Type 1:

RHS $= e^{ax}$

Replace D by a.

Q. Solve $(D^2+1)y = e^{-x}$

Soln.

The Auxiliary eqn. is $m^2+1=0$

$m^2 = -1$

$m = \pm i$

$\therefore$ The roots are imaginary.

$CF = e^{0x}[A\cos x + B\sin x]$

$CF = A\cos x + B\sin x$

$PI = \frac{1}{D^2+1} e^{-x}$

$= \frac{1}{(-1)^2+1} e^{-x}$ Replace $D \to a = -1$

$= \frac{1}{2} e^{-x}$

$PI = \frac{e^{-x}}{2}$

$\therefore$ The soln. is $y = CF + PI$

$y = A\cos x + B\sin x + \frac{e^{-x}}{2}$

2]. Solve $(D^2+4D+4)y = 11e^{-2x}$

Soln.

The auxiliary eqn. is, $m^2+4m+4=0$

$$(m+2)^2 = 0$$

$$m = -2, -2$$

The roots are real and same.

$$CF = (A+Bx)e^{-2x}$$

$$PI = \frac{1}{D^2+4D+4} 11e^{-2x}$$

$$= 11 \frac{1}{(-2)^2+4(-2)+4} e^{-2x}$$

Replace $D \to a = -2$

$$= 11 \frac{1}{4-8+4} e^{-2x}$$

$$= 11x \frac{1}{2D+4} e^{-2x}$$

[If $Dr. \to 0$, then multiply x in the Nr. and differentiate the Dr. w.r. to D]

$$= 11x \frac{1}{2(-2)+4} e^{-2x}$$

$$= 11x^2 \frac{1}{2} e^{-2x}$$

$$= \frac{11x^2}{2} e^{-2x}$$

∴ The general soln. is,

$$y = CF + PI$$

$$= (A+Bx)e^{-2x} + \frac{11x^2}{2}e^{-2x}$$

3]. Solve $(D^2-2D+1)y = \cosh x$

Soln.

Given $(D^2-2D+1)y = \frac{e^x+e^{-x}}{2}$

$$= \frac{1}{2}[e^x+e^{-x}]$$

$$= \frac{e^x}{2} + \frac{e^{-x}}{2}$$

AE

$m^2 - 2m + 1 = 0$

$m = 1, 1$

CF

$CF = (A + Bx)e^{x}$

$PI_1 = \frac{1}{D^2 - 2D + 1} \frac{e^{x}}{2}$

$= \frac{1}{2} \frac{1}{1^2 - 2(1) + 1} e^{x}$ $\quad D \to 1$

$= \frac{x}{2} \frac{1}{2D - 2} e^{x}$

$= \frac{x^2}{2} \cdot \frac{1}{2} e^{x}$

$PI_1 = \frac{x^2}{4} e^{x}$

$PI_2 = \frac{1}{D^2 - 2D + 1} \frac{e^{-x}}{2}$

$= \frac{1}{2} \frac{1}{(-1)^2 - 2(-1) + 1} e^{-x}$

$= \frac{1}{2} \frac{1}{1 + 2 + 1} e^{-x}$

$PI_2 = \frac{1}{8} e^{-x}$

The general soln. is

$y = CF + PI_1 + PI_2$

$y = (A + Bx)e^{x} + \frac{x^2}{4} e^{x} + \frac{1}{8} e^{-x}$

Type 2:

$RHS = \sin(ax+b)$

or

$\cos(ax+b)$

Replace $D^2 \to -a^2$

I. Solve $(D^2+3D+2)y = \sin 3x$

Soln.

CF

$m^2+3m+2 = 0$

$(m+1)(m+2) = 0$

$m = 1, 2$

$\therefore CF = Ae^{x} + Be^{2x}$

$PI = \frac{1}{D^2-3D+2} \sin 3x$

$= \frac{1}{-9-3D+2} \sin 3x$ $\qquad D^2 = -a^2 = -9$

$= \frac{1}{-3D-7} \sin 3x$

$= \frac{1}{(-3D-7)} \frac{(-3D+7)}{(-3D+7)} \sin 3x$

$= \frac{-3D+7}{9D^2-49} \sin 3x$

$= \frac{-3D+7}{9(-9)-49} \sin 3x$ $\qquad D^2 \to -9$

$= \frac{-3D+7}{-130} \sin 3x.$

$= \frac{-1}{130} [(-3D+7) \sin 3x]$

$= \frac{-1}{130} [-3D \sin 3x + 7 \sin 3x]$

$= \frac{-1}{130} [-3(3) \cos 3x + 7 \sin 3x]$

$= \frac{1}{1^2 - 3(1) + 2} 2e^x$ $\quad D \to a = 1$

$= x \frac{1}{2D-3} 2e^x$

$= x \frac{1}{2(1)-3} 2e^x$

$= \frac{x}{-1} 2e^x$

$= -2xe^x$

$\therefore$ the soln. is,

$y = CF + PI_1 + PI_2$

$= Ae^x + Be^{2x} - \frac{1}{20}[6\sin(2x+3) + 2\cos(2x+3)] - 2xe^x$

3). Find the PI of $(D^2+5D+6)y = \sin 3x \cos x$

Soln.

