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INTEGRATED UTILITIES MANAGEMENT SYSTEM FOR AIRCRAFT.

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ABSTRACT.

Aircraft utility systems generally include fuel, hydraulic, engine, electrical power and distribution systems, landing gear, brake systems, among others.

These systems became in time more and more sophisticated creating an increase in the number of electronic and electrical units, power and control wires.

According to the approach developed in Israel Aircraft Industries (IAI) the whole aircraft space is divided into several operational areas with a high density of electrical components including electrical sensors, command devices, electrically controlled devices of utility systems and other electrical loads.

In each such area local control units are installed and connected to all the electrical components in the area. They are interconnected by data and power buses providing utility systems' control, monitoring, BIT and fault-tolerance management and communication with avionic systems and with the pilot.

This approach significantly saves weight, improves system fault-tolerance and maintainability.

1. INTRODUCTION.

Aircraft utility systems generally include fuel, hydraulic, engine, electrical power and distribution systems, landing gear, brakes, nose wheel steering systems, flight surfaces servo control, enviromental control systems, nose wheel steering, lighting, auxilary power system, among others.

Utility systems management includes their automatic control or remote control by pilot, monitoring, BIT, fault tolerance management, data exchange and presentation to pilot and to maintenance crew.

Utility systems management in existing aircrafts is based on the functional concept. Each system is controlled and monitored by specific functional electronic or electrical units.

These units generally receive commands from pilot command devices (switches, pedals, throttle, etc.), data from sensors (pressure, temperature, actuators position sensors, limit switches, voltage, current sensors, etc.).

They also receive their electrical power from electrical power and distribution system using separate power lines protected by circuit breakers or fuses. These electronic and electrical control units process received data and send commands to electrically controlled devices like actuators, valves, heaters, electrical lights, electrical motors, and to other aircraft electrical loads.

In time utility systems became more and more complicated and sophisticated thus creating an increase in the number and complexity of electronic and elctrical control units and number of power and control wires.

This in turn increases electrical equipment weight, mostly because of wiring weight as a direct outgrowth of aircraft size. An increase in the number of different types of electronic and electrical units also causes increase in number of spare parts and test equipment creating additional maintenance problems. The functional concept of utility systems management also increases the difficulties in finding some standard and common solution for their fault tolerance and maintenance management and to provide the utility systems interconnection with the avionic system and with the pilot.

Various types of systems integrated management are already in use now in aircraft: Electctrical Load Management System (ELMS) for power management and distribution and Engine Indication and Crew Alert System (EICAS) for aircraft system data integrated monitoring, display and maintenance.

A similar integrated concept was developed for avionic systems, Integrated Modular Avionics (IMA).

The approach which is under development in IAI can be considered as a further step in aircraft systems integration management. This approach is based on the area management concept and is intended to resolve the above mentioned problems.

This paper presents explanation of the approach and contains analyses of their different aspects, like weight and fault-tolerance management.

2. AREA MANAGEMENT CONCEPT.

According to area management approach the entire volume of the aircraft is divided into several operational areas with high density of electrical components, such as electrical sensors, command devices, electrically controlled devices of utility systems and other aircraft electrical loads.

In the example of Integrated Utilities Management System (IUMS) shown in Fig.1, these areas are nose, tail and several intermediate areas on left and right sides of the aircraft. In each such area, as close as possible to their "center of gravity" from the standpoint of wiring minimum total weight, the local control units are installed and connected to the electrical components of all utility systems and to all electrical loads in their corresponding operational areas.

Local Control Units (LCUs) are generally redundant electronic computerized units, containing output power drivers for activation and protection of electrically controlled devices and loads. All LCUs are interconnected by double redundant data bus which in turn is connected to avionic system and to pilot displays.

All LCUs are also interconnected by several power buses (PB-1-PB-4 on fig.1) which in turn are connected to power sources of Electrical Power System (EPS).

Each power bus consists of power wires of different cross sectioned area so that each of them corresponds to maximum required current through the wire.

