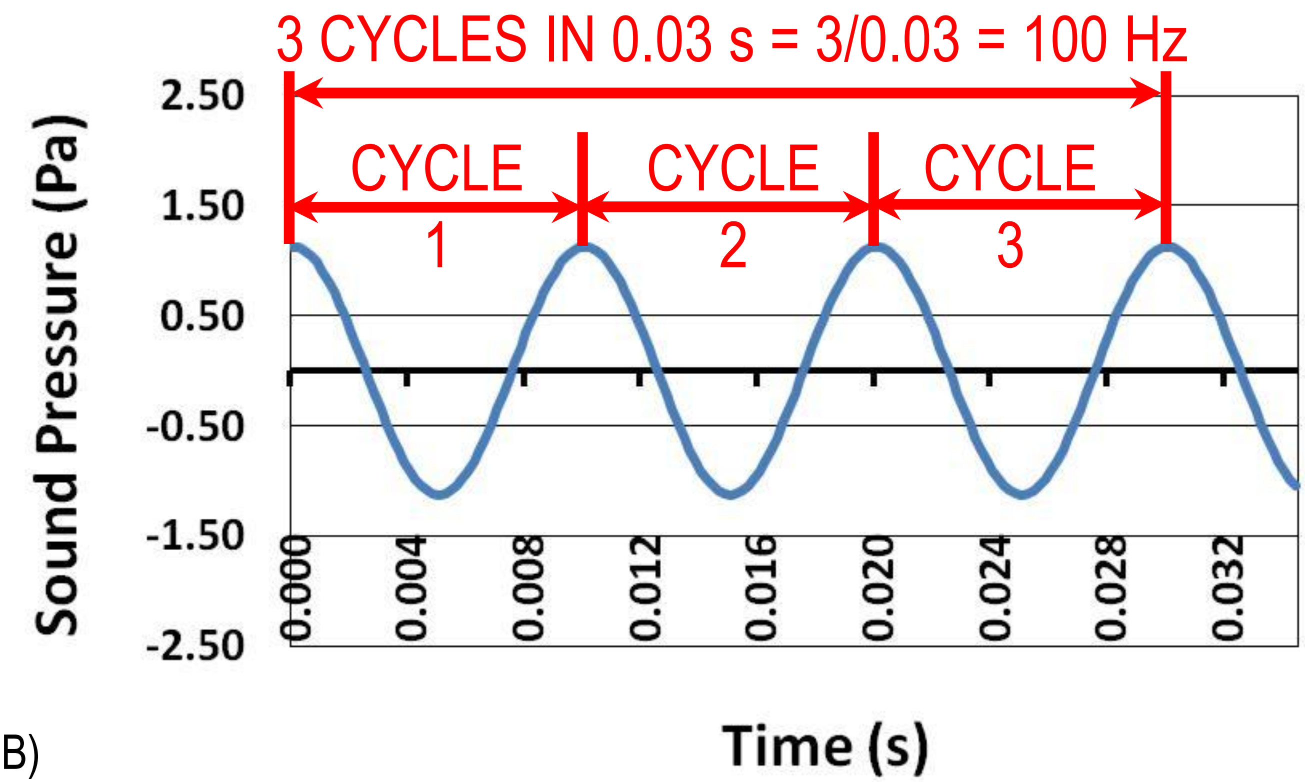
- The distance from one point on an acoustic wave to the corresponding point on the following wave (feet, meters, etc.)
- Typically given the symbol *lambda*, “λ”



(100 Hz, 92 dB)

Frequency

- The number of wave cycles occurring at a point in one second
- Typically given the symbol “f”
- Measured in cycles per second (cps), referred to as Hertz (Hz)



(100 Hz, 92 dB)

Wavelength-Frequency Relationship

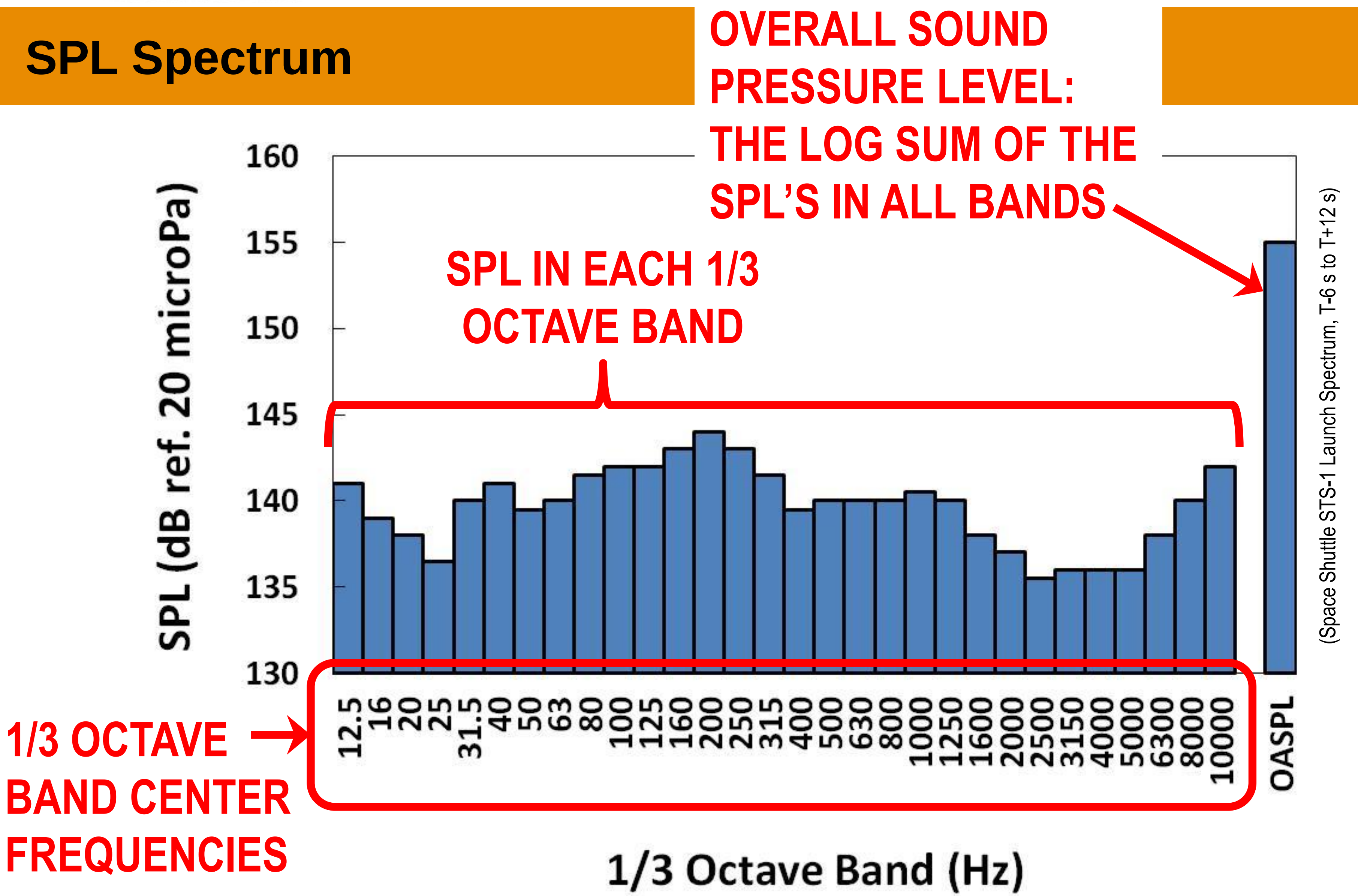
- Wavelength and frequency are inversely proportional:
  - $c = f * \lambda$
- Here are some examples:

Frequency f (Hz)	Gas	Temp. T (C)	Speed of Sound $c = (\gamma RT)^{0.5}$ (m/s)	Wavelength $\lambda = c/f$ (m)
100	air	20	343	3.433
100	H2	20	1305	13.052
15000	air	20	343	0.023

Sound Pressure Level (L_P or SPL)

- $SPL = 20*Log_{10}(P_{RMS}/P_{REF})$
  - Measured in decibels, stated as “dB”
  - P_{REF} = 20 microPa *in gases*
  - Other reference values are used for the SPL in water, for intensity level, etc.
- *Be careful to use the correct reference value.*
- “85 dB ref. 20 microPa” is a complete statement of the sound pressure level, but it will generally be stated simply as “85 dB”.

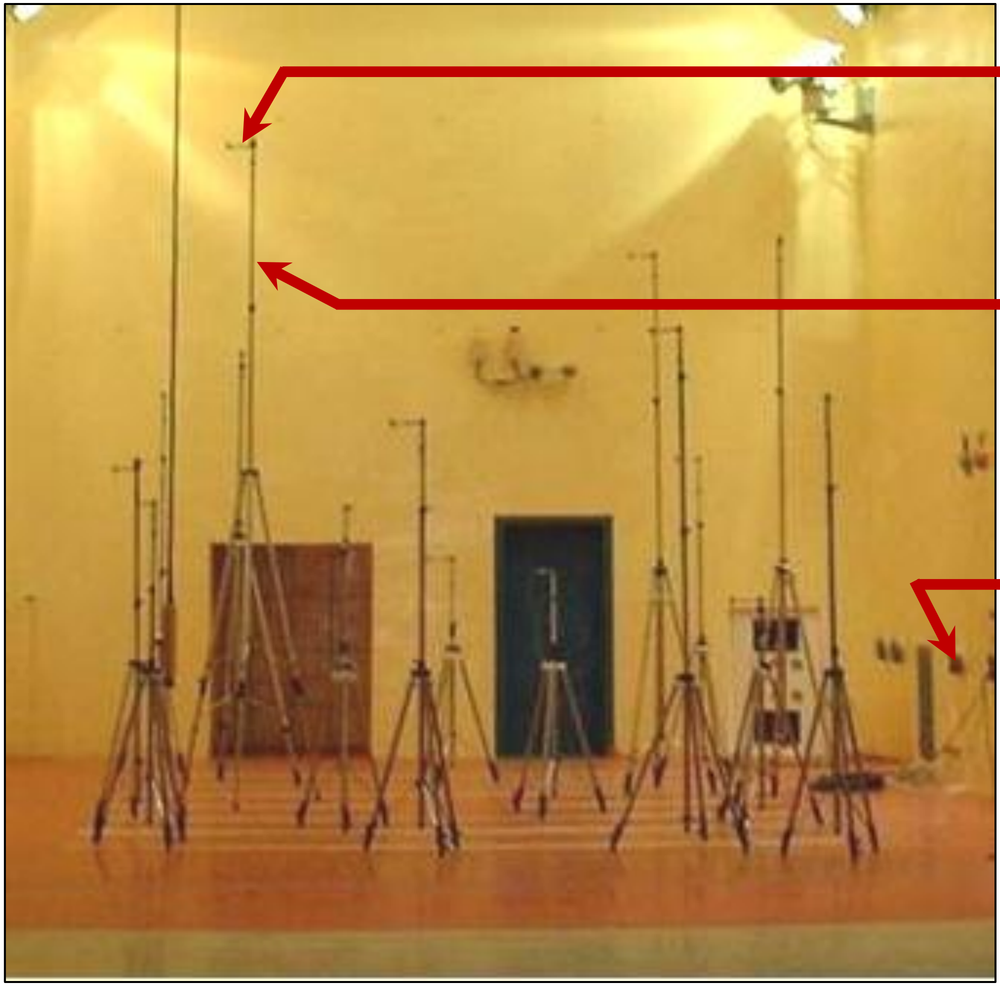
SPL Spectrum



Microphones for Test and Measurement

- Microphones are used to measure acoustic pressure fluctuations and convert them into an electrical signal.
- Common microphones for test and measurement applications: condenser and piezoelectric.
- Microphones are meant for different sound fields: pressure field, free field, random-incidence field.
- Microphones must be calibrated.
- When choosing a microphone, talk to the vendors.
- Know your requirements: sound field, environment, SPL range and tolerance, frequency range, cable length, standards, existing instrumentation.

Array of Microphones in a Reverberant Test Chamber



(Courtesy of INPE, Brazil)

