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Jet Engine Hot Parts IR Analysis Procedure (J-EIRP)

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Summary

The Jet Engine IR Analysis Procedure (J-EIRP) is a set of computer programs developed to evaluate jet engine cavity hot parts source radiation. These programs were intended for use on a personal computer, but include the ability to solve large problems on a mainframe or super-computer. The goal is to introduce the terminology and solution process used in J-EIRP, and provide insight into the radiation heat transfer principles used in this procedure. A sample jet engine cavity analysis demonstrates the procedure and capabilities within J-EIRP, and is compared to a simplified method for approximating cavity radiation.

Introduction

Thermal radiation from partially enclosed jet engine cavity surfaces can lead to complex analysis methods due to nonuniformly distributed surface radiant energy resulting from reflecting radiation and non-uniform surface cooling. Depending on engine internal surface geometry and thermophysical properties, the energy leaving a cavity can be composed of direct emission and reflected energy. Following the propagation of energy within the cavity becomes an enormous problem as the complexity of the geometry increases. Applying computer models and numerical approaches to evaluate the emission and propagation of multi-reflecting radiation can be an involved process. Currently, there are a variety of computer programs and simplifying analytical techniques used to analyze radiation as it propagates from a jet engine cavity. Each computer program has advantages and disadvantages based on the fundamentals of physics, modeling requirements and limitations, computer requirements, solution convergence requirements and computer limits.

This paper describes an analysis procedure used in conjunction with a personal computer to evaluate the thermal radiation from complex jet engine cavities. The Jet Engine IR Analysis Procedure (J-EIRP) was developed to give the user flexibility in analyzing both simple and complex jet engine cavity geometries. A major objective of this effort was to develop a highly accurate thermal analysis procedure that can analyze a variety of radiation heat transfer problems with limited computer resources. J-EIRP was designed to manage components of radiation heat transfer problems on a personal computer, but also include the ability to solve more computer intense problems on a mainframe or super-computer. J-EIRP also provides the user a tool for developing thermal design experience and engineering judgment through analysis experimentation, while using minimal computer resources.

Symbols

A	*surface area*
B	*radiation interchange factor*
C_1, C_2	*Planck's spectral energy distribution constants*
C_o	*speed of light in vacuum*
e	*emissive power*
E	*emissive energy per unit time*
F	*view factor*
h	*Planck's constant*
i	*radiant intensity per unit area*
I	*radiant intensity*
J_{so}	*source radiation per unit solid angle (PIREP notation)*
k	*Boltzmann constant*
n	*nth surface*
r	*radius distance*
T	*absolute temperature*
σ	*Stefan-Boltzmann constant*
ϵ	*emissivity*
θ	*polar angle*
ϕ	*circumferential angle*
Γ	*emissive power fraction in spectral region*
δ	*identity matrix*
λ	*wavelength (vacuum) in micrometer* (μm)

Superscript

$'$	*directional quantity*

Subscripts

A	*of surface A*
b	*blackbody*
i, j	*ith and jth surfaces*
λ	*spectrally dependent wavelength*
∞	*infinity*

Method of Analysis

The computer programs that comprise J-EIRP are displayed in flow chart form in figure 1. The following brief descriptions of the computer codes exposes the required steps used in the J-EIRP solution process. Appendix A contains background information on radiation heat transfer terminology and concepts applied in the following programs. Appendix B contains the general solution method used in J-EIRP.

Model

The term "model" represents a data set that contains required information that defines the physical attributes of the jet engine cavity for analysis. A model supplies parameters that represent the physical jet engine cavity geometry, surface thermophysical properties, and solution requirements. The cavity geometry is subdivided into a number of finite surfaces called nodes. The actual number of nodes and their geometry depends on the desired model representation, accuracy of results, structural design considerations, computer capabilities, and computer computational time requirements. Each node represents an average surface temperature defined over the entire surface. Using the ray tracing approach, restrictions on uniform node energy distributions (radiosity and irradiation) may be eliminated (ref.1).

NEVADA

The Net Energy Verification and Determination Analyzer program or "NEVADA" (ref. 2), was selected to simulate the radiation propagating from modeled surfaces. NEVADA is a software package consisting of several programs in which a Monte-Carlo mathematical technique is applied to radiation propagation. The NEVADA program was attractive to use because of its ability to model the complex laws of physics associated with radiation propagating from various geometry defining surface types and thermophysical properties. In the NEVADA code, a statistical numerical method using the Monte-Carlo technique is applied to a ray tracing procedure to model radiation exchange. The ray tracing procedure mathematically traces emitted rays (simulating emitted radiation) as they propagate. Each ray leaving a surface is considered a bundle of photons which carries equal, discrete, amounts of energy. The path of the bundles (rays) may interact with various surfaces, which may reduce the energy level of the bundle. The interacting surfaces may have different thermophysical properties and geometric configurations that may affect the propagation of each bundle differently. By accounting for all the emitted bundles as they propagate, percentages of incident and absorbed energy at different locations can be computed. The percentages of absorbed energies (radiation interchange factors) are then applied to the energy balance equations.

