Sonic Boom : an introduction

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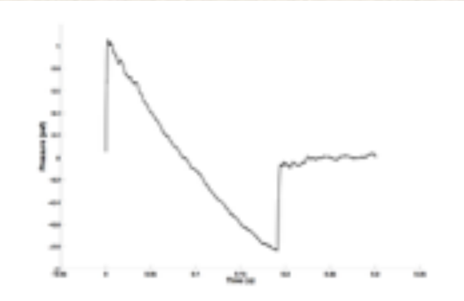
Concorde & military fighters



General objective

« … ensuring that no unacceptable situation for the public is created by sonic boom from supersonic aircraft in commercial service »
(ICAO resolution A39–1 - Appendix G, 2016).

Some key questions on sonic boom

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- *How does a sonic boom propagate in the atmosphere ?*

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- ***How does a sonic boom propagate in the atmosphere ?***
- ***Who is annoyed by a sonic boom ?***

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- *What influences a sonic boom ?*

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- *What influences a sonic boom ?*
- *Why is a sonic boom annoying ?*
- *What is the future of sonic boom ?*

What is a sonic boom ?

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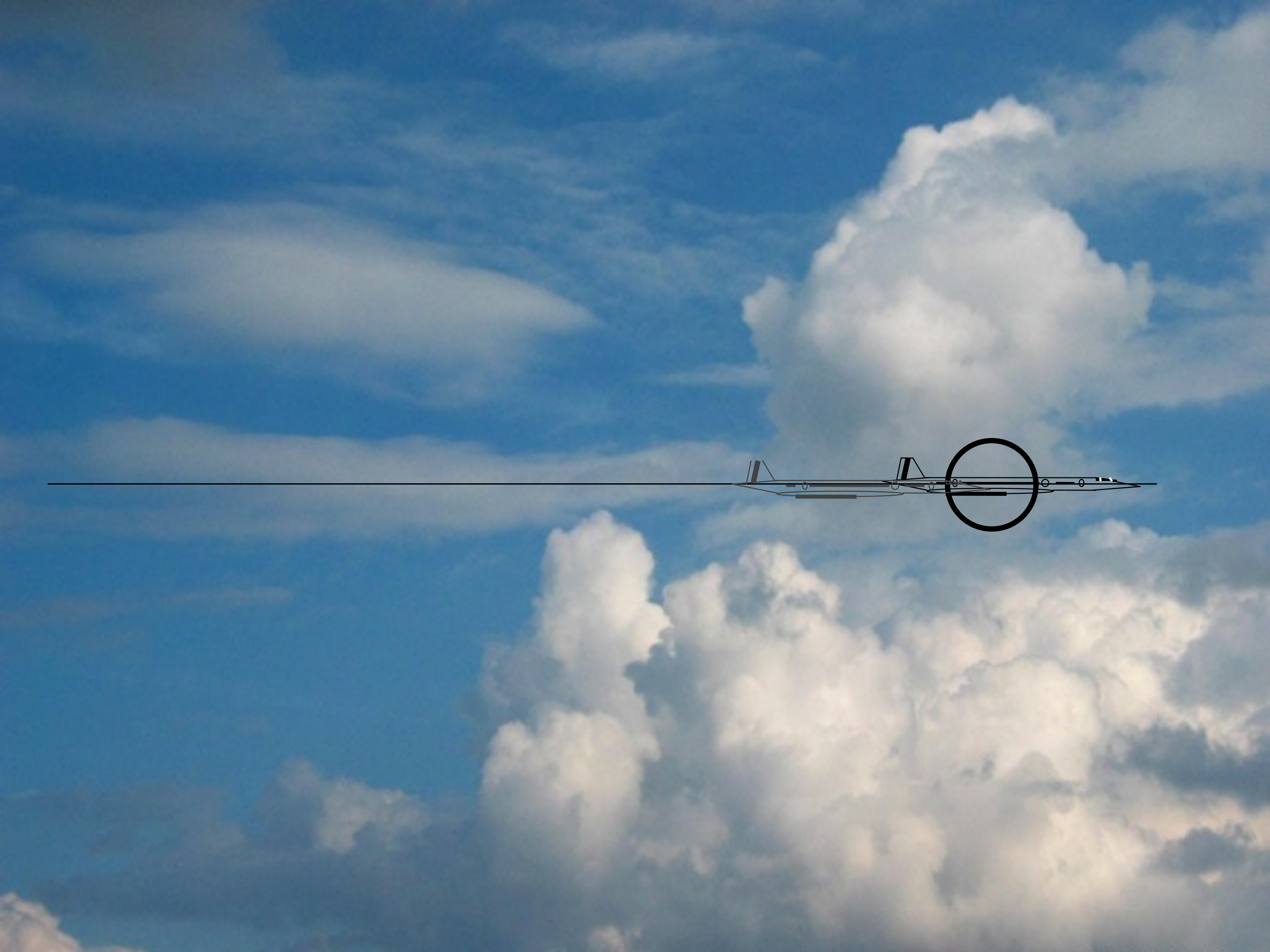
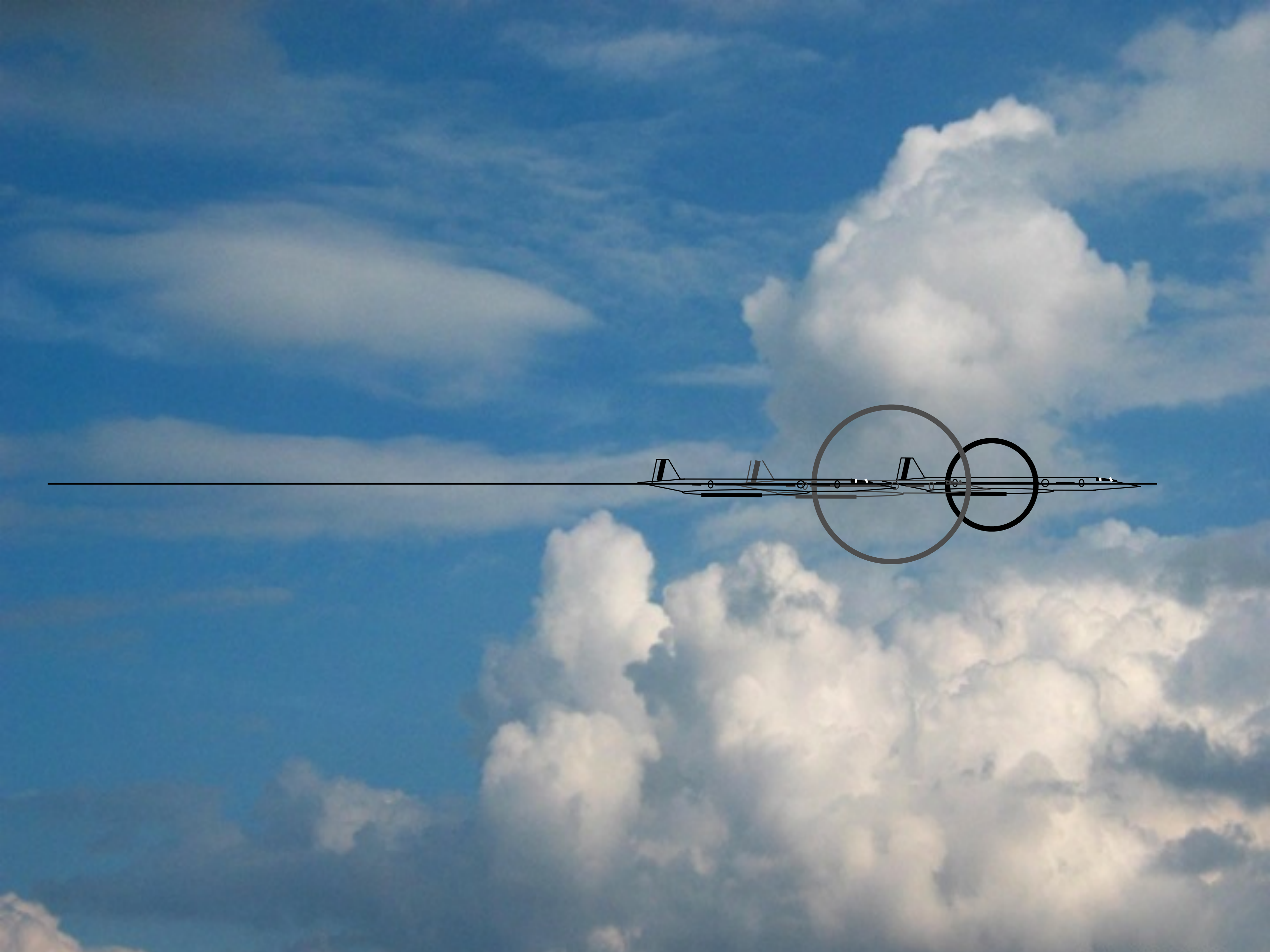
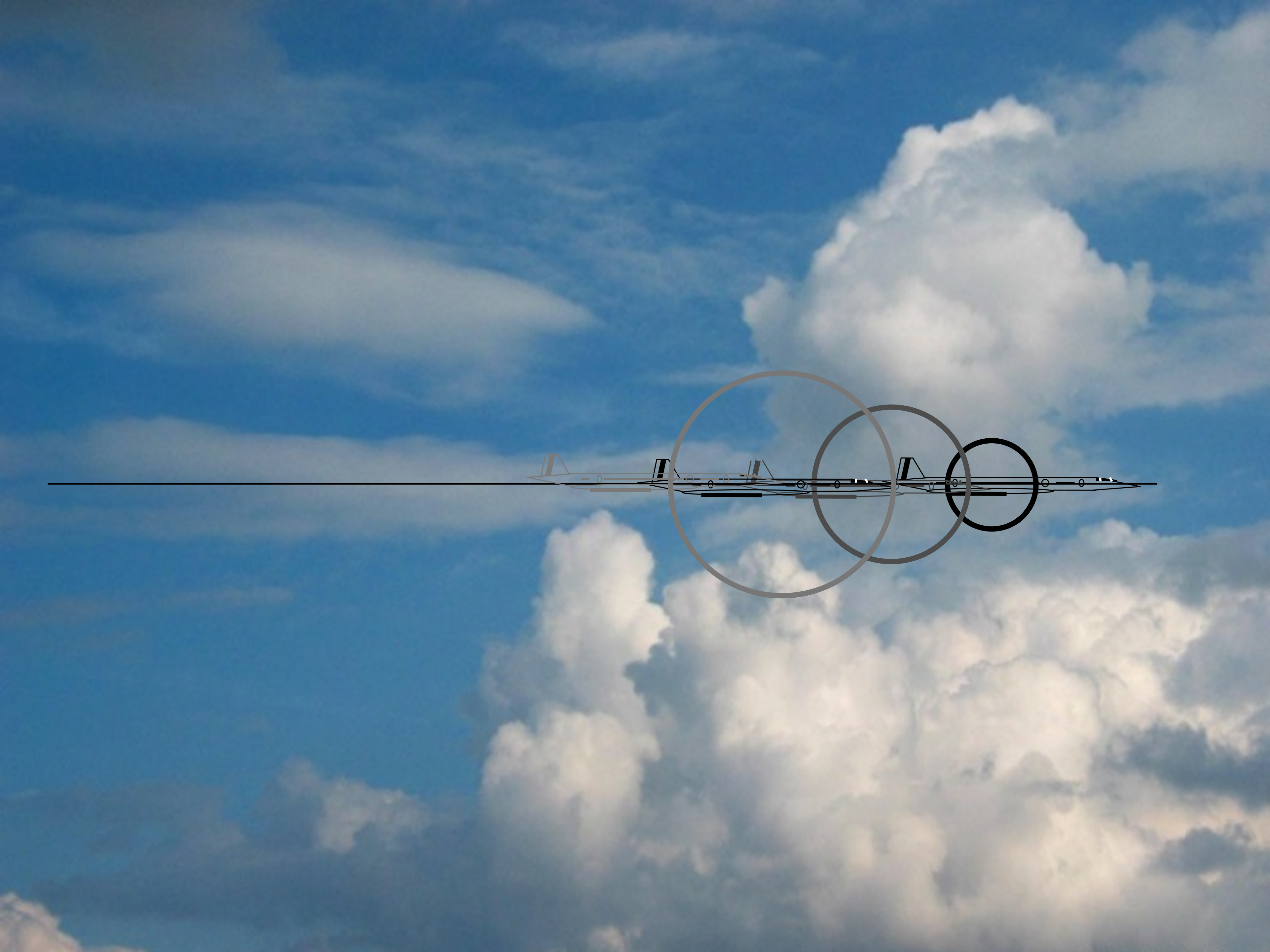
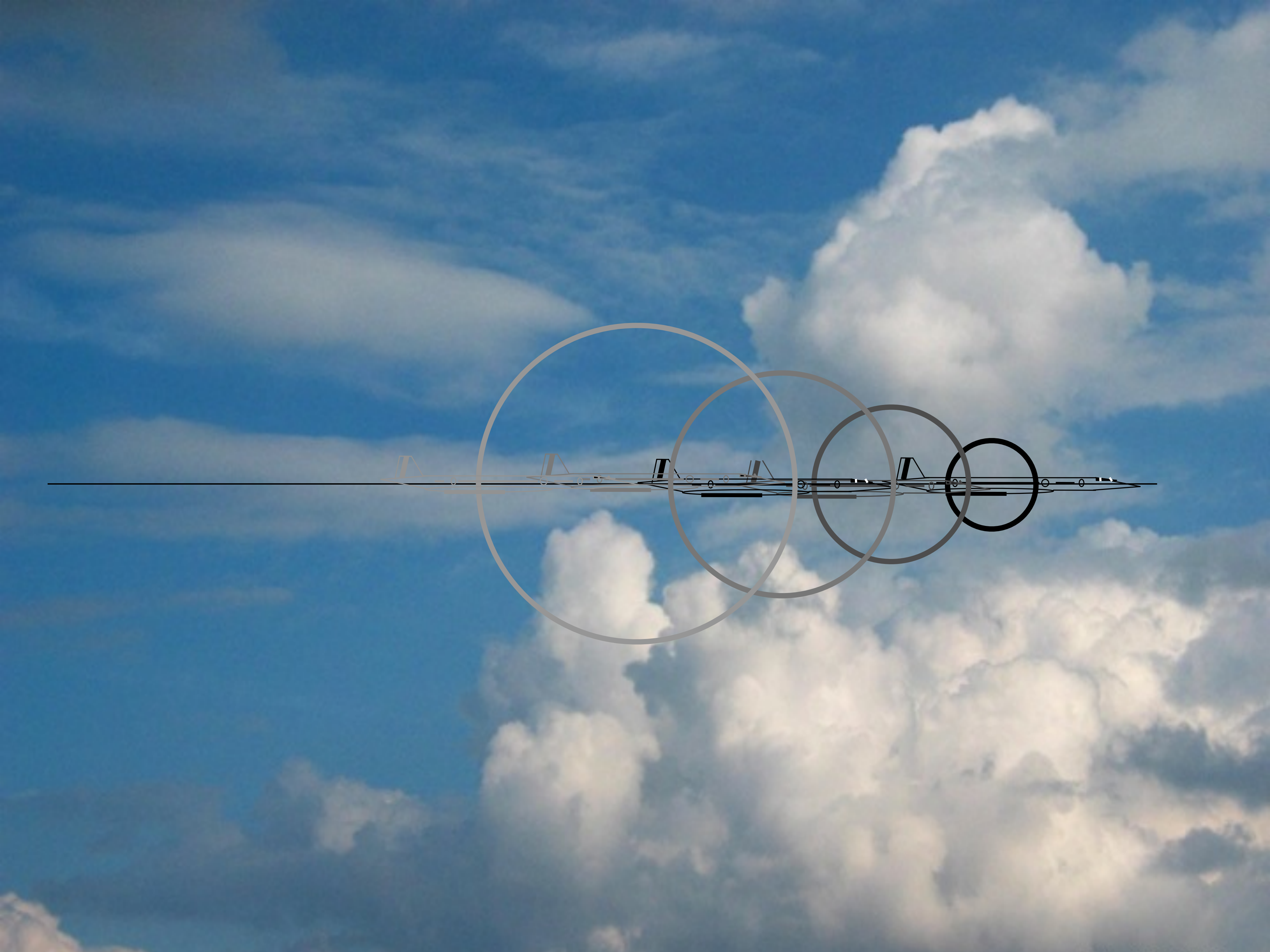
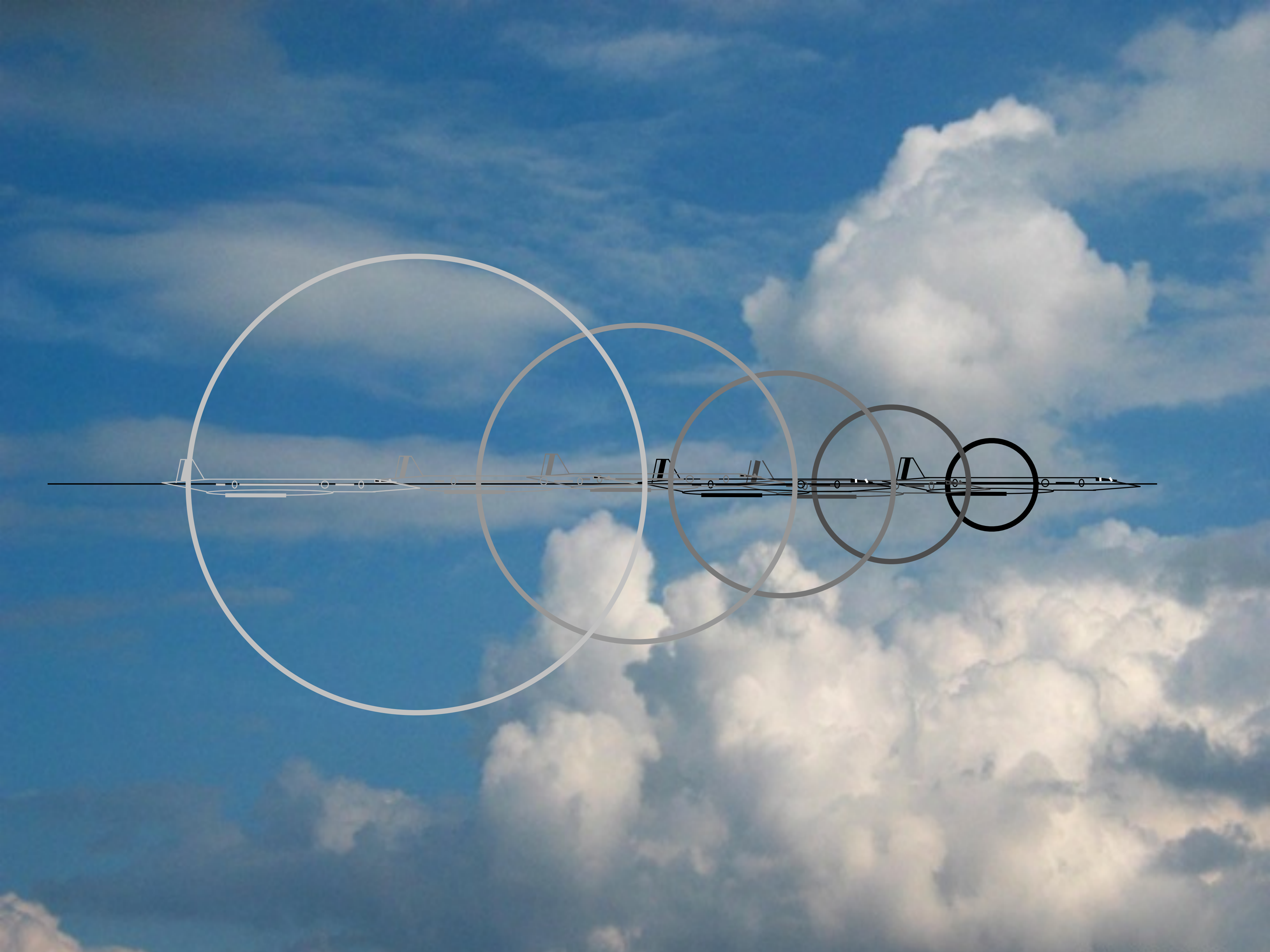
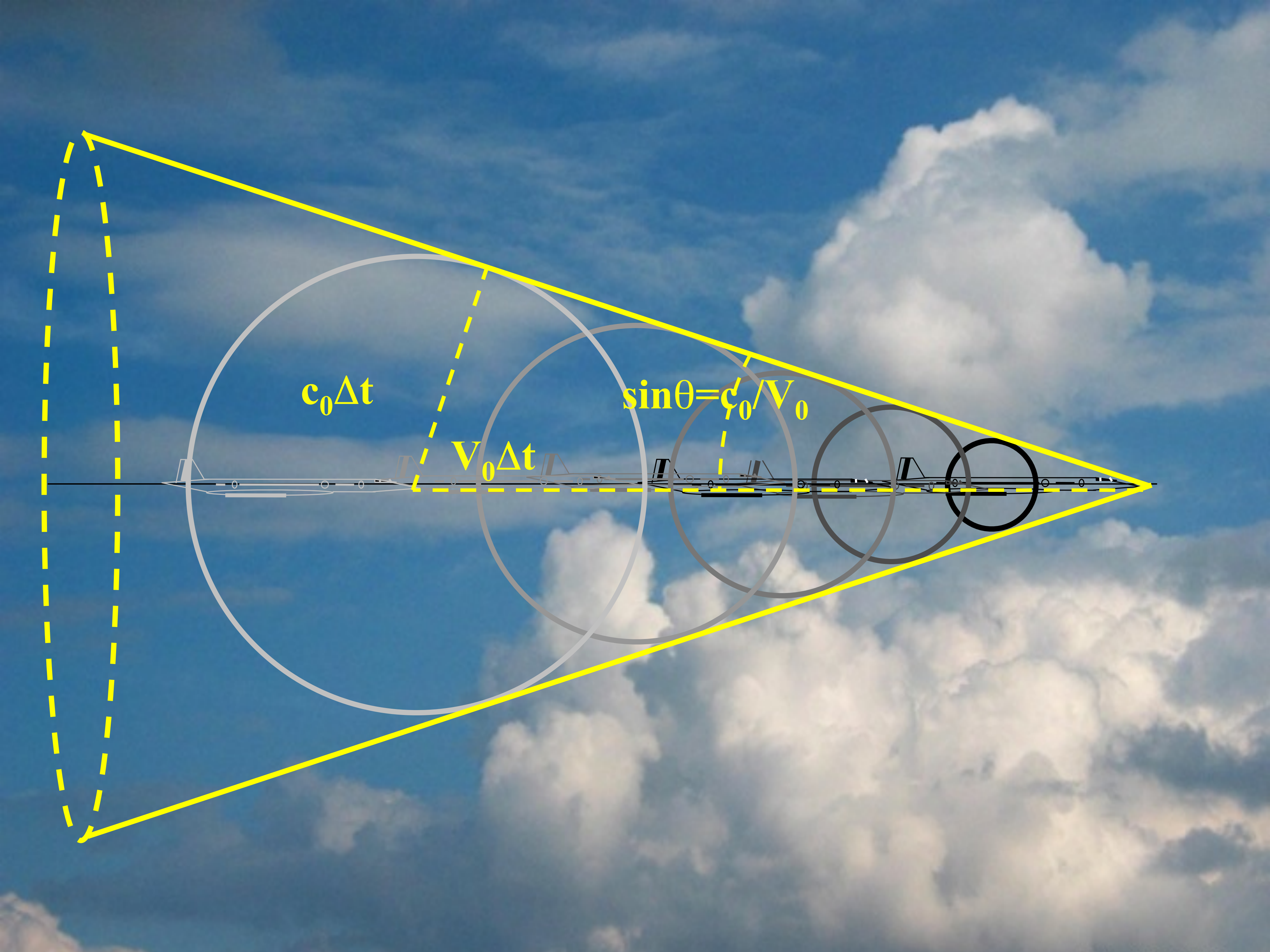




