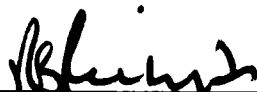


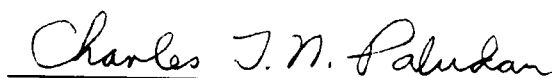
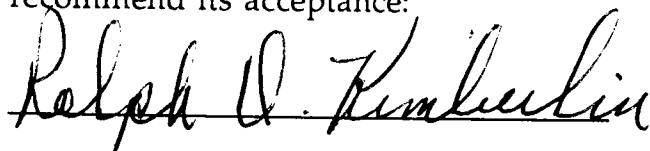
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THE TRANSFER OF OPERATOR-TO-VEHICLE
INTERFACE TECHNOLOGY BETWEEN AVIATION
AND AUTOMOTIVE FIELDS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee Space Institute, Tullahoma

Michael John Eddy

May 1992

DEDICATION

This thesis is dedicated to my wife

Mrs. Kelly Anita Eddy

and to my father

Mr. Clare Melvin Eddy

who have provided me with the encouragement needed
to continually strive to do my best in all pursuits

ACKNOWLEDGEMENTS

I would like to thank my major professor, Mr. Robert Richards, for his guidance and assistance in completing this thesis, and for his commitment to the University of Tennessee students stationed and working at Patuxent River Naval Air Station. I would like to thank Ms. Pat Alt of the Patuxent River Naval Air Station library. Without her help my literature search and research would have been much slower and not as complete. Finally, I would like to thank the librarians at the Department Of Transportation library, who helped me located and copy many hard to find reference materials.

ABSTRACT

This study was an in-depth look at the transfer of operator-to-vehicle interface technology between aviation and automotive fields. The four major areas of technology transfer which were examined included: system control switches, auditory displays, Head-Up Displays (HUD's), and navigation systems. In each area the history and evolution of the technology as implemented in aircraft was profiled. Then the current state of aviation technology was examined in detail. This examination included reviewing those human factor considerations the technology was designed around. Following each section's presentation of aviation technology, the particular technology was evaluated for its ability to be and past success in being transferred to the automotive industry. Particular attention was paid to alterations in, and compromises to the technologies that were required to overcome, economic, technological, and human factor differences between the two industries. Finally, for each area suggestions for future technology transfer were presented.

It was concluded that significant technology transfer had taken place, but that more could be facilitated. A suggested generic operator-to-vehicle interface configuration for future automotive use based on the findings in each area of technology transfer was presented.

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I. INTRODUCTION AND PURPOSE

INTRODUCTION

Technology transfer is a broad and mostly undefined term. Generally it has been utilized to describe the action of transferring technological discoveries from one field of engineering or science to a distinctly different field of engineering or science. While this definition basically does describe the general meaning of technology transfer, it does not contain all the supplemental parts of technology transfer. Technology transfer must include not only science and engineering discoveries, but also the hardware, software, and methodologies which made the advances possible. If the meaning of technology transfer is broadened in this way, it is easy to see that besides discoveries, many human factors concepts, engineering processes, and lessons learned can be termed as technology transfers from one discipline to another.

The aviation and automobile industries have a lot more in common than just the fact that they both design, test, and produce moving vehicles which transport human beings. Throughout history, these two industries have been closely linked by technology both in design and manufacture. An early example of this technology linking is the U.S. Standard Aircraft engine, more commonly known as the Liberty engine, which was designed for World War One fighter aircraft. This engine was modeled after the automobile technology of the time period. Specifically, the technology that was transferred included water cooling and an automotive (coil and distributor)

type ignition system.¹ Granted this engine may have not been the most technologically advanced engine of the time, but it does serve as an example of early technology transfer between the two industries.

Technology transfer between the automobile and aviation industries encompasses a vast and endless arena. Technology transfer has been prevalent in the design and manufacture of components for chassis/airframe, engine, braking, electrical, and drive-train systems. This paper will discuss none of the above areas, but will instead will deal with technology transfer in the area of operator-to-vehicle interface.

Operator-to-vehicle interface primarily occurs in either the cockpit of an aircraft or from the driver's seat of an automobile. Since the early days of the first aircraft and automobiles operator-to-vehicle interface has been an evolving and important facet of vehicle design. Throughout the evolution of the aircraft and automobiles, designers from both industries have borrowed ideas and technology from the other industry. In more recent times, due to the rising costs of technology and the huge impact of government funding on the aviation industry (especially in the field of military aircraft), the aviation industry has been on the leading edge of operator-to-vehicle interface technology. Due to this fact, the technology transfer between the aviation and automobile industries has been primarily a one way street, with the traffic flow being from the aviation industry to the automobile industry.

¹ Christy and Wells (1982)

HINDRANCES TO TECHNOLOGY TRANSFER

Automobile Of Tomorrow

As technology advances many changes from the norm or ordinary are constantly being thrust upon the general public. Automobiles of tomorrow will be vastly different from those of today. When a driver sits down to go for a drive numerous changes will be evident to him. A peep into the future can be seen in Ford Motors Company's Concept 100 vehicle, shown in figure 1, which was developed in 1986.² A quick look at this design concept, shows that in the operator-to-vehicle interface area much of the future technology will be in some form transferred from the aviation industry. In particular, the Concept 100 vehicle foretold the use of voice alerts, voice command (interactive voice system), a detailed warning module/system, and a satellite navigation system. While these technologies are all presently installed in operational aircraft, their transfer to automobiles will be no simple matter. Many economic, technical and human factors problems must be dealt with before there can be a successful transfer of the technology.

Economic Hindrances

One primary obstacle to technology transfer is economic. While many consumers would enjoy and benefit from the projected increase in technology, the overall cost to the consumer may be prohibitive.

"Cost is a major consideration because as costs increase there is an increasing burden on the product to deliver. A *price wall* reminds us that new features must be affordable. This *price wall* factors in *sticker shock*. These features are being *purchased* after the vehicle is acquired for *basic transportation*. A customer does not buy technology, but the benefits or features produced by technology."³

² Gromley (1986)

³ Gromley (1986)

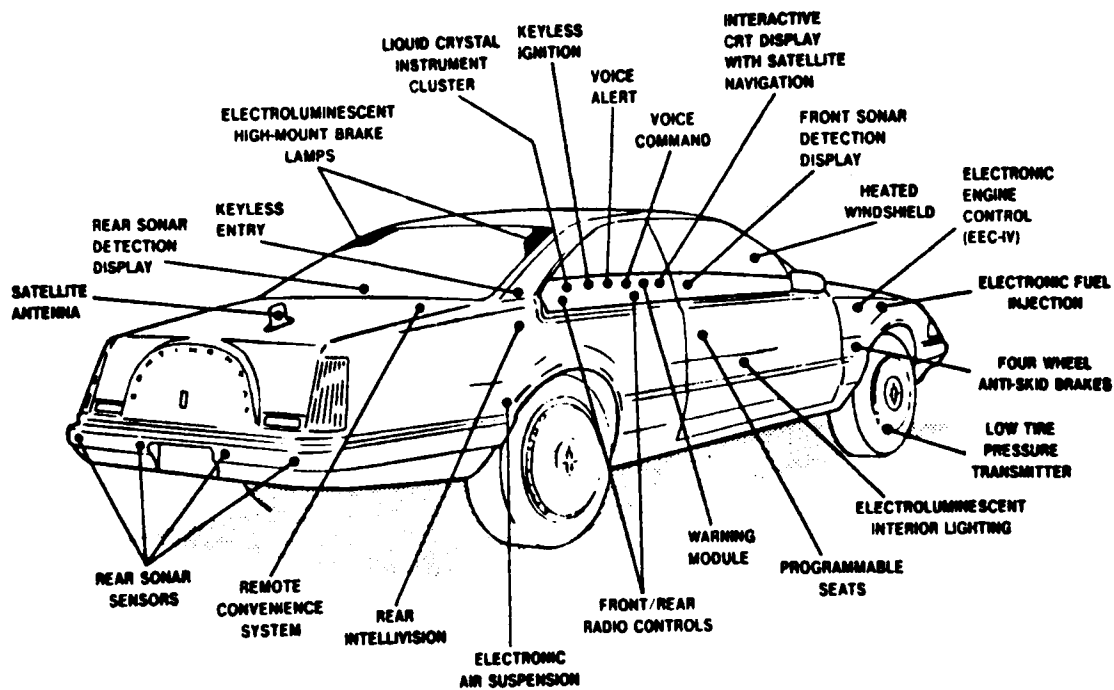


Figure 1

Ford Motor Company's Concept 100 Vehicle

Source: Gromley, Joseph. "Trends In Vehicle Personalizing." Proceedings - Society of Automotive Engineers, P-183 (1986), p. 246.

One economic factor the automobile industry does have in its favor is that it produces its vehicles in volume, most automobile manufactures produce individual models in the hundreds or at least tens of thousands, while most aircraft are produced in numbers many factors lower, usually in the hundreds. Additionally, since much of the basic technology research has been completed by the aviation industry, the automotive industry will not have to recoup these research costs in the price of individual vehicles as the aviation industry has had to do.

Technological Hindrances

The primary technological hindrance to transferring much of the operator-to-vehicle interface technology is that most automobiles do not at this time possess a data bus system. The data bus system in an aircraft, automobile, or any piece of equipment for that matter is similar to the nervous system of an animal. Data is transmitted along the bus from one component to another. The data bus system has a set code for the data, which is in a digital format. The true purpose of a data bus is to make information available from one component to the many other components without having to directly link each component together, instead the components are each linked to the data bus which in turn is linked to the other components. A good example of the concept is illustrated by a airspeed measurement in an aircraft. The aircraft's airspeed sensor computes the airspeed (actually the pressure differential), and puts this data onto the data bus. The data bus then carries the encoded information to the other components such as computers, displays, or engine controls, which utilize the data. If the aircraft did not have the data bus, then the airspeed sensor would have to individually transmit this data to each component along individual lines.

Military aircraft started to extensively utilize data buses in the 1980's, when on-board computers became powerful enough to handle the required data bus controller functions. The F/A-18, which was designed in the late 1970's, has an excellent example of an electrical based aircraft data bus system.

The F/A-18 data bus system is designed to provide for integrated and centralized system control, and a standard interface of all components connected to the data bus. The F/A-18 component groupings which are interconnected by the data bus system are shown in Figure 2.

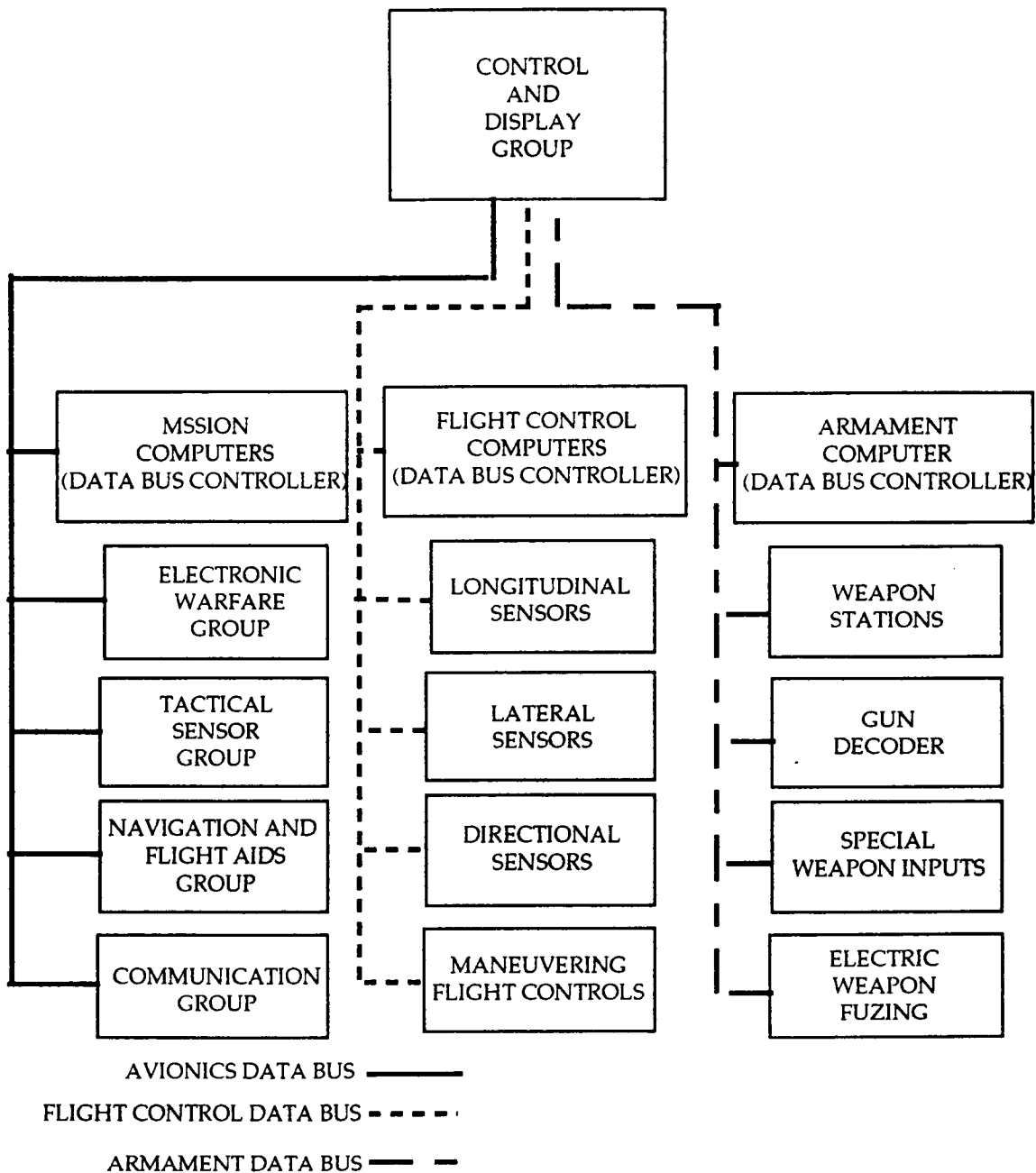


Figure 2

F/A-18 Data Bus Connected Component Groupings

Source: Adapted from: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. FO-41.

The F/A-18 data bus system is based on a military standard for data buses known as MIL-STD-1553. The MIL-STD-1553 sets the method, speed, and format of the digitalized transmitted information. The information, or data, from each component is encoded on a Manchester II (biphase) electrical waveform operating at a bit rate of one megabit per second.⁴ MIL-STD-1553 also dictates the data bus's medium and component interconnections. The transmission medium is twisted pair shielded cable, and in the F/A-18 all components are connected with at least two such cables to provide for redundancy. Information can flow in both directions along the data bus, but not simultaneously. The F/A-18 has many system components, and because of this its data bus system is split into three separate sections. Each of these sections must have a separate bus controller. The bus controller acts as the "traffic cop" for the data bus, ensuring that the information from each component reaches its destination at the correct time. In the F/A-18 the mission, flight control, and armament computers act as the bus controllers.

While data bus technology is now prevalent in all new forms of military aircraft and large commercial aircraft it has yet to be integrated into general aviation aircraft. The next generation of data busses will not be totally electrical in nature, but instead will rely partially on fiber optic technology. Fiber optic data busses will provide for increased data flow rates and capacity.

In the automobile industry today, few if any automobiles have a true data bus system. Many automobiles do have limited data bus systems. These systems are usually similar to Ford Motor Company's electronic engine control system, which utilized a data bus system to link numerous sensors, actuators, and a computer/controller together to control the engine's

⁴ MIL-STD-1553 Lecture Notes (undated)

functions.⁵ A simple and generic data bus system for automobiles which was proposed in 1986 is illustrated in figure 3.

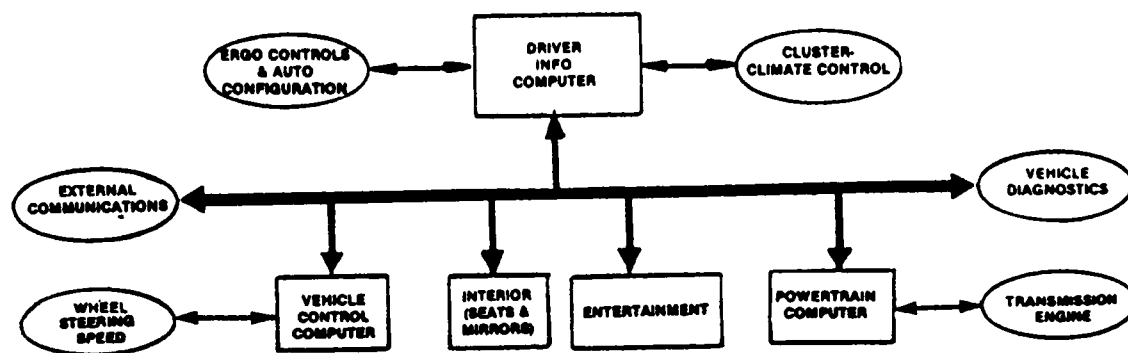


Figure 3

Simple And Generic Automotive Data Bus System

Source: Gromley, Joseph. "Trends In Vehicle Personalizing." Proceedings - Society of Automotive Engineers, P-183 (1986), p. 252.

This proposed system, as should be expected, has many similarities to any of the modern day aircraft data bus systems. The primary difference is that it is much less complicated due to the limited the number of data bus linked components and sensors. The true necessity for a data bus system for applying operator-to-vehicle technology will be discussed in later sections covering the individual technologies. Suffice it to say for now that without a data bus system the technology can be transferred, but at increased difficulty.

⁵ Gromley (1986)

Human Factors Hindrances

Most human factors work with modern day operator-to-vehicle interface technology issues has resided in the aviation industry. While human factors is a large and varied field, this discussion will concentrate on displays and controls. Displays and controls are the normal method components with which an operator interacts with a vehicle. Displays present information about the state of the operator-to-vehicle system, while the controls allow the operator to manipulate or control the vehicle.

While it has been stated that, "the requirements of flying have placed the most severe demands on human information processing capabilities"⁶, this is not to imply that all aviation human factors research and findings can be directly applied to conditions that are less demanding, such as automobile driving. In truth, many human factors considerations which have driven the design of aviation operator-to-vehicle interface technology may not be appropriate for automobile usage. The majority of these human factors differences can be categorized into three groupings: (1) population differences in personnel operating aircraft and ground vehicles, (2) operating conditions, and (3) unique features of aircraft versus ground-vehicle operation.⁷

The population considered for most human factors work in the aviation industry includes highly trained, usually college educated males. This population is trained to use one language, and is somewhat familiar with the basic displays and control formats which are prevalent in the design.

