of the

WORKSHOP ON GENERAL AVIATION ADVANCED AVIONICS SYSTEMS

Stanford University

November 5-6, 1975

Transcription Of The

WORKSHOP ON

GENERAL AVIATION-ADVANCED AVIONICS SYSTEMS

at Stanford University
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PREFACE

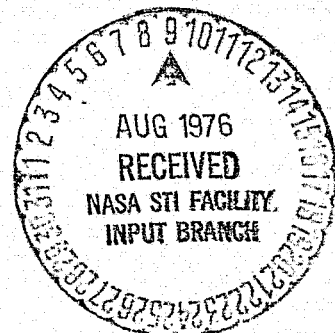STANFORD UNIVERSITY   *STANFORD, CALIFORNIA 94305*

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24 October 1975

WORKSHOP ON
GENERAL AVIATION-ADVANCED AVIONICS SYSTEMS

at Stanford University, Durand, Rm 450
November 5-6, 1975

The NASA Ames Research Center is implementing a program to provide the critical information required for the design of reliable, low cost, advanced avionics systems applicable to general aviation in the 1980's and beyond. As a part of this program, a Workshop is being held to (1): identify emerging electronic technologies in other industries that may have application to General Aviation Avionics and (2): provide guidance for the NASA General Aviation-Advanced Avionics Systems program.

Enclosed is a preliminary agenda. The first five agenda items will consist of semiformal presentations, and are intended to set the stage for two Panel discussions which are the heart of the Workshop. Although the Panels will be conducted in the presence of the Workshop attendees, it is intended that the discussion will be restricted to the pre-selected panel members. The Panels will then join the Workshop in joint discussion to formulate the final conclusions and recommendations.

The "General Aviation Avionics Overview" will be presented by general aviation airframe and avionics supplier representatives, with critiques by selected participants of the Workshop. Agenda items 4 and 5 are primarily intended to bring source material to the Workshop on electronic developments resident in advanced military and commercial systems, remotely piloted vehicles, the automotive industry, and the solid state electronic industry. It is intended that the participants in these two agenda items will focus on those technologies that they think could be beneficial to General Aviation.

The first Panel will discuss the application of advanced component technologies to General Aviation. This will include sensors, displays, integrated circuits, microprocessors, minicomputers, etc. This Panel will identify where NASA support could benefit the development of needed basic components for General Aviation through modifications of components produced for other industry groups. The Panel will also be asked to form a position on NASA support of other component developments such as the design of special purpose LSI chips that could be used by the General Aviation Avionics industry.

The second Panel will discuss system architectures for future General Aviation Avionics Systems. Such topics as the role of multiplexers, use of microprocessors or minicomputers, and the advantages of distributed vs centralized systems for General Aviation will be discussed. The Panel will then be asked to make recommendations for NASA sponsored research in these areas.

All members of the Workshop will then participate in an open discussion to suggest topics overlooked, and to prepare the way for the Workshop summary and recommendations. In the afternoon of the second day, small groups will be formed to draft portions of the Final Report.

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WORKSHOP SUMMARY

(DeBra, Denery, Mc Ruer, Smyth, Tashker)

General Aviation is a diverse market with product prices spanning
two orders of magnitude. This causes a need for a wide range of models
and types of equipment which, in turn, keeps the total number of any
one product very small in proportion to other industries. Nevertheless,
general aviation has aggressively adapted new technology to provide the
user with a wide range of avionics equipment from which to choose in
order to enhance the safety and utilization of general aviation aircraft
at a reasonable price. Factors that affect the cost of the different
lines of equipment are performance and level of capability. Reliability
is not sacrificed in the lower cost systems.

The price constraints, the relatively small market, and the severe
environment in which general aviation avionics must operate, present
a technological challenge for providing desired improvements. Of primary
importance are further improvements in reliability, ability to remove
heat from the avionics compartments, reduction of weight and space require-
ments, ability to interface different manufacturers equipment in a
convenient manner, time-sharing of displays, and reduction of the pilot
workload devoted to navigation, communication, and control tasks. As a
result of technology advancements in certain higher volume product lines,
there is promise that many of the avionic system improvements can be
attained at little additional costs over todays' systems. For example,
advances in the semiconductor and calculator industries allow sophisticated
computation at relatively low cost.

Sensors, displays, and actuators appear to be the principal problem
areas. The automotive, watch, appliance, and television industries have
similar needs and should be watched carefully for advances in these
technologies. The electronic market potential for the automobile industry
alone is more than one billion dollars. The sensor, display, and actuator
requirements for the automobile appear, in many ways, similar to those for

general aviation. Although the cathode ray tube still appears to be the least expensive high resolution general-purpose display, the watch, calculator, and television industries have been pursuing other display technologies extensively that could have application to General Aviation. The commercial and military aircraft fields have many requirements that are similar to those of general aviation and have, in many cases, developed a technology for achieving these requirements. However, the cost of these technologies is beyond the range of general aviation. It was the feeling of the Workshop that General Aviation Avionics will continue to depend on the fallout of both non-aerospace and aerospace applications.

Even with the chance of significant technology transfer from the above mentioned industry groups, it was emphasized by one participant that this would probably not result in significantly lower cost, but would allow more capability for the same cost. It was pointed out that today, even if the electronics components were supplied to the manufacturer at no charge, the cost to the user for the end product would only be reduced by 20 to 30 percent. The labor, packaging, retailing, servicing and warrantee protection--which account for the largest portion of the costs--would not be affected.

The Workshop was unanimous in its belief that the use of advanced digital technology will improve capability and thereby enhance safety. Automated procedures for navigation, communication, and control are only a few of many possibilities that exist. The recent developments of integrated circuit transducers might be usable with digital processors to provide estimates of all the aircraft states, including attitudes and attitude rates, thereby replacing the need for conventional gyros. The use of built-in test equipment to ease maintenance could become feasible without adding additional sources of failure to the unit as is the case in contemporary analog avionic systems.

It was felt that advanced digital avionics would evolve towards federated or distributed systems although some participants felt that the single central processor concept was still viable. In either case, problems associated with a common data bus were considered an area for

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NASA study. A major concern was that the data bus would become a critical single-point failure element. A caution offered in the design of integrated digital systems was the need for an approach that would allow evolutionary change so as not to become outdated with the advent of new technology.

The consensus of the Workshop was that standards, unless evolved naturally, would stifle innovative developments. However, a minority felt that standards in selected areas would be beneficial in future digital avionic systems. It was pointed out by one participant that the semiconductor industry was gradually standardizing component interfaces and that these standards should be adhered to in avionics design if possible in order to take maximum advantage of developments in other industries. The consensus was that any suggestions for standards should be developed by the "Industry", using existing organizations or professional Societies.

Several areas, in addition to the data bus design previously mentioned, were identified by the Workshop for avionics component research and development. It was the general feeling that work was needed in the development of displays, heat pipes or other means of extracting heat from the avionics compartment, and a replacement for the current attitude and attitude rate gyros. It was also the consensus that NASA should not pursue product development, but should support basic research in high risk areas. The consensus was that research and development on product improvement cannot effectively be done by the government and any attempt to do so would interfere with the free enterprise system. The development of special purpose LSI chips, for example, should not be attempted by NASA.

Although the Workshop was oriented towards the use of advanced electronic technology in avionics design, several recommendations for concept studies were suggested. It was pointed out that new navigation techniques such as Omega (VLF) or Global Positioning System (Satellite Nav) could lead to a single navigation system, thereby eliminating the need for a proliferation of different navigation receivers in the cockpit. Some basic research on how these systems can be used and data on the

accuracy that can be achieved would be beneficial to the manufacturers. Another study that could be of immediate benefit to the manufacturers is the development of a procedure to identify "infantile" failure with a greater success than attainable with current methods. An airframe manufacturer indicated that up to 30% of the avionic components he received had to be returned for repair or replacement before the aircraft left the factory. It was agreed that success in the development of a better procedure would result in a reduction in costs to the user.

There was some discussion concerning the worth of developing Category III capability for general aviation. The feeling was that Category III capability will not be a requirement for general aviation in the 1980s, and that even autoland may be beyond economic reality. The use of HUD for lowering general aviation landing minimums to Category II or Category III was also discussed. At least one member of the Workshop felt that NASA should study the use of HUD for general aviation. However, there did not appear to be general agreement with the need for this type of study.

Other recommendations concerned the development of an improved communications system, collision avoidance system, power plant or engine management systems, and an overall study to reduce the pilot workload. The latter study received considerable endorsement with an emphasis on defining the information that should be presented to the pilot and how it can be time-shared using a few basic displays.

Finally, there was some discussion concerning the cost of getting a new system certified by the FAA. FAA regulations, although not intended to inhibit innovation, put the burden of proof concerning safety of a new device on the originator of the device. The cost of proving the safety of the new concept, in some cases, has caused the originator to stay with existing but less efficient systems. It was suggested by one participant that NASA might be able to assist the introduction of these new devices by performing some of the tests required by the FAA for certification. Although this was an interesting recommendation, it did not receive further discusssion.

DEAN KAYS: One of the more pleasant functions that I seem to have
as Dean of the School of Engineering is to welcome groups such as
this to workshops, symposiums, programs, and conferences, all on
behalf of the University and particularly, on behalf of the
Stanford School of Engineering. Events such as this, and we have
many of them, are just one of the several ways by which we attempt
to keep ourselves involved. We take great pride in being one of
the outstanding centers in the country in both electronics research,
and in the production of very highly trained people in the
electronics area.

What particularly interests me today is that you are here talking
about general aviation avionics, and although Dan DeBra may want
to contradict me, I can't recall any occasion in the past where
general aviation has formed the subject of a conference on this
campus, although I certainly do remember many, many dozens of
conferences concerned with space navigation, radio physics, and
numerous other problems associated with astronautics. Now I hope
those days aren't totally gone, but in the meantime, I think we
should all be happy to see attention being paid to some of the
problems a little nearer earth and of great concern to a large
body of the citizenry.

I promised Dan that I wasn't going to talk to you for a long period
of time and I wasn't going to do any more than welcome you here to
the campus, because I know you have a very very busy schedule, both
today and tomorrow. We're delighted to have you here on the campus
and trust that your stay is going to be both interesting and pro-
ductive. Thank you very much.

DR. De BRA: Thank you very much for coming, Bill. Dallas Denery and
I of course both add our welcome to you.

Now in the nature of what we're trying to do here, I thought maybe
I might start by just telling a little story to illustrate a point.
In the Air Force, they've done quite a bit of animal training over
the years and it wasn't too many years ago that they discovered
that they had two really extraordinary animals: a couple of racoons
that just seemed to test way-off scale from anything they'd ever
had before. One of them has a little kind of tiny tail but he had
a great big head and intellectually, he just was way, way out in
front. Eventually through the testing and some special training,
they sent him out here to Stanford and he got his Ph.D in aero-
nautics and went on to work in some of the Air Force laboratories
and became extremely well known and respected for his technical
evaluation of aircraft and their behavior. His buddy had a little

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bit smaller head, but a great big bushy tail, and he just tested
way-off scale on motor skills and they eventually sent him to
flight school and eventually after becoming an excellent fighter
pilot, he went on to the test pilot school down at Edwards and
became one of the most respected test pilots. Well, the Air Force
had a problem with an airplane and there were some difficulties.
The big-headed racoon was called in and he decided, after looking
at the data, that he was sure this thing had never occurred in any
kind of testing situation; there were no equations to describe the
behavior, and that it really was going to require some kind of
observation of the phenomenon in flight, so he requested a flight
test.

At Edwards, and there quite by accident, he was pleasantly sur-
prised to find that the test pilot assigned to this flight was his
'ole buddy, the other racoon. So they went up, and sure enough,
the airplane got in trouble and they had to punch out and they
floated down on their chutes, and got into the woods, got their
stuff all put away where it could be picked up later, and started
to walk their way out. Zap! they both stepped into a trap almost
simultaneously. The big headed racoon kind of looked the situation
over and said to his buddy, "You know, we're in real trouble. If
the hunters come back and find us in these traps, we're going to
end up as skins on the wall. There's just no way we're going to
explain our way out of these things. It really calls for some
special action." So he leaned over and chewed off his paw and said,
"Come on, we better get going," and he started to hop down the
trail. Pretty soon he noticed that his buddy wasn't with him, so
he turned around and went back and sure enough, here was his buddy
with a long, sad look on his face. And he said, "What's the matter?
I showed you a solution to the problem." The other racoon kind of
shook his head and said, "Well, it may have worked for you, but
I've chewed off three paws already and I'm still locked in."

There's some basic problems with a technology transfer, and what we
wanted to emphasize here was that this is not an audience; that each
of you will not be giving a presentation to an audience, but rather,
we're a group of specialists from a fairly heterogeneous background;
that the technology that each of you know could be applied to general
aviation. It isn't going to transfer without difficulties along the
way, and these pet ideas of how one can take a little piece of tech-
nology and put it into general aviation should be challenged. I
think you'll find that the group here is both very constructive in
their attitude toward seeing that new technology moves into the area,
and is going to have some concerns about how that gets done and
whether it can be done effectively. And so what we're trying to
do here is to get you to get your own thoughts out, to make them
available for other peoples' thinking, and also to get them aired
with a group that can give you some constructive comments that may
even change your own attitudes about some of these things.

What we've scheduled here is about 10 minutes of discussions after
these talks that have been scheduled for the first part of the
morning. During that 10-minute period, we'd like you to feel as if
you're making as much of a contribution as the person who was asked
to make the preliminary comments.

We expect these proceedings to be available some time by early
February, 1976, and the uncertainty at this time, of course, depends
a little bit in the cooperation that we get. We may come back to
you for clarification of the things that have been said during the
course of the Workshop. Because the numbers got a little larger
than we originally intended, we had hoped originally to be able to
go around the room and ask each person to introduce themselves;
we've decided that that would take a little too much time, so we hope
that during the coffee break you'll continue with what was going
before we started--namely, of introducing yourselves to each other
and getting to know each other well.

I certainly want to thank you all for coming, and your cooperation,
and to each of you for helping us put together an agenda which I
hope will be not only interesting while you're here, but useful.

DR. DENERY: Before we get on with the Workshop, I would like to make a
few comments concerning the NASA General Aviation-Advanced Avionics
Systems Program in order to put the Workshop into proper perspective
and perhaps provide a little better definition of its purpose. The
objective of the General Aviation-Advanced Avionics Systems Program
is to provide information that would be useful for the design of
low-cost advanced avionics suitable for general aviation in the 1980's
and the 1990's. We are not talking about today's systems, but are
trying to look ahead to tomorrow's needs.

The intent is to look at both functional capabilities such as new
and novel techniques for navigation, flight control, and powerplant
management, as well as ways of implementing these functions into
avionics hardware--the emphasis in the latter being on the utiliza-
tion of new technology and systems integration. The approach that
we're taking to accomplish these objectives is shown in Fig. 1.

The first step represents an attempt to forecast what the environment's
going to be within which general aviation will have to operate in the
next 10 to 20 years. It is an attempt to estimate what the National
Air Space System is going to be like, and specifically, what avionics
requirements are going to be imposed on the general aviation pilot
as a result of that system.

The second step is an electronics forecast. The intent is to try
to assess the trends in electronic technology over the next 10 to 20
years in the areas of sensors, displays, processors, and actuators,
to determine which of these, if any, will offer significant benefit
to the general aviation pilot.

PROGRAM SCHEDULE

TECHNICAL APPROACH	1975	1976	1977	1978	1979	1980	1981

FORECAST ATC ENVIRONMENT

FORECAST ELECTRONICS TECH.

SUBSYSTEM CONCEPT STUDIES

AVIONIC COMPONENTS R&D

DESIGN & EVAL. (IN FLIGHT)
TOTAL AVIONICS SYSTEM:

   AVIONIC STANDARDS

   COST-BENEFITS-ANALYSIS

   PRELIMINARY SYSTEM DESIGN

   FINAL SYSTEM SPEC.

   FINAL SYSTEM DESIGN

   SYSTEM FABRICATION

   SIMULATOR EVALUATION

   ENG. FH EVALUATION

   GUEST PILOT FLIGHT EVAL.

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FIGURE 1

(Denery Cont)

The third step is a series of subsystem concept studies. The idea here is to look at new and novel techniques for navigation, flight control, and powerplant management. Work is currently ongoing in that area, both at NASA-Ames and at NASA-Langley. Figure 2, which I will discuss later, indicates what work is presently going on at Ames and Langley. Any questions concerning work ongoing at Ames can be addressed to me. Questions concerning work ongoing at Langley should be addressed to Jack Reid, who is responsible for the general aviation work going on at the Langley Research Center.

The fourth step is an attempt to develop or evaluate electronic components that could have application to general aviation. Right now, we do not have any work identified in this particular area. Hopefully, one of the outcomes of this Workshop will be an assessment of what, if anything, NASA should be doing in avionics components R&D.

Finally, we get down to the heart of the program which is the design and evaluation of concepts that could lead to a total avionics package for general aviation. The emphasis here is in demonstration of new technology and systems integration. There are several sub-steps that we will be considering in this part of the program. First, we will be addressing the question of the desirability of having some sort of industry controlled standards. The standards considered will range the full gamut--anywhere from cockpit panel layout to data format. We will also be conducting a cost-benefits analysis. The intent is to monitor the tradeoffs between system cost, maintainability, reliability, and other factors that will influence the eventual use by general aviation of the concepts being considered.

We have just, within the last week, released an RFP for the design of a candidate avionics system for general aviation -- a total integrated system. This RFP is for a design and not for hardware fabrication. It will be done under contract and could result in more than one contract if more than one promising concept is proposed. The intent is to solicit ideas from outside sources for the design of general aviation advanced digital avionics systems.

The results of these earlier steps will go into specifying a final system in 1978, which we will then have designed and built. The final system design will incorporate as many concepts that warrant further evaluation as possible. The system will then be built, installed in a simulator for further evaluation, and eventually installed in a Cessna 402B aircraft in order to gain some experience with the hardware concepts that have been proposed, and with the functional capabilities that have been evaluated. The flight evaluation will include a guest pilot evaluation during which pilots from different segments of the general aviation community, both private and corporate, will be invited to participate and to look at some of the pilot system interface questions.

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SUBSYSTEM CONCEPT STUDIES

AMES

- GUIDANCE AND NAVIGATION
- FLIGHT CONTROLS UTILIZING LOW-COST SENSORS
- POWERPLANT MANAGEMENT

LANGLEY

- FLUIDICS
- STALL WARNING SENSORS
- NAVIGATION (OMEGA)
- FLAT PANEL IFR DISPLAY AID
- ANTENNA DESIGN

FIGURE 2

(Denery Cont)

I would now like to go to Fig. 2 which, as I mentioned previously, will give a breakdown of the subsystem concept studies currently on-going at Ames and Langley. At Ames we have a program ongoing in guidance and navigation systems for general aviation. That program is presently based on the use of multiple VOR and DME information using frequency scanning techniques, but will be expanded to include other aids in the near future. We have also initiated a program in flight controls utilizing low-cost sensors. This study will involve both inhouse and contractual work. We are in the process of negotiating a contract with Stanford University to continue some work that they had already initiated in this area. Finally, we plan to initiate a program in powerplant management, including diagostic testing of engines, emission control, fuel efficiency, and automation or consolidation of some of the manual controls. As shown, Langley has programs ongoing in the use of fluidics for flight control systems, the development of stall warning sensors, the use of Omega for navigation, the use of a flat panel display as an IFR display, and basic antenna design.

So with that, I'd like to get on with the Workshop. Any questions concerning the work being done at Ames or Langley may be addressed to either myself or Jack Reid.

QUESTION: Dallas, who is doing the ATC environment study?

DR. DENERY: Aerospace Systems Inc. has been awarded that contract. The start date was November 24, 1975. Honeywell is doing the electronics technology study.

MR. GORHAM: Just one other point, and this may be something still on your program. You've got guest pilot flight evaluation. I hope that there is a whole regular series of guest pilot evaluations, right from the beginning.

DR. DENERY: Yes, we do have the Cessna 402 aircraft which will be used for flight testing of various subsystem concepts, and we will be bringing in guest pilots throughout the program.

DR. DeBRA: To get things started, we have two different points of view to give us an overview to start. The first of these will be the airframe manufacturer's point of view, Paul Vanden Berge representing Cessna.

OVERVIEW: AIRFRAME MANUFACTURER

VANDEN BERGE: General aviation avionics is, without a doubt, the broadest, most complex subject that can be discussed relative to avionic systems. Due to the wide variation in types of aircraft and in price range in the general aviation market, avionics suppliers are required to

produce systems compatible with the $8000 small aircraft flown for fun on the weekends by the local butcher, as well as systems for the $3,000,000 high performance jets that are owned and operated by the billion-dollar corporations.

To add to the complexity of the situation, general aviation is frequently the testing ground for new systems, components, and techniques. The general aviation market can normally respond more quickly to new technology and new systems than can the airlines or military due to our much higher production rates and our faster response rates in new aircraft. Unfortunately, the cost of advanced systems in technology is sometimes out of our reach until it is refined into a product that can be produced in larger quantities at reduced cost. We've come a long way from the day when a general aviation aircraft with a two-watt VHF Com system and a superhomer was considered well equipped. Today, essentially all aircraft must fit into the same air traffic control system and be equipped to meet the requirements of that air traffic control system. The FAA, with the help of Congress, has pushed us along in the interest of safety and control from the ground. Let's take a quick look at the types of systems most commonly used in general aviation today.

First is shown some systems to communicate with the ground which include VHF, HF, transponders, altitude reporting and electronic locator transmitters to assist rescue operations in locating a downed aircraft. All of these systems, with the exception of HF, are required on most flights in the U.S. today.

NAV systems required on-board are, according to the regulations, those commensurate with your intended flight. The systems installed on any given airplane, however, will depend completely on how and where the owner intends to use that aircraft. VOR, localizer, glide-slope, and marker beacon are, of course, the most common systems used domestically. DME provides a lot more information about your location and is required on flights above certain altitudes.

ADF is commonly used where the VOR, DME, or the VORTAC system is not well established. VLF and Omega are relatively new systems to general aviation that provide long range navigation data from a few ground based transmitters. We have great hopes that VLF and Omega will some time in the future allow us to reduce the quantity of navigation systems required on-board these aircraft.

Inertial and Doppler systems are self-contained and are very useful for long range navigation, especially over the ocean where you're out of range of most other NAV aids. Microwave landing system is the ILS of the future and currently under development although there are few systems being installed in general aviation today. I would include weather radar and radar altimeter in the list of NAV systems commonly used in general aviation since they're intended for special purpose navigation such as flying through or around storms or on approach.

(VANDEN BERGE Cont)

An assortment of other systems are commonly used to take data from
the NAV systems and massage it in such a manner that it will control
the aircraft and display information to the pilot in a convenient
manner to reduce his work load: autopilot, flight director, RNAV/
VNAV, RMI, GPWS, and map plotters. This certainly is not a complete
list of avionics systems available today, but I've tried to include
those that are most frequently used in the general aviation aircraft.
Now, let's take a look at a few typical avionics packages.

I've tried to isolate segments of the general aviation market by
price, weight, and type of avionic systems normally installed. The
first segment is the $15,000 to $25,000 aircraft such as the
Cessna 172 (Fig 3). This category of aircraft is normally used
for training and VFR flight, and the typical package will include
a single NAV, a single COM, ADF, transponder, and audio system. If
the aircraft will be used for IFR flight or instrument training as
many of this class are, the second NAV/COM, a glide slope, marker
beacon, DME, altitude reporting, a single axis autopilot (a wings-
leveler type of autopilot), and a locator beacon are added. Look
what happens to the price on the well-equipped airplane: $15,000
is nearly equal to the price of the aircraft. And 68 lbs of weight
will often mean an hour's less range if all the seats are filled.

Here is shown the $40,000 to $70,000 aircraft such as the Cessna
210 (Fig 4). I think many of the high performance single engine
airplanes fit into this category--most with retractable gear. A
typical package would include dual NAV/COM, ADF, glide slope
marker, transponder, again the single-axis autopilot, audio and
the locator beacon, for around $11,000 and 65 lbs of weight. Now
in addition to that, on the well equipped packages, we have added
the DME, RNAV, HSI, a two-axis autopilot which gives you the pitch
control and altitude reporting. The package has gone up to 128
lbs of weight then, and that's for a single engine aircraft.

Next we show, in the $70,000 to $130,000 category such as the
Cessna 310 (Fig 5), we have about the same package, dual NAV/COMs,
ADF, etc., although the well equipped airplane will normally get
a better quality of radio equipment. It's a step up in the quality
and some of the features and performance that are available in the
equipment. This category will include an RNAV, generally some type
of flight director, and a small radar system. The flight director
that goes in this kind of aircraft will generally be the most basic
type of system integrated with the autopilot and using 3" displays.
However, they work well and provide a lot of information for the
convenience of the pilot. Only in the last five or six years has
an integrated flight director and autopilot system been available
in the $8,000 to $15,000 price range--within the reach of most
large single and light twin owners.

AVIONICS   PACKAGE
$15,000 — $25,000   AIRCRAFT
(CESSNA 172 SKYHAWK)

<u>TYPICAL</u>   PRICE = $5,000   WT = 27 LBS

      NAV/COM   TRANSPONDER

      ADF   AUDIO

<u>WELL EQUIPPED</u> PRICE = $15,000   WT = 68 LBS

ADD — NAV/COM   DME

      GS   REPORTING

      MB   AUTOPILOT (1 AXIS)

      ELT

FIGURE 3

AVIONICS   PACKAGE
$40,000 – $70,000   AIRCRAFT
(CESSNA 210 CENTURION)

TYPICAL   PRICE = $11,000   WT = 65 LBS

DUAL NAV/COM   TRANSPONDER
ADF   AUTOPILOT (1 AXIS)
GS   AUDIO
MB   ELT

WELL EQUIPPED PRICE = $29,000 WT = 128 LBS

ADD – DME   AUTOPILOT (2 AXIS)
RNAV   REPORTING
HSI.

FIGURE   4

AVIONICS   PACKAGE
$70,000 – $130,000   AIRCRAFT
(CESSNA   310)

TYPICAL   PRICE = $23,000   WT = 113 LBS
DUAL NAV/COM   TRANSPONDER
ADF   REPORTING
GS   ELT|
MB   AUDIO
DME   AUTOPILOT (2 AXIS

WELL EQUIPPED PRICE = $41,000   WT = 160 LBS
ADD: DUAL NAV/COM +   FLIGHT DIRECTOR
ADF +   RADAR
RNAV

FIGURE 5

AVIONICS   PACKAGE
$150,000 — $300,000   AIRCRAFT
(CESSNA   421)

TYPICAL   PRICE = $43,000   WT = 163 LBS

DUAL NAV/COM	TRANSPONDER
ADF	REPORTING
GS	RADAR
MB	AUDIO
DME	AUTOPILOT (2 AXIS)
RNAV	FLIGHT DIRECTOR

WELL EQUIPPED PRICE = $81,000   WT = 260 LBS

ADD: | | |
|---|---|
| DUAL COM + | 2nd TRANSPONDER |
| DUAL NAV + | 2nd GLIDE SLOPE |
| ADF + | RMI |
| RADAR + | RADIO TELEPHONE |
| AUTOPILOT + | ALT. ALERTING |
| FLT. DIR. + | |

FIGURE 6

Here is the $150,000 to $300,000 class of airplanes which includes the medium to heavy pressurized twins--most commonly owned by corporations for executive transportation (Fig. 6). This class of airplane is normally well equipped but notice the weight, especially for a very complete package. The well equipped prices and weights there reflect the weight and cost of remote avionics systems, about $81,000 and 260 lbs of weight.

Finally, in the price categories, is the half-million to two-million dollar aircraft such as the Cessna Citation (Fig. 7). This equipment covers the turboprops and most of the business jets. This is all top quality avionics and the package will vary widely depending on the intended use of the aircraft. The well equipped airplane has $210,000 worth of avionics in it at 480 lbs, including dual flight directors, a second transponder, and a second DME. Some aircraft will get dual VLF systems, an inertial system, Doppler, or very sophisticated RNAVs if intercontinental flights are to be common. Prices of the avionics can hit half a million with the weight of the package being well over 600 lbs.

All avionics systems and installations are bothered by many of the same problems. Reliability is probably the No. 1 weakness that needs attention. The more expensive systems used in the higher priced aircraft are generally more reliable than the ones used on the smaller aircraft. However, the larger aircraft needs so many more systems and more complex systems that the failure rate of the avionics package on the larger aircraft is equal to or greater than that on the small aircraft. Avionics maintenance is one of the most significant costs of aircraft ownership.

We have got to find a way to improve the reliability of avionics systems and installation. I believe a lot can be done with component and packaging technology. If we need a goal for improvement, I think that we should shoot for an individual system MTBF of 10,000 hours. Many of the systems in use today are experiencing less than 1,000 hours meantime between failures. Improved reliability would not only result in a reduction of maintenance costs; it would reduce the quantity of systems that would be required on an aircraft. In many cases, the technology for the improved reliability is available but not within the price range of general aviation. I suspect the general aviation market may be willing to forfeit any new system developments for the next five years if the avionics industry could, in that time, improve the reliability of today's systems by a factor of 3 to 5.

Heat, by itself, would not be of much concern except for its tremendous effect on reliability. We were all glad to see the demise of the vacuum tubes, with the red hot filaments, and the "inherently reliabile solid state devices" come on the scene. But that led to much denser packaging, and with lots of encouragement from the aircraft manufacturers to smaller boxes. I'll bet the thermal density

AVIONICS PACKAGE
$500,000 — $2,000,000   AIRCRAFT
(CESSNA CITATION)

TYPICAL   PRICE = $140,000   WT = 340 LBS

DUAL COM	TRANSPONDER
DUAL NAV	REPORTING/ALERTING
DUAL GS	AUTOPILOT (3 AXIS)
DUAL MB	FLT. DIR.
ADF	ADC
RADAR	DUAL RMI
DME	RNAV
DUAL AUDIO	

WELL EQUIPPED PRICE = $210,000 WT = 480 LBS

ADD: 2nd FLT. DIR.   RAD. ALT.
     2nd TRANSPONDER RADIO TELEPHONE
     2nd DME   VLF

FIGURE 7

of the average Com system today is greater than it was 20 years ago.
We must find the means either to generate less heat or get rid of it
more efficiently. In the last two or three years, the awareness of
this problem has increased considerably. Many companies have done
some in-depth studies on reliability, primarily relating to tempera-
ture. The installers are now giving it more attention, but a fan
blowing air around the box will never produce the desired result.

Cost and weight have been previously discussed but deserve a lot of
attention. Again, improved technology could attack both of these
problems. Note what happened to the pocket calculators. Airplanes
are built and sold to carry people and cargo efficiently. The weight
of the avionics package reduces either the amount of cargo or people
on the airplane, the aircraft performance, or its range. Aircraft
manufacturers commonly spend thousands of dollars to increase the
payload as little as five pounds.

Interference between systems exists to some degree on any airplane
that's ever been built. A wandering course deviation pointer, and
maybe a flag on the NAV's when transmitting on the Com, fuel-flow
meters that go berserk when you key the HF, the ADF pointing at the
A-C inverters, the autopilot disconnecting when the coffee pot is
plugged in, and on and on. All these interferences and hundreds
more have all been experienced at some time or another. Most of the
interferences can be solved, at great expense. But when the only
solution becomes a filter that occupies two cubic ft. and weighs 45
lbs, you find that you can live with your NAV needle jiggling a little
once in a while. Any avionics R&D program must include a thorough
evaluation of noise generated by the system and the system's sus-
ceptibility to unwanted signals.

Panel space is at a premium on any aircraft. You'd think the larger
aircraft wouldn't have this problem, but due to the greater number
of systems required on the large birds, it is really more of a
problem than in the small ones. In most cases, the human factor or
aspects of a readable display and a controllor switch you can get
your fingers on are the controlling factors on the panel unit size.
I think the only hope in this area lies with reducing the number of
controls required rather than simply making them smaller. Hope-
fully we can get some further advice on this later today when we talk
about displays.

To summarize, I would suggest a large portion of the R&D funds avail-
able throughout the avionics industry, and the government be dedicated
to advancing technology for improved reliability. This improvement
will provide the greatest value for the general aviation community.
Second, we must be cautious of our tendency to rely too heavily on a
"centralized computer." Some of the general purpose computers
currently being developed for aircraft have the capacity to handle
the entire navigation requirement with capacity left over to perform
numerous other functions such as fuel management, engine instrumen-
tation, etc. We must be concerned with what happens when that

(VANDEN BERGE Cont)

computer fails, and leaves the pilot with more than a control wheel
in his hand and a blank look on his face. Third, long range avionic
system development should be directed towards replacing various
types of NAV aids in use now with a single world-wide system. This
would be a system that provides all the NAV information required in
the cockpit and will get an airplane anywhere, anytime, and by any
route the pilot chooses. It must handle precision approaches, as
well as intercontinental flights. The navigation package in all
aircraft would then consist of two or maybe three of these world-
wide systems.

I appreciate the opportunity to participate in a Workshop of this
nature. It's one of the few opportunities we have to get together
and collectively look ahead and figure out where we go from here. I
think if we all pull in the same direction, we'll get there faster
and at far less expense to any of us. Thank you.

DR. De BRA: Mr. Swearingen of Beech Aircraft will help us with the
discussion.

MR. SWEARINGEN: There are a couple of additional things I want to point
out. It was mentioned that the environment to which an aircraft is
subjected to is quite harsh. Imagine the effects on the avionic
system when an aircraft is parked out in the Southwestern desert for
a day, sitting out in the sun with temperatures in the avionics com-
partments area reaching 180°. And then all of a sudden subjecting
them to the temperatures experienced when flown at higher altitudes.
It seems throughout the industry that these problems are continually
haunting us but unfortunately this is the environment we have to sub-
ject the avionics to, because we are not going to change the usage
of the aircraft.

I'd like to amplify Paul's statement on weight and dollars spent.
Twenty to forty percent of the cost of the aircraft comes out of the
cost of the avionics system, and as you say, people sometimes must
be left behind or fuel off-loaded, just to have these systems avail-
able in the aircraft. Of course, this significantly limits the air-
craft usability. When so many dollars have been committed to this
aircraft it is quite difficult for the end user to tolerate these
restrictions.

The other thing I'd like to amplify on is the work load that the pilot
experiences when he flies from point A to point B. Most of the time
is spent with the communications system: the communications work load
is quite prohibitive along with the navigational work load. This is
an area where we feel that something must be done to help the pilot.
From the manufacturer's point of view also, the work load required to
manage avionics systems takes away from the time required by the pilot
to monitor aircraft systems and perform his other flight duties.

(SWEARINGEN Cont)

We also feel there needs to be some significant improvements in the pilot's ability to navigate from point A to point B. This is an area where we felt use of RNAV systems or inertial systems would greatly enhance his abilities but some of these systems are being used now and there are some restrictions imposed on the pilot's use of these systems. When we talk about selected RNAV routes, rather than just the ability to fly from point A to point B without unnecessary coordination with the ground, this limits the use of the total capabilities of these systems.

I think also when we speak of the future, we need to speak about areas of display technology and control devices. The avionics systems and controls are in some instances, utilizing well over half the available panel space in the aircraft. So we have to agree with Paul's list of areas where we need to employ greater technology and advancements.

Another area I'd like to mention is how the user requirements change for even one particular aircraft. The user may be flying into Washington National one day, and then out to Oshkosh or Cheyenne, Wyoming the next day, so he needs extreme versatility in his avionics systems and this versatility must be included by the manufacturers as far as implementation in the systems, and also the agencies dictating the avionics requirements for particular users. An area that I think we could use significant work in is a modular approach to avionics which gives the end user the ability for quick changes in his avionics to meet the requirements for a particular mission. Airframe manufacturers are also confronted with significant problems since it is necessary to interface varieties of systems into the aircraft, since we're not always installing an all-King or all-Collins system.

We appreciate the opportunity to be here. We would like the opportunity to make our inputs into the systems since we sometimes feel that we have these systems requirements almost jammed down our throats. I'd like to leave the remainder of our time open to some points of discussion and I'd like to point out some good gentlemen to you to direct questions in this area: Mr. Jay Johnson and John Mucci from Beech Aircraft who are responsible for incorporating the avionics systems and design into our production aircraft.

DR. De BRA: Any questions for either speaker or any comments that you'd like to make in general?

MR. SCHOENMAN: In these types of aircraft, cabin space is one factor that isn't going to expand to any great degree, and we all know that the number of functions seems to be growing and the only choices we are left with are: (1) to make the instruments themselves smaller, which is objectionable from the pilot's operational standpoint; (2) integration of these functions to simplify the navigation system that's developed by the FAA. I would like to get your opinion on that.

MR. SWEARINGEN: I think electro-mechanical displays have been well inte-
grated and I think we've reached a point there where perhaps we are
overloading the pilot's capabilities. Timesharing of displays is an
area of possible advancement. The displays would be devoted to the
requirements for a particular flight segment and could be switched
for different segments.

MR. VANDEN BERGE: That's very true. I agree we can't make anything
smaller, but there's a lot of instruments on the panel that you don't
need a continuous display from, and I think that those are the areas
that need to be attacked by timesharing or some kind of a CRT type
display that can show you anything you need but when a problem
develops, display all the information relevant to that problem. Many
functions don't require full-time displays. For instance the engine
instrumentation is not something that is needed 100 percent of the
time but it sure takes up a lot of panel space.

MR. ALBERTS: We did a study called the Integrated Information Presenta-
tion and Control System with Boeing, in which we showed that a tacti-
cal fighter or bombing mission could be performed as well with a
single CRT as with two CRT's. It was a display by exception
concept. Only those things that were changing that were needed for
that phase of the mission were displayed. LSI and digital scan con-
verters are making this a very feasible thing to do. I refer you to
that particular study because it was well done; it was flown by test
pilots and had pilot acceptance which is very important.

DR. De BRA: I wonder if we'll....we'll take an opportunity to get some
of these comments as we do, but I would rather keep to the schedule
if we could right now. We now have the avionics manufacturers' point
of view. Jerry Farrar of King Radio will give the first talk and then
the subject will be taken up by George Lucchi of RCA.

OVERVIEW: AVIONICS MANUFACTURER

MR. FARRAR: The first thing that I would like to talk to you about is
the constraints under which we as avionics manufacturers must operate.
The most dominating constraint is the free enterprise system in which
we all live and do business. If our company's goal is anything less
than offering avionics with the maximum utilization and reliability,
at the lowest cost, then we won't be in business very long.

The maximum utilization is fixed by product definition. It is up to
us to configure our products so that they perform 100% of the intended
functions while minimizing the necessary pilot interfaces. We feel
gimmick features are not acceptable in avionics. They increase the
cost of the equipment, reduce its reliability, and we feel, reduce it's
salability, since pilots know which features are useful and which are
not.

Maximizing reliability while minimizing cost is the most challenging engineering task we have. We definitely can't use Mil-Spec components and minimize cost. Therefore, we design with commercial grade components and derate them in our designs to increase their reliability. Smart or ingenious engineering designs are the best way to obtain reliability and low cost. The engineer who can design a circuit, a unit, or a system that satisfies the specified requirements with the fewest number of parts has, at the same time, maximized the reliability and minimized the cost.

