CAN SUPERSONIC TRANSPORT BE ULTRA-QUIET ?

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THE SUBJECT : WHAT IS A SUPERSONIC TRANSPORT AIRPLANE ? (SST)

MTOW : 320 METRIC TONS (700 000 Ib)

RANGE : 10 000 Km

ABOUT 250 PASSENGERS

MAIN DIFFERENCE WITH A SUPERSONIC BUSINESS JET

- Supersonic operation over populated areas cannot be expected since the sonic boom cannot be reduced at an acceptable level
- Thus a fraction of flight could have to be subsonic with an efficiency not too different of that of usual subsonic aircraft
- As a consequence, the question « Can supersonic transport be ultra-quiet » only concerns takeoff and landing noise

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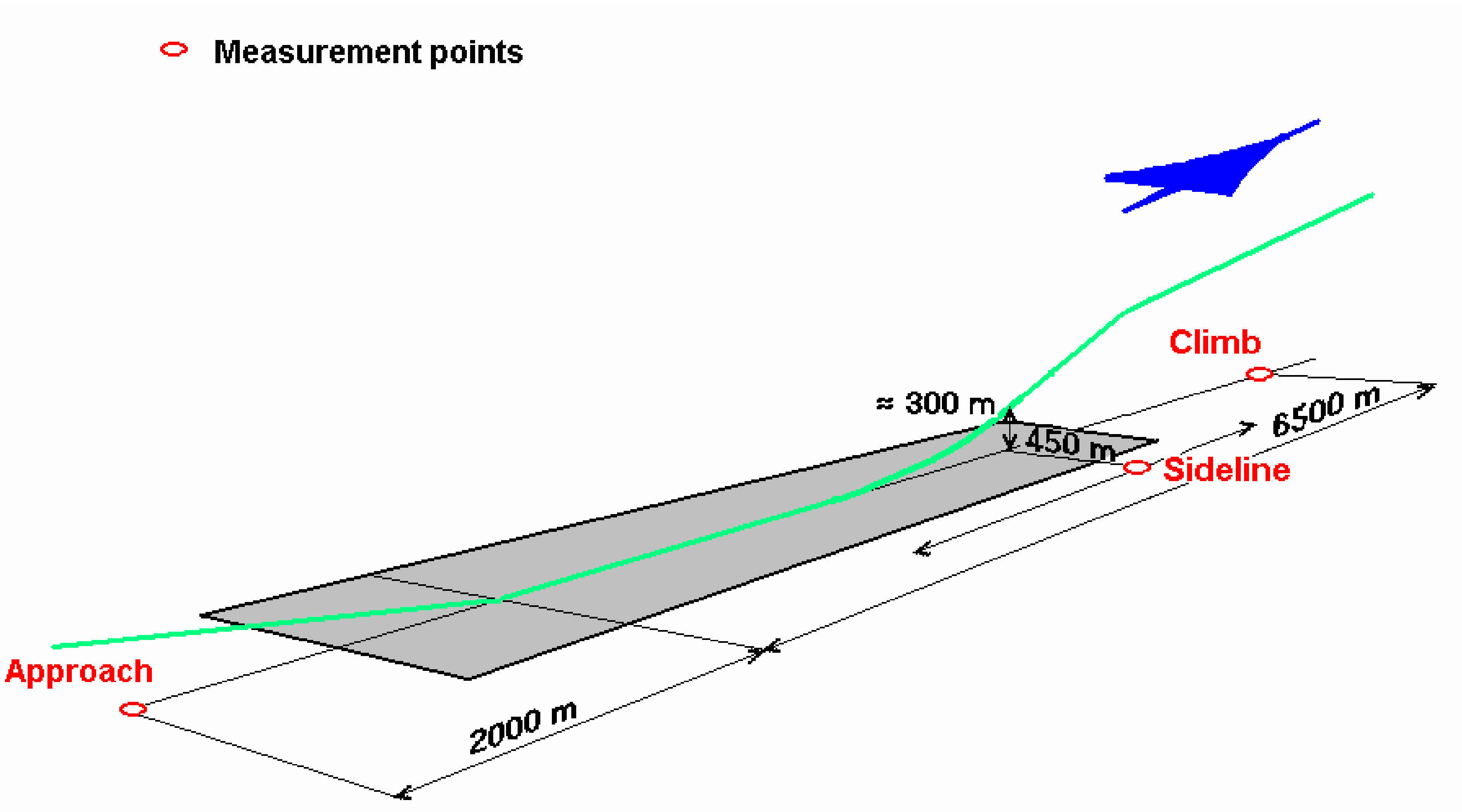
NOISE CERTIFICATION



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WHAT IS A « QUIET » SST ?

ICAO Sideline Stage 3 limit for 320 m. tons :

