SOME SYSTEM CONSIDERATIONS IN CONFIGURING A DIGITAL FLIGHT CONTROL – NAVIGATION SYSTEM

J. H. Boone and G. R. Flynn
Boeing Commercial Airplane Company

SUMMARY

A trade study has been conducted with the objective of providing a technical guideline for selection of the most appropriate computer technology for the Automatic Flight Control System of a civil subsonic jet transport.

The trade study considers aspects of using either an analog, incremental type special purpose computer or a general purpose computer to perform critical autopilot computation functions. It also considers aspects of integration of non-critical autopilot and autothrottle modes into the computer performing the critical autoland functions, as compared to the federation of the non-critical modes into either a separate computer or with a R-Nav computer.

The study is accomplished by establishing the relative advantages and/or risks associated with each of the computer configurations.

INTRODUCTION

To justify an investigation of the impact of introducing a new technology into an existing commercial field, two considerations must be ascertained:

1. The motivation behind seeking new technology, and
2. The real advantages to be gained by introducing a particular technology.

Automatic Flight Control systems of civil jet transports have reached the stage of seeking a newer electronic technology. Digital control systems are the candidates.

The purpose of this paper is to describe a method of conducting the background trade studies to define the risks and advantages of a technological change. Although the application of the method is illustrated in terms of civil aircraft, the principles are basic and are applicable in many different areas of industry.

MOTIVATIONS

The analog automatic flight control systems installed on civil jet transports represent significant contribution to the overall cost of development to the airframe manufacturer. In the most recent aircraft, the wide bodied jumbo jets, the automatic flight control systems (AFCS) accounted for development and certification monies ranging from $10,000,000 to $30,000,000 (1969 to 1970 dollars). On the average, the production costs of the wide-bodied jets' AFCS are $300,000.

Cost of ownership has also become substantial, considering that airlines maintenance figures show an annual maintenance cost of 1.5¢/$100 of initial system cost. That amounts to $4500 annually, or $90,000 over the normal life span of the aircraft.

In general, such high costs have been incurred because of increased performance and safety requirements. A particular point is the general requirement for automatic landing systems, resulting in increased redundancy in the sensors, computers, and actuators of the AFCS.

Technological advances in the analog art, in terms of computer architecture and electronic component packaging, have managed to keep costs under reasonable control. For example, considering only the AFCS electronics, a dual-pitch simplex monitored roll configuration of 1966 vintage costs the same as a total duplex pitch-roll system developed in 1969. This is in spite of the fact that the latter system has approximately 40% greater capability due to redundancy and increased operational requirements.

However, the situation doesn't appear to be stable. That is, advancement of analog state-of-the-art isn't sufficient to maintain an adequate margin against further total cost increase for future airplanes. One possible solution is to change the system technology from analog to digital to provide a more competitive condition in meeting yet higher performance and safety requirements.

Substantial investigation and development has been conducted with digital flight control systems (DFCS). However, the accumulated data and conclusions are not directly transferable to civil transports because the greatest majority of the programs have been militarily oriented. The result is that the basic ground rules of development rely on calculated risk levels for safety, performance, and costs which could not be justified for commercial aircraft.

Therefore, any attempt to realistically judge the attendent risks and advantages of developing a commercial DFCS stumbles over the absence of hard trade data. "Absolute" data is available for analog systems because of comprehensive, empirical do's - dont's derived from past experience. Such data are not available for commercially feasible DFCS.

A reasonable comparison - or trade study - methodology can be developed in the absence of "absolute" data by establishing a relative comparison referenced to a known quantity. In the present case, the known quantity is represented by an analog AFCS design in which there is a high level of confidence that it will comply with a significant requirement; the high level of confidence resulting from the absolute data embodied in established design techniques and practical experience.

The reference system can then be arranged in terms of known risk parameters. A comparison of each risk parameter, individually with a counterpart parameter of a DFCS, can be conducted in a relative sense to determine the increment of risk incurred with the DFCS (a negative increment spotlights an advantage). In effect, a sort of chain rule is established which allows evaluation of the newer technology system in known and understood terms of the older technology system.

IDENTIFICATION OF REAL ADVANTAGES

In order to arrange and select appropriate risk parameters, it is necessary to identify the risk points of the analog AFCS. A general survey of latest generation analog systems will result in the following conclusions:

1. Computational Accuracy

   Operational amplifier techniques have reduced computational tolerances to levels between 2 and 5%. However, considering the total AFCS - i.e., sensors, guidance signals, actuators, as well as the computers - further reduction of computational tolerances loses significance in view of the tolerances and inaccuracies of the sensors, guidance signals, etc., which typically range between 8 and 20%.

2. Reliability

   Design and packaging techniques have resulted in analog AFCS computers with mean time between failures of thousands of hours. Manufacturer warranties of 3000-4000 hours are not uncommon. However, with system-wide MTBF's of 200-300 hours, it can be seen that the computers' contribution to system railure rates is relatively insignificant. Therefore, substantial design activity to further increase computer reliability will not pay off proportionately in overall system reliability.

   Another aspect of system relaibility is its availability - a direct function of the system owner's ability to maintain the system. In this respect, analog systems have been shown by experience to be deficient.

   Build-in-test-equipment (BITE) is generally provided in all modern analog equipment. However, each test feature, being itself analog, requires additional circuitry dedicated to testing only. The increased complexity generated by BITE motivates the designer to restrict BITE to within the individual computer. System-wide tests are prohibitive.

   The end result is that fault isolation - to indicate appropriate maintenance activity - within the computer is relatively efficient (about 86% in the 747). But the "system effectiveness", defined as

$$\left[\frac{\text{CONFIRMED FAILURES}}{\text{TOTAL COMPONENT REMOVALS}}\right] \times 100\%,$$

   ranges between 20 and 50%. Thus, more than half the owners maintenance actvities are inappropriate.

3. Redundancy Requirements

Within the scope of commercial jet transports, existing and imminent, redundant systems have relatively little application outside of yaw damping (simple stability augmentation) and automatic landing. More exotic requirements - flight critical modal suppression or control configured vehicles stability systems - are anticipated to be well beyond the next generation of civil aircraft.

Consequently, analog technology has been successfully applied to existing redundancy requirements since 1966.

4. General Cost Considerations

Each new generation of aircraft is accompanied by a redesign of the analog AFCS. Invariably the redesign is necessary to incorporate newer packaging techniques to maintain reliability and reduce costs. In effect, the AFCS is tailor-made.

Peripheral costs are induced by the tailoring. Test equipment, technician training, etc., must be revised each time an airline re-equips.

The general conclusions are that an effective comparison between a digital and analog AFCS must be parameterized to show substantial advantages in terms of system maintainability and costs. Structuring the trade to prove that a digital system is as good as an analog system, or to high-light relatively insignificant advantages will not provide the supporting data necessary to introduce digital technology into commercial AFCS service.

Therefore, selection of risk parameters associated with maintainability on a systems basis, and cost reduction (particularly through reasonable integration of system functions) will provide the most effective trade study.