Labor is a large part of the cost in avionics. In fact the costs of assembly and testing a piece of avionics equipment are usually a greater percentage of the total manufacturing cost than is the cost of the components. It therefore falls on the Engineering Department to design radios that are straightforward in construction and with more than adequate tolerance limits. The unit that is built in the shortest time, with the fewest errors that must later be found, is the unit that is the most reliable and that can be sold for the lowest cost. Testing a piece of avionics equipment is time consuming and expensive, because it requires complicated test equipment and a high grade of technician. The engineer who designs a radio with the minimum number of test adjustments and with the most repeatable characteristics is the best man for our industry.

Operating temperature is the greatest factor in avionics reliability. From all the data we have been able to gather, on the average, a component that is operating in an ambient temperature of 65°C will have a failure rate 50 times greater than if it were operating at 25°C. That number goes to 500 times if the component is operating at 85°C. Therefore, it again falls on the Engineering Department to design equipment that operates cool, not only as a unit by itself, but also when installed in an aircraft with a full avionics system.

Ease of installation is also a very important aspect of avionics engineering. It is a sales feature in that the distributor who uses less of his profit to install a piece of avionics equipment will sell it harder. It is a reliability factor because if it is easy to install there is less chance of an error that can later cause problems.

I can summarize all these constraints in the following way. Engineering for Engineering's sake only is not acceptable in a commercial avionics company. Engineering for a product has to be our goal.

I was asked to comment on what factors cause avionics boxes to cost as much as they do. About two weeks ago I received a letter from a young man attending college in Florida. He was giving a paper on a grand scheme he has using a television screen in an aircraft to perform multiple functions in the cockpit including a major portion of the air traffic control problem. His ideas were reasonable except

for the last sentence in his paper. It said, "I feel this system could sell for between $50 and $100 because anybody can buy a black and white television for that price today." I think there is probably a good comparison to be made here. Why does avionics cost approximately 10 times more than a black and white television? The first factor would be the increased complexity of avionics over a black and white television. The amount will depend on which piece of avionics equipment you are comparing, but on the average, avionics are more complex than a television.

Quantity sold is the next factor. A black and white television manufacturer will probably build 1,000 sets per day on his line while our quantities run from 1 to 50 depending on the line. Since their quantity is so high, their parts cost are very low. They can also use a lesser grade of component since the operating environment of a television is a constant room temperature. They are also able to highly tool their products due to quantity, which keeps the mechanical piece part cost low. Again, because of quantity, they can afford to use highly automated equipment on their production lines.

The higher discount structure to the avionics distributor is yet another factor. This higher discount structure is necessary to cover the cost of installation, the lower sales volume he has, and the cost of the required and expensive specialized test equipment he must have to satisfy his warranty obligations. Also in most cases when a customer buys a piece of avionics he gets everything he needs for a working system. That is, the antenna, connector, etc. He doesn't get these when he buys a television.

Warranty costs are higher for avionics. Not only is specialized test equipment necessary, but a higher grade of technicians is required. This raises the cost of warranty labor to between $16 and $20 per hour.

Factory overhead is a very large cost in avionics. While the television manufacturer will probably have 3 lines running which produce 1,000 units a day; our factory has 125 lines that produce from 1 to 50 units a day. The supporting functions necessary to keep 125 separate lines running is tremendous.

The large amount of engineering expenditures per unit sold also increases the cost of avionics. Last year 7 1/4% of our total sales dollars went back into engineering. This is necessary due to the intense competitive pressures in the avionics market, and the fast evolving state-of-the-art of our industry.

The final factor is due to federal requirements. These requirements, which are necessary to insure safety of flight, not only impact the complexity of the basic units themselves, but also dictate that our manufacturing process, quality control, and configuration control must meet the Federal Aviation Regulations.

Considering all these factors, the only answer I have is that avionics will continue to cost more than a television, and I do not see any change in this situation in the future. The question could then be asked, "What does the pilot of a small aircraft give up when he buys the lowest cost avionics?"

The first is operational flexibility. An example of this is the lower cost NAV/COMs. These units usually share one receiver for both the navigation function and the communication transceiver which means that only one of the two functions are available to the pilot at any one time. This is an acceptable sacrifice in many cases since the aircraft owner can save $1,000 or more on the purchase cost of the shared receiver NAV/COMs.

Manual operation of functions versus automatic is another tradeoff in the lower cost units, but in the cockpit of an aircraft where the work load is small this again is an acceptable sacrifice for the savings in cost.

Receiver selectivity is often reduced in the lower cost units. This reduction of selectivity is only to the point of operational acceptability and does not in anyway jeopordize safety of flight.

Reliability is one thing the pilot does not give us when buying the lower cost avionics. We use the same grade of components and the same care in construction and testing of the low cost units that we do in the high price units. Because of this and because of the fewer number of parts, the low cost units will give the owner reliability equal to, or greater than, the more complicated systems.

The final question would be, "Does the Owner give up safety of flight when he buys the lower cost units?" Our answer is NO. In fact, we feel that by offering low cost units we increase his safety because he can now afford equipment and functions that would otherwise be too expensive for his aircraft.

Finally, I was asked to comment on how avionics will evolve in the future. As with any prediction, a look at past history is probably the best starting point. The first product ever sold by King Radio Corporation was a KY 90 communication transceiver. The KY 90 and 90 channel crystal-controlled unit that had a remote power supply and sold for $995 in 1960. The design was all tubes except for germanium transistors in the power supply and audio amplifier. The components were hand wired from point to point on the bottom side of the chassis.

A product King presently produces is the KX 145 with the associated KI 205 indicator. This is a shared receiver NAV/COM system and provides the pilot with 720 communication channels or 200 navigation channels complete with its own NAV converter. It is totally solid state and all of the components are mounted on printed circuit boards

that are wave soldered. This unit sells for $895 today. When you
consider inflation, the old KY 90's price today would be $1,885. So
you can see the KX 145 offers the pilot more than three times the
functional capabilities at approximately one half the cost. This
will give you an idea of how far avionics has come in the last 15
years. The per function cost to the aircraft owner today is 1/6 of
what it was in 1960.

In the future, we feel this reduction in cost per function will con-
tinue giving the aircraft owner even more capabilities for less
dollars spent. Factors that will continue this trend are new com-
ponents such as microprocessors, higher frequency semiconductors,
and large-scale integrated circuits, new materials such as poly-
sulfoam for components and mechanical piece parts, new transducer
techniques for measuring physical properties, new manufacturing tech-
niques to reduce labor and, above all, the free enterprise system
that keeps us all lean.

We in the avionics industry are proud of our record and we feel that
we are only one step behind the state-of-the-art. Thank you.

MR. LUCCHI: I would like to make a couple of comments having to do with
integrated displays in the cockpit. I think that is something NASA
should take a good look at because it can reduce space in the panel
and there are techniques today (for which the costs are coming down)
using digital technology and scan converters where a decent display
can be presented for most of the navigation functions in one inte-
grated display. If necessary, a dual display could be used for
redundancy and reliability. We have developed radars in the past with
multi-function displays. They have not been successful yet because
of cost and FAA requirement, because they did have other displays as
backup. But we did provide a TV capability on radar displays and we
could show Loran. When you can show TV on a display, you can now dis-
play complete characteristics whenever you want. So we're not limited
by the technology and I don't think the price is out of line today.

I agree fully with Jerry's comments. It's very hard for me to expand
on what he said because he hit it right on that the low cost of
avionics today are just as reliable as high cost items. High cost
items have more functions and more test functions. Some of our equip-
ment in the past had self-tests built into them which actually degraded
the reliability of the system and really provided very minimal return
on that investment and cost. Complexity was increased so the cost went
up, and reliability went down because of the number of functions that
were required in that box. So I think self-test is another area we
should look into. I think if avionics are designed correctly, the self-
test modes are not needed in flight. They may be useful in the lab or
in the repair facility, but the self-test features should be designed
on the bench and not in the equipment in the interest of reliability
and cost.

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This challenges with the engineer who must operate in a competitive environment and design a low cost, high performing piece of avionics equipment in a very low production environment. That's why the cost is high. Somehow we've got to get the production costs down and the production economy up.

DR. NOYCE: What do you figure it costs to have that CRT with the radar display in the cockpit?

MR. LUCCHI: The CRT is already here. Our radars today have the capability of displaying alpha numerics and we can add a TV feature to it for about $500.

DR. NOYCE: So if you're going to put anything else on there, it's simply the cost of the electronics interface.

MR. LUCCHI: We use a standard TV format. About that $500 price; we don't mean list price. This is what we would sell it for now, net, so far. List price would be maybe 1.6 times that amount depending on discount.

MR. MUCCI: Is there any research done into the possibility of integrating flight director systems with CRTs, using the radar displays already in the aircraft on a time-shared basis.

MR. GORHAM: I disagree completely. The flight director is an instrument that we perhaps need to simplify, but timesharing benefits in the cockpit (aside from the navigation function) is increased mainly for the systems which only need to be looked at when they go wrong, such as fuel and thrust management and some other factors which don't change rapidly.

MR. LUCCHI: As I said before the technology is here. There are CRT flight directors in the military today and we do have digital scan converters that can provide that function. It's a matter of priorities and the question of whether timesharing is useful. It's not a technology problem.

MR. FOY: With all this discussion of avionics, I'm struck by the lack of comments about false checking, redundancy and failure warning of these units. I'm thinking of the instances where somebody has made a flight and gone in for a landing, only to find that his glide-slope indicator was not even connected. Why don't you worry about this sort of thing using the existing package?

MR. LUCCHI: Well there are flags that warn of this.

MR. FOY: That's a visual function.

MR. VANDEN BERGE: Another thing to be concerned with is on many of the smaller planes, you don't have two glide slopes to check against. So I think we have to rely on the fact that there are other cues in the cockpit that the pilot has to check against; is his glide slope working relative to his altimeter, for example. A pilot can check it against other cues rather than the automated monitoring system.

MR. GORHAM: Let me tell a short story about a test. This is about a certain manufacturer's autopilot, a one-box system that had a very poor record of fault found which most of the autopilots used to have and every time the box was pulled it would squawk and 80% of the time there would be no fault found with the box and it would be put back. Even today our general record is about 60% no fault found. One of the reasons was that it was a one-box system that was near the door, so when the client came in, the guy said "autopilot fault, pull the box." Now the way this airline solved this was to put the box further down inside the airplane and weld it into the racks. And they put a built-in test box in and this had a little lamp and a little button that said "Push to see the health of the autopilot computer." There was nothing inside the box except for a small battery and the lamp, so when the button was pushed the lamp lit. Any time there was an autopilot problem, the pilot would push the button and the light would say "it's OK" so he'd look for the fault somewhere else and they improved the finances of autopilot operation considerably this way.

MR. OSDER: There is a contradiction in the remark concerning the elimination of a lot of the built-in self-test capability. We then have the problem of people pulling the wrong box. We did learn a long time ago, even in the 1950's, that reliability was directly proportional to inaccessibility of the equipment. Calculations were done, for example, that showed that some of the electro-mechanical or electro-hydraulic servo mechanisms were less reliable than the electronics. But in records it turns out that they were never removed because you'd have to climb up into the tail and get yourself dirty and nobody pulled them. The problem was that this is a integrated system with many elements interacting with each other. In order to diagnose which element of the system was bad, very complex self-test mechanisms were incorporated into the system. So that you pulled the electronic box, rather than pull the electro-hydraulic servo parts, for instance. But the net result was complex built-in test equipment that deteriorated the reliability of the equipment.

MR. LUCCHI: Another problem is that the airlines generally have people who are trained and who do maintenance at one facility. Generally, this is not true in general aviation; we have to design a little bit better box for maintainability in general aviation. You can't guarantee the same level of skill for maintenance.

I think what Jerry was pointing out was that the lower price equip-
ment have less packed in them and fewer functions and the number of
parts in direct proportion to the reliability. One way to get reli-
ability is by having fewer functions, less complexity, and wider
tolerances. Potentially, reliability for a small simple system is
considerably higher than the large integrated systems with many
functions.

MR. SCHOENMAN: In the commercial aircraft industry market, we've found
one thing that's rather interesting: the reliability of autopilots,
for instance, hasn't changed much in the last 15 years. The increase
in number of functions has about been equal to the improvement in
reliability. So for instance, an autopilot today can get about two
or three hundred hours MTBF. That's about what we got 15 years ago.
But of course the number of functions performed has been maybe as
many as five times increased. That seems to be a trend. We seem
to increase the number of functions to match what people can stand
in terms of reliability.

MR. VANDEN BERGE: We've talked about reliability a lot, there is one
problem we really haven't addressed; that is, we have very little
ability to get good reliability data from the field. In the general
aviation airplane it's not a controlled situation; therefore, when
we figure mean time between failures we're normally guessing at the
operating hours. It's not accurate data as you can get from the air-
line operations that monitor it very closely.

MR. LUCCHI: Paul the airline industry is not quite that good either
because they have a very high, unscheduled removal rate, even today,
according to people at the organized manufacturer's conference.

DR. De BRA: We want to start now to talk a little bit about the sources
of technology that might be carried over into general aviation. The
automotive industry will be a source of technology because of the
cost for certain kinds of components and Frank Jaumot is going to
give us a little overture on that. Frank is with Delco--GM.

SOURCES OF APPLICABLE TECHNOLOGY AND SYSTEM ARCHITECTURES: AUTO INDUSTRY

DR. JAUMOT: I would like to point out that since Delco is a supplier of
avionics, of computers for commercial and industrial use, and of high
voltage electronic systems and solid state components, I want to keep
my hat straight today. I'm to talk only about automotive electronic
systems. Great strides have been made in the developmrnt of solid
state devices, particularly in large-scale integration. These have
made it possible to perform very complex signal processing functions
at relatively low cost. Perhaps more important, primarily through
reduction of interconnections, reliability promises to be greatly

improved. Thus, we have the first step toward extensive use of electronic controls in the automobile. I say the first step advisedly because there is a lot more to an automotive electronic system than signal processing electronics. In fact, the most serious problems in all three of the important aspects of an automobile system--performance, reliability and cost--do not lie in the basic electronics. That is basically what I've heard here this morning about general aviation.

Figure 8 is an over-simplified representation of an automotive electronic system, or any system for that matter. Note that, since a transducer is anything that transforms one kind of energy into another, each of the boxes, except the information processing, can be said to be transducers. This is where most of our problems are.

For the purpose of our discussion today, we can dismiss manual commands since these usually are simple switches or keyboards. Each of the remaining boxes present certain challenges in the automotive applications and I would like to take a look at them in more or less increasing order of the difficulties they present.

I need to enter a caveat. And that is, what I am about to say by no means represents complete agreement in the automotive industry, or even within GM for that matter.

First of all, let's consider the computer, or more properly the microcomputer.

The automobile like any other application has specific requirements and these requirements can be met in a number of ways. However, we decided that the most cost effective and flexible system architecture, particularly with regard to future expansion, was a central microprocessor with most of the work load--and particularly the requirement for quite varied data gathering and output controllers done by the input/output electronics.

Figure 9 is just a slightly better picture of Fig. 8. This approach does two basic things for us. First, it permits us to use the same processor over quite a range of control functions in applications ranging from the simplest control functions that require significant signal processing to very elaborate systems that perform more than 30 functions. Second, it permits us to implement in a more cost effective way, the requirement that critical control systems "fail soft" as we say. That is, if the fuel control loop experiences a failure in the electronics, we must still be able to provide fuel to the engine so that the driver can at least limp to the nearest repair station.

For those of you who are believers in distributed architecture, and I have to admit this includes Delco's commercial avionics group, I need to point out that once you have made the decision to go in the direction I indicated we favor, one finds that a relatively unsophisticated

TYPICAL AUTOMOTIVE ELECTRONIC SYSTEM
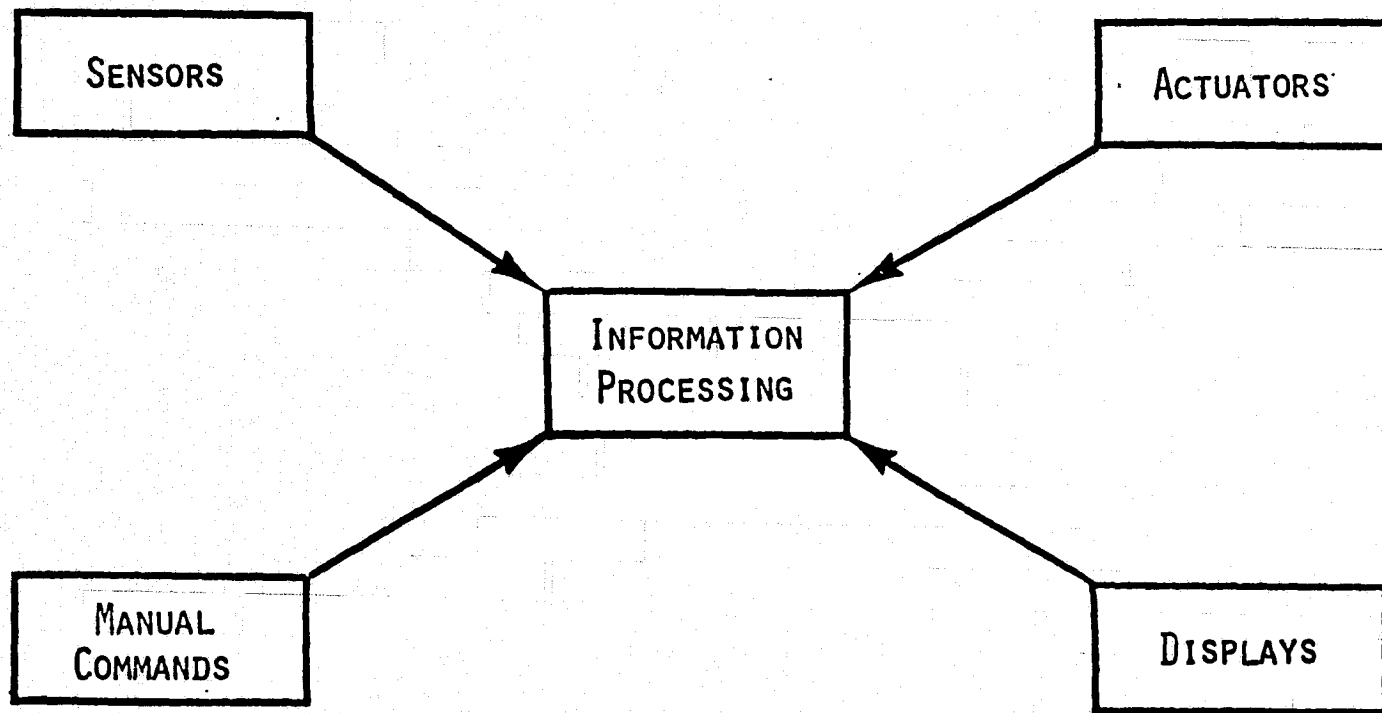
FIGURE 8

INTEGRATED VEHICLE SYSTEM
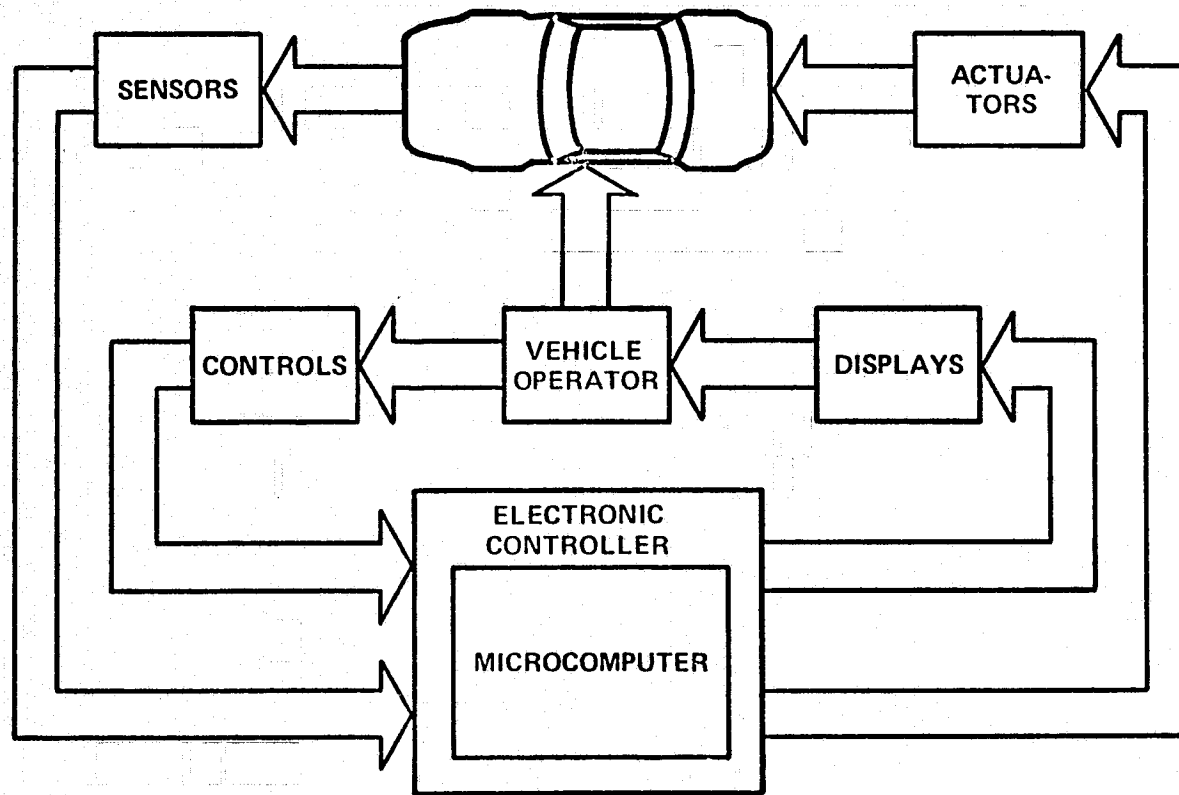
FIGURE 9

microprocessor has more than enough computational capacity to do just about anything one wants to do. So, we would do better from the reliability standpoint to have redundant central processors. However, we don't even have to do that because we have positively imposed upon us this fail safe requirement which, at least to a first approximation, does provide the redundancy.

To be a little more specific--once we admitted what everyone knows, that the major problem is the interface between the microprocessor hardware and the vehicle transducers, which to us meant custom interface chips--the microprocessor becomes almost a trivial item. So, for reasons of throughput, speed and expansion capability, we at Delco Electronics have chosen an 8-bit parallel machine approach. In case I have confused you with my remark about speed, since it means an entirely different thing to us than to a mainframe manufacturer, we find that an instruction cycle of four microseconds is good enough, although we prefer less.

More important, the memory and central processing unit with address and data bus structure are commercially available microprocessor hardware. There are any number of these devices available from many different manufacturers. They may each have their own sets of instructions and various means of manipulating data but their use requires only a learning process on the part of the user.

We prefer to solve the interface problem I mentioned using a building block approach to configure the complete electronic system (Fig. 10). We believe the set of building blocks we have established can be used to configure an electronic system tailored to solve almost any automotive control and display function.

The real solution to the interface problem, however, is the two other building blocks--GM custom IC chips--which provide the interface between the CPU and the transducers; that is, the interface with the vehicle. Both of these are extremely complex LSI chips. One is a clock/multiplexer chip, which provides (i) the timing pulses needed to operate the other devices, (ii) a time of day function, and (iii) multiplexes 8 digits of data in a format compatible with segmented electronic displays. This is the interface to the vehicle instrument panel.

The other GM chip is an input/output device which receives and stores input data from sensors and transmits control signals to actuators. This design was made as versatile as possible and, although it undoubtedly will have to undergo detail redesign as electronic control applications progress, we believe the concept will hold up. In summary, this chip makes the data gathering function completely independent and .synchronous to the CPU operation. The output function is essentially the inverse process. By selection of the proper clock and enable-signals, input data scaling and resolution can be varied

MICROCOMPUTER "BLACK BOX" CONTENT

INPUTS

MICROPROCESSOR CHIP SET

CPU CHIP

CONTROL

MEMORY CHIPS

ROM

RAM

CLOCK/MUX CHIP

OUTPUT

DISPLAYS

SIGNAL CONDITION

INPUT

ALU

OUTPUT

BUFFERS

ACTUATORS

INPUT/OUTPUT CHIPS

POWER SUPPLY
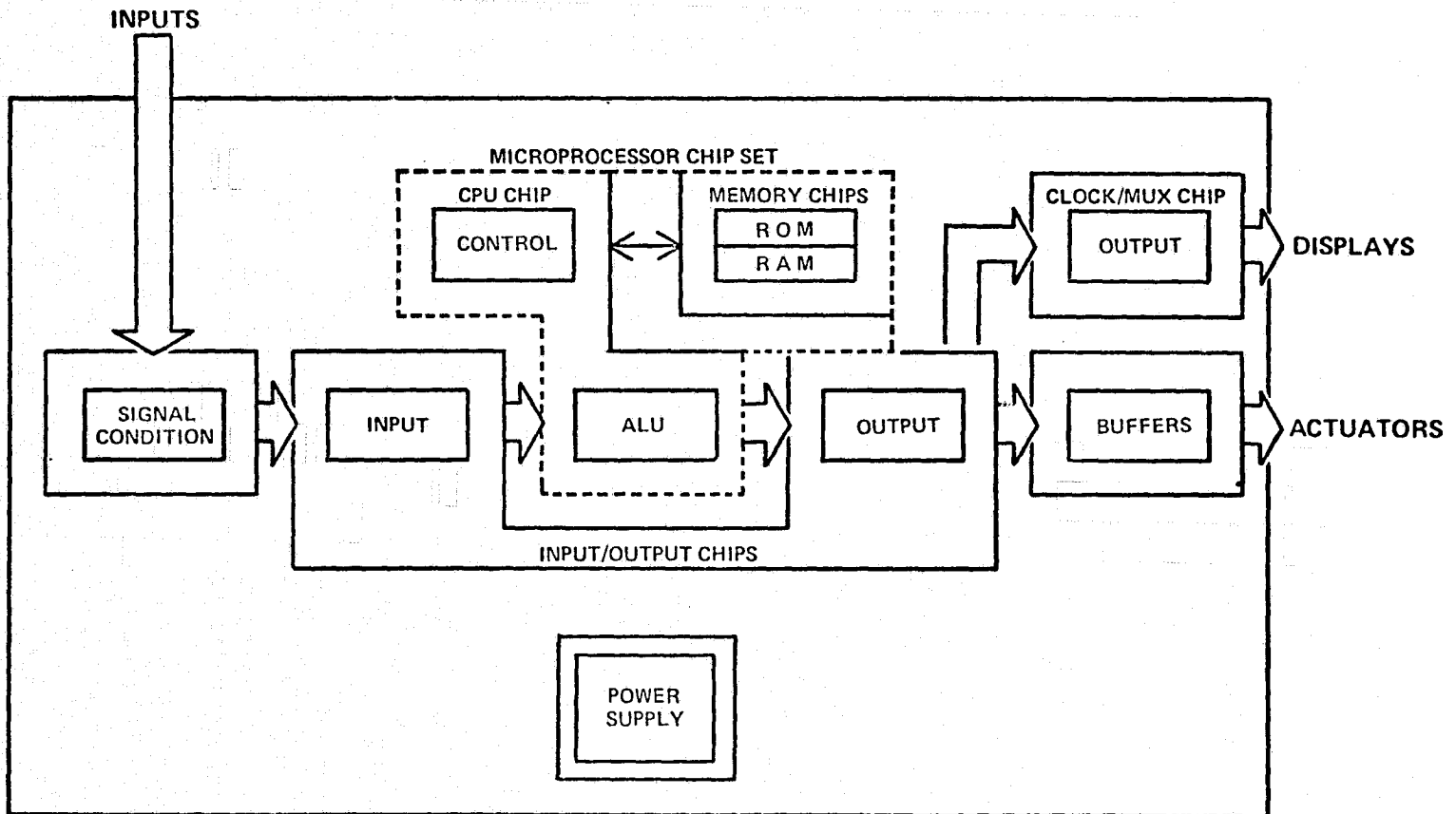
FIGURE 10

for different applications. Output events such as fuel injection or spark timing pulses can be performed slaved to the vehicle. In addition, pulse-width modulated output signals can be generated for controlling linear type servo actuators. Four discrete input or output signals for logical type controls or status indicators are also available. Two sets of inputs and outputs can be handled by a single device, and as many as 8 devices can be interfaced to a CPU. In fact, adding additional memory chips and additional interface chips permits even further expansion if needed. For example, we use a high speed 8-channel multiplexed analog-to-digital converter to interface existing low cost analog sensors.

Let me repeat the three considerations used in the design approach to the interface. One was to provide for a synchronous input and output control. Two was to include all calculator and logic functions in the software rather than the interface, and three was to utilize commonality in circuits for similar input and output signals.

We believe this interface results in a cost effective solution which relieves the central processing unit of burdensome data gathering and output control and, in turn, allows a simple microprocessor to not only perform the functions, but provide for future expansion.

I didn't intend to talk that long on the computer but at least it gives me an excuse to cut down discussion on displays, which I don't like anyway.

The obvious objective of any display is to provide the vehicle operator with information that he needs or just wants. Certainly, this needs to be done effectively and it is always wise to make them as attractive as possible. For future automotive systems we are concentrating on digital displays.

Apart from pizazz, there are three basic reasons for considering digital displays. First, the application of digital signal processing provides a source of data that has been collected and stored in a digital format. It is only logical to make this information available to the driver in digital displays.

Second, electronic digital displays are readily time shared to display several functions with a single grouping of digits. This capability enables simplicity in panel displays by eliminating the need for adding a new gage for each function. That's another way of saying that by sharing, you can reduce, somewhat, the cost penalty of digital displays.

DR. SMYTH: Frank, are those alphanumeric or just numeric displays?

DR. JAUMOT: All of the ones I'll talk about this morning are numeric.
We do have one alphanumeric, but so far we can't afford it. The
third reason for digital displays is design freedom. In addition
to the obvious new freedom in physical interior design, certain
display functions we would like to provide as "goodies" can only
be made available with digital displays.

The types of displays that have received not only serious considera-
tion but careful study and life and environmental testing are LEDs,
gas discharge, electrochrome, incandescent and liquid crystal. So far
none of these have proved to be entirely satisfactory when tested
against automotive requirements for brightness, environment, multi-
plexing, dimming, color filtering, etc.

To date, against these requirements, gas discharge displays are the
most nearly acceptable with the new developments in brighter yellow
and green LEDs improving their chances, particularly for certain
display functions.

Since gas discharge displays seem to be preferred what are their
problems? First, the high voltage supply is costly and generates
emi which gives the radio fits. Second, a gas discharge display
can be filtered to provide varied colors, but without going to the
new high intensity displays which present power supply problems it is
not bright enough for visibility against outdoor illumination. Third,
dimming is not very satisfactory and, most important, our results as
to their survival in the automative environment hasn't been anything
to write home about.

Another problem area often overlooked is the human factors area.
Digital processing techniques like hysteresis and averaging can
eliminate flickering, but flickering has to be eliminated. Further,
a variable response has to be incorporated in the display behavior
that adapts to transient as well as steady state driving conditions.
Some functions, like a digital fuel gage, are normally filtered for
slow response. However, fast initialization when the key is turned
on is a must. The point is, awareness of such requirements and
implementation of appropriate techniques to meet them are essential
to effective display systems.

Now to my favorite subject--and the automotive electronic systems
biggest burden--sensors and actuators.

Input information is almost invariably analog and the output units
usually want analog muscle. Since it is most desirable that the
data processing be done digitally, it would be nice if the sensors
provided digital data and actuators accepted it. In any event, it
is the transducers--a word I'll use to mean sensors and/or actuators
--that determine the basic limitations of the system performance,
require the majority of effort in system development, and result

in the major part of the system cost. Trevor Jones of GM's
Engineering Staff, in a recent paper, identified some 60 future
electronic systems. Of these, 35 required major sensor develop-
ments and 25 needed more effective actuators. Cost barriers,
usually due to sensors or actuators, were present in 56 of the 60
applications. The signal processing electronics was considered a
problem in only seven systems and four of these were automatic
brake systems. That's why automotive people say the electronics
are easy. It's the rest of the system that causes the trouble.

There are many transducers in today's cars. Also, a broad range
of rugged and precise sensors have been developed for aerospace
applications. So where are the problems?

Figure 11 shows the primary factors in any transducer application.
Obviously, I'll get arguments on this, but using automotive require-
ments as a base, I think I can defend it.

What this figure says is that automotive electronic systems and
especially transducers must have aerospace precision, industrial
long term stability and reliability, commercial costs, and
resistance to environmental conditions worthy of being included in
Dante's neither world. I strongly suspect from what I have heard
this morning that general aviation has very nearly the same require-
ments as the automobile. As I mentioned there are many transducers
used in today's cars and obviously they meet most of these criteria.
However, they tend to be relatively simple mechanical devices based
on bellows, bi-metallic strips, fluid expansion, and so on. Outputs
are typically analog and generally of a type not easily converted to
a digital signal. The principal shortcoming is that they tend to be
too slow in response time and lack the accuracy required for elec-
tronic controls. In addition they lose their cost attractiveness if
we attempt to digitize their outputs.

In order to meet the design objectives of an electronic system,
transducers must be accurate--under all conditions--to +1% or at
most +2%, and they must have much faster response than most devices
used in cars today. Unless we can achieve these levels of precision,
we tend to lose all advantages over existing mechanical systems and
devices since an electronic approach really only offers better per-
formance to offset the almost invariable cost permium.

Of course, a number of transducers have been developed which pro-
vide or accept digital signals and which have the required perform-
ance for automotive electronics. By and large they were developed
for aerospace and, to a lesser degree, special industrial applica-
tions. But apart from performance, in general, these devices do not
satisfy the other requirements. Since the production volumes
involved are relatively small, designs to minimize fabrication and
assembly labor or material cost were not needed. The costs of

ELECTRONIC SENSOR APPLICATIONS

Primary Factors

	PERFORMANCE (PRECISION & RESPONSE)	LOW COST	LONG LIFE	RESISTANCE TO ENVIRONMENTAL EXTREMES
Aerospace	X	-	-	X
Industrial	?	-	X	-
Commercial	-	X	-	-
Automotive	X	X	X	X

FIGURE 11

38

(JAUMOT Cont)

developing, marketing, calibrating and inventorying dictated
pricing much more than labor and material content. This is one
attractive feature of the transducer market for automobiles; high
volume requirements permit lower cost designs and spread fixed
costs over a much larger number of parts. Further, and the
dangers of over-generalizing aside, aerospace sensors while
designed for moderately extreme environments are generally expected
to have relatively short operating life and industrial sensors
while designed for long life are expected to operate in a relatively
benign environment. Unfortunately, the result is that many of
these otherwise attractive devices don't always work in an appli-
cation requiring a long life in an extreme environment. Figures
12 and 13 give some information on automotive transducer needs.

Let's look at the matter of long life and the extreme environment
in the automobile. I'm sure that everyone is aware of the fact that
the basic warranty is one year or 12,000 miles. However, the design
goal is a minimum of 50,000 miles and for some systems maintenance,
responsibility for 50,000 miles is a legislated requirement. En-
tirely aside from this, the car performance for the entire life of
the car is a matter of concern to the manufacturer since poor per-
formance after two or three years could easily send a customer to
the competitor's showroom for his next car. In addition, there is
the very considerable cost of warranty which provides a strong
economic motive for long life.

I'd like to put some numbers to the argument. Assuming a system
with 25 parts--which is not a very complex system--and assuming
a failure rate average of one failure per million miles of each of
these parts if the average car is driven 12,000 miles per year,
then, on the average, 30 out of every 100 cars would fail during
the first year because of this system. If one failure per million
miles isn't a familiar number it equates to a mean time between
failure of 33,000 operating hours. However, the number ignores the
possibility of storage life failures in spite of the fact that during
a million miles the part will have been stored, experiencing tem-
perature cycling and possibly reverse bias, for over 700,000 hours.
This gives us a combined failure rate of 0.1% per 1000 hours.

Obviously, 30 cars in every 100 failing due to a simple system is
unsatisfactory from the customer's point of view--and from the
manufacturer's who would be facing on the order of a $100 million
warranty bill for the U.S. car population on this one simple system.
I'll admit a 0.1% per 1000 hours isn't a particularly attractive
failure rate but, in the extreme environment under the hood, we
can't seem to find satisfactory transducers that will meet the level,
nor can we find displays that completely fill the bill. Fortunately,
the processor electronics exceed this modes requirement.

SELECTED TRANSDUCER NEEDS

MANIFOLD ABSOLUTE PRESSURE SENSOR:

REQUIREMENTS:

- ±1% ACCURACY AT 25° C OVER 0" TO 30" HG RANGE
- LONG TERM STABILITY AT "UNDERHOOD" ENVIRONMENTAL CONDITIONS

CONTENDERS & LIMITATIONS:

- SOLID STATE SILICON DIAPHRAGM — COST, UNPROVEN STABILITY
- METAL DIAPHRAGM — LVDT — COST, SIZE
- RUBBER DIAPHRAGM-POTENTIOMETER — ACCURACY, CONTACT LIFE

AIR MASS FLOW SENSOR:

REQUIREMENTS:

- ±2% ACCURACY OVER 0.75 TO 35.0 #/MIN FLOW RATE
- TIME CONSTANT ≤5 MS, PRESSURE DROP 0.1 PSI.
- LONG TERM STABILITY AT UNDERHOOD ENVIRONMENTAL CONDITIONS

CONTENDERS & LIMITATIONS:

- VORTEX SHEDDING — COST, PRESS.& TEMP.COMPENSATION REQ'D
- MOVING VANE — ACCURACY, PRESS.& TEMP.COMPSA. REQ'D
- ORIFICE PLATES, PRESSURE GAGES — SIZE, ACCURACY, RANGE, PRESSURE AND TEMPERATURE COMPENSATION REQUIRED
- HOT WIRE ANEMOMETER — NONLINEAR, CONTAMINATION

FUEL FLOW SENSOR:

REQUIREMENTS:

- ±2% ACCURACY OVER 0.3 G/H TO 30 G/H RANGE
- -40°C TO +150°C UNDERHOOD ENVIRONMENT
- ΔP <0.5 PSI AT FULL FLOW, FAIL SAFE FUEL FLOW

CONTENDERS & LIMITATIONS:

- TURBINE TYPE — PULSATION SENSITIVE, COST, ACCURACY
- VORTEX DEVICES — COST, UNPROVEN, REQUIRES AMPLIFIER
- POSITIVE DISPLACEMENT — COST, SIZE, FAIL SAFE FEATURES
- ROTOMETER — LIMITED RANGE, ACCURACY

FIGURE 12

SPEED SENSORS (Engine, Wheel, Vehicle)

REQUIREMENTS:

- ±1% ACCURACY OVER 0 TO 100 MI/H OR 0 TO 6000 R/MIN RANGE
- UNDERHOOD ENVIRONMENTS, STEAM CLEANING, INSENSITIVE TO EMI
- SINGLE LEAD WIRE, UNDER 1.0 IN^3 VOLUME

CONTENDERS & LIMITATIONS:

- VARIABLE RELUCTANCE
- HALL CELL
- INDUCTIVE
- REED SWITCH - MAGNET

- OPTICAL

- LOW SPEED DROPOUT, COST
- ACCURACY OVER TEMP RANGE
- HIGH SPEED ACCURACY NOT PROVEN
- CONTACT BOUNCE, SENSITIVITY TO LOAD CONDITIONS, FRAGILITY
- SENSITIVITY TO CONTAMINATION AND STRAY LIGHT SOURCES

EXHAUST TEMPERATURE SENSOR OR SWITCH

REQUIREMENTS:

- ±10°C ACCURACY OVER 400° TO 1100°C RANGE
- <1 SECOND TIME CONSTANT
- LONG TERM STABILITY IN EXHAUST GAS STREAM, CHASSIS OR UNDERHOOD ENVIRONMENTS

CONTENDERS & LIMITATIONS:

- THERMOCOUPLE

- THERMISTOR
- BIMETALLIC DEVICES
- CURIE EFFECT MATERIALS

- LEAD WIRE EFFECTS, NEEDS AMPLIFICATION FEW DOMESTIC SUPPLIERS
- FEW DOMESTIC SUPPLIERS, COST
- RELIABILITY, LIMITED RANGE
- TEMPERATURE LIMITATIONS, EASILY FOULED

HUMIDITY SENSOR:

REQUIREMENTS:

- ±1800 PPM ACCURACY BETWEEN 7000 AND 21,000 PPM, RANGE 0-36,000 PPM
- TIME CONSTANT 10 SECONDS, -40° TO +85°C OPERATING RANGE

CONTENDERS & LIMITATIONS:

- POROUS SEMICONDUCTOR
- HYGROSCOPIC SALT
- DEW POINT SENSING

- NEEDS ELECTRONICS - EASILY CONTAMINATE
- NEEDS ELECTRONICS - STABILITY
- NEEDS ELECTRONICS - EASILY CONTAMINATE

FIGURE 13

To put these numbers more in terms of product requirements, it is seldom possible to get a reliability budget for a relatively simple system more generous than 1% failure rate over the car design life of five years or 50,000 miles. This says that our components should have an average mean time between failure of over 4 million operating hours or a combined storage/operating failure rate of less than 0.001% per 1000 hours. That still means that nearly 20,000 cars in the U.S. population would experience a failure during the first year because of this simple system.

