MANFRED KLOSTER, FH München

Die Bewertung künftiger Überschall-Verkehrsflugzeuge (SST) mittels des Schallknall-Kriteriums

Manfred Kloster
Fachhochschule München FB 03 FA Luftfahrzeuge

Die Bewertung künftiger Überschall - Verkehrsflugzeuge mittels des Schallknallkriteriums

DGLR - Workshop "Bewertung von Flugzeugen" , 26./27. Oktober 1998
Technische Universität München Luftfahrttechnik , D-85747 Garching

In den letzten Jahren wird immer wieder die Neuauflage eines Überschall - Verkehrsflugzeugs vorgestellt. Hierbei gerät das Schallknallkriterium, das z.B. der Concorde den Inlandreise-Überschallflug nach den bisher bekannten FAA - Richtlinien verbietet, zunehmend in Vergessenheit.

Ziel dieses Workshop - Vortrags soll es sein, hieran wieder zu erinnern.
Die wesentlichen Forschungsarbeiten gehen auf die fünfziger, vor allem auf die sechziger und siebziger Jahre zurück.

<u>Folien 1 und 2</u> geben den Artikel des NASA - HSCT Projekts vom 13. Oktober 1997 aus der Aviation Week & Space Technologie wieder. Das Flugzeug ist für Ma = 2,4 ausgelegt.

<u>Folie 3</u> gibt aus der gleichen Zeitschrift die Bemühungen der Europäischen Industrie für ein neues SST - Projekt wieder. Neben der "weiseren" Entscheidung für Ma = 2 (wie CONCORDE) wird auch ein Ma = 1,6 - Reiseflugzeug angesprochen.

<u>Folien 4 und 5</u> zeigen ein Projekt SST 1994, das in der Auslegung dem HSCT auch mit Ma = 2,4 sehr nahe kommt.

<u>Folien 6 und 7</u> geben das DASSAULT SSBJ (supersonic business jet) Projekt wieder, Aviation Week & Space Technologie 1. Juli 1998.

<u>Folie 8</u> zeigt zum Vergleich die CONCORDE, die in der Formgebung auch für die neueren Projekte Vorbild zu sein scheint.

<u>Folie 9</u> In ganz groben Zügen wird die Theorie zur Berechnung des Schallknalls nach WHITHAM und WALKDEN aus PIETRASS Jb WGLR 1964 skizziert. Für die Lösung wird für den Rumpf mit einer Querschnittsverteilung eines Rotationsparaboloids gearbeitet. Der Auftrieb wird entsprechend der Theorie schlanker Körper für Deltaflügel mit dA/dx=const. angenommen, was auch für den Ogee-Flügel hinreichend sein möge.

<u>Folie 10</u> Hier wird die sich ergebende Berechnungsformel für eine Flügel - Rumpf - Kombination mit den eingehenden Parametern und Faktoren vorgestellt.

<u>Folie 11</u> zeigt eine Tabelle (nach PIETRASS s.o.) mit dem Zusammenhang der Schallknall - Intensität und möglichen Schäden.

Es wird auch noch die Umrechnung des Lärmpegels L(dB) zum Drucksprung Δp(Pa) unbewertet angegeben.

Folie 12

Meßwerte mit der CONCORDE des Institut Saint Luis, France aus dem Bericht von RIGAUD et al. ISL-RT 2/72 sind dargestellt. Insbesondere sind das ausgeprägte N-Profil des Schall - Doppelknalls und die kurzen verstärkenden Spitzen beim ersten Drucksprung zu sehen. In allen Berichten zu diesem Thema wird immer wieder auf die großen Streuungen hingewiesen.

Folie 13

zeigt verschiedene Beschränkungen des durch Schub F gleich dem Widerstand W möglichen Flugbereichs. Insbesondere die Begrenzungen durch den gesetzlich zulässigen Schallknall können den Flugbereich im Überschall sehr einschränken, sogar gar nicht möglich machen.

Folie 14

zeigt Berechnungen mit den Daten der CONCORDE bei 80% MTOW (145to) im Vergleich zu Messungen. Die Übereinstimmung ist sehr gut, aber bei Ma = 2 wird die Berechnung mit dem Machzahlabhängigen Reflexionsfaktor K_R etwas zu gering.
Eingezeichnet ist noch ein kleiner Ausschnitt F = W für 145 to , man sieht, das hier ca. 125 Pa Schalldruck (am Boden) erzeugt würden, was die FAA - Forderungen weit überschreitet.

Folie 15

Die Berechnung des Drucksprungs Δp mit der kombinierten Gleichung und der separaten Volumen- bzw. Auftriebsgleicheung zeigt, daß in großen Höhen die Auftriebsgleichung dominiert und hier vielleicht auf eine integrierte Rumpf - Flügel - Lösung geschlossen werden kann, s.u..

Folie 16

Die Entwicklung der Begrenzung der Flugenveloppe durch den Schallknall mit dem Fluggewicht ist dargestellt. Bei 80% MTOW ist kein stationärer Horizontalflug für den Drucksprung von 100 Pa möglich, der ja schon über den bisherigen FAA-Forderungen läge.

Folie 17

Erhöht man die Flügeltiefe auf die gesamte Flugzeuglänge, so würde sich bei 80% MTOW (145 to) ein Flugbereich von 1,1 bis 2,2 der Machzahl ergeben, der einen Schalldruck von ca. Δp = 120 Pa am Boden erzeugen würde, der Schub F wäre noch etwas größer als der Widerstand.
Obwohl der Schalldruck zu groß ist, wird hier deutlich, daß die Vergrößerung der Flügeltiefe auf Rumpflänge hinsichtlich der Schallknall - Problematik die Lösung für künftige Projekte ist.

Folie 18

zeigt eine entsprechende integrierte Flügel - Rumpf - Kombination von COURTNEY (J. Royal Aeronautical Society, Vol. 68, 9/64) *)

Folie 19

Für das Projekt NASA HSCT (ca.) wurde der Verlauf des Schalldrucks mit der Flughöhe sowohl mit dem konstanten Reflexionsfaktor K_R=1,9 als auch mit dem von der Machzahl abhängigen Reflexionsfaktor K_R = 1 + 1/Ma (Machscher Winkel: sin μ = 1/Ma) berechnet.

Theoretisch ergäbe sich erst bei der Flughöhe H = 20 km etwa ein Schalldruck von Δp = 81 Pa , bzw. bei 24 km Flughöhe Δp = 72 Pa am Boden. Das Projekt SST 1994 liegt ganz nahe dabei, aber das DASSAULT SSBJ - Projekt erfüllt die bisherigen FAA - Vorschriften und ließe sogar mögliche Verschärfungen zu.
Zum Vergleich sind noch CONCORDE Werte eingezeichnet.

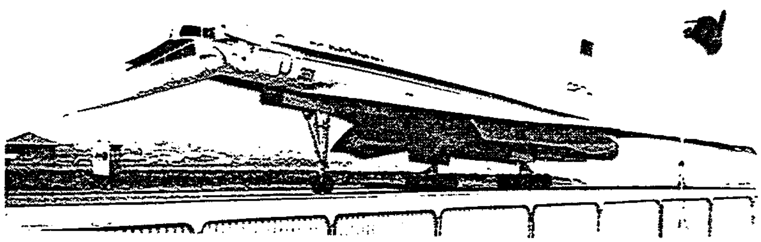
*) *siehe dazu auch:*
STUFF, Die Auslegung von Überschallverkehrsflugzeugen...ZFW 24
DARDEN/MACK Current Research in Sonic-Boom Minimization NASA-CPOO
SEEBASS/GEORGE Sonic Boom Minimization J Acoust.Science 51,2

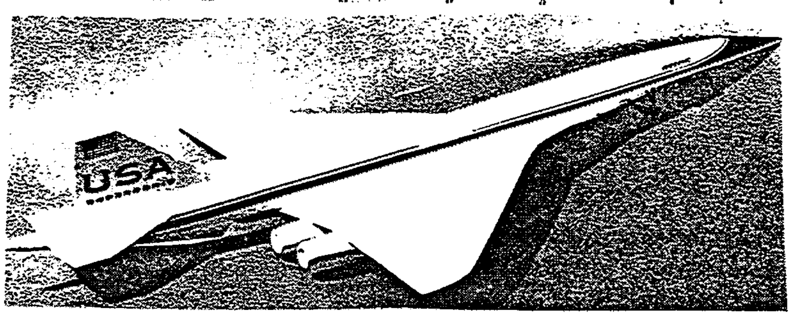
Folie 20 zeigt aus Messungen, daß sich bei Manövern die Schalldruckwerte verdoppeln und verdreifachen können.

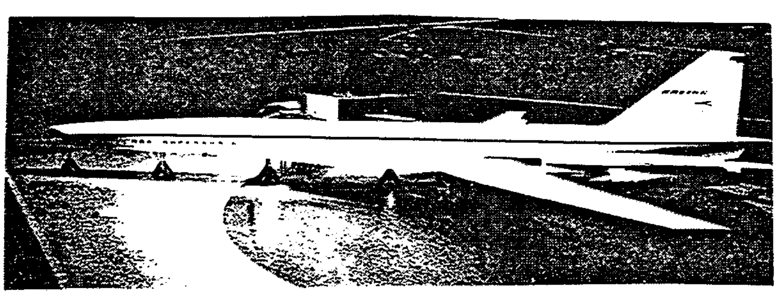
Mit dem Manövergrenzwert von Δp = 120 Pa könnte die CONCORDE bei m = 105 to gut fliegen aber den Wert von 81 Pa für den stationären Horizontalflug könnte sie bei diesem Gewicht gerade noch nicht erfüllen. Mit 58% MTOW ist der Flug beendet (9% Reserve) .

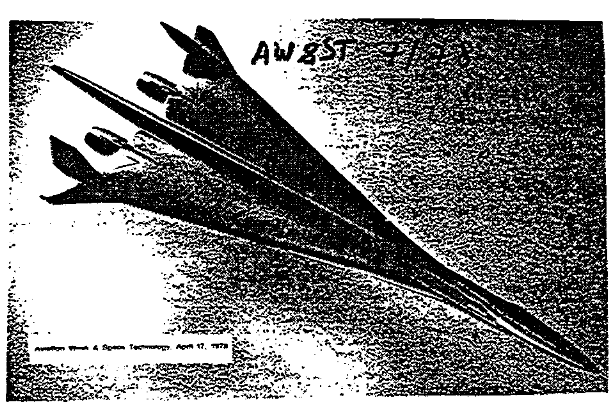
Die sich ergebenden Schallknall - Werte hängen sehr stark von der tatsächlichen Atmosphäre und dem Wetter ab. Es können Fokussierungen zum Superknall, aber auch zur Auslöschung führen. Viele Untersuchungen der Wirkungen des Schallknalls auf den Menschen (usw.) ergeben keine eindeutigen Aussagen. So sollen Schalldrücke von fast 6000 Pa ! bei Testpersonen keine physiologischen Schäden ergeben haben, aber bei einem Schalldruck von 50 Pa bereits 85% der Personen bei offenem Fenster in ruhiger Umgebung aus dem Schlaf wecken, siehe bei PIETRASS, Jb WGLR 1964.

Die Dias zeigen die Sichtbarmachung des Verdichtungsstoßes im Windkanal und im Flug, sowie einige der älteren Projekte und die TU 144.









Folie 1

HSCT Computer Model Takes Shape at NASA

JAMES OTT/HAMPTON, VA.

NASA and industry engineers are deciding on the basic form of a High-Speed Civil Transport that will strongly influence future U.S. commercial supersonic aircraft.

A December deadline has quickened the pace at NASA to complete the work on a preliminary technical configuration aircraft. A computer-based model, it will become the focus of intense study in NASA's High Speed Research program throughout next year. A final technical copy of the aircraft should be in place to meet a December 1998 program milestone.

ALAN W. WILHITE, deputy director and airframe manager of the HSR program at NASA Langley Research Center, regards the aircraft as a common base on which design engineers can work as the aerospace industry continues the decision process toward a program launch. He doesn't expect radical changes in the configuration aircraft in the year ahead.

NASA's base model supersonic transport has been taking shape—and changing frequently—since research began in 1987 toward a economically viable and environmentally acceptable supersonic transport (*AW&ST* Aug. 17, 1987, p. 33). Confident that its goals can be met, NASA is now halfway through the second phase of a $1.9-billion research program, scheduled to end in 2002.