102,2 EPN dB

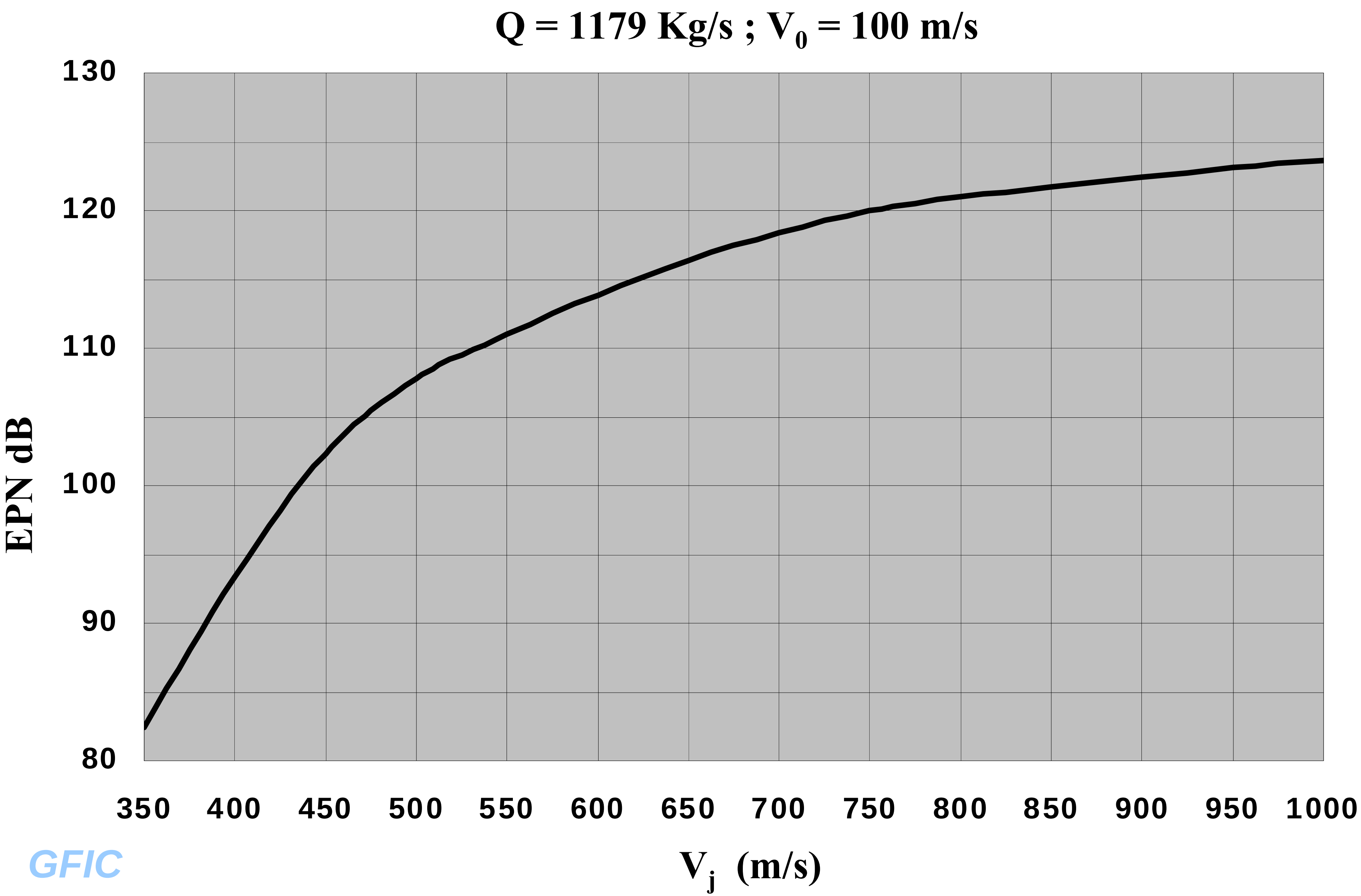
Stage 4 is chosen at : 99 EPN dB

Jet noise limit is : 96 EPN dB

With a margin of 3 dB,

aim jet noise at **93** EPN dB

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



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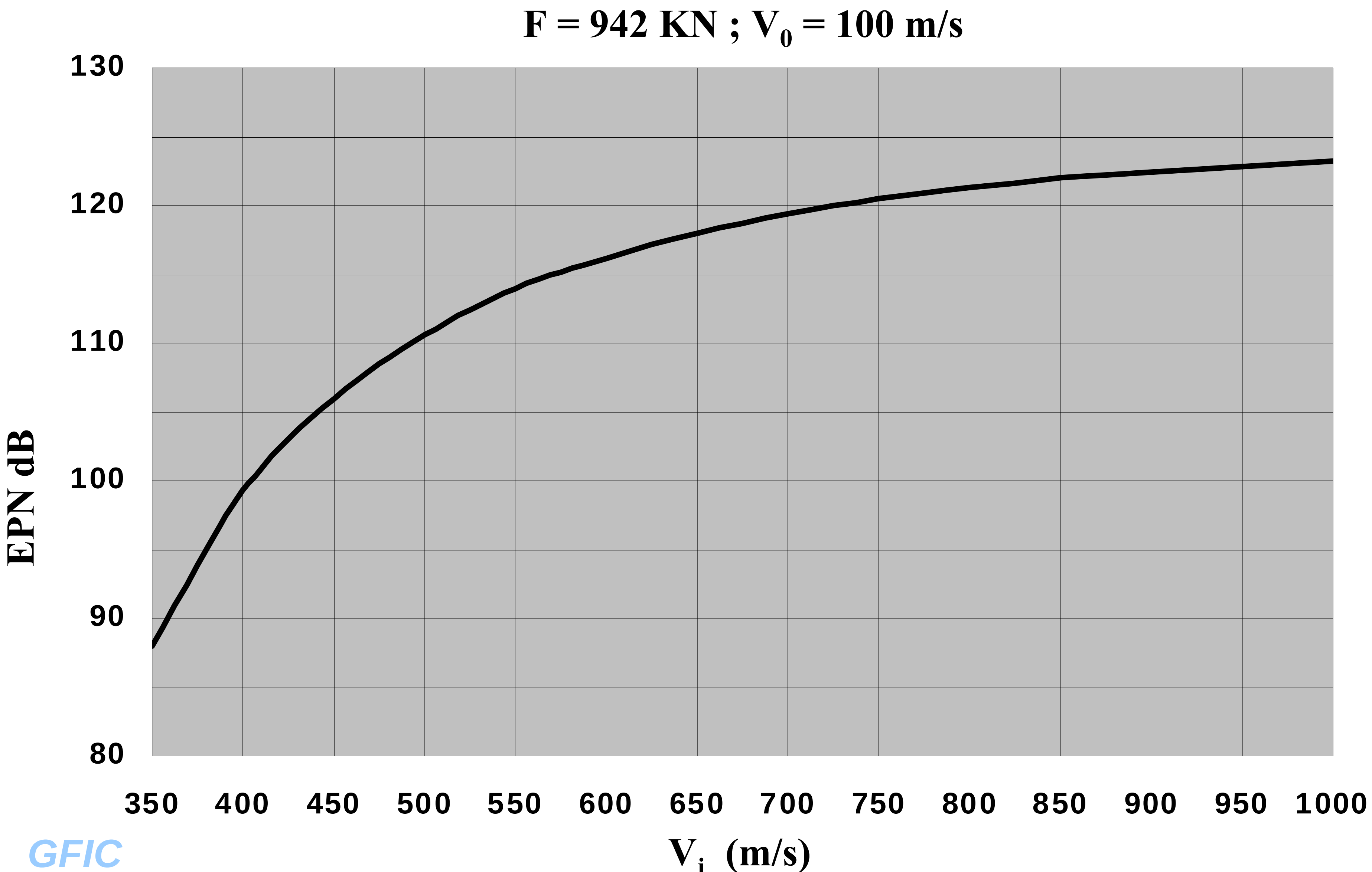

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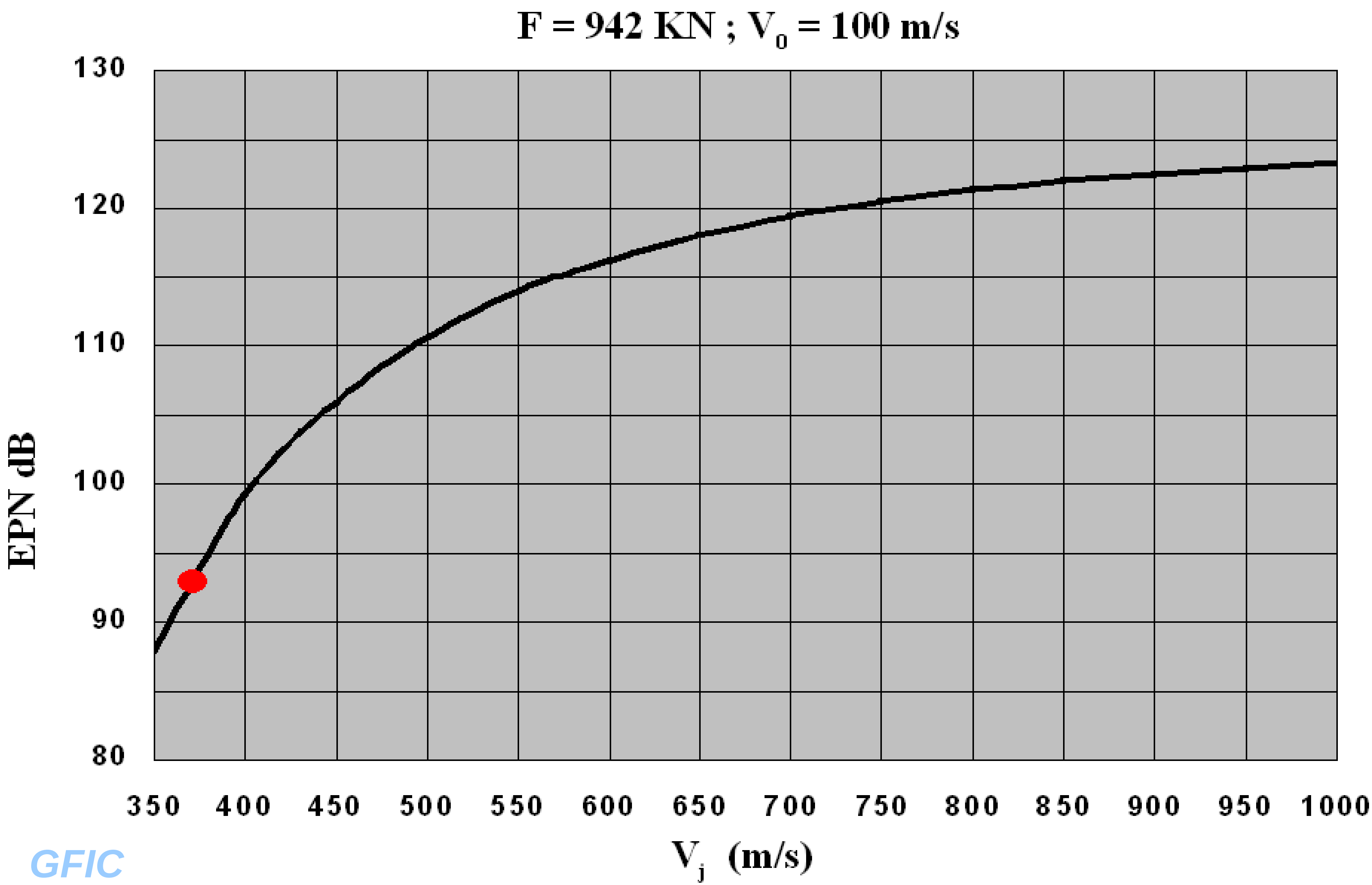

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MECHANICAL PROPERTIES

Take off requirements

The thrust available at take off F_g is

$$F_g = Q_g (V_j - V_o)$$

V_j : jet velocity limited to 370 m/s

V_o : aircraft takeoff speed, about 100 m/s

The takeoff thrust requirement is

$$F_g = 9.81 \beta M_t \qquad (\beta \sim 0.3)$$

Thus

$$Q_g = 9.81 \beta M_t / (V_j - V_o)$$

or **3 489 Kg/s**

MECHANICAL PROPERTIES

Supersonic climb requirements

$$F_{ec} = 9.81\ \gamma\ \delta\ M_t\ /\ (L/D)$$

Practically F_{ec} in KN is equal to M_t in metric tons (i. e. 320 KN)