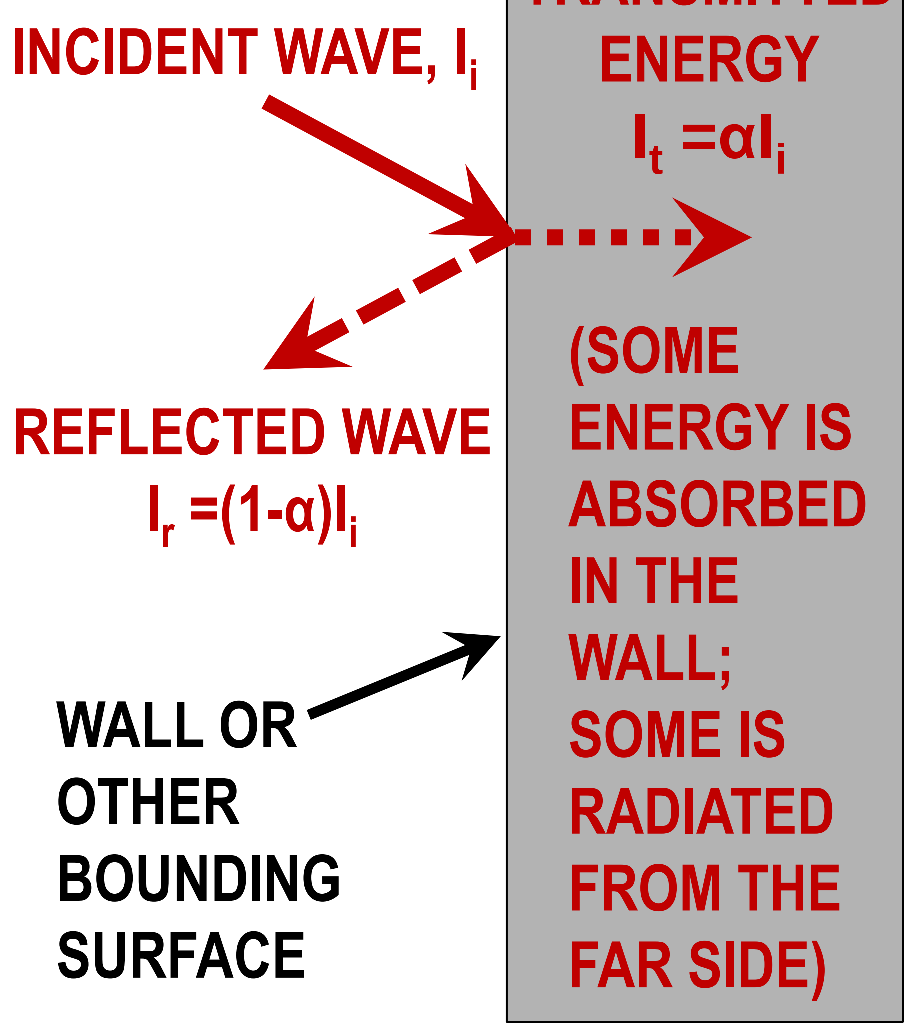
MICROPHONE & CLAMP SUPPORT

TRIPOD

COAXIAL MICROPHONE CABLES LEAD OUTSIDE THE TEST CHAMBER TO THE MICROPHONE POWER SUPPLY, SPECTRUM CONTROLLER, & DATA ACQUISITION SYSTEM

Reflection and Boundary Absorption

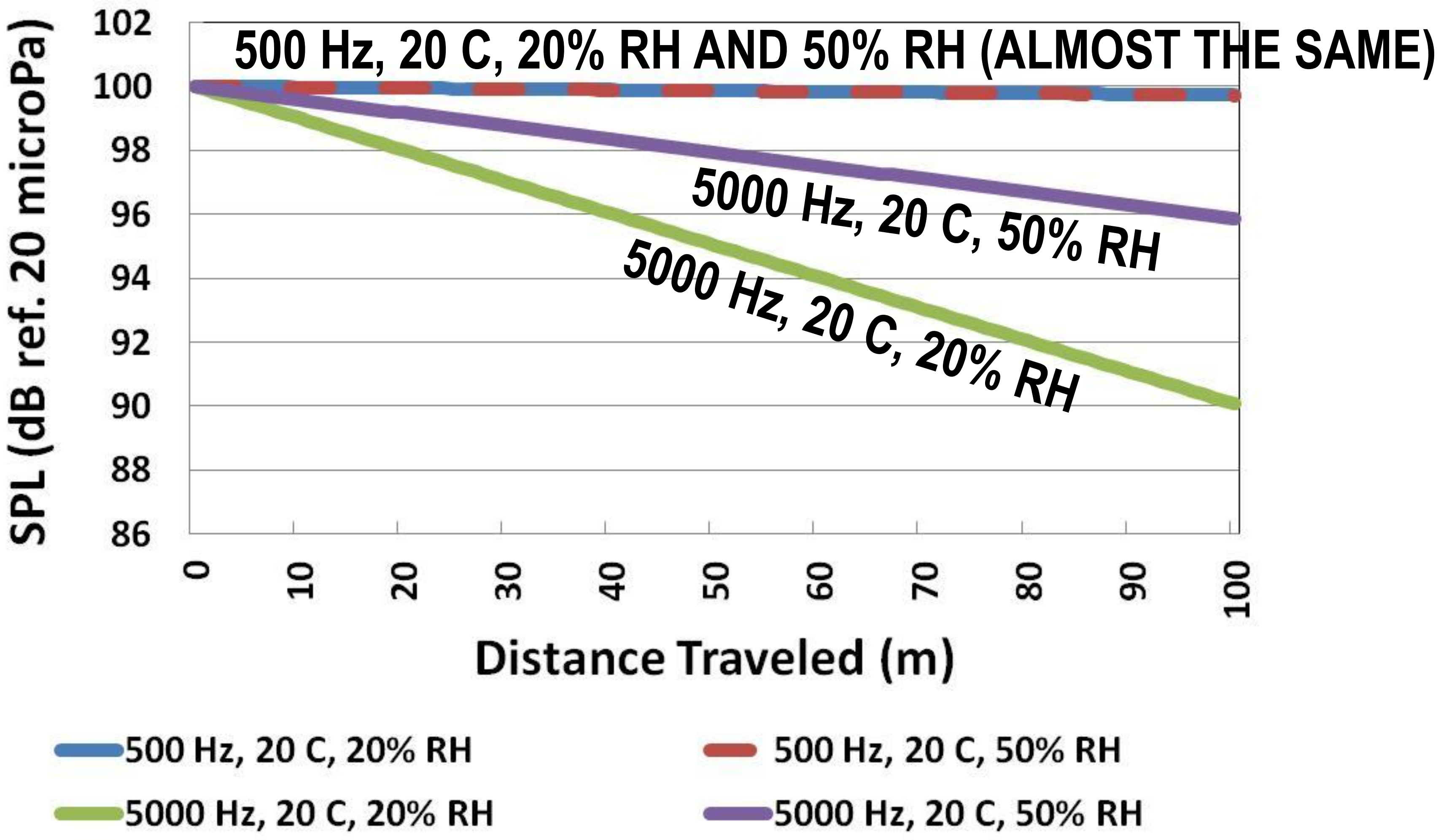
- Sound is reflected from surfaces like a wall
- The reflected intensity, I_r, is reduced according to the absorption coefficient, "α" (alpha)
- α depends on the material, surface, angle, and frequency
- $0 \le \alpha \le 1$



Absorption in Air (or Other Gases)

- An acoustic wave will be attenuated (weakened) as it travels through air.
- Absorption in air is primarily a function of:
  - Frequency
  - Temperature
  - Relative humidity
  - Distance traveled
- Absorption in air is most important at high frequencies (f > about 1000 Hz).

Examples of Absorption in Air (Gas Absorption Only)



Nonlinear Behavior

- Most of the everyday noise you will run into can be analyzed under the assumption of linear behavior:
  - Human voice
  - Factory floor
  - Automobile
  - Music from loudspeakers
  - Etc.
- However, nonlinear acoustic behavior can be important, such as the distortion of an acoustic wave at very high sound pressures.

