

Utility System Characterization, an Overview

RATIONALE

AIR5428 has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE:

Modern air vehicles consist of many subsystems, traditionally managed as a federation of independent subsystems. Advances in control technologies, digital electronics and electro-mechanical hardware, provide potential opportunities to integrate subsystems for future aircraft. This document does not define any particular integration strategy. Its purpose is to provide information about traditional federated subsystems from the functional, control, resource, and hardware perspective. To be able to integrate subsystems, one must have a basic understanding of the subsystems, and this document provides an introduction or starting point for initiating the integration process.

The focus is on the aircraft subsystems, which includes utility, flight and propulsion control (e.g., electric power, environmental control subsystem (ECS), fuel, etc.) The depth of the information intends to provide an introduction to the subsystems. Trade studies must be performed to maximize the potential benefits of integration. Although this document introduces technical issues, business arrangements must also be addressed.

This document consists of six sections.

- Section 1 introduces the scope of this document.
- Section 2 introduces the references and acronyms of this document.
- Section 3 introduces the content of this documents appendix.
- Section 4 discusses the typical development approach and considerations for integrating the traditional subsystems.
- Section 5 briefly discusses the integration technology trend.
- Section 6 suggests an approach to design of integrated subsystems.

2. REFERENCES:

2.1 Applicable Documents:

Joint Service Specification Guides (JSSG)

AGARD Report Number 343, "Integrated Vehicle Management Systems"

2.2 Acronyms:

θ	Pitch Attitude
ϕ	Roll Attitude
ψ	Heading
ΔP	Differential Pressure
q	Pitch Rate
AC	Alternating Current
AMAD	Aircraft Mounted Accessory Drive
AOA	(α) Angle of Attack
AOS	(β) Angle of Side slip
APB	Auxiliary Power Breakers
APS	Auxiliary Power System
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio, Inc.
ATS	Air Turbine Starter
BIT	Built-In Test
BITE	Built-In Test Equipment
BTB	Bus Tie Breakers
CAD/AM	Computer Aided Design/And Manufacturing
CAS	Control Augmentation System
CASE	Computer Aided Systems Engineering
CPU	Central Processor Unit
DC	Direct Current
DDV	Direct Drive Valve
ECAE	Electrical Computer Aided Engineering
ECL	Emitter Coupled Logic
ECS	Environmental Control Subsystem
EED	Electro-explosive Device
EGT	Exhaust Gas Temperature
EHA	Electro-Hydraulic Actuator
EHV	Electro-Hydrostatic Valve
EICAS	Engine Indication & Crew Alerting System
EP	External Power
EPS	Electric Power System
EPU	Emergency Power Unit
FBW	Fly-By-Wire
FADEC	Full Authority Digital Electronic Control
FCS	Flight Control System
FPS	Fire Protection System
GCB	Generator Circuit Breaker
GCU	Generator Control Unit
GND	Ground
HMG	Hydraulic Motor Generator
HX	Heat Exchanger

2.2 (Continued):

ICAWS	Integrated Caution Advisory Wiring System
ICECS	Integrated Closed Environmental Control Subsystem
IDG	Integrated Drive Generator
IGV	Inlet Guide Vane
JFS	Jet Fuel Starter
LCC	Life Cycle Cost
LGS	Landing Gear System
LRU	Line Replaceable Unit
LVDT	Linear Variable Differential Transformer
MES	Main Engine Start
MPU	Magnetic Pickup Unit
NBC	Nuclear Biological Chemical
N_x	Longitudinal Acceleration
N_y	Lateral Acceleration
N_z	Normal Acceleration
OAT	Outside Air Temperature or On Aircraft Test
OBIGS	On-Board Inerting Gas System
OBOGS	On-Board Oxygen Generating System
p	Roll Rate
PAO	Polyalphaolefin
PLA	Power Lever Angle
PM	Permanent Magnet
PMA	Permanent Magnet Alternator
PMG	Permanent Magnet Generator
POR	Point of Regulation
PSI	Pounds Square Inch
PWM	Pulse Width Modulation
r	Yaw Rate
RAT	Ram Air Turbine
RCCB	Remote Controlled Circuit Breaker
RDC	Remote Data Control
RIU	Remote Interface Unit
RPC	Remote Power Controller
RPM	Revolutions Per Minute
RTCA	Radio Technical Commission for Aeronautics
RTD	Resistive Temperature Device
RVDT	Rotary Variable Differential Transformer
SAE	Society Automotive Engineers
SAS	Stability Augmentation System
SOF	Safety of Flight
SOV	Shutoff Valve
SSPC	Solid-State Power Controller
TF/TA	Terrain Following / Terrain Avoidance
T/M Bus	Test / Maintenance Bus

2.2 (Continued):

TRU	Transformer Rectifier Unit
VAC	Volts Alternating Current
VCS	Vapor Cycle System
VDC	Volts Direct Current
VMS	Vehicle Management System
VSCF	Variable Speed, Constant Frequency
WOW	Weight On Wheels

3. SUBSYSTEM CHARACTERIZATION:

This document provides an overview of several systems. Each system is shown in an individual appendix, which contains several sets of figures to characterize the aircraft subsystems. These figures provide a broad perspective and general understanding of the various subsystems, to facilitate the identification of potential integration opportunities. Since the requirements for the subsystems are highly dependent upon the aircraft, it would be difficult to document all the specific requirements. Therefore, much of the information provided is in general terms. For each subsystem, there is a dedicated appendix, which provides a Functional Overview, System Block Diagram, Signal Inputs, Internal Actuators, External Actuators and Bandwidth Requirements. The following describes the content in each appendix:

- Functional Overview (Figure x1; where x is the appendix letter) - This is a top-level view of the subsystem. At the center of the chart is a general functional description that defines the typical scope and purpose of the subsystem. The inputs and outputs shown on these charts consist of five areas:
 1. Signal Inputs and Signal Outputs - These are the I/O interfaces from other aircraft subsystems necessary to operate appendix x subsystem, or to communicate its operating status.
 2. Physical Inputs - Consist of inputs that will be either operated on or transformed to produce the required output of the subsystem (e.g., shaft-input power converted to electric power). This output may also be necessary to power or operate the subsystem (e.g., electric power, cooling oil/air).
 3. Physical Outputs - These show the required output of the subsystem and and/or byproduct.
 4. System Dedicated Sensor and Actuators - This information identifies the I/Os within and managed by the subsystem.
- Block Diagram (Figure x2) - For each subsystem a block diagram describing the components within the subsystem, and their interconnections. A short write-up is provided for each subsystem block diagram.