The IUMS provides integrated management of utility systems including their control and monitoring, fault tolerance and maintenance management and communication with avionic system and pilot. It also provides electrical power and distribution management for all aircraft electrical loads.

This approach permits the elimination of most interconnections between different aircraft operational areas and energy flow "loops" which in turn allows to minimize the wiring weight. (A "loop" occurs when the energy flows from the power sources to the distribution or control unit and then returns to the load).

3. LCU BRIEF DESCRIPTION.

An example of an LCU block diagram is shown in Fig.2. Each channel contains output power drivers (OPDs) including Solid State Power Controllers (SSPCs) for power and control of electrically controlled devices and overcurrent protection. Each channel also contains an Electronic Control Module (ECM) which performs data aquisition and processing of all input signals from sensors and command devices in its area and operates output power drivers.

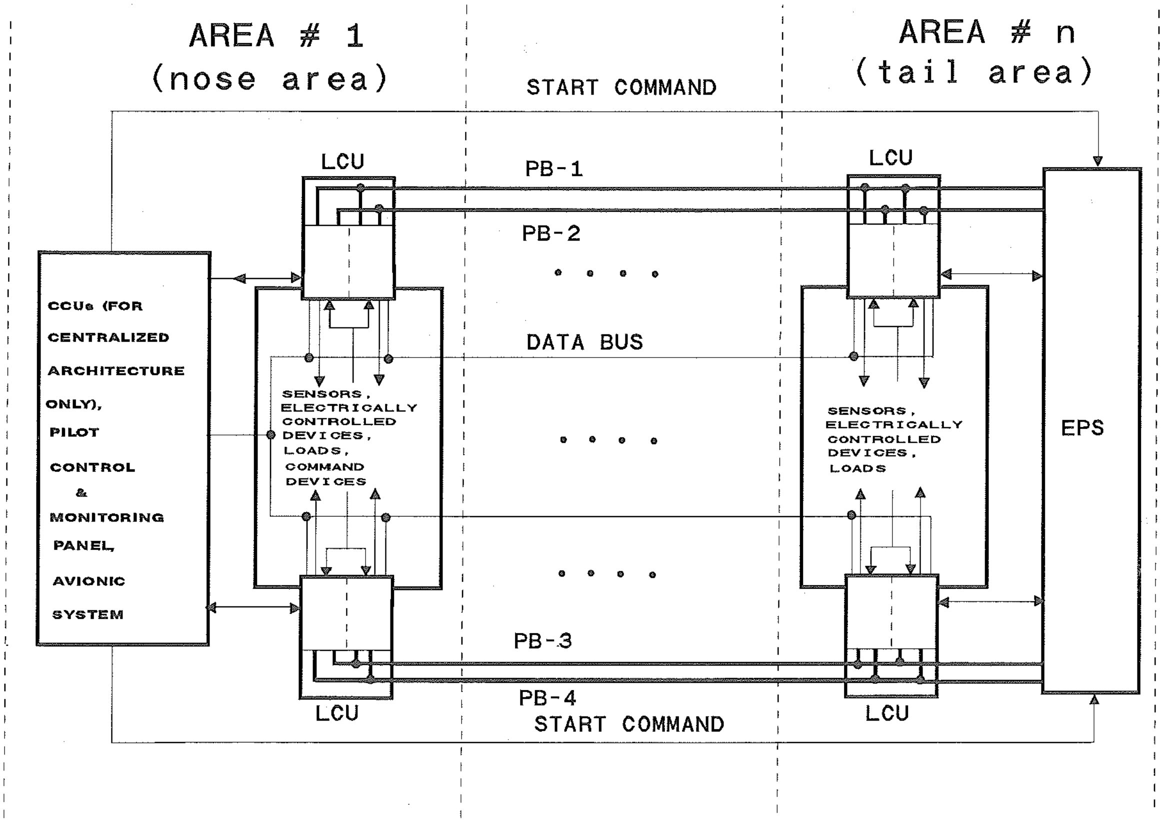


FIG. 1 IUMS BLOCK DIAGRAM

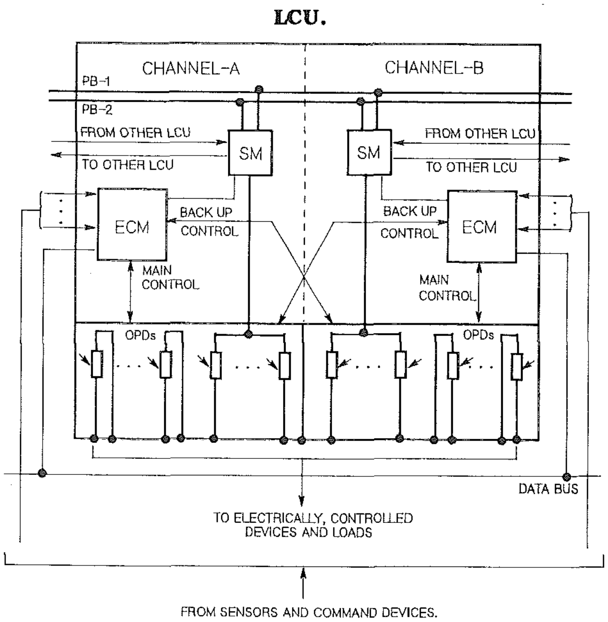


FIG.2. LCU BLOCK DIAGRAM

Output power drivers can be implemented by SSPCs and connected to any of the power buses by relays in the Switching Module (SM) controlled by the ECM. They can be connected in series, if necessary to prevent actuator runaway because of failure. They can also be connected in the form of a bridge for reversable actuators (see Fig.3). Output power drivers can provide on/off or proportional control, for example, by pulse width modulation.

In case of a major failure in one of the channels (CPU, power supply, etc.), the other channel can operate output power drivers of both channels.

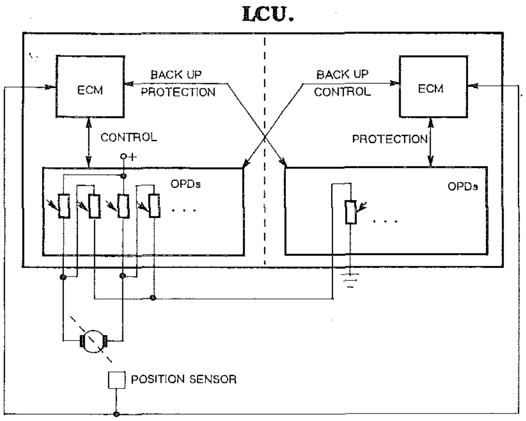


FIG.3. EXAMPLE OF ELECTRICAL ACTUATOR CONTROL

4. SYSTEM ARCHITECTURE.

