Defence Technology & Science Course
AF 06 : Flight Dynamics and Control

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Flight Dynamics & Control, Gerard Leng
Course Information

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Grading

1 open book test at the end of the course
Training Programme

1 : Basic flight dynamics and control terms and concepts
   *or it helps if you speak the language*

2 : The design of combat aircraft and flight stability
   *or why are the control surfaces located there?*

3: MIL-SPECS requirements & flying qualities
   *or what flight control systems can and cannot do*

4 : Recent developments
   *or the shape of things to come*
References

AIAA Education Series

Bandu N. Pamadi
Performance, Stability, Dynamics and Control of Airplanes, 1998

Louis V. Schmidt
Introduction to Aircraft Flight Dynamics, 1998

Gareth Padfield
Helicopter Flight Dynamics: The Theory and Application of Flying Qualities and Simulation Modeling, 1996

Darrol Stinton
Flying Qualities and Flight Testing of the Airplane. 1996
AIAA Industry Practice Guides

ANSI/AIAA G-003-1990
Guide to Reference and Standard Atmosphere Models

ANSI/AIAA R-004-1992
Atmospheric and Space Flight Vehicle Coordinate Systems
1. 1 : Angle of attack (AOA) $\alpha$ and sideslip angle $\beta$

AOA is the angle between the direction of the airflow and the wings.
Sideslip angle is the angle between the velocity vector and the aircraft plane of symmetry.

By convention sideslip to the right is positive.

Typically one tries to fly with zero sideslip.
1.2 : Definition of lift & drag coefficients CL and CD

Aerodynamic forces are typically expressed as

\[ L = \frac{1}{2} \rho V^2 S \text{ CL} \]
Question: How does the lift coefficient vary with AOA?
Question: How large are lift forces for a typical combat aircraft?

From Jane’s all the World’s aircraft

F16C (F100 PW engine)

Weight empty = 8 433 kg

Maximum Takeoff Weight = 12 138 kg (2 AAM, no tanks)

So what’s the lift force?
Question

How does the weight vary with a typical mission?
Question: How does the operational altitude and airspeed vary?
Question: So what are typical values for the lift coefficients?

F16, 1g sustained (level flight) at 700 kts, 50 kft

air density (15.2 km) =

airspeed =

weight (2 AAM 50% fuel) =

wing area =

Hence CL =
Question: Is CL constant throughout flight?

Example: F16 flap schedule
1.3: Describing wing shapes

b: span

c: chord

S: surface area

Λ: aspect ratio $b^2/S$

F16

$b = 9.14 \text{ m}$

$S = 27.87 \text{ m}^2$

$\Lambda = 3.00$
1.4 : Concept of wing loading

A measure of force distribution on an aircraft

\[
\text{Wing loading} = \frac{\text{Lift force}}{\text{Wing area}}
\]

For level flight,

\[
lift = weight
\]

hence

\[
\text{wing loading} = \frac{W}{S}
\]
**Question:** What is the wing loading for typical combat aircraft?

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>b (m)</th>
<th>S (m²)</th>
<th>AR</th>
<th>W/S (N/m²)</th>
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</thead>
<tbody>
<tr>
<td>F104</td>
<td>6.68</td>
<td>18.2</td>
<td>2.45</td>
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<td>Jaguar</td>
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<td>3</td>
<td>4263</td>
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<tr>
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<tr>
<td>F16</td>
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<td>27.87</td>
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<tr>
<td>F18</td>
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<td>F14</td>
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<tr>
<td>MIG 25</td>
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</table>

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Figure 1.4.1

The diagram shows a scatter plot of wing loading (N/m²) against aspect ratio for various aircraft models. Points are labeled with the names of the aircraft models, including Tornado, Kfir, Mirage 2000, Mirage III, Viggen, Jaguar, F18, and X31. The aspect ratio ranges from 0 to 4 on the x-axis, and the wing loading ranges from 0 to 7000 on the y-axis.
Moral

Large W/S ⇒ less sensitive to gust

Small W/S ⇒ better manoeuvrability

Question : Why ?
1.5 Axis System

1.5.1: For flight dynamics and control the axis system or reference frame is *fixed* to the flight vehicle.

1.5.2: The *convention* for flight dynamics is to place the origin at the centre of mass of the aircraft with

I) The positive x axis points towards the nose
II) The positive y axis points towards the right wing
III) The positive z axis points *downwards*.

NB: Aerodynamics, propulsion & structures use different conventions
1.6 Describing Aircraft Motion

The aircraft can rotate about the 3 axes

<table>
<thead>
<tr>
<th>Term</th>
<th>Physical description</th>
<th>rotation axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>roll</td>
<td>wings up/down</td>
<td>X</td>
</tr>
<tr>
<td>pitch</td>
<td>nose up/down</td>
<td>Y</td>
</tr>
<tr>
<td>yaw</td>
<td>nose right/left</td>
<td>Z</td>
</tr>
</tbody>
</table>

Positive direction of rotation determined by right hand rule
1.7 Means of controlling roll, pitch & yaw

Present aircraft use control surfaces to generate the aerodynamic forces/moments for roll, pitch and yaw.
Question: What’s downwash?

Downwash refers to the effect airflow coming off from the wing has on the tail.

Basically, it changes the direction of the airflow at the tail.
1.8 Nomenclature & symbols

\( \alpha \) : angle of attack (AOA)
\( \beta \) : sideslip angle
\( \delta_a \) : aileron deflection
\( \delta_e \) : elevator deflection
\( \delta_r \) : rudder deflection
\( \rho \) : air density
\( \phi, \theta, \psi \) : roll, pitch and yaw angles

\( l.m.n \) : roll, pitch & yaw moments
\( p,q,r, \) : roll, pitch and yaw angular rates
\( u,v,w \) : velocity X,Y & Z components