ЦАГИ GFIC

Are New Supersonic-Transport Configurations Insuring Engine Noise Reduction ?

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SUMMARY

- Takeoff silencing requires new configurations
- A fraction of the propulsion means could be retractable large-bypass-ratio engines similar to those used in subsonic aircraft
- Is the sideline noise of those same engines used in new supersonic configurations not greater than in usual subsonic aircraft ?

- Introduction
- New shape requirements resulting from noise regulations
- Diffraction of engine noise by fuselage under wings
- Results
- Conclusions and recommendations

INTRODUCTION

Many current projects of supersonic buiseness jets have similar characteristics :

- A moderate cruise Mach number (1.3 – 1.6)
- A limited weight (~ 30 tons)

Those modest numbers are expected to result in 2 main chances for success :

- They could be certified for flying supersonically over land since their sonic boom (moderate, according to low Mach and low weight) COULD be accepted.
- Engines with a relatively high bypass ratio (3 – 4) could comply with future noise regulations.

INTRODUCTION

Context entirely different for big transport aircraft ($\geq$ 300 tons) at high Mach number ($\geq$ 2) :

- A single type of engine cannot insure silent takeoff and economic cruise

- Cruise over land will have to be subsonic and that fraction of flight must be economic

SUMMARY OF TAKEOFF NOISE REQUIREMENTS

1 - Jet Velocity

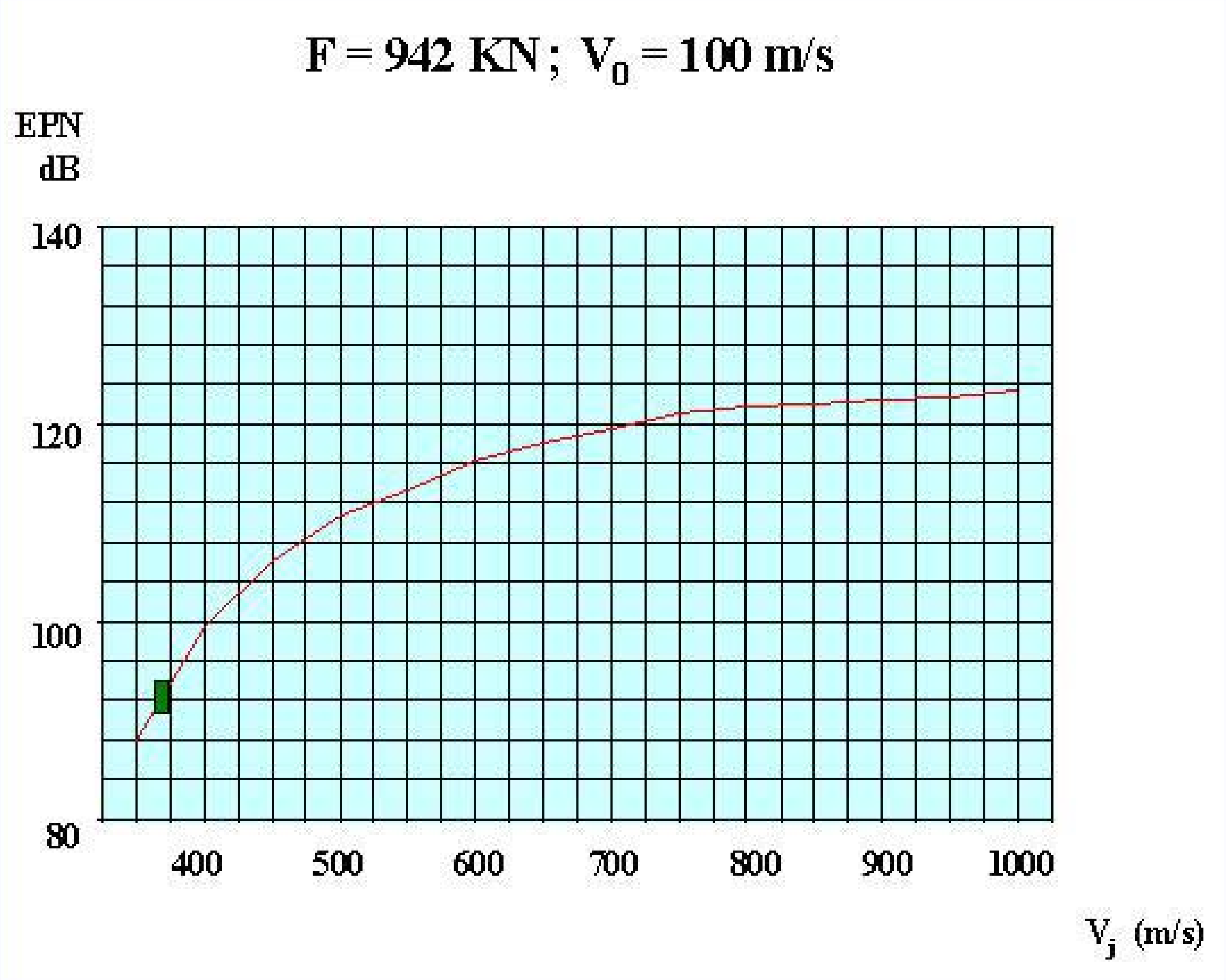
ICAO Stage 3 noise regulation for 320 t (subsonic) aircraft is 102 EPN dB (sideline)

Aim at 6 dB less for future regulation

Provide a margin of another 3 dB for fan and airframe noise

Thus have a jet sideline noise less than 93 EPN dB which results in a jet velocity limit $V_j \leq 370$ m/s

Effect of jet velocity on sideline noise of 320 t. aircraft



SUMMARY OF TAKEOFF NOISE REQUIREMENTS

2 - Air Intake Cross Section

A 942 KN takeoff thrust at 370 m/s jet velocity and 100 m/s aircraft speed needs a 3 489 Kg/s mass flow rate corresponding to **18.4 m^2**

At end of supersonic climb, a 320 KN thrust at a 320 m/s specific thrust needs a 1 000 Kg/s mass flow rate, that is 1510 Kg/s at ground conditions corresponding to **8 m^2**

Such a difference in required cross sections cannot be obtained with a single type of engine (neither ejector nor mid tandem fan)

SUMMARY OF TAKEOFF NOISE REQUIREMENTS

3 - Propulsion Means (Minimum weight)

- **2 Fixed turbofans : Optimal design for end of climb and supersonic cruise . Bypass ratio ~ 1.25 (no ejectors)**
  Used at a lower power setting (370 m/s jet velocity) for takeoff
  ~ 2.4 m in diameter

- **2 Retractable turbofans : Boost thrust at takeoff (534 KN)**
  Similar to subsonic aircraft engines
  ~ 2.8 m in diameter

FUEL CONSUMPTION REQUIREMENTS

Fortunately, the choice of propulsion means resulting from the noise requirements provides the aircraft with an economic solution for subsonic cruise as required