⁶ Stokes et al. (1989)

⁷ Stokes et al. (1989)

The population which the automobile industry is concerned with is much different:

"The car-driving population, spans a wide age and ability range, includes many cultural and subcultural groups, and is not subject to regular proficiency or medical checks. Many segments of the driving population, for example the elderly and the hearing-impaired, tend to be poorly represented in the subject pool used in aviation human factors research."⁸

It is easy to surmise that some of the aviation technology designed for such a select group may have to be modified for the general population during the transfer of the technology to the automobile industry.

The operating conditions of aircraft and automobiles are also very different. Beyond the basic differences, that aircraft normally operate in the air mass while automobiles normally operate in contact with the earth, automobiles also are not subjected to the same stresses as aircraft. This is not to imply that the operating conditions for aircraft are any harsher, just different from those of automobiles. The vibration environment is a good example. While jet aircraft are subjected to more high frequency vibration, which is due to the high Revolutions Per Minute (RPM) of jet engines, automobiles are more likely to be subjected to irregular, low frequency, but high intensity vibrations which may be caused by poorly maintained road surfaces. Which of these operating conditions is harsher is hard to determine since it ultimately depends on the type of equipment being subjected to the environment and the environment itself. Aircraft components also receive much more maintenance and service attention than the average automobile. If a gauge or indicator of an aircraft is not functioning within tolerances it is

⁸ Stokes et al. (1989)

more likely to be fixed than a similar gauge which is out of tolerance in an automobile. Again, these factors must be considered when the technology transfer is attempted.

The unique features of aircraft versus ground-vehicle operation must also be considered when viewing human factors driven technology. Aircraft normally operate in three axis (pitch, roll and yaw) and in three dimensions (x: east/west, y: north/south, and z: altitude), while automobiles normally operate in only one axis (yaw), and in two dimensions (x: east/west and y: north/south). This difference alone will have a great bearing on the complexity and implementation of some displays and controls. Additionally, in aircraft the attention paid to interior displays may at times be the pilot's primary task, such as during Instrument Flight Rules (IFR) flying conditions. In automobiles the most important display is always the outside world, which is viewed through the vehicle's windows. This difference in task loading is accurately stated by Stokes, Wickens, and Kite:

"Observation of (and control response to) instrument panel displays in a car is always a secondary task, and instrumentation must be evaluated for which it may distract from the primary task, the stabilization, control and navigation of the car."⁹

PURPOSE

The purpose of this paper is to examine the current state of operator-to-vehicle interface technology transfer from the aviation industry to the automobile industry. Specific technologies which will be examined include:

⁹ Stokes et al. (1989)

system control switches, auditory displays (including voice interactive systems), Head-Up Displays (HUD's), and navigation systems.

For each specific technology the history and current state of the technology as it applies to the aviation industry will be detailed. Next, any past and current attempts to transfer the technology to the automobile industry will be examined. In this examination the alterations needed to make the technology work will be examined primarily for human factors issues. Finally, suggestions for further technology transfer to the automobile industry and any advances in the technology that have been matured by the automobile industry which may be transferred back to the aviation industry will be discussed.

II. SYSTEM CONTROL SWITCH TECHNOLOGY

INTRODUCTION

In any vehicle the primary medium through which the operator manipulates the vehicle is the vehicle's controls. The term "controls" is a very general term and in an airplane encompasses everything from rudder pedals to the switches which control the airplane's mission systems. Likewise, in an automobile the term "controls" can mean various components such as the steering wheel, brake pedal, gear selector, and various system switches. This discussion will deal mainly with the switches which control either the airplane's or automobile's non-vehicle positioning controls.¹⁰ To avoid confusion and promote brevity these non-positioning controls will be termed switches for the rest of this discussion. While not the focus of the discussion, some mention of displays will be necessary as increasingly switches have been integrated into display units.

To begin the history and present day utilization of switches in aircraft will be examined to access the current state of aviation technology. This examination will be followed by a look at the current state of automobile switch technology. Finally, alternative ways of transferring aviation technology to the automobile will be suggested.

¹⁰ The author defines vehicle positioning controls as those controls which allow the aircraft or automobile to maneuver about its primary axes such as: rudder pedals, control stick, throttles trim switches, steering wheel, and gas pedal.

AVIATION SWITCH TECHNOLOGY

Combating The Switch Explosion

Throughout the history of aviation switches have been present in aircraft. The Wright Flyer and other early aircraft had only a few required switches, those designed to control the engine functions. As additional systems were added to aircraft more switches had to be installed and utilized to control these systems. As an example, take the simple radio. When this communication system was added to the airplane along with it came switches for: (1) power, (2) frequency selection, (3) volume, and (4) transmit initiation. These four additional switches of course are the minimum number, as many modern day "communication systems" have many more switches. The point is that if we multiply the four switches of this one simple system by the number of additional systems which have been added to the modern aircraft it is easy to see why the total number of switches has become extremely high. An example of this "switch explosion" is the A-6E "Intruder", a U.S. Navy attack jet which was built by the Grumman Corporation from 1960 until 1992. In the latest version of the A-6E the total number of cockpit switches is 414.

To combat this "switch explosion" one way the aviation industry compensated was by increasing the number of crew members in the aircraft. This was true both in military and commercial aviation fields. For example, the introduction of a Weapon Systems Officer (WSO) into the F-4 was a method of ensuring all the systems were controlled in a proper manner. Additionally, this gave the designers more space to locate the control boxes and displays required. Granted the primary job of the WSO was to monitor and utilize the air intercept radar system, but the primary workload in

accomplishing this task was the adjustment of switches which controlled and displayed the radar system,s output.

Seeing that this trend of explosive growth in cockpit controls in all new aircraft was relentlessly taking an increasingly steeper upward trend, and that increasing the number of aircrew was not the ultimate answer to the problem, various organizations in the United Kingdom and the United States began investigations into reversing this trend.¹¹ Because of the overriding factor that new mission systems would continue to be introduced, these designers determined that the only method of reducing this trend was through the use of switches which could possess multiple functions. The key innovation which allowed the implementation of such a versatile switch system was digital data transmission, the so called "data bus" concept.¹²

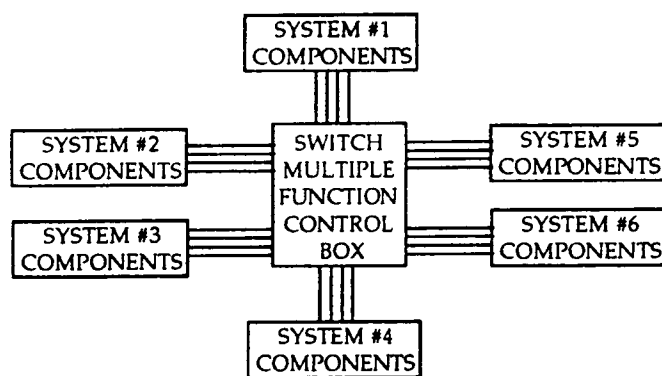
Data Bus Concept

The data bus system simplified the process of allowing a single switch to be utilized for more than one function.¹³ The reasoning behind this simplification is illustrated in figure 4. In a non-data bus system, as shown in part (a) of figure 4, each individual component has to be hard wired to the control box . This not only limits the number of systems a single control box can control due to limited wiring space, but also makes component (system) upgrading nearly impossible. The data bus connection system, as shown in part (b) of figure 4, reduces the wiring and makes component replacement or system expansion simple. The data bus also makes adding additional systems

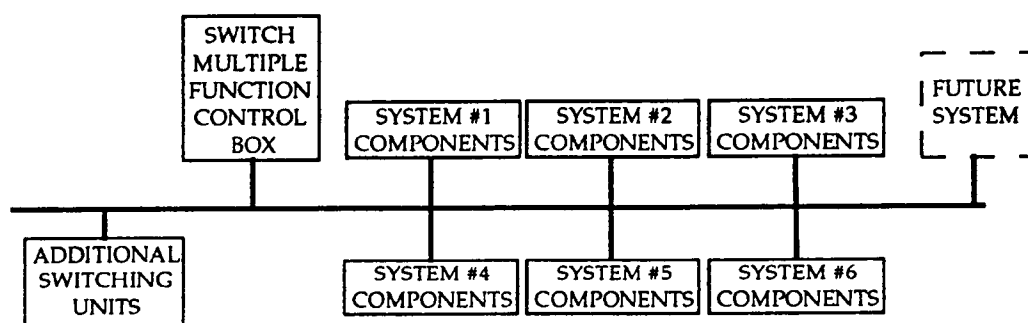
¹¹ Roe (1981)

¹² Roe (1981)

¹³ For an explanation of the data bus concept please see section 1.



A) NON- DATA BUS SYSTEM



B) DATA BUS SYSTEM

Figure 4
Control Box-To-System Connection Methods

to be controlled by the same group of switches an easy matter. Finally, the data bus gives a designer the ability to add a second switch activation mechanism to the overall switch system. This second mechanism allows the pilot to have more options available for selecting system functions.

Switch Multiple Function Technology

A prime example of the ability of aviation designers to use switch multiple function technology is the primary switch control unit of the F/A-18 Hornet, the Up-Front Controller (UFC). The UFC is designed as the main data entry terminal for the following systems: inertial navigation, autopilot, radio navigation, instrument landing, datalink, beacon, airborne direction finder, and communication (2 radios).

The UFC essentially combines the switches of these nine systems into a single control box. It accomplishes this by altering the switch functions depending on which system the pilot has chosen to be addressed. The primary input switches of the UFC are the alpha-numeric keys. The scratch pad display is the switch output display, and each switch actuation is accompanied by a presentation of the selected alpha-numeric on the scratch pad. This combination, of numerous switch control boxes into a single switch box, not only saves a vast amount of space, but also and more importantly allows the aviation designer to locate the switches for all of these systems in the primary vision field of the pilot. No longer must the pilot search the cockpit visually to find the control box and switch he wants to utilize.

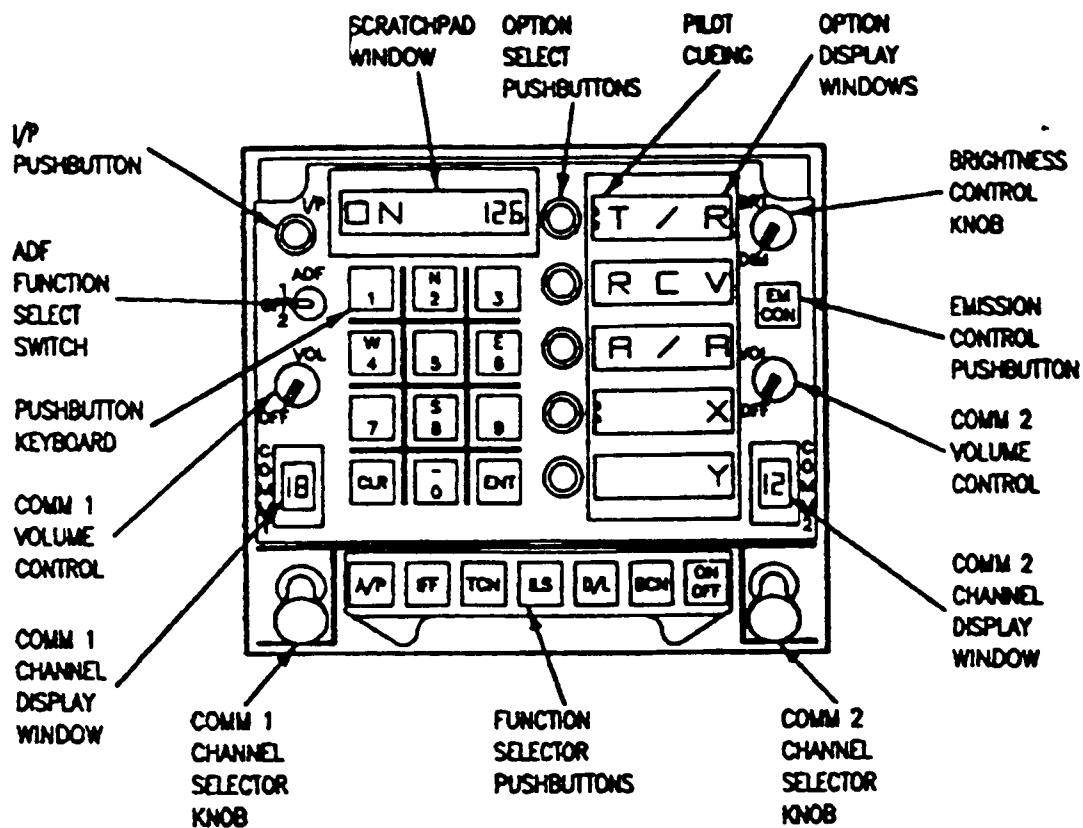


Figure 5

F/A-18 Up-Front Controller

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy
 Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-81.

Hands-On-Throttle(s)-And-Stick Concept

The second enhancement in switch technology allowed by the data bus system is the concept referred to as Hands-On-Throttle(s)-And-Stick (HOTAS). "The HOTAS concept utilizes switches on the stick and throttle to allow the pilot to control the weapons, sensors, and displays during critical portions of the attack while maintaining full control of the aircraft."¹⁴ This HOTAS concept as implemented into the F/A-18 is illustrated in figures 6 and 7, which show the control stick and throttle switches. The two primary HOTAS switches are the Sensor Control Switch (SCS) on the control stick and the Throttle Designator Controller (TDC) on the throttle. The SCS allows the pilot to select one of four primary displays as an active switching unit.¹⁵ Each of the three head-down displays have various display formats, one of which is shown in figure 8, which contain up to 16 switch selections that can be selected with a movable crosshair pointer via the TDC.

To activate a switch the TDC is used to skew a cross-hair around the active display and position it over the switch function desired. Then the TDC is depressed downward and the switch is activated. The pilot also receives feedback of his switch selection, as at least two of his primary displays will show some change in their display formats indicating that the switch activation was accepted.¹⁶ The HOTAS concept of combining multiple displays formats with a single set of remote hands-on switches is only possible with a data bus. This is due to the ability of the data bus controller to

¹⁴ Adams (1981)

¹⁵ The four primary displays are: the Head-Up-Display (HUD), and three Cathode Ray Tube (CRT) units referred to as the right and left multipurpose color displays and the horizontal situation display.

¹⁶ Adams (1981)

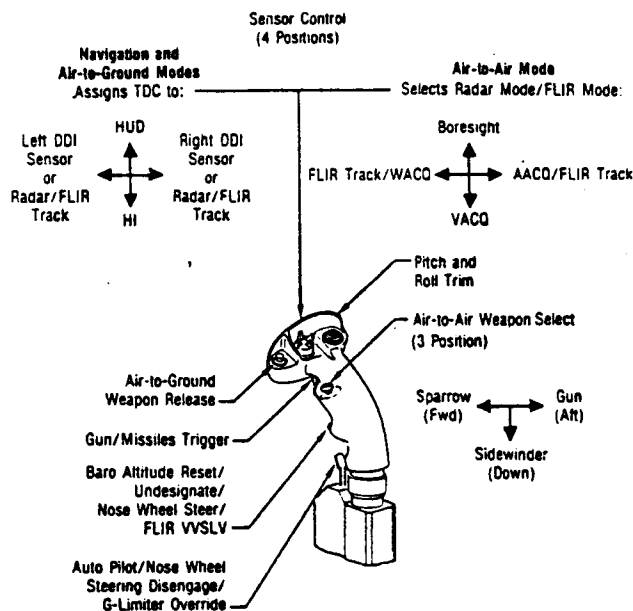


Figure 6

F/A-18 Control Stick HOTAS Switches

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-37.

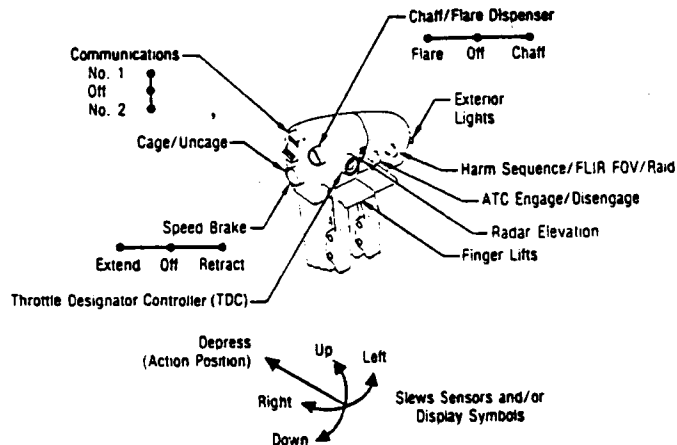


Figure 7

F/A-18 Throttle HOTAS Switches

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-6.

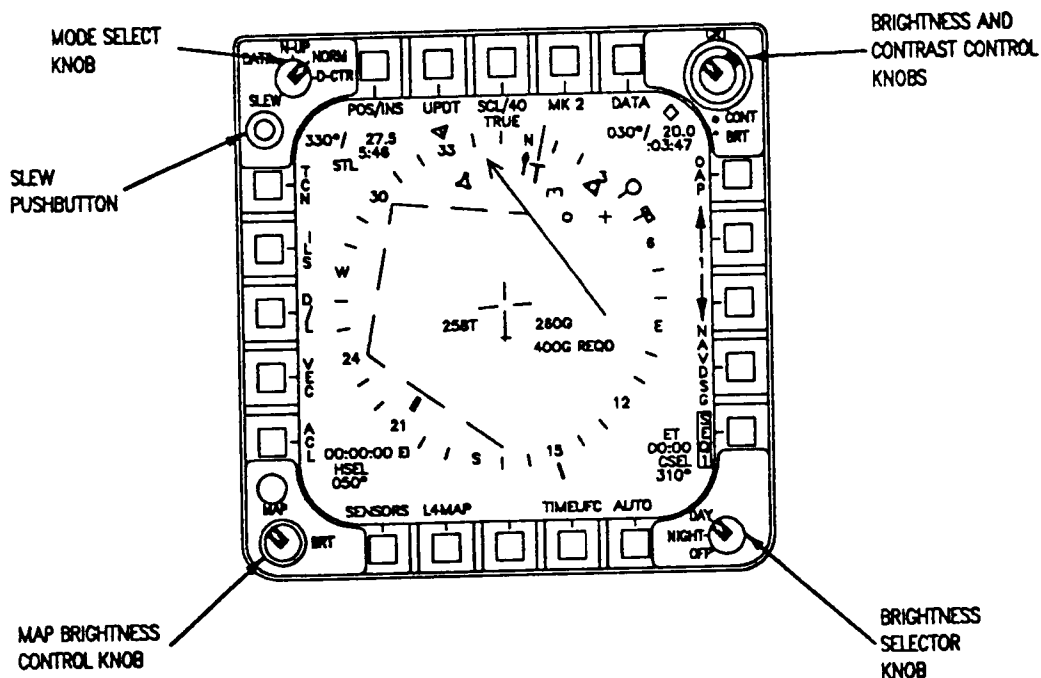


Figure 8

Typical F/A-18 Head-Down Display Format

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-70.

coordinate displays formats to the switches. The important thing to note is that this set-up allows the pilot to alter various system switches without removing his hands from the throttle and control stick, which previous to the HOTAS implementation was an impossibility.

