DOT/FAA/AR-04/30

Office of Aviation Research
Washington, D.C. 20591

THERMOD Composite Airframe Temperature Prediction Tool Evaluation, Validation, and Enhancement With Initial Steady-State Temperature Data

September 2004

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-04/30		

4. Title and Subtitle THERMOD COMPOSITE AIRFRAME TEMPERATURE PREDICTION TOOL EVALUATION, VALIDATION, AND ENHANCEMENT WITH INITIAL STEADY-STATE TEMPERATURE DATA	5. Report Date September 2004 6. Performing Organization Code
7. Author(s) L. Scott Miller, James Waltner, Tejas Mazmudar, Monal Merchant, and John Tomblin	8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Aerospace Engineering National Institute for Aviation Research Wichita State University Wichita, KS 67260	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ACE-110

15. Supplementary Notes

The FAA William J. Hughes Technical Center Technical Monitor was Peter Shyprykevich.

16. Abstract

General aviation aircraft airframe temperatures can reach extreme levels while parked on the ground, depending on ambient conditions (e.g., temperature and solar radiation) and airframe construction (e.g., material types, geometry, and paint color). The implications of this situation are extremely important to understand since composite aircraft structural limits are dependent on the airframe temperatures. The THERMOD computer code predicts both steady-state and transient airframe temperatures based on a comprehensive range of factors, including those mentioned above. Unfortunately, however, the THERMOD program has not been fully validated. Previous experimental investigations, conducted at Wichita State University, suggest that THERMOD code predictions for convective cooling effects are reasonable, typically conservative. However, a few key questions surfaced, specifically (1) What is the impact of input variable uncertainties? (2) What is the accuracy of THERMOD in predicting steady-state or initial temperatures? and (3) Are there ways to improve THERMOD's utility or ease of use? These issues became the goals for the current work. A sensitivity study, using the THERMOD code itself, showed that the impact of input variable uncertainties is typically small, depending most on the obvious geometry and material properties. Atmospheric testing, using solar radiation to heat test panels, suggests that THERMOD steady-state predictions are reasonable. The temperature data generated will be useful for design and certification. However, the code can underpredict temperatures in some cases, perhaps due to the fact that THERMOD assumes a constant 10-mph wind in it's analysis. A Windows® style interface, called the THERMOD Analysis Assistant (TAA), was developed and is undergoing initial user evaluations. TAA is composed of two parts, an input file generation interface and an output file viewer. Each element offers a more familiar user environment incorporating graphics and controls to ease THERMOD code use. A brief TAA introduction and overview is included in this report.

17. Key Words	18. Distribution Statement
Aircraft airframe temperatures, Temperature predictions, Atmospheric testing	This document is available to the public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	27	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

A number of people participated in this project and deserve special recognition and thanks. Over the years Peter Shyprykevich and Larry Ilcewicz from the Federal Aviation Administration provided significant project support, guidance, feedback, and help. In addition, special gratitude goes to NASA/AGATE and specifically Steve Hooper who helped initiate these efforts, supplied insight, and advice that was most appreciated. Thank you all very much.

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LIST OF ACRONYMS AND SYMBOLS

α	Absorptivity or scatter factor value
ε	Emissivity or scatter factor value
k	Thermal conductivity
Cp	Specific heat
ρ	Composite material density
t	Temperature
T_{air}	Airflow temperature
T_{Bond}	Bondline, between T-Beam and panel, temperature
T_i	Indicated temperature
FAA	Federal Aviation Administration
IR	Infrared
TAA	THERMOD Analysis Assistant

EXECUTIVE SUMMARY

General aviation aircraft airframe temperatures can reach extreme levels while parked on the ground, depending on ambient conditions (e.g., temperature and solar radiation) and airframe construction (e.g., material types, geometry, and paint color). The implications of this situation are extremely important to understand since composite aircraft structural limits are dependent on the airframe temperatures. The THERMOD computer code predicts both steady-state and transient airframe temperatures based on a comprehensive range of factors, including those mentioned above. Unfortunately, however, the THERMOD program has not been fully validated. Previous experimental investigations, conducted at Wichita State University, suggest that THERMOD code predictions for convective cooling effects are reasonable, typically conservative. However, a few key questions surfaced, specifically (1) What is the impact of input variable uncertainties? (2) What is the accuracy of THERMOD in predicting steady-state or initial temperatures? and (3) Are there ways to improve THERMOD's utility or ease of use? These issues became the goals for the current work. A sensitivity study, using the THERMOD code itself, showed that the impact of input variable uncertainties is typically small, depending most on the obvious geometry and material properties. Atmospheric testing, using solar radiation to heat test panels, suggests that THERMOD steady-state predictions are reasonable. The temperature data generated will be useful for design and certification. However, the code can underpredict temperatures in some cases, perhaps due to the fact that THERMOD assumes a constant 10-mph wind in its analysis. A Windows® style interface, called the THERMOD Analysis Assistant (TAA), was developed and is undergoing initial user evaluations. TAA is composed of two parts, an input file generation interface and an output file viewer. Each element offers a more familiar user environment incorporating graphics and controls to ease THERMOD code use. A brief TAA introduction and overview is included in this report.

1. INTRODUCTION.

1.1 PURPOSE.

A computational, experimental, and programming effort was undertaken to better evaluate and improve the use of an existing thermal modeling computer program called THERMOD [1 and 2]. This report's specific intent is to describe these efforts and document the results.

1.2 BACKGROUND.

General aviation (GA) aircraft airframe temperatures can reach extreme levels while parked on the ground due to solar radiation and extreme ambient conditions. The implications of this situation are extremely important to understand since composite aircraft structural limits are highly dependent on temperature. Put simply, a very hot and thermally soaked composite airplane is potentially weaker.

It is commonly assumed (conservatively) that there is minimal airframe cooling prior to application of the highest expected air loads during flight. Any effect that might reduce airframe temperatures or a tool that could more accurately predict the true values offers the potential for aircraft weight, strength, and capability improvements.

Resultant airplane temperatures depend on a range of factors. For example, ambient weather conditions (e.g., temperature, solar radiation and reflections, and wind velocity), airframe composition, and construction (e.g., material types, geometry, windows, and paint color) all contribute to actual airframe temperatures and strength. As was mentioned before, any type of airframe cooling can have a positive effect. Aircraft operation, for example during taxi, takeoff, and climb, can have a favorable impact on strength, as a result of convective heat transfer or cooling.

The THERMOD computer code, developed by Govindarajoo, calculates airframe temperatures based on a comprehensive range of factors, including those mentioned previously [1 and 2]. Both steady-state and transient airframe temperature distributions are predicted. Unfortunately however, the THERMOD program has not been fully validated. Limited evaluations have taken place, but high confidence results from this and other analysis tools (e.g., NASTRAN) are necessary to ensure that composite airframe designs are both safe and not over- or underdesigned.

Previous Wichita State University wind tunnel experiments, aimed at evaluating only THERMOD convective cooling capabilities, suggest predictions are reasonable and conservative (typically within ±10°) [3]. However, a number of issues surfaced during this work that require further attention. Specifically, given the uncertainty in some input parameters (e.g., matrix thermal conductivity, emisivity, etc.), what is the impact on temperature predictions and what is the accuracy of THERMOD steady-state or initial temperature predictions? In addition, given that most engineers work in a Windows® environment and THERMOD is a DOS style computer program, a more user-familiar interface is desirable.

1.3 GOALS.

The specific investigation goals were to

- perform a sensitivity study to evaluate input parameter uncertainty impact on THERMOD predictions or experimental results.

- conduct tests and obtain data to evaluate THERMOD steady-state or initial temperature predictions, as a result of solar heating. The temperature data could be used for design and certification purposes.