3. (Continued):

- Signal Input (Table x3) and Signal Output (Table x4) provide information about each subsystems I/O interface:
 1. What are the Signal Types - They are analog, data bus or discrete inputs. Signal types are vehicle dependent, resulting in one type of signal input for one aircraft, and may be a different interface for the next aircraft type.
 2. Criticality of the I/O Signal - The definition of criticality here is not the same as in flight critical systems, rather, the importance of the signal to the function of the subsystem. A high criticality means that the subsystem can not function without this I/O signal. A medium criticality implies that losing the signal results in degraded subsystem performance (or that a back up I/O signal must be available). Finally, a low criticality suggests that losing such an I/O signal will not affect the subsystem performance (e.g., a subsystem status indication signal.)
 3. Application or Use - Applications can be classified into three areas, and the I/O signals may be used for multiple purposes. The first application is for control or subsystem reconfiguration (failure mode accommodation). The second application is for built-in-test (BIT) or status (e.g., operating state such as ready to load, etc.) The last application area is for information for post-flight maintenance and performance monitoring.
- Internal Actuators (Table x5) - Internal Actuators, are those I/O provided as a part of the subsystem hardware. This table shows the characteristics of the drive interface to the subsystems internal actuators.
- Internal Sensors (Table x6) - This general information shows the types of sensor provided as a part of the subsystem, the typical sensing ranges, and the signal interface from the sensor to the subsystem Control Unit (in many cases, the control unit is mounted remotely from the mechanical hardware).

Control Channel Bandwidth (Table x7) - This table provides an overview of the typical control, protection and communication loops as well as their typical signal or control bandwidth (update rates may be 5 to 10 times the control bandwidth). This table only lists those items that require electronic controls (using hardware and/or software). Items not listed in these charts are those for control or protections that are implemented using mechanical, hydraulic or pneumatic techniques.

4. TRADITIONAL MANAGEMENT OF SUBSYSTEM DEVELOPMENT:

In the past, the individual subsystem was usually developed independent of other aircraft subsystems. This approach provides the required subsystem level fault tolerance and robustness such that problems or faults in one subsystem do not easily migrate or manifest themselves into others. For example, corrupted sensor signals only impact the subsystem connected to those sensors.

An aircraft is not designed as a single component, or defined as a single item. Rather, a top-level design objective is specified, and then details are added as the supporting components are identified. Partitioning the aircraft development into various subsystems lends itself to facilitate management of a complex system. The work progresses from one level of abstraction to another level by adding system details as requirement flow down to the subsystems. The results of the above approach divide the original design problems into manageable units. Figure 1 presents these concepts in a typical development process. The following sections discuss each of the major blocks within Figure 1.

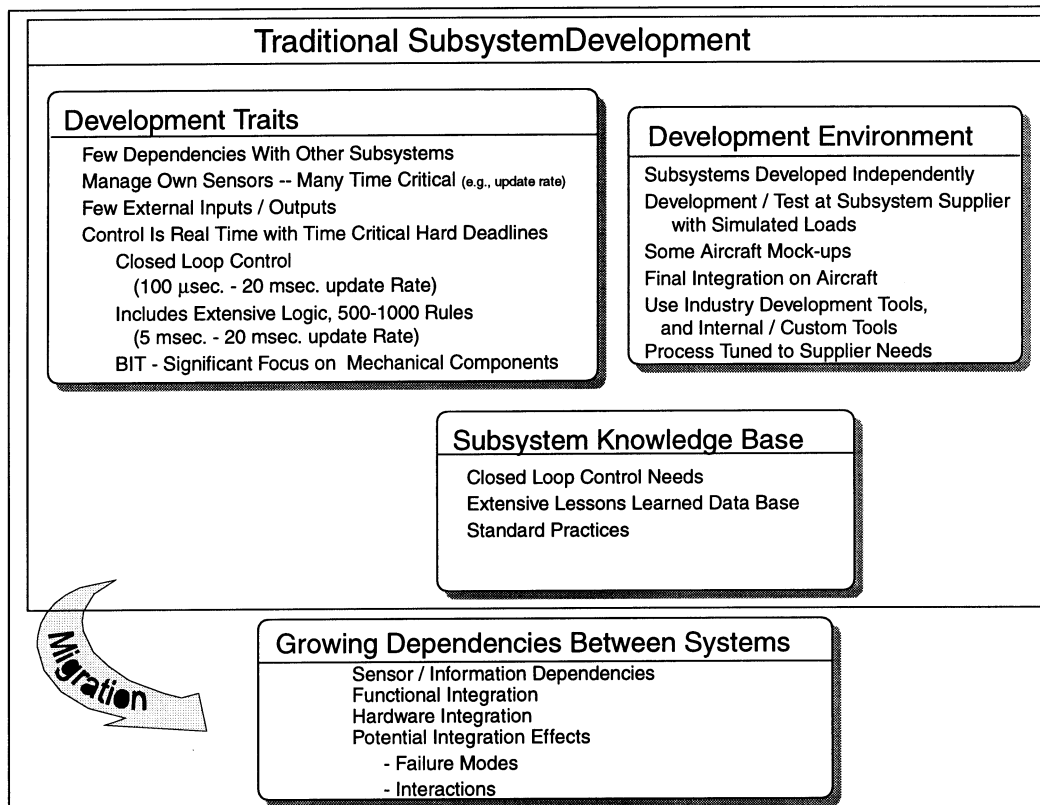


FIGURE 1 - Subsystem Development

4.1 Traditional Development Traits:

There exists physical interdependence among aircraft functions. However, in practice, partitioning the subsystems so that each can be treated as an individual component, with well-defined interface points minimizes these interdependencies. An interface example would be the cooling oil temperature, pressure and flow rate. Therefore, with a well-defined interface, the individual subsystem can be developed analogous to a standalone component, and tested at those interfaces.

Today, there are very few data or signal exchange interfaces among subsystems. Other than those specific interfaces for the flight deck switches and displays, the subsystems typically control and manage their own sensors and actuators. This approach allows the subsystem supplier to customize their sensors and actuators to meet their specific needs. The supplier also has the ownership of these devices and understands the impact of these sensors upon their subsystem.

- 4.1.1 Real Time Control Considerations: To operate the subsystems, the control must be running in real time within assigned time constraint. This means that if the sensing and timeliness of the control actions are not maintained, proper control of the subsystem will be lost, possibly resulting in a total subsystem shut down or causing potential damage to other subsystems.

There may be multiple control loops within one subsystem. Closed loop control updates are dependent upon the physical constraints of the subsystem hardware, and the required performance. Update rates vary between microseconds and seconds. Sensed input data and actuator output update rates are usually 5 to 10 times faster than the control channel bandwidth. In addition, to manage the subsystem (e.g., power-up, applications of load, subsystem protection, etc.), logic equations update rate at 500 to 1000 times faster than the control bandwidth is not unusual. Logic update rates could be as fast as 5 to 20 ms. For flight and propulsion controls, the update rate could be significantly higher.

