

Agile Aircraft Installation Architecture In a Quick Reaction Capability Environment

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Abstract. Military mission systems are continuously upgrading equipment to keep pace with rapidly changing technology refresh rates and evolving global threats. Many of the programs that demand extensive changes are also demanding quick reaction capability, or QRC. It is increasingly challenging to quickly accommodate a mix of equipment without standardized physical interfaces, a wide range of cooling needs, and multiple power types. This paper focuses on a combined architecture for secondary power distribution, structural support, and environmental control that directly supports a mission system installation in a military acquisition context. An aircraft installation architecture that has the flexibility to rapidly adjust to changing power, weight, heat load, and space allocations could lower modification cost, reduce schedule, and lower risk.

Introduction

The United States is continually modifying its military aircraft to include both different and more electronic equipment. Customers are requesting faster integration times and increased flexibility for field changes and future modifications. This creates a need to understand how agility can be designed into the aircraft architecture to enable the quick reaction capability (QRC) customers expect. The challenge is to accommodate both the customer's known present day needs and the unforeseen future needs as technology refreshes. This paper focuses on a combined architecture of secondary power distribution, structural support, and environmental control that directly supports a mission system installation in a military acquisition context.

In the aircraft modification business, installing mission systems can be messy. The customer often wants the mission system installed yesterday, and the mission system requirements are often only partially defined. The boxes that require integration can be MIL SPEC or COTS, small or big, bottom or side mounted, and you often don't know what you are going to get until the project is already behind schedule. As the boxes are integrated, there are always interface requirement changes and last minute box additions.

Understanding QRC and Agility

To ensure a mutual understanding of how the terms QRC and agile are used throughout this paper, the context of these terms will be discussed. It should be noted that there is no universal definition, and the definition can shift depending on the context of use.

QRC. The term QRC is an acronym that stands for quick reaction capability. The term is used to describe any phase of the product life cycle that is accelerated to provide a faster than normal response. The term QRC is primarily used in the context of military acquisition and logistics, but

can be applied in a generic sense to anything that requires a quick response. Examples could include QRC acquisition process, QRC product development, QRC maintenance, QRC equipment supply, and many others. For the purposes of this paper, QRC refers to a streamlined acquisition process in which the customer is primarily interested in fielding a new technology in an existing aircraft in the shortest time possible.

Agile. The term agile has many meanings, depending on the context of its use. Here the word agile is defined as being proficient at change, with proficiency measured in time to change, cost to change, quality of change, and scope of change in accordance with (Dove 2001, 71).

Agile Design Principles. According to (Dove 2001, 140) ten design principles enable a system to have a proficiency at change, as shown in Table 1.

Table 1. Agile Principles

Reusable
Self Contained Units (Components) – Components are distinct, separable, self-sufficient units cooperating toward a shared common purpose.
Plug Compatibility – Components share defined interaction and interface standards; and are easily inserted or removed.
Facilitated Reuse – Components are reusable and replicable; responsibilities are specifically designated for inventory management, module maintenance, and upgrade of module inventory.
Reconfigurable
Flat Interaction – Components communicate directly on a peer-to-peer relationship; parallel rather than sequential relationships are favored.
Deferred Commitment – Component relationships are transient when possible; decisions and fixed bindings are postponed until immediately necessary; relationships are scheduled and bound in real-time.
Distributed Control and Information – Components are directed by objective rather than method; decisions are made at point of maximum knowledge; information is associated locally, accessible globally, and freely disseminated.
Self Organization – Unit relationships are self-determined; unit interaction is self-adjusting or negotiated.
Scalable
Evolving Standards – Frameworks standardize inter-component communication and interaction, define component compatibility, and are monitored/updated to accommodate old, current, and new components.
Redundancy and Diversity – Duplicate components provide capacity right-sizing options and fail soft tolerance; diversity among similar components employing different methods is exploited.
Elastic Capacity – Component populations in response-able systems may be increased and decreased widely within the existing framework.

The Needs That Drive an Agile Aircraft Architecture

The problem addressed in this paper is focused on the installation architecture that directly supports a mission system installation in a military acquisition context. The problem is viewed at three levels as shown in Figure 1.