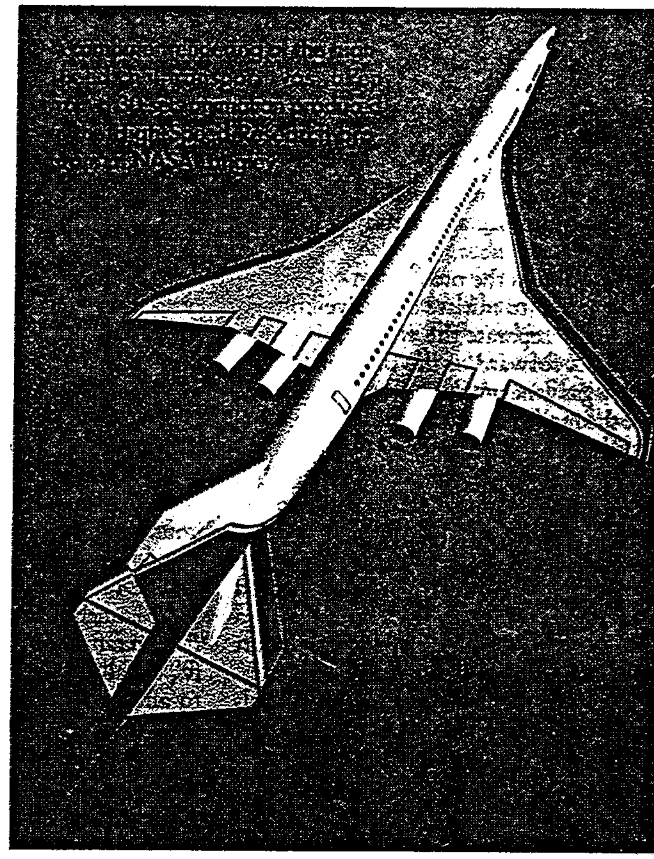
A Phase 2A program extension, now under consideration at the Office of Management and Budget, would be geared toward developing materials and processes for building the fuselage and wing. In a recent report, the National Research Council recommended the program extension in the HSR program as an added incentive for industry.

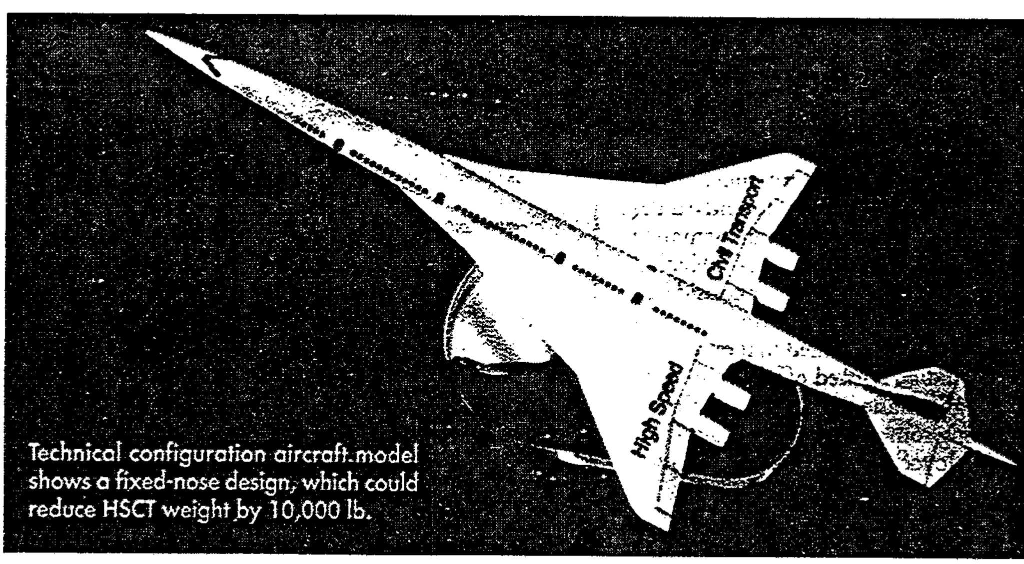
The HSR program has been moving along with steady support of team leader Boeing and other U.S. major aerospace manufacturers, and some 50 subcontractors. The program has gained considerably in importance since Boeing, in 1996, canceled plans for a rival future project, a high-capacity, super-jumbo transport.

NASA has been spending one quarter of its annual $1-billion aeronautics budget for high-speed research, and industry has matched the government outlays "dollar for dollar," said Wallace C. Sawyer, director of NASA's High-Speed Research Project Office at NASA Langley.

Emerging from the research is a Jet A-fueled, four-engine, Mach 2.4, 300-passenger aircraft with a range of 5,000 naut. mi. The configuration aircraft is 320 ft. long, with a wingspan of 130 ft., and a takeoff weight of 750,000 lb. Cruise altitude is 60,000 ft.

"Not much different than the original [U.S.] SST," observed Wilhite, referring to the contender that did not materialize after Congress, 25 years ago, ruled against funding an SST program. "But we'll be able to do it this time. We're going further, faster and at just about the same weight, and carrying more passengers."





Technical configuration aircraft model shows a fixed-nose design, which could reduce HSCT weight by 10,000 lb.

Folie 2

Market studies conducted by industry and used in the HSR program indicate that U.S. development of an SST would play a critical role in strengthening the nation's leadership in the long-range jet transport market.

The studies indicate a market for 1,000-1,500 aircraft. If built under U.S. industry leadership, the studies say, the SST would displace subsonic transports. The U.S. share, currently at 67%, would increase to 87%, account for 140,000 jobs and increase the balance of trade position by $500 billion. If European industry built the SST, it would capture 73% of the market, leaving the U.S. trailing with 27%.

The researchers are keenly aware of future noise regulations and other environmental standards as they design the technical configuration aircraft. Originally, they assumed that noise levels would be achieved in the middle range of current FAR 36 Stage 3 standards. More recently, researchers have set the goal at 3-5-dB. improvement, anticipating stricter standards in the next century.

"Noise has been the number one driver of the configuration airplane," Wilhite said.

FINDINGS FROM EXTENSIVE surveys of people's responses to sonic booms, conducted in the first phase of the HSR program, have left a deep impression. The research turned up ways for NASA to minimize the peak sounds of the boom, but the surveys "basically said that people would tolerate no sonic boom," Wilhite said.

From that point on in the HSR program, the focus has fallen on an aircraft that would operate at supersonic speeds only over water, estimated to be 80% of its flying time.

While none of the characteristics of the configuration aircraft is firmly in place, the NASA-industry team is looking at double delta wings and plain hinge flaps. Engines are mounted to the rear of the underwing area, and long, noise-attenuating engine nozzles project out from beneath the wing. The far-rear engine mounting is a protection of fuel lines in case of a rotor burst.

THE CONFIGURATION AIRCRAFT displays considerable overhang of the front fuselage. Canards are under consideration for the forward fuselage to improve low-speed performance and handling.

Researchers have discarded the variable-geometry drooping nose and retracting windshield visor of the Anglo/French Concorde. No forward cockpit windows are contemplated for the aircraft, only side windows. An external-vision team comprising Boeing and Honeywell engineers, working under FAA guidance, is investigating the technologies to provide the pilots with the functional equivalent of forward vision.

One idea is to mount video cameras on the landing gear and vertical tail to provide a panoramic forward view in a cockpit display. The display would be overlaid with symbols; and altitude, attitude and speed information would be provided. For landing, the symbols would include goal posts to aid runway alignment.

For operations at night and in low-visibility, the aircraft would be equipped with dynamic-range video sensors augmented by X-band radars to detect obstacles. In cruise operations, the aircraft would be protected by a traffic collision avoidance system.

A further aid would be in a differential global positioning system database, providing flight profile information and drawing the runways of major airports on the display screen.

Weight savings was the chief reason for discarding the drooping nose. Researchers estimate a savings of 10,000 lb. when the mechanisms—guide rails, hinge joints and jacks for drooping and returning the nose and visor in place—are eliminated from the design.

Researchers make a case that a synthetic vision system would enhance safety. According to NASA research, pilots' forward vision in a conventional cockpit can detect only 35% of potential hazards. "In our system, we have a radar on board the airplane that is scanning the sky and will pick up everything, and using computer processing will actually tell the pilot of any kind of immediate danger," Wilhite said.

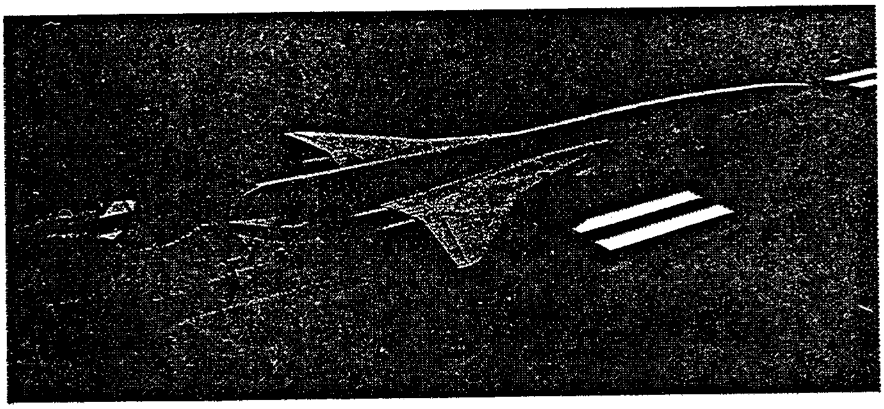
The technical configuration aircraft poses operational challenges, and a series of tests has been developed to work out procedures. A Surface Operations Research Vehicle simulating the characteristics of an aircraft with an extended forward fuselage will begin runway and turning tests this month at Moses Lake, Wash. The cockpit location could be 60-ft. forward of the front landing gear, which would complicate turning the aircraft, Wilhite said.

TESTING OF THE SYNTHETIC vision concept is underway in a modified ground-based van on Boeing airfields near Seattle. A NASA Boeing 737 is operating with a second windowless cockpit, from which a crew can fly the aircraft with the aid of video and infrared vision. The Calspan SRL Corp. of Buffalo, N.Y., is modifying the Total Inflight Simulator aircraft, the USAF NC131H, a Convair 580 that simulates other aircraft, for use in the program.

NASA and industry participants are weighing the merits of two airframe structures—the traditional sandwich style of a honeycomb flanked by layers of composite materials and a skin-stringer design. The sandwich design, on its own, has the lightweight advantage, but the use of tear stoppers and frames required under damage tolerance considerations increases the weight. The skin-stringer design "is hanging in there" as an option in the competitive search, Wilhite said.

TO WITHSTAND THE AERODYNAMIC heating generated by supersonic speeds—up to 370F—the nose and leading edges would be made of titanium. But the researchers are looking at composites for other areas. For its computational aircraft, NASA adopts a polyimide PETI-5, a lightweight composite resin, that was developed at NASA Langley.

Tests are being conducted to meet a 60,000-hr. durability standard. PETI-5 has shown promise after the equivalent of 15,000 hr. A similar material, K-3B, has been tested up to 40,000 hr. in isothermal exercises (heat up to 350F for 4.5 hr.). In thermo-mechanical fatigue tests at Langley, the materials are subjected to heat and physical loads that are typical of the SST flight profile.



Computational High-Speed Civil Transport features a double delta wing and side windows. The aircraft is 320 ft. long with a wing span of 130 ft. and takeoff weight of 750,000 lb.

European Industry Pursues SST Technology Readiness

Folie 3a

PIERRE SPARACO/PARIS

Despite tight budget constraints in research and technology funding, Europe envisions building an all-new supersonic commercial transport that could enter service late in the next decade.

The European aircraft and engine manufacturers' advanced technology effort is complemented by national aerospace research agencies such as the British Defense Research Agency, Onera in France and DLR in Germany.

"Several years of technological research still are required before conceiving a viable next-generation SST [concept]. And, in the shorter term, the ultra-high-capacity Airbus A3XX will remain Europe's primary goal [in the commercial transport market]," said Elie Khaski, supersonic program manager at Aerospatiale.

Airbus Industrie tentatively plans to launch the 555-seat A3XX in the next two years to meet the proposed 2002 service entry date. The aircraft's development cost is estimated at $8 billion.

Daimler-Benz Aerospace joined Aerospatiale and British Aerospace (the two companies that produced the French-British Concorde) in the European Supersonic Research Program (ESRP). In addition, Rolls-Royce and Snecma, which developed Concorde's Olympus 593 turbofan engine, are considering new engine designs that could be used to power an efficient Mach 2 long-range aircraft.

However, Europe is investing no more than an estimated $12 million per year on ESRP exploratory work, exclusive of company-funded research and technology spending. Although Europe acquired a unique expertise in developing and operating the Concorde, it now lags behind the U.S., industry officials said. They cited the NASA/Boeing-funded Tupolev Tu-144 tests underway in Russia that also involve Pratt & Whitney and General Electric (*AW&ST* Sept. 8, p. 50).

The Europeans' primary goal today is to better assess major carriers' long-term fleet requirements, gather their views on foreseeable supersonic operations and refine a market forecast. Such input will help in determining the next-generation supersonic transport's economical feasibility.