NEVADA is an industry standard code used in predicting radiation interchange factors. Various documented uses and results are published. The NEVADA numerical ray tracing technique as applied to cavity radiation propagation for isothermal and nonisothermal gray-diffuse cylindrical geometries with uniform surface emissivity values was verified in reference 1.

TRACK-E

The Track Energy Procedure or "TRACK-E" is a FORTRAN program used to evaluate the energy propagation between defined surface nodes. The TRACK-E program calculates and sums the surface energy emitted and absorbed through the radiation conductor values (term used to represent the energy flow paths between separated surfaces). The radiation conductors incorporate the NEVADA radiation interchange factors. The TRACK-E program can also modify the radiation conductor values to include wavelength band evaluation of the IR spectrum. If the NEVADA model includes spherical or hemispherical surfaces that enclose the cavity opening for energy propagation studies, TRACK-E can then be used to evaluate the total and component energy distribution over these surfaces. Appendix B defines the general radiation exchange equation solved in the TRACK-E program with the radiation interchange factors from the NEVADA program. The user can also evaluate radiant energy calculations for individual surfaces by entering radiation interchange factors, areas, emissivities, and temperatures. The program also tabulates the emitted and absorbed energy from each surface.

Sample Calculation

The use of J-EIRP to evaluate the radiation emission from a conceptual jet engine cavity will now be described. This example problem will serve to illustrate the programs and computer requirements to achieve radiation wavelength band solutions. This sample cavity analysis will model diffusely reflecting radiation propagating from a jet engine cavity to its surrounding environment using a personal computer (80386 microprocessor, 33 MHz speed) for all calculations. Figure 2 displays a computer-generated representation of jet engine cavity surface geometry. This jet engine surface geometry is defined by eight surface nodes. These eight nodes accurately represent the jet engine cavity because of the cavity symmetry and uniform surface temperatures over the individual node regions. An 18-node hemisphere, spherically sectioned, and placed behind the cavity exit plane is used to absorb and evaluate the incident radiant energy from the cavity surfaces. The computer-generated representation of the hemisphere is shown in figure 3. This sample cavity analysis will display several J-EIRP features. Various other options exist within J-EIRP, including a variety of ray tracing options within NEVADA, which may be beneficial depending on the scope and requirements of the analysis.

The NEVADA ray tracing analysis computes the view factors and radiation interchange factors between the cavity and hemispherical surfaces. These results relate the percent of energy emitted and reflected between the cavity surfaces, and the cavity and hemispherical surfaces. Figure 4 is a polar plot displaying the radiation interchange factor results for two jet engine cavity components to the hemispherical surfaces. The solid line represents radiation from the jet engine turbine geometry while the dotted line represents radiation from the jet engine divergent nozzle. These results show the relationship of component geometry and surface properties on the engine radiation emission before introducing surface temperatures. These results may be useful for evaluating the influence of geometry and surface properties on the transfer of energy to the hemispherical sections. In this example, the 90 degree location represents the axial direction or angle normal to the jet engine cavity exit plane. Due to the statistical nature of the ray tracing analysis, computer computational time depends on the desired accuracy. These results represent solutions with small error bands (high accuracy), which required roughly two hours of computer computational time. Useful but less accurate results require much less computer computational time.

The TRACK-E program now allows one to assign temperatures to the engine cavity surfaces and evaluate the radiant energy emission from the total jet engine cavity, groups of cavity components, or individual cavity components. The user has the option to evaluate a wavelength band of the IR spectrum or the total IR energy transfer. In this example the TRACK-E program will be used to evaluate several wavelength bands and the total IR energy transferred to the hemisphere. The TRACK-E program reads the NEVADA output data set that contains surface areas and the radiation interchange factors. A second file providing surface temperatures is required for evaluating the total or wavelength band energy transferred between the surfaces. The user has the option of reviewing J-EIRP results in terms of energy through each radiation conductor, net energy results for individual surfaces, total hemispherical energy results, total cavity energy results, and tables of hemispherical results used for graphing. Polar plots can also display the radiant energy emission results in the form of watts per unit solid angle (steradian). Figure 5 displays the total radiant energy emitted by the cavity and figure 6 displays two wavelength band results of interest. Figure 7 compares the divergent nozzle component energy emission to that of the total jet engine cavity (radiation interchange factors for this case were shown in fig. 4). The importance of component analysis is seen in figure 7. The divergent nozzle contributes nearly all the off-axis radiation (0.0 to 45.0 and 135.0 to 180.0 degrees). This sample TRACK-E cavity analysis, which evaluated 160 NEVADA radiation interchange factors, required less then five minutes of computer computational time.

A simplified jet engine hot parts radiation analysis method called PIREP (ref.3), described in appendix C, can now be compared to the J-EIRP results for the direction normal to the exit plane. The same jet engine configuration was analyzed using the PIREP method for the 3.0 to 5.0 micrometer wavelength band. This PIREP analysis resulted in 204.6 watts per steradian. This value corresponds to the J-EIRP results of 291.7 watts per steradian, as shown in figure 6. The PIREP procedure does not have the ability to calculate off-normal radiation emission or individual engine component contributions to the total radiation emission.

