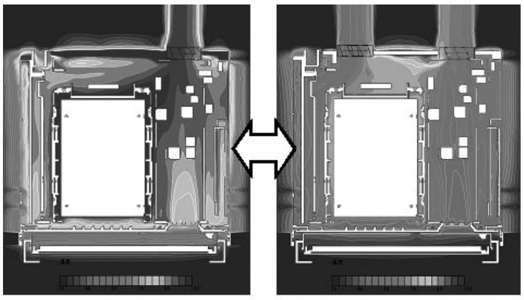
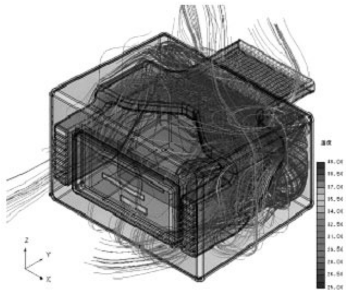
Development/Practical Application of Thermal Hydraulic Analysis Technology and Heat Design (Effective Utilization for AVN Heat Design)

Yoshikatsu Hara
Syouhei Miwa



AVN: Comparative validation of air flow and temperature distribution



Validation of effects due to console structure

Abstract

As Audio Visual Navigation (AVN) systems increase in both high specification and density, their power consumption (heat value) has also been increasing on an upward yearly trend. For this reason, problems related to heat have become extremely serious. However, complicated heat transfer phenomena cannot be solved using simple hand calculations. For these reasons, Fujitsu Ten creates visual representations of heat and air flows to seek out effective measures regarding thermal design to support efforts that have begun in relation to Computational Fluid Dynamics (CFD) thermal hydraulic analysis and thermal design for product development activities that have been initiated with a view to introduce practical applications in 2002. This article introduces related case studies, examples of practical applications and effective CFD application methods. Next, the essay presents the basic principles of heat dissipation, the limits of "heat countermeasures" and unique heat problems related to on-board devices. Finally, we expand on the importance of changing approaches in order to move towards "design that takes heat into consideration".

1 Introduction

Fig. 1 shows representative examples of Audio Visual Navigation (AVN) units released by Fujitsu Ten during the fall of last year. These units represent the progress being made in creating systems that offer "additional high performance" and "additional high density".

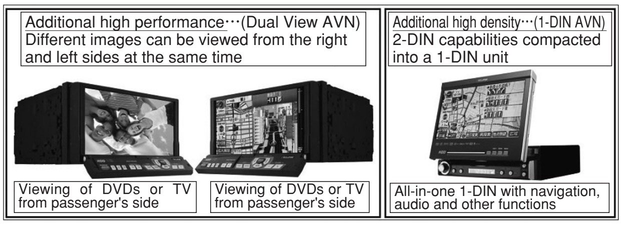


Fig.1 AVN7905HD and AVN075HD

- **Additional high performance (Dual View AVN):** Different images can be viewed from the left and right sides at the same time. When viewed from the driver's side, the screen displays navigation information while allowing for DVD's or television to be viewed at the same time from the passenger's side.
- **Additional high density (1-DIN AVN):** 2-DIN capabilities have been compacted into a 1-DIN unit. Navigation and audio functions are all included in an all-in-one 1-DIN unit.

As car navigation systems increase in both performance and density, and are required to function with the same high-speed processing capabilities as computers, their power consumption (Heat value) has also been increasing on an upward yearly trend causing problems related to heat to reach a critical level. Additionally, as the thermal environment of on-board devices becomes increasingly more severe, it is imperative to satisfy certain extremely rigorous requirements.

Heat transfer consists of three general forms: ① Heat conduction, ② Convection (Natural convection/Forced convection), and ③ Emission (Radiation). Although Fig. 2 shows a simplified representation of heat transfer from a unit that generates heat, the actual phenomena is more complicated as these forms affect and interact with each other.

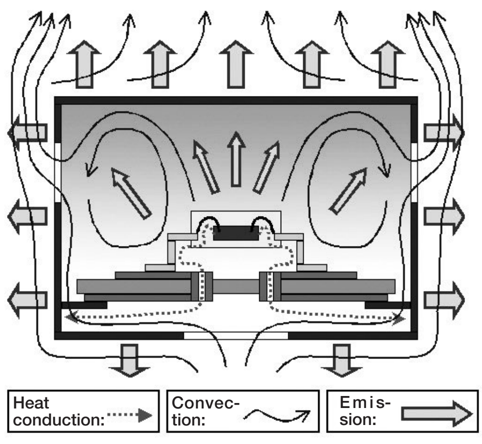


Fig.2 Three patterns of thermal transfer

Electronic devices, and especially AVN units, have hundreds to thousands of heat generating parts so their combined thermal transmission patterns results in the formation of extremely complex heat radiation path. Due to this, it is extremely difficult to resolve heat transfer phenomena with simple hand calculations.

