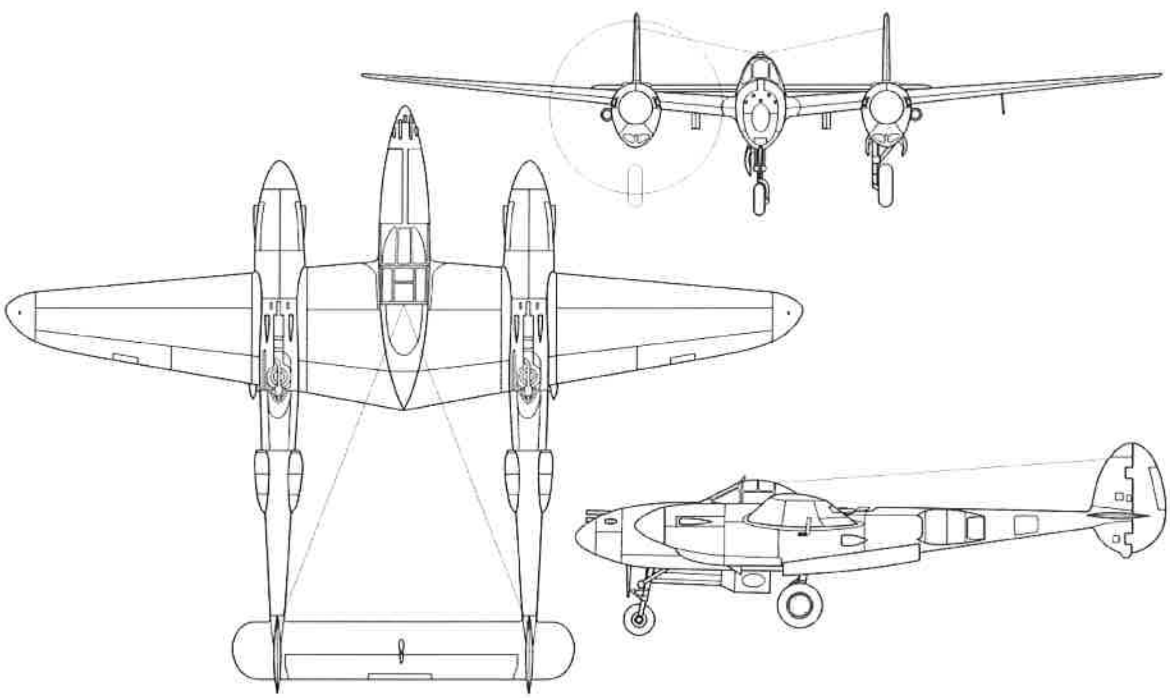
Lesson 14

Compressibility

FVA Chapter 8
ADTA Chapters 15 – 17

Lockheed P-38:
Twin engine “heavy” fighter from pre-WW2
414 mph at FL250



5 November 1941
Compressibility Kills

WEDNESDAY MORNING. Los Angeles Times NOVEMBER 5, 1941. B

Pursuit Plane Crashes Into Glendale House After Breakup in Air

P-38 Test Plane Falls and Burns

Pilot of Military Craft Killed by Dive Into Glendale Home

Continued from First Page

bedroom of the home at the time of the crash. He attempted to help rescue Virden. Glendale city firemen were dousing the wreckage with water an hour after the crash.

Virden resided at 1511 Ben...

