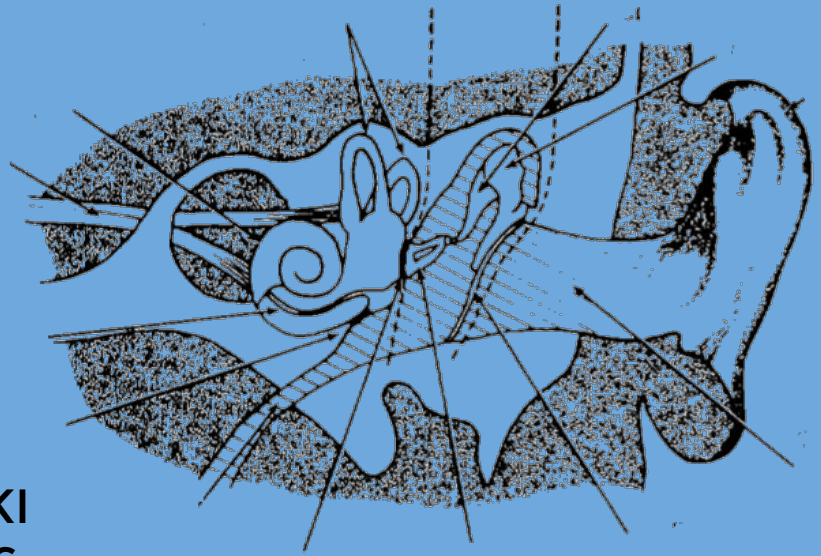
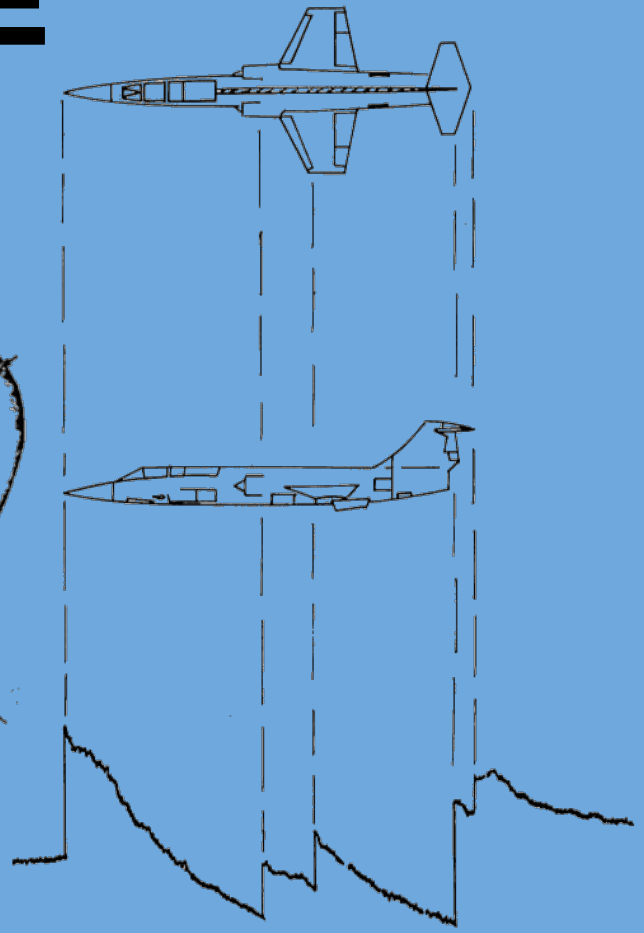
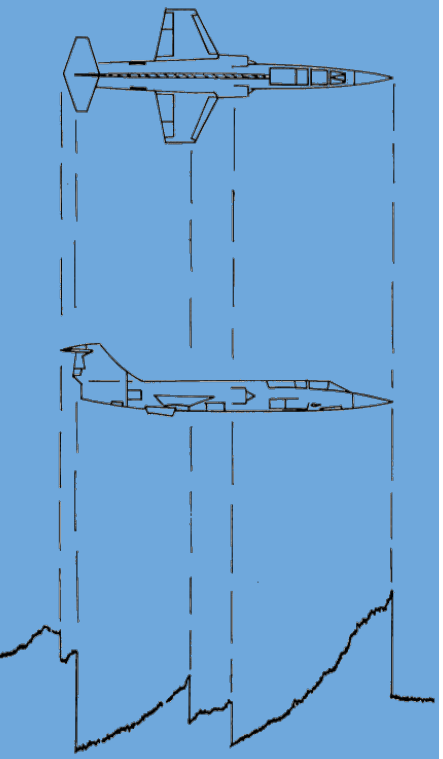
HUMAN RESPONSE TO SONIC BOOMS





JOHN KARASINSKI
DECEMBER 1, 2016

Chuck Yeager, Bell X-1 (1957)

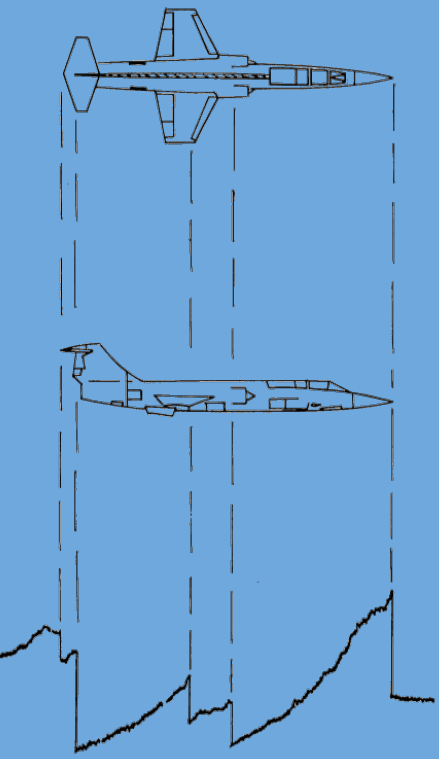


THE EARLY YEARS

- 1950 USAF
- Correlate pressure with theory
- Keep humans “far enough away”
- Weapon?

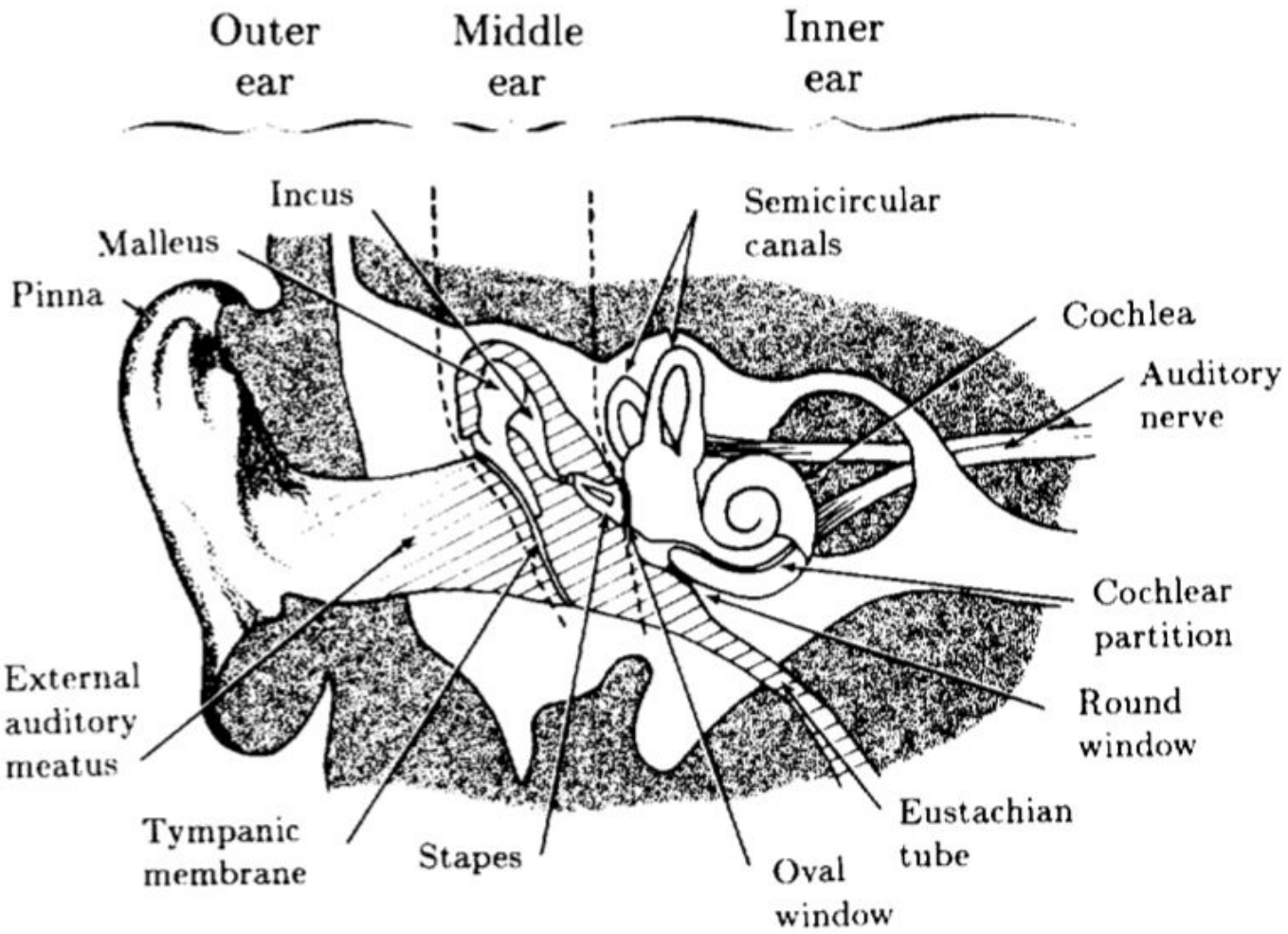
LOCATION OF STUDY	PARTICIPATING AGENCIES	CALENDAR YEAR															
		50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
WPAFB	USAF																
WPAFB-EDWARDS	USAF																
WPAFB-EDWARDS	USAF																
EDWARDS AFB	NASA																
EGLIN AFB	USAF/USA																
WALLOPS STATION	NASA																
WALLOPS STATION	NASA																
WPAFB	USAF																
NELLIS AFB	USAF/NASA																
EDWARDS AFB	USAF/NASA/FAA																
ST. LOUIS	USAF/NASA/FAA																
CROSS COUNTRY SPEED RUN B-58	USAF																
WALLOPS STATION	USAF/NASA/USN/FAA																
EDWARDS AFB	USAF/NASA/FAA/USA																
OKLAHOMA CITY	USAF/NASA/FAA																
WHITE SANDS	USAF/FAA																
EDWARDS AFB	NASA																
CHICAGO	USAF/NASA																
WALLOPS STATION	USAF/NASA/USN																
JTF-2 (TONAPAH)	USAF																
EDWARDS AFB (B-70)	NASA/USAF																