The specific thrust F_s is defined as

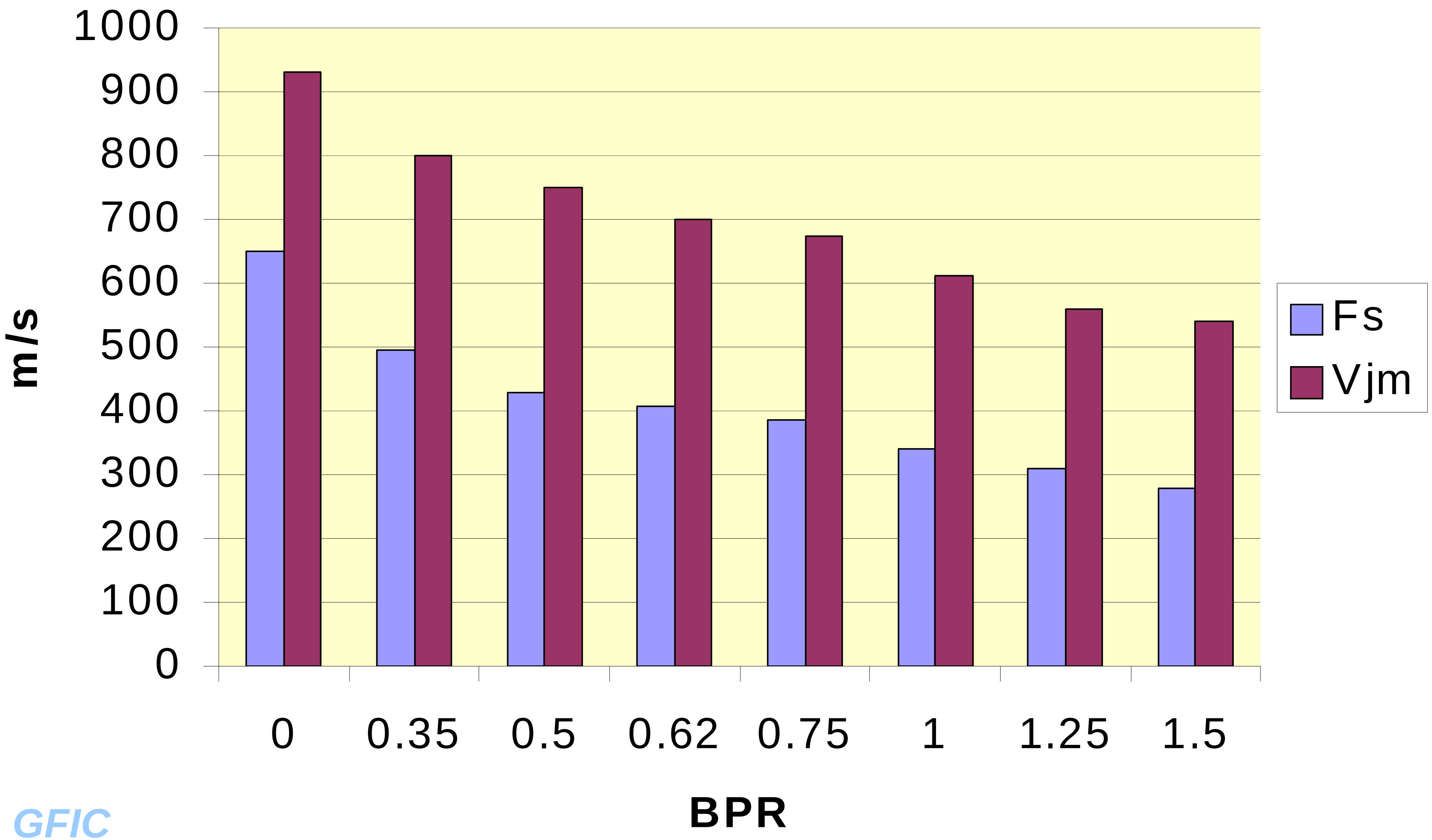
$$F_s = F_{ec}\ /\ Q_{ec}$$

Q_{ec} being the mass flow rate at end of climb. If the end of climb at Mach 2 occurs at 16 154 m (53 000 ft), the mass flow rate for the same engine at ground conditions is

$$Q_g = \eta\ Q_{ec}$$

with η close to 1.51

Specific thrust F_s and maximum jet velocity V_{jm} versus bypass ratio



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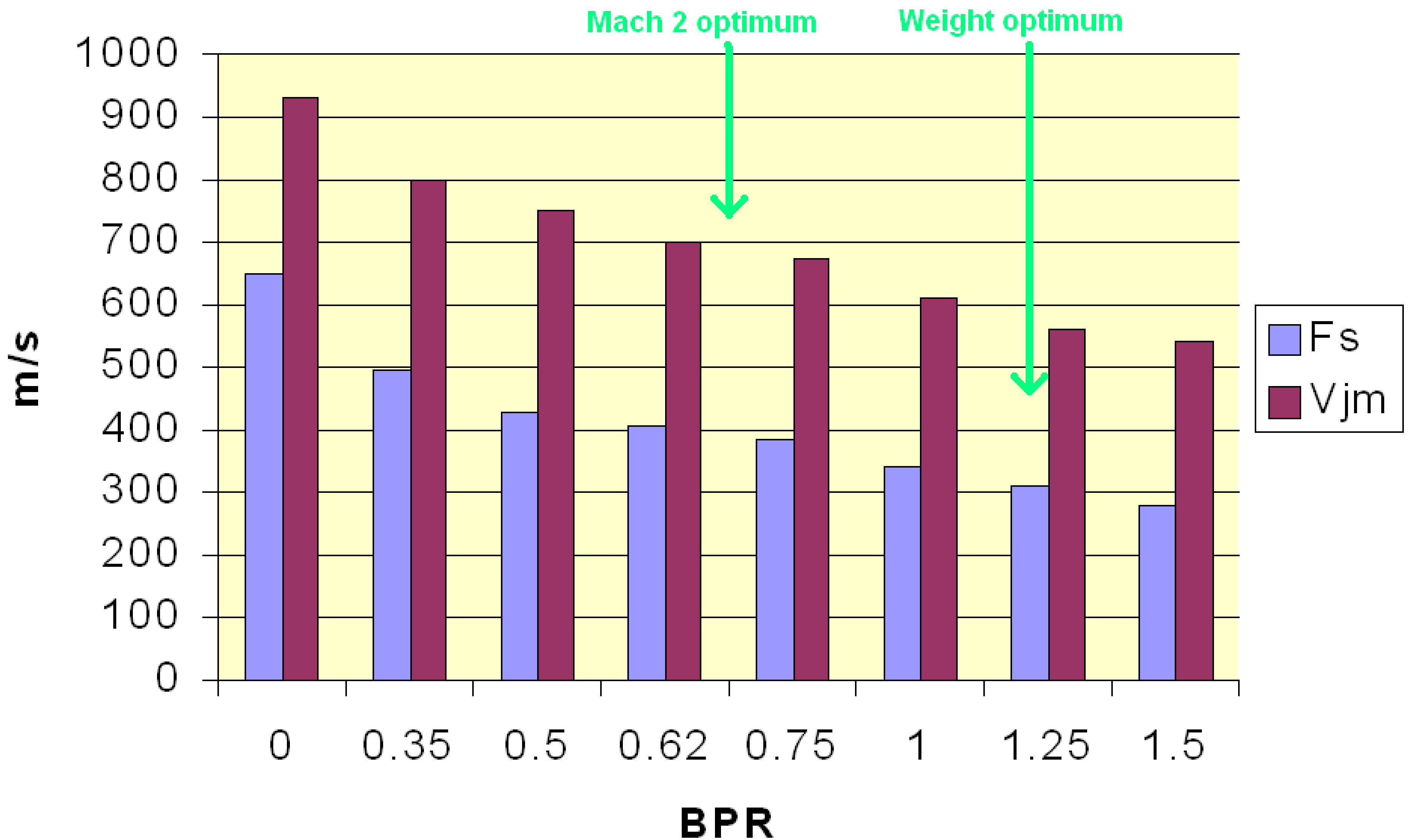
Specific thrust F_s and maximum jet velocity V_{jm} versus bypass ratio



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SUMMARY OF CROSS SECTIONS REQUIREMENTS

A supersonic airplane with M_t = 320 000 Kg which would take off with a 942 KN total thrust (β = 0.3) would need Q_{to} = 3 489 Kg/s to insure the V_j = 370 m/s noise limit. Such a Q_{to} requires an air inlet cross section of

18 m²

according to a practical engine capability of 190 Kg/s per square meter (hub included).

End of climb needs a 320 KN thrust with a specific thrust of 320 m/s that is a 1000 Kg/s air flow rate becoming 1510 Kg/s for ground conditions.

The corresponding cross section requirement is

8 m²

Thus the cross section requirement at takeoff is about 2.3 times that at end of climb.