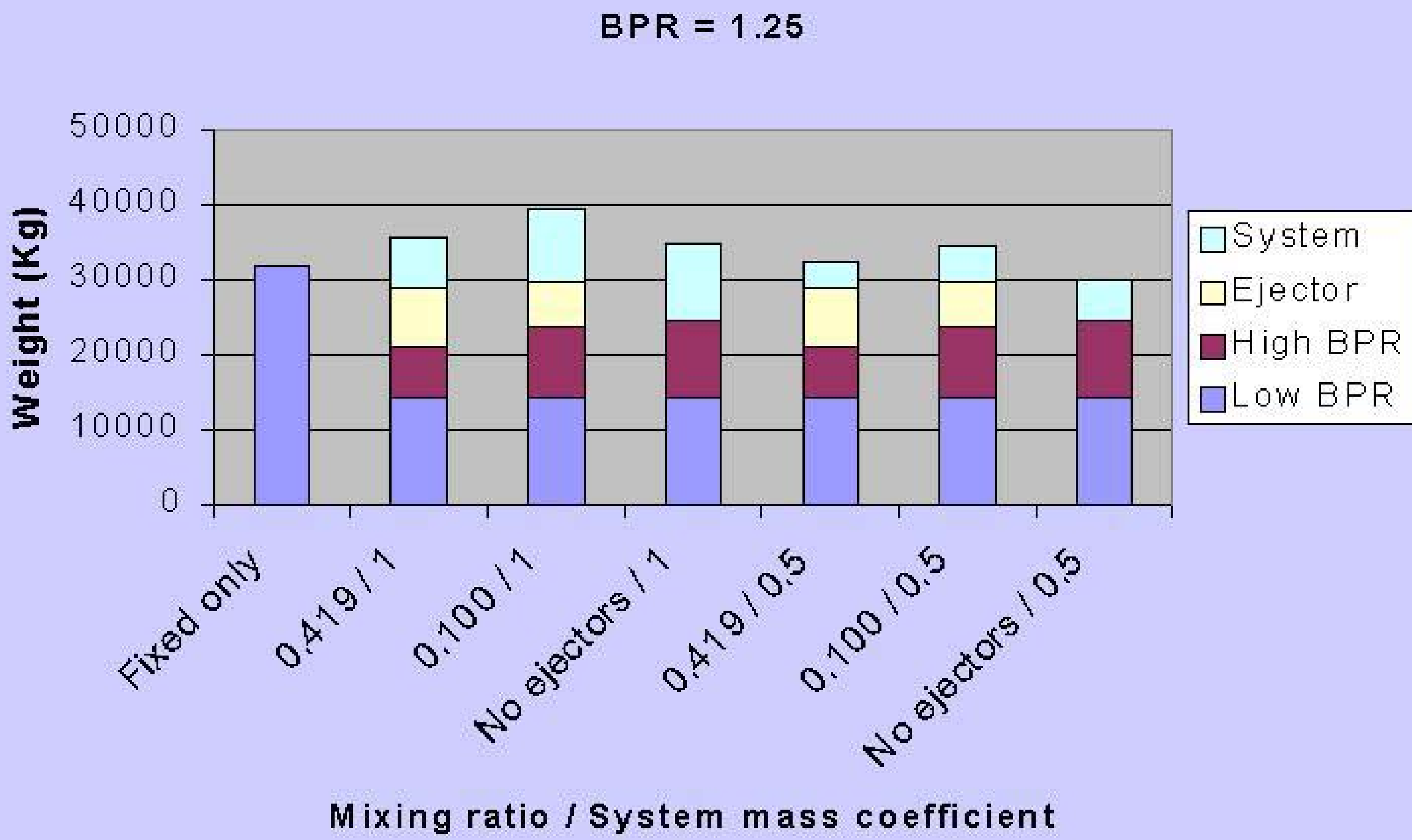
WEIGHT REQUIREMENTS

According to previous investigations, the system insuring motion and storage of the retractable engines must have a weight lower than ½ of that of those engines

Rails for engine motion (short horizontal translation) must be existing wing beams

Engine storage volume must not increase structure weight

PROPULSION SYSTEM WEIGHT ($\sigma = 3.5$ s)



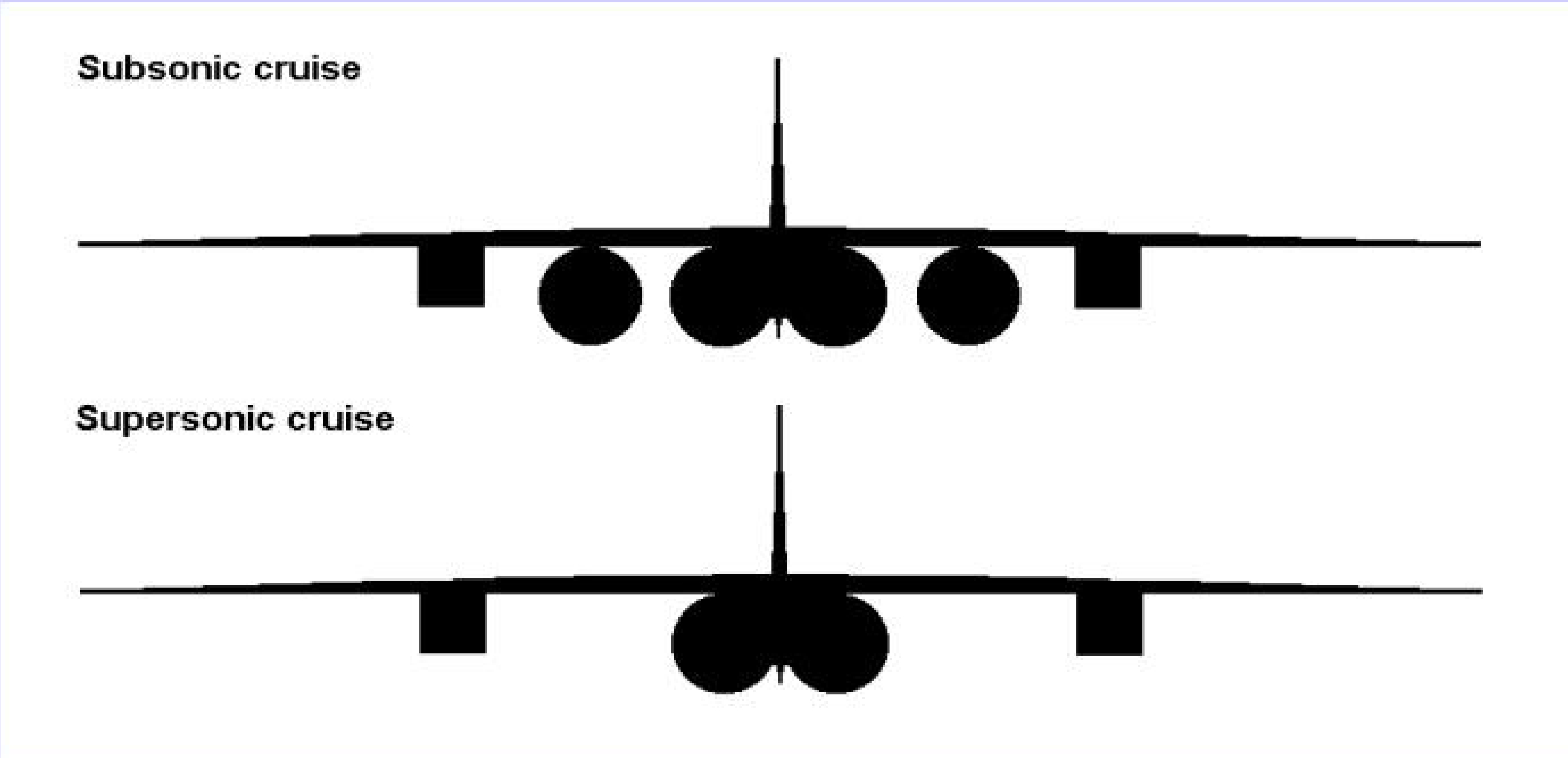
CONSEQUENCES OF ALL PREVIOUS REQUIREMENTS

A unique solution for aircraft configuration :

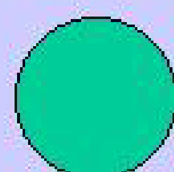
- Retractable engines AND fuselage under wings
- Double cylinder fuselage