For this reason, we have created visual representations of heat and air flows to seek out effective measures regarding thermal design to support efforts in relation to Computational Fluid Dynamics (CFD) thermal hydraulic analysis and thermal design that have been initiated with a view to introduce practical applications in 2002. This article discusses related validation case studies, practical applications and effective CFD application methods.

Next, this paper examines the basic principles of heat radiation and the limits of heat countermeasures in order to foster upstream thermal design. We also touch on the on-board environment, especially the effects of console construction on raising unit temperature. Additionally, this article discusses raising this problem with auto manufacturers, with a means of a presentation to garner their cooperation with CFD application. Finally, we expand on the importance of changing approaches in order to move towards "design that takes heat into consideration".

2 Development and Utilization of Applied Technology for Unit Design

2.1 Development of thermal hydraulic analysis technology

2.1.1 Approaches to development of analysis technology

Analysis is effective when applied from the conceptual design step of a unit. An important truism in this regard is, "One should strive for analytical accuracy for a single heat generating part or at the circuit board level". However, since from the initial step of unit development we thought that, "Generalities are acceptable since if a relative correlative comparison to the unit as a whole can be ascertained, that will be sufficiently helpful to the design process". With this in mind we started our investigations in the following manner.

2.1.2 Case study I "Car audio"

1) Analysis object: 2-DIN size car audio (CD, MD and tuner)
2) Validation contents: Comparison of changes in housing emissivity with/without fan(s)
   ①Housing (All-SECC)
   ②Housing (Top side only changed to black galvanized steel plate)
   ③Housing (Top and both lateral sides changed to black galvanized steel plates)
   ④ to ⑥: Under the above conditions with a fan attached

In this way, we attempted to comparatively validate CFD and experimental values.

From comparing the results of CFD with the experimental values (data omitted due to space considerations), the relative correlation can be easily ascertained even though there was some difference in the absolute temperature values. From the results of this validation study, we immediately determined that "this can be used right away for a comparative analysis!" and then decided upon the application procedures for thermal hydraulic analysis.

The results of this validation study also demonstrated that fluctuations in emissivity were minimal

2.1.3 Case study II "Car navigation"

We shall discuss a validation study in which we varied the air volume of the fan (drive voltage) and then tracked the temperature variations of various parts of the car navigation unit.

Using a rated 12V fan, the drive voltage was varied in the following sequence and the correlation between CFD and the experimental values was examined: No fan drive ⇒ 6.5V ⇒ 7.5V ⇒ 8.5V ⇒ 10V ⇒ 11V ⇒ 12V ⇒ 13.2V.

P (static pressure) − Q (flow quantity) characteristics were established for each drive voltage.

Fig. 3 shows a comparison between the CFD and experimental results of temperature rise when the fan drive voltage was varied.

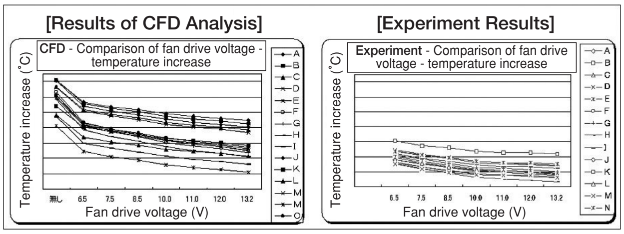


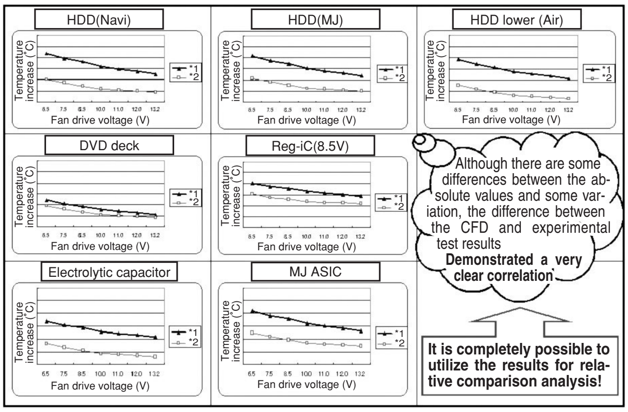
Fig.3 Comparison of CFD and experimental results

The following two conclusions were drawn from the results of this validation study.

1) The heat dissipation resulting from the forced convection caused by the fan was extremely large.

2) As the air volume of the fan (drive voltage) increased, the temperature of the unit parts decreased uniformly in a nearly proportional manner.

