Appendix B

Auxiliary Functions for Load Recovery

B.1 Mounting Function

Strain gauges can be mounted at different orientations at a certain location. Each design point, or optimal candidate point, in the design matrix, will correspond to a specific combination of gauge location and orientation. The purpose of this algorithm is to assist the technician in mounting strain gauges using the NASTRAN input (DAT or BDF) file.

CQUAD4 elements virtually represent strain gauges in the FE environment. The optimal orientation, θ, of each gauge is defined with respect to the elemental coordinate system (Figure B.1). For a given list of element ID‘s and corresponding angle θ, the mounting algorithm yields the mounting coordinate points and orientation angles of the gauges in a desired global coordinate system. The user is allowed to choose between outputting the mounting location in any predefined global rectangular coordinate system with respect to the origin of that coordinate system or a reference grid point.

B.1.1 Coordinate Systems in NX Nastran

A short description of coordinate systems in NX Nastran is required to understand the finer details of the algorithm. Two types of global coordinate systems exist: the basic or a local coordinate system. Another coordinate system that is also used is the elemental coordinate system, but an elaborated description of how it is defined can be found in Siemens (2014*a*, pg. 12-73).

The basic coordinate system is the implicitly defined absolute coordinate system. A local coordinate system is explicitly defined, and two bulk data cards exist for each type of local coordinate system. The first type (CORD1R, CORD1C, CORD1S) defines a local coordinate system using three grip points and the second (CORD2R, CORD2C, CORD2S) uses the coordinates of three points in a previously defined coordinate system (Siemens, 2014*b*, pg. 6-2).

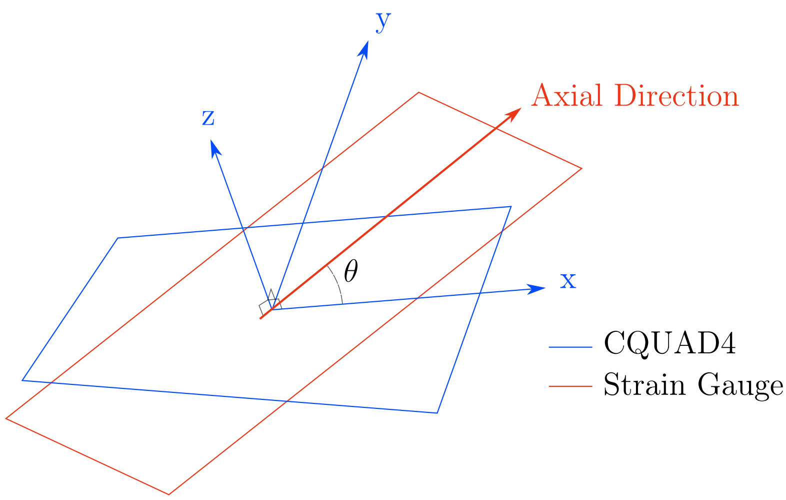

Figure B.1: Orientation of strain gauge with respect to CQUAD4 element and its elemental coordinate system (ECSYS)

Only the CORD2R data card will be considered since modern pre-/post-processor no longer makes use of Type 1 data cards and rectangular coordinate systems are sufficient for solving the problem at hand.

B.1.2 Mathematical Background

The axial direction of the strain gauge can be visualized as a vector in the xy-plane of the elemental coordinate system (ECSYS) as shown in Figure B.1. This vector, denoted as $\boldsymbol{A}$, can be transformed to global coordinates using vector transformations. The magnitude of $\boldsymbol{A}$ remains the same, irrespective of the coordinate system (Widnall, 2009):

$$\boldsymbol{A} = A_1\boldsymbol{i_1} + A_2\boldsymbol{i_2} + A_3\boldsymbol{i_3} = A_1'\boldsymbol{i_1'} + A_2'\boldsymbol{i_2'} + A_3'\boldsymbol{i_3'} \tag{B.1}$$