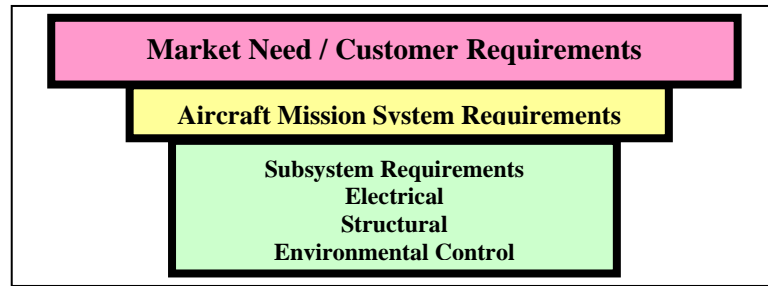


Figure 1. Hierarchical Requirement

The market is driven by the customer's need for the latest technology. Technology advances are creating new mission systems at an increasing rate, driving the demand for QRC. Personal experience has seen projects that routinely took two years being pushed to deliver in eighteen months or less. The goal is to shorten the completion time without compromising quality; however, there is a limit to the ability to drive down schedule by merely working harder, longer, or with more people since there are only twenty four hours in a day and only so many people can work inside an aircraft at one time. With the US military working hard to reduce their internal acquisition process, there is a strong expectation for industry to provide a faster turn around time on the deliverable product. For example, the US Army has expressed the need for intelligence surveillance reconnaissance (ISR) capabilities to be robust, scalable, and tailorable in a QRC environment (Blair 2007, 6). The Air Force stated that QRC capabilities will continue to be a challenge since their success is measured by the Air Force's ability to rapidly adapt its EW capabilities (U.S. Air Force 2007, 3). Although the military is working to foster quick reaction capabilities, there is also a strong focus on making sure the solution is agile. For instance, the Army is developing a system called DCGS-A, or Distributed Common Ground System-Army. The Army's DCGS-A capability goals of modularity, scalability, interoperability and distributed operation reflect agile design principles (Abercrombie 2007, 13). The military is also working to develop airframes that are flexible enough to support multiple mission systems. Joint Strike Fighter (JSF) was envisioned as a multi-role aircraft that could handle the weapon system needs of the Air Force, Navy, and Marines (F-35, 2009). The requirements at this level are no longer viewed as a discrete upgrade capability, but rather a continuous fast upgrade capability.

Once the market need is established, a series of derived requirements are created at the aircraft mission system level. Aircraft requirements cover inherent aircraft performance parameters such as range and altitude, and mission system performance parameters like radar coverage, data link rates and other functions. As this paper will focus on the architecture for enabling QRC installation, we will assume certain pre-conditions: a mission-appropriate aircraft has been chosen with sufficient on-board capacity for equipment space, power, cooling, and weight. Let us also assume that the customer has defined the general mission system capability requirements, but details like exact number of boxes, size, weight, power, and cooling needs are only partially known. In the aircraft modification business, these are typical circumstances that an aircraft systems engineer encounters. Box definition can be in flux during the bidding phase of a program and many times are not resolved even up to the preliminary design review. Even if the boxes are defined early in the design lifecycle, box changes could occur at integration or test. We no longer have the luxury of watching technology develop and slowly planning the aircraft integration for these emerging technologies. Often times the technology arrives as an unexpected surprise.

The subsystem level is divided into three parts: secondary power distribution, structural support, and environmental control. These three subsystems are required to support a mission

system installation. Each of these subsystems face agility issues that must be answered by the mission system installation architecture. Secondary power distribution must address power conversion and circuit protection. The power distribution system will need to convert the aircraft generated power to a form that is usable at the box level. The power distribution system will also need to provide circuit protection to protect the wiring from over current conditions. To make the power distribution system agile, the system must be scalable to handle increases and decreases in power usage, and be reconfigurable to handle changes in power type or circuit protection levels. Structurally, the proposed solution will need to be capable of withstanding the inertial loads such as shock, vibration, and sustained G-loads. To make the system agile, the rack must also accommodate boxes of varying size, shape, weight, and mounting provisions without requiring a new structural design for each mission system box change. The environmental control system will need to provide cooling to each heat load at the correct temperature and flow rate while properly disposing of the waste heat to prevent reheating of adjacent boxes. To provide agility, the cooling system will need to accommodate a continually changing mix of heat loads and required environments. The cooling system will also need to accommodate boxes with the cooling intakes on the front, rear, top, or bottom.