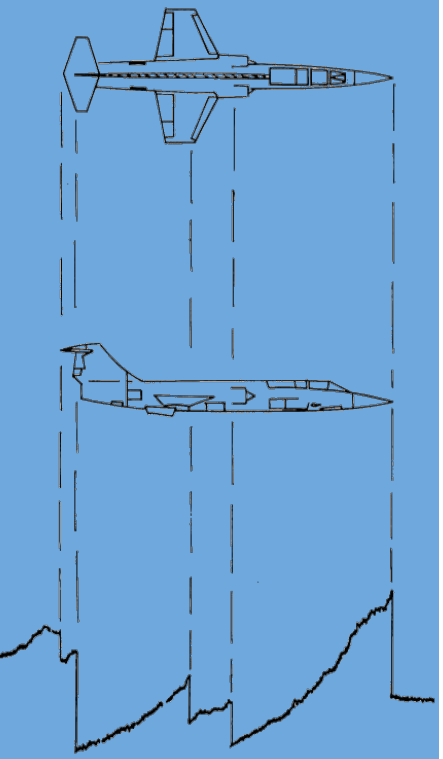
PHYSICS OF SONIC BOOM BIOLOGICAL STRUCTURES



INITIAL EXPERIMENTS

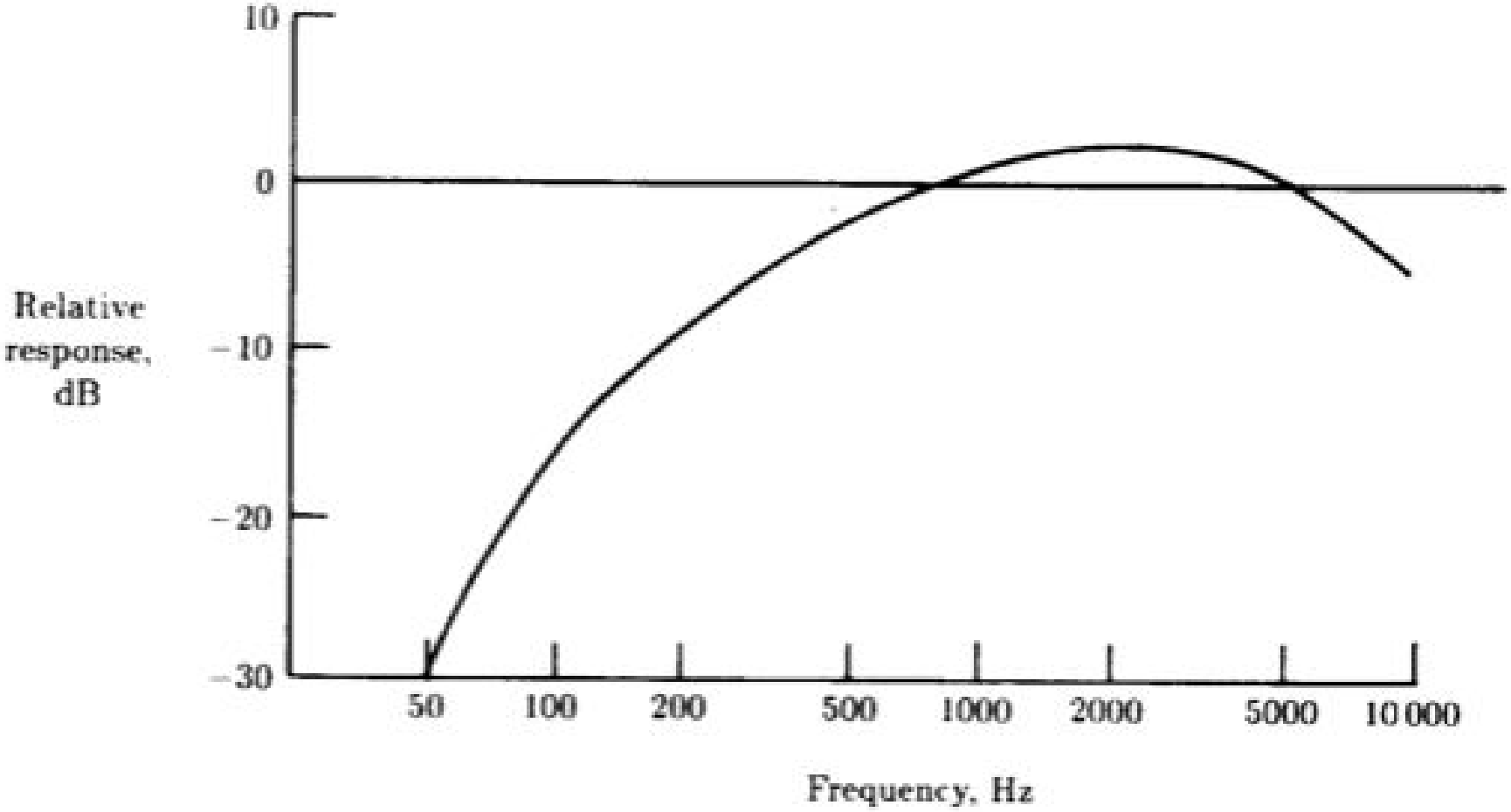
- Two aircraft at Mach 1.05-1.16
- Unique wave shapes
- Glass breakage
- Test on humans within 50 feet