Since I mentioned the extreme environment under the hood, let's take a look at our present environment requirements for under-the-hood applications (Fig 14 and Fig 15), and the passenger compartment requirements aren't all that much less. These are typical for most applications. In addition, each application may or may not have individual requirements. One of the more common is thermal fatigue which typically requires self-heating the device (if it is a powered device) to a case temperature rise of 75° C, turning off the power for 200 sec or so, reapplying power and so on, for 7500 cycles. Another "cutie" that shows up a lot of applications is the static electricity or lightning test. This calls for a 1.5 microsec 15,000 V pulse.

I'm finally going to quit. While I have talked only about automotive systems and requirements--including environments--I suspect that general aviation avionics will have to meet very similar performance, reliability, and cost requirements. I think these requirements can be met if we do our homework properly. I have no doubt that we can provide the end user with real value for his money and I'm going to be interested in what you think.

DR De BRA: I think maybe we'll stop for coffee here, unless somebody has particular comment they want to make.

REMOTELY PILOTED VEHICLES

MR. FRANKLIN: I'm not here to show you what I can sell you; I'm here to find out what I can buy from you. I'm going to talk about remotely piloted vehicles, specifically, little airplanes. These airplanes range in weight from 100 to 300 lbs. They're a little bit bigger than model airplanes and quite a bit smaller than drones. They're propeller driven and gasoline engine powered. What makes them important and interesting is the complexity of their mission. This is an airplane which has to be a very small, very cheap, and usable by people who don't know anything about airplanes. So we have to worry about cost of components and how easy it is to check out, launch, and operate the bird, and how easy it is to make it do its mission. A typical mission for a vehicle of this kind and

ENVIRONMENTAL REQUIREMENTS
(UNDERHOOD)

STORAGE (NONOPERATING)   -50°C TO +150°C, ANY TEMP - 1000 HRS

TEMP CYCLING (NONOP)   -50°C TO +150°C (30 MIN DWELL AT TEMP
EXTREMES, MAX TRANSITION TIME, 5 MIN.,
1000 CYCLES.

POWER & TEMP CYCLING   1000 HRS, -40°C TO +125°C TEMP CYCLING
(1 HR DWELL, 0.5 HR TRANSITION TIME)
DEVICE OPERATED WITH POWER ON 5 MIN.,
OFF 5 MIN. DURING TEST

THERMAL SHOCK   -50°C TO +150°C, LIQUID-TO-LIQUID,
5 MIN. DWELL EACH EXTREME, TRANSFER
TIME 5 SEC. MAX., 150 CYCLES.

HUMIDITY   85% RELATIVE HUMIDITY, 85°C FOR 1000 HRS.
ALL INPUTS REVERSE BIASED.

ELECTRICAL TRANSIENTS   ALL VOLTAGES MEASURED FROM +14 V DC BIAS;

LOAD DUMP: 50 V OR 100 V DEPENDING ON APPLICATION,
EXPONENTIALLY DECAYING TO 20 V IN 200 MS.

+32 V TRANSIENT: BOTH + AND - PULSES MUST EXCEED 20 µS DURATION

+250 V TRANSIENT: BOTH + AND - PULSES MUST EXCEED 0.5 µS

+450 V TRANSIENT: 5 MHZ BURST, 20 µS IN DURATION

VOLTAGE EXTREMES   MUST WITHSTAND +24 V DC FOR 5 MIN. (25°C)
MUST WITHSTAND -6 V DC FOR 30 SECONDS (25°C)
MUST OPERATE FROM 4 V TO 24 V, BUT IN MANY
CASES MUST MEET FULL OPERATING REQUIREMENTS
ONLY FROM 8V TO 16 V DC.

FIGURE 14

Environmental Requirements (Cont'd)

MECHANICAL SHOCK

Handling –	3 ft drop to smooth concrete – all 6 faces
Low Impact –	500 g's – 1 ms; 10 times in each of 3 planes
High Impact –	1500 g's – 100 μs; 1 drop normal to plane of horizontal mounting position.

VIBRATION

Variable Low Freq: Sinusoidal sweep of 10 to 100 Hz at rate of 10 Hz per min, constant displacement of 0.065 in., 2 hrs in each of 3 mutually perpendicular planes.

Variable High Freq: Frequency range of 100 to 2000 Hz with approximate logrithmic variation of frequency and constant peak acceleration of 20 g's. Entire range traversed in not less than 4 min. – 3 planes.

Resonance: 30 min. dwell at resonance

PLUS (Without damage and without change in logic states during test)

Radio Frequency Interference

Rock and Dust Hazards

Salt Spray

Oil and Gasoline Exposure

FIGURE 15

size is: fly 20 to 100 miles slowly, a few 100 ft. above the
ground, while looking for targets of opportunity like trucks and
tanks; and send video messages back continuously to a TV monitor
at the control site. If something is found, put a laser beam on
it and keep it there, while a laser homing munition is launched.
Now that's a pretty difficult mission for something that weighs
150 lbs and is not supposed to cost anything at all.

I've come here today to tell you that we can't find the components
to fit into these airplanes. We're having to make our own com-
ponents which we don't really want to do. Let me run through some
of these things we're looking for.

We'd like to find some very low cost and very small rate gyros.
There's a real gap in the industry in the area in which we're
interested. If you go to a model airplane store, you can find a
rate gyro for $75. Model airplane people buy them and put them on
model helicopters, but it's basically a toy with quality just too
low for our use. Two years ago we were required to build an air-
plane with the cheapest possible autopilot. We chose to use the
conventional wing-leveler autopilot based on the tipped rate gyro
concept. We went to a general aviation source and bought a rate
gyro for $245. At the last minute we decided not to fly it because
we were afraid of its reliability so we paid $600 for a Condor-
Pacific rate gyro. Although it was really too heavy for our
application it suited our purposes in other respects because it has
its inverter and demodulators inside the case. We could supply it
with 28 volts and just make it go.

We flew that one successfully, but it's much too heavy and much
too costly. When we won a contract from the army we had to build
a somewhat better autopilot and go to two gyros. Now we're talking
about a tipped rate gyro for the wing leveler mode and a pitch rate
gyro for augmented pitch damping. We went to industry and asked
them for a two-rate gyro package with all the electronics inside.
Hamilton-Standard came through with a package which costs only $300
more than the Condor-Pacific gyro. Here is an example of their
product. You can see that the package is still a little too large
and heavy. Visualize that in a 100 lb airplane, which also has to
carry a TV system, and a gimballed laser package. What we want is
a really small rate gyro like this one from Honeywell. But we can't
afford it.

This Honeywell tiny gyro does exactly the same thing the Hamilton-
Standard package does but it costs $2500, so we've gone beyond the
knee of the weight-cost curve. We can't afford the Honeywell gyro
even though we love its size and weight. So if one of you would
like to make some two-axis gyros like these and sell them to us at
$500 to $600 a piece, we'll buy a bunch of them.

We have problems in other sensors too. Our airplanes are too
small to contain directional and vertical gyros. I can't find
them for less than 3 lbs, which is too heavy. They cost $3500
and that's too expensive, and so we stabilize our airplanes in
pitch with pressure sensors. We don't have any attitude sensing
in pitch at all. We use air-speed hold, and therefore we need a
dual-port pressure sensor to measure indicated air speed. This
Rosemount sensor is too expensive and too big, but it's interest-
ing to us because it puts out an accurate linear analog voltage
which is a function of indicated air speed. What we really want
is something like the dual-port sensor from National Semiconductor.
Functionally, this is the same as the Rosemount device but it costs
only $75. All of a sudden we're in the right price range; and
obviously it is the right size, but it is not suitable because its
"second order effects" are dominant. We can't use them because of
excessive hysteresis and poor temperature stability.

Well you see the situation we're in: we find ourselves trying to
shop in areas where there's just nothing available. Model air-
plane devices are not quite good enough, although we use some of
them. For instance we've been forced in one of our military R&D
ventures to go to the model airplane store and buy plastic actua-
tors. I believe the best one costs about $47.50 retail. We've
used this for the engine throttle, elevator, and rudder of a
military aircraft, but it just barely does the job. And once in a
while, the plastic gears come back with their teeth deformed and
the output shaft distorted and permanently set.

DR. SMYTH: Chuck, may I ask a question about your attitude indicator?
Did you see an article written by someone in model airplanes about
measuring voltage potential?

MR. FRANKLIN: Yes, we use electrostatic autopilots too. Electrostatic
sensing is being used all over the United States now by model air-
planers. It consists of putting a device on each wing tip which
can sense the electrostatic potential of the earth. Electrostatic
potential lines, of course, go radially between the earth's surface
and the ionisphere. If you can measure the potential difference you
can determine whether or not one device is higher than the other.
It works well in test applications but you can't sell it to the
military. They don't want to depend upon a device that has to be
kept clean, for instance. If a little engine oil gets on these
devices they stop working. If you fly in a thunderstorm, everyone
says that the airplane turns upside down. Well, maybe it will. If
you fly under power lines it may do this too. What I'm saying is
that there are many military applications for which it might serve,
and offer complete two-axis stabilization, pitch, and bank for $100,
not including servos to operate the elevators and allerons.

We would like to go to conventional attitude gyros because the systems that we build now under the constraints of weight and cost are very loose systems. If you are going to fly around holding pitch only on air speed, the airplane is going to pitch around quite a bit in gusty conditions. You really can't find a way to tighten it up and hold attitude very well. It's like trying to fly on an angle of attack. If it gets hit with a gust, the airplane is going to feather into the gust. The airplane is supposed to be on a reconnaissance mission so you'd like to provide a stable platform for the TV and the laser; so there is an incompatibility. We want a very stable aircraft platform that responds to commands, and holds its attitude in bank but we don't want to spend any money or weight to put in attitude gyros. The problem isn't being solved at the present time.

You might be interested to know that we're using true RNAV guidance. This is accomplished with all of the equipment on the ground, since we are in continuous communication with the aircraft. The operator on the ground prepares his mission and punches in up to 99 way-points. The airplane goes to those way-points without human intervention. The thing that is interesting about it is that the equipment on the airplane is absolutely minimal. The wing leveler autopilot will respond to turn-rate commands so all the guidance computation is done on the ground, and steering commands are sent to put it back on the proper ground course. Not only is way-point guidance built in at this time but also the poor man's equivalent of an ILS system.

DR. De BRA: Thank you, Chuck. Any comments or questions for Chuck beyond what we already have?

MR. VANDEN BERGE: Chuck, I hope you find the solution to all those problems because we could use the same devices in the real airplane.

DR. De BRA: It looks like the speakers from the two areas we hoped would bring salvation to general aviation are hoping it goes the other way. Clearly the sensor and actuator problems seem to require most attention in both of those fields which were peripheral to general aviation to the two areas of aviation which are sisters of the general aviation: commercial and military aviation. We'll start with Dick Schoenman's comments on the commercial aircraft.

COMMERCIAL AIRCRAFT

MR. SCHOENMAN: The commercial aviation industry is in a difficult place with respect to certain constraints on avionics; for instance, price and weight. The cost of electronics equipment for those types of airplanes are 3 to 5 percent of the total price of the vehicle. The weight is also quite small in terms of the total payload: 2 to 3 percent. You can see that in the commercial aviation industry we have relatively more freedom with regard to cost and weight, that is, as compared to the general aviation field. Now you'd think with those relaxed constraints we might have a quantum jump on reliability; but we really don't. We package size in some cases. We can improve reliability, for instance, by improved dissipation. methods.

I'd like to discuss first a group of improvements in technology that relate to systems. I'll just say a few words about electronic displays, inertial sensors, digital computation, and system integration. Then if we have time I will talk about the second group which is more associated with operational capability: low visability, and approach and landing, and 3-D and 4-D area navigation.

In the area of electronic displays, there is a fair amount of research done in industry relating to the use of electronic attitude director indicators and horizontal situation indicators. The object here in going to these types of displays is to gain some measure of integration of functions. Fig 16 is an electronic attitude director indicator combined with a forward-looking TV camera which allows an actual visual scene of the runway to be displayed. Other functions are displayed including radio altitude, potential flight path angle, and pitch attitude information. Fig 17, is an electronic HSI with additional information added: a horizontal deviation bar, vertical deviation scale, attitude information, selected course, actual heading, the airplane's position, and predicted flight path for 30-sec intervals. This is an indication of things that are being worked on. The problem with incorporating this type of display into the general aviation market is cost.

The next item I'll talk about is inertial sensing. One of the major expense items in the electronics complement of a 747, is three inertial navigation systems. Their cost is on the order of $100,000 per unit so that is $300,000 for a triplex system. In addition to the navigation function they're very useful for getting good basic information such as attitude, and cross-track velocity which can be used for automatic landing systems. However, we've found that although this information is very useful for autolanding system design, it's too expensive to acquire unless the airplane has a requirement for inertial navigation. There is an industry move towards strapdown systems. A strapdown system is essentially one in which rate gyros and accelerometers are strapped down on a platform. This information is processed through a computer and

Electronic Attitude Director Indicator Format
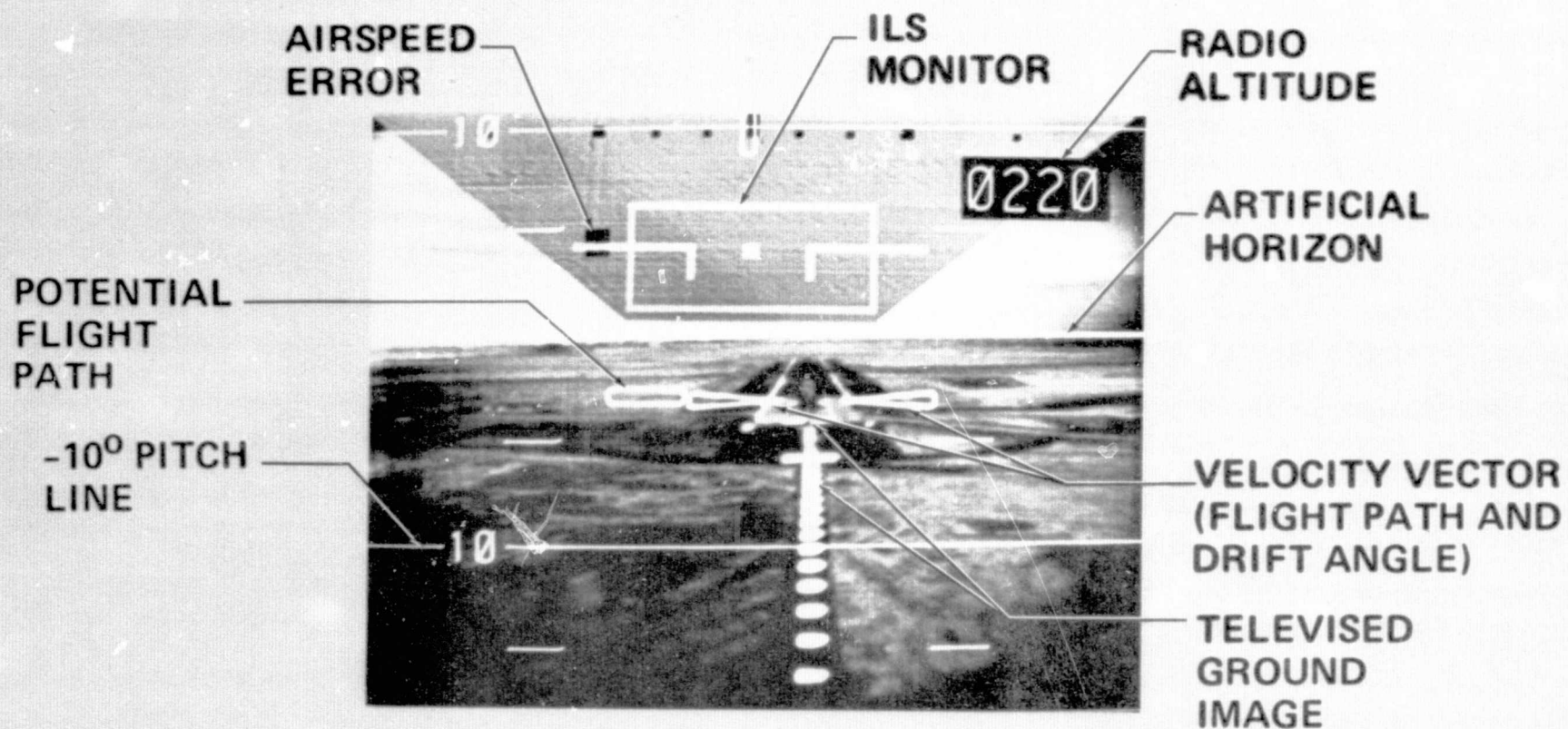
FIGURE 16

ELECTRONIC HORIZONTAL
SITUATION INDICATOR

"TO" WAYPOINT
NAME

SELECTED COURSE

COMPASS ROSE

TREND VECTOR

AIRPLANE SYMBOL

HEADING

SELECTED COURSE

TIME TO GO

WAYPOINT
(3 PLACES)

DESIRED PATH

VERTICAL DEVIATION

HORIZONTAL
DEVIATION

RECIPROCAL POINTER
& SCALE

THE *BOEING* CO.
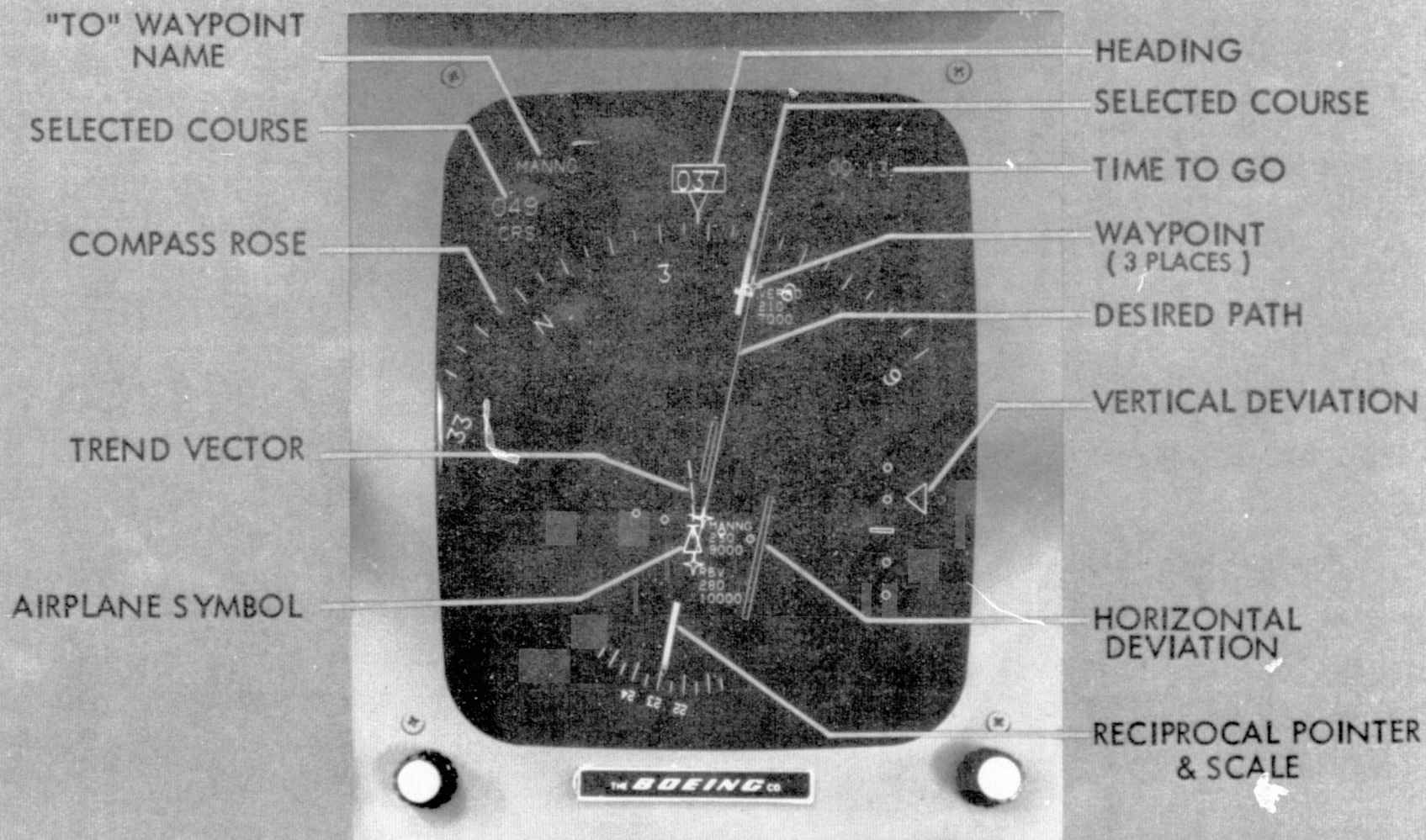
7X7P39-40R1
3-20-75

FIGURE 17

accelerations and linear and angular velocities, and positions are produced along with somewhat degraded navigation information. A system like this is predicted to cost half as much as the standard inertial system. It will supply the same quality of input you normally get from directional and vertical gyros, rate gyros, and accelerometers at comparable cost. We've flown a system at Boeing that has an error of about 2 N miles per hour, which is about competitive with gimballed systems. Some reasons for pursuing strapdown and replacing the rate gyros, accelerometers, DG, VG, and compass systems are equivalent or lower cost, higher quality data, higher MTBFs, lower airline user cost, and a potential to reduce flight navigation and display cost. In addition, there are some very interesting other potentials because of the possibility of integrating air data with it or even flight control functions. The strapdown inertial navigation data is not quite as good as that of a gimballed system. On the other hand, if Omega is the primary method of navigation, it can be used to update the strapdown system.

I'd like now to discuss the field of digital computation. I think we all pretty much accept the premise that we're moving very quickly to digital technology for air data and inertial NAV systems. I think the next round of flight control systems will be digital, and there's a great deal of interest and research money being spent by a number of companies these days to develop automatic flight control systems using digital processors. One of the problems we have to face with our airline customers is that they're very concerned about integrating on too large a scale with respect to functions. We have come to the conclusion that integration will occur in two distinct categories: those systems that are required for dispatch, vs those that are not required for dispatch. Now it's very likely that we will, in fact, integrate a number of functions that are not required for dispatch, but systems such as air and attitude information will not be integrated on a large scale. The NASA Langley 737 is probably a first attempt to perform large-scale integration of digital navigation and flight control.

Concerning the use of strapdown systems or inertial information in automatic landing systems, I should point out that there's been some work done to indicate that if you do use inertial information as the primary means of obtaining attitude and path information, you can use the glide-slope information as a kind of long term update. It is then much less susceptible to failure conditions or problems associated with localizer or glide-slope noise. This type of system has been flown under an FAA contract and has been used in a number of other experimental autopilots for the past 3 or 4 years. I'll skip over the RNAV and close with a brief summary of what we see could occur in the next five years: digital flight control electronics, automated 3-D flight path control, automatic thrust control, low cost inertial measurement, expanded digital implementation, and of course, advances in flight deck displays.

MR. MC RUER: Dick, there's been a certain amount of emphasis on autoland in your talk. I'm reminded of a comment by the Vice President in charge of Engineering for an unnamed airline. I'd like to repeat it here and see whether it's your current experience that autolanding is as important a future requirement as you've indicated. The comment was: "So far autolanding hasn't been worth a pinch of (expletive deleted)." Now, how much has it turned out to really be worth in operations?

MR. SCHOENMAN: I would say that within the United States, interest in automatic landing is at a fairly low level, because the percentage of time it's really needed is low. There's a great deal of interest right now in trying to extend capability beyond Cat II to something like Cat II+ or Cat IIA. The decision height would be down to something like 50 ft and still allow the pilot to make the actual landing. In other words, it would not require a fail operational system, and so there is a move afoot today to see whether or not the fail-passive system could be extended down to that region. The airlines are quite interested in it, but the basic reason for this controversy is that they say they can't afford the initial cost or the maintenance cost of a Cat III system.

MR. GORHAM: It is not that we're trying to get better than Cat II without autoland, with the pilot taking over at 50 ft. The premise of that system is to use autoland even if it had one level of redundancy less. At 50 ft, the pilot either has to continue on the autopilot because it's obviously unreasonable to expect him to take over a heap of airplane at 50 ft, or he goes around if he doesn't like what he sees. It's still autoland but it's a lower cost autoland because it has one less level of redundancy. I think that's what you're saying, isn't it?

MR. SCHOENMAN: No, not quite that. My understanding is that the pilot could in fact continue the landing at 50 ft. if he did lose the auto-landing system.

DR. De BRA: Do these conditions also apply to general aviation?

MR. SCHOENMAN: It would apply to general aviation as well as commercial, if this particular approach is in fact really certified by the FAA.

MR. MC RUER: My question in the first place was whether autoland should be a significant or just a minor goal for the future of general aviation avionics?

MR. SCHOENMAN: My guess is that general aviation will approach pretty cautiously in the Cat II capability first before they move into anything as sophisticated as automatic landing. I'm not even sure it's necessary in that particular area.

I would like to just make one other comment. There is a fair amount of interest in autolanding in Europe. A couple of our customers who fly 747s are very keen on this now. Some are disappointed at the performance of the systems they've been using but they're still interested in getting this capability on other airplanes.

DR. De BRA: Thank you. Dick Smyth will talk about the Military aircraft, the other half of the larger airplane business.

MILITARY AIRCRAFT

DR. SMYTH: I have the pleasure of addressing the other end of the spectrum. We talked about $20-$30,000 avionics systems up to a half-million dollar avionics systems. I've been involved in the F-111 avionics system which was $1.2 million and the B-1 avionics system which is approximately $5 million. You might ask why we are discussing such a subject in this meeting. Well, I think there are some lessons to be learned; and there are some ideas in architecture that are now made possible, particularly in the computation area, by the advent of microprocessors. I think that everything that anybody's ever thought of implementing, and certainly everything that's been talked about this morning, has now been done in military avionics systems.

I'd like to speak briefly of some of the functions, mechanization techniques, and architecture involved in some of the more complex military avionics systems. I have a couple of examples of the impact of the new technology, particularly the microprocessor technology, on the next generation of military avionics systems.

A weapons delivery system which has the objective of delivering a weapon to a target is different from a general aviation system. However, many of the functions of the weapon system are the same as for a general aircraft avionics system such as navigation, control, etc. Some of the topics involved in our weapon delivery system are navigation, target acquisition, and tracking, release point guidance, weapons release computation (in which you compute where a weapon's going to hit on the ground and adjust the release so that it hits the target).

There are a number of navigation systems. Some simple ones include TACAN/DME, and dead reckoning using air speed and heading, (see Fig. 18).The figure also shows various radio navigation aids that you're all familiar with. Someone mentioned today that we're looking for a universal worldwide navigation system. The Dept. of Defense and the Air Force has now come up with that answer: GPS or NAVSTAR, which is a form of a navigation satellite.

NAVIGATION

- SIMPLE NAVIGATION SYSTEMS

    - TACAN / DME
    - Dead Reckoning

- RADIO NAVIGATION SYSTEMS

    - LORAN C / D
    - OMEGA
    - NAVSAT

- INERTIAL NAVIGATION SYSTEMS

- MULTI-SENSOR NAVIGATION SYSTEMS

    - Doppler - Inertial
    - Inertial - LORAN C / D
    - Doppler - Inertial - LORAN
    - Doppler - Stellar - Inertial

FIGURE 18

Whether everybody's willing to drop everything they're doing and use that is another question, but the Air Force thinks that they will.

Inertial navigation systems are still here and the trends toward strapdown systems that have been mentioned are certainly strong and part of the future setting. By putting the various navigation sensor systems in digital form, you arrive at some interesting multi-sensor results through the use of Kalman filter algorithms. For example, the Mark II Avionic System included Doppler-Stellar-Inertial Navigation with position updating by means of radar, visual and electrooptical subsystems.

The concept of functional redundancy is important in avionic systems containing digital computers. Someone has mentioned the term "central computer." A single central computer (with the single CPU) can very well become a fuse for the avionic system. To avoid this, the concept of functional redundancy has been introduced. For example, the B-1 system has three general-purpose computers, each one of which computes certain functions so if any one of the computers is lost the other two can still provide all functions, perhaps in a degraded fashion. If you look at the kind of computers that are in the B-1 or the F-111, you say we must be out of our minds talking about multi-computers for General Aviation, because those computers cost $60,000 in large scale production. But if you start looking at what a microprocessor CPU costs these days, $20 to $100 (and the trend is certainly down), having multiple CPUs in a general aviation aircraft systems architecture certainly is a feasible thing to do from a cost point of view. So functional redundancy for computers means computation redundancy spread over more than one computer.

Figure 19 is a picture of a simple air-to-ground fire-control system that has TV displays, radar, and the other components displayed. The question of the usability of CRT displays comes up. On the F-111 Mark II avionics there were 5 CRT display surfaces including a vertical situation display on the commander's side, multi-sensor display on the System operator's side, horizontal situation display (basically a moving map) in the center, and each pilot had a CRT projected head-up display. All of the primary flight information was put on the CRT surfaces and there was 4-way redundancy. There was early skepticism as to whether pilots would accept CRT displays but they did. However, there was a little 2" electromechanical ball as backup in case all those computers and the signal converters which drive the CRT surfaces failed.

The next example I have is similar to the last system except the objective here was to define a helicopter fire control system including all the sensors and the computation for something in the range of $5 to $10,000. The question was: can it be done? The

SIMPLE AIR-GROUND FIRE CONTROL SYSTEM

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**T.V. TRACKER
LASER TRACKER**

CURSOR COMMANDS

ANGLES & RATES

**WEAPON DELIVERY
COMPUTER**

CURSOR COMMANDS

LEAD ANGLES

HEAD UP DISPLAY

**GUNS, BOMB
AND MISSILE
TRAJECTORY
SIMULATION**

T.V. DISPLAY

CURSOR COMMANDS

LOCK ON, RELEASE

**MANUAL
CONTROL**

**COORDINATE
CONVERSION**

**GUNS, BOMB AND
MISSILE
BALLISTICS**

AIRSPEED

PRESSURE ALTITUDE

ANGLE OF ATTACK

**AIR DATA
COMPUTER**

ANGLES

RANGE

RADAR

**HELMET
SIGHT**

**WEAPON
RACK**

RELEASE

RELEASE
VERIFICATION

**STORES
MANAGEMENT**

PITCH

ROLL

HEADING

**ATTITUDE
REFERENCE**

FIGURE 19

answer is: maybe. Certainly the use of microcomputers is one
thing that may make it possible. In this system there was a very
low cost PWSR (Pilot weapon system readout), basically a very
simple head-up display with about 10° field of view. A similar
low cost head-up display was used for the Apollo rendezvous. There
are three reticles that can be directed by the microcomputer. One
is reticle to command flight path relative to a fixed reticle, one
is the target location vehicle, and the third reticle indicator is
the electro-optical sensor boresight. In this case the electro-
optical sensor included a laser range-finder pointed by a manually-
steered pantograph which directed the line-of-sight towards the
target. The gun gimbals were slaved to the EO line-of sight with
the corrections computed by the microcomputer to take the account
of ballistic droop. There was also a similar computation for the
rockets. The sensor inputs for this system include air data and
other simple sensors. All of the required functions could be
implemented with an existing, fairly slow (5 microsec) microprocessor
and a hardware multiplier. The microcomputer parts would cost about
$400 in quantities of a thousand for providing all these functions.

Another example is based on an air defense missile guidance and
control, which includes a strapdown inertial system for both the
flight control attitude reference and for inertial navigation. It
is a very low accuracy inertial navigation system since it is
updated by ground radar every two sec. The implementation used two
CPUs and a shared memory; one processor is for the inertial and
homing guidance and the other is for flight control functions. This
system was implemented using a bipolar Schottky microprocessor, the
Intel 3000 series, and again the cost for parts of the microcomputer
is less than $6,000.

Future trends: We are going towards simpler weapon delivery systems.
Strapdown inertial systems represents a strong trend, eliminating the
gimbals and hopefully resulting in lowering cost. Terminally guided
weapons reduce a lot of requirements on the launched aircraft's
systems and requires a fairly gross acquisition basket for launching.
The impact of dedicated MOS-LSI computers are beginning to be
strongly felt in the systems being designed for the next set of
requirements.

I think that microprocessor technology will permit the implementa-
tion of most avionic functions that we can imagine, provided we
can devise means to convert the sensor information into digital
form for the computer, drive the actuators, and display the informa-
tion to the pilot.

Just to give one personal example of what this technology can do and
its potential, I've now skippered boats on the trans-Pac race to
Honolulu three times. The first two times, we used the age-old way
of navigating by having a big thick set of documents that stored
the star almanac, the sun almanac and other navigation tables.

We would read the sextant and then spend another hour or so plotting all results on a board and hope we didn't make a mistake in plotting.

On this last race I had a Hewlett Packard 65 and I bought the $40 HP 65 navigation pac. All the dead reckoning was done with two little cards feeding into the calculator, which gave me my dead reckoning position within 60 ft. (How accurate it was was another matter.) I had another set of cards for taking sun shots. All I needed then was my $50 sextant, a $70 microcomputer watch, my $800 microcomputer or calculator, which you can now buy from TI for $400, and these little magnetic programming cards.

DR. DENERY: Dick, what is the status of military development of Universal digital avionics module?

DR. SMYTH: I've been following that closely. The Air Force Avionics Lab is sponsoring that program, the ACTRON Division of McDonnell-Douglas has had one of the principal contracts. They have come up with a very interesting 16-bit microprocessor that is supposed to be very fast. The basic idea is a modular avionics approach to satisfy the simple close-air support missions, which usually has the very simplest avionic systems to a more complicated all-weather inter-diction mission, which has more complicated avionic systems. The program includes display technology, the computation technology, etc., to build on a modular basis from the simple systems to those that are more complex.

DR. De BRA: I'd like to introduce Bob Noyce who is Chairman of the Board at Intel. He will talk with more than a little authority on the electronic solid state industry.

SOLID STATE ELECTRONICS

DR. NOYCE: I was more than a little interested in hearing from repre-sentatives of the automotive industry who sell products for $1 a lb, and from the avionics industry whose products sell for from $300 to $500 a lb. I did some rough calculations and our solid-state devices, as packaged, sell for about $10,000 per lb. The semi-conductor chips, which are the heart of our product, would sell for half a million dollars a pound without the package.

While this figure sounds like a lot, the history of pricing in the semiconductor industry provides a startling contrast in terms of price reduction. For example, if you look at the cost per function vs. time, the cost of a flip-flop in integrated circuit form dropped from $10 in 1963 to less than a penny today. This is a thousand to one decrease in cost over a ten-year period. I can think of few other products that have dropped in price since 1963 and certainly none so drastically.

The low cost of individual functions is even more amazing in some
of our newer, more complex circuits. Of course, the reason for
this accomplishment is the number of functions we've been able to
put on a chip. In the early 1960's the first integrated circuits
had 3 or 4 components per circuit (Fig. 20). Now we are putting
tens of thousands of components in about the same area. Our 16K
CCD serial memory, which is now on the market, has something in
the order of 35,000 components on a single chip. Nor is there any
reason to expect this kind of improvement to slow down. We are far
from reaching the fundamental limits in the complexity of circuitry
that we can put on a single chip; we have at least a couple of
orders or magnitude improvement to go before we get into any major
problems. However, we did face another dilemma as complexity
increased.

From the first IC's, the industry went to multiple functions--dual
gates and flip-flops, and then quads, and so on. We still dealt in
basic circuits, but managed to put more and more of the Boolean
functions on each chip. At that point, it became apparent that we
were going to have to develop not only more circuits, but different
circuits that would satisfy the needs of fewer customers. The
market for each new product became smaller and smaller, a disaster
for any industry predicated on making its profit in volume.

The design of an integrated circuit used to cost $10,000. Recently,
with more complex circuits, the average cost rose to $100,000 and,
now, with highly complex circuits, the cost of designing and debugg-
ing a major, new circuit might run up to a million dollars.

It became apparent that it was impractical to do a competent engineer-
ing job with one of these new, complex devices which have a limited
application. For a period of time, we thought the answer might lie
in the use of computer aided design. For an expenditure of 10
million dollars, automatic systems were developed that could produce,
in a short time, a number of circuits. Those circuits considered
unsatisfactory could then be scrapped. The problem was that we
estimated that we would have to design 30 circuits a day, at a cost
then of $30,000 to keep individual costs down. Because other tech-
niques would have cost a million dollars a day, it did seem as though
the computer was the only solution to our problems.