PRELIMINARY SELECTION OF CANDIDATE SYSTEMS

Systems can be examined under two aspects, viz, 1) organization, 2) level of redundancy. These factors interact to some extent, but generally speaking, system organization is the more fundamental factor. Accordingly, candidate systems are initially selected by consideration of alternate system organizations.

A variety of system organizations are available once the decision to employ digital technology has been made. Potential candidate systems range between the extremes of a central computer that performs all electronic computation, (total integration) to a one-for-one replacement of analog LRU's (Line Replaceable Units) with digital LRU's. The number of potential system candidates must be reduced to make detailed trade studies between alternate systems feasible.

The extremes, or limiting cases, in the type of system organization may be disposed of by general considerations. For example, the one-for-one replacement of analog computing LRU's by digital elements obviously negates the advantage of time shared digital computing elements in addition to proliferating I/O requirements. Plainly, it offers no advantages in the present application. Indeed, to the authors' knowledge, it has never seriously been proposed as a viable digital flight control system and it is mentioned and disposed of here for the sake of logical completeness.

The other limiting case - total integration, wherein a number of disparate computations such as air data, navigation, cruise autopilot, etc., are performed in one computer - has been seriously proposed for a number of applications. From certain aspects this is an attractive candidate. Specifically, such a system organization yields the minimum number of LRU's, minimizes interface complexity and simplifies system test. Nevertheless, this arrangement must also be rejected as inappropriate for the application under study.

The rejection is based on a consideration of the significance of various computations that would be performed in a central computer. Some of these computations are dispatch critical; i.e., the computations must be available if the airplane is to be dispatched. Air data computations are an example of computations that fall in this category. Other computations, such as cruise autopilot modes or autoland are not necessary for dispatch. It is highly desirable from an airline point of view, that a "deferred maintenance" policy be employed to the extent possible. That is, airlines desire to be able to defer maintenance action until such action is convenient from the standpoint of airplane schedule or location. The integration of dispatch critical and nondispatch critical functions in a common computer is not compatible with a deferred maintenance policy. Furthermore, reliability of the dispatch critical computations will suffer from piece part considerations alone. It should be noted that for some applications, such as an RPV, where all computations are required for mission success, total integration might be the logical choice for system organization.

There still remains a large number of potential candidate systems even after the limiting cases have been rejected. The rationale for further reduction to several candidates most promising for detailed trade studies is based on classifying the functions and assessing the redundancy requirements. These are shown in Table 1.

Examination of Table 1 reveals that there are only two functions that are classified as flight critical; Category III Autoland and Yaw Damping. Both of these functions are accordingly assigned a fail-operational redundancy requirement. There is a significant difference in these two computations however, since the yaw damping function is assumed necessary for high altitude and high Mach number flight (normal cruise envelope). Therefore, an operational yaw damper is required for unrestricted dispatch. The redundancy requirement for this function results from the requirement to maintain artificial yaw damping until a speed-altitude reduction can be effected.

In contrast, the autoland function is flight critical only during those times that Category III conditions prevail; in addition, this function is not required for dispatch. The economic penalty for the nonavailability of the yaw damping function is consequently much more severe than the penalty for the nonavailability of Category III autoland.

TABLE 1

FUNCTION	CLASSIFICATION	REDUNDANCY REQUIREMENT
CATEGORY III AUTOLAND	FLIGHT CRITICAL	FAIL OPERATIONAL
AUTOTHROTTLE	NON-CRITICAL	NONE
CRUISE AUTOPILOT MODES	NON-CRITICAL	NONE
YAW DAMPER	FLIGHT CRITICAL AT HIGH MACH & ALTITUDE; REQUIRED FOR UNRESTRICTED DISPATCH	FAIL OPERATIONAL
NAVIGATION	NON-CRITICAL[1]	NONE
FLIGHT DIRECTOR	NON-CRITICAL	NONE

The remaining functions are seen to be classified as non-critical and similar in redundancy requirements. A logical candidate for further study is consequently obtained by structuring the system on the basis of a critical/non-critical division of functions. This results in a system wherein fail safe functions are performed in dual Nav/Flight Control computers and the flight critical autoland is performed in a triplex computer arrangement. In the following discussion this system structure is designated as a "Federated System".

Another candidate system (Integrated System) is obtained by performing all autopilot and autothrottle functions, regardless of criticality, in a set of triply redundant computers and navigation functions in separate computers.

[1] Subsequent to 1980 this classification may change to dispatch critical with a minimum redundancy requirement of fail-op, but without a requirement for graceful degradation of capability after first failure.

Based on the previous discussion, three system configurations are developed (Figures 1 through 3). The analog computer arrangement in Figure 1 provides the "reference" for established technology. It should be noted that this particular arrangement shown is not presently in service. Rather, it is a logical evolution of system arrangement based on current requirements, and represents the level of technical risk acceptable if a change in electronic technology - to digital - were not also under consideration. (To attempt the trade study using systems technology of, say, 1969, would insert a definite bias factor which could unrealistically effect the conclusions.)

Two types of digital computer technology are considered: General Purpose (GP) and Incremental (ICP). The latter shares many of the characteristics of analog machines; accordingly, similar system architecture (Figure 1) is postulated for systems employing these machines. The similar characteristics make it possible to treat the analog and the incremental systems as synonymous except for software development and control.

Application of the general purpose digital computers to the AFCS are illustrated in Figures 2 and 3. These configurations were selected to provide comparative evaluation of significant design considerations while minimizing unnecessary system variables. Figure 2 represents an integrated autopilot system which provides the greatest feasible reduction of equipment and interface complexity. Figure 3 represents a system arrangement which provides greatest possible isolation of flight critical modes to reduce the risks of failure modes compromising system safety requirements.

The selection of these three candidate systems thus provides a means of evaluating contrasting major design factors, that is:

1. Direct evaluation of digital (General Purpose or Incremental) vs. analog technology by consideration of Figure 1 versus Figure 3;

2. Direct evaluation of the impact of substantial integration by consideration of Figure 2 versus Figure 3; and

3. Direct evaluation of maximum feasible benefits of the digital approach by consideration of Figure 1 versus Figure 2.

After selecting the basic candidate systems, major variations within a system configuration may also be considered, as shown by comparing the federated DFCS illustraded in Figures 3 and 4. The effect of including variations will be to provide a band of merit in the eventual study results. Such a band of merit provides a means of further assessing the sensitivity of system risks/advantage to configuration.

TRADE STUDY METHODOLOGY

The identification of key parameters is fundamental in conducting trade studies. Two sets of parameters were identified to evaluate the alternate systems, viz: "System Parameters" and "Trade Parameters".