320 METRIC TONS SUPERSONIC AIRCRAFT

Front view

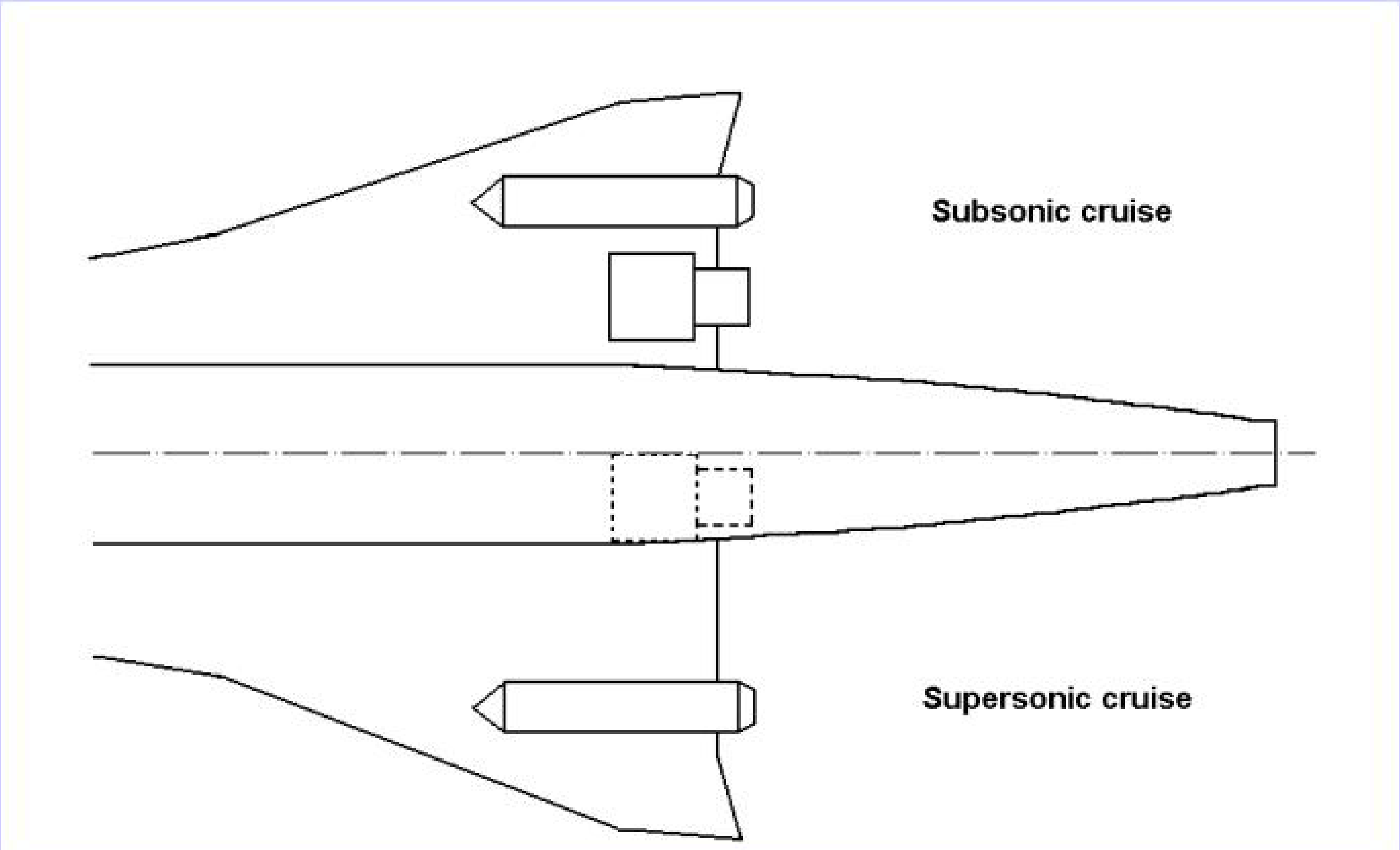


Same cross section
for a unique cylinder



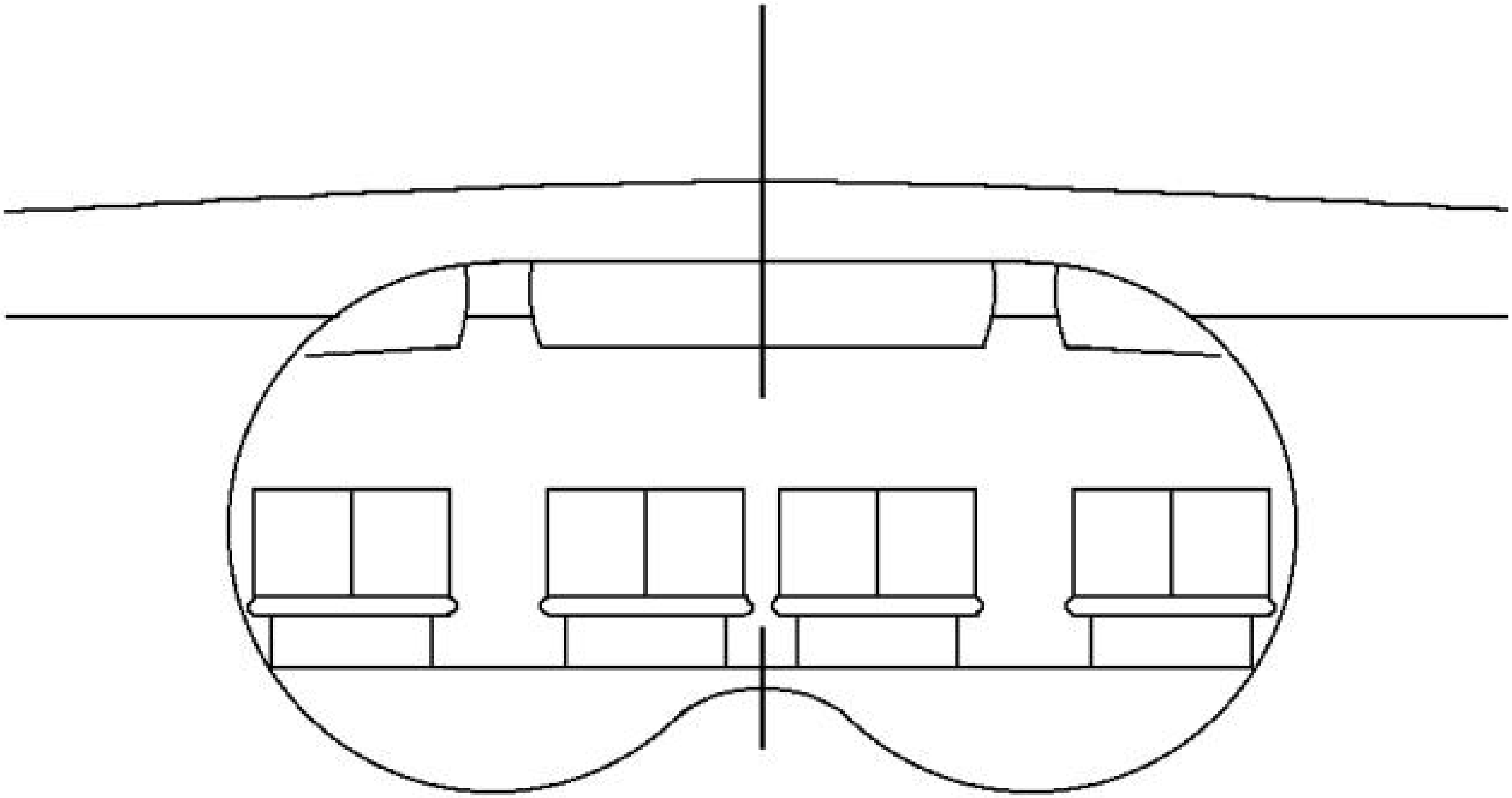
320 METRIC TONS SUPERSONIC AIRCRAFT

Underside view



320 METRIC TONS SUPERSONIC AIRCRAFT

Cabin section



320 METRIC TONS SUPERSONIC AIRCRAFT

Advantages of a flattened fuselage

Approximative cabin length for 250 passengers with 1.5 m rows:

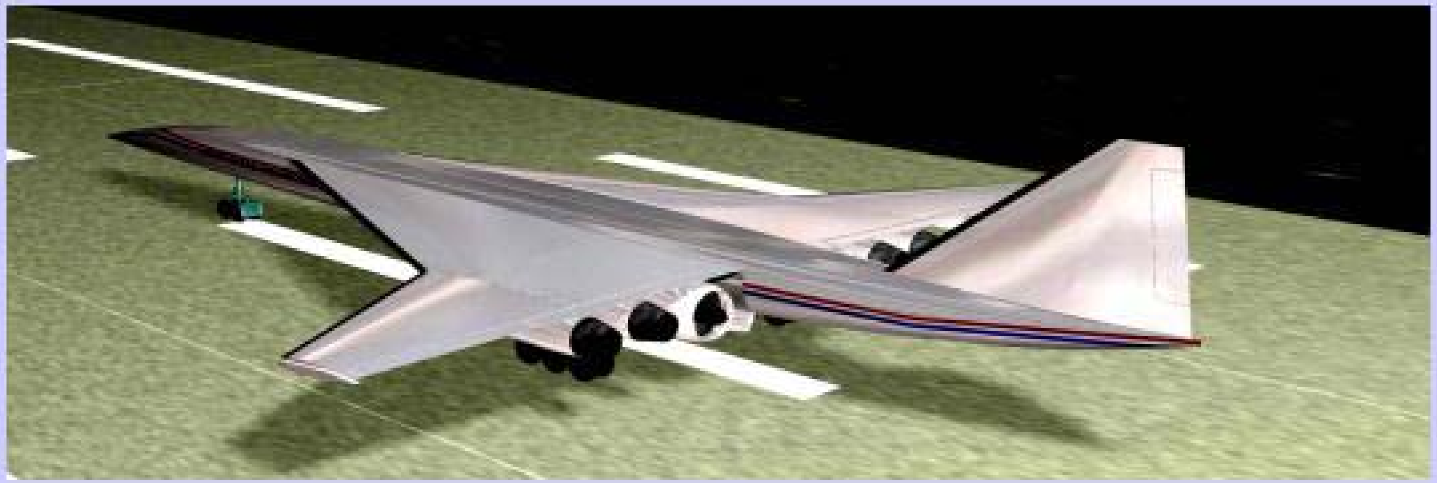
- rows of 6 (circular fuselage)	62 m
- rows of 8 (flattened fuselage with same cross-section)	47 m