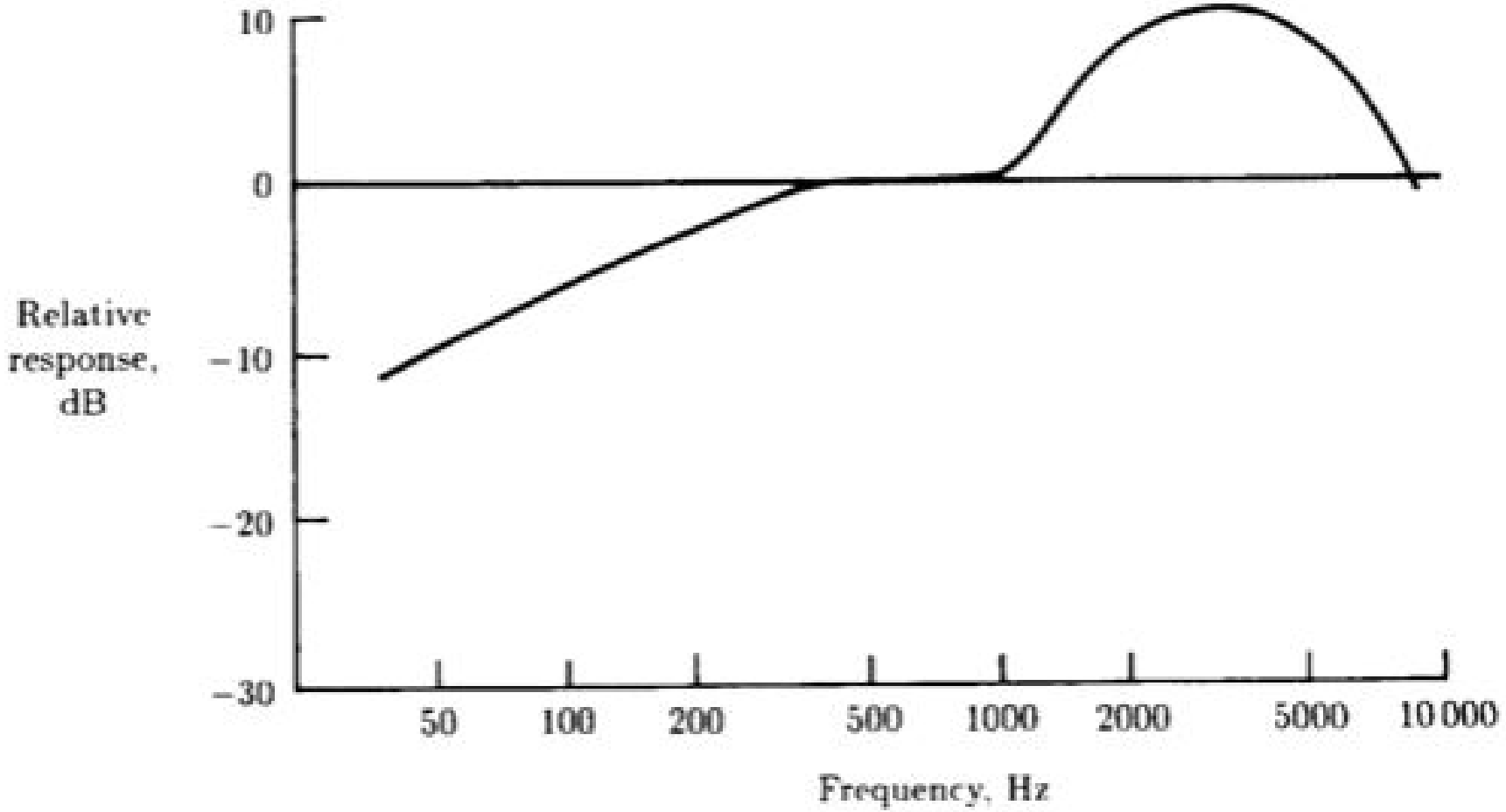

Outer ear
Middle ear
Inner ear
Incus
Malleus
Pinna
Semicircular canals
Cochlea
Auditory nerve
Cochlear partition
Round window
Eustachian tube
Oval window
Stapes
Tympanic membrane
External auditory meatus

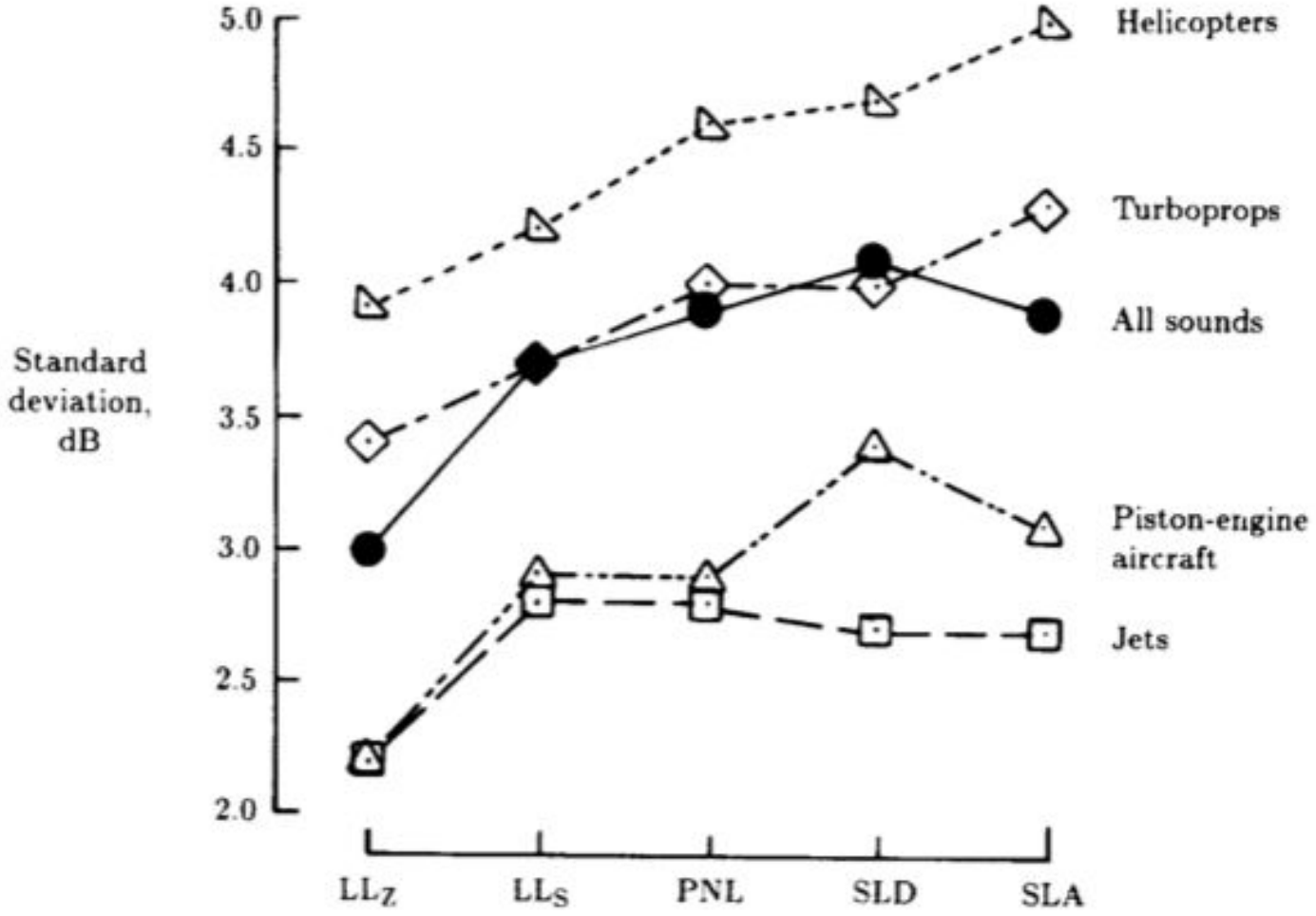


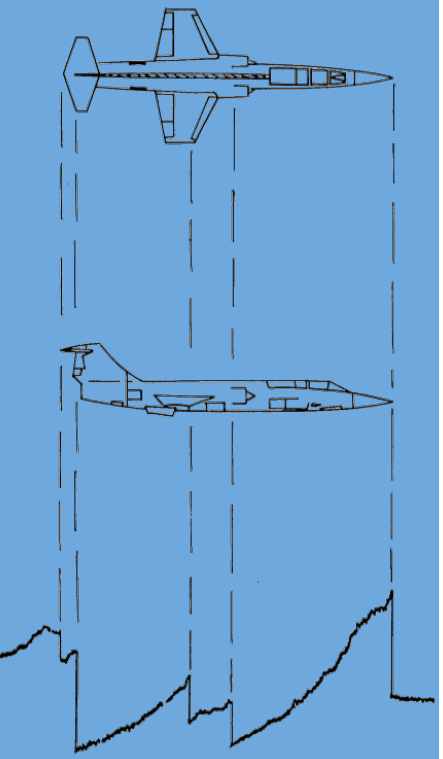
MANY NOISE METRICS

- Predict loudness, or annoyance, or...
- Sound Pressure Levels (SPL)
- $$L_A = 10\log_{10}\left[\sum_{i=1}^{n} 10^{L_A(i)/10}\right]$$
- SLA, LL_S, LL_Z, PNL, PL, EPNL...