We now know that this is not the case. There simply were not enough
engineers in the world versed in semiconductors to handle all of the
potential design requirements. The answer was the development of
microprocessors, capable of simulating any digital logic combination.
Introduced in late '71, and still in their infancy, the market for
these devices in 1975 was about $50 million (Fig. 21). From the
number of references to microprocessors during this morning's dis-
cussion, you can see that their potential is already beginning to
have a profound effect on everyone's thinking.
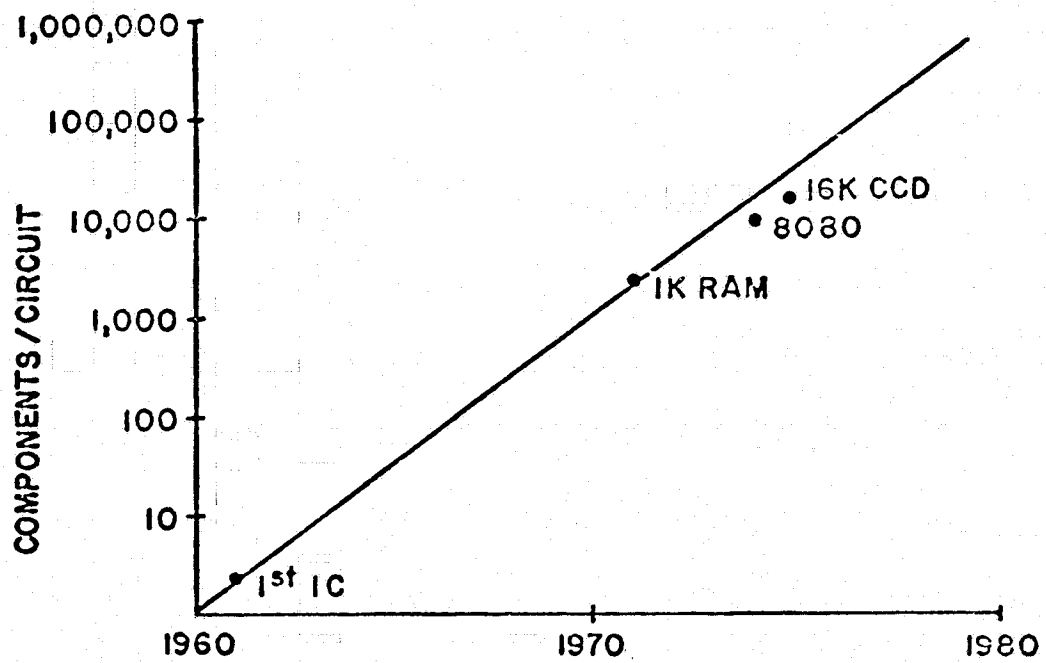
COMPLEXITY OF INTEGRATED CIRCUITS CONTINUES
TO INCREASE, NEARLY DOUBLE EVERY YEAR.

FIGURE 20

MICRO-COMPUTER
MARKET

THE µCOMP MARKET IS JUST BEGINNING TO
DEVELOP, IT INCLUDES MUCH MORE THAN THE CPU.

FIGURE 21

61
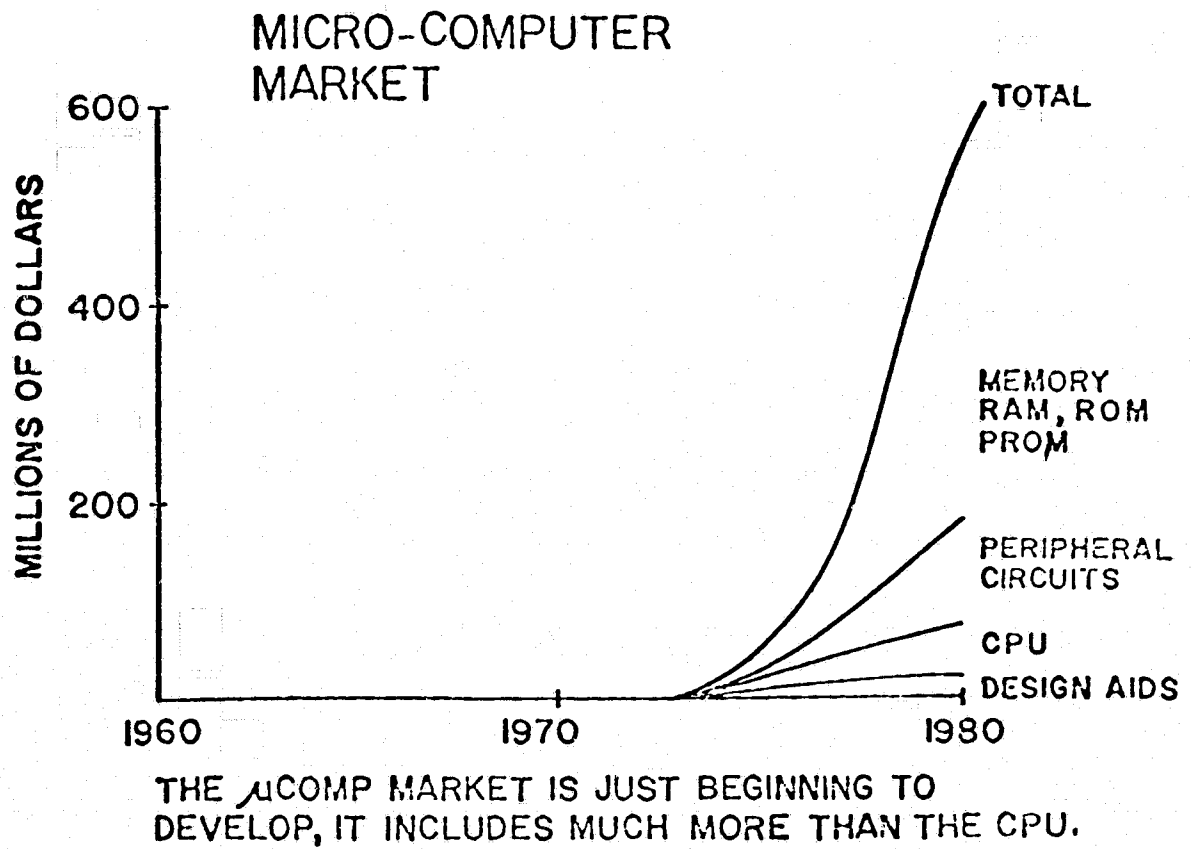
Microprocessor CPU's represent 10 to 20% of the market so their total sales in 1975 were in the $10 million range. There are also numerous design aids that have to be provided along with CPU's. Peripheral circuits previously not available are also becoming available. Incidentally, many of these peripheral controllers are much more complex than the processor itself, so we have to be careful in developing these circuits to be sure that their volume requirements are sufficient to keep us from going broke again. And, of course, the major part of the microprocessor market is the memory that serves as the brain for the whole system.

Microprocessor technology is changing quite drastically (Fig. 22), following the historical precedents set by digital IC's. Looking back at IC development, the first integrated circuits, RCTL, were very slow and very inefficient in terms of computation power, although in 1974 they did manage to get us to the moon. That lag between development and utilization seems to be inherent in this business.

DTL and TTL circuits came along next. TI decided that they weren't going to make DTL, dropped the price of TTL, raised the price of DTL and literally drove that product out of the market. Yet, TTL is much faster than is required in most of the applications in which it is being used. Now high speed computers are using ECL which came into maturity in the late '60's and early '70's.

In LSI technology, the first calculator chips were in the speed range of the early integrated circuits which had preceded them a decade before. They were PMOS metal gate devices, Now, NMOS silicon gate devices are most widely used today, and they, surprisingly enough, have about the same switching speeds as TTL. This comparison is important to note, for MOS technology is commonly thought of as being a "slow" technology when it really is as fast as TTL. I will also mention I^2L here because of the amount of publicity it has received. In my opinion, I^2L will not become a widespread technology because the switching speed of NMOS is improving rapidly and because I^2L has some fundamental limitations.

As a result of the changes that I have discussed, the role of the semiconductor manufacturer has changed quite drastically over the past 15 years (Fig. 23). In the late '50's, we were simply manufacturing components. We had to have some circuit designers so that we could at least specify the devices in terms of circuit parameters. With the advent of IC's, we were obviously in the circuits business and we had to consider how the user was going to integrate these chips into his logic. As we progressed to larger logic blocks and then to medium-scale integration, we had to take into account the architecture of a system to make sure that what we were providing were practical subsystems.
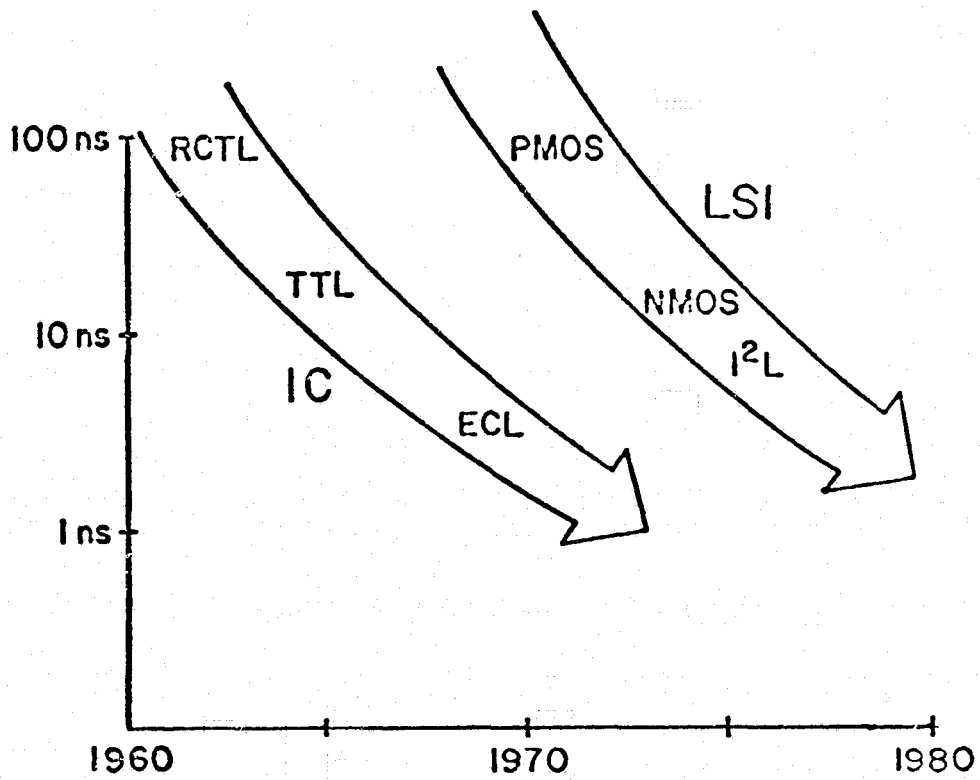
AFTER INTRODUCTION, THE PERFORMANCE OF IC'S
IMPROVED RAPIDLY. THE SAME IS TRUE OF LSI.

FIGURE 22

EACH CHANGE OF LEVEL OF INTEGRATION HAS
FORCED THE COMPONENT SUPPLIER TO ASSUME
ADDITIONAL RESPONSIBILITIES.
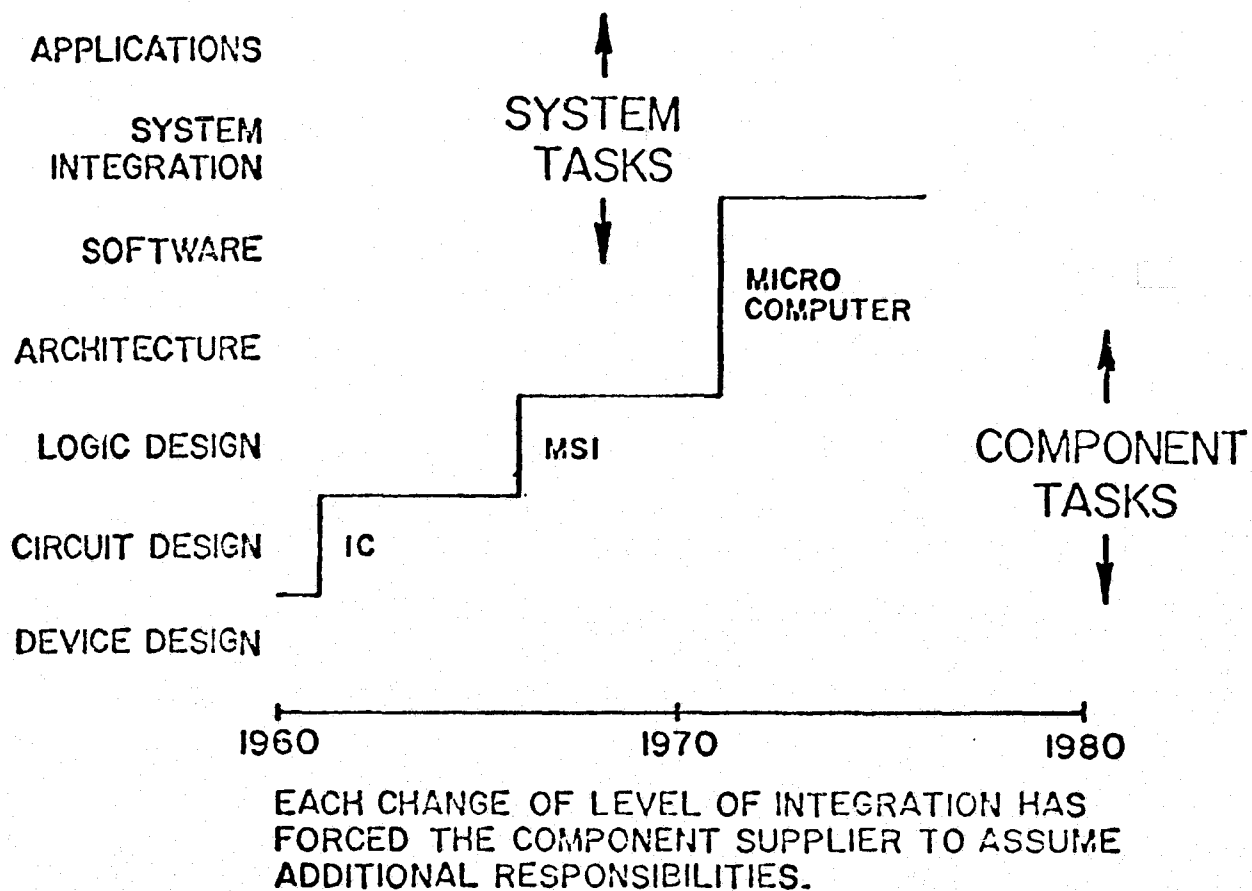
FIGURE 23

(NOYCE Cont)

With the microprocessor, we are taking on another major task. The word "software" in Fig. 23 refers to the design aids that we must provide to help the user who is actually programming the processor. Because we must increasingly become more knowledge-able about system architecture, the task we are undertaking becomes increasingly more sophisticated.

Yet, there is a limit to what we can do to exploit the literally thousands of applications for the microcomputer. It will be up to you, the avionics industry, to help find the right applications for these devices. The reason for this is simple. In terms of fanning out from our abilities to design and produce micro-processors, we're much better off using our capabilities to educ-ate the world than to try to do the additional jobs that are required. That is why, on an average day, Intel will run classes in which there are 30 people who are not associated with the company.

As I said earlier, there is no reason to think that trend toward greater complexity is going to stop. Also, the drive for greater speed is continuing. Projecting these trends out to 1980, where will we be?

The 8080 is very close to the level of complexity of the mini-computer, although somewhat slower and less sophisticated in terms of architecture (Fig 24). In a sense, you could say that the microcomputer now is where the general purpose computer industry was a decade ago. In terms of the improvement in capability, this time lag, represented by the time required to progress from a CPU made of individual components to a CPU on a single chip, is shortening. By 1980 those computers on the market a couple of years ago will be available as a single chip computer. Looking further ahead, by 1985 we will be able to put the entire main frame of a 1980 computer on a single chip.

I realize that these projections may be of primary importance to the data processing industry. However, as was pointed out in several talks this morning, one of the first cars GM built with a microcomputer control used a 4-bit P-channel microprocessor which handled 20 functions and still had time to spare to handle any other jobs required. Of course, they had to have about 6 cards full of other logic surrounding the CPU to enable it to interface with the rest of the car. Typically, control functions are slow compared to data processing requirements, so there isn't much need for increased speed.

The present day 8080 is already 10 times as fast as its predecessor. There will be another improvement, by a factor of 10, within a year, and a factor of 10 improvement a year after that.
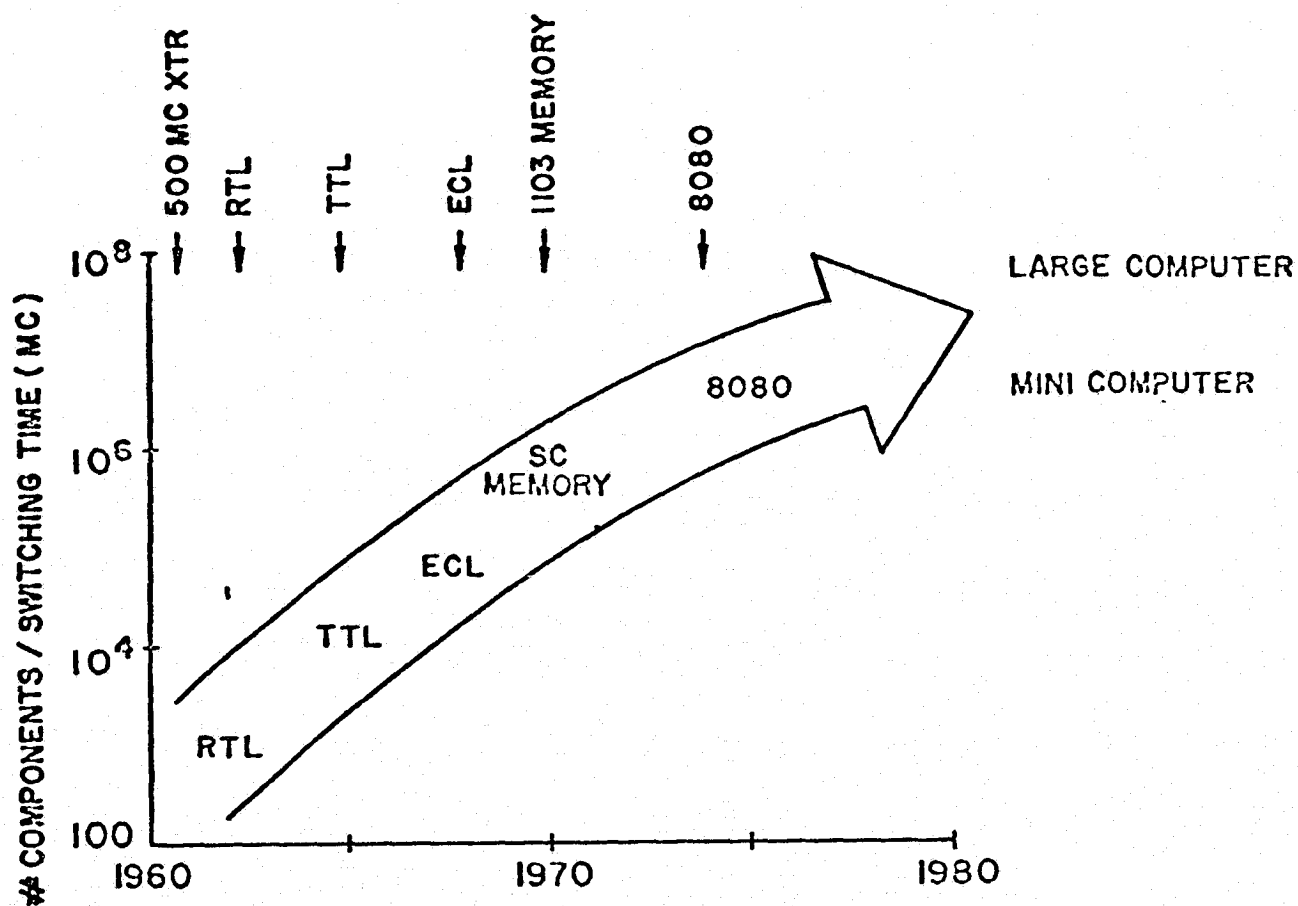
BY 1980 THE SPEED COMPLEXITY OF THE MICRO-
COMPUTER WILL BE COMPARABLE TO THAT OF
TODAY'S LARGE CPU'S.

FIGURE 24

(NOYCE Cont)

Price is another important consideration. The 4004, with one-tenth the speed of the 8080, was selling at $40 during 1974. The 8080 is now selling for $30 according to the most recent ads by our competitors. (And that is out of date one month later--Ed.).

It is also important to note that this device is now being manu-factured by Advanced Microdevices, Texas Instruments, Siemens and by Nippon Electric as well as Intel, so there are five suppliers worldwide. That means that we are getting a de facto standard in at least one class of microcomputer. Thus, peripheral circuits will be capable of being interfaced to that processor whether they are made by the present suppliers of the processor or by the rest of the industry. This is going to be an absolutely critical factor from the standpoint of cost.

It's obvious from the comments made this morning, that sensors are going to be the problem. Processing represents no problem in today's microcomputers. But it is essential that we have low-cost ways of getting the input and making use of the input.

The other point that was so heavily emphasized this morning was the need for reliability. In that context, I would like to make a couple of remarks. As a pilot, I don't really care a great deal about fail-safe type failures as long as I am warned about what is happening. I am still supposed to be there in the cockpit, and I can turn off various pieces of equipment and reconfigure the system. With a redundant system, someone else has made those decisions in advance and they are not necessarily the best answers. I would much prefer to consider that decision making process one of my responsibilities when I am the pilot.

There are numerous analog phenomena that would be very useful if we were able to put it into digital form for processing. This is another area in which our industry can make major contributions. For example, 10-bit A to D converters are now available which are microprocessor compatible. If it were used in the measurement of absolute pressure, you would then be able to determine altitude within a 50-ft error. However, it does require some other infacing chips to make the whole system work.

The point, though, is that it is only another single chip of sili-con, capable of being used for numerous measurements. With sufficient volume, that chip could be produced for a dollar to two.

There are other applications for this type of device, besides measurement, which would cause the market to explode. The proper way to transmit messages over a telephone is to digitize voices at the instrument and then convert to an analog signal at the other end. For that application to be practical, the converter would have to have a 6- or 7-bit accuracy and sell for about $2.50.

(NOYCE Cont)

With sufficient motivation, the high cost of analog to digital conversion could be drastically reduced. I believe that it will be accomplished, and reasonably soon, because large volume applications do exist.

Another area with great potential is the self-scan linear optical arrays. Typically, these consist of a string of 120, 250 or 512 photodiodes, with a digital output. If you wish to transmit a mechanical motion, you just count the number of diodes that are dark, and the number that are light and get a digital output that indicates the position of the object being sensed. These devices have been used for position sensors in the process industries and some other applications. They sell at relatively high prices, although the cost to manufacture is low, because of the volume and nature of the market in which they are being used.

I'm convinced that we know what has to be done to produce avionics that are reliable, low cost and a significant technological improvement over what is presently available. To make something reliable, we must make it in large quantities so that we can find and eliminate failure modes. To make it low cost, we must also have the economic benefits of high volume production.

The technology is already here, having been developed for the data processing industry. Despite the fact that microcomputers have been in production for two years for the data processing industry, they have not had the impact on avionics that they should have had. There are only three major systems being designed around the earliest MCS-4. The 4-bit processor could be packaged with enough memory at a cost of $100 and would be quite adequate for most jobs.

The conclusion that I offer is that to get the kinds of devices required for avionics with the reliability and low cost required, you must stay right in the middle of the commercial mainstream, depending upon the automotive industry for the development of trans-ducers and the data processing industry for data processing capabilities. These industries will produce the large volume applications of the types of devices that are compatible with avionics.

On your part, the most compelling need I see is that of standar-dizing on a data bus interface. I don't know whether it will be practical for avionics, but certainly the data bus that will become the standard for most of the data processing industry will be set by IBM.

MR. GORHAM: You made a comment about redundant systems and said
          you didn't care too much about failures as long as they were
          passive and you received a warning when they occurred. That
          is the same philosophy we have in the airline industry. The
          reason we do use automatic redundancy (where we use more than
          two systems on the basis that a failure would still provide
          you with a survival capability automatically) is that in some
          flight modes, there isn't time to reconfigure. Two such modes
          are in automatic landing when you're near the ground and in the
          use of the stabilization system, the failure of which will leave
          the airplane unstable.

DR. NOYCE: In the general aviation field, you're not apt to have
          automatic landing systems, and you're not going to fly airplanes
          that are characteristically unstable. It would be unsafe.

MR. GORHAM: I think we'll talk about that tomorrow. But if the
          technology is available, as you know, somebody will take advant-
          age of it; so there's a chance that is going to happen too.

MR. SEACORD: You recommend the data processing industry as the source
          of electronics. Is the data processing industry going to produce
          or demand something to meet the temperature requirements for
          avionics? If not, what is it going to cost to get that tacked on?

DR. NOYCE: Typically, we are right now qualifying all of these
          microprocessors for the military temperature range. In some cases,
          the 125° limit is being relaxed to 100°, or even 85° (Centigrade).
          One of the problems that we may face here is over-specification.
          I certainly agree that it provides a harsh environment but it's
          certainly no worse than the automobile. The automobile industry
          is going to write commercial specs to operate in their environments.
          That's 10 million units a year instead of 100,000. I would heartily
          endorse the idea of adopting their specs and not military specs.
          They're probably going to be more severe in some cases but they're
          going to be more realistic.

MR. OSDER: When you talk about next year's avionics being 10 times
          faster than this year's, to what extent is next year's equipment
          software compatible?

DR. NOYCE: That's a difficult question. It is certainly possible
          to increase the speed of the straight 8080, by a factor of 3, but
          there are important advantages to be gained by changing the archi-
          tecture of the device doing the instruction decoding while you're
          taking care of the execution of the last instruction, etc. In those
          cases there will not be compatibility at the op-code level. We
          will try to maintain compatibility at the programming level,
          whatever that is, but if it is too rigidly controlled for its
          total software compatibility, performance will be degraded.

DR. SMYTH: What do you see in the development of higher level
    languages for your microprocessors?

DR. NOYCE: Let me go back to what I said as to the meaning of soft-
    ware, to the component supplier. This is going to be programming
    languages only, where the designer has set up a particular ROM for
    solving his particular problem. We have a lot of customers that
    are writing FORTRAN, BASIC or whatever to run an 8080. They're
    writing it in these programs. It's a question of who's doing it.
    It is certainly possible to get a general purpose computer to run
    any high-level language on it if you're willing to sit down and
    write a compiler. The question is: whose expense that is going
    to be at? One of the problems that we get into in this business,
    because we expect multiple sourcing is that the first supplier goes
    in and develops the market and spends a million dollars on software;
    the second supplier comes in and copies the drawing of it,
    reproduces it and sells it only at hardware cost. That is the
    problem and I frankly don't know the answer to it. You need enough
    money flowing into the system to provide for new development costs.
    So far it hasn't been a problem because there has been enough time
    lapse between the original supplier and the second supplier coming
    in to permit the first supplier to recover his development costs.

DR.De BRA: Let's go on to talk about the most often referred to,
    sometimes editorially called "distasteful" but clearly, one of the
    key items in this whole thing: displays. Parvis Soltan of the
    Naval Electronics Lab is going to give us a rundown.

ADVANCED DISPLAY TECHNOLOGY

DR. SOLTAN: I am delighted that emphasis has been put on display
    technology by this morning's speakers, and I certainly agree with
    the previous speakers that with the development of a computer
    aboard aircraft and its interaction with display devices inside
    the cockpit, great things for avionics can be expected. Now, first,
    I'd like to talk to you about the essential parts of the display
    system and try to point out that there is not a single display
    system that can solve all display needs. Then, as you have all
    expressed interest in Advanced Display Technology and its future
    trends, I shall give you my views in that respect.

    Parts of Display System: There are actually five essential parts in
    any display system, as shown in the block diagram of Fig 25. They
    are: Information for Imaging, Transformation, Memory, Panel Drive,
    and Display Media. Reviewing this data flow, one has to receive
    high quality analog or digital information at the Imaging section,
    properly scan and convert it at the Transformation section, use the
    Memory block for stored codes, speed buffering and information
    refreshing, then drive and scan a specific panel, and finally display
    the information to the viewers in an acceptable form on a display
    medium.

ESSENTIAL PARTS OF DISPLAY TECHNOLOGY

(1)   (2)   (4)   (5)

Information Imaging	→	Transformation	→	Panel Drive	→	Display Media

* Sensors   * Scan Conversion   • Electron Bean   * CRT
• Computers   • Symbol Generation   • Laser Scan   • Flat Panels { LED
           •   • Matrix addressing &   Plasma
           •(3)   Scan   Liqiud crysta
                           EL
                           Fiber optics

Memory

* CCD
• Buble
• Plated wires
• Charge storage
• Magnetic Thin film
•
•
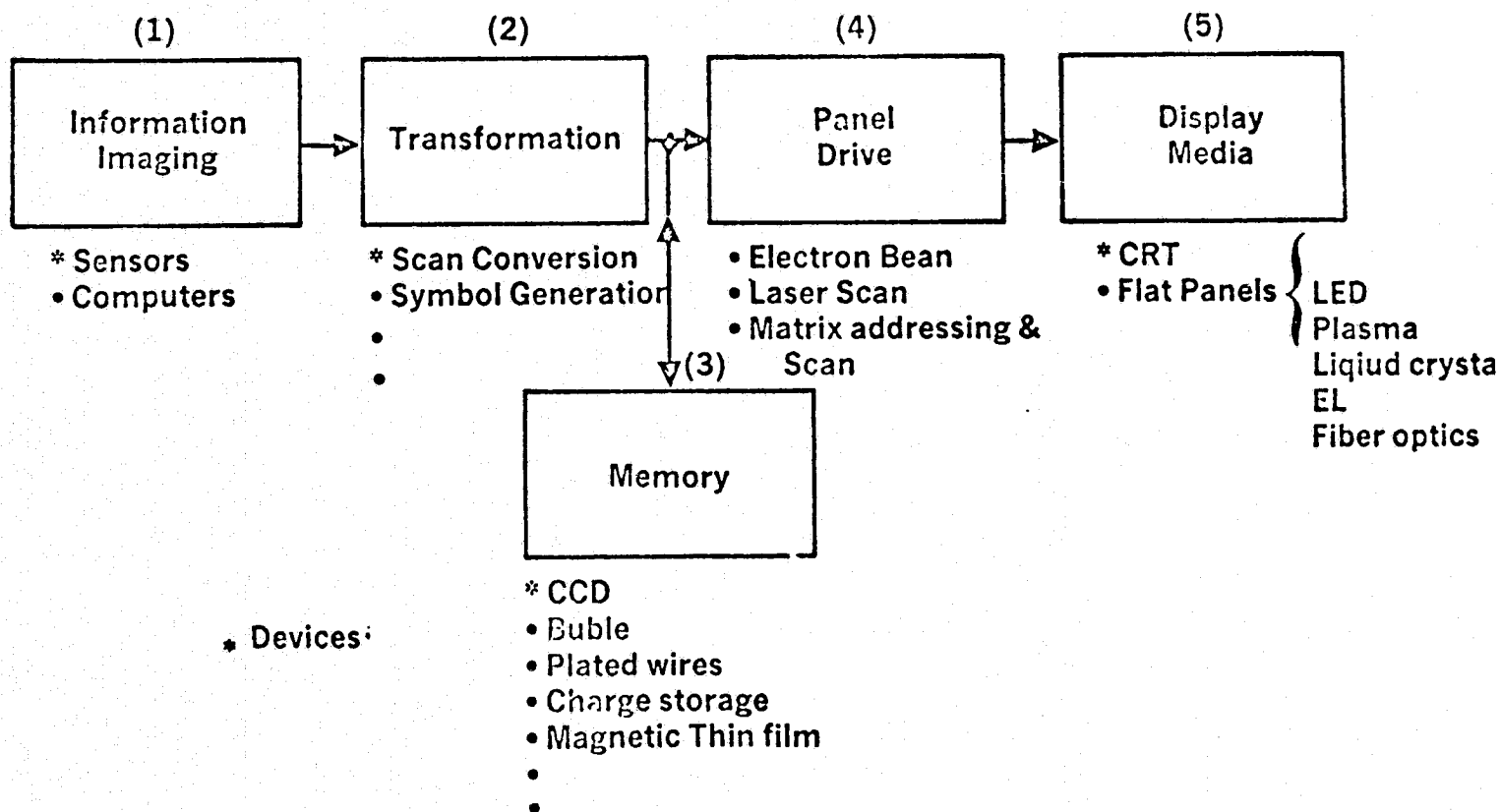
* Devices·

FIGURE 25

(SOLTAN Cont)

Looking again at these five essential parts of a display system, one should realize that there are competing devices and technologies within each section. For example, for Memory, technologies like charged couple devices (CCD), bubbles, plated wires, magnetic cores and magnetic drums compete. For the Panel Drive section, electron beam technology competes with matrix addressing scheme. Or for Display Media, CRT competes with flat panels, i.e., plasma panel light emitting diodes (LED), electroluminescence (EL), and liquid crystal (LC) panel.

It is evident that a display system designer has no easy time selecting an optimum combination of all these competing technologies and devices for an ideal single display system. In other words, there is not a single system that can be a solution to all display needs.

Military and commercial industry are concerned about the cost of display systems. Presently, CRT is unquestionably the leader as far as low cost is concerned. Looking again at the five essential blocks of Fig 25, it costs less than a dollar for a CRT oriented system to display an alphanumeric character. No other display system can compete with this cost. As for the plasma panel, it is presently less than $3.00 per character; LED, less than $4.00.

Although cost is important, for some military applications it is not the only factor. A CRT that can be purchased commercially for under $100 will not meet military requirements. To satisfy the Air Force's electromagnetic interference (EMI), electromagnetic pulsation (EMP), radiation, shock, vibration, intensity and resolution requirements, the cost of a CRT climbs to $4,000 to $5,000 a unit. So one recognizes that the cost alone, for some applications, is not the main factor.

A display media is very slow as compared to the computer and the sensor inputs. The Memory section of the display system plays an important role in acting as a buffer between the fast computer and the slow display panel. The recent trend is to move the memory block and incorporate it within the display media. Display panels with inherent memory, like plasma panels, are becoming very attractive because the need for refreshing will be eliminated.

The trend in advanced display technology is toward digital display and large system integration (LSI) of all the five essential blocks that were discussed earlier. It is apparent that the new field effect liquid crystal (LC) panel, with less than 6V panel requirements, is suitable where plasma display, which requires over 100V for panel operation, and especially the CRT, with a voltage requirement of 10,000 to 25,000V are not compatible with this LSI trend.

To summarize this part, one should realize that there is not a single display system or display media that could be the panacea for all display needs. One must choose, shop around, in order to select the right combination of the FIVE essential display parts for one's display needs.

Display Media: For the rest of my presentation, I will concentrate on the display media (the fifth block of Fig 25). The display media can be divided by size (Fig 26) into three categories:

    1 - Instrumentation Display size under 4 in^2

    2 - Tactical Display size around 20 in^2 or less

    3 - Large area Command and Control Displays size
       6' x 6' to 20' x 20'.

1.   Instrumentation Display

Let us look at Fig 27, the Instrumentation Display. Here, the aircraft and other instrumentation systems use a large number of single function displays and indicators for displaying status information such as flight parameters, navigation information and equipment conditions. Present devices that perform the display functions are generally less than 4 in^2 in size and are scattered around the cockpit of the aircraft. Small CRT, neon bulbs, electroluminescent panel, incandescent lamps and gas discharge indicator tubes are a few examples. As many of the previous speakers have indicated, the trend and the future requirements for this class of display devices are integration and on board monitoring by a digital computer. Fig 28 shows the requirements and display candidates for future aircraft displays.

Let us review this area a little deeper. With the exception of some gradual improvement in format and reliability, and some successes in the integration of displays, there has been little change in the cockpit instrumentation, its supplements and various housekeeping aids over a considerable span of aviation history. As a result, the pilot's burden has constantly increased in pace with the increasing complexity of weapon systems and air missions. A large percentage of the pilot's time and attention must be focused on scanning and reading "raw" parametric data representing the output of discrete, dedicated sensors. With few exceptions, this information must be interpreted by the pilot into mission specific or housekeeping information meaningful in terms of satisfying a need for knowledge of the tactical situation, safety-of-flight and weapon system status. Another important aspect of the operational problem lies in the area of military effectiveness.

MILITARY
CLASSIFICATION OF DISPLAY
APPLICATIONS

1 — Instrumentation Displays (4 in^2 or less)
Aircraft and other instrumentation systems
which use a large number of single function
displays and indicators for displaying status
information

2 — Tactical Displays (20 in^2 or less)
For the presentation of raw data from sensors
used in such applications as fire control,
mapping, terrain following, and surveillance

3 — Large Area Command and Control Displays
(6 $\times$ 6 Ft to 20 $\times$ 20 Ft)
Large area displays for tactical or fixed sight
applications

FIGURE 26

1 — INSTRUMENTATION DISPLAYS (4 IN² OR LESS)

Purpose

Single function displays and indicators for displaying:

- Flight parameters
- Equipment conditions
- Navigation information

Present display systems

- Incandescent lamps
- Indicator tubes
- Neon bulbs
- Gas discharge indicator tubes
- Electroluminescent panels
- Light emitting diodes (LED)
- Electromechanical indicators

FIGURE 27

TREND AND NEW CANDIDATES FOR AIRCRAFT INSTRUMENTATION DISPLAYS

Requirements

Integrated instrumentation systems for optimum information transfer of all flight information including on board check out from a computer

Display Candidates

- Improved CRT
- Plasma Panel
- LED Panel
- Liquid Crystal Panel
- CRT + Fiber Optics Flat Panel

FIGURE 28

The accuracy of functional control, e.g., weapon delivery,
is limited by display resolution and controlability.
Current cockpit instrumentation systems are primarily imple-
mented with electromechanical devices, servo-driven mechan-
isms, and, in more advanced systems, complex optical and analog
electronic circuits. The maintenance of such equipment and its
logistic support requires high skill levels and results in a
significant impact on life cycle cost. A parallel set of
problems exists in the area of cockpit controls. Tradition-
ally, the pilot has been confronted with an array of bat
handle, rotary and push botton switches, all dedicated to
discrete functions and identified with abbreviated nomencla-
ture. A high degree of virtuosity, coupled with extensive
(and expensive) training, has been necessary in mastering the
manipulation of a sophisticated weapon system.

The trend is for a totally new approach to the man-machine
interface. This approach will satisfy the existing deficien-
cies in cockpit instrumentation and controls. Specifically,
provisions should be made for:

a. Strong emphasis on human factors engineered func-
    tional utilization, format and symbology. Fully
    integrated display/control, including backup cap-
    ability between terminals.

b. Introduction of a system of integrated, interactive
    displays and controls, and design of cockpit instru-
    mentation as a visual information system for the
    pilot to permit rapid assimilation of data.

c. Provide a versatile capability in order to accommodate
    the various aircraft sensors without costly reconfigu-
    ration of the cockpit, and provide for a major reduc-
    tion in the number of discrete switches by providing
    multifunction control for increased man-machine
    compatibility.

d. Provide multifunction displays for operations in all
    modes under night and nonvisual conditions; provide
    for display and annotation of all current and planned
    sensors on a single, multifunction terminal.

2. Tactical Display

Figure 29 gives the tactical displays category for 20
in^2 sizes or less. Here the display devices are generally
used for the presentation of raw data from sensors in such
applications as fire control, mapping, terrain following,
and surveillance. Presently, CRT monitors are widely employed.
Note, however, the limitations of CRT, especially its high
voltage, poor form factor, and incompatibility with IC tech-
nology. The future trend and advanced technology, as shown
in Fig 30, are with improved CRT technology and digitally
controlled flat display panels.

3. Large Area Command and Control Display

Figure 31 presents the large screen display devices where
the size category ranges from 6' x 6' to 20' x 20' or larger.