4.1 CENTRALIZED ARCHITECTURE.

The system architecture is based on centralized architecture where all utility system management functions are implemented in Central Control Units (CCUs) connected to the data bus and to the avionic system and pilot displays. CCU functions can also be implemented in avionic system computers.

LCUs are used for data aquisition and transfer to the CCUs via the data bus and to operate output power drivers according to commands received from CCUs via the data bus. This architecture allows to implement LCUs in the simpliest way. On the other hand concentration of all management functions in the central control units creates significant problems if we are to avoid common mode failures and to provide logical partitioning between utility systems. As a result it can create significant certification problems for commercial aircrafts.

4.2 DISTRIBUTED ARCHITECTURE.

According to the distributed architecture approach utility system management functions are distributed between LCUs. This reduces the difficulties of common mode failures, logical partitioning and fault tolerance management. Therefore this method is described more in detail below.

4.2.1 UTILITY SYSTEMS CONTROL.

Each LCU channel controls no more than one flight critical or essential utility system, while another channel of the same LCU performs protection of this system (Fig.4).

The LCU receives data and commands via data bus from sensors and command devices of the corresponding utility system connected to any of LCUs. It processes the data and activates the utility system electrically controlled devices connected to any of LCUs using the same data bus.

Each of LCU channels operate one of the output power drivers connected serially for activation of flight critical actutators or other electrically controlled devices (Fig.4). One of output power drivers is used for control and the other for preventing actuator runaway.

