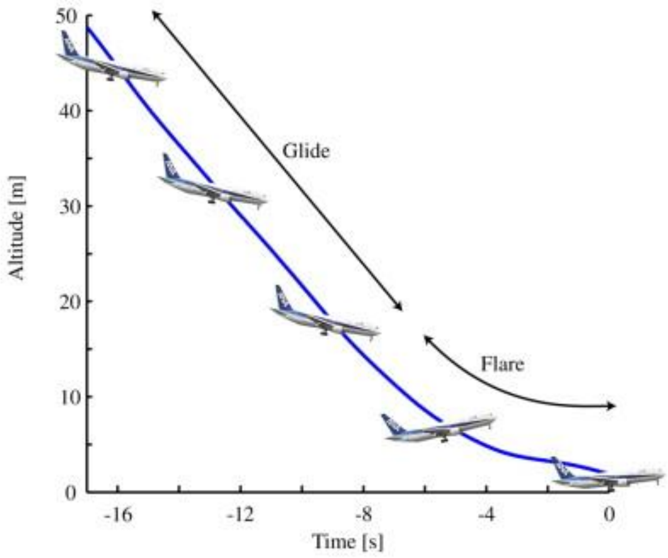
AUTOMATIC FLARE MODE



Prepared
by

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- The vertical touch down velocity of aircraft onto the runway is determined by
  - Passenger and crew comfort
  - Landing gear and its attachment structures

Passenger and crew comfort

- Hard landings (touchdown rates of 6ft/sec or more) are not accepted by everyday operations.

- Firm landings(touch down rate of 2-3ft/sec) are desirable.
- Egg-landings (close to zero touchdown rates) are also undesirable. The reason is that an inevitable consequences of very low touch down rates is “floatation” of the airplane and lack of control over the touchdown point on the runway.

Landing Gear and its attachments

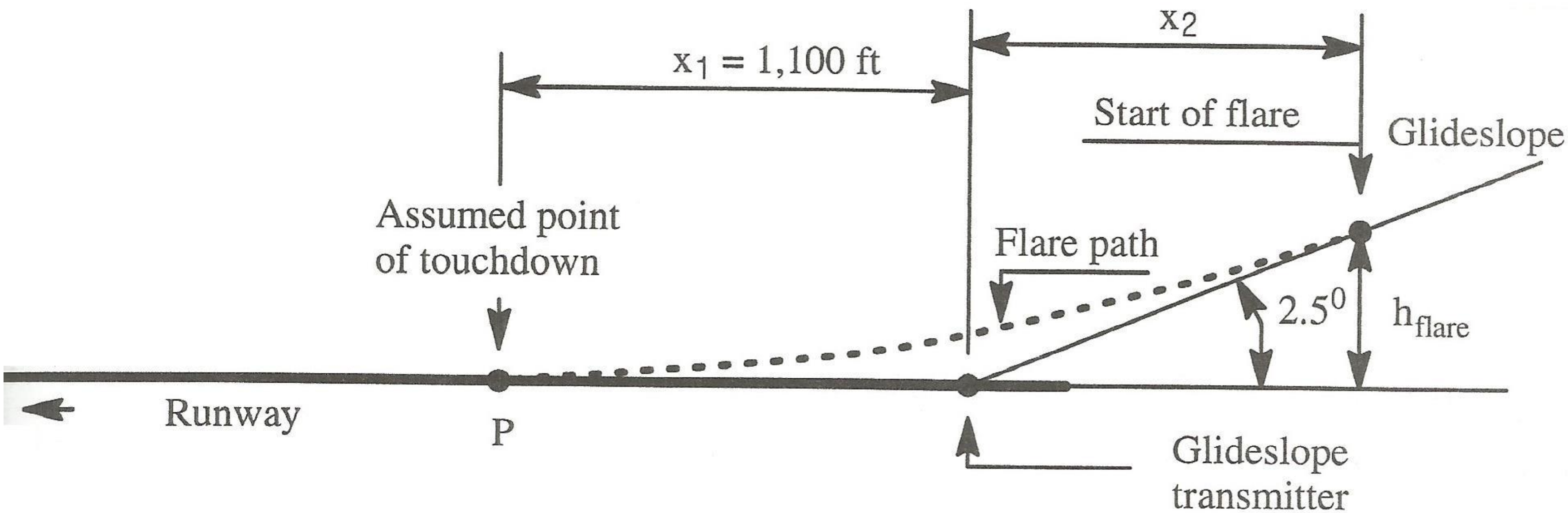
- The landing gear and the attachment may incus damage if the touchdown velocity are too high.
- Civil aircraft landing gears are designed to withstand a vertical touch down velocity rate of about 10ft/sec
- Certain carrier based airplanes the touchdown rate can be as high as 25ft/sec

- The carrier based airplanes do not flare when coming on onboard carrier. These airplanes are **driven straight into the deck** (aiming for the number three arresting wire) along the glide slope.