10
0
−10
−20
−30
Relative response, dB
50
100
200
500
1000
2000
5000
10 000
Frequency, Hz

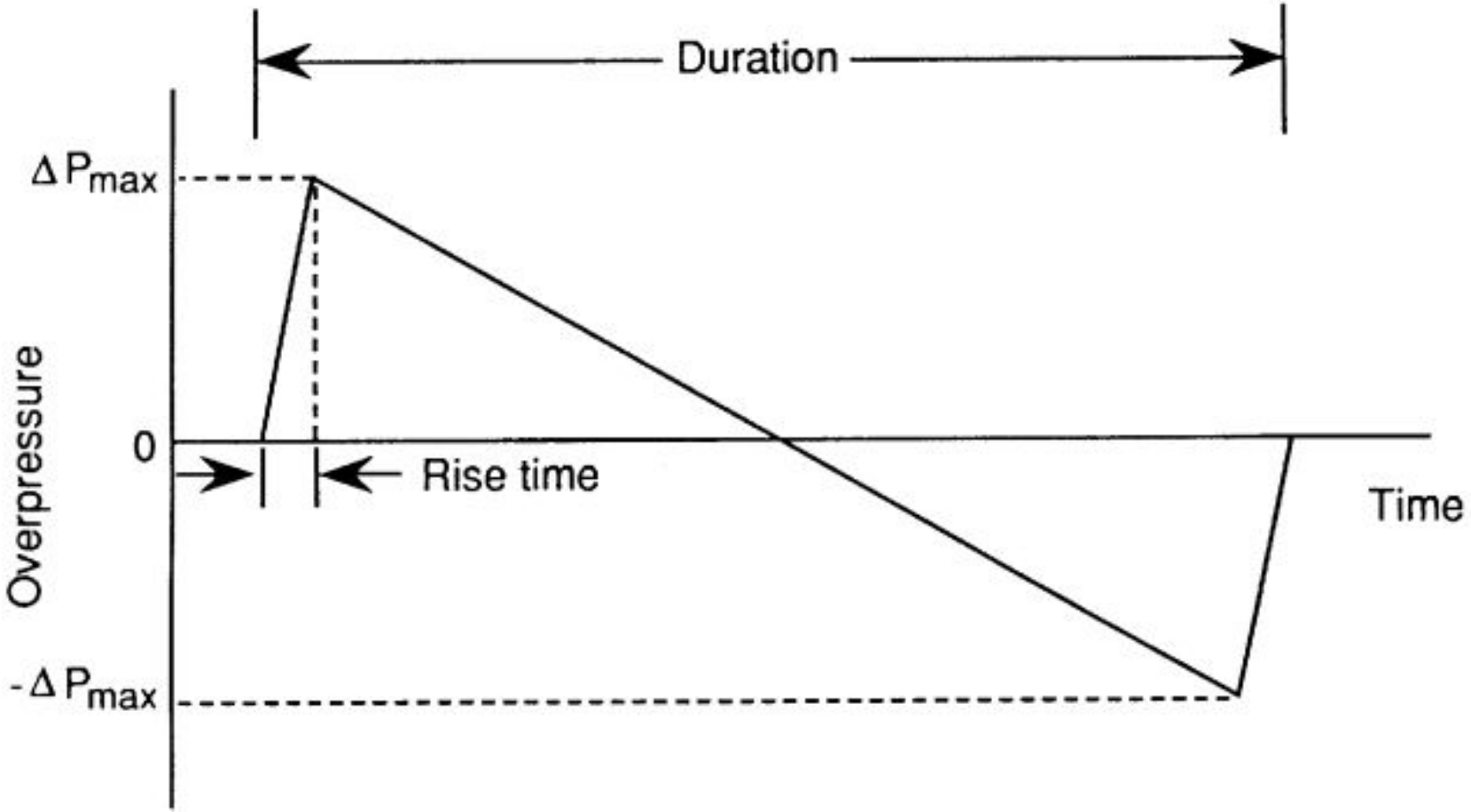

10
0
−10
−20
−30
Relative response, dB
50
100
200
500
1000
2000
5000
10 000
Frequency, Hz

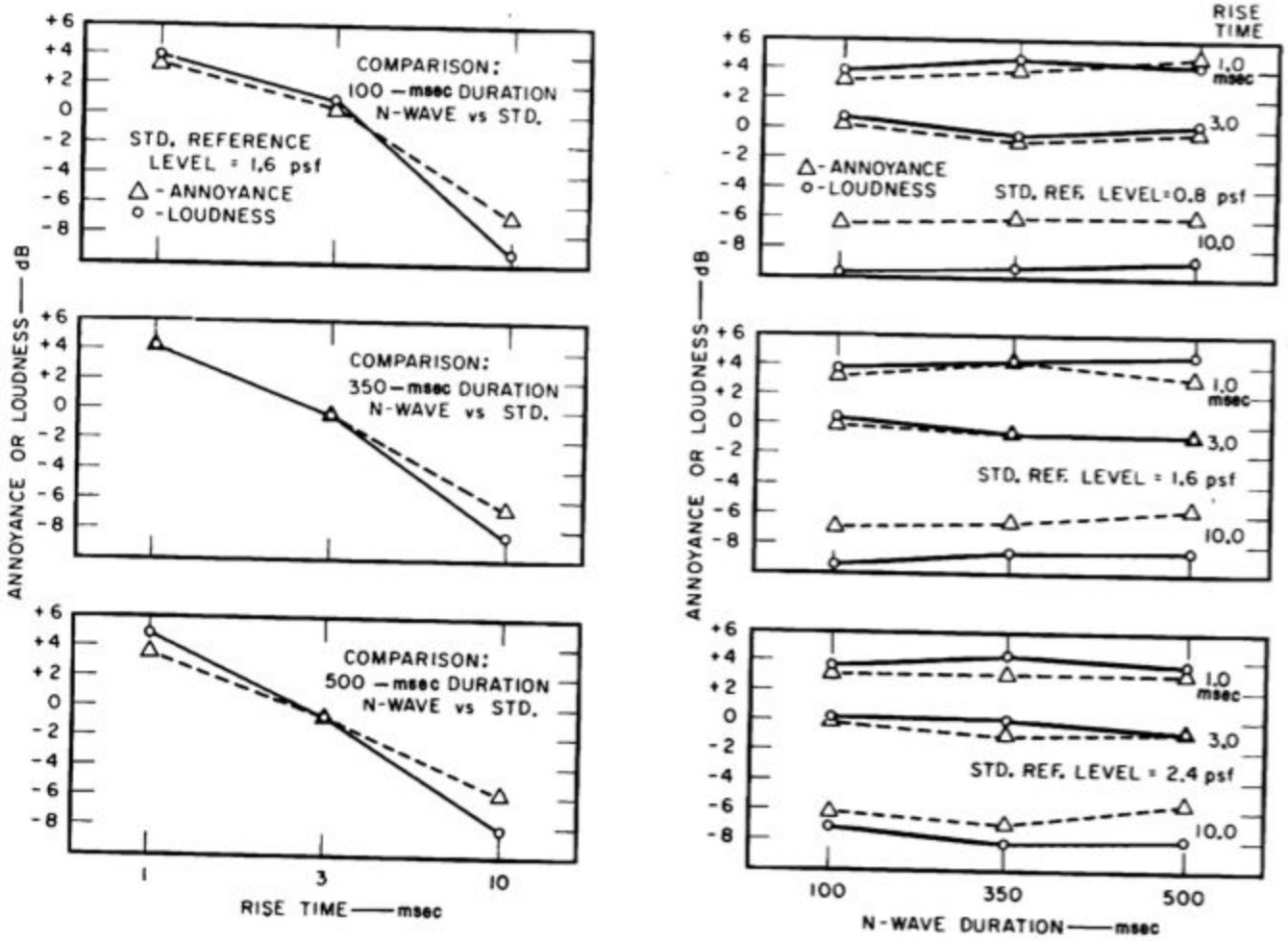

Standard deviation, dB
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Helicopters
Turboprops
All sounds
Piston-engine aircraft
Jets
LLZ
LLS
PNL
SLD
SLA