Distortion of a High-Intensity Sine Wave (165 dB)

NEAR THE SOURCE, THERE IS A SINE WAVE (A SINGLE FREQUENCY)

27.6 FT DOWNSTREAM, THERE IS A SAWTOOTH WAVE (LOTS OF HIGHER FREQUENCIES)

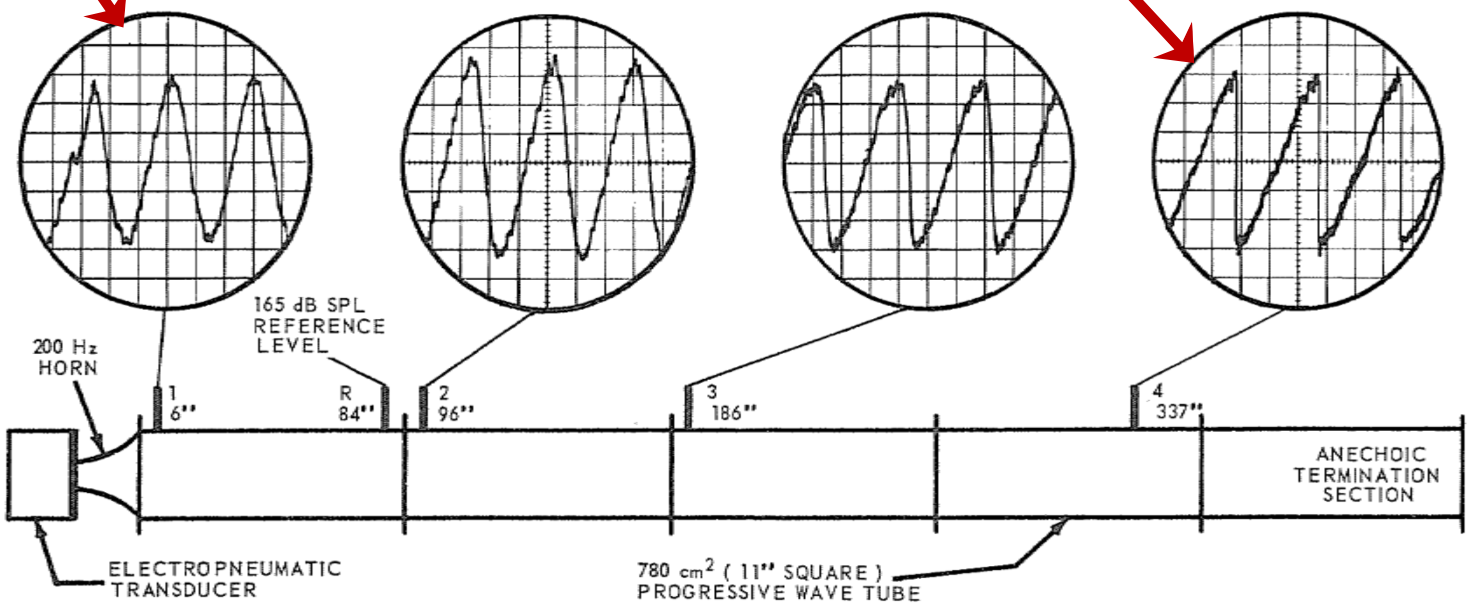


Fig.2 315 Hz High Intensity Sound Pressure Wave as a Function of Propagation Distance

(Miller, “Development of a Wide-Band, Ten Kilowatt Noise Source,” IEST Proceedings, 1967)

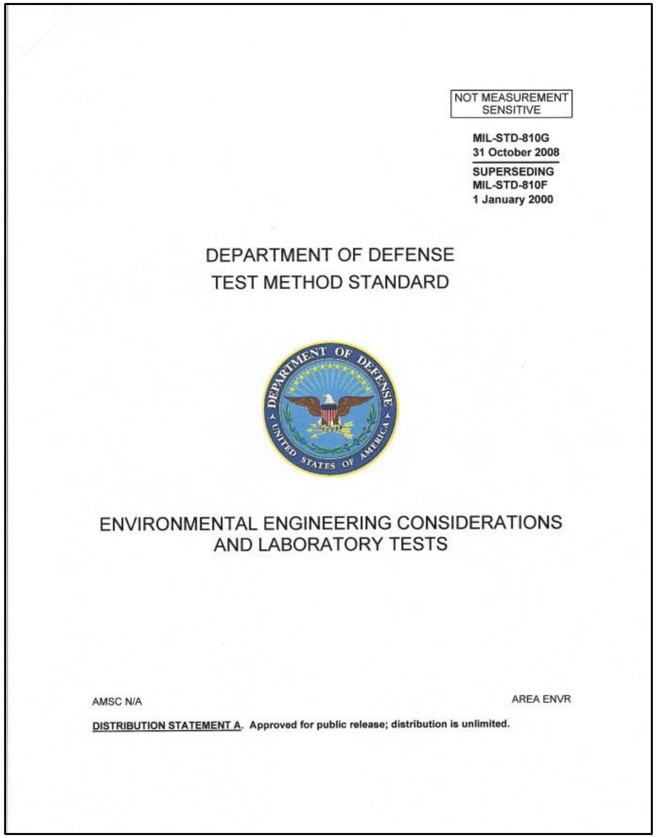
HIGH-INTENSITY ACOUSTIC TEST SYSTEMS FOR AEROSPACE APPLICATIONS

Acoustic Test Levels for Rockets and Aircraft (A/C)

Vehicle	Location	OASPL (dB)
Transport A/C[1]	Away from jet exhausts	130.0
Transport A/C[1]	Internal, close to jet exhausts	140.0
Delta IV Rocket[2]	Inside 5-m payload fairing (Acceptance Level)	140.6
High-Performance A/C[1]	Away from jet exhausts	145.0
Delta IV Rocket[2]	Inside 5-m composite payload fairing (Qualification Level)	146.1
Med-Performance A/C[1]	Air-to-air missile on A/C	150.0
Hi-Performance A/C[1]	Inside nose cone	160.0
Hi-Performance A/C[1]	Air-to-air missile on A/C	165.0

1. MIL-STD-810G, "Environmental Engineering Considerations and Laboratory Tests," Oct., 2008.
2. United Launch Alliance, "Delta IV Payload Planners Guide," Sep., 2007.