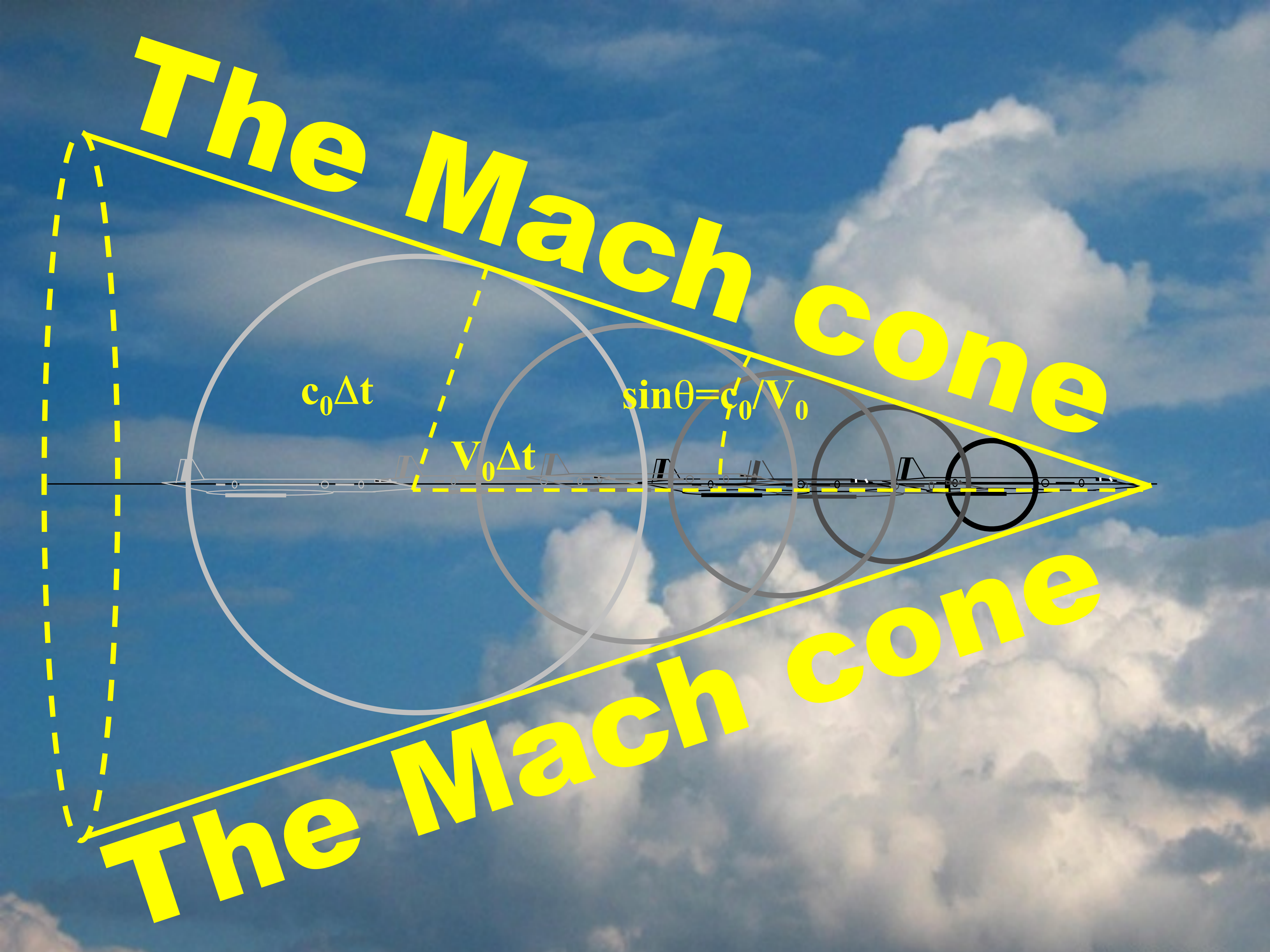




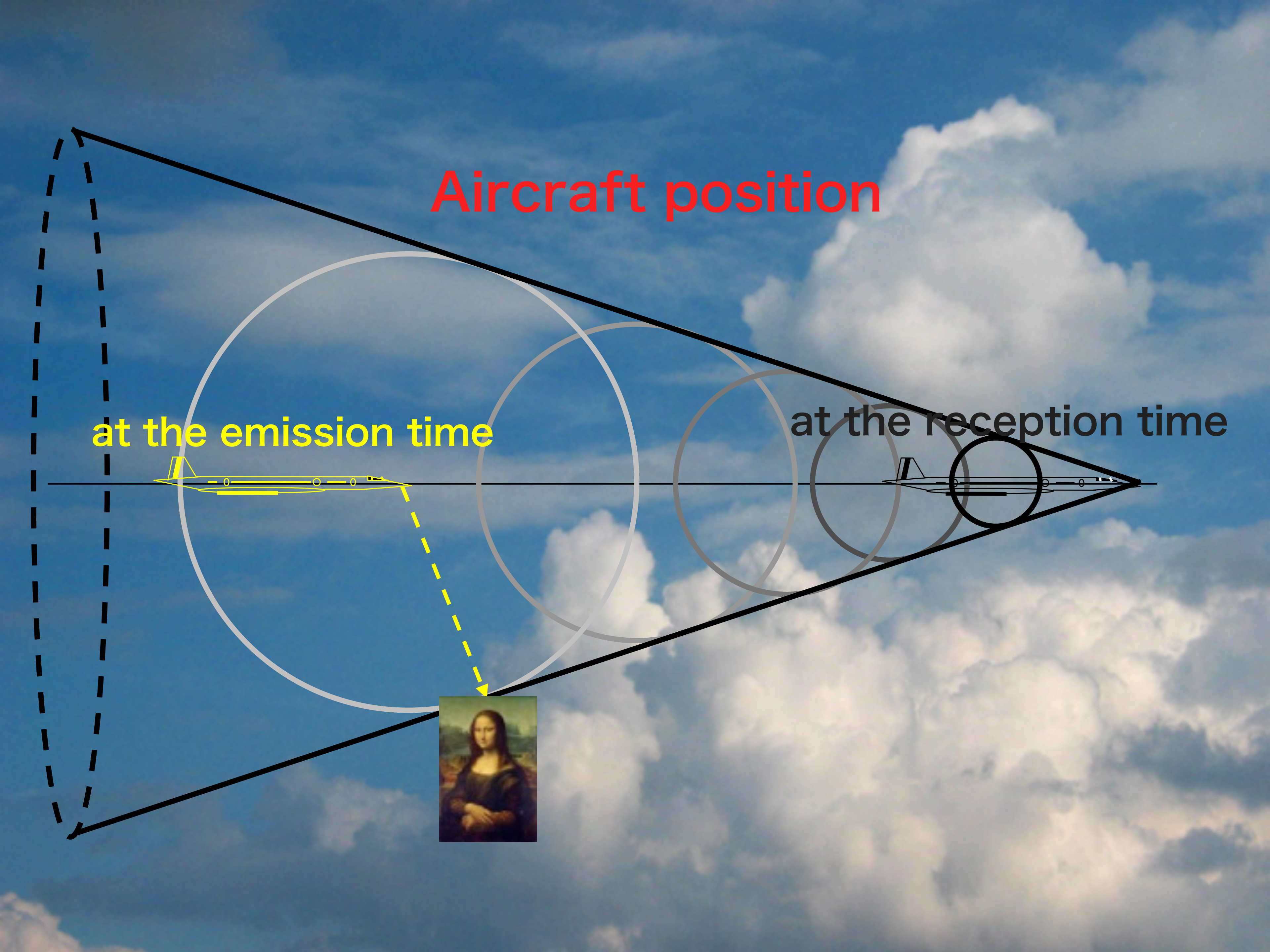




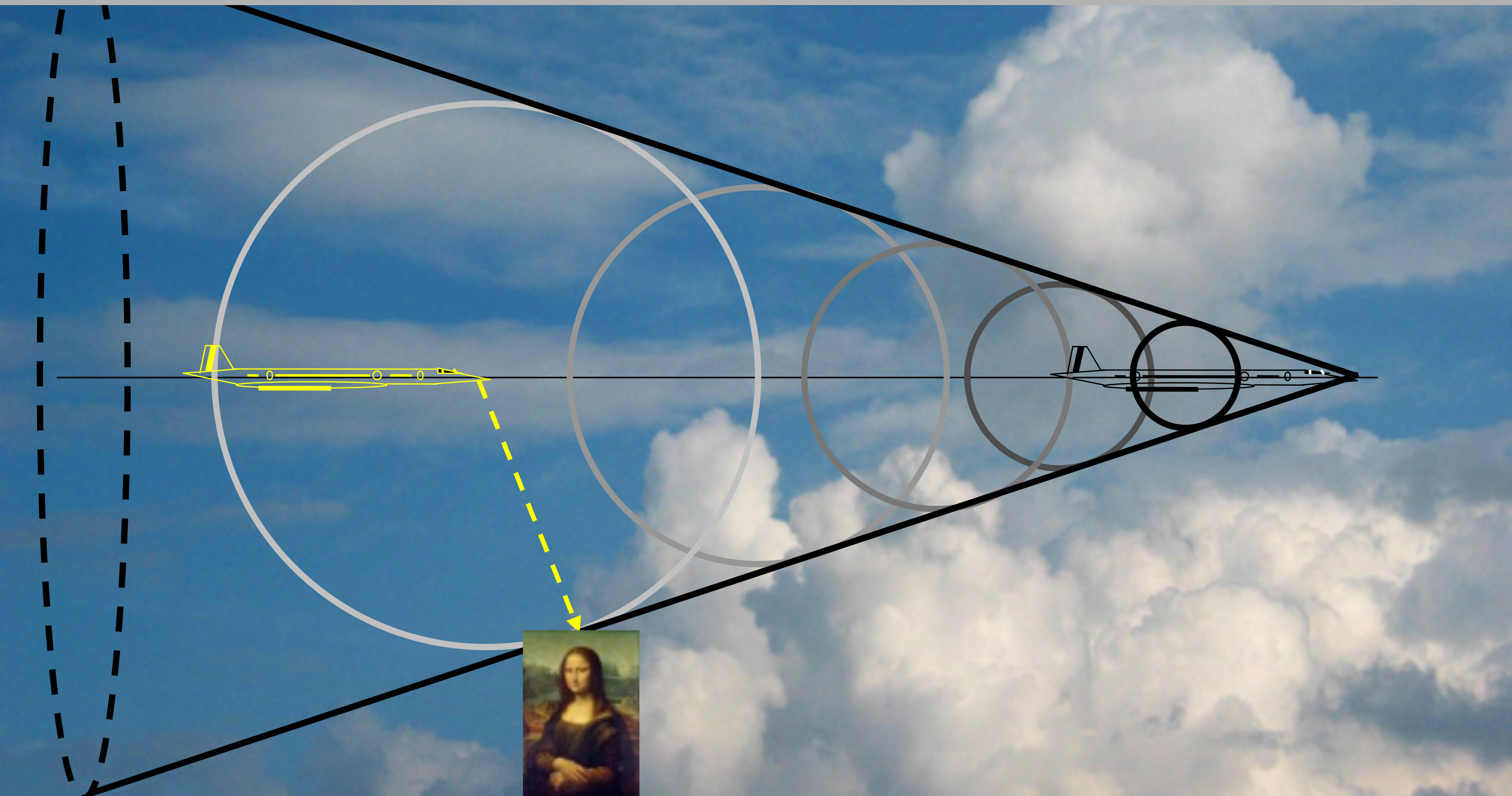
$c_0\Delta t$
$\sin\theta = c_0/V_0$
$V_0\Delta t$



The Mach cone
$c_0\Delta t$
$V_0\Delta t$
$\sin\theta = c_0/V_0$
The Mach cone


Aircraft position
at the emission time
at the reception time

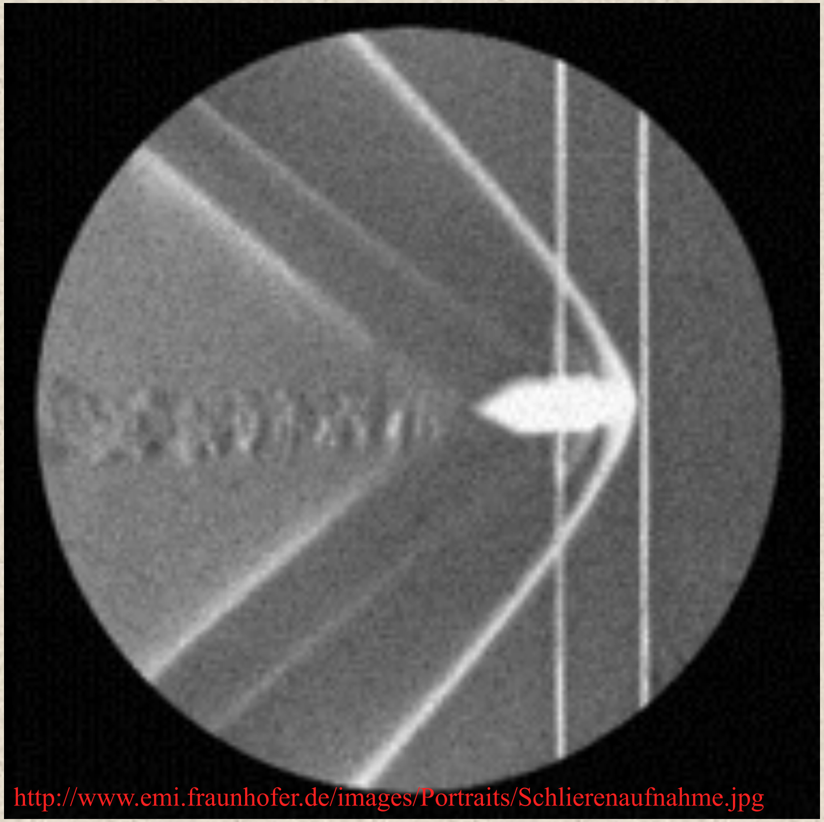
What is a sonic boom ?

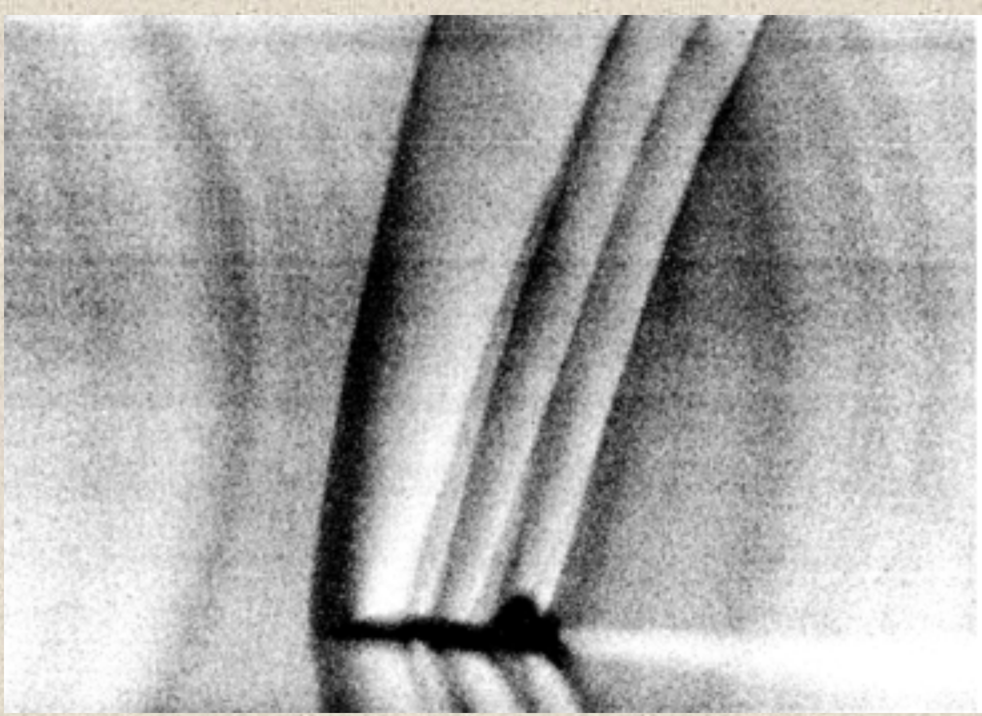


Sonic boom is the acoustical « trace » at the ground level of the aerodynamic flow past a supersonic body

The Mach cone

Theory : Doppler (1847)
Experimental observation (Schlieren) : Mach 1888





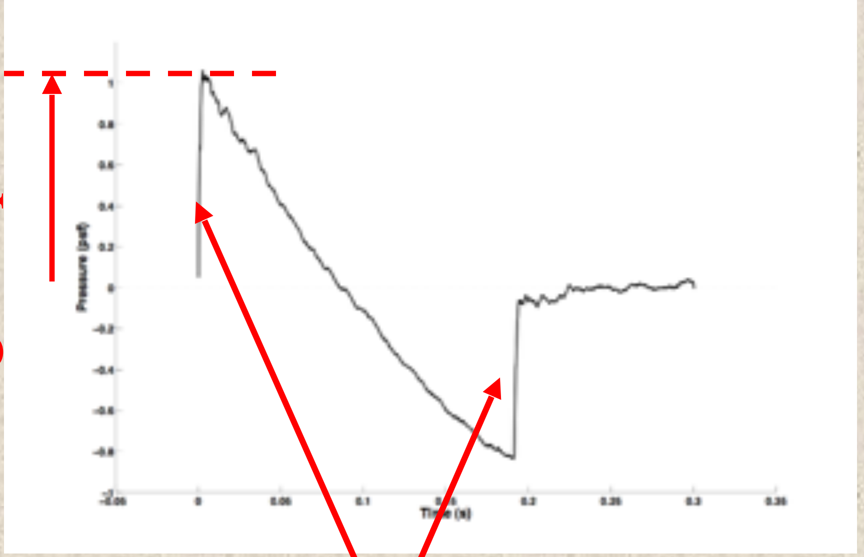
In flight *observation*
(NASA - Schlieren - T38 at M 1.1)

The main characteristics of a sonic boom

SR-71, BoomFile database, USAF

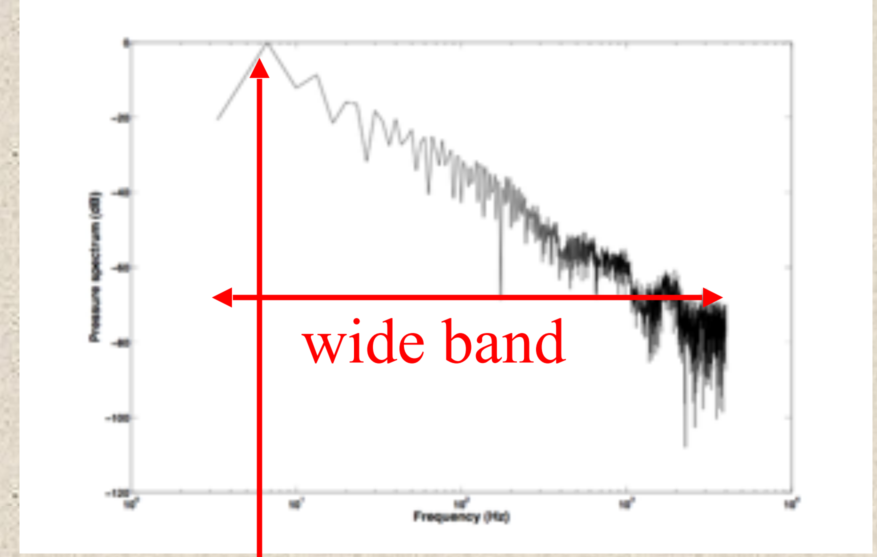
Time waveform

high amplitude



impulsive

Frequency spectrum



wide band

low frequency

Whitham theory (1952-1956)

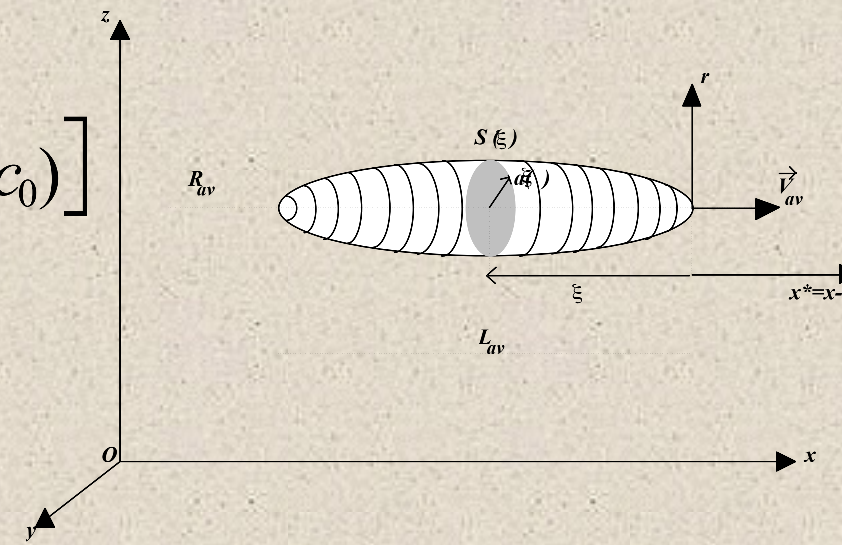
Whitham's theory (1952)

Axisymetric body (no lift)

Slender body ⇒ Wave equation (linearized Euler - no shock)

Farfield (r >> L)

$$p_a(x,y,z,t) = \frac{\rho_0 c_0^2 M_{av}^2}{\sqrt{2r\sqrt{M_{av}^2 - 1}}} F_W\left[c_0 M_{av}(t - \vec{x}.\vec{n}/c_0)\right]$$



$$F_W(x) = \frac{1}{2\pi}\int_{-\infty}^{x} \frac{1}{\sqrt{x-y}} \frac{d^2 S(y)}{dy^2} dy$$

F_W : Whitham function, relates the fuselage geometry to the pressure field

Linearized equations with source term

Fuselage → Mass flow

Mass

$$\frac{\partial \rho_a}{\partial t} + \rho_0 \,\mathrm{div}\,\vec{v}_a = \rho_0 V_{AV} \frac{dS}{d\xi}\left(c_0 Mt - x\right)\delta(y)\delta(z)$$

Momentum

$$\rho_0 \frac{\partial \vec{v}_a}{\partial t} + \overrightarrow{\mathrm{grad}}\, p_a = 0$$

State

$$p_a = c_0^2 \rho_a$$

Linearized + homogeneous

Solution

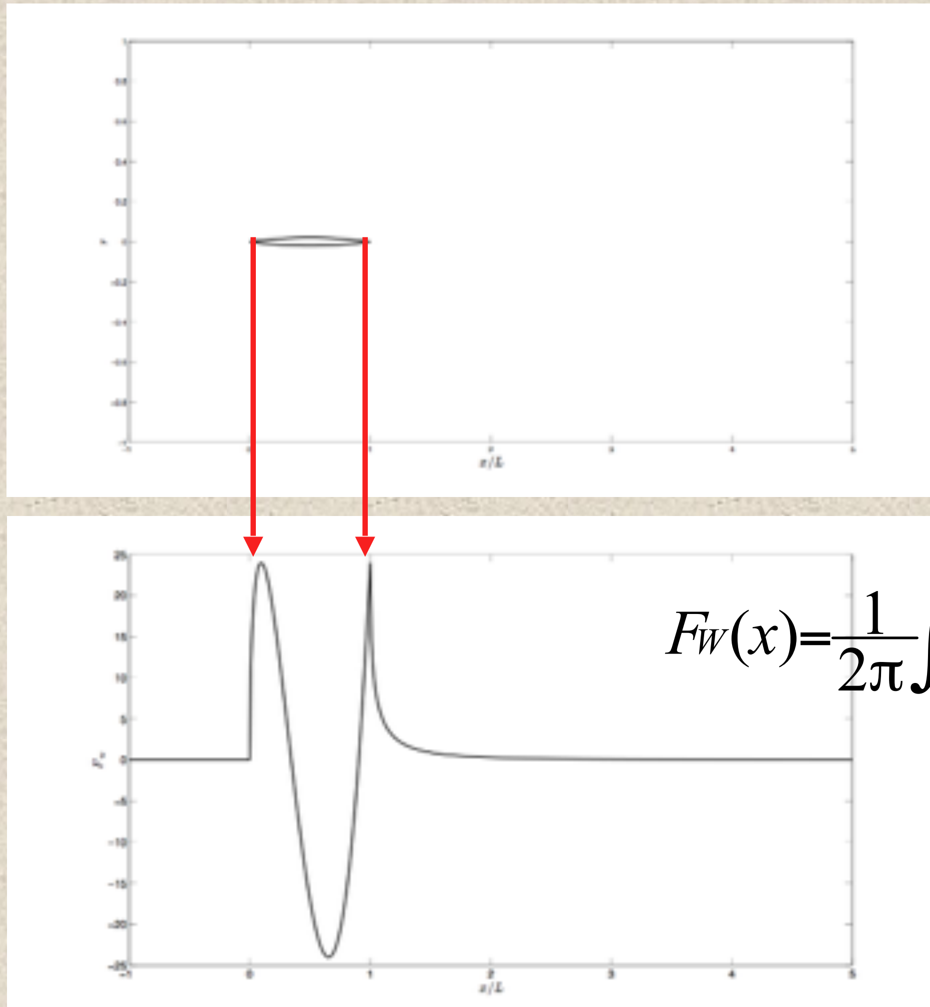
Wave equation + source term

$$\frac{1}{c_0^2}\frac{\partial^2 p_a}{\partial t^2} - \Delta p_a = \rho_0 c_0^2 M_{av}^2 \frac{d^2 S}{d\xi^2}\left(c_0 M_{av} t - x\right)\delta(y)\delta(z)$$

Exact solution (Green function) + farfield approx.

$$p_a(x,y,z,t) = \frac{\rho_0 c_0^2 M_{av}^2}{\sqrt{2r\sqrt{M_{av}^2-1}}} F_W\left[c_0 M_{av}(t - \vec{x}.\vec{n}/c_0)\right]$$

Example : parabolic body



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Example : parabolic body

$$p_a(x,y,z,t)=\frac{\rho_0 c_0^2 M_{av}^2}{\sqrt{2r\sqrt{M_{av}^2-1}}}F_W\left[c_0 M_{av}(t-\vec{x}.\vec{n}/c_0)\right] \qquad F_W(x)=\frac{1}{2\pi}\int_{-\infty}^{x}\frac{1}{\sqrt{x-y}}\frac{d^2S(y)}{dy^2}dy$$

Pressure dependance

Mach number (singular at M = 1, optimum M=1.414)