WARTIME REPORT

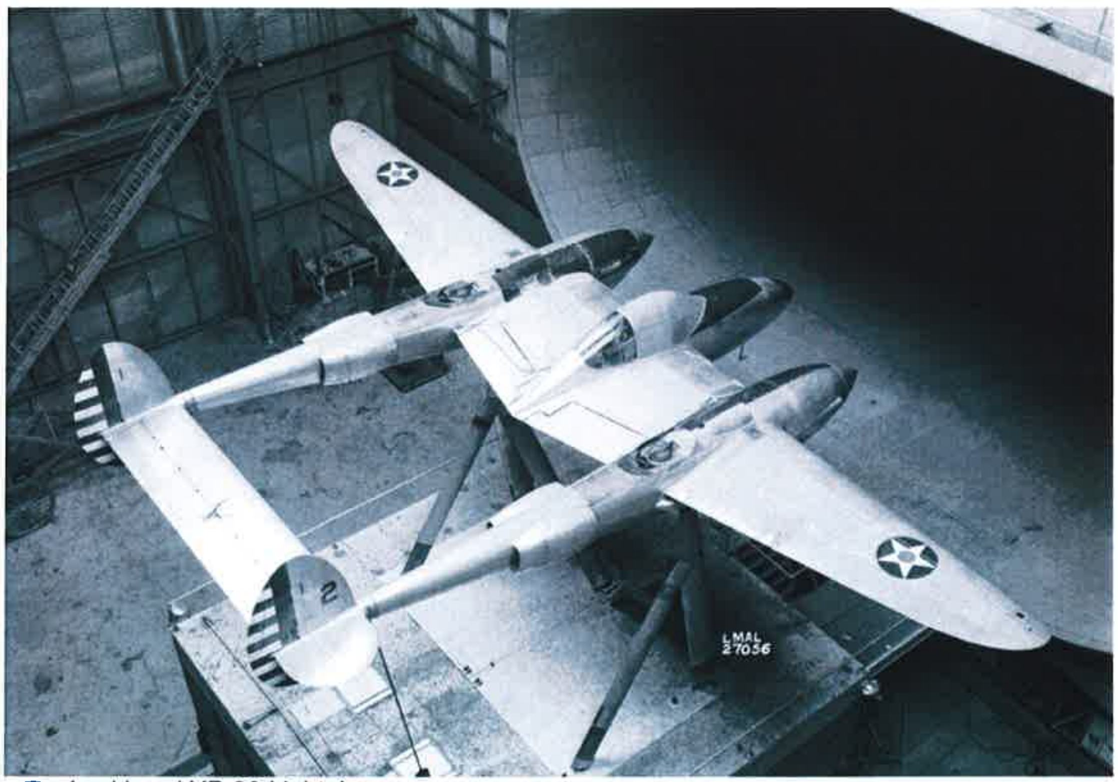
ORIGINALLY ISSUED

October 1942 as
Memorandum Report

INVESTIGATION OF DIVING MOMENTS OF A PURSUIT AIRPLANE
IN THE AMES 16-FOOT HIGH-SPEED WIND TUNNEL

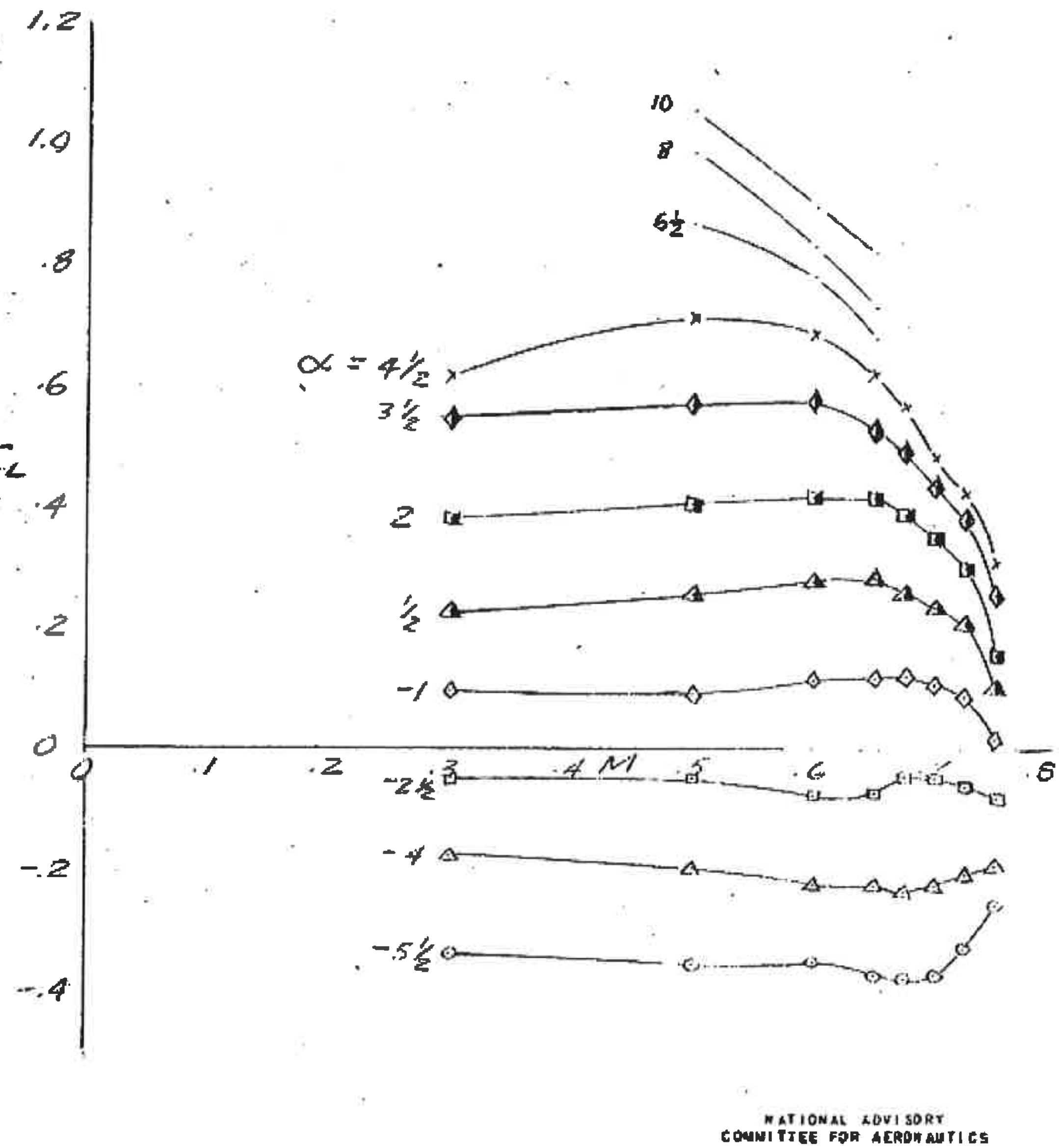
By Albert L. Erickson

- Mach Tuck. Flutter. Tail breaks off.
- How do you fight a war when your aircraft are killing pilots?
- Pilots were afraid to engage adversary aircraft for fear of an uncontrollable dive.