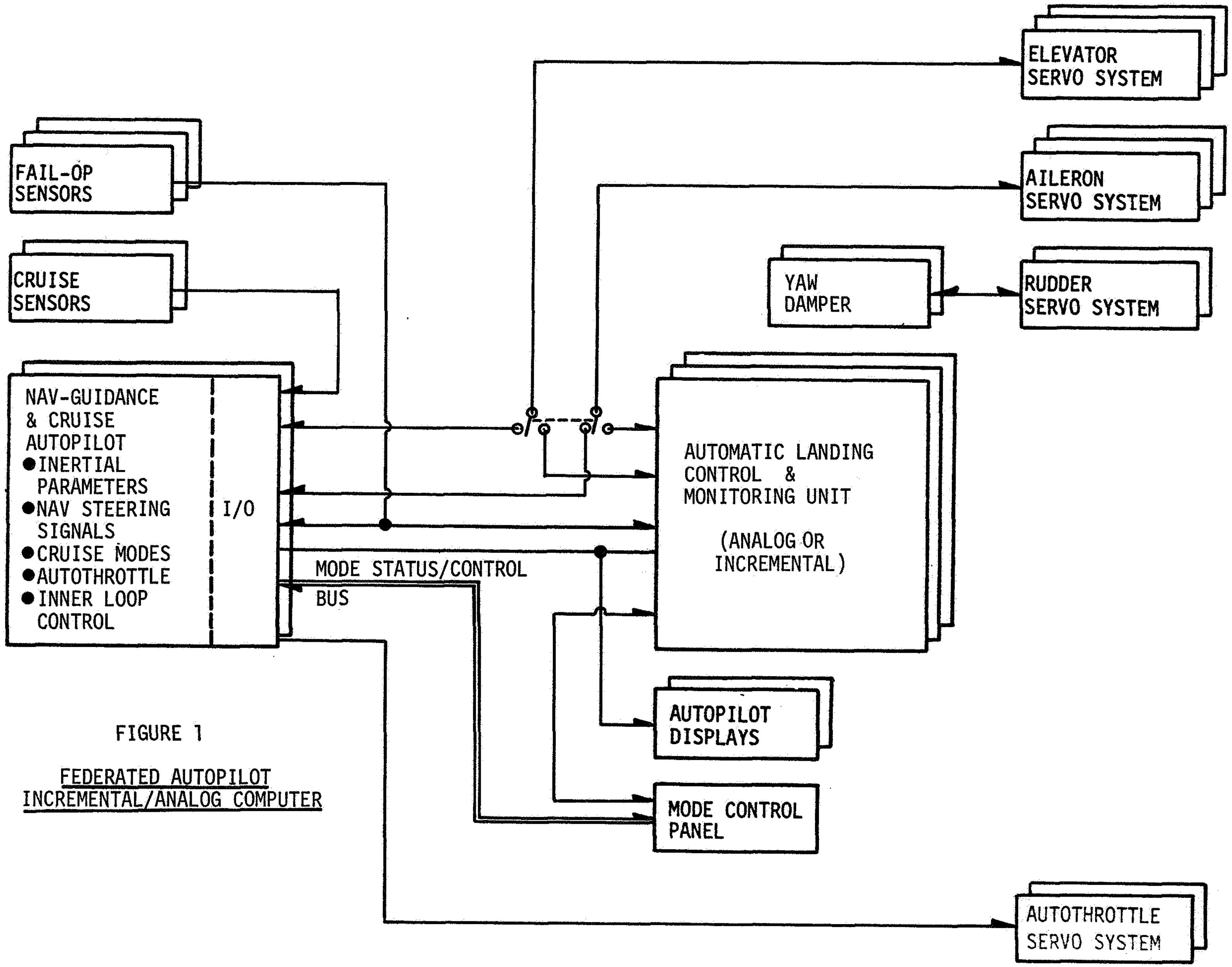

FIGURE 1

FEDERATED AUTOPILOT
INCREMENTAL/ANALOG COMPUTER

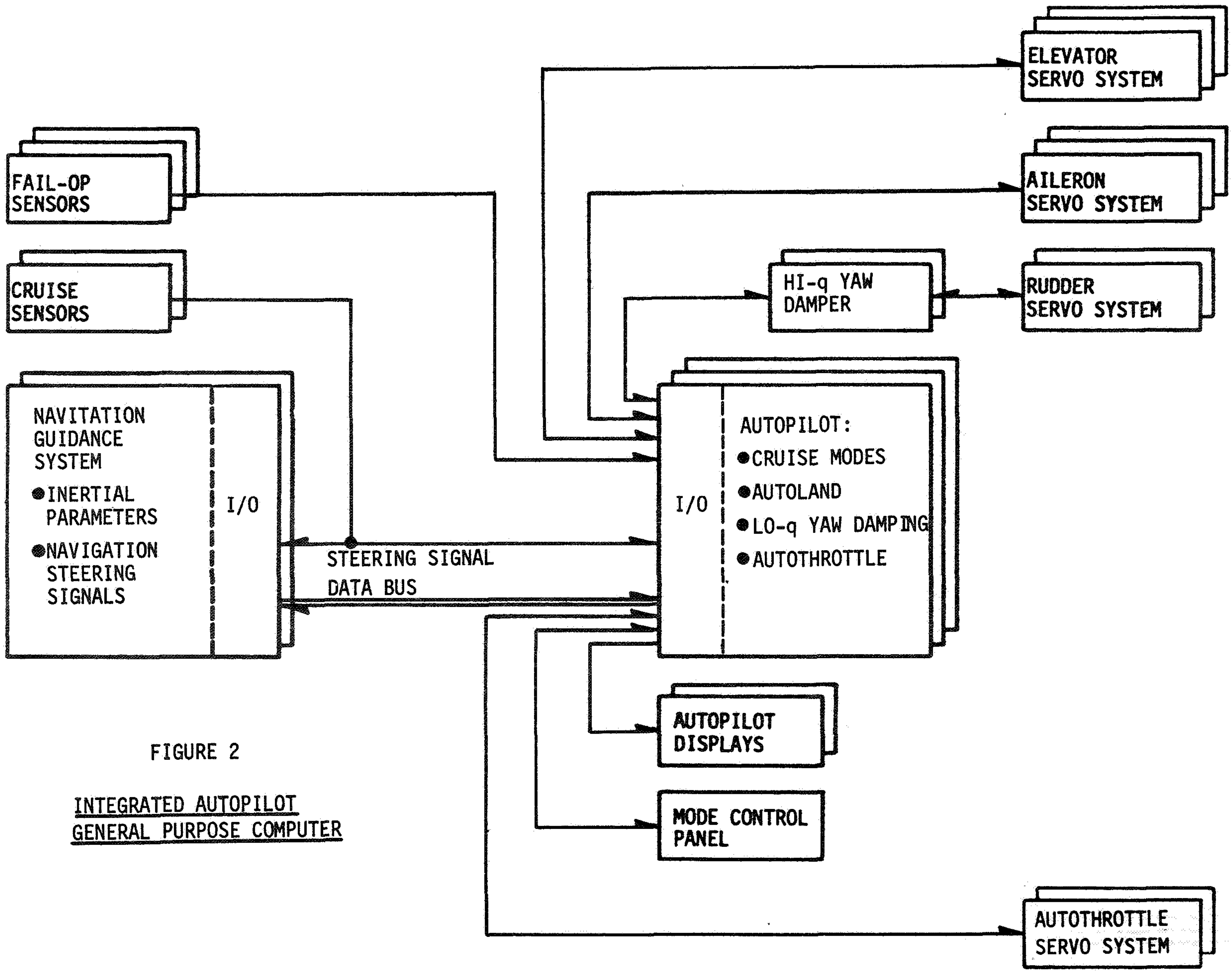

FIGURE 2

INTEGRATED AUTOPILOT
GENERAL PURPOSE COMPUTER

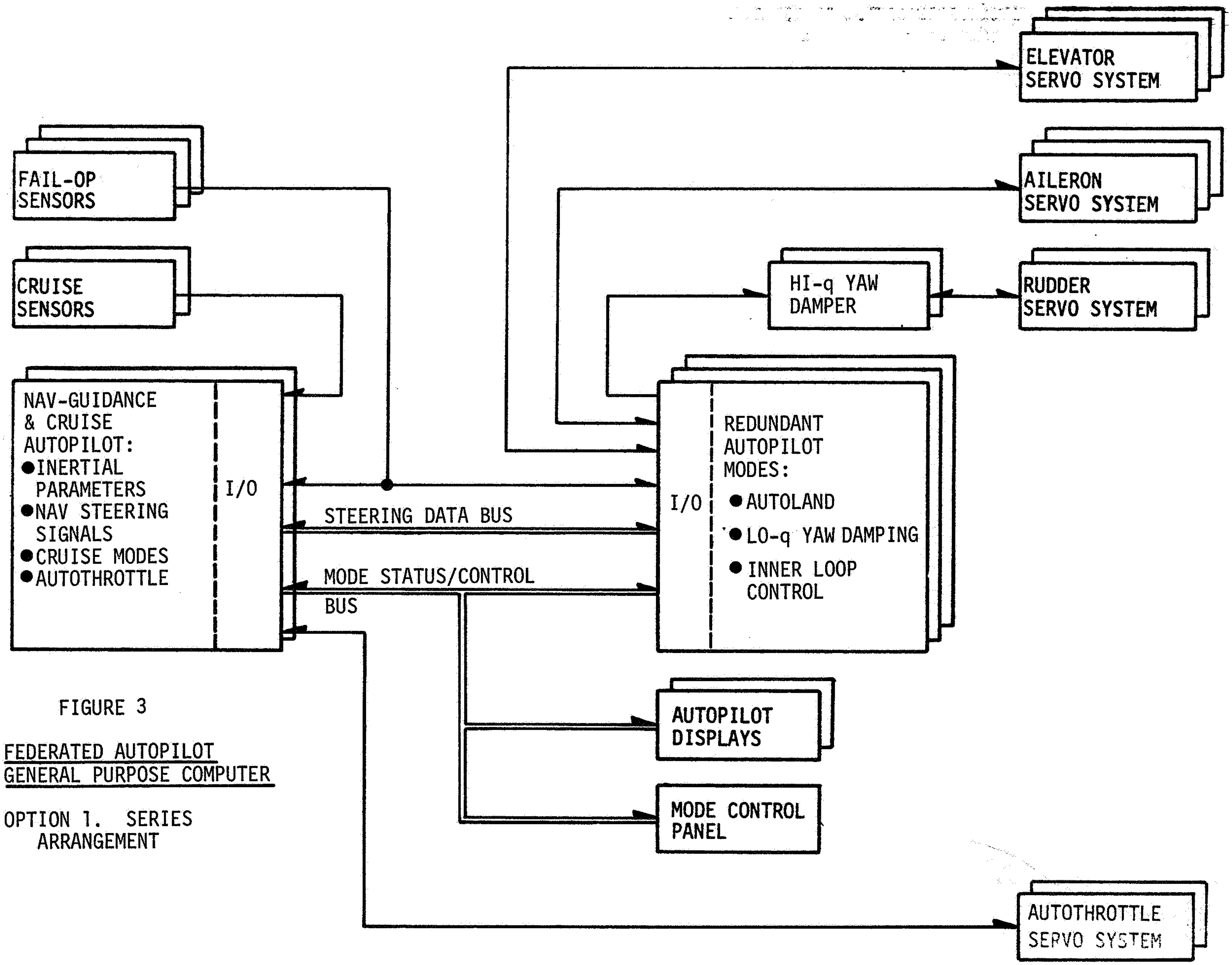

FIGURE 3

FEDERATED AUTOPILOT
GENERAL PURPOSE COMPUTER

OPTION 1. SERIES
ARRANGEMENT

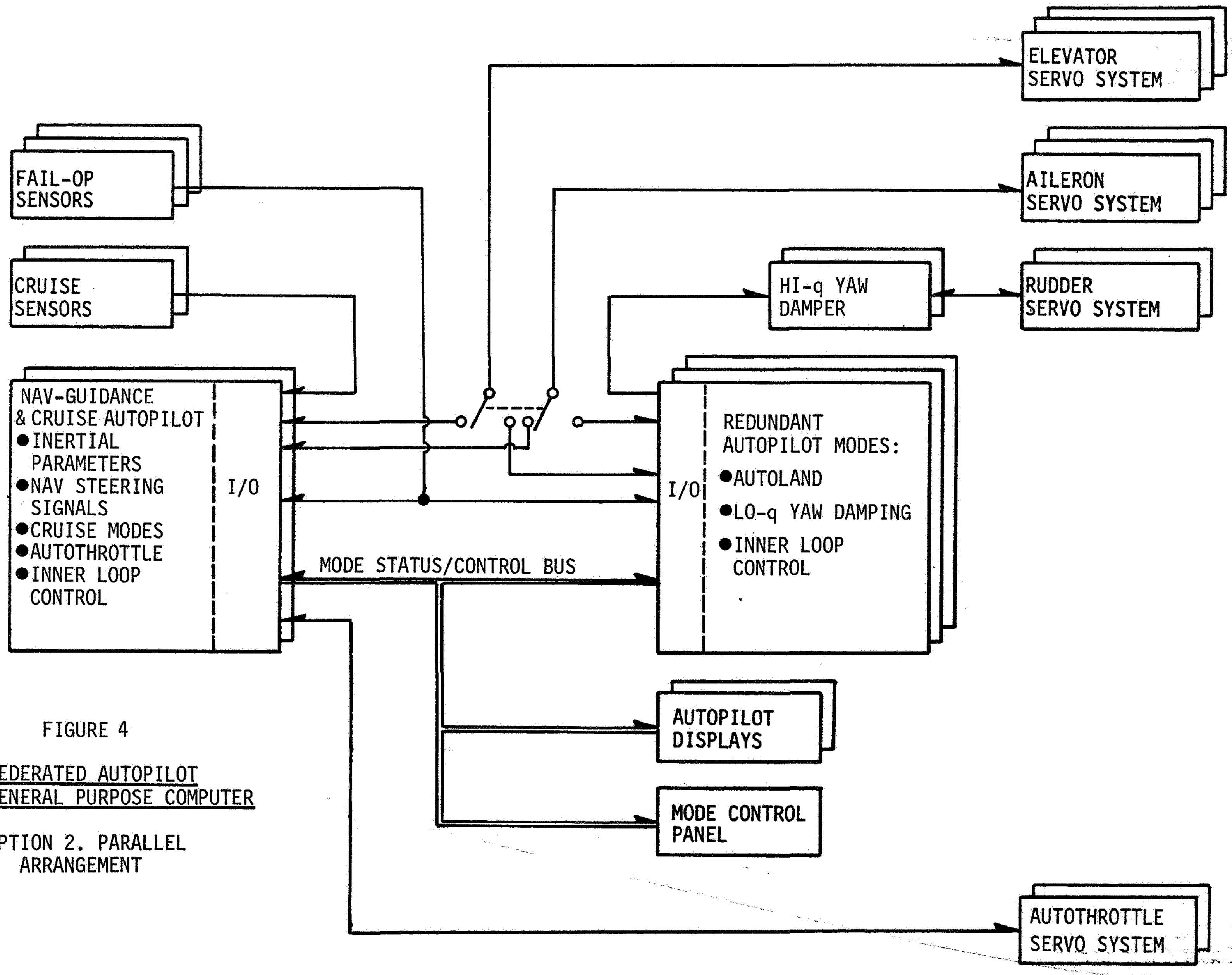

FIGURE 4

FEDERATED AUTOPILOT
GENERAL PURPOSE COMPUTER

OPTION 2. PARALLEL
ARRANGEMENT

Trade Parameters were selected to use as a basis of comparison between major features of each system. The major features were designated as System Parameters. Trade Parameters are weighted according to a Relative Advantage/Risk Factor rationale. System Parameters are weighted in accordance with their relative importance to the overall makeup of the system. System Parameters along with their weighting (relative importance factors) are given in Table II.

TABLE II

SYSTEM PARAMETER	RELATIVE IMPORTANCE FACTOR
Software Development, Verification and Control	1.0
I/O Equipment	1.0
System Test	0.7
Sensor Signal Selection and Fault Detection	0.6
Mode Logic and Interlocks	0.5
Interties	0.5
Processor & Memory Sizing	0.2
Control Law Implementation	0.1

Trade Parameters are defined as follows:

Reliability	The impact which the System Parameter under consideration has on the system integrity, operational availability and ability to meet safety requirements (autoland and dispatch critical functions).
Testability	The requirements imposed on system test in terms of hardware/software by the System Parameter being evaluated.
Monitorability	The requirements (in terms of hardware, software and engineering development) to provide failure detection for those elements of the System Parameter being evaluated.