Concluding Remarks

A thermal radiation analysis method called Jet Engine IR Analysis Procedure (J-EIRP) was developed to evaluate jet engine cavity hot parts source radiation. The objectives of the J-EIRP development were to achieve the greatest accuracy in model representation and solution, while minimizing computer resources and computational time. The computer programs that comprise J-EIRP were selected on the basis of their performance, accuracy and flexibility to solve both simple and complex problems, while retaining the ability to add or substitute programs based on user requirements. These programs were intended for use on a personal computer, but include the ability to solve large problems on a mainframe or super-computer. J-EIRP was also designed so programs could be added or substituted based on user requirements. These options produce a working environment for solving complex problems that require limited or minimal computer resources. J-EIRP also provides the user a tool for developing thermal design experience and engineering judgment through analysis experimentation.

Appendix A - Basic Radiation Heat Transfer Concepts

The following discussion briefly introduces some basic radiation heat transfer concepts. These radiation heat transfer concepts are used to define the solution technique and requirements for use in J-EIRP. The basic definitions, equations, units, and notation used to define the radiation characteristics were selected from reference 4.

The simplest mode of radiation heat transfer occurs when energy is emitted from a single flat surface in a vacuum where no reflected energy is involved. If the surface is a perfect absorber and emitter of radiant energy, it is called a blackbody. This blackbody also emits the maximum amount of radiant energy to its surrounding hemisphere. The intensity of radiation emitted by a blackbody in any direction for a single wavelength is defined by Planck's Law as:

$$i'_{\lambda b}(\lambda,T) = \frac{2C_1}{\lambda^5(e^{C_2/\lambda T}-1)} \quad \left[\frac{BTU}{hr\ \mu m\ ft^2\ sr}\right] \tag{A1}$$

where C_1 and C_2 represent Planck's spectral energy distribution constants, as shown:

$$C_1 = hC_o^2 \qquad C_2 = \frac{hC_o}{k}$$

$$C_1 = .18878x10^8\ \frac{BTU\ \mu m^4}{hr\ ft^2} \qquad C_2 = 25897.84\ \ \mu m\ {}^\circ R$$

The prime notation defines a directional quantity of radiation per unit solid angle for a single direction. The subscripted terms specify the quantity as spectral (λ - one wavelength), and the surface as a blackbody (b). The dependent variables are listed in the parentheses. The emissive power radiated from a blackbody over an entire hemisphere in a vacuum at a particular wavelength is defined as:

$$e_{\lambda b}(\lambda,T) = \pi i'_{\lambda b}(\lambda,T) = \frac{2\pi C_1}{\lambda^5(e^{C_2/\lambda T}-1)} \quad \left[\frac{BTU}{hr\ \mu m\ ft^2}\right] \tag{A2}$$

By integrating equation (A2) over the entire wavelength band, the total blackbody hemispherical emissive power at a specific surface temperature is then:

$$e_b(T) = \int_0^\infty e_{\lambda b} d(\lambda) = \int_0^\infty \pi i_{\lambda b} d(\lambda) = \int_0^\infty \frac{2\pi C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} d(\lambda) = \sigma T_A^4 \quad \left[\frac{BTU}{hr\ ft^2}\right] \tag{A3}$$

where σ represents the Stefan-Boltzmann constant:

$$\sigma = 0.17123x10^{-8} \quad \left[\frac{BTU}{hr\ ft^2\ {}^\circ R^4}\right]$$

Applying the emitting surface area to equation (A3) gives the total blackbody hemispherical emitted energy per unit time as:

$$E_{b\,A_1}(T_A) = \int_0^\infty A_1 e_{\lambda b}(\lambda) d\lambda = A_1 \sigma T_A^4 \quad \left[\frac{BTU}{hr}\right] \tag{A4}$$

For a real (non-blackbody) surface, thermophysical properties control the radiant energy absorbed, emitted, and reflected from the surface. These properties can be a function of incident and reflected angles, wavelength, and temperature. Frequently, several simplifying assumptions can be made regarding the surface thermophysical properties. Averaged surface properties may be derived if one can average over all directions and wavelength bands. Applying these assumptions, a surface that absorbs and emits a fixed fraction of radiation from any direction and at any wavelength is now defined as a diffuse gray surface. The directional and spectral absorptivity and emissivity then become:

$$\epsilon'_\lambda(\theta,\phi,\lambda,T_A) = \epsilon_A(T_A)$$

$$\alpha'_\lambda(\theta,\phi,\lambda,T_A) = \alpha_A(T_A)$$

From Kirchhoff's law the directional, spectral and hemispherical total values of absorptivity and emissivity are equal, thus:

$$\epsilon(T_A) = \alpha(T_A) \tag{A5}$$

The dependence of the surface temperature on the surface emissivity value also may be averaged over the radiation heat transfer band.