Summary

The aviation industry has succeeded in reducing the number of switches in a typical cockpit. While some of this switch reduction has been accomplished through the automation of system tasking, the vast majority of the switch reduction has been through the use of utilizing a single set of switches for multiple functions. This switch multiple function technology

was attainable largely through the introduction of the data bus concept. Further, this data bus concept has allowed the use of HOTAS controls which allow the pilot to maintain his concentration external to the cockpit while manipulating various systems. Now, the next questions that need to be explored are: How is this technology applicable to automotive design ?, and, What if any of the technology has or should be transferred to the automotive industry?

AUTOMOTIVE SWITCH TECHNOLOGY

Coming Automotive Switch Explosion

Throughout the history of automobiles and aircraft, control switches have been the primary method of controlling the vehicle's non-positioning systems. The primary difference between automobiles and aircraft is the number of systems which require control. In aircraft the number of systems requiring switches has rapidly multiplied in the past 20 years, such that, aircraft have undergone what could be termed a switch explosion. Automobiles while undergoing their own increase in the number of systems needing switches, have not had as large an increase in the number of systems as aircraft have had. This is about to change as the information age fully hits automobiles. Soon systems for navigation, low visibility driving aids, rear-view cameras, collision avoidance, full audio-visual systems, and inter-car communications may be an integral part of all automobiles or at least the more expensive models. Similar to the aviation industry, the automobile industry will soon need to find a way to avoid the control switch problems inherent to increases in the number of systems. As in the aviation industry, the answer will not be found in increasing the number of crewmen, because

for automobiles this is impractical. So, what will the automotive industry do to solve this problem?

Automotive Data Bus Concept

As stated earlier, automobiles at this present time do not have full data bus systems. Changing this situation is the first step towards overcoming the emerging switch explosion. In May 1991, it was estimated that 14 of the 20 major world wide automobile manufacturers were involved in some type of data bus research.¹⁷ The primary problem they have found in integrating a data bus system is that the costs are prohibitive due to the expensive integrated circuits required to control the system.¹⁸ The only way to solve this cost problem is through economies of scale. If all of the automobile makers can agree on a single data bus protocol, or language, then the costs could be substantially reduced. There are standardized protocols, such as the SAE J-1850 data bus system, but the manufacturers still have not agreed on a standard. Until they do, the cost reductions related to economies of scale will not be fully realized.¹⁹ One last thing that should be mentioned about data bus systems is that the automotive industry, like the aviation industry, is starting to investigate fiber optic data buses for their ability to transfer high rates of data. This type of data bus may be the only type of data capable of handling the amount of data required to control functions such as active suspensions, anti-lock brakes, and advanced engine controls.

¹⁷ Kobe (1991)

¹⁸ Kobe (1991)

¹⁹ Grime (1990)

Automotive Switch Multiple Function Technology

In the past, auto makers have seen no reason to combine multiple functions into one set of switches. Instead, they have simply put another switch control box into the driver's domain. Figure 9 shows a 1978 suggested arrangement for system switch control boxes. As the casual observer can tell, while being adequate for now, this type of system will soon be inadequate if more than two new systems were added. One solution that might seem to work would be to make the switches smaller, but there are human factors considerations which dictate the lower limit of switch sizes. For the automobile population, this lower limit is also normally based on elderly driver dexterity.²⁰ So if switches cannot be reduced in size, a natural alternative would be switch multiple function technology.

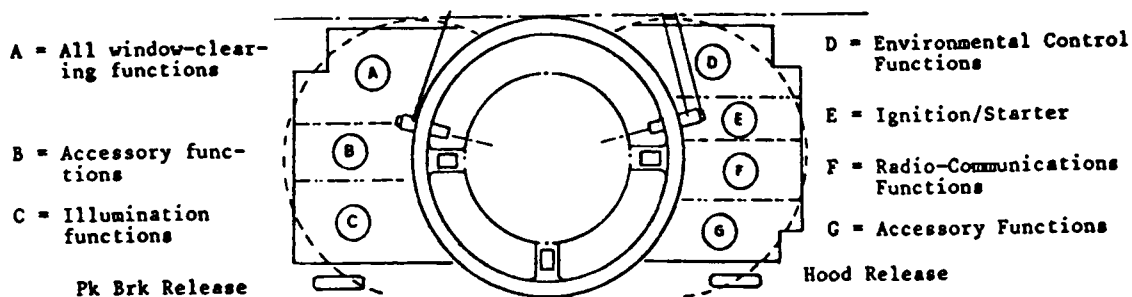


Figure 9

1978 Suggested Arrangement For System Control Boxes

Source: Black, T. L., W.E. Woodson, and P.H. Shelby. Development Of Recommendations To Improve Controls Operability. Man Factors Inc. Report For U.S. Department Of Transportation, Contract No. HS-6-01445, 1977, p.57.

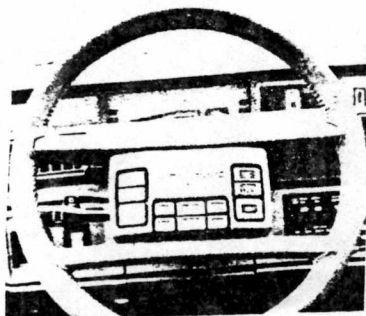
²⁰ Gromley (1986)

Some automobile designers are looking to transfer aviation switch technology, and have begun to promote switch multiple function technology. In the automotive field this technology is termed "soft-key" technology.²¹ Like the F/A-18 UFC, automobile designers must ensure that this technology is implemented in such a way that it does not draw the driver's attention away from the external view, or unnecessarily block the driver's field-of-view. This will more than likely require the input switches to be separated from the display.

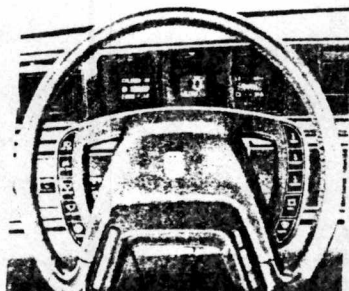
Hands-On-Throttle(s)-And-Stick Concept for Automobiles

As was mentioned earlier, the introduction of the data bus also allowed aircraft designers to implement the HOTAS concept. This has given the pilot the ability to control multiple systems with a group of tactile controls located on the throttle and control stick. In automobiles the equivalent of the throttle and control stick is the steering wheel. The steering wheel is where the driver must position his hands when maneuvering the vehicle needs his primary attention. In the past automobile designers have utilized switches located near or on the steering in three primary configurations. Switches have been mounted: (1) on the steering wheel, (2) on multiple stalks around the steering wheel and (3) on the extensions of the instrument panel which can be reached while maintaining hands on the steering wheel. These three types of switch configurations are presented in figure 10.

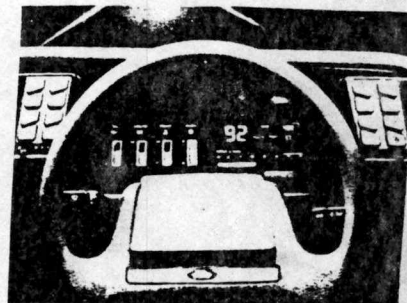
²¹ Wierwille and Peacock (1990)



On Steering Wheel



Multiple Stalks



Extension of Panel

Figure 10

Conventional Steering Wheel Switch Configurations

Source: Gromley, Joseph. "Trends In Vehicle Personalizing." Proceedings - Society of Automotive Engineers, P-183 (1986), p. 251.

The primary difference between these switch configurations and the HOTAS concept is that the automobile switches have only a single function. Human factors wise, this is probably a smart thing for two reasons. First, to utilize the multiple switch functions of HOTAS switches requires a certain amount of training to ensure the logic of the switches is understood. It would be unlikely that this type of training would be undertaken by the general automobile driving public. Second, the use of HOTAS switches, when not being used with a HUD, requires the pilot to look away from the real world and concentrate on a head-down display.²² An automobile driver does not have this option, as studies show that the maximum amount of time a driver

²² HOTAS switches also control functions which are presented on the HUD, allowing the pilot to maintain his view on the real world, but a majority of HOTAS switch functions are tied to a head-down display.

should study a display is two seconds.²³ Therefore, because of these reasons, HOTAS type controls will probably never be applicable to automobiles.

Summary

Automobiles will soon undergo a switch explosion similar to the one aircraft underwent. This explosion will be caused by the addition of various types of new systems to automobiles. Presently, the automobile industry is moving toward utilizing the data bus concept to aid in adapting to these new systems. The biggest gain from the data bus will be the introduction of switch multiple function technology. A set-up similar to the F/A-18 UFC, which combines switches for various systems into a single set of switches, will have to be developed. The use of HOTAS type switches in automobiles is more unlikely due to the training required to use the switches efficiently, and because the driver cannot afford to spend anything but a short period of time concentrating on a head-down display.

SUGGESTIONS FOR FUTURE SWITCH TECHNOLOGY USAGE

Switch multiple function technology will soon be transferred from aircraft to automobiles due to the introduction of the data bus concept into automobiles. Care must be taken to ensure that this technology is implemented correctly so that it neither takes away from the driver's external world concentration nor blocks his primary field of view. A suggested set-up for implementing switch multiple function technology is shown in figure 11.

²³ Kobe (1991)

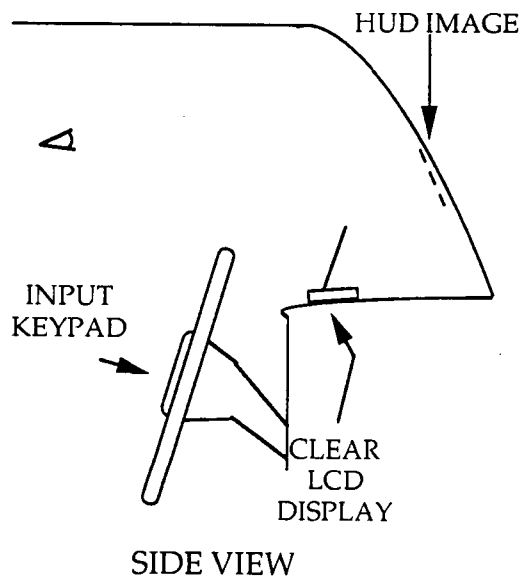
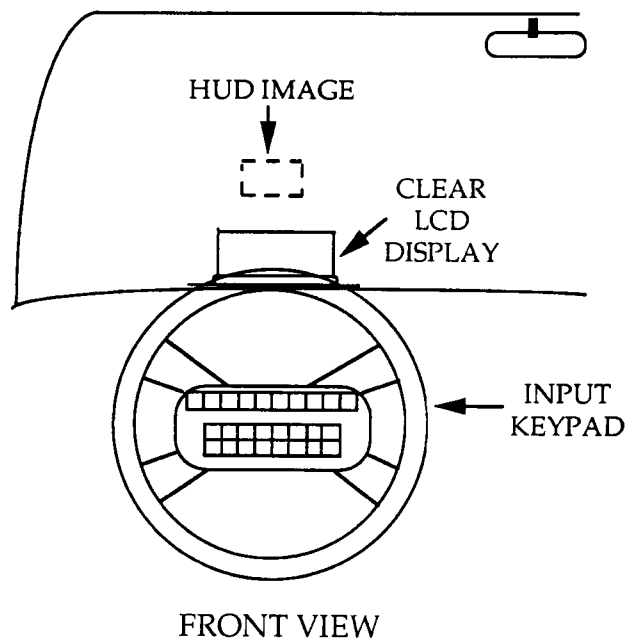


Figure 11

Suggested Switch Multiple Function Technology Implementation

This configuration will allow the driver to maintain his view on the road while altering system inputs. As shown the switch display output would be either via a HUD or high positioned clear Liquid Crystal Display (LCD). The HUD of course would allow the driver the advantages of a virtual display, but the LCD option would be a good low cost alternative. Either way the configuration is implemented so as to allow for additional systems to be integrated into automobiles without increasing the overall number of switches. While this is only one suggestion, the automobile industry will have to find some solution similar to this to control the upcoming switch explosion.

III. AUDITORY DISPLAYS

INTRODUCTION

Auditory displays in any vehicle can be defined as those displays which through the audio or sound wave medium transfer information from the vehicle to the operator or occupants. Auditory displays can range from bells and tones to synthesized voice. Auditory displays have been present in aircraft for many years, but the implementation and nature of these displays has changed greatly in the last 20 years. The history of auditory displays will be reviewed and the current state of aviation auditory display technology will be presented. This review of current technology will also include a discussion of voice interactive displays. Next, the discussion will turn to automotive usage of auditory display technology, and will examine what technology transfer has taken place and what alterations to the technology were required. Finally, suggestions for furthering the transfer of auditory display technology will be presented and discussed.

AUDITORY DISPLAYS IN AIRCRAFT

Reasons For Auditory Displays

The primary reason for the introduction of auditory displays in aircraft was as an attempt to reduce the pilot's overloaded visual information channel. Due to the rapid increase in aircraft systems, many aircraft designers soon found that the one limiting factor in introducing additional new

systems was the amount of visual displays an operator could monitor. As new systems in aircraft proliferated the visual senses of the pilot or crew were becoming severely overloaded. This not only reduced the ability of the aircrew to operate the new systems in an efficient manner, but also at times caused them to miss critical visual warning or caution displays. Auditory displays were initially chosen as an alternative method of transmitting warning or caution information to the aircrew as it was found that: "Auditory signals (displays) alert the user quickly, irrespective of the head position or eye-fixation, and appear to do so faster than visual displays."²⁴ An additional benefit of auditory displays for aircraft implementation is that audio perception is less affected by high g-forces or anoxia than is the perception of visual displays²⁵. Finally, audio displays also do not require the use of already severely limited cockpit instrument panel area.

Aircraft Tonal Auditory Warning Displays

The first implementation of audio displays in aircraft was the use of tones or bells as warning devices. These sounds were tied to conditions which the designers felt needed the immediate attention of the pilot or aircrew. Typical uses for the first auditory display sounds were: landing gear not down, low altitude warning, and excessive angle of attack. It should be noted that these audio warnings were not the only information source of these conditions. Normally, the audio warnings were tied to a visual display and were only triggered when conditions became such that the situation required the immediate action of the pilot or aircrew. The audio warning and

²⁴ Stokes et al. (1989)

²⁵ Stokes et al. (1989)

caution system of the A-6E "Intruder", a 1960's designed attack aircraft, is typical of a mature audio display system which only utilized sounds. The A-6E contains five separate warning tones generators which are described in table 1.

Table 1
A-6E Audio Warning Tones

TONAL WARNING CAUSE	TONE TYPE
Low Altitude	Warble Tone
Weapon Release	Single Beep
Anti-Radiation Missile	Tone With Frequency Of Target
Missile Warning Receiver	Variable Frequency Multiple Tones And High Or Low Frequency Warble
Missile Defense Transponder	Tone With Frequency Of Threat

Source: Adapted from: NATOPS Flight Manual-Navy Model A-6E TRAM/KA-6D Aircraft. U.S. Navy Publication Number: 01-85ADF-1, (15 September 1991), p. VII-25-5.

It should be emphasized that some of these tones can and do vary in frequency. This fact, which means there are many more than five different tones, has in some instances led to what could be called auditory overload. As pointed out in a study dealing with the AV-8B "Harrier" attack jet, "the major complaint among pilots was that the tones were too numerous and in many cases indistinguishable from other tones."²⁶ This indistinguishability resulted in the pilots not correcting the problem which caused the auditory warning immediately, but instead forced them to look inside the cockpit to verify what had triggered the audio warning. This of course defeated some of

²⁶ O'Donoghue (1991)

the warning utility, but more importantly unduly delayed initiation of pilot corrective action.

Aircraft Synthesized Speech Auditory Displays

The problem of audio sensory overload was backed up by a study in 1979 which found that, "subjects (in this case pilots) could certainly learn to identify at least ten auditory signals, but tended to forget the meaning of them over time."²⁷ Obviously aircraft designers had to find a better means of transmitting information in the audio medium. This search led to the introduction of auditory displays which utilized synthesized speech. The aviation human factors engineers found that auditory warning voice messages were superior to non-speech tones. Specifically, they reported that:

"A visual display combined with a voice warning provided shorter response times than did the same display combined with a non-speech (tonal) warning, and that voice warnings had the potential to be more flexible and informative than simple tone warnings since they not only alert the user to the existence of the problem, but simultaneously provide more cues to its nature, and assist the user in taking immediate action."²⁸

The F/A-18 Hornet is an excellent example of how designers implemented synthesized voice audio displays into the aircraft. For critical warnings and cautions, as listed in table 2, synthesized alerts are transmitted to the pilot's headset.

²⁷ Stokes et al. (1989)

²⁸ Stokes et al. (1989)

Table 2

F/A-18 Voice Warnings And Cautions

VOICE WARNING OR CAUTION CAUSE	VOICE ALERT
Identification System Activation	"Mode Four Reply"
Flight Control Malfunction (Multiple causes)	"Flight Controls"
Flight Control Computer Overtemp	"Flight Computer Hot"
Engine Malfunctions (Multiple Causes)	"Engine Left (Right)"
Low Fuel Condition	"Fuel Low"
Return To Base Fuel Level (Pilot Sets Value)	"Bingo"
Low Altitude	"Altitude"
Bleed Air System Leak	"Bleed Air Left (Right)"
Engine Fire	"Engine Fire Left (Right)"
Auxiliary Power Unit Fire	"APU Fire"

Source: Adapted from: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-100.