Maintainability	The impact on system fault isolation to the LRU level.

Growth Capability	The ability of the particular parameter to accommodate growth due to expanded system requirements, or improvements.
Cost	The impact of the parameter on system cost in terms of hardware requirements and/or engineering development cost.

Trade Parameter weightings are given in Table III.

TABLE III

RELATIVE ADVANTAGE	RELATIVE RISK	WEIGHTING FACTOR
Definite Advantage		2
Probable Advantage		1
No Advantage	No Risk	0
	Minor Risk	-1
	Moderate Risk	-2
	Severe Risk	-3

It will be noted that the weighting system is balanced at "definite advantage" vs. "moderate risk". Hence, a severe risk will negatively influence a definite advantage making it less desirable.

Detailed definition of the descriptive terms of Table III are given in Table IV.

The manner in which the System Parameter/Trade Parameter weighting factors are combined is shown schematically in Figure 5. A comparison across the systems under study, for a given System Parameter is used to select the Advantage/Risk weighting factor or score. Engineering judgement enters, of course, into selecting the Advantage/Risk score. However, two factors work to minimize purely subjective influences. First, a careful choice of System Parameters will isolate the most significant aspects of the system structure; likewise the choice of Trade Parameters displays those features or system characteristics that are regarded as significant in choosing between competing systems. Thus on this level, tacit assumptions are either exposed or rendered nugatory. Secondly, the Advantage/Risk scores are selected only after