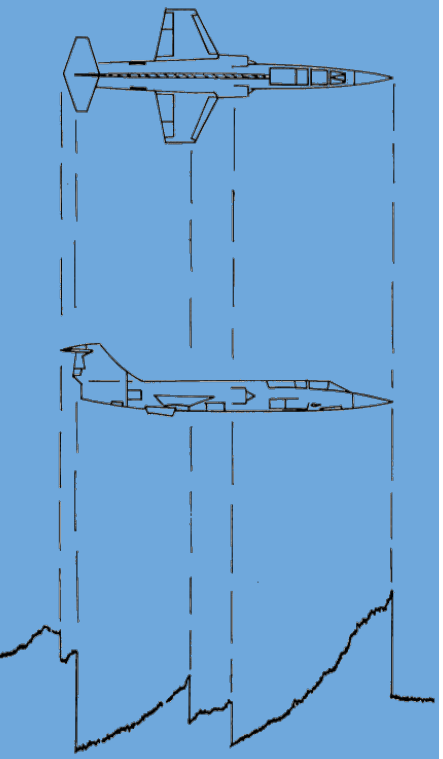


MODELLING BOOMS (PART 1)

- N-wave signature
  - Rise time, P_{max}, Duration

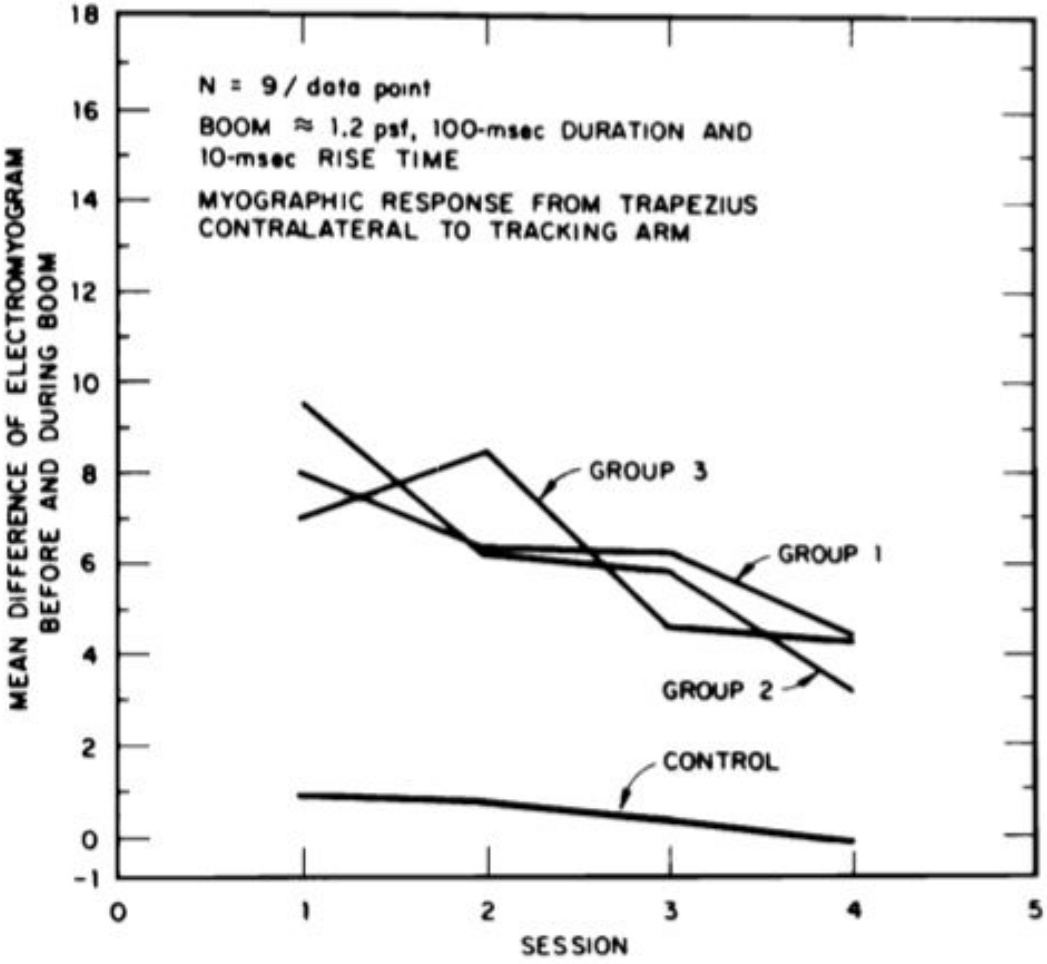

Duration
ΔPmax
Overpressure
0
Rise time
Time
-ΔPmax

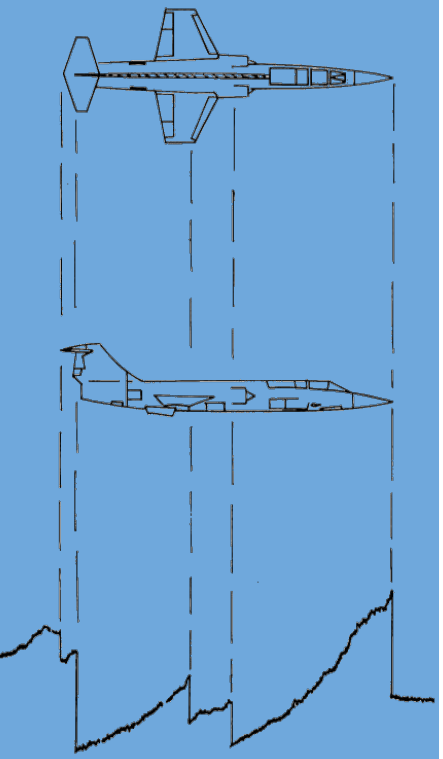

COMPARISON:
100 — msec DURATION
N-WAVE vs STD.
STD. REFERENCE
LEVEL = 1.6 psf
△ - ANNOYANCE
○ - LOUDNESS
COMPARISON:
350 — msec DURATION
N-WAVE vs STD.
COMPARISON:
500 — msec DURATION
N-WAVE vs STD.
ANNOYANCE OR LOUDNESS — dB
+6
+4
+2
0
-2
-4
-6
-8
1
3
10
RISE TIME — msec
RISE TIME
1.0 msec
3.0
10.0
△ - ANNOYANCE
○ - LOUDNESS
STD. REF. LEVEL = 0.8 psf
STD. REF. LEVEL = 1.6 psf
STD. REF. LEVEL = 2.4 psf
100
350
500
N-WAVE DURATION — msec



STARTLE RESPONSE

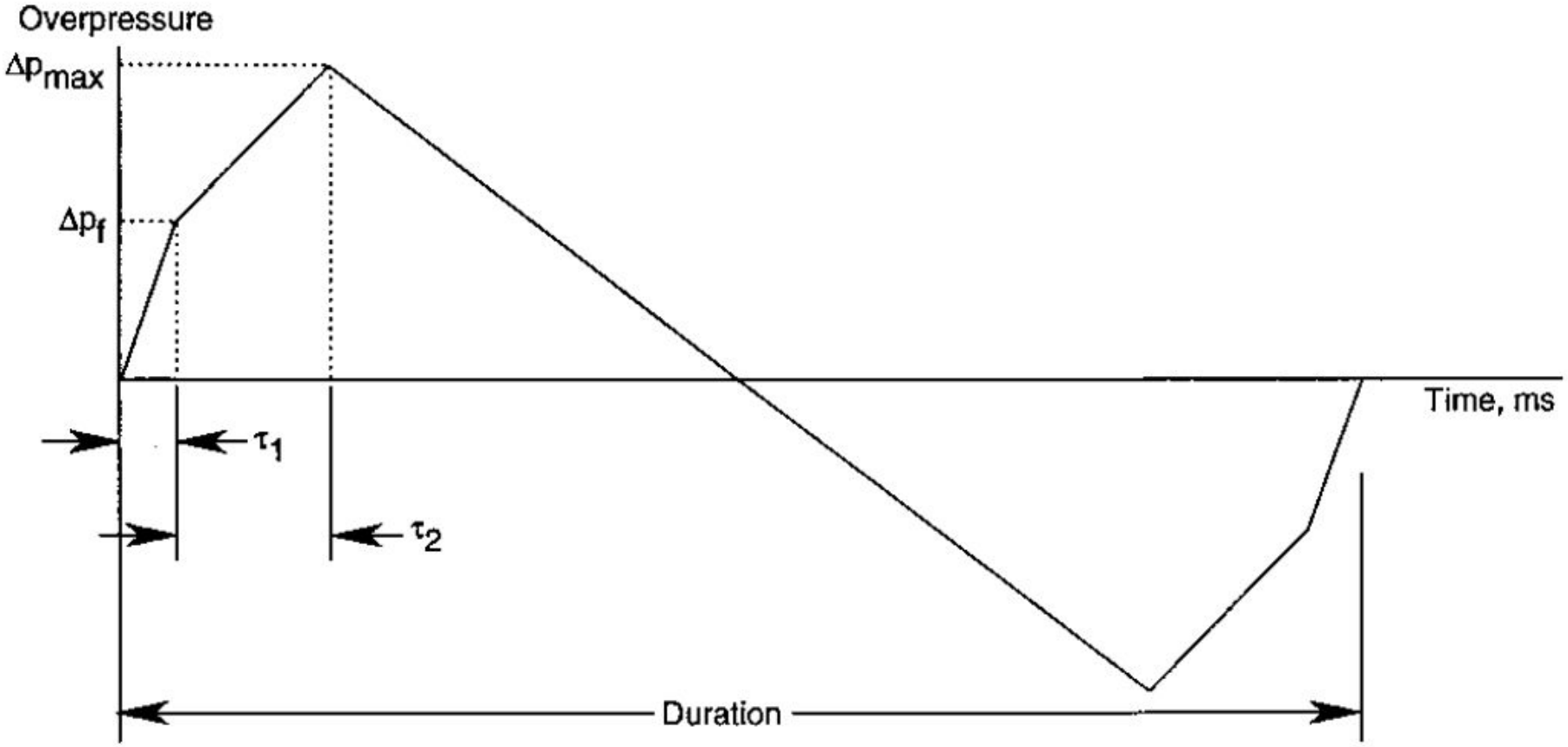
- Short rise times -> Large annoyance
- Abrupt, loud noises are startling
- Can you adapt?

