

RADIATION HEAT TRANSFER WITH SPECTRAL SURFACE BEHAVIOR

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INTRODUCTION

Prior to Version 68, MSC/NASTRAN radiation exchange was restricted to ideal black/grey opaque surfaces exhibiting diffuse emission, absorption, and reflection characteristics. Most real surface behavior is considerably more complicated due to varying degrees of specular, spectral, and temperature dependent properties as well as radiant transmission. Generalized numerical treatment of all of these phenomena simultaneously is beyond the scope of the current Version 68 effort, however, most materials in a practical engineering sense may be characterized by one or two dominant surface conditions. In particular, most solar collection device materials as well as high temperature metals can be satisfactorily described in terms of their spectral and temperature dependent surface properties. This problem class is addressed with a method known as the radiation energy-band approximation.

PROBLEM DEFINITION

Figure 1 illustrates the essence of the solution technique when radiation surfaces exhibit temperature dependent spectral behavior. Within each discrete wave-band, the radiation exchange procedure used in MSC/NASTRAN remains valid provided fractional corrections are made to account for that portion of the spectrum under consideration. Equations 1 through 5 examine this procedure.

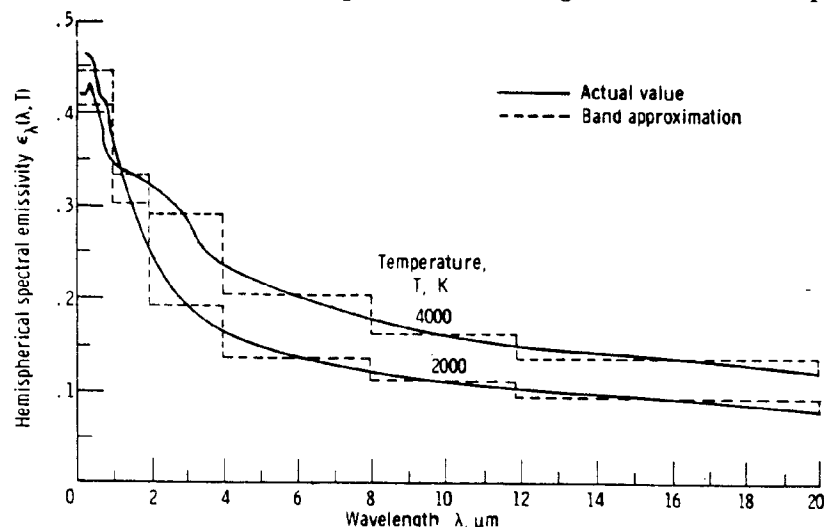


Figure 1 - BAND APPROXIMATIONS TO HEMISPHERICAL SPECTRAL EMISSIVITY OF TUNGSTEN

SPECTRAL RADIATION BAND HEAT LOADS

1. $\{Q_e\} = \sum_{\lambda} \{Q_e^{\lambda}\}$
2. $\{Q_e^{\lambda}\} = [A] \left(\{q_e^{\lambda}\}^{\text{in}} - \{q_e^{\lambda}\}^{\text{out}} \right)$
3. $\{q_e^{\lambda}\}^{\text{in}} = \sigma \left[(A - F(I - \alpha(\lambda)))^{-1} F \epsilon\{\lambda\} \right] \{f_e\} \{U_e\}^4$
4. $\{q_e^{\lambda}\}^{\text{out}} = \sigma \left[\epsilon(\lambda) + (I - \alpha(\lambda))(A - F(I - \alpha(\lambda)))^{-1} F \epsilon(\lambda) \right] \{f_e\} \{U_e\}^4$
5. $\{f_e\} = \{ \text{FRAC}_{0-\lambda_2} U_e - \text{FRAC}_{0-\lambda_1} U_e \}$

where:

- $\lambda \rightarrow$ Wavelength
- $Q_e \rightarrow$ Elemental Heat Load
- $Q_e^{\lambda} \rightarrow$ Elemental Heat Load per Wavelength Band
- $q_e^{\lambda} \rightarrow$ Elemental Heat Flux per Wavelength Band
- $\sigma \rightarrow$ Stefan-Boltzman Constant
- $A \rightarrow$ Element Area
- $I \rightarrow$ Identity Matrix
- $\alpha(\lambda) \rightarrow$ Wavelength Dependent Absorptivity
- $\epsilon(\lambda) \rightarrow$ Wavelength Dependent Emissivity
- $U_e \rightarrow$ Element Temperatures
- $F \rightarrow$ View Factors
- $f_e \rightarrow$ Fraction of the total radiant output of a blackbody that is contained in the n^{th} wavelength band where $\Delta\lambda = \lambda_2 - \lambda_1$.