When a condition activates the F/A-18's speech caution and warning system, the system simultaneously presents the caution or warning visually on the aircraft's primary head-down display. Each voice warning or caution is repeated twice for each causing action. All voice alerts are triggered only for immediate action required conditions, and are kept to a maximum length of three words. Some of the voice alerts have more than one activating condition, and these therefore are designed only to alert the pilot as to which system is malfunctioning, and not to direct the pilot to perform an automatic response. Pilot feedback has shown that these voice warnings are preferable

to tones, though they can be irritating at times because of their "nagging" nature.²⁹

Aircraft Voice-Interactive Auditory Displays

The last form of auditory display technology presently being implemented in aircraft is voice-interactive displays. The simple explanation of a voice-interactive display is as follows: (1) you tell the machine to do a function, (2) the machine recognizes that you are telling it to do a function, (3) the machine performs the function. Of course in reality the voice-interactive process is much more complex than this, but this paper is not designed to nor will it attempt to explain the inner workings of this technology.³⁰ Some important parameters and limitations of the technology do require mention before the current implementation of the technology is reviewed.

Voice-interactive displays rely on Automatic Speech Recognition (ASR) technology which has five critical dimensions that affect the user interface and system design: connectedness of speech, speech dependence, vocabulary, grammar, and the environment.³¹ The first dimension, connectedness of speech, is where the designer must choose if he wants to allow the user to say words in a connected or "normal" speaking fashion, or will require him to pause between each word (unconnected speech). The trade-off is that connected speech is easier for the user, but an unconnected speech ASR system is easier technologically to design. The second

²⁹ Author subjectively surveyed local F/A-18 pilots as to their thoughts about the voice warning system.

³⁰ The author suggests the reader consult the University of Tennessee Thesis (1991) by O'Donoqhue if further information on this subject is required.

³¹ O'Donoqhue (1991)

dimension, speaker dependence, is where the designer must choose between a speaker dependent or a speaker independent system. A speaker dependent system is where the system only responds to a single (but interchangeable) user voice. This type of system also requires that a template be produced for the intended user. A speaker independent system on the other hand can be used by anyone and does not require templates, but again as expected, a speaker independent system is much harder to implement. The third and fourth dimensions, vocabulary and grammar, are interconnected. A voice-interactive system does not have an unlimited vocabulary, and because of this only certain words in a set order (grammar) will be recognized by the system. The more words and the looser the grammar laws (variances in word order) a designer requires of the system, the more difficult the system will be to produce, the slower the system will react, and the more prone the system will be to misinterpreting user commands. The final dimension, environment, is somewhat self-explanatory. The designer must be cognizant of the type, volume, and frequency of the background noise and its effects on the system as well as environmental effects which may have some effect on the users speech pattern (vibration, high-g, oxygen mask, etc.).

While voice-interactive displays are on the verge of being utilized by military aircraft, at this time no production systems have been installed. There have been numerous Research and Development (R&D) installations which have been tested. One of the most recent of these R&D programs was on the TAV-8B Harrier, a trainer version of the U.S. Marine Corp attack jet, and was performed at the Naval Air Test Center. The voice-interactive system installed in the Harrier utilized speaker dependent and connected speech technology. It had a 800 word vocabulary and was designed to respond

with some (limited) synthesized voice outputs to user status queries. Additionally, the system had a voice calibration function which could sample the ambient noise level of the cockpit and set the optimum signal-to-noise ratio. The results of this R&D program were encouraging with the primary results being:

- 1) Vocabulary was cumbersome and difficult to use especially in remembering the proper sequence of words required for a command.
- 2) Areas which voice-interactive system showed good potential for decreasing operator workload included: data insertion, visual display manipulation, and status report functions.
- 3) System showed a 95.7% recognition accuracy when properly used (system turned on and correct command word sequence).

The final conclusion of the test team was that the system would be useful and that it should be further developed and introduced in operational aircraft.³²

Summary

It has been shown that the aviation industry first introduced auditory displays as a method of lessening a pilot's visual workload. The progression of auditory displays from the tonal type to full voice-interactive systems has been outlined. The automotive industry has also realized the benefits associated with auditory displays. The discussion will now turn to the examination of this usage of auditory displays in automobiles, what technology they have adapted from the aviation industry, and what the future holds or should hold for automotive use of auditory displays.

³² O'Donoghue (1991)

AUDITORY DISPLAYS IN AUTOMOBILES

Reasons for Auditory Displays

The reasons for the implementation of auditory displays in automobiles was, at first, to alert the driver of conditions which he might not visually perceive. As stated before, aviation auditory displays were used to reduce the visual overload experienced by pilots. In automobiles, the visual overload was not from the instrument panel, but from the real world. An automobile driver must concentrate more of his visual attention to the real world than a pilot. Therefore, auditory displays were implemented to draw the driver into the interior of the automobile to check what was causing the auditory display. This is a subtle difference between aviation and automotive auditory displays. While aviation auditory displays may actually draw the pilot to the instruments, they are really designed to elicit an immediate corrective action.

All of the advantages of auditory displays over visual displays in aircraft also apply to automobiles except the one dealing with better perception under high g-forces or anoxia, which do not normally occur in the automotive environment.

Automobile Tonal Auditory Warning Displays

The first implementation of auditory displays in automobiles, like aircraft, was the use of tones, bells, and chimes as warning devices. The reasons for activation of the warning signals included: seatbelt not utilized, keys still in ignition, lights on/engine off, parking brake set/engine on, and

door or hatch ajar.³³ Except for the last, door or hatch ajar, none of the auditory tonal displays require immediate corrective action to avoid possible injury to the operator, as do most of the tonal warnings in aircraft. While this is a significant difference it is more than likely due to aircraft having more immediate corrective action required critical areas where auditory warnings are effective.

One variable which must be considered when dealing with tonal auditory displays is the number of tonal warnings which can be correctly interpreted by the operator. Studies have shown that since automobile drivers are not trained in the same manner as pilots, their ability to distinguish the meanings of different tones may be limited to three.³⁴ While tonal warnings in automobiles are implemented similar to aircraft, there is no reason to believe that the technology was transferred from aircraft. More likely, the two industries discovered the usefulness of tonal auditory displays independently.

Automobile Synthesized Speech Auditory Displays

The first use of synthesized speech displays in automobiles was the Audi Quattro in 1982, approximately 3 years after the introduction of the technology in aircraft.³⁵ This suggests that the technology hardware was probably a spin-off from the aviation industry. A 1984 report listed the following reason as one of the major benefits of synthesized speech displays: "The speech response systems allows for plain instructive messages to be

³³ Wierwille and Peacock (1990)

³⁴ Wierwille and Peacock (1990)

³⁵ Stokes et al. (1989)

furnished in case of failures."³⁶ The benefit is very similar to the benefit that aviation human factors engineers found: providing more cues to the warnings nature. Obviously, plain instructive messages provide more cues to the warnings nature.

Synthesized speech displays were quickly installed by other automobile manufacturers besides Audi, but as quickly as they appeared during the mid-80s they disappeared in subsequent years. The obvious question is why. Why do aircraft still use synthesized speech, but most automobile manufacturers eliminated it? The answer to this question has two parts, human nature and human factors. The human nature part of the answer can be best explained by the following taken from a report on automotive human factors: "The first synthesized voice messages either implied taking orders or scolding and seemed to be just more gadgetry to many drivers."³⁷ Again, this may be due to the importance contained in the messages. Where a pilot may not like the voice messages either, he realizes and senses the importance of them to the safe execution of his flight.

The second reason why synthesized voice may have failed to catch on in automobiles involves human factors. As stated earlier, the population of automobile drivers is distinctly different from the population of pilots. Automobile drivers include many whose primary language is not English and some who have hearing difficulties. These groups may have found synthesized voice less beneficial than tonal or visual warnings. Additionally, voice warnings have been found to increase operator tension when the severity of the warning is questionable. This tension may have tended to

³⁶ *Automotive Electronics Part 2: Future Driver Information Systems* (1984)

³⁷ Wierwille and Peacock (1990)

make synthesized voice warnings disliked by the driving public. Pilots, on the other hand, are usually trained on their systems and may be more aware of what the voice warnings imply, and therefore less tense by their appearance.³⁸ Finally, the sound environments of the two types of vehicles are different. Aircraft usually have only a few human voice inputs (air traffic controller or other crewmembers). Automobiles have many more and varied sources of human voices including: multiple passengers, broadcast radio, and external world voices. This increase in human voice inputs more than likely caused synthesized voice inputs to be missed, further declining their effectiveness and acceptance by the automobile driving public. In the end, synthesized voice was just not seen as providing enough benefits over tonal warnings to make them accepted by the driving public. If synthesized voice displays are to return to automobiles the benefits from them must increase.

Automobile Voice-Interactive Auditory Displays

Like the aviation industry, the automobile industry has shown interest in voice-interactive displays, but at this time no evidence could be found of any R&D or operational system which has been tested. So far, all automotive use of this technology has been on paper. The benefits which are drawing automobile manufacturers to voice-interactive technology include the following function groupings: data insertion, status report functions, subsystem activation, and security. The first two benefits grouping were found to be benefits in aircraft. While all of the theorized automotive benefits have

³⁸ Stokes et al. (1989)

merit, the problem with voice-interactive displays in automobiles is technology maturity.

At this time, voice-interactive systems have only been proven to work efficiently using speaker-dependent technology.³⁹ For voice-interactive displays to be usable by the automobile industry the systems must be based on speaker-independent technology.⁴⁰ The reasoning behind this statement is that unlike military aircraft, automobiles are mass-marketed, and for a system to be bought it must be demonstrated to the user before the purchase is made. With speaker-dependent systems this would require everyone taking a test drive to make a voice template to see the system function. This is probably economically unfeasible. Another reason why speaker-independent systems must be used in automobiles is that the purchased vehicle is not always used by the same user or a small group of users. Who would want to buy a vehicle where not everyone who drove it could utilize all of its functions? Also, when the automobile was sold to another individual, how would a new template be produced?

Finally, the last reason why any voice-interactive display system, speaker dependent or independent, may never be applicable to automobiles is the limited vocabulary of voice-interactive systems. As was seen in the AV-8B test, if an operator does not follow a set vocabulary and grammar the system is useless to the operator. To ensure the correct vocabulary and grammar is used takes training. Few if any consumers would feel this training would be worth the benefits of a voice-interactive system.⁴¹

³⁹ O'Donoghue (1991)

⁴⁰ Helms (1986)

⁴¹ Stokes et al. (1989)

Summary

Auditory displays have been used extensively in automobiles. In particular, tonal and voice synthesized auditory displays have been utilized in a similar manner as they have in aircraft. It was also found that unlike aircraft synthesized voice auditory displays in automobiles have not provided enough distinct benefits to warrant their continued use. Finally, it was found that while voice-interactive displays have been theorized for use in automobiles, they probably will not see actual use until speaker independent technology and vocabulary expansion technical difficulties are overcome.

SUGGESTIONS OF FUTURE USE OF AUDITORY DISPLAYS

For aviation applications auditory displays and in particular voice-interactive systems should be continued to be implemented. This is because the benefits related to reducing pilot workload are real, and will allow the pilot to perform his mission in a more efficient manner. Additionally, the limited population demographics of pilots will allow the systems to be tailored for human factors, and thus, be usable in the near future.

The implementation of new auditory display systems in automobiles is a more difficult situation. Until some greater benefit can be gained from synthesized voice and voice-interactive systems, they should not be further implemented. Additional benefits may be forthcoming with the advent of automobile navigation systems. Synthesized voice would be a valid and beneficial application of driver instructions from a route guidance system. This type of application would allow the driver to maintain his real world visual concentration while obtaining useful information from the auditory

display. Finally, two additional suggestions can be made to the application of synthesized voice in automobiles. The first is to implement a repeat function which the driver could activate if the command was missed. Secondly, the radio should be automatically lowered in volume when a warning or guidance command is issued. This would eliminate the problem of missed signals due to the automotive sound environment.

IV. HEAD-UP DISPLAY

INTRODUCTION

The term Head-Up Display (HUD) is almost always associated with aircraft, and in particular high performance military jets. While it is true that in the past 99% of HUD research, development, and production has been geared towards military aircraft, today engineers in other fields are starting to investigate the usage of HUD's for their particular applications. The automotive industry has already started to produce limited numbers of HUD's for its vehicles. In this section the history and reasoning behind the usage of HUD's in military aircraft will be examined. This will be followed by an in-depth look at how the automotive industry has attempted to transfer this technology to its vehicles. Additionally, suggestions for future use of HUD's in automobiles will be investigated. First though, a quick explanation of generic HUD technology and terminology is presented.

HEAD-UP DISPLAY TECHNOLOGY

The display device referred to as a Head-Up Display (HUD) can be defined as: a display that presents data in the form of a virtual image superimposed on or in the operator's view of the real world.⁴² Normally this virtual image is produced by using a light source to produce the "display symbology" of the image. This "display symbology" can be thought of as a point source of light which must be collimated and superimposed over the

⁴² Newman (1981)

operator's real world view. Collimated lighted sources are sources which appear to be imitating from an infinite distance. The rays of a collimated light source appear to be parallel to the viewer, while the rays of an uncollimated source do not, as shown in figure 12.

The source (display symbology) light rays can be collimated by three different optical methods: reflection, diffraction, and refraction. These three methods are all basic physical ways of altering the direction of a light wave front. As mentioned before, the display symbology must be superimposed upon the real world view after it is collimated. This process is done by the combiner which is a partial reflector which allows both the display symbology and the real world views to be viewed superimposed. A simple schematic of a HUD system is shown in figure 13.

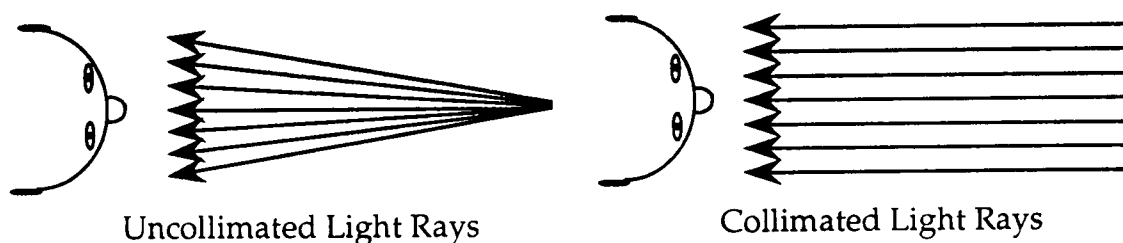


Figure 12
Collimated And Uncollimated Light Sources

The collimated rays of the display symbology light source of a HUD can be thought of as a "bundle" of rays. If the viewer moves one of his eyes outside of this "bundle" then the display symbology will no longer appear to be collimated, and thus will appear emanate from a distance of less than infinity. The limits of where the viewer can view the display symbology as a collimated or virtual image is referred to as the "head box". A single dimension of this "head box" is shown in figure 13. While the above described HUD system is extremely simple it does serve to explain the basic mechanics of a HUD system. Now an historic view of the HUD in aviation technology is in order.

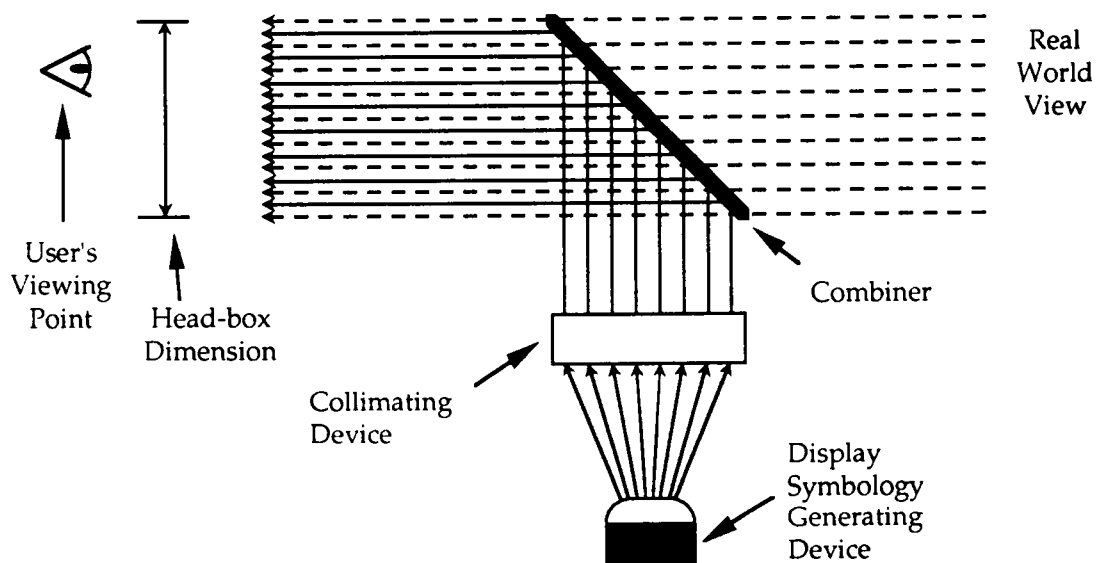


Figure 13
Simple (Generic) Head-Up Display System

HEAD-UP DISPLAY USAGE IN AIRCRAFT

Head-Up Display Development

HUD's were first introduced into aircraft in the late 1950's. The Sperry Corporation started working on the first HUD system in 1956. The funding for this first HUD was from the U. S. Navy and the U. S. Air Force in a joint program.⁴³ Previous to the HUD's development, most military bomber and fighter aircraft had optical gunsights, which provided only a weapon aimpoint as a virtual display. These gunsights were limited to only presenting a single piece of information to the pilot. The intention of the development of the HUD was to present additional useful information to the pilot in his primary external visual line of sight. Specifically, in the beginning this useful information consisted of aircraft attitude (pitch, roll) indications.