BASIC STATEMENT

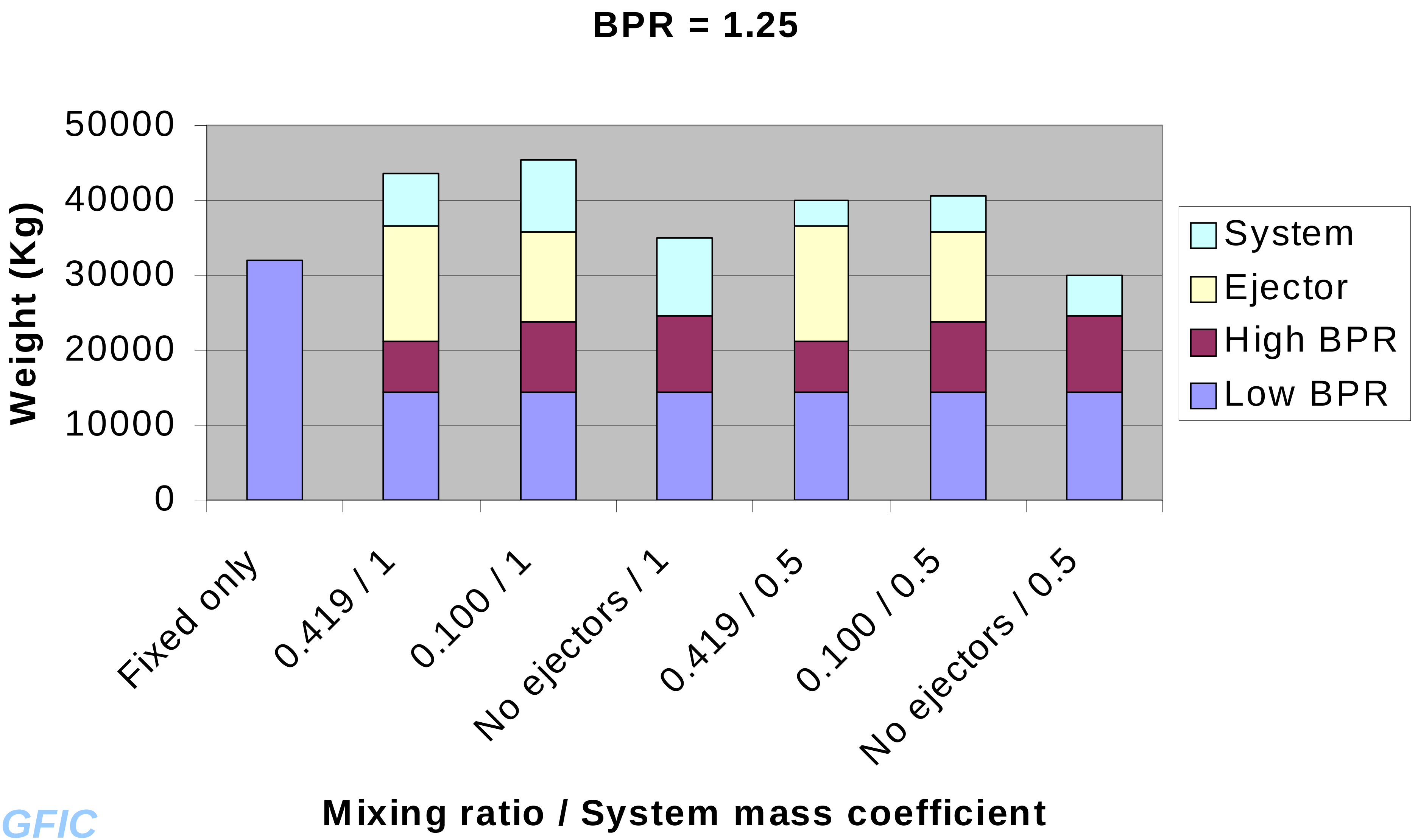
This factor of 2.3 for air inlet cross section cannot be obtained by :

- Any variable – cycle engine for which the design is practically limited to a factor less than 1.5
- Any ejector for which the mixing ratio is practically limited to 100%, that is a factor of 2 in terms of cross sections

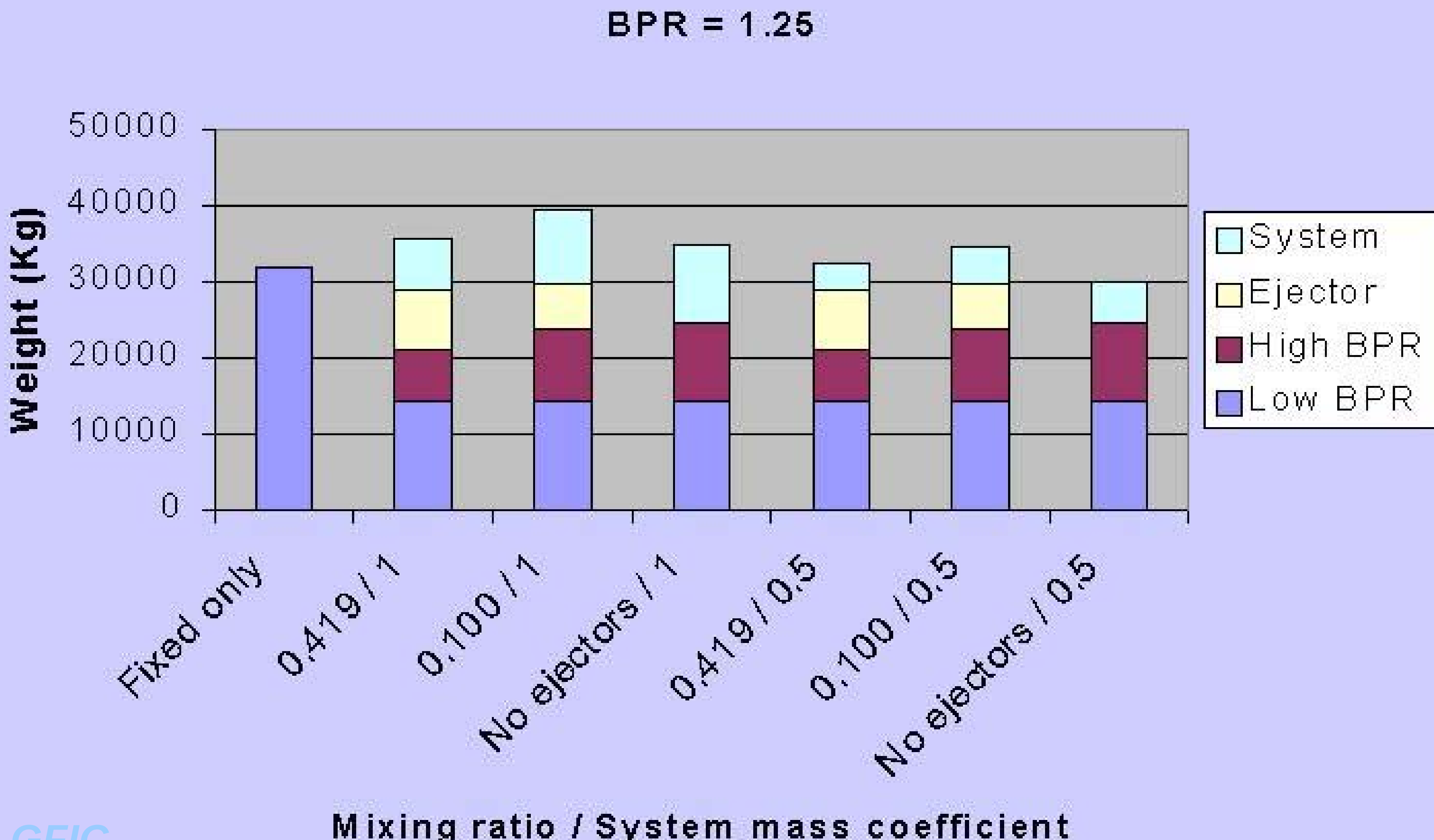
As a consequence, propulsion means for supersonic transport must include :

- Low - BPR turbofans for supersonic climb and cruise, which are operated at a lower setting or/and with some ejector for noise reduction at takeoff
- High - BPR turbofans for boost at takeoff, which are to be stowed for supersonic operation

PROPULSION SYSTEM WEIGHT ($\sigma = 7$ s)



PROPULSION SYSTEM WEIGHT (σ = 3.5 s)



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MAIN RESULT

The unique solution for having a Mach 2 aircraft with $M_p / M_t < 0.1$ (Concorde had a $M_p / M_t > 0.1$) requires :

- Fixed engines optimized for supersonic cruise with a BPR > 1
- No ejectors
- High-BPR boost turbofans
- A moving and stowing system with a mass coefficient $\upsilon \leq 0.5$

SUMMARY OF PROPULSION REQUIREMENTS

- 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
  Similar to subsonic aircraft engines (GE CF6, PW 4000, RR Trent)
  ~ 2.8 m in diameter