Fig. 4 shows a comparison of the trends in temperature rise for each area separately.



*1: CFD *2: Experiment

Fig.4 Correlation comparison of CFD and experimental results (For each area)

Although there are some differences between the absolute values and some variation (refer to "Causes of calculation errors in the analysis results" below for an explanation), the difference between the CFD and experimental test results demonstrated a very clear correlation. From these results also, it can be said that the technical development has reached a level where, "it is completely possible to utilize the results for relative comparison analysis.

2.1.4 Causes of calculation errors in the analysis results

In this section, we will discuss the basic procedures of thermal hydraulic analysis by explaining the required boundary conditions and causes of calculation errors in the analysis results.

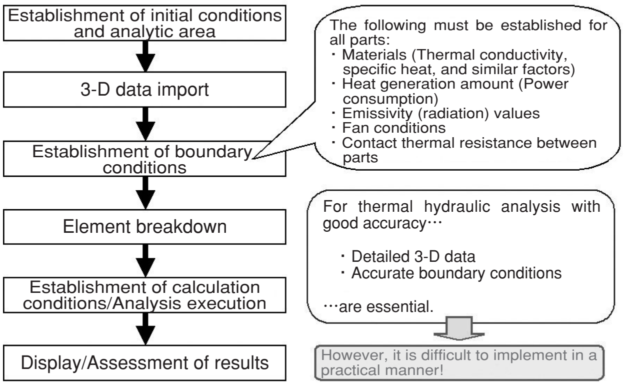


Fig.5 Basic procedures of thermal hydraulic analysis

Fig. 5 shows the basic procedures of thermal hydraulic analysis. A very large factor contributing to the rise of calculation errors in the analysis results is due to the various factors that must be established at each step. The factors that cause disparities between the absolute values of temperatures for the CFD and experiments can be divided into four main types.

1) Calculations cannot be made for detailed 3-D models because the scope of analysis (element count) is too large.

・A detailed model for decks, electronic components, printed circuit boards and similar items is not realistic.

・While simplification of models and element breakdown is necessary, this is dependent on the know-how of each company or person.

2) There are a large number of unclear boundary conditions. (The number of parts alone causes variations.)

・The heat value of all heat generating parts (Both calculation and measurement are difficult.)

・Physical values for each part (Thermal conductivity, specific heat and similar factors)

・Values for physical properties of printed circuit boards (Large variations due to patterns, number of layers, through-holes and similar factors.)

・Emissivity (radiation) values for parts

・Values of contact thermal resistance between parts

・Fan characteristics (P (static pressure) − Q (flow quantity) characteristics are necessary for each drive voltage) ⇒ Characteristics change as these are incorporated into devices

3) Accuracy of CFD calculation program

・There is still actual phenomena that cannot be mathematically calculated

・The uncertain boundary conditions mentioned above contribute to causing concern for the relative verification capacity of the software accuracy

・Calculation results vary due to element breakdown, convergence criterion and similar factors. (It is not always true that Know-how = Correct answer!)

4) Measurement errors

・There are several degrees of variation depending on how the thermocouple is attached.

・Thermal values usually vary towards the low side.

In addition, since Fujitsu Ten produces units with thousands of parts, boundary errors arise due only to the variations caused by the number of parts and making it difficult to obtain results that agree. In other words, it is extremely difficult, even using all the technology currently available, to create a model that can perfectly calculate actual phenomena. In the future, we would like to see that those who wish to take on the challenge of thermal hydraulic analysis possess a thorough understanding of CFD characteristics and that they have clearly defined their application goal when attempting such an effort. This is a highly effective tool for successful application.

2.2 Practical application of thermal hydraulic analysis design

2.2.1 Example of practical application of AVN thermal design

This section presents an example of thermal design utilizing CFD for an AVN (summer 2004 model) developed by Fujitsu Ten and based on the validation study results previously presented.

Heat dissipation occurs due to the forced convection of an axial-flow fan positioned on the backside of the unit. CFD was used to make a comparative validation in order to assess the effectiveness of fan position and air volume using the three patterns of fan arrangement shown in Fig. 6.

①Single fan (right-side)　②Single fan (left-side placement)　③Double fans (right and left-side)

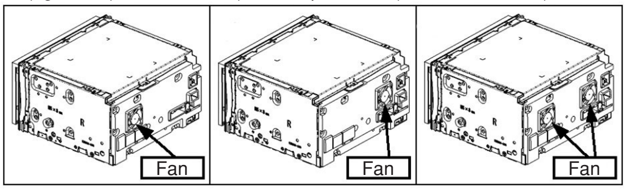


Fig.6 Models for comparative analysis (Rear view of car navigation unit)

Figs. 7 to 9 show the analysis results. The figures show the top view of the HDD cross-section. The figures show a flux vector diagram on the left side and air temperature contour diagram on the right side.