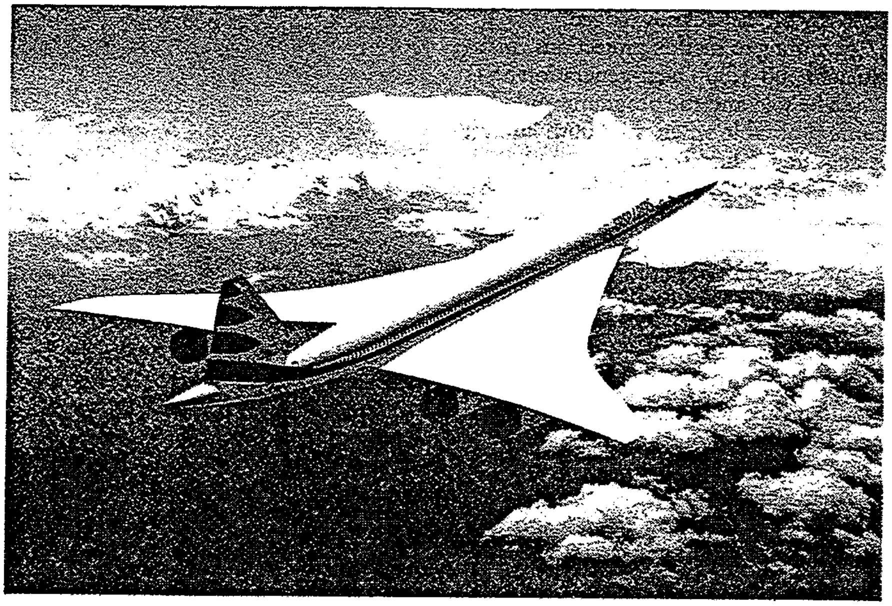
Potential sales will depend largely on the envisioned aircraft's direct operating costs (DOC) and compatibility with environmental issues. "In the absence of a specific timeframe, this is an unusual challenge," a company executive acknowledged.

> Europe's baseline is a Mach 2, 250-seat aircraft with a 5,500-naut.-mi. range

According to Khaski, several years of research and technology work still are required before a decision can be made on whether to start an industrial program. This viewpoint is shared by other airframe and engine manufacturers, he said.

Discussions with major international airlines, travel agents and air travel panels in the last few years clearly indicated a desire to cut flight time on long-haul routes. Today, the European industry's baseline is a Mach 2 cruise speed, 250-seat aircraft with a 5,500-naut.-mi. range.

Although higher capacity theoretically could be required for an aircraft expected to enter service late in the next decade, a bigger airframe would further complicate noise-related issues as well as the primary goal of transpacific-class maximum range.



European airframe and engine manufacturers' joint research effort is centered on a 2-3-class, 250-seat, Mach 2 cruise speed aircraft concept.

The envisioned European SST is expected to be operated in 2-3-class cabin configuration, with a still unspecified "high-speed premium" added to subsonic service fares. "The Europeans are not envisioning a supersonic commercial transport that would be used only by 'elite travelers.' It should carry a full mix of passengers. We are talking about an aircraft just like the others," Khaski said.

EARLIER FEASIBILITY STUDIES were conducted around a Mach 2.4 aircraft concept. "But Mach 2 is a wiser choice. For example, on transatlantic routes, at Mach 2.4 cruise speed, flight time would be reduced no more than 20 min. but the aircraft's DOC would be significantly higher," he noted. "In addition, we plan to evaluate the merits of a Mach 1.6 cruise speed aircraft."

Development costs are estimated at $15 billion. However, according to European industry officials, the next-generation SST's cost will depend largely on initial investment in technology readiness. The ongoing effort involves a variety of disciplines such as advanced propulsion sys-

Folie 3b

tems, new materials, innovative aerodynamics, as well as enhanced fly-by-wire flight controls.

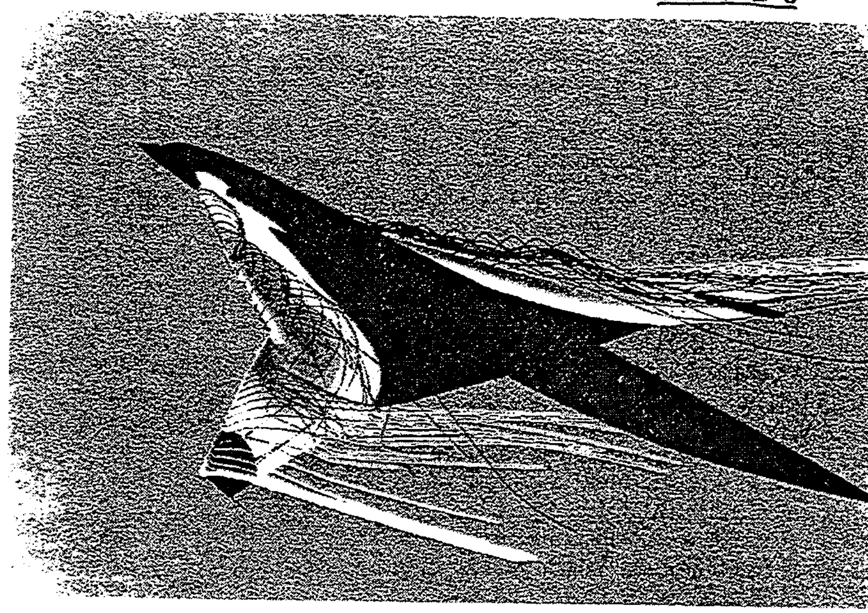
Development costs will be lower than current estimates if technology readiness is a strong reality by the time the program obtains go-ahead. However, increased funding is required to acquire new technology. "This looks like an unusual challenge, not to say a vicious circle," a French industry official acknowledged.

According to market projections, an estimated 500-1,000 next-generation SSTs could be sold and the program would become profitable when the 600th aircraft is delivered, Khaski said.

IN THE LAST FEW YEARS, Rolls-Royce and Snecma, joined by Italy's FiatAvio and Germany's Motoren- und Turbinen-Union, refined preliminary studies centered on the envisioned Mid-Tandem-Fan variable-cycle engine concept. The MTF's maximum takeoff thrust would be in the 50,000-60,000-lb. range. Bypass ratio would be about 2 for takeoff and climb, and decrease to about 1 during the Mach 2 cruise phase.

Khaski said low specific fuel consumption must be achieved at high subsonic speeds (for example, at Mach 0.95) to ensure the economic viability of the aircraft.

"Although no regulations have been determined yet, environmental constraints are playing a critical role in the ongoing technology effort," said Eric Portejoie, who heads Snecma's advanced commercial programs.



ONERA

France's Onera is participating in the European Supersonic Research Program, especially in aerodynamics. However, funding remains weak.

Snecma's current research work is focusing on combustor design and oxides of nitrogen levels. Noise and emissions are linked directly to the engine's power, weight and size.

The MTF's basic characteristics would play a critical role in the airframe's overall design. However, at this very early stage, airframe manufacturers have not determined a specific power requirement, Portejoie noted. "To some extent, we're in the waiting mode."

In addition to in-house studies and the ESRP, Snecma established direct partnership links with Boeing that are focusing on potential "show-stoppers" and more specific issues such as acoustics. The engine's fan is a major contributor to noise levels and also imposes constraints on the nacelle's size and aerodynamics, Portejoie noted.

IN THE SAME VEIN, Rolls-Royce worked closely with McDonnell Douglas' design office. In the wake of the Boeing/McDonnell Douglas merger, such partnership agreements are expected to be revised or unified.

In the early 1990s, McDonnell Douglas also evaluated the merits of a Mach 1.6 cruise speed commercial transport. The lower supersonic speed concept required less power and led to a smaller air intake.

"It would be even more difficult to 'hide' the engine's core behind a smaller air intake," Portejoie noted. But a Mach 1.6 aircraft would operate at lower cruise altitude than a Mach 2 aircraft, and the impact on the ozone layer would be significantly reduced, he added.

Snecma's high-speed flight research and technology efforts also briefly included a quick look at the propulsion requirements of the supersonic business aircraft concept proposed by the Sukhoi design bureau.

The French company may now participate in Dassault Aviation's feasibility studies, which is expected to pave the way for a Mach 1.8 cruise speed business trijet (see story at left). Snecma's engine could be based on the M88, a 7.5-metric-ton-thrust turbofan that powers Dassault Aviation's Rafale combat aircraft.

Dassault Assesses Outlook For Supersonic Bizjet

Dallas

Dassault Aviation has initiated a study to determine whether corporate aviation is ready for a supersonic business jet.

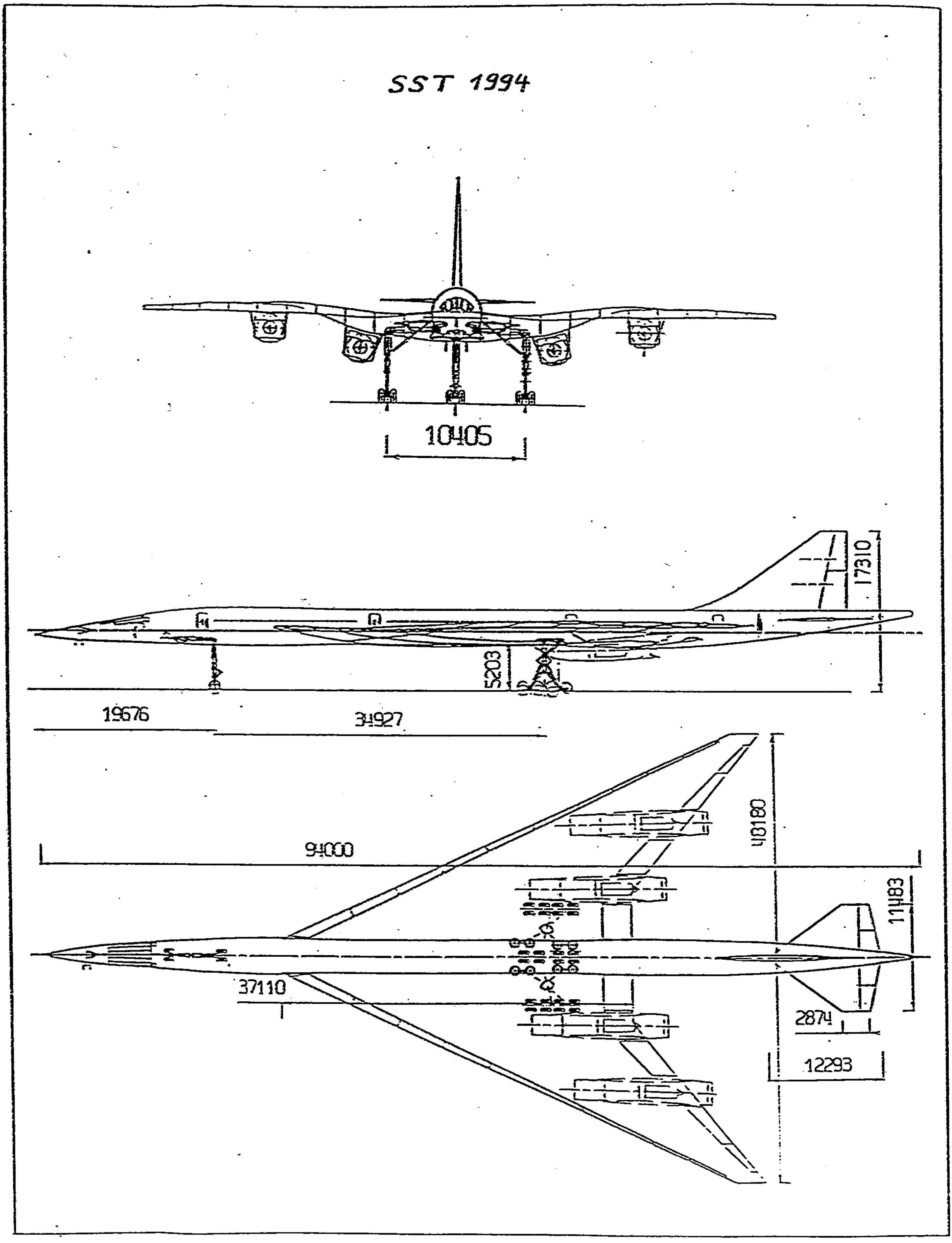
The French manufacturer said it will initially poll Falcon Jet operators, and then other corporate jet operators, to assess the operational feasibility of the supersonic business aircraft. A second study will look at the technical feasibility of building the jet. If the studies determine that there is a market for the aircraft, it could be operational in about 10 years. The potential impact on the ozone layer and the sonic boom issues will be looked at during the studies.

While Dassault has not decided on a configuration for the aircraft, earlier studies indicate that the supersonic business jet must have a range near 4,000 naut. mi., a minimum cabin size for eight people and use three nonafterburning engines. Target speed would be Mach 1.8.

Dassault also plans to discuss risk-sharing opportunities with other companies. Dassault would prefer to team with a U.S. company with experience in building supersonic aircraft. Dassault has a long heritage of building supersonic military aircraft. Other risk-sharing partners will be considered to supply engines, avionics and aircraft systems.

The most recent effort to develop a supersonic business jet was a teaming of Gulfstream Aerospace and Russia's Sukhoi in the late 1980s. The Sukhoi-Gulfstream concept had four engines. The effort faded with a combination of factors—the buyout of Gulfstream, development risk and the lack of money in the former Soviet Union.