- The below table shows the relation ship between vertical touch down velocity and forward air speed at 2.5 degree glide slope.

Forward Velocity		Vertical touchdown velocity on a 2.5 degree glideslope	
Knots	Ft/sec	Ft/sec	
10	17	0.7	"soft landings"
20	34	1.5	
40	68	3.0	
80	135	6.0	"hard landings"
120	203	9.0	
160	270	12.0	

- The following assumptions will be made while doing flare path
  - The airplane will be controlled on the flare path by the pitch command system.
  - The flare path starts at a height of h flare.
  - The intended point of touch down is 1100 ft from the glide slope transmitter.


x2
x1 = 1,100 ft
Start of flare
Glideslope
Assumed point
of touchdown
Flare path
2.5⁰
hflare
Runway
P
Glideslope
transmitter

- Assume that the flare path can be approximated by a relation which makes it tangential to a point P

$$h = h_{flare} e^{-t/\tau}$$

By Differentiating $$\dot{h} = -\frac{h_{flare}}{\tau} e^{-t/\tau} = -\frac{h}{\tau}$$

$$\text{Assuming that the airplane touches down in } t = 4\tau$$

$$X_1 + X_2 = 4\tau U_1 \qquad 1100 + X_2 = 4\tau U_1$$

$$1100 + X2 = 4 \times \tau \times 221$$

$$1100 + X_2 = 884\tau$$

$$X_2 = 884\tau - 1100$$

however from the geometry

$$X_2 = \frac{h_{flare}}{\tan 2.5^\circ}$$

At the start of flare, the rate of descent is given by

$$\dot{h}_{at\,h_{flare}} = -\frac{2.5}{57.3}U_1 = \left(-\frac{2.5}{57.3}\right)221 = -9.64\,ft/\sec$$