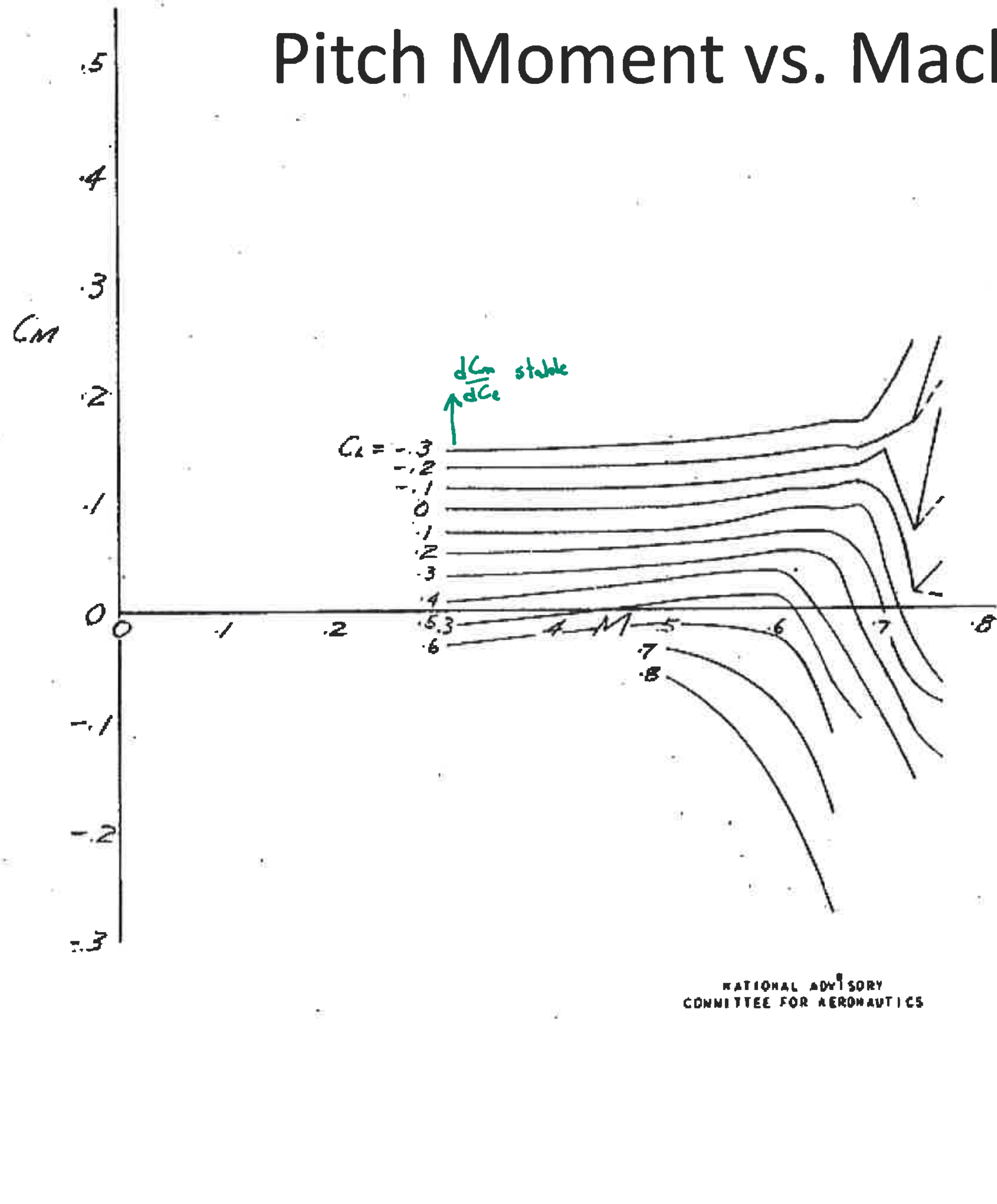
Lockheed YP-38 Lightning
NASA Langley Research Center 12/31/1942 Image # EL-2001-00380

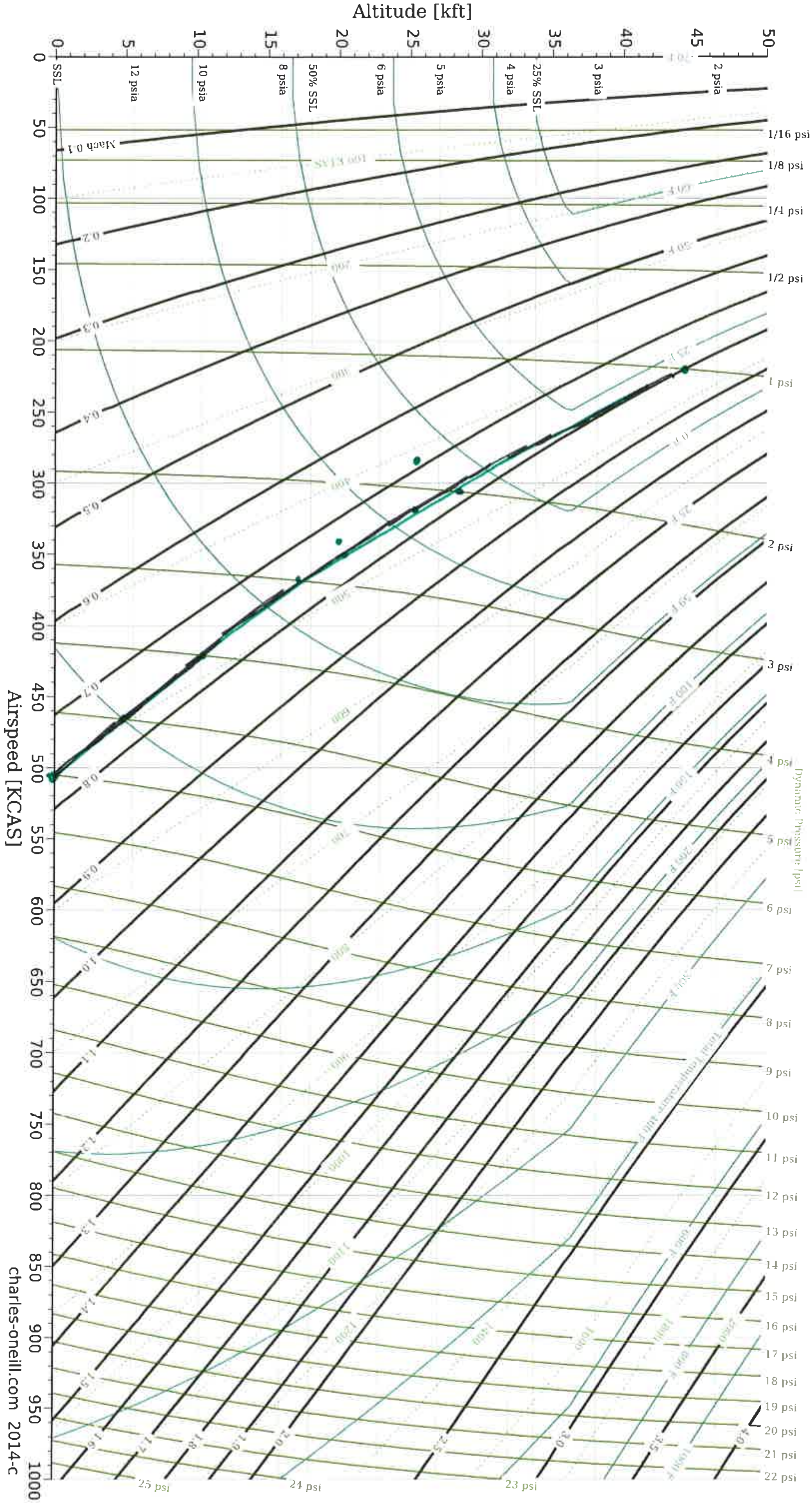
Lift vs. Mach



1.2
1.0
.8
.6
.4
.2
0
-.2
-.4
C_L
10
8
6½
α = 4½
3½
2
½
-1
-2½
-4
-5½
0
.1
.2
.3
.4 M
.5
.6
.8
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