Folie 4


SST 1994
10405
17310
5203
19676
34927
94000
48180
11483
37110
2874
12293

Tabellarische Gegenüberstellung der wichtigsten technischen Daten und Abmessungen

Daten	CONCORDE		SST 1994	
Flügelspannweite	25,60	m	48,18	m
Flügelfläche	358,25	m²	956,24	m²
Gesamtlänge	62,12	m	94,0	m
Spurweite	7,71	m	10,48	m
Flügelstreckung	1,7		2,4	
max. Startgewicht	181 440	kg	336 761	kg
max. Landegewicht	79 270	kg	186 500	kg
Nutzlast	11 340	kg	23 655	kg
Betriebsleergewicht	145 156	kg	179 270	kg
Kraftstoffvorrat	95 430	kg	ca. 150 000	kg
max. Reiseflughöhe	15 - 18	km	18 - 22	km
max. Reisegeschwindigkeit	2,02	Ma	2,4	Ma
Unterschall - Reisegeschwindigkeit	0,93	Ma	0,95	Ma
Startstrecke	3 170	m	ca.3 000	m
max. Reichweite	5 953	km	10000-11000	km
max. Sitzzahl	144		ca.250	
<u>Betriebslärm</u>:				
Start : 6,5 km vom Beginn des Rollens	118	dB	-	
Abflug: 1,85 km von der Landeschwelle	112	dB	-	
0,65 km seitl. Pistenmittelinie	115	dB	-	
<u>Triebwerke</u>:				
Startschub	170	KN	ca.265	KN
Reiseschub	45,5	KN	ca. 71	KN
Grundgewicht, trocken	2762	kg	3961	kg

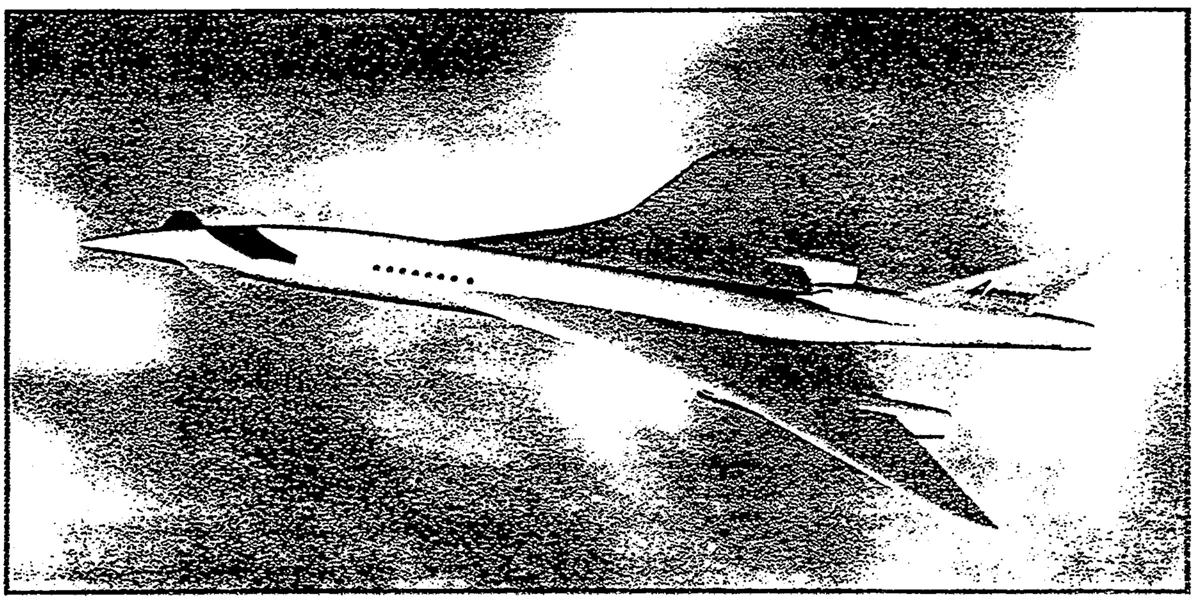
Folie 6

1st July '98

Dassault reveals more about its proposed supersonic business jet

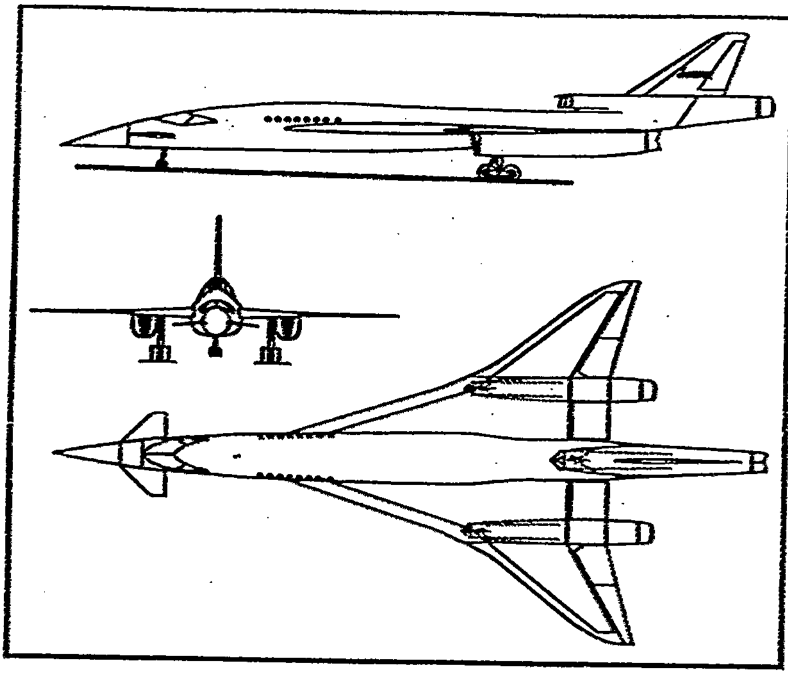
by R. Randall Padfield

In September 1997, Dassault Aviation and its U.S. arm, Dassault Falcon Jet, surprised attendees of the National con operators' Maintenance & Operations Seminar scheduled for May this year. On May 19, before an audience of nearly 1,000, the French airframer made good on its promise.



Dassault's initial design concept for a supersonic Falcon business jet resembles–perhaps not surprisingly–previous SSBJ designs of Gulfstream, Sukhoi and British Aerospace. Performance specs call for a 4,000-nmi range at Mach 1.8.

Folie 7



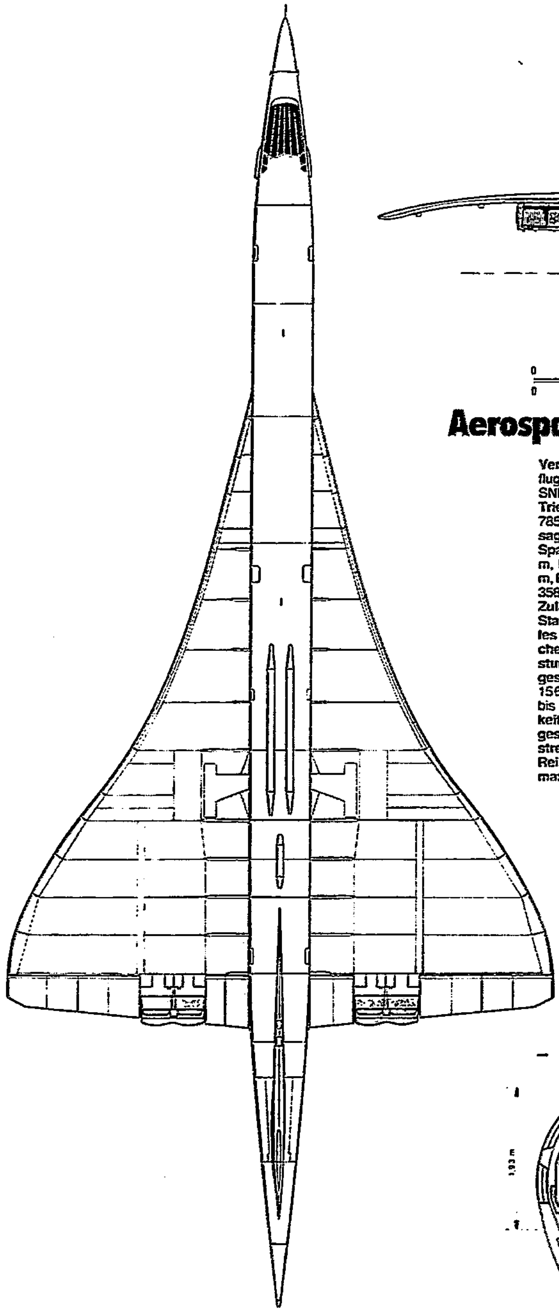
DASSAULT SUPERSONIC BUSINESS JET

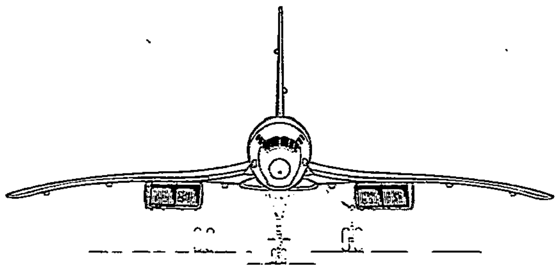
Preliminary Specifications and Performance

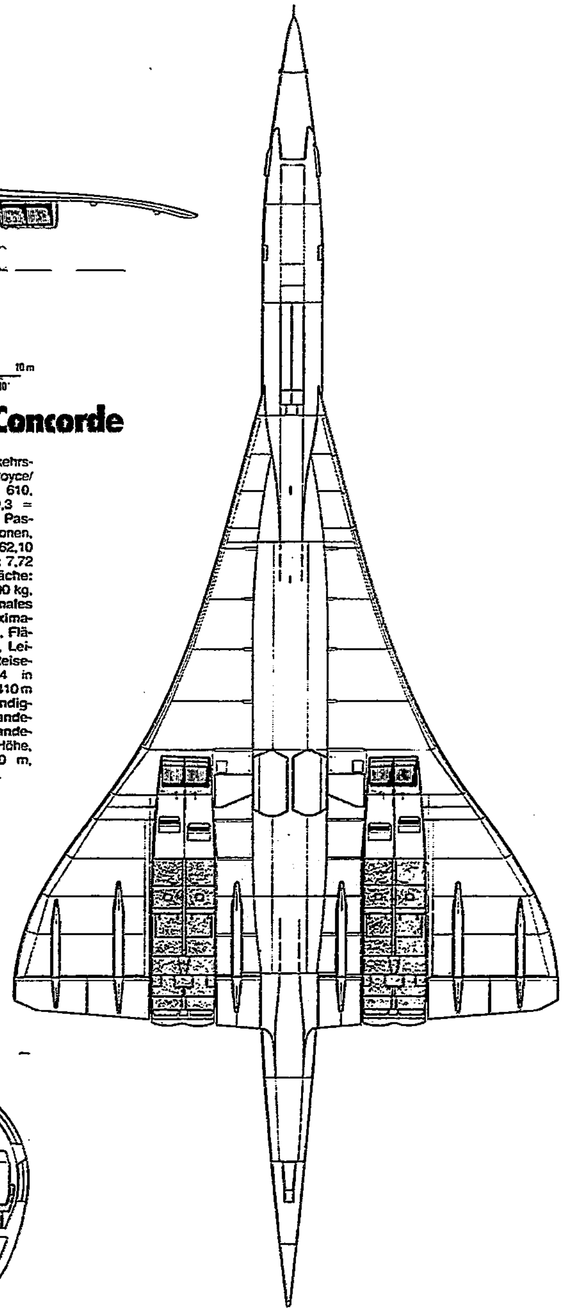
Engines	Three non-afterburning engines 12,000 lb static thrust each
Weights	
Max takeoff	85,826 lb
Max zero fuel	40,026 lb
Empty	37,600 lb
Fuel capacity (6,836 gal)	45,800 lb
Crew	826 lb
Passengers (eight)	1,600 lb
External dimensions	
Wingspan	55.6 ft
Length overall	104 ft
Wing area	1,400 sq ft
Internal cabin dimensions*	
Max height	5.9 ft
Max width	6.1 ft
Length (excluding cockpit)	23.5 ft
Cruise performance	
Supersonic cruising speed	Mach 1.8
Transonic cruising speed	Mach 0.95
Range at Mach 1.8 *(two crew, eight pax, NBAA IFR reserves)*	4,000 nmi
Operating altitude	60,000 ft (est.)