Fuselage radius R^2

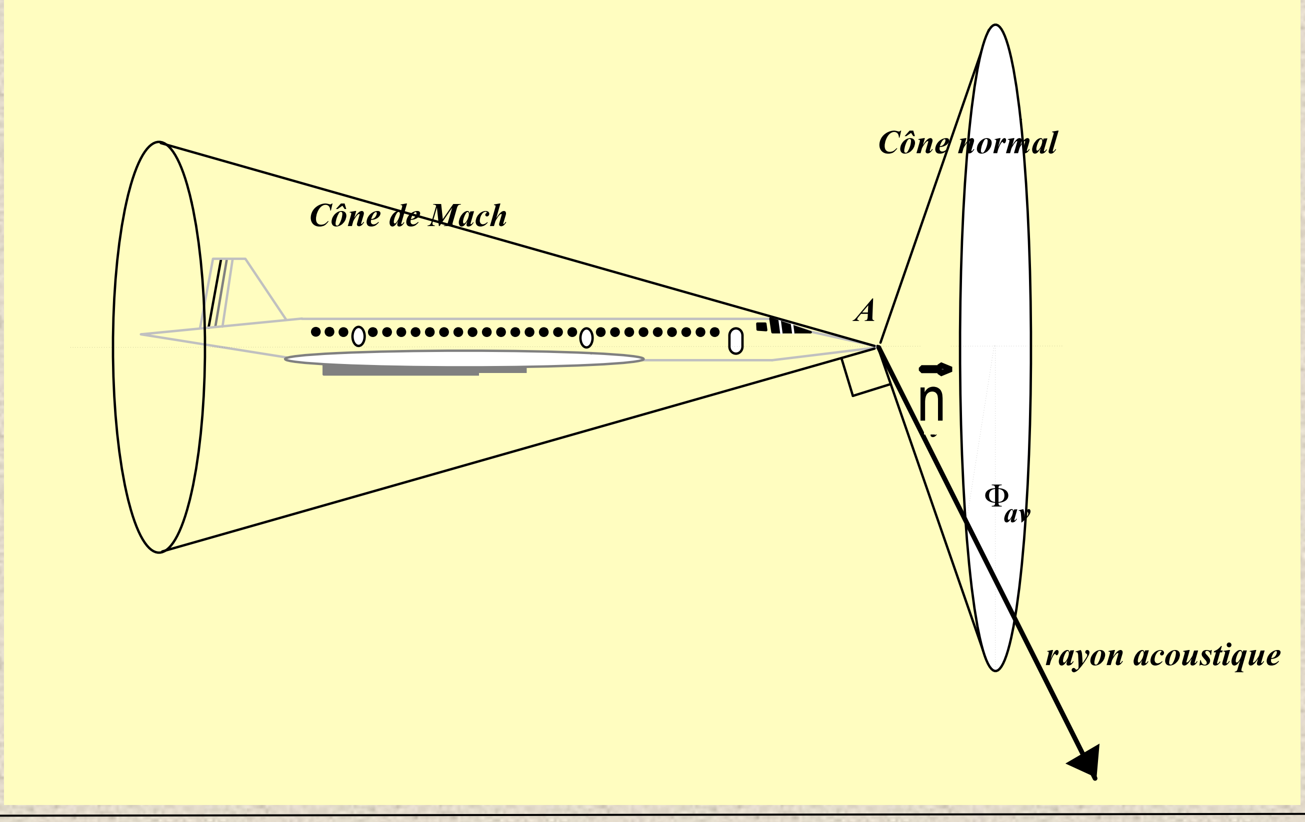
Fuselage length L^{-3/2}

Distance r^{-1/2} (half a line source)

Sharp variations in geometry

Whitham theory, Mach cone & ray theory

$$p_a(x,y,z,t) = \frac{\rho_0 c_0^2 M_{av}^2}{\sqrt{2r\sqrt{M_{av}^2 - 1}}} F_W\left[c_0 M_{av}(t - \vec{x}.\vec{n}/c_0)\right]$$



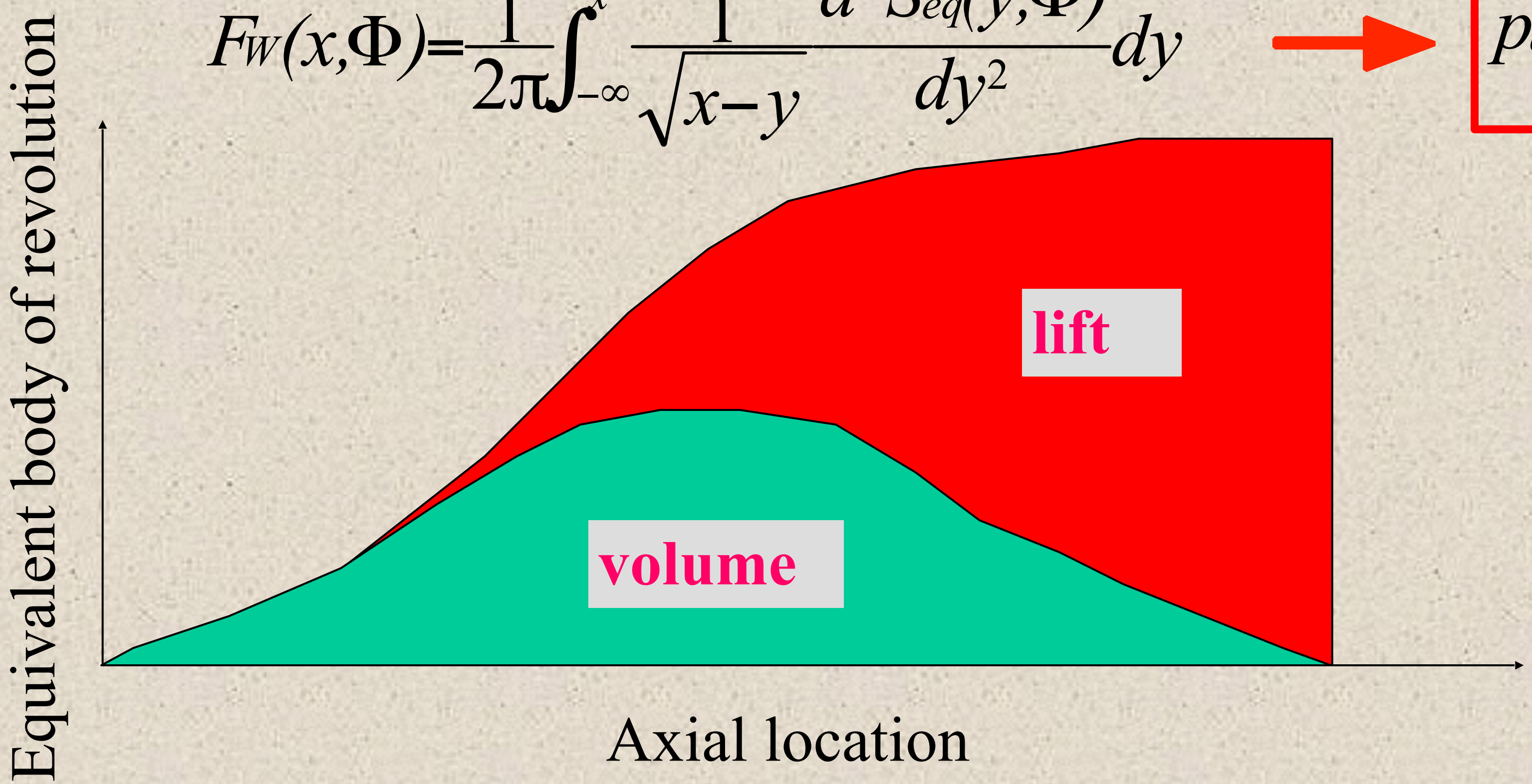
Mach cone in-flight visualization

Extension to lifted bodies (Walkden, 1958)

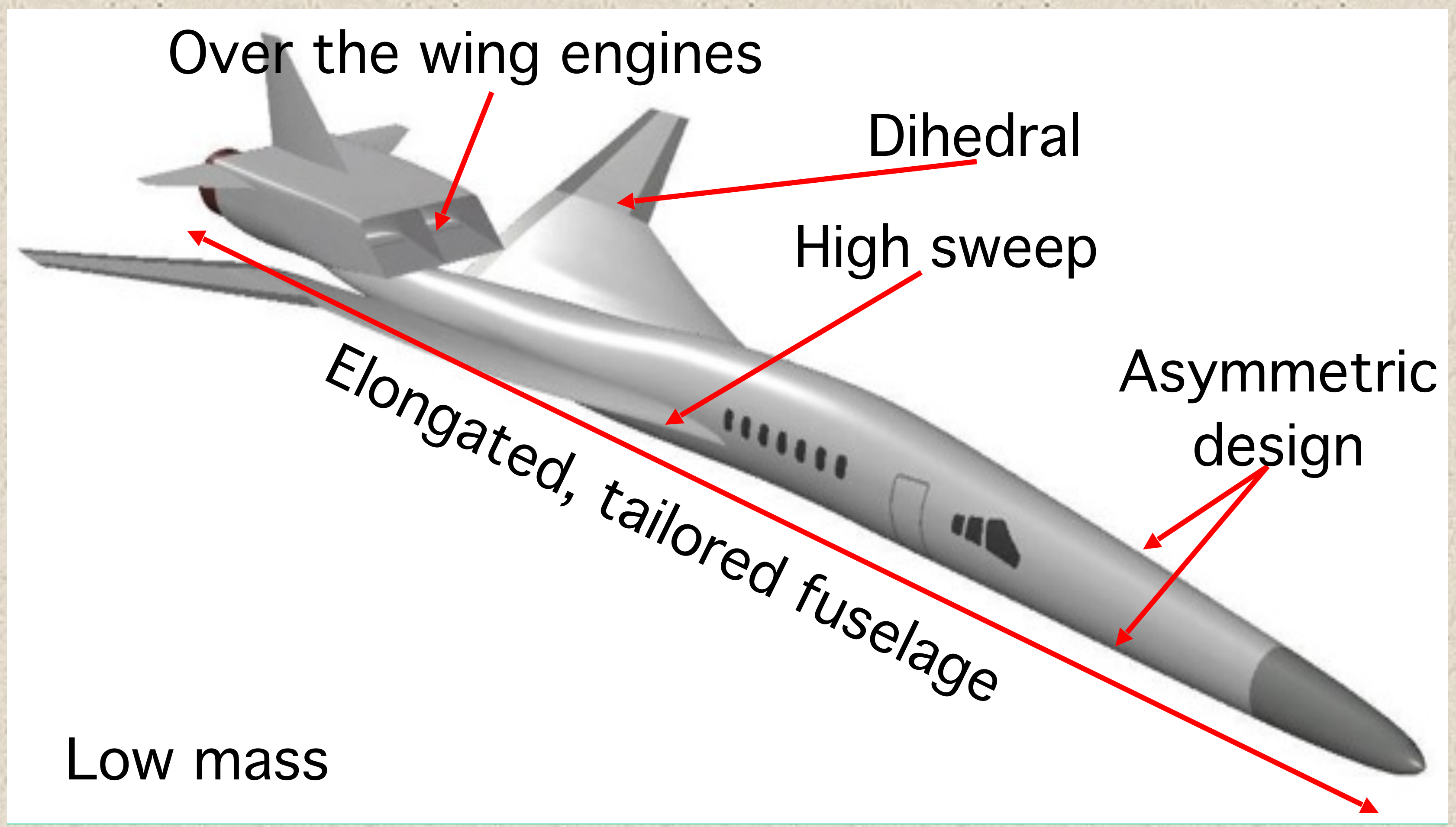
$$p_a(x,y,z,t) = \frac{\rho_0 c_0^2 M_{av}^2}{\sqrt{2r\sqrt{M_{av}^2 - 1}}} F_W\left[c_0 M_{av}(t - \vec{x}.\vec{n}/c_0), \Phi_{av}\right]$$

$$F_W(x,\Phi) = \frac{1}{2\pi}\int_{-\infty}^{x} \frac{1}{\sqrt{x-y}} \frac{d^2 S_{eq}(y,\Phi)}{dy^2} dy$$

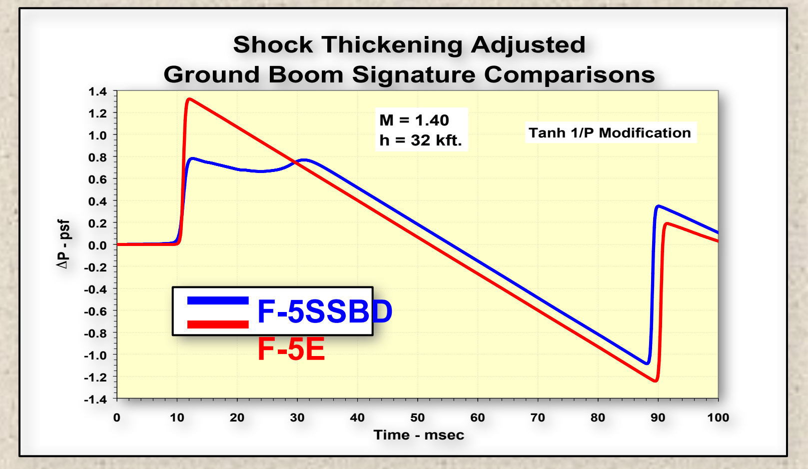
$$\rightarrow \quad p_a \propto \frac{W}{L_{eff}^{3/2}}$$

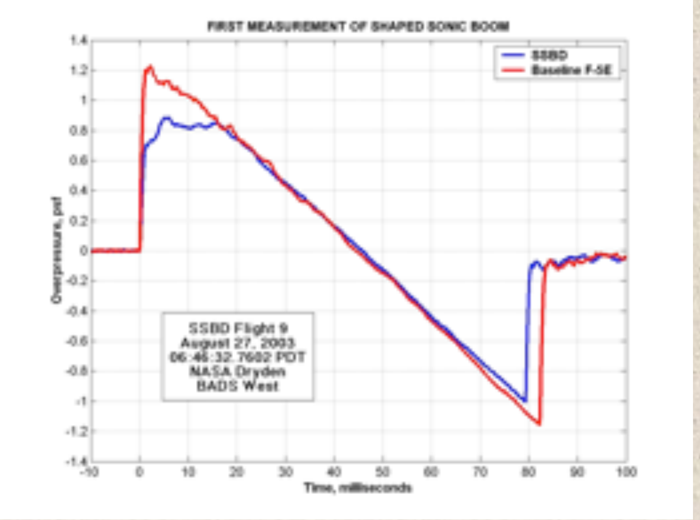


Elements for low boom design



The Shaped Sonic Bonic Demonstrator (2005)





The Shaped Sonic Bonic Demonstrator (2005)

Blunt nose (why ?)

Fuselage expansion compensating engine intake shocks

Some key questions on sonic boom

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- ***How does a sonic boom propagate in the atmosphere ?***

Nonlinear speed of sound

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Linear speed of sound

$$c_0^2 = \left(\frac{\partial p}{\partial \rho}\right)_s (\rho_0, s_0)$$

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Linear speed of sound

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Flow convection

$$c = c_0 + \vec{u}_0 . \vec{n}$$

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Nonlinear speed of sound

$$c = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s (\rho_0 + \rho_a, s_0)} + \vec{u}_a . \vec{n}$$

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Locally plane wave

$$\rho_a = p_a / c_0^2$$

$$\vec{u}_a = \frac{p_a \vec{n}}{\rho_0 c_0}$$

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Locally plane wave

$$\rho_a = p_a / c_0^2$$

$$\vec{u}_a = \frac{p_a \vec{n}}{\rho_0 c_0}$$

$$c = c_0 + \frac{\beta p_a}{\rho_0 c_0}$$

Nonlinear parameter

$$c = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s (\rho_0 + \rho_a, s_0)} + \vec{u}_a . \vec{n}$$

State equation

Convection

$$B/A = \frac{\rho_0}{c_0^2}\left(\frac{\partial^2 p}{\partial \rho^2}\right)(\rho_0, s_0)$$

$$\beta = 1 + B/2A$$

Inviscid Burgers' equation

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1D wave equation

$$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2} - \frac{\partial^2 p}{\partial x^2} = 0 = \left(\frac{1}{c_0}\frac{\partial p}{\partial t} + \frac{\partial p}{\partial x}\right)\left(\frac{1}{c_0}\frac{\partial p}{\partial t} - \frac{\partial p}{\partial x}\right)$$

Inviscid Burgers' equation

1D wave equation

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Nonlinear speed of sound

$$c=c_0+\frac{\beta p_a}{\rho_0 c_0}$$

Nonlinear "one way" wave eq.

$$\frac{1}{c_0}\frac{\partial p}{\partial t}+\frac{\partial p}{\partial x}=\frac{\beta}{\rho_0 c_0^3}p\frac{\partial p}{\partial t}$$

Inviscid Burgers' equation

1D wave equation

$$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2} - \frac{\partial^2 p}{\partial x^2} = 0 = \left(\frac{1}{c_0}\frac{\partial p}{\partial t} + \frac{\partial p}{\partial x}\right)\left(\frac{1}{c_0}\frac{\partial p}{\partial t} - \frac{\partial p}{\partial x}\right)$$

Nonlinear speed of sound

$$c = c_0 + \frac{\beta p_a}{\rho_0 c_0}$$

Nonlinear "one way" wave eq.

$$\frac{1}{c_0}\frac{\partial p}{\partial t} + \frac{\partial p}{\partial x} = \frac{\beta}{\rho_0 c_0^3} p \frac{\partial p}{\partial t}$$

Inviscid Burgers' eq.

$$\tau = t - \frac{x}{c_0} \quad \Rightarrow \quad \frac{\partial p}{\partial x} = \frac{\beta}{\rho_0 c_0^3} p \frac{\partial p}{\partial \tau}$$

Shock formation distance

Shock formation distance

- **Inviscid Burgers' eq.**

$$\frac{\partial p}{\partial x} = \frac{\beta}{\rho_0 c_0^3} p \frac{\partial p}{\partial \tau}$$

Shock formation distance

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$$\frac{\partial p}{\partial x} = \frac{\beta}{\rho_0 c_0^3} p \frac{\partial p}{\partial \tau}$$

- **Dimensionless**

$$p = P_0 \bar{P}$$

$$\bar{\tau} = \omega_0 \tau$$

$$\sigma = x / L \quad L?$$

Shock formation distance

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- **Dimensionless**

$$p = P_0 \bar{P}$$

$$\bar{\tau} = \omega_0 \tau$$

$$\sigma = x / L \quad L?$$

$$\frac{\partial P}{\partial \sigma} = P \frac{\partial P}{\partial \tau}$$

by choosing

$$L = \frac{\rho_0 c_0^3}{\beta \omega_0 P_0} = \frac{1}{\beta k_0 M_0}$$

Poisson's solution

Poisson's solution

$$\frac{\partial P}{\partial \sigma} = P \frac{\partial P}{\partial \tau}$$

Poisson's solution

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+

$$P(\sigma = 0, \tau) = P_0(\tau)$$

Poisson's solution

$$\frac{\partial P}{\partial \sigma} = P \frac{\partial P}{\partial \tau} \quad + \quad P(\sigma = 0, \tau) = P_0(\tau)$$

Exact implicit Poisson's solution (1802)

$$P(\sigma, \tau) = P_0(\theta) \quad \textit{with} \quad \tau = \theta - \sigma P_0(\theta)$$

Poisson's solution

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+

$$P(\sigma = 0, \tau) = P_0(\tau)$$

Exact implicit Poisson's solution (1802)

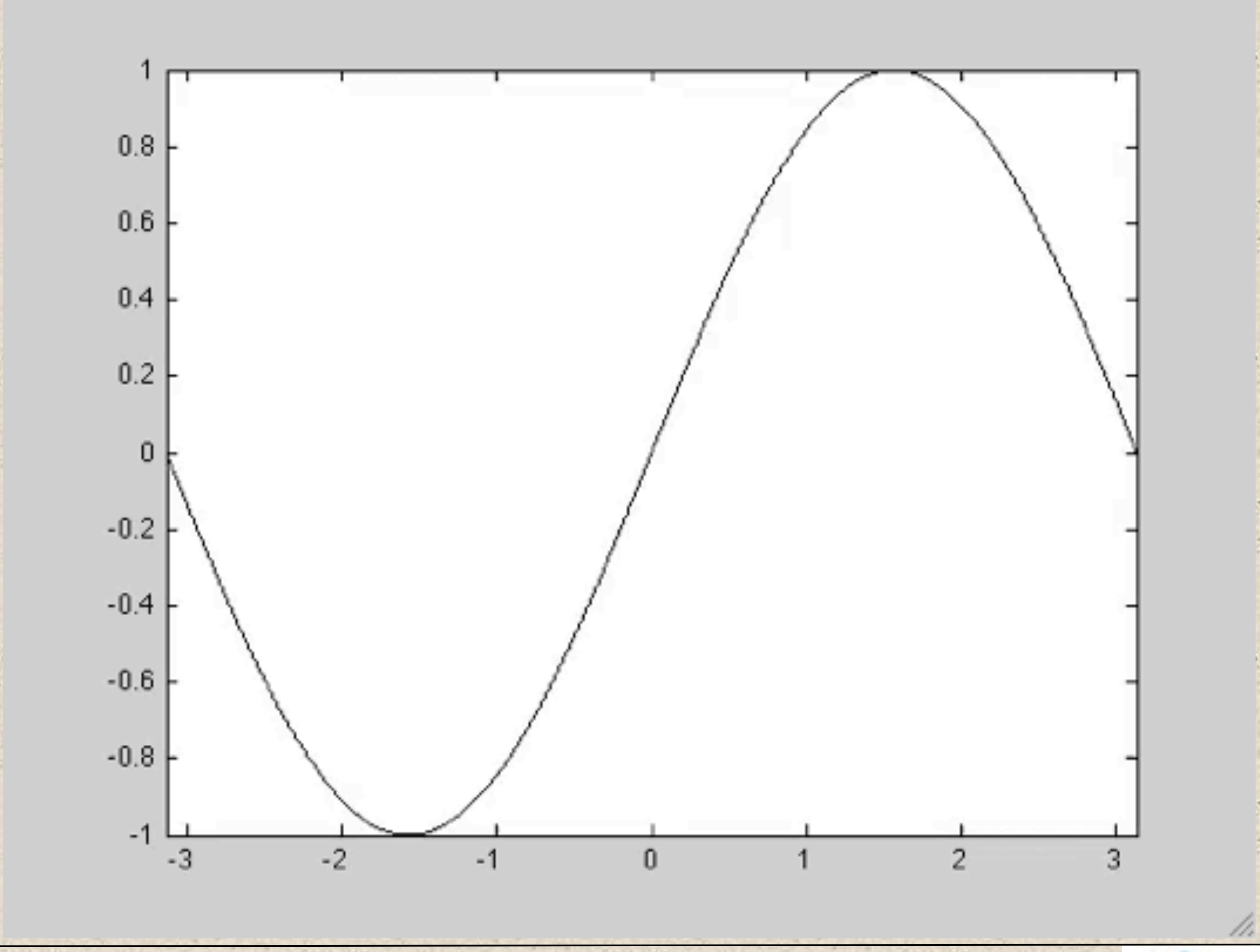
$$P(\sigma, \tau) = P_0(\theta) \quad \textit{with} \quad \tau = \theta - \sigma P_0(\theta)$$

Single-valued as long as

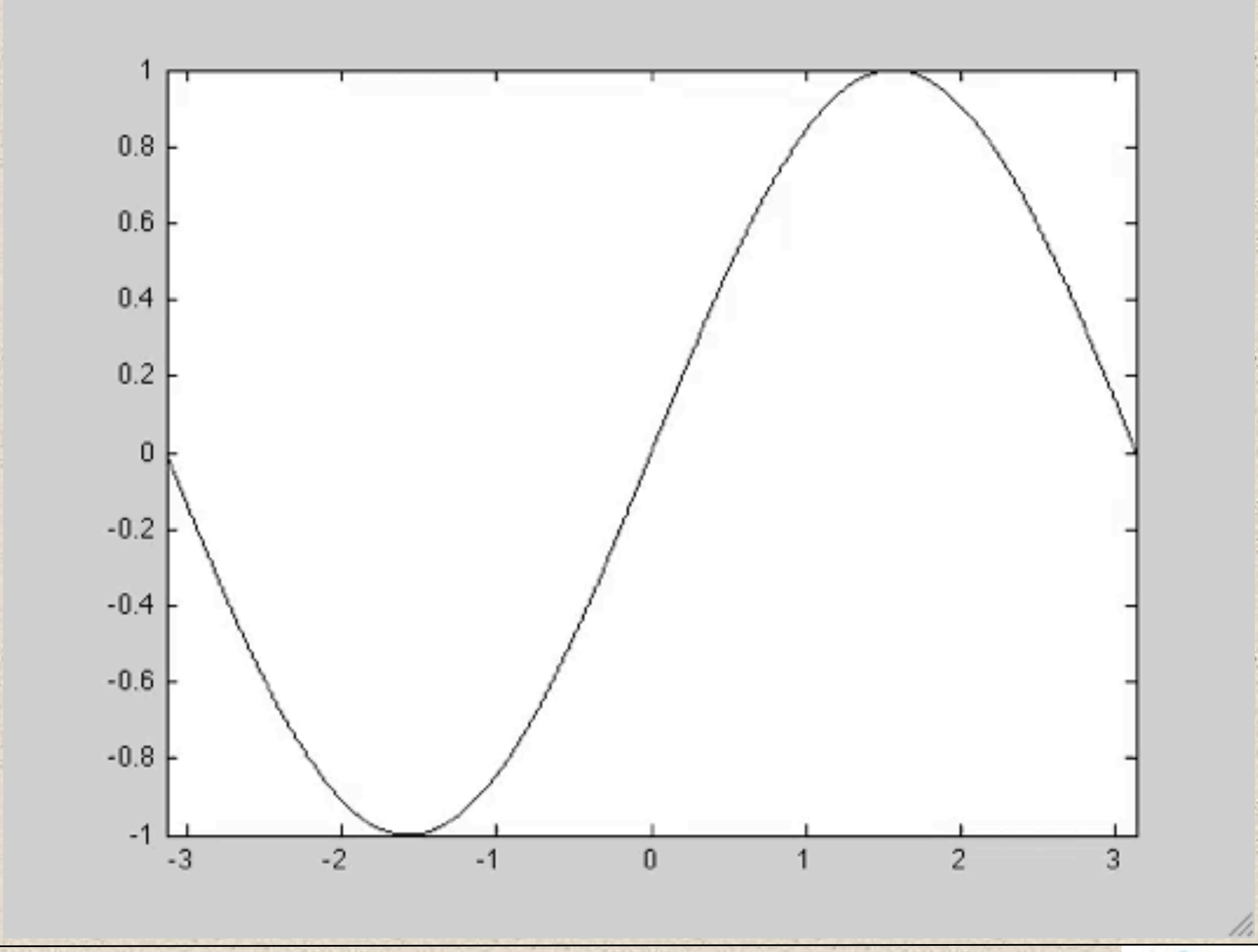
$$\frac{\partial \tau}{\partial \theta} = 1 - \sigma P_0^{/}(\theta) > 0$$

$$\sigma < \frac{1}{\max\left(P_0^{/}(\theta)\right)} \quad \left(= 1 \quad \textit{if} \quad P_0 = \sin\theta \right)$$