Large displays for group viewing are not as highly
developed as the individual displays. At present, because of
cost effectiveness, the projection type of display system is
widely employed both in civilian and military applications.

For increasing numbers of military requirements where
space is at a premium (aircraft and submarines), or at control
centers where key personnel function in synchronization, the
projector based display system seems cumbersome and inadequate.
For example, the projection throw distance, bulk, weight, power
drain, and incompatibility between an analog device and digit-
ally generated information signals are among the reasons that
the military is exploring other competitive techniques for
developing large area flat panel type displays for command
control and communication (C^3) systems.

In Figure 31, a number of present systems that are employed
are reported; however, in the past several years, industry has
sought a large flat display technology to free users from space
problems, large power consumption, and the high maintenance
requirements of the projector based large screen displays. Up
to now, however, from the four leading competitive technologies
(electroluminescence, light emitting diode, liquid crystal, and
plasma), none are cost effective nor free from inherent technical
problems sufficiently to be seriously considered as an alternative
method to replace the projector based approach.

Figure 32 gives the requirements for an acceptable large screen
display, and Fig 33 reports on a new promising technique called
"Fiber Optics Image Expander." This technique is based on the
employment of low loss, or medium loss, fiber cable and expansion
of that image at the other end over a large display panel. If

2—TACTICAL DISPLAYS (20 IN^2 OR LESS)

Purpose:

To display generated information from Computer, electro magnetic sensors, radar, and IR surveillance systems.

Present systems

- A Single Color CRT for each sensor is widely used.

CRT Limitations

- Poor Form Factor
- High power requirements (10-25 Kv)
- Short life (500-1000 hrs)
- Difficult to view under high ambient light
- Difficult to interface directly with computer (Interface circuitry must be used)
- Commercial Color CRT's are not suitable for military

FIGURE 29

TREND AND NEW CANDIDATES FOR TACTICAL DISPLAYS

Requirements

- Advanced, high performance aircraft mission requirements dictate the use of avionic systems with a centralized high speed computer.

- Displays that are easily interfaced with computer circuitry are needed.

- Display must be capable to operate in complete darkness as well as in high intensity (10,000 FL Lamberts) ambients.

- Memory and storage, or variable persistence is desirable to lessen the update rate required from computer.

Trend and new candidates

- Improved CRT coupled with solid state memory

- Digitally controlled
  Flat display panels with integrated driving electronics (plasma, LED, liquid crystals)

- Flat fiber optics display panel

FIGURE 30

3—LARGE SCREEN DISPLAYS
(6' x 6' TO 20' x 20')

Purpose
Large area multiple viewer displays for tactical or fixed site command and control applications.

Present Systems
- Manual Plotting
- Scribing Projectors
- Rapid Process Film
- Projection CRT
- Oil Film light valves
- Projection laser displays
- Photochromics, thermoplastic and liquid crystal light valve projection schemes

FIGURE 31

TREND AND NEW CANDIDATES FOR LARGE SCREEN DISPLAYS
(6' x 6' TO 20' x 20')

Requirements

- Intensity — 50 ft. lambert on screens
- Resolution — 30 lines per in minimum
- Contrast — 10:1 in typical environment
- MTBT — 5000 to 10,000 hrs
- Power & maintenance — Low
- Operating mode — Dynamic & static

Trend and new candidates

- Light emitting diodes (LED) panel
- Plasma panel
- Fiber optics image expander

FIGURE 32

FIBER OPTICS IMAGE EXPANDER
LARGE SCREEN DISPLAY PANEL
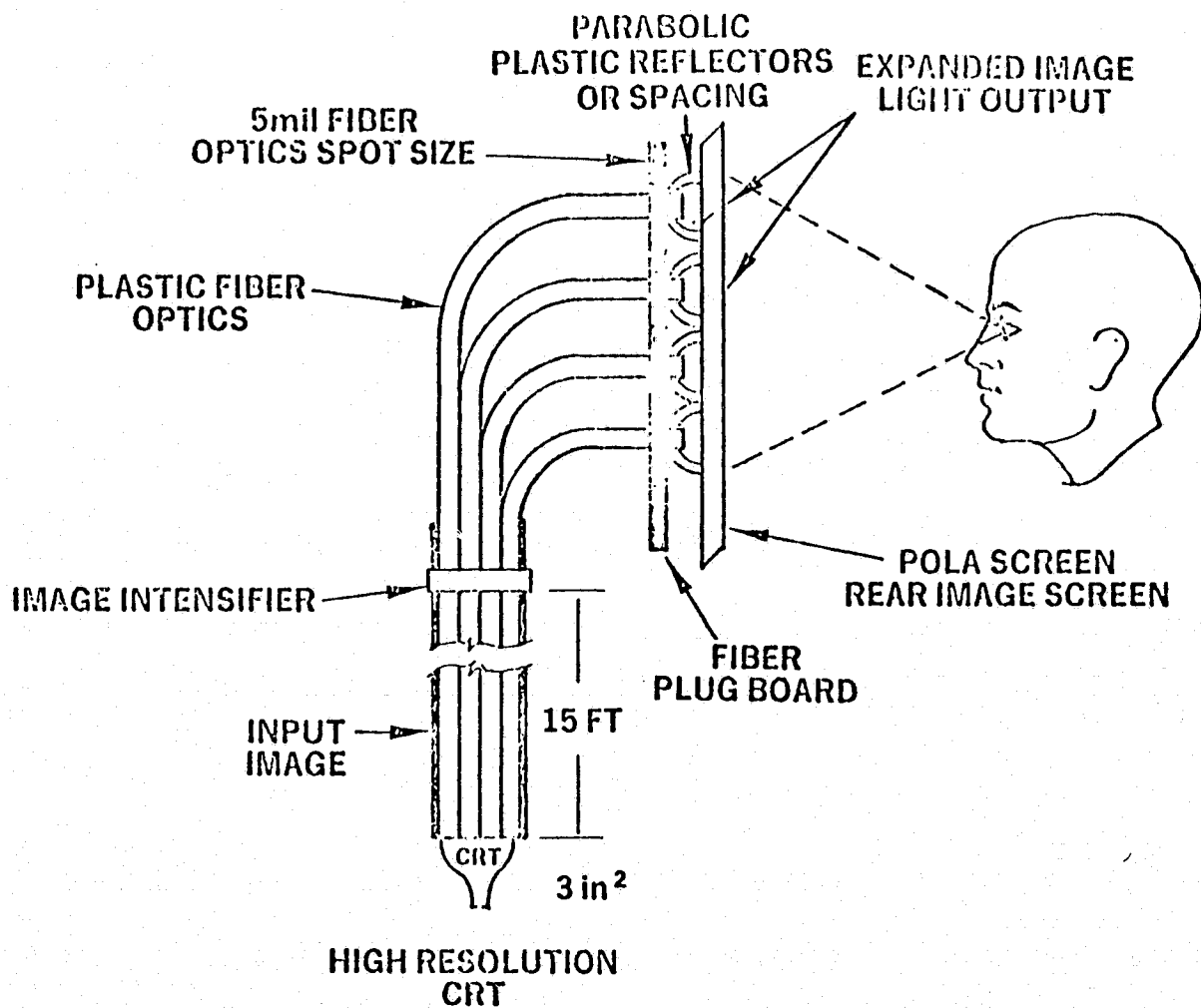
FIGURE 33

this technique proves feasible, enormous cost savings will
be realized by elimination of the traditional panel drivers,
circuits with electronic components necessary for scan and
selections, as well as power needs for the large screen dis-
play panel and its maintenance.

Device Problem Areas and Future Direction in Display Technology:
There are many unexplored technologies whose merit to the display
art has yet to be determined. Liquid crystals, electrochromics,
fiber optics, ferroelectrics, etc., are just a few examples. Work
in these areas must be continued to the point where careful evalua-
tion can be made of competing techniques to determine which approach
will be acceptable and the most cost effective.

Supporting technologies must also be pursued. Work should be con-
tinued on techniques for matrix addressing, memory systems for CRT
refresh, deflection, etc., to support and improve the utilization
of available technology.

Present aircraft that employ sensors like FLIR, SLR, low light level
TV, sonar, and lasers for weapon delivery or navigation, utilize
either individual displays or analog scan converter tubes to provide
selected multisensor data on a single display. Such systems are
highly complex and lack resolution, dynamic range, and reliability
and because of the sophisticated analog circuitry, they require cons-
tant adjustments and continual maintenance. Currently, two approaches
to alleviate these problems are envisioned. The first approach is to
develop solid state storage targets to be used in storage tubes and
scan converter tubes in order to provide simultaneous read and write.
The other approach is to apply digital techniques for data conversion
and storage for multisensor display applications.

At the present time, there is no practical solution to the problem of
providing group displays for mobile, tactical systems. Required is a
technique for providing a 6' x 6' display, or larger, that is light,
compact, low power and rugged. The preferable embodiment of such a
device would be some type of flat panel, matrix display.

There are presently at least three candidates for such applications;
the plasma panel, modular light emitting diode, and the liquid crystal
matrix. These techniques have not progressed to the point where com-
plete operational feasibility has really been proven.

Tactical Display: Ground mobile, seaborne and airborne displays are
heavily reliant on CRT oriented devices for display. These devices
have serious handicaps, especially where size and weight are important
system parameters. These equipments are also subject to the most
stringent environmental stress of all categories of display hardware.
A replacement for the CRT is needed to fill this gap. Some candidate
technologies are liquid crystals, electro-chromics, light emitting
diodes, fiber optics, plasma panels and digitally addressed CRTs.

At the present time, none of these approaches have progressed
to the point where testing can demonstrate conclusive superiority
of any approach from a given problem. Figures 34 and 35 summarize
the critical display problem areas and areas for future development.

DR. SMYTH: Could you comment about seeing display panels in bright
sunlight in the cockpit?

DR. SOLTAN: As far as panel brightness is concerned, there are two
extreme requirements in the cockpit; viewing in total darkness
and within the 10,000 ft lamberts. The latter is the equivalent
of having the sunshine over the pilot's shoulder, directly onto
the display panel. Using a liquid crystal panel, for example,
the direct sunlight is no problem because of reflectivity of the
panel. Viewing in pitch darkness, however, is of some concern
and artificial light is necessary to illuminate the panel.

FIRST PANEL DISCUSSION

CHAIRMAN: Duane McRuer; PANELISTS: Frank Jaumot,
Bob Noyce, Frank Riddell, Louis Seeberger, Purvis Soltan

MR. MC RUER: The primary reason that I'm the Chairman of this Panel
has little to do with my technical competence in any of the com-
ponent areas that we're going to be discussing. Instead, I rather
believe that it's because I'm a guidance and control systems
engineer and Dan thought that a systems viewpoint coupled with
component ignorance would be useful in keeping the other people
around here honest.

Since this is a Panel Workshop, one of the primary functions of
the Chairman is to lay out the ground rules and procedures that
we are going to follow, so I thought I'd tell everybody all at
once--including the panel members. Several of the people on the
Panel have had an opportunity to speak before; thus we'll give the
rest a similar opportunity to speak for not more than 5 minutes to
say something, in order to permit them to catch up with the others,
although they won't have the time for presentations like those
made this morning and this afternoon.

With that out of the way, we will turn to the basic charter of the
Panel. This is given in terms of the three questions in your agenda.
The context from which we're going to address the questions is
based upon today's presentations. We will go in a formal round-
table fashion starting with Frank. For instance: on question

CRITICAL OR PACING DEVICE PROBLEM AREAS

NEEDS FOR:

- MULTI-SENSOR DISPLAYS
- TACTICAL LARGE SCALE DISPLAY
- TACTICAL (AIRBORNE, SEABORNE AND GROUNDMOBILE DISPLAYS)
- MAN/DISPLAY INTERACTION

FIGURE 34

ISSUES, RECOMMENDATIONS, AND
FUTURE DIRECTION

- CRT Improvement

- Flat Display Technologies

- Human Factor (Man/display Interaction)

- Supporting Technologies:
  - O MATRIX ADDRESSING
  - O MODULAR TECHNIQUES
  - O MEMORY SYSTEMS
  - O SCAN CONVERSION

FIGURE 35

One, Frank will say something and then we will turn to Jerry
and so on. We'll do that, hopefully three times, and I'll
attempt to maintain some sort of control.

I'd like to be forgiven one other function of a panel chairman
and that is to get all the generalities out of the way at the
outset so that we don't have to go through that every time.
First off, I want you to know I am both against inflation and
deflation and for flation--we all are. Secondly, the answer
to the questions at issue are going to be based on the grounds
of utility, cost and reliability. These are the driving factors;
they've been pounded upon in each of the discussions here
earlier this morning.

Utility is simple enough. Being somewhat of a skeptic it has
been my general observation that utility is converted to those
things that are "Absolutely Required;" and "absolutely required"
converts to those things which one can do and, more often than
not, those ultimately get put on the airplane. Obviously, things
that are absolutely required are quite different in the varieties
of aircraft in general aviation ranging from $2 to $5,000, all
the way to $200,000.

Cost and reliability are achieved by high volume, and are probably
tied in with technology transfer from the automotive and other
high volume businesses. That would have as a corollary that we
should avoid all peculiar general aviation environments which are
not consonant with the automotive environment. We would like to
have, in going into the 1980 to 1990 time frame, not just a simple,
straightforward evolution in general avionics, but instead, a
resolution. The revolution is here in one set of components, i.e.
the electronic components; the followup of this electronic
revolution with advances in the sensors and the actuating elements
is clearly going to be the key driver for an overall avionics
revolution. Another remark on reliability that ties in with the
one on utility is the note that Dick Schoenman made this morning,
that functions will tend to expand such that the reliability of
the overall system remains constant.

Now, with the general remarks concluded, I'd like to turn to those
members of the panel who have not yet had a chance to say anything.
We will start with Frank Riddell.

MR. RIDDELL: Well, I'm like Mr. Franklin: I'm here today with hat
    in hand to ask for help. I feel like a maverick in this deal. I'm
    the only engine man here. The price of the typical electronic
    equipment in the 172 Sky Hawk is $5,000, which is more than the cost
    of the engine. Now if that electronic equipment quits, the man is
    still able to get home, but if that engine coughs once, all hell
    happens. To me it is quite something.

(RIDDELL Cont)

I was also interested in the gentleman's statement that in the
automotive electronic equipment you're talking about, fail safe,
and being able to limp back to the repair station. Well, flying
at 25,000 ft above the clouds and over the Rockies, you can't
very well limp home. Our bad experience with electronics in the
engine field is with the highly sophisticated computer that
occupies the left seat of the airplane and can't remember from
time to time to either put fuel in the tank or to drain water out
of them. So far we haven't been able to run the engine on air or
water. So that's our experience with computers.

We're going to have to get into electronics equipment if for no
other reason than the new emission laws. The fuel controls that
we have now are fine for max-power, for climb, for cruise, but
we have problems around the airport during taxi-idle conditions,
because of the emission laws. The biggest percentage of the
emission cycle is based on idle taxi conditions so we're after
something that will give us better fuel control in those areas.

We do have a difference in operation between the aircraft and the
automobile. We don't have the up and down. We don't have the cold
start. Our engines are at constant speed, they operate on a prop
load and because they operate on a prop load, in an emergency
condition it is nothing to take the engine from idle-power idle-
speed, to full-speed full-power in less than two seconds. I
might point out that another restriction we have is in the eyes
of the experimental pilot. At one time we built a 907-20 engine
that Piper put in their Commanche. Bill McNary, who was then
Chief Engineer at Hartford, was complaining because the engine
wouldn't idle properly. I said, "Bill, show me." So he locked
the brakes (it was a warm day) and we ran the engine at full power
until everything came up against the red line--the cylinder head
temperatures and oil temperatures. The engine was just sitting
there cooking fairly well. He said, "Now watch." He jammed the
throttle and said, "See, it doesn't idle!" And you've got to
remember that we don't have a flywheel like the automotive people.

When they asked me to come out and talk, I went back through some
of the requirements of the aircraft engine. I'll give you some of
the ranges of operation. Manifold pressures on flare is below 7"
Maximum manifold pressures are 47". These are absolute figures.
Pressures ahead of the throttle can run anywhere from 13" to 50".
Temperature ranges are from -30° for starting and operation at
altitude. Normally, aspirated engines will get up to 150°. On
turbo-charged engines the temperature range will go up to 400°.
This 400° is a temperature in the nacalle, when the engine sits
on a hot day when the airplane has come in and you shut down the
engine. It's called a hot soak.

Fuel pressures: Right now we're running anywhere from 35 to 40
lbs per sq in. We'd like to maintain about 15. The main reason
for that is that we do have a requirement in the FARs that air-
craft have a backup fuel pump and this backup fuel pump in the
aircraft requires either low pressure or a very expensive pump.
The fuel flow ranges on the 4 cylinder engines are pretty good,
4 to 100 lbs an hour. In the highly turbocharged engines we do
from 6 to 340. We would like to end up with electronic fuel
injectors which would have a plus or minus 0.1" of mercury
variation and a 10° temperature variation. There is another re-
quirement and that's the electric voltage that will be available.
The planes are normally 12 to 24 volts, depending on what the
customer wants. However, we did have one airplane that they asked
us to work on to try and standardize on a starting procedure.
We tried it. We had a battery in it that was fully charged. On
a cold day we went out and cranked it and the prop came up. The
standard procedure of the aircraft people is to put a very small
wire between the battery and the starter and we thought that was
our problem. Just for the heck of it we put in a volt meter on
the battery. Lo and behold, that 12 volt battery dropped down to
3 volts and the battery is so small; the internal resistence is
so high.

Vibration spectrum: We have recorded on some of our engines, the
following g-loading: 23 1/2 at 175 HZ; 14 1/2 at 835 HZ; 15 at
800 HZ and 30 g at 150 HZ. Those vibrations were a smoker's
dream because everytime the airplane went down to the end of the
runway and full power was applied, all the ash trays popped open!

Some of the questions we have is the accuracy of sensors, tempera-
ture drift of black boxes because these black boxes are going to
have to be put on the engine, and what can we expect if we can't
get 1/10" mercury accuracy? What can I expect in pressure and
temperature measurement or sensors?

MR. MC RUER: Thank you, Frank. Next we'll hear from Lee Grismore.

MR. GRISMORE: I want to just illustrate one or two points that
may not have been emphasized today. First, to reiterate one
point that was made, there are 131,000 general aviation air-
craft now, and 197,000 projected for 1982. These figures
may not be exactly right but they were taken from the 1974 Avia-
tion Almanac so they're probably in the ball park. New production
was supposed to be something like 8800 aircraft and 21,006 pro-
jected for 1982. If you assume that any new avionic system we con-
ceive probably will not be highly retrofitted in existing aircraft
because of expense and non-compatibility with panels, air frame,
and a hundred other things, then you're talking about a market of
something like 10 to 20 thousand units even if you installed your

system on every new plane that's manufactured. This means that it's not a high-volume market. It means that general aviation is not going to force the market appreciably, and it just emphasizes the fact that we literally are going to have to design systems that live with advances made in other areas. Even if business flying has a certain percentage done by private businessmen with 172s and 182s and what not, you get the strong feeling that it's not a good idea to help general aviation design a $100,000 avionics package. We are talking primarily about the small user who is by far the most predominent. There are $100,000, $200,000 and $2,000,000 airplanes in the general aviation fleet. But in terms of actual distribution of tasks, I submit that that's probably a very small percentage of the general aviation community and that one needs to be careful when he talks about advanced system to make sure he addresses the bulk of that community.

Along those lines then, if you look at rough numbers, single engine aircraft from something like $8K to $50K, multi-engine (I'm not talking about jets or turboprops or anything like that) aircraft run from $38K to $240K. And that price does not include the avionics package that we've talked about today, but just the basic engine and flight instrumentation. The biggest share of operations are in the single-engine area with $8 to $50,000 airplanes. Look at the number of holes in the panel of those kinds of airplanes and look at what instrumentation costs in the run-of-the-mill general aviation operation. Count holes and you'll see that there are roughly 12 instruments that monitor engine parameters in a single-engine aircraft: oil temperature, oil pressure, fuel pressure, etc. Put a number with those instruments and say that at the plant they cost $150 an instrument to put that in the aircraft. That's $1.8K of engine parameter instruments. Flight maintenance will normally run somewhere around seven instruments and that's air speed, artificial horizon turn and bank, that kind of instrument--so those are only $250 per instrument. Again, you're $1.8K; and then assume you've got a VOR receiver, maybe two receivers, ADF, transponders; of that group, let's say navigation takes five instruments--that runs $6 1/2K--you're talking about a package around $10,000 in instrumentation. If we're talking about a complete avionics system, not just navigation but a complete aircraft maintenance system, then we are talking about a run-of-the-mill general aviation aircraft having $10,000 worth of instruments in it. If we are going to talk about a future system that is lower cost and higher reliability than what we've got now, we're talking about designing an avionics package that runs somewhere from a basic system of around $4,000 to maybe a high performance system of $25,000. Suppose we could design and conceive a basic package of high-performance electronics to do a systems job for somewhere in the vicinity of $8,000, and on the basis of addressing the major general aviation community today, that seems to me to be where we are. In terms of the dollars that we've heard from the speakers today, there is a large gap here. If those

numbers are right, and they probably will be disputed, then we indeed are not talking about a slight improvement in things; we're talking about a quantum jump to a significantly different system.

MR. SEEBERGER: I came today to tell you a little bit about what Hughes Aircraft has been doing in the display area. What I'm going to show you is the result of about five years of effort on the part of our company, plus a little bit of help from the Air Force and the Navy--and I mean a little bit--because we put more money in ourselves than we've got in our contract so far.

About five years ago we looked into the question of providing a pictorial display in an aircraft where you have a wide range of ambient illumination to deal with, particularly the high end of the scale. After a very careful tradeoff study we concluded that the liquid crystal approach was probably the one that had the most promise. There were a lot of fundamental problems with liquid crystals at that time--remember I'm talking about five years ago. Most of them dealt with the question of life, speed of response, contrast ratio, and things of that sort, but our studies indicated that all those things were capable of being improved, and I think we've gotten to the point where we have improved them.

We are manufacturing at the present time, a liquid crystal panel which is essentially a matrix built in the form of an LSI chip. The matrix that we're manufacturing at the present time is 1" sq. It has 100 picture elements along the line, and 100 lines on the chip; in other words there are 10,000 elements in each one of the 1" squares.

This chip is formed on a 2" wafer using standard LSI technology. Remember there are 100 of these along a 1" section of the chip and 100 lines deep; and at each one of the crosspoints we have a small MOS transistor, a capacitor, and the liquid crystal itself. This is essentially a sample-and-hold circuit that will take video which is addressed into the display, sample it in an analog fashion, and hold that charge for a full frame period of television. We are using a very thin liquid crystal layer; in fact it's less than a mil in thickness, and it is a specially formed layer. The system that we have running in the laboratory right now will reproduce a TV image with no discernible lag. In our experimental form right now, we are mounting these on much larger substrates so we can get to them. Our plan, of course, is to provide LSI drive chips. Right now we're driving these with MSI--ICs are on the outside simply as a matter of expediency because we're interested in demonstrating that you can, in fact, build a cell of this type.

Figure 36 is a photographic reproduction of the kind of image that we were able to produce on this cell over a period of time. This particular one, dated 1974, shows a number of line defects that occur in the process of producing this kind of a chip. About mid-year we were able to produce this chip and although it's hard to see from where you sit, if you come and look at this closely you will see that this isn't a painting; it actually is a matrix display which has been formed by the 10,000 elements and it has zero defects. Actually, that's a bit of a misnomer; there are three defects out of 10,000 on that chip, and we've produced over 12 of them of that quality since June--that was one of the milestones in our Air Force contract that we had to meet.

The problem was one of process control; handling the masks in such a way that we minimize the number of defects as we put the chip together. We think that it's the way to go for video or pictorial display in aircraft and at the present time we're moving in the direction of making larger displays by putting these 1" modules together. Yesterday I saw for the first time, a quad of four of these modules that had been put together and were operating with a TV input signal. Our plans at the present time are to proceed with the development of inter-connect techniques that will allow us to assemble more than four of these chips to create an even larger display. The problem is rather apparent: once you have more than four, you have a problem of how you access the inner one. We are in the process of developing inter-connect techniques that will permit that to occur.

We've been working hard in the area of the liquid crystal material itself. I think we have found the solution to the problem of speed, temperature range, and it will be possible to use devices of this kind for direct pictorial display. Now the question of cost is uppermost in everyone's mind on a device of this kind. At the present time they are very expensive because the yield is low but we anticipate that with sufficient demand and sufficient quantity, the price of these chips will be the same as any other LSI chip. A good example would be the kind of LSI chip that you find in a pocket calculator. We expect that by 1980, perhaps 1985, displays of this kind will be available at a price comparable to what you see in the pocket calculator field today.

DR. SMYTH: What is Hughes doing to place this on the mass market where the price will go down?

MR. SEEBERGER: I guess the only thing I can tell you is that we have an automated integrated circuit facility in our Carlsbad plant, and we're producing these chips there. It is our intention to tool for quantity production. I think the application of this device is obvious, not only to a market like general aviation, but also to the commercial market, the home market, as well as the military market. We anticipate a large volume will develop but it will take a while.

KEY ADVANTAGES OF
LIQUID CRYSTAL DISPLAY

VG—1906B / 1

94

100 x 100 MATRIX ARRAY
(10,000 PICTURE ELEMENTS)

|←———— 1″ ————→|

- HIGH CONTRAST IN SMALL AND LARGE AREAS

- GRAY SHADE CAPABILITY UNDER ALL LEVELS OF ILLUMINATION

- UNIFORM HIGH RESOLUTION OVER ENTIRE DISPLAY AREA

- INTERFACE SIMILAR TO CRT TV DISPLAY

- LOW POWER, WEIGHT, VOLUME

FIGURE 36

DR. SMYTH: So you are going to market it commercially?

MR. SEEBERGER: That's right. In fact it's being manufactured right now by our commercial division.

QUESTION: Have you solved the ambient light problem?

MR. SEEBERGER: Well, of course, this is a display that does not emit light. The brighter the ambient light, the better you can see it. At night we treat it exactly the same as we do an aircraft instrument --provide artificial light. We ran a series of tests. The reflectivity in our liquid crystal turns out to have the same contrast ratio as the white pointer on a typical aircraft instrument, and at night you know how the panel is illuminated on most aircraft, either by light within the panel or by flood lighting from behind. And that's the way it will be solved. We've worked out other techniques such as a plastic wedge placed on the top of the display which gives you a distribution of light. There are many ways in which you can illuminate it at night.

QUESTION: Is it restricted to black and white and shades of grey, or do you have a potential for color?

MR. SEEBERGER: It has a potential for color and we will demonstrate color by the end of the year.

MR. MC RUER: Very good! That's a fine supplement to Parvis Soltan's talk this morning and is a fascinating and desirable piece of apparatus to consider. Let's start that consideration now.

As you're all aware, this Panel comprises a very diverse set of people in terms of their backgrounds. I'd like to start off with the first question. What advances in component technologies are expected from someplace else (presumably, none really being developed in general aviation per se, that could have some general aviation application?

MR. RIDDELL: I'd like to talk about the fact that it's coming from elsewhere for two reasons. Bob Noyce covered the fact that it would, but using Prof. Grismore's numbers, for example, the '72 volume figures of aviation systems are less than today's automotive volume; one day's automotive volume in just one of the companies.

The other thing is that despite an avionics system that may cost $8,000 and the car had at most, $200 in electronics, you're still talking $100 to $200 million in general aviation vs $2 billion for the automobile. I suspect that the real advances hardly ever come from within the industry from which they should come. Take the steam locomotive, for example. No steam locomotive manufacturer still exists because they had a lot of pride and wouldn't go to diesels or electrics.

We have got to stop thinking about transducers in the way we've thought about them. I think we're going to think very much as Mr. Seeberger just said. He's not going to think about a display, he's going to think about an IC.

DR. NOYCE: I can't disagree. I'm a little afraid of 1" sq. integrated circuits; it's going to be a while before they get down to the cost of a 100 mil chip.

Thinking of places where things would be coming from: there's aways citizen's band.

MR. FARRAR: As far as components, we look heavily towards the TV industry and I think I see some breakthroughs in the new synthesized TV. Also the FCC is opening up the 960 MHz public service band that's going to help as far as components. As far as transducers, I'm sure we'll be looking at the automotive market. In fact, there's just nothing like the auto industry as far as getting low-cost components.

MR. MC RUER: Anyone have anything to say about Jerry's comments?

MR. RIDDELL: I was hoping that we could tie ourselves to the tail of the automotive industry. But the automotive industry may decide that they don't want to have anything to do with us--because of the FAR regulations and the quality control regulations of the flight aircraft. At one time DELCO used to make all of our generators and they finally told us to take our business elsewhere and they'd give us all the tools that they had made for us. And this, I think, is going to be a problem that we're going to have to face as far as equipment. I think that we in the engine business are going to have to depend on the automotive engine.

MR. HOLLAAR: I too see the auto industry as being the high volume, low-cost market that is going to be the big source of device technology. I thought also that possibly there will be a number of timing functions performed in advanced avionic systems that could be applied from some of the developments in the watch market.

Also, in terms of timing and control, the market is developing rapidly in appliance systems. Here you have completely different environmental problems. Whether or not these are really going to be applicable, whether you can really take commercial specs and just simply operate with a very conservative system design, I'm not sure, but those are two areas that can provide technology to general aviation.

MR. MC RUER: On that point I'd like to go back to Frank's comments-- none of us picked it up at the time--but his remark on the appliance industry being environmentally, fundamentally different, or likely

to be, from, say, automotive or general aviation, in terms of
engines. Is it not the case that the aircraft engine and the
automotive engine share a remarkable similarity in their environ-
ments, especially if it comes down to automatic engine control
systems and things of that order?

MR. RIDDELL: Yes. You've got emission control and fuel control and
we do have one other thing that I don't know if they have yet or
not, the turbocharger control. If we can make this work we expect
that we'll end up with a single control for the engine/propeller
combination. That means now you have also to control the propeller
at the same time. But, yes, there is a lot of similarity between
the automotive and the aircraft engine as far as the basic working
of the engine. It's just that we have different criteria or
different areas that we operate in. We don't have to worry about
idle and startup because we tell the people that they should use
supplementary heat when it's below 10°F. The fact that nobody idles
an airplane engine means we don't have to worry about acceleration
because we're operating on a propload curve; we don't have the drag
of the automobile so we've always got excess power for acceleration.
And the other fact that we're essentially a constant speed machine
makes it a lot simpler than the automotive engine as far as these
controls are concerned. But it's a case of getting the types of
sensors to pick up the different parameters. That's the same as
the automotive problem.

MR. MC RUER: So there's some hope there for additional cross-
fertilization. Bob, do you want to address question #1?

DR. NOYCE: Certainly the largest number of displays that are being
made now are for the hand-held calculator, and those numerics
are going to continue to go on down in price. One of the areas
that hasn't been emphasized here except in remotely piloted
vehicles is the question of the data links. A great deal of
communications is just normal hand shaking. "I'm here and I
recognize you're here." A lot of the other data is indeed being
put over data link on the transponder: identification and
altitude. My friends often ask me how you can ever understand
those controllers. The answer is that there is so much redundancy
that all you have to do is just distinguish that it's one of 10
messages. That's a very simple data link; send a number from 1 to
10; that's all you have to do. So I would think that what we're
doing in communication could very easily be simplified from that
standpoint anyway.

Another area that seems to me to be critical is maintenance costs. In terms of complex equipment, certainly the data processing industry has had a problem in space and maintenance and a high degree of what is going on now is such things as error correcting, so when a failure occurs the system still works.

Another one is diagnostic programs which identified which card you ought to pull out and replace by a new card. While this is operating you want to have something to tell the pilot that it is not operating correctly. I don't need to have full diagnostics there, but when you get down on the ground it's convenient to run programs to get the maintenance diagnostics to figure out which connector point isn't making contact now.

We're getting a lot more into computer control of machine tools, in the sensors and the actuators that are used; that may be an area to watch.

MR. FRANKLIN: I'd like to tell a story about actuators. When we first started to build RPVs I needed a small actuator and somebody overheard me and said that there's a fellow over in the Polaris program that knows all about actuators and why not call him? So I did, and he brought a small hydraulic actuator with him. It weighed 15 lbs and was worth $3,000. I said no. I showed him a little plastic model airplane actuator and he turned and walked away.

So we went to the Chevrolet store and bought seven motors that are normally used to actuate the head lamps on the Corvette because they were only $17.00 a piece. We bought these because they had the right torque and speed characteristics for aileron and nose-wheel steering, etc., on the RPV. The primary reason, however, was because the counterman said, "I'll have to order some for you--there's only two or three in the Bay area." He said they never get calls for those.

What I'd like to point out here is that when we have large pro- duction runs of any item and pay any attention whatsoever to what we're doing we're going to get reliability eventually. I don't get that kind of reliability in short production runs of experimental hardware. So we turn to the automotive industry again.

DR. SOLTAN: I think the $1.2 billion potential market for the electronics display in the automotive industry is really remark- able. If I were in the industry I certainly would be committed for the next three or four years to making advanced display panels for the automotive industry. I'd like to mention the application of fiber optics. Some companies already are planning that, especially for the automotive industry.

DR. JAUMOT: I think you'd be surprised at how much fiber optics
   are actually used along the street today in automobiles and how
   much work is going on. I'm not talking about the type of fiber
   optics you're talking about. I'm talking about a way to get
   illumination to a spot.

MR. MC RUER: The driving force up to this point was mostly appli-
   cations. Of course, it's been noted to be automotive. Now, I
   want to follow up on this point with Frank again. What's driving
   you?

DR. JAUMOT: Everybody's leaning on us but we're leaning very heavily
   on the data processing industry and the communications industry
   because they do much more sophisticated things in processing
   signals than we have been used to doing. So in those areas we have
   been relying very heavily on them. What's driving the automobile?
   There are really three things. One is the requirements on the
   emissions and safety. There's no question that that's been a major
   driving force because now you're getting into certain things where
   there is a guarantee that to reach certain standards you require
   accuracies much better than we had before. Fuel economy is the
   name of the game and we are going to be in even bigger trouble if
   the present proposed law passes. There won't be any big cars to
   hold all these electronics that we're talking about. The third
   thing is that the customer has seen all this sophistication. By
   the way, we're also depending on the commercial industry, the watch
   industry, calculator industry, the appliance industry, and when you
   talk about number of operating hours per dollar, they're the
   toughest of anybody. I'm sorry we don't have a representative here.
   We are depending on all of these people, but our driving interests
   are the need for fuel economy, the requirements on emissions and
   safety, and the desire on the part of the customer. This desire
   for a more efficient machine means also more sophistication all the
   time.

MR. MC RUER: Is there a desire for novelty?

DR. JAUMOT: Yes, there is a desire for what we call pizzazz but it
   goes deeper than that.

MR. SEEBERGER: I'd like to make a couple of comments in connection
   with display requirements. In the integrated circuit industry,
   there is a trend, I believe, for larger wafers for LSI. I know
   that we're looking into the possibility of 3" wafers and probably
   in five or six years it will be 4" wafers. I think this is some-
   thing that we should watch because we have plans for going to
   higher density in the technology that I described on the little
   matrix display. In fact, we will by this time next year, have 256
   to the inch where today we have 100. And the larger wafer is
   going to make it possible to get a flat panel display in one single
   piece instead of four or a multiplicity of them. If you're looking

at what advances in component technology is needed, we need an industry that can support a 4" wafer. There will probably be other applications than just the display device that will support it, obviously, or it will never go.

QUESTION: Can you get a 4" cylinder wafer without any defects in it?

MR. SEEBERGER: Not today you can't.

DR. NOYCE: The practical place where the integrated circuit business has worked is at the 30% raw yield point. If you get more than that you can integrate more and make it cheaper and if it's less than that the costs go up exponentially. I think the most telling thing that you commented on is that you've made 12.

MR. SEEBERGER: I didn't tell you how many we had to make to get 12.

DR. NOYCE: If we look at the size of chip that is in the 30% range, it has moved from a 25 mil chip 15 years ago, up to a 150 mil chip now! A factor of 6 in 10 years in linear dimension. We're not going to get large panel flat displays out of this industry within the time frame we're talking about. The reason for going to larger wafers is strictly economic. It is not larger chips, it's just handling 300 chips at once instead of 200 chips at once; that's the only motivation for that.

MR. RIDDELL: Incidentally, in answer to one of the statements you made a little while ago, if you take all of the piston engines which are manufactured both by Lycoming and Continental (there are only two piston engine companies in the world, as far as that's concerned) you have about 20,000 a year.

DR. NOYCE: So you need the technology also.

MR. RIDDELL: Yes. Very much so.

DR. JAUMOT: Bob made a very telling point this morning. The industry was beginning to stew in its own juice because he had so many designs to do. I don't know whether the solid state industry or the data processing industry forced it, but the emergence of the microcomputer replaced all the customer ways of doing these things. Once someone finds a good way to adopt that, there is no reason why you can't adopt that. You may have to use more memory but that's trivial.

MR. MC RUER: While it wasn't made all that evident, the solid state transducer business appears to be going much the same way in terms of its revolution on growth, including the CPU kind of business. Aren't we on a threshold?

DR. JAUMOT: We'd like to think we are but we're very nervous.
I have considerable nervousness about being able to get all the
hysteresis out of all the transducers we want.

MR. MC RUER: So what's the matter with dither?

DR. JAUMOT: Dither is very widely investigated at the moment. There
are many problems with dither. One question is what rate do you
dither? We can get significant acceleration in one-third of the
turn of the drive shaft. You therefore have to dither at a faster
rate than that. If you dither too fast you'll get detonation
because you've advanced it beyond the point too quickly. So it
sounds like the automobile is a quick and dirty thing, but it's a
significant systems problem.

DR. De BRA: The question is components and I think one of the advances
that's going to be made is in the way in which we think about com-
ponents. You can start thinking of these sensors as chips--as
being part of the electronics. It's going to continue to go on.
Any time you've got something like the pressure transducer becoming
part of silicon technology you know that almost any of the trans-
ducers will take advantage of things of that type. You can just
bet that there are going to be accelerometers that are silicon
technology kinds of sensors. We begin to think about components
differently in that the integration of these basic sensing devices
is going to become part of something which puts a more complex
function together in one box. We're going to be forced to think
about components as being more things combined at once. I don't
think that's going to change the communications receivers and some
of the RF kinds of sensors immediately. They are relatively newer
than some of the other panel display information that are already
quite complex in terms of the number of functions that go on in
there in order to get an answer out. But I think one area that we
can really put some pressure on is one of the groupings that Lee
showed: that of 7 sensors to get the orientation in speed, states
and altitude. You don't need 7 sensors as separate distinct
indications when we all know that one of the first things the pilot
learns is how to cross-check these instruments against each other
because they're not independent. They have to be interrelated
because airplanes behave in certain ways--physical laws that are
telling you that if one thing happens something else happens. If
you drop the that in your VSI right away. So I think the two
things that are going to happen here that will change our way of
thinking about components are 1) sensors will be smaller; 2) there
are some areas in the airplane that have not changed since 1920 in
the way that we think about components and these are the 7 groupings;
I think it's one of the first areas that's going to get hit by it.