As the development of HUD's continued in the 1960's more information began to appear in HUD formats. This information included aircraft airspeed, altitude, and heading. Then in the mid to late 1960's the HUD was developed to the point where it could be included in weapon delivery systems of military fighters. The first two significant U. S. aircraft to use a HUD for his purpose were the A-7D/E, Corsair II, and the AV-8A, Harrier.⁴⁴ At this point in HUD development, HUD's installed in aircraft were still not considered to be primary flight instruments. Instead, they were considered supplementary or secondary instruments. In essence, instruments which could assist the pilot, but were not to be used or relied upon for critical flight information.

⁴³ Hudson (1964)

⁴⁴ Newman (1981)

The HUD's in modern day military aircraft, such as the F/A-18, differ from their early counterparts in that they now contain all the information required to be utilized as the primary flight instrument. An excerpt from a F/A-18 display description states:

The HUD is the primary flight instrument for weapon delivery and navigation including manual and automatic carrier landing modes. All essential flight data such as speed, altitude, heading, attitude, alpha numeric cues, and steering commands are projected on the HUD combiner and focused at infinity for easy assimilation by the pilot.⁴⁵

Aircraft Head-Up Display Formats

To accomplish the feat of putting primary flight instrumentation and mission system information on the HUD, aircraft designers have developed various HUD display formats. The information contained on each display format is tailored to the portion of the mission that the aircraft is executing. In the F/A-18 there are different display formats for navigation, carrier landing, air-to-air combat, and air-to-ground weapon delivery. The F/A-18 HUD format for navigation is shown in figure 14.

The designers of these formats realized that the formats could at times present too much information to the pilot, and thus overload his visual information channel. To alleviate this, the designers also incorporated "symbology rejection" options with which the pilot can selectively choose to eliminate some of the information. The two symbology rejection formats available for the F/A-18 navigation HUD format are shown in figure 15.

⁴⁵ Harned et al. (1991)

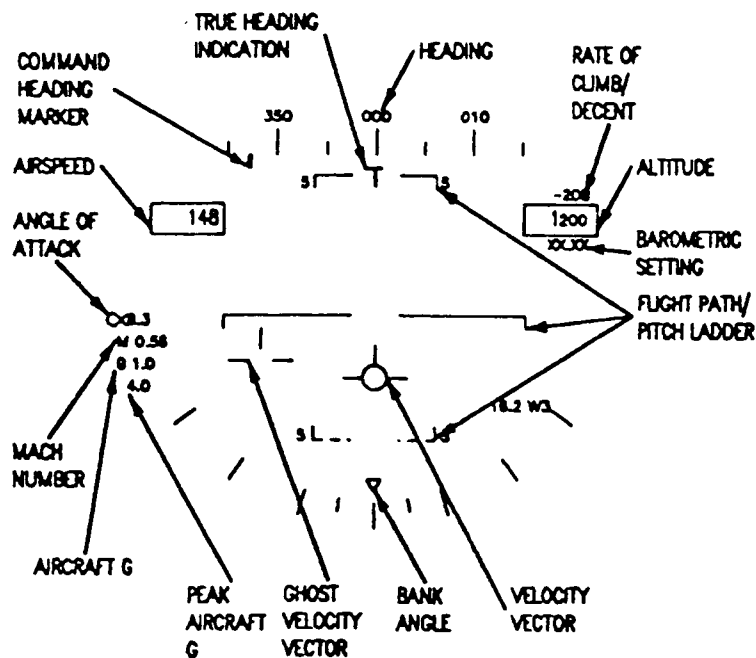


Figure 14

F/A-18 Navigation HUD Display Format

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy
Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-74.

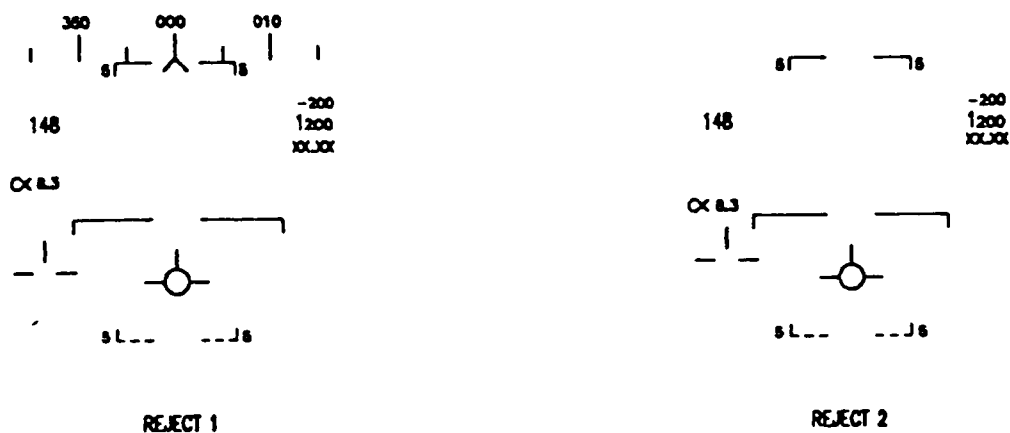


Figure 15

F/A-18 Navigation Symbology Rejection HUD Display Formats

Source: NATOPS Flight Manual - Navy Model F/A-18 A/B/C/D, U. S. Navy
Publication Number: A1-F18AC-NFM-000, (15 January 1991), p. 1-75.

Future Head-Up Display Developments

Aviation HUD development is not standing still. Due to increased aircraft mission tasking, the designers of HUD's are exploring increased capabilities of HUD's. Future developments are geared towards:

- (1) Adding color to HUD displays to make the information contained on the easier HUD easier to decipher.⁴⁶
- (2) Displaying forward looking infrared imagery simultaneously with the present symbology.⁴⁷
- (3) Increasing the HUD field of view.⁴⁸

This last development has also led to attempts to produce a HUD which is helmet mounted and allows HUD symbology to be available to the pilot regardless of the direction his head is pointing.

Summary

While HUD's have had many problems in their implementation into aircraft, they are still well received by most pilots because:

"Pilots find the HUD a very compelling display, presumably because of its information content, prominent location in the pilot's visual field, novel display mode, and overall integrated relationship of the HUD to flying the aircraft and accomplishing the mission".⁴⁹

The question now that must be answered is can a HUD be useful in an automobile, and can it assist the driver in accomplishing his mission.

⁴⁶ Newman (1981)

⁴⁷ Berry (1981)

⁴⁸ Berry (1981)

⁴⁹ Tober (1987)

HEAD-UP DISPLAY USAGE IN AUTOMOBILES

Introduction

Head-Up Displays have recently begun to appear in production automobiles. Both General Motors (GM) Corporation and Nissan Corporation now offer HUD's in some of their expensive models. It is obvious by the design of these HUD's, and their appearance in the market place after aircraft HUD's, that the technology used in them has been taken directly from the aviation industry.⁵⁰ In fact many of the engineers that worked on the GM design were from the former Hughes Aircraft Company which was purchased by GM in 1985.⁵¹ While GM's and Nissan's designs are direct descendants of the typical military aircraft HUD they do vary in some specific and important ways. To illustrate these differences the GM design will be examined in detail.

General Motor's Head-Up Display

The GM HUD design first appeared in 1988 in the Oldsmobile Cutlass Supreme Indianapolis 500 Pace Car Edition. According to GM's own account the actual production unit was, "designed, fabricated, and installed by a team from Oldsmobile, CPC Advanced Engineering, Delco Electronics, and Hughes in less than four months."⁵² The primary reasons behind GM's decision to

⁵⁰ An interesting side-light in automobile HUD development is that a working prototype of a HUD for automobiles was designed and built for the U.S. Department of Transportation by the Kollsman Instrument Company in 1968. This early HUD was very rudimentary in component usage but the basic design concept is extremely close to the GM and Nissan designs. For further reading on this early development see, *Route Guidance Head-Up Display* (1968).

⁵¹ King and Lefort (1990)

⁵² King and Lefort (1990)

introduce the HUD, besides the HUD's ability to showcase GM's advanced technology, were based on human factors engineering. Hughes engineers had convinced GM management that much like a pilot one of the primary tasks of a driver is to keep continuous visual contact with the environment external to his vehicle. They also put forth the notion that the HUD would accomplish the following three things. The HUD would allow the driver to "keep his eyes trained on the road while accessing and responding to information."⁵³ The drivers eyes could remain adapted to the ambient light level in his primary visual field.⁵⁴ If a HUD was installed, the requirement for visual reaccommodation (the refocusing of the eyes to different viewing ranges) would be reduced over that of a conventional instrument panel display.⁵⁵

When GM management was convinced of the possible utility of a HUD, they looked at the economics of the situation, and decided that to be economically viable the HUD had to be manufactured at a cost reduction factor of approximately 1000 compared to military systems.⁵⁶ To accomplish such a great savings the engineering team decided on the following five cost saving compromises:⁵⁷

- (1) The optical system should only use mirrors, not lenses.
- (2) The vertical disparity (a measure of optical quality) could be relaxed from military standards.

⁵³ Goesch (1990)

⁵⁴ Weihrauch et al. (1989)

⁵⁵ Weihrauch et al. (1989)

⁵⁶ King and Lefort (1990)

⁵⁷ King and Lefort (1990)

- (3) Some parallax between the projected image and the outside scene was acceptable.
- (4) Adequate image brightness could be achieved without the use of a combiner.
- (5) The HUD package could be designed to fit unobtrusively on the dash without extensive rework of the vehicle.

With these limitations in mind the final design was completed. A schematic of the overall design layout and optical light ray paths is shown in figure 16.

The GM HUD utilizes a flat segmented Vacuum Fluorescent Display tube (VFD) as an image producer. While the VFD is inexpensive, and produces adequate luminance, its one draw back is that the graphics available are limited to what graphics are printed onto backside the tube face. The GM HUD graphics set is shown in figure 17.

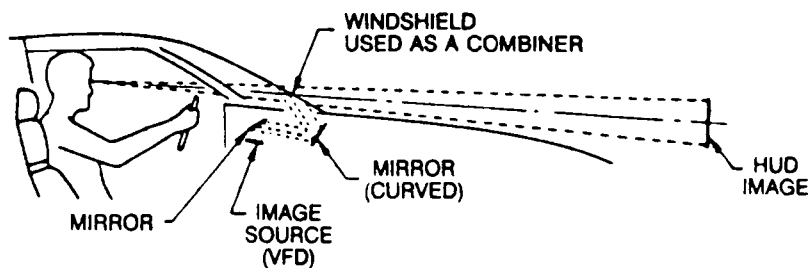


Figure 16

General Motors Head-Up Display Design Schematic

Source: Goesch, Thomas C. "Head-Up Displays Hit The Road." Information Display, 7&8 (1990), p. 12.

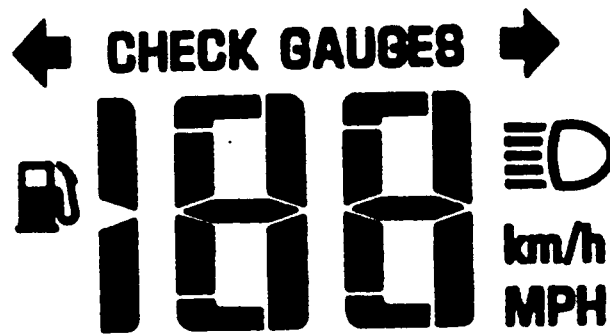


Figure 17

General Motors Head-Up Display Graphics

Source: Weihrauch, M., G. G. Meloeny, and T.C. Goesch. "The First Head Up Display Introduced By General Motors." Society Of Automotive Engineers Reprint, 890288 (1989), p. 60.

The optical design of the GM HUD utilizes only reflective optics (mirrors). The first mirror is a flat mirror, the second mirror is a curved (concave) mirror, and the final element of the optical path is the automobiles windshield. The windshield acts as the combiner. The system utilizes a "folded" optical path to allow it to fit into the tight irregular space of the dashboard.⁵⁸ The HUD display inputs are independent of the instrument panel displays to allow the HUD and the conventional instruments to act in a redundant fashion. The HUD unit also has a variable tilt feature that allows the image to be adjusted vertically to suit various driver heights and display positioning preferences.⁵⁹ The brightness of the display has two modes, day and night, and is variable from 1 to 500 ft lamberts. Table 3 outlines other specific performance parameters of the HUD.

⁵⁸ Goesch (1990)

⁵⁹ Weihrauch et al. (1989)

Table 3
GM Head-Up Display Performance Parameters

PARAMETER	VALUE
Image Size	1.5 degrees high x 3 degrees wide
Elevation Tilt	-2 degrees to -6.5 degrees
Color	Blue-Green (505 nm peak)
Head Box	130 x 130 mm (130 x 65 mm: instantaneous)
Vertical Disparity	Average: .7mrad Maximum: 1.5mrad
Image Range	2.4 meters from Design Eye Point

Source: Adapted from Weihrauch, M., G. G. Meloeny, and T.C. Goesch.
"The First Head Up Display Introduced By General Motors." Society
Of Automotive Engineers Reprint, 890288 (1989), p. 61-62.

Effects of General Motors Compromises

As stated before, GM management was very concerned with cost of the HUD production unit, and because of this the engineers had to make certain compromises. The first effect of these compromises was to shorten the image range to 2.4 meters. The image range of a HUD is the distance from the viewer that the display image appears to be located. This short image range, as compared to aircraft HUD's, was caused by three factors. The first being the VFD's inability to produce a display image as fine as a Cathode Ray Tube (CRT), which is typically used as a symbol generator in aviation HUD's. The second factor was the use of reflective optics vice refractive optics. The third was using the windshield as the optical combiner. These three factors combined to give the GM HUD more inherent vertical disparity then an aviation type HUD. Though, if one looks at GM's vertical disparity value (.7-

1.5 mrad) this value seems very close to the typical military HUD value of 1 mrad. Here is where the short image range comes into play. If a designer limits the image range to a shorter distance then the vertical disparity value will be less. If GM had tried to make the image range longer then the associated increase in vertical disparity might have caused the user to sense diplopia or double vision which accompanies large vertical disparity. Obviously, GM engineers felt a short image range was an acceptable trade off to prevent this situation.

The potential problem with this trade off is that while the 2.4 m visual range may shorten visual reaccommodation time, as compared to a conventional instrument panel, some studies have found that a short image range may cause driver eye strain after long periods of driving. This is due to the driver unknowingly trying to constantly reaccommodate his vision between the image and the outside environment, both of which are in his primary field of view.⁶⁰

The second effect of the compromises was low symbol brightness. It also comes from the use of a VFD. A typical military HUD CRT produces 20,000 to 25,000 ft lamberts while GM's VFD only produces 3000 ft lamberts.⁶¹ This combined with the reflective optics and use of the windshield as a combiner results in a maximum of 500 ft lamberts of display luminance at the user eye. The normal range for an aircraft HUD system is 1,200 to 1,800 ft lamberts.⁶² While the bright light environments that the two HUD vehicles are required to work in are different, it is interesting that both environments

⁶⁰ *Final Technical Report: Route Guidance Head-Up Display* (1968)

⁶¹ Weihrauch et al. (1989)

⁶² Gard (undated)

are considered equal in magnitude (10,000 ft lamberts). Brightness of this magnitude requires that the display image be a least 1000 ft lamberts to be detectable.⁶³ Therefore, for some severe ambient light conditions (bright day/snow or sand) the GM HUD image may be undetectable to the driver. GM does admit that this was a design trade off: "This (500 ft lamberts) is sufficient for visibility under normal driving conditions. Higher image brightness is desirable for extreme ambient light levels."⁶⁴

So the end result of GM's HUD design is a display that does not truly project at infinity and does not provide enough display luminance for the most severe conditions. While these conditions would probably be unacceptable for military aircraft, they are reasonable for automobiles considering the cost saving they entail. The GM HUD unit shows that HUD technology is transferrable into the low cost automotive field. The next questions that need to be answered are: (1) Are the benefits of a automobile HUD great enough to justify their use ?, and (2) Can any new uses for the HUD be suggested?

Benefit Analysis of Automobile Head-Up Displays

Reviewing, the three primary benefits of HUD usage in an automobile are: keep the driver's eyes on the road, keep the driver's eyes adapted to ambient light level, and shorten visual reaccommodation time. These benefits it is believed will result in better directional control of the vehicle,

⁶³ *Final Technical Report: Route Guidance Head-Up Display* (1968), The author has chosen not to use contrast rating here, but 1000 ft Lamberts will produce a contrast ratio of approximately 1.2 for a windshield that allows 75% transmission of ambient light on a bright day with snow/sand.

⁶⁴ Weihrauch et al. (1989)

and lessen reaction times to road obstacles. This hypothesis is supported by some research. One laboratory study done in 1990 showed that drivers utilizing a HUD and traveling at 60 mph perceived hazardous situations 440 ms or 12.2 meters before drivers using conventional displays.⁶⁵ GM's own in-house study found obstacle response times decreased along with steering variability when HUD's were utilized.⁶⁶ The GM report did not state under what conditions the results were found so these results can only be viewed subjectively. Some additional advantages of the HUD were suggested by a study done in England in 1989. This study found that 90% of drivers felt they were more aware of their speed and 70% felt the HUD was more comfortable to read and easier to use than a conventional speedometer.⁶⁷ Unfortunately, these advantages had no effect on the speed at which the subjects drove.⁶⁸ These are the positive aspects of HUD usage, but are there any disadvantages or problems that could be caused by automobile HUD's?

One disadvantage or problem HUD's may cause is during low visibility conditions (foggy night), when visual background clues are absent, the distance to a leading automobile taillights may be minified. This could result in the leading car's distance being overestimated which would lead to an increase in the likelihood of rear-end collisions.⁶⁹ This minification would be caused by the driver's resting vision being pulled to a shorter range by the HUD's presence.

⁶⁵ Sojourner and Antin (1990)

⁶⁶ Cass (1990)

⁶⁷ Briziarelli and Allen (1989)

⁶⁸ In other words, HUD's will not prevent speeding, but their usage may put to rest the time tested excuse of: "Officer I didn't realize how fast I was going."