Poisson's solution

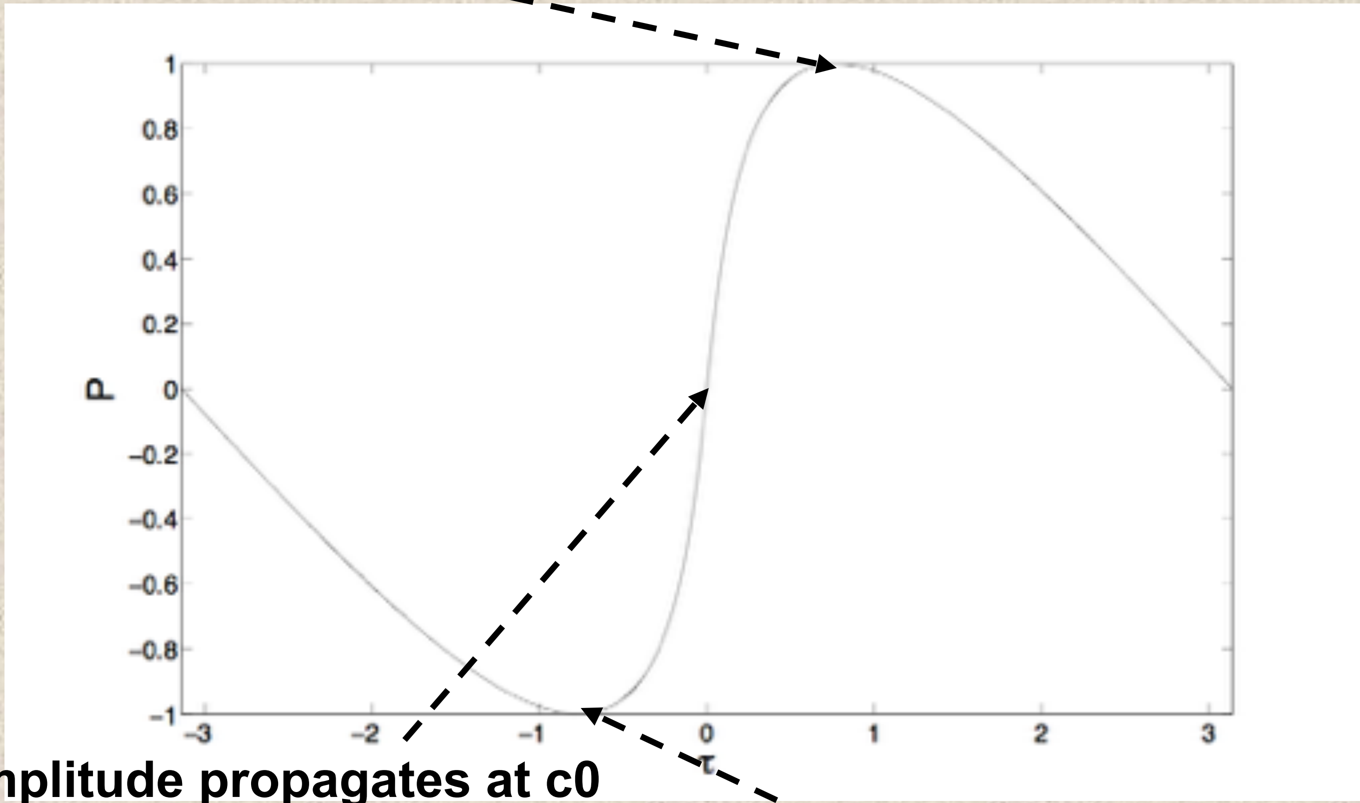


Poisson's solution



Nonlinear signal distorsion

Max propagates at c > c0 : ahead of time



Zero of amplitude propagates at c0

Min propagates at c < c0 : retarded

Bessel-Fubini solution

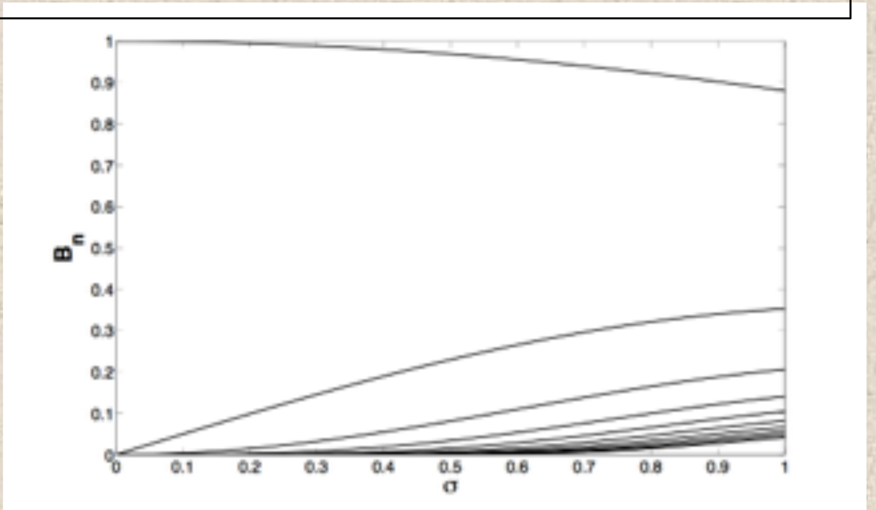
Case of an initially sine wave

$$P(\sigma,\tau) = \sin(\theta) \quad avec \quad \tau = \theta - \sigma\sin(\theta)$$

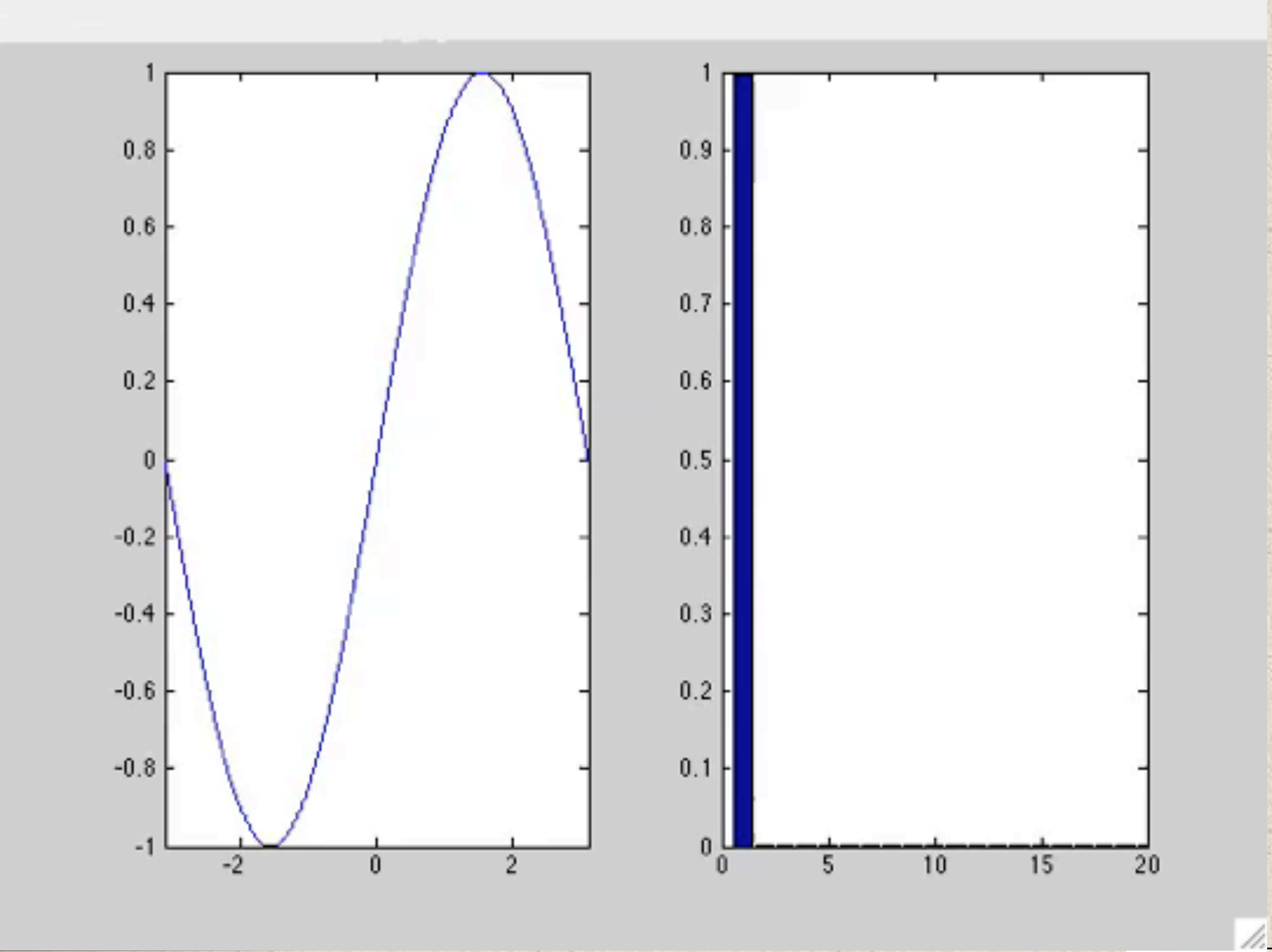
Nonlinearity keeps parity and periodicity ⇒ Fourier series

$$P(\sigma,\tau) = \sum_{n=0}^{+\infty} B_n(\sigma)\sin(n\tau) \quad avec \quad B_n = \frac{2}{\pi}\int_0^{\pi} P(\sigma,\tau)\sin(n\tau)d\tau$$

$$B_n = \frac{2J_n(n\sigma)}{n\sigma}$$



Nonlinear distorsion and harmonic generation



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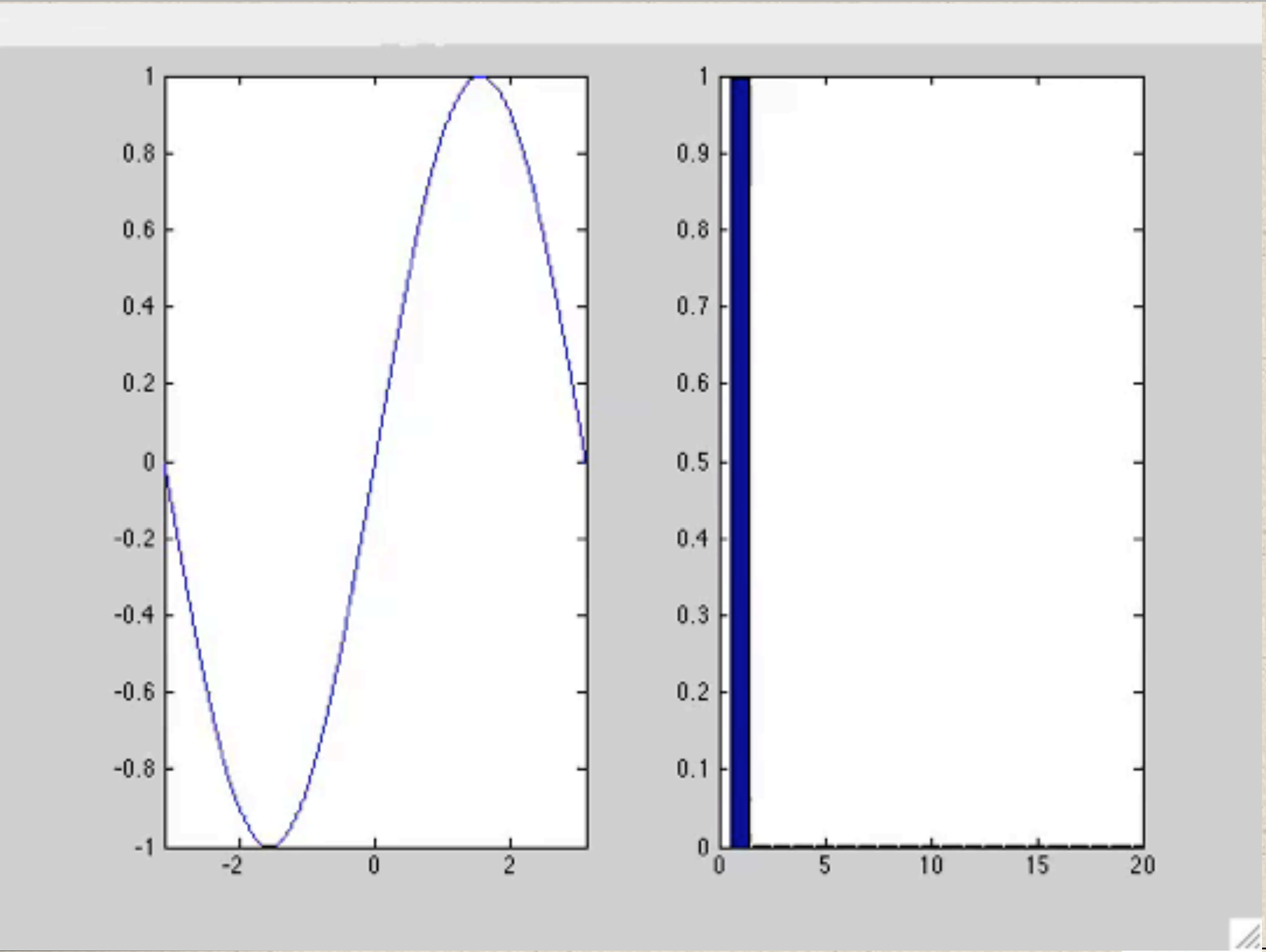
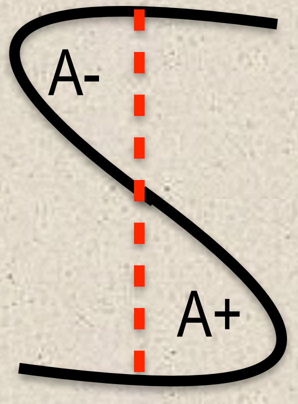


Shock position : 3 methods

1) Rankine-Hugoniot
(weak shock theory)

$$W = \frac{1}{2}\left(c_1 + c_2\right)$$

2) Law of equal areas
(Landau 1944)



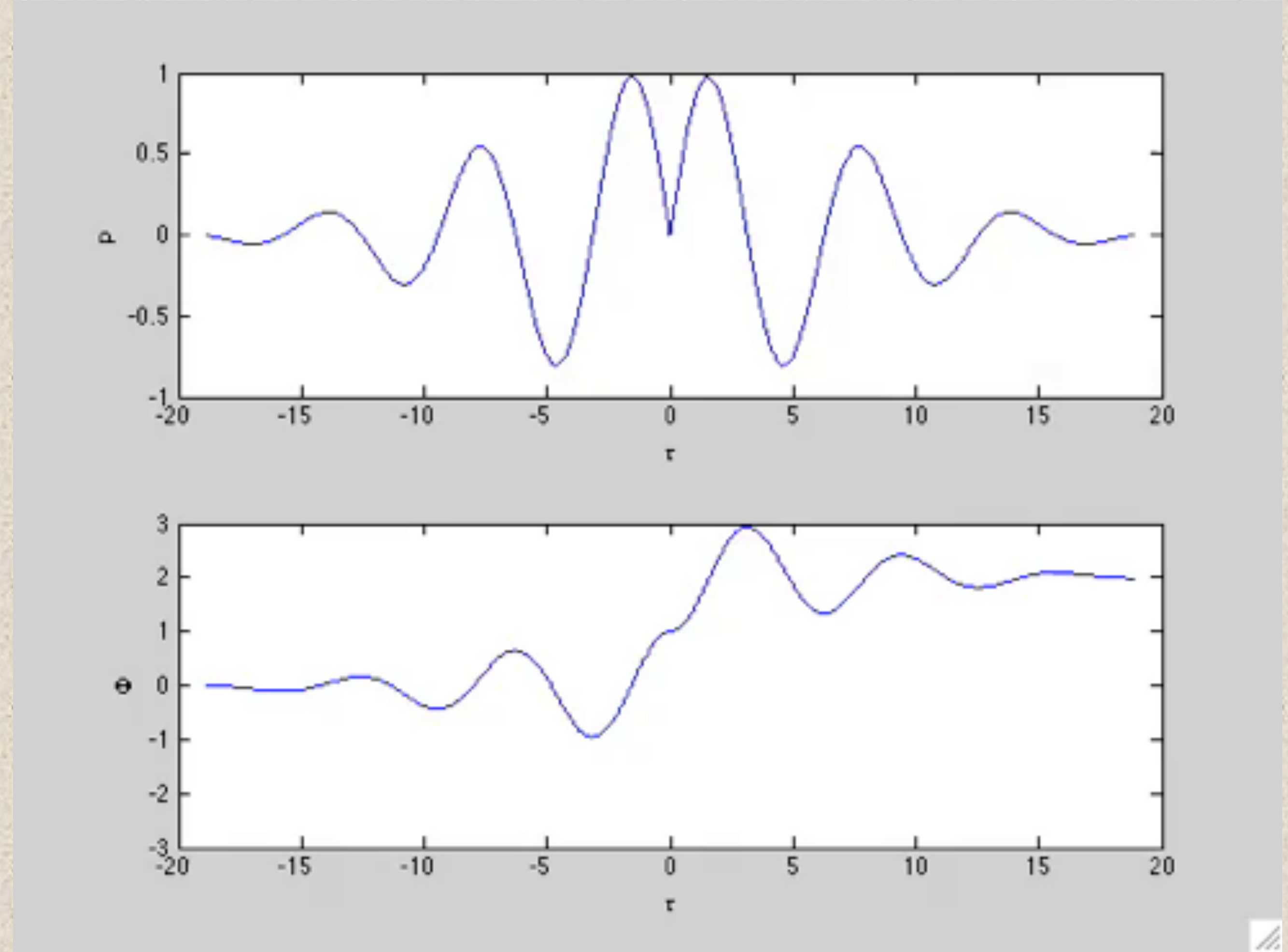
A+=A-

3) Burgers-Hayes potential (1954-1969)

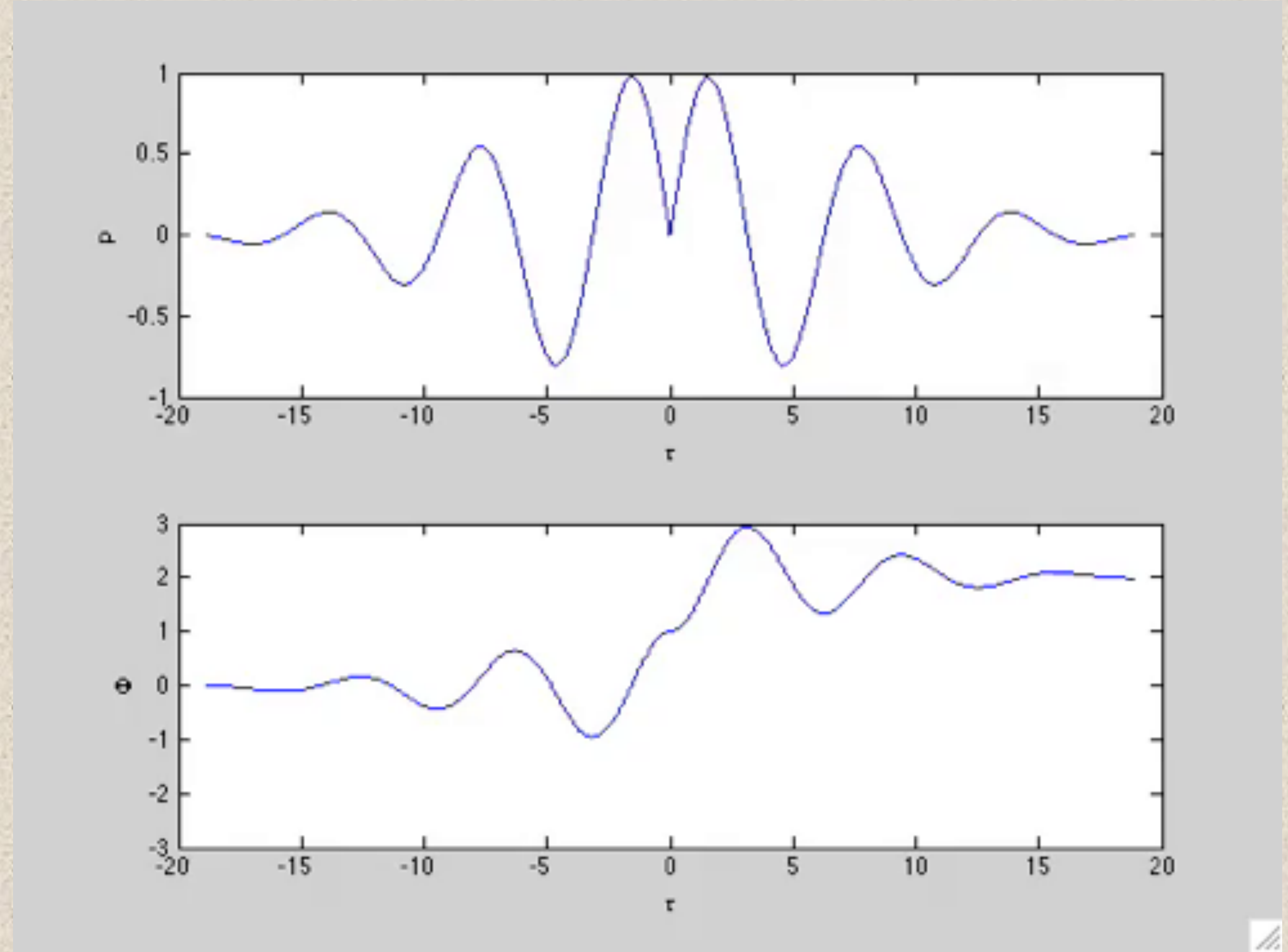
For potential $\Phi(\sigma,\tau) = \int_{-\infty}^{\tau} P(\sigma,\tau')d\tau'$ monovalued solution

is max of multivalued one $\Phi_{mono}(\sigma,\tau) = \max\left(\Phi_{multi}(\sigma,\tau)\right)$