$$\text{FRAC}_{0-\lambda U_e} = \frac{15}{\pi^4} \sum_m \frac{e^{-mv}}{m^4} \{ [\{mv+3\}mv+6]mv+6 \}, v \geq 2, m = 1, 2, \dots$$

$$\text{FRAC}_{0-\lambda U_e} = 1 - \frac{15}{\pi^4} v^3 \left\{ \frac{1}{3} - \frac{v}{8} + \frac{v^2}{60} - \frac{v^4}{5040} + \frac{v^6}{272160} - \frac{v^8}{13305600} \right\}, v < 2$$

$$25898 \mu\text{m } ^\circ\text{R}$$

$$v = \frac{\text{PLANCK2}}{\lambda U_e}, \text{ where PLANCK2} = \quad \text{or}$$

$$14344 \mu\text{m } ^\circ\text{K}$$

In addition to being available for radiation enclosure analyses, the wave-band approximation has been extended to include the surface loading from a QVECT solar source as well as the RADBC radiation to space boundary condition. A simple example follows of an ideal solar selective surface demonstrating the classic greenhouse effect using just two wave-bands.

ANALYSIS

Example: An ideal solar selective surface is exposed to a normally incident radiant flux corresponding to the average solar constant Q . Q , as determined from measurement, is generally acknowledged to be approximately 442.Btu/HrFt**2. Figure 2 represents the surface character for an ideal solar selective surface where λ_c is the cutoff frequency for the emissivity and absorptivity. The idealized surface is designed to absorb a maximum of solar energy while emitting a minimum amount of longer wavelength energy.

