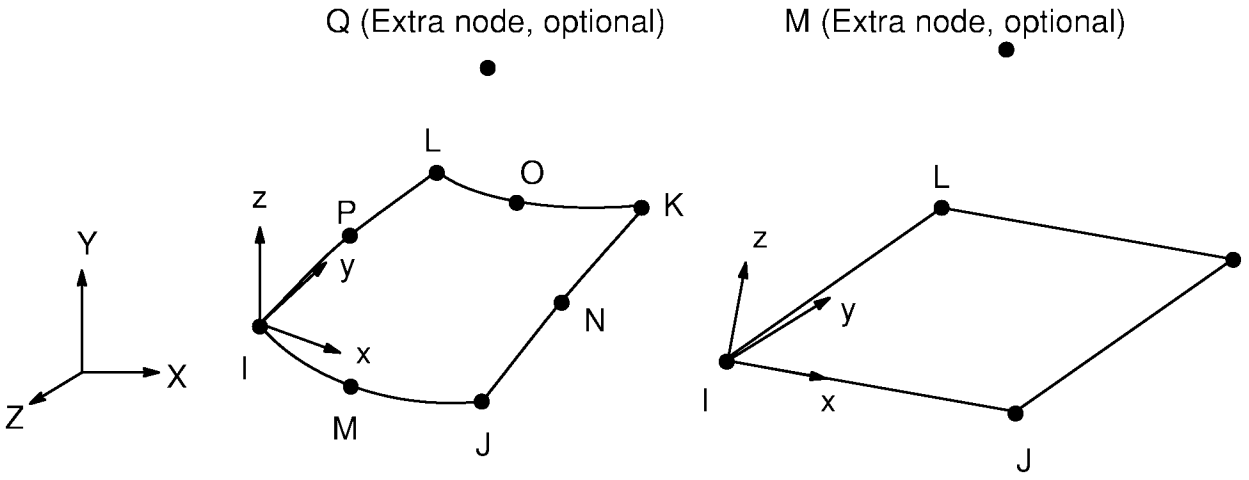
14.152 SURF152 — 3–D Thermal Surface Effect



Matrix or Vector	Geometry	Midside Nodes	Shape Functions	Integration Points
Convection Surface Matrix and Load Vector	Quad	If KEYOPT(4)=0 (has midside nodes)	Equation (12.5.10–20)	3 x 3
		If KEYOPT(4)=1 (has no midside nodes)	Equation (12.5.8–20)	2 x 2
	Triangle	If KEYOPT(4)=0 (has midside nodes)	Equation (12.5.2–20)	6
		If KEYOPT(4)=0 (has no midside nodes)	Equation (12.5.1–20)	3
Heat Generation Load Vector	Same as convection surface matrix.			

Load Type	Distribution
All Loads	Same as shape functions

14.152.1 Matrices and Load Vectors

When the extra node is not present, the logic is the same as given and as described in Section 6.2. The discussion below relates to theory that uses the extra node.

The conductivity matrix is based on one–dimensional flow to and away from the surface. The form is conceptually the same as for LINK33 (equation (14.33–1)) except that the surface has four or eight nodes instead of only one node. Using the example of convection and no midside nodes are requested (KEYOPT(4) = 1) (resulting in a 5 x 5 matrix), the first four terms of the main diagonal are:

$$\int_{area} h_f \{N\}\, d(area) \qquad (14.152\text{–}1)$$

where:

h_f = film coefficient (input on **SFE** command with *KVAL*=1)

h_f = h_u (If KEYOPT(5) = 1 and user programmable feature USRSURF116 output argument KEY(1) = 1, this definition supercedes the other.)

h_u = output argument for film coefficient of USRSURF116

$\{N\}$ = vector of shape functions

which represents the main diagonal of the upper–left corner of the conductivity matrix. The remaining terms of this corner are all zero. The last main diagonal term is simply the sum of all four terms of expression (14.152–1) and the off–diagonal terms in the fifth column and row are the negative of the main diagonal of each row and column, respectively.

If midside nodes are present (KEYOPT(4) = 0) (resulting in a 9 x 9 matrix) expression (14.152–1) is replaced by:

$$\int_{area} h_f \{N\}\{N\}^T\, d(area) \qquad (14.152\text{–}2)$$

which represents the upper–left corner of the conductivity matrix. The last main diagonal is simply the sum of all 64 terms of expression (14.152–2) and the off–diagonal terms in the ninth column and row are the negative of the sum of each row and column respectively.

Radiation is handled similarly, except that the approach discussed for LINK31 in Section 14.31 is used. A load vector is also generated. The area used is the area of the element. The form factor is discussed in a subsequent section.