Applying surface thermophysical properties results in the surface being defined as a non-blackbody. The total non-blackbody (diffuse-gray) hemispherical emissive power is:

$$e(T_A) = \int_0^\infty \epsilon_A e_{\lambda b}(\lambda)\,d\lambda = \epsilon_A \sigma T_A^4 \quad \left[\frac{BTU}{hr\ ft^2}\right] \qquad \text{(A6)}$$

The total non-blackbody hemispherical emitted energy is:

$$E_{A_1}(T_A) = \int_0^\infty A_1 \epsilon_A e_{\lambda b}(\lambda)\,d\lambda = A_1 \epsilon_A \sigma T_A^4 \quad \left[\frac{BTU}{hr}\right] \qquad \text{(A7)}$$

For radiation to be exchanged between surfaces, a geometric relationship (geometric configuration factor or view factor) between the surfaces must be defined. The view factor for blackbody isothermal surfaces is the fraction of emitted radiant energy leaving a surface i that reaches another surface j. Since both surfaces are blackbodies or perfect absorbers of radiant energy, no reflected energy is introduced into the view factor value, $F_{i \rightarrow j}$. The total blackbody emitted energy from surface A_1 that is incident and absorbed by surface A_2 is then:

$$E_{b\,A_1 - A_2}(T_A) = A_1 F_{A_1 - A_2} \sigma (T_{A_1}^4) \quad \left[\frac{BTU}{hr}\right] \qquad \text{(A8)}$$

For simple geometric configurations various view factor references are available. For complex geometric configurations, various computer techniques have been developed where the surfaces are defined, and mathematical or ray tracing techniques are applied to solve the surface relationships.

For non-blackbody surfaces the blackbody view factor is replaced by the radiation interchange factor, $B_{i \rightarrow j}$, which represents real surface radiation exchange. The radiation interchange factor is the fraction of emitted energy by a real surface i that is absorbed by real surface j, including all reflections from other real surfaces including the emitting surface i. Computer programs are also available to calculate $B_{i \rightarrow j}$ values. For the radiation exchange between two real surfaces, defined as A_1 and A_2, the total non-blackbody emitted energy from surface A_1 that is absorbed by surface A_2 is:

$$E_{A_1 - A_2}(T_{A_1}) = A_1 B_{A_1 - A_2} \epsilon_{A_1} \sigma T_{A_1}^4 \quad \left[\frac{BTU}{hr}\right] \qquad \text{(A9)}$$

This is where the $B_{i \rightarrow j}$ term defines the relationship between the energy emitted from surface A_1 that is absorbed by surface A_2 directly and indirectly. This indirect radiant energy may be in the form of multi-reflecting energy between A_1 and A_2, and energy from A_1 that is reflected from other surfaces to A_2. The radiation path for a multi-surface cavity configuration may include all surfaces, which can result in a large number of total non-blackbody emitted energy terms:

$$\textit{Energy Transfer From All Possible Radiation Paths} = \sum_{I=1}^{\infty}\sum_{J=1}^{\infty}\epsilon_I \sigma A_I B_{I-J}(T_I^4)$$

The radiation exchange also can be evaluated within a particular wavelength region or fraction of the total emissivity power. This is done by simply using the total blackbody hemispherical emissive power, equation (A3), and modifying the limits of integration as shown:

$$e_b(\lambda_1 T \to \lambda_2 T) = \int_{\lambda_1}^{\lambda_2} e_{\lambda b}\, d(\lambda) = \int_{\lambda_1}^{\lambda_2} \frac{2\pi C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}\, d(\lambda) \qquad \text{(A10)}$$

The non-blackbody hemispherical emitted energy within a wavelength band becomes:

$$E_{A_1}(\lambda_1 T \to \lambda_2 T) = \epsilon_{A_1} A_{A_1} \int_{\lambda_1}^{\lambda_2} e_{\lambda b}\, d(\lambda) = \epsilon_{A_1} A_{A_1} \int_{\lambda_1}^{\lambda_2} \frac{2\pi C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}\, d(\lambda) \qquad \text{(A11)}$$

Applying the radiation interchange factor results in the non-blackbody emitted energy from individual surfaces within a wavelength band:

$$E_{A_1 - A_2}(\lambda_1 T \to \lambda_2 T) = \epsilon_{A_1} A_{A_1} B_{A_1 - A_2} \int_{\lambda_1}^{\lambda_2} \frac{2\pi C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}\, d(\lambda) \qquad \text{(A12)}$$

The integration term can be solved using a numerical polynomial curve fit resulting in the total non-blackbody hemispherical emitted energy equation as:

$$E_{A_1 - A_2}(\lambda_1 T \to \lambda_2 T) = \epsilon_{A_1} A_1 B_{A_1 - A_2} \left[\Gamma_{0-\lambda_2 T_{A_1}} - \Gamma_{0-\lambda_1 T_{A_1}}\right] \sigma T_{A_1}^4 \qquad \left[\frac{BTU}{hr}\right] \qquad \text{(A13)}$$

where the $\Gamma_{0\text{-}\lambda T}$ is represented (ref. 4) as:

$$\Gamma_{0-\lambda T} = \frac{15}{\pi^4} \sum_{n=1}^{\infty} \left[\frac{e^{-nx}}{n} \left(x^3 + \frac{3x^2}{n} + \frac{6x}{n^2} + \frac{6}{n^3}\right)\right] \qquad \text{(A14)}$$

$$\textit{where}\quad x = \frac{C_2}{\lambda T}$$

Tabulated values of these polynomial approximations are also available as a function of wavelength-temperature products in reference 4.