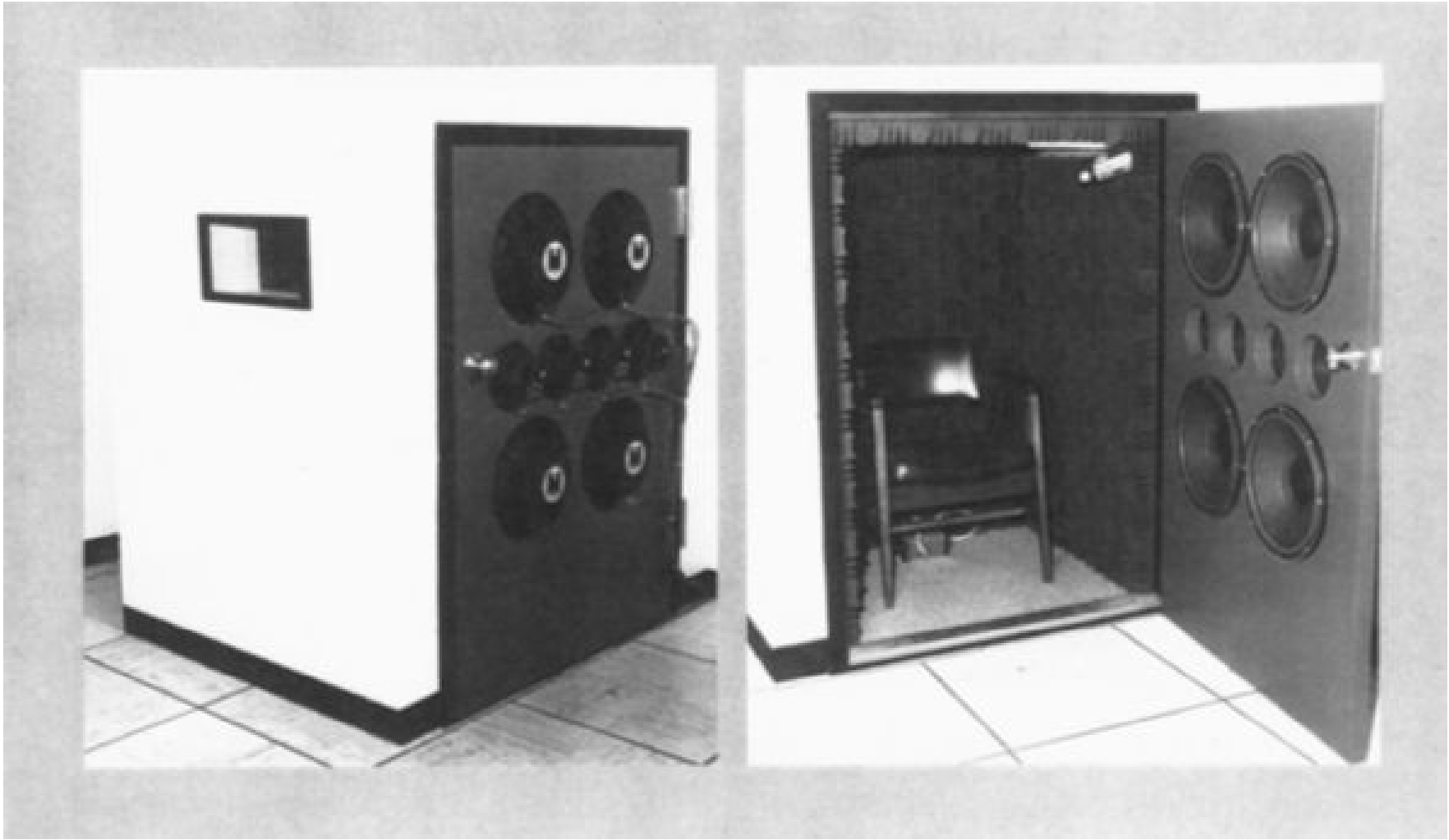

N = 9 / data point
BOOM ≈ 1.2 psf, 100-msec DURATION AND 10-msec RISE TIME
MYOGRAPHIC RESPONSE FROM TRAPEZIUS CONTRALATERAL TO TRACKING ARM
MEAN DIFFERENCE OF ELECTROMYOGRAM BEFORE AND DURING BOOM
SESSION
GROUP 3
GROUP 1
GROUP 2
CONTROL
18
16
14
12
10
8
6
4
2
0
-1
0
1
2
3
4
5