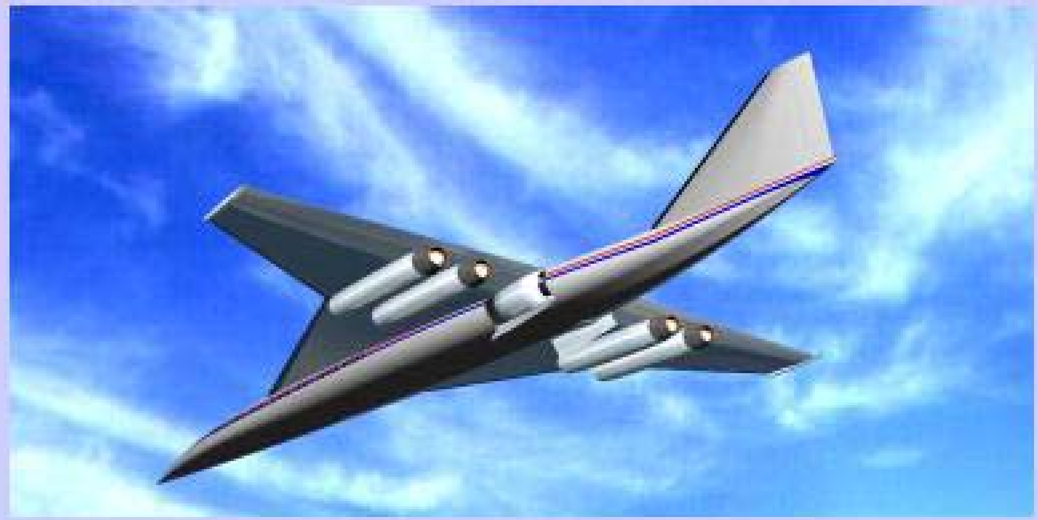
With the same aircraft length, 15 m are thus available for :

- Engine hold	6 m
- Baggage hold	9 m

A flattened fuselage provides :

- Much better fittings possibilities
- Twin aisle comfort
- Large volumes for hand baggages
- An augmented stiffness in horizontal plan

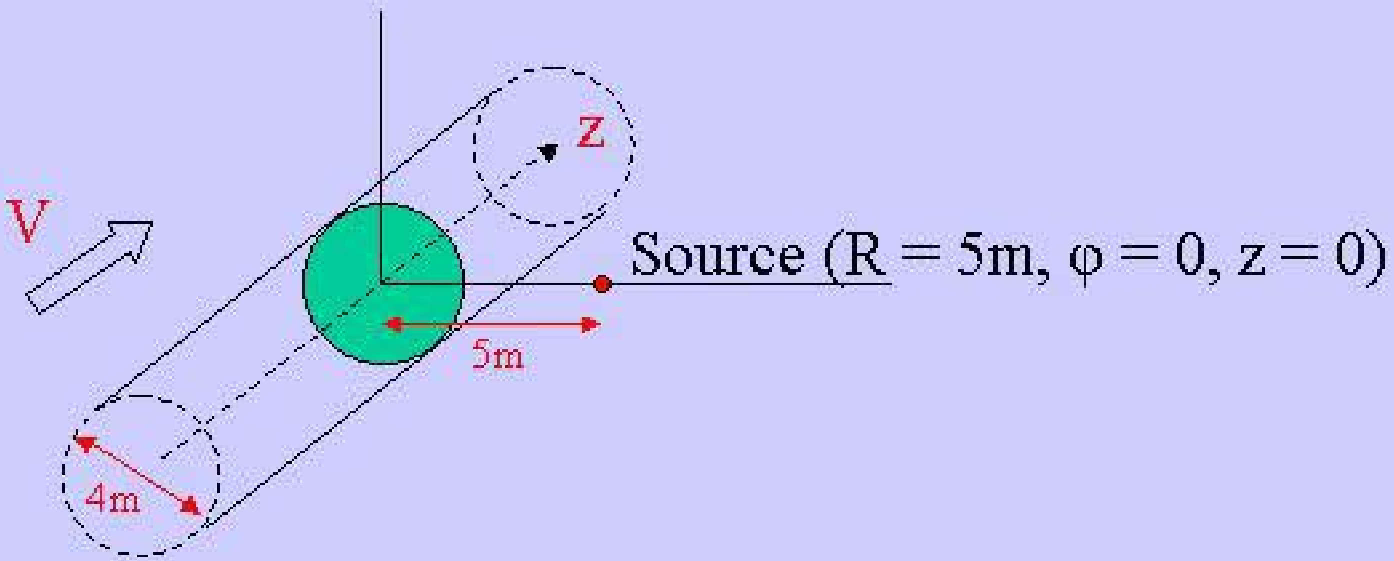


QUESTION

- The beauty of the retractable engines is that they are available from the shelf of commercial subsonic aircraft and should insure an identical noise level for supersonic and subsonic aircraft
- But does the fuselage under the wings (instead of above) change the sideline noise level ?

MODEL



Fuselage ($-\infty < z < \infty$, a = 2 m, hard)

Neither ground nor wings effect taken into account

APPROACH

Wave Equation: point source localized near the cylinder (D=4m, R=5m)

$$\nabla^2 P - \frac{1}{a^2}\left(\frac{\partial}{\partial t} + V_0 \frac{\partial}{\partial z}\right)^2 P = \frac{1}{R}\,\delta\left(\rho - R\right)\delta\left(\varphi\right)\delta\left(z\right)e^{-i\omega t}$$

$$P\left(r,\varphi,z\right) = \frac{1}{4\pi^2}\sum_{m=-\infty}^{\infty} e^{im\varphi}\int_{-\infty}^{\infty} P_m\left(\alpha,r\right)e^{i\alpha z}\,d\alpha + G$$

$$P_m\left(\alpha,r\right) = \frac{i\pi}{2}\,\frac{J_m'\left(i\beta r_0\right)H_m\left(i\beta R\right)}{H_m^{(1)'}\left(i\beta r_0\right)}\,H_m^{(1)}\left(i\beta r\right)$$

$$G = \frac{e^{ik\left[\frac{M}{1-M^2}\left(z'-z\right)-\frac{R'}{1-M^2}\right]}}{4\pi R'}$$

$$R' = \sqrt{\left(z'-z\right)^2 + \left(1-M^2\right)\left(y'-y\right)^2 + \left(1-M^2\right)\left(x'-x\right)^2}$$

METHODS

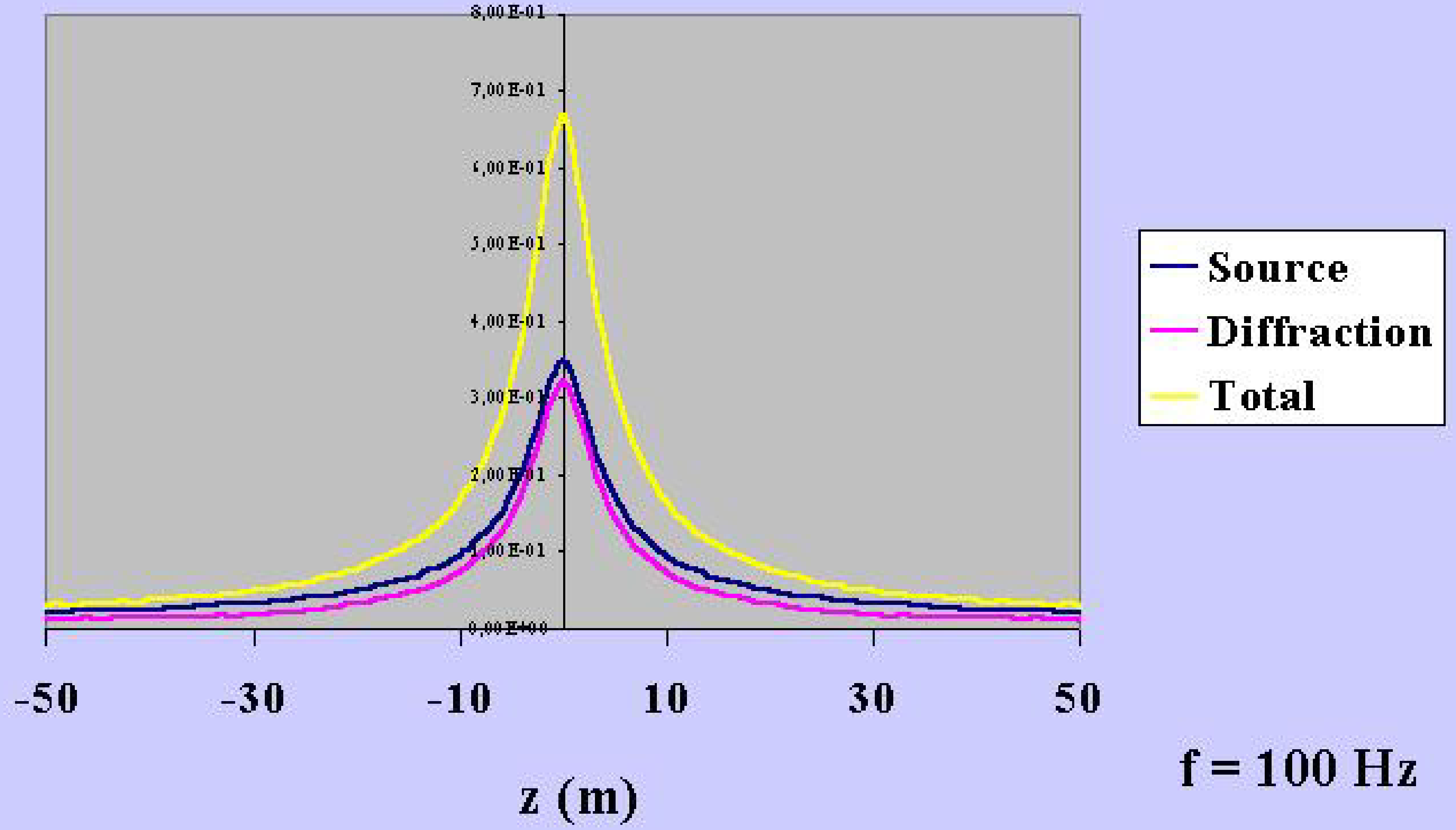
- Exact solution (Bessel function series)
- Boundary Element Method