The essence of the problem comes down to taking a partially defined mission system and integrating it into the aircraft quickly. The partially defined mission system is an eclectic mix of boxes without standardized physical interfaces, a wide range of cooling needs, and multiple power types. The boxes consist of all sizes, weights, and shapes. Often the boxes can not be modified, so the installation architecture must accommodate the box variations. Normally this involves time consuming custom engineering and fabrication for every box installation. To respond quickly on a QRC program, time intensive customization needs to be minimized.

Modular Concepts in Use Today

Systems engineering is constantly building on existing technologies and combining them in new ways to meet emerging needs. In this case, the aircraft installation architecture can benefit from the modular concepts employed in other businesses such as unit load devices used for quick-load air cargo, data centers that need to expand and contract to match enterprise needs, and modular rack systems used for military navel electronic systems, as shown in Figure 2.

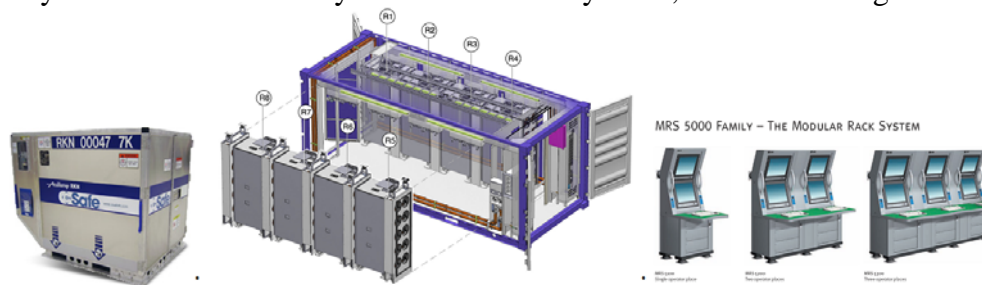


Figure 2: Unit Load Devices (ULDs), Data Centers, Navy Ship Modular Racks

A unit load device (ULD) is a container with an integral pallet that can directly interface with the cargo restraint system on an aircraft. When installed the ULD becomes an integral part of the aircraft structure. Some ULDs such as the Acutemp RKN shown in Figure 2 even provide self-contained environmental control (AcuTemp 2009). Since the units are modular they can be loaded with cargo prior to the aircraft arriving. These devices have been used for years in the air cargo industry by companies such as UPS and FEDEX. These companies have a critical need for getting cargo on and off the aircraft in as little time as possible. On a QRC program, time to load

mission equipment is also critical. By utilizing the ULD cargo restraint concept, modular racks could be pre-loaded with mission equipment before the aircraft arrives, saving valuable modification time. As with ULDs, modular racks should have a common interface with the aircraft cargo restraint system.

Data centers offer multiple concepts that can be utilized in an agile aircraft architecture. Data centers are designed with a twenty year lifespan but are seeing server replacement cycles every three to four years. Data center designers are looking for ways to make a cost effective data center that provides scalability, efficiency, and easy maintenance (Liebert Corporation 2006, 1). Data centers have traditionally used racks as a modular medium for expanding structural mounting space for equipment, but have struggled with scaling the power and cooling that must accompany an expansion. Sun Micro Systems (2009) has taken the idea of modularizing beyond just a structural rack and has included wiring and cooling in their modular solution. As seen in Figure 2, Sun Micro Systems has adapted a shipping container to hold eight equipment racks complete with wiring, structure, and environmental controls. The concept here is that power, cooling, and structure must come as a unit rather than as separate parts to obtain a readily scalable system that can also adapt to rapidly changing equipment configurations. Data center designers have also been challenged by the increase in heat density of racks. Server racks have increased in heat load from approximately 1000 watts per square foot in the year 2000 to over 3000 watts per square foot in the year 2008. Liebert Corporation (2006, 6) recommends two adaptive cooling methods that are applicable to an aircraft installation. Method one, as shown in Figure 3, is the use of hot and cold aisles as recommended by the American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE). This method allows cold air to mix evenly in the equipment and ensures the hottest air is returned to the cooling system heat exchangers. The hotter the air entering the cooling system the more efficiently it can reject heat to the ambient environment. The second method is to bring the cooling closer to the rack, cutting down on the infrastructure required to supply a rack with cooling, and allowing the cooling to scale up in modular sections as equipment needs increase.