The idea behind measurement right now still is that if you want a certain piece of information you measure it; and yet, we've been using Kalman filtering for quite a while in some of the navigation areas. So we've been rubbing information against each other to try and milk more out of it than we get out of any one basic measurement. You were showing the stellar-Doppler-inertial combination, and, of course, there are many others where we're trying to extract from basic measurements more than that one basic measurement itself would give, by combining them in a filtering technique. What I think is going to happen here is that as we start to put more of these basic sensors into a small package, and if the computation really is not a problem area (I think that is the closest thing to a consensus that has come out of this thing so far--that computation is essentially free), you start taking more advantage of your understanding of the physics of the airplane and maybe using some of these sensors, not because they measure directly what you want, but because indirectly they contain the information you want.

I think it's interesting to speculate here as to which end of the general aviation market is likely to take advantage of that first. I think whenever you depend upon the physics of the airplane you're depending upon your understanding of how it behaves; those modeling errors that you inevitably have will introduce another class of errors other than just the basic measurement errors. This may be tolerable in the smaller aircraft where you're used to paying much less money and having instruments that maybe aren't quite as accurate and reliable as you might have in something which has got the full treatment that we saw in the larger packages. It may very well be that when you take these seven instruments away their cost is enough to cover a fairly sophisticated selection of electronics with these integrated sensors all put together. Then it may be that you'll end up with a lower cost, albeit comparable accuracy kind of a system, that wouldn't be acceptable in the business jet but would be acceptable in the 4-place light aircraft.

MR. MC RUER: To wind this up, I think the Panel has done an excellent job in covering this whole area. Most of what has been said really implies an evolutionary sequence--one in which current functions remain functions and are simply replaced by better, more reliable, or integrated ways of doing it. I don't know any answer to this but before we leave this subject I'd just like to ask a more general question: Is there anything in any panel member's experience that leads to the inevitable question, "Now if the FAA would only do this, or if the general aviation manufacturers would only do this, a whole pile of problems would be completely solved, or at least completely changes?"

DR. NOYCE: Just a thought on Dan's comment here. If I'm not mistaken the FAA says that you will have an altimeter (a single unit), and a compass, a certified this-and-that and the other thing, and I just question whether if you did bring in an integrated system that measured pressure temperatures, etc., and you derived everything else from that, whether it would be accepted anyway. Could you write your specs functional instead of by pieces of equipment?

MR. BOROWSKI: Always it's the intent of the regulations. If you can provide altitude information with something other than an altimeter the answer is "Yes."

REMARK: The way the TSO is written today you even have to have a pointer. That's specifically mentioned.

MR. BOROWSKI: Well, I think your question was if you could present altitude information in some way other than as traditionally been done, certainly the answer is "Yes."

REMARK: But that's not really true. If you make an altimeter that shows altitude and doesn't have a moving needle on it, it won't be TSOed because the TSO specifically calls out: You shall have a moving needle display. Now if the TSO is ages old that's fine but it is still the spec that we have to work under today.

MR. MC RUER: All right. So it is possible that some of the regulating activities might have to move somewhat faster to keep up with the technology if it did develop.

DR. NOYCE: You asked if in our wildest dreams we had something to suggest. What I'm suggesting is that the regulations move in front of having the equipment there so that there is motivation on the part of avionics industry to find a better way to do it without the constraints that are presently imposed by the regulations. I would love to see that happen.

DR. De BRA: If I can rephrase your question, what you're really asking for is to change to functional specs and that, as a single statement, would summarize most of the complaints I've ever heard about.

MR. BOROWSKI: I think that has a better chance of coming to pass particularly with the FAA's statements now that they're going to have an air-worthiness review every two years. I think also that what you were talking about--the needle on the altimeter--is an outgrowth of the only way they had to make one years ago, and it was a good display. I think that they can be changed if you can come up with a good solid argument against them or for an alternative way of doing it.

MR. MC RUER: Let's turn to question #2, which is probably going
to be capable of being addressed much more rapidly. The ques-
tion is whether we can identify any components that are being
developed for some other industry group that could be made
applicable to general aviation through component modifications.
This has a subsidiary question associated with it: which ones
of these should be developed by NASA or evaluated by NASA? This
is the first hunting license question we've had.

MR. SEEBERGER: In our area of the liquid crystal display we
already are tied in with NASA in the respect that we're about
to go under contract to investigate interconnect techniques to
put a number of small modules together. It's a study of tech-
nology, to try to find a way of doing it. That's the beginning
of the kind of thing you're talking about and we'll be under
contract for that in another month.

In the technology that we're talking about for solid state dis-
play, there needs to be support of manufacturing methods if solid
state displays of that kind are going to be developed rapidly. We
are attempting to get support from other agencies.

DR. NOYCE: I'm afraid I would disagree. I don't think that's
a fruitful place to explore. The contacting problem is easily
handled by a multiplexing display and perhaps the multiplexing of
the liquid crystal display is a more fruitful path to go instead
of worrying about attaching 500 wires, which is an impossible task.

MR. SEEBERGER: No. I'm referring to the contacting problem when you
have more than four modules making up the display. The multiplexing
is already being addressed. The next addition of our display will
have the shift registers built into the edge. So instead of 100
wires you have one or two in your clock. So that's well under way,
but there is the question of how you get to a larger area if somebody
wants a 10" display or a 6" display out of a 1" module, which is the
current state of the art right now.

MR. FARRAR: Since temperature is so important in the aircraft and
in avionics, there are things on the market today called heat pipes,
but they are so expensive we can't afford to use them. I can see
that NASA could spend some time coming up with a low-cost type of
heat pipe so that we could cool the radio rack more efficiently, and
maybe a heat exchanger to the outside world to get rid of the heat.

Gyros are notorious in an aircraft because they are mechanical; a
lot of people have been working on non-moving-part gyros, both rate
and position gyros, I think now that they are probably a gleam in
somebody's eye to be used in military-type application but I think
they have good possibilities in general aviation.

DR. De BRA: Just one comment to add to what Jerry's saying about the gyro area: because of the tremendous drive that you have on reliability, both in commercial as well as general aviation, the angular accelometer developed at Syston-Donner, for example, has been used as replacement for some of the body-mounted rate gyros in the 727 fleet. They started putting them in as replacement units about seven years ago; they mounted an angular accelometer in a can and just used some electronic integration on it to get the angular velocity. It won't go down to d-c, but in the band where these things are used for stabilization, it's a fine replacement and they package it so it's plug-in replacement. Apparently the MTBF on that is considerably higher, so in some applications I think there is a lot of room for what Jerry is suggesting.

DR. JAUMOT: As Jerry mentioned, you could develop a $10 replacement for an equivalent gyro and accelometer; I think that's one of these wild dream things though I can see a lot of applications in the automobile industry.

MR. MC RUER: I was just going to turn to that. We have a couple of variable stability cars that we use for handling experiments, and it's the nicest thing on earth to change what we call the stability factor or the oversteer/understeer properties of the car with a stability augmenter essentially using a rate gyro. Now if you guys could only use that on all your cars then you'd solve our problem. You give us a good rate gyro and we'd be in great shape!

DR. JAUMOT: It occurred to us but we can't get that under $10. We do need a correctional stability. We'd like our steering ratio to be exactly $1/V^2$ and it turns out not to be very easy to do mechanically.

I'd like to go back to that point about NASA support. I feel agencies need to support, primarily on the basis of three things: seed money is very important; they need to support where a mission needs to be accomplished; and they need to support those cases where there is a viable social reason for it and the market will not support it as such. But to support something that there is a good market for is probably unnecessary. I don't think Bob Noyce is a bit more interested than I am in selling engineering, which is what happens so often when you assume a government contract.

MR. MC RUER: That's a very fundamental set of points, especially since so much of the technology in this area will come from places that have exactly that attitude.

DR. NOYCE: I have often felt that the integrated circuit was more motivated by the fact that there was a market for the output of the industry than by any of the money that went into the development of the industry by the government.

DR. JAUMOT: The early performance of semiconductors were motivated by the military requirements for performance. But there was a lot of money put into integrated circuits. That was not the real motivator and many of the advances came completely aside.

DR. NOYCE: In many cases, I think, Frank, it was a deterrent to advances in the industry because the thing that was supposed, and engineers were taken off the thing that should have been done, were those things that the company would not do themselves; and if the company would do it themselves it wasn't supported. There was the forecasted most profitable path to take by the people in the industry. It was the sidelines that were supported and they amounted to approximately nothing.

DR. De BRA: Bob, can I ask a question that would be consistent with Frank's guidelines, namely if there is a mission to be done it wouldn't be done any other way. In general aviation there is a small market, and it is an awfully big investment to develop a particular chip. Some of the chips that are developed are not usable anywhere except in certain kinds of communication or navigational receivers that are unique to aviation in general. Is it appropriate for NASA to get involved in something of that type?

DR. NOYCE: Well, I guess I challenge you to point one out.

DR. De BRA: Okay. Jerry, help me out. You're presently using some LSIs.

MR. FARRAR: Well, I'm not trying to shoot you down, but we don't need you to design that kind of chip today. Collins has the capability, Bendix has the capability, we now have the capability to design our own chips and we are in the process of making our own designs. We do not fabricate the actual wafers; we take it to the mask-making point and get out of the loop. When we get the die back we pick it up from there. So we're probably in a better position to define what goes on that chip.

DR. JAUMOT: Challenging you on the basis of the fundamental physics, you'll certainly agree that a vehicle is a vehicle, and communications are communications. The modification is that what is developed for one will do for the other. I don't really believe that general aviation meets my guidelines of what needs to be done.

DR. NOYCE: The integrated circuits that we used in the computer had no military or NASA money behind their development. There was a lot of money that went into integrated circuits for Apollo but that is not what was used in the computer.

MR. MC RUER: I think you've made this point very well. Whether it's seed money or to meet a mission, or for some social good, those are perfectly adequate criteria and whether it applies to general aviation will depend probably upon the eye of the applier. Frank,

did you want to add anything more on the first item in question? In other words, any component being developed that could be used by us?

DR. JAUMOT: I'm sorry that I said there's nothing in general aviation. I do believe that there are some safety aspects which are not going to be worthwhile in the eyes of either the pilot or the company supplying.

MR. RIDDELL: In regard to heat pipes, that has also been brought up for use in the aircraft engine to get the heat out of the engine. As has been stated before, the cost is going to be prohibitive and the application is going to be a monstrosity. I don't really have anything that I could definitely say NASA should be into.

DR. GRISMORE: I think it's interesting that we're here on a Panel like this. We're talking about the use of technologies other than our own industry. I spent a number of years in the Federal Systems Division of IBM in which we were constantly bombarded with the idea: "Can't you use something from Commercial Division? They make so many and they make it cheap." And we said, "No, obviously not; they have completely different requirements. Our requirements are completely different than theirs and we're not even going to think about them." And the not-invented-here syndrome has hurt technology, I think, in terms of many industries.

In any event, I said I wanted to tell my Intel story: along the lines of not-invented-here, I was actively involved in memory development for years and became an avid proponent of thin-film memories--a loser. At one of the magnetics conferences, outsiders were invited to discuss competing technologies in about 1968. Bob Noyce's cohort, Gordon Moore, was invited to present the semi-conductor competitor's point of view and he got up at the conference and he said, "Gentlemen, I come not to praise you but to bury you." We were memory people from years back, and we thought that would never happen. They didn't know anything about this industry. And sure enough, they buried us as thin-film people and they buried the memory market--at least the CPU market that we were talking about then.

The semiconductor industry is a fantastically versatile industry. You need to look outside. I'm impressed that we're really serious about looking into other areas. If you look at the problems that we've got, functionally they range all the way from analog to digital; frequency-wise, all the way from d-c to microwave-- fantastic-spectrum--and there is no single technology which solves all those problems for everybody. We have technology such as dis-crete devices and analog ICs, digital ICs, each with their own area of utilization. The problem is as has been raised: is there some way that these diverse concepts can be addressed with bits and pieces from the auto industry, from the watch industry, from the hand-held calculator industry; can all this stuff be brought together to make some kind of a usable system? I'm opposed to the

concept of designing special purpose LSI chips to do the job we're talking about. I think that's foolish for the kind of market we've got. It would be a transition for the avionics industry to leave the idea of printed circuit boards and sockets and go to a concept of hybrid microelectronics where one can integrate diverse types of chips into one major functional unit. What hybrid microelectronics offers us is the ability to provide high levels of functional integration so that if I can use Noyce's 8080 and somebody else's high frequency wide-band amplifier and so forth, I can integrate them into a single functional package to do a job which makes serviceability and maintainability much easier. Now I have one basic functional module which I can identify with some part of the system. In overall reliability one has the possibility of making a significant improvement under the technologies that we're using now. This is not a new technology. Hybrid microelectronics started well before the monolithic technology, I guess. It simply did not have the versatility. But I think it's a technology that has some usefulness to us.

MR. FARRAR: One thing I must bring up is that if you integrate all that, the part that you integrate has to be able to fail such that the aircraft people can buy that module without having lost the total function and without having to pay the same price as he originally did.

DR. GRISMORE: That's right. So your level of functionality has to be defined in that way. Of course, Quasar has done that in the printed circuit boards and I guess everybody else in the TV industry has done that; there are something like four or five major functional boards in the color TV system. When the serviceman comes, his satchel has four boards; the symptoms are fairly indicative of which board is wrong; he pulls out, plugs a new board in. He sends the old board back to Chicago to have it refurbished at a central facility and the newest mods are incorporated into the board when it's refurbished. That's not a bad scheme.

MR. FARRAR: That scheme is being used today. King Radio Corp. has a replacement board program.

DR. GRISMORE: My point was not that the problem in reliability and the problem of integrating diverse technologies into one functional unit is better done at a high reliability level. I think it might be better done in a hybrid microelectronic technology than in a PC board socket in one-solder technology.

In microprocessor technology I want to make my list longer than Bob's. He suggested PMOS, NMOS, bi-polar, and I^2L but he left out CMOS. I like CMOS for aircraft systems. I think CMOS has some advantages in terms of high noise margin and low power. It's maybe not something we push hard on, but as avionics get bigger and the problems of heat dissipation increase, I think that that's more a problem than people have been willing to admit.

Transmission gate technology is natural with CMOS and this gives
you some multiplexing capabilities right within the technology
so that you don't have to mix technologies. It's compatible with
12 to 14 volt system bus and it's easy to come down from a 28-
volt bus with minimum regulation problems. I think the power
system problem is very real. It provides compatible driver
levels for liquid crystal or electrochromic displays that we
talked about. We're talking about driver displays in the 12 to
15 volt range. Now I know that there are some field effect LCs
that we can talk about, 2 to 3 volt, but when you talk about the
problems of contrast ratio, at least at the present state of the
art, 12 to 15 volt drive levels are much better. The main
factor with CMOS is cost and maybe the automobile industry is
interested in CMOS. I don't understand why they might not be,
but that would be a driving force. So somebody else would have
to want to use it and I'm not sure that NASA can do anything
about that. That's got to be industry acceptance.

In displays, I don't particularly like liquid crystal. It's
better than most anything else but there are still problems.
What are your display requirements? These are my requirements
but I think they are typical of the industry. If you look at
your engine parameters, you basically want multicolor kinds of
displays: red, yellow, green; any pilot likes that, and right-
fully so. There is a lot of engineering involved in multicolor
displays for engine parameters.

Flight maintenance instruments are typically black & white
although there is some yellow and blue involved in some instru-
ments. In the engine parameters, we're talking about moving
bar displays plus numerics; in flight maintenance moving bar
display, possibly some numeric graphics. In navigation, we are
basically talking about black & white. I've talked to a lot of
people about this, and they don't like red navigation displays,
they don't like green navigation displays; black & white gets
rid of the problem of danger, caution, and is safe. It's
neutral. And there we're talking about graphic and numeric
capabilities.

You've seen all the display technologies, LED, plasma, liquid
crystal, the whole gamut except one which is a very recent
technique using material called PLZT. This display is similar
to liquid crystal in the sense that it's a light control display.
It makes use of the electro-optic phenomena that's inherent in this
particular transparent ceramic material. The advantage of the
display is that it is not a heterogeneous liquid-solid combination.
It does not have the potential temperature problems that liquid

crystal has, and it does not have the potential long-term degradation problem because it's simply a layer of three solid materials, glass, PLZT, and glass, with some tin oxide transparent conducting kinds of things. I think this is a technology which has the potential of being really viable in all of industry, and maybe NASA can talk about development here. That work, by the way, was originally done by Land & Thatcher.

MR. MC RUER: Are there any comments upon some of Lee's proposals?

DR. NOYCE: I don't have any argument with you on CMOS. CMOS is coming in now. I don't feel it has the enormous advantages but it depends on the way the market goes and whether that becomes the most economic thing or not.

One of the things that could be developed here is software and algorithms which are easily transferred from one group to another so that once they're developed they can be a building block for everybody else to use. There isn't any proprietary technology if it is indeed published, so you don't have the problem of building up a capability unfairly at one place at the expense of the competition, etc. I believe that trying to figure out how to do the digital systems where they could be used, and precisely what algorithms you're going to use for control, etc., could be very usefully done by an outside agency.

MR. FRANKLIN: We're talking about a lot of goodies that possibly could be sold if they existed now, but because the general aviation market is so small, we'll require somebody else to develop them. At the same time, we're asking what NASA can support.

NASA tests can fall into the goody category or the necessary category. We have not talked very much about the necessities. For instance, NASA should support things more related to safety, which I further broke down into engine health requirements rather than navigation and flight control. I haven't heard much about engine health.

We have such things as EGTs now and the ability to switch from cylinder head to cylinder head; but one thing that is not being offered for sale is a system which would continuously monitor each individual cylinder health and trend, and display what's going on. Another thing that NASA probably should do is concern itself with inherent stability problems, basic airframe configurations rather than microprocessors to improve display.

MR. MC RUER: You mean you want to improve the basic handling characteristics of general aviation aircraft? In other words, basic aircraft, no control system association, or avionics?

MR. FRANKLIN: Yes.

MR. BOROWSKI: I think you've got the human factor in the pilot who's flying the airplane too. I know of one case where there was a red warning light in the cockpit and the pilot complained that this blinded him, so he put a piece of tape over it and that took care of it--warning be damned. We've gone through an air-worthiness change right now to require double locks on baggage doors in the front end of the fuselage because one lock came loose. The reason it came loose is because the pilot didn't bother to lock it, so they're going to put another one on so that he doesn't lock that one. It also signals back into the cockpit to tell him that he hadn't locked it and we found the wires were removed. So I don't know how far you can go on trying to make safe aircraft as long as you have the computer in the left seat.

MR. MC RUER: It is probably worthwhile emphasizing a little bit more those things that have not really received a great deal of attention in this meeting thus far; things which enhance either the pilot's confidence in his knowledge of the situation, or his capability to cope with the situation. At one end of the spectrum this would certainly include things like simple onboard computational capability. For instance, it's been pretty well demonstrated that humans are excellent estimators of individual conditional probabilities. Now Bayes' rule is an easy thing for a computer to handle and you could just plug in your estimates of the component probabilities and out would pop the desired answer.

On Question #3, should NASA support other developments, that other-wise couldn't be done without some seed money?

MR. FRANKLIN: I don't understand why that's such a wild dream. For instance, we have a transponder on board; that transponder ought to be expanded and the other electronic items cut down. The transponder should be a two-way data link so almost no voice communication's going on--just voice communication for exceptional purposes. When your clearance is amended, it should come out hard-copy, or on a flat plate readout so it's there and you don't have to remember what it was. If it's all done properly and there's a good up-link too, the transponder could accept steering signals and all the RNAV equipment that's now onboard the airplane could be kept at center and the only thing transmitted up is the Go Left, Go Right signal.

DR. NOYCE: I was trying to hint towards that when I was talking
about data links because certainly terminals of various computer
nets have been handshaking and acknowledging messages and identify-
ing themselves and making requests for a long time and it's expanding.
That technology is one that could be used in the communications
environment here very easily. I don't see any need for a printer.
We're going to have an alphanumeric display somewhere, I presume,
within this time period. The printers are unreliable compared to
soft-copy displays.

There's a computational problem in collision avoidance; there's
data existing within the system as to where the airplanes are.
The only question then is to sort through that data and present
to the pilot the data that is appropriate to his flight. I do
think that general aviation has quite a different problem than the
air carrier does here. He is spending a lot more of his time in
close proximity to other airplanes. I watched the gliders over
Mission Peak; 100 ft is a reasonable separation. I fly through
them with a power plane too.

DR. GRISMORE: Of course, some of your basic ideas are at the
of DABS (Discrete Address Beacon System) that is being worked on
now and it's probably going to come to pass.

MR. FARRAR: Well, since we're talking components and since I'm
looking for reliability more than anything else, what I would ask
from NASA is to come up with a nice low-cost method of burning in or
testing avionics, whichever way you want to call it, that would
give me a probability that I'll find greater than 95% of the
instrument failure components before I ship it out the door. That's
going to save me a lot of money and that's going to save the people
that are buying the equipment a lot of money.

MR. MC RUER: You said 95%?

MR. FARRAR: Greater than 95%. I'll take 100 if you can give it
to me; the highest probability that I've got all the infant failures
out there I can get.

DR. NOYCE: What do you estimate you do get?

MR. FARRAR: 80-85%.

DR. SMYTH: How long do you burn in?

MR. FARRAR: We take a radio that's just been built and align it
against a working system. It then goes into a burn-in room and it
is actually cycled from room temperature to plus 44° and back and
is turned off and on. This goes on for 96 hours. The radio then
comes out and gets aligned once more to meet the minimum performance

specifications and the covers are put on. We then take it to cold
temperature and test it and make sure it meets the minimum perform-
ance specifications; then to hot temperature and in this case it's
+55, make sure it meets the minimum performance specifications. We
then shake it; this is not an extension test, it's more a case of
putting it on a paint shaker to make sure the parts aren't loose.
It then goes back into another 48-hour burn-in and has to go through
that burn-in cycle without any failures. If it does then we ship it;
if it doesn't it goes back through the procedure of being fixed, i.e.,
through the hot, cold and last burn-in. It has to go through the
last 48 hours failure-free before we ship it.

MR. FRANKLIN: Does that explain why the automotive radio cost $70.00?
How long are they burned in?

MR. JAUMOT: Depends on which ones. The AMs are burned in only on a lot
sampling basis. Premium sets are burned in from 24 hrs up to 96 hrs.
On avionics we do what he says. We test them off the table and we
just arbitrarily chop off the top and bottom. I would like to see
NASA do those things Bob was talking about--get some new way of doing
something that might be in opposition to the present regulations
because those regulations are a great barrier to the average industrial
firm.

MR. MC RUER: Okay. The Panel's done its job I think. We will have an
opportunity tomorrow as Agenda Item 2 on the Workshop discussion and
Panel interaction. However, if anyone has any all-compelling statement
that they'd like to make about anything that the Panel has said today,
and you would like to get on record now or start the argument now, I
think we can devote about another five minutes to it.

MR. LUCCHI: Let me speak on collision-avoidance. It isn't the computa-
tion problem, it's a sensor problem to sense the other aircraft and to
make sure you can sense them in all directions. So the computational
problem is simple; it has been solved and demonstrated. But the sensor
is a difficult thing to do. Where do you locate it--where do you have
the antenna patterns? There is no good DFing on airborne equipment
now that determine his direction or his actual location; only closing
velocity at collision course, that's all. That has been the problem.

MR. SEACORD: In regard to collision-avoidance, Honeywell has a system
that has been demonstrated and it prevented all the collisions between
helicopters, whereas there were about one or two a month before that.
So I don't think the collision-avoidance thing is an insoluble problem.
I think the problem has been that the FAA has not wanted to allow it to
be done by airplane-to-airplane and wants it to be done by pilot-to-
ground control.

MR. MC RUER: I'd like to thank the Panel members once again. I think
you all did well.

SYSTEMS ARCHITECTURE PANEL

CHAIRMAN: DR. SMYTH.   PANELISTS: Messrs: ANNIN, BAIL,
   FENWICK, GORHAM, MC CALLA, OSDER AND SEACORD.

DR. SMYTH: I'm pleased to find so many outstanding people
on the Panel. I feel that the diverse backgrounds of the panel
members will contribute significantly to our answering the three
questions with which the Panel is charged. I've put an abbreviated
form of those questions on the board: (1) Our consideration of
systems architectural concepts which are applicable to general
aviation avionics, (2) What impact will systems control standards
have on the system architecture, (3) What guidelines can the Panel
suggest to NASA for the general aviation avionics study that is in
progress, and that Dallas Denery described to us yesterday.

I'll just remind the panel members and other participants which
primary functions we're considering in this avionics system:
navigation, communication, identification in the sense of ATC
identification, flight control, guidance (the outer loop aspect
of control, whether it is automatic or through flight displays),
and lastly, flight management including fuel management, flight
planning, both before flight and perhaps unscheduled changes
during the flight. Another issue, that hardly needs mentioning
is reliability. The system architecture-type issues include com-
patability between the flight crew and the controls and displays.
My experience in configuring avionics systems, is that the most
difficult area is to get controls and displays that pilots accept.
Ten different pilots give 10 different answers as to the answer
for controls and displays.

Obviously, the interface among elements is very important; for a
digital system, how do we get the signals in digital form? These
interface problems are more difficult than almost any other
problem. Obviously the degree and extent of redundancy and self-
test is a very key issue to the system architecture, both with
regard to what the hardware looks like and with regard to the
software structure inside the computation elements. The applic-
ability of advanced digital technology is a key issue and the
impact upon both digital technology and other technology on the
system architecture is something we're attempting to address.

Before I turn the meeting over to the other panel members, I'd
like to discuss the mechanics of how we're going to operate this
morning. First, I've asked each panel member to address one or
more of the three questions in short prepared comments. I would
ask that during these prepared comments they tell us which
question they are addressing. Secondly, we will ask each panel
member to comment on each question separately following pretty
much the same format that Duane McRuer established with the
Component Panel yesterday.

But before the other panel members make their opening comments,
I would like to make a few opening comments of my own. Yesterday
we heard a lot of ideas. We heard about a lot of new components,
a description of them, how they work, and a lot of other concepts
were presented to us. The objective of systems architecture
obviously, is to organize a number of diverse elements to perform
numerous functions to meet the system requirements. I've been
involved personally in a number of overall avionics systems and
it has always turned out that the unifying element in all of these
systems has been the central computer complex. I choose those
words carefully because I don't mean a central computer but a
complex of computational elements or computers in which all the
data resides in that computer complex and can be shifted back and
forth.

Converting sensor data into digital form and then enjoying the
resulting synergistic benefits is a key point. Now this syner-
gism that results from all this data from the system being in
digital form, is of both organized synergism, using such things
as Kalman filtering to take different sensors and come up with
system states, and also unstructured synergism which often isn't
thoroughly understood when you begin the system design. In fact,
it's been my experience that as you proceed and have access to
all this system data in digital form, you come up with crucial
modes and functions which are important to meeting requirements
that are now possible that you hadn't thought of when you began.

Well, computers have been with us for a long time. Why suddenly
is general aviation avionics ready for the synergism of digital
computers, and the synergism that military avionics has already
experienced? The answer's very simple: microcomputers are
inexpensive and becoming more so, as Dr. Noyce pointed out in a
very graphical fashion yesterday. I'd like to define a few terms
regarding microcomputers since this is a key technical area.
You've all heard the terms microcomputers and microprocessors.
First of all, a microcomputer is an organized collection of LSI
components, usually MOS LSI, but as Dr. Noyce pointed out, using
other technology also. These components include the microprocessor

or central processing unit [CPU] (different companies call this
element different things but it's basically the microprocessor).
Then there is data memory, random access memory which, so far,
has generally been volatile so that if you turn off the power
you lose the memory. Then there's the program memory or the read-
only memory which is non-volatile, and a very important type of
memory particularly used in the development of systems: PROM
programmable read-only memory. One of the exciting things about
components is the input-output or peripheral chips that Dr. Noyce
talked about as being very expensive to develop these days. Each
of the companies that make these kinds of systems have a variety
of special purpose 1/0 chips which, in themselves, are micro-
processors. They have a limited instruction set and they off-load
the main central processor, getting some of the detail housekeeping
processing out in the peripheral area, rather than in the
processor. These include chips to interface with displays, key-
boards, telecommunications elements, which should help with some
of the data link functions that we discussed yesterday and parallel
latches so parallel data can be sent in and out of the computer,
and other very specialized types of devices. In fact, one company's
even working on a special chip to interface with the CRT displays
so that all of the refresh and other housekeeping functions
associated with interface with the CRT is available on a single chip.

Now the important thing is that these building blocks are available
here, now, today, and the chips are inexpensive (not necessarily
the integrating into a system). I think that a fair question to
ask is: Who makes them? The answer is almost everyone. However
there are three companies I feel that sort of dominate the market
at this point: Intel, Rockwell, and National. They don't
necessarily dominate the market in terms of having all the ideas
but they have the dominant market share which is always important.
Motorola is certainly coming on strong and fighting to get a
bigger share of the market. Companies like TI and RCA have thrown
their hats into the ring and will probably become a factor in the
market, but are not a big factor yet. Then there are a number of
innovative companies with small market positions whose products
deserve attention but they're too numerous to mention here.

There are a number of different types of microprocessors. There
are 4-bit microprocessors that have instruction cycles of 5 to 10
microsec or 8-bit microprocessors with 2 to 4 microsec and then
there is the so-called bit-slice microprocessors that can be
stacked up to get as big a word as you want. Some of the newer
things coming along are bipolar microprocessors that generally have
150-300 nanosec instruction cycles. The features of these exist-
ing off-the-shelf microcomputer family of chips really permit
almost an infinite variety of system architectures for us to consider
and there are obviously many problems in implementing general
aviation avionics that are not answered by the microprocessor.

The amount of time I spent talking about microprocessors doesn't detract from these other problems that have to be addressed such as actuators, better RF elements, interference problems, EMI and the need for low-cost sensors, particularly those in which we can get digital information into the computation complex. However, I still feel that the digital technology represents the unifying element in what we're trying to accomplish. So with those comments, I'd like to start on my left, with Jay Johnson.

MR. JOHNSON: I'm Jay Johnson from Beech Aircraft. I'm responsible for the avionics installations in the complete line of the aircraft. Maybe I should give you a brief outline of how this is done at Beech. We totally customize 100% of the heavy and light twin aircraft, and we customize approximately 70% of the singles. We produce approximately one of the heavy twin aircraft a day, which becomes quite a problem because we do this on a production line basis and a production line schedule and the task of the interface becomes quite complex to meet a schedule. So I'd say that for the advancements of the 1980's high on our priority list would be the simplification of the interface. With the increasing demand for the sophisticated navigation and communication systems, the general aviation manufacturer is pressured by the customer's request. That leads me into the topic of systems architecture. After sitting through yesterday's comments this is a rehash of what we went through but I had already prepared these notes so I'll read them.

I'll start off with systems architecture concepts applicable to general aviation from other industry segments. This is a tough subject because most industries have an impact on general aviation. For instance, the computer industry with smaller, more compact computers, better reliability, less power requirements, is a 'must' in today's general aviation avionics. The plastics industry with lighter weight packaging, antenna build-ups, tougher wire coating, radomes, and many other by-products necessary for the avionics industry is essential to general aviation. The electronics industry with new concepts of microprocessors, multiplexers, LSI chips and many others, will play a big role in the avionics of tomorrow. Even the industries that do not manufacture a product used by general aviation, purchase aircraft with avionics and then feed back valuable information.

On the industry controlled standards impact of systems architecture, I would speak to this with somewhat of a forked tongue as I'm opposed to hard and fast standards because they stop progress in any new design. However, some things must be controlled. One of the bad situations we have in avionics when we customize is connectors. It seems as though about every manufacturer has his own idea for a connector and we wind up with about one whole crib full of tools just to be able to put one airplane together. We

build these in three different plants so we have a large connector
inventory. So I'd like to see a uniform standard for crimp-type
connectors. Another standard we should get to is needle movements
and loads. For instance, the linear deviation varies from one to
four miles depending on the manufacture and/or the system. Some
manufacturers with one or more systems have two different loads
for the same linear deviation. I'd also like to see standardiza-
tion of autopilot servo capstans who would allow installation
during initial rigging for a much simpler and more reliable system.
This could also allow an airplane manufacturer to design better
pulleys and control cable routing for less friction loading.

The third item: guidelines for systems architecture for the NASA
General Aviation Avionics Program. The basic guidelines for NASA
should be no different in the 80's than they have been for the past
five years as far as general aviation is concerned, because the
requirements to advance the state of the art always exist. How-
ever, the following would be my suggestions for items to be
investigated: the use of a minicomputer to tune and control
functions of navigation and communication boxes; fully electronic
displays vs mechanical displays for better reliability and more
compact indicators; equipment that can accept tougher environments.
The avionics boxes in most pressurized general aviation aircraft
do not have the advantage of being installed in a pressure vessel.
Therefore they are subject to heat, cold, altitude and moisture.
Heat and moisture are the greatest problems. It is not uncommon
to have temperatures in excess of 160° F on equipment that's
located in the instrument panel when an aircraft is sitting on a
ramp on a hot sunny day. This would indicate that the TSO and RTCA
standards are inadequate. I'd like to see better lighting design
for instrument panel displays, such as coated dials that would
reflect in black light, liquid crystal, LEDs, and probably several
others.

The ability to control systems without the use of interfacing
wiring or a minimum of wiring is important. We presently have 600
to 700 wires running through the forward pressure bulkhead on a
heavy twin-aircraft. This could and should be substantially
reduced. By minimizing the number of boxes per system a certain
amount of redundancy would be eliminated within the system. For
example, many autopilot flight director systems use two or more
computers to perform their required function. The flight director
computes the raw data from the navigation system and feeds this
information to the autopilot computer and displays. The second
computer is redundant.

(JOHNSON Cont)

The antenna system could possibly be built into the skins or the fairings of the aircraft. After all, no matter how good the black box system is, if you don't have a good antenna system you're out of business.

So in summary, general aviation manufacturers design and build an aircraft that meets the public's demand with the most space available for the passengers, fuel, and baggage. Unfortunately, the avionics gets the space that's left over. Therefore, I would say that the task for NASA participation in future avionics would be miniaturization and reliability--with high priority on reliability.

MR. FENWICK: I think it might be appropriate for me to follow Jay's lead and give you some idea what my function is so that you know what sort of poison darts to throw in this direction. I am responsible for the development of system concepts and new products. I am in the business aviation (so-called) product line of Collins Radio. I'm quite interested in the emphasis that we've heard in the last two days on microprocessors, and it reminds me of an incident which occurred a couple of months ago. We saw a seemingly learned article in a rather prestigeous trade magazine, a statement about what technology, such as microprocessors, was going to mean in aviation and avionics. The climax of the article was a prognostication that it can only be a matter of a few months or perhaps a year before some enterprising manufacturer introduces an RNAV with a micro-processor as part of it. Well, since we'd had one of these on the market for two years, I found it rather disturbing that apparently there isn't too much awareness of what is being done inside these boxes in the avionics industry.

I had some difficulty with question (a) because when I think of systems architecture I think of a detailed response to require-ments in an environment, and if anything, they're getting more specialized. Five years ago in business jets and turboprops, it was almost universal to have Arinc radios, e.g., the same radios that the air transport airplanes had. There has now been a divergence and it's relatively uncommon to have air transport radios in these airplanes. Now we and other manufacturers are developing special lines that are more appropriate to the size, weight, and certain other functional constraints of these air-planes, and I would project further proliferation of this; the overall system architecture in avionics shows differences between military, air transport, business, and general aviation.

(FENWICK Cont)

Agree that microprocessors have a lot to offer. We'll be using
them in a number of places that make sense. We think of them
just like any other component, and if we're thinking of systems
architecture at that level, certainly that has come into general
aviation avionics from other industry groups. I agree totally
with what we heard yesterday--that our quantities are so small
that the idea that we could be the forcing function for any basic
device technology development is out of the question. This is a
cross we're going to have to bear indefinitely as far as I can
see.

About Question (b) regarding standards, I can certainly sympathize
with Jay's remarks about connectors and the interface with the
airplane. As far as standards within avionics systems as might
relate to such subjects as data exchange formats and so on, I
think this would be a uniquely poor time to undertake standardiza-
tion activity in the industry because we're undergoing a rather
dramatic transition to a very different way of doing things and it
could have the stifling effect that Jay referred to.

Question (c) is the one which intrigues me and makes me want to go
back to an event that occurred 15 years ago last month, when I
interviewed for a job at Collins Radio and they were telling me
how great it was going to be to work in this avionics business.
They said my first assignment would be to develop the concepts
for EADI and probably just after that we'd get to a projected
headup display, and no telling what exotic things thereafter.
Well, I found that (with some pride, I might add) for 15 years
I've been able to prevent the company from spending any significant
amount of money for any of those and I do think it makes a point,
however, that it's all too tempting (and we're all guilty of this)
to get fixated on gadgets in this business because it's so
difficult to deal with concepts.

What NASA can do in my opinion is to pursue the more revolutionary
concepts where it isn't so clear there's going to be a payoff. I
want to give you at least one example of such a concept: I've
been a student of accident reports for a number of years and I had
a rather disturbing privilege of going over a bunch of very smashed
instruments just a week ago. O think the trend is very definitely
toward accidents in which all of the equipment is functioning as
designed, the ATC system is functioning as designed, the pilot is
totally oblivious to any problem being present, and ground is
impacted. This brings into question of how cockpits are organized,
what happens to information? That is to say, the basic concept
implicit in today's cockpit is that the pilot on his own initia-
tive, his own instigation will, on a timely basis, make himself
aware of the information that's being presented to him and take
the initiative in pushing buttons and turning knobs, to perform
in a manner implied by the flight manual.

I think it would be an appropriate function of NASA to question whether this is the ultimate way that a cockpit should be organized, seen as an information system. The beauty of digital technology is that we can now manipulate large quantities of data in cockpits if you can figure out what data to make available, and so it is conceivable that the pilot would no longer have to be a one-man band under the communication load we talked about yesterday.

I think that an appropriate function then, would be to think about the concept feasibility studies of revolutionary ideas of cockpit automation in selected areas. The communications area, an area that I've worked in quite a bit and the navigation area, seem to lend themselves to it. And I challenge the industry and NASA with the concept of a totally automatic navigation system where there is a gauge, if you please, on the instrument panel that simply tells the pilot where he is at all times with respect to meaningful reference points. This means he doesn't have to fool with pushing buttons. I believe that this is fully practical today and is something that some people have to do a lot of thinking about--all the ramifications and the ins and outs. Since it doesn't clearly lead to cash register bells for very many people in the avionics industry, I don't suppose then, this would be something for NASA. I think that such work would not start out with simulators or airplanes with CRTs, keyboards, and lots of computer capacity. It starts out with the smartest people you can find, perhaps with a little bit of the mad scientist tinge in talking and thinking about the subject, diagramming and modeling and so forth, before he does anything that someone can point at and say, "Ah, ha, that's a fancy simulator, fancy airplane."

MR. GORHAM: Chuck, I'd like to comment that nearly everything you've said, I probably would have said myself, so I can shorten this. It's very true that the first thing you do is sit down and figure out what you want to do before you start playing with gadgets. That's the message that the panel gives to some other NASA organizations doing research in a similar area.