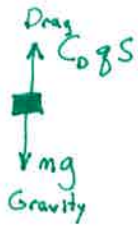
Pitch Moment vs. Mach





Altitude [kft]
Airspeed [KCAS]
Dynamic Pressure [psi]
SSL
12 psia
10 psia
8 psia
50% SSL
6 psia
5 psia
4 psia
25% SSL
3 psia
2 psia
Mach 0.1
100 KEAS
1/16 psi
1/8 psi
1/4 psi
1/2 psi
1 psi
2 psi
3 psi
4 psi
5 psi
6 psi
7 psi
8 psi
9 psi
10 psi
11 psi
12 psi
13 psi
14 psi
15 psi
16 psi
17 psi
18 psi
19 psi
20 psi
21 psi
22 psi
23 psi
24 psi
25 psi
charles-oneill.com 2014-c

Dive Velocity



$$mg = C_D q S \Rightarrow q = \frac{mg}{C_D S} = \frac{W}{C_D S} = \frac{1}{C_D}\frac{W}{S}$$

$\frac{W}{S}$: wing loading

$$C_D = C_D(M)$$

$$q = q(M, h) = \frac{1}{2}\rho V^2 = \frac{1}{2}\gamma p M^2$$

P38: $W \approx 18000$ lbf, $S \approx 327$ ft² $\Rightarrow \frac{W}{S} \approx 55$ psf ≈ 0.38 psi

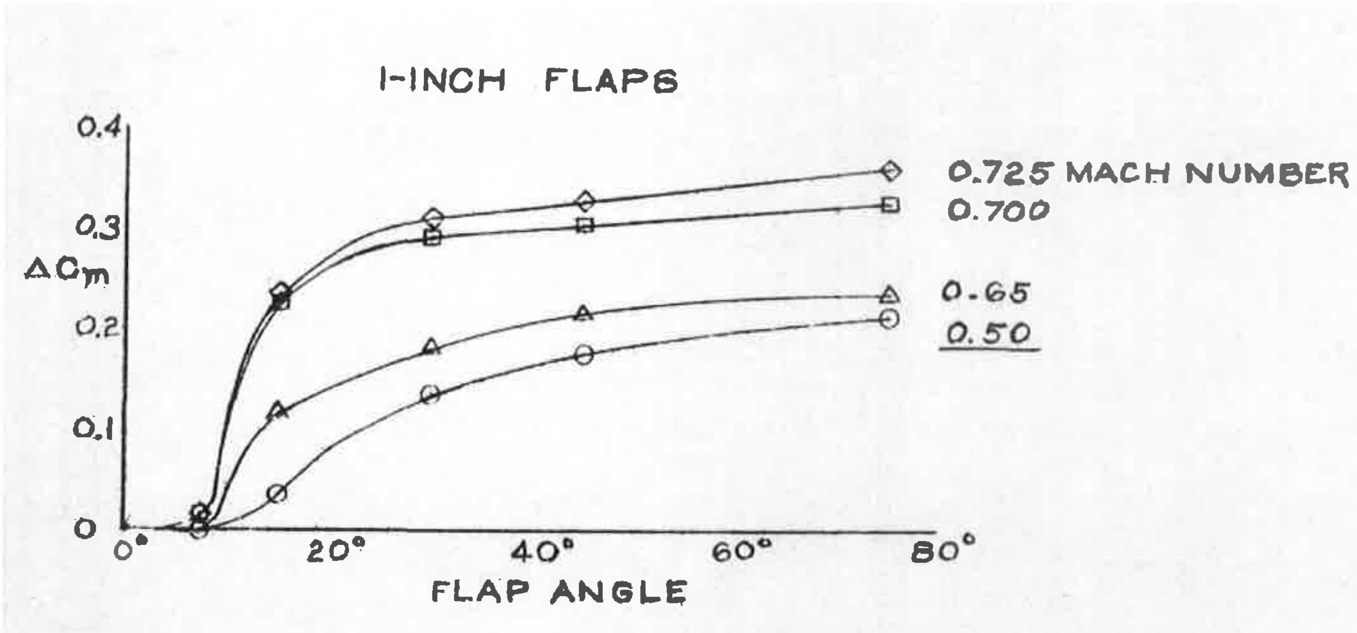
For equilibrium

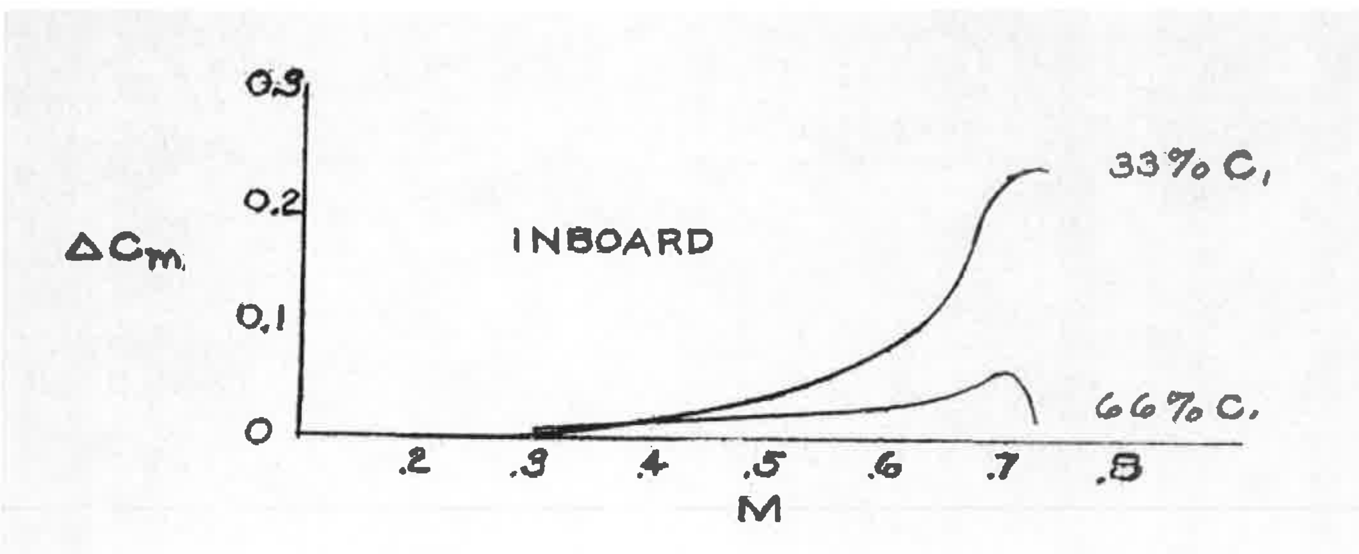
$$C_D = 0.381^{psi} \cdot \frac{1}{q[psi]}$$