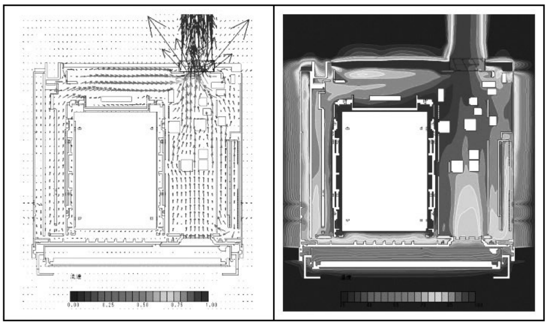


Fig.7 ① Single fan (right-side placement)

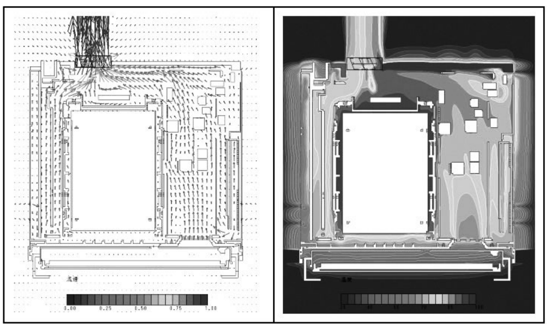


Fig.8 ② Single fan (left-side placement)

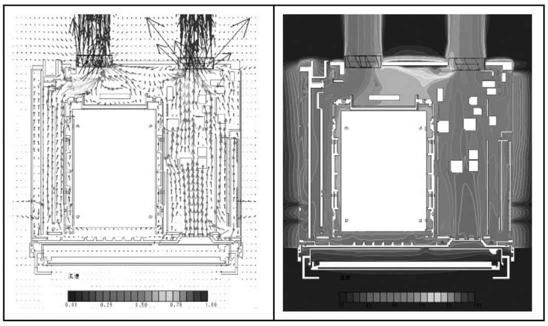


Fig.9 ③ Double fan (right and left-side placement)

The analysis results show that among the single fan models, the "①Right" placement was better than the "② Left" one, and, as would be expected, the double fan model proved to be much more effective than the single fan models. This difference in effectiveness can be clearly visualized even without testing an actual unit. Using this analysis, the differences in cooling effectiveness due to variation in fan positioning and amount was "visualized" and thereby explained visually to the design team, giving an example of where analysis has been used to provide the basis for establishing design principles. As a result, it was decided to use two fans but to also reduce the fan speed by reducing the drive voltage in order to satisfy both temperature and fan noise requirements.

2.2.2 Effects of CFD application

Since only a rough model can be created at the initial design stage, an accurate heat value for individual electronic parts cannot be easily ascertained. Although the rough model presents the airflow within the unit, this can be used from the beginning to relatively compare the general merits of the model. Afterwards, as progressively more detailed models can be created, an effective application method is to perform detailed analysis as necessary, including temperature of factors such as only the flow, at the stage when ascertaining the heat value of individual electronic parts.

The following questions can be used to show the effectiveness of utilizing relative comparison analysis.

1) How many degrees celsius will the temperature decrease if holes are made in the housing? Where should the holes be made?

2) How effective for changing the emissivity are application of plating, paint or other materials/methods to the housing, heat sink and similar parts?

3) What are the better and best positions for the fan and heat generating parts?

4) What are the effects of changing the position, air volume and amount of the fans?
Is air effectively reaching the areas that you want to be cooled?

To answer these questions, CFD provides a great deal of satisfaction by allowing you to see the airflow, to see the temperature distribution, that is to say a "visualization" of these factors. By using this visualization, validation studies can be performed in the shortest possible time and then promptly reflected in the design, proving that the role of CFD is of foremost importance. In this way, CFD can be applied to the examination and planning of an optimal heat dissipation construction from the design conception stage (refer to Fig. 10) and is already being utilized on a wide scale at Fujitsu Ten.

