A scatter matrix S is defined by

$$\mathbf{S} = \sum_{k=1}^{n} (\vec{x_k} - \vec{m})(\vec{x_k} - \vec{m})^T \tag{9}$$

which happens to be the sample covariance $n - 1$ times.

We use it in

$$\begin{aligned}
J_1(\vec{e}) &= \sum_{k=1}^{n} a_k^2 - 2\sum_{k=1}^{n} a_k^2 + \sum_{k=1}^{n} ||\vec{x_k} - \vec{m}||^2 && (10)\\
&= -\sum_{k=1}^{n} |\vec{e}^T(\vec{x_k} - \vec{m})|^2 + \sum_{k=1}^{n} ||\vec{x_k} - \vec{m}||^2 && (11)\\
&= -\sum_{k=1}^{n} \vec{e}^T(\vec{x_k} - \vec{m})(\vec{x_T} - \vec{m})^T\vec{e} + \sum_{k=1}^{n} ||\vec{x_k} - \vec{m}||^2 && (12)\\
&= -\vec{e}^T\mathbf{S}\vec{e} + \sum_{k=1}^{n} ||\vec{x_k} - \vec{m}||^2 && (13)
\end{aligned}$$