- 4.1.2 Health Monitoring and Built-In-Test: As aircraft subsystems become more complex, traditional Built-In-Test (BIT) enhanced functions must be included for reducing subsystem down time and for achieving fail safe operation in the event of either subsystem or component failures. It is a common practice to incorporate BIT functions into the subsystem controller to achieve these goals. BIT functions have long been used in avionics, utility subsystems and flight safety subsystems. In the past, they were simple, now they are more rigorous. BIT functions are still oriented to the individual subsystem in which they reside. The BIT provides diagnosis information to assist scheduled or unscheduled maintenance and to estimate impending component failures. They have the potential to reduce the ownership costs of complex systems and subsystems by:

1. Replacing fixed intervals of maintenance or component replacement, with on-condition maintenance (service component when the system indicates a need to do so);
2. Giving advanced warning of unscheduled maintenance, permitting advanced scheduling of flight vehicle down-time and maintenance resources;

4.1.2 (Continued):

3. Reducing inspections or replacing data collection currently performed by removing the vehicle from service, by using data collected during flights;
4. Increasing the vehicle availability by reducing non-revenue time (e.g., diagnostic flight, engine run-up);
5. Reducing maintenance undertaken because of suspected component failure or incompletely documented misuse (e.g., no fault found);
6. Assisting fault isolation of the subsystem.

Present BIT installation generally uses many sensors, connected either to a central data recorded subsystem or the electronic controller of the subsystem or equipment. Quantitative data is collected in flight from subsystems and components throughout the vehicle. This data can be processed in flight to support the on-board safety warning subsystem. It is also transferable to ground based subsystems at regular interval for further analysis. Typically, this data: (1) Shows subsystem operation, status; (2) Monitors the health of components; and (3) Records the number of operational cycles. A complete subsystem BIT package must include the ground based data analysis, presentation, and recording subsystem.

4.2 Development Environment:

For those subsystems which are not tightly coupled (e.g., not highly dependent upon other subsystems to complete their tasks - a characteristic of most utility systems), the interfaces are usually established from previous applications. For other systems, the interfaces need to be defined, and once done, it is possible for the suppliers to develop, test, and qualify their subsystems independent of other subsystems and the aircraft. This leads to the delivery of a complete subsystem suite that, upon installation and integration on the aircraft, will only require some minor adjustments to meet the aircraft needs. Based on the historical data and experience associated with these subsystems, requirements and tests can be adapted to assure that the delivered subsystems meet the expected performance. This approach tends to minimize the redesign effort when the subsystems have been integrated on the aircraft. One area that has a significant impact on the development of the subsystem is the required aircraft operating environment (thermal, mechanical, vibration, installation, maintenance, EMI / HIRF and other areas). The subsystem suppliers have an extensive knowledge base to meet the demanding needs of these operating constraints, and can help the airframer in the necessary trades in the development of the final operating requirements (e.g., cost versus benefit trades). It is essential that the worst case conditions be determined at the beginning of the project, to assure that the proper solution be developed.

Throughout the development process, the supplier uses a mixture of development tools. Many of these tools are commercial available tools (e.g., CAD/AM, CASE, ECAE, etc.) In addition, suppliers developed their own custom tools (and will continue to develop) to assist them in the design of their subsystems. As the pace of integration increases, the interoperability of these tools and processes needs to be considered.

4.3 Subsystem Knowledge Base:

Subsystem suppliers accumulate a great deal of application knowledge from implementation in traditional federated subsystems. Many subsystems on the aircraft evolve over many years. Some changes occurred to meet either tighter control or higher output requirements. Many of these changes are the results of lessons learned from field experience, and become the airframer or industry standard or requirement. In addition, the subsystem suppliers usually have accumulated a large lesson learned database from their development processes, testing, and field experience. When designing new applications, this data enables the suppliers to design subsystems to function over the entire operating environment of the aircraft. These suppliers apply these learned lessons to incorporate appropriate “check points” in their design, analysis and testing to verify the product meets performance in a most cost effective manner.

5. INTEGRATION TREND - GROWING DEPENDENCIES BETWEEN SUBSYSTEMS:

The airframer and the subsystem suppliers are gaining confidence that they can manage the risk of integration within acceptable limits. Integration risks are deemed acceptable in order to achieve significant improvements in the aircraft subsystem life-cycle-cost (LCC), weight, volume, and performance. Some integration trends are:

1. Shared Sensing - Sharing sensed parameter information results from joint efforts among the airframer and two or more subsystem suppliers. The integration task is to define and coordinate the flow of information from one supplier to the other. This is usually done on a sensor by sensor basis. Examples are: INS, Air Data, Engine Data, etc.
2. Shared Processing – The subsystem suppliers either supply their hardware into a common chassis, or share a standard processor and I/O card of a common platform. One example of shared processing is described in ARINC’s Integrated Modular Avionics (IMA).
3. Mechanical Hardware Integration - Some subsystems have complex operational interfaces with other aircraft subsystems. To achieve a higher operational efficiency, lower volume, and lower weight, appropriate functions are combined and provided by multi-functioning electromechanical hardware. An example is the Thermal Energy Management Module (T/EMM) which uses common hardware to provide environmental control, secondary power, engine start and similar functions.
4. Control Function Integration - Some subsystems expand their boundaries to include functions that were previously parts of other subsystems. Also, some subsystems are closely dependent upon each other and control integration is necessary to achieve more efficient management. An example is the integration of Air Data into Flight Controls.

Physical interactions complicate many hardware integration cases. These physical interactions may be manifested in additional subsystem requirements (e.g., thermal demand, mechanical, electrical, EMI, etc.). If new aircraft demands or loads are not addressed properly, they can cause subsystem operation instability. For example, changes in electrical power waveform could be caused by load variation and impact the overall power subsystem stability, if not considered early during the design process.

5. (Continued):

Subsystem integration is the key to satisfy new demands and performance at the aircraft level. Where there are interactions among subsystems, stand-alone subsystem validation is not sufficient. For these cases, an integrated validation approach is needed.

To support the evolution to integrated subsystems, there are six key areas that require careful considerations:

1. Development Environment and Tools (engineering and management),
2. Shared Processors,
3. Data Sharing and Data Fusion,
4. System Testing,
5. Failure Modes, and
6. Integrated Diagnostics.