⁶⁹ Sojourner and Antin (1990)

A second problem has to do with parallel processing. Successful parallel processing in a vehicle means that the operator has the ability to, "divide attention between two information sources (HUD and real world) processing information on one while monitoring for events on the other."⁷⁰ While no studies of parallel processing have been completed involving automobile HUD's, research from aircraft studies shows that HUD's may not allow parallel processing to take place.⁷¹ Therefore the pilot or driver would gain no advantage having the HUD superimposed on the real world in this context. In fact, other studies show that if parallel processing does not work, then the HUD may prohibit serial processing (attention being given to different information sources in a sequential manner). This is because positional scanning, as one would have with an instrument panel, is much more effective than attentional scanning, which a HUD to real world set-up would require. Attentional scanning may lead to the operator attending to the HUD information to the exclusion of the external scene.⁷²

Finally, since the HUD display is only viewable from a limited head-box location, the driver will tend to maintain his head in a single position for long periods of time. This may lead to increased fatigue as driver head movement is an essential reliever of fatigue.⁷³ This is more of a factor in automobiles, since the average time spent behind the wheel is normally longer than a typical military aircraft mission. Also, unlike the pilot of a high

⁷⁰ Stokes et al. (1989)

⁷¹ Stokes et al. (1989)

⁷² Sojourner and Antin (1990)

⁷³ *Final Technical Report: Route Guidance Head-Up Display* (1968)

performance fighter jet, the driver does not routinely rotate himself to scan the rear of his vehicle.

While none of these potential problems with HUD integration have been proven to exist, they should be studied further. The automobile HUD at this time does seem to provide certain known advantages over conventional instrument displays. The question is, are the potential problems real, and if they are, do they override the advantages? If we look at the advantages closer we see that they are limited at best, and therefore, do not warrant the widespread use of HUD's in automobiles.

Summary

As it has been shown automobile HUD's are a reality today. The technology was directly transferred from the aviation industry, but modifications in its implementation has allowed the cost of a HUD to be reduced significantly. While automobile HUD's do have some advantages in allowing drivers to maintain better directional control and in avoiding road obstacles, potential human factors problems still need to be investigated before HUD's are seen as being advantages over conventional instrumentation. HUD's in automobiles may be more useful if they displayed more information to the driver. While the HUD might not be useful today, it could become a vital display in automobiles of the future.

SUGGESTIONS FOR FUTURE AUTOMOBILE HUD USAGE

Unlike aircraft HUD's which provide, attitude, aircraft state, weapon, navigation, and other information, automobile HUD's that are presently installed only provide velocity and a few rudimentary warnings. For the

automobile HUD to become a useful display it must be utilized to its full potential by displaying additional system information. The GM unit, which has been described, only gives the driver his velocity, turn signal position, a gauge check indication, and a low fuel indication. All of this information, except the velocity readout, could be provided just as efficiently to the driver with an auditory display or warning lights located in the driver's primary field of view.⁷⁴ These methods would be more cost effective and technologically easier to implement. This is not to suggest HUD's do not have a future in automobiles, just that they need to contain more pertinent information to the external environment. The HUD could be used for instance to show closure rate or distance to a vehicle in front of the HUD equipped vehicle. The HUD could also be used to provide route navigation or guidance information either with arrows or contact analog displays. HUD's could be used to superimpose low visibility driving aids on the real world (low light TV, FLIR).

Of course there are two problems with all of the above suggestions: (1) none of the systems required to provide the data for these presentations are currently available, and (2) the present day HUD is limited in its display capability because of the use of a VFD. Answering the first problem will take time, but systems to provide data for all of the above mentioned presentations is currently being investigated by one or more of the automobile manufactures.

The second problem, HUD display capabilities, is also a difficult one to solve. The automotive industry cannot today switch from VFD's to high

⁷⁴ Unfortunately warning lights today are buried in the instrument panel and are not always viewable while monitoring the external environment.

luminance CRT's because of cost. CRT developments may drive the cost down, but the cost is unlikely to reach a level low enough for automobile use.⁷⁵ Instead the answer may lie in LCD technology. A prototype of a LCD driven HUD has been produced in Japan utilizing double-layer super twisted nematic technology. The results were promising as the entire LCD matrix (110 x 110) could present any type of display information required. The only problem was slow switching time which affected the presentation of rapidly changing data, such as a speedometer.⁷⁶ While this LCD technology is just in its infancy it does seem to hold excellent potential. So, while automobile HUD's have limited value today, they have great potential to be the primary display for navigation, closure rate/distance, and low visibility aid systems in the future.

⁷⁵ Dunn (1992)

⁷⁶ Nakagawa (1989)

V. NAVIGATION SYSTEMS

INTRODUCTION

The ability to navigate has always been one of the most difficult tasks an operator of a vehicle must perform. The operator must interface with the vehicle by taking information from the vehicle and interpret it so he can control his vehicle in a manner that his destination will be reached. To accomplish this task the navigation system must at a minimum provide the operator with an accurate location of his position and his velocity vector. The velocity vector must consist of a heading direction and vehicle speed. Additionally, the navigation system must present this information in a usable fashion to the operator.

These three primary parameters of a navigation system must be present whether the vehicle is an aircraft or an automobile. While the aviation industry has been concerned with aiding the pilot in performing navigation for many years, the automotive industry is now just beginning to provide navigation information to the driver. This section will examine navigation systems and their development in the aviation industry, and see what, if any, technology has been, will be, or should be transferred to the automotive industry.

AVIATION NAVIGATION SYSTEMS

Dead Reckoning And Position Fixing

In the field of aircraft navigation systems the first navigation system was the pilot's vision and possibly a chart and magnetic compass. The aircraft

was not a true part of the navigation system, except that it allowed the pilot to elevate himself to increase his visual range of identifying landmarks. The first true modern aircraft navigation system was the Airborne Direction Finder (ADF). The ADF, or radio compass, utilized the directivity of a highly directional receiving antenna to determine the relative bearing to a known transmitting station."⁷⁷ If the location of various transmitting stations were known by the pilot then he could periodically obtain a navigation fix of his location by taking ADF readings from two or more stations. While ADF position fixing eliminated the need for the pilot to visually locate his location, he still had to use a technique called dead reckoning to navigate between fixes. Dead reckoning is where the pilot uses his known position at a certain time and applying his estimated vector (speed and direction) over a time period would then be able to estimate his new location.

While newer position fixing systems such as VHF Omni-directional Range with Distance Measuring Equipment (VOR/DME), Tactical Air Navigation (TACAN), Long Range Navigation (LORAN), Omega, Global Positioning System (GPS), and Terrain Referenced Navigation (TRN) have been developed to increase the accuracy of position fixes, the pilot still needs to perform dead reckoning since none of these systems provide continuous, guaranteed position fixes.

To improve the process of dead reckoning the aviation industry has developed better magnetic compasses, improved speed sensing devices, doppler radar, and the Inertial Navigation System (INS). All of the above have been designed to improve the computation of the aircraft's velocity

⁷⁷ Masters (1981)

vector (direction, speed). Concurrent with these improvements in the aircraft's vector determination, the industry has also introduced computers which can accurately apply this vector to the aircraft's position fixes, thereby performing the dead reckoning and position updating computations for the pilot.

The modern day aircraft navigation system still uses both position fixing and dead reckoning systems to provide information to the operator. Typically the dead reckoning system is an INS, and the position fixing system is based on visual, radar, GPS, or TRN or a combination of the aforementioned information sources.

Inertial Navigation Systems

The INS is designed to provide an accurate output of an aircraft's speed and direction. The INS does this by measuring acceleration of the aircraft in the three standard earth axes. These accelerations are measured using accelerometers which are mounted on a gimbaled platform. The platform and therefore the accelerometers are kept oriented in line with the three earth axes by gyros. The acceleration sensed by the accelerometers is then integrated over time to produce three velocities. These velocities are then be combined to compute the aircraft's flight vector (direction, speed). ⁷⁸

⁷⁸ The author realizes that this is a simplistic way of describing an INS, and that other methods of implementing INS's exist, but the purpose here is to introduce the concept.

Position Fixing Systems

As mentioned above the modern day aircraft can update its dead reckoning solution by obtaining a position fix. In the past this has primarily been done visually by noting a visual landmark, or with a land-mapping radar by detecting a radar significant landmark. The two newest ways of fixing an aircraft's position are TRN and GPS. Both of these methods are thought to hold the promise of being more accurate than visual or radar position fixing. While visual or radar position fixing will not be eliminated by TRN or GPS the newer technology requires a more detailed explanation.

Terrain Referenced Navigation

TRN consists of taking an accurate readings of the terrain height variations overflown by the aircraft for a certain period of time. The terrain height variation is computed by continuously taking a reading of the aircraft's height above the terrain (usually with a radar altimeter), and then subtracting this from the aircraft's absolute height above mean sea level. The absolute height usually is derived from the aircraft's barometric altimeter. The terrain height variation data is then compared to a terrain data base stored in the aircraft's computer memory. The computer then finds the best match of the data base to the terrain readings taken and computes a position fix.

Limitations to this type of position fixing system include: the requirements for accurate altitude reading equipment (both above the ground and above sea level), an accurate data base of terrain heights, and a somewhat accurate known position. This last requirement, known position, is required to reduce the time the terrain matching computation takes to a reasonable figure. If the position was totally unknown the terrain matching would have to take place

over the entire data base, and the likelihood of a quick and accurate match would be reduced.

Global Positioning System

Global positioning system position determination is based on the fact that if a user can determine his distance from multiple satellites, whose positions are known, then the user can determine his own position. The overall GPS system, as illustrated in figure 18, consists of separate, but mutually dependent segments: the space segment, the control segment, and the user segment. Each segment is vital to ensuring the functionality and accuracy of the overall system. The GPS system is based on the theory that if the user knows where a satellite is, and he knows when the satellite transmits

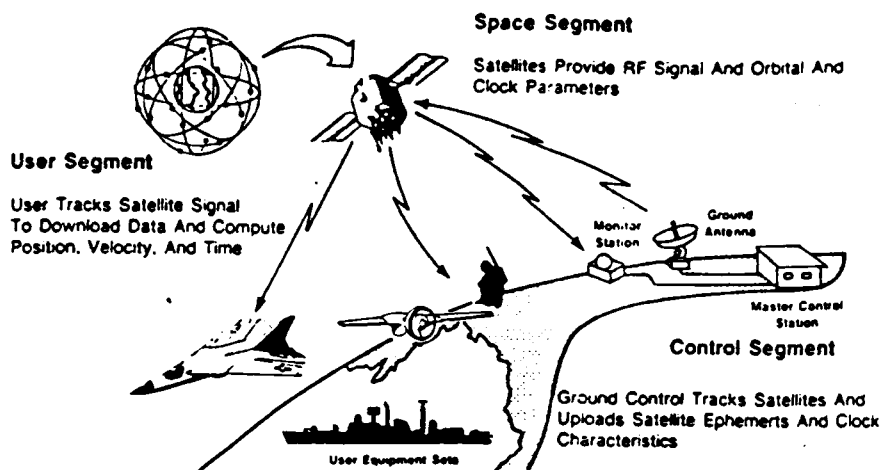


Figure 18

GPS System Segments

Source: Adapted from: (Arnold, J.L., and R.W. Blank. "GPS/INS Integration For Range Instrumentation." Rockwell International Corp. Publication. Ceder Rapids, IA, p. 277.)

a certain signal he can receive that signal, note its time of reception, and then compute his distance from the satellite. The above is true if the user assumes the transmission travels at the speed of light, and that the signal is sent in a straight path from the satellite to the user. The user distance from the satellite would be equal to the time required for the transmission (reception time-transmission time) multiplied by the speed of light. This single range computation of course doesn't give the user a position in a three coordinate system. Since this is a problem of three unknowns (X,Y,and Z), a user would have to make three distance measurements from three different satellites. There is actually a fourth unknown in this computation. This fourth unknown is the difference between the satellite's absolute time and the user's absolute time. To solve for this fourth unknown a measurement from an additional satellite must be taken. Basically, to obtain a fix in three axes requires four measurements from four separate satellites. If the altitude (Z value) is not needed by the user then the position (X, Y) can be solved by measuring only three satellite distances.

The biggest factor in GPS accuracy is also the methodology and reasoning behind GPS development. The GPS system as described is capable of deriving accuracies of position (X,Y, and Z) to a Spherical Error Probable (SEP) of 16 meters. This level of accuracy is termed Precise Positioning Service (PPS). PPS was originally designed for the U.S. military only. Another less accurate, but still highly useful level, known as Standard Positioning Service (SPS) is available to civilian users. The SEP for SPS is 100 meters.⁷⁹

⁷⁹ Wysocki (1991)

Differential GPS (DGPS) is the latest large technological advance in GPS accuracy. DGPS is designed to nearly eliminate all errors associated with GPS. The concept is simple. First, a GPS receiver is placed at a known position. The difference between the known position and the GPS derived position is computed. This difference, or differential correction, then can be applied to other receiver position (stationary or mobile) to derive a more accurate position. The only equipment needed in an aircraft to utilize GPS is a receiver, an antenna, and a display unit or method of integrating the GPS derived position into the overall navigation system.

Current Navigation System Accuracies

Currently the aviation industry is starting to integrate INS with TRN or GPS. The most recent implementation of INS/TRN system was an R&D program on an A-6E. The set-up utilized a TRN system developed by the Ferranti Corporation of England, called Penetrate, with the A-6E's ASN-92 INS. The ASN-92 would first inform the Penetrate system of the aircraft's general position, then the Penetrate system would refine the position using TRN. The combination of these two systems proved to be more accurate than the ASN-92 alone, but there were some difficulties noted. The primary two were: one, the digital data base of terrain heights was not precise enough to permit TRN over relatively flat terrain, and two, the system could not be utilized over water. The final conclusion was that while the test was limited in scope, it did prove the general TRN concept, and it was suggested that TRN systems be further investigated.

INS/GPS combinations have received much more attention recently than INS/TRN systems. Recent tests by the U.S. Navy have shown that the

integration of INS with GPS will significantly improve the overall accuracy of a navigation system. R&D tests of INS/GPS systems have been completed on the P-3C Orion, A-6E Intruder, and the AV-8B Harrier. The flight test results showed that the INS/GPS systems was on the average accurate to 5 to 13 meters in position, and had a maximum single position fix error of about 40 meters.⁸⁰ The tests were completed with five channel GPS units and did not utilize PPS. Another important result of these tests was that if the GPS updating feature was lost for any reason (blockage of satellites, turned off, system failure) the INS drift rate from that time on was less than if the INS had never been updated by the GPS.⁸¹ These results have convinced the U.S. Navy of the advantages of a INS/GPS combined system, and plans are underway to retrofit this combination into older aircraft navigation systems, and to ensure new generation aircraft have this capability.

Navigation Displays

Navigation systems are only usable by the pilot if the information is accurately and usefully displayed. In the past the pilot would normally have only a needle pointer on the compass rose or a "carrot" on his HUD heading display to tell him which direction to fly to reach his designated destination. If he wanted to relate his position to the real world he would have to use a data read-out of his position (usually in latitude and longitude), and reference this to a paper navigation chart which he would have had to prepare prior to the flight. Luckily for today's pilot modern technology has done away with

⁸⁰ Harned et al (1991) and Manski et al. (1991) Average accuracies are Root Mean Square values from the tests.

⁸¹ Stevens (1990)

this work intensive method. Now, the pilot has available to him on-board map systems. There are three basic types of map display systems:⁸²

- (1) Direct view projected film displays with or without overlaid symbology.
- (2) Remote film map readers that relay the video to a color or monochrome cockpit display.
- (3) Digitally generated maps from data bases that vary from simple stick maps to complex raster shaded relief maps in either plan or perspective view.

The first two types of map displays are older systems which have been virtually eliminated by the newer digitally generated maps. The older film systems required transparent photographs of the maps to be taken and then loaded onto reels. These reels were then loaded into the map readers in the aircraft. This process proved to be workable, but cumbersome, time consuming, and the film reels were limited in the area coverage they could hold. It was not a rare occurrence for a pilot to fly out of his map coverage on a mission.

The digital map on the other hand requires that the maps be digitalized by a optical scanner, then this digital data base is loaded on to an optical disc. Because the optical disc medium has such a high storage capacity it has been found that digital maps of three different scales (operational navigation charts 1:1,000,000, tactical pilotage charts 1:5,000,000, and joint operational graphics 1:250,000) for the entire United States can be stored on two 3 1/2 inch discs.⁸³ Other advantages of a digital map are the ability to rotate the map to a north-up or aircraft heading up orientation, to zoom-in or zoom-out, to integrate

⁸² Adams (undated)

⁸³ *Aircraft Map Data* (1991)

other data bases into the digitalized map data (i.e. high threat areas, satellite imagery), and to pre-plan the aircraft routing on a mission planning system which utilizes the same data base. Currently all these options are available in operational digital map systems.

The last thing which should be noted about digital map systems is the ability of the system to overlay other information on the displayed map. Besides the aircraft position being displayed on the map, the pilot can choose to have his route, his air-to-air radar contacts, and other weapon or electronic warfare information overlaid atop the map.

Summary

Modern day aviation navigation systems are highly accurate but complex systems. They normally will contain a dead reckoning velocity vector sensor (INS), a position fixing source (radar, GPS, or TRN), a computer to perform dead reckoning and update the dead reckoning solution with position fixes, and a digital map system to display the information to the pilot. The questions that now need to be answered are: how much of this technology has been transferred, how much is applicable for transfer, and how should this transfer take place?

AUTOMOTIVE NAVIGATION SYSTEMS

The Coming Revolution

The driver of an automobile, like the pilot of an aircraft, in unfamiliar territory must rely upon a map of his environment, information provided to him by his vehicle, and his view of the outside world to accurately navigate to his destination. As it has been detailed previously, the aviation industry for

years has been putting various kinds of navigation systems into aircraft to aid the pilot. In the past the driver of an automobile has had to rely only on a map. Additionally, once the driver's journey has begun the situation has usually digressed to only the driver using his memory of the map, because, "there is not time or opportunity to use the map during driving and most drivers hesitate to stop and park in order to consult the map."⁸⁴

The above situation will soon be revolutionized, and in fact is changing at this very moment. Nearly every automobile manufacturer in Europe, Japan, and the United States is involved in either producing or researching some type of navigation system. While automobile navigation systems have yet to appear as standard equipment or as an option in the U. S. market, it is estimated that 200,000 of the 60 million cars in Japan are equipped with a navigation system.⁸⁵ Additionally, 20% of Japanese luxury car buyers are interested in ordering a navigation system.⁸⁶ Finally, the Toyota Motor Corporation has been selling luxury models equipped with navigation systems at a rate of 1,200 per month for the past year.⁸⁷ As stated in a report completed for the Federal Highway Administration:

"These Japanese results show that in-car navigation and route guidance technologies meet the basic needs of a population greedy for communication. Knowing that communication devices like cellular phones, faxes, etc. have also had an exponented rate of development in Europe and the U.S., there may be a niche for in car navigation and guidance systems."⁸⁸

⁸⁴ Rumar (1990)

⁸⁵ Montgomery (1992)

⁸⁶ *Electronic Map Market Set For Strong Growth* (1990)

⁸⁷ *Toyota's GPS-Equipped Cars Selling Quickly In Japan* (1991)

⁸⁸ Ygnace et al. (1990)

To back this statement up, the report went on to say that during the 1990 Greater Los Angeles auto show 23.5% of the visitors polled stated they would purchase a navigation system if it was priced at around \$600.⁸⁹

Clearly the facts show that navigation systems will soon be a integral part of many new automobiles. If this is the case, what will these navigation systems consist of, how much of the technology has been transferred from the aviation industry, can more be transferred, and can any new ideas developed by the automobile industry be applied to aircraft?

