Lecture 9 : Understanding MIL-F-8785C

Or the flying qualities of piloted airplanes

G. Leng, Flight Dynamics, Stability & Control

1.0 The concept of a reduced order approximation

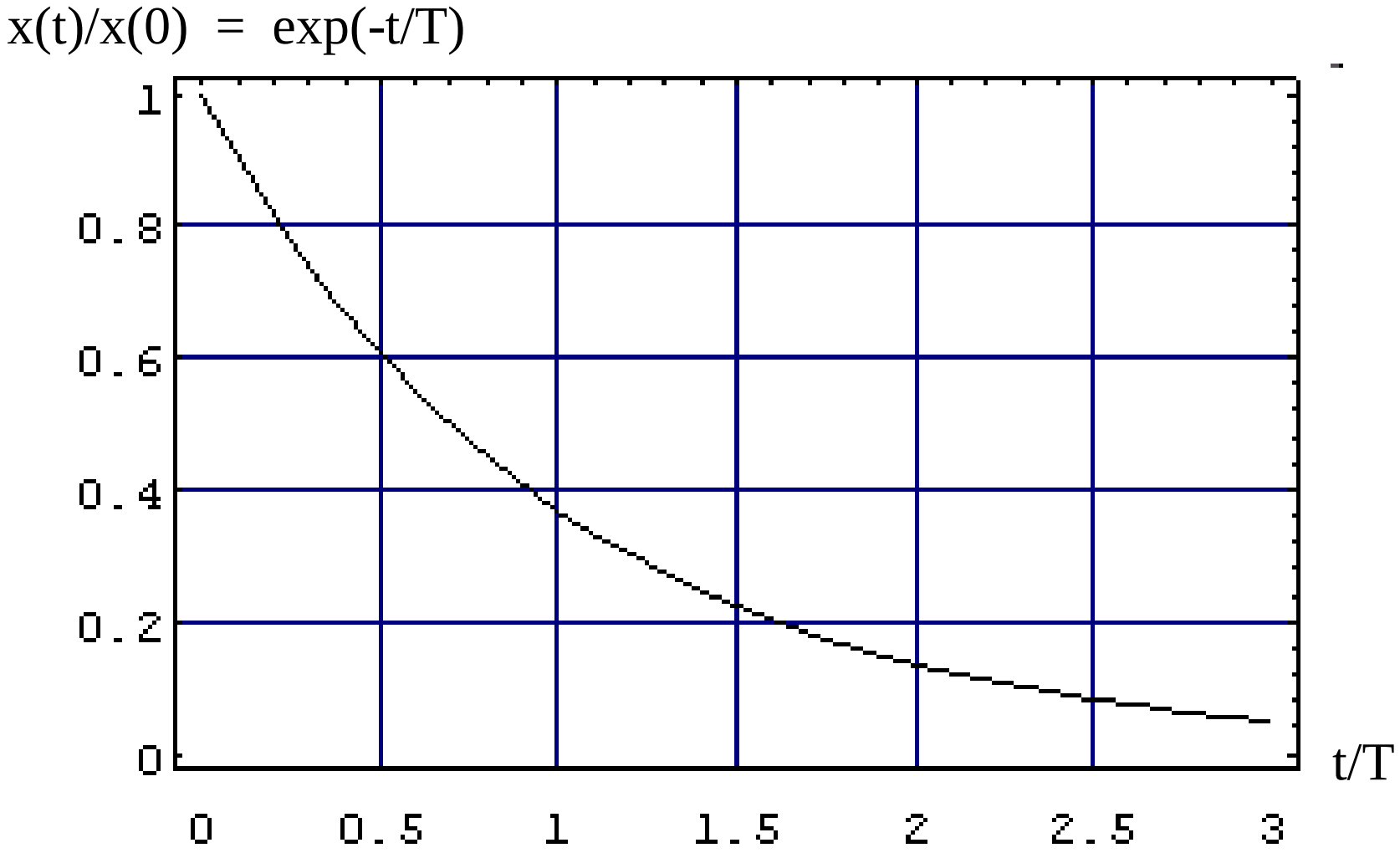
1.1 Each stable real eigenvalue define a reduced (first) order approximation of the form:

$$x' + (1/T)\,x = 0$$

T : time constant

The real eigenvalue is of the form:

Figure 1.1 : 1st order system



1.2 Each complex pair of eigenvalues define a reduced (second) order approximation of the form:

$$x'' + (2\xi\omega)\, x' + \omega^2 x = 0$$

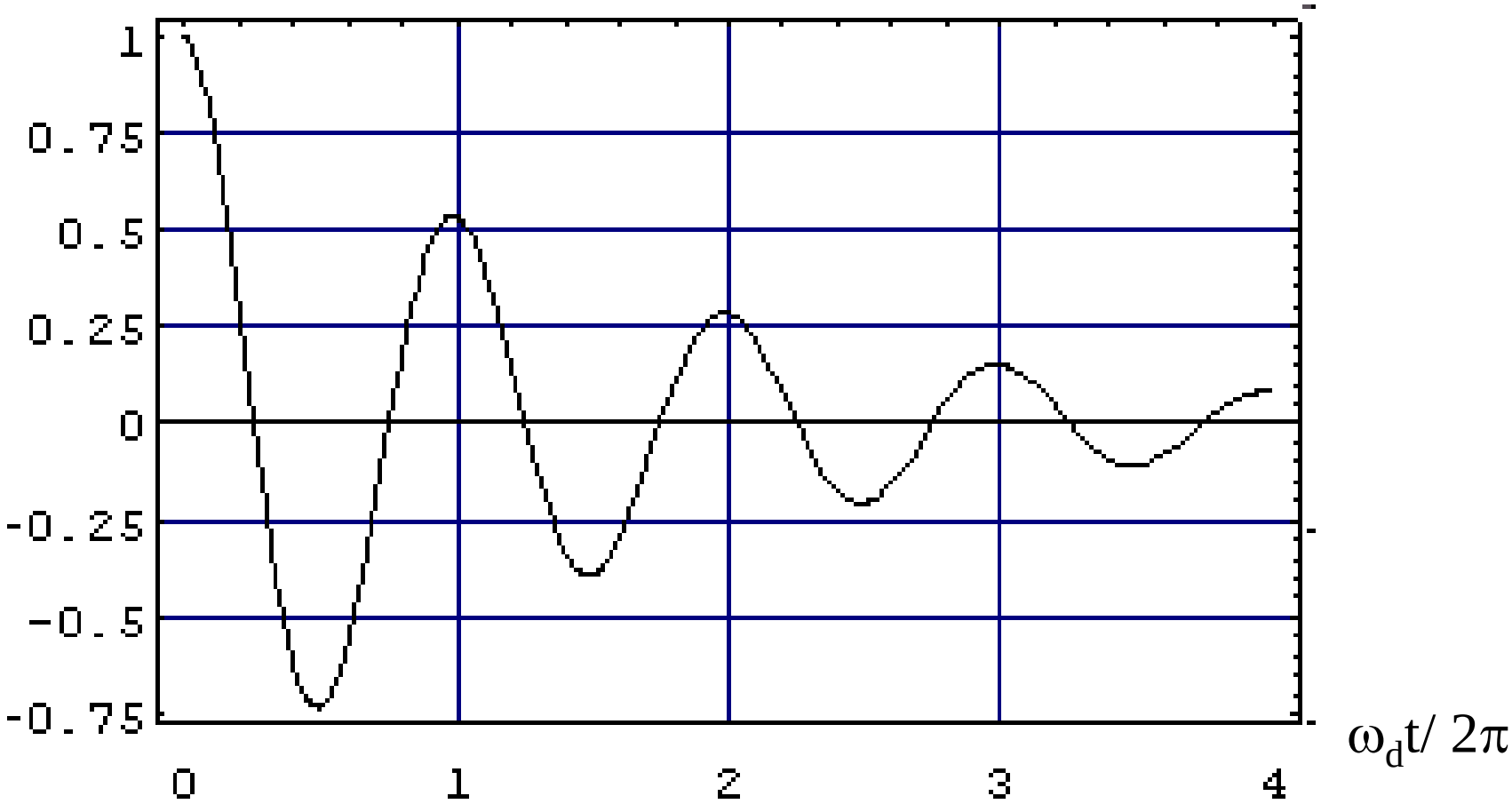
ξ : damping ratio $0 \leq \xi \leq 1$

ω : undamped natural frequency

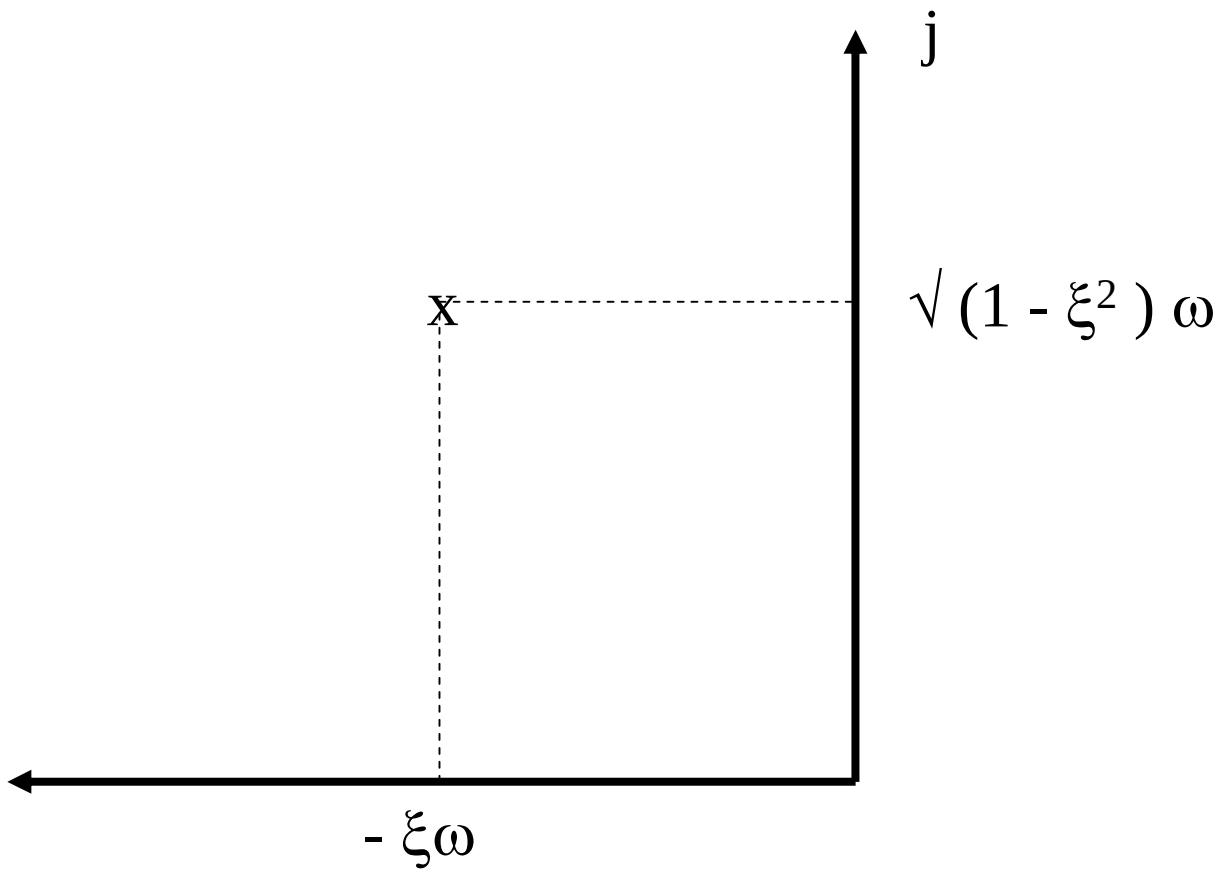
2. The complex pair of eigenvalues is of the form:

Fig 1.2 : 2nd order system

$$x(t)/x(0) = \exp[-(\xi\omega)\, t\,]\ \cos(\omega_d t)$$



In the complex plane, the damping ratio and the undamped natural frequency for a complex eigenvalue can be deduced as follows:



Important note

1. Eigenvalues with the same natural frequency are at the same distance from the origin.

2. Eigenvalues with the same damping ratio make the same angle with the imaginary axis.

3. MIL-F-8785C specifies flying qualities using these concepts.

2.0 MIL-F-8785C requirement for phugoid mode

Recall that the phugoid mode is marginally stable or unstable...

3.2.1.2 Phugoid stability. The long-period oscillations which occur when the airplane seeks a stabilized airspeed following a disturbance shall meet the following requirements:

a. Level 1 ----- ζ_p at least 0.04

b. Level 2 ----- ζ_p at least 0

c. Level 3 ----- T_2 at least 55 seconds

These requirements apply with the pitch control free and also with it fixed. They need not be met transonically in cases where 3.2.1.1.1 permits relaxation of the static stability requirement.