Burgers-Hayes potential method



Burgers-Hayes potential method



Saw-tooth wave

$$P = \sin(\theta) \approx \frac{\pi - \tau}{1 + \sigma}$$

$$\tau \in \left]0, \pi\right]$$

$$E \downarrow \sigma^{-2}$$

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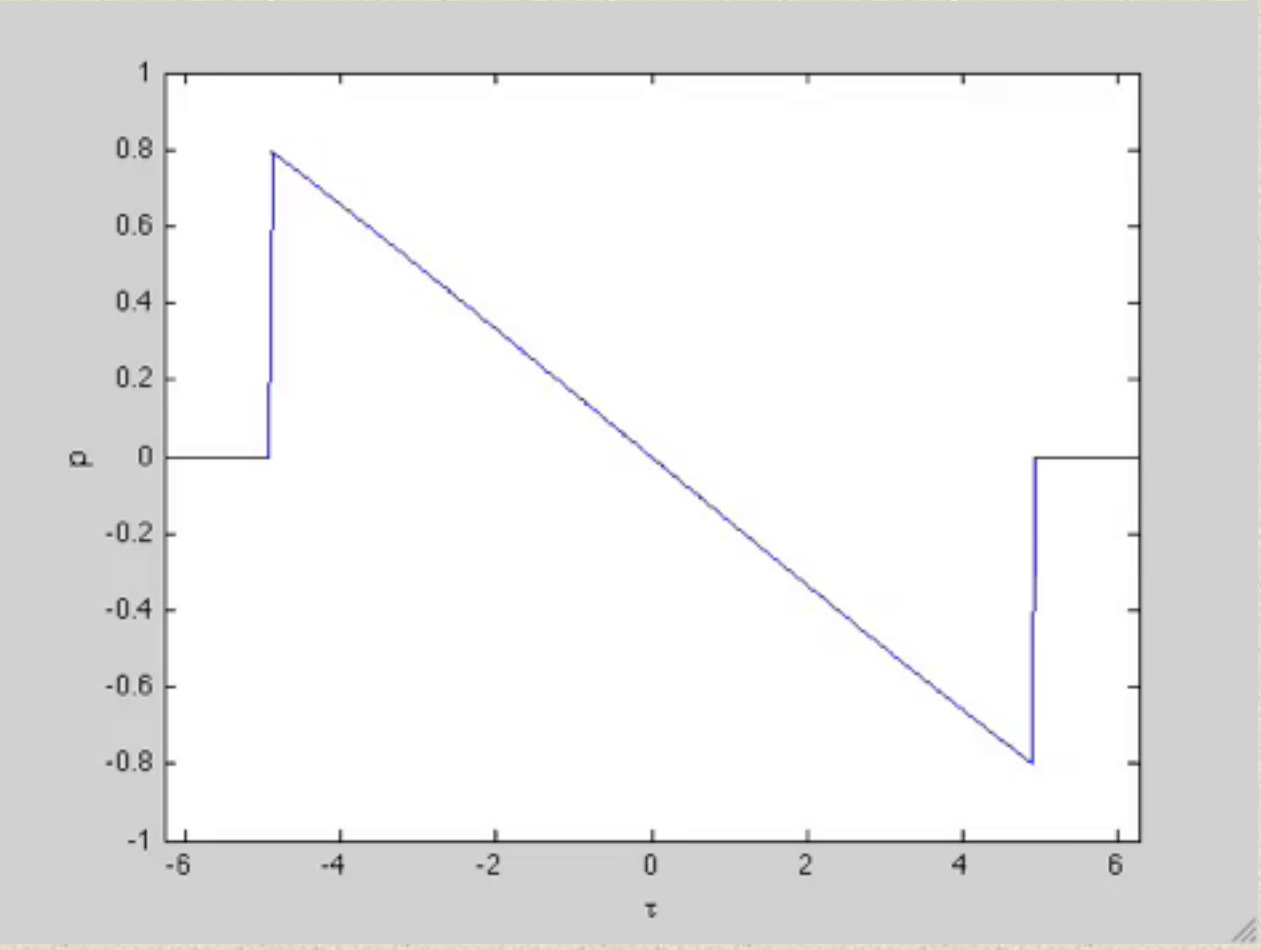
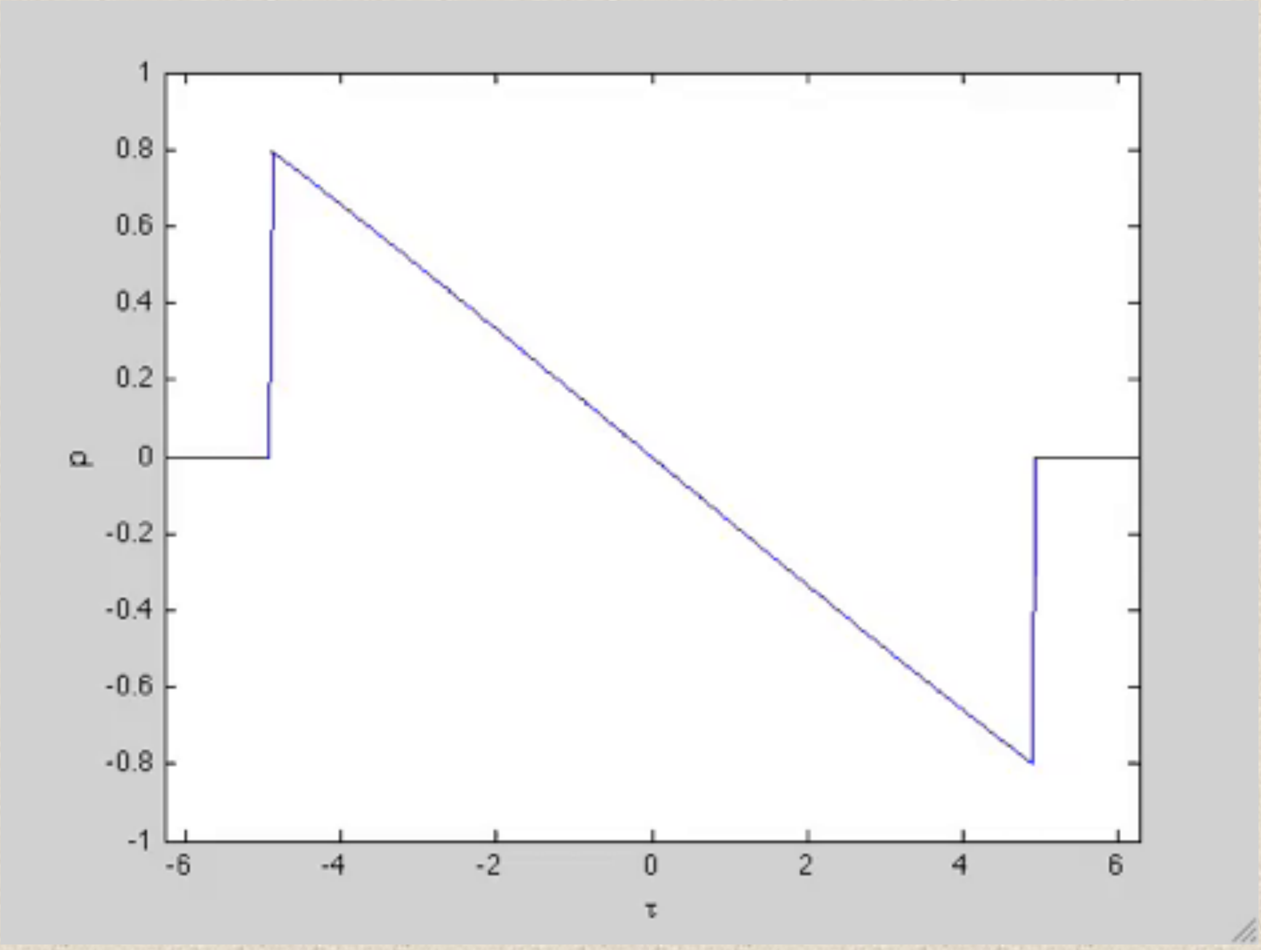
N-wave



$$P(\sigma,\tau) = \begin{cases} -\dfrac{\tau}{1+\sigma} & \text{si} \quad |\tau| < \sqrt{1+\sigma} \\ 0 & \text{sinon} \end{cases}$$

$$E \downarrow \sigma^{-1/2}$$

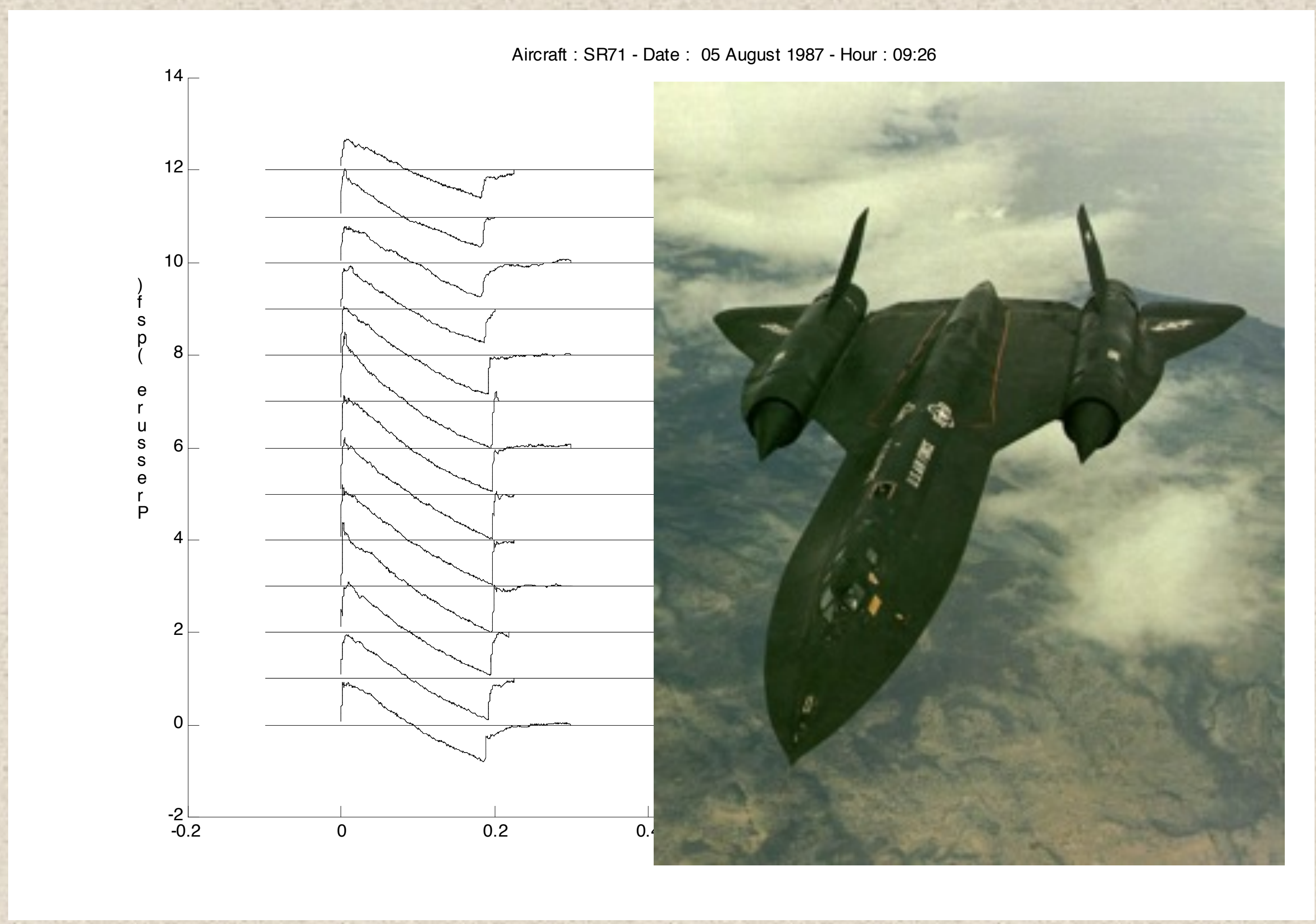
N-wave



$$P(\sigma,\tau) = \begin{cases} -\dfrac{\tau}{1+\sigma} & \text{si} \quad |\tau| < \sqrt{1+\sigma} \\ 0 & \text{sinon} \end{cases}$$

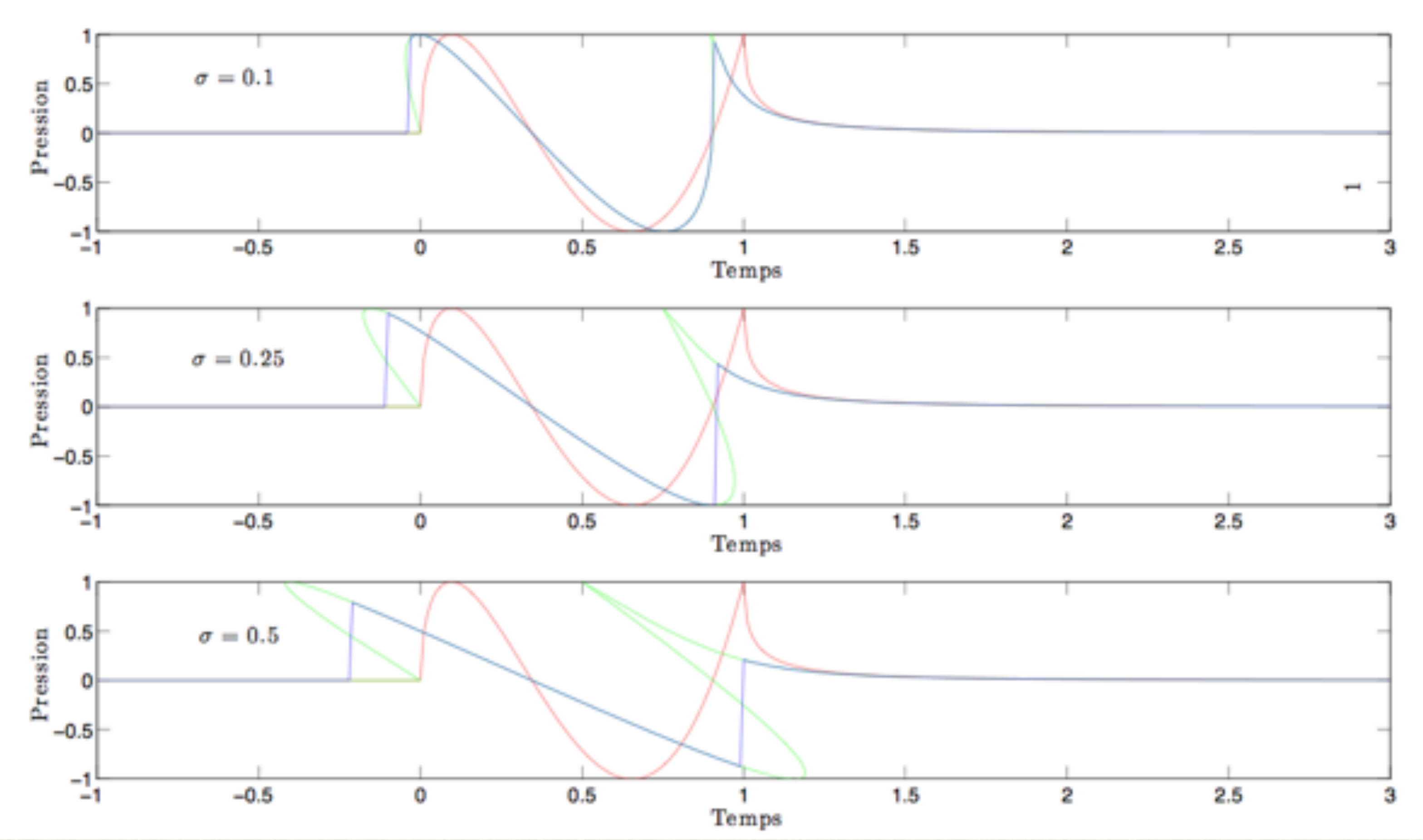
$$E \downarrow \sigma^{-1/2}$$

Sonic boom is an N-wave !



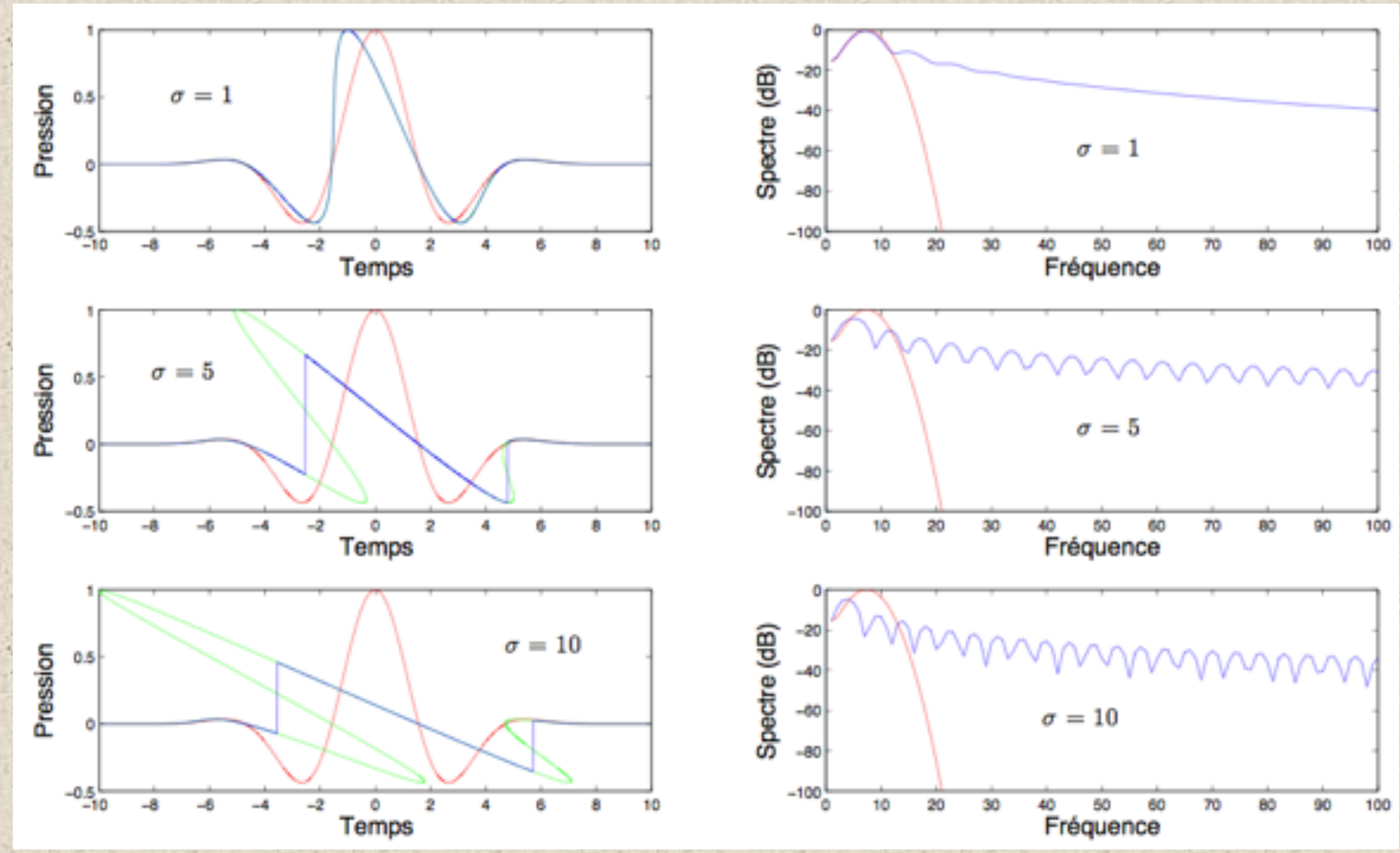
From Whitham function to N-wave

Nonlinear propagation of an N-wave

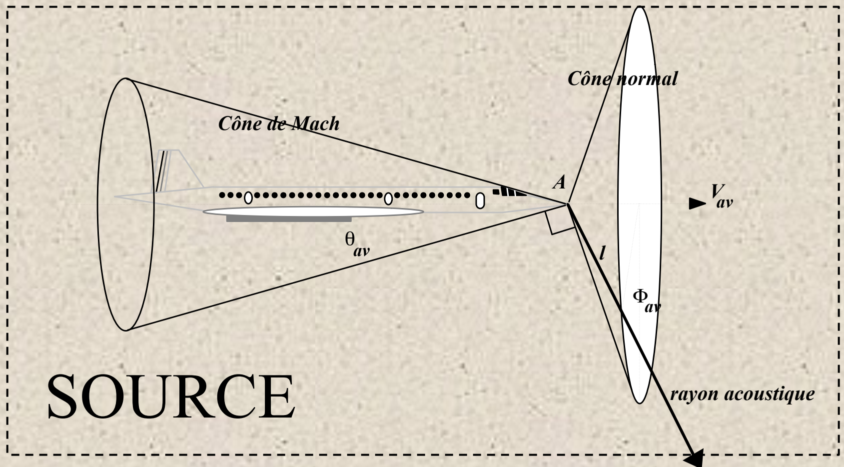


From Whitham function to N-wave

Nonlinear distortion : time waveform versus frequency spectrum



From 1D to 3D : nonlinear ray theory



3D heterogeneous atmosphere :

rays = curves

(Fermat's principle :

time from source to observer is minimized

OBSERVER

Linear ray theory (cf D. Juvé's lecture)

Nonlinear ray theory

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l)=Cte$$

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l)=Cte \quad \Leftrightarrow \quad \frac{\partial p_a}{\partial l}+\frac{1}{c}\frac{\partial p_a}{\partial t}+\frac{1}{2B}\frac{dB}{dl}p_a=0$$

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l) = Cte \quad \Longleftrightarrow \quad \frac{\partial p_a}{\partial l} + \frac{1}{c}\frac{\partial p_a}{\partial t} + \frac{1}{2B}\frac{dB}{dl}p_a = 0$$

Non linear

$$c \rightarrow c + \frac{\beta p_a}{\rho_0 c_0}$$

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l) = Cte \iff \frac{\partial p_a}{\partial l} + \frac{1}{c}\frac{\partial p_a}{\partial t} + \frac{1}{2B}\frac{dB}{dl}p_a = 0$$

Non linear

$$c \rightarrow c + \frac{\beta p_a}{\rho_0 c_0} \longrightarrow \frac{\partial p_a}{\partial l} + \frac{1}{c}\frac{\partial p_a}{\partial t} + \frac{1}{2B}\frac{dB}{dl}p_a = \frac{\beta}{\rho_0 c_0 c^2} p_a \frac{\partial p_a}{\partial t}$$

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l)=Cte \iff \frac{\partial p_a}{\partial l}+\frac{1}{c}\frac{\partial p_a}{\partial t}+\frac{1}{2B}\frac{dB}{dl}p_a=0$$

Non linear

$$c \to c+\frac{\beta p_a}{\rho_0 c_0} \longrightarrow \frac{\partial p_a}{\partial l}+\frac{1}{c}\frac{\partial p_a}{\partial t}+\frac{1}{2B}\frac{dB}{dl}p_a=\frac{\beta}{\rho_0 c_0 c^2}p_a\frac{\partial p_a}{\partial t}$$

Change of variable

$$q(\sigma,\tau=t-\Psi(l))=\sqrt{B(l)}\,p_a(l,t)$$

Nonlinear ray theory

Linear ray theory

$$p_a^2(l,t-\Psi(l))B(l) = Cte \quad \Leftrightarrow \quad \frac{\partial p_a}{\partial l} + \frac{1}{c}\frac{\partial p_a}{\partial t} + \frac{1}{2B}\frac{dB}{dl}p_a = 0$$

Non linear

$$c \rightarrow c + \frac{\beta p_a}{\rho_0 c_0} \quad \longrightarrow \quad \frac{\partial p_a}{\partial l} + \frac{1}{c}\frac{\partial p_a}{\partial t} + \frac{1}{2B}\frac{dB}{dl}p_a = \frac{\beta}{\rho_0 c_0 c^2} p_a \frac{\partial p_a}{\partial t}$$

Change of variable

$$q(\sigma,\tau = t - \Psi(l)) = \sqrt{B(l)}\, p_a(l,t)$$

$$\frac{\partial q}{\partial \sigma} = q\frac{\partial q}{\partial t}$$

Burgers with

$$\sigma = \int_0^l \frac{\beta}{\rho_0 c_0 c^2}\frac{dl}{\sqrt{B(l)}}$$

Age variable

$$\sigma = \int_0^l \frac{\beta}{\rho_0 c_0 c^2} \frac{dl}{\sqrt{B(l)}}$$

« age variable »

Plane wave	$B \propto l^1$	so	$\sigma \propto l$
Cylindrical wave	$B \propto l^1$	so	$\sigma \propto l^{1/2}$
Spherical wave	$B \propto l^2$	so	$\sigma \propto \log l$

Nonlinear effects much more important for plane waves or line sources (like sonic booms) than for point sources

Sonic boom in a homogeneous atmosphere

$$q(\sigma,\tau = t - \Psi(l)) = \sqrt{B(l)}\, p_a(l,t)$$

<u>Cylindrical wave</u> $B \propto l^{1}$ so $\sigma \propto l^{1/2}$

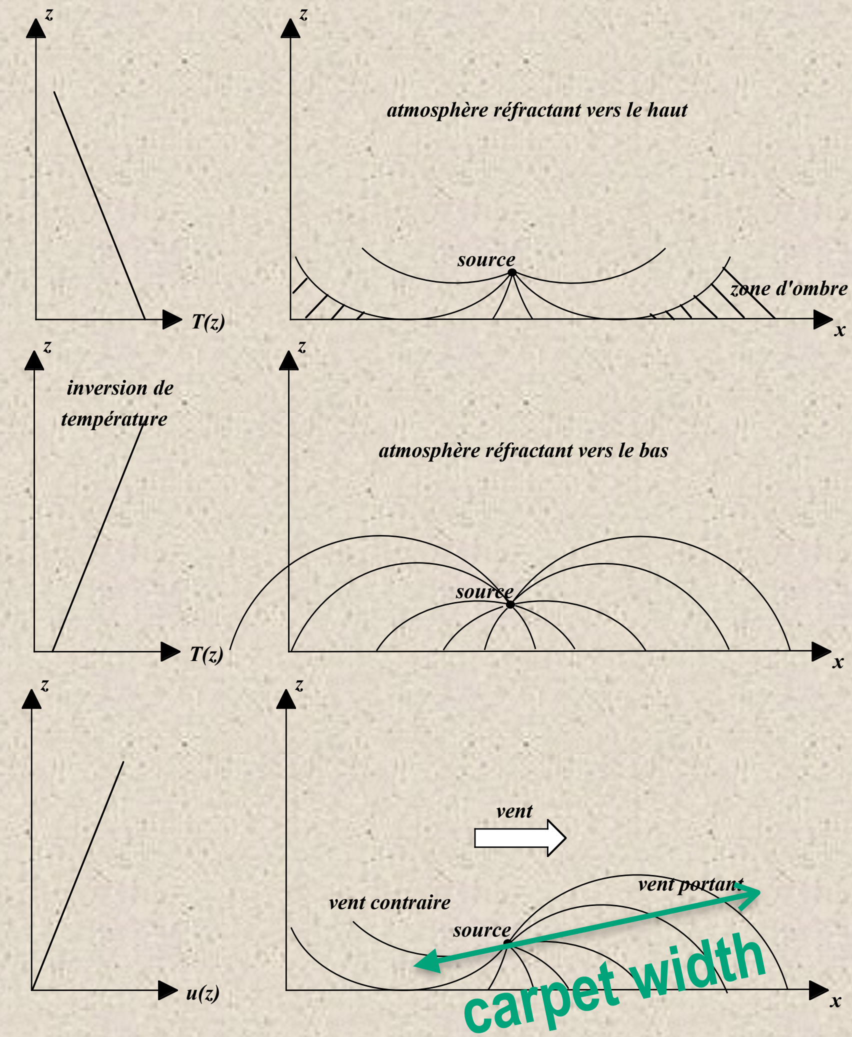
N-wave is farfield solution of inviscid Burgers' equation : $q \propto \sigma^{-1/2}$

$$p = qB^{-1/2} \propto l^{-1/4} \times l^{-1/2} = l^{-3/4}$$

Sonic boom in homogeneous atmosphere decays as power 3/4 of distance

Sonic boom in standard atmosphere

-6.5°C /km (z < 11 km)
0 °C /km (z > 11 km)