Such approach provides fully independent control and protection circuits so that there is no failure which affects operation of control and protection circuits simultaneously.

4.2.2. UTILITY SYSTEMS MONITORING.

Utility systems monitoring includes:

- Measuring of utility system parameters (fuel and oil quantity, level, pressure and temperature, actuators position, engine speed, electrical sources and bus voltages, currents).

This function is performed by each LCU for all data measured in its operational area.

- Aircraft systems status during their normal operation definition (ground/air, landing gear position, doors position, fuel management system status, electrical power system, emergency power system, starting system status, etc.).

This is done by the same LCU which performs control of the particular system.

The relevant results of utility systems monitoring are sent to the avionic system and to the centralized pilot displays. In commercial aircraft they are sent to EICAS displays that eliminate the use of Data Concetrator Units (DCUs) of the EICAS thus saving weight and cost. These data are also used for systems Built-In Test (BIT) and diagnostics.

4.2.3. UTILITY SYSTEMS BIT.

Utility systems BIT is performed:

- for utility systems fault-tolerance management.
- to provide warnings to pilot.
- for maintenance purposes.

BIT for each system is done by the LCU which performs system control.

BIT for fault-tolerance management detects failed control or monitoring channel. This type of BIT is performed mostly as a continuous BIT.

The BIT for maintenance purposes detects failed Line Replacable Units (LRUs) as a design goal, and complimentary data to each failure (for example, time of failure appearance, altitude, voltages). This BIT is performed using all kinds of BIT technics: continuous BIT, power on BIT and initiated BIT.

Relevant BIT results are sent by the LCUs to the avionic system and to the pilot displays (EICAS) as warnings, and to the central maintenance computer for recording.

4.2.4. FAULT-TOLERANCE MANAGEMENT.

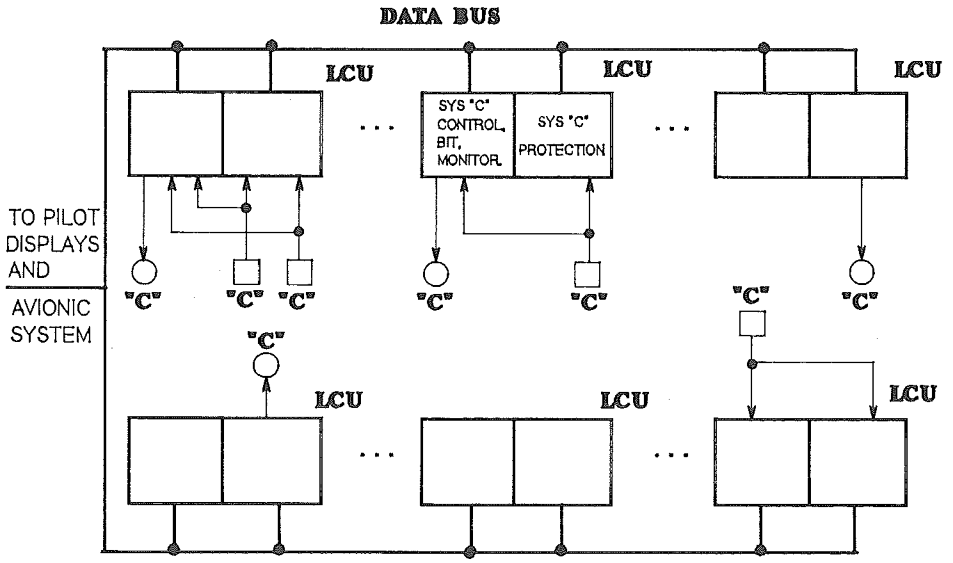
Fault tolerance management of a particular utility system is done by the LCU which is responsible for the system control or monitoring.

a) Fault tolerance management in case of LCU major failure.

Such failures (CPU, power supply failure, generic software failure) causes the failed channel to be disconnected from the output power drivers (fail-safe). The other LCU channel performs all functions of both channels. This includes control of all output power drivers and provides full redundancy (fail-operate).