Erstflug Prototyp 9.4.69
Vorserie 17.12.71
Serie 6.12.73
Linie 21.1.76

Folie 8



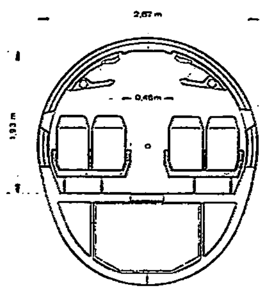




0 2 4 6 8 10 m
0 10 20 30'

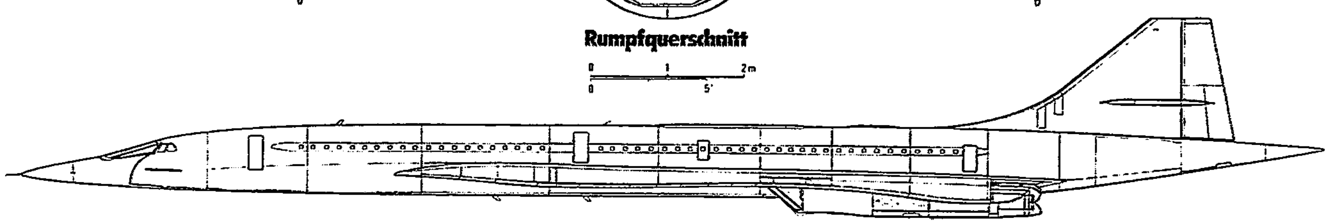
Aerospatiale/BAC Concorde

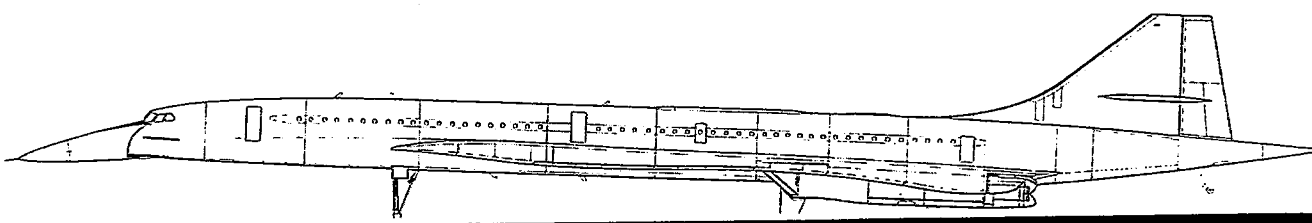
Verwendung: Überschall-Verkehrsflugzeug, **Triebwerk:** 4 Rolls-Royce/SNECMA Olympus 593 Mk. 610. **Triebwerkleistung:** 4 × 169,3 = 785,2 kN, **Besatzung:** 4 Mann, **Passagierkapazität:** 118 Personen, **Spannweite:** 25,56 m, **Länge:** 62,10 m, **Höhe:** 11,40 m, **Spurweite:** 7,72 m, **Radstand:** 18,19 m, **Flügelfläche:** 358,25 m², **Rüstgewicht:** 78700 kg, **Zuladung:** 106365 kg, **maximales Startgewicht:** 185065 kg, **maximales Landegewicht:** 111130 kg, **Flächenbelastung:** 516,58 kg/m², **Leistungsbelastung:** 2,35 kg/kN, **Reisegeschwindigkeit:** Mach 2,04 in 15635 m Höhe, **Startstrecke:** 3410 m bis 10,6 m Höhe, **Steiggeschwindigkeit:** 25,41 m/s in Bodennähe, **Landegeschwindigkeit:** 300 km/h, **Landestrecke:** 2220 m aus 10,6 m Höhe, **Reiseflughöhe:** 15500–18290 m, **maximale Reichweite:** 6580 m.



Rumpfquerschnitt

0 1 2 m
0 5'





siehe PIETRASS, Jahrbuch 1964 WGLR (S. 216 – 222)

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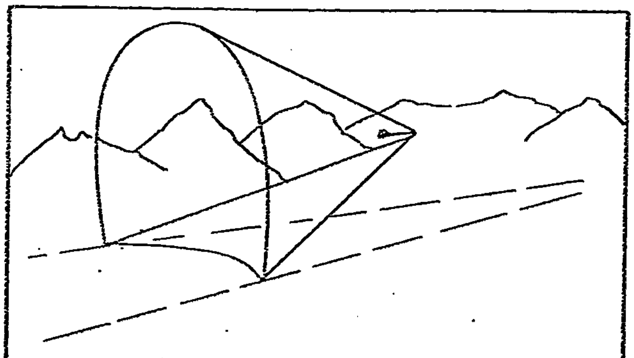
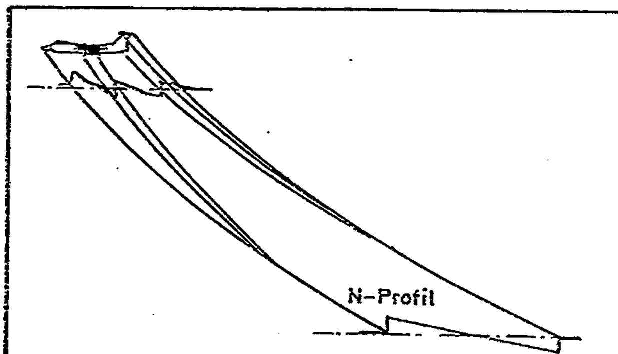

Stoßwellenfläche und Stoßfront am Boden



Schalldruck in der Nähe des Flugzeugs und am Boden

Theorie zur Berechnung des Schallknalls nach WHITHAM/WALKDEN:

Potentialgleichung in Zylinderkoordinaten x, r

$$\phi_{rr} + \frac{1}{r}\phi_r - (Ma^2 - 1)\cdot \phi_{xx} = 0$$

Lösung durch Störpotential

$$\phi = -\int_0^{x-\alpha r} \frac{f(\tau)\,d\tau}{(x-\tau)^2 - \alpha^2 r^2} \qquad \alpha^2 = Ma^2 - 1$$

Drucksprung in großer Entfernung nach WHITHAM

$$\frac{\Delta p}{p_\infty} = \underbrace{\frac{2^{1/4}\cdot k}{(k+1)^{1/2}}}_{1{,}075} \cdot \frac{(Ma^2-1)^{1/8}}{H^{3/4}} \left[\int_0^{\xi_0} F(\xi)\,d\xi\right]^{1/2} \qquad k = \frac{c_p}{c_v} = 1{,}4$$

$r \Rightarrow H$ Flughöhe

Rumpf-äquivalenter Rotationskörper

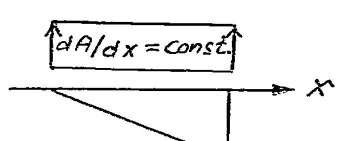
$$F(\xi) = \frac{1}{2\pi}\int_0^{\xi} \frac{S''(\tau)}{\sqrt{\xi - \tau}}\,d\tau \; ;$$

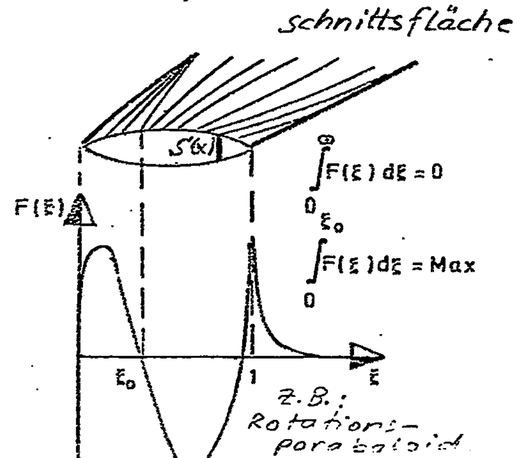
S: Verlauf der Querschnittsfläche

Flügel-Auftriebsstiefenverteilung

$$F(\xi) = \frac{1}{2\pi}\int_0^{\xi} \frac{\sqrt{Ma^2-1}}{k\,Ma^2}\,\frac{dA}{dx}\,\frac{1}{p_H}\,\frac{d\tau}{\sqrt{\xi-\tau}}$$

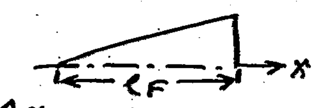
z. B. Deltaflügel



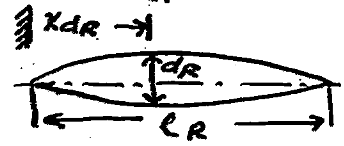


Gleichung für den Schalldruck einer Kombination

aus Flügel : $\frac{dA}{dx} = 0$: $A(x) = \text{const.}$



und Rumpf : Rotationsparaboloid



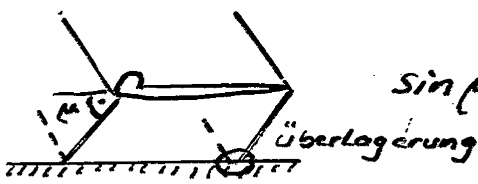
Abnahme mit der Flughöhe

$$\Delta p_K = \sqrt{p_H \cdot p_0} \cdot K_R \cdot (Ma^2 - 1)^{1/8} \cdot \left[K_V^2 \left(\frac{d_R}{l_R}\right)^2 \cdot \left(\frac{l_R}{H}\right)^{3/2} + K_A^2 \cdot \frac{(Ma^2-1)^{1/2}}{Ma^2} \cdot \frac{mg}{p_H \cdot l_F^2} \cdot \left(\frac{l_F}{H}\right)^{3/2} \right]^{1/2}$$

(PIETRASS/KLOSTER)

$$\frac{mg}{p_H \cdot l_F^2} = \frac{mg}{p_H \cdot S} \cdot \frac{\Lambda_\Delta}{4}$$

$\frac{mg}{p_H \cdot S}$: Flächenbelastung; Λ_Δ: Streckung Delta-F.

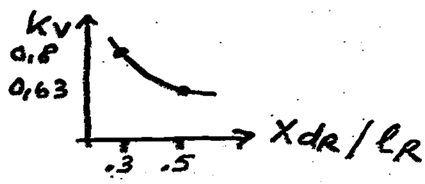


$\sin\mu = \frac{1}{Ma}$

$k_R < 2$ z.B. 1,9 oder $K_R = 1 + \frac{1}{Ma}$ Reflexionsfaktor

$K_A \approx 0{,}6 \approx \text{const.}$ Faktor für real. Auftriebsverteilung

$K_V \approx 0{,}8$ für $x_{dR} \approx 0{,}2$



Ma : Machzahl

H : Flughöhe in [m]

p_H : Luftdruck in Flughöhe in [Pa]

$p_0 = 101325$ [Pa] (ISA, SL) oder aktueller

d_R : Rumpfdurchmesser (dickster) in [m]

l_R : Rumpflänge bzw. Flugzeuglänge in [m]

l_F : Flügeltiefe innen für $\frac{A}{l_F} = \text{const.}$ in $\left[\frac{N}{m}\right]$

$m \cdot g$: Fluggewicht in [N] stationär horizontal $m \cdot g = A$

Verstärkung bzw. Verminderung bei instationären Flugmanövern bzw. auch durch günstiges und ungünstiges Zusammenwirken der Einzelstörungen am Flugzeug Rumpf – Flügel – Leitwerk – Ecken ...
Fokussierung: $\Delta p_{max} = 300 \cdots 750$ Pa (Gebäudeschäden)

$\Delta p = 50$ Pa : erträglich

$\Delta p \geq 100$ Pa : Fensterscheibenbruch möglich nach PIETRASS

$\Delta p\ [kp/m^2]$ $\cdot 10\ [Pa]$	Schäden	vergleichbare Geräusche
1000÷500	Schäden an primären Strukturen bei Explosionswellen	Kanonenschuß in unmittelbarer Nähe
500÷50	Sichere Zerstörung kleiner Fenster	
50÷15	Verbreitete Fenster und Putzschäden, Rißausbreitung in Decken u. Wänden	
15÷10	Fenster und Putzschäden in Einzelfällen	naher Donner
10	keine Schäden	entfernter Donner

$$L = 20 \cdot \log \frac{\Delta p\,[Pa]}{p_0\,[Pa]} = 20 \cdot \log \frac{I\,[\frac{W}{m^2}]}{I_0\,[\frac{W}{m^2}]}$$

Schalldruck Schallintensität

$p_0 = 20 \cdot 10^{-6}\,[Pa]$ $I_0 = 10^{-12}\,[\frac{W}{m^2}]$

Wahrnehmungsgrenze

$\Delta p\,[Pa]$	$20_{10}{}^{-6}$	1	10	20	30	40	50	60	70	80	90	100	110	120
L [dB]	0	94	114	120	124	126	128	130	131	132	133	134	135	136