Sonic boom in standard atmosphere

-6.5°C /km (z < 11 km)
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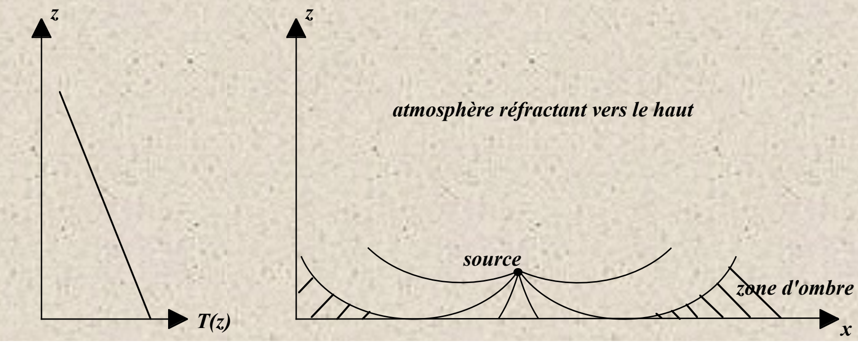
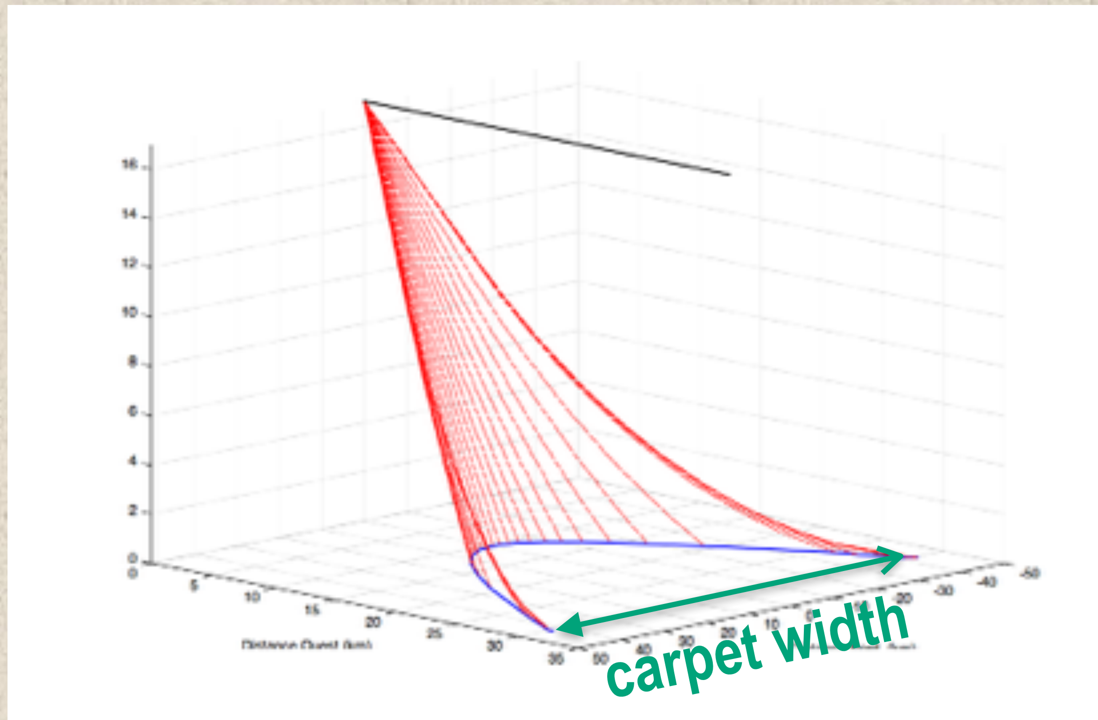
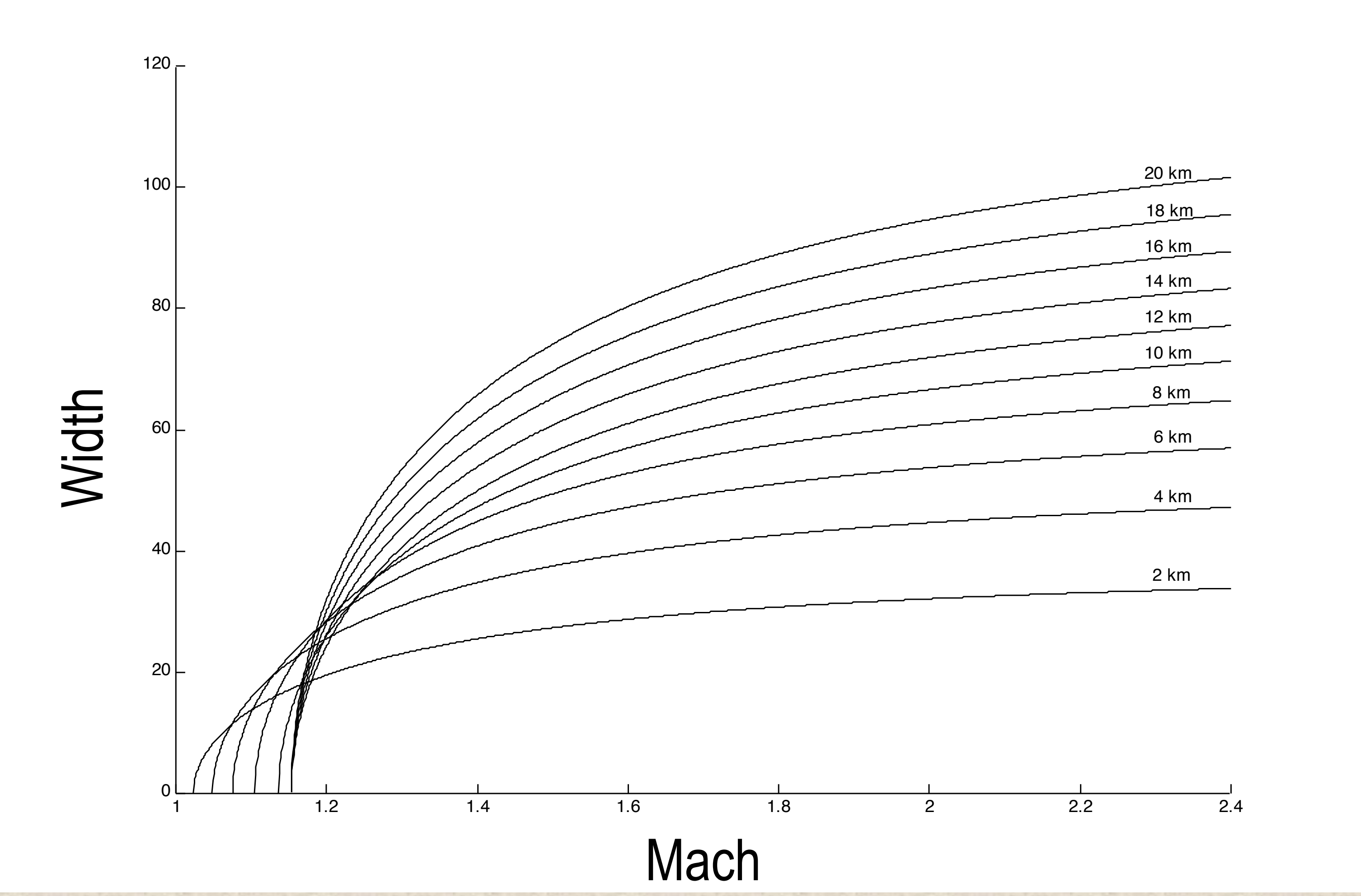


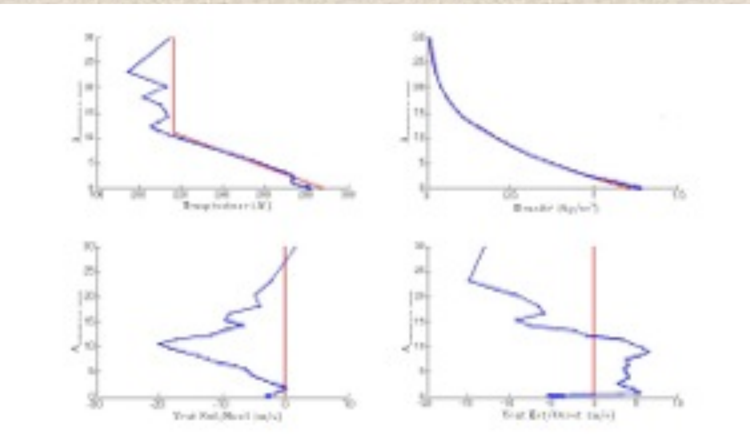


Carpet width



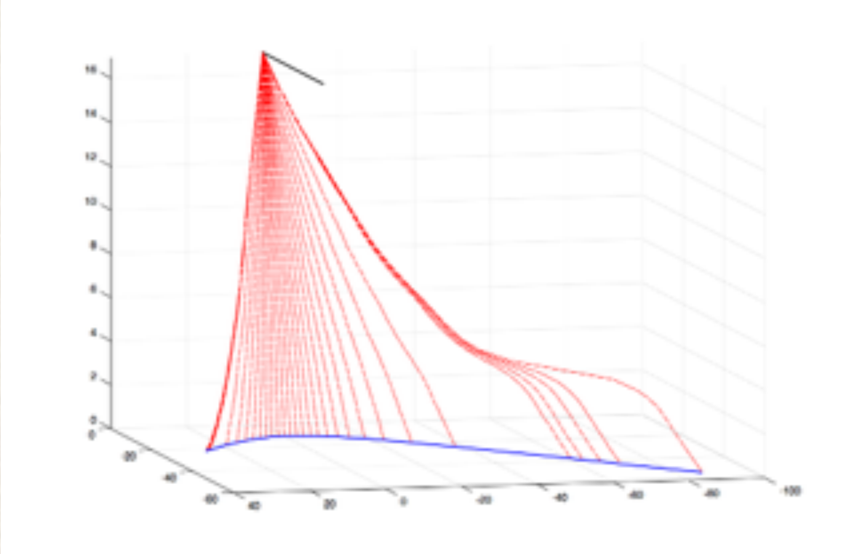
Carpet width vs meteorological variability

Standard atmosphere

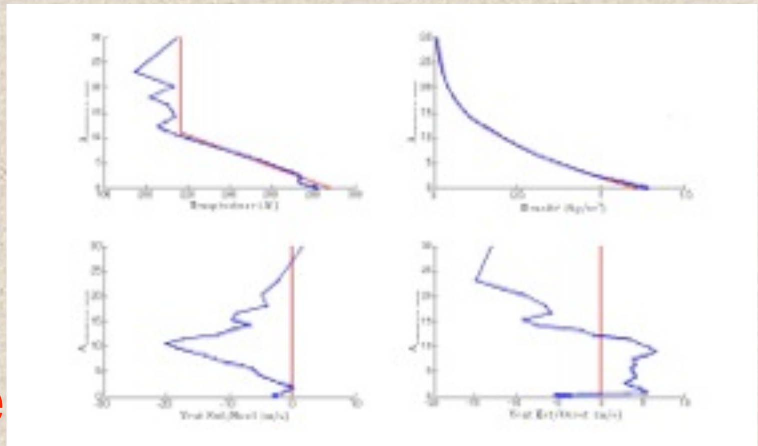


« Real » atmosphere

(St George Channel, 24/01/1985, ECMWF data)

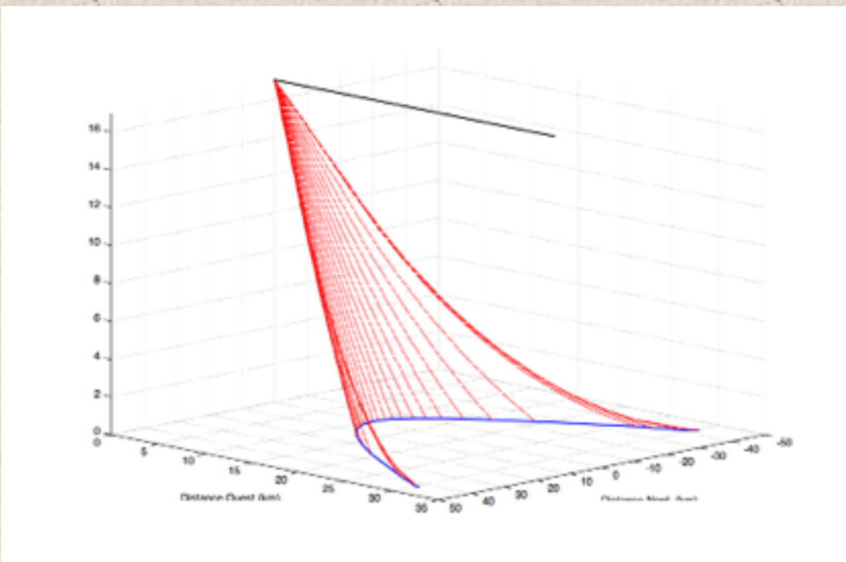


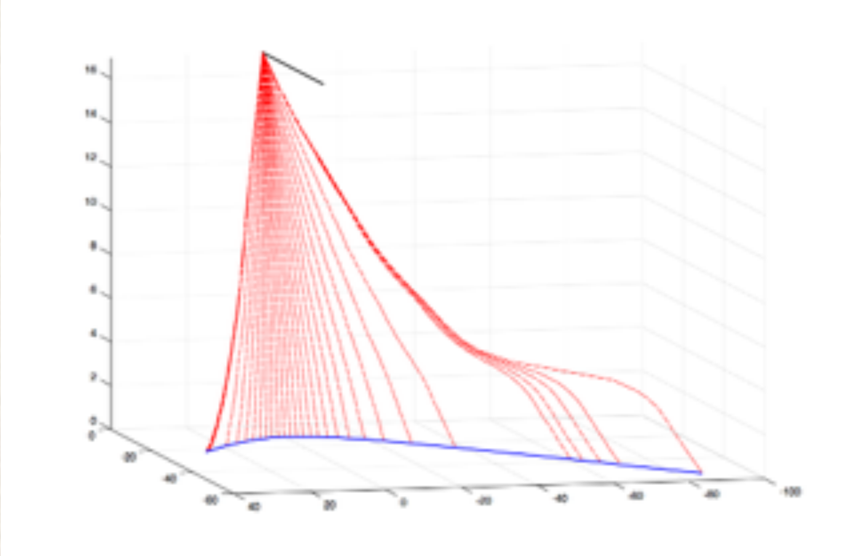
Carpet width vs meteorological variability



Standard atmosphere

« Real » atmosphere
(St George Channel, 24/01/1985, ECMWF data)





Carpet width vs meteorological variability

Ground impact of sonic boom (Mach 1.6 - Edwards CA - year 1993)

Width (km) | **Peak overpressure (Pa)**

East to West

West to East

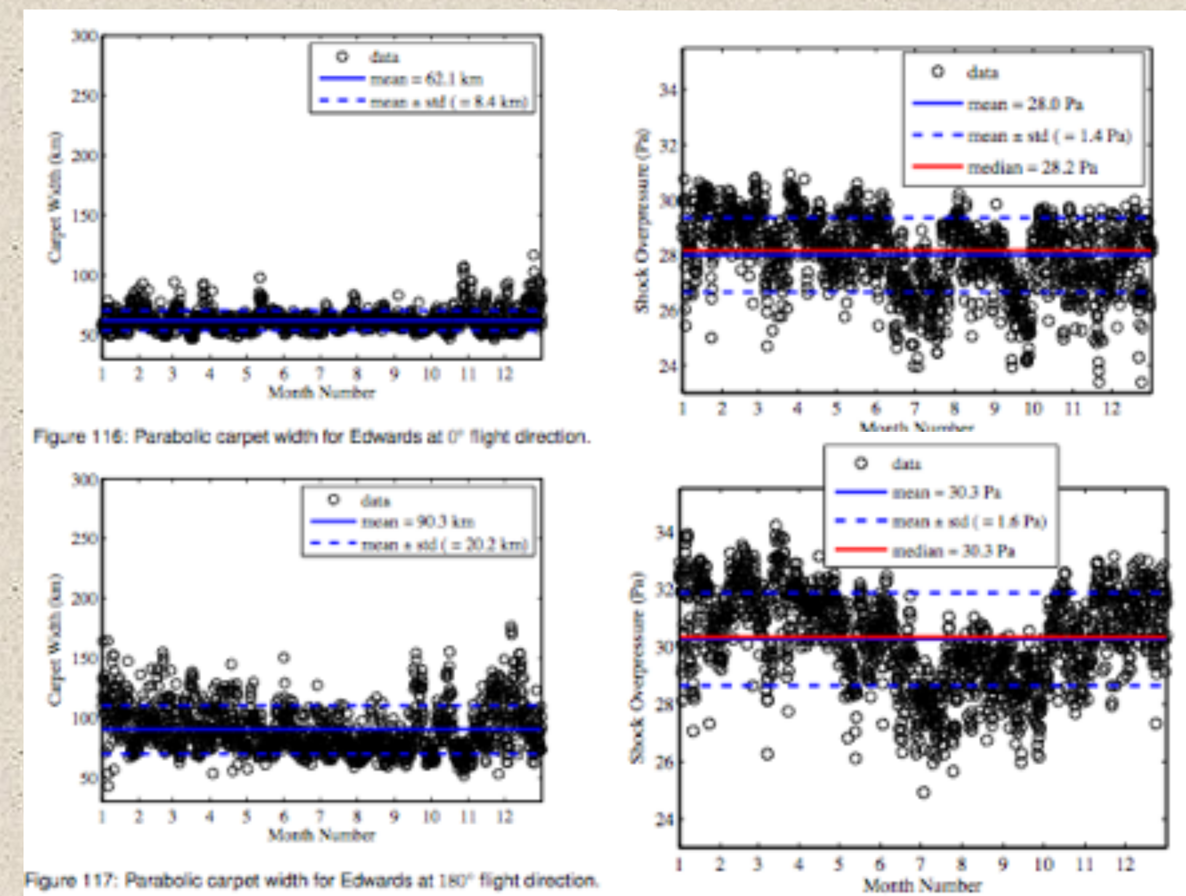


Figure 116: Parabolic carpet width for Edwards at 0° flight direction.

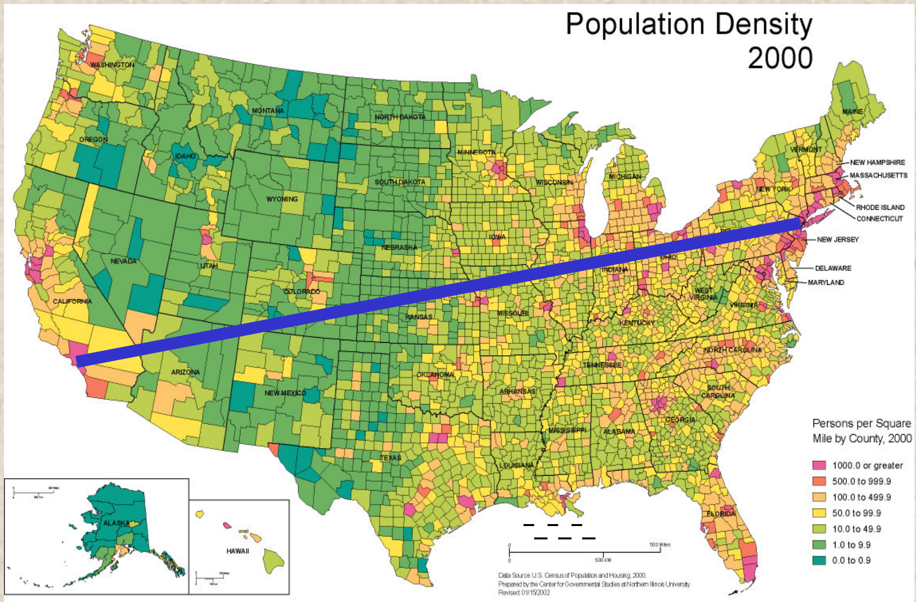
Figure 117: Parabolic carpet width for Edwards at 180° flight direction.

Some key questions on sonic boom

- *What is a sonic boom ?*
- *How does a sonic boom propagate in the atmosphere ?*
- ***Who is annoyed by a sonic boom ?***

Who is annoyed by sonic boom ?

Sonic boom …



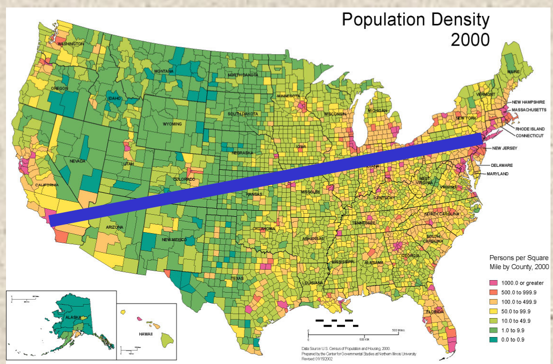
NY/ LA= 3950 km - 2 X 200 km = 3550 km

3550 km ×65 km ×30 hab/km^2 =**6,922,500 people**

How many highly annoyed ? We don't know yet

Who is annoyed by sonic boom ?

Sonic boom …



- A large number of people exposed to an « unfrequent » event (to be quantified)

… opposite to airport noise

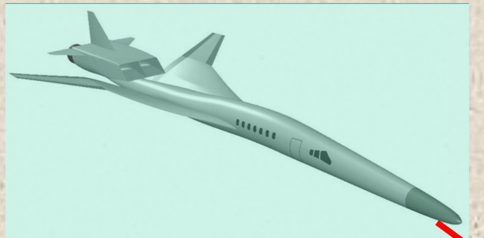
- A relatively « small number » of people exposed to a very frequent event (almost continuous)

Amsterdam Schiphol, 2005, 1180 flight movements
About 230,000 people highly annoyed by airport noise

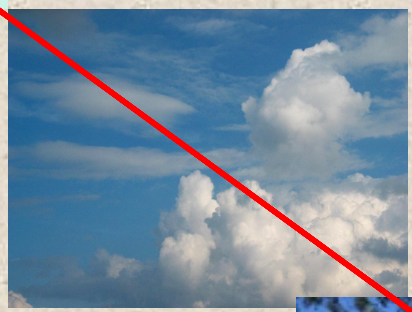
Some key questions on sonic boom

- *What is a sonic boom ?*
- *How does a sonic boom propagate in the atmosphere ?*
- *Who is annoyed by a sonic boom ?*
- *What influences a sonic boom ?*

What influences a sonic boom ?