Appendix B - The J-EIRP Solution Concept

The programs that currently comprise J-EIRP solve the radiation heat transfer concepts described in appendix A. The same definitions, notations, and equations defined in appendix A apply, but a conversion factor modifying the units to watts has been included. The total non-blackbody hemispherical emitted energy in equation (A13) is the general form of J-EIRP solution concept.

To absorb, identify, and evaluate the radiation from an engine cavity, a sectioned hemisphere placed behind the cavity exit plane can be used. This multi-sectioned hemisphere reveals the uniform intensity over the finite hemispherical surfaces areas from the jet engine cavity. By selecting a distance where the emitted and reflected cavity radiation results in nearly normal intersections with the hemispherical surfaces, the radiant energy can be calculated as a function of solid angle. The equation describing the radiant energy emitted from a defined cavity surface to a defined hemispherical surface in terms of a solid angle is as shown:

$$I'_{A_1-A_2}(\lambda_1 T \rightarrow \lambda_2 T) = \epsilon_{A_1} A_1 B_{A_1-A_2}\left[\Gamma_{0-\lambda_2 T_{A_1}} - \Gamma_{0-\lambda_1 T_{A_1}}\right] \sigma T^4_{A_1} \ (.2931) \left(\frac{r^2_{A_1-A_2}}{A_2}\right) \qquad \text{(B1)}$$

$$\left[\frac{Watts}{sr}\right]$$

In this equation r represents the distance from the source cavity surface area A_1 to the target hemispherical surface area A_2 for a solid angle calculation. By calculating the radiant energy emitted and reflected from each jet engine cavity surface to each hemispherical surface and summing the hemispherical results, the jet engine cavity radiation emission is calculated. Equation (B1) summarizes all the basic concepts within J-EIRP. The radiation interchange factors (B_{i-j} values) are calculated using the NEVADA program which analyzes a model representing the jet engine cavity. The summed radiant energy from all the jet engine cavity surfaces to each hemispherical surface is calculated using the TRACK-E program. TRACK-E also evaluates the component radiant energy distributions over the hemispherical surfaces, and the radiant energy emitted and absorbed within the jet engine cavity.

Appendix C - The PIREP Solution Concept

The Preliminary Infrared Radiation Emissions Program (ref. 3) includes a simplified method of calculating the jet engine cavity hot parts emission. The general PIREP method applies Planck's Law directly to a solution where the jet engine cavity geometry is simplified to represent a flat plate emitting energy at the size of the exhaust nozzle throat. Therefore, this method evaluates only the directly emitted energy from a flat plate and eliminates cavity wall reflections. To better understand the general PIREP equation and results, the PIREP jet engine hot parts analysis method will be derived in the following discussion.

The intensity of radiation emitted in any direction for a single wavelength is defined by Planck's Law in equation (A1) as:

$$i'_{\lambda b}(\lambda,T) = \frac{2C_1}{\lambda^5\left(e^{C_2/\lambda T}-1\right)} \quad \left[\frac{BTU}{hr\ \mu m\ ft^2\ sr}\right]$$

Applying Planck's spectral energy distribution constants as given in appendix A and converting units, equation (A1) becomes:

$$i'_{\lambda b}(\lambda,T) = \frac{2\,(0.18878x10^8)}{\lambda^5\left(e^{25897.84/\lambda T}-1\right)}\left(\frac{.2931}{144}\right) = \frac{76849.1917}{\lambda^5\left(e^{25897.84/\lambda T}-1\right)} \quad \left[\frac{Watts}{\mu m\ in^2\ sr}\right] \qquad \text{(C1)}$$

This is the general form of Planck's Law used in PIREP. Planck's Law, which is for a single wavelength calculation, is normally integrated over the IR spectrum or wavelength band. To simplify the wavelength band integration, the integration is replaced with a wavelength delta. This assumes the wavelength band is small and that an average wavelength can be substituted into Planck's Law as follows:

$$i'_{b\,A_1}(\lambda_1 T \rightarrow \lambda_2 T) = \int_{\lambda_1}^{\lambda_2} \frac{76849.1917}{\lambda^5(e^{25897.84/\lambda T}-1)} d\lambda \approx \frac{76849.1917\ \Delta\lambda}{\lambda^5(e^{25897.84/\lambda T}-1)} \tag{C2}$$

where:

$\Delta\lambda$ = *wavelength difference*
λ = *average wavelength*

This represents the intensity of emitted radiation per unit solid angle from a flat plate in all directions, where temperature is defined by the turbine exit total temperature. By introducing the exhaust nozzle throat area into equation (C2), PIREP evaluates the intensity from a jet engine cavity. This is shown in the following equation along with the notation changed to reflect PIREP's form.

$$i'_{b\,A_T}(\lambda_1 T \rightarrow \lambda_2 T) = \frac{J_{so}}{A_8} \approx \frac{76849.1917\ \Delta\lambda}{\lambda^5(e^{25897.84/\lambda T}-1)} \quad \left[\frac{Watts}{in^2\ sr}\right] \tag{C3}$$

The PIREP method was designed as a fast approximation tool for calculating the emission from jet engine cavity hot parts. Alternative solution methods are required if component effects are to be evaluated, or increased analytical accuracy is required. Equation (C3) differs slightly from the actual PIREP equation due to the use of updated values for Planck's spectral energy distribution constants (C_1 and C_2).

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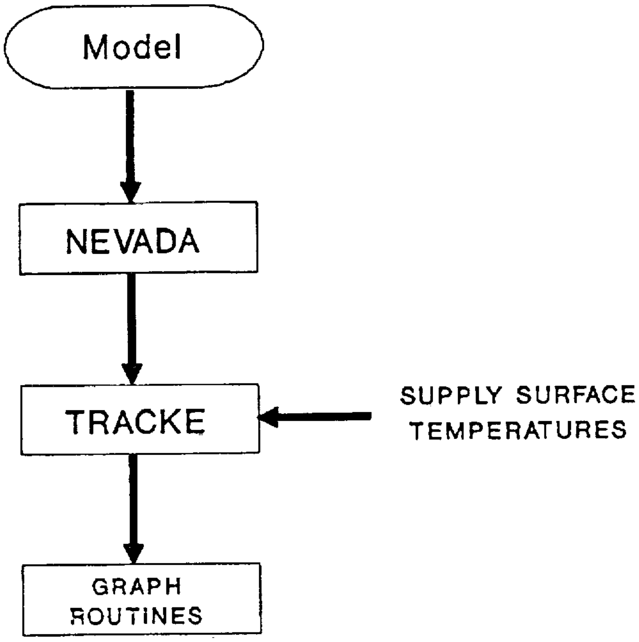

Figure 1. - Jet Engine IR Analysis Procedure (J-EIRP).

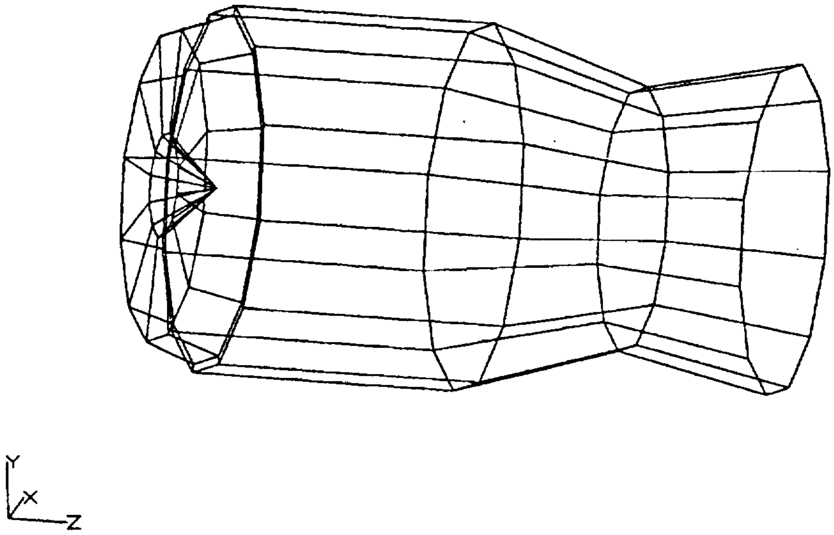

Figure 2. - Surface geometry of a sample cavity model.

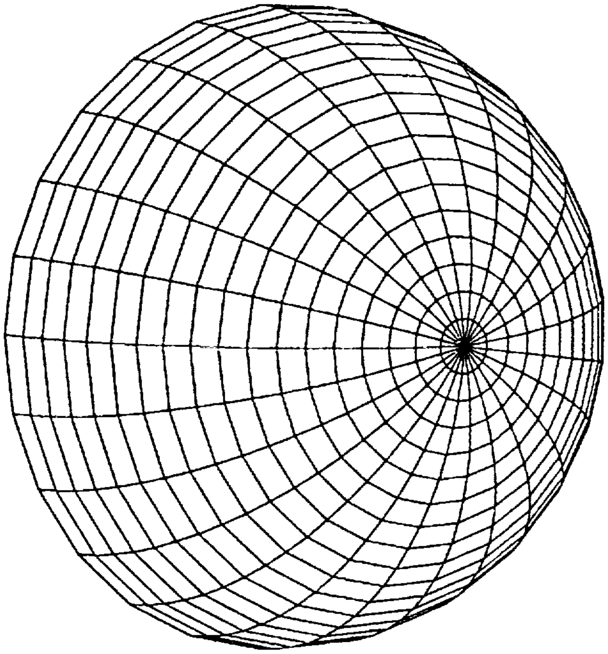

Figure 3. - Surface geometry of sample hemisphere model section.