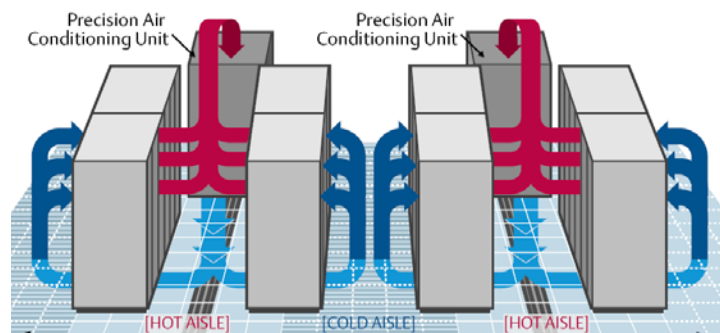


Figure 3. Hot Aisle and Cold Aisle (Liebert Corporation 2006, 7)

Digital Reality Trust, a provider of flexible, reliable and cost-effective datacenter solutions, has also been exploring the idea of modularization. In a report by (Miller 2009), it was stated that “Digital Reality is using computer models to design the facility and off-site construction of components in pre-fab modules that can be assembled later on site. The key is combining standardization and the ability to customize elements of the process.” Digital Reality is using the concept of connecting pieces together as opposed to constructing them on site. The process of constructing a data center normally requires one to two years, but is reduced to less than 28 weeks using Digital Reality’s process. This concept can be applied to aircraft to allow an accelerated mission system integration.

The naval industry has been successful in using the concept of modular racks. Companies like Dinrack and Hagenuk Marinekommunikation build modularized racks that can be installed on either surface vessels or submarines. Shown in Figure 2, the Hagenuk Marinekommunikation (2009) MRS 5000 modular rack system is designed to allow easy disassembly into three major subsections: the display section, the desk section and the equipment section. The split design in combination with the modularity allows for flexible individual configurations and customization. The split design also supports easy installation into areas with limited space for access. Aircraft also have limited space for installation access and would benefit from this type of architecture. A split rack would aid installation and allow scalability by installing only the subsection of rack that is needed. This facilitates the reuse of rack designs by allowing designers of small aircraft to select a smaller subsection of the same racks that larger aircraft use. By using a common rack design across multiple aircraft, part logistics and manufacturing could be improved to provide QRC for unplanned installations.

Matching the Solution to the Need

To start, the solution will be described at an abstract level before adding the details of a proposed implementation. It is proposed that the architecture utilize a three level design as shown in Figure 4. A grouping of equipment makes up a zone module, a grouping of zones makes up a rack, and a group of rack modules creates a unique mission system that is connected to the existing aircraft via the installation infrastructure.