detailed comparative studies of the System Parameters under the aspect of the Trade Parameters are made. Again, this procedure works to minimize the influence of subjective factors. In addition, the procedure isolates any relatively high risk items in the system configuration that is finally selected

TABLE IV

DESCRIPTIVE TERM	DEFINITION
Definite Advantage	A feature that has, through past experience, been demonstrated to be a definite advantage to the airplane system or design task in terms of: Performance simple design task, desing validation, customer acceptance.
Probable Advantage	Feature may result in a sugnificant improvement; or extentent of improvement is minor; or anticipated benefits are based on extrapolation of similar experience in non-related applications.
No risk	Feature has been successfully applied in past commercial airplanes; or feature has been successfully applied in similar situations without difficulty.
Minor Risk	Has been a problem in past applications, but satisfactory solutions were found; or has not been applied before, but current evidence shows that it can be done without difficulty; or associated problems are defined and solutions are available.
Moderate Risk	Has been a problem in past applications and solutions were difficult to achieve; or depends on a new feature with only limited substantiation in practive (i.e. Lab, etc.): or no specific well defined solutions are currently available although the problem is well defined.
Severe Risk	Has been a failure or near failure in past applications; or depends on a new, unsubstantiated feature; or may require radical system redesign if solution is deemed unacceptable; or problems are not clearly defined.