$$X_2 = \frac{9.644\tau}{\tan 2.5^\circ} = 221\tau$$

we already know that

$$X_2 = 884\tau - 1100$$

$$221\tau = 884\tau - 1100$$

$$\tau = 1.66\,\text{sec}$$

The flare height hflare from which the flare is begun is

$$9.64 \times 1.66 = 16\,ft$$

The flare control law now expressed as

$$\dot{h} = -\frac{h}{1.66} = -0.6h$$

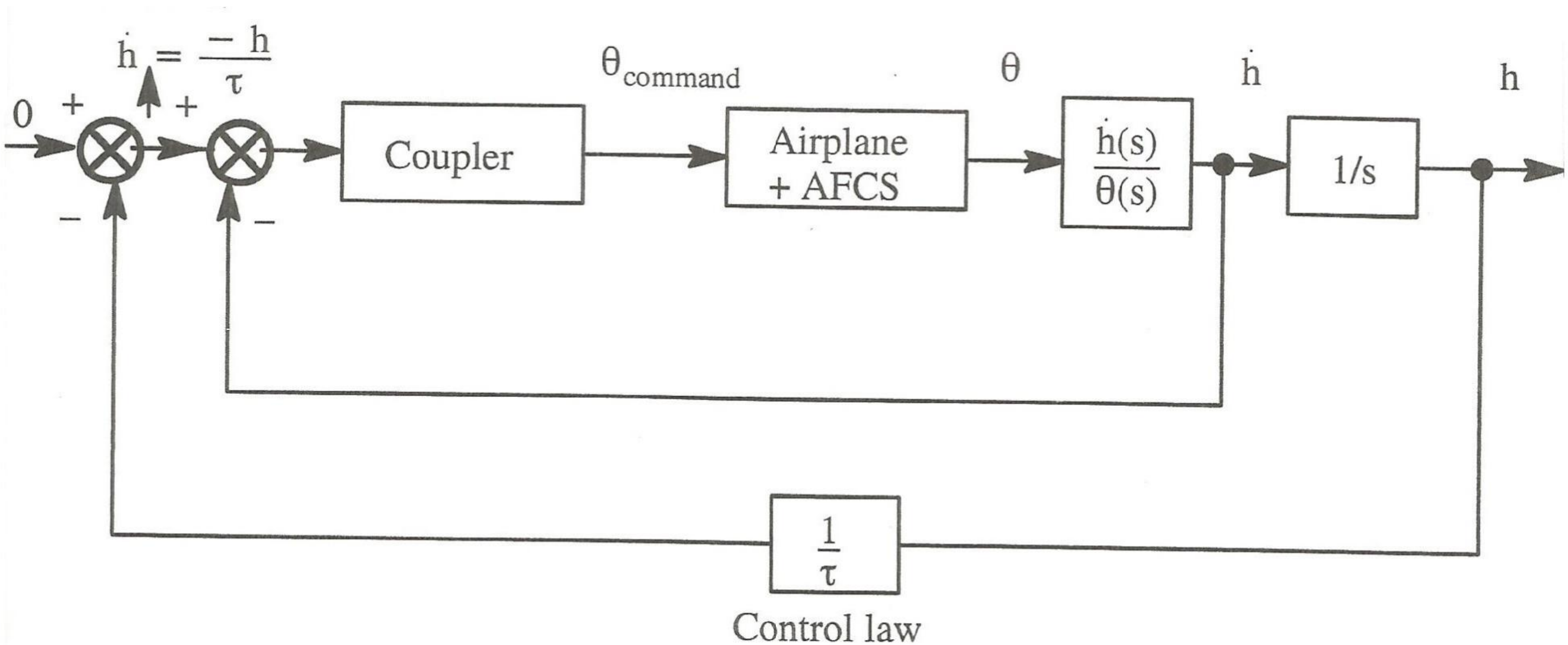
During the flare the rate of decenth will be controlled by pitch attitude command system

$$note\ that\ \dot{h}\ also\ given\ by \qquad \dot{h} = U1\gamma(radians)$$

$$Divide\ the\ equation\ by\ \theta(s)$$

$$\frac{\dot{h}(s)}{\theta(s)} = \frac{\gamma(s)U_1}{\theta(s)57.3} \qquad (\gamma\ in\ degress)$$

$$\frac{\dot{h}(s)}{\theta(s)} = \left(\frac{221}{57.3}\right)\frac{6.555s^3 - 2.4s^2 - 42.2s + 0.296}{-91.01s^2 - 44.6s - 3.097}$$



$\dot{h} = \frac{-h}{\tau}$
0
+
+
−
−
$\theta_{command}$
θ
$\dot{h}$
h
Coupler
Airplane
+ AFCS
$\frac{\dot{h}(s)}{\theta(s)}$
1/s
$\frac{1}{\tau}$
Control law

- The first coupler transfer function to be tried is

$$TFF_{coupler} = K_c\left(1+\frac{0.1}{s}\right)$$

0.1 *is the weighting constant.*

$K_c - Coupler\ Gain$

0.1 *is the weighting constant.*

- The transfer function of the airplane plus its pitch attitude command system is

$$\frac{\theta(s)}{\theta_{command}(s)} = \frac{910.2s^2 + 446.4s + 30.97}{228.5s^5 + 4787s^4 + 6307s^3 + 4648s^2 + 633s + 107.3}$$

where

$$\frac{\dot{h}(s)}{\theta(s)} = \frac{\gamma(s)U_1}{\theta(s)57.3} \qquad (\gamma \; in \deg)$$

