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MATB42: Assignment #10 Apr 3rd 2018

1. Let $\boldsymbol{F}$ be a vector field on $\mathbb{R}^3$ given by $\boldsymbol{F} = (F_1, F_2, F_3)$ where F_1, F_2, and F_3 are C^1-functions from $\mathbb{R}^3 \to \mathbb{R}$

   (a) Let η be the 2-form given by

$$\eta = F_3\,dx\,dy + F_1\,dy\,dz + F_2\,dz\,dx$$

   Show that $d\eta = (\operatorname{div}\boldsymbol{F})\,dx\,dy\,dz$
   (page 489, #6)

$$\begin{aligned}
\eta &= F_3\,dx\,dy + F_1\,dy\,dz + F_2\,dz\,dx \\
d\eta &= d(F_3\,dx\,dy + F_1\,dy\,dz + F_2\,dz\,dx) \\
&= (dF_3)\,dx\,dy + (dF_1)\,dy\,dz + (dF_2)\,dz\,dx \\
&= (\frac{\partial}{\partial x}F_3\,dx + \frac{\partial}{\partial y}F_3\,dy + \frac{\partial}{\partial z}F_3\,dz)\,dx\,dy + (dF_1)\,dy\,dz + (dF_2)\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dz\,dx\,dy + (dF_1)\,dy\,dz + (dF_2)\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dx\,dy\,dz + (\frac{\partial}{\partial x}F_1\,dx + \frac{\partial}{\partial y}F_1\,dy + \frac{\partial}{\partial z}F_1\,dz)\,dy\,dz + (dF_2)\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dx\,dy\,dz + \frac{\partial}{\partial x}F_1\,dx\,dy\,dz + (dF_2)\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dx\,dy\,dz + \frac{\partial}{\partial x}F_1\,dx\,dy\,dz + (\frac{\partial}{\partial x}F_2\,dx + \frac{\partial}{\partial y}F_2\,dy + \frac{\partial}{\partial z}F_2\,dz)\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dx\,dy\,dz + \frac{\partial}{\partial x}F_1\,dx\,dy\,dz + \frac{\partial}{\partial y}F_2\,dy\,dz\,dx \\
&= \frac{\partial}{\partial z}F_3\,dx\,dy\,dz + \frac{\partial}{\partial x}F_1\,dx\,dy\,dz + \frac{\partial}{\partial y}F_2\,dx\,dy\,dz \\
&= \frac{\partial}{\partial x}F_1 + \frac{\partial}{\partial y}F_2 + \frac{\partial}{\partial z}F_3\,dx\,dy\,dz = (\operatorname{div}\boldsymbol{F})\,dx\,dy\,dz
\end{aligned}$$

(b) Show that $dF_1 \wedge dF_2 \wedge dF_3 = (\det D\boldsymbol{F})\, dx\, dy\, dz$

$$df = \sum_{i=0}^{n} \frac{\partial f}{\partial x_i}\, dx_i$$

$$\begin{aligned}
dF_1 \wedge dF_2 \wedge dF_3 &= (\frac{\partial F_1}{\partial x}\, dx + \frac{\partial F_1}{\partial y}\, dy + \frac{\partial F_1}{\partial z}\, dz) \wedge (\frac{\partial F_2}{\partial x}\, dx + \frac{\partial F_2}{\partial y}\, dy + \frac{\partial F_2}{\partial z}\, dz) \wedge dF_3 \\
&= (\frac{\partial F_1}{\partial x}\, dx \wedge (\frac{\partial F_2}{\partial x}\, dx + \frac{\partial F_2}{\partial y}\, dy + \frac{\partial F_2}{\partial z}\, dz) \\
&\quad + \frac{\partial F_1}{\partial y}\, dy \wedge (\frac{\partial F_2}{\partial x}\, dx + \frac{\partial F_2}{\partial y}\, dy + \frac{\partial F_2}{\partial z}\, dz) \\
&\quad + \frac{\partial F_1}{\partial z}\, dz \wedge (\frac{\partial F_2}{\partial x}\, dx + \frac{\partial F_2}{\partial y}\, dy + \frac{\partial F_2}{\partial z}\, dz)) \wedge dF_3 \\
&= ((\frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial y}\, dx\, dy + \frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial z}\, dx\, dz) \\
&\quad + (\frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial x}\, dy\, dx + \frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial z}\, dy\, dz) \\
&\quad + (\frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial x}\, dz\, dx + \frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial y}\, dz\, dy)) \wedge dF_3 \\
&= ((\frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial y} - \frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial x}\, dx\, dy) \\
&\quad + (\frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial z} - \frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial y}\, dy\, dz) \\
&\quad + (\frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial x} - \frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial z}\, dz\, dx)) \wedge (\frac{\partial F_3}{\partial x}\, dx + \frac{\partial F_3}{\partial y}\, dy + \frac{\partial F_3}{\partial z}\, dz) \\
&= (\frac{\partial F_3}{\partial z}(\frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial y} - \frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial x}\, dx\, dy\, dz) \\
&\quad + \frac{\partial F_3}{\partial x}(\frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial z} - \frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial y}\, dy\, dz\, dx) \\
&\quad + \frac{\partial F_3}{\partial y}(\frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial x} - \frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial z}\, dz\, dx\, dy)) \\
&= \frac{\partial F_3}{\partial x}(\frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial z} - \frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial y})\, dx\, dy\, dz \\
&\quad - \frac{\partial F_3}{\partial y}(\frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial z} - \frac{\partial F_1}{\partial z}\frac{\partial F_2}{\partial x})\, dx\, dy\, dz \\
&\quad + \frac{\partial F_3}{\partial z}(\frac{\partial F_1}{\partial x}\frac{\partial F_2}{\partial y} - \frac{\partial F_1}{\partial y}\frac{\partial F_2}{\partial x})\, dx\, dy\, dz \\
&= \frac{\partial F_3}{\partial x}\begin{vmatrix} \frac{\partial F_1}{\partial y} & \frac{\partial F_1}{\partial z} \\ \frac{\partial F_2}{\partial y} & \frac{\partial F_2}{\partial z} \end{vmatrix} - \frac{\partial F_3}{\partial y}\begin{vmatrix} \frac{\partial F_1}{\partial x} & \frac{\partial F_1}{\partial z} \\ \frac{\partial F_2}{\partial x} & \frac{\partial F_2}{\partial z} \end{vmatrix} + \frac{\partial F_3}{\partial z}\begin{vmatrix} \frac{\partial F_1}{\partial x} & \frac{\partial F_1}{\partial y} \\ \frac{\partial F_2}{\partial x} & \frac{\partial F_2}{\partial y} \end{vmatrix}\, dx\, dy\, dz \\
&= \begin{vmatrix} \frac{\partial F_1}{\partial x} & \frac{\partial F_1}{\partial y} & \frac{\partial F_1}{\partial z} \\ \frac{\partial F_2}{\partial x} & \frac{\partial F_2}{\partial y} & \frac{\partial F_2}{\partial z} \\ \frac{\partial F_3}{\partial x} & \frac{\partial F_3}{\partial y} & \frac{\partial F_3}{\partial z} \end{vmatrix}\, dx\, dy\, dz
\end{aligned}$$