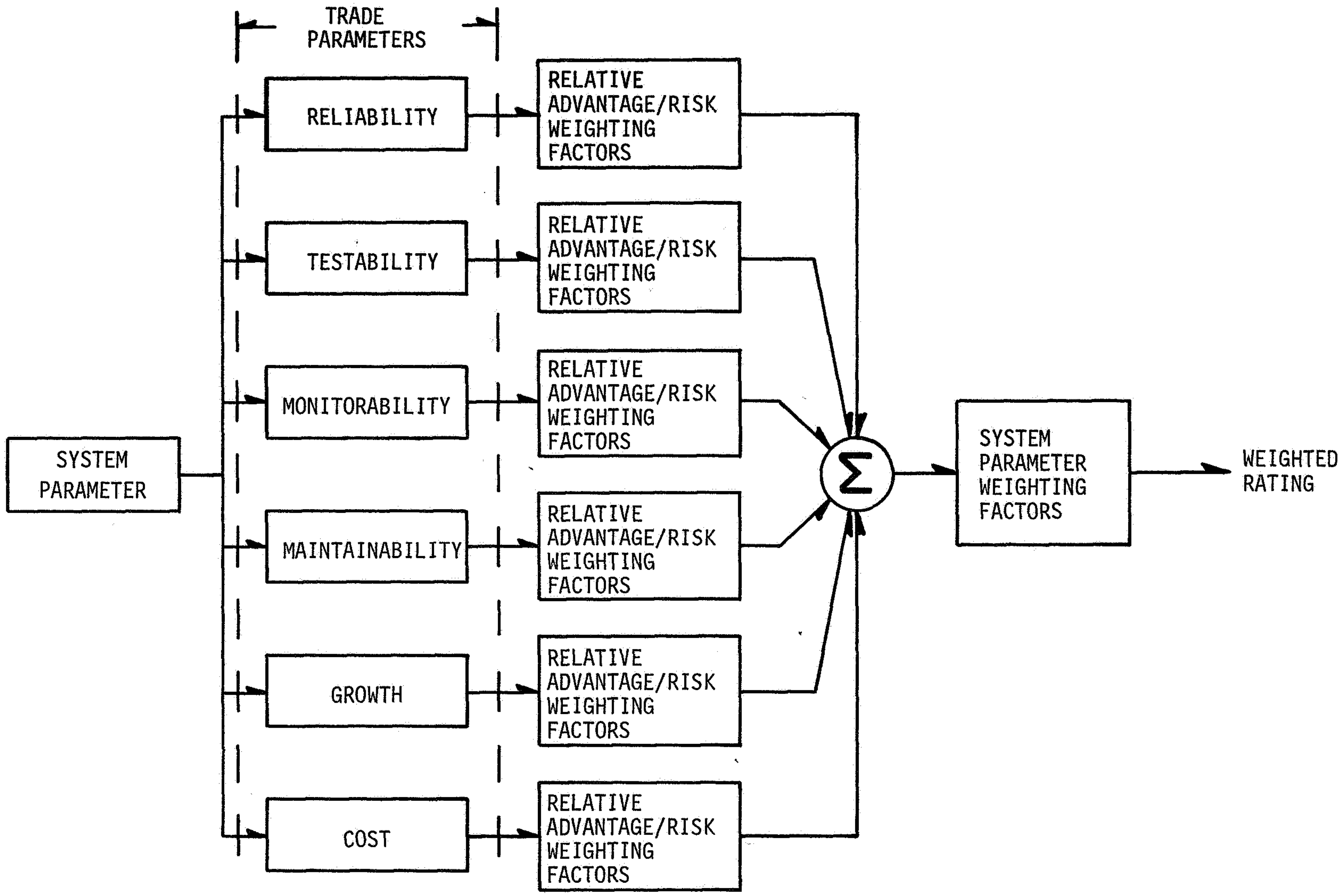

FIGURE 5
TRADE STUDY STRUCTURE

and consequently it serves to focus design efforts on critical items.

A typical example of this procedure taken from a recent trade study is given in the Appendix.

STUDY RESULTS

Application of the above methodology to the systems of Figures 1, 2, 3, and 4 yields the data of Figure 6. Summing the weighted rating of this figure for the various system parameters gives the following overall figure of merit for the systems shown in Figure 7.

The choice of an analog or incremental system is not warranted because of the negative overall ralative rating. The lack of relative advantages for these systems are a function of the nature of the computers. Specifically, they perform only a part of the automatic flight control system tasks, namely control law calculations. The remainder of the tasks - self tests, mode logic, etc. - must be performed by additional, external means.

The figure of merit indicates that the integrated system has the greatest overall potential. However, by reviewing the results for each of the system parameters as displayed in Figure 6, it can be seen that a potentially high level of risk is associated with software development and control. This clearly indicates that a major follow-on effort is necessary to resolve the issue and reduce the risk.