thus, the components of $\boldsymbol{A}$ in the global coordinate system (GCSYS) can be determined in terms of the components in ECSYS by taking the dot product of the unit vectors,

$$A_j' = A_1\boldsymbol{i_j'}\cdot\boldsymbol{i_1} + A_2\boldsymbol{i_j'}\cdot\boldsymbol{i_2} + A_3\boldsymbol{i_j'}\cdot\boldsymbol{i_3}$$

and as a result,

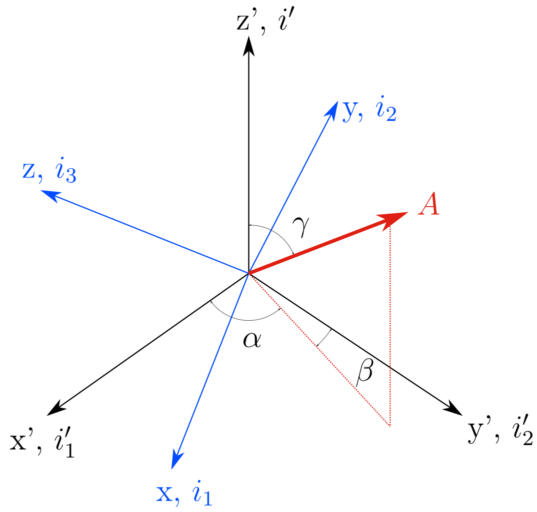

Figure B.2: Rotation angles of vector A with respect to global coordinate system (GCSYS)

$$\begin{pmatrix} A'_1 \\ A'_2 \\ A'_3 \end{pmatrix} = \begin{pmatrix} \boldsymbol{i'_1} \cdot \boldsymbol{i_1} & \boldsymbol{i'_1} \cdot \boldsymbol{i_2} & \boldsymbol{i'_1} \cdot \boldsymbol{i_3} \\ \boldsymbol{i'_2} \cdot \boldsymbol{i_1} & \boldsymbol{i'_2} \cdot \boldsymbol{i_2} & \boldsymbol{i'_2} \cdot \boldsymbol{i_3} \\ \boldsymbol{i'_3} \cdot \boldsymbol{i_1} & \boldsymbol{i'_3} \cdot \boldsymbol{i_2} & \boldsymbol{i'_3} \cdot \boldsymbol{i_3} \end{pmatrix} \begin{pmatrix} A_1 \\ A_2 \\ A_3 \end{pmatrix} \tag{B.2}$$

The dot product of two unit vectors equal the cosine of the angle between these vectors. From this, the transformation matrix is given as:

$$\boldsymbol{Q} = \begin{pmatrix} \boldsymbol{i'_1} \cdot \boldsymbol{i_1} & \boldsymbol{i'_1} \cdot \boldsymbol{i_2} & \boldsymbol{i'_1} \cdot \boldsymbol{i_3} \\ \boldsymbol{i'_2} \cdot \boldsymbol{i_1} & \boldsymbol{i'_2} \cdot \boldsymbol{i_2} & \boldsymbol{i'_2} \cdot \boldsymbol{i_3} \\ \boldsymbol{i'_3} \cdot \boldsymbol{i_1} & \boldsymbol{i'_3} \cdot \boldsymbol{i_2} & \boldsymbol{i'_3} \cdot \boldsymbol{i_3} \end{pmatrix} = \begin{pmatrix} \cos(\theta_{11}) & \cos(\theta_{12}) & \cos(\theta_{13}) \\ \cos(\theta_{21}) & \cos(\theta_{22}) & \cos(\theta_{23}) \\ \cos(\theta_{31}) & \cos(\theta_{32}) & \cos(\theta_{33}) \end{pmatrix} \tag{B.3}$$

The orientation of the strain gauge with respect to the GCSYS is depicted in Figure B.2 and can be calculated using Equations B.2 and B.4:

$$\begin{aligned} \alpha &= \cos^{-1}(A'_1) \\ \beta &= \cos^{-1}(A'_2) \\ \gamma &= \cos^{-1}(A'_3) \end{aligned} \tag{B.4}$$

B.1.3 Performance of Mounting Algorithm

The algorithm was assessed on its ability to find the correct location and orientation of a strain gauge in a desired global coordinate system. Calculating its orientation is more complicated than finding the location of the strain gauge and will be elaborated on in the following content.

