# Lesson 2

# Loads

# What are Loads?

Forces and pressures imposed/generated on the aircraft. or vehicle.

Ex: Space Shuttle
Listen to a launch, at about 1 minute after launch and about 35000 ft, you can often hear. "Throttling down for max q". The main engines go down to 65% thrust to prevent too high of aero loads.

**Table 14.1 Aircraft loads**

| | | |
|---|---|---|
| Airloads | Landing | Other |
| –Maneuver | –Vertical load factor | –Towing |
| –Gust | –Spin-up | –Jacking |
| –Control deflection | –Spring-back | –Pressurization |
| –Component interaction | –Crabbed | –Bird strike |
| –Buffet | –One wheel | –Actuation |
| –Hailstones (3/4 in.) | –Arrested | –Crash |
| | –Braking | –Fuel pressure |
| Inertia loads | Takeoff | Powerplant |
| –Acceleration | –Catapult | –Thrust |
| –Rotation | –Aborted | –Torque |
| –Dynamic | | –Gyroscopic |
| –Vibration | Taxi | –Vibration |
| –Flutter | –Bumps | –Duct pressure |
| | –Turning | –Hammershock |
| | | –Prop/blade loss |
| | | –Seizure |

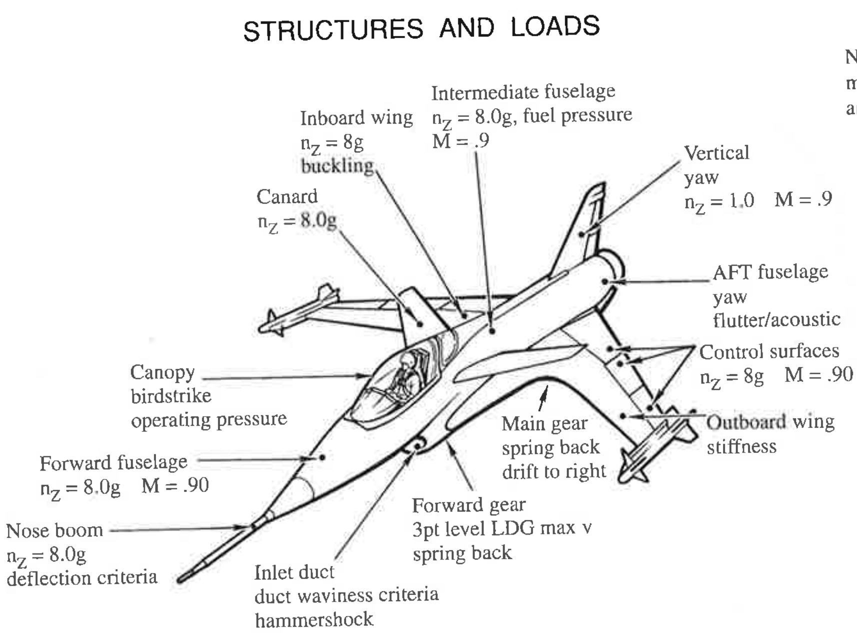



**Fig. 14.1 Typical fighter limit loads.**

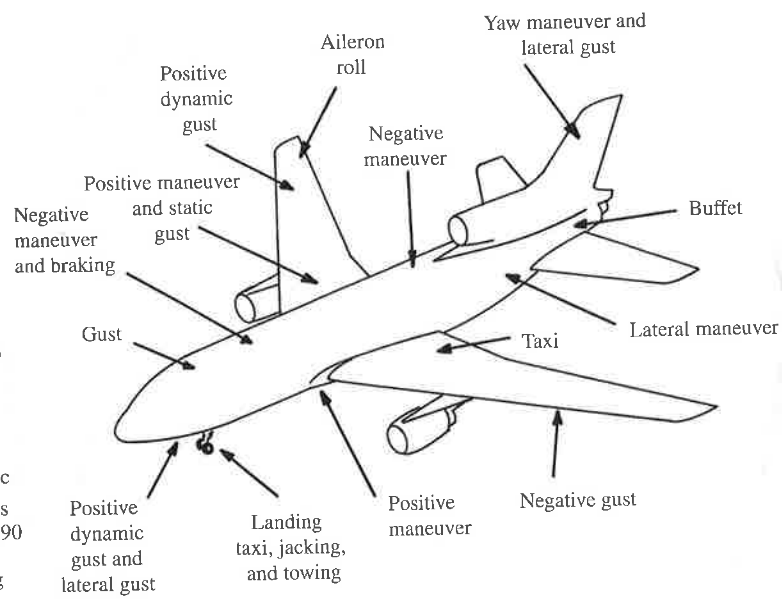
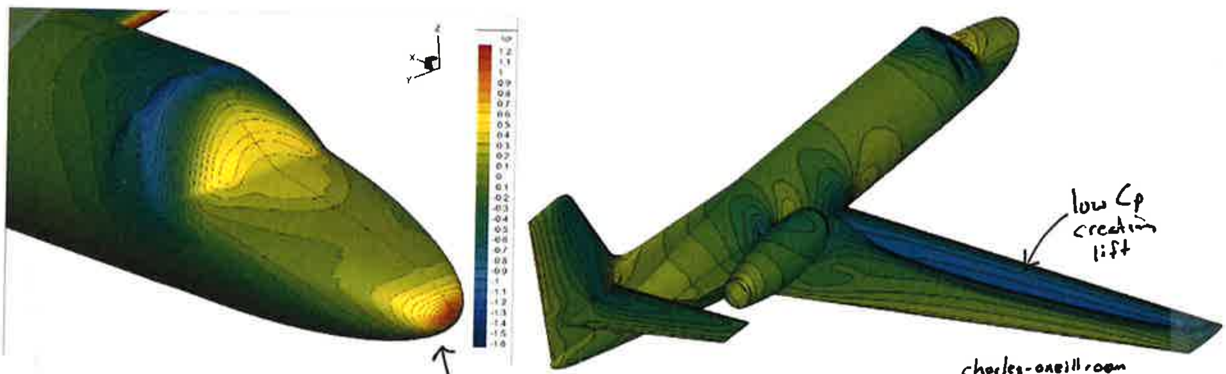



**Fig. 14.2 L1011 critical loads.**

# Aerodynamic Loads

When operating in an atmosphere, aerospace vehicles experience aerodynamic load associated with the motion of a fluid over the structure. When surface pressures are integrated over the vehicle's surface, so called "integrated forces" such as lift, drag, and moment result. Surface pressures are usually shown as $C_p \equiv \dfrac{P - P_\infty}{\frac{1}{2}\rho V^2}$. Thus, the surface pressure varies with $V^2$.

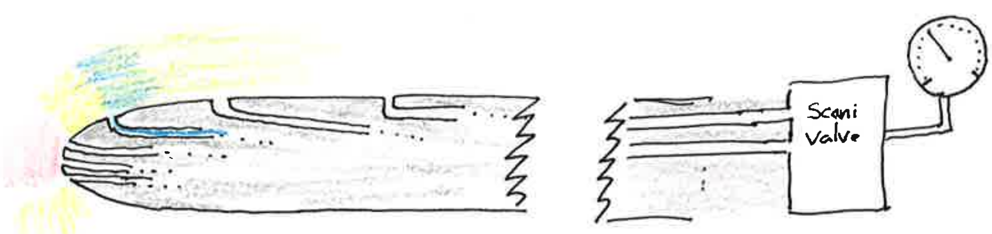




high $C_p$ at nose.

Often, the aerodynamics group will provide surface pressures from analytical, experimental and computational sources.

wind tunnel
or
flight test.



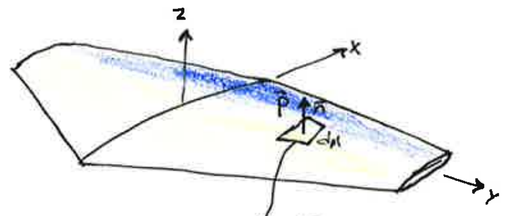

Each port is expensive. Limited space. Aero and Loads will have different areas of interest. Trade offs

1 wind tunnel test in industry $\approx \$500^k$

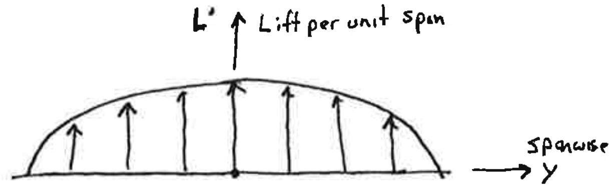
tiny.cc/AEM341 Boeing Model

# Wing Aero Loading

Simplify loading with aerodynamics concept of lift distribution (3D $C_p \Rightarrow$ 1D lift dist)




$\Rightarrow$



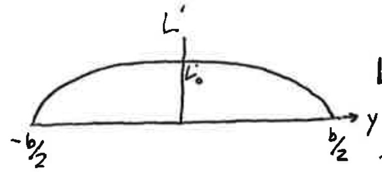

$$\text{Lift} = \underbrace{\int p \cdot n \, dS}$$

difficult surface integral. Requires $C_p$ over entire surface

$$\text{Lift} = \underbrace{\int L' \, dy}$$

simple distribution with analytical estimates

From aerodynamics (i.e. AEM 313), you will learn that the wing shape and twist strongly determine the lift distribution. However, the classic lift distribution shape is elliptical.



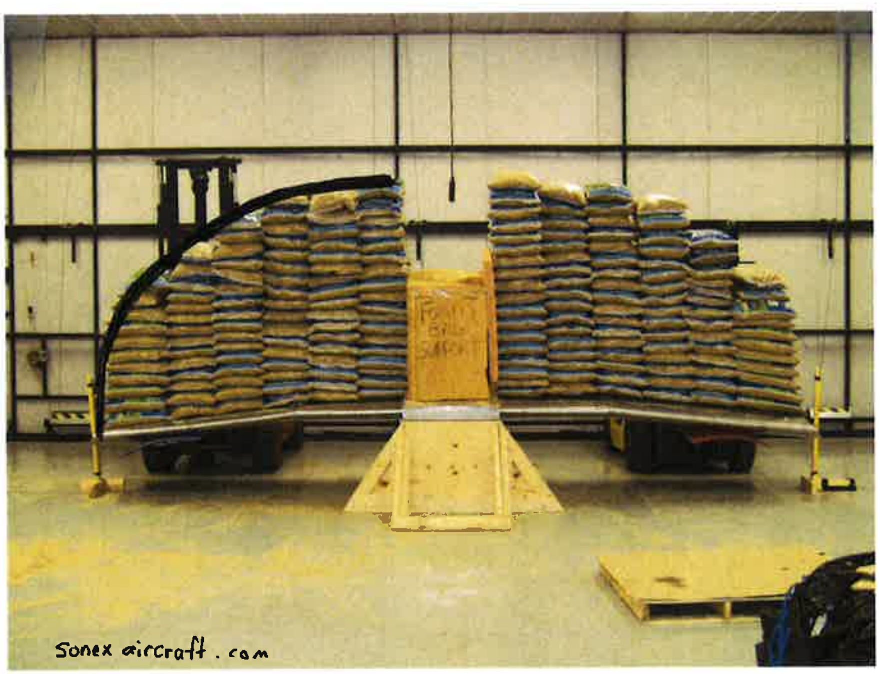

$$L'(y) = L_0' \sqrt{1 - \left(\frac{y}{b/2}\right)^2}$$

The total lift is $L = \int L' \, dy = \int_{-b/2}^{b/2} L_0 \sqrt{1 - \left(\frac{y}{b/2}\right)^2} \, dy$

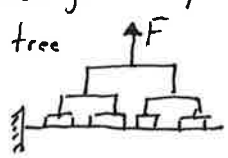
$$= \frac{b\pi}{4} L_0$$

Thus, a reasonable estimate for the lift distribution is

$$L' = \frac{L\,4}{b\,\pi} \sqrt{1 - \left(\frac{2y}{b}\right)^2}$$




Experimentally, we can simulate lift distributions with distributed loading with sandbags or hydraulics or a whiffle tree




tiny.cc/AEM341A380Wing

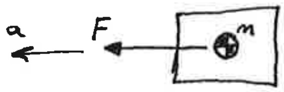
tiny.cc/AEM341B787Wing

tiny.cc/AEM341BoeingFatigue

# Inertial Loading

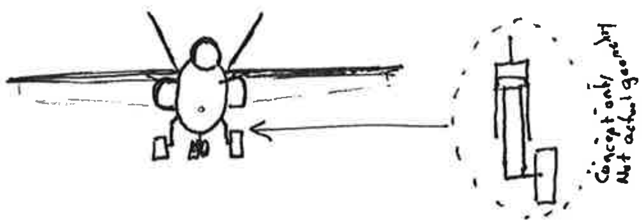
Accelerating mass creates forces. Newton's law is Mass × Acceleration = Force

$$\boxed{F = ma}$$




Ex:

A 37000 lb F-18 shows a 3g vertical deceleration when landing on a carrier with a vertical velocity of 1500 ft/min. What is the reaction force and stroke of the oleo strut? The wheel and strut weigh 1000 lbf.




① Free Body Diagram


$$\Sigma F_y = ma$$

$$R + R = ma$$

② Vehicle Mass

$$mg = \underbrace{37000^{\,lbf}}_{W} \qquad \text{So} \qquad m = \frac{W}{g} = \frac{37000\ lbf}{} \left| \frac{s^2}{32.174\ ft} \right| \frac{slug\ ft}{lbf\ s^2} = 1150\ slug$$

But the wheel + strut is already in fixed contact with the ground (assumption!), so only the upper aircraft mass is needed. $W_u = 37000 - 1000 = 36000\ lbf$

$m_u = 1118.9\ slug$

Alternatively, we could say $ma = Wg = 36000^{lbf} \cdot 3 = 108000^{lbf}$

③ Solve for R

$$R = \frac{ma}{2} = \frac{Wg}{2} = \frac{108000^{lbf}}{2} = \boxed{54000^{lbf} = R}$$

④ Stroke (assume constant 3g)

$$\frac{d^2s}{dt^2} = a \Rightarrow s = \frac{1}{2}at^2 \quad \text{and} \quad V = at \Rightarrow s = \frac{1}{2}a\frac{V^2}{a^2} = \frac{1}{2}\frac{V^2}{a}$$

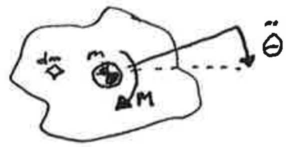
$$S = \frac{1}{2} \left| \frac{1500^2\ ft^2}{\cancel{min^2}} \right| \frac{\cancel{s^2}\ \cancel{g}}{32.174\ ft} \left| \frac{}{3\cancel{g}} \right| \frac{\cancel{min^2}}{60^2\ \cancel{s^2}} = \boxed{3.2\ ft} \qquad \text{for } t = \frac{V}{a} = 0.26\ s$$

⑤ Power?!

$$F \cdot V = P \Rightarrow 54000^{lbf} \cdot 1500\ fpm = 2500\ hp \text{ for } 1/4 \text{ second!}$$

# Rotational Inertial Forces

$$I\ddot{\theta} = M$$




with the inertia matrix

$$I = \int r^2\, dm = \int r^2 \rho\, dx\, dy\, dz$$

Also remember the parallel axis theorem

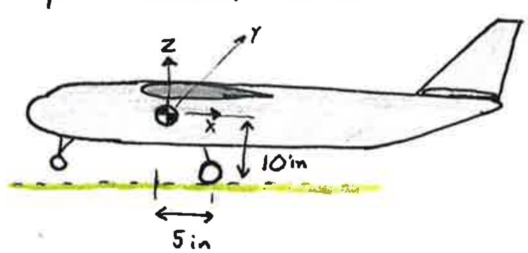

$$\underbrace{I_o}_{\text{New Inertia}} = \underbrace{I_{cg}}_{\text{old inertia about Center of gravity}} + \underbrace{M\bar{x}^2}_{\text{mass times offset distance squared}}$$

Also, radius of gyration

$$R_g^2\, m = I$$

Equivalent "hoop"

Ex: Given a transport aircraft with:




$W = 10\ \text{lbf}$

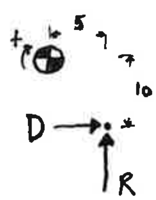
$L = 72\ \text{in}$

$R_g = 36\ \text{in}$

$m = \frac{10}{32.174} = 0.311\ \text{slug}$

The aircraft lands hard (5g) with a rolling coefficient of 0.25. What is the rotational acceleration? What are the x and z accelerations?

① Free body diagram




Rolling coeff $= \frac{D}{R}$ and $R = W \cdot 5g = 50\ \text{lbf}$

② Translational

$$\Sigma F_z = m a_z = R \Rightarrow a_z = \frac{R}{m} = \frac{50\ \text{lbf}}{0.311\ \text{slug}} = \boxed{160\ \text{ft/s}^2 = a_z}$$

$$\Sigma F_x = m a_x = D \Rightarrow a_x = \frac{D}{m} = \boxed{40\ \text{ft/s}^2 = a_x} \qquad \boxed{a_y = 0}$$

③ Rotational (about the Center of gravity)

$$I\ddot{\theta}_y = M \Rightarrow \ddot{\theta} = \frac{M}{I} = \frac{M \leftarrow \text{Moment}}{R_g^2\, m \leftarrow \text{mass}} = \frac{-R \cdot 5 - D \cdot 10}{R_g^2\, m}$$

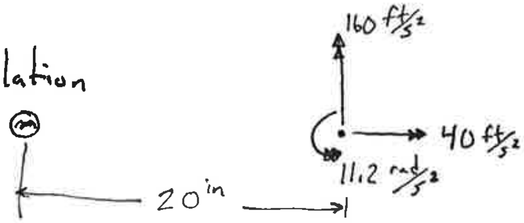
$$= \frac{(-50\ \text{lbf} \cdot 5\ \text{in} - 12.5\ \text{lbf} \cdot 10\ \text{in})}{36^2\ \cancel{\text{in}}^2 \cdot 0.311\ \cancel{\text{slug}}} \left| \frac{\cancel{\text{slug}}\ \cancel{\text{ft}}}{\cancel{\text{lbf}}\ \text{s}^2} \right| \frac{12\ \cancel{\text{in}}}{\cancel{\text{ft}}}$$

$$\boxed{\ddot{\theta} = -11.2\ \frac{\text{rad}}{\text{s}^2}}$$

Ex: A 0.2 lbf Go-Pro 5 Session  is mounted in the nose 20 in forward of the CG. Determine the inertial forces.

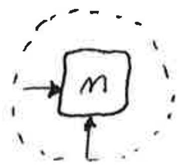
① FBD

Translation




$$m = \frac{0.2^{\,lbf}}{32.174} = 0.0062 \text{ slug}$$

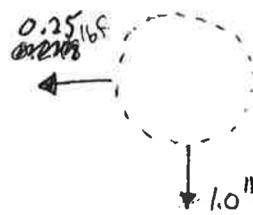
place a control volume around the Go-pro




$$F = ma = \underbrace{m\begin{pmatrix}40\\0\\160\end{pmatrix}}_{\substack{\text{vector}\\\text{form}\\\text{is}\\\text{ok}}} = 0.0062\begin{pmatrix}40\\0\\160\end{pmatrix}$$

$$\begin{matrix}F_x\\F_y\\F_z\end{matrix} = \begin{pmatrix}0.\cancel{248}\,25\\0\\1.0\end{pmatrix}$$

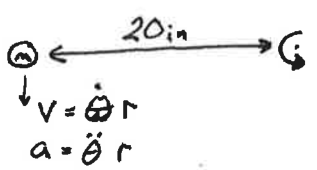
Given the forces necessary to accelerate the mass, the opposing outside side of the control volume must have an equal but opposite reaction.

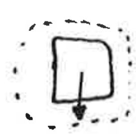



$$F_x = -0.25^{\,lbf}$$
$$F_z = -1.0^{\,lbf}$$

Rotation

The rotation acceleration $\ddot{\theta}$ at a distance $20^{in}$ creates a force



$$a = \ddot{\theta} r = 11.2 \frac{rad}{s^2} \Big| 20 in = 224 \frac{in}{s^2}$$

The reaction force would be

$$R = ma = \frac{0.0062 \text{ slug}}{} \Big| \frac{224 \text{ in}}{s^2} \Big| \frac{ft}{12 in} \Big| \frac{lbf\, s^2}{slug\, ft} = 0.11 \text{ lbf} = F_y$$

② Summation

$$\boxed{F_x = -0.25^{\,lbf}}$$

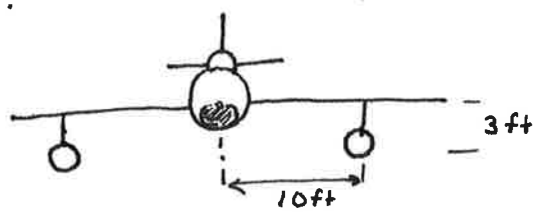
$\approx 1g$

$$F_z = -1.0^{\,lbf} + 0.11^{\,lbf} = \boxed{-0.89^{\,lbf} = F_z}$$

$$\boxed{F_y = 0}$$

$\approx 4.5g$

Ex: A fighter aircraft is rolling at 180 °/s. The aircraft has a 500 gallon (1900 liter) fuel tank located 10 feet outboard mounted on a 3 foot tall pylon. What are the reaction forces and moment at the pylon-wing interface? The tank weighs 500 lbf.

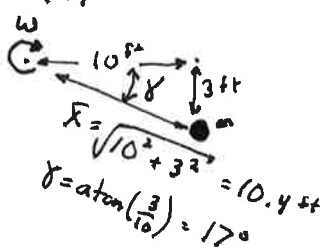


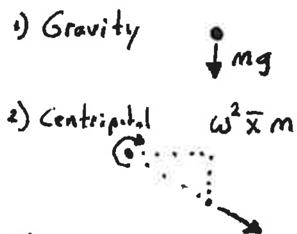

① Fuel

Looks like a jet, which burns JetA / JP8 with a density of 6.7 $\frac{lbf}{gallon}$

$$W_{fuel} = 6.7 \cdot 500 = 3350\ lbf \Rightarrow m = \frac{3350}{32.174} = 104\ slug$$

② Geometry & Physics




③ Gravity

$$mg = 3350\ lbf + 500\ lbf = 3850\ lbf \Rightarrow m = 120\ slug$$

④ Centripetal

$$\omega^2 \bar{x} m = \frac{180^{2\,\circ 2}}{s^2} \left| \frac{(\pi)^2 rad^2}{180^2\,{}^{\circ 2}} \right| 10.4\ ft \left| 120\ slug \right| \frac{lbf\ s^2}{slug\ ft} = 12300\ lbf \quad (!!)$$

Decompose into y and z directions

$$F_y = \cos(17°) \cdot 12300\ lbf = 11800\ lbf \longrightarrow$$

$$F_z = \sin(17°) \cdot 12300\ lbf = 3540\ lbf \downarrow$$

⑤ Summation of forces

$$\boxed{F_x = \text{drag} \qquad F_y = 11800 \text{ outboard} \qquad F_z = 3850 + 3540 = 7390\ lbf \text{ down}}$$

⑥ Moment at pylon-wing interface

$$M = \vec{r} \times \vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -3\ ft \\ 0 & 11800\ lbf & 7390\ lbf \end{vmatrix} = 3 \cdot 11800 = \boxed{35400\ ft \cdot lbf = M}$$

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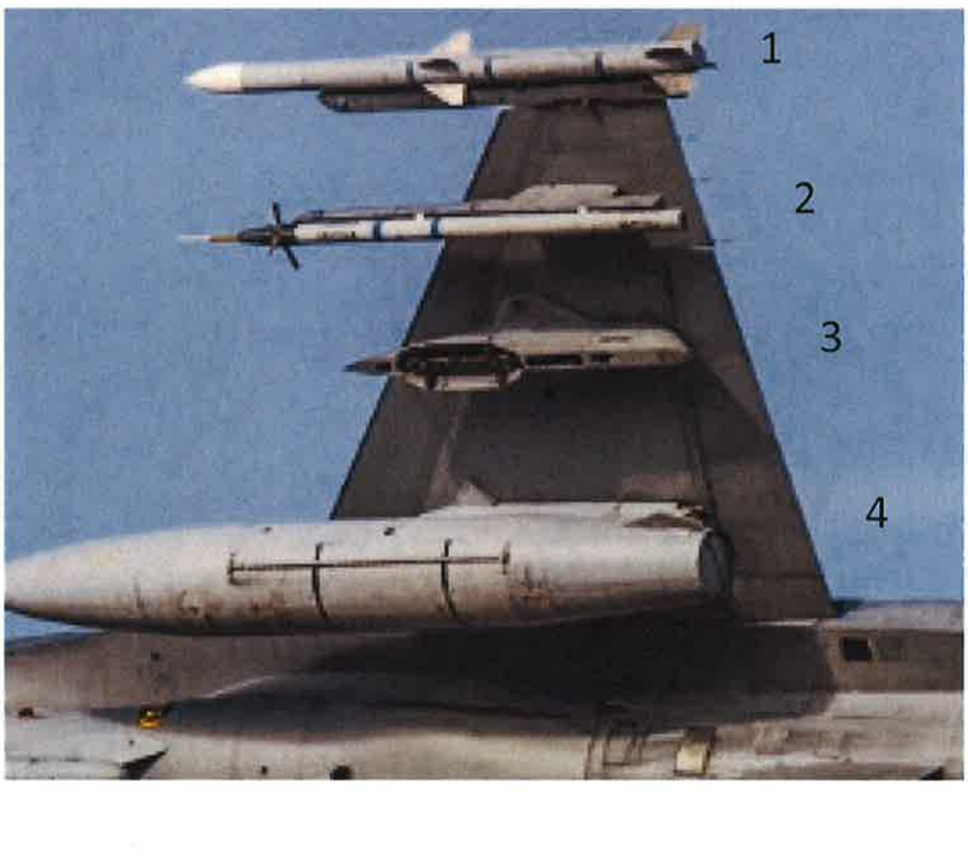

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