5.1 Development Environment and Tools:

It is essential that systems engineering and program management development tools and processes be available (and validated for use), to manage the aircraft wide integration. Information management for the integrated system is more complex than federated subsystems because of a greater volume of data to be shared amongst subsystem suppliers. The issues to be considered are:

1. Should a common set of Systems Engineering tools be used across the industry? Perhaps a better solution is to establish a common database of subsystem requirements and design data?
2. How and who should control proprietary data?
3. How to manage the volume of data that is changing on a daily basis across a number of subsystems. It is important to:
 - determine what information is pertinent;
 - to flow that information on a timely basis.

5.2 Shared Processors:

In traditional federated architectures, each subsystem that required software used its own processor(s). With new technology providing higher processing speeds, soon only a few processors, or even a single processor, will be needed. However, the required redundancies for safety and availability at the subsystem or aircraft level will need to be addressed as a fundamental part of the design process for the architecture selection.

The sharing of processor resources introduces many issues, both technical and business. Prominent issues are:

1. Hardware and Software Partitioning

- The operating system, and control hardware must be robust enough to ensure that one function cannot interfere with another.
- The analysis of the partitioning should support the aircraft safety requirements.

2. Certification and Re-certifications

The subsystem and software architecture should be designed such that one function can be modified independently without affecting the certification of another. Areas to consider in top level design include:

- Changes to common libraries has wide spread impact;
- Providing for spare memory and execution time in each subsystems partition;
- Tools that allow recompiling, linking, and loading of one partition without affecting another; and,
- Automated test processes to reduce regression test time.

3. Economic Considerations

An integrated environment must be economically viable and usable by suppliers implementing simple or complex functions. These considerations includes:

- The suppliers development cost must not be driven up by integration.
- The aircraft integrator cost.
- The aircraft maintenance support needs.

5.3 Data Sharing and Data Fusion:

Data Sharing - Sharing of input signals reduces the need for redundant conversion electronics and sensors, thus reducing cost. Data sharing among federated subsystems, however, is limited by a number of factors, including:

1. Concerns about signal integrity and availability when multiple subsystems are in the signal data path.
2. Sharing a small amount of data with a subsystem may not warrant the cost of adding a digital communication bus to that subsystem control unit.
3. Signal lags (transport delay) and time coordination between signals (e.g., that all signals for a control loop are within the same relative time period).
4. For analog signals, sensor conversion should consider accuracy requirements (such as resolution, linearity, and filtering) for all subsystems that would use that data.

Data Fusion - It is possible to use and merge sensor information from various subsystems to monitor and optimize overall aircraft subsystem behavior, to perform reasonableness checks on sensor information, to isolate faults, and to provide backup information in the case of primary sensor failure. For example, information from required temperature, pressure, and flow sensors in the environmental control system may be used to estimate the temperature at a location where the cost of installing another sensor is unwarranted.

5.4 System Testing:

Testing of the subsystems occurs throughout the development process - starting at the subsystem supplier, with final testing on the aircraft during flight test. For each phase of testing, industry experience shows that the following questions should be addressed early in the development of highly integrated subsystems and vehicles.

1. Is it necessary for the subsystem supplier to have a complete, full-up integrated test environment?
2. Will a partial control subsystem provide a true representation of the dynamics of the final subsystem (e.g., the control subsystem would not have all of the final control software (behavior) present from other subsystems)?
3. How does a supplier simulate data that is to be provided by other subsystems?

5.4 (Continued):

4. Who is responsible to provide the integrated test environment (cost), to maintain it, and to assure that it is properly configured (with the latest software)?
5. What is the proper mix of real hardware / software and simulated test environment?
6. How do the subsystem suppliers work together to define the integration and test environment?

All levels of test should be considered.

1. Vendors verify requirements (hardware and software) flowed down to them from the system integrator. Verification of the subsystem hardware and software usually occurs after hardware/software integration at the box level. Hardware verification is usually referred to as qualification test. Software verification is also referred to as qualification test, but the software has usually been tested stand-alone at the unit, CSC and CSCI level prior to verification. The purpose of verification testing is to prove that the requirements were implemented properly.
2. System integrators are required to validate the original requirements, which are flowed down to them from the airframer. Validation determines that the original requirements were truly what were needed for the air vehicle. This level of test is usually done at the integrator's facilities with interfacing equipment in the loop, but can also be accomplished at the vendor's facilities with real hardware, models or simulated input/outputs/environments. The purpose of validation testing is to reduce the risk associated with waiting to get to the next phase of test to find out that the requirement were not defined.
3. Aircraft Checkout/ Functional Testing is completed as the last phase of testing in the integrated system environment prior to flight test. Problems and requirement deficiencies discovered during this phase of testing are usually more costly to correct than ones discovered during the validation phase, but are usually less expensive than those discovered once the flight test program begins.

5.5 Failure Modes:

The problem of multiple functions failing simultaneously were not major issues in federated subsystems, except when dealing with common power sources, cooling, and physical damage to the boxes. Typically each subsystem had its own dedicated sensors and processing to independently meet its own requirements. As a result, the probability of more than one or two independent and unrelated functions failing simultaneously due to unintended interactions was highly unlikely.

Faults in integrated subsystems can manifest themselves in highly undesirable ways. One example is use of a common element such as a sensor, processor, or software function (e.g., operating system) to service a number of sub-functions. Failure of this common element will obviously affect all of the sub-functions in a manner not characteristic of federated subsystems. Although each of the sub-functions may be non-critical, simultaneous loss may result in excessive crew workload or passenger inconvenience.

5.5 (Continued):

A more insidious failure results from a common mode or generic (hardware or software) latent design fault that simultaneously effects all channels of a redundant, fault-tolerant system such as a fly-by-wire flight control system. Such a common failure mode may well result in total loss of a flight critical function. Traditional approaches used dissimilar redundancy to obviate common mode faults. Examples include mechanical backups for fly-by-wire systems and dissimilar software and/of digital processors within redundant channels that perform the same function. Each of these dissimilar means introduces design and verification problems of their own, which may be more undesirable than designing without them. For example, the original F/A-18 design had a mechanical backup for the primary fly-by-wire FCS; inadvertent reversion to the mechanical backup occurred on a number of occasions causing degraded performance, which would have not occurred without the mechanical backup system. The latest version of the F-18 (F/A-18 E/F) does not have a mechanical backup.

The 777 fly-by-wire system was initially to have dissimilar processing hardware and software. However, owing to the complexity of dissimilar software, only a single language was used in the flight certified system. The FAA is beginning to consider critical systems with neither dissimilar hardware nor software, but rigorous extensive verification and validation is required to satisfy safety concerns.

The designer should then consider that rigorous testing of hardware and software at each level of development can be used to reduce the probability of a system containing a generic design flaw to an acceptable level. The time and cost required to perform the required level of test must be balanced against economic and program constraints.