The aircraft
design / operations

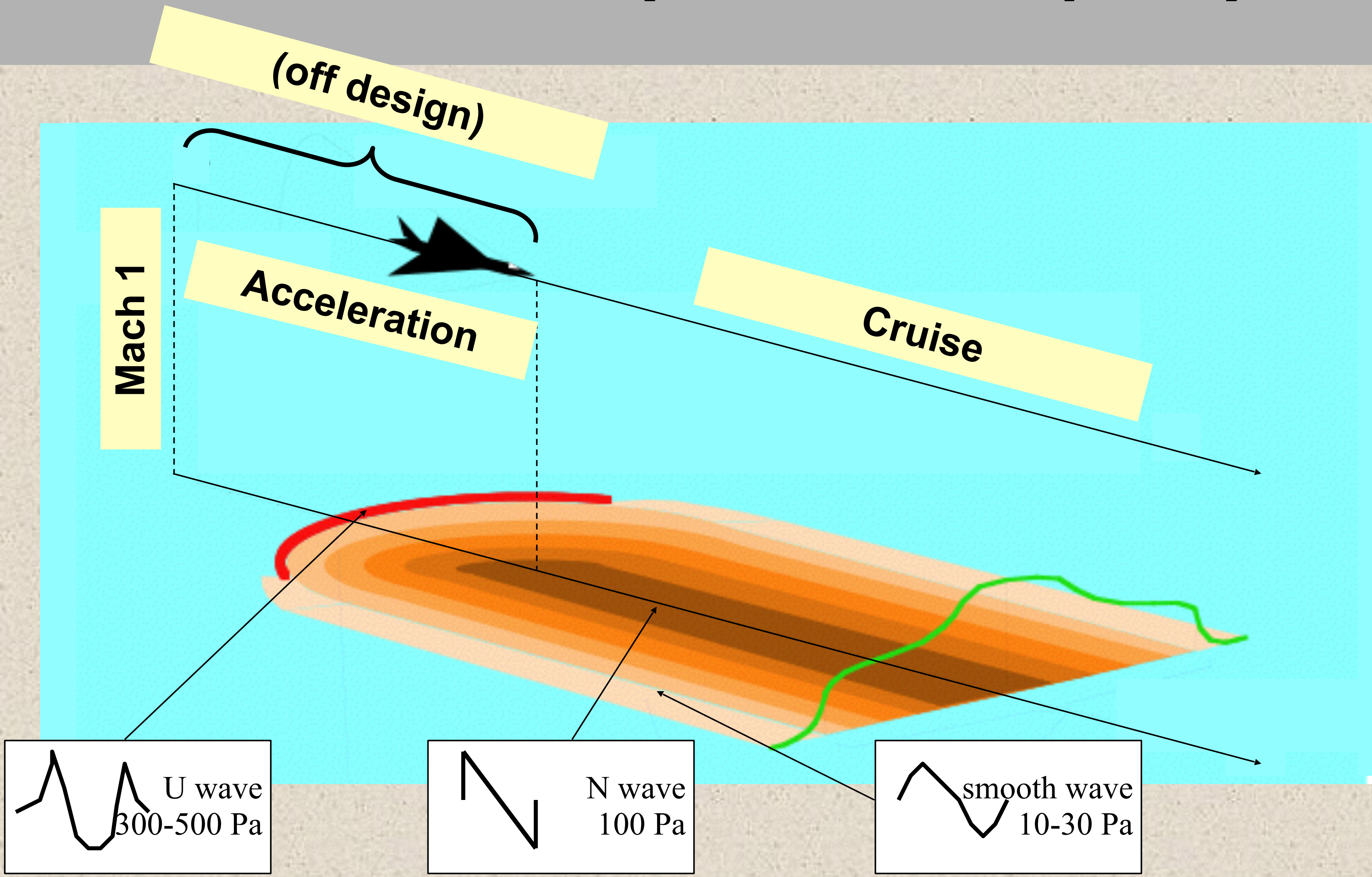


The atmosphere
large / medium / small scales

The buildings
type & quality

The people

The sonic boomS (smooth atmosphere)



Molecular relaxation

Simplified mechanism

$$N_2^* + H_2O \leftrightarrow N_2 + H_2O + énergie$$

$$O_2^* + H_2O \leftrightarrow O_2 + H_2O + énergie$$

Relaxation time (chemical kinetics)