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

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

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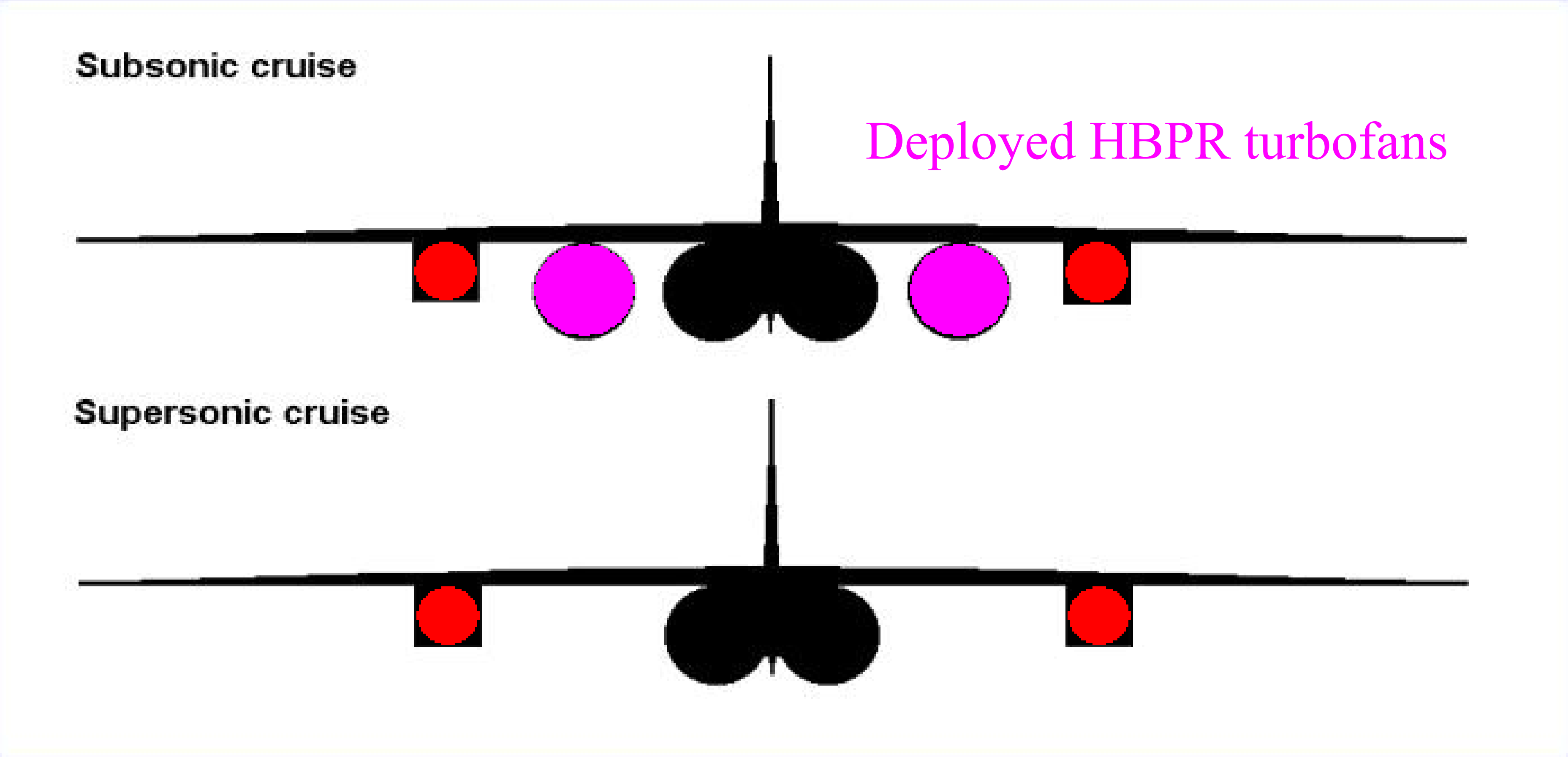
CONSEQUENCES OF ALL PREVIOUS REQUIREMENTS

A unique solution for aircraft configuration :

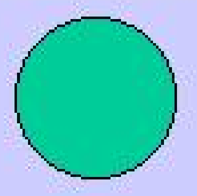
- Retractable engines AND fuselage under wings
- Twin cylinder fuselage

320 METRIC TONS SUPERSONIC AIRCRAFT

Front view



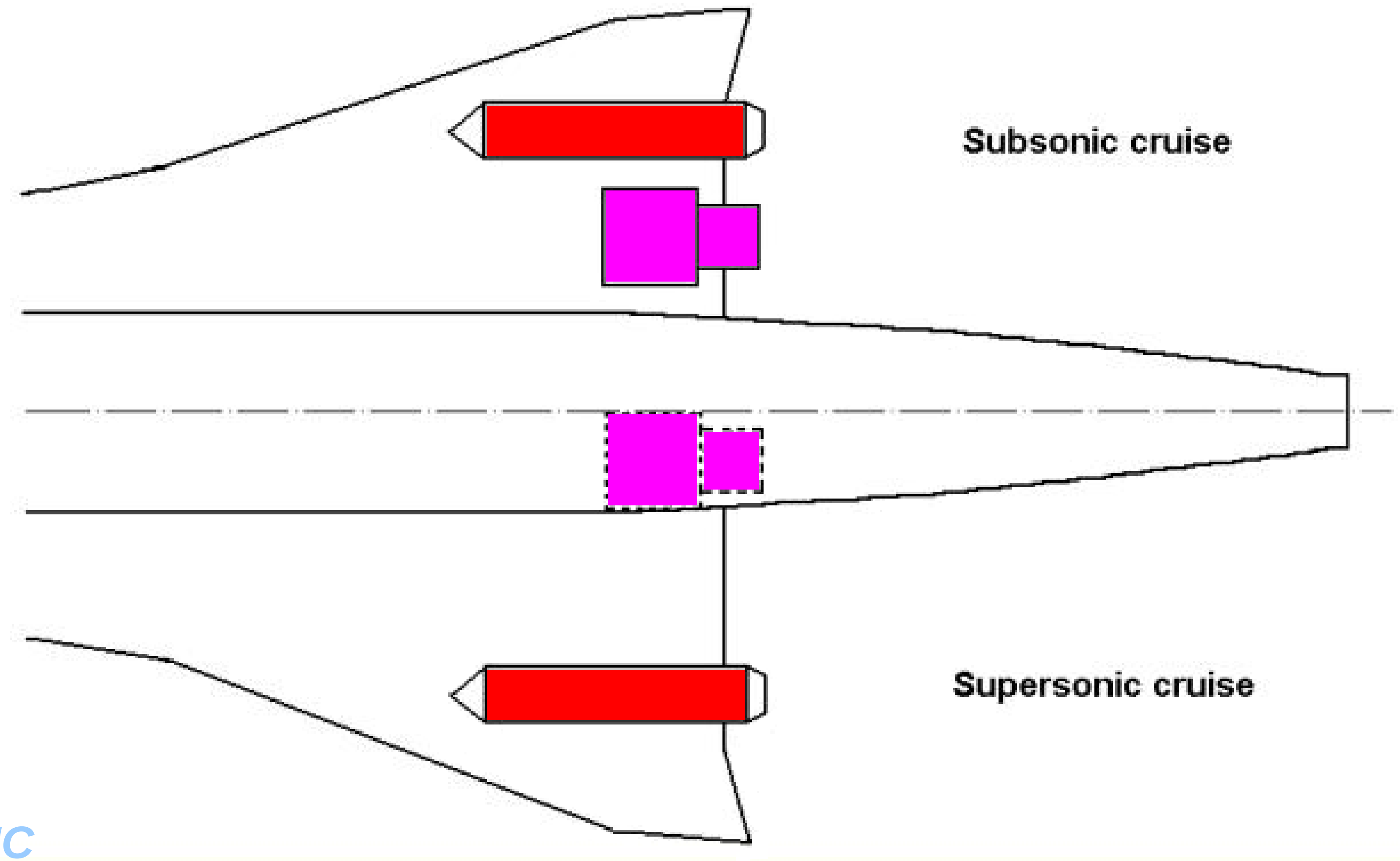
Same cross section
for a unique cylinder



(4.2 m in diameter)