$q = 2$ psi $\Rightarrow C_D = 0.19 \Rightarrow M \approx 0.78$

$\alpha = 0$

q^{psi}	C_D	M	h[ft]
1	0.3800	0.8	44000
2	0.1900	0.78	27000
2.5	0.1500	0.75	
3.0	0.1270	0.75	17000
4.0	0.0950	0.74	
5.0	0.0760	0.74	4000
6.0	0.0640	0.73	← Sea level


1-INCH FLAPS
0.4
0.3
ΔCm
0.2
0.1
0
0°
20°
40°
60°
80°
FLAP ANGLE
0.725 MACH NUMBER
0.700
0.65
0.50


0.3
0.2
0.1
0
ΔCm
INBOARD
33% C,
66% C,
.2
.3
.4
.5
.6
.7
.8
M

WARTIME REPORT

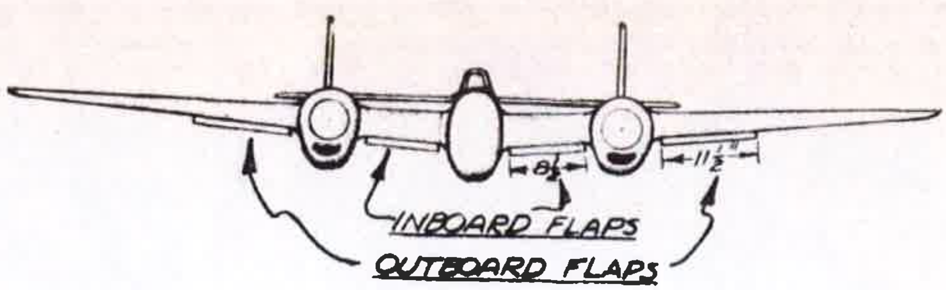
ORIGINALLY ISSUED

April 1943 as
Memorandum Report 3F12

WIND-TUNNEL INVESTIGATION OF DEVICES FOR IMPROVING THE DIVING CHARACTERISTICS OF AIRPLANES

By Albert L. Erickson

Ames Aeronautical Laboratory
Moffett Field, California



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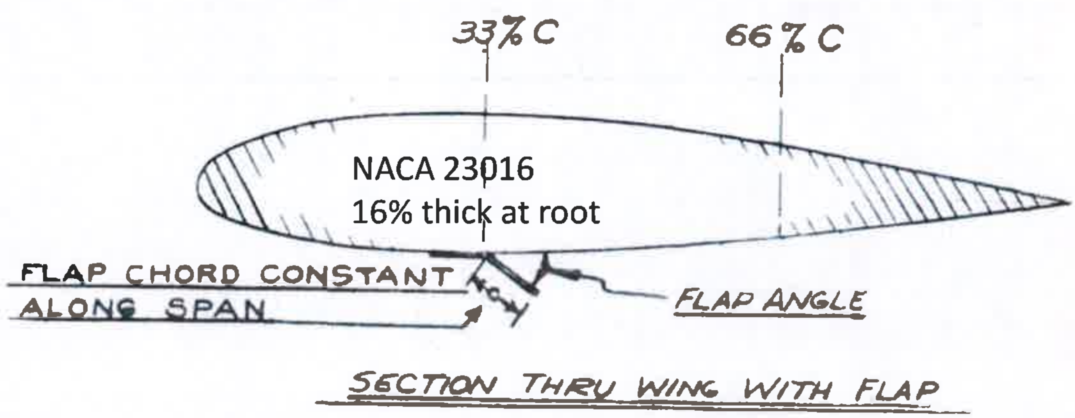