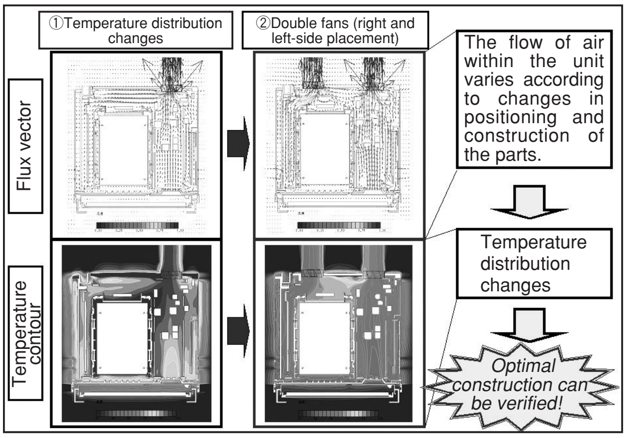


Fig.10 Effectiveness of the relative comparison analysis approach

3 Further Upstream Incorporation of Thermal Design

We have used examples of CFD application to discuss the effectiveness of such application. However, the mere application of CFD will not completely solve all heat-related problems. Before using CFD to perform validation studies, it is necessary to carry out effective "design that takes heat into consideration". The following strategies are important to such a design approach.

[Unit design] ・**Selection and refinement of adequate heat dissipation measures**
・**Low power consumption design**

[Vehicle design] ・**Console construction design that provides adequate heat dissipation**

In this section, we shall explain the basic principles of heat radiation and discuss how there are limits to heat countermeasures applied to navigation units. Additionally, we touch on the on-board environment, especially the effects of console construction on raising unit temperature and also expand on the importance of changing approaches in order to move towards "design that takes heat into consideration".

3.1 Limits of heat countermeasures

3.1.1 Heat radiation paths of electronic devices

As shown in Fig. 2, heat radiation of electronic devices consists of three general forms: ① Heat conduction, ② Convection (Natural convection/Forced convection), and ③ Emission (Radiation). Although in reality these forms arise from numerous interconnected heat sources that mutually affect and interact with each other to create a more complicated aspect, Fig. 11 roughly shows a macroscopic representation of how a heat radiation path with mounted forms might appear

Heat emitted from the heat source (chip parts) is first transmitted to the heat radiating part (part case) via heat conduction within the part. Heat transmitted to the case is largely transmitted by convection to the surrounding air (internal unit air) with a portion of the heat passing through the lead to the printed circuit board and another portion is transmitted to the housing via emission. The heat transmitted to the printed circuit board is gradually

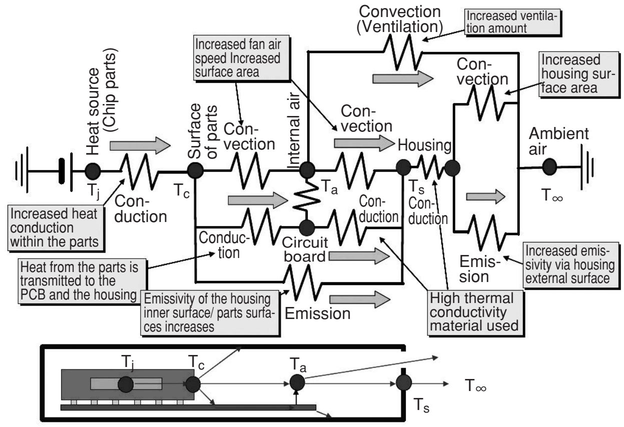


Fig.11 Heat radiation paths for electronic devices[2)]

diffused through the internal air and conducted to the housing. Most of the heat transmitted to the internal air is released to the external atmosphere through the ventilation holes although some of it is transmitted to the housing. The heat passes through a variety of paths while being transmitted to the housing until eventually it is released through the housing surface and diffused in the external atmosphere.

This gives a rough approximation of the heat radiation paths of electronic devices. The minimization of the thermal resistance created by these heat radiation paths is a required heat countermeasure for electronic devices. The figure shows countermeasures for lowering heat resistance at every point. While these are referred to as heat countermeasures, the methods are completely different depending on the section targeted by the countermeasure. It is important to use this approach by creating a heat radiation map like this one in your mind when considering the cooling of electronic devices.[2)]

3.1.2 Limits of heat countermeasures

The following challenges exist for Fujitsu Ten navigation units.

1) **Heat conduction** Measures such as using a "heat sink" have been suggested to deal with heat conduction but possible problems mentioned include that, "satisfactory capacity could not be ensured since there is a limit to the depth and it would be porous due to the numerous connectors" or that "heat from CD/DVD discs, MD packs or optical pick-up cannot be directly conducted".
2) **Natural convection** Measures such as "holes in the housing" or "fan attached to a heat sink and increased surface area" have been suggested to deal with natural convection but problems mentioned include that, "holes cannot be made in the top surface of the housing due to the possibility of a short circuit caused by water drops formed by condensation from air conductor" or that "there is no space to have fins on the heat sink due to depth limits".
3) **Emission** Measures such as "black paint or black galvanizing for the housing or heat sink" have been suggested to deal with emission but problems mentioned include that, "no matter what is done regarding emissivity, it cannot be increased above 1".