Acoustic Test Requirements


NOT MEASUREMENT SENSITIVE

MIL-STD-810G
31 October 2008
SUPERSEDING
MIL-STD-810F
1 January 2000

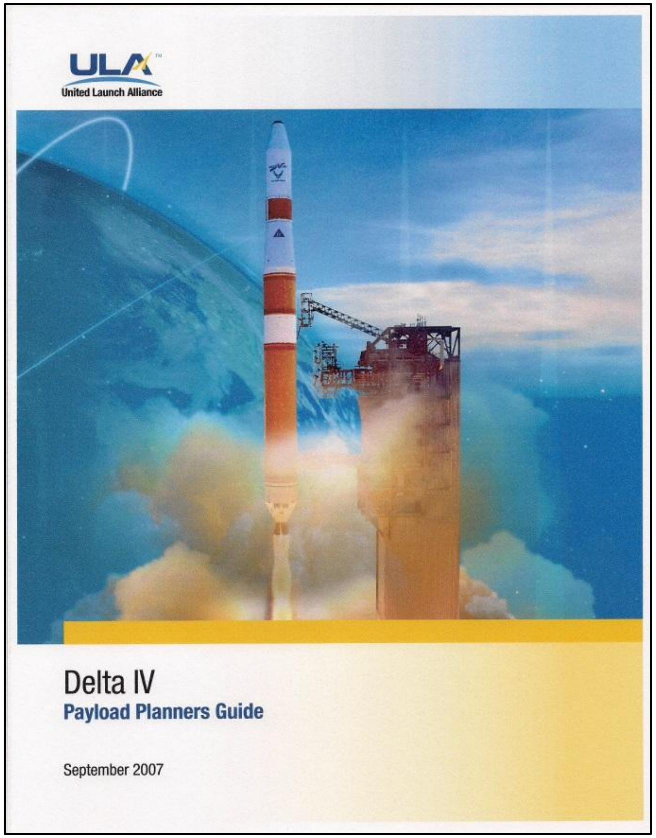
DEPARTMENT OF DEFENSE
TEST METHOD STANDARD

ENVIRONMENTAL ENGINEERING CONSIDERATIONS AND LABORATORY TESTS

AMSC N/A

AREA ENVR

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.



Government Standard:

MIL-STD-810G

(Ref. Method 515.6)

Commercial Standard:

Delta IV Payload Planners Guide

(Ref. Section 4.2.3.3)

Common High-Intensity Acoustic Test Facilities

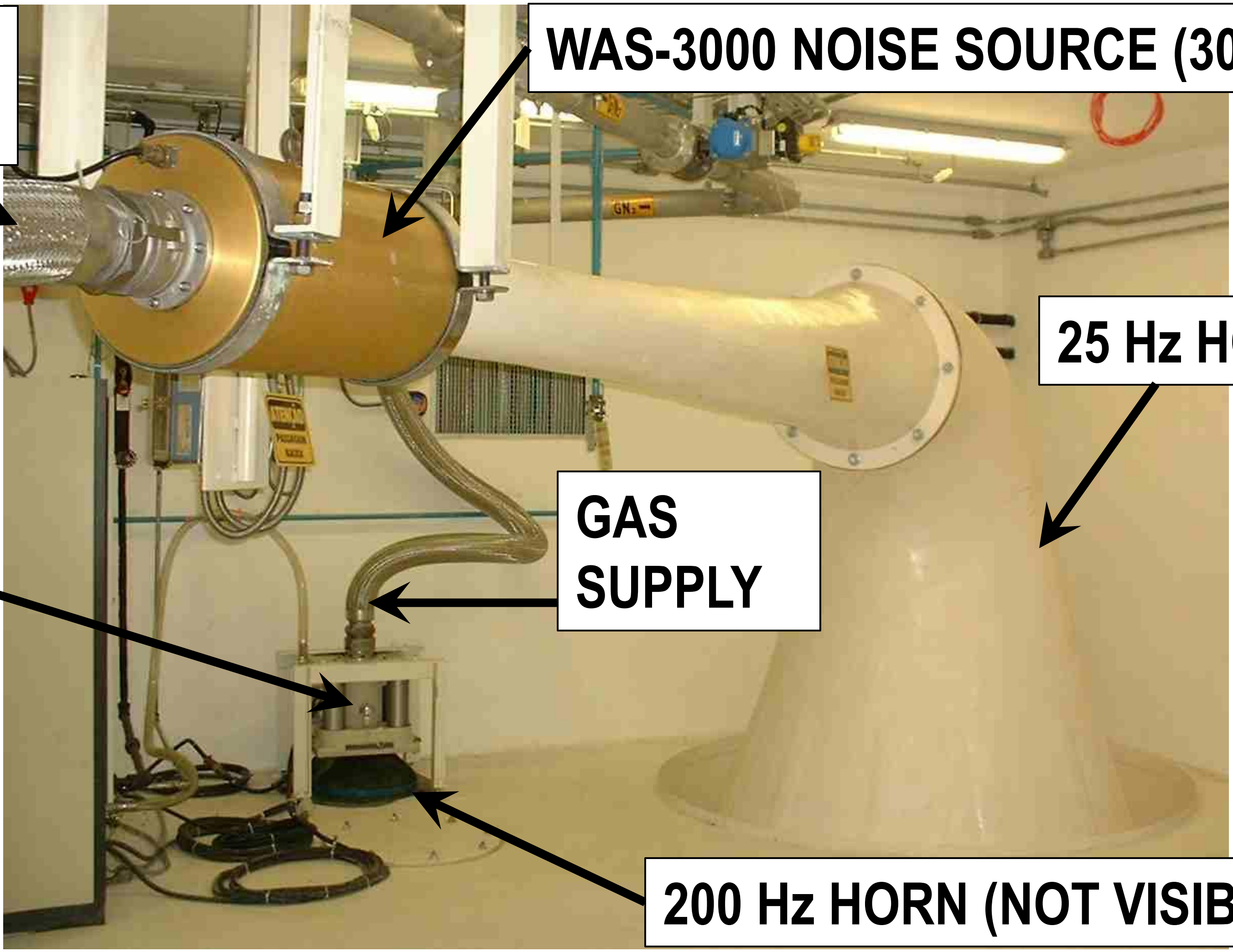
- **RATF: Reverberant Acoustic Test Facility**
  - Closed, reflective room or cavity for the sound field
  - Approximates a diffuse field
  - Waves at all frequencies, from all directions
- **PWT: Progressive Wave Tube**
  - Duct of constant cross-section
  - Progressive (flat) waves moving in only one direction
- **DFAT: Direct Field Acoustic Test**
  - Cylindrical bank of loudspeakers surround a test article
  - Direct acoustic wave impingement (mostly normal)