- develop a Windows type interface for the THERMOD program.

2. SENSITIVITY STUDY.

2.1 BASIC APPROACH.

The THERMOD code itself was used as the primary tool to perform the sensitivity study. The program was run using representative input parameter variations, and the resulting prediction effects were observed. A single test geometry, the Glass/Nomex test panel investigation, was used (described in more detail in a following section) [3]. Individual and combined input variable variations were examined, as were steady-state and transient predictions.

2.2 INPUT PARAMETER VARIATIONS.

Fundamental or key panel input parameters varied in the investigation included:

- Skin, core, and spar thickness
- Density, thermal conductivity (k), and specific heat (Cp)
- Scatter factors (i.e., absorptivity and emissivity)
- Skin temperatures (top or bottom)

Twenty-six parameters were perturbed either individually or in combinations using a factorial analysis scheme [4]. This approach required a total of 1056 THERMOD runs. Initial (i.e., steady-state) and transient temperature prediction results were generated and evaluated as a result.

The individual input parameter values examined are summarized in table 1. The baseline, low, and high values were selected to reasonably represent extremes one might expect to encounter during modeling or testing.

TABLE 1. INPUT PARAMETER VALUES AND VARIATIONS

No.	Parameter Description	Numerical Values			Units
		Low	Baseline	High	
1	t of composite outer skin	0.0166	0.0184	0.0202	in.
2	ρ of composite	115.96	118.065	120.17	lbm/ft^3
3	k of composite	0.3363	0.3403	0.3623	(Btu/hr)/(ft °F)
4	Cp of composite	0.2429	0.258	0.2995	Btu/(lbm °F)
5	t of foam core	0.3342	0.3453	0.3564	in.
6	ρ of foam core	3.96	4.4	4.84	lbm/ft^3
7	k of foam core	0.01942	0.0204	0.02138	(Btu/hr)/(ft °F)
8	t of composite inner skin	0.0168	0.0192	0.0216	in.
9	t of composite spar cap	0.0847	0.0916	0.0985	in.
10	Scatter factor of wing surface	0.3	0.9	0.95	Nondimensional
11	Scatter factor of fuselage side	0.3	0.9	0.95	Nondimensional
12	α of fuselage side	0.94	0.95	0.96	Nondimensional
13	ε of fuselage side	0.94	0.95	0.96	Nondimensional
14	α of wing surface	0.94	0.95	0.96	Nondimensional
15	ε of wing surface	0.94	0.95	0.96	Nondimensional
16	Initial core T matching type: exp. surface matching: 122°F exp. bondline matching: 176.5°F	122	149.25	176.5	°F

t = Temperature
ρ = Composite material density
k = Thermal conductivity
Cp = Specific heat
α = Absorptivity or scatter factor value
ε = Emissivity or scatter factor value

2.3 RESULTS.

Table 2 provides the sensitivity analysis results summary for the examined cases. Specifically, the table's third column identifies THERMOD-predicted output variations (temperatures) based on the input variations outlined in table 1. The results suggest that THERMOD prediction differences lay outside the uncertainty or sensitivity domains and typical input parameter uncertainties, since they produce less than 10 degrees of impact on predictions [3].

As one might expect, significant laminate, core, or spar input values, such as thickness, Cp, thermal conductivity, and density values, are most important. Interestingly, as shown in table 2, individual effects are more pronounced than the combined uncertainty effects.

TABLE 2. OBSERVED SENSITIVITIES

Effect Identifier (McLean)	Factor Effects Considered (Normal Text: Main Effects) *(Italic Text: Coupled Effects)*	Temperature Effect (Final ΔT, °F)
[J]	ΔT initial	6.44
[I]	Cp of composite	6.40
[E]	t of Spar Cap	4.25
[G]	k of foam core	-3.32
[D]	t of foam core	2.42
[C]	t of outer and inner skin	1.60
[IJ]	*Cp of composite, ΔT initial*	*0.90*
[F]	ρ of foam core	0.65
[EI]	*t of Spar Cap, Cp of composite*	*0.59*
[GJ]	*k of foam core, ΔT initial*	*-0.44*
[A]	Fiber/Matrix volume fraction	0.39
[DJ]	*t of foam core, ΔT initial*	*0.32*
[CJ]	*t of outer and inner skin, ΔT initial*	*0.22*
[EI]	*t of Spar Cap, Cp of composite*	*0.16*
[B]	α and ε	0.11
[FJ]	*ρ of foam core, ΔT initial*	*0.10*
[GI]	*k of foam core, Cp of composite*	*-0.10*
[EG]	*t of spar cap, k of foam core*	*-0.07*
[CI]	*t of outer and inner skin, Cp of composite*	*0.06*
[AJ]	*Fiber/Matrix volume fraction, ΔT initial*	*0.06*
[DI]	*t of foam core, Cp of composite*	*0.06*
[DG]	*t of foam core, k of foam core*	*-0.05*

3. ATMOSPHERIC TESTS.

3.1 BASIC APPROACH.

The wind tunnel models or test panels used in a previous investigation [3] were again employed in the current work. Each panel is fabricated using aircraft-representative composite materials and methods. Temperature time history and environmental conditions were recorded as the panels approached and reached thermal equilibrium after direct exposure to solar radiation. The results from these experiments were compared to THERMOD predictions.

3.2 TEST COMPONENTS.

Tables 3 and 4 summarize the composition of each test component, and figure 1 shows the lower surface of two test panels. Important dimensions are given in tables 5 and 6, with figures 2 and 3 identifying the associated nomenclature.

TABLE 3. TEST PANEL COMPOSITIONS

Panel	Plies	Fabric/Matrix	Core
Carbon/Nomex	4	3K70P/E765	3/8″ Honeycomb
Glass/Foam	2	7781/NB321	3/8″ Divinycell
Carbon Laminate	6	3K70P/E765	None
Glass/Nomex	2	7781/NB321	3/8″ Honeycomb

TABLE 4. T-BEAM COMPOSITIONS

T-Beam	Plies	Fabric/Matrix
Carbon/Nomex	14	3K70P/E765
Glass/Foam	12	7781/NB321
Carbon Laminate	14	3K70P/E765
Glass/Nomex	12	7781/NB321

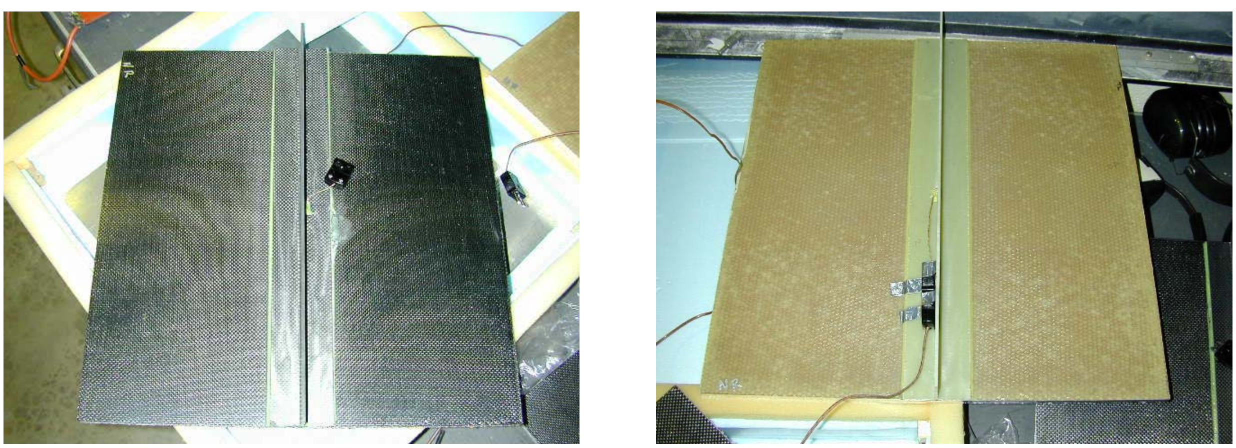

FIGURE 1. LOWER SURFACE OF TWO UNPAINTED TEST PANELS
(Note the bondline thermocouple connectors and wires.)