5.6 Integrated Diagnostics:

There is a wealth of information within the control units of a federated aircraft subsystem. Each individual controller uses this information to determine the health and faults within its respective subsystems. However, because the information is limited to the individual subsystem, an aircraft wide analysis of either actual causes of faults or validation of an intermittent fault is inhibited (or expensive to implement).

An integrated aircraft subsystem should be able to improve upon the health monitoring and BIT of the traditional subsystem. The aircraft subsystem developers can take advantage of the information across the multiple applications and significantly reduce the number of "Retest OK / Cannot duplicate" conditions. Through the integrated information approach, the speed and accuracy of the trouble shooting or maintenance of an aircraft can be improved. It is incumbent upon the designer to assure that the diagnostics subsystem provides a benefit to the operation of the aircraft, and does not reduce the readiness of the aircraft subsystems.

6. SUMMARY:

To design a suitable integrated subsystem at affordable costs, a System Engineering approach to define and derive all requirements is needed. It is then necessary for the subsystem developers and the systems integrator to approach the design issues from the overall vehicle performance. This approach demands that the systems integrator work closely with the subsystem suppliers as partners. The purpose is to foster a closer cooperation among all partners and to encourage a free flow of design and subsystem information for understanding aircraft impacts. The subsystem suppliers can then draw upon their extensive knowledge base to perform the trade-off studies, analysis, and simulation to optimize the subsystem design effort. The team recommendations would form the basis to generate requirements for each subsystem.

There are a number of SAE and ARINC organizations dedicated to specific subsystems. It is strongly recommended that the potential integrators and suppliers should contact these organizations and the members of AS-4 committee for guidance in future integration system development. Figure M1 provides a representative list of components that make up the individual aircraft subsystems and Table N1 provides a list of some SAE organizations. In addition, this table also lists any general overview documents that the specific committees generated to define their products.

In addition to the SAE activities, the reader should reference the government work on the Joint Service Specification Guides (JSSG). These are a series of documents to support the Joint Aeronautical Commanders' Group (JACG) initiative to create and use JSSG in the development of new military aeronautical weapon systems. Of particular interest to readers of this SAE document is the Vehicle Control & Management Spec Guide section of the JSSG. Note that distribution of the JSSG is limited to U.S. citizens only; contact Artmanre@asc-en.wpafb.af.mil for a CD ROM copy of the document.

Also, the Advisory Group for Aerospace Research & Development (AGARD) developed an advisory report (number 343) "Integrated Vehicle Management Systems". AGARD is a NATO organization. From the AGARD executive summary "... an integration of technology to proved high performance electronic systems at affordable prices." Continuing, "The desire to functionally integrate subsystems so as to achieve better performance has been greatly assisted by discoveries in the field of data processing."

PREPARED UNDER THE JURISDICTION OF
SAE SUBCOMMITTEE AS-4B, VEHICLE SYSTEMS OF
COMMITTEE AS-4, VEHICLE MANAGEMENT SYSTEMS

APPENDIX A
AUXILIARY POWER SYSTEM

Auxiliary Power System

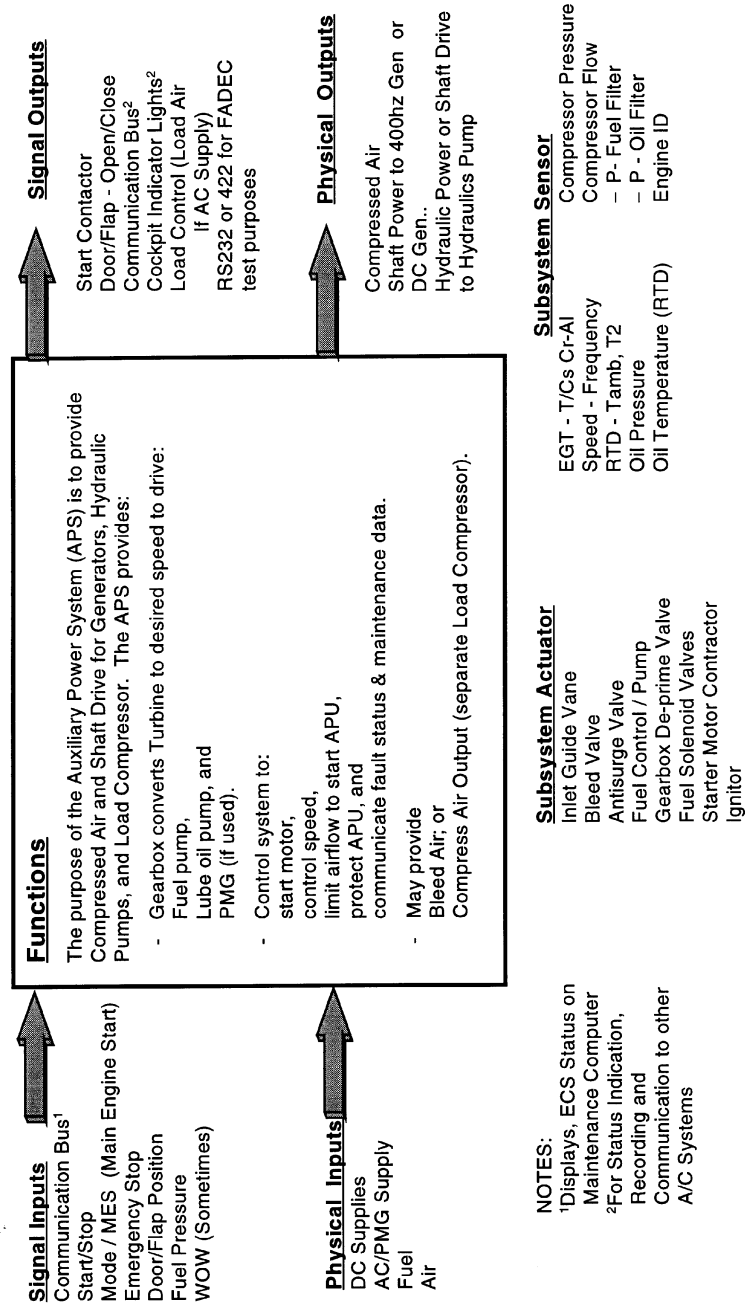


FIGURE A1 - Auxiliary Power System Functional Diagram

APU Operation

The following describes the APU operation, as shown in the following APU block diagram. This is typical of one configuration of APU; different APU configurations may be used on different aircraft.