Large RATFs

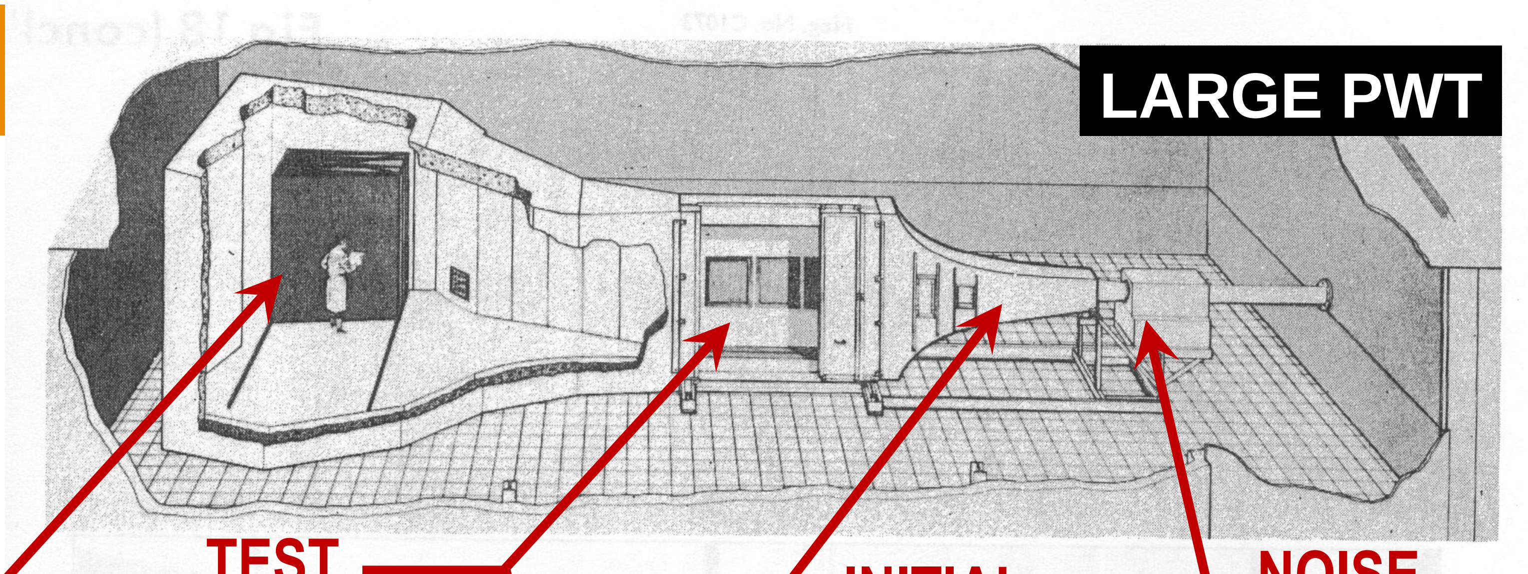
(Courtesy of INPE, Brazil)

- Large RATF for testing spacecraft
- Typical of large RATFs built outside the US in the last 25 years
- 1213 m^3 (42,800 ft^3)
- 100 kW of acoustic source power
- Nitrogen vaporization system

Electropneumatic Noise Sources & Horns



(Courtesy of INPE, Brazil)

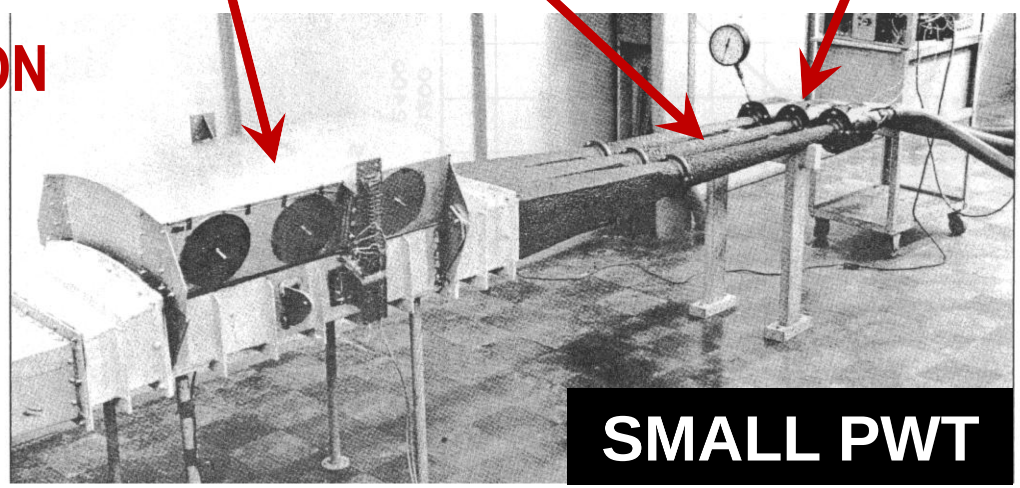


TEST SEGMENT

INITIAL HORN(S)

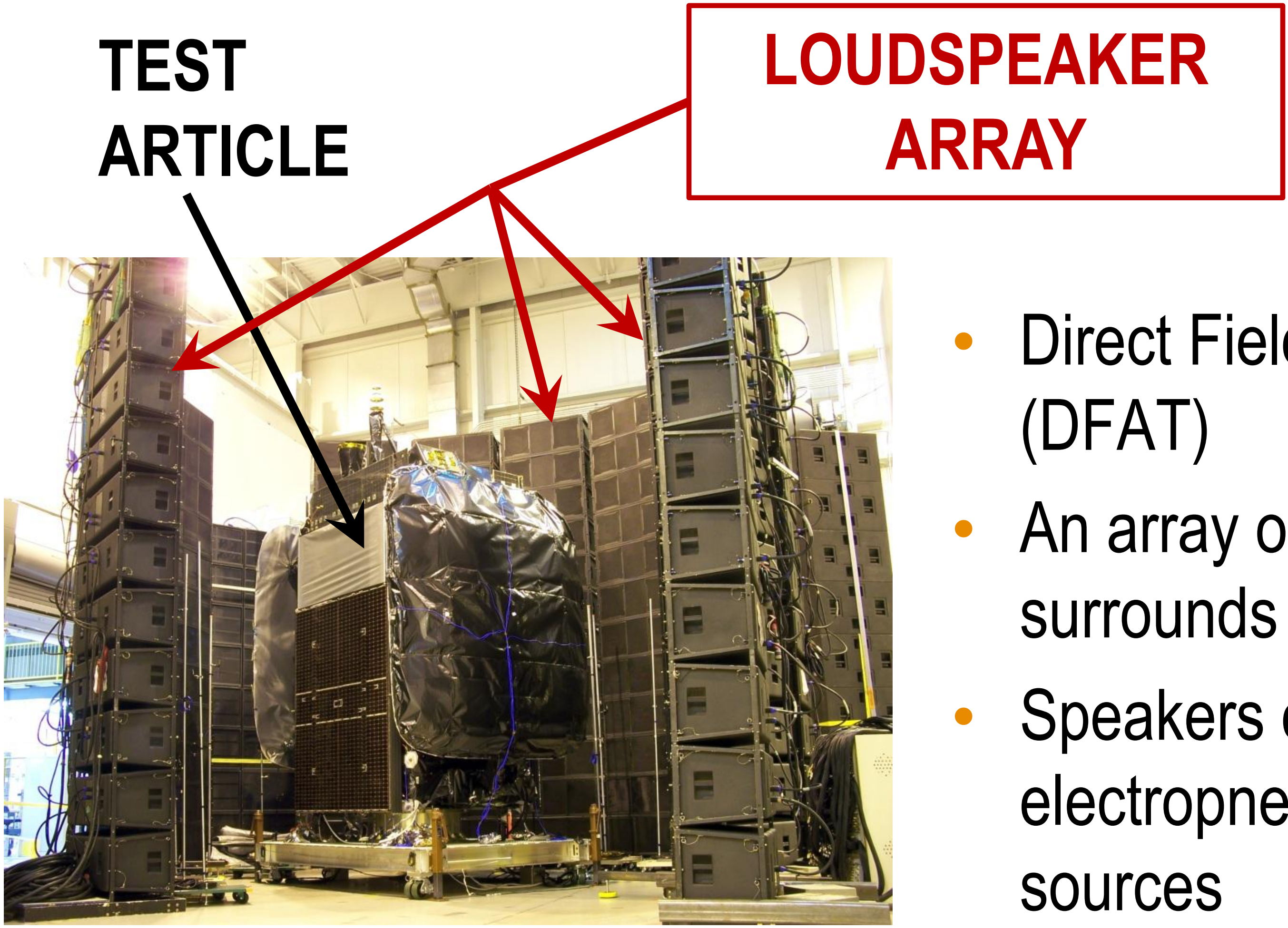
NOISE SOURCE(S)