General Overview Of Automobile Navigation Systems

The basics of vehicle navigation are the same no matter whether the vehicle is an aircraft or an automobile. The navigation system must interface with the operator by providing him with his present location and velocity vector in a presentable and usable fashion. Like aircraft this means that automobiles must have a dead reckoning system or velocity vector sensor, some sort of position fixing equipment, and a display. This part of the discussion will look at these three navigation system components as they apply to automobiles, and compare them to what was found to be the current technology in aircraft.

Automobile Dead Reckoning Systems

In aircraft the primary system utilized for determining the dead reckoning velocity vector is the INS. Unfortunately for auto manufacturers the lowest priced INS on the market today costs about \$20,000. While

⁸⁹ Ygnace et al. (1990)

economies of scale could bring this number down by a few factors, the cost would still be prohibitive. Additionally, the INS's inherent drift rate which grows over time, would prove to be troublesome after a few minutes due to the slow velocity and required accuracy of automotive navigation. Finally, few drivers would be willing to wait for the INS to align, which normally takes at least 4-5 minutes in the most accurate systems.

The automobile industry has instead opted to use wheel rotation sensors and a geomagnetic sensor for determining the vehicles velocity vector. Both of these technologies, while not presently used as primary navigation sensors, can trace their roots somewhat to the aviation industry. The wheel rotation sensors, simply count the number of times a wheel rotates, then this value is multiplied by the tire circumference to compute the vehicle's velocity. The actual wheel rotation sensors being used are the same sensors that are utilized in the vehicle's anti-lock braking systems.⁹⁰ This technology of course first appeared in aircraft, but not in this capacity. The wheel rotation sensors can also be used to compute changes in direction by comparing the distance travelled by the right and left wheels.

The most common device for directional data is the geomagnetic sensor, perhaps better known as a fluxgate compass. Modern flux gate compasses, unlike magnetic compasses, have no magnet which aligns itself with the earth's field. They operate more like a transformer, converting magnetic flux into electricity. This mode of operation is the primary advantage of fluxgate compasses, "since the flow of electricity is unaffected by mass or inertia, many of the problems which plagued conventional

⁹⁰ Otmar (1986)

compasses disappear."⁹¹ Other advantages of the fluxgate compass include its ability to react instantaneously to changes in direction, and its ability to be remotely located away from the system which receives its data output. The fluxgate compass has been utilized in aircraft in the past, and is still used today as a back-up system to the INS for direction.⁹²

Wheel sensor accuracy can be affected by tire pressure, tire construction, tire wear, tire velocity, and tire slippage. Studies have shown that these factors are small and can be negated through either continuous or periodic compensation.⁹³ Fluxgate compass accuracy is primarily affected by the magnetic properties of the vehicle, and magnetic anomalies either natural (large ore deposits) or man-made (bridges, tunnels, buildings).⁹⁴ As stated before the fluxgate compass can be remotely located. This will allow the compass to be located far from the engine and this along with a compass calibration can eliminate most of the vehicle effects. The magnetic anomalies can be compensated for by comparing the fluxgate direction output to the wheel sensor direction output to negate or smooth out any transients caused by such anomalies.

On-road tests have shown this type of system (wheel sensors/fluxgate compass) to have an overall error rate of about 5% of the distance travelled.⁹⁵ It should be noted that this is a constant error and does not grow over time like an INS drift error. Unfortunately, a 5% error is not acceptable. For

⁹¹ Kits van Heyningen (1987)

⁹² *NATOPS Flight Manual-Navy Model A-6E TRAM/KA-6D* (undated)

⁹³ Hall (1986)

⁹⁴ Hall (1986)

⁹⁵ Tanaka et al. (1990) Both distance and direction errors are included in this figure.

instance, if a city block averages 100 meters in length then a navigation system must have an accuracy of 50 meters to place the vehicle in the correct location. With a 5% error the wheel sensor/fluxgate system will exceed the 50 meter limit after only traveling 1 kilometer. So like aircraft navigation systems, for automobile systems to work accurately, a position fixing source is also required.

Automobile Position Fixing Systems

There are three primary methods of obtaining position fixes currently in use by operational automobile navigation systems. Position fixes can be obtained either by the use of map-matching, GPS, or beacons. Each method has been proven to provide accurate position fixes for updating a dead-reckoning system. Each system has also had difficulties in obtaining an accurate position fix under certain adverse conditions. Each type of position fixing system will be explained and analyzed for its particular advantages and disadvantages.

Position fixing by map-matching is by far the most popular position fixing system at this time. While not all operational navigation systems employ map-matching, a large majority do. Map matching is an artificial intelligence process which uses algorithms to determine a vehicle's location by matching its apparent path (that sensed by the dead reckoning system) with the patterns of the digital road maps stored in a computer file. For example, "each time a vehicle makes a turn whose location, direction, etc. closely matching those of a mapped turn, the vehicle is presumed to be at the

mapped location." ⁹⁶ An illustration of how map-matching works is presented in figure 19.

Part (a) of figure 19 shows apparent path of the vehicle derived from dead reckoning, and Part (b) gives the computed path after dead reckoning. Map-matching position fixing has no direct link to aviation technology, but it does appear very similar to a TRN type system in its methodology. No actual transfer of TRN technology could be found, but this does not mean that the system's conception may not have been a spin-off of TRN.

The main advantage of map-matching is that it requires no outside information source. It is a completely self contained system. It also appears to

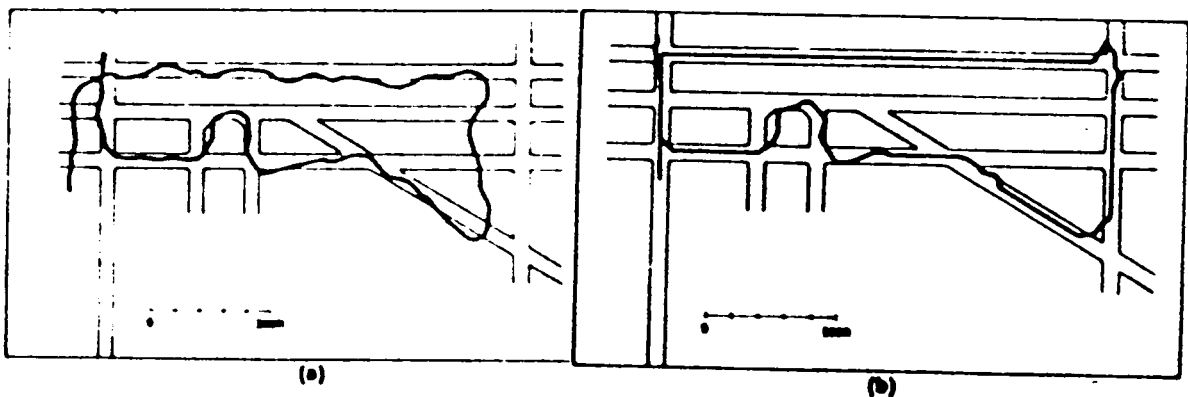


Figure 19

Illustration Of Map Matching

Source: Hall, Herbert H. "Alternate Approaches To Automotive Navigation." Society Of Automotive Engineers Reprint, 861057 (1986), p 216.

⁹⁶ French (1990)

work very well in areas that have complex road systems. One disadvantage is that map-matching requires a detailed and updated road data base. All driveable roads and any new roads must appear in the data base. If the data base is not complete and up-to-date then the possibility of the system incorrectly fixing the vehicle's position is increased. Map-matching has been mainly tested in areas with complex road matrixes, and its accuracy, reported to be 50 ft, is highly dependent on the number of turns taken for the distance travelled.⁹⁷ There is some question as to its accuracy in more open areas where turns are typically made less frequently. An example of where a problem might arise is when a vehicle turns off of an interstate after a long straight run. Will the system correctly determine the interchange used or will it misplace it at a near-by one? The map-matching system has been proven under some conditions, but testing needs to be completed under more adverse conditions to fully evaluate this type of system.

The second position fixing system used in automobile navigation systems is GPS. This system is directly derived from its use in aviation. The implementation of GPS in automobiles is very similar to that of aircraft. The important technological difference being that automotive GPS systems only require three satellites to obtain a fix since altitude is not a required output. GPS position fixing initially was not favored by the automobile manufacturers primarily due to the high cost of the receivers and the lack of full satellite coverage.⁹⁸ In recent years GPS receiver prices have dropped significantly; Rockwell International now offers a full 5-channel receiver which is expected to cost as little as \$225; and full satellite coverage is on the

⁹⁷ Stokes et al. (1989)

⁹⁸ Bannister (1991)

horizon. This has prompted many manufacturers to include GPS receivers into their navigation suites.

One advantage of GPS is its ability to automatically set the vehicle's initial location.⁹⁹ In map-matching or beacon systems the initial navigation position input must be by the user. Secondly, GPS has the ability to find itself, unlike map-matching systems, where if the position is computed wrong, the error usually continues to multiply.¹⁰⁰

The primary disadvantage of GPS is that it tends not to work well in urban areas, where navigation may be most needed, because, "the high frequency signals from the satellites not directly overhead are often blocked by buildings."¹⁰¹ Finally, another concern is the stated accuracy of SPS, the only service guaranteed to be available to civilian users, of 100 meters. This accuracy may not be good enough for some situations (close parallel roadways, complex road systems). Luckily, the results of many tests of SPS have shown the accuracy to be much better than 100 meters. One test which was completed recently in Sweden with automobile type systems reported an average accuracy of 53 meters.¹⁰² One method of ensuring the required accuracy would be the use of a differential GPS. Australia, it is reported, will soon have a nation wide differential GPS system on line designed for the tracking of land vehicles.¹⁰³

While GPS is going to be increasingly utilized as a position-fixing source it is unlikely that it will be the only position-fixing source in a

⁹⁹ Yamaguchi (1990)

¹⁰⁰ Tsunoda (1986)

¹⁰¹ Vehicles Grab Spotlight at VNIS Conference (1991)

¹⁰² Otto (1991)

¹⁰³ Bannister (1991)

automobile overall navigation system. This is primarily due to the fact that it is incapable of providing position fixes in urban type areas. GPS will mainly be used as a secondary, but highly accurate source used for checking other position-fixing source's fixes when GPS signals are available.

The third position-fixing source used in automobile navigation is the beacon or signpost type system. Beacon position-fixing systems are electromagnetic type systems which utilize a receiver and a transmitter, they are similar to TACAN or VOR/DME system except they do not provide a bearing from the source -- just a distance. "The beacons are short-range (tens of meters) signal emitters that are strategically located at key intersections. Reception of the location-coded signals confirm the location of passing vehicles."¹⁰⁴ The beacons usually are designed to work in the infra-red or microwave bands.¹⁰⁵ The system requires a on-board receiver and has always been tied to a dead-reckoning system to navigate the car between beacons. A schematic of one proposed beacon system is shown in figure 20. Beacon accuracy is dependent on only the accuracy to which the beacon can be placed, which by today's technology is within a fraction of a meter.

The primary disadvantage of a beacon system is that it requires an extensive infrastructure. Beacons theoretically, while not being required at every intersection, will be required at a substantial percentage. In Los Angeles alone, it has been estimated there are 36,000 intersections, and even if the percentage of beacons is small, multiply this by the entire U.S., and the number of beacons required could be astronomical.¹⁰⁶ A Federal Highway

¹⁰⁴ French (1990)

¹⁰⁵ Shibata (1989)

¹⁰⁶ Shibata (1989)

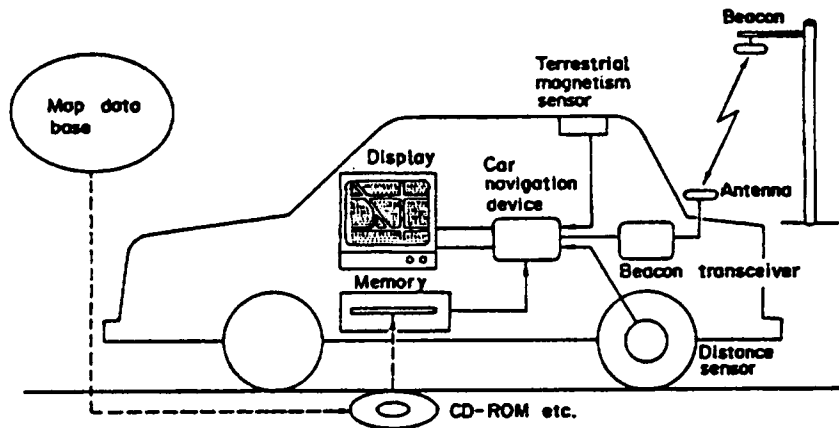


Figure 20

Proposed Beacon Navigation System

Source: Kawashima, Hironao. "Japanese Perspective Of Driver Information Systems." Transportation Journal, 17-3 (1990), p. 274.

Commission report has estimated the cost of each beacon to be \$ 20,000.¹⁰⁷

That cost may seem high, but this is because the beacons are not planned only to be used for navigation.

The beacon system is being advocated as an adjunct part of intelligent highway systems. Before these intelligent systems are explained, it is imperative that the differences between automobile navigation and automobile route guidance are presented.

Automobile Navigation Vs Automobile Route Guidance

Automobile navigation can be defined as the ability of the automobile to inform the driver of his location and in what direction and at what speed

¹⁰⁷ Hall (1986)

he is traveling. Route guidance includes all of the above parameters, but also has the ability to tell the driver what his actual routing should be to arrive at his destination. To accomplish this task, route guidance systems require a much more detailed map data base than simple navigation systems. This is because route guidance must also look at factors such as, street directional flow, location identification (street numbers), and other road limitations (prohibited traffic, alternate flow patterns, etc.) There are two types of route guidance systems: self-contained and centrally controlled.¹⁰⁸

Self-contained route guidance systems are stand-alone or nearly stand-alone systems. The guidance instructions which are presented to the operator are derived from the previously mentioned road data base. The data base can be either updated by periodic issues of new data bases (stand-alone) or it can be continuously updated by radio transmissions (nearly stand-alone). The advantage of the continuously updated, or real-time, type system is the ability to input into the data base transient occurrences such as road-repair work or major accidents. The route guidance system could then work around these transients to ensure the quickest routing was presented to the driver.

A centrally controlled system is similar to the air traffic control system. The central control tracks the vehicles and adjusts each individual vehicle's routing to meet the demands of road usage and capacity. This type of system is presently being investigated by numerous public and private agencies throughout Europe, Japan, and the U.S. These agencies have completed various tests utilizing beacons both as transmitters of information to the automobiles, and as receivers to track the vehicles.

¹⁰⁸ Ross (1990)

In the U.S. the common name all centrally controlled guidance systems are grouped under is Intelligent Vehicle Highway System (IVHS). Current IVHS programs and tests are being conducted in California, Florida, Michigan, and Illinois.¹⁰⁹ The basic components of a full IVHS as visioned by its supporters is shown in figure 21.

The stated goals of IVHS is to lessen traffic congestion and to improve safety. There is some question to the obtainability of these goals.¹¹⁰ The important factor of IVHS to automobile navigation is that through IVHS programs and tests many of the basic components for navigation systems are being developed and refined. In fiscal 1992 the Federal government funded IVHS at \$234 million.¹¹¹

Map and Road Data Bases

In reviewing aviation navigation data bases it was found that two primary attributes (separate pieces of information for each data point) were needed to make the systems functional. Digitalized map data was needed for drawing the map and terrain heights were needed for TRN systems. Automobile map and road data bases on the other hand can be either simple or complicated. If the data base is only needed for navigation (no route guidance) then the data base only requires digitalized road maps of various sizes. On the other hand, if the database is utilized for a route guidance system then it may need to contain up to 150 different attributes for each road

¹⁰⁹ *Intelligent Vehicle Highway Systems* (1992)

¹¹⁰ The report by Commeignes (1990) gives a through discussion of the possible effects of IVHS on traffic congestion and automobile safety.