I've been closely involved with navigation and flight control systems for about 34 years now--in airplanes in Europe and in England and France. I was responsible for the Trident program in England, and several small airplanes. In this country I've been with Arinc for a couple of years, and from 1967 to 1972 I had the total responsibility on the L-1011 for all of the cockpit displays, avionics, electrical, and flight controls, which was a kind of unique position and it probably hasn't happened before and maybe won't ever happen again, but that's how it should really be done.

Figure 37 was prepared in 1967 when the 1011 first started. I
think that a lot of the messages that Chuck has given us are
there. Some of them are engineering requirements which have
already been started and it's obvious that whatever we do in the
way of development has to minimize interface problems. We can
no longer afford to pass the buck and say, "Well, I built the
autopilot and it doesn't work with the NAV receiver." We can't
afford that anymore with complex systems; the penalty is too great.

Closer testing doesn't need to be discussed here particularly.
Maximum pilot involvement I think is vital. Our Chairman has
said that you get 10 opinions from 10 pilots; you don't--you get
11! But nevertheless, they are people that can be reasoned with
and one of the reasons we've fallen into this trap is that we
haven't reasoned with them. We haven't told them what our concept
is and we haven't told them what we are going to do early enough.
The worst thing in the world you can do to a so-called expert is
to say, "here's how it's gonna be, friend." And he says, "oh, no
it isn't." So you can get pilot involvement and agreement, since
after all they're the guys that are going to use it. They do
have to be in early in the game in the guideline phase.

I think it's absolutely vital to establish what your operational
requirements are first before you fiddle with your electronic
designs, whether it be microcomputers, displays or whatever. And
that's the trap we've fallen into in the past. We've triec to
put together the flight director. (I agree with you Chuck. I wish
that thing had never really been invented--at least in the form it
has finally finished up in). If we step back today and consider
what we really want in order to manage the systems, fly the airplane,
we might find that there is a completely different set of instru-
mentation that would be better. In designing the system to reduce
in-service maintenance, here it says, make maximum use of self-test,
maximum enunciations of failures; that was written in 1967. I
should have put a line through that in 1968 because we had about
30-40% of self-testing in the 1011 system which we found didn't
really do very much. It predicted failures with the probability
of maybe 90%, it cost 35% more in weight and in price, and we
finally caught on to the fact that with redundant systems you've

AVIONIC DEVELOPMENT PROGRAM OBJECTIVES

DESIGN SYSTEMS TO MINIMIZE IN-SERVICE INTERFACE PROBLEMS

PERFORM MAXIMUM CLOSED-LOOP TESTING PRIOR TO SYSTEM DESIGN FREEZE

ESTABLISH MAXIMUM PILOT INVOLVEMENT EARLY IN THE PROGRAM

DESIGN SYSTEMS BY ESTABLISHING OPERATIONAL REQUIREMENTS FIRST - ELECTRONIC DESIGNS LATER - TO MINIMIZE INTERFACE PROBLEMS AND TO ACHIEVE OBJECTIVES IN A LOGICAL SEQUENCE

DESIGN SYSTEMS AND COMPONENTS TO REDUCE IN-SERVICE MAINTENANCE PROBLEMS BY MAXIMUM USE OF SELF-TEST AND LATCHING · ANNUNCIATION OF FAILURES

FIGURE 37

got self-test. If you've designed it properly as a redundant
system it's going to know when it has an operational fault so
you use that circuit and that logic and there's your self-test.
One of the other problems which I think Johnson's mentioned is
that you must do this design in a more leisurely way, and do
it before the airplane starts because once the airplane starts
you haven't got time for anything that isn't certain. If you
don't know exactly where your antenna is going to be, it's
going to be wherever someone in the structures department is
going to put it, and don't grumble later that the airplane
doesn't work because it's your fault--you should have told him
before. You have to think of all these things.

Even with a modern airplane like the L-1011, you are considerably
constrained by industry and by user with the spares and the equip-
ment he already has as sensors. If a major airline has 700 VHF/
NAV receivers he doesn't want his next airplane to have a com-
pletely new type of receiver. So while we do need a big advance-
ment in sensors, we have to be careful it's done in somewhat of a
progressive way so that you don't suddenly finish up with Beech
or Cessna or Piper trying to sell an airplane that just isn't
compatible with a bigger operator's spares situation or with the
distributor.

As far as industry influence is concerned, in the commercial
industry we have a similar although somewhat different influence.
Arinc quite obviously has considerable influence about what we
can put in airplanes; the standardization is both a friend and an
enemy. That could be debated later on, maybe in the panel dis-
cussion. As far as the manufacturers are concerned, that is,
Collins, Sperrys, Bendix, etc., the state-of-the-art data develop-
ment cost and the number of the strategies affect what they're
going to do too. So it would be nice if what NASA was doing was
done out of that environment and then there would be a big scramble
for what NASA produces but it would sort itself out. RTCA obviously
has influence with minimum performance standards which are TSOs.

Incidentally, I came across a very modern helicopter the other day that had two flight directors and nothing connected to the pointers. When you switched the power on, the pointers disappear; I thought that was great. That's the best system I've seen yet. I'm not decrying the flight director; it has a lot of uses, but if you're going to use automatic pilots, make up your mind what you're going to do-- don't expect the flight director to monitor the autopilot. It certainly doesn't in modern aircraft. It's connected to the same computer. The 1011 has a fairly clean **cockpit** but with all the best intentions in the world, we still have a **standard** instrument panel, mainly because we weren't prepared in time. **Even** if we had been, if somebody'd said, "Here's a nice display you could use," I'd want to know all sorts of things about it; has it ever been tried with the system? Has it ever been flown? Has it been hooked up, tested? I'd ask a whole lot of questions before risking the company's money by putting it into an airplane.

Figure 38 shows the application of new technology in general aviation. First, it should be used to improve navigational capability. I'm not sure if it's agreed on as far as Chuck suggested, but certainly you have to have a flexible NAV system. We developed some pretty horrible things today called Mark II RNAVs which have a whole lot of keyboards and they're great except they don't handle the flexible situation and the workload really starts going up when you get into an unusual situation in air traffic. Obviously, accuracy should be improved. The more accuracy we can get out of navigation, the more people we're going to get into air space and the better we're going to operate. Navigational capability being improved would help the IFR and low visibility operation. It would let you get further down and get better operation in weather.

As far as flight control is concerned, one of the problems there is workload. Flight control can help the workload considerably pro- viding it's designed right. If it's flight control that keeps lights flashing on and off, then it's no good; it'll be turned off or a piece of black tape put over the light. Flight path accuracy again, can be improved with good flight control in combination with navigation.

Modifying basic airplane response is quite interesting. I don't know if this will happen soon in general aviation. I imagine it might happen in the next two decades, with some smart guy trying to beat the competition on a fairly advanced jet aircraft by modify- ing the characteristics and get better DOCs or low approach speeds or whatever. He'll use electronics in a critical mode to modified carping, or even produce a control configured vehicle. This may still happen. So we mustn't say that isn't going to happen. That's a farther-out objective but it's something that should be looked at.

APPLICATION OF NEW AVIONIC SYSTEMS TECHNOLOGY
TO GENERAL AVIATION

IMPROVE NAVIGATIONAL CAPABILITY
- o FLEXIBILITY
- o ACCURACY
- o IFR/LOW VISIBILITY OPERATION

IMPROVE FLIGHT CONTROL
- o WORKLOAD
- o FLIGHT PATH ACCURACY
- o MODIFY BASIC AIRPLANE RESPONCE
- o IFR/LOW VISIBILITY OPERATION

ENHANCE SAFETY
- o WORKLOAD
- o PRECISION FLIGHT PATH
- o BETTER STATUS, INFORMATION

FIGURE 38

Enhancing safety must be the objective of the application of technology, especially in general civil aviation. Again, you can help considerably by keeping the workload low. Whatever we invent to put in the cockpit must not increase the workload, it must decrease it. We can get safety if we have better precision flight paths; the pilot being able to fly more accurately. Obviously, he must know where he is and have good information that he is doing all these things.

What does improving performance really mean? As we talked earlier, on the 1011 we found it meant a lot of things: If you just added something to an airplane to improve performance you had to take account of pilot skill. For instance, if you add a new system, the FAA will want reasonable demonstration that the guy can use it-- which is not unreasonable to ask. The pilot's skill level: does he need extra simulator training to do it? Does he need repetitive simulator training to keep up to date with it? That's a fairly big cost factor. At the moment it's not a big factor in general aviation, I imagine, because simulation isn't used, but as your systems become more advanced, that's what is going to happen.

Maintenance. The airplane manufacturer and the avionic manufacturer isn't going to be able to sell anything that's not maintainable and it ought to be better than the one before. I don't know what you're doing in general aviation but in the commercial airline field, there are hard and fast guarantees and they just can't afford to have low maintainable systems or low reliability systems.

I'm not sure self-testing is a way to go. I think you should explore different ways. You remember the story about the box with nothing in it, that was told by an airline man and that was meant seriously. So let's be careful with the self-test we put in; let's show that it really means something. The best self-test in the world from my point of view is what the pilot can do simply as a pre-flight check and the more that they can tell you, the better, rather than pushing the button after the event.

Basic airplane design modification. If you really put advanced systems in an airplane you're going to come across a problem that you haven't hit too much yet in general aviation. For instance, if you go for an automatic landing system for Cat III you are going to modify aircraft wiring, plumbing, connectors, special wiring to install, segregation of wiring, and special mechanical racks which wouldn't have to be there if they weren't performing a critical function. You'll have a whole new gamut of things. So before we get into that mode of operation in general aviation, remember that it has a lot of penalties. That doesn't mean we shouldn't start. But it means automation to get there.

Certification: I think there are just two or three of us in this
room that have had experience in the commercial industry of certi-
fication of redundant systems and it really shakes you up when you
realize how much effort there is involved. For instance, on the
1011 autopilot alone, to cover the automatic landing Cat III, 160
engineers spent nearly full time for about four years--something
like 300 to 400 man years, just on the design and development of the
autopilot and the failure analysis. So if you can find some way of
getting your failure analysis program arranged so that that effort
doesn't have to be done..., but at the moment, federal requirements
and good common sense, demand demonstration.

Summarizing then, I've mentioned on the first point, compatible
displays and controls. As far as I'm concerned, combatible means
that the pilot is advised properly that the system's operating
correctly or if there is an abnormal or emergency situation. Also
the controls are easily identified there can't be any misuse of
them due to their being close to each other with the same shape;
in other words, human engineering and consideration of the opera-
tional role of the airplane. That's what the pilot will look for;
it's what any reasonable airplane company looks for and that's what
the FAA certainly looks for.

As far as the interface among elements, I mentioned earlier we can
no longer afford to pass the buck of the proper pilot system air
space operation to the other guy. If we're responsible for dis-
plays we've got to go talk to the guy with computers.

MR. OSDER: I've been involved in guidance and control technology
    instrument systems, computer technology, and so on and I'd like
    to address the subject a little bit more from the perspective of
    the unique requirements of general aviation. In the last couple
    of days I've seen concepts and block diagrams that show all kinds
    of remarkable things and, of course, there's a tendency for a very
    large gap to exist between the block diagram and reality. As a
    matter of fact, a few years ago I wrote a computer program that
    would generate block diagrams for anything you wanted; that was
    to put the block diagram drawers out of business. The problem can
    be stated though, in terms of the historical role of systems
    architecture. In the 1960's when you probably saw the first pro-
    liferation of avionics, it was quite apparent that there was a lot
    of duplication in aircraft and there was an obvious need to look
    at the entire problem from a system viewpoint as to how to eliminate
    some of the duplication. And with the development of the airborne
    digital computer the possibility for integrating a large chunk
    of avionics functions within a common computer became quite
    noticeable. Those were the first applications of systems inte-
    gration and standardization in the digital world for the aircraft.
    The result of some of those experiences involved extraordinarily
    overruns that got into the newspapers. The costs were

something like the gross national products of half the nations on earth. New villains developed and the new villians were software.

We're speaking today of digital systems. Of course trends have changed; the centralized concepts have lost their flavor with the development of lower cost computation elements, so we now see a trend toward the federated system, but the only way you can hold the federation together is with good communication links between the systems. Therefore the interface has now become the key issue. These are not trivial. The computation elements associated with keeping those interfaces together are not trivial because software costs are still going to be the dominant problem. When we try to develop software that we freeze in ROMs we've actually magnified the problem considerably more than anything we've had in the past. In the 1960's and even in the early 1970's, we used airborne digital computers with core memories that are easily reprogramm-able and they fly with the core memories. Even when systems become operational we see needs for changes and we do change those programs. If we have to change those programs in a ROM the costs are high. You can do something with PROMs and you can do something with erasable ROMs. But still to mask a new ROM because you want to make one small change in logic turns out to be a fairly expensive task.

But let's get back to general aviation. Its unique problem is cost. It cannot afford these $100 million to $1 billion type of development probrams where system integrators are involved; soft-ware development houses are brought in to aid the effort. You don't have the time, you don't have the resources. So one of the first things you want to look at is what makes general aviation avionics lower cost.

To begin with, general aviation products sell in the marketplace for something like 30-70% of the sales price for equivalent func-tions of the commercial airplanes. And the environment is even more severe. If you sacrifice reliability it hurts. That obviously can't be done; there are equipment warantees in general aviation that are quite severe. If you send out a box and it doesn't work you're going to be hurt.

I drew up an interesting chart just to verify this (Fig. 39), and it's the cost per lb for various types of avionics equipment. It compares things like VHF, NAV-receivers, flight director systems, DMEs, transponders, radio altimeters and VHF transceivers. The trend seems to be scattered, yet in general, general aviation avionics costs more than commercial airline products. I'll show you a little later exactly why that happens.

There are probably three main reasons for that lower cost per lb. If you look across the board you'll find that on the average, in general, aviation avionics seems to be about $500/lb. Why are they
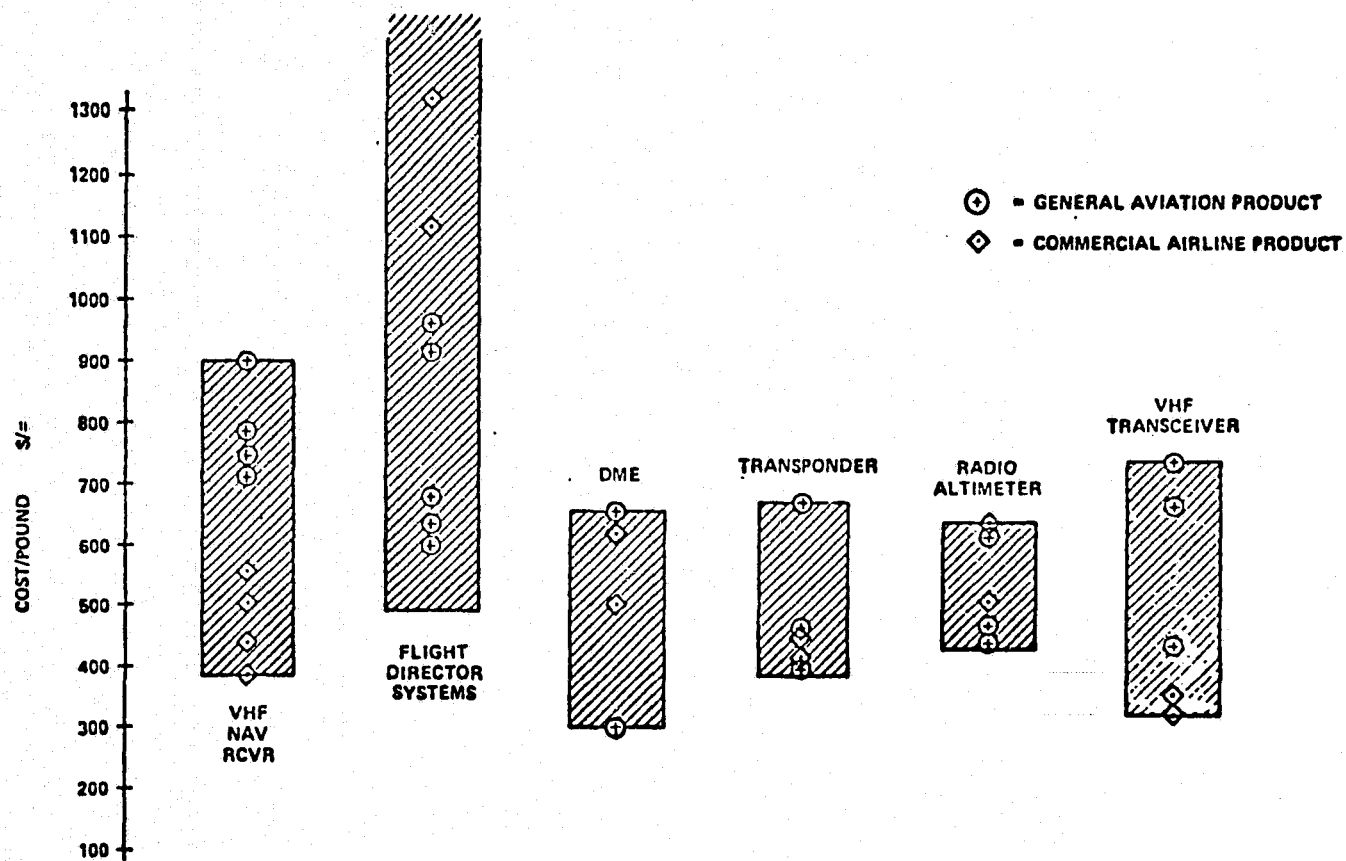
Cost Per Pound For Various Avionic Equipment

FIGURE 39

lower cost? What are the differences in the way things are implemented? First, there is less monitoring. As John pointed out, and a lot of us know, the cost of the built-in test equipment in the commercial avionics has been a lot greater than anybody is willing to admit and there are a lot of hidden costs in there that don't even appear. There are certainly reduced accuracy and performance requirements in the general aviation products. The arinc standards demand more than the TSO requirements in many cases: in radios the power levels are higher for the Arinc standard for commercial airlines for various reasons, not necessarily that they need them. Things like the selectivity of channels in radio are the accuracy of the radio altimeter used in general aviation is a few feet less accurate below 100 ft than the commercial product. But the most important reason for the lower cost is the absence of standardization constraints. The problems that the general aviation aircraft manufacturer talks about--of engineering and tailoring a product toward his aircraft and the difficulty he has in trying to interface all the elements --could be a real problem, but the reason he gets lower cost avionics is because the avionics manufacturer for general aviation did not provide him with those complete standard interfaces. As a matter of fact, the way you get a low cost general aviation product is by integrating a number of functions with unique interfaces just to put that total package together. So that if you want to build an autopilot flight director system for example, and you incorporate the air-data computer in that system, that air-data computer will have the capability of driving uniquely the displays that are being used in that system. It will provide the functions required within that computation complex and will meet just those interfaces that you've provided and will have very little capability of doing anything else or any kind of other interfacing subsystem, unless you do some additional engineering to tie them together. Now, there are things like the mechanical standards. You've heard the trouble we have with connectors; it probably cost about $1,000 to $2,000 more per box and a lot of other problems to use standard Arinc connectors. The non-standard connector approach saves a lot of money in the general aviation avionics. If you want to standardize, up goes your price.

When we start looking at the potential in the digital technologies for interfacing equipment, the first thing that comes up, we see, is always the communication data boxes. Now we have some new problems where integration might lead to cost increases. For example, here's a simple problem of, control and display talking to three subsystems via some bus interface. Now we're faced with this problem: any one of the devices tying into the bus makes the bus very vulnerable as far as malfunctions are concerned. In avionics systems where we use data busses there are much more complex isolated terminals. They are monitored in a much more complex way and the cost goes way up to try to minimize the vulnerability of

that bus. What happens is the bus can easily fail. Any one of
those devices can start putting out spurious data on the bus and
foul it up. As a matter of fact there are a lot of ways of design-
ing the bus. The easiest and most efficient one if you do a paper
tradeoff study, is to make the bus a two-way communications bus.
In avionics, so far, data busses that transmit digital data had
been one-way busses even from the beginning of the military
avionics systems in the 1960s. A subsystem output spouts a lot
of serial data and anybody tied into it receives it but the guy
who receives doesn't transmit on the same line. So that if you can
build a high impedance buffered receiver on any bus it's very
difficult to fail that bus but once you have systems that both
talk and receive on a bus you are vulnerable to failures. Here's
the problem: If the bus fails and I have different subsystems,
perhaps radios receiving a frequency select command for a control
and display unit; if the busses fail I must still get these sub-
systems autonomous and independent of the centralization. So
there is a cost involved. I could build an autonomous interface
here and maybe the radio can be tuned by the two-out-of-five
tuning techniques that's standard in so many radios today. Then
you've added the cost of the bus interface but you still have the
autonomous interface so it can be treated independently or you
can go to redundant busses. John, if you believed that the problem
was difficult in terms of guaranteeing safety for wires and flight
critical functions, you don't begin to realize what the problems
are when you try to guarantee against failures on redundant busses;
the reconfiguration of the busses; the switching of the bus and so
on. Even in the larger avionics systems today like the space
shuttle, which has a two-way data bus system and a lot of very
expensive interfacing elements that try to manage that bus, they
are probably because you have all kinds of concepts concerned with
switching over in case the bus fails. But then how do you know it
failed? Is it one spurious transmission that told you it failed,
or two, or three? What do you do and what kind of logic do you
put into the device that manages that bus? The software develop-
ment for this is going to become very costly. These are real and
difficult problems that lend themselves to solutions generally by
the expenditures of great treasure that probably are not available
in the general aviation marketplace. There are possibilities based
on the appearance of the microprocessor and its incorporation in a
product. The gentlemen from Collins has told us, Chuck, that he
has microprocessor products. Almost all companies I know of have
them. They've been incorporated from 1973 and 1974 on, but not in
terms of centralized or large integrated systems. You use the
microprocessor because it gives you a superior method of computing
and you incorporate it in your product. But the problem of systems
integration is one that has been solved thus far by avoiding
standardization, and if you try to combine constraints of standardi-
zation and still require intergration, the potential for cost increase
is very high. However, if you follow the direction of integration

without standardization, then you have the possibility for using the new elements in a low cost environment.

DR MC CALLA: After all these distinguished gentlemen, I have to say "Me too!" It's my order of priorities that we have to be reliable. If we're actually going to control surfaces, fiddle with the engine, and actually control the mixture. An engine's a very reliable thing, as is the airplane. Now if we're going to put one electronics system in there it's going to have to be simple to operate and simple to maintain. It's going to have to be modular as we mentioned so that we start at $2,000 or $3,000 and then go on up to the business jets. It needs to be adaptable. Things keep changing. We have changes in technology, changes in government regulations in the NAVaids, we will have to be able to change what we plug into the computer system. Right now we have VORs and there is a big push to satellite navigation. Maybe in between there is a VLF Navy station.

There are a couple of points to mention. Reliability. If we have a number of things and they all have about the same reliability, two of them that could only carry half the load are actually worse than only having the one. If we're going to add things in parallel they each need to be able to carry a good proportion of the load. Our twins are counted in that predicament. Most of those twins can't really make it on one engine. They become a long range glider.

Let's go back and look at the development of computers for a minute. First it was just great to have a computer and we tacked everything into it. Then as logic elements became a lot cheaper we got into the situation that seems to be prevalent today where we stick our decision making elements over all the machine and the central one could become a lot smaller. We have little local controllers on the input and on the output. Now as Bob Noyce pointed out, the logic is free. Logic is becoming very cheap and so we can have multiple central processors. So it looks like we might have a little bit of a logic on output and input, and we could come back to something where we have multiple central units.

Loading. What isn't acceptable on a decision maker is if it goes bad you really don't know its gone bad. Only if it fails completely do you know it went bad. Experience in the hybrid computer lab is that a lot of times the digital computer doesn't just quit, it gives you erroneous outputs; kind of like analog, like the OMNI systems in my airplane. The checkout, then, after I fly a couple of hours IFR are reading 15° apart. One of the pilots now have three OMNIs in his airplane. If you have two you can tell if they're working; if they both agree, they're working. Four gives you an operational redundancy. Maybe for general aviation if we're going to put a great burden on the logic, which we might because it is going to be cheap--we may change the way we do things. Maybe we'll just do with three and let it tell the pilot when one drops off that he'd

better get to the nearest airport, because he's in real trouble
if he loses one of the two remaining. Some military situations
like the system Teledyne's building, have four complete systems
so he can lose one and still be operational.

Let's look at a system with four decision makers. We have the task
list of things that the machine has to do and since ROM is cheap,
we'd use PROM or read-mostly memory. But all the machines can do
all of the tasks. They periodically check each other as well as
themselves. All four are vote totalers. Each one of them
totals the vote. As a team member drops out, you throw off some
of the less critical tasks. The list of tasks is stored inside
every machine, and when one of the machines picks up a task it
tells the other ones what it's doing so that they won't do that
task, and what you have is kind of a high overhead of machines
telling each other what is going on. When you go to a little
higher complexity you actually have to put in a supervisor. A
multi-level hierarchical structure has to have a coordinator and
you put some of the same structure in there to switch the coordinator
around to get your multiple redundancy. You can't have just a
voting machine since the voting machine becomes critical; that's
no good. You make them all voting machines.

MR. SEACORD: I started out in airplane and missile stability control
and moved into automatic control in general avionic systems, and I
have been associated with the B-58 and the X-20 that was probably
the first fly-by-wire system scheduled to be built. I feel somewhat
like the last guy in a ski meet: the ruts have been worn and I'm
going to ride down those same ruts.

I think that people get killed in airplanes mostly because they
can't land. There are engine failures but these are uncommon. I
think part of the problem when they are landing and trying to
navigate, is that the airplane is not a particularly good airplane.
Now I realize that shouldn't be universally applied but it certainly
applies to some very popular light airplanes. There are some that
wander all over, even with augmenters.

Desirable New Functions: They're got to adapt to MLS. A type of
device that has been mentioned previously; a flight management
computer complex, that will tell the pilot where he is and even in
some cases, where he should point the airplane to get to his
destination. I think that would probably involve a CRT display
for the next five years or so. Now some of these things come from
talking to operators of fairly advanced general aviational business
aircraft. I include headup display because I think that for Cat II
landing, for anyone but the very well-trained and highly used pro-
fessional pilot, the only satisfactory solution is going to be a
headup display. I don't know whether it's going to come at the
right price or not, but I don't think you're ever going to get pilots
that can pop their head up and land the airplane in the last 100'.

The hard copy printer has been mentioned and perhaps it could
be a storage display that's not hard copy, but anyway, some-
thing so that the pilot doesn't have to immediately absorb all
the transmissions, but they will be there for him to use at his
leisure.

Reliability: It needs improving, both MTBF and functional redun-
ancy. The current light plane has a great deal of functional
redundancy. The pilot starts down the glide slope and, as some-
body mentioned, he can keep his eye on the altimeter and it tells
him something if that doesn't look right. If, when he goes over
the marker he isn't at the right altitude that tells him, if he
doesn't hit the marker when he thinks he ought to, that tells
him something. The pilot is the computer that's monitoring all
these systems. There's a lot of redundancy. If you integrate a
system completely and make it the most efficient in terms of hard-
ware you will lose all of that functional redundancy because you
won't have the duplicate sources of information. So we have to
maintain this functional redundancy and I think that means
independent subsystems.

Cost reduction: Using low cost equipment tends to favor using a
mature concept hardware. The data bus was mentioned. Well, the
data bus may have weight and space advantages and in a lot of
cases that can be shown very definitely. It probably will also
cost more to have more MTBF. We did a study on the NASA F-8 air-
plane, considering a pseudo-shuttle-type bus arrangement and the
piece-part count went up and the cost went up because you had to
have more piece parts.

If you look at the general requirements performance, reliability,
cost reduction, and the types of technology we're talking about
here, there is zero effect of improved performance on RF electronics
because I think the current electronics work pretty well when they
work. You will get an effect of the digital electronics because
you'll get more accuracy in NAV and in display computation, or for
that matter, in flight controls. The problem of building a
redundant digital flight control system is really a great deal
easier than it is in analog because of the tracking accuracy. You
can get all the accuracy you need for general aviation out of
current inertial sensors. You can't get what you want with the
displays now so there could be a large influence of new technology
on the display in terms of improving performance. New functions in

digital electronics have a high influence because of the possibility of doing things you couldn't conveniently or economically do before. All of them could have a high effect on reliability if the reliability of those types of hardware could be improved.

Incidentally, when I said I agreed with John Gorham on one thing, I want to disagree with him on something: I disagree on the self-check. In a digital system the self-check is very feasible and very successful; it may cost a lot to do the design work but it costs very little in terms of hardware. Computer and memory are low-percentage costs, certainly not the determining factor in the system cost. In inertial navigation 70% of the cost is in the inertial sensors; even for a flight director 40% is in the inertial sensors, and for the autopilot it is equal to the computing costs. For ILS and communications, 75% is in the RF. The main point here is you're not going to get the needed cost reduction out of digital electronics because if you eliminated all of it you'd still have a problem.

Back to the systems architecture for a moment: a dedicated approach has sensors and the computing elements, servos, and displays. Integrated systems are of two sorts: one has dedicated wiring and the other is the data buss approach. You have a minimum list of sensors; if you need inertia references you have one--you don't have one for the auto pilot and one for the flight director, and so on. Now when you do that you may end up having to put two or three of these whole systems in because you don't have the redundancy that you get by having an independent autopilot and flight director.

Now, an opinion of what I think the characteristics of those architectures would be. The dedicated system has fall-back capabilities by virtue of the fact that it has some functional redundancy; it's easier maintenance and probably cheaper spares, because the spares are less complex in themselves. One that hasn't been mentioned here very much but is very important: the software design checkout and control is much simpler, much cheaper, and much more certain. It may be inefficient; you may duplicate sensors, and it might lead to a higher MTBF, but one thing is, the computer failure will end up being small compared to the failure in the sensors and the display. The integrated one has its obvious advantages: you can size things and completely use the computer capability; you won't have an inefficiently utilized computer. Packaging costs will probably be lower and you can eliminate the duplication of sensors. If you're not careful you may lose some of your fall-back capabilities. The disadvantages are, if you go to the completely integrated system, you're going to have to use parallel redundancy or high coverage self-check which does become feasible but it doesn't help much in terms of an inertial sensing or even RF sensing.

(SEACORD Cont)

The software complexity goes up. [This is a wild guess of mine; I think it's probably N^2 where N is the number of subsystems you start tying together and running through one computer.] The troubleshooting is much more difficult. I asked a couple of pilot friends who operate airplanes what they wanted. They wanted more reliable equipment and they also added that they'd like to have some way of getting it fixed when it did fail. They said it was just like taking your TV set to get it fixed; you had about a 50% probability that it would be fixed.

Some trends: I think that the decrease in cost of digital electronics will encourage the use of dedicated computers. The low computer cost will promote the use of parallel redundancy and self-check, and under those circumstances the failure probability of the computer function would be negligiable compared to the other failure areas. New developments in inertial sensor technology will offer improved capability and that comes back to what was mentioned yesterday. I think strapped-down sensors in conjunction with the new and cheap digital computing will take over.

Electronic displays are probably a necessity if we're ever to get the right amount of information into the cockpit without overrunning both the space and the cost. Existing aircraft operational data that is available now in an airplane (which the pilot calculate on his fingers or does whatever he does to figure out what it all means) can certainly be put into a computer and made a lot more useful.

Now in regard to some questions: I think the standards that were mentioned probably could be developed to some extent and I guess I don't understand why this should have such an effect on cost. I know of a couple of examples. We have a small radar altimeter to be sold to airlines. If you sell it to the airline they have to put it into an ATR box. So they went and bought an ATR box and this little altimeter sits in the middle of the ATR box; there must be room for four of them in there. That's inefficient in terms of space, but it turned out to be the most cost effective way of getting that so-called standard ATR altimeter. So I think the standards could help, but I don't think they'll have much effect on system architecture, and in fact they might lead to a more varied system architecture because then you could literally plug things in where you wanted to and customize the architecture.

The contribution of other industries: We've heard about the digital electronics and I think that's certainly true and obvious. I don't see other industries except the communications industry that will help on RF. I think that's an important part of the problem. When you consider DME and MLS, even the popular communications industry is not going to help much; they are not in the right frequency. MLS receivers are going to be expensive because the RF front end is expensive.

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As to suggestions for NASA work, I think that starting from a clean sheet of paper and aiming to reduce pilot workload with a complete display is certainly something NASA can do. The headup display is unlikely to be done by any avionics manufacturer and I think that would do more to help the pilot landing situation than anything else.

Other programs in the past have created very sophisticated panel displays. But those displays were expensive; they required very highly trained pilots; they weren't for the general aviation pilot. If the general aviation pilot is ever going to confidentally make even Cat II landings, we needs a better display and headup. I think it's the right way because he doesn't go through the transfer of his sensing. The inertial system integration and improvement, RF integration, trying to cut down the number of separate RF front ends you have on the airplane, the number of sensor types is worth looking into.

In summary, landing display, working toward more reliability and improved RF and inertial sensors is something NASA can do.

MR. ANNIN: I'm with the Boeing Company, Commercial Division, up in Seattle; I'm also a general aviation pilot, and flight instructor with instrument rating. I'd like to speak first from a Boeing point of view and take a brief look at the architecture of two of the systems that are being built. One is the 747 flight director and autopilot complex, and the associated sensors and displays. A new thing is a Boeing 727 company-owned test airplane which is now equipped with a dual Sperry RNAV system with quite some capability.

There's nothing too unusual about the 747 captain's panel except at the bottom, there is a little switch that enables the captain to look at any one of three integrated autopilot flight director computers which is standard equipment on all 747s. In addition, he's got switches at the bottom of his panel so he can look at deviations from the opposite side of his navigation receivers; he can look at the second INS and derive his attitude source from the second system in case of failures. The integrated control panel which handles the mode selection for all autopilot flight director computation was originally developed for the SST and found its way into the 747 through the request of one of our customers. The 707, 727, 737s suffer from having three mode selectors to appropriate positions. Well, in the 747 that's taken care of. The wings can only assume one attitude at a given moment and the nose can only assume one pitch attitude. So one mode selector controls all three computers. The pilot can turn the flight director off.

This is a switch that some of my friends will like--you can just turn the flight director off and use the raw data for monitoring.

In the basic airplane, unless the customer has some special require-ments for additional redundancy, there are two basic sets of sensors. INS is standard equipment whether you want it or not. There are three computers all feeding into the automatic flight control system which is dual in the standard installation. But if a customer is interested in Cat III landing, a third channel is added with appropriate sensors.

The new 727 has a dual RNAV system and two digital computers. The focal point is the computer. It has a disc-memory of about 156,000 words and you can store the location of every VOR in the world if you so desire; the location of the airports that you intend to operate to; and all the published way points of the structured high altitude airways that the FAA has published. The pilot has access to that through his little control display unit. There is an inter-system communications buss so that the two systems can check on each other and alert the pilot if there's a discrepancy in the computation. Since this is an old fashioned 727, each pilot has a mode selector for his flight director, then a common mode selector for the autopilot. So there is just the one autopilot and the controls are not repeated on the other side.

The inputs to the RNAV computer at present are all analog; that's the kinds of sensors we have to deal with. There are five outputs from the air data computer such as altitude, vertical speed Mach number, air speed, etc., and conventional directional gyro and vertical gyro supply heading and pitch information. There's no bank angle information needed.

Another interesting feature is that all VHF Nav and Com selection is made through a push-button controller and when you're operating in the RNAV mode, which is normally most of the time, you don't do anything with that control because the Sperry computer reports to you on the alpha-numeric display what frequency it's working on at the present time. So you just sit there and it gets to the appropriate point and tunes in the next station. All the time the pilot is monitoring the situation independent of the RNAV computer because the RMI is dedicated to the VOR station which is tuned by the RNAV equipment, so he can always look at the bearing and distance to the station that's being utilized by the RNAV computer.

When the pilot's sitting on the ramp, passengers getting loaded and the pre flight checks are being made, he can set up the entire instrument departure if there is one published, or he can make one up appropriate to the departure route he'd like to take. There are three separate phases: departure phase which he selects on the ground. The enroute. phase--if it's an airline company they would use route numbers for all their commonly flown routes so

you don't have to go through and name all the way points. Just
call up the route number you want and then if you have the time
you can sit there on the ground and go through the flight way
point by way point and examine all the route segments and all the
altitudes that are stored. It's three-dimentional. The entire
vertical profile can be programmed in advance. And yet it's easy
to make changes. If you get a new altitude clearance you just
punch a couple of buttons and she'll just settle down to the new
altitude.

To make this convenient, Bendix modified the autopilot and put
some push buttons on the control panel so we can select lateral
navigation on vertical navigation and couple it in with the auto-
pilot. We have about 25 hours of area navigation flight testing
now on the 727, and about 75 hours for certification and proving
on the customer's airplane.

I'd like to put on my Cessna 150 driver's hat for a minute and
make some suggestions for the lower spectrum of the general avia-
tion business--things I've been thinking about for quite a number
of years. I think one of the biggest things we lack is a realistic
usable attitude display for a pilot who can't spend a lot of time
on simulators and instrument training. I don't know what the
answer is but I think it's something that NASA could work on. For
example, you might conceive of filling up the door post on an
airplane with electro-luminescent panels or something of that sort
as display technology is coming along, driven by the vertical gryo
so that it fills in the horizon that you normally have. You know
how easy it is to maintain attitude and heading under VFR conditions,
and when you are experienced on instruments this is no great
problem; but it's that group of pilots in between that don't get
the time and haven't had the experience. So I think something like
this would give them a natural mode of instrument flight.

I have to agree with Buster on the need for a little bit of
stability augmentation. I think that on an instrument flight, it's
foolish to sit there keeping the wings level, keeping the heading
in the right direction, and watching the altitude if simple
electronic means can be provided to give the airplane directional
stability; make it more or less hold the heading. I think that
there are airplanes on the market that do this. For instance,
Mooney considers lateral stability argumentation as normal. If you
want to make a sport plane of it you push the button down and you
can maneuver all you like but when you turn the airplane on, it's
got directional stability and the wings tend to stay level.

I think the other thing that we need to work on is in the accident-
prevention area. Up in Seattle we have two major problems: One is
flight into rocklined clouds--you just don't know the mountain is
there and you run into it. The other is the stall-spin accident

(ANNIN Cont)

that continues to be with us in great numbers. I think that
some work could be done to somehow limit the authority of the
elevators, get rid of the ailerons and provide a lateral control
that always works.

MR. BAIL: The ground has been very well plowed. I'd like
to back up and talk a little bit about some of yesterday's
discussion and ramble around this question of what NASA
should do. I would start out with the DC-3 which is an imminently
successful machine. It probably put commercial aviation in the
black, and it was an advanced machine for its day. The engines
were reliable; it had the NACA cowling retractable landing gear,
low wing configuration, monocoque constructed cantilevered wings;
(2) two engines instead of three and an NACA developed air-foil.
It was the marriage of a lot of technology and effort up to that
time. I believe that's the way significant things happen in the
avionics business also. The things which are particularly success-
ful are the marriage of a number of previous efforts. Along that
line it seems to me that NASA's role is clearly not that of product
design. It also seems to me that it is clearly basic research; it
should supply the avionics equivalents of better air-foils, of the
NACA cowling, things of that sort. But don't go designing flight
directors, a cheaper dispaly, a lower cost MLS receiver, etc. The
basic research necessary to fund the components needed for those
worlds has got to come from a much larger marketplace than that
which NASA can provide from seed money. Now there may be a
particular spark somewhere that the seed money can kick off. But
it must be very carefully done.