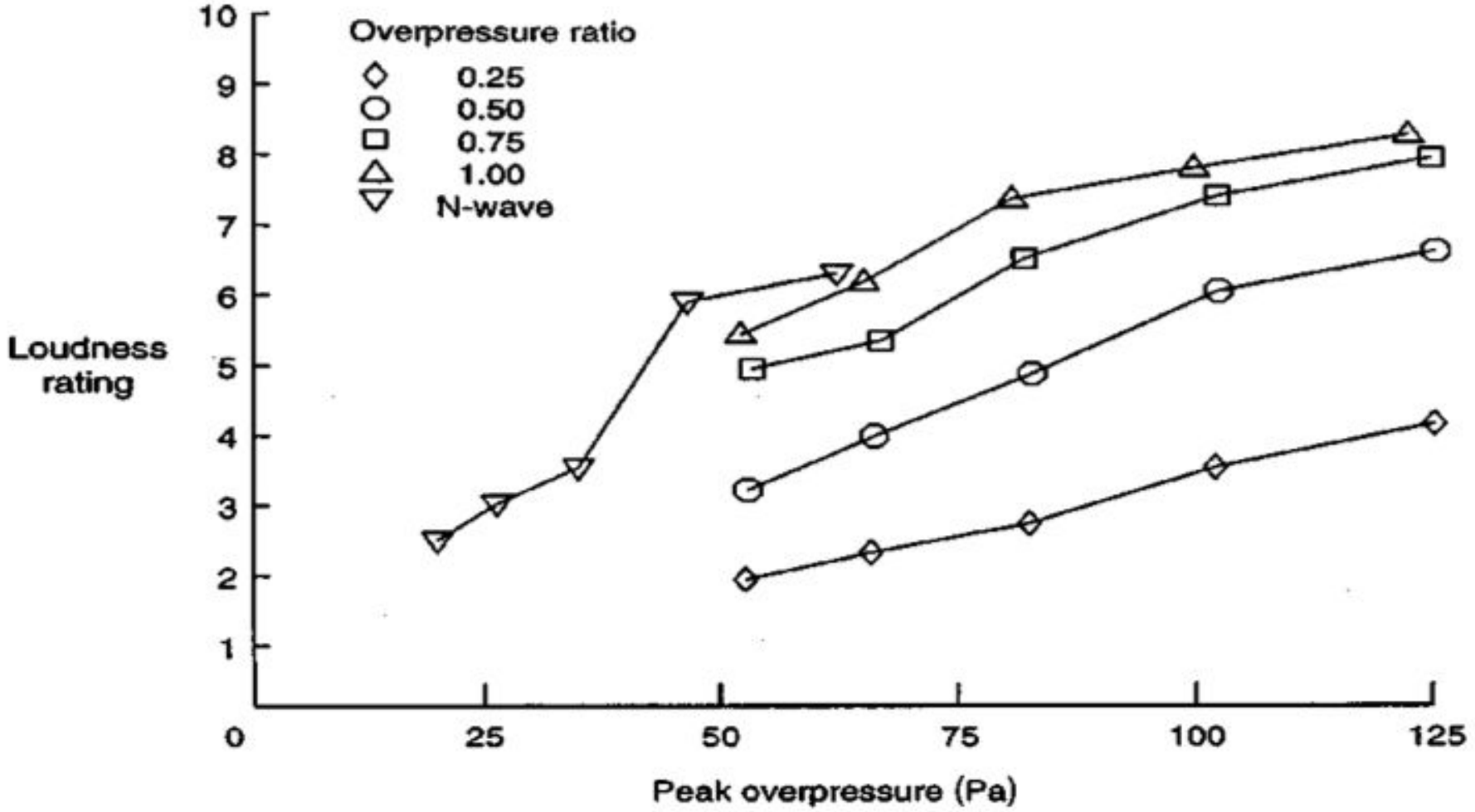


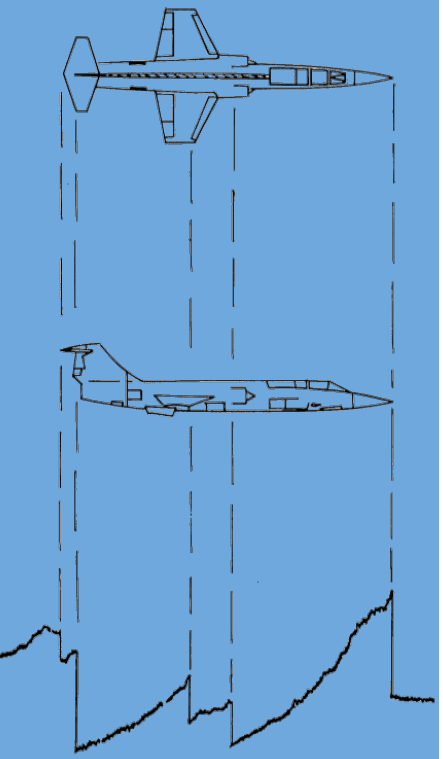
MODELLING BOOMS (PART 2)

- N-wave signature
  - Rise time, P_{max}, Duration
- Front-shock-minimized (FSM)
  - Front-shock rise time, secondary rise time, peak overpressure, front-shock overpressure


Overpressure
Δp_{max}
Δp_f
Time, ms
τ_1
τ_2
Duration

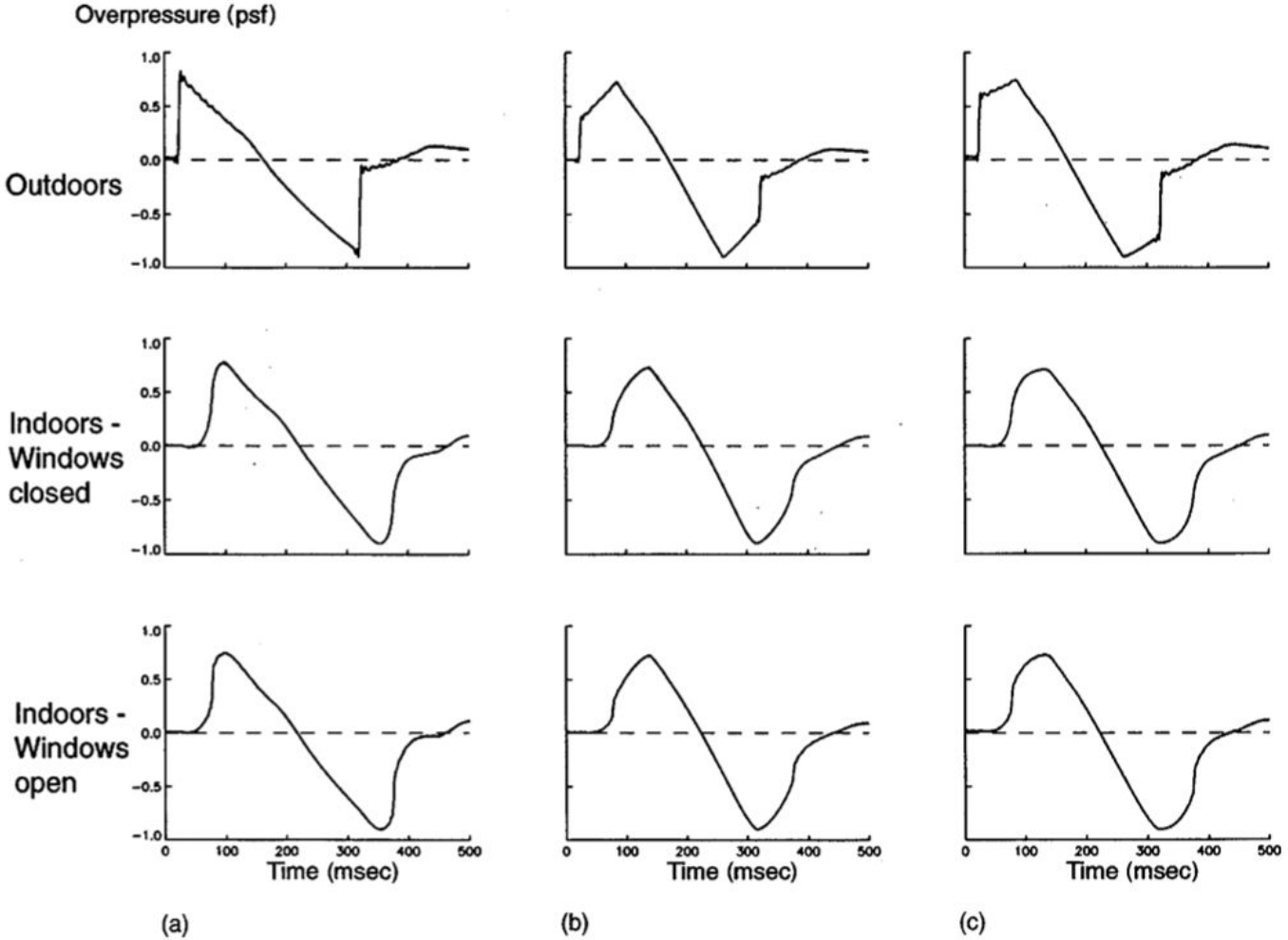


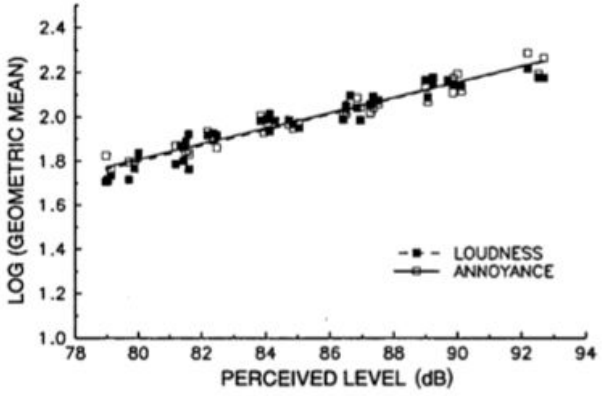

Overpressure ratio
0.25
0.50
0.75
1.00
N-wave
Loudness rating
10
9
8
7
6
5
4
3
2
1
0
25
50
75
100
125
Peak overpressure (Pa)



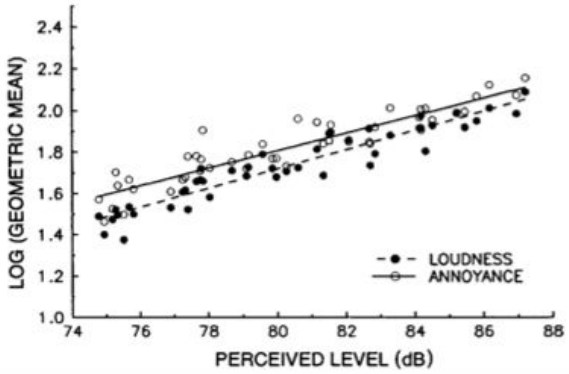
COMMERCIAL TRANSPORT

- It would be nice to make money off this
- Effects on the population?
- Indoor vs outdoor perceptions