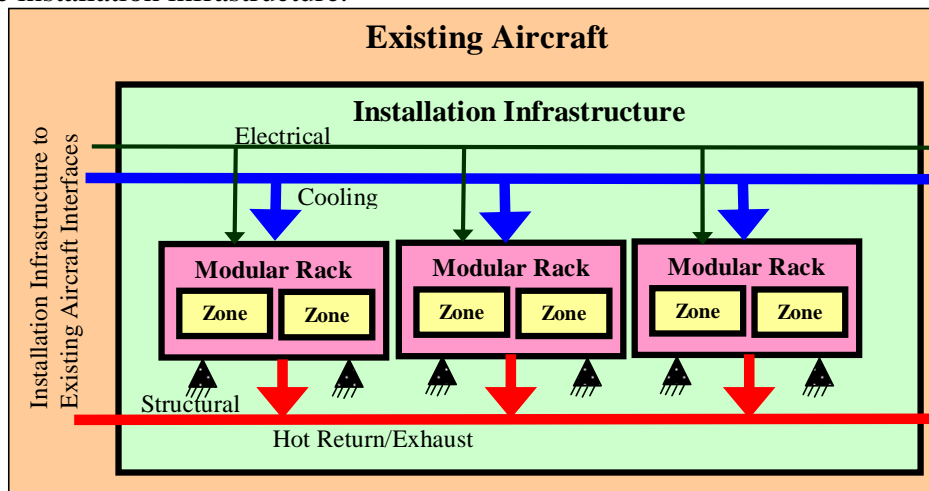


Figure 4. Architectural levels

The architectural levels provide several functions. The infrastructure level provides the means to distribute power and cooling from the main aircraft source to each of the racks. The infrastructure level also provides the main structural interface between racks and existing aircraft structure. Racks are stand alone systems that can be added to and subtracted from the infrastructure to customize the available space for mission system equipment. Aside from the rack's dependence on power and cooling sources, a rack provides all of the equipment installation needs. Zones provide a level of customization to each rack that allows equipment with varying needs to be segregated. The philosophy for creating architectural levels is to reduce the number of interfaces, isolate changes to the lowest level, and prevent time consuming incidental changes to adjacent equipment. This requires the architecture to be a parallel design and avoid sequential dependent relationships among box installations. It also requires the interfaces between architectural levels to

be minimized.

Since every aircraft is unique, the installation infrastructure requires custom interfaces to connect to the main cooling source, electrical source, and existing aircraft structure to standardized rack level interfaces. In some cases, there may be more than one cooling source or multiple generators. Ideally, the infrastructure would combine the multiple sources before splitting the utilities off to each rack in parallel. This combination would provide a level of redundancy to the system. A good example of this is when multiple generators are tied to a single electrical bus. By utilizing a parallel approach to the infrastructure design, there is a natural redundancy that allows operation to continue with the loss of a power, structure, or cooling source. The parallel approach also allows racks to be designed as modular units.

To accelerate the installation process, equipment racks could be modularized units that can be removed, reconfigured, and reinstalled without affecting adjacent equipment. Traditional thinking sees racks as structural items that only provide mounting interfaces for equipment. To fully modularize a rack, the rack system boundary must be expanded to provide a more holistic system view that includes wiring and cooling. Imagine an equipment rack that could be removed as a stand-alone unit and retain full functionality if the cooling and wiring interfaces were connected. Also, when a rack is removed, the remaining racks retain full functionality.

Within a rack system, variability in box requirements is addressed by utilizing adjustable rack zones. These zones can be expanded or contracted depending on the equipment size, cooling, or wiring needs. Rack zones segregate boxes for the purpose of supplying the unique needs of one box without affecting the needs of adjacent boxes. This is analogous to the way a refrigerator has a freezer, produce compartment, and the general refrigerated area. The idea is to provide only what is needed to each box, no more, no less.

Guidelines for Agile Aircraft Installation Architecture

The abstract architectural levels presented in Figure 4 are helpful at a high level, but they need to be given some practical steps for implementation. The proposed methods below are suggestions for how the architectural levels could be implemented, but are by no means the only way. Technology, fresh ideas, and market need will undoubtedly drive improved methods in the future. As shown in Table 2, power, weight, space, and cooling interfaces need to be allocated and managed consistently across racks to maintain plug compatibility between the racks and the installation infrastructure. The idea is to allow maximum flexibility within predefined limits while maintaining a minimum set of standardized interfaces. Without predefined limits, a rack could be too heavy for the aircraft floor structure or draw too much power.

Table 2. Rack Standardization Parameters

Parameter	Nature of Standard
Space	Racks shall be designed in preset widths, depths and heights.
Power	Each rack shall have a maximum kW equipment load rating. For racks with multiple power types, such as 115 VAC 400 Hz and 28 VDC, limits should be set on each type.
Weight	Each rack shall have a maximum equipment weight rating.
Cooling	Each rack shall rate the kW cooling capacity at a specified exhaust temperature.
Physical Interfaces	Rack mounting provisions, cooling connections, and electrical connection interfaces shall have standard locations and configurations.

With a standardized rack interface established, work can be performed in parallel on both the rack and the installation infrastructure, thereby reducing mission system installation time.

Although the installation infrastructure must be modified, this would typically be a one time event during the original modification. Once the installation infrastructure is installed, rack modules can be removed and re-connected on multiple platforms without further modifications as illustrated in Figure 5.