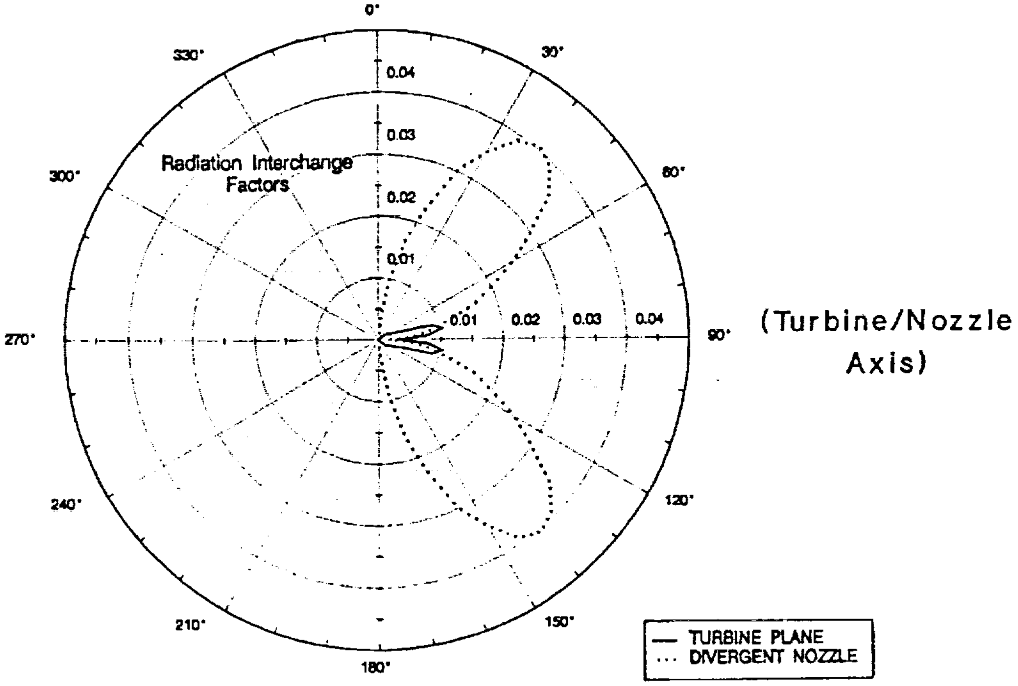

Figure 4. - Sample cavity component radiation interchange factors.

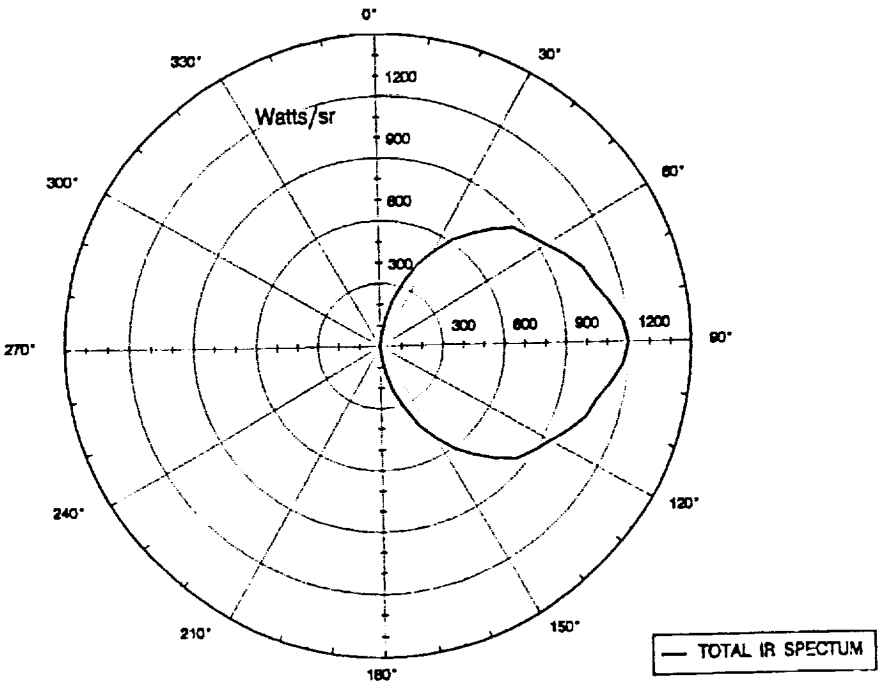

Figure 5. - Sample cavity total radiation emission.