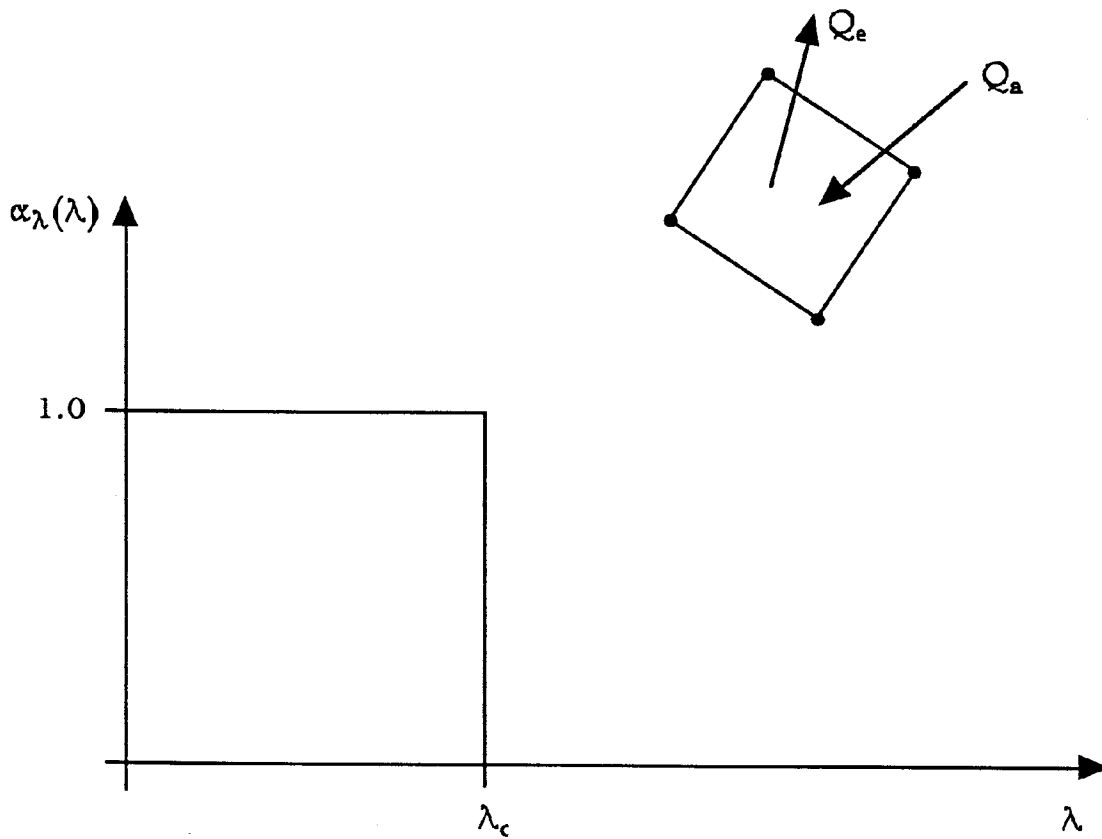


Figure 2 - ABSORPTIVITY FOR IDEAL SOLAR SELECTIVE SURFACE

The energy arriving from the sun is assumed to have a spectral distribution proportional to that of a blackbody at a temperature of 10400. R. Equations 6 through 8 describe the analytic formulation for this simplified analysis.

$$6.) \quad Q_a = (1) \text{FRAC}_{0-\lambda_c}(T_s) q_s A$$

$$7.) \quad Q_e = (1) \text{FRAC}_{0-\lambda_c}(T_{eq}) \sigma T_{eq}^4 A$$

$$8.) \quad T_{eq}^4 \text{FRAC}_{0-\lambda_c}(T_{eq}) = \frac{q_s \text{FRAC}_{0-\lambda_c}(T_s)}{\sigma}$$

DISCUSSIONS

Figure 3 plots the MSC/NASTRAN results of the radiative equilibrium temperature as a function of the cutoff wavelength. As the cutoff frequency is decreased, the equilibrium temperature continues to increase even though less energy is absorbed, because it also becomes more difficult to emit energy. For a blackbody, the equilibrium temperature is 713 R. We would find this result to be the same for a greybody.

