

$$\begin{aligned}
&= 2 \int_{-\pi/2}^{\pi/2} du \left( 1 + \frac{a\delta \sin u}{2} + \frac{\delta^2 \sin^2 u}{8} + \frac{a\delta^3 \sin^3 u}{16} \right)^{1/2} \\
&= 2 \int_{-\pi/2}^{\pi/2} du \left( 1 + \frac{1}{2} \left( \frac{a\delta \sin u}{2} + \frac{\delta^2 \sin^2 u}{8} + \frac{a\delta^3 \sin^3 u}{16} \right) \right. \\
&\quad \left. - \frac{1}{8} \left( \frac{a\delta \sin u}{2} + \frac{\delta^2 \sin^2 u}{8} + \frac{a\delta^3 \sin^3 u}{16} \right)^2 \right. \\
&\quad \left. + \frac{1}{16} \left( \frac{a\delta \sin u}{2} + \frac{\delta^2 \sin^2 u}{8} + \frac{a\delta^3 \sin^3 u}{16} \right)^3 + O(\delta^4) \right) \\
&= 2 \int_{-\pi/2}^{\pi/2} du \left( 1 + \frac{a\delta \sin u}{2} + \frac{\delta^2 \sin^2 u}{8} + \frac{a\delta^3 \sin^3 u}{16} \right. \\
&\quad \left. - \frac{a^2 \delta^2 \sin^2 u}{8} - \frac{a\delta^3 \sin^3 u}{16} + \frac{a^3 \delta^3 \sin^3 u}{16} + O(\delta^4) \right) \\
&= 2 \int_{-\pi/2}^{\pi/2} du \left( 1 + \frac{a\delta \sin u}{2} + \frac{\delta^2 (1-a^2) \sin^2 u}{8} + \frac{3a\delta^3 \sin^3 u}{16} + O(\delta^4) \right) \\
&= 2 \int_{-\pi/2}^{\pi/2} du \left( 1 + \frac{a\delta \sin u}{2} + \frac{\delta^2 (1-a^2) (1-\cos 2u)}{16} + \frac{3a\delta^3 (3\sin u - \sin 3u)}{64} + O(\delta^4) \right) \\
&\quad \left( \text{using } \sin^2 u = \frac{1}{2}(1-\cos 2u) \right. \\
&\quad \left. \text{and } \sin^3 u = \frac{1}{4}(3\sin u - \sin 3u) \right) \\
&= 2 \left[ u - \frac{a\delta \cos u}{2} + \frac{\delta^2 (1-a^2)}{16} \left( u - \frac{1}{2} \sin 2u \right) + \frac{3a\delta^3}{64} \left( -3\cos u + \frac{1}{3} \cos 3u \right) + O(\delta^4) \right]_{-\pi/2}^{\pi/2} \\
&= 2 \left( \frac{\pi}{2} - \frac{\pi}{2} \right) - a\delta (\cos \frac{\pi}{2} - \cos(-\frac{\pi}{2})) + \frac{\delta^2 (1-a^2)}{8} \left( \frac{\pi}{2} - \frac{1}{2} \sin \pi \right) \\
&\quad - \left( -\frac{\pi}{2} - \frac{1}{2} \sin(-\pi) \right) + \frac{3a\delta^3}{32} \left( (-3\cos \frac{\pi}{2} + \frac{1}{3} \cos \frac{3\pi}{2}) - (-3\cos(-\frac{\pi}{2}) + \frac{1}{3} \cos(-\frac{3\pi}{2})) \right) + O(\delta^4) \\
&= 2\pi - 0 + \frac{\delta^2 (1-a^2) \pi}{8} + O(\delta^4) \\
&= 2\pi \left( 1 + \frac{\delta^2 (1-a^2)}{16} + O(\delta^4) \right) \text{ as required}
\end{aligned}$$

Phew!

Amazing! — well done

Your perseverance paid off

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Total 25