The power to turn the engine rotor assemble is initiated by the starter which rotates the gearbox, which in turn, drives the rotor assembly. Air is drawn into the engine by the rotating compressor. The compressor delivers the air to a diffuser, which slows the airflow for delivery to the combustor, where fuel is mixed with the air. The combustion process begins when fuel is injected into the combustor liner and ignited by the ignition system. The fuel and part of the air from the compressor are burned to produce heat. The heated gasses expand and accelerate through the turbine nozzle to impinge on the blades of the turbine wheel. Energy from the heated gas stream is extracted to drive the compressor, gearbox, and the gearbox accessories. Gas then exits through the exhaust system. The fuel flow is modulated to maintain the APU engine at the designed setpoint (the APU is operated at a fixed speed).

During the combustion process, not all of the air produced by the compressor is used. The excess air is available as bleed air to operate the aircraft pneumatic systems (air cycle system, main engine start). The Bleed Valve controls the flow of air to the pneumatic system. The control monitors the pressure (usually a differential pressure) to detect flow. This is also used in the management of the Anti-Surge Valve. This valve is generally opened when there is no load flow to provide a path for the compressor output.

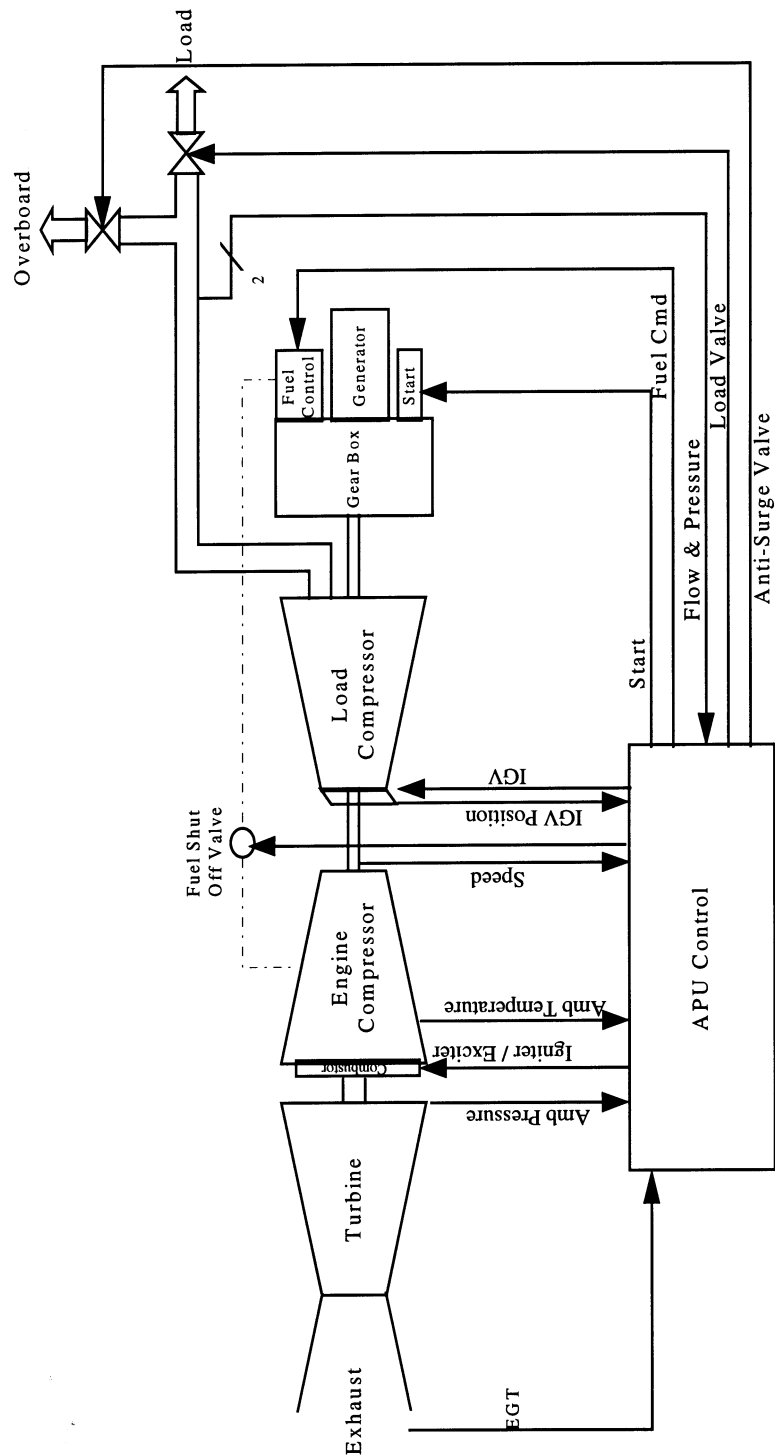


TABLE A1 - External Signal Inputs - Auxiliary Power

	Signal Type			Criticality			Application		
	Analog	Data Bus	Discrete	High	Medium	Low	Control or Reconfiguration	BIT Status Monitoring	Information Only
External Input Signal									
Weight On Wheels		X	X		X		X	X	
Door / Flap Position (Air Intake)			X	X			X	X	
Emergency Stop			X	X			X	X	
Start / Stop			X	X			X	X	
Mode (e.g. Main Engine Start)			X	X			X	X	
Central Maintenance System Bus		X				X		X	X
Other Aircraft Bus		X	X		X		X	X	

TABLE A2 - Signal Output - Auxiliary Power Unit

[illegible]

TABLE A3 - Internal Actuators - Auxiliary Power Unit

<u>Actuator</u>	<u>Common Actuation Signal Range</u>
Inlet Guide Vane	0 to 100 mA with LVDT Feedback
Pneumatic Load Valve	0 to 100 mA with LVDT Feedback
Antisurge Valve	0 to 100 mA with LVDT Feedback or Discrete (open/close)
Fuel Control	0 to 100 mA
Oil De-prime Valve	Discrete
Fuel Valves	Discrete
Starter Motor Contactor	Discrete
Ignitor	Discrete

TABLE A4 - Typical Internal Sensors - Auxiliary Power Unit

<u>Sensor</u>	<u>Common Technology</u>	<u>Sense Range</u>	<u>Sensor Output Range</u>
EGT	Thermocouple	-65 F to 2000 °F	mv equivalent
Ambient, T2	RTD	-65 to 150 °F - Inlet	1000 Ω $\pm$ Temperature effect
		0 to 400 °F Oil	
		0 to 600 °F Compressor Discharge	
Speed / Frequency	MPU	0 to 60,000 rpm	0 to 60 kHz, mv
Oil, Fuel Pressure	Switch	30 Dpsig	Contact Closure
		10 psid $\pm$ D P (Filters)	Contact Closure
Pressure	Transducer	0 to 150 psig - Compressor	0 to 50 mV
		0 to 10 PSID Flow	0 to 50 mV
		0 to 20 psia - Inlet	0 to 50 mV
Engine ID	Resistor Network		

TABLE A5 - Control Channel Bandwidth - Auxiliary Power Unit

<u>Control Channel Type</u>	<u>Control Channel Bandwidth (Hz)</u>
Startup Control (Temperature & acceleration profile)	50
Speed Control	50 - 100 (1)
Surge Control	100
Load Control	
IGV	50
Bleed Air	50
Protection	
Speed	100 (2)
Other	50
BITE Monitor	1 - 100

1. Speed Control is dependent upon APU performance requirements.
2. For protection, usually speed is very critical and is monitored every CPU frame - while other protections may be scheduled across several frames, dependent upon system needs.