TABLE 5. PANEL AND T-BEAM DIMENSIONS

Panel	L	W	H_{Beam}	W_{Beam}	t_{Beam}
Carbon/Nomex	17.9688″ (±0.0313″)	18.0313″ (±0.0313″)	2.0900″ (±0.0395″)	2.5400″ (±0.0395″)	0.1240″ (±0.0200″)
Glass/Foam	17.9688″ (±0.0069″)	18.0000″ (±0.0313″)	2.0600″ (±0.0395")	2.5250″ (±0.0395")	0.1107″ (±0.0200″)
Carbon Laminate	18.0000″ (±0.0313″)	18.0313″ (±0.0313″)	2.1300″) (±0.0395″)	2.5450″ (±0.0395″)	0.1208″ (±0.0200″)
Glass/Nomex	17.8750″ (±0.0313″)	18.0000″ (±0.0313″)	2.0850″ (±0.0395″)	2.5100″ (±0.0395″)	0.1125″) (±0.0200″)

L – Panel length, along flow direction
W – Panel width, perpendicular to flow direction
H_{Beam} – T-Beam height
W_{Beam} – T-Beam width
t_{Beam} – T-Beam web thickness

TABLE 6. PANEL AND T-BEAM THICKNESS

Panel	t_{Panel}	t_{Mid}	t_{Top}	t_{Inside}	t_{Beam}
Carbon/Nomex	0.4275″ (±0.0034″)	0.5371″ (±0.0104″)	0.0398″ (±0.0093″)	0.0465″ (±0.0086″)	0.1240″ (±0.0068″)
Glass/Foam	0.3829″ (±0.0069″)	0.4745″ (±0.0039″)	0.0184″ (±0.0018″)	0.0192″ (±0.0024″)	0.1107″ (±0.0066″)
Carbon Laminate	0.0502″ (±0.0009″)	0.1616″ (±0.0017″)	- -	- -	0.1208″ (±0.0045″)
Glass/Nomex	0.3993″ (±0.0014″)	0.5040″ (±0.0021″)	0.0380″ (±0.0038″)	0.0298″ (±0.0033″)	0.1125″ (±0.0028″)

T_{Panel} – Panel thickness, top skin, core, inside skin, and T-Beam
T_{Mid} – Total thickness, top skin, core, inside skin, and T-Beam
T_{Top} – Top skin thickness
T_{Inside} – Inside skin thickness
T_{Beam} – T-Beam web thickness

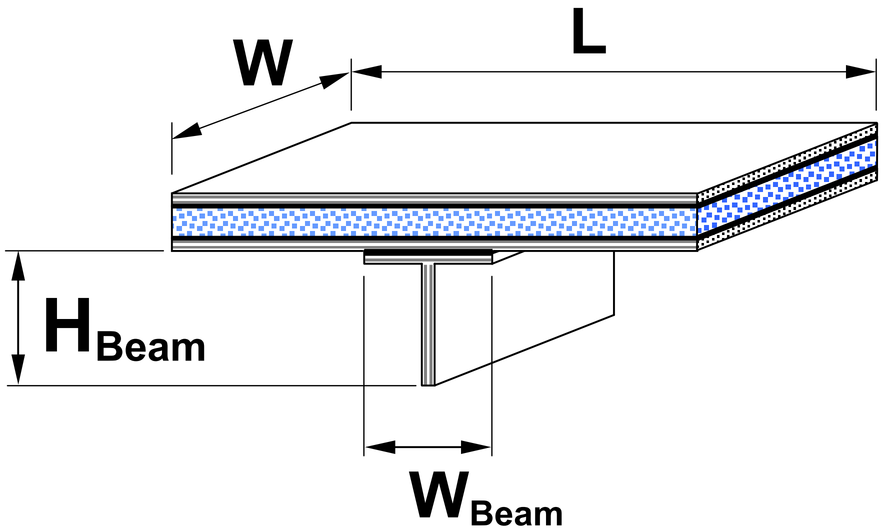

FIGURE 2. TEST PANEL DIMENSIONAL NOMENCLATURE

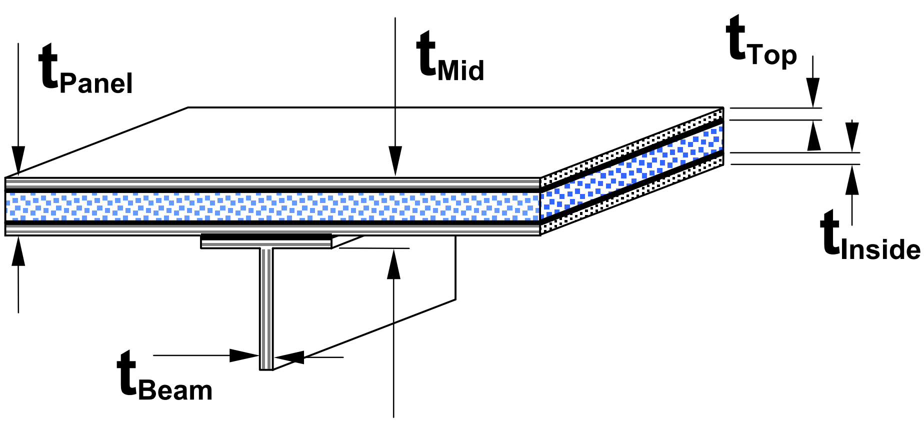

FIGURE 3. TEST PANEL THICKNESS NOMENCLATURE

3.3 TEST APPARATUS, SENSORS, AND PROCEDURE.

Atmospheric experiments, performed during warm portions of the year, focused only on solar or radiant heating effects. THERMOD's ability to model reflections, greenhouse effects, and forced convection were not included in this effort. The fundamental test apparatus consisted of a shallow box frame that holds two panels, each thermally insolated from the surroundings on all sides except one. During a test, the box is intentionally exposed to the sun. One panel, a flat-black-painted aluminum sheet, serves as the solar radiation sensor and the other panel is the one undergoing tests. Figure 4 shows the test fixture, with two panels and the temperature sensors. Besides a natural composite panel surface finish, a variety of different colors were also evaluated to provide data that will be used for design and certification.

