

2.5 Euler–Cauchy Equations

Euler–Cauchy equations⁴ are ODEs of the form

$$(1) \quad x^2 y'' + axy' + by = 0$$

with given constants a and b and unknown function $y(x)$. We substitute

$$y = x^m, \quad y' = mx^{m-1}, \quad y'' = m(m-1)x^{m-2}$$

into (1). This gives

$$x^2 m(m-1)x^{m-2} + axmx^{m-1} + bx^m = 0$$

and we now see that $y = x^m$ was a rather natural choice because we have obtained a common factor x^m . Dropping it, we have the auxiliary equation $m(m-1) + am + b = 0$ or

$$(2) \quad m^2 + (a-1)m + b = 0. \quad (\text{Note: } a-1, \text{ not } a.)$$

Hence $y = x^m$ is a solution of (1) if and only if m is a root of (2). The roots of (2) are

$$(3) \quad m_1 = \frac{1}{2}(1-a) + \sqrt{\frac{1}{4}(1-a)^2 - b}, \quad m_2 = \frac{1}{2}(1-a) - \sqrt{\frac{1}{4}(1-a)^2 - b}.$$

Case I. Real different roots m_1 and m_2 give two real solutions

$$y_1(x) = x^{m_1} \quad \text{and} \quad y_2(x) = x^{m_2}.$$

These are linearly independent since their quotient is not constant. Hence they constitute a basis of solutions of (1) for all x for which they are real. The corresponding general solution for all these x is

$$(4) \quad y = c_1 x^{m_1} + c_2 x^{m_2} \quad (c_1, c_2 \text{ arbitrary}).$$

EXAMPLE 1 General Solution in the Case of Different Real Roots

The Euler–Cauchy equation $x^2 y'' + 1.5xy' - 0.5y = 0$ has the auxiliary equation $m^2 + 0.5m - 0.5 = 0$. The roots are 0.5 and -1 . Hence a basis of solutions for all positive x is $y_1 = x^{0.5}$ and $y_2 = 1/x$ and gives the general solution

$$y = c_1 \sqrt{x} + \frac{c_2}{x} \quad (x > 0). \quad \blacksquare$$

⁴LEONHARD EULER (1707–1783) was an enormously creative Swiss mathematician. He made fundamental contributions to almost all branches of mathematics and its application to physics. His important books on algebra and calculus contain numerous basic results of his own research. The great French mathematician AUGUSTIN LOUIS CAUCHY (1789–1857) is the father of modern analysis. He is the creator of complex analysis and had great influence on ODEs, PDEs, infinite series, elasticity theory, and optics.

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