APPENDIX B
BRAKING SYSTEM

Braking System

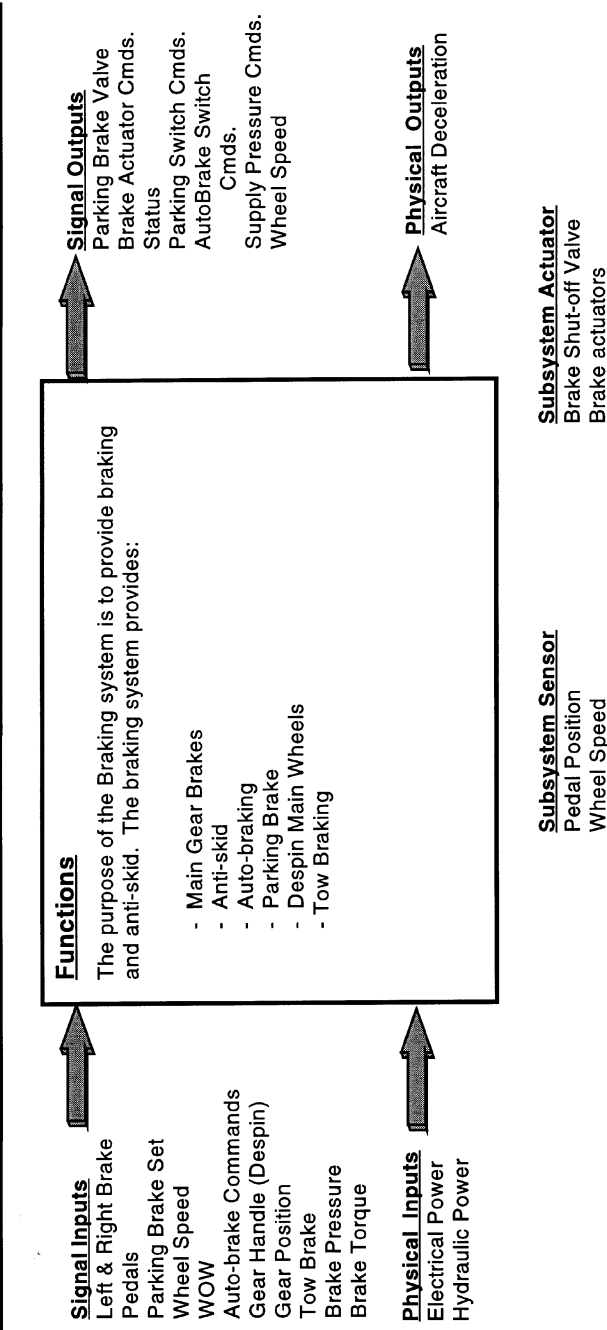


FIGURE B1 - Example Brake System

Brake System

Typical brake systems are powered from the hydraulic system. Brake pedals control the brakes. The right brake pedal controls the right brakes (the brakes on the right main gear) and the left brake pedal controls the left brake (the brakes on the left main gear). The brake pedals are connected to the brake metering valves by cables or by electric control wires (brake-by-wire). The metering valves apply hydraulic pressure to the brakes in proportion to the pedal movement. Modern brake systems often incorporate two (2) control functions, antiskid and autobrake.

Separate metering valves and antiskid valves control the hydraulic pressure to the brakes. The brake system (antiskid/autobrake) control unit controls the antiskid and the autobrake system. The primary function of the antiskid system is to control brake pressure to prevent tire skid. Each wheel has a wheel speed transducer which supplies signals back to the antiskid/autobrake control unit. When a tire skids, the control unit decreases the brake pressure to keep wheel skid to a minimum.

The autobrake function applies the brakes automatically, upon touchdown. Deceleration rates are selectable by the pilot. The application of the autobrakes is usually dependent on the thrust levers being at the idle position.