ANECHOIC TERMINATION



(Webb, Royal Aircraft Establishment Tech. Report No. 65170, Sep., 1965)

Array of Loudspeakers

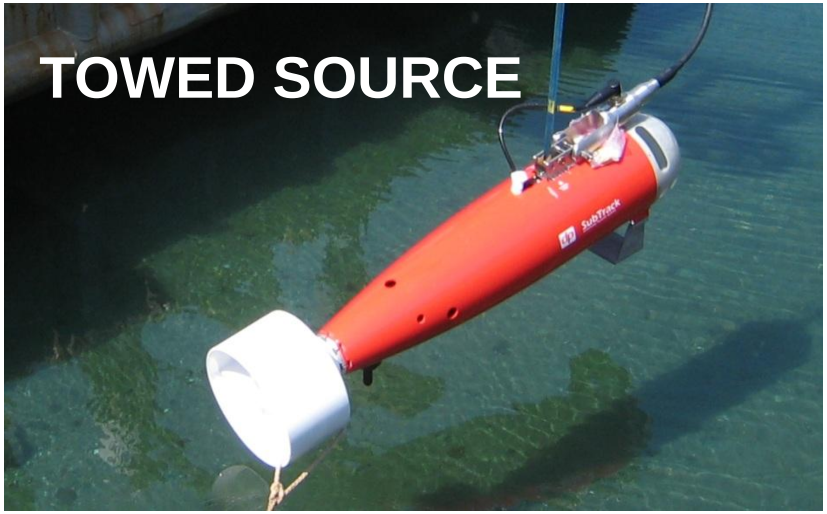


(Courtesy of Orbital Sciences Corporation)

- Direct Field Acoustic Test (DFAT)
- An array of loudspeakers surrounds the test article
- Speakers only; no electropneumatic noise sources

UNDERWATER ACOUSTIC SYSTEMS FOR SHIP AND SUBMARINE APPLICATIONS

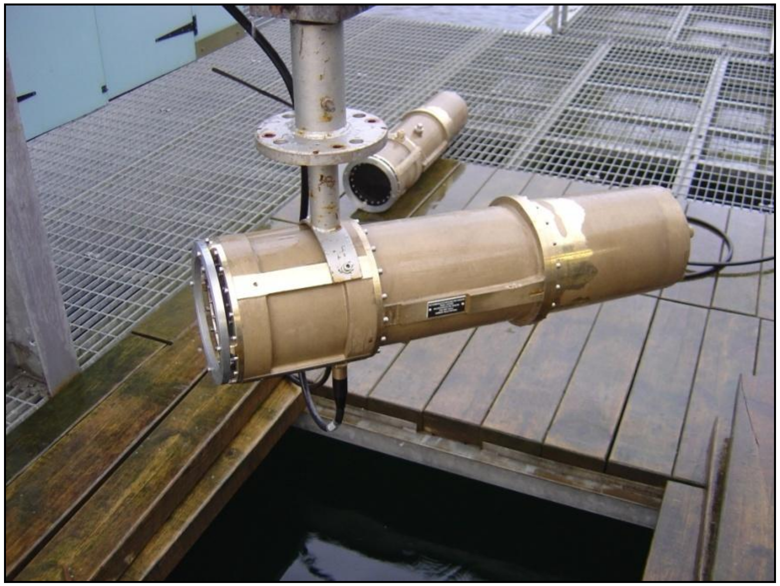
Some Types of Underwater Systems



WIDE-BAND CALIBRATION SOURCE

(Courtesy of Data Physics Corp.)

Moving-Coil Underwater Projectors (Hydrosounders)