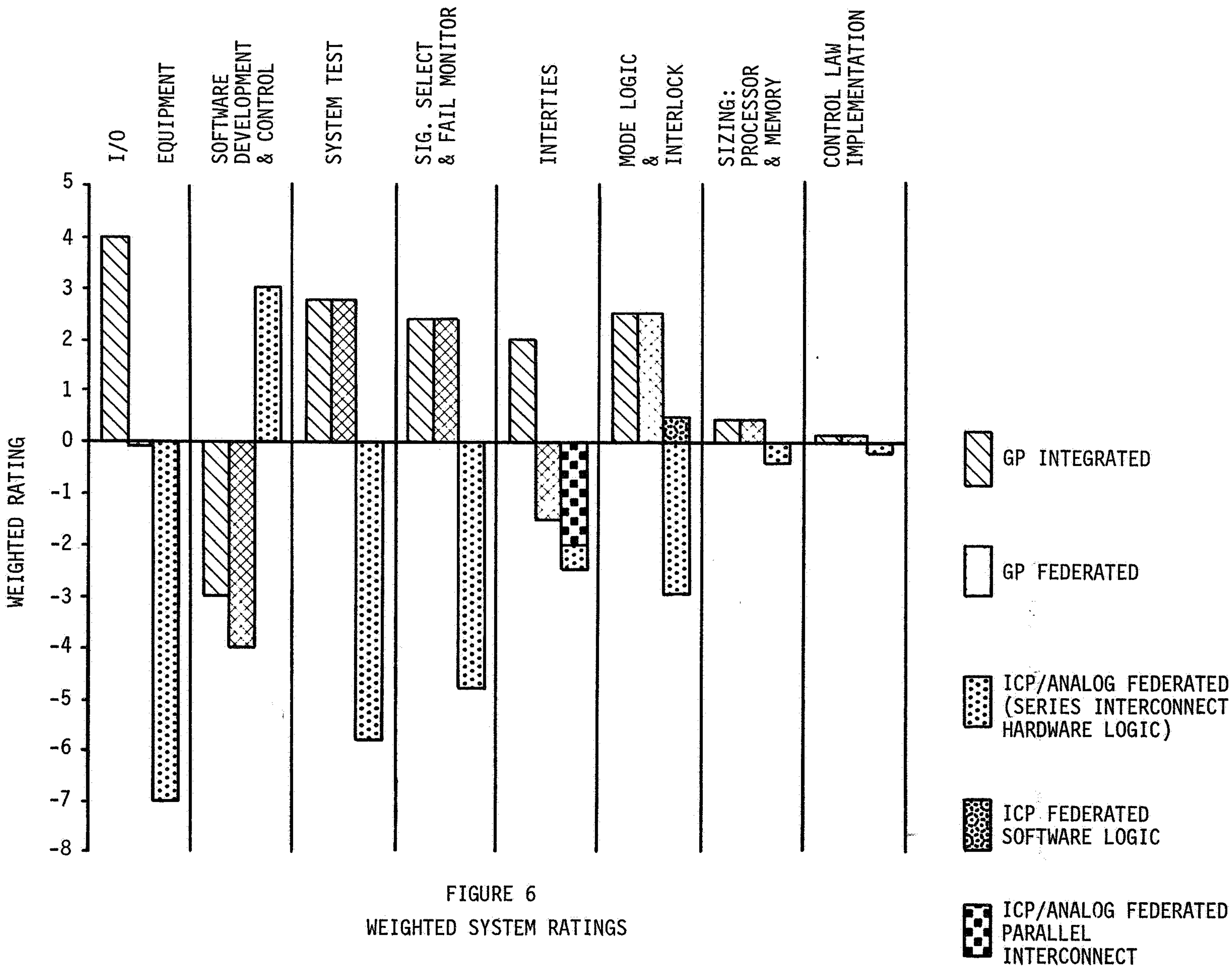

FIGURE 6
WEIGHTED SYSTEM RATINGS

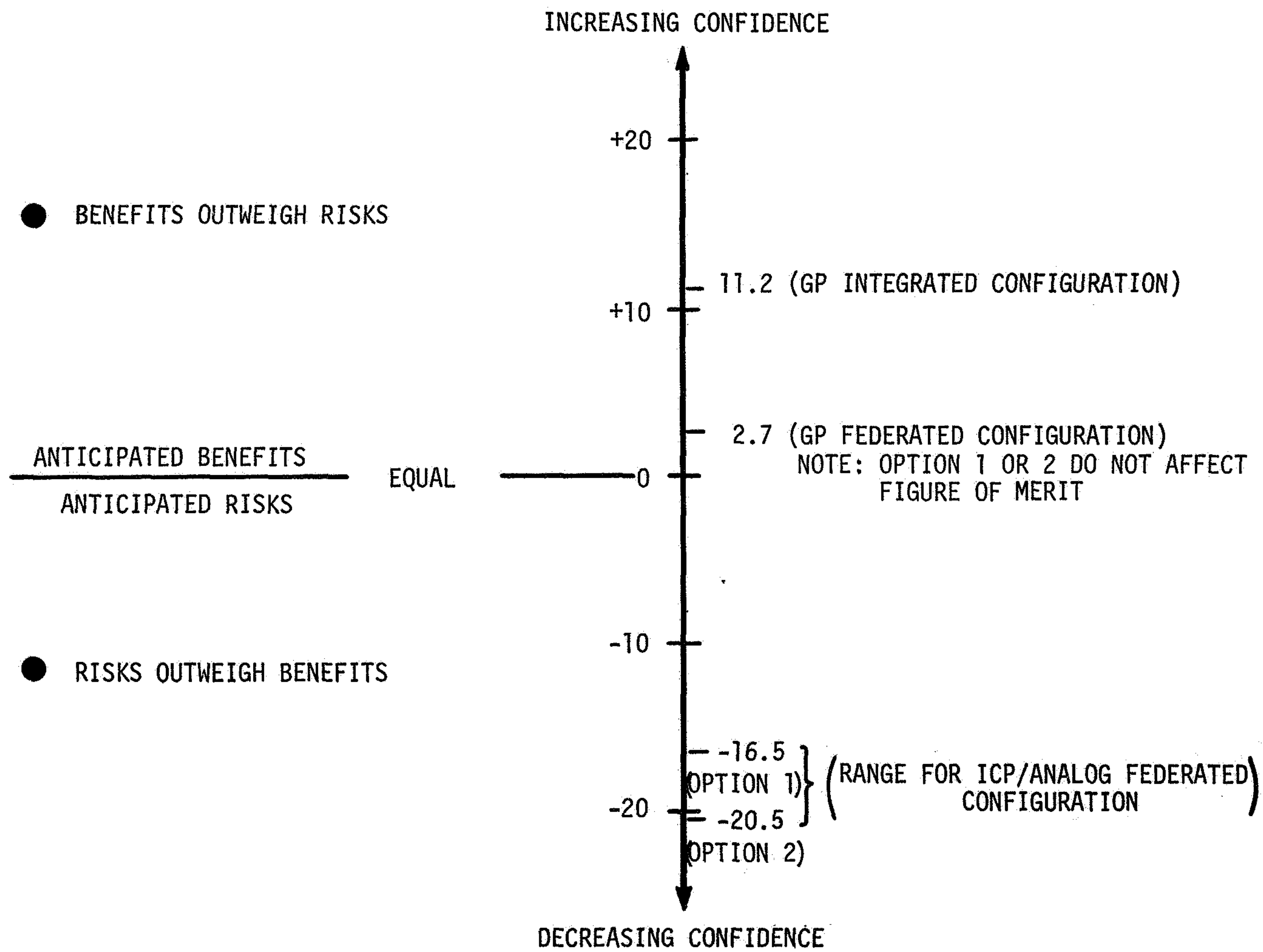

FIGURE 7

RELATIVE MERIT FIGURES

UNCLASSIFIED RISK OR ADVANTAGES

Certain aspects are important in the final selection of a system which are not readily quantifiable, such as vendor support, commonality of equipment, customer choices, ARINC implications, or organizational aspects. The fact that the ICP computer is available from a single source would seem to be a risk with regards to the above consideration since by selecting that architecture one would effectively select the supplier. Customer choices and ARINC implications tend to increase the risk incurred by including the non-critical autopilot and autothrottle functions in the R-NAV computer.

Commonality in the various computers used in the airplane would benefit the customer by reducing his maintenance and possibly inventory costs.

The advances in the digital computer hardware state-of-the-art, through large scale integration and improved semi-conductor devices, reduces cost while increasing computational capacity as well as increasing predicted reliability by reducing the number of interconnections within the computer. However, there is the risk incurred in the early stages of application of new technology.

Failure modes effect and criticality analyses (FMECA) present an area of severe risk for digital systems. The risk is in terms of assessing the effort required to do the FMECA and the probable success achievable. Results of the studies done in the "DOT/SST follow-on" program indicate that any attempt at a FMECA according to the traditional approach may be a gargantuan task even with computer aided evaluations. Similarly, contact with vendors have not revealed any clear methodology for performing a thorough FMECA of digital computers.

Further study is required to assess the FMECA bounds that must be attained to meet certification requirements with a digital autopilot.

The FMECA risk may be alleviated by system design such that the safety is assured by "isolated" simple monitoring devices which are amenable to a thorough FMECA.

With regards to the relative comparison of the ICP and GP computers there is no appreciable difference in the FMECA risk.

CONCLUSIONS

Interpretation of the results of a "relative merit" trade study - such as previously described - can be made only within the frameowrk of level of confidence. One system configuration which rates relatively lower than another cannot be concluded as infeasible. Rather, the confidence of achieving the desired advantages is less than the confidence associated with the higher rates system.

The results of a relative merit trade study, carefully performed, can provide quantified conclusions which clearly indicate the best engineering solution for the system architecture. Also, weakness of the chosen system are identified in such a manner as to indicate the degree of urgency for follow-on engineering efforts to reinforce the weak points.

Having made relative comparisons against a known quantity (in this case, the established technology), reasonable predictions can be formed in terms of the actual engineering effort required to introduce the newer technology.

ACKNOWLEDGEMENT

The contributions of Maximus Leone and Enrico Cavatorta are gratefully acknowledged.