The product line which NARCO makes are sensors in all the systems
architecture we're talking about today: DME, COM, NAV. Suppose
NASA contracted for super digital guys to design super digital
circuits, and gave them to us and we got all of the electronics
functions free. Now let's configure a business on that basis.
Clearly, my engineering percentage of cost decreases. My
electronics costs go to zero and I have only mechanical costs now.
In mechanical (I'm including such things as connectors, PC boards
to hold these parts, panels, drums, frequency indicators, dust
covers, shields, EMI and all kinds of good stuff), the cost savings
to the customer would be somewhere between 20 and 30% and that's
all, with all the electronics free. We've still run our sales
force about the size it is today. We still must have production
control because we have to manage 20 or 30 lines at one time. We
have to have purchasing because of all the mechanical stuff that
goes in these boxes. We have the G&A cost, cost for building; all
those things are still there and they're an appreciable part of
the cost. So I think a lot of caution has to be used in where you
apply the money, effort, and thinking.

Now, to follow that line of reasoning further, I say that
salvation has to come from what we call system architecture.
I don't believe there's a supplier to the general aviation
world who hasn't said "If I could sit down and make one box that
had the COM, the NAV, the DME, the RNAV in it and I start making
these things common, we could save lots of bucks." I don't think
there isn't anyone who hasn't considered that as a possibility.
I could save money but I don't believe it's a viable approach for
a couple of reasons. One is, not everybody wants to buy the
whole bag at once. A sizable part of the marketplace is upgrading:
new transponder, meeting new requirements such as altitude report-
ing. The buyer may not be able to afford the full bit now so he
gets one COM and one NAV, and then a couple of years later, perhaps,
adds equipment. You can't afford to have the initial purchase be
too dear. You'll shake a lot of people out of the market. The
other reason is reliability. Functional redundancy just must be
preserved. You can't afford to have one thing go and have the guy
dead in the water. It's not practical to do it that way. Most
people will appreciate it, but here's a case where we may have to
do some protecting of the customer against himself.

I'm of two minds on all these things--I would like very much to
stand up and endorse the big effort to make it easier for me to
do something or make the world better; I think you have to be very
careful what areas are attached. And so while I say I think basic
research is where it is, I don't quite really know what basic
research is. If you can invent something, like an IC or transistor--
something of that sort that millions and millions of people are
going to use in billions of quantities, you've done something
significant. But if you go and invent a synthesizer or a VOR
processor or a whatever to fit some airplane architecture, you're
doing the wrong thing.

I'd like to make a controversial statement: I don't believe the
equipment needs more reliability. Perhaps it should be safer, but
you've got to be very careful in sorting out those two thoughts.
Reliability is mainly an economic factor. Safety is something else.
Let me illustrate what I mean here. Reliability is the classical
MTBF kind of thing. We make radios, with 1000 hours MTBF. If we
did everything super in that radio, we might make that 4 or 5 thou-
sand hours but it takes a considerable investment to do so, much
more than 5 times the investment to make the 1000 hours; much more
than five times the cost of the product. You've got a factor
improvement in the probability of failure. It may be 3 or 5 times
more reliable. So let's take this 1000 hour MTBF box, start charging
around the air with it, and I say to myself, "Well, I'm five times
less likely to have a failure than with the 1000 hour box; but with
two of those 1000 hour boxes in there, I'm about 1000 times less
probable to have a failure, and that would only cost me twice." So
I can obtain functional reliability by redundant equipment much
cheaper than I can improve the reliability of the box. Now, on the

other hand, the operator says, "Your box fails. It's down all the time. Gotta fix it. I keep pouring money into it." That's economics--but not safety. We must be careful in thinking reliability vs safety, and in my mind I was reading safety in a lot of the reliability talks. Reliability is mainly a cost factor but cheaper to maintain, is something else. You can get there by more than just making it more reliable.

I've had the opportunity a number of times to go through and apply operations research, system engineering, or whatever optimization you want to talk about to several areas that I thought were clearly non-optimum. They mainly were economically forced situations. If you sit down and do a real thorough analysis, you reach some funny conclusions. And so I'm going to propagate Bail's law: An economically forced system, where the system is a result of a large number of seemingly chaotic economic or time-constrained decisions is nearly optimum. It's a hard thing to believe but I do believe that very strongly.

I have some things to say on systems architecture. The statement was made that you can't afford a system that won't allow revolutionary change. There's several things wrong with that. Not only would you have a severe reaction by the users but industry just couldn't possibly undergo revolutionary changes every time you wanted to change something. The pilot's training and his inertia must be considered. The systems and box designers think of the pilot as a reactionary individual; he is, and he's got good reason to be. You can give a guy a better altimeter display but if he was trained on a 3-pointer and his reactions are based on a 3-pointer kind of thing, his response is, "Hey man, I don't like that. I'm trained. I'm used to this thing." There is the inside-out outside-in attitude gyro argument. The guys are trained one way. Probably the wrong way, but they are trained that way. At a critical moment of approach, if he looks up and makes a response based on his training, he's liable to accelerate the attitude displacement rather than degenerate it.

Another comment that I really don't know what to make of. Buster proposes making all kinds of improvement for the bigger machines and the airlines are doing all those good things but it's a severe inversion of skill compared to the equipment we give the guy. It seems imminently stupid to me to keep providing 5" great big displays for an air carrier crew, highly trained, competent, current, and put a little 3-inch hole for the general aviation guy to look into for an attitude indication.

Also in the area of things that I look at and feel are terribly wasteful, is that the navigation problem is really a very slow developing problem. What kind of bandwidth, what kind of real information rate is being transmitted to give a guy's position in

space or his maneuvering situation? It's a very small part of
a cycle per sec and yet we use up at least 10 MHz today, 50 kHz per
OMNI station. That's terrible. For communication, we burn up 18
MHz for an average, very low, information rate. We invest things.
If you want to get a more reliable, less difficult to operate
communications system, why don't we just put a one-channel radio
on an airplane and have the ground frequency move around to talk
to him? The ground sits there with a multi-thousand dollar
communications transceiver with one channel. How many of those
are there in the US? The airplanes have got half a million COM
systems up there--all of them assignable to 720 channels. This is
not smart.

The only other argument you can enter into concerns the processor.
Processors almost have to be distributed. I think the simple pro-
cessor concept has got to be very carefully looked into. Someone
said, "Let's put the operational requirement in front of it."
Today, we say, "Hey man, we can do it. Isn't it beautiful? It's
getting cheap." Why do you want to do it? What's it going to do?
The sensors we're talking about: VHF, LF, magnetic heading,
altitude, temperatures, those things, with included computation,
do present a situation display if this processor is to do nothing
but combine several things. You don't need a big processor for
that.

DR. SMYTH: Well, John, thank you for some very realistic comments.

DR. De BRA: Dick, why don't you continue for a minute and let the
     Panel interact while we have you here together.

DR. SMYTH: Okay. We're now 18 mins over our allotted period, but
     I'm sure you've all been saving up remarks that have been generated
     by your fellow panel member's comments. We'll give each of you one
     minute to vent your feelings. I'll start with Jay Johnson.

MR. JOHNSON: I would have to agree with you, Bail, on the MTBF reliability
     of 100 hours if we receive that. However, what I'm talking about is
     the failures prior to the airplane's being delivered. We're talk-
     ing about 15% failure rate in the house. This is what I'm talking
     about regarding reliability. Once the airplane's delivered, and the
     infant mortality problem is past, we are getting fairly good
     reliability.

MR. FENWICK: I suppose the distinction you're making there is between
     reliability and quality control. I remain remarkably free of
     anxiety reactions in what I've heard here this morning. I was taken
     by Steve Osder's remarks about standardization's causing costs to
     balloon. A novel idea. I've never heard of it before, and I
     appreciate your having said it.

MR. OSDER: I've been most perplexed by the problem of giving
Dallas a positive recommendation for something NASA could work
on. I've observed that each person made recommendations. For
NASA that was furthest away from what they themselves were doing.
There are important contributions that NASA can make in research.
Of course, it's very hard to identify research with some of the
practical reality we're trying to accomplish, but I do think that
NASA has the facilities to accomplish testing in a fairly good
environment that would actually prove the feasibility of many of
the concepts that were discussed. NASA is equipped with a lot of the
engineering resources that a lot of the rest of us can't afford to
apply to these kinds of tasks. They have the flight research test
equipment, the ability to record, measure the accuracy, measure the
performance of devices or new inventions that people come up with,
and I think NASA ought to exploit that capability and provide that
flight research support to the new inventions that everybody would
like to see developed.

DR. MC CALLA: It remains to be seen whether or not NASA ought to move
towards the standard. Yesterday it was mentioned that IBM seems to
be Snow White, everybody else is the Seven Dwarfs, and they follow
along. Another group that's moving towards an international
standard are the instrument manufacturers, and Hewlett Packard is
one of the foremost of these. It seems as though the aircraft is
more an instrumentation situation and I'd like to look quite closely
at the instrument manufacturers' standards.

MR. SEACORD: I agree with what John Bail said about the display and
the pilot. It would be very nice if the best possible display
could be in the cheapest airplane with the most inexperienced
pilot. Unfortunately, I think cost is going to prevent that but it
certainly would be the right way to do it. On the realibility thing,
though, I heard the same figures, only I heard the rejection rate
from one leading manufacturer was 20% to 40% before it ever got
installed in the airframe at the airframe manufacturer's plant. The
man who told me this didn't know the reason, and he didn't offer a
solution, he just said it. I would like to cite one example, infant
mortality, and that is the digital data computer that Honeywell
supplied for the DC-10 when they first built it. It was a Nightmare
from Honeywell's financial standpoint and probably from the
government's. It turned out that it was economical to go back to
and put in the right parts and do the right burn-in. They did more
than meet the requirements. They quadrupled the original after
burn-in MTBF had been, by putting in high quality parts and perform-
ing a rather rigorous incoming inspection and acceptance testing, so
I don't think the cost of getting a reliable piece of equipment is
necessarily what you described. Maybe that was a special piece of
high cost equipment so that it couldn't be made much more expensive,
I don't know.

I don't understand why it would not be entirely Proper and useful
for NASA to work at developing more efficient means of getting RF
signals into the airplane. It doesn't mean they're going to design
the product at all. But it could mean they're going to explore new
ways of building synthesizers, new ways of doing other things and
publish this just as they design airfoils. [Although they don't
design wings for airplanes, generally.] It's been very useful work.

NASA should not get into standardizations. I don't think NASA as
an organization has the people, or the organization, or the back-
ground to try and create standards.

DR. De BRA: Who should, Buster?

MR. SEACORD: Well, I think it probably should be some organization like
RTCA, SAE, or Arinc.

DR SMYTH: I'd just like to reinforce one of Bail's comments about
functional redundancy. About a year ago, I was flying a small
4-place plane on instruments from Dulles to Oklahoma City, and I
noticed it went for a long period without any noise coming over the
speaker. All the needles were working so obviously the radios were
working. There were two of them, but there was only one speaker
and it had failed. Obviously, we have a functional redundancy in
that case because we have an earphone plug, so I opened the case to
get my earphone, but it was not there. That also reinforced his
comments on pilot training. I was stupid.

MR. ANNIN: A little bit of a red flag came up for me when somebody
suggested that headup display was the solution to any of our land-
ing problems. Now Boeing has had some experience with that. As
you know, AOPA has been very strong for headup display. I don't
know exactly why, but we finally got pressured into putting one in
the 747 and we've done a lot of testing on it and that is a problem:
We've got very expensive objects, and very stringent sensor require-
ments, to get the accuracy needed to overlay the flight path bar on
the runway. Now I'd just suggest we forget all about the headup
displays.

MR. GORHAM: Yes, I agree with you. They should be looked at with
caution. Regarding standardization from the airplane builders'
point of view, I'm not quite sure whether the cost of standardiza-
tion balloon is because of the total cost you're dealing with when
you design the box. I don't know what the story is when you take
the whole airline picture. Now whether that's related to general
aviation, I don't know. What I'm just pointing out is one part of
the story. I'm not sure of the total cost of balloons, otherwise
we wouldn't be standardizing. I think it's worth exploring the
redundancy and reliability question for a moment.

In 1961 when we developed the Trident triplicated system, we had a quick look at the reliability of the single channel autopilot which we all had then. Looking back on every record, we found that the single landing autopilot, single channel autopilot would adequately meet the requirements of 1 in 10^7 for safety. But you just wouldn't do it. The point of that is, let's just make sure that when we apply redundancy we don't just apply it willy-nilly on the basis of a math function. Let's be sure that we really do need it because once you apply redundancy, you've got two boxes instead of one, or three instead of one. The tendency is to let them get half the reliability because that's all you need for the redundancy and safety level and now you've got at least four or six times the problem on the operator. So there's a great big penalty to be paid for redundancy.

And then the final point: we really didn't discuss the attitude gyro yesterday. We talked about determining attitude with rate sensors and with inertial sensors, but the lousiest bit of equipment on any modern airplane today is the basic attitude vertical gyro, and the smaller airplanes won't be able to afford anything much better than that. They won't be able to afford inertial platforms for a long long while yet. Let's see if we can do something like basic flight attitude.

The FAA is obviously very reasonable when you put something in. The constraint is not so much the difficulty of meeting the FAA requirements or at least getting new requirements which may adapt to the equipment you've got. For instance, there were no regulations for Cat IIIA automatic landing, when we started the L-1011 so we got together with a few industry people, and 3 months later we had an acceptable means of compliance and were all free to go. So it can be done. The problem is the question of how far does NASA go if NASA goes only to the point of demonstrating a system concept with non-representative hardware? There's a problem still because when somebody starts a new airplane, FAA isn't going to say that it flew around fine in that Cherokee that NASA had up there with that equipment that Sperry, Collins, and Bendix put in the program. FAA isn't going to take any account of that, because it's non-representative and while a little bit of credit may be given, it would want to see that equipment in production form, getting some hours accumulated to it before it would say "Okay, go put in a new airplane." What I'm saying, is there's a development phase. If NASA wants to do work which would help the airframe manufacturer and the user to get new equipment, there's a process the manufacturer's previously gone through, from feasibility to engineering development. He's done all sorts of things to get this demonstration of reliability and performance, which is the evidence the FAA requires. So how do we get that gap filled?

MR. BOROWSKI: I think the first thought that occurs to me if NASA develops data, writes a report, etc., we put all kinds of weight on that. That means a lot to us and it goes a long way towards substantiating a production design. The burden of proof of substantiation is always on the applicant. But when the applicant comes in with a NASA report, he's a long way home.

MR. VANDEN BERGE: I think the point is that the results of any conceptual programs that NASA undertakes that will result in changes required in the regulations must be communicated with the FAA to determine if there will be some regulatory reason that that concept cannot be implemented once the testing and development work is done.

MR. BOROWSKI: We have an FAA coordinator here.

MR. GREER: There's a couple of things I want to make clear. One thing I've been concerned about a little as this meeting has progressed is that this group of people understand that the interest of the program which we are sponsoring here, is not product improvement. It is not intended to intrude in the affairs of the general aviation avionics or airplane manufacturers relative to near-term objectives. The intent of the program is to project towards the five, six, or seven years, to the technology available then, and do some reasonably far out examination of concepts--both in terms of subsystem as well as total systems, in an attempt to lay up a store of information which will aid in avionics designers. We will do research work that is too risky for people who are in business for profit. That point I wanted to make, lest there be some misunderstanding. From the comments and discussions I've heard, we're shooting a little short of our objectives.

Another point that I'd like to make plain is that NASA doesn't intend to fool around in the area of standards. NASA's intent is to provide some money and a little bit of a push for industry to get together and to reexamine the issue of standards to see if there is anything beneficial to them which would drive either the cost, the maintainability, the reliability, or user ability in a favorable direction.

The third thing I want to make plain is the relationship with regard to the FAA. I say make it plain, and I make it plain that I don't understand it. We recognize that what we do in terms of research must have some degree of practicality to it, even though we are talking about systems concept research five, seven, or ten

years from now. To that end, we have sponsored studies to examine the environment. The system which we will work with would bear some practical relationship with that. I will say that the two agencies cooperate. There is a very honest instinct on our part to develop liaison with the FAA that will allow us to be of service.

What we really want to do is develop for the avionics industry another NACA catalog or its equivalent. The purpose of the Workshop is to gather comments and opinions from you people which would aid in formulating that research approach, or that research program, which would develop significant steps in advance of general aviation. We are trying to spend seed money wisely, which will accomplish this, but to a large extent the direction we go and the progress which we'll make will be dependent upon the general aviation industry themselves. It is those people we'll go to for advice. This is probably one in the first of our series of Workshops.

MR. HOLLAAR: I'd like to address some things that haven't really been covered and I think they may fit in with what Brent has talked about regarding revising the old NACA catalog of designs. The (NACA) agency didn't dictate to you but helped you. One of the things we're seeing is that the hardware cost is becoming a negligible cost in the development cycle; the software cost is becoming more and more the factor in digital design. In this regard it's possible that NASA could do a limited development of the basic algorithms; not the software; checking them for reliability; checking them to make sure they meet the requirements; indicating what accuracy is required; indicating what speed is required to execute these algorithms. This would aid immensely someone who is developing, for example, an RNAV system in that this basic development wouldn't be necessary. As navigation systems become more complex, like Omega, there is a tendency of having to reinvent the wheel or recalculate the trig formulas and figure out what error bounds there are. The designer could go to a catalog of NASA programs, much like one went to one's friendly NACA wing section catalog.

Another area which NASA could get into is human factor design of displays. Very few manufacturers can afford the money and time necessary to run the thousands of subjects to evaluate innovative display procedures. And it does require a large number of subjects, e.g., to figure out what the scale factor should be on a NAV instrument after you decide what the NAV instrument should be. We did a lot of the work at Illinois in evaluating subjects for RNAV and I tell you we've run hundreds of subjects through flight simulators just to determine what the vertical and course deviation factors should be for RNAV. It's not an easy process, not the type of process which is easily supported by industry. It's certainly

the type of process that you want the standard result to come
out. We find that scale factors are acceptable within quite
a range but if every manufacturer came up with a different scale
factor, the poor general aviation pilot--many of whom don't know
the plane, rent a plane on weekends--would be at even more of a
disadvantage because not only now isn't he proficient in one
instrument, but he sits down and there's a completely different
instrument. If this isn't attempted by some industry group, or
by NASA providing seed money and basic research facilities, then
we'll have chaos. Imagine the case of a VOR, sold by manufacturers
who had different scale factors and different forms of instru-
ments; how useful would VOR systems be to the general aviation
pilot? Nil. Once an autopilot becomes more of a simple wing
leveler how easily can the person renting a plane, the casual
user, use an autopilot? And now you're talking about much more
sophisticated hardware, much more sophisticated displays. I say
the productive area is to achieve some uniformity and to achieve
what the pilot wants.

Another area, and it's really important, is the area of training.
We have no program for training pilots, no standard values of how
to train pilots in air navigation equipment. Pilots aren't
familiar with it. The saving grace of an ILS is that the ILS
approach is tied to a piece of cement. They know that the needles
are centered; there's a piece of cement in front of them. They
don't have to set up anything. RNAV is a little spooky. It's
not tied to anything. There's this transmitter which isn't really
connected with anything on the approach. You twist some dials,
and this black box, which they don't trust implicitly, and
shouldn't, says that they'll arrive at an airport. It's a scary
concept to many of them, and until that's adequately addressed,
and that's only through training, these sophisticated techniques
we're talking about won't work for the pilot. The pilot is still
going to want to have some cross check which he's familiar with.

Another area is the training of maintenance personnel. There's
no uniform way of training maintenance personnel, except how to
sew fabric or how to paint airplanes. As we become more and more
sophisticated, things are certainly going to fail and that's going
to have to be repaired by the people in the field. And the
standard problem right now with aviation is finding a person who
knows how to repair that box. And if we're not addressing that
area and providing the training for the people in the field in
terms that they can understand, then no matter what we decide.
it'll be a failure because the first time it fails in the field,
the thing won't be able to be repaired properly and all our work
will be for nought.

MR. MC RUER: Let's turn now to more general comments. Are there any points that we've missed?

MR. GORHAM: I think we've missed one point I mentioned earlier. We lightly glossed over the attitude sensor and said that we'd either use a rate gyro, and integrate, or use inertial platforms. It's my feeling that that's the weakest link still in the lower cost airplane. Some research on just improving basic attitude information is necessary. You obviously couldn't certificate unless you had the basic means of measuring attitude--whether it be a gyro or a second-order gyro or an inertial platform.

MR. SEACORD: I'd like to comment on the suggestion made by Mr. Hollaar on the software. I completely agree with his suggestion on the software development. You can take specific examples, and I'm familiar with two types of systems--autopilots (a little bit), and somewhat more recently, strapdown inertial navigations systems. The software is intimately connected with the algorithms and the iteration rates are intimately affected by the hardware being used. And you cannot design those things without knowing what gyro, what computer, or what airplane you use. For example, you can put out attitude at 10 per sec for one airplane and it's completely satisfactory. Or for another application, if you're going to mix it with MLS for that application you might have to have one rate; don't mix it, and it might be another rate. The software gets to be too much tied up with the applied details of the hardware. And also, I don't think software is as big a bugaboo as it's been made out to be, e.g., the complete software including the most extensive self-check development I know of was between 10 to 15 man years on a particular autopilot program. This included the complete failure modes, checking out, etc., while our hardware development was three times that. So software is not the overriding factor.

MR. HOLLAAR: What about the next time?

MR. SEACORD: Well, the next time I would say that the self-check methods that were developed would probably be applied, and take less time. That project was a completely fail-safe single auto-pilot, but it had to have 99% plus self-check capability in it; it had to be proved; and it was. The next time we do it the effort will probably be half of what it was. The hardware design will be just as great since somebody always wants a different size box. Also, in another two years there will be different components available. You start all over again every time.

MR. HOLLAAR: I want to say that I'm not proposing NASA write software for people, and I'm not proposing that if the algorithm can't be made specific, that it be made specific. But, if there are bounds, they should be indicated. People don't sit down and start from scratch and code square root routines;

there's no reason why people should start from scratch coding navigation and flight control routines. Your comment that if you design the software today, it'd probably take half the time, in part reinforces my case. What you're saying is that there's a tremendous premium in learning how to do it once. When it's been done once, then it's much easier. I'm saying that to help the industry, NASA can teach it the general rules for doing it once, and then from that time on, everyone's on the learning curve. And at that time, I agree, software won't be the bugaboo; it isn't for anyone with a great deal of experience.

MR. FRANKLIN: I'd like to ask a question in the area of reliability for a small aircraft. I rent one and I have some understanding of down time when an aircraft goes in a shop or gets fixed. I've wondered why aircrafts have to go down when it's radios are down? Why can't a replacement program be instituted? The radio goes out and another one comes in and you're on your way and the broken one goes back to the factory to be fixed. The answer I've gotten is that most of the problems are in the harnesses. But why aren't the harnesses standardized?

MR. MUCCI: We do a lot of modification installations and this means that we just don't put in a standard package; we put in whatever the customer wants. If he wants an RNAV, a sophisticated auto-pilot, he's going to have to get the harness that goes with it. Now you are talking about a small airplane which does more or less get a standardized package but still there's a variety and the number of harnesses and interfaces are tremendous.

MR. FRANKLIN: Well it seems to me we've spent a lot of time on far-out ideas here when aircraft utility is a real problem. Maybe it's not very glamorous but a lot of money's involved.

MR. HOLLAAR: I think one of the difficulties we see in harnesses aren't with the original factory equipment harness which are laid out in a controlled environment. The standard cycle of general aviation planes is that a guy buys something, and then a year later when he has another $600, he goes to his friendly neighborhood radio store and he gets something else installed and the harness is then played around with to get this next thing installed. That's where many of the harness difficulties come; not from a nicely planned harness by an original equipment manufacturer, but by a harness wired by someone crawling under the dash who did it the easiest way he could because his back was starting to hurt. That's where your harness problems are.

MR. BAIL: An interesting thing is happening here. We sell pre-built
harnesses but nobody buys them. What it amounts to is all those
shops take a great deal of pride in the way they do this. They
don't want to stuff in any store-bought harness. Their view is
just the opposite: the things they put in are better than those
that are put in by manufacturers. Now you go from that kind of
shop to a shop which does buy all the stuff because he either doesn't
want to fool with it or he doesn't have the capability. There are
a lot of owner-installed things too.

MR. MC RUER: Just to be sure we get something from everybody, George
Lucchi, would you like to give some comments?

MR. LUCCHI: Yes, we hear of a large proliferation on navigation systems
for the future such as OMEGA, inertial, LORAN, RNAV, Doppler, and
we hear about SATCOM. I would like to ask NASA if one of the studies
they might do is to review all of these systems and establish a
minimum system required for navigation for various missions. Unless
we address this one, we'll continue to talk about ILS which was
developed over 30 years ago. We're still using it. Are we going to
continue using it 5, 10, 15 years from now? I think that a system
study is needed to provide direction to us manufacturers. On what
should we concentrate for the new, most cost effective, mission-
oriented avionics of the future. So we need to know what to inte-
grate before we start.

DR. SMYTH: Wade Foy. Let's hear from you.

MR. FOY: I would like to advance one of my pet ideas since somebody
pointed out the drastic inefficiency of our current communication
system. I would like to propose that NASA undertake the study of
random access solutions for current communications systems. We
have techniques that involve pseudo-random codes, and things like
this that can provide random access. There are a number of good
theoretical solutions around studied in the military. I would like
to suggest this might be a possible solution to some of the diffi-
culties in the communications business.

DR. SMYTH: Any comments to Wade's thoughts about random access
communications?

QUESTION: Yes, I'd like to ask, what is it?

MR. FOY: The basic scheme is that instead of frequency channelized
communication, you provide what I think of as code channelization.
And there're enough codes around so that some digital process that
(everybody says doesn't cost anything anymore), can separate the
different codes. So you can call an individual airplane if you want
to; the airplane pilot can call the individual ground station he
wants, and there isn't any of this business, "Did he say 118.3 Mc,
or what?". In effect, it's a fast telephone system only you don't
have to dial, you just pick it up and call it.

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MR. MC RUER: I'd like to hit on one more point that's troubled
    me during a good deal of this conference. One gets the
    impression that many of the things NASA was told to do--are highly
    negative, and that general aviation avionics should simply continue
    on the way that it has, waiting for salvation from Detroit, which,
    one might point out, is in desperate need of self salvation in some
    ways right now. I find it difficult to believe we should wait for
    the automotive industry to solve our problems.

    I'd like to provoke some kind of a response from those of us
    involved in aviation on what I sense is almost a senile attitude
    on our part; that we're going to sit back and wait for somebody
    else to solve our unique problems, or better yet, to take leader-
    ship in a field, which is a major part of the aviation business.

MR. GORHAM: You put it better than I did. There's a kind of
    standing wave in technology and when you start a new airplane, you
    grab hold of as much as is sensible and run. And if that standing
    wave is small when you start a new airplane, you're not going to
    grab it at all. So I think the analogy is: don't let that wave
    keep moving ahead of us so much that there's a big gap in the
    middle.

DR. NOYCE: I feel that in general, innovation has typically gone
    on in areas where there hasn't been any control, and I'm a little
    afraid of working in an environment where we're trying to standar-
    dize, as was pointed out this morning. On the other hand, I'm
    also very much afraid we'll go off in all directions at once and
    we won't get enough effort concentrated in one area to get any
    advances. The point I was trying to make there was simply that
    you've got to have volume to get cost down, and cost seems to me
    to be really critical in the general aviation case.

MR. BAIL: I don't want to be misunderstood in what I'm trying
    to say. There is a role for NASA in the general aviation world.
    The role should be in inventing systems that permit architectures
    that are much less costly. Their role should not be trying to
    guide the equipment manufacturer in how to make less costly boxes
    that have functions that exist today. That's the differentiation
    I would try to make. The role perhaps should be (in participation
    with FAA studies) asking questions: is OMEGA the way to go 10 years
    from now? Does it really have the accuracy? There's where I see
    NASA's role. I don't see the NASA role in giving Bob money to
    develop the synthesizer, or an OMNI converter, or things of that
    sort. Don't read it as negative. There is basic research:
    systems design.

MR. SEACORD: I'd like to draw an analogy to another situation.
    The NACA did a tremendous amount of research on control circuits
    configuration. World War II came along and in spite of all their
    best efforts, forced the adoption of hydraulic controls. There was
    no other way to do it (for a lot of other reasons) but they ended

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by having hydraulic controls in airplanes. In the immediate post war picture, when they really got into the picture, there was a considerable lack of fundamental knowledge on how to design a hydraulic valve for a fast acting hydraulic servo, as far as generally applicable parametric studies. You could find people who swore you had to have a closed center valve; people who swore you had to have an opened center valve, underlapped or overlapped, and anything else you could think of. There wasn't any data. The military was forced; they went to hydraulic controls, and the various manufacturers blundered through; some of them blundered badly and some of them didn't blunder so badly. The equipment people in the hydraulics industry learned how to do those valves. It took a long time to get on commercial airplanes, even after it was already demonstrated to be a usable concept in the military. It was usable, it was expensive, it wasn't too reliable, and it was messy and several other things. It was an economic problem then; it wasn't a technical problem anymore. But there was one other decisive factor: it was the safety factor.

We see the same thing coming now. We talk about the use of flight control to handle critical flight modes in an unstable airplane. This has been done for some time in the military. I don't know when it'll ever be done commercially unless the government does something to sufficiently establish the reliability of that principle of control, not necessarily a detailed design. The air-craft operators made a comment on a study that NASA had made on the mass transport technology program. Their comments were to be on the use of this advanced technology. They said they would use it if you give us 50,000 operating hours of data that says we can safely fly an airplane that's unstable and maintain it. Until we have data of about that magnitude we will not buy an airplane like that. So, if fly-by-wire or CCV, for example, is going to be used short of 20 years from now, somebody in the government is going to have to put a lot of money into industry. And the same thing goes for all these other things.

I mentioned headup display. I certainly don't know whether any-body could ever build up a headup display that's cheap enough. I also don't know if that's the right way from the human standpoint. I think it is but I certainly don't know that. NASA is the perfect organization to examine first the human factors. They have the simulators and the aircraft, and they can determine if that's a good way or a bad way to land an airplane in whether. I think there is a place for NASA to work in the hardware realm but not in the detailed design for the final product.

DR. DE BRA: What we wanted to do at this point is to give you some flavor of the kind of summary we have in mind. As you see on the program, there's a lofty statement that we're going to do a Final Report preparation this afternoon. I hope you'll read between the lines; what actually will happen is Duane, Dick, Dallas, Mike and I will get together after lunch here and if any of you have a specific sentence or two that you just really feel ought to be in, we'd love to have you write it down so we can incorporate it. I'm going to read a couple of hundred words here that summarizes most of what we discussed yesterday, and I'm going to ask Dick to then add a hundred words or so on his Panel this morning. We would like to spend a few minutes here before lunch to get your feedback on the direction in which we're going. This is known as "making as big a target of yourself as possible".

General Aviation is a diverse market with product prices spanning about two orders of magnitude. This causes a wide range of models and types of equipment which keeps total numbers of any product small. However, general aviation has been aggressive in adopting new avionics technology through encouragement from the market field and the FAA--particularly for enhanced safety. The price constraints, low volume, and nature of the aircraft in which the avionics is mounted result in several problem areas. The most frequently mentioned are: reliability with heat, cost, weight, commonality, interfacing different manufacturers' components, and limits in panel space.

There is promise that with digital processing approaching negligible expense, avionics can overcome some of the problems by appropriate architecture and development. Sensors and displays appear to be the principal problem areas in information handling. Actuators are the needed area in control.

General aviation will have to depend on other large volume indus-tries for development of basic components. The development of inte-grated electronics has been the response to commercial markets. The electronic market potential of the automobile industry is more than one billion dollars. The watch and calculator industries have been pushing display technology although the cathode ray tube remains the least expensive for a high resolution, general purpose display. The commercial and military aircraft fields have done all things that are feasible with a few exceptions (e.g., develop-ments in fluidics) but the technology is not likely to be within acceptable costs for most of the general aviation aircraft. So, in general, general aviation will continue to depend on commercial main stream technology and shouldn't develop special purpose LSI.

A significant effect of changing sensor technology is that they can be thought of as another "chip" (e.g., the Si technology pressure transducer). Becoming part of the Si technology development can lead to small size and power, and major improvement in reliability. If incorporated into the electronics, we may not have to measure each state directly but may find an "attitude component" replacing the D.G., turn and bank, artificial horizon, etc., in which filtering will take advantage of the physics of the aircraft to infer some states from measurements of others. Special areas of interest are displays, heat pipes, and gyros.

NASA could contribute

(1) in developing algorithms
(2) ideas on architecture
(3) establishing system requirements
(4) establishing effective test methods
(5) provide seed money for certain types of sensors, but, in general,
(6) should not become involved in the development of hardware.

DR. SMYTH: Just going through my notes from the Panel this morning. Already the pressures of free enterprise have produced products using some of the advanced technology we've been talking about. A number of our panel members shared their experiences in developing sophisticated systems for commercial aircraft from which we can distill some messages.

(1) Improving navigation capability seems to be a common consensus.

(2) Reducing the pilot workload was a key element that came out of the discussions.

(3) Requirements for good status information on the whole situation--not only navigation, but fuel, and range to go, etc.

(4) There were some disagreements and controversy regarding software development and whether it should or should not be sponsored by NASA. I think that's still a good question open for discussion.

(5) It was pointed out that the use of such things as data busses in the avionic system can give single point failure modes which would wipe out everything.

(6) I thought Buster Seacord did a nice job of summarizing some of the new functions we need, and how these vary with the complexity of the aircraft. He noted a requirement for flight management, for flat surface displays, CRTs, and RNAV, even for the lower category aircraft. He also cited the need for microwave landing systems, which may reflect his recent assignments in that area.

(SMYTH Cont)

(7) Woven through all these comments were the beneficial aspects of functional redundancy, and I think that any-body configuring a system right now would retain functional redundancy in any systems architectures they'd come up with.

(8) I thought John Bail had some very good points--one of which was the allowance of evolutionary change. We may need revolutions in certain areas, but not overall.

(9) The question of what new functions we really need must be addressed. There are some areas that could be improved.

(10) Navigation status information which is clear and easy to understand is vital.

(11) Fuel and range reserves that can be presented in a clear, unambiguous fashion is necessary. I think one of the kinds of problems the general aviation pilot has that the air-line pilot doesn't have as much is that he does have limited range. He's also operating at a speed regime where wind can have a large impact on range. If he could have some aids to tell him whether he could overfly the intended fuel spot and go a bit further, or whether he's going to have to land sooner, he could perhaps save an hour or so on a 4 or 5 hour flight, and also do it safer.

These are some of the functions and problems that pilots in general aviation don't have right now.

DR. DE BRA: Again, please let us know what you think has been omitted or what you'd like to see included. We'd be even happier if you'd jot down a sentence right now and leave it with us.

COMMENT: I'm just a little concerned. I know there's a lot of people here who make autopilots, and I hear a lot about the possibilities of taking the workload off the pilot by letting the airplane fly itself. I'd feel a little uncomfortable with that, maybe because I learned to fly 20 years ago. It seems to me that maybe we ought to think more seriously about the problem of relieving the pilot of his workload by minimizing the communications rigmarole that he goes through; e.g., minimize the problems of monitoring that he has to do, and let him devote more of his time to literally being pilot in command and flying the airplane. When worse comes to worst, functional redundancy that leaves the pilot in command seems to me to be the best solution. And I would just like to throw that out as a general philosophical consideration: to what extent do we want to leave the pilot, the final link, in control of the airplane, and is it reasonable to talk about reducing work-load by simply taking away from him the command of his airplane?

DR. SMYTH: I would say the biggest problem in control for the general
     aviation aircraft is directional control. You look away from the
     flight instruments for 30 seconds and you change heading by 30 deg.
     To me, that's a problem.

DR. NOYCE: The reason we're most often turning away from the instru-
     ment panel is to tune the radios or to look at a chart. So if
     you could get that out of the way, you could leave the pilot flying
     the airplane.

DR. SMYTH: The kinds of systems we're talking about would certainly
     alleviate that problem.

DR. NOYCE: One thought that came up while we were talking about the
     dual RNAV of the Boeing airplane was, were the total number of bits
     in that machine on the order of a megabit or a megabyte?

REPLY: That was only the data storage.

DR. NOYCE: Yes, but I would just like to point out that that's about
     one flex disk, so that you could put your entire airways manual
     on one flex disk. That means that you can save weight because you
     can leave 20 lbs of equipment at home.

MR SEACORD: Concerning airplane flying problems, I don't think there's
     any attempt to take the control away from the pilot, but rather to
     make the airplane easier to control.

MR. LUCCHI: What are the possibilities of having completely "eyes off"
     control of the airplane, all the instruments, all of the functions,
     and having the capability of merely reaching over there and feel
     something, and touch it? Choose the right heading without having
     to look at the instrument, only looking outside; knowing you've
     got the right lever; knowing you've done the right thing without
     having to look at it.

MR. GORHAM: Work has been done in this area. The L-1011 and the 747
     had a lot of attention paid to shapes. You couldn't inadvertantly
     go to one close to it; it would be squares vs round.

MR. HOLLAAR: We shouldn't accept as an article of faith that automation
     of communications will make it simpler or take any less of the
     pilot's time. You can talk to just about any air traffic controller
     in a center who's just gone through automation and now doesn't
     have to work those ugly flight strips and plastic board, but has
     alphanumeric readout and ask him what he feels it did to his time.
     By and large, he'll tell you it's more cumbersome for him now than

it was before. Flight strips seemed easier for him. Maybe it's a
training problem; maybe it's that he hasn's completely accepted
this new type of device.

DR. DE BRA: Any other comments? I suggest we continue those comments
at lunch but before we break, Dallas and I would both like to thank
you very much for all your help and participation.

DR. DENERY: Yes, I want to say a few words before you leave. First
of all, I want to thank everybody for coming. I know you all have
a very heavy schedule and I really appreciate your participation.

I want to reemphasize the intent of the Workshop. When I gave
the opening comments during the Program Overview, I indicated that
the General Aviation-Advanced Avionics Systems Program was princi-
pally looking at two things:

(1) Ways for improving the functional capability, such as
     improved NAV algorithms, flight control systems, and
     ways of reducing a pilot's workload;

(2) The other is how to implement these ideas in avionics hardware,
     the emphasis being on the utilization of new technology
     and systems integration.

It was towards the latter that this Workshop has really been directed.
Based on what I've heard, the consensus is that NASA should support
basic research in these areas, but should exercise extreme caution
so that it doesn't get into near-term product development. We
share your concern and recognize the possibility of falling into
the trap of product development unless we are careful and work
closely with industry. The purpose of the Workshop is to assist
us in defining areas where NASA could provide meaningful research.
Therefore, I would like to ask that you not consider the Workshop
as ending now. If you have any thoughts as to where NASA should
be concentrating its research effort--what that level of far-out-
ness is so that it's not ridiculous, but is also not product devel-
opement, I'd appreciate your comments, either on the phone or what-
ever. Finally, again, I'd like to say "thank you".

DR. TASHKER: I, too, would like to thank you all. We hope to have the
proceedings of this Workshop back to you soon.