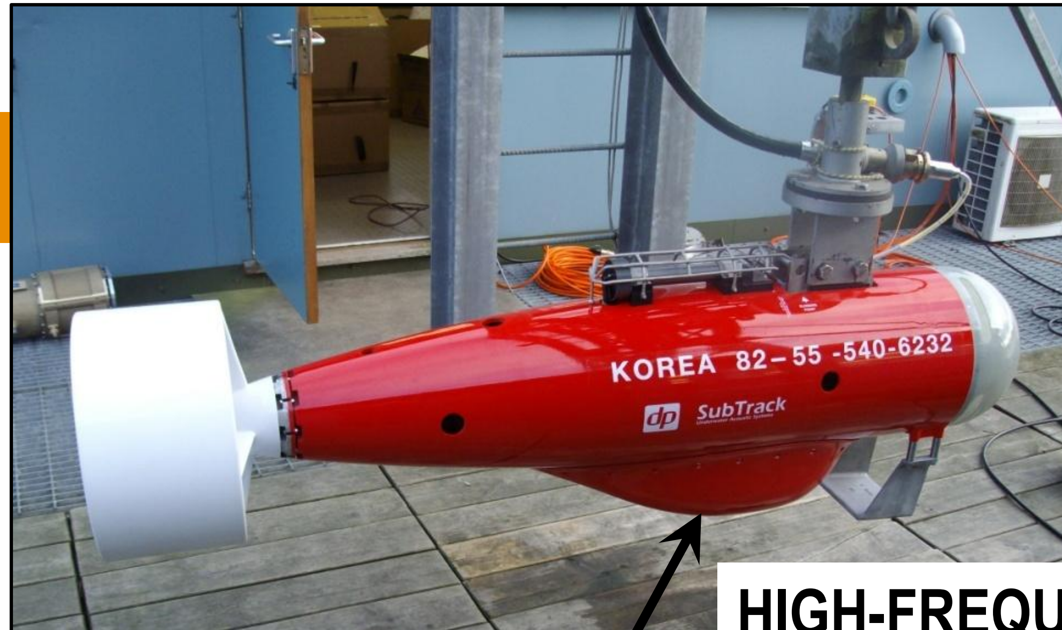


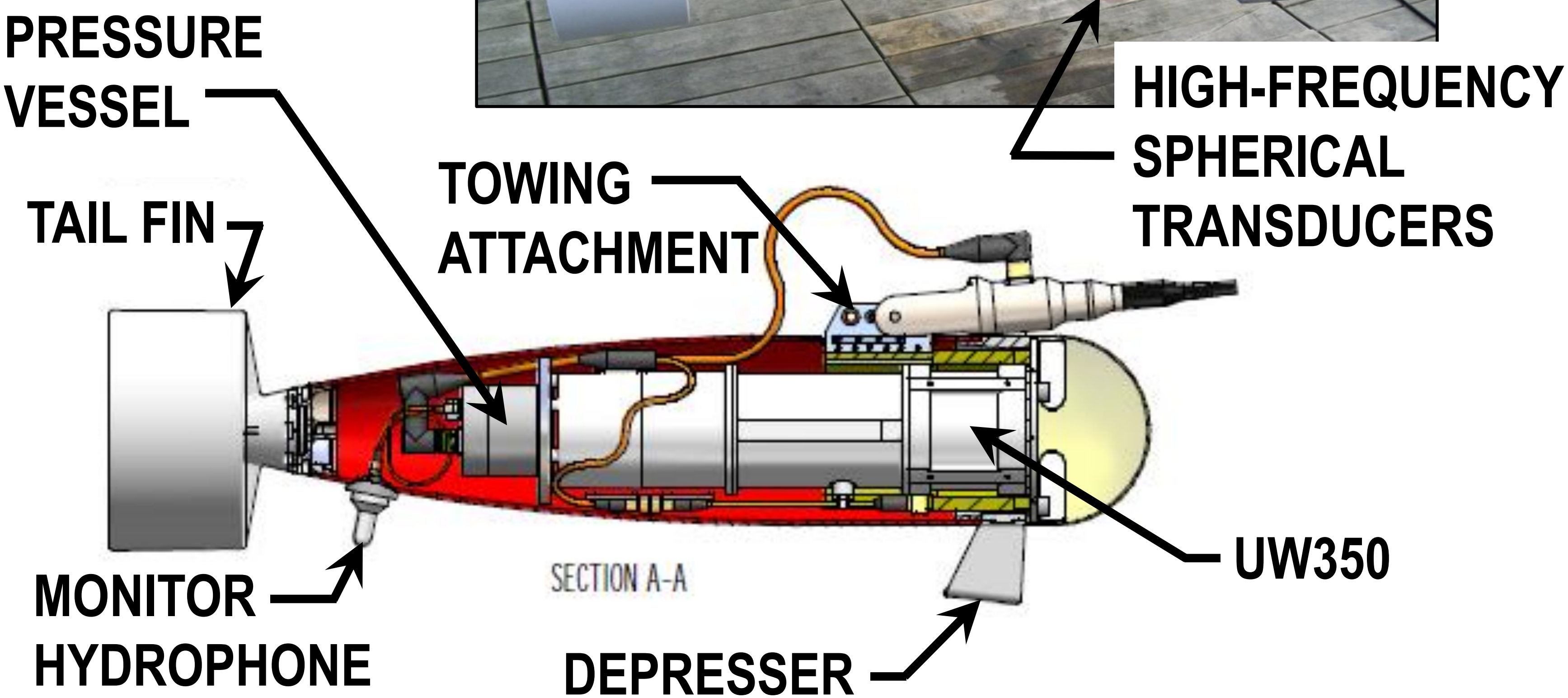
(Courtesy of Data Physics Corp.)

- UW350 Type A low frequency projector
- 20 Hz to 20 kHz
- Max SPL: 170 dB re 1 μPa @ 1 m
- Amplifier drive: 1 kVA
- Weight: 100 kg

- UW600 very low frequency projector
- 4 Hz to 600 Hz
- Max SPL: 188 dB re 1 μPa @ 1 m
- Amplifier drive: 25 kVA
- Weight: 1310 kg

Towed Systems (Towfish)

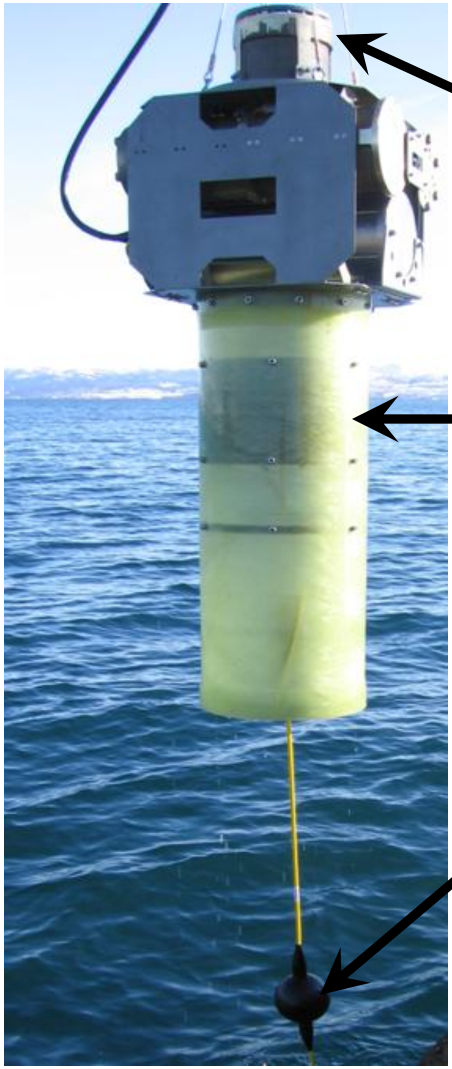




(Courtesy of Data Physics Corp.)

Calibration Systems

- Statically deployed
- 20 Hz – 100 kHz
- SPL up to 200 dB
- Omnidirectional beam patterns
- In service in the United Kingdom and in Korea
- Containerized system for easy deployment



UW350 TYPE B

RING TRANSDUCERS

SPHERICAL TRANSDUCERS

(Courtesy of Data Physics Corp.)

Thank you for listening.

Shaping the Future of Aerospace

Questions?