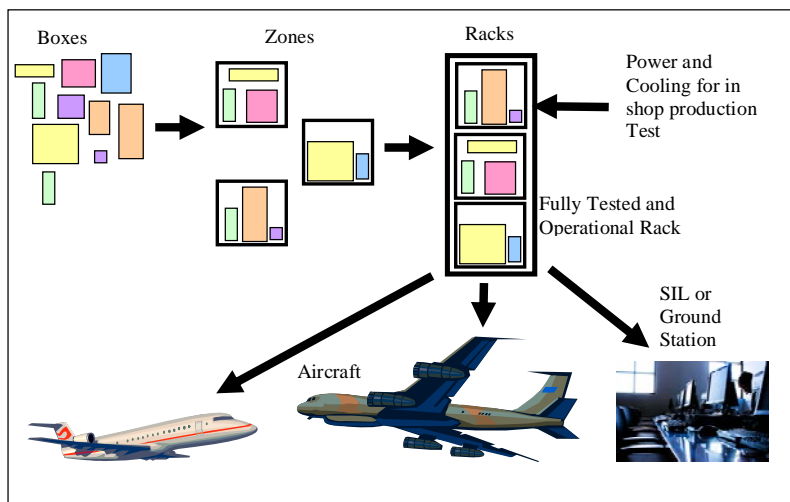


Figure 5. Modular Installation

Aircraft-generated power must be converted to supply equipment with three common power types. Racks can have a modular approach to secondary power distribution using one of two methods. Method one converts the aircraft-generated power within the installation infrastructure level and supplies each rack with three separate interfaces, one for each equipment input power type. The benefit is that racks would be interchangeable between aircraft with different generated power types. The drawback is three interfaces are required rather than one. Method two converts aircraft-generated power within the rack. The benefit is that only a single power interface is required; however, racks are only interchangeable between aircraft with the same generated power types, and small power conversion equipment would be inefficient and take up valuable rack space.

Once the power is converted to the proper form it must be distributed to each piece of equipment. Traditionally a breaker panel at a centralized location distributes power to each box. Since circuit breakers are sized to protect the wiring, each box typically requires its own circuit breaker creating an interface for every box and numerous wire routing paths. With some aircraft containing over 1000 boxes, wire routing can become a large modification effort. To reduce the number of interfaces, decrease wire routing effort, and allow rack modularity, it is proposed that the secondary power distribution for rack mounted boxes be moved from the aircraft to within the rack itself. A single breaker would provide power to the rack, and a secondary breaker panel within the rack would distribute power to each box. This creates modularity, but reduces the convenience of having a centralized circuit breaker panel within reach of an operator. This inconvenience can be eliminated through the use of solid state power controllers, or SSPCs. SSPCs combine the function of a relay and a circuit breaker into a single device that is controllable through a data bus (Moir and Seabridge 2008, 205). Not only can SSPCs be remotely operated, they allow the power trip point curve to be programmed rather than requiring a physical change to the breaker wiring. This benefits a QRC program by simply re-programming an SSPC instead of changing a breaker out and routing a new wire the entire length between the breaker box and the rack. Figure 6 illustrates the difference between traditional rack power distribution versus the proposed agile rack

power distribution.