Indicate these boundaries on the complex plane

2.1 MIL-F-8785C, Section 1.5 : Levels of Flying Qualities

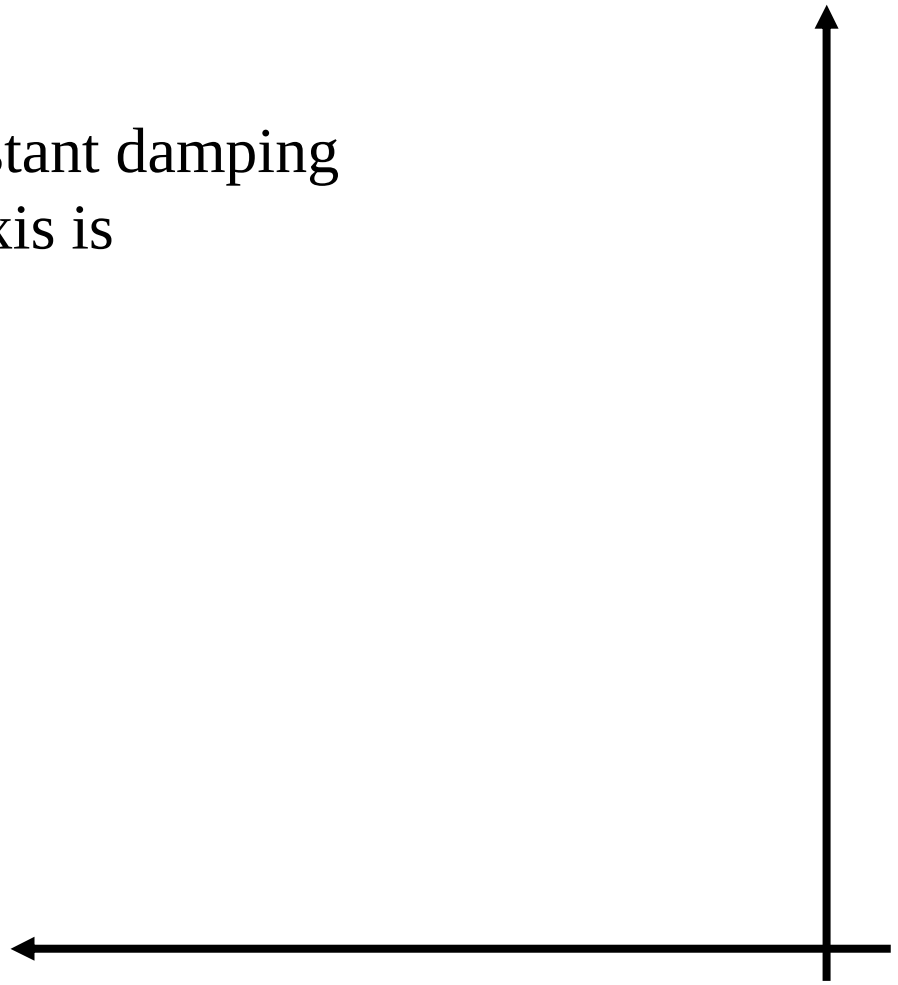
Level 1	Flying qualities clearly adequate for the mission Flight Phase
Level 2	Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists
Level 3	Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A Flight Phases can be terminated safely, and Category B and C Flight Phases can be completed.

2.2 MIL-F-8785C boundaries for phugoid mode

The angle of the constant damping with the imaginary axis is

=

=



3.0 MIL-F-8785C : Short period damping requirements

3.2.2.1.2 Short-period damping. The equivalent short-period damping ratio, ζ_{SP}, shall be within the limits of table IV.

TABLE IV. Short-period damping ratio limits.

Level	Category A and C Flight Phases		Category B Flight Phases	
	Minimum	Maximum	Minimum	Maximum
1	0.35	1.30	0.30	2.00
2	0.25	2.00	0.20	2.00
3	0.15*	-	0.15*	-

* May be reduced at altitudes above 20,000 feet if approved by the procuring activity.

Note

damping ratio ξ	0.35	0.25	0.15
angle with imaginary axis (^{o})			

3.1 MIL-F-8785C, Section 1.4 Flight Phase Categories

Cat A : non terminal flight phase, rapid maneuvering, precision tracking, precise flight path control, ex: CO - air to air combat, GA - ground attack

Cat B : non terminal flight phase , gradual maneuvers, no precise tracking, may need precise flight path control, ex : CR - cruise, CL - climb, D - descent, LO - loiter

Cat C : terminal flight phases, gradual maneuvers, accurate flight path control, ex : TO - takeoff, L - landing

4.0 MIL-F-8785C 3.3.1.1 Dutch roll requirements

TABLE VI. Minimum Dutch roll frequency and damping.