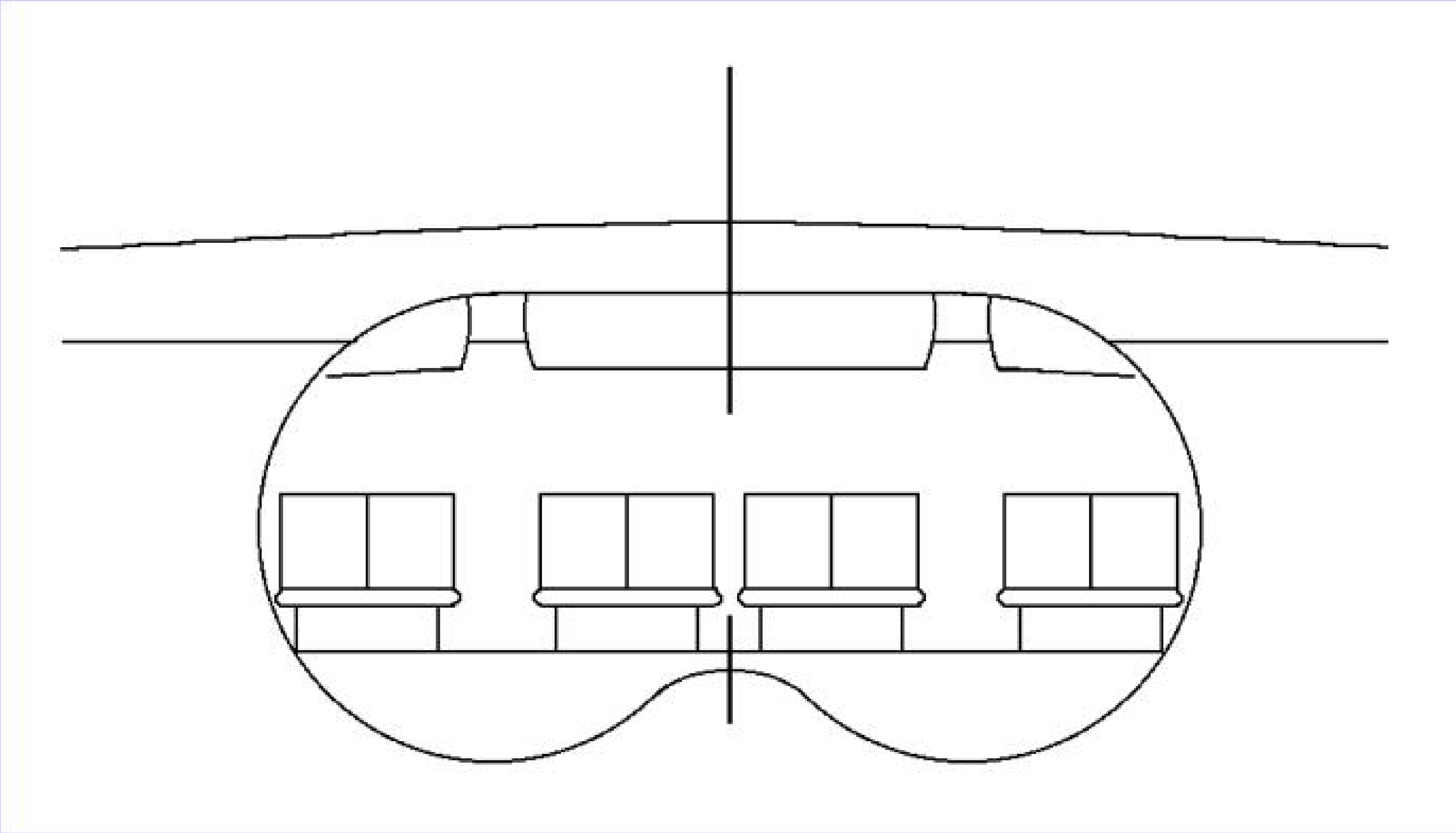
Quiet SST

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**

QUIET SUPERSONIC TRANSPORT

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With permission of Tupolev Design Bureau

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- Requirements for a « quiet » (Stage 4) SST
- Description of a « quiet » SST
- Drawbacks and limits
- From « quiet » to « ultra-quiet » SST
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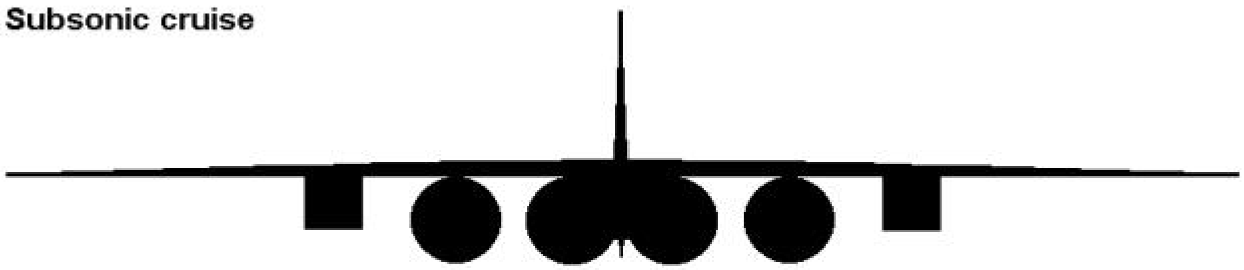
DRAWBACKS

Move 2 big HBPR engines under the wings

- Large weight (2 x 5 tons)
- Large bays
- So many connecting parts

LIMITS



The fuselage is completely filled by the 2 retracted HBPR turbofans

No possibility to increase engine diameter any more to reduce noise

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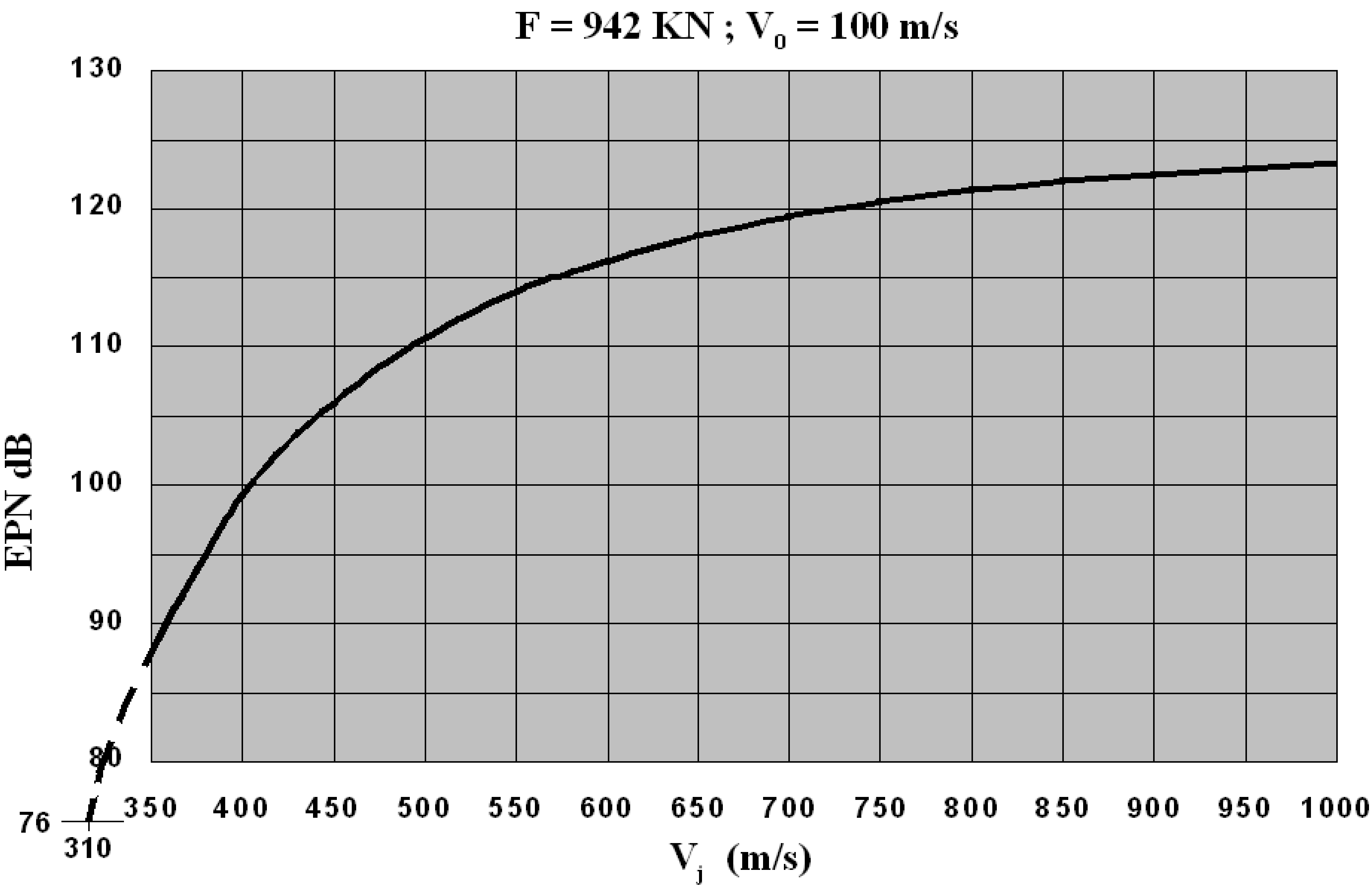