For the same reason all LCU inputs are connected to both LCU channels (Fig.2), and CPU of each channel can operate the output power drivers of both channels.

b) Fault tolerance management for failures which cause output power driver to be in conductive condition.



□ - SENSORS AND COMMAND DEVICES

○ - ELECTRICALLY CONTROLLED DEVICES AND ELECTRICAL LOADS

FIG.4.ILLUSTRATION OF DISTRIBUTED ARCHITECTURE OPERATION (FOR UTILITY SYSTEM "C" CONTROL, MONITORING AND BIT)

Undesirable activation of electrically controlled devices (for example, actuator runaway) can be a result of any single failure which cause the output power driver to be in conductive condition. Protection in this case is provided by connecting serially of output power drivers of different channels (see Fig.3).

One of output power drivers is activated by the utility system control channel, while the other is activated by utility system protection channel.

Such approach makes actuator runaway extremely impropable (failure rate $< 10^{-9}$ per hour) because of any combination of failures. It also reduces probability of actuator runaway as a result of generic software failure (software bug) because the application software of both LCU channels is different. For this reason control and protection algorithms shall be completely different.

c) Fault tolerance management in case of failures in output power drivers or in output circuits which cause them to be disconnected.

In case of such failures switch-over to the other channel will not be helpful. Therefore, redundant control shall be provided by different LCUs (Fig.5).

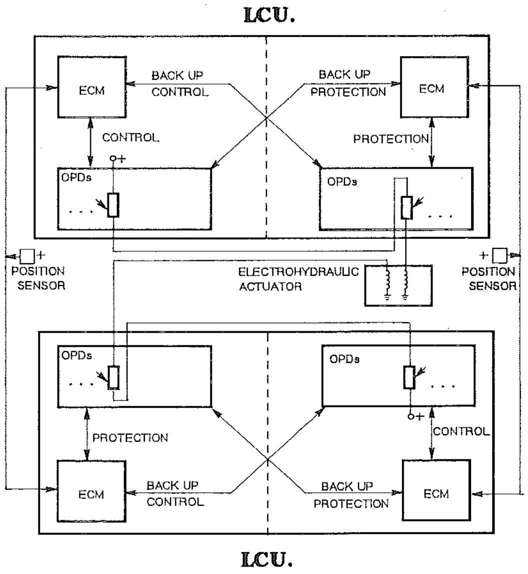


FIG.5. EXAMPLE OF REDUNDANT ACTUATOR CONTROL

d) Combination of major failures in both channels of the same LCU can cause non operation of all connected to the LCU electrically controlled devices and, therefore, can disturb operation of group of utility systems.

The system can be designed in such a way that even in this case most important flight critical and essential systems continue to operate at least in a reduced mode, providing continuation of safe flight. It can be achieved using for redundant control and monitoring different LCUs located close each to other, for example on both sides of the aircraft.

The another way is to design LCU hardware so that a total failure of both LCU channels as a result of combination of failures will be extremely impropable. Calculations show that this goal is difficult to achiave even when using very reliable electronic components.

An LCU with three independent channels allows us to solve this problem using regular electronic components. In this case each channel shall be able to take control of the output power drivers of the other channels.

e) Power bus failures.

If any of the power buses is deenergized all LCUs connected to the failed power bus switch-over to one of remaining power buses (Fig.2) by Switching Module (SM). According to the power distribution management algorithm some of non essential loads will be disconnected.

f) Failures in command devices and sensors.

For system which requires prevention of improper operation because of any failure the corresponding command devices and sensors shall be redundant (for example, double command potentiometers, double command switches).

g) Mechanical and hydraulical failures.

In this case the LCU activates redundancy capabilities of mechanical or hydraulic part of corresponding utility system (for example, emergency hydraulic power system is activated in case of main hydraulic system failure).

h) Data bus failures.

In case of data bus failures fault tolerance management is provided by double or triple redundant data buses (for example MIL-STD-1553B Muxbus for military aircraft or ARINC-629 data bus for commercial aircraft).