Given that $(D^2+5D+6)y = \sin 3x \cos x$

$= \frac{1}{2}[\sin 4x + \sin 2x]$

$\sin A \cos B = \frac{1}{2}[\sin(A+B) + \sin(A-B)]$

$PI_1 = \frac{1}{D^2+5D+6} \frac{1}{2} \sin 4x$

$= \frac{1}{-16+5D+6} \frac{1}{2} \sin 4x$ $\quad D^2 \to -a^2 = -4^2 = -16$

$= \frac{1}{5D-10} \frac{1}{2} \sin 4x$

$= \frac{1}{2} \frac{5D+10}{25D^2-100} \sin 4x$

$= \frac{1}{2} \frac{5D \sin 4x + 10 \sin 4x}{25(-16) - 100}$

$$= \frac{1}{2\times(-500)}\left[20\cos 4x + 10\sin 4x\right]$$

$$PI_1 = \frac{-1}{+100}\left[2\cos 4x + \sin 4x\right]$$

$$PI_2 = \frac{1}{D^2+5D+6}\,\frac{1}{2}\sin 2x$$

$$= \frac{1}{2}\,\frac{1}{-4+5D+6}\sin 2x \qquad D^2 \to -a^2 = -4$$

$$= \frac{1}{2}\,\frac{5D-2}{25D^2-4}\sin 2x$$

$$= \frac{1}{2}\,\frac{\left[5D\sin 2x - 2\sin 2x\right]}{25(-4)-4}$$

$$PI_2 = -\frac{1}{104}\left[5\cos 2x - \sin 2x\right]$$

The Soln. is,

$$y = ~~CF +~~ PI_1 + PI_2$$

$$= \frac{-1}{100}\left[2\cos 4x + \sin 4x\right] - \frac{1}{104}\left[5\cos 2x - \sin 2x\right]$$

Type 3: $RHS = x^n$

1). $(1-D)^{-1} = 1 + D + D^2 + D^3 + \cdots$

2). $(1+D)^{-1} = 1 - D + D^2 - D^3 + \cdots$

3). $(1-D)^{-2} = 1 + 2D + 3D^2 + 4D^3 + \cdots$

4). $(1+D)^{-2} = 1 - 2D + 3D^2 - 4D^3 + \cdots$

Q. Solve $(D^2+2)y = x^2$

Soln.

<u>AE</u> $m^2 + 2 = 0$

$m^2 = -2$

$m = \pm\sqrt{2}\, i$

$\alpha \pm i\beta \Rightarrow \alpha = 0,\ \beta = \sqrt{2}$

$CF = A\cos\sqrt{2}x + B\sin\sqrt{2}x$

$PI = \frac{1}{D^2+2} x^2$

$= \frac{1}{2\left[1 + \frac{D^2}{2}\right]} x^2$

$= \frac{1}{2}\left[1 + \frac{D^2}{2}\right]^{-1} x^2$

$= \frac{1}{2}\left[1 - \frac{D^2}{2} + \frac{D^4}{4} - \cdots\right] x^2$

$= \frac{1}{2}\left[1 - \frac{D^2}{2}\right] x^2$ $\qquad D^2 x^2 = 2x \to 2$

$= \frac{1}{2}\left[x^2 - \frac{D^2 x^2}{2}\right] = \frac{1}{2}\left[x^2 - \frac{2}{2}\right]$

$= \frac{1}{2}\left[x^2 - 1\right]$

$\therefore$ The soln. is, $y = CF + PI$

$= A\cos\sqrt{2}x + B\sin\sqrt{2}x + \frac{1}{2}\left[x^2 - 1\right]$

2]. Solve $(D^2+3D+2)y = x^2$

Soln.

AE $m^2+3m+2=0$

$(m+1)(m+2)=0$

$m=-1,-2$

$CF = Ae^{x} + Be^{-2x}$

$PI = \frac{1}{D^2+3D+2} x^2$

$= \frac{1}{2\left[1+\frac{D^2+3D}{2}\right]} x^2$

$= \frac{1}{2}\left[1+\left(\frac{D^2+3D}{2}\right)\right]^{-1} x^2$

$= \frac{1}{2}\left[1-\left(\frac{D^2+3D}{2}\right)+\left(\frac{D^2+3D}{2}\right)^2\right] x^2$

$= \frac{1}{2}\left[1-\frac{D^2}{2}-\frac{3D}{2}+\frac{9D^2}{4}\right]x^2$

$= \frac{1}{2}\left[x^2-\frac{D^2x^2}{2}-\frac{3D}{2}x^2+\frac{9D^2}{4}x^2\right]$

x^2
$D' = 2x$
$D'' = 2$

$= \frac{1}{2}\left[x^2-\frac{2}{2}-\frac{3(2x)}{2}+\frac{9(2)}{4}\right]$

$= \frac{1}{2}\left[x^2-1-3x+9/2\right]$

$PI = \frac{1}{2}\left[x^2-3x+\frac{7}{2}\right]$

The Soln. is, $y = CF + PI$

$y = Ae^{x}+Be^{-2x}+\frac{1}{2}\left[x^2-3x+\frac{7}{2}\right]$

Type-4

RHS $= e^{ax}\,\phi(x)$ where $\phi(x) = \sin bx$ or $\cos bx$ or x^m

Replace $D \to D + a$

I. Solve $(D^2 - 4D + 3)y = e^{x} \cos 2x$

Soln.