The heat dissipation capability for "solid heat sources" of electronic devices can be expressed as follows:

[Heat dissipation capability = Heat dissipation surface area × Heat transfer rate of the surface area × Temperature difference]

This means that unfortunately only a combination of the following two measures exist for increasing the heat dissipation capability:

- **Increase the heat dissipation surface area**
- **Increase the heat transfer rate**

Fig. 12 shows an overview of approaches to heat countermeasures.

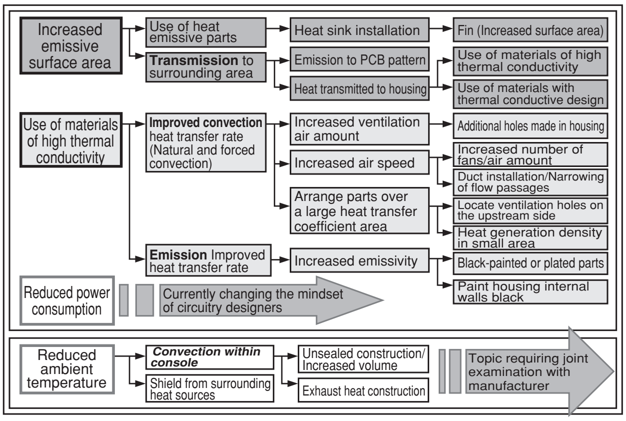


Fig.12 Overview of approaches to heat countermeasures

Heat dissipation capability by "natural convection" and "emission" are determined by the unit size. Also, these countermeasures have a low cost/effectiveness ratio. For the above heat dissipation countermeasures, the only viable method is the installation of a fan to improve convection heat transfer by "forced convection". "Forced convection" refers to measures such as "fan installation, increasing air volume or increasing fan speed" but these measures engender related problems such as fan noise or dust adhering to pick-ups due to increased fan speed. This shows how there are definite limits to implementation of mechanistic "heat countermeasures". In addition to the above heat counter measures, the approaches shown in Fig. 12 such as "Reduced power consumption" or "Reduced ambient temperature" are also important.

3.2 Effects of On-Board Environment

3.2.1 Heat problems unique to on-board devices

Attention must be given to the vehicle console when considering approaches to reducing the ambient temperature.

With home audio units, personal computers and other consumer electronics, a fan or similar device is used to release heat from inside the unit into a nearly infinite space existing outside of the unit. However, on-board devices such as AVN units cannot resolve heat problems with similar ease.

Fig. 13 shows AVN units installed in actual vehicles. There are various installation configurations but attention should be especially paid to how some console constructions can place the unit so that it receives the direct rays of the sun causing heat to build up inside the unit.

Heated air that is released by the unit due to fan operation is initially exhausted within the instrument panel console. Depending on the construction, the heated

Fig.13 Installation samples in actual vehicles

air that has been released from the unit might remain within the console thereby causing console temperature to rise steadily and as a result the unit temperature does not actually decrease. This is one of the typical heat problems that emerge for onboard devices.

If some measures were used that could provide even a fractional degree of convection on a constant basis, then unit temperature reduction could be expected to be very effective.

Now we will examine how these aspects were verified in "Example of an experiments conducted with an actual vehicle" and "Example of an experiment with CFD hydraulic analysis of a simple console model".

3.2.2 Case study of effects of vehicle console

Presence of convection and temperature change within a console of a vehicle were tested and validated by switching the air conditioner mode in the following order: From "①A/C Off" ⇒ "②Auto A/C On (Ambient air induction) ⇒ "③Auto A/C On (Internal air circulation)". Again, a simple model was used for a comparative validation by using CFD for the same phenomena.

1) Visualization of airflow

Incense was used in order to visually demonstrate the convection aspect within the vehicle console and to verify the existence of convection.

Fig. 14 shows images of how the experiment was conducted.

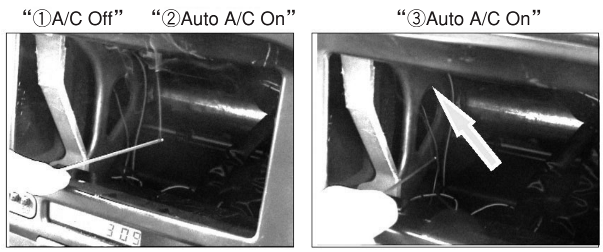


Fig.14 Confirmation of convection within a vehicle console using incense

There was no convection of the air within the console at the "①A/C Off" and "②Auto A/C On" positions.

When switched to "③Auto A/C On", air within the console is observed being suctioned to the upper left corner (shown by the arrow in the photo). This shows that air convection does, albeit slightly, occur within the console.