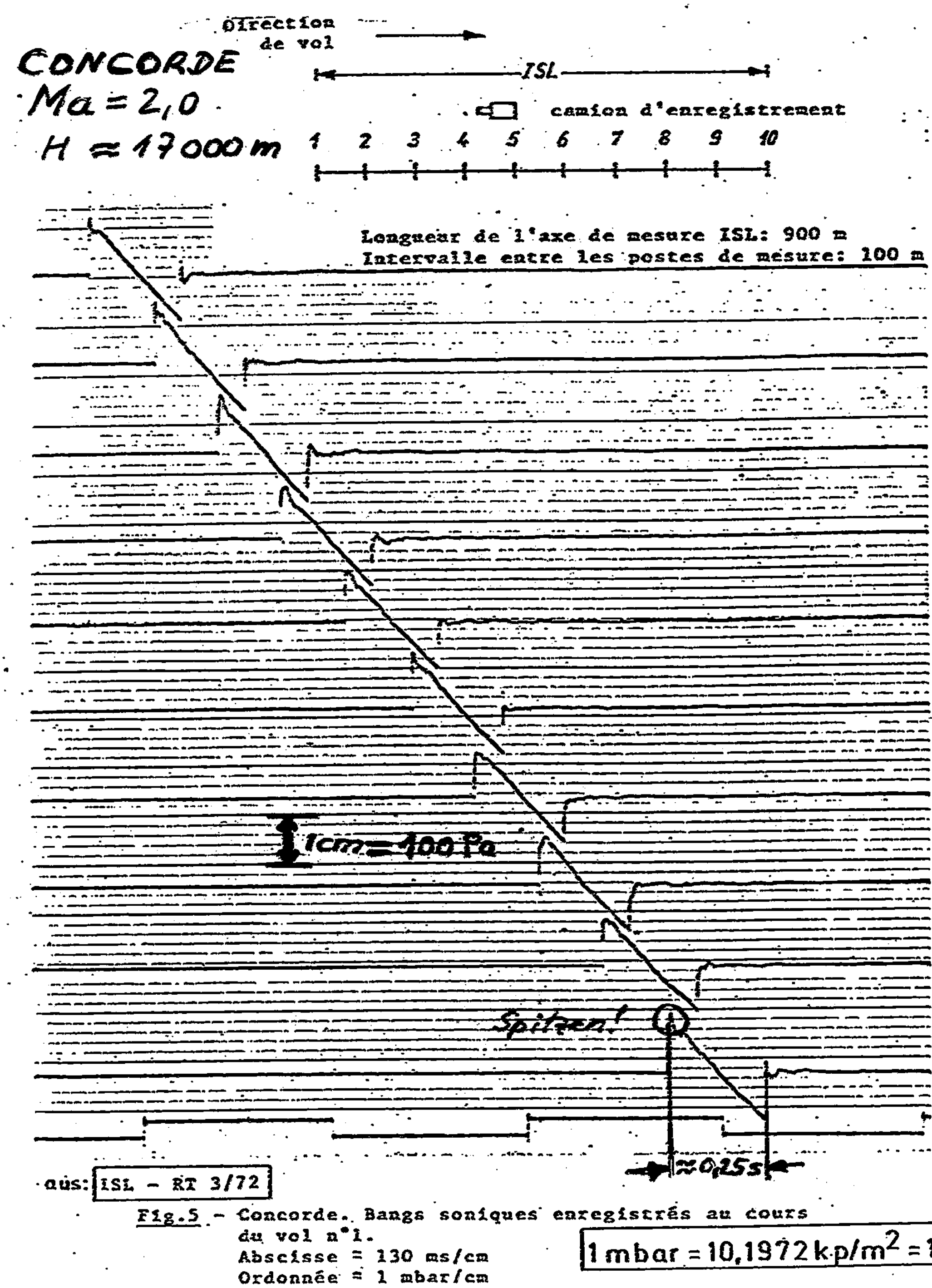
gerundete Werte

← −4 dB →

120 dB: vom Gehör kurzzeitig noch toleriertes Geräusch (ohne Schädigung)

nach NIESEL, Prakt. Techn. Akustik

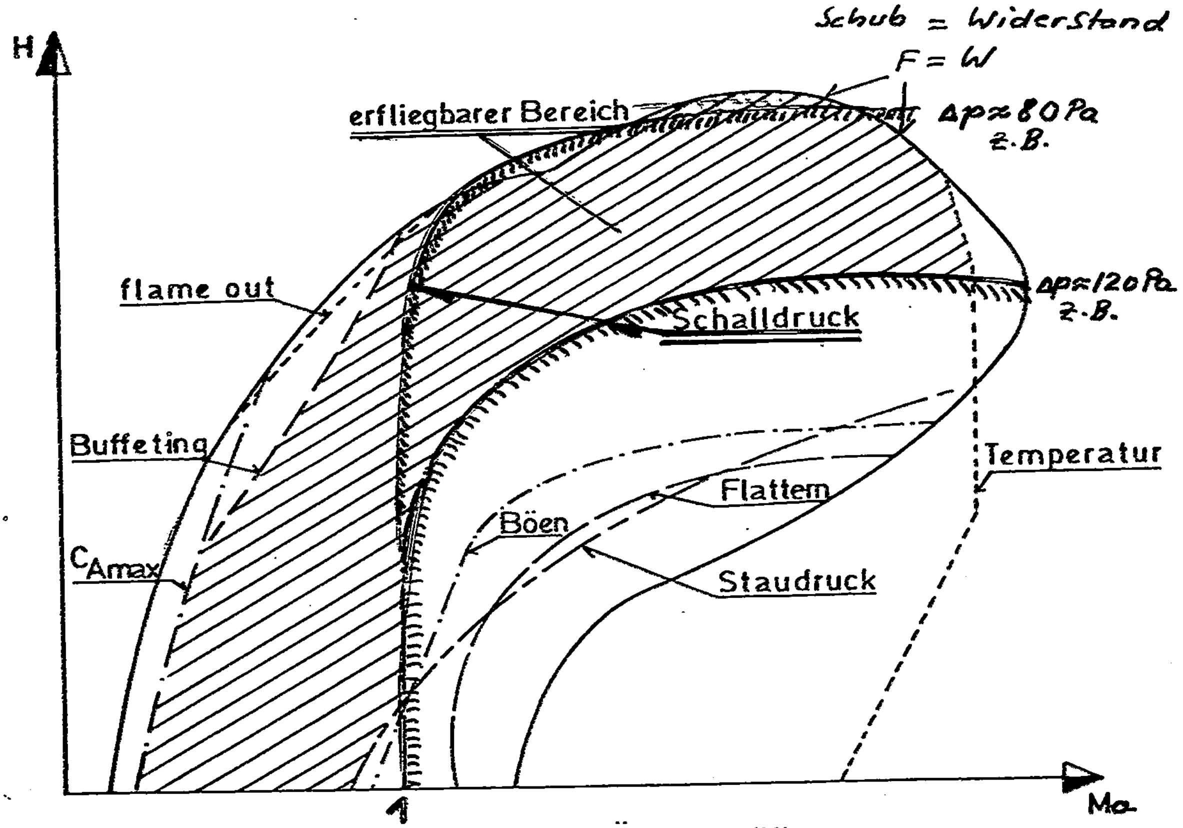
Folie 12



aus: ISL - RT 3/72

Fig.5 - Concorde. Bangs soniques enregistrés au cours du vol n°1.
Abscisse = 130 ms/cm
Ordonnée = 1 mbar/cm

1 mbar = 10,1972 kp/m^2 = 10^2 Pa



Begrenzungen des Flugbereichs für Überschallflugzeuge

FAA - Grenzwerte

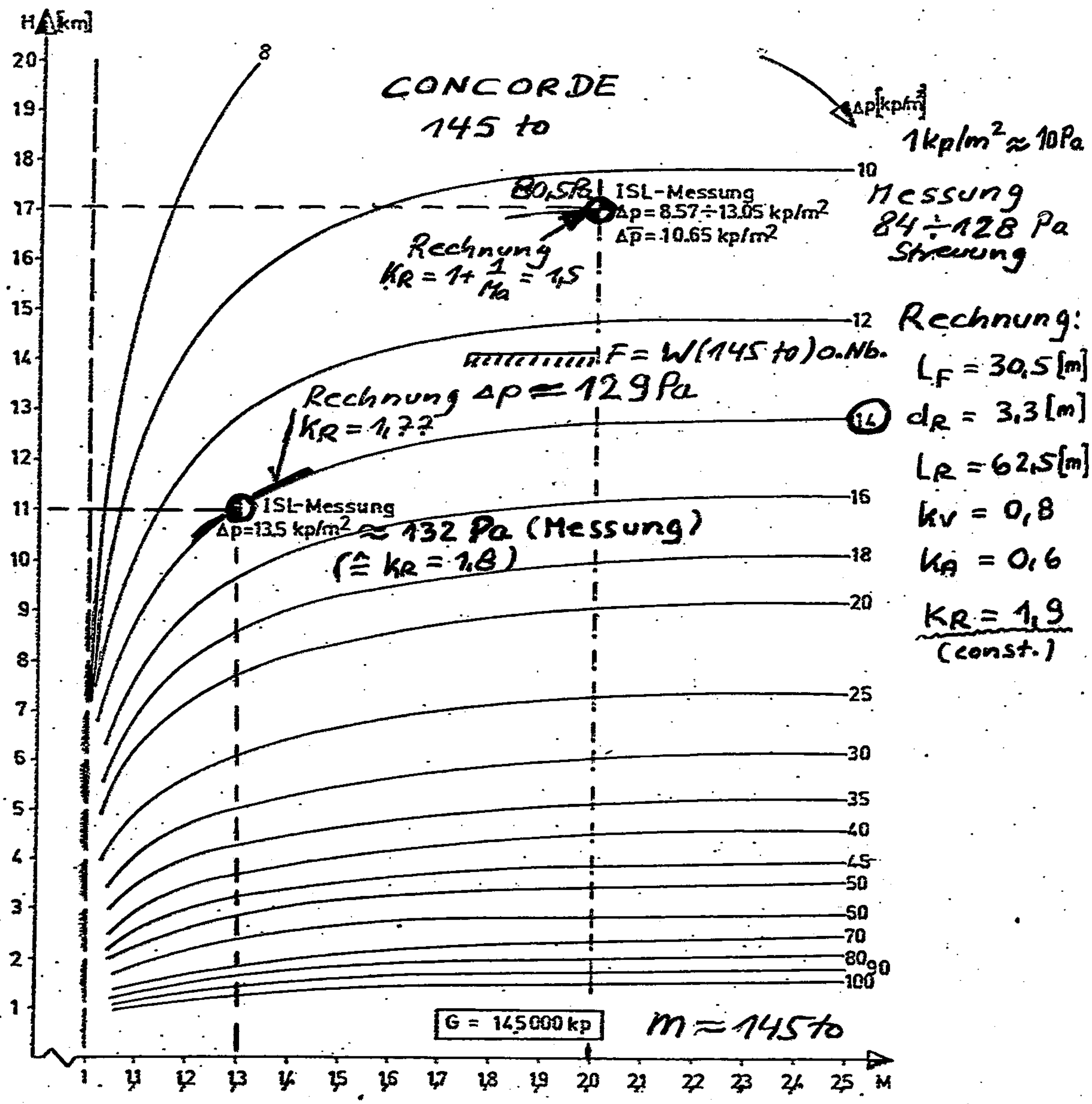
nach PIETRASS 36 WGLR 1964

Steigflug 9,8 kp/m² ≙ 96 Pa
Reiseflug 7,3 kp/m² ≙ 72 Pa

Inland-Operationen
8,8 kp/m² ≙ 86 Pa
6,4 kp/m² ≙ 63 Pa

nach ELBEL Luftfahrttechnik · Raumfahrttechnik 13 (1967) Nr 9

Steig-/Beschl. flug 12,2 kp/m² ≙ 120 Pa
Reiseflug 8,3 kp/m² ≙ 81 Pa



$$\Delta p_K = \sqrt{p_H p_o}\, K_R (M^2-1)^{1/8} \left[K_V^2 \left(\frac{d_R}{l_R}\right)^2 \left(\frac{l}{H}\right)^{3/2} + \frac{(M^2-1)^{3/2}}{M^2} K_A^2 \frac{G}{p_H l_F^2} \left(\frac{l_F}{H}\right)^{3/2} \right]^{1/2}$$

Linien konstanten Schalldrucks am Boden im Höhen-Machzahl-Diagramm für das Flugzeugmuster CONCORDE mit der kombinierten Gleichung

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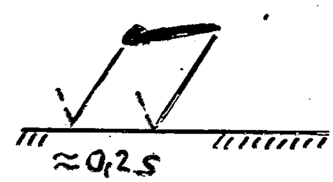
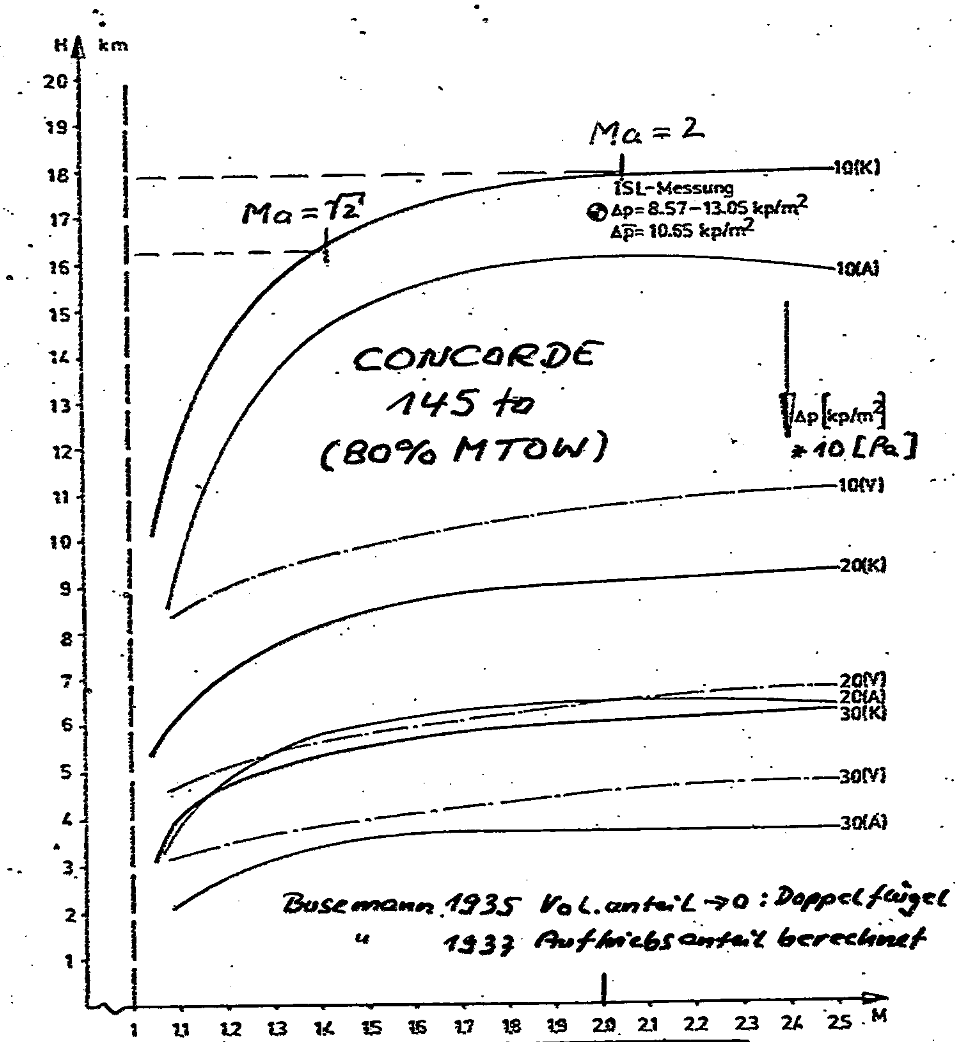
Benutzte Näherung für Machzahl-Abhängigkeit des Reflektionsfaktors

$$K_R = 1 + \sin\mu = 1 + \frac{1}{Ma}$$





$$\Delta p_K = \gamma\sqrt{p_H p_0}\, K_R\, (M^2-1)^{1/8}\left[K_V^2\left(\frac{d}{l}\right)^2\left(\frac{l}{H}\right)^{3/2} + \frac{(M^2-1)^{3/2}}{M^2} K_A^2\, \frac{G}{p_H\, l_F^2}\left(\frac{l_F}{H}\right)^{3/2}\right]^{1/2}$$