¹¹¹ Montgomery (1992)

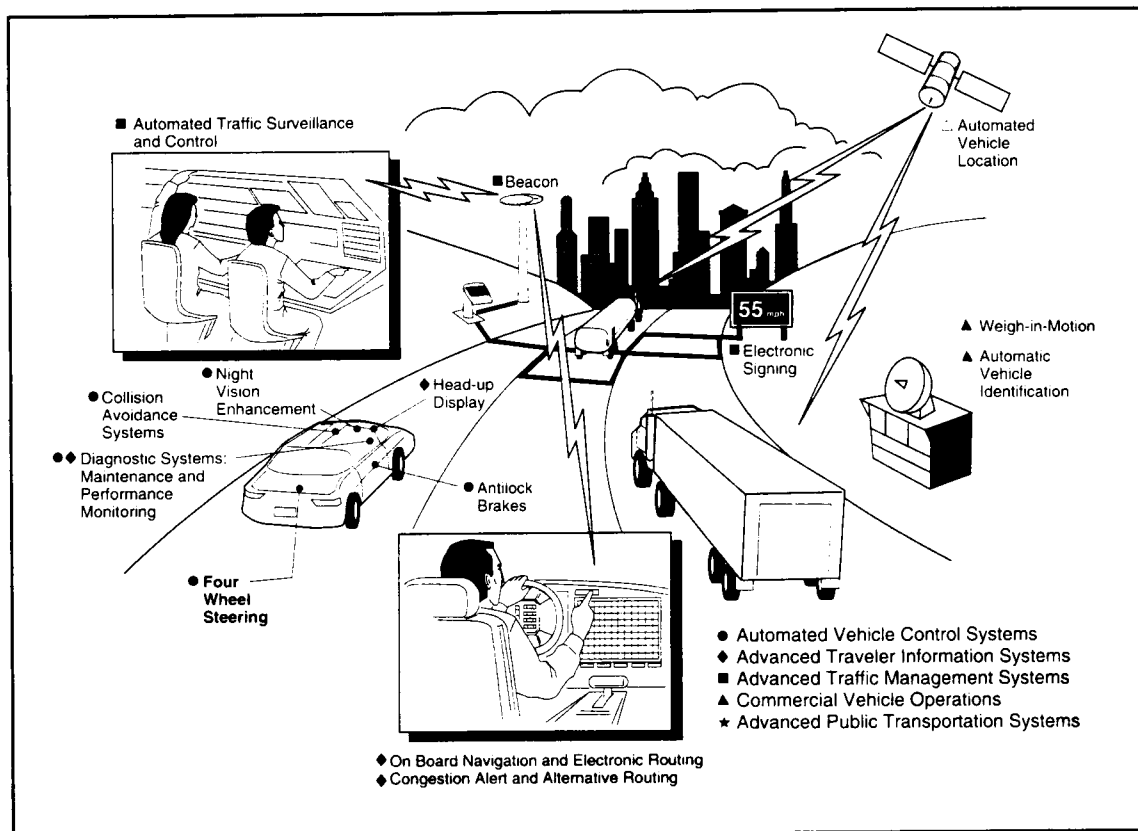


Figure 21

Components Of An Intelligent Vehicle Highway System

Source: "Intelligent Vehicle Highway Systems." Federal Highway Administration Report, Washington D.C. (01 January 1992) p. 7.

section.¹¹² These attributes vary from road speed limit to road carrying capacity, and are set by the manufacture of the route guidance system for the logic he wants to use to guide the driver. Unlike aviation map and terrain data bases which tend to vary little over time, the attributes of a route guidance system are constantly changing due to new construction or changes in regulations by various governmental agencies.

One additional problem facing automobile navigation designers is that the data bases for their systems have not been standardized in format or medium. Aviation data bases also suffered from this problem, but recently this was corrected through joint military committees.¹¹³ The automobile manufactures need to force this standardization. So far, Japan is leading the way on this as it has taken the far-sighted step of having their in-country data bases standardized by a committee of the manufacture's and the Department of Construction.¹¹⁴

Automobile Navigation Displays

Automobile navigation displays include digitalized map, auditory, CRT symbolic, and in the near future symbolic and contact analog HUD presentations. The digitalized map displays are simply lower cost versions of aircraft map displays. They contain most of the features found in aircraft map displays: variable scales, north-up or vehicle heading-up orientation, zoom, scroll, and full color. The only major difference between the two applications is that automobile maps either blank or significantly reduce their detail when

¹¹² Cass (1990)

¹¹³ *Aircraft Map Data* (1991)

¹¹⁴ Shibata (1989)

the vehicle is moving.¹¹⁵ This feature was incorporated to ensure drivers were not overly distracted by the display and for liability concerns.¹¹⁶

Automobile systems which provide route guidance in addition to navigation information also use auditory and CRT symbolic displays. The auditory displays are simply verbal commands to the driver to guide him to his destination, such as "turn right next corner".¹¹⁷ The CRT symbolic displays simply show the driver routing instructions in symbols on a CRT. Normally, these symbols are replaced by the digitalized map when the vehicle is stopped. An example of a CRT symbolic display as installed in a GM vehicle is shown in figure 22.



Figure 22

General Motors CRT Symbolic Display

Source: "Vehicles Grab Spotlight at VNIS Conference." IVHS AMERICA, Volume I Number 9, November 1991, p. 5.

¹¹⁵ French (1990)

¹¹⁶ Cass (1990)

¹¹⁷ RSC To Offer DAB, GPS, Two-way Data And More To Car (1991)

The final type of automobile navigation display is the HUD presentation. While no navigation HUD presentations are presently on the market, two types are under investigation: symbolic, which is where the route guidance symbols are simply presented on the HUD instead of a CRT, and contact analog. A contact analog display is one that appears to mimic the real world. In a route guidance system a contact analog display could appear as a line drawing of a road with turns which is overlaid atop the real world. An arrow could be used to show the direction the driver should take, as illustrated in figure 23. Neither auditory and nor contact analog HUD route guidance displays have been implemented into aircraft navigation systems.

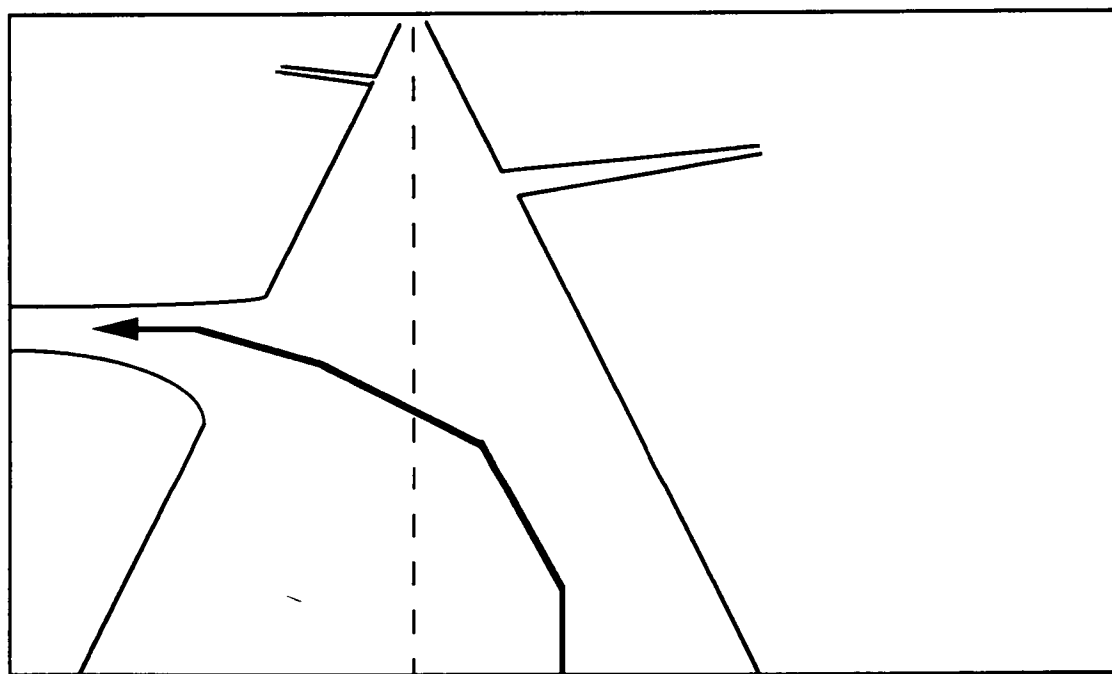


Figure 23

HUD Route Guidance Contact Analog Display

Summary

Today automobile navigation systems are accurate and sophisticated systems. They contain components to provide for both dead-reckoning and position fix updates. While not all of these components are exactly the same ones that are found in aircraft, they can trace their heritage for the most part to the aviation industry. Therefore, it is safe to say that there has been a large amount of navigation system technology transfer from the aviation industry to the automotive industry.

The automobile industry has gone beyond this technology transfer and implemented new navigation ideas into their own systems. The primary example of this is route guidance. Automobile navigation systems are not just limited to informing the driver of his position and relative motion, but now can direct him to his destination either autonomously or with the aid of external information. This external information gives the system the ability to react to changing conditions which may effect the drivers routing in a real-time fashion.

SUGGESTIONS FOR CONTINUED TECHNOLOGY TRANSFER

As has been stated before, the automobile industry has done an excellent job of transferring navigation technology from the aviation industry. The question now is can the automobile industry learn any new ideas from the aviation industry? One part of aviation technology which can easily be transferred to the automobile industry is navigation mission planning. In their present configuration automobile navigation systems only function during driving. Since most data used for these systems are contained on optical discs it would be a simple matter for the manufacturers

to design a system that could either hook up to a home computer or television. This would allow the owner to plan his route or view it prior to entering the the vehicle. While this type of pre-planning would not be useful to the commuter, it could find heavy use by tourists or businessmen traveling in unfamiliar locations. The manufacturer could defray the cost of these systems and the data base updates by allowing hotels, restaurants, and tourist sites to advertise their services in the data base.

In the reverse sense the aviation industry could learn from the automobile industry. The idea of route guidance could be utilized to assist attack pilots in completing their missions. As it now stands, a pilot must plan his route prior to entering the cockpit. To do this he must take into account geography, target location, and threats. From these variables he decides which route, altitude, and tactics are appropriate. This decision can be made manually or with help of a mission planning system. The important point is that no matter how the mission is planned it is set when the pilot enters the cockpit. If the pilot encounters new threats or weather then he must, in the air, alter his mission parameters or abort the mission. This decision must be made while performing intensive flight and mission tasking. Usually these decisions are based on partial information, and do not take into account all the variables with which the original mission was planned. In essence, they are limited by the amount of information a pilot can disseminate while flying in a stressful situation.

If the the pilot had a "mission guidance system" then he could continually be directed to the target by the best routing regardless of in-flight alterations. The mission guidance system would scan its data base, and recompute the new routing, ensuring that all pilot designated factors were

taken into account. The data base could also be updated via a data link to take into account any "pop-up" type threats. More than likely the biggest obstacle to the implementation of this type of system would be pilot objections to letting a machine make decisions of this importance. Hopefully, through testing and demonstration of this type of system's capabilities these objections could be overcome.

Another automotive technology which should be considered for transfer to aircraft is auditory route guidance displays. If this technology was utilized in an aircraft performing a low level mission the pilot could be informed of his next turn-point's description, and his required outbound heading prior to reaching the turn-point. Presently the pilot must view this information on a digitalized map display which sometimes is difficult to interpret due to its small size, and the requirement for the pilot to keep his attention outside the cockpit. Auditory displays could also be used to warn the pilot of known (data base) threats near his route. This would improve the pilot's situational awareness, and serve as a reminder to him as to those areas he wants to avoid. If the pilot felt these auditory displays were too distracting, the designer could allow the pilot the ability to disable them. Also, to avoid confusion with auditory warnings (synthesized voice), the designer could ensure that the mission guidance commands were given in a distinctly different voice.

While these are just a few suggestions, they do point out that while in the past most navigation technology has been transferred from the aviation industry to the automotive industry, there are possibilities for the transfer to reverse.

VI. CONCLUDING REMARKS

SUMMARY

It has been shown that in the past few years there has been a high level of operator-to-vehicle interface technology transfer from the aviation to automotive industry. While there are numerous areas within operator-to-vehicle interface technology where technology transfer could have taken place, this paper has specifically concentrated on: switch technology, auditory displays, Head-Up Displays (HUD's), and navigation systems. In each of these areas, the history of aviation technological advances and its evolution has been traced. This was followed by a detailed look at the current state of aviation technology. Next, the transfer of this technology to automobiles was examined for what had been transferred, how that transfer had taken place, and what alterations to the technology were required for its implementation in automobiles. Finally, suggestions for additional technology transfer were presented. In each area these suggestions were designed to enhance the use of aviation operator-to-vehicle technology in an automotive environment. There were also some suggestions put forward for the use of mature automotive technology in aviation design. The main thrust of the suggestions though was geared towards improving future automobile design. Therefore, since these ideas were presented separately, it is now advantageous to put them together in an automobile of the future design.

AUTOMOBILE OF THE FUTURE

The automobile of the future should have many of the ideas illustrated in figure 24. In figure 24 many of the ideas presented in previous chapters are combined to show one possible operator-to-vehicle interface configuration. In this configuration the driver will be able to select the HUD format desired when he needs it via the HUD format select buttons. With the exception of the low visibility driving aid format, the HUD display format will only be presented upon either driver command (vehicle speed and closure rate/distance), or when the vehicle requires the drivers attention (warnings, extreme closure rates, route guidance). The time the HUD format is presented should be limited in duration so as to not serve as a constant attention grabber of the driver's concentration.

The switch multiple function system is the same system as discussed in Section II, and the output displays of driver switch selections can either be presented on the clear LCD scratchpad or the HUD. The systems controlled by the switch multiple function system include: radio, navigation, car phone, environmental, and other future systems such as low visibility driving aids and collision avoidance systems.

The synthesized voice system only presents navigation guidance commands. All other warnings or cautions will be indicated by an auditory tone, which will direct the driver to the HUD for identification of the malfunctioning system. When a synthesized voice guidance command is given the radio volume will automatically lower. The driver also has the option to have the command repeated through use of the repeat button located on the right side of the steering wheel. No voice-interactive system will be utilized.

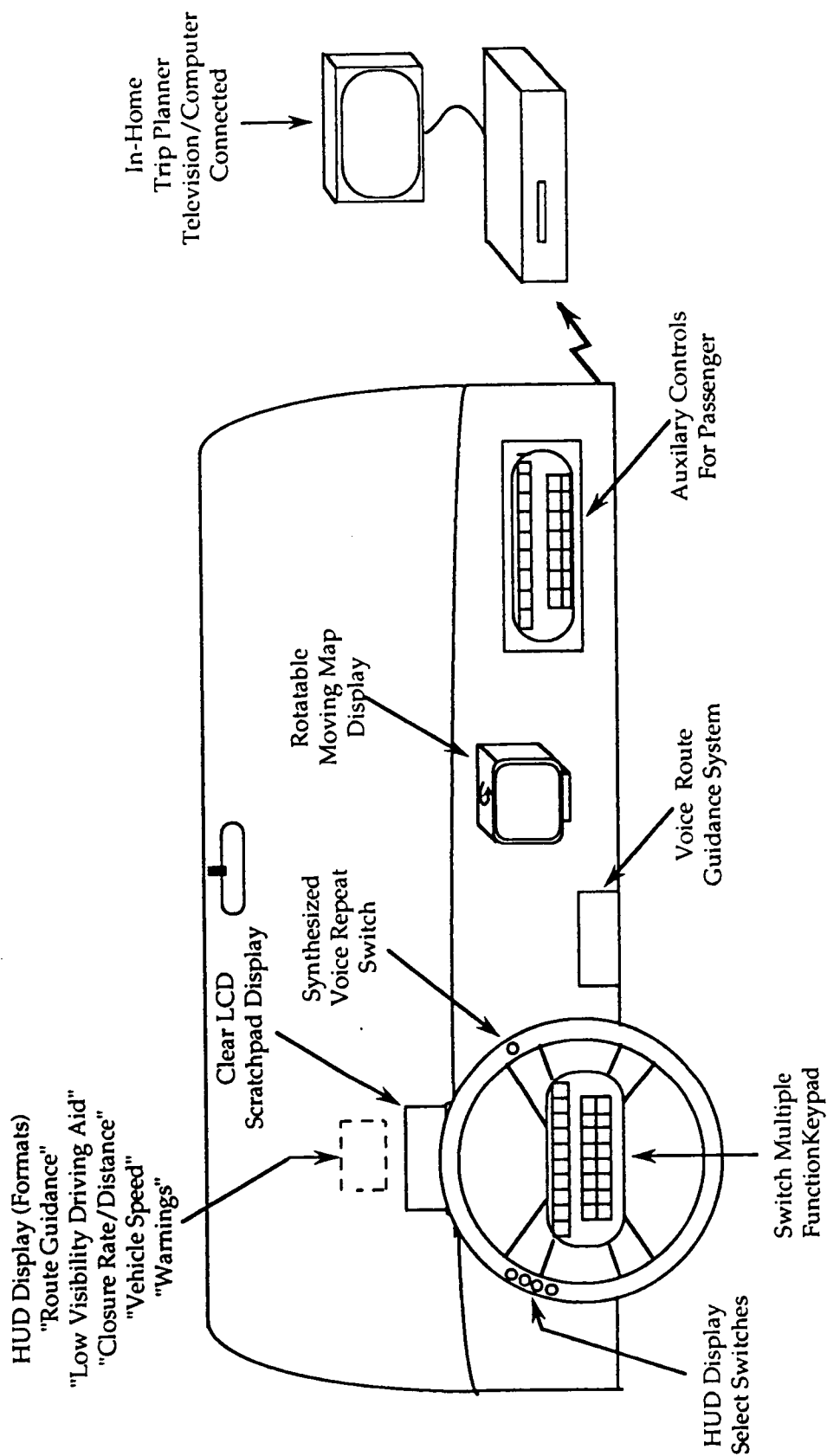


FIGURE 24

Future Automobile Operator-To-Vehicle Interface Configuration

The navigation system will be a self-contained route guidance system, with continuous updates to the data base via the radio system, in locations where updates are available. The system will dead-reckon using a combination of wheel sensors and a magnetic fluxgate. The navigation solution will be updated utilizing position fixing from GPS and map-matching. The primary navigation displays will include, route guidance symbols on the HUD, CRT route guidance symbols, audio commands, and a full-color moving map. The mentioned CRT will alter from showing only route guidance symbols to the full map when the vehicle is stationary. The moving map display can be rotated away from the drivers line of sight, to a position where it is only viewable by the front seat passenger. In this position the map will display continuously to allow the passenger to aid the driver in navigation. The navigation system will also include an in-home trip planning module that will utilize the same data base (on compact disks) as utilized in the vehicle.

Finally, the passenger will have a full set of switches for all non-vehicle positioning systems. With these switches the passenger can aid the driver in system set-up and control. These auxiliary switches can be disabled by the driver if required (small children as passengers, etc.). While many other configurations can be developed, it is believed that many of the components of the suggested configuration should and will be adapted by the automobile industry.

The automobile of the future will be distinctly different from the driver's view point. The driver will have many more systems to demand his or her attention. It is imperative that that these systems be engineered and implemented into the automobile so that they are an aid to the driver and

not a burden. One idea must be paramount: The driver's primary focus must remain on driving the automobile in a safe manner. To ensure this idea is always in the forefront, human factors engineering must be heavily relied upon. In the automobile industry follows these simple guidelines then future aviation technology will be successfully transferred and readily accepted by the driving public.

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