2) Temperature verification in an actual vehicle

Next, an AVN unit was installed in an actual vehicle and temperature changes were measured for each mode. Fig. 15 shows the results of this experiment in the form of a graph.

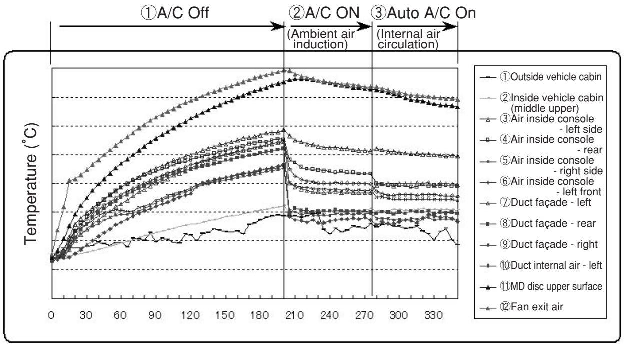


Fig.15 Measurements of heat variation within consoles

The temperature rises steadily in "①A/C Off".

Although there is no convection of the air within the console in "②Auto A/C On", as 25℃ air flows in through the air conductor, it has the effect of slightly lowering the temperature inside the console.

When switched to "③Auto A/C On", convection occurs among the air within the console and the temperature within the console decreases again.

From the results of this experiment, it can be concluded that, "if heated air within the console can be exhausted then the unit temperature will also decrease".

3) CFD trial using a simple console model

For the next experiment, a simple console was constructed as shown in Fig. 16, a comparative model was built as shown in Fig. 17, and reproduction validation testing was carried out.

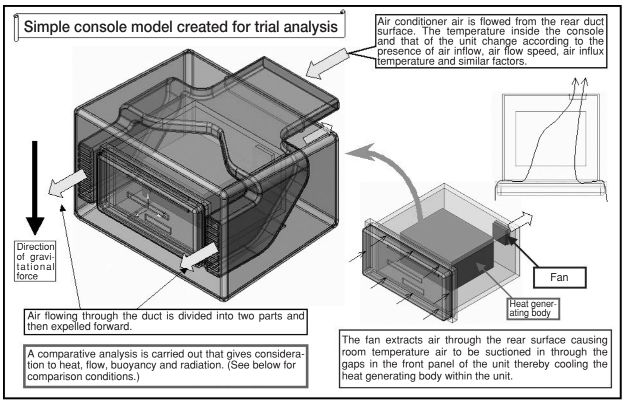


Fig.16 Simple console model for CFD-use

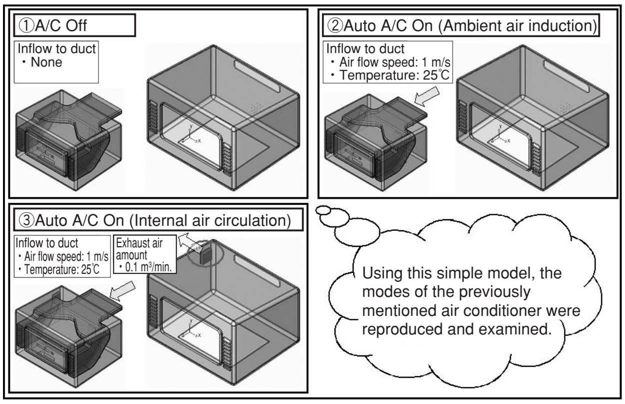


Fig.17 Comparative models

The results of the CFD analysis trial are as follows. Fig. 18 presents a comparison between the results of the CFD analysis with the simple model mentioned above by showing the temperature distribution on the front of the unit using infrared thermal tracing images. Although it is obviously impossible to perfectly recreate the model or boundary conditions, and there are differences in the absolute values, the patterns do appear to be very similar.

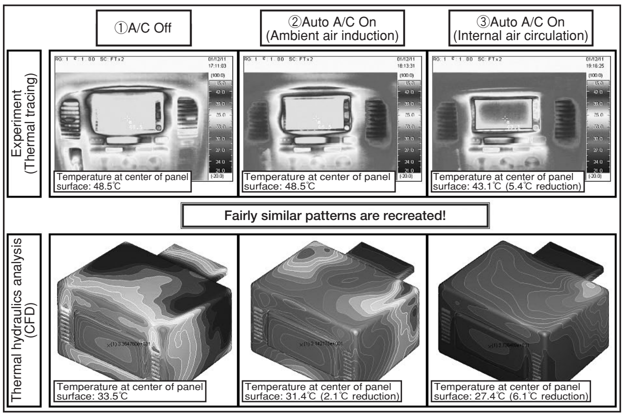


Fig.18 Comparison of surface heat distribution (Experiment ⇔ CFD)

Fig. 19 shows the internal aspects of the results of CFD analysis and the comparative model. The upper row shows the streamline contour images while the bottom row shows the temperature contour for the middle cross-section viewed from the right side. These images permit us to visually understand aspects such as the retention and distribution of hot air within the unit, and the changes in cooling efficiency due to changes in console construction. It is even easier to understand these factors if the images were animated.