An additional load vector is formed when using the extra node by:

$$\{Q^c\} = [K^{tc}]\ \{T^{ve}\} \qquad (14.152\text{–}3)$$

where:

$\{Q^c\}$ = load vector to be formed

$[K^{tc}]$ = element conductivity matrix due to convection

$$\{T^{ve}\} = \begin{bmatrix} 0 & 0 & \dots & 0 & T_v^G \end{bmatrix}^T$$

T_v^G =
- output argument TEMVEL if the user programmable feature USRSURF116 is used.
- T_v if KEYOPT(6) = 1 (see next section)
- 0.0 for all other cases

TEMVEL from USRSURF116 is the difference between the bulk temperature and the temperatue of the extra node.

14.152.2 Adiabatic Wall Temperature as Bulk Temperature

There is special logic that accesses FLUID116 information where FLUID116 has had KEYOPT(2) set equal to 1. This logic uses SURF151 or SURF152 with the extra node present (KEYOPT(5) = 1) and computes an adiabatic wall temperature (KEYOPT(6) = 1). For this case, T_v, as used above, is defined as:

$$T_v = \frac{V^2\ F_r}{2C_p^f} \qquad (14.152\text{–}4)$$

where:

V = relative velocity (see equation (14.152–5))

F_r = recovery factor

$$= \begin{cases} F_r^i & \text{if } F_r^i > 0 \\ (Pr)^n & \text{if } F_r^i = 0 \end{cases}$$

F_r^i = input as NRF on **R** command

Pr = Prandtl number

$$= \frac{C_p^f \cdot \nu^f}{K_x^f}$$

C_p^f = specific heat of fluid (from FLUID116)

ν^f = viscosity of fluid (from FLUID116)

K_x^f = conductivity of the fluid (from FLUID116)

$$n = \begin{cases} 0.5000 & \text{if Re} < 2500.0 \\ 0.3333 & \text{if Re} > 2500.0 \end{cases}$$

$$\text{Re} = \text{Reynold's number} = \frac{\rho^f V D}{\nu^f}$$

ρ^f = density of fluid (from FLUID116)

D = diameter of fluid pipe (from FLUID116)

The relative velocity is computed as:

$$V = \begin{cases} V_{116} & \text{if } \Omega\text{–}F_s\,\Omega_F = 0 \\ R\,(\Omega\text{–}F_s\,\Omega_F) & \text{if } \Omega\text{–}F_s\,\Omega_F \neq 0 \end{cases} \qquad (14.152\text{–}5)$$

where:

V_{116} = velocity of fluid at extra node (from FLUID116)

Ω = angular velocity (input as OMEG on **R** command)

R = average radius of this element

F_s = slip factor (from FLUID116)

Ω_F = angular velocity of fluid (from FLUID116)

If V is computed to be negative, it is converted to be positive. The adiabatic wall temperature is reported as:

$$T_{aw} = T_{ex} + \frac{V^2}{2C_p^f}(F_r - 1) \qquad (14.152\text{–}6)$$

where:

T_{aw} = adiabatic wall temperature

T_{ex} = temperature of extra node

14.152.3 Radiation Form Factor Calculation

The form factor is computed as:

$$F = \begin{cases} \text{input as FORMF on } \textbf{R} \text{ command} & \text{if KEYOPT(9) = 1} \\ B & \text{if KEYOPT(9) = 2 or 3} \end{cases} \qquad (14.152\text{–}7)$$

also,

F = output quantity FORM FACTOR

Developing B further

$$B = \begin{cases} \cos\alpha \text{ if } \alpha \leq 90° \\ -\cos\alpha \text{ if } \alpha > 90° \text{ and KEYOPT(9) = 2} \\ 0 \quad \text{if } \alpha > 90° \text{ and KEYOPT(9) = 3} \end{cases}$$

α = angle between element z axis at integration point being processed and the line connecting the integration point and the extra node (see Figure 14.152–1)

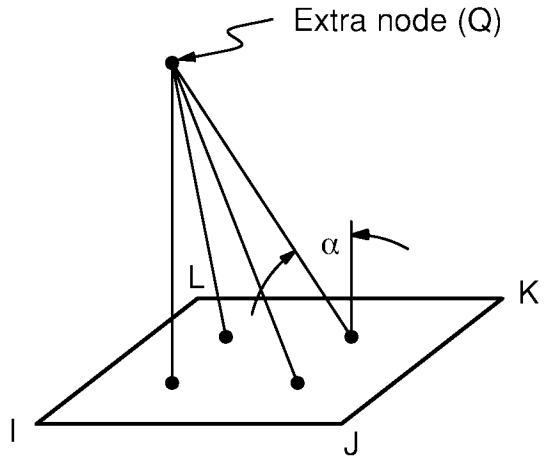


Figure 14.152–1 Form Factor Calculation

F is then used in the two–surface radiation equation:

$$Q_c^r = \sigma \epsilon A F \left(T^4 - T_Q^4\right) \qquad (14.152–8)$$

where:

σ = Stephan Boltzman constant (input as SBCONST on **R** command)

ε = emissivity (input as EMIS on **MP** command)

A = element area

Note that this "form factor" does not have any distance affects. Thus, if distances are to be included, they must all be similar in size, as in an object on or near the earth being warmed by the sun. For this case, distance affects can be included by an adjusted value of σ.