V.F. Kopiev, A.A. Maslov and S.A. Chernyshev, "Prop-fan sound field shielding by the fuselage boundary layer", DGLR/AIAA Paper N° 92-02-068, 1992

P. Malbequi, S.M. Candel and E. Rignot, " Boundary integral calculations of scattered fields : Application to a spacecraft launcher", J. Acoust. Soc. Am. 82 (5), p. 1771 – 1781, November 1987

RESULTS

Acoustic loading on the surface, $\varphi = 0$

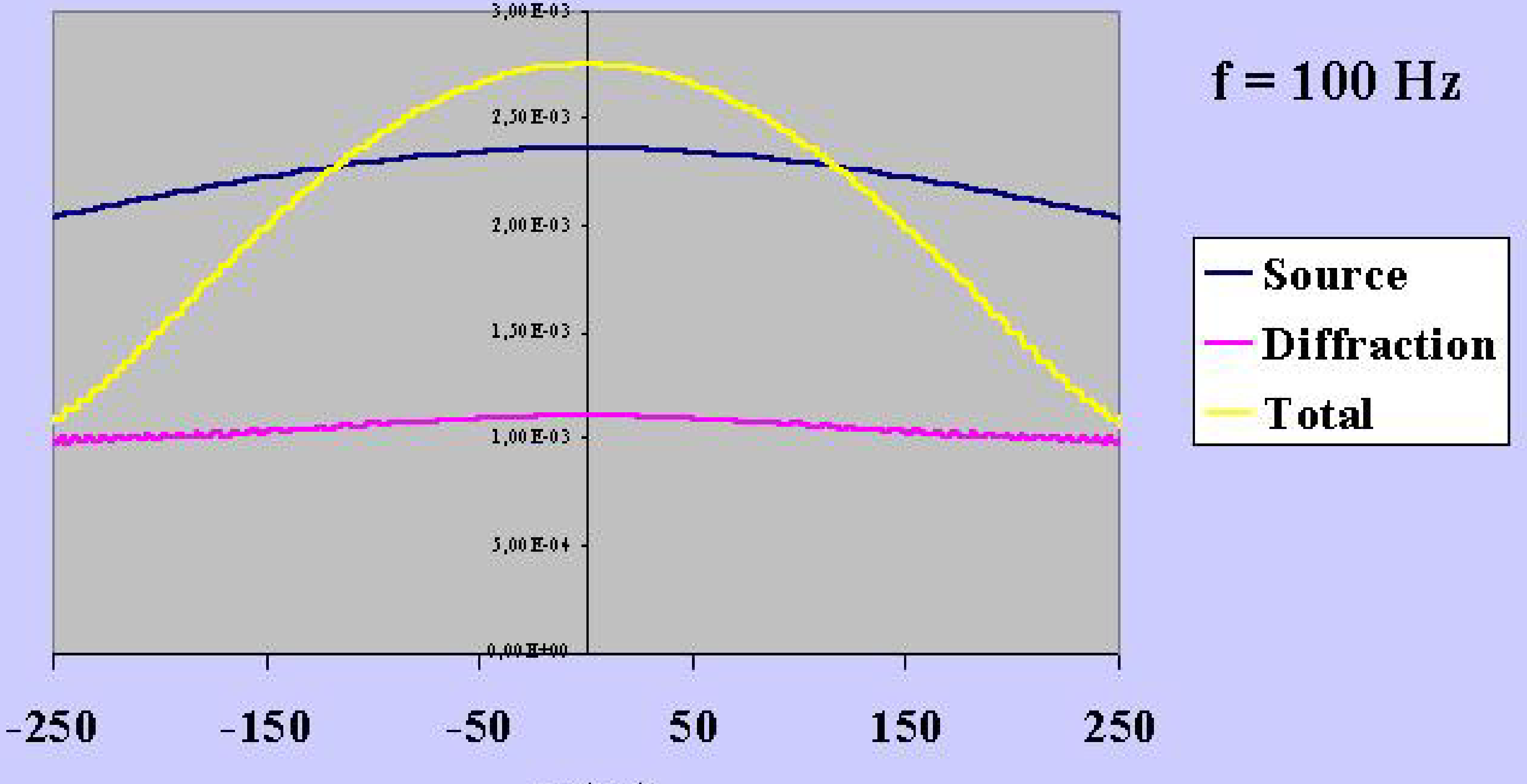


f = 100 Hz

RESULTS

Pressure amplitude at r = 450 m, φ = 0

Amplitude is symmetrical at z=0



f = 100 Hz

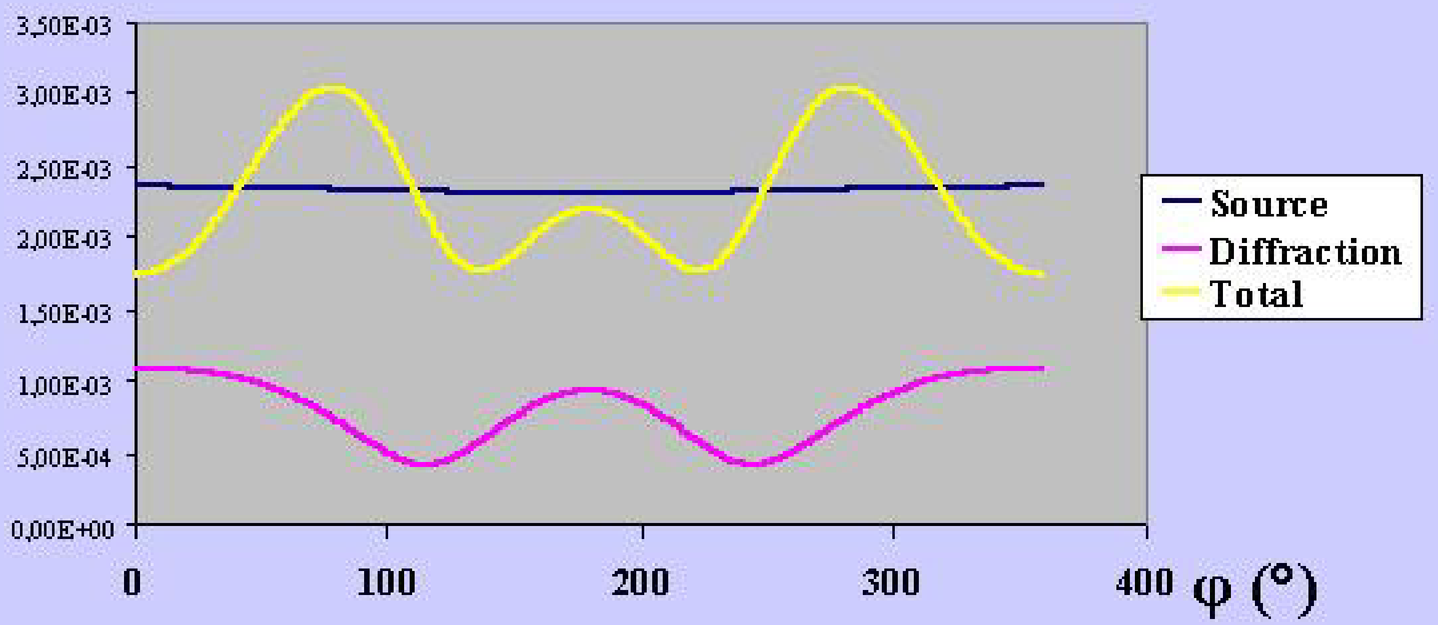
ka = 3.81

RESULTS

-<u>At lower frequencies</u> :

- Practically there is never (ka < < 1)
- The fuselage is never "transparent"
- There is always some reflection or masking effect