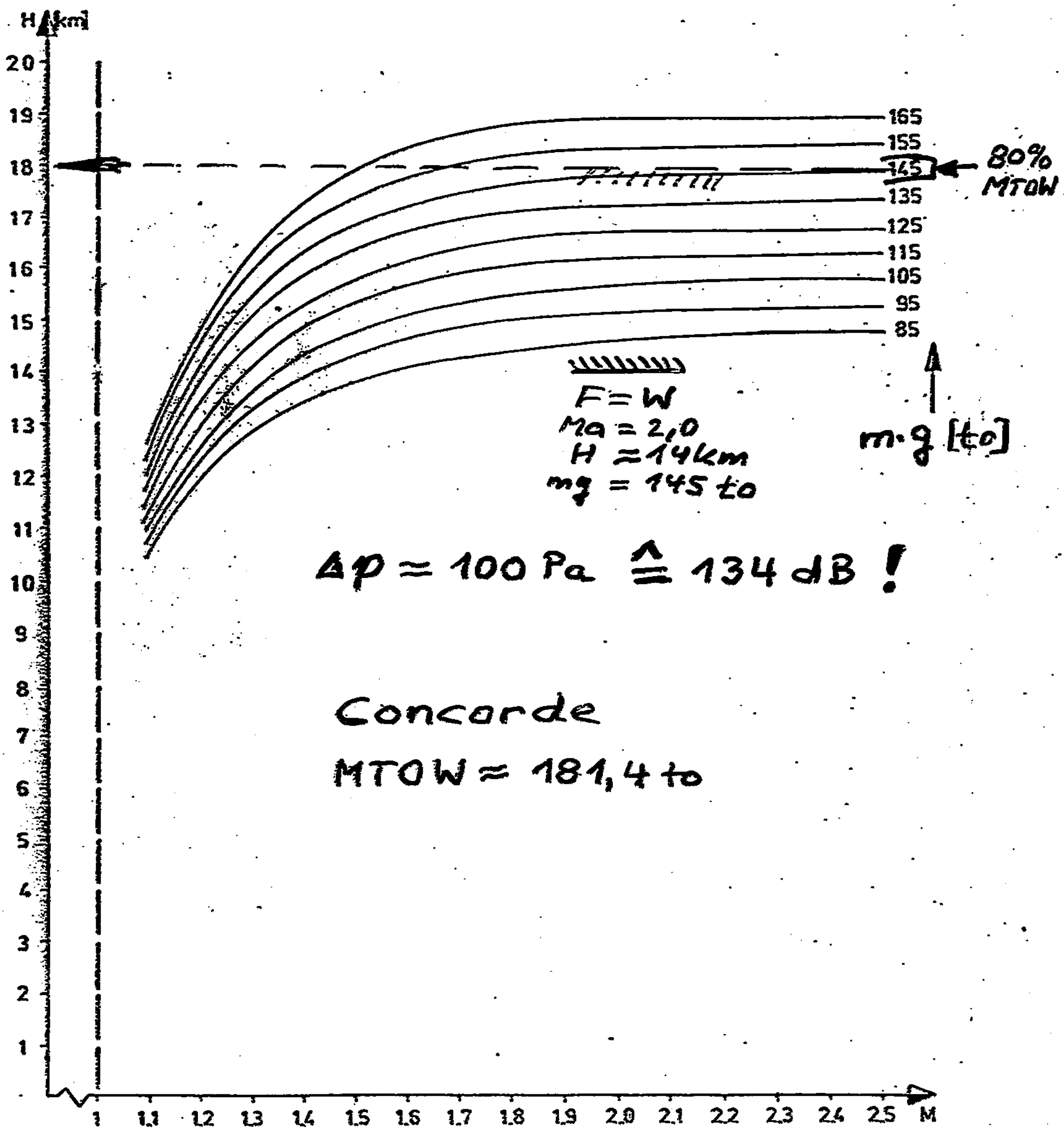
$$\Delta p_V = \gamma\sqrt{p_H p_0}\, K_R\, (M^2-1)^{1/8}\left[K_V^2\left(\frac{d}{l}\right)^2\left(\frac{l}{H}\right)^{3/2}\right]^{1/2}$$

$$\Delta p_A = \gamma\sqrt{p_H p_0}\, K_R\, (M^2-1)^{1/8}\left[\frac{(M^2-1)^{3/2}}{M^2} K_A^2\, \frac{G}{p_H\, l_F^2}\left(\frac{l_F}{H}\right)^{3/2}\right]^{1/2}$$

Volumenanteil : Rumpf ≙ Rotationsparaboloid mit $\frac{d_R}{l_R}$

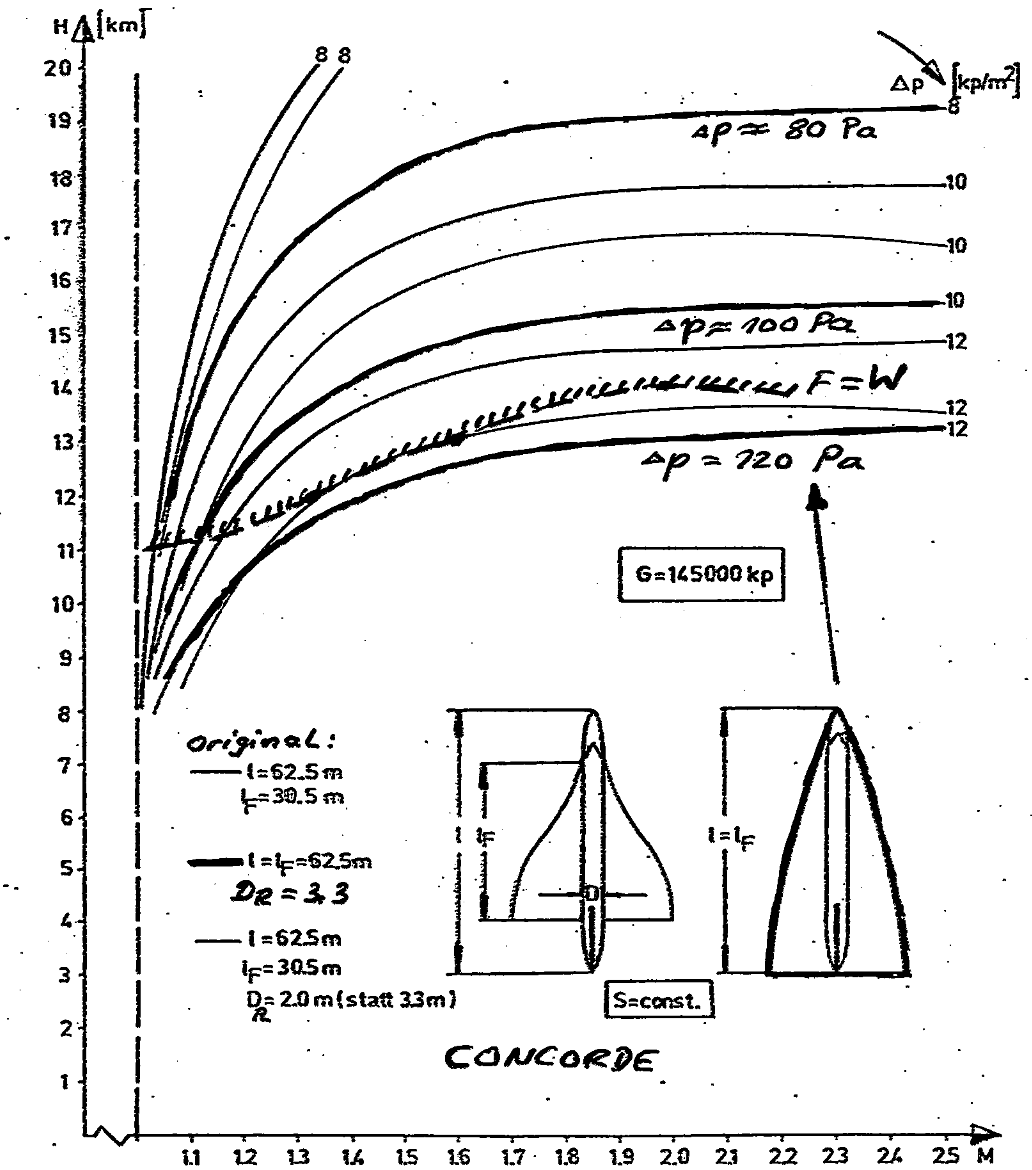
Auftriebsanteil : Auftrieb nach Theorie schlanker Körper für Ogeeflügel konstant über der Flügelmittellinie angenommen

$$\frac{dA}{dx} = \frac{m \cdot g}{l_F} = const.$$

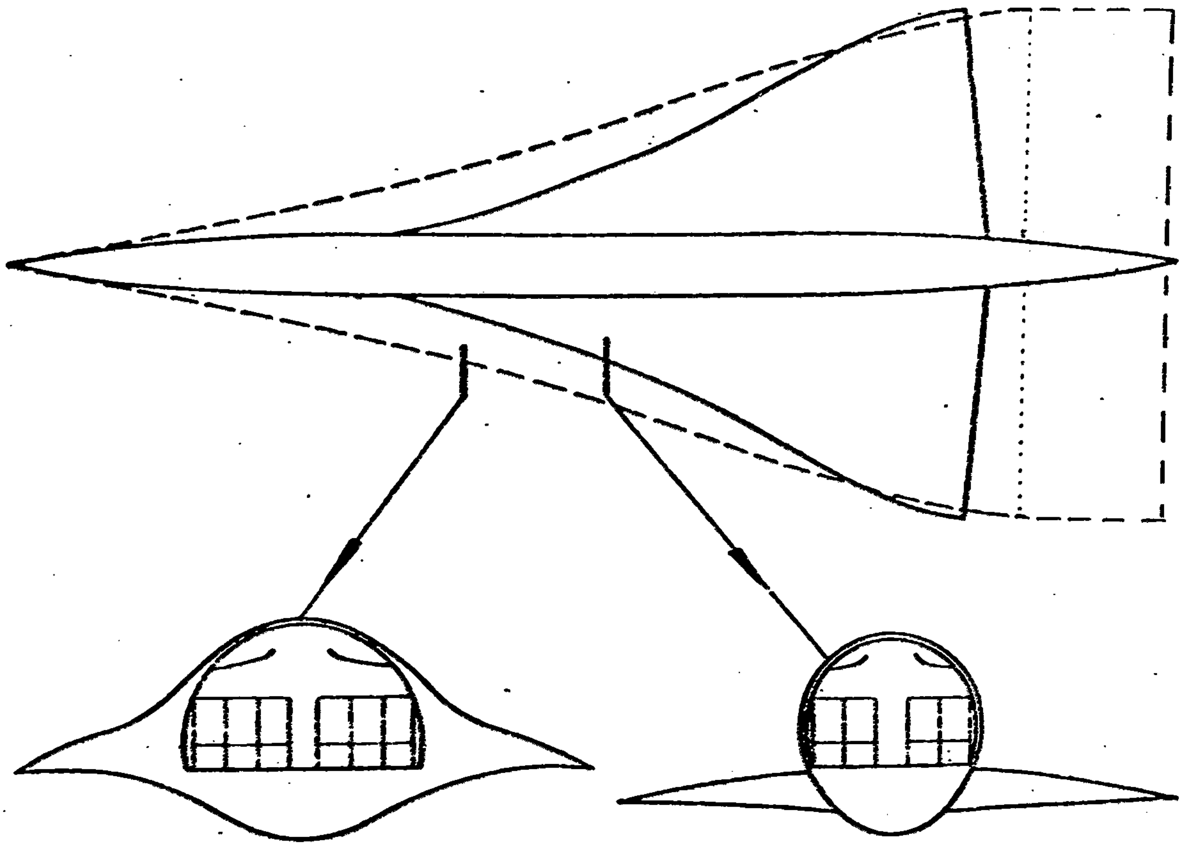


$$\Delta p_K = \sqrt{p_H p_0}\, K_R\, (M^2-1)^{1/8} \left[K_V^2 \left(\frac{d}{l}\right)^2 \left(\frac{l}{H}\right)^{3/2} + \frac{(M^2-1)^{3/2}}{M^2} K_A^2 \,\frac{G}{p_H\, l_F^2} \left(\frac{l_F}{H}\right)^{3/2} \right]^{1/2}$$