4.2.5. POWER DISTRIBUTION MANAGEMENT.

All aircraft electrical loads are powered from one of the power buses by the nearest LCU. The connection to the power bus is done by the SSPCs in LCUs. The SSPC also provides short circuit and overcurrent protection. Power distribution is performed for each operational area by correspondent LCU using SSPCs and Switching Module (SM) in LCU.

Normally different channels of the LCU are connected to different power buses which are approximately equally loaded. If some of the electrical loads require redundant and uninterruptable power supply (for example, flight control computer, avionic computers), it can be done by connecting the load to more than one LCU channel, while correspondent SSPCs are always open (Fig.6).

If one of the power buses is deenergized (for example, because of a short to ground), the Switching Module (SM) connects electrical loads and actuators to the remaining power bus located on the same side of the aircraft (Fig.1,2).

LCU.

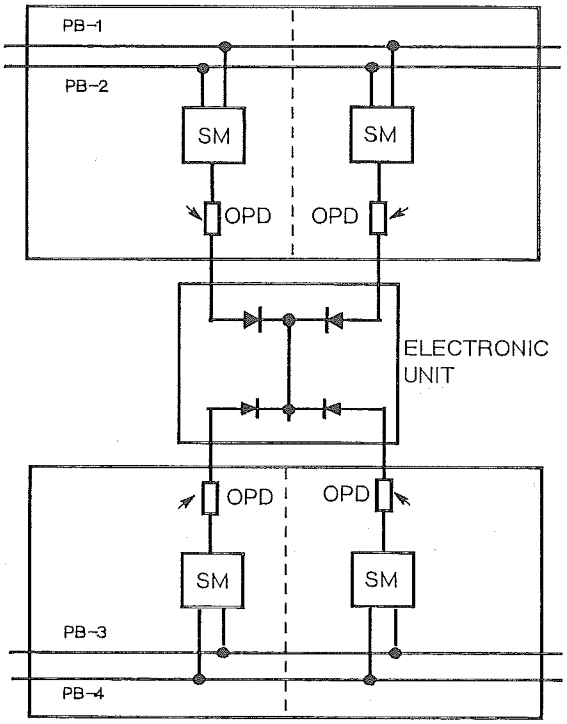


**FIG.6.
EXAMPLE OF TRIPPLE
REDUNDANT NON INTERRUPTABLE
POWER SUPPLY.**

If both of power buses on the same side of the aircraft are deenergized then the Switching Module (SM) connects electrically controlled devices and loads of the LCU to power buses located on the other side of the aircraft.

In all the above mentioned cases and in other emergency modes, part of the non-essential loads are shedded according to the load capabilities of the remaining power buses and power sources and depending on the stage of flight.

LCUs located close to electrical power sources perform their control and monitoring functions (Fig.7). Starter Generators (S/G) and aircraft Batteries (B) can be connected to any of power buses PB1-PB4 by contactors controlled by generator control units (GCUs) and local control units (LCUs) located close to them.

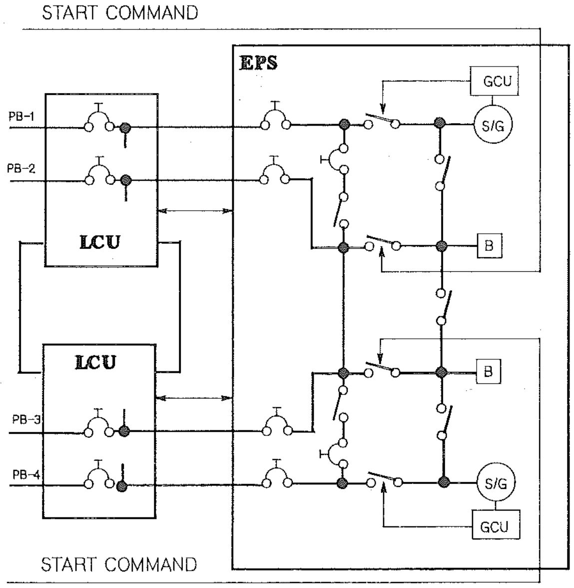


FIG.7. EXAMPLE OF EPS IMPLEMENTATION

5. SYSTEM START UP.

In order to operate the integrated utilities management system the pilot sends commands to start up the Electrical Power System by hardwire interface in order to energize one of power buses from aircraft battery or external power sources. This allows energizing all LCUs and to continue system control via data bus.