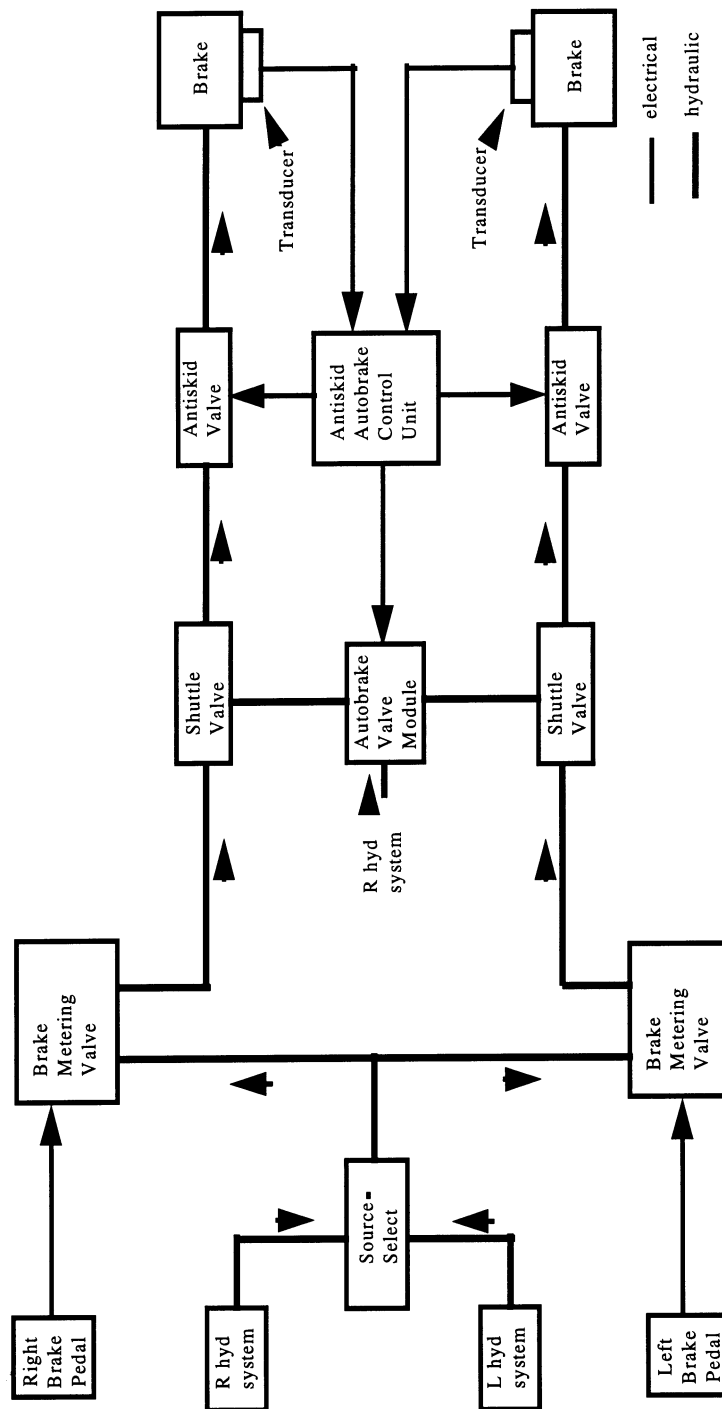


FIGURE B2 - Example Brake-By-Cable System Block Diagram

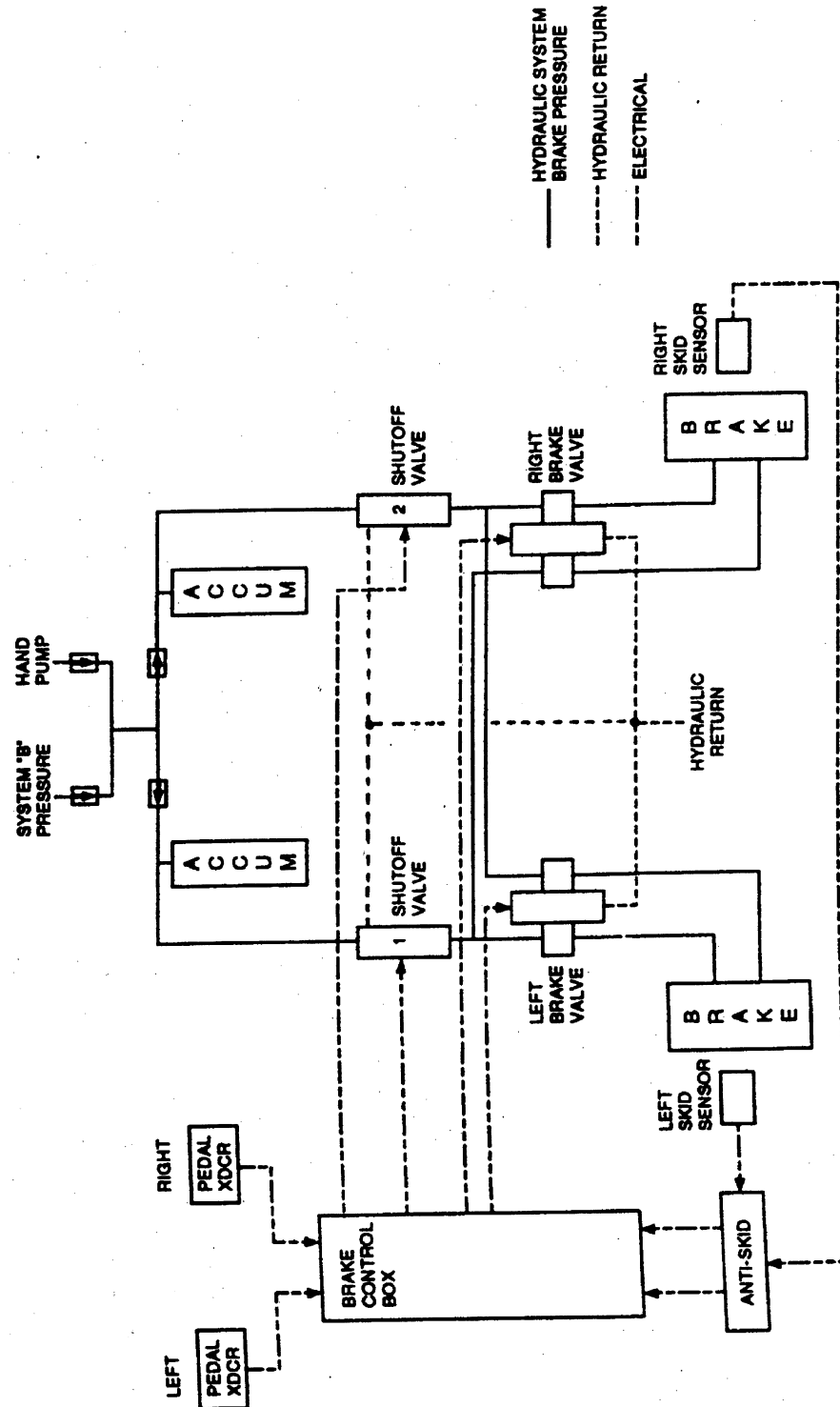


FIGURE B3 - Example Brake-By-Wire System Block Diagram

TABLE B1 - Signal Input - Brake System

External Input Signal	Signal Type			Criticality			Application		
	Analog	Data Bus	Discrete	High	Medium	Low	Control or Reconfiguration	BIT Status Monitoring	Information Only
Left brake pedal position	X			X			X		
Right brake pedal position	X			X			X		
Left Wheel Speed	X			X			X	X	
Right Wheel Speed	X			X			X	X	
Left Brake Servo Position	X			X			X	X	
Right Brake Servo Position	X		X		X		X	X	
Parking Brake Command			X	X			X		
Weight on Wheels			X	X			X		
Autobrake Commands			X		X		X		
Optional Left and Right Brake Torque	X				X		X		
Gear Handle & Position			X		X		X		
Tow Command			X	X			X		

TABLE B2 - Signal Output - Brake System

External Output Signal	Signal Type			Criticality			Application		
	Analog	Data Bus	Discrete ¹	High	Medium	Low	Control or Reconfiguration	BIT Status Monitoring	Information Only
Left brake servo command	X		Lo				X	X	
Right brake servo command	X		Hi				X	X	
Parking brake valve Command					X		X		
Status		X				X		X	X
Park Switch			X		X		X		
Autobrake Switch			X		X		X		
Brake Supply Commands				X			X		

¹ Hi - 28 V 2 A
Lo - 28 V 200 mA

TABLE B3 - Internal Actuators - Brake System

Internal Actuator	Common Signal Range
Brake Servo	0 to 100 mA DC
Parking Brake Valve	28 VDC 2 A
Supply Pressure Actuator	28 VDC 2 A