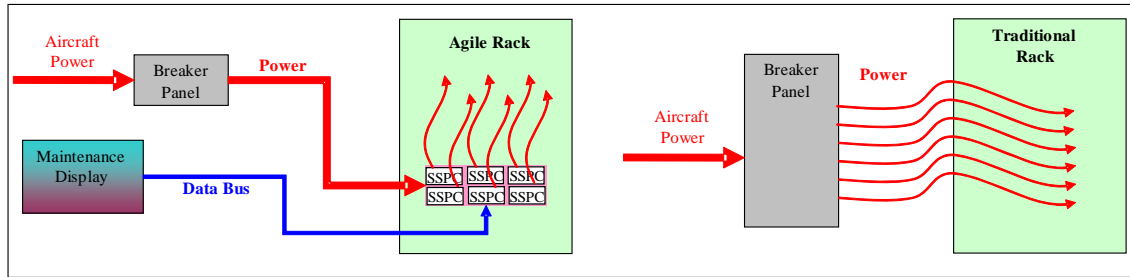


Figure 6. Agile versus Traditional Power Distribution

Structurally, the rack must accommodate boxes of varying size and shape by increasing or decreasing the available rack volume. With a set of constant rack dimensions, volume can be scaled by adding or subtracting to the quantity of racks. The naval concept of allowing easy disassembly into major subsections to aid installation in space restricted areas would be beneficial, but the final assembled dimensions should remain constant. Since not all aircraft can accommodate a full size rack, classes of racks could be established. Just like ULD shipping containers used by FEDEX, small aircraft use different ULD size standards. The rack must also provide a standardized mounting structure to attach to the installation infrastructure level. The mounting structure could have a pre-set maximum weight rating to allow for a range of box weights. A drawback to a pre-set weight is that the rack must be designed for a worst case fully loaded rack and partially loaded racks would be oversized adding to the aircraft's gross weight without functional benefit. A standardized rack mounting interface can be designed either as a single cantilevered base connection or with multiple connection points at both the base and top of the rack. A recommended approach would be to design the rack to hold a lower max equipment weight using a single base connection, and then have provisions for a secondary overhead connection for platforms requiring higher equipment weight ratings. By using this approach, the rack structure could be a lower size and weight while still having the flexibility to accommodate a larger range of inertial loads or higher equipment weights. To allow for redundancy and damage tolerance, a secondary load path can be obtained by connecting adjacent racks. The secondary path would only be used if the primary load path at the base or top of the rack failed. This allows for added safety while still maintaining the rack as a self-contained modular unit.

To accommodate boxes of varying size, shape and mounting location, an adjustable intra-rack structure is suggested. This could consist of a variety of pre-made standardized parts that can be interconnected without additional fabrication. Some of the standard rack parts could be adjustable height shelves that have a matrix of mounting holes for a surface. The matrix of holes attach to brackets that can be adjusted to line up with a variety of box interface locations. Another standard part may be rail mounts that could be attached in a grid pattern to accommodate any size rail mount box. There are many ways an adjustable intra-rack structure could be implemented, but the major architectural philosophy is to have standardized parts that can be interconnected within the rack to provide a fully custom mounting arrangement. The benefit would be that parts could be pre-made and available for QRC installations without knowing the final mission system box configuration. This maximizes the window for box design and defers commitment to a fixed intra-rack structure until aircraft delivery.

Cooling is a vital part of the rack modular design but difficult to implement in a scalable manner within the confines of an aircraft fuselage. Compared to wiring, air ducting is larger and more difficult to route effectively. For this reason, the solution presented attempts to mitigate the

rerouting effort of any existing aircraft ductwork. The proposed cooling architecture is really a combination of a cold air distribution subsystem that gets cold air from the aircraft source to the boxes, and a hot air exhaust subsystem that must dispose of the waste air. Although much more compact, this is similar to the hot aisle/cold aisle method used in data center design.

There are many types of cooling sources, but they all eventually end up as either air or liquid at a specified flow, pressure, and temperature. Since most transport aircraft supply cold air from a centralized overhead air duct this will be the primary interface discussed. The aircraft infrastructure level must adapt the existing cold air supply to match up with a rack level common interface. Supplying each rack in parallel is recommended so that the addition or removal of a rack doesn't cause design changes to adjacent racks.

Once the air is supplied to the rack interface, the challenge of getting the cooling to each equipment box must be accomplished. Since the mix of equipment boxes is constantly changing, the distribution will need to accommodate boxes with the cooling intakes on the front, rear, top, or bottom. It is proposed that the rack cooling be a semi modular section of the rack as shown in Figure 7. A narrow rectangular plenum duct running the full height and depth of the rack will be connected to the side of each rack. The plenum duct will have a matrix of variable size openings that will allow cooling flow to be adjusted, to any portion of the rack. For front intake boxes, openings can be adjusted at the front of the plenum. For rear intake boxes, openings can be adjusted at the rear of the plenum. For boxes with top or bottom intakes, hollow shelves could be used. The shelves would mate with a section of the plenum matrix on the right and left of the rack to fill the shelf with cold air. The shelf would then use its own matrix of variable openings on the top and bottom to supply cold air to the equipment intakes. The use of rack zones as an architectural level can help to efficiently use available cooling. Non structural partitions could be used to segregate the environment of boxes with differing cooling needs. By doing this, a zone can be cooled only as much as the equipment needs.