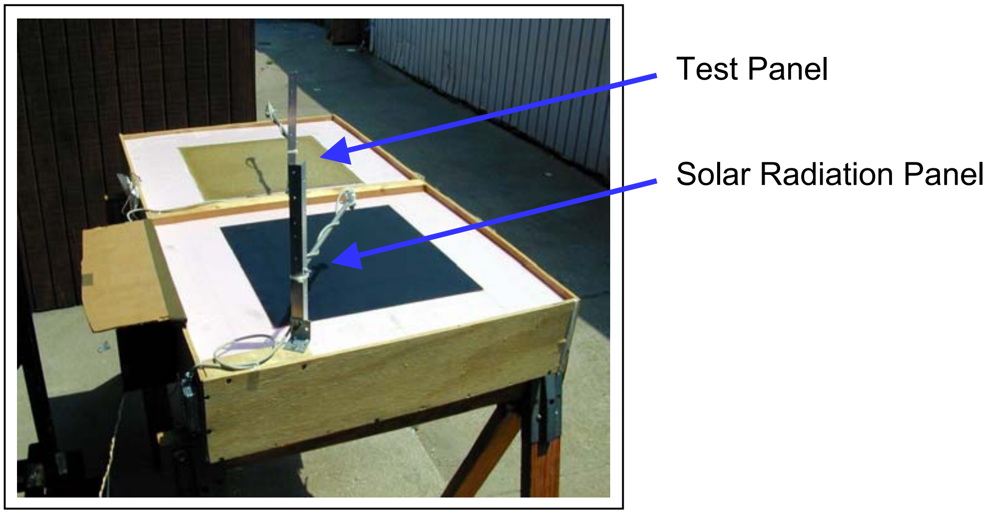

FIGURE 4. TEST FIXTURE POSITIONED OUTSIDE IN DIRECT SUNLIGHT

A computer-based data acquisition system recorded solar radiation, surface, air, and bondline temperatures until equilibrium was established (0.5 to 3.0 hours). Embedded thermocouples and Infrared (IR) sensors measured the panel interior and surface temperatures. Conditions were closely monitored during experiments to ensure radiant heating was the primary effect influencing temperature. The heavily insulated test fixture was carefully positioned in direct sunlight and oriented so that the IR sensor's support shadow will not fall within the measurement area. In addition, the tests were stopped if the winds exceeded about 5 mph, as measured by a hand-held anemometer.

IR sensors offered a flexible means to measure temperatures without direct contact. This ability is particularly attractive since it greatly simplifies component construction and measurement capabilities. Each sensor (Cole-Parmer, P-39669-04), with an adjustable emissivity capability, used a 10:1 distance-to-target-size ratio lens. As a result, given the sensor distance is about 6.0 inches away from the surface, the measured temperature represented the spatial average over about a 0.61-inch area. The variable emissivity feature proved valuable since it also offers a means to both ensure measurement accuracy and to identify each panel's emissivity value (which is needed as input data for the THERMOD computer code).

Prior to testing, simple calibration surveys were performed, with each panel in thermal equilibrium. In each case, the signal-conditioning electronics emissivity jumper was properly adjusted until the IR sensor temperature reading matched the panel temperature, as measured by a thermocouple. As was mentioned, this activity serves the functions of properly adjusting the IR sensors and, simultaneously, identifying panel emissivity values. IR sensor accuracy limitations are estimated at ±2°F in reference 3.

Data from the IR sensors, the bondline thermocouple, the solar radiation sensor, and the ambient air temperature thermocouple were continuously measured and recorded by a digital data acquisition system (DataQ DI-720 16-Bit, 8-Channel Analog-to-Digital converter and a PC running HP-VEE software). Data were archived to a hard disk and CD-ROM.

A test begins by simply exposing the frame and panels to direct sunlight. The data system continuously records temperatures of interest. The resulting equilibrium condition solar radiation and air temperature and panel thermal/material properties are later input to the THERMOD program. Equilibrium is defined to occur when panel temperatures hold roughly equal and steady for at least 2 minutes. The principle goal of this portion of the investigation was to compare steady-state temperature predictions from THERMOD and the experiment. Figure 5 shows a typical time history for atmospheric test parameters measured.

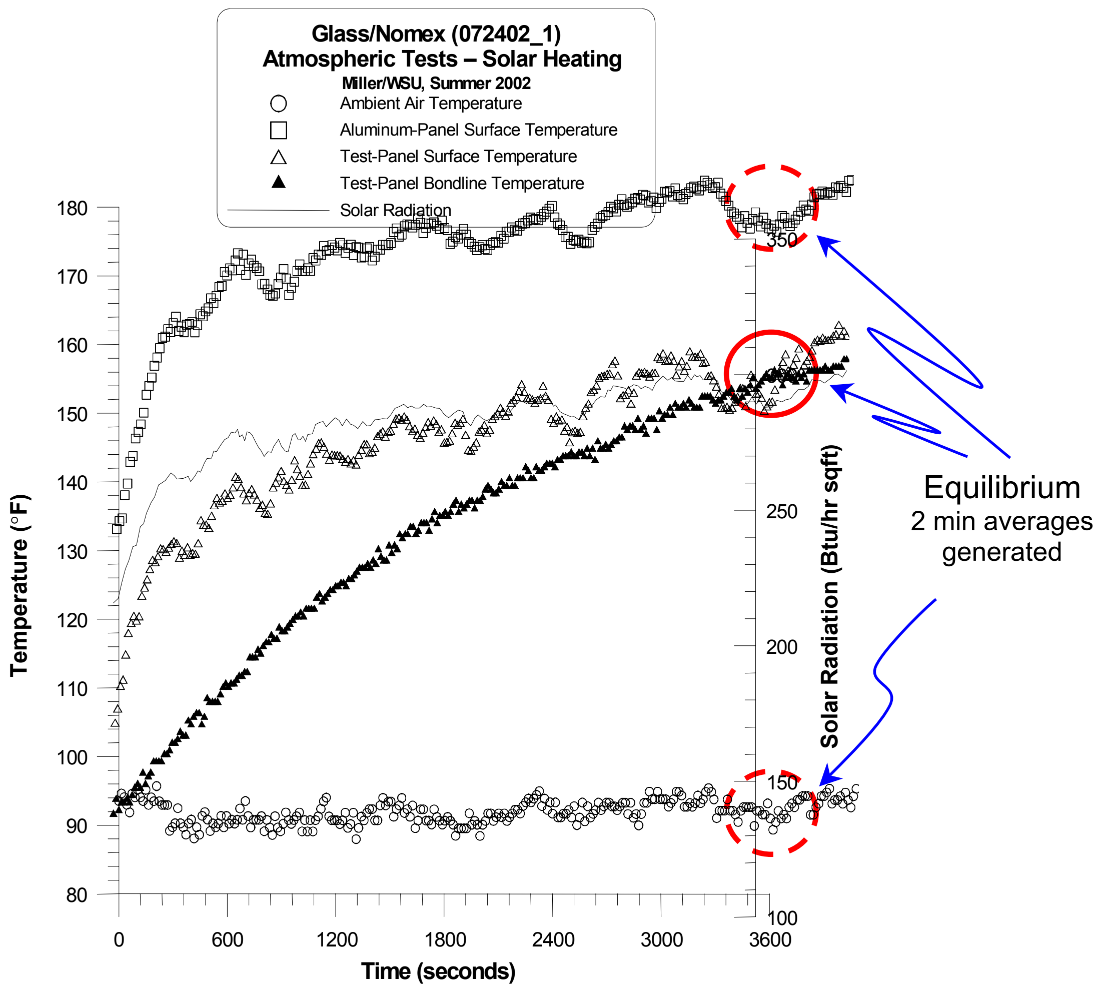

FIGURE 5. EXAMPLE OF EXPERIMENTAL DATA, SHOWING TEMPERATURE AND SOLAR RADIATION TIME HISTORIES

3.4 TEST RESULTS COMPARISONS.

Figures 6, 7, and 8 directly compare atmospheric test and THERMOD steady-state temperature results. Computer code predictions are plotted as a function of measured experiment values and, as a result, data in perfect agreement should lay exactly along a diagonal line.