REQUIREMENTS FOR « ULTRA-QUIET » SST

As V_j is changed from 370 to 310 m/s,

the total air intake cross section is changed from 18.4 to 30.4 m2

The total thrust is the same but 12 more square meters are needed

It is suggested to use 2 more retractable fans (coreless), 2.8 m in diameter, powered by shafts from the 2 HBPR turbofans

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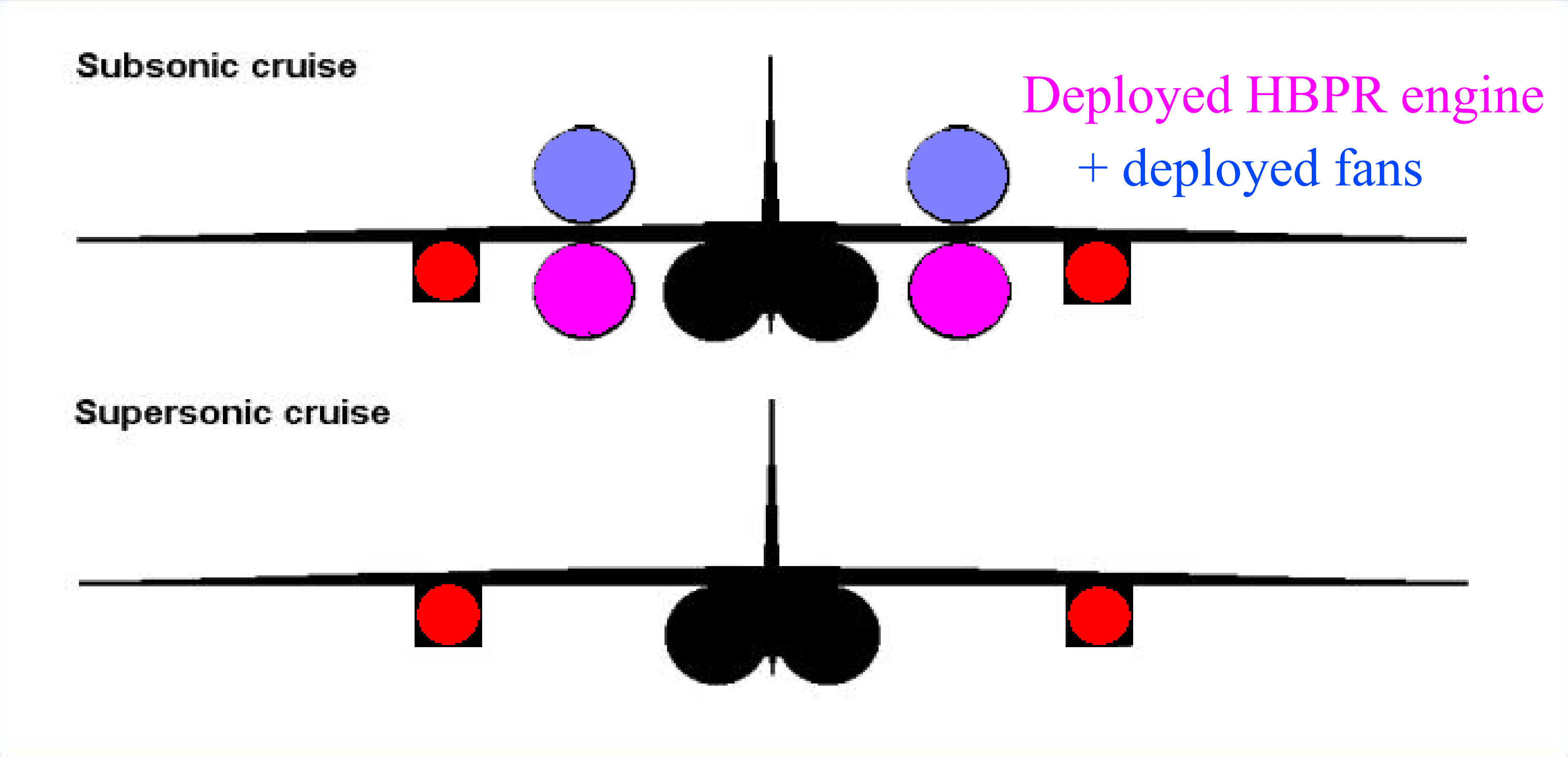
ULTRA-QUIET SST

Front view



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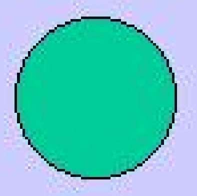

(4.2 m in diameter)

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ULTRA-QUIET SUPERSONIC TRANSPORT

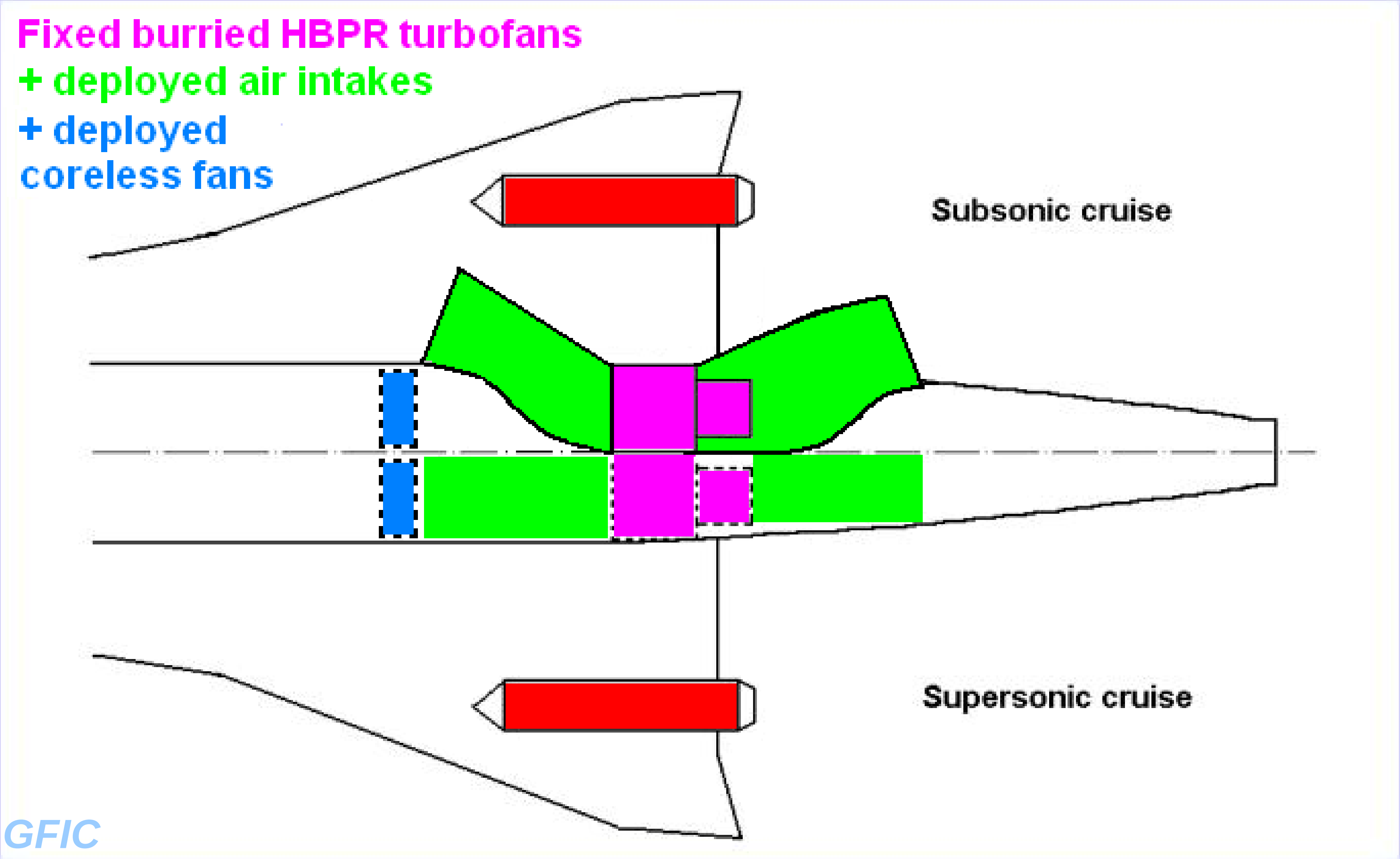
COMMENTS ON THE PREVIOUS DESIGN

The limits (front area) are well pushed

The drawbacks are increased ! HELP !