6. POWER BUS PROTECTION.

Power buses consist of power wires with different diameters. Each of them is chosen according to the maximum current which can flow through the wire and can be protected by circuit breakers or fuses.

In order to provide protection from a power bus with a partial short to ground and to avoid use of fuses and circuit breakers the following method can be used.

The protection can be done by comparing of power bus input current with sum of all LCU current consumptions from the power bus. If input current of the power bus excees the sum of LCUs currents then the power bus is disconnected from power sources. Comparison is done by one of the LCUs which receives data concerning other LCUs current consumption via data bus.

7. COOLING REQUIREMENTS.

LCUs design shall provide normal operation continuously under all aircraft conditions without forced cooling because the Enviromental Control System (ECS) (which in turn is controlled and powered by the same LCU) can be non operative.

8. COMBINED ARCHITECTURE.

Some utility systems actually should be managed by their electronic control units when the manufacturer of mechanical or hydraulic parts is required to be responsible for complete system operation. For example, aircraft engines should be supplied with their electronic controllers which are usually installed on the engine.

In these cases such subsystems are treated by IUMS as electrical loads and sources of the system data, and the whole system combines both functional and area management.

9. WEIGHT ANALYSIS.

The proposed concept allows weight saving due to the following:

a. Weight reduction of control wires, because sensors and command devices are generally located close to their respective LCUs.

b. Weight reduction of power wires, because of following reasons:

- Energy flow "loops" can be reduced to a minimum. For example, the necessity of a pilot's overhead panel which usually creates many such "loops" can be eliminated.
- Maximum current peaks do not appear simultaneously for most of dynamic loads. Electrical power flows from the power source to the load mostly by the aircraft common power bus, enabling us to choose power bus cross-sections sized to the maximum peak currents load which appear simultaneously. This approach is useful even for loads with small power consumption, if the power wire cross-section cannot be reduced due to mechanical strength limitations.

The total weight of wiring and LCUs can be calculated according to following equation:

$$Q = \sum_{j=1}^{n} \{Qc \sum_{i=1}^{l(j)} Lc(i,j) + \sum_{i=1}^{m(j)} Lp(i,j)\ Qp(i,j) +$$

$$+ Lpb(j)\ [Qpb1(j) + Qpb2(j)] +$$

$$+ Qdb + Ql(j)\} \qquad (1)$$

where:

$Lc(i,j), Lp(i,j)$ = length of control and power wires respectively, connected to LCU number "j".

n = number of LCUs.

$Lpb(i)$ = length of power bus conductors from previous LCU to the LCU number "j".

Qc, $Qp(i)$ = control and power wires weights per meter respectively.

$Qpb1(j), Qpb2(j)$ = power bus conductors weight per meter for both power buses connected to LCU number "j".

$Ql(j)$ = weight of LCU number "j".

Qdb = weight of data bus wiring.

$l(j)$ = number of wires from sensors and command devices connected to the LCU.

$m(j)$ = number of power wires connected to the LCU.

Qp(i), Qpb1(j) and Qpb2(j) shall be chosen such that total voltage drop will not exceed permitted level for any electrical load. Optimization of power bus network can be performed for total weight minimization.

Cross sectional area S(i) of power bus conductor "i" shall be chosen so that:

$$Qpb = \delta \sum_{i=1}^{n} S(i)\ Lp(i) = \min \qquad (2)$$

where: Qpb = weight of power bus

δ = specific gravity of power bus conductors

The minimization can be done with the following limitations:

a) Limitation of maximum voltage drops on the power bus parts:

$$\rho \sum_{i=1}^{j} \frac{Lp(i)\ I(i)}{S(i)} \leqslant \Delta Vpb(j) \quad \text{for } j = 1 \text{ to } n-1; \qquad (3)$$

$$\rho \sum_{i=1}^{n} \frac{Lp(i)\ I(i)}{S(i)} = \Delta Vpb(n); \qquad (4)$$

where: $i=n$ = for LCU connected to the end of power bus.