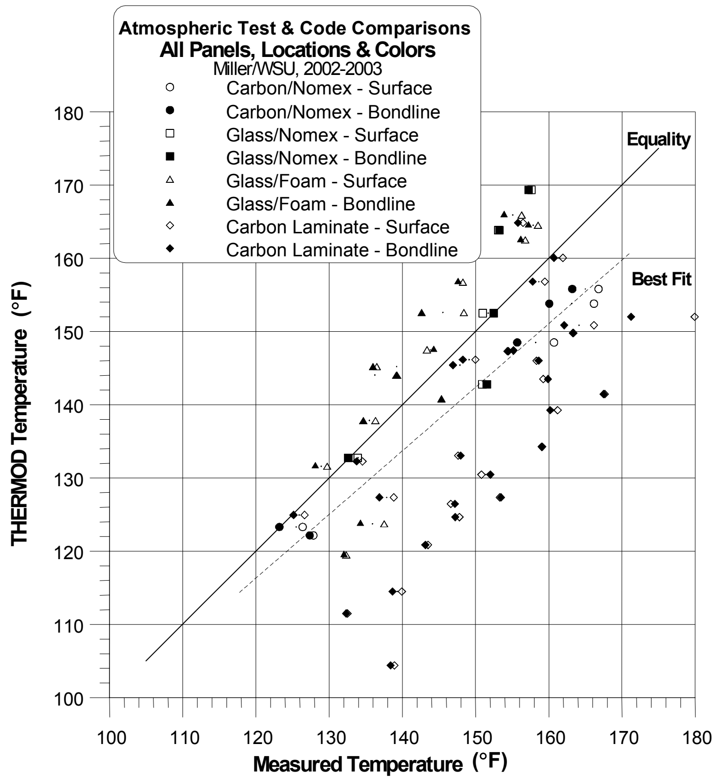

FIGURE 6. COMPARISON OF ALL EXPERIMENTAL AND THERMOD-PREDICTED STEADY-STATE TEMPERATURES

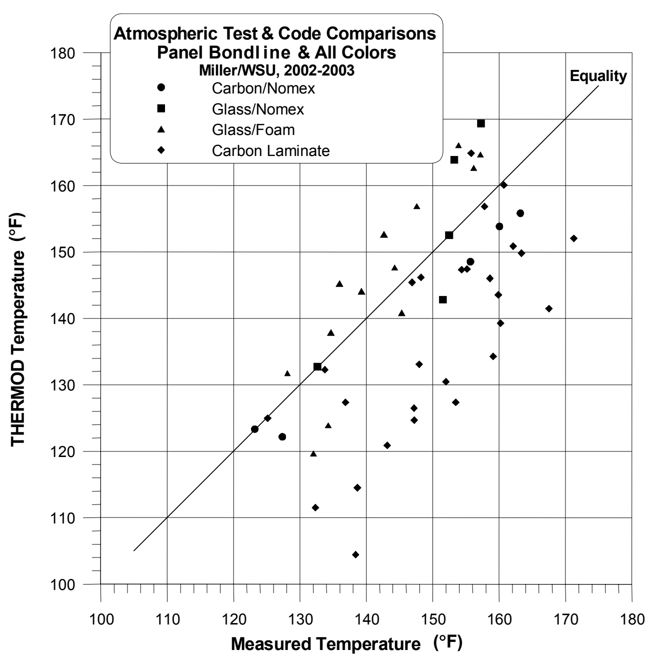

FIGURE 7. EXPERIMENTAL AND THERMOD-PREDICTED BONDLINE STEADY-STATE TEMPERATURE COMPARISONS

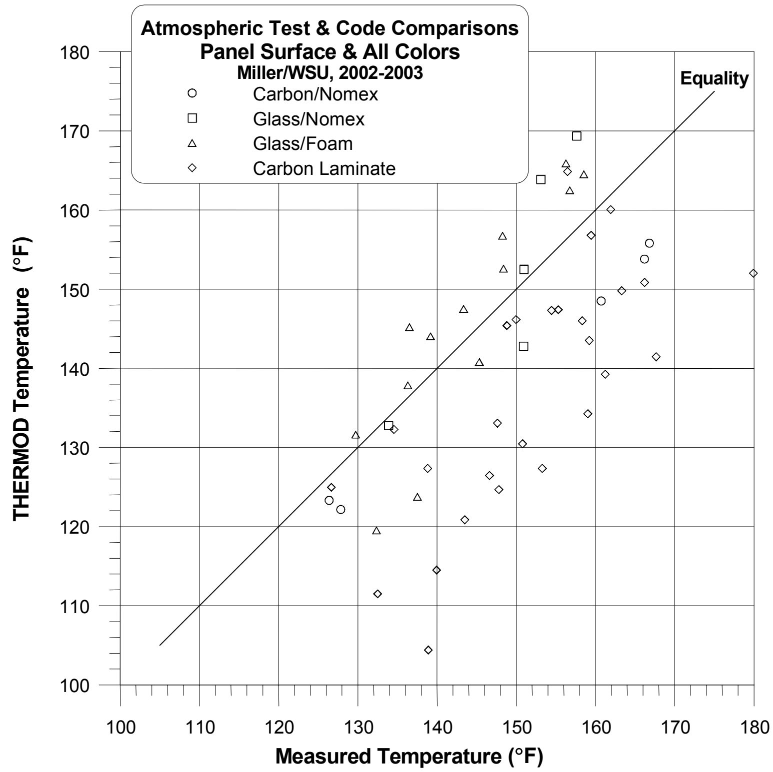

FIGURE 8. EXPERIMENTAL AND THERMOD-PREDICTED SURFACE STEADY-STATE TEMPERATURE COMPARISONS

A best-fit line for all the data shown in figure 6 illustrates that in most cases THERMOD code predictions appear to underpredict measured temperatures. The largest differences are associated with the carbon laminate panel, which is lighter and without a sandwich core. Closer review of the THERMOD method reveals that a constant 10-mph wind is assumed to exist during analysis, whereas the atmospheric tests terminate if winds exceed about 5 mph [1 and 2]. Higher wind speeds can easily result in lower temperatures, especially with lighter and thinner panels due to their greater sensitivity to convective cooling effects.

Tables 7, 8, and 9 list corresponding numerical values for all experimental and THERMOD cases examined and are shown graphically in figures 6 through 8. Table 10 identifies the surface finish or paint color and emissivity values used.

TABLE 7. RESULTS FOR NATURAL COLORED PANELS

Panel	Color	Test Conditions		Prediction	Measured	
		Temperature (°F)	Solar Radiation (Btu/hr ft^2)	THERMOD (°F)	Bondline (°F)	Surface (°F)
Carbon/Nomex	Natural	94.0	263.8	153.8	160.1	166.2
		97.3	251.0	148.5	155.7	160.7
		94.2	261.4	155.8	163.2	166.8
		87.6	206.6	123.3	123.2	126.4
		83.9	200.1	122.2	127.4	127.9
Glass/Nomex	Natural	94.7	290.2	169.4	157.2	157.6
		88.8	243.8	132.8	132.6	133.9
		96.0	267.0	152.5	152.5	151.0
		77.3	159.1	98.7	88.8	89.0
		96.1	281.4	163.9	153.3	153.1
		87.5	273.4	142.8	151.5	150.9
Glass/Foam	Natural	91.6	273.9	152.6	142.6	148.4
		89.7	251.7	137.9	134.7	136.3
		94.7	237.7	145.2	136.0	136.5
		82.2	276.5	140.8	145.3	145.3
		91.0	238.5	144.1	139.3	139.2
Carbon Laminate	Natural	105.8	257.1	156.8	157.8	159.4
		89.4	224.7	127.4	136.9	138.8
		89.1	240.6	130.5	152.0	150.8
		96.7	248.5	139.3	160.2	161.2
		91.2	232.7	133.1	148.0	147.6
		90.2	240.6	126.5	147.2	146.6
		95.2	250.9	146.0	158.6	158.3
		97.7	243.5	147.3	154.4	154.5
		96.7	214.6	132.3	133.7	134.6
		91.6	271.7	152.0	171.3	179.9
		94.7	263.6	141.5	167.5	167.7
		94.1	257.3	149.8	163.4	163.3
		88.0	247.1	127.4	153.5	153.3
		86.7	238.5	124.7	147.2	147.8
		92.6	262.7	150.9	162.1	166.2
		93.2	249.4	134.3	159.1	159.0
		89.9	237.7	120.9	143.1	143.5
		96.7	258.9	143.5	159.9	159.2