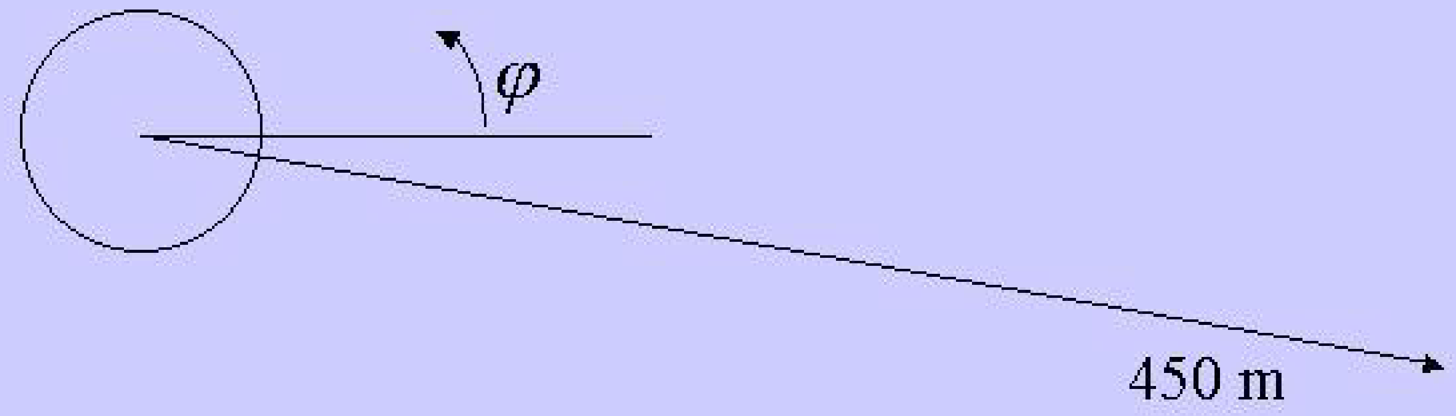
$p(\varphi)$, z = 0 m, f = 25 Hz



ka = 0.95

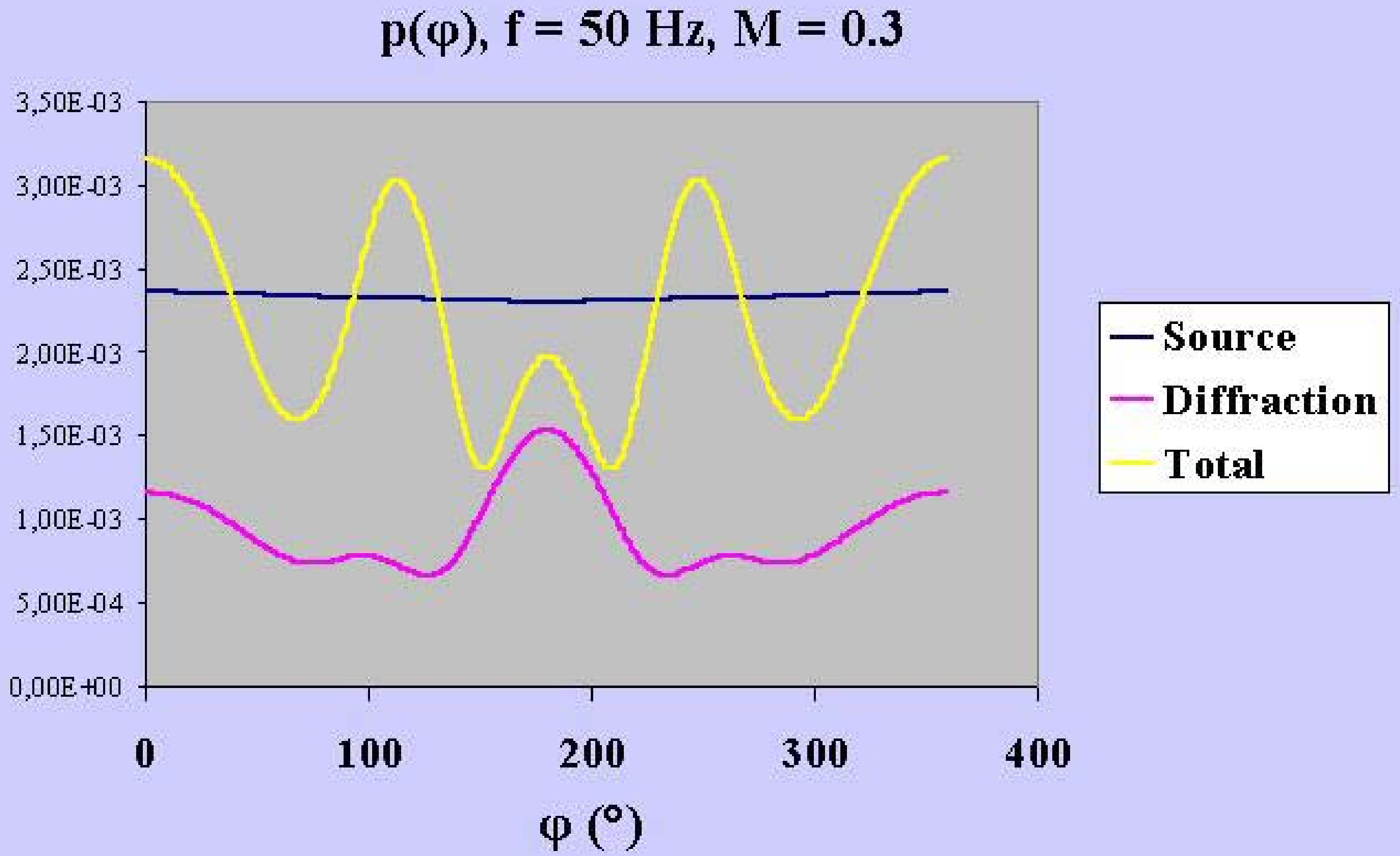
RESULTS

- **At moderate frequencies (ka = 1 – 10) :**



Cross-section z = 0, characterized by a maximum of $p(z)$ at $\varphi = 0$

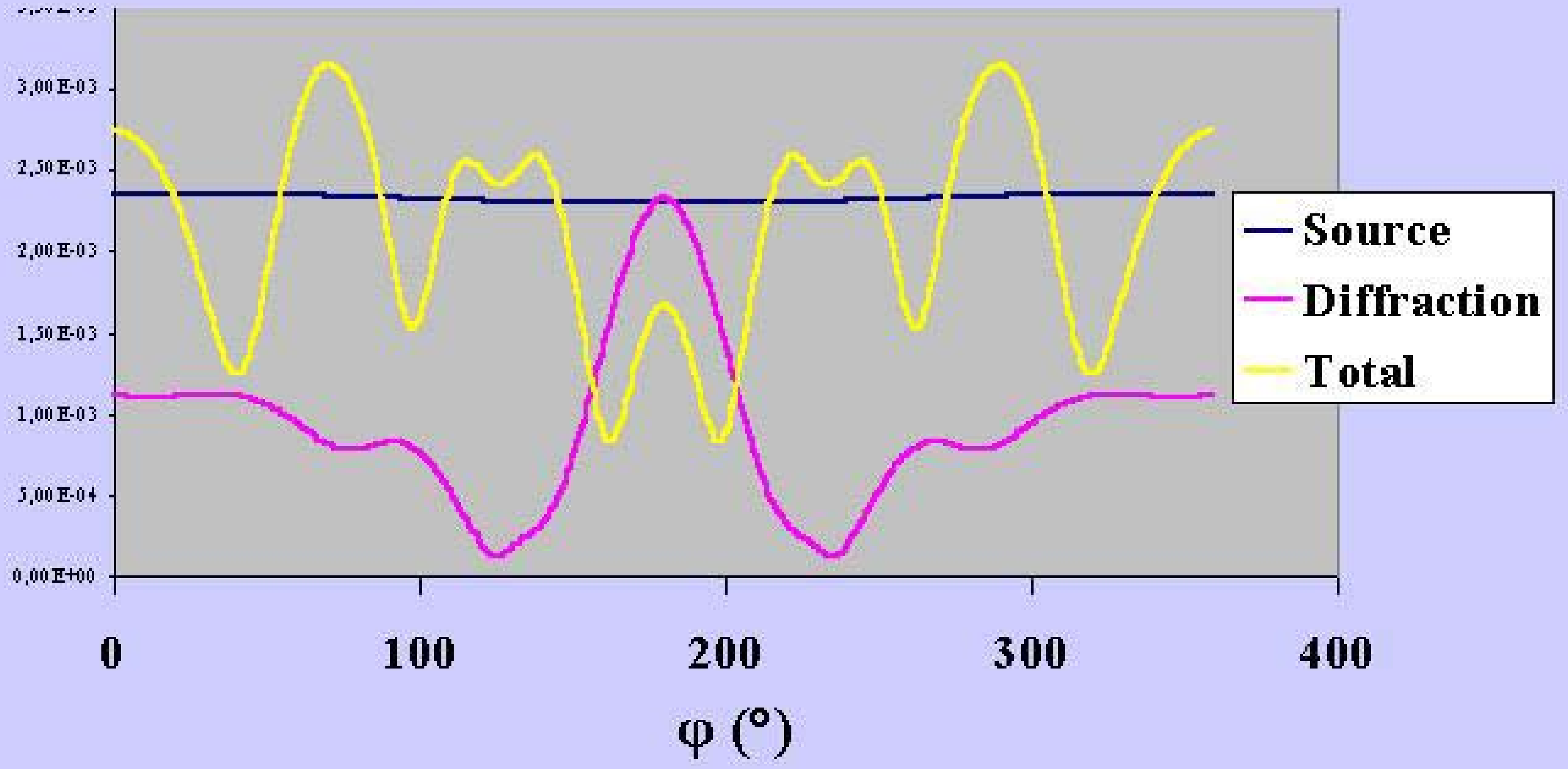
The source function is a δ



V = 100 m/s

ka = 1.90

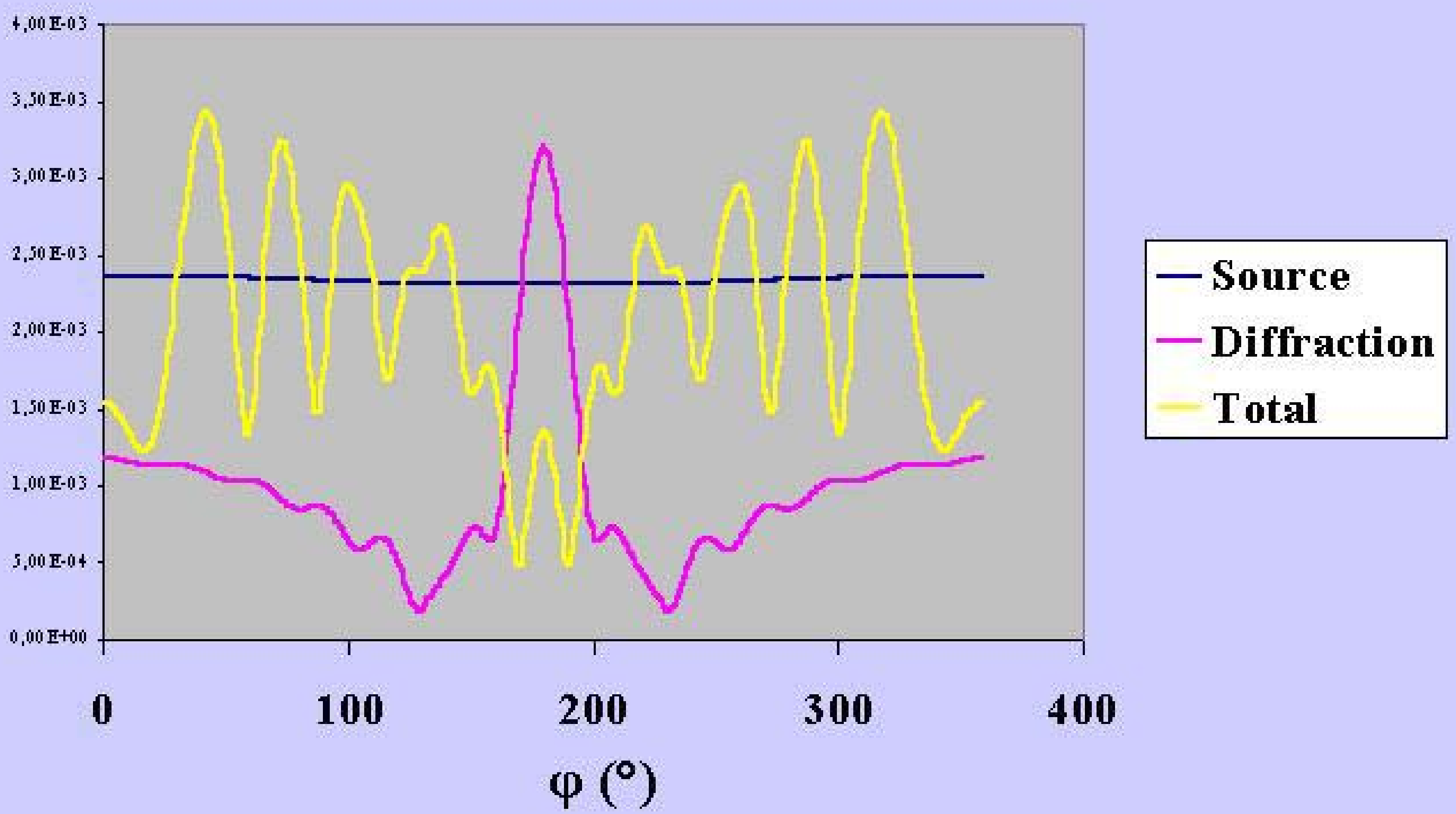
p(φ), f = 100 Hz, M = 0.3



V = 100 m/s

ka = 3.81

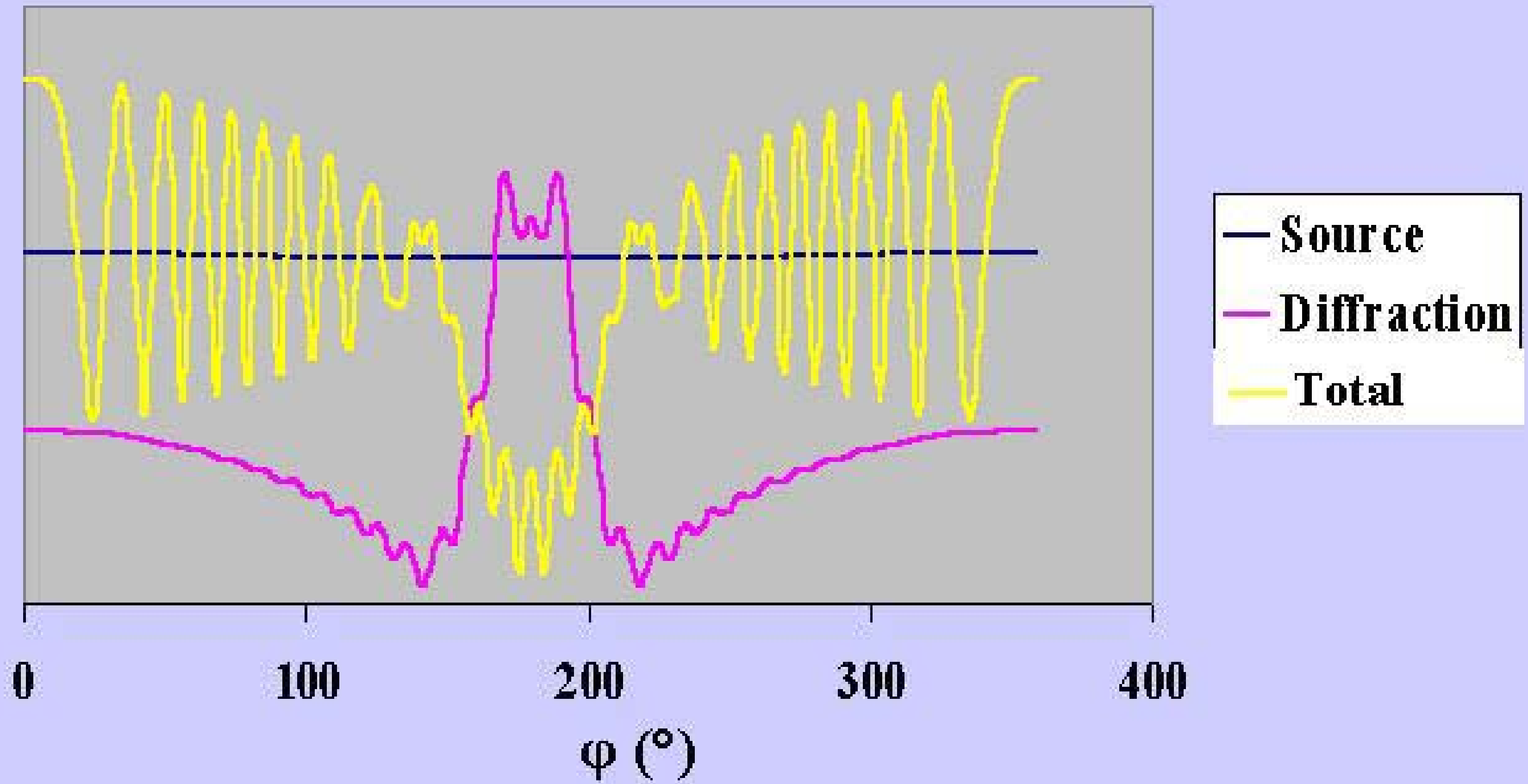
p(φ), f = 200 Hz, M = 0.3



V = 100 m/s

ka = 7.62

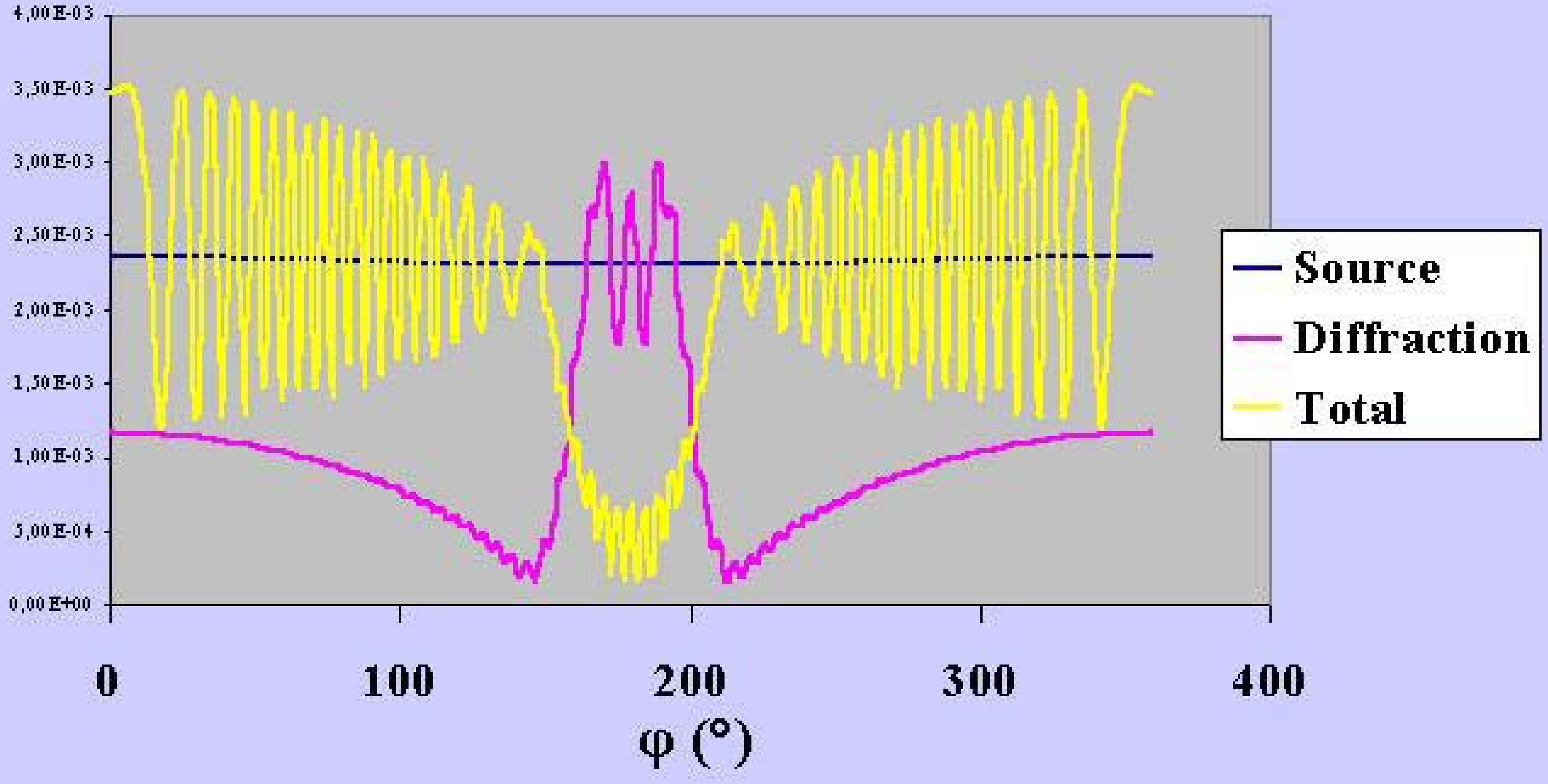