$m^2 - 4m + 3 = 0$

$m = 1, 3$

$CF = Ae^{x} + Be^{3x}$

$PI = \dfrac{1}{D^2 - 4D + 3} e^{x} \cos 2x$

$= e^{x} \dfrac{1}{(D+1)^2 - 4(D+1) + 3} \cos 2x \qquad D \to D + a = D + 1$

$= e^{x} \dfrac{1}{D^2 + 1 + 2D - 4D - 4 + 3} \cos 2x$

$= e^{x} \dfrac{1}{D^2 - 2D} \cos 2x$

$= e^{x} \dfrac{1}{-4 - 2D} \cos 2x \qquad D^2 \to -a^2 = -2^2 = -4$

$= e^{x} \dfrac{-2D + 4}{4D^2 - 16} \cos 2x$

$= e^{x} \dfrac{-2D \cos 2x + 4 \cos 2x}{4(-4) - 16}$

$= \dfrac{e^{x}}{-32} [4 \sin 2x + 4 \cos 2x]$.

$= -\dfrac{e^{x}}{8} [\sin 2x + \cos 2x]$

$\therefore$ The Soln. is $y = CF + PI$

$y = Ae^{x} + Be^{3x} - \dfrac{e^{x}}{8} [\sin 2x + \cos 2x]$

2]. Find the PI of $\frac{d^2y}{dx^2} + 4\frac{dy}{dx} + 4y = xe^{-2x}$

Soln.

Given that $(D^2+4D+4)y = xe^{-2x}$

$$PI = \frac{1}{D^2+4D+4} e^{-2x} x$$

$$= e^{-2x} \frac{1}{(D-2)^2+4(D-2)+4} x \qquad D \to D+a = D-2$$

$$= e^{-2x} \frac{1}{D^2+4-4D+4D-8+4} x$$

$$= e^{-2x} \frac{1}{D^2} x$$

$$PI = \frac{e^{-2x} x^3}{6}$$

$\frac{1}{D}x = \int x = \frac{x^2}{2}$

$\frac{1}{D^2} = \frac{x^3}{6}$

HW 1]. Solve $(D^2-4D-5)y = xe^{x}$

2]. Solve $(D^2+4D+4)y = e^{-2x} x^2$

3]. $(D^2+4D+4)y = e^{-2x} \sin x$

Type - 5

case 1: $RHS = x\,\phi(x)$ where $\phi(x) = \sin ax$ or $\cos ax$

$$PI = x\frac{1}{f(D)} \phi(x) - \frac{f'(D)}{[f(D)]^2} \phi(x)$$

case 2:

$RHS = x^n \phi(x)$

i). PI = Imaginary part $\left[\frac{1}{f(D)} x^n e^{iax}\right]$ if $\phi(x) = \sin ax$

ii). PI = Real part $\frac{1}{f(D)} x^n e^{iax}$ if $\phi(x) = \cos ax$

1). Solve $(D^2+4)y = x\sin x$

Soln.

$m^2+4=0$

$m^2=-4$

$m=\pm 2i$

$\alpha=0,\ \beta=2$

$CF = A\cos 2x + B\sin 2x$

$$PI = \frac{1}{D^2+4} x\sin x$$

$$= x\frac{1}{D^2+4}\sin x - \frac{2D}{(D^2+4)^2}\sin x.$$

$$= x\frac{1}{-1+4}\sin x - \frac{4\cos x}{(-1+4)^2} \qquad D^2 \to -a^2 = -1^2 = -1$$

$$= \frac{x\sin x}{3} - \frac{4\cos x}{9}$$

∴ The soln. is $y = CF + PI$

$$y = A\cos 2x + B\sin 2x + \frac{x\sin x}{3} - \frac{4\cos x}{9}$$

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2). Solve $(D^2-2D+1)y = xe^x\sin x$

Soln.

$m^2-2m+1=0$

$m=1,1$

$CF = (A+Bx)e^x$

$$PI = \frac{1}{D^2-2D+1}e^x x\sin x$$

$$= e^x\frac{1}{(D+1)^2-2(D+1)+1}x\sin x \qquad D\to D+a = D+1$$

$$= e^x\frac{1}{D^2+1+2D-2D-2+1}x\sin x$$

$$= e^{x} \frac{1}{D^2} x \sin x$$

$$= e^{x}\left[x \frac{1}{D^2} \sin x - \frac{2D}{D^4} \sin x\right]$$

$$= e^{x}\left[x \frac{1}{-1} \sin x - \frac{2\cos x}{(-1)^2}\right]$$

$$PI = -x e^{x} \sin x - 2 e^{x} \cos x$$

The soln. is,

$$y = CF + PI$$

$$= (A + Bx) e^{x} - x e^{x} \sin x - 2 e^{x} \cos x$$