REFERENCES

1. "The Implications of the Developing Technology in the 1970's", technical paper presented by T.A. Wilson to AER Tatal,Dublin, April 17, 1969

2. Wilkinson, K.G., "Automatic Landing in BEA's Trident Operations - A Review of Effort and Achievement", Second Sir Geoffery De Havilland Memorial Lecture, 16 April 1969

3. AIAA Paper 70-1032, "A Practical Solution to Automatic Landings Using Digital Flight Control Computers", H. Tobie and K. Ramby

4. Onken, R., et al, "Digital Fly-by-Wire Control System with Self-diagnosing Failure Detection", Technical Paper presented at Guidance and Control Panel Seventeenth Symposium, 24-26 September 1972, Geilo, Norway

5. Sklaroff, J. R., et al, "Redundant System Design for Advanced Digital Flight Control", AHS paper No. 721, presented at American Helicopter Society Annual National Forum, Washington ,D.C., May 9-11, 1973

6. Contract No. DOT-FA72WA-2893, SST Technology Follow-On

7. Minutes of Airline Maintenance Conference, Spring Conference, Minneapolis, Minnesota, April 21-24, 1974

8. Koudela, John Jr., "The Past, Present, and Future of Minicomputers", Proceedings of the IEEE, Vol. 61, No. 11, November 1973

9. Harrison, Thomas J., and Thomas J. Pierce, "System Integrity in Small Real-time Computers", Paper presented at National Computer Conference, 1973

10. Trainor, W. Lynn, "Software - From Satan to Saviour", Technical Paper, NAECON - '73 Record

11. "Software and Its Impact: A Quantitative Assessment", Boehm, Barry W., Datamation, May 1973, pps 48-59

APPENDIX

The following considerations are typical of the judgement required to assess the risk or advantage increments between candidate systems for a given parameter.

The system parameter discussed in this appendix is typical of the various parameters which must all be considered to complete the study. For the example described in this paper, there were eight major parameters identified.

I. INPUT/OUTPUT STAGE

GENERAL NOTES

1. General Purpose Computer Configurations

All interfaces for incoming and outgoing signals are accomplished within the I/O stage.

Incoming signals are individually conditioned in dedicated signal-conditioning circuits. Two multiplexing units are required, one each for critical and non-critical analog signals. The output of each MUX goes through common time gating circuits and a single A/D converter, then into a parallel-load/serial-output buffer register.

Digital inputs are loaded into their respective buffer registers preparatory to being gated into the computer memory for storage. The A/D converter buffer register, and the digital input buffer registers are gated as serial data into the computer by a common gating circuit.

This arrangement is necessary to allow card-level isolation between critical and non-critical signals. Common circuitry is always downstream of adequate buffering.

The output signals generated by the computer are treated in a similar fashion, i.e., a single D/A conversion followed by individual signal conditioning as required.

Servo amplifiers for elevator and aileron position servos are included as part of the I/O stage.

The high speed yaw dampers are independent analog systems comprising control law calculation, engage and disengage control, and servo loop electronics in a package separate from the AFCS computer. However, low speed (flaps down) yaw damping is augmented by turn coordination and yaw damping control generated within the AFCS computer. Channels A and B provide the upper and lower yaw damper augmentation respectively. Channel C's augmentation may be used for monitoring purposes and as a switchable hot-spare for either, upper or lower yaw damper.

1. General Purpose Computer Configurations (continued)

The I/O stage also includes an interface between the generated autothrottle commands and the autothrottle (dual) servos. In a similar arrangement to the yaw damper augmentation signals, channel C serves as a monitoring function and switchable hot spare for autothrottle control.

2. Analog Computer Configuration

The description of the analog "I/O" essentially follows that given in Note 1, with the following exceptions:

a. Obvious deletion of MUX requirements.

b. "Brickwall" configuration, i.e., federated configuration does not include interface mixing of critical and non-critical signals. Only critical signals are routed into the analog computer.

c. All yaw damping functions are eliminated from the analog computer as illustrated in Figure 1.

A COMPARISON OF ALTERNATIVE FLIGHT CONTROL COMPUTER CONFIGURATIONS

INTEGRATED GP

INPUT/OUTPUT

The integrated I/O comprises the functions described above and is integrally packaged with the computer. (A minor risk in the possibility that computer volume will dictate separating the I/O stage into a separate package requiring some additional effort to build, test, and install the I/O).

As discussed in other sections, mode logic, monitoring, self test capability, and such, are functions resident in the computer itself. Therefore, the integrated configuration represents the least complex I/O of the three configurations under study.

FEDERATED GP

INPUT/OUTPUT

Separating the non-critical from the critical functions has only a moderate impact on the I/O stage associated with the critical computer. The signal input is cut approximately in half materially reducing the dedicated signal conditioning circuits. Output functions are reduced only by elimination of autothrottle servo interface. The resulting reduction in I/O stage electronic complexity is somewhat offset by the continuing requirement for an integrated self test of the AFCS for maintenance purposes. That is, additional self test program control discretes will be required to interface between the critical system I/O and the non-critical system. The net effect, however, is a general decrease in complexity of the critical I/O stage which is a definite advantage when certification and certification-documentation requirements are considered.

The trade off must also consider the impact of locating non-critical functions and their associated interface requirements in a host machine (such as the RNAV) or in completely separate packaging. In either case, substantial additional equipment must be located where it otherwise wouldn't exist. The result is a moderate risk in terms of cost, reliability, and flexibility (growth) of the overall system but with no particular advantage accruing from the separation. Additionally, it might be expected that the separation will further complicate management and

FEDERATED ICP/ANALOG

INPUT/OUTPUT

ICP

This I/O stage follows the same description as for the general purpose integrated and federated configurations and also includes the following notable increases in hardware complexity:

a) Sensor Signal Select and fault detection circuitry

b) Discrete logic voter and monitor

c) Mode logic

d) Hardware required for System Self Test

These additional functions, assumed to be resident in the software of the general purpose machine, will be performed by dedicated hardware in this configuration. That hardware may take the form of a specially made whole word machine, or a combination of whole word computation and solid state switching mode logic (similar to that employed by contemporary autopilot systems). In either event, this represents equipment/circuitry yet to be developed and thus is considered as a moderate risk in terms of reliability, monitorability, testability, and growth capability.

Further, the I/O state is to be separately packaged from the computer resulting in an estimated moderate cost risk.

A COMPARISON OF ALTERNATIVE FLIGHT CONTROL COMPUTER CONFIGURATIONS

INTEGRATED GP	FEDERATED GP	FEDERATED ICP/ANALOG
	conduct of the required self testing leading to an assessment of minor risk.	ANALOG The assessment of the analog interface generally follows that of the ICP except as qualified by General Note 2. Also, the analog interface does not include signal sensor selection. This decrease in complexity is not reflected in terms of significant circuit reduction however. Therefore, the overall assessment remains similar to that of the ICP, i.e., moderate risk in terms of reliability, monitorability, and testability. Growth capability is very difficult to achieve, therefore it represents a severe risk. The interface is inherently integrated with the analog system, thus costs are predictable. Consequently, no risk can be established here. However, no significant advantage is identified either.