Level	Flight Phase Category	Class	Min ζ_d*	Min $\zeta_d\omega_{nd}$* rad/sec.	Min ω_{nd} rad/sec.
1	A (CO and GA)	IV	0.4	-	1.0
	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4**
	B	All	0.08	0.15	0.4**
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.10	0.4**
2	All	All	0.02	0.05	0.4**
3	All	All	0	0	0.4**

4.1 MIL-F-8785C 1.3 Classification of Airplanes

1.3 Classification of airplanes. For the purpose of this specification, an airplane shall be placed in one of the following Classes:

Class I — Small, light airplanes such as
- Light utility
- Primary trainer
- Light observation

Class II — Medium weight, low-to-medium maneuverability airplanes such as
- Heavy utility/search and rescue
- Light or medium transport/cargo/tanker
- Early warning/electronic countermeasures/airborne command, control, or communications relay
- Antisubmarine
- Assault transport
- Reconnaissance
- Tactical bomber
- Heavy attack
- Trainer for Class II

Class III — Large, heavy, low-to-medium maneuverability airplanes such as
- Heavy transport/cargo/tanker
- Heavy bomber
- Patrol/early warning/electronic countermeasures/airborne command, control, or communications relay
- Trainer for Class III

The most demanding class of airplanes…

Class IV	High-maneuverability airplanes such as Fighter/interceptor Attack Tactical reconnaissance Observation Trainer for Class IV

5.0 MIL-F-8785C 3.3.1.2 Roll mode requirements

3.3.1.2 Roll mode. The roll-mode time constant, τ_R, shall be no greater than the appropriate value in table VII.

TABLE VII. Maximum roll-mode time constant, seconds.

Flight Phase Category	Class	Level		
		1	2	3
A	I, IV	1.0	1.4	
	II,III	1.4	3.0	
B	All	1.4	3.0	10
C	I. II-C, IV	1.0	1.4	
	II-L, III	1.4	3.0	

6.0 MIL-F-8785C 3.3.1.3 Spiral mode requirements

Recall that the spiral mode affects the roll (bank) angle...

3.3.1.3 Spiral stability. The combined effects of spiral stability, flight-control-system characteristics and rolling moment change with speed shall be such that following a disturbance in bank of up to 20 degrees, the time for the bank angle to double shall be greater than the values in table VIII. This requirement shall be met with the airplane trimmed for wings-level, zero-yaw-rate flight with the cockpit controls free.

TABLE VIII. Spiral stability - minimum time to double amplitude.

Flight Phase Category	Level 1	Level 2	Level 3
A & C	12 sec	8 sec	4 sec
B	20 sec	8 sec	4 sec

7.0 MIL-F-8785C 3.3.4.1.1 Roll performance (class IV airplanes)

TABLE IXc. Flight Phase CO roll performance in 360˚ rolls.

Time to Achieve the Following Bank Angle Change (Seconds)

Level	Speed Range	30˚	90˚	180˚	360˚
1	VL	1.0			
	L		1.4	2.3	4.1
	M		1.0	1.6	2.8
	H		1.4	2.3	4.1
2	VL	1.6			
	L	1.3			
	M		1.3	2.0	3.4
	H		1.7	2.6	4.4
3	VL	2.5			
	L	2.0			
	M		1.7	3.0	
	H		2.1		

7.1 MIL-F-8785C 3.3.4.1 Speed ranges for roll performance

Speed Range Symbol	Equivalent Airspeed Range For Level 1	For Levels 2 & 3
VL	$V_{o_{min}} \le V \le V_{min} + 20$ KTS	$V_{min} \le V \le V_{min} + 20$ KTS
L	$V_{min} + 20$ KTS$^{(1)} \le V < 1.4\ V_{min}$	$V_{min} + 20$ KTS $\le V < 1.4\ V_{min}$
M	$1.4\ V_{o_{min}} \le V < .7\ V_{max}^{(2)}$	$1.4\ V_{min} \le V < .7\ V_{max}$
H	$.7\ V_{max}^{(2)} \le V \le V_{o_{max}}$	$.7\ V_{max} \le V \le V_{max}$

(1) or $V_{o_{min}}$ whichever is greater

(2) or $V_{o_{max}}$ whichever is less

V_{max} , V_{min} : maximum (minimum) service speed

V_o : above as adjusted by a factor in Table 1

Question : Is there life after MIL-F-8785C ?