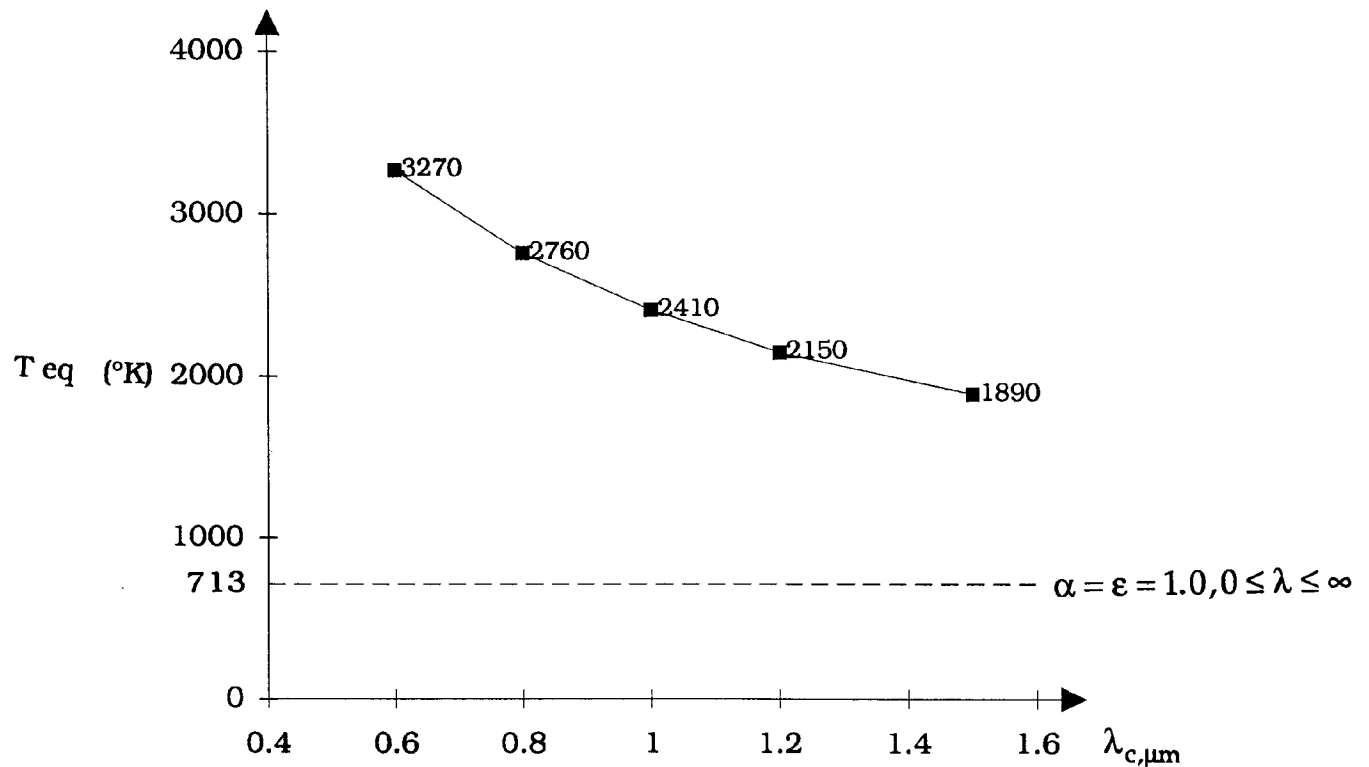


Figure 3 - RADIATIVE EQUILIBRIUM TEMPERATURE VS. CUTOFF WAVELENGTH

Figure 4 provides a commented listing of the MSC/NASTRAN input file used to examine this problem.

```

ID MSC-NASTRAN V68
SOL 166
TIME 10
CEND
TITLE = RADIATION BOUNDARY CONDITION
SEALL = ALL
TEMP(INIT) = 20
SPC = 10
LOAD = 30
THERMAL = ALL
FLUX = ALL
ANALYSIS = HEAT
NLPARM = 100
BEGIN BULK
PARAM,TABS,0.0
PARAM,SIGMA,.171E-08
$
$ The NLPARM statement provides the nonlinear solution control data.
$ In this example, the default values are used.
NLPARM,100
$
GRID,1,,0.0,0.0,0.0
GRID,2,,1.0,0.0,0.0
GRID,3,,1.0,1.0,0.0
GRID,4,,0.0,1.0,0.0
GRID,5,,1.0,1.0,1.0
GRID,100,,10.0,10.0,10.0
$
CQUAD4,1,1,1,2,3,4
PSHELL,1,1,.01
MAT4,1,1.0,,,1.0
$
$ V68 has several forms of boundary surface elements.
$ CHBDYG is the grid point form.
CHBDYG,1,,AREA4,,,2,,,+CH1
+CH1,1,2,3,4
$
$ MRAD provides the radiative surface properties ;
$ emissivity and absorptivity
MRAD,2,1.0,1.0,0.0
$
$ QVECT includes the solar temperature of 10400.R
QVECT,30,442.0,10400.0,0,0.0,0.0,-1.0,0,+QV1
+QV1,1
$
$ TEMPBC defines the background at zero degrees for radiation to space.
TEMPBC,10,STAT,0.0,100
TEMPD,20,500.0
$
$ BNDRAD supplies the radiation break points for the radiation band analysis.
BNDRAD,3,25898.0,1.0,1.0
$
$ The radiation boundary condition allows for radiant exchange with space
RADBC,5,1.00,,1
$
ENDDATA

```

Figure 4 - INPUT DECK FOR RADIATION TO SPACE EXAMPLE PROBLEM

CONCLUSIONS

The capability described allows MSC/NASTRAN to account for radiation surfaces that exhibit varying degrees of spectral character. A simple example demonstrating how significant this effect can be was included for a radiation to space boundary condition. The waveband concept has been fully generalized for Version 68 to account for temperature and wavelength surface property variation within full or partial enclosures. This will allow for analysis of precesses taking place in finite regions where the physics and/or chemistry of the system tends to be dominant in selected portions of the electromagnetic spectrum.

REFERENCES

1. R. Siegel & J.R. Howell, *Thermal Radiation Heat Transfer, 2nd Edition* (1981)
2. Richard H. MacNeal, *MSC/NASTRAN Theoretical Manual* (1972)
3. W.H. Booth, *MSC/NASTRAN V65 Handbook for Thermal Analysis* (1986)