TABLE 8. RESULTS FOR COLORED GLASS/FOAM PANELS

Panel	Color	Test Conditions		Prediction	Measured	
		Temperature (°F)	Solar Radiation (Btu/hr ft^2)	THERMOD (°F)	Bondline (°F)	Surface (°F)
Glass/Foam	Gray	79.7	220.8	123.8	134.3	137.5
		87.5	211.1	119.5	132.0	132.3
		62.6	191.3	79.1	115.8	119.7
		82.1	205.8	131.6	128.1	129.7
Glass/Foam	Red	93.2	258.3	156.8	147.6	148.3
		89.8	248.9	147.5	144.3	143.4
Glass/Foam	Blue	95.1	284.4	164.5	157.2	158.5
		100.7	274.6	162.5	156.2	156.8
		102.2	278.6	165.9	153.9	156.3
Glass/Foam	Green	85.7	224.9	131.9	138.6	139.0
		86.9	278.7	155.5	165.5	168.2
Glass/Foam	Yellow	103.7	251.6	171.2	136.2	134.8

TABLE 9. RESULTS FOR COLORED CARBON LAMINATE PANELS

Panel	Color	Test Conditions		Prediction	Measured	
		Temperature (°F)	Solar Radiation (Btu/hr ft^2)	THERMOD (°F)	Bondline (°F)	Surface (°F)
Carbon Laminate	Gray	80.7	223.2	114.5	138.7	139.9
		67.9	216.1	111.5	132.3	132.5
		72.0	226.7	104.4	138.4	138.9
		81.7	199.7	125.0	125.1	126.7
Carbon Laminate	Red	87.6	247.8	145.4	146.9	148.8
		95.1	254.9	147.4	155.2	155.3
Carbon Laminate	Blue	101.0	249.3	146.2	148.3	150.0
		96.3	278.8	160.1	160.7	161.9
		102.4	267.9	164.9	155.8	156.5
Carbon Laminate	Green	80.3	210.3	127.0	134.7	135.2
		88.3	247.1	146.7	156.1	157.4
Carbon Laminate	Yellow	103.3	239.0	154.0	131.3	137.0

TABLE 10. SURFACE FINISH DATA FOR ALL TEST PANELS

Panel	Color	Emissivity	Description
Carbon/Nomex	Natural	0.90	No primer or paint (i.e., raw material)
Glass/Nomex	Natural	0.95	No primer or paint (i.e., raw material)
Glass/Foam	Natural	0.95	No primer or paint (i.e., raw material)
	Grey	0.90	Krylon, 1358 All Purpose Gray (Primer)
	Red	0.92	Rust-Oleum, 1966 Apple Red, Multipurpose Gloss
	Blue	0.88	Rust-Oleum, 1926 Brilliant Blue, Multipurpose Gloss
	Green	0.95	Rust-Oleum, 1938 Hunter Green, Multipurpose Gloss
	Yellow	0.60	Rust-Oleum, 1945 Sun Yellow, Multipurpose Gloss
Carbon Laminate	Natural	0.96	No primer or paint (i.e., raw material)
	Grey	0.88	Krylon, 1358 All Purpose Gray (Primer)
	Red	0.95	Rust-Oleum, 1966 Apple Red, Multipurpose Gloss
	Blue	0.95	Rust-Oleum, 1926 Brilliant Blue, Multipurpose Gloss
	Green	0.95	Rust-Oleum, 1938 Hunter Green, Multipurpose Gloss
	Yellow	0.60	Rust-Oleum, 1945 Sun Yellow, Multipurpose Gloss

4. THERMOD ANALYSIS ASSISTANT.

4.1 MOTIVATION.

The THERMOD code is a compiled Fortran program that runs in a DOS window under current Windows operating system environments. An engineer normally uses a separate text editor program to generate a formatted input file that defines the airframe of interest and the conditions for analysis. After code execution, a text editor or plotting package is used to view predictions stored in a formatted file. Hence, a more integrated and familiar Windows style interface surfaces as a logical enhancement, given that recent validation studies show the program provides reasonable data.

4.2 BASIC APPROACH.

The original THERMOD code is left untouched and is not modified. As a result, all capabilities, shortcomings, or limitations that exist in THERMOD are retained. The program is simply treated as an executable that is called by a new Windows program or interface. This new program, written using Visual Basic, contains two interface routines referred to as front-end and back-end (see figure 9). The first interface (front-end) is used for input file generation, and the second (back-end) is for output or results review. The intent is to simply make THERMOD a more integrated, convenient, easy, and familiar code to use. Given this approach, the new interface is called the THERMOD Analysis Assistant (TAA).

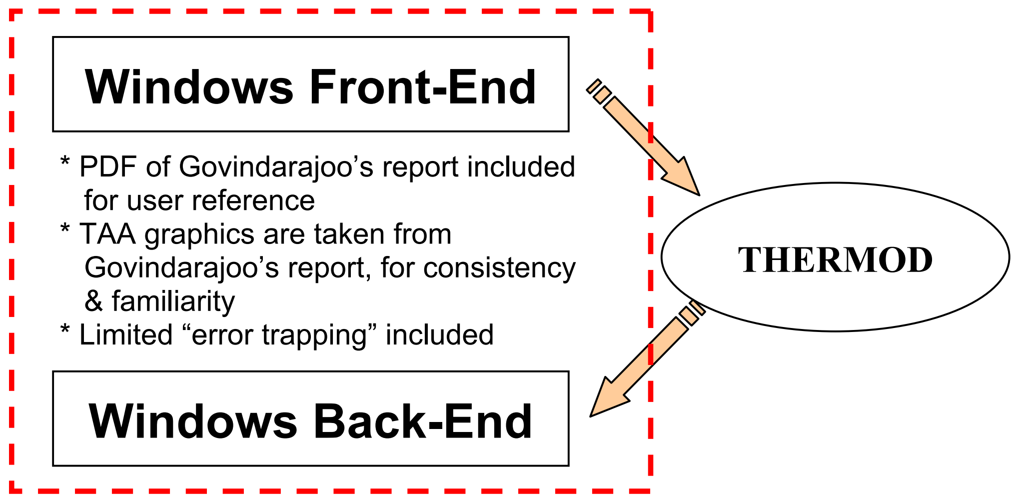

FIGURE 9. WINDOWS PROGRAM DIAGRAM
(TAA is contained inside the dashed rectangle.)

TAA operation parallels THERMOD in many respects, with the obvious exception that it is a Windows program. Govindarajoo’s excellent graphics and nomenclature are included in the TAA to ensure familiarity. A copy of the THERMOD manual can also be accessed from within the TAA Windows program for user reference purposes if desired.

4.3 OPERATION AND FEATURES.

A user needs only to open an existing THERMOD input file or define a new file incorporating the necessary input parameters (i.e., geometry, material properties, atmospheric and flight conditions, etc.) to begin analysis. A default file, with typical example values, is included to help first-time users get started or to serve as a basis to develop an entirely different analysis case.

TAA presents users with windows that include graphics, tabs, text boxes, or tables that require review or modification. The program windows present themselves to a user in an order that makes THERMOD familiar and easy to use. Color-coded indicators are also incorporated to help track input changes, making sure that values are defined, modified, or left alone, as appropriate. Limited error trapping is also included in the TAA program to catch obvious mistakes or errors during input (e.g., accidentally typing a specific heat that is negative or of a magnitude that is too large).