SECTION THRU WING WITH FLAP

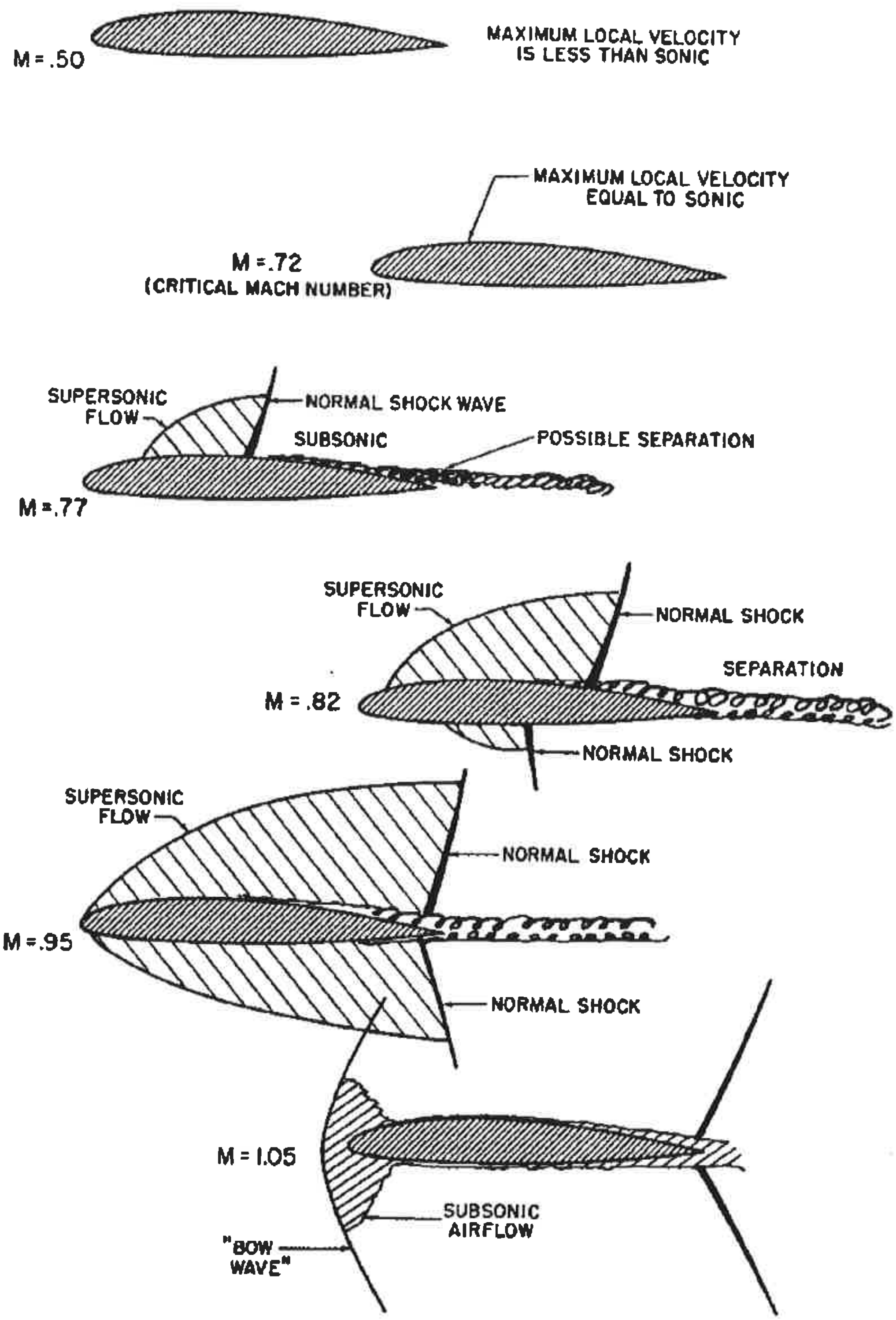
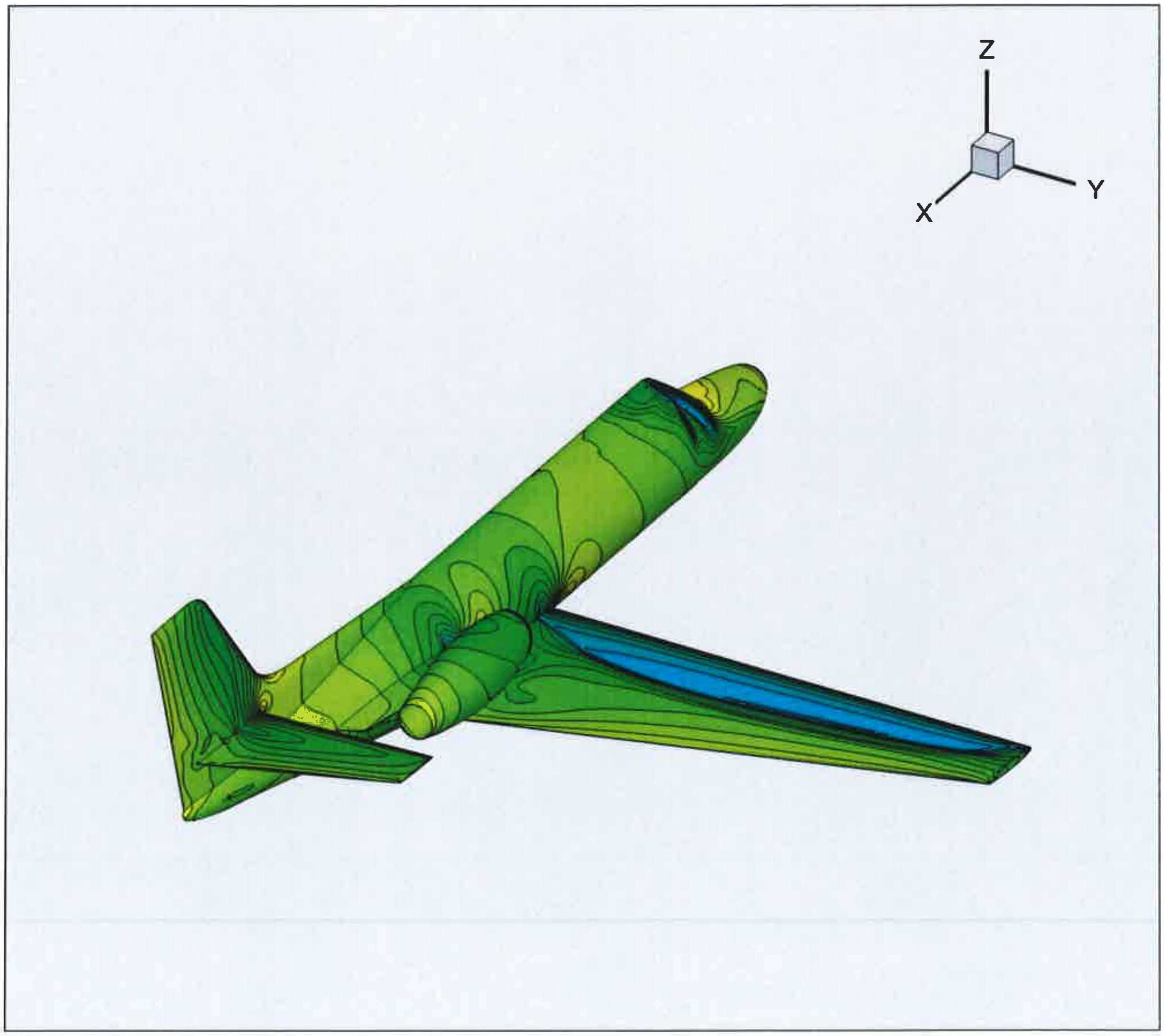
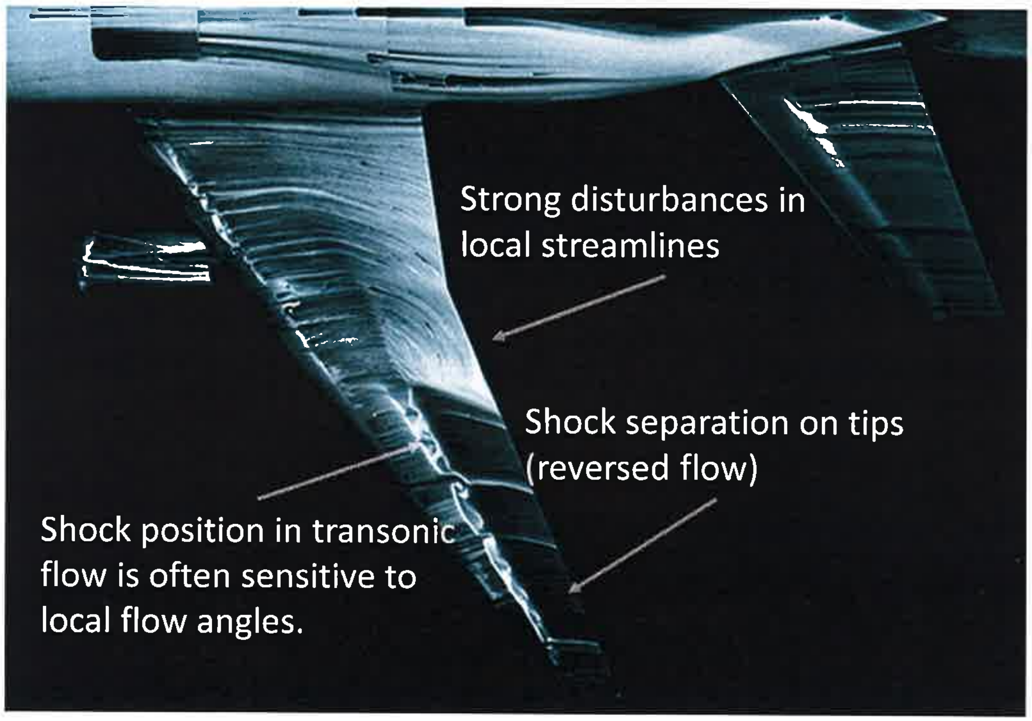