A simple FE model (see Figure B.3) was created using Siemens NX 11.0 of which the material parameters, mesh size, boundary and loading conditions are not of importance for its purpose. Three local coordinate systems were additionally defined. It is important to note that these local coordinate systems will not be written to the Nastran input file if it is not reference, for example by a boundary condition, in the model itself.

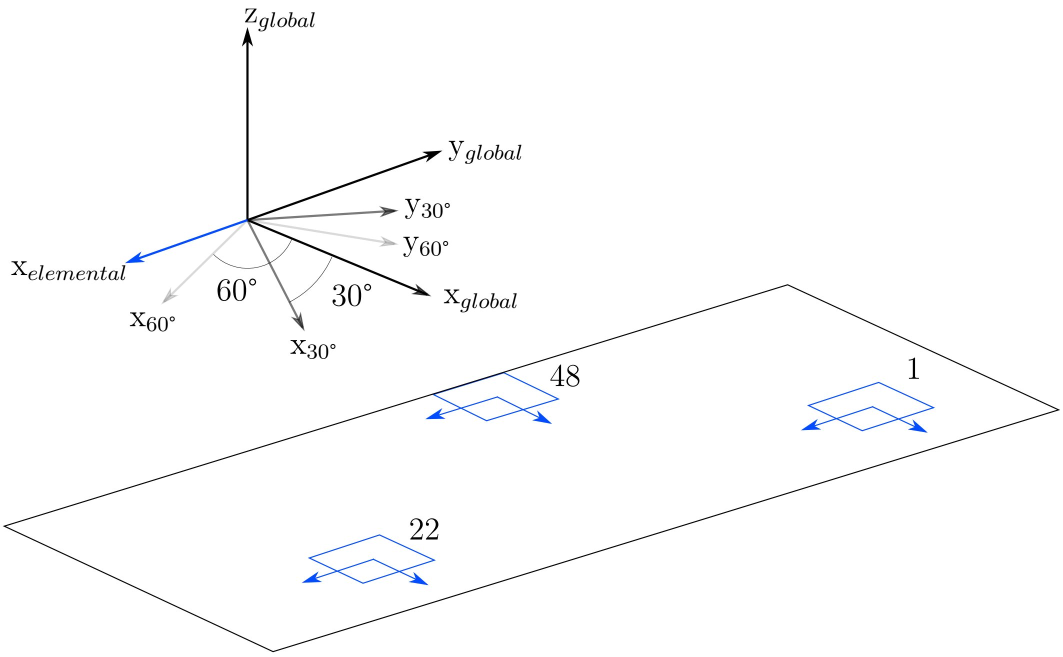

Figure B.3: Simple FE model to test mounting algorithm

CQUAD4 elements were chosen using a random integer generator and the ECSYS of these elements are shown in Figure B.3. It was assumed that the strain gauges need to be mounted at 0°and 45°with respect to the ECSYS of each element. The results for Element 1 is shown in Table B.1 and proofs that the algorithm accurately obtains the correct angles of orientation in any locally defined global coordinate system.

Table B.1: Testing performance of Mounting Algorithm to accurately obtain

θ	GCSYS	Theoretical Calculations			Mounting Algorithm Output		
		α	β	γ	α	β	γ
0°	30°	60	150	90	59.999	149.997	90.000
	60°	30	120	90	30.003	120.000	90.000
45°	30°	15	105	90	15.006	104.999	90.000
	60°	15	75	90	15.006	75.001	90.000