The user simply moves through each window or tab until they finish generating the input and are ready to run THERMOD. The run tab includes a last check on the input data modification status, using the same color-coded indicator scheme mentioned previously. After the THERMOD program has been called and executed by the TAA, the user is presented with additional windows that allow text or graphic (i.e., plotted) review of the steady-state or transient output predictions.

Figures 10 through 14 show a few TAA program screen captures illustrating the environment and some of the features mentioned above.

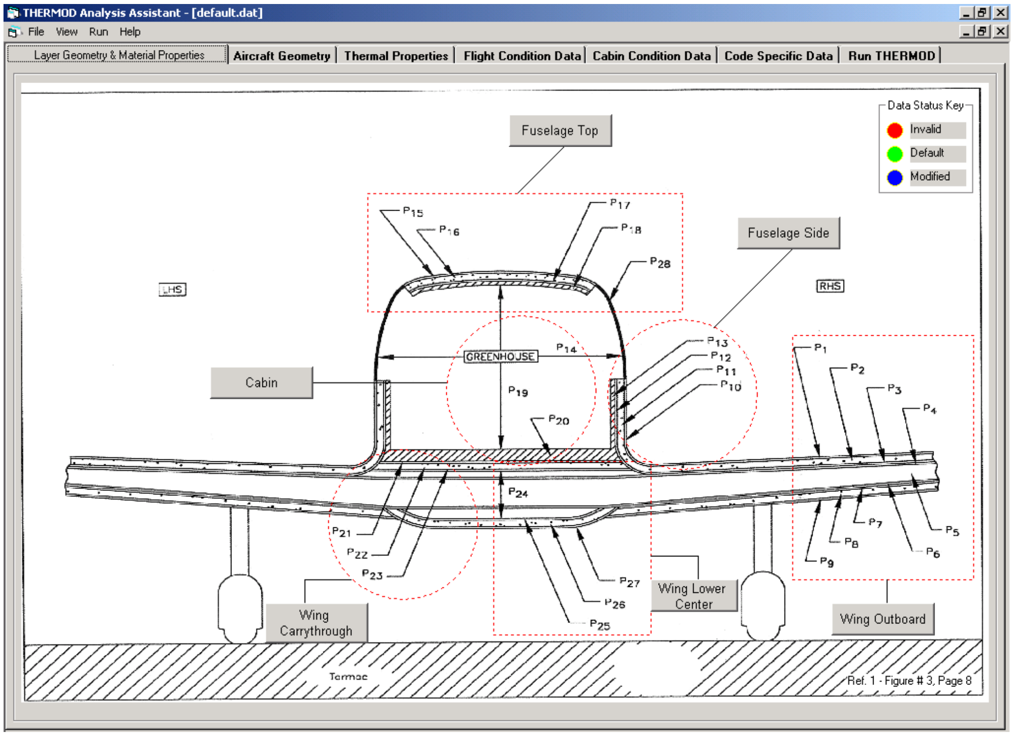

FIGURE 10. THE TAA INPUT SPECIFICATION WINDOW EXAMPLE, GEOMETRY AND MATERIAL PROPERTIES

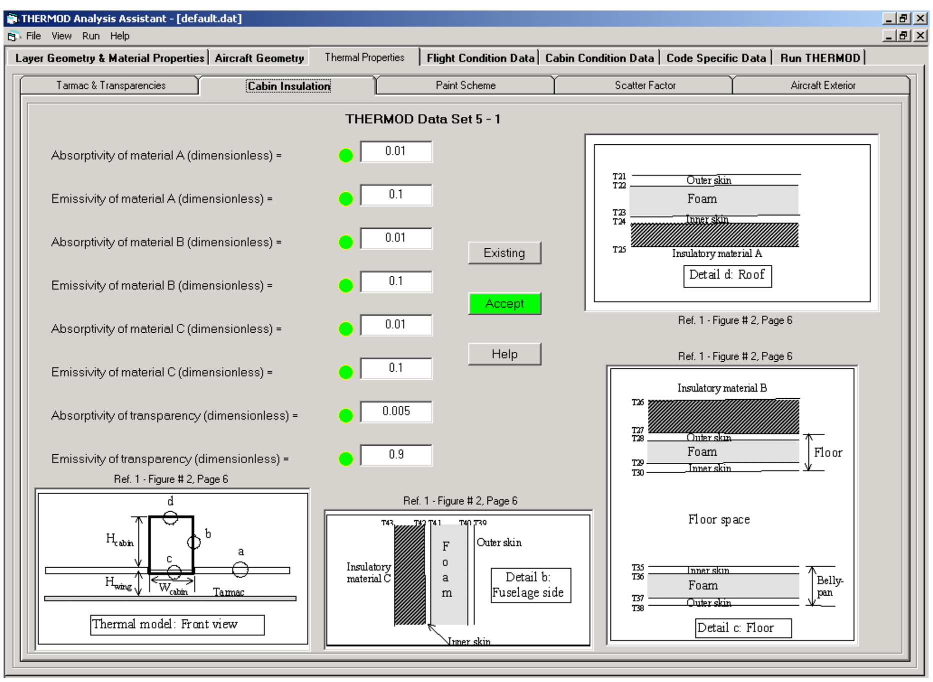

FIGURE 11. THE TAA INPUT SPECIFICATION WINDOW EXAMPLE, CABIN PROPERTIES

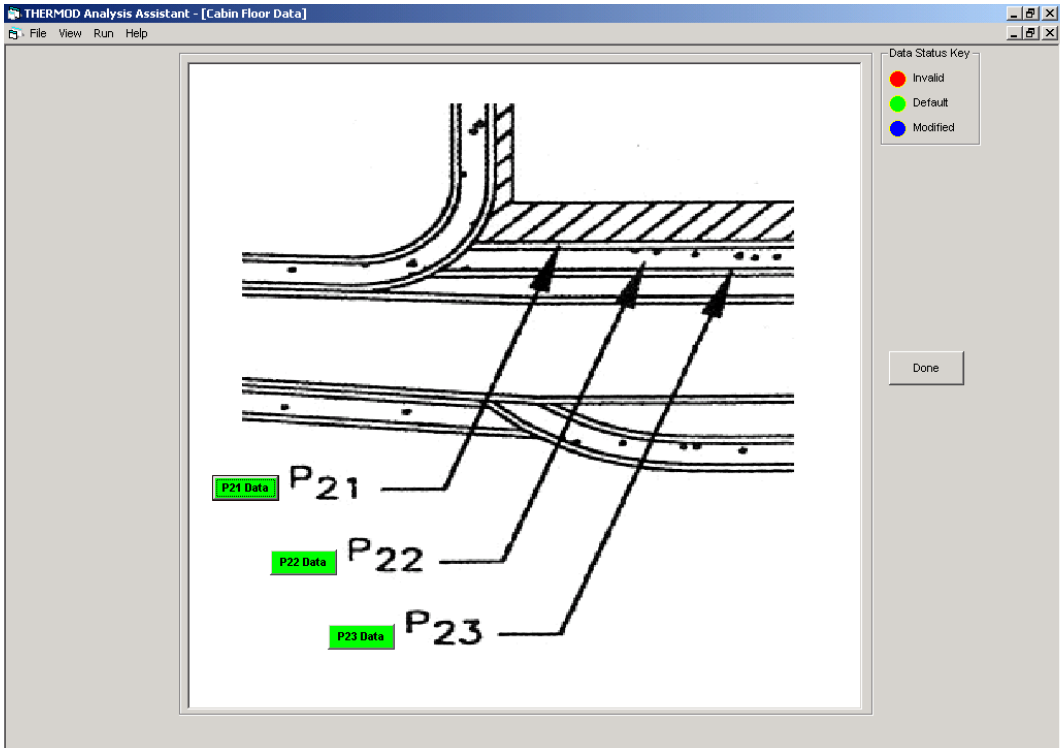

FIGURE 12. THE TAA INPUT SPECIFICATION WINDOW EXAMPLE, CABIN FLOOR PROPERTIES

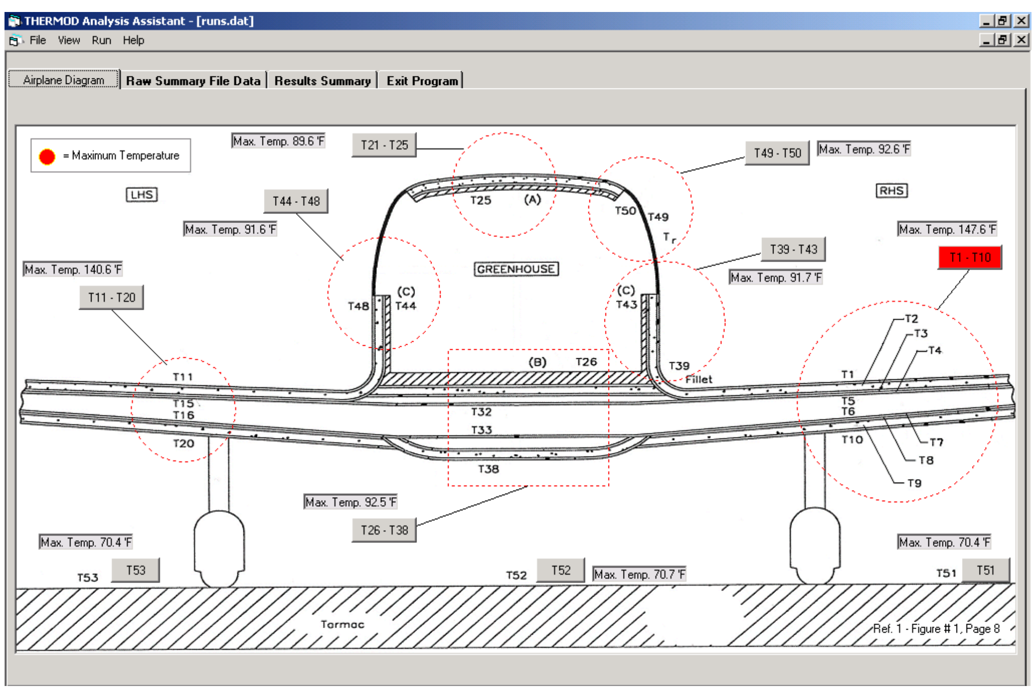

FIGURE 13. THE TAA OUTPUT OR RESULTS WINDOW EXAMPLE, SHOWING TEMPERATURE SUMMARY AND EXTREMES

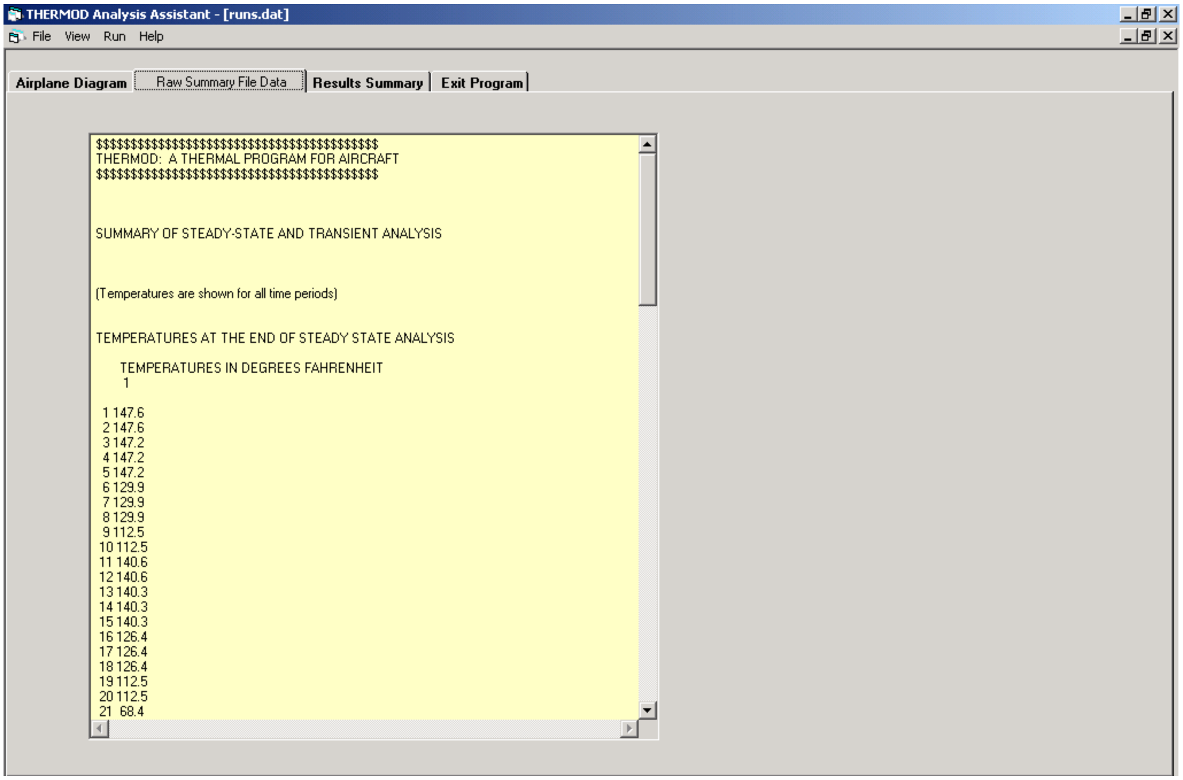

FIGURE 14. THE TAA OUTPUT OR RESULTS WINDOW EXAMPLE, SUMMARY TEXT FILE

The TAA is currently undergoing beta testing by experienced engineers, and TAA Version 1.0 will be released for general use shortly. Newer versions of the TAA are planned, given additional user feedback, support, and time for development.

5. CONCLUSIONS.