$f_N \sim 300$ Hz $\qquad f_O \sim 30$ kHz

Dispersion

N at equilibrium
O at equilibrium

f_N

N frozen
O at equilibrium

f_O

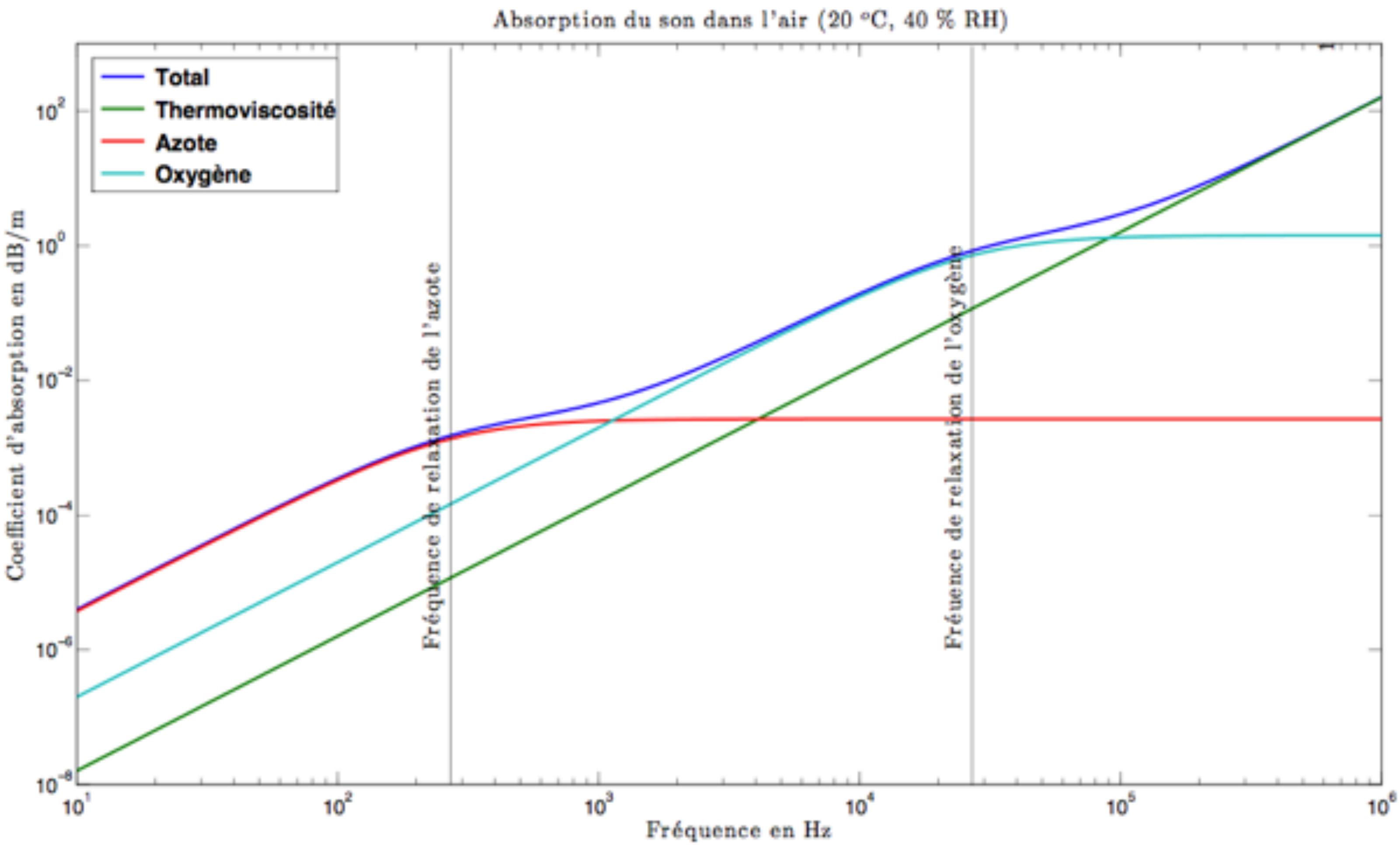
N frozen
O frozen

300 Hz

30 kHz

frequency

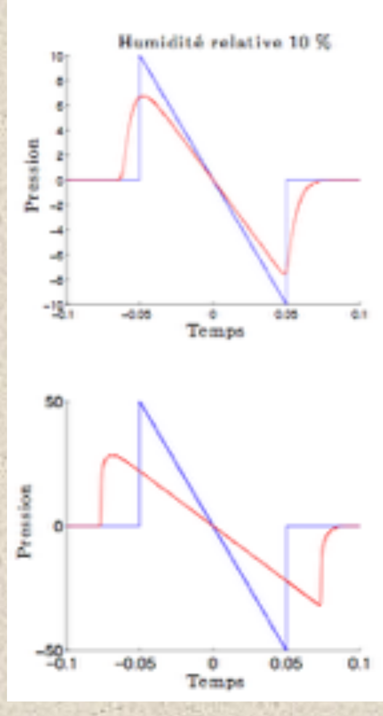
Atmospheric absorption



Influence on sonic boom

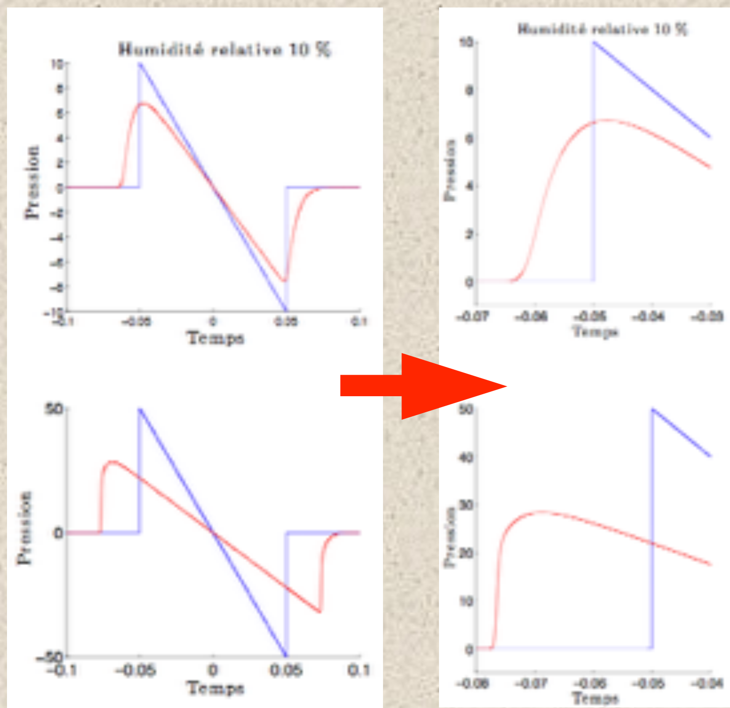
Low humidity

High humidity



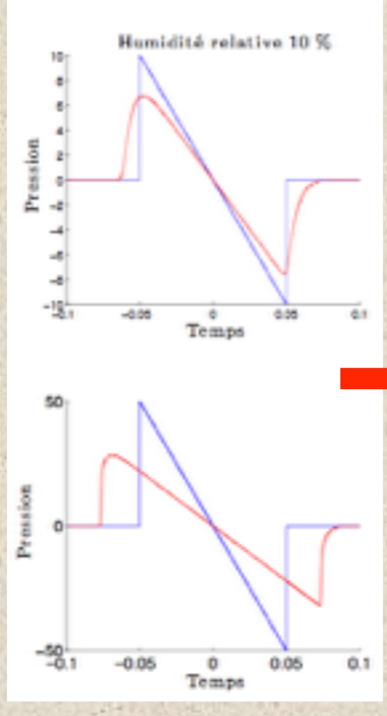
Influence on sonic boom

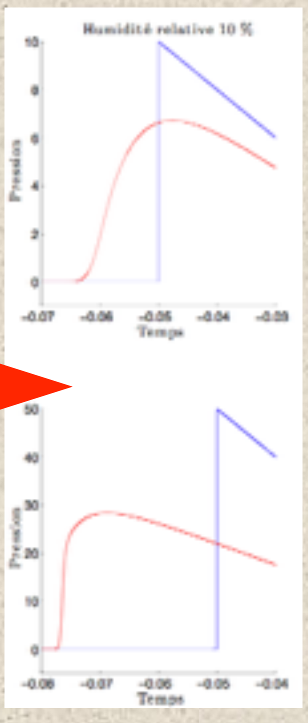
Low humidity | High humidity



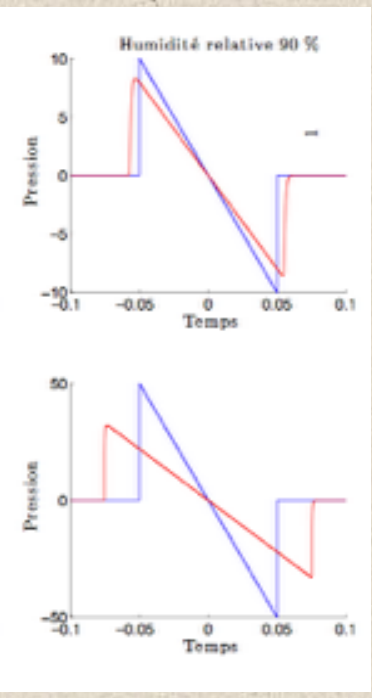
Influence on sonic boom

Low humidity



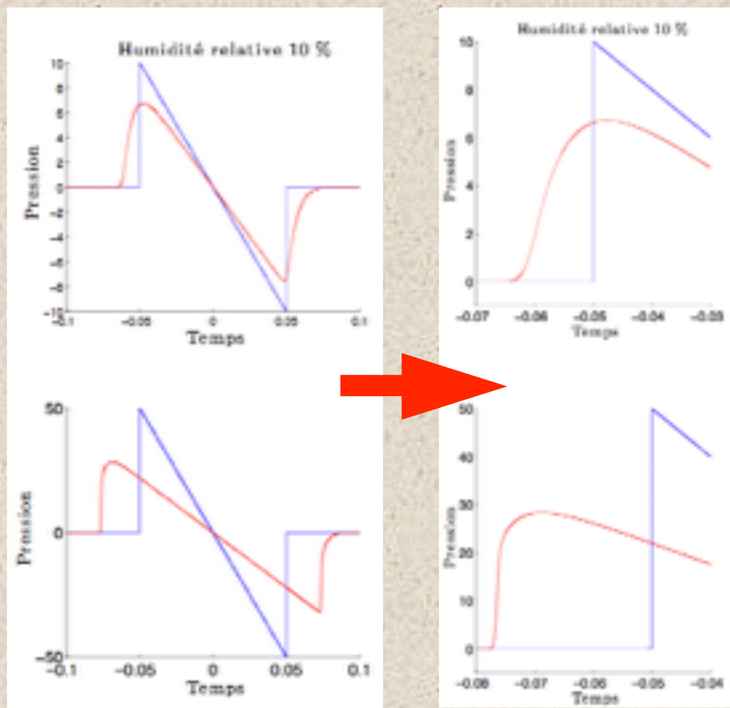


High humidity

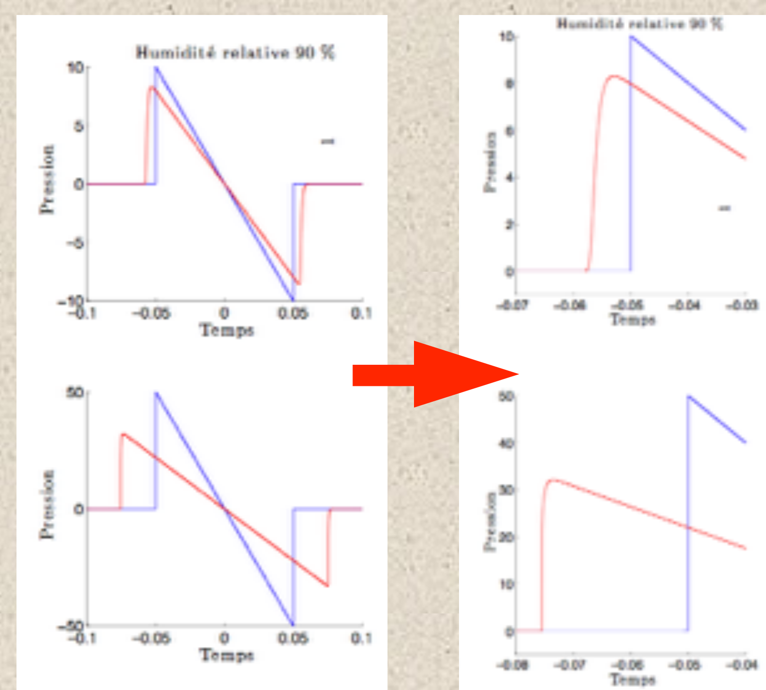


Influence on sonic boom

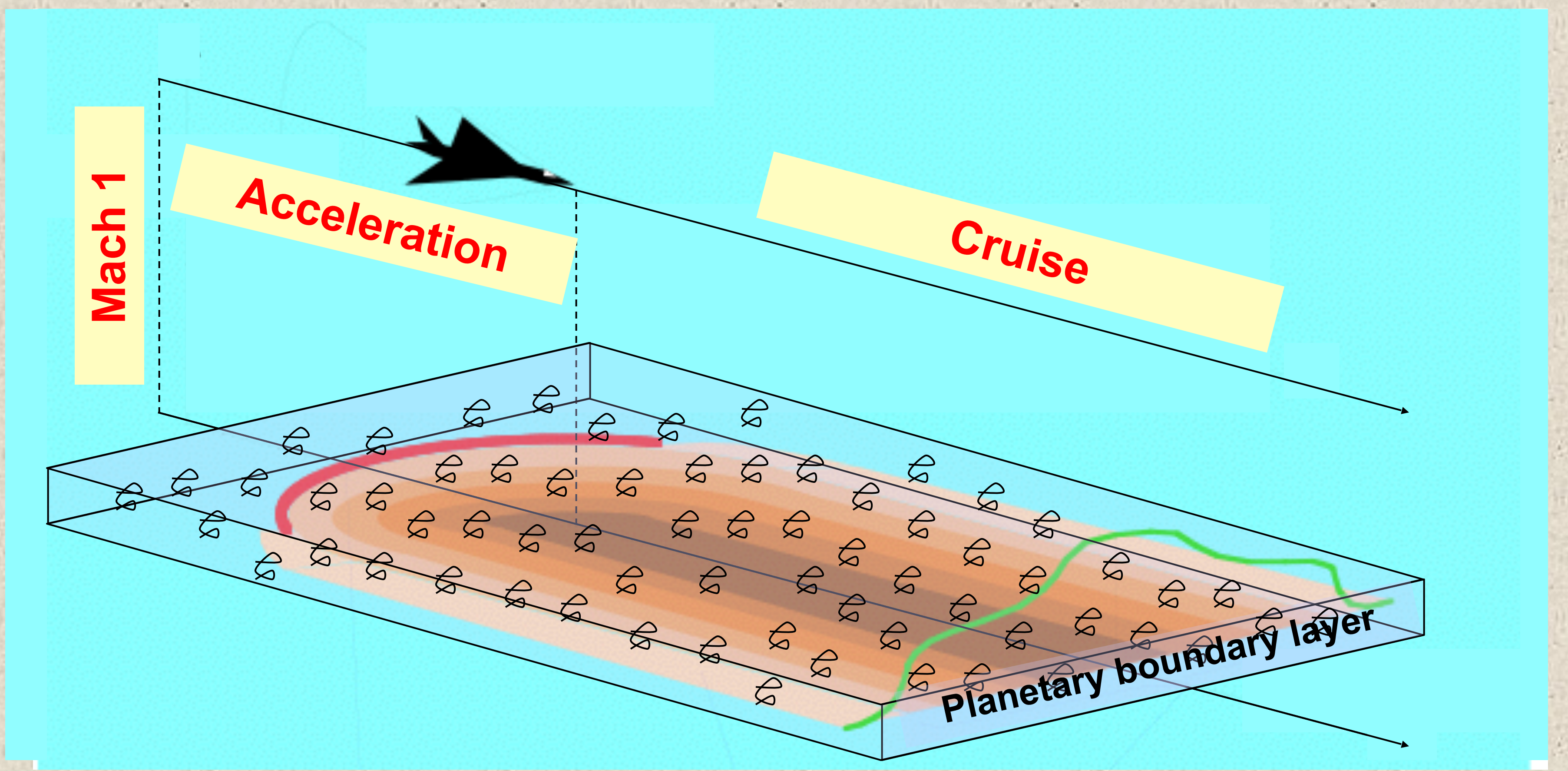
Low humidity



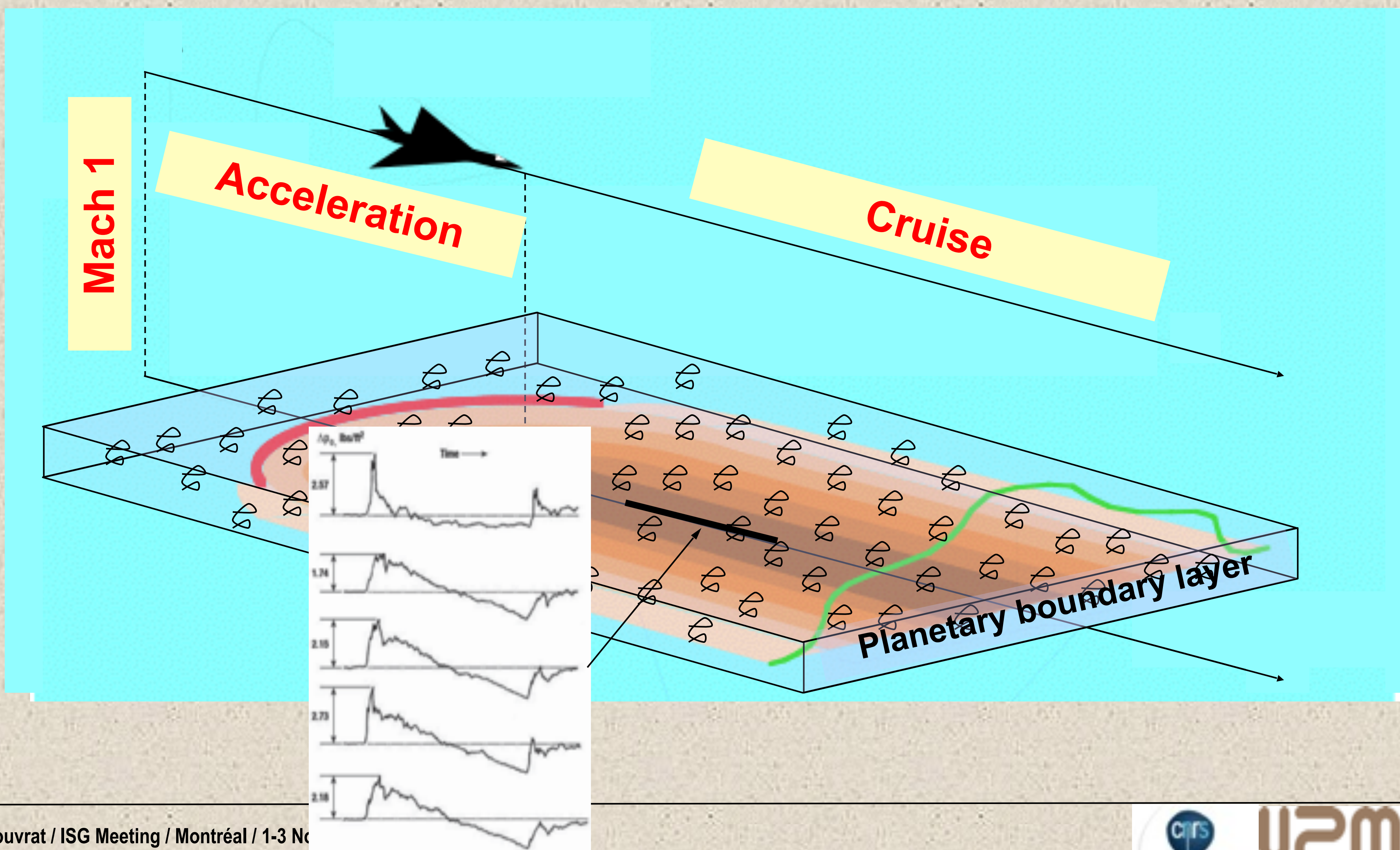
High humidity



Scrambling by turbulence

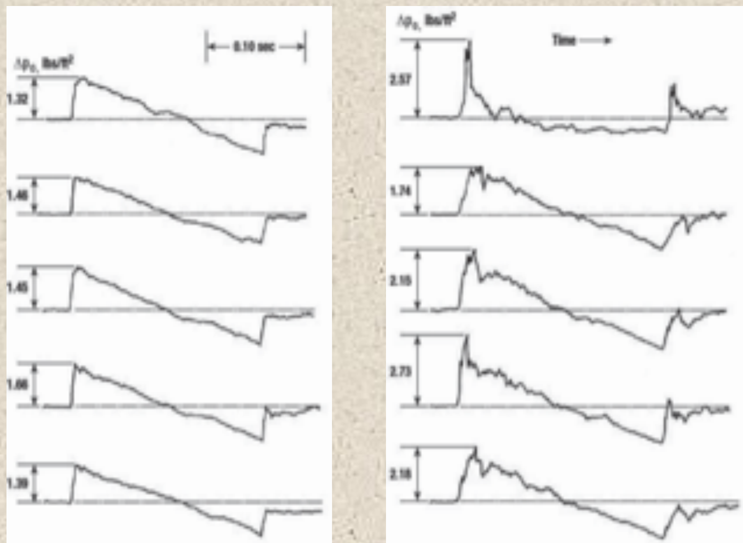


Scrambling by turbulence



Scrambling by turbulence

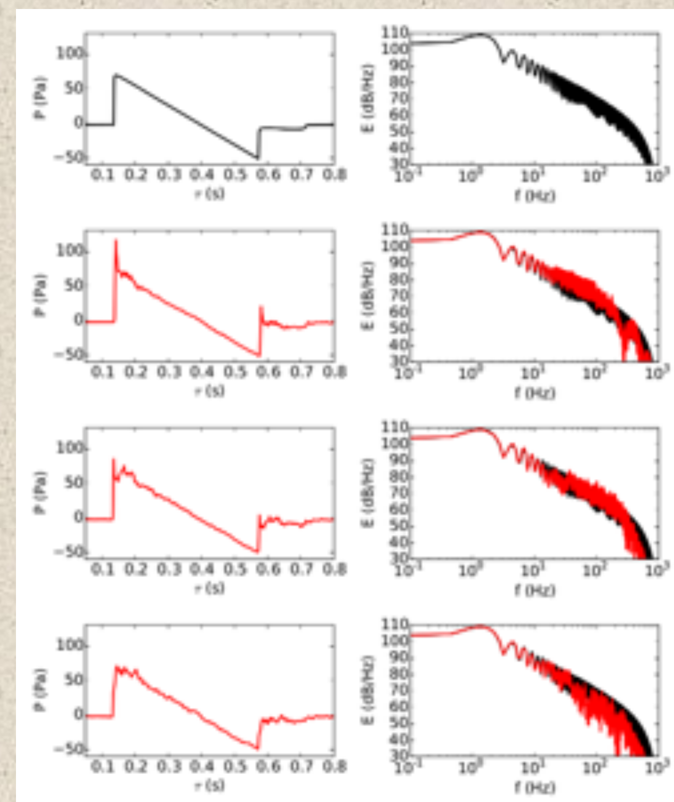
Flight tests
Turbulence
Low ← → High



Numerical simulation
(FLHOWARD3D)
Luquet et al., 2016

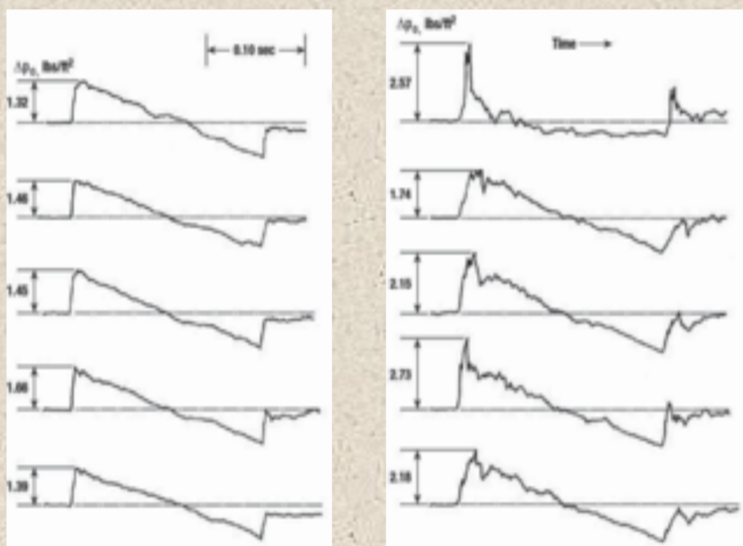
without

with turbulence



Scrambling by turbulence

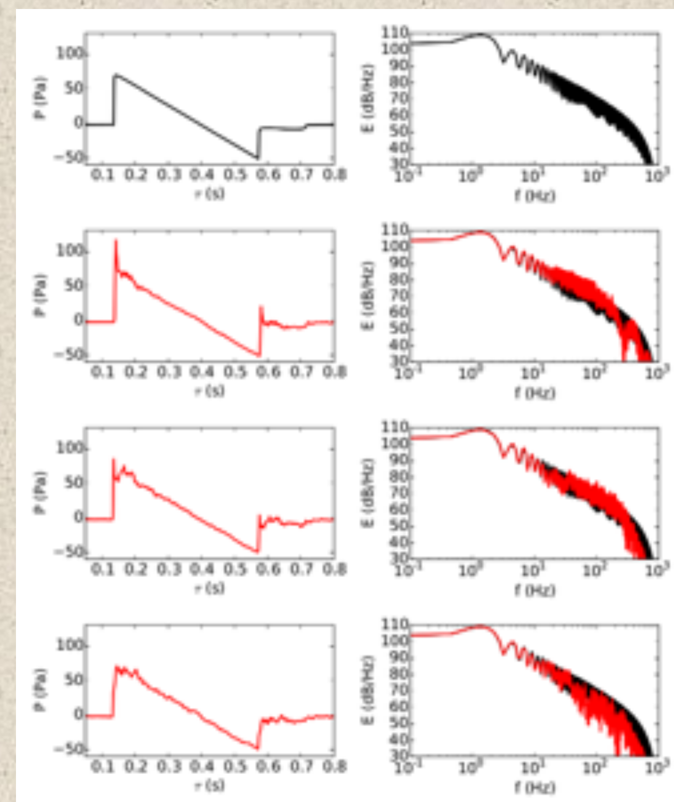
Flight tests
Turbulence
Low ⟵ ⟶ High



Numerical simulation
(FLHOWARD3D)
Luquet et al., 2016

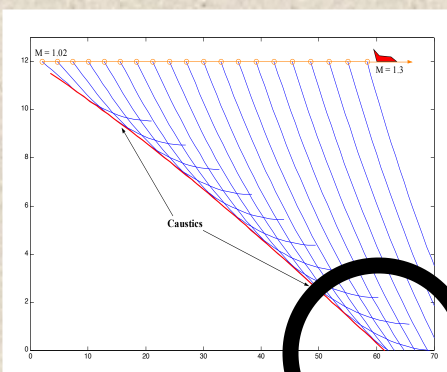
without

with turbulence



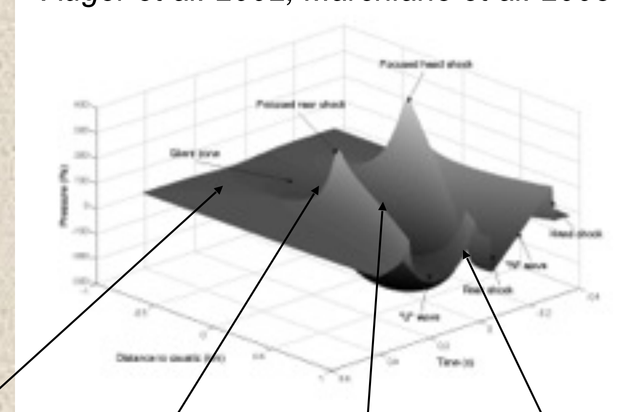
Focused boom

Low supersonic acceleration



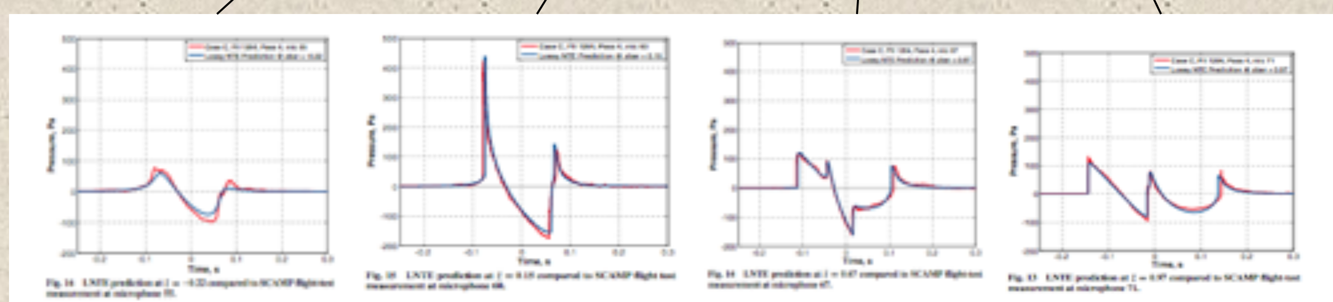
Simulation (NL Tricomi)

Auger et al. 2002, Marchiano et al. 2003



Simulation vs SCAMP tests

Salamone et al. 2003



Focused boom

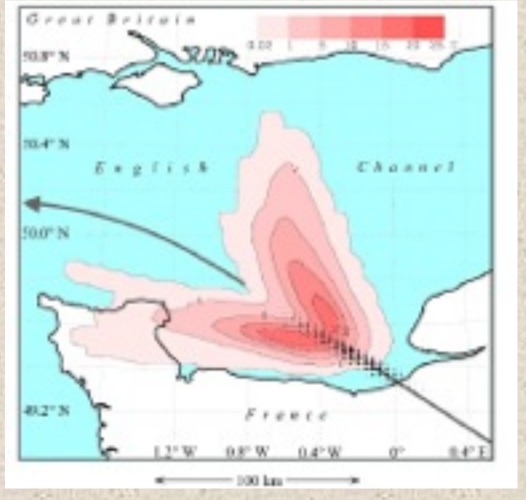
Low supersonic acceleration ⇒ focused, higher amplitude boom

Sensitivity to turbulence ?

Off design ⇒ robustness to low boom design ?

Relatively local ⇒ impacted population ?

Higher amplitude ⇒ higher annoyance ?



Blumrich et al. 2005

Focused boom

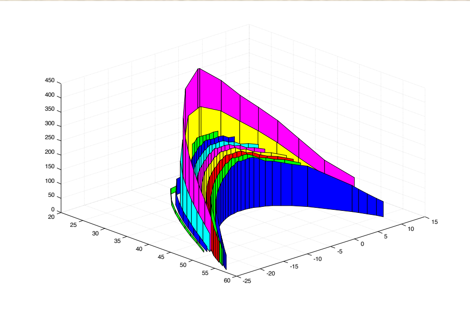
Low supersonic acceleration ⇒ focused, higher amplitude boom

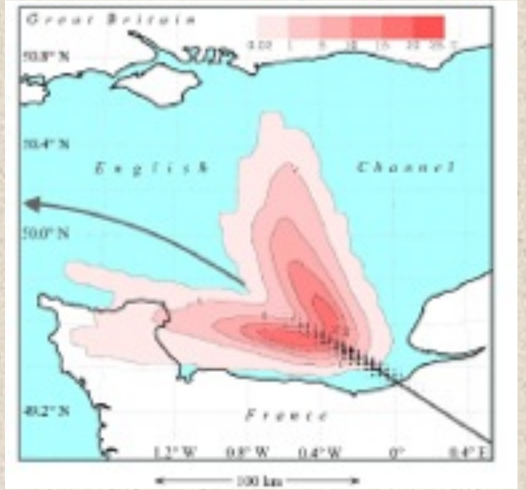
Sensitivity to turbulence ?

Off design ⇒ robustness to low boom design ?

Relatively local ⇒ impacted population ?

Higher amplitude ⇒ higher annoyance ?





Blumrich et al. 2005

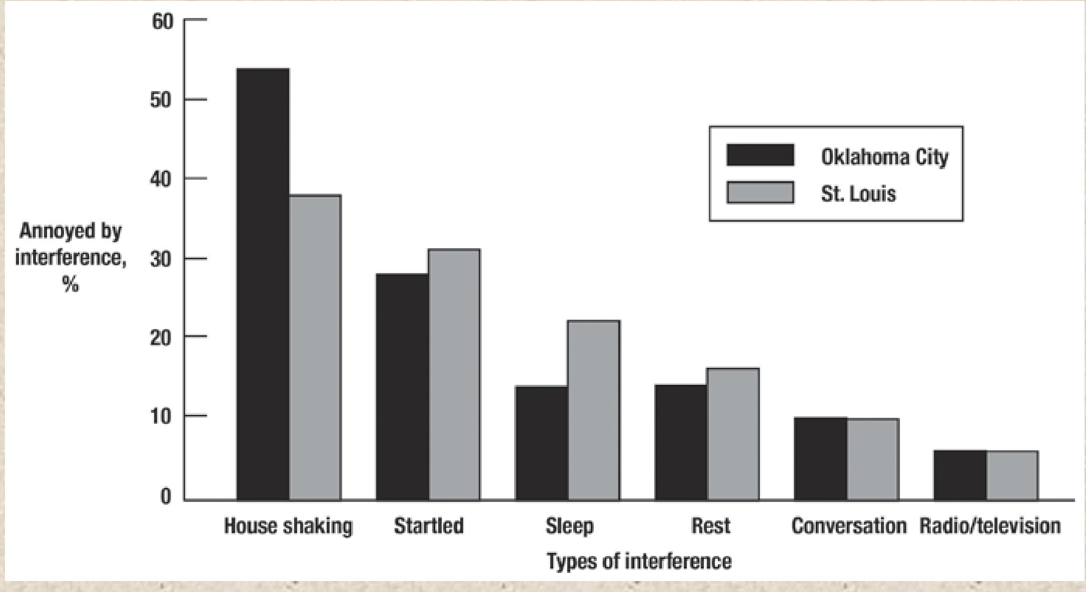
Some key questions on sonic boom

- *What is a sonic boom ?*
- *How does a sonic boom propagate in the atmosphere ?*
- *Who is annoyed by a sonic boom ?*
- *What influences a sonic boom ?*
- ***Why is sonic boom annoying ?***

Field studies

2 field studies

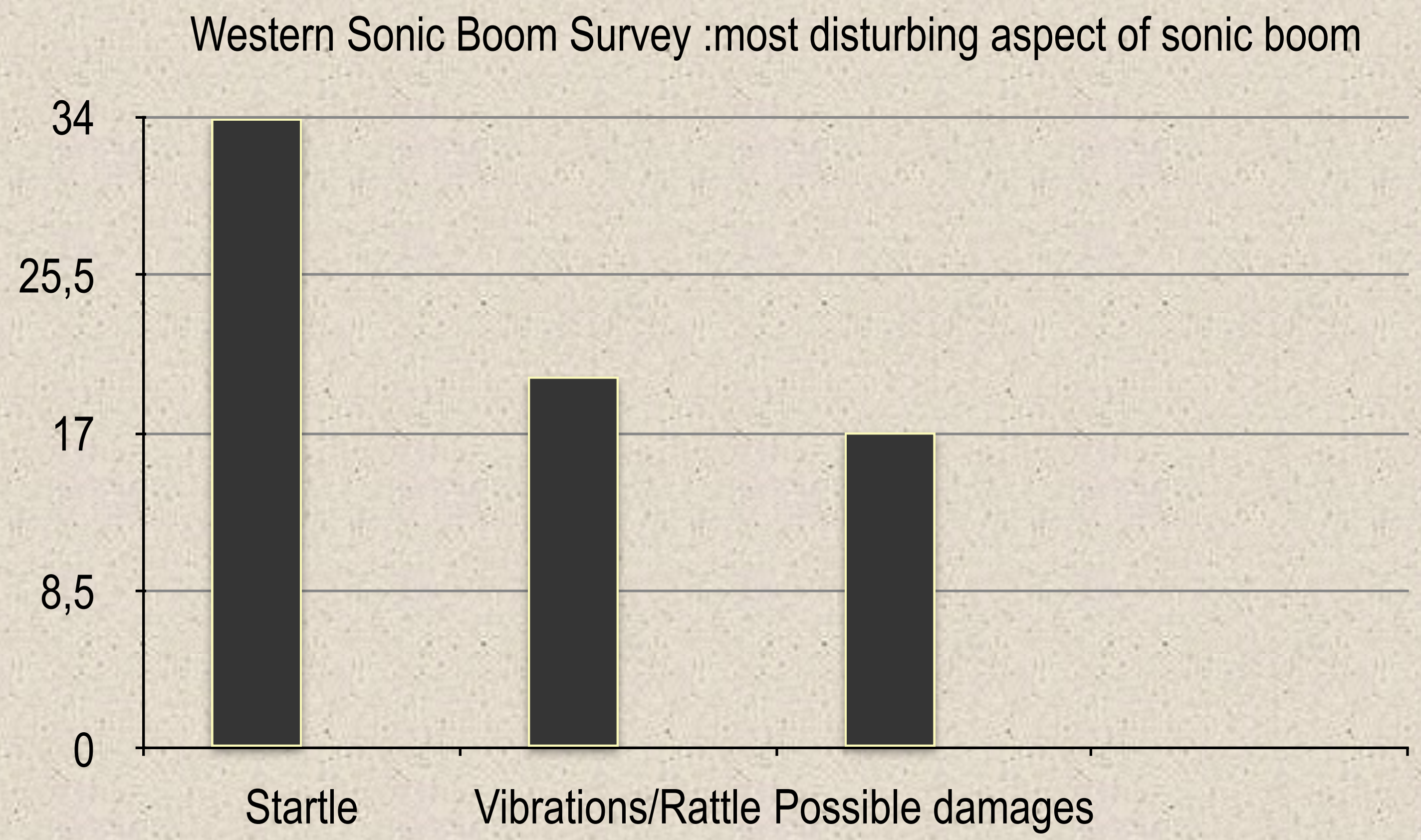
- St Louis (Minnesota) 1961-1962, 76 flights / 45 flights during 9 pm-4 am
- Oklahoma City 1964, 1225 flights, 0 during night



Brown and Sutherland NASA CR-189643, 1992

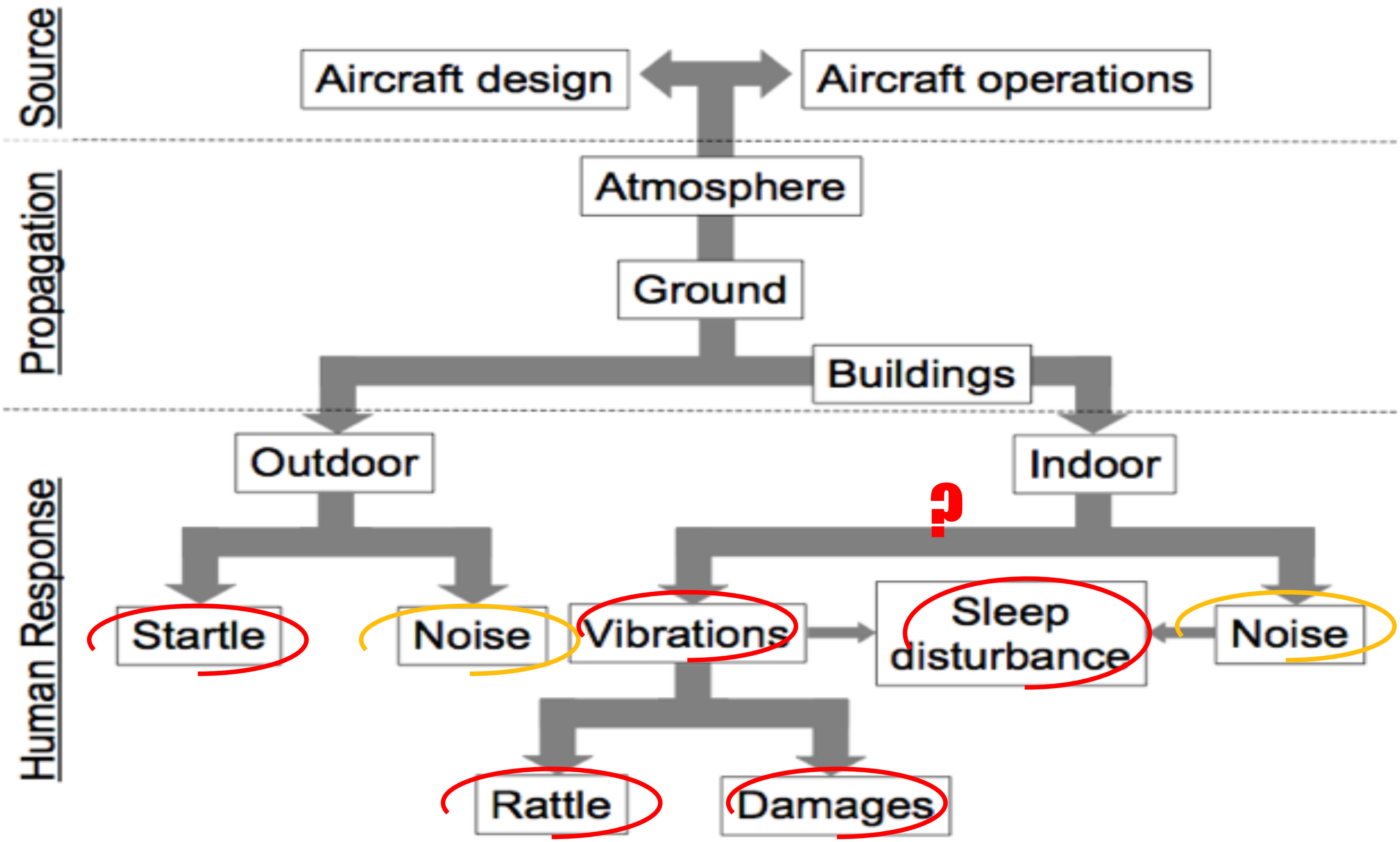
Western Sonic Boom Survey

- **1 Community Survey** : Western Sonic Boom Survey, Nevada & California, 1992-1995, 20 communities, 1595 booms, 1573 interviews - poor correlation with metrics except # booms / day



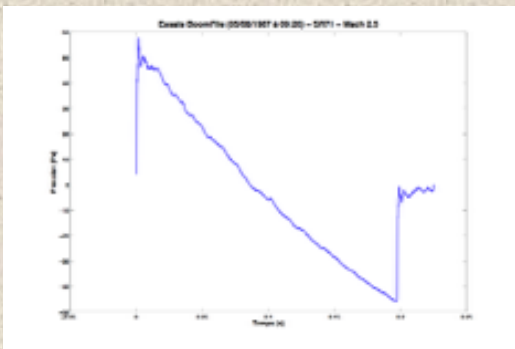
Brown and Sutherland NASA CR-189643, 1992

Why is a conventional sonic boom annoying ?



Expectations for a low sonic boom

Conventional boom



Startle

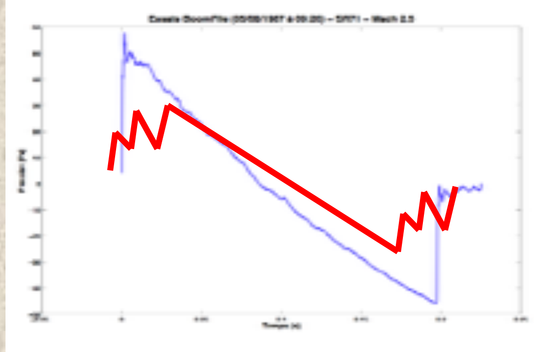
Vibrations & rattle

Potential damages

Direct noise

Sleep disturbances ?

Low boom



~~***Startle***~~

Vibrations & rattle

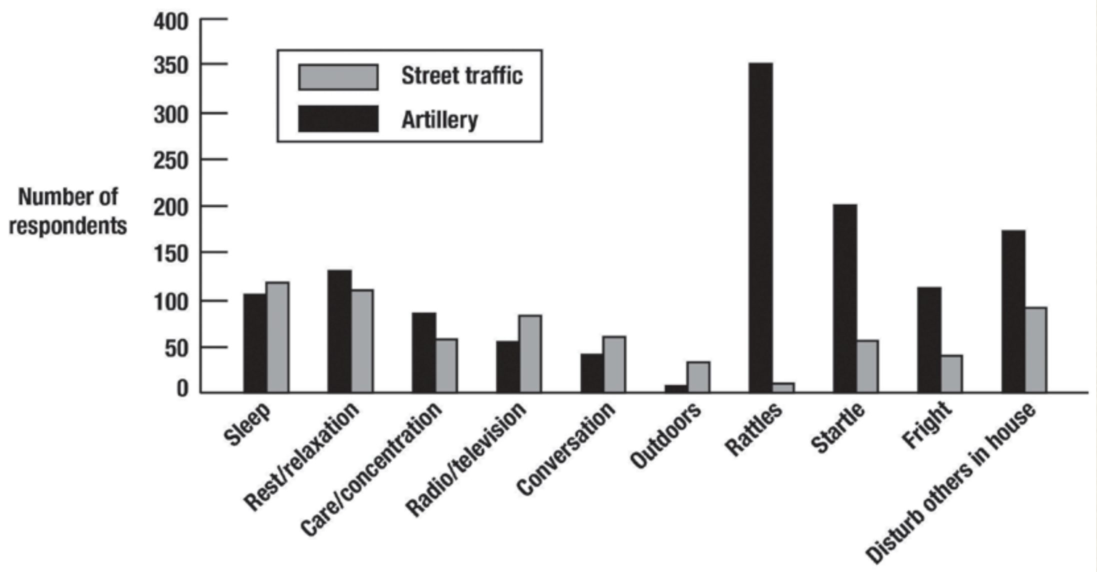
~~***Potential damages***~~

Direct noise

Sleep disturbances ?

Sonic boom vs artillery noise disturbances

Relatively similar response regarding artillery noise



Schomer, Noise Con. 2004

Night noise: WHO Europe 2000 recommendations

During night, World Health Organization (Guidelines for Community Noise 2000, Berglund et al.) recommends « for a good sleep indoor sound pressure level should not exceed approximately 45 dB Lamax more than 10-15 times per night, and most studies show an increase of awakenings at SEL values of 55-60 dBA » (pp.28)

And « …special attention should be given to the following considerations

- environment with a low background noise level
- environments where a combination of noise and vibrations are produced
- sources with low-frequency components. Disturbances may occur even though the sound pressure level during exposure is below 30 dBA » (pp.28)

Note that sonic boom may satisfy **all** these three conditions.

A special attention to sonic boom during night (22:00-07:00) should be given.

European Directive

European Directive 2002/49/EC relative to environmental noise protection

1) Selects noise indicator L_{night} (A-weighted long-term average sound level ISO 1996-2; 1987 over night period from 23:00 to 07:00) to assess sleep disturbances
2) Special noise indicators may be used in the following cases relevant to sonic booms
   - noise source under a small proportion of the night
   - average number of events is low
   - low frequency content of noise is strong
   - noise has an impulsive character
   - $L_{A,max}$ or SEL for night period protection in case of noise peaks

Some key questions (and answers) on sonic boom

What is a sonic boom ?

Sonic boom is the acoustical « trace » at the ground level of the aerodynamic flow past a supersonic body

How does a sonic boom propagate in the atmosphere ?

Sonic boom propagates nonlinearly along acoustical rays

Who is annoyed by a sonic boom ?

Millions of people will be exposed to the sonic boom of a single aircraft over one transcontinental flight, but the % of annoyed people is unknown

What influences a sonic boom ?

Sonic boom is influenced by the aircraft design, its flight parameters including transonic acceleration, and the local atmosphere below the aircraft including turbulence

Why is sonic boom annoying ?

For classical boom, mostly because of startle, house vibrations, and fear of potential damages. Sleep disturbances and people response to future low sonic booms are unknown

Prospects : key points for future research

Better knowledge is needed about :

- Various booms (lateral boom / focused boom / sensitivity to turbulence)

- Future supersonic trafic to quantify global exposure

- Boom transmission through structures

- Potential damages of low booms to structures (a likely source of unacceptability)

- Effets of low booms on sleep disturbances (a likely source of unacceptability)

- Noise metrics including rattle noise

- Community surveys ⇒ need for a demonstrator

Critical issues

- Extrapolation of scientific surveys to global population

- The X % of the population that are the most annoyed are those about whom the most information is needed

- A regulation process (ICAO / FAA…) should be accompanied by an information one

Past, present, future

Past
Concorde

« Present »
SSBD

Future
?