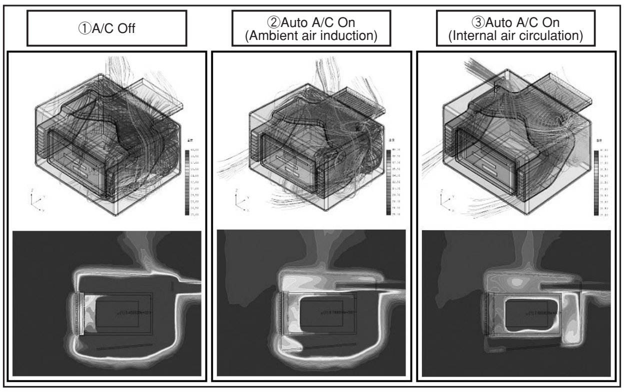


Fig.19 Results of CFD analysis (Flow line/Cross-section temperature contour drawing)

We have reached the limits of heat diffusion countermeasures for AVN units and other on-board electronic devices. From now on, heat diffusion structural design, including for the vehicle itself, is essential due to the acute situation regarding heat generation. In order that heat diffusion structural design that is heat-conscious can be integrated into the basic console design step of the vehicle manufacturer, the issue is first raised with the manufacturer and then a presentation is used to gain the assistance of the manufacturer in actions that can further improve thermal design.

3.3 Towards a "design that takes heat into consideration

This article has presented examples of CFD thermal hydraulic analysis applied to AVN thermal design as well as comparative application methods. The use of CFD thermal hydraulic analysis technology permits the effective application of thermal design at an even earlier stage than previous application. However, thermal design at Fujitsu Ten is currently at a stage where we are moving from Step 1 "Conventional heat countermeasures" to Step 2 "Heat validation using CFD". This implies that in order to truly front-load thermal design, our most essential and primary task is to move towards the next step of "Design that takes heat into consideration".

Hereafter, it will be necessary to strengthen strategies and actions for moving towards Step 3 "Design that takes heat into consideration" where essential tasks to reach this goal of total thermal design include the understanding and locating of thermal generation amounts and parts, PCB/circuitry/software design, deck construction design and vehicle console construction design. To this end, the cooperation and assistance of all departments is essential.

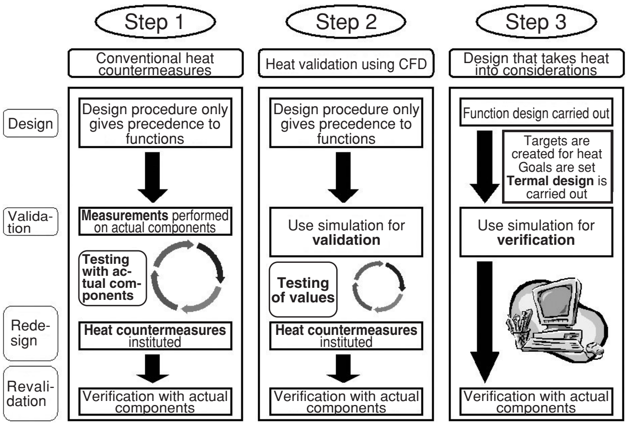


Fig.20 Steps to move towards "Design that take heat into consideration"

4 Conclusion

CFD thermal hydraulic analysis technology has been developed and adapted for practical application to the point where it can be effectively utilized for thermal design of AVN units and similar components.

We feel that it can be utilized even more as we move ahead towards a "design that takes heat into consideration".

Finally, the authors wish to express our most sincere gratitude to all the various individuals, institutions and companies involved in thermal design/thermal hydraulics analysis including: Mr. Naoki Kunimine of Oki Electric Industry Ltd., Co. for allowing us to quote his work, and Prof. Masaru Ishizuka of Toyama Prefectural University for his assistance and support for Research Committees RC214-RC227 of the Japanese Society of Mechanical Engineers.

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Profiles of Writers

Yoshikatsu Hara

Entered the company in 1979. Since then, engaged in the design of mechanisms for car audio systems, car navigation systems, and wireless devices. Began working with CAE in 1999. Currently in the Digital Engineering Department of Research & Development Group.

Syouhei Miwa

Entered the company in 1982. Since then, engaged in the development of electronic devices for automobiles and development support tools. Currently the Manager of the Digital Engineering Department of Research & Development Group.