This investigation addressed several key issues in the THERMOD computer code, which predicts both steady-state and transient airframe temperatures. The issues addressed were (1) What is the impact of input variable uncertainties? (2) What is the accuracy of THERMOD in predicting steady-state or initial temperatures? and (3) improve THERMOD's utility.

The conclusions reached by this investigation were

1. A sensitivity study showed that the impact of typical input variable uncertainties, on THERMOD predictions or experimental results, are small. Defining obvious geometric parameters as best as possible appears most critical in ensuring prediction or measurement accuracy.

2. Atmospheric tests suggested that solar radiation-heated THERMOD steady-state or initial temperature predictions were reasonable, but low in most cases. This difference could be

due to the assumed wind speed built into the THERMOD analysis method (it assumes a constant 10-mph wind).

3. A Windows® interface for the THERMOD program, called the THERMOD Analysis Assistant (TAA), has been developed. The TAA provides users with an easier to use interface for the THERMOD code. TAA Version 1.0 is currently undergoing beta testing, and therefore, opportunities for continued TAA interface development are being pursued.

Data collected for panels in different colored finishes provided useful data for design and certification.

6. REFERENCES.

1. Govindarajoo, Renganathan, "THERMOD: A Thermal Model for Predicting Aircraft MOL Temperatures," Report no. REK0002A.DOC, Cirrus Design Corporation, Duluth, MN, October 1996.

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