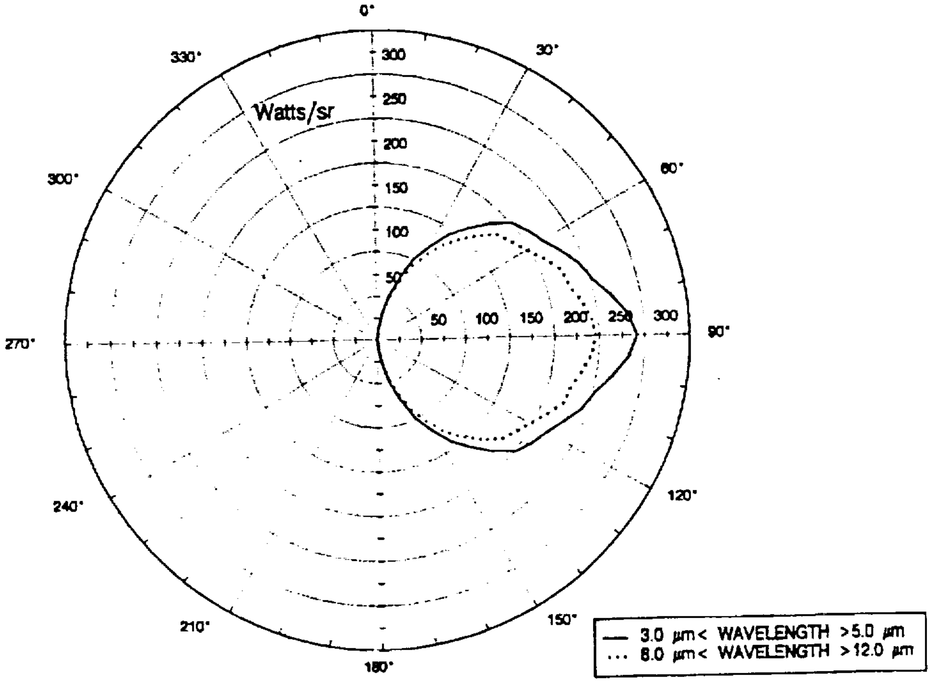

Figure 6. - Sample cavity wavelength band radiation emission.

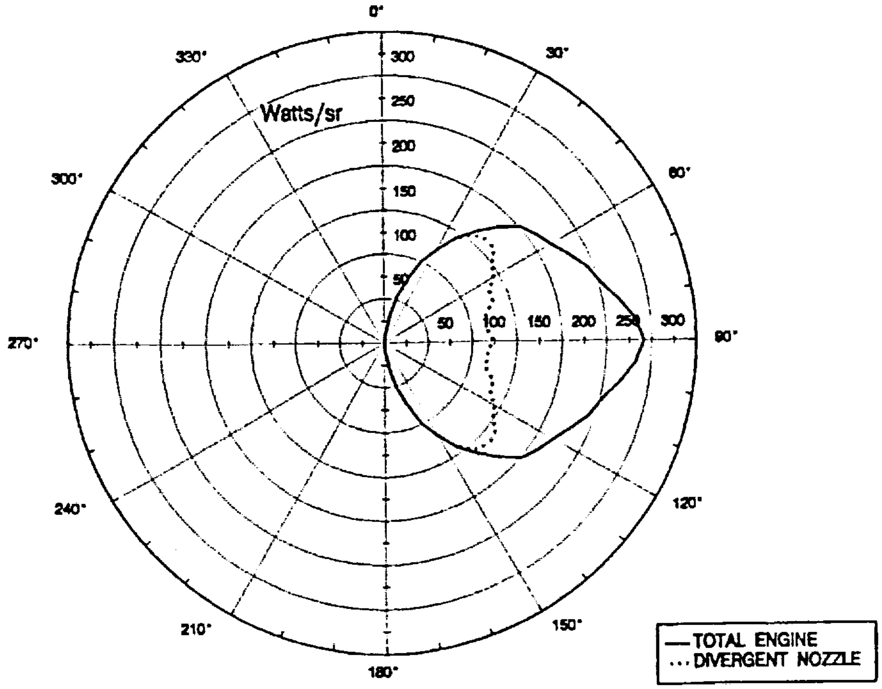

Figure 7. - Sample cavity divergent nozzle effect on radiation emission. (3.0 µm<wavelength<5.0 µm)

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13. ABSTRACT ***(Maximum 200 words)***

A thermal radiation analysis method called Jet Engine IR Analysis Procedure (J-EIRP) was developed to evaluate jet engine cavity hot parts source radiation. The objectives behind J-EIRP were to achieve the greatest accuracy in model representation and solution, while minimizing computer resources and computational time. The computer programs that comprise J-EIRP were selected on the basis of their performance, accuracy and flexibility to solve both simple and complex problems. These programs were intended for use on a personal computer, but include the ability to solve large problems on a mainframe or super-computer. J-EIRP also provides the user a tool for developing thermal design experience and engineering judgment through analysis experimentation, while using minimal computer resources. A sample jet engine cavity analysis demonstrates the procedure and capabilities within J-EIRP, and is compared to a simplified method for approximating cavity radiation. The goal is to introduce the terminology and solution process used in J-EIRP, and provide insight into the radiation heat transfer principles used in this procedure.

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