Figure 3.9. Transonic Flow Patterns (sheet 1 of 2)

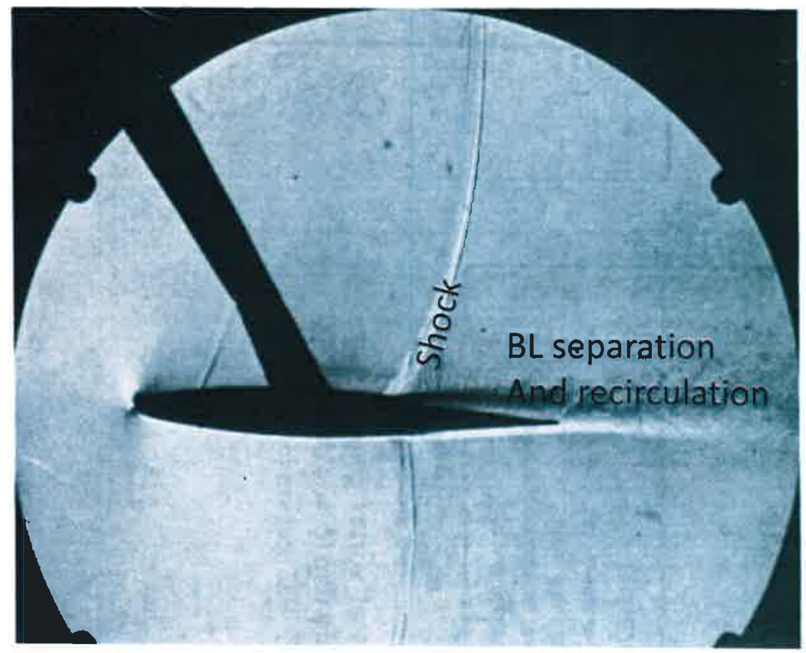


Z
Y
X

Physics of Phenomenon:

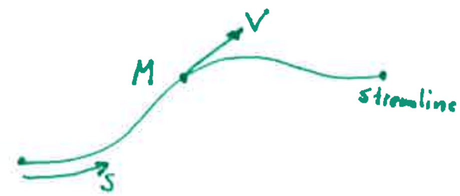


M=0·83 (UNCORRECTED)



A compressible flow contains large variations in density. Previously, the mass continuity equation was used to show that the source density for all flows scale as:

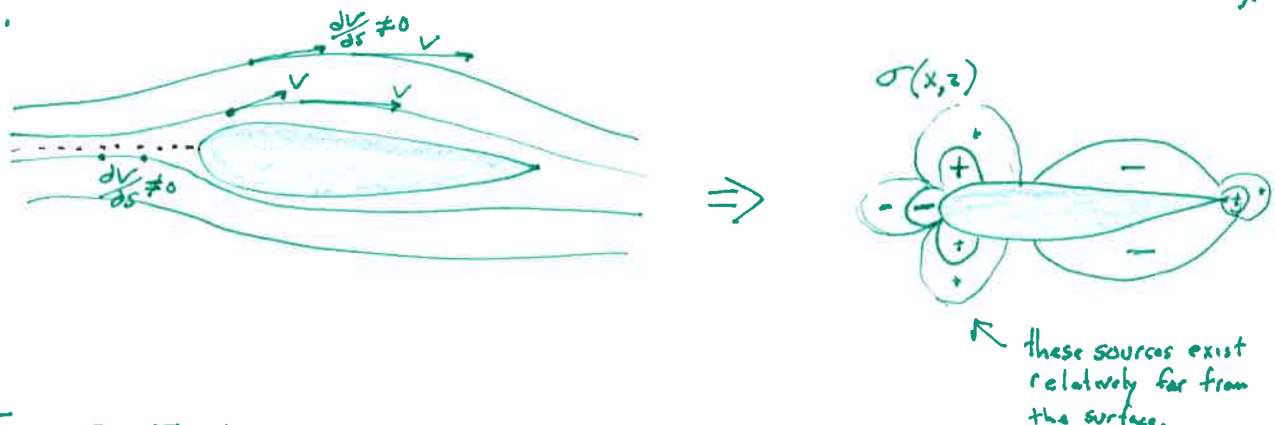
$$\sigma = M^2 \frac{\partial V}{\partial s}$$



So all flows are compressible, but when M^2 is near zero, the flow can be considered incompressible.

Notice that $\sigma = M^2 \frac{\partial V}{\partial s}$ occurs throughout the flow (not just at the surface).

The thin airfoil theory assumption of lumping sources to the surface is no longer valid.