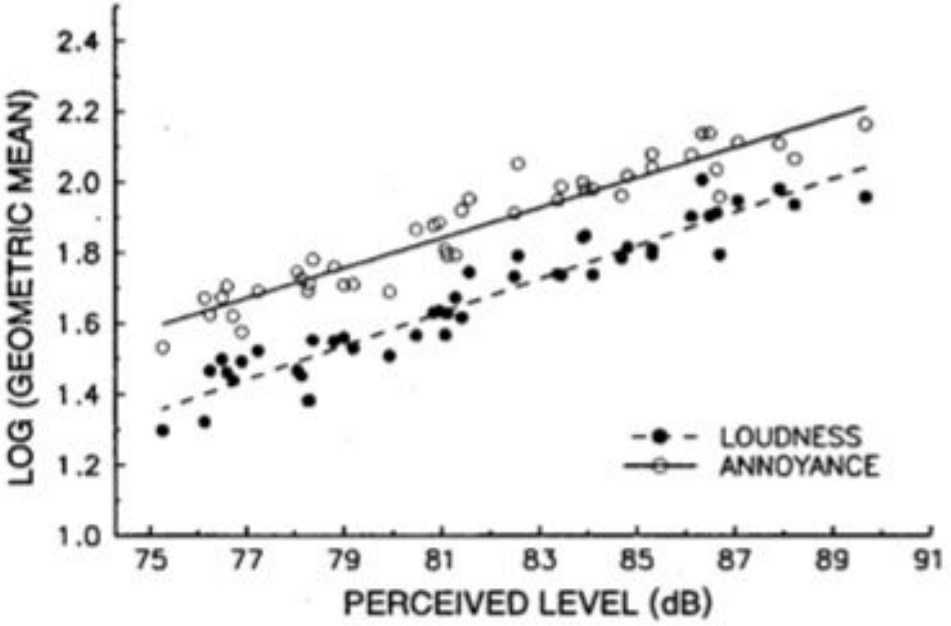

Overpressure (psf)
Outdoors
Indoors - Windows closed
Indoors - Windows open
1.0
0.5
0.0
-0.5
-1.0
0
100
200
300
400
500
Time (msec)
(a)
(b)
(c)


LOG (GEOMETRIC MEAN)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
78
80
82
84
86
88
90
92
94
PERCEIVED LEVEL (dB)
LOUDNESS
ANNOYANCE

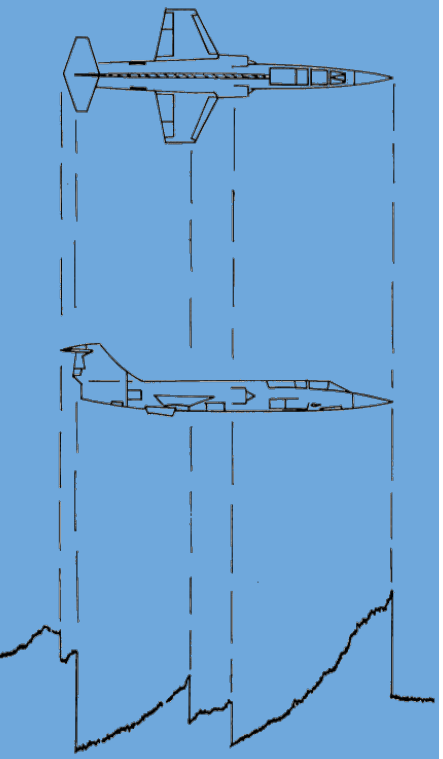
(a)


LOG (GEOMETRIC MEAN)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
74
76
78
80
82
84
86
88
PERCEIVED LEVEL (dB)
LOUDNESS
ANNOYANCE

(c)

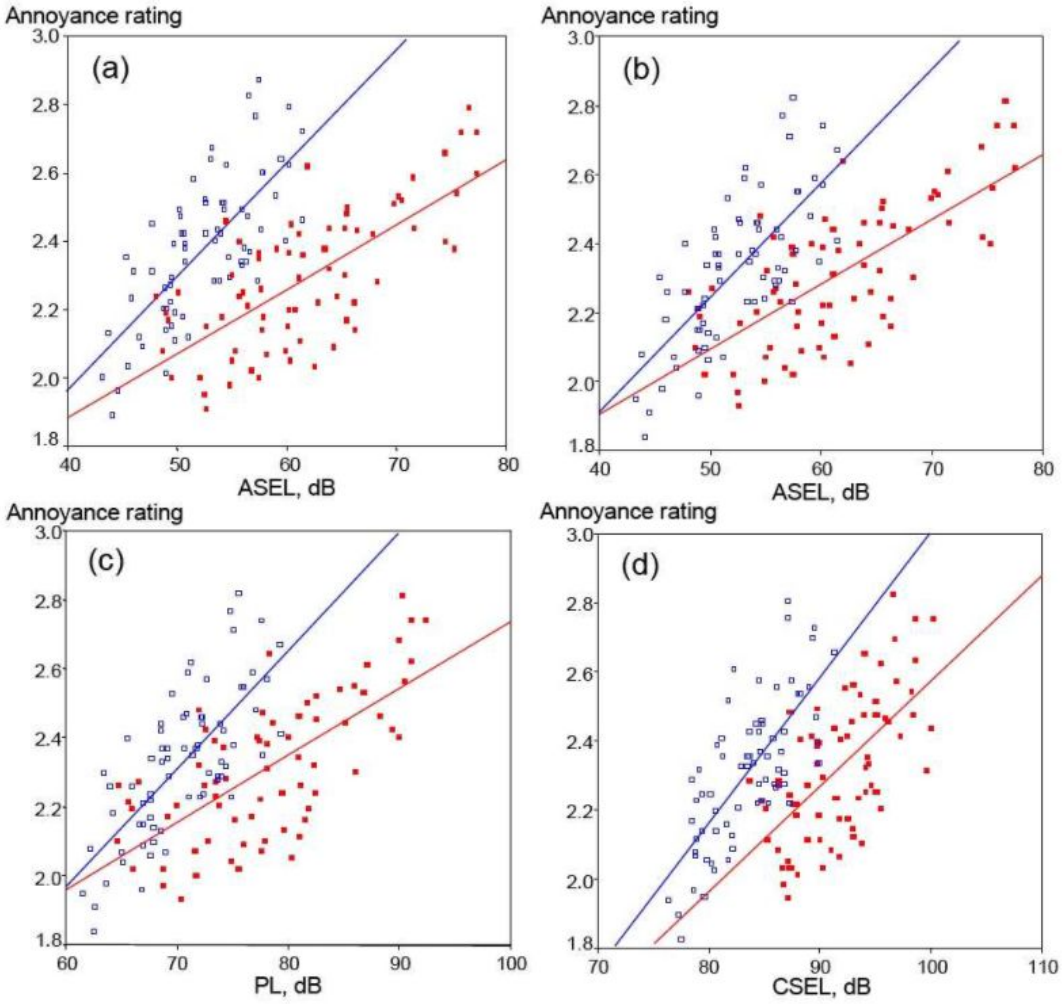

LOG (GEOMETRIC MEAN)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
75
77
79
81
83
85
87
89
91
PERCEIVED LEVEL (dB)
LOUDNESS
ANNOYANCE

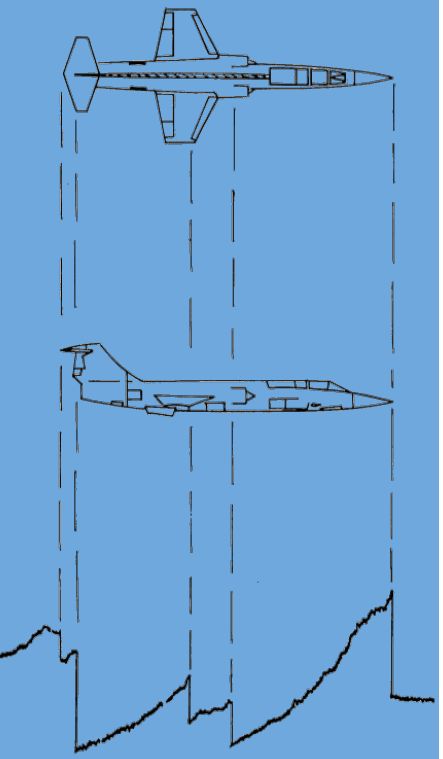
(b)



SUBJECT TESTING

- So far this is modelling
- Actual humans?


Annoyance rating
(a)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
40
50
60
70
80
ASEL, dB
Annoyance rating
(b)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
40
50
60
70
80
ASEL, dB
Annoyance rating
(c)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
60
70
80
90
100
PL, dB
Annoyance rating
(d)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
70
80
90
100
110
CSEL, dB



FUTURE RESEARCH

- Still no clear agreement
- Will aircraft ever be able to go supersonic over land?