Folie 17



$$\Delta p_K = \sqrt{p_H p_o}\, K_R\, (M^2-1)^{1/8} \left[K_V^2 \left(\frac{d}{l}\right)^2 \left(\frac{l}{H}\right)^{3/2} + \frac{(M^2-1)^{3/2}}{M^2} K_A^2\, \frac{G}{p_H\, l_F^2} \left(\frac{l_F}{H}\right)^{3/2} \right]^{1/2}$$



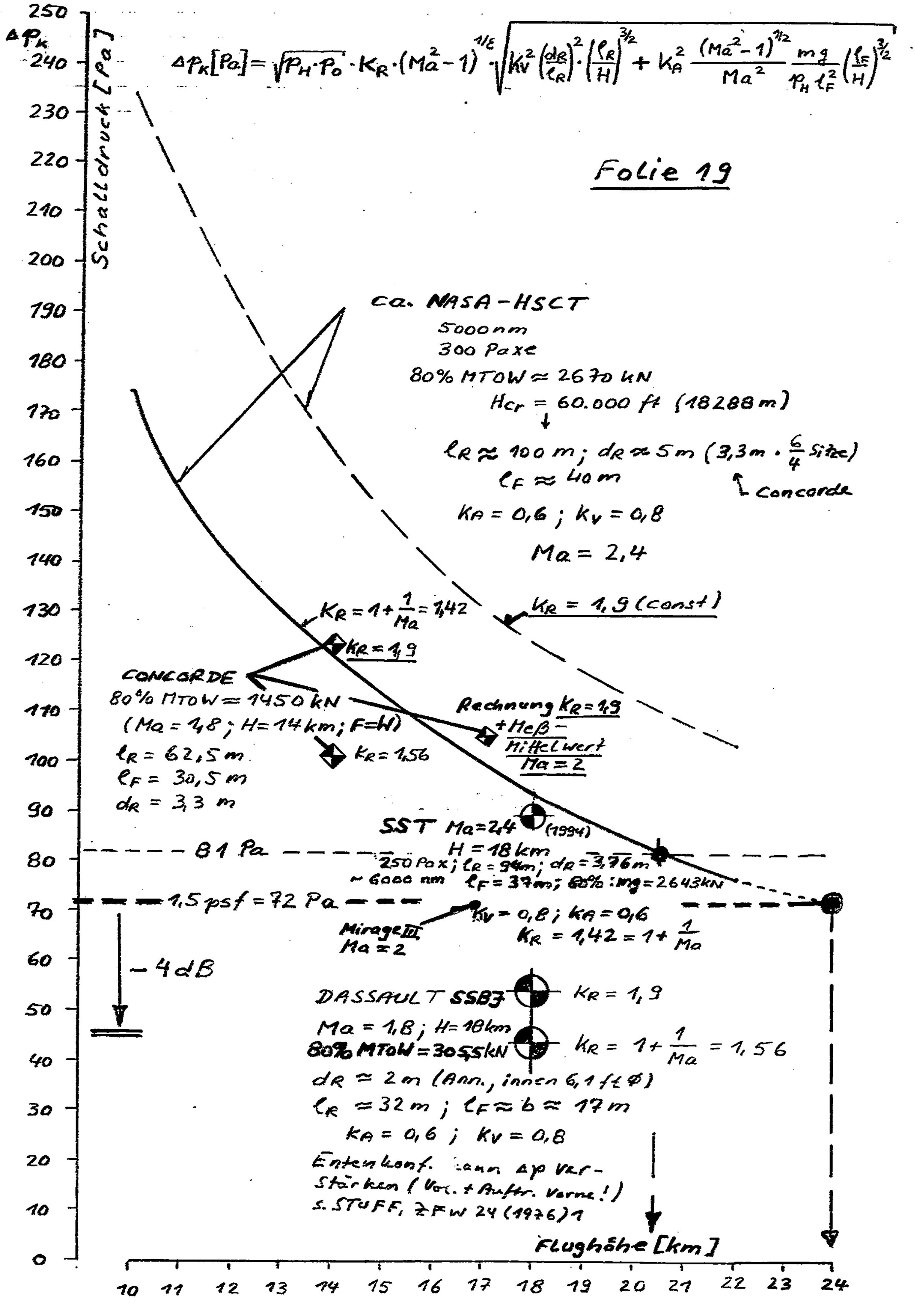
"Integrated" and discrete wing/body layouts.

nach COURTNEY J. Royal Aer. Society Vol 68 Sept. 1964

Optimierung nach KANE (siehe STUFF, ZFW 24(1976) Heft 1; siehe auch SEEBASS/GEORGE: Sonic Boom Minimization, J. Acoust. Soc. Am. 1972

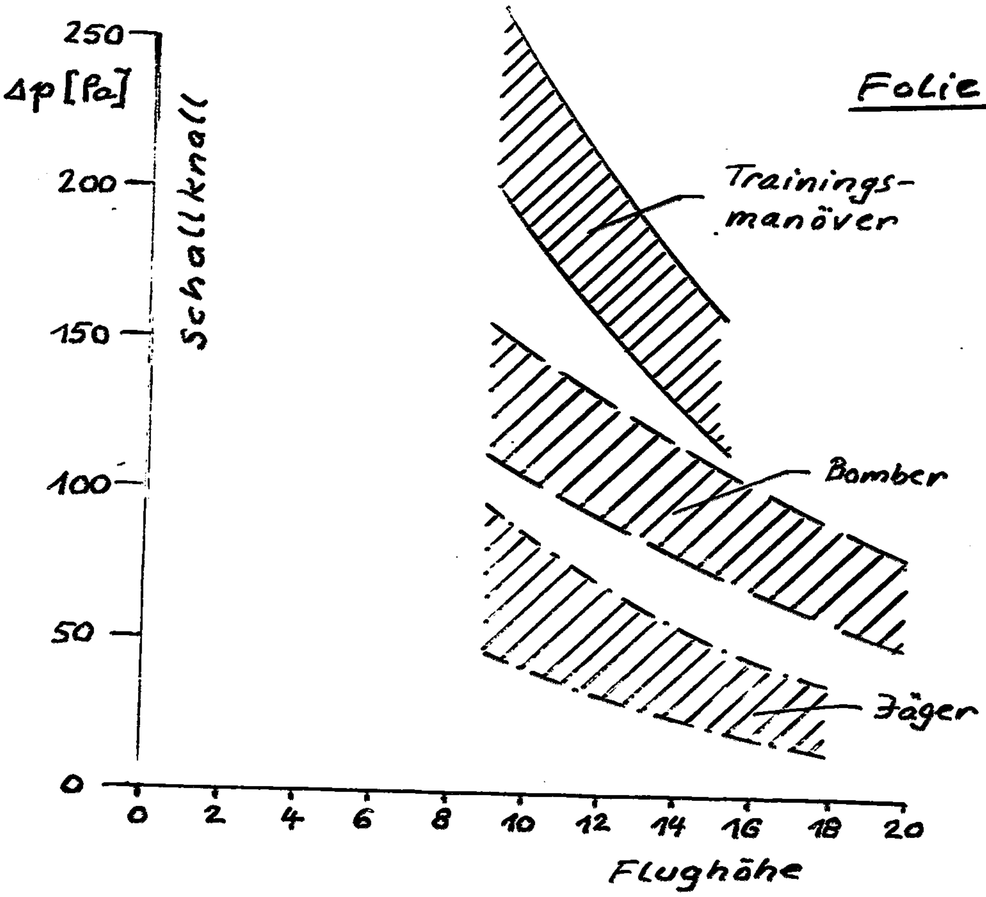
	Ma = 2,7	Ma = 1,5 (Reisen b. ε_{min})
Drucksprung Δp	50 Pa *)	25 Pa
Flughöhe H	16,8 km	13,7 km
Fluggewicht	2450 kN	2781 kN
Länge	91,5 m	103,5 m
MTOW	~ 3500 kN	~ 3600 kN
Landegewicht	~ 1900 kN	~ 2000 kN
Passagiere	151 (theor. 210; $x_N - x_S$ groß)	180
Reichweite	3720 nm (~ 7000 km)	3220 nm (~ 6000 km)
Startstrecke FAR	6,5 km	4,7 km
(Staupunkttemp.	260 °C	41 °C)

*) s. auch dazu DARDEN/MACK SCAR-conf. 1976 NASA CP-001

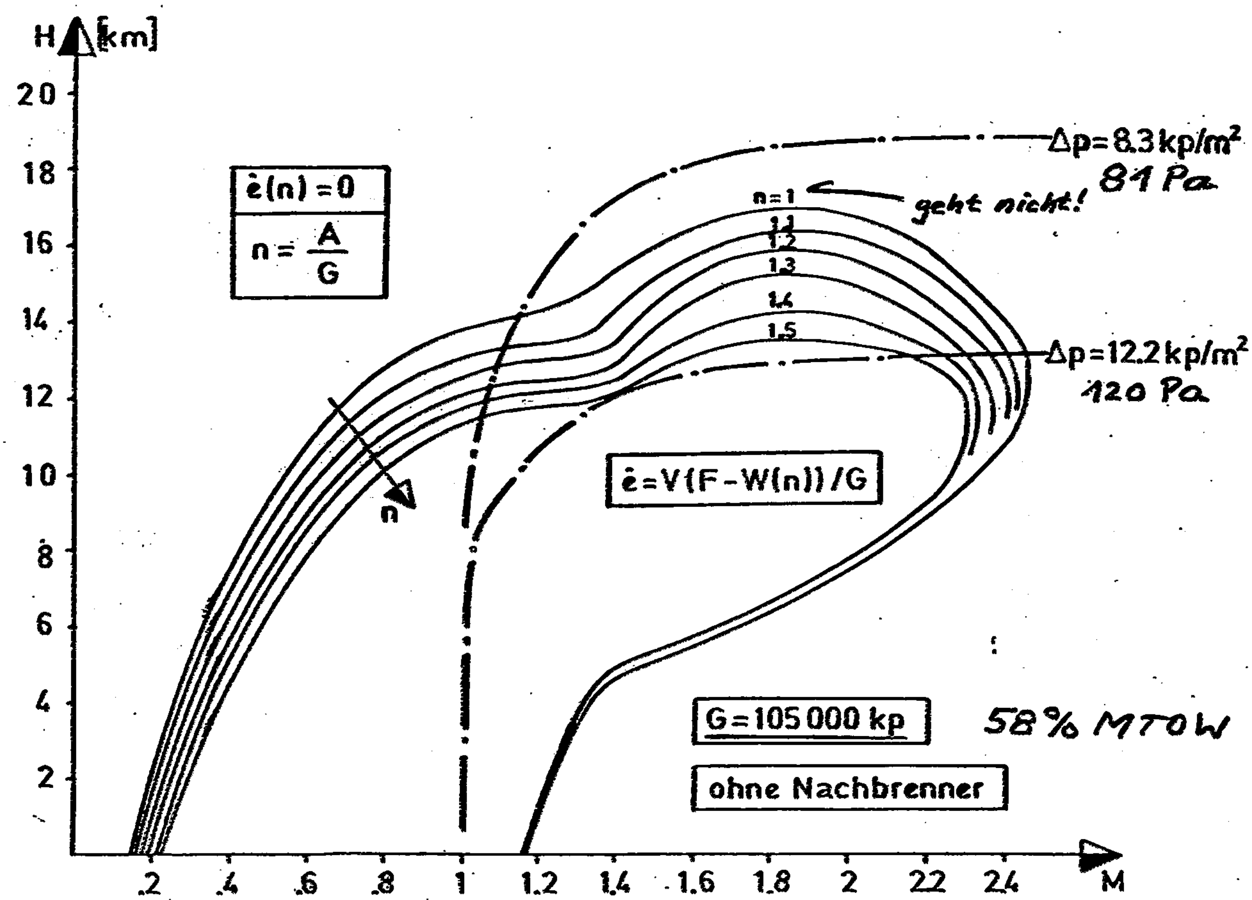


Klenter 18.10.98 n. KANE, SEEBASS/GEORGE opt. theor. ΔP = 50 Pa (H ≈ 17 km, Ma = 2,7); 25 Pa (H ≈ 14, Ma ≈ 1,5)

Folie 20



nach HUBBARD/MAGLIERI, AIAA Paper No. 64548



Leistungsgrenze $\dot{e} = 0$ als Funktion konstanter Lastvielfacher n und Schalldruckgrenzen Δp für den stationären Horizontalflug und den Manöverflug für das Flugzeug CONCORDE