$I(i)$ = maximum current of power bus conductor "i".

ρ = power bus conductors resistivity.

$\Delta Vpb(j)$ = maximum voltage drop on the power bus from power source to the LCU "j".

$$\Delta Vpb(j) = \Delta Vmax - \Delta Vl(j) \qquad (5)$$

where: $\Delta Vmax$ = maximum voltage drop on power wiring from power source to an electrical load (for example, $\Delta Vmax = 2v$ for $V = 28vdc$).

$\Delta Vl(j)$ = maximum voltage drop on the power wires from the LCU "j" to loads.

b) Power bus conductors thermal limitations:

$$S(i) \geqslant Smin[I(i)] \quad \text{for } i = 1 \text{ to } n; \qquad (6)$$

where Smin[I(i)] is a minimal cross section area for current I(i) of power bus conductor "i".

Linear approximation of expressions (3), (4) in range of S(i) limited by expression (6) and some reasonable maximum value permits the use of linear methodology for minimization of function (2) (power buses weight minimization).

Increase of number of LCUs reduces the length of local wiring Lc(i) and Lp(i) and, as a result, their weight in equation (1). In the same time it increases total weight of LCUs. In each case optimal number and location of LCUs can be defined. Example of IUMS location in aircraft is shown in Fig.8.

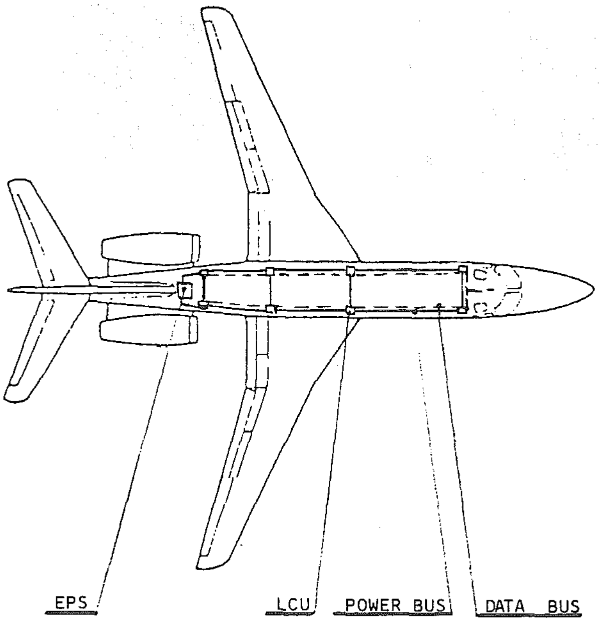


FIG.8 EXAMPLE OF IUMS LOCATION IN AIRCRAFT

Calculation provided for IAI's buisness jet "ASTRA" showed that use of IUMS for this aircraft resulted in total weight reduction is estimated as 124 lbs. For larger aircraft the weight reduction will be greater. In a time, further progress in electronic technology will reduce weight of LCUs and will increase reduction of total weight.

10. DEVELOPMENT AND MAINTENANCE COST.

All LCUs consist of standard cards and modules (central processing module, output circuits module, etc.). This reduces initial development cost in relation to development cost of completely different electronic and electrical unit in case of functional management. It also reduces the number of test equipment, spare parts and maintenance personnel, and as a result, reduces maintenance cost.

In order to provide interchangebility of LCUs, each LCU contains software packages of all LCUs, while necessary software packages are chosen using external identification pins.

Spare inputs and outputs in LCUs and possibility to install additional LCUs provide good flexibility for utility systems modification.

CONCLUSIONS

1. The proposed concept of utility systems integrated management can provide significant reduction of power and control wiring, and as a result significantly reduces systems total weight.
2. The proposed concept permits the improvement of utility systems fault-tolerance capabilities, their maintanability and flexibility, and to reduce initial development cost and installation cost.

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