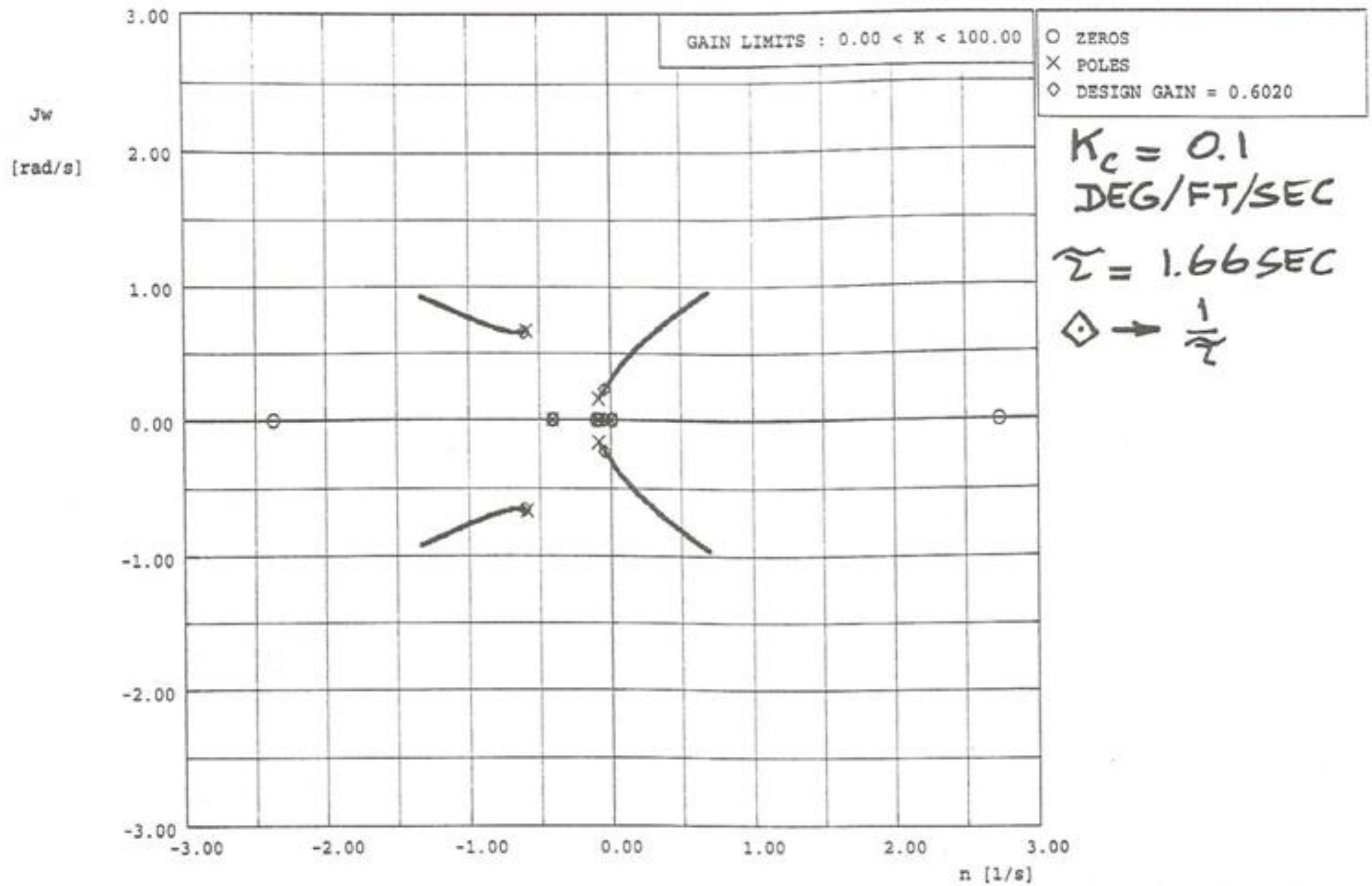
We know that

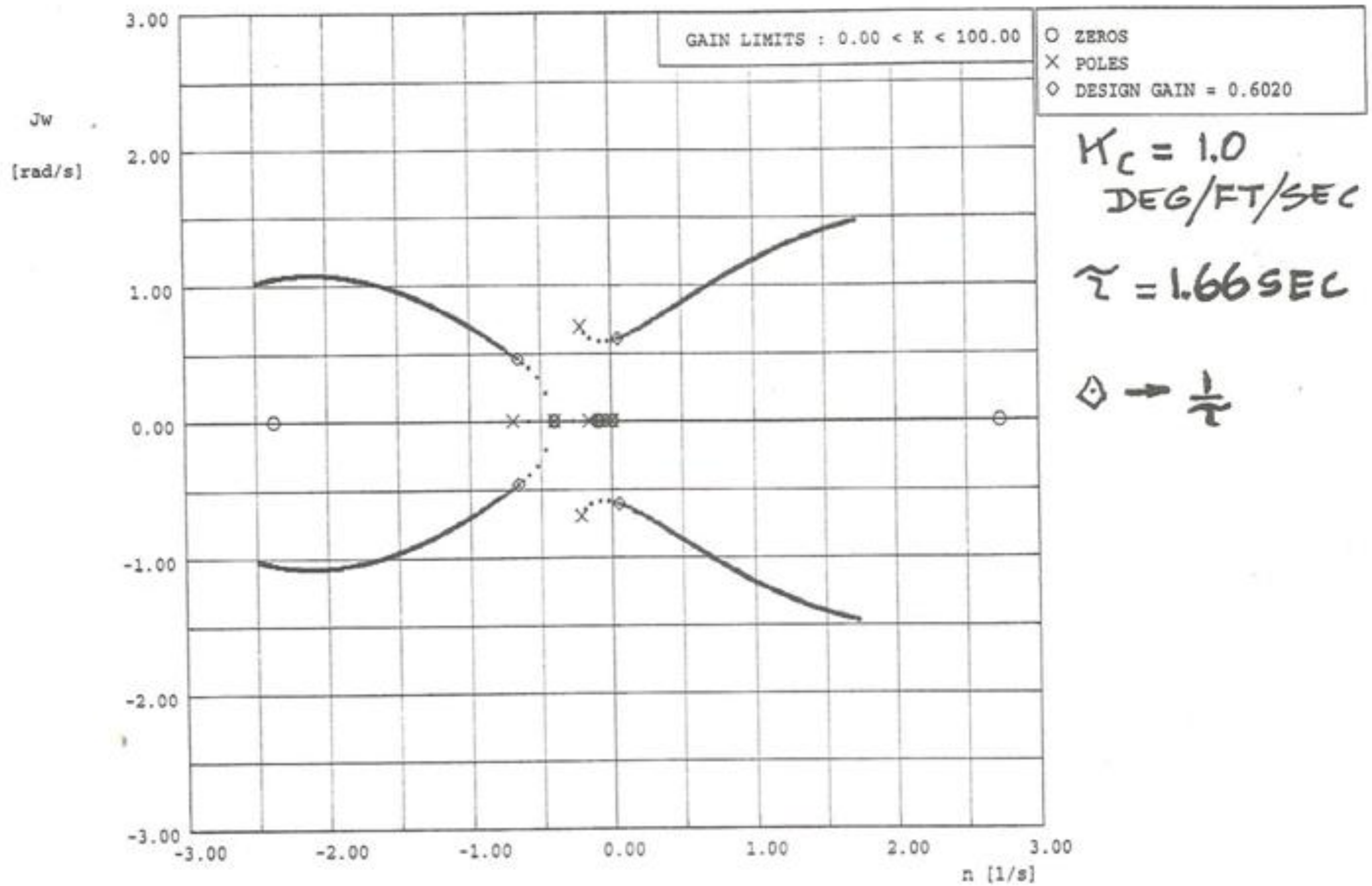
$$\frac{\gamma(s)}{\theta(s)} = \frac{6.555s^3 - 2.4s^2 - 42.5s + 0.296}{-91.01s^2 + 44.6s - 3.097}$$

So

$$\frac{\dot{h}(s)}{\theta(s)} = \left(\frac{221}{57.3}\right)\frac{6.555s^3 - 2.4s^2 - 42.5s + 0.296}{-91.01s^2 + 44.6s - 3.097}$$

- Figure.1 and Figure.2 shows the root locus diagram for the flare path control system for kc=0.1 deg/ft/sec and kc=1.0 deg/ft/sec respectively.
- Observe the fact that the stability of the operating point is strongly influenced by the selection of the coupler gain.
- The reader is encouraged to find lead lag compensator which lowers this sensitivity.
- The autopilot carry out maneuvers with much great accurate than human pilots. Therefore, the flare path control system will ensure runway damage by always touching airplane down at point P in the figure.
- To avoid this in the real worlds, most flare control laws include some form of "Monte Carlo" scheme to vary the intended point of touch down.
- This creates the type of touchdown dispersion which human pilots, because of their lack of repeatability, always exhibit.


GAIN LIMITS : 0.00 < K < 100.00
O ZEROS
X POLES
◇ DESIGN GAIN = 0.6020
Jw
[rad/s]
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
n [1/s]
$K_c = 0.1$
DEG/FT/SEC
$\tau = 1.66$ SEC
$\diamond \rightarrow \frac{1}{\tau}$



$K_C = 1.0$ DEG/FT/SEC

$\tau = 1.66$ SEC

◇ → $\frac{1}{\tau}$

Thank you