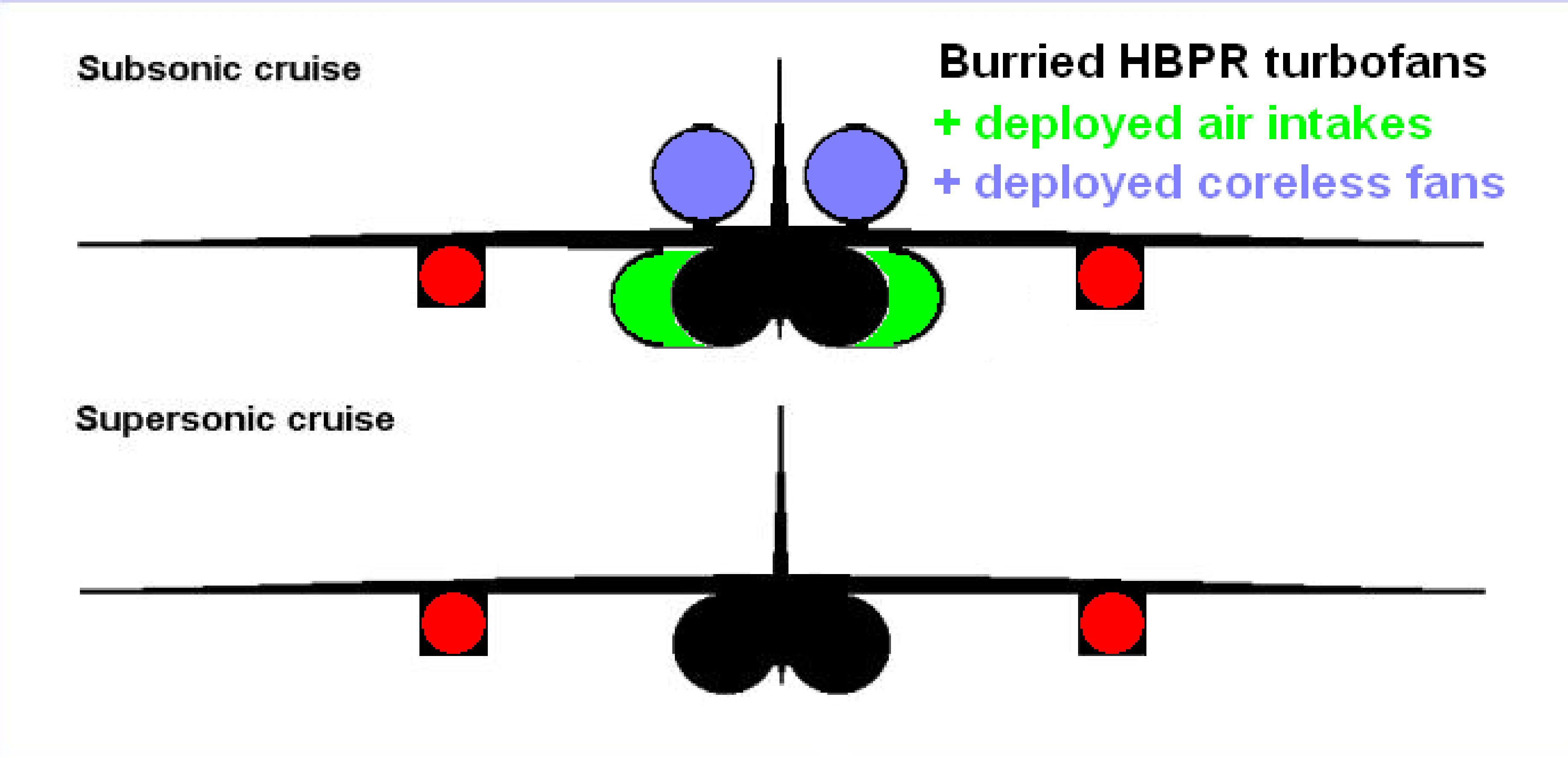
MORE REALISTIC ULTRA-QUIET SST

Underside view



ULTRA-QUIET SST

Front view



Same cross section
for a unique cylinder

(4.2 m in diameter)

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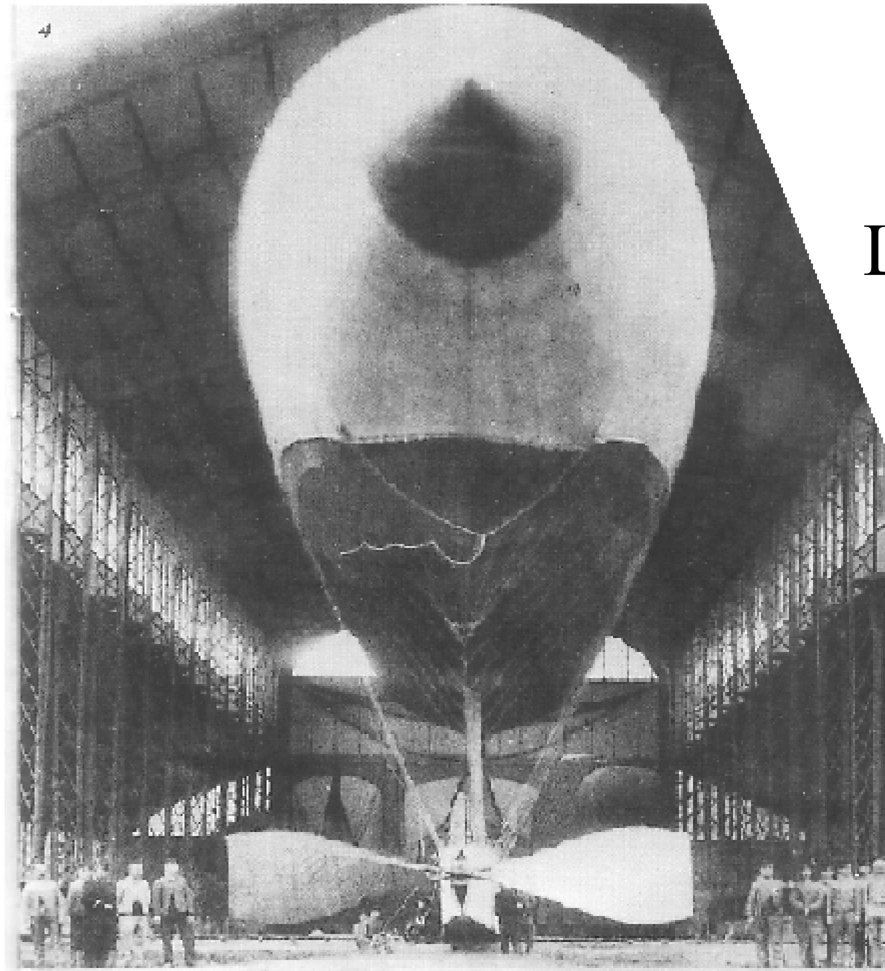
YES, SUPERSONIC TRANSPORT CAN BE ULTRA-QUIET

- No dubious assumptions
- No risks of new–engine development
- The ultra-quiet SST is entirely determined by noise priorities (well before 2050 possibly)
- Thus aeroacousticians will influence civilian aviation deeply
- Aeroacousticians have to predict noise of new airplane shapes equipped with different engine types with intricate installation

ELECTRIC DEPLOYING FANS ?



La France, 1884
6 KW

Needs : Tens of MW

Present design : The MW

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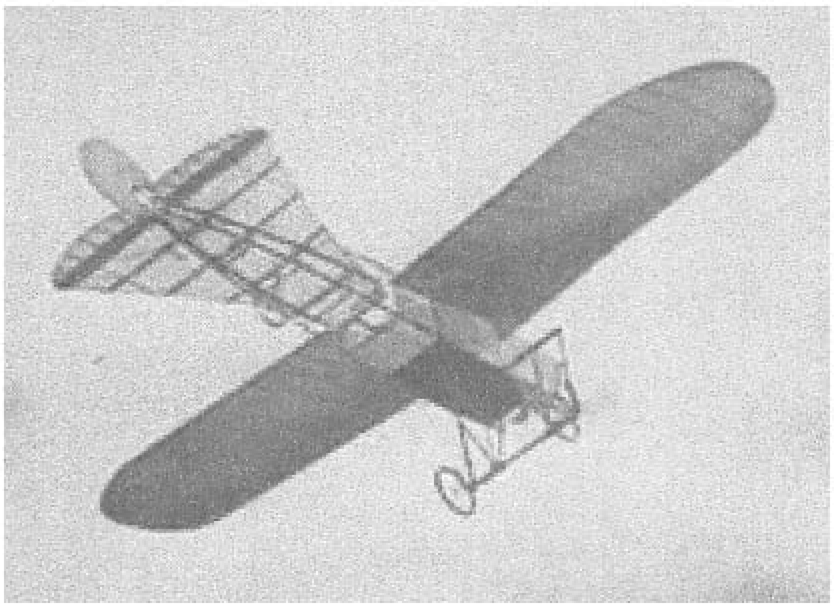
OTHER PERSPECTIVE

Deploying fans could also be of interest for subsonic ultra-quiet transport

GENERAL CONCLUSION

Airplane structure and propulsion will be included in a unique integrated design

THE END



THANK YOU