Q: Is $\sigma = \nabla \cdot V$ and $\omega = \nabla \times V$ still valid?

Q: Is the reverse operator still valid?

$$V = V_b + V_\sigma + V_\omega$$

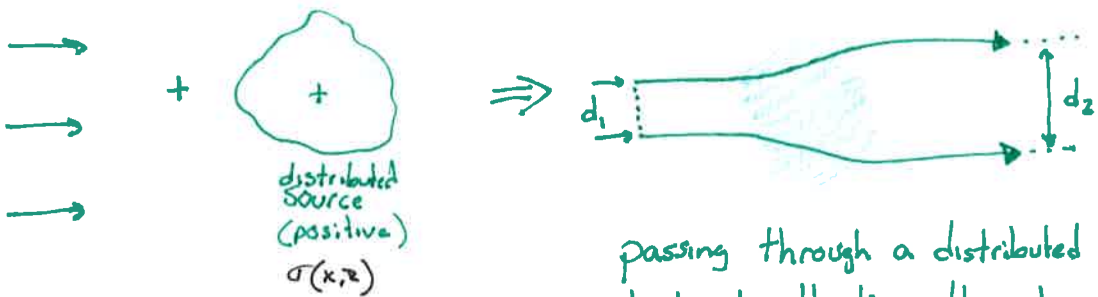
$$= V_b + \frac{1}{4\pi}\iiint \sigma(r') \frac{r-r'}{|r-r'|^3} dx'dy'dz' + \frac{1}{4\pi}\iiint \omega(r') \times \frac{r-r'}{|r-r'|^3} dx'dy'dz'$$

A: Yes and Yes

Review of sources and sinks in flows:

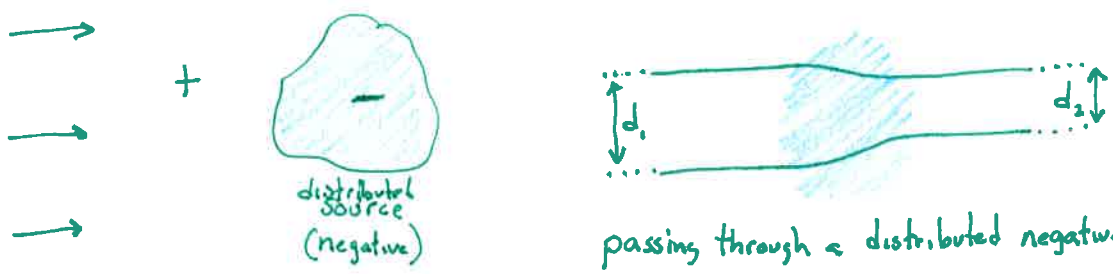
1)

2)



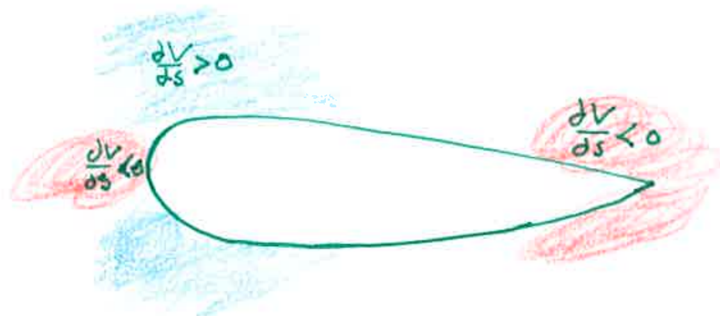
passing through a distributed source (positive) tends to thicken the streamtube

3)



passing through a distributed negative source tends to thin the streamtube

For a subsonic airfoil, where are the accelerating and decelerating regions?

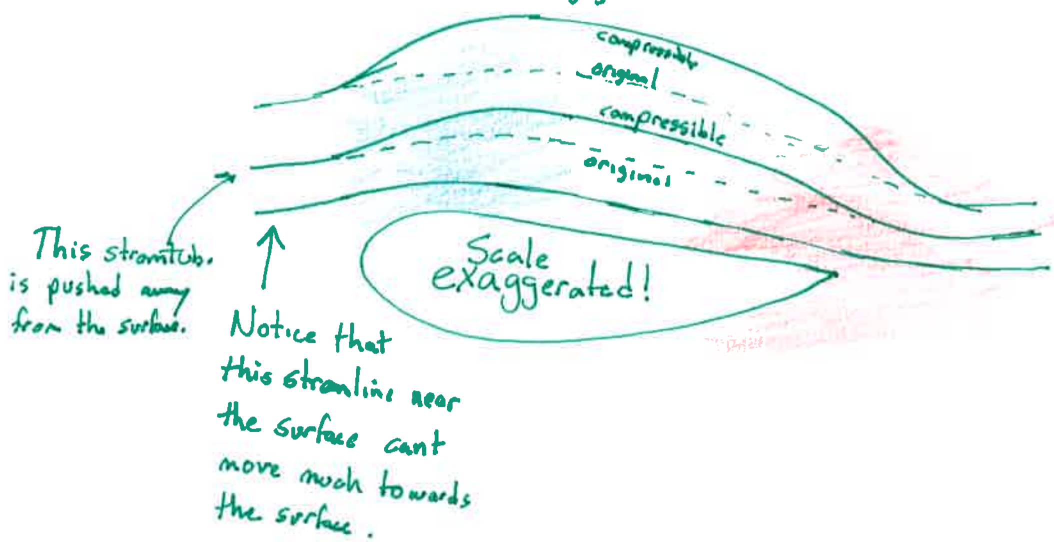


$$\sigma = M^2 \frac{\partial V}{\partial s} \Rightarrow \begin{array}{ll} \sigma > 0 & \text{when } \frac{\partial V}{\partial s} > 0 \\ \sigma < 0 & \text{when } \frac{\partial V}{\partial s} < 0 \end{array}$$

Thus

Streamtubes thicken when $\frac{\partial V}{\partial s} > 0$

Streamtubes thin when $\frac{\partial V}{\partial s} < 0$



Also, the positive source tends to slow the flow upstream and speed the flow downstream.

In comparison to subsonic incompressible flows, the streamtubes thicken and the velocity increases in a compressible flow.

Compressible flows tend to magnify both perturbations and the distance at which the disturbances act.