p(φ), f = 500 Hz, M = 0.3



V = 100 m/s

ka = 19

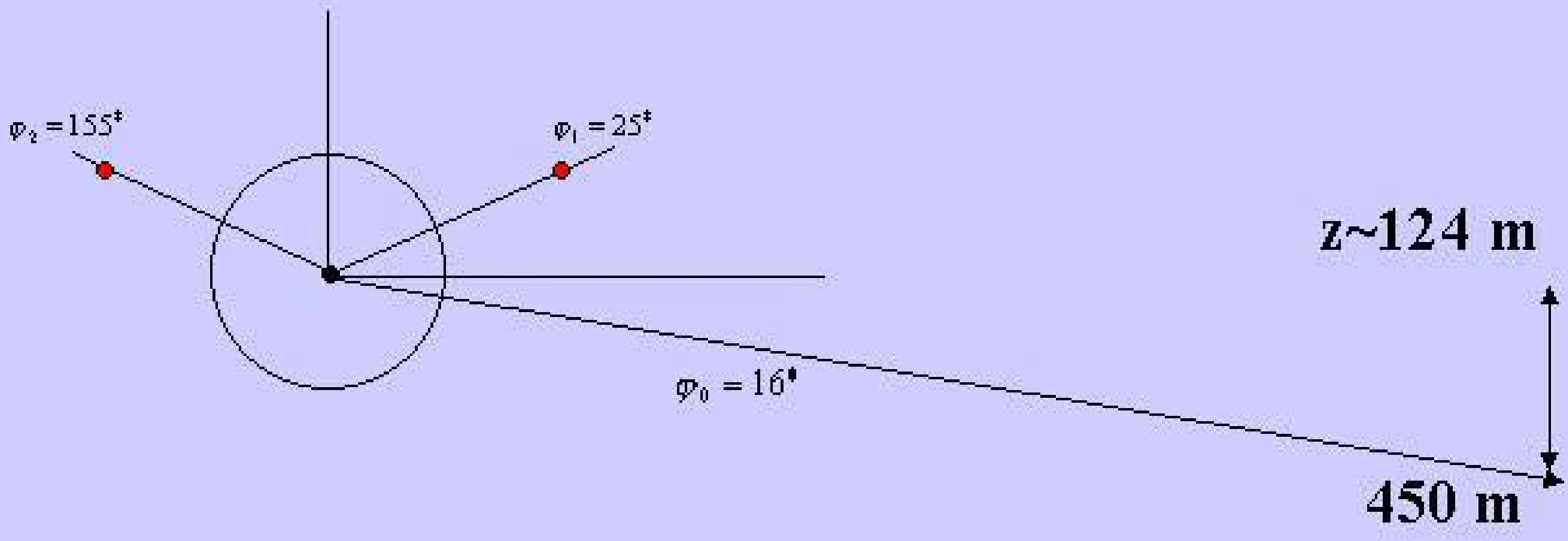
p(φ), f = 1 000 Hz, M = 0.3



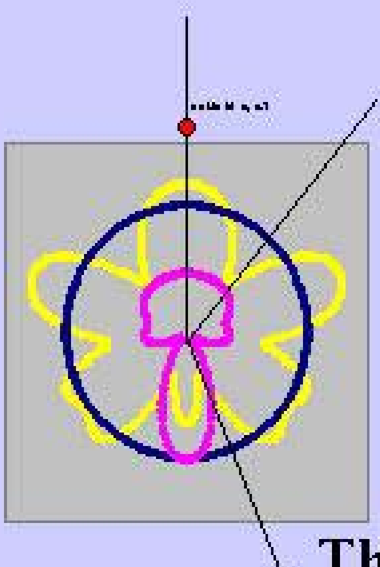
V = 100 m/s

ka = 38

Positions of "engines" when side point is located in diffraction minimum for both, f =100Hz



First minimum 41°



Third minimum 156-170°

ka = 3.81

CONCLUSIONS

- Diffraction effects are important at any frequency of interest

- Moderate variations of p, changing with f drastically

- But those sharp variations are smoothed for narrow- or broad-band noise instead of tones and the process of calculating the sideline EPN level should erase any peak in the results

- The (averaged) reflection effects are weak whereas the masking effects are significant or strong

Thus the presence of the fuselage under the wings is rather beneficial

RECOMMENDATIONS

- The effects of V need to be more investigated
- The effects of cylinder truncation need to be more investigated
- The diffraction effects will have to be looked at for the final design
- All details will have to be taken into account for evaluating the sideline noise EPN level
- Acoustic liners on some fractions of the fuselage (and wings) could be proposed