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

3.1 Degrees of freedom (DOF)

The aircraft dynamical model consists of 6 kinds of motion or *degrees of freedom*. They are

a) Translation along the X (forward/back), Y (left/right) and Z (up/down) axis

b) Rotation about the X (roll), Y (pitch) and Z (yaw) axis
3.2 The size of the Flight Control System (FCS) problem

Most dynamical systems are governed by a set of ordinary differential equations:

\[ x_1' = f_1(x_1, x_2, \ldots, x_n) \]
\[ \ldots \]
\[ x_n' = f_n(x_1, x_2, \ldots, x_n) \]

or more simply denoted by \( x' = f(x) \)
Question: How many ode's do we need for an FCS?
Answer: For the 6 DOF model....

Dynamics
Translational :
Rotational :
Orientation :

Control (simple)
Accelerometers :
Gyrosopes :
Other sensors :
Actuators :
Lead/Lag :

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So the bottom line is for a full-fledge FCS expect about ..... 

_____ to ____

NON-LINEAR !
COUPLED !
FIRST ORDER !

ordinary differential equations
3.3. How do we analyse systems of ODE's?

The math consists of 4 main steps:

1. Find fixed points, i.e. solve \( f(\mathbf{x}_0) = 0 \)

2. Linearise about \( \mathbf{x}_0 \), i.e. set \( \mathbf{x} = \mathbf{x}_0 + \Delta \mathbf{x} \)
   \[
   \Delta \mathbf{x}' = \left[ \frac{\partial f}{\partial \mathbf{x}} \right]_{\mathbf{x}_0} \Delta \mathbf{x}
   \]

3. Find singular points, \( \det \left[ \frac{\partial f}{\partial \mathbf{x}} \right] = 0 \)

4. Do nonlinear (bifurcation) analysis
In aeronautical engineering terms, the 4 steps corresponds to:

1. Find trim conditions

2. Do stability and flying qualities check using e.g., MIL-F-8785C

3. Determine aoa, β and other limits.

4. Check post-stall and departure behaviour e.g. nose-slice, wing-rock, pitch-up, etc.
3.4. Typical model assumptions

Most common FCS models assume that

1) C.G. movement is insignificant for the time interval of interest.

2) The XZ plane is a plane of symmetry.

3) The thrust vector lies in the plane of symmetry, at an orientation angle $\varepsilon$ from the X axis.

Question: Are these reasonable assumptions?
Figure 3.4.1. Thrust vector
Question: Do you know of any aircraft with an asymmetric configuration?
Question: Is the thrust angle always constant?
3.5 Military Specifications

FCS performance requirements are stated in

1. MIL - F - 8785C
Flying Qualities of Piloted Airplanes, 1980

2. MIL - STD - 1797A
Flying Qualities of Piloted Vehicles, 1987

3. MIL - F - 9490D
3.6: Longitudinal and Lateral Modes

MIL 8785 specifications group the 6 degrees of freedom into longitudinal and lateral modes.

**Longitudinal Modes**
- Translation: Forward/back, Up/down
- Rotation: Pitch

**Lateral Modes**
- Translation: Left/right
- Rotation: Roll, Yaw

Question: Why?
Example: MIL 8785 roll requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Speed Range</th>
<th>30°</th>
<th>50°</th>
<th>90°</th>
<th>180°</th>
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<tbody>
<tr>
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<td>1.1</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>L</td>
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<td></td>
<td>H</td>
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</tr>
</tbody>
</table>
Example : MIL 9490 FCS requirements

**Table III: Gain and Phase Margin Requirements (dB, Degrees)**

<table>
<thead>
<tr>
<th>Mode Frequency Hz</th>
<th>Airspeed</th>
<th>Below ( V_{omin} )</th>
<th>( V_{omin} ) To ( V_{omax} )</th>
<th>At Limit Airspeed (( V_L ))</th>
<th>At 1.15 ( V_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_M &lt; 0.06 )</td>
<td>GM = 6 DB (No Phase Requirement Below ( V_{omin} ))</td>
<td>GM = ±4.5</td>
<td>GM = ±3.0</td>
<td>GM = 0</td>
<td>GM = 0 (Stable at Nominal Phase and Gain)</td>
</tr>
<tr>
<td>( 0.06 \leq f_M \leq ) First Aero-Elastic Mode</td>
<td>GM = ±6.0</td>
<td>PM = ±30</td>
<td>PM = ±20</td>
<td>PM = 0</td>
<td></td>
</tr>
<tr>
<td>( f_M &gt; ) First Aero-Elastic Mode</td>
<td>GM = ±8.0</td>
<td>PM = ±45</td>
<td>PM = ±30</td>
<td>GM = ±6.0</td>
<td>PM = ±45</td>
</tr>
</tbody>
</table>

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3.7 What happens when FCS limits are exceeded?

Case study 1: A7 high AOA flow separation (Johnston & Hogge)

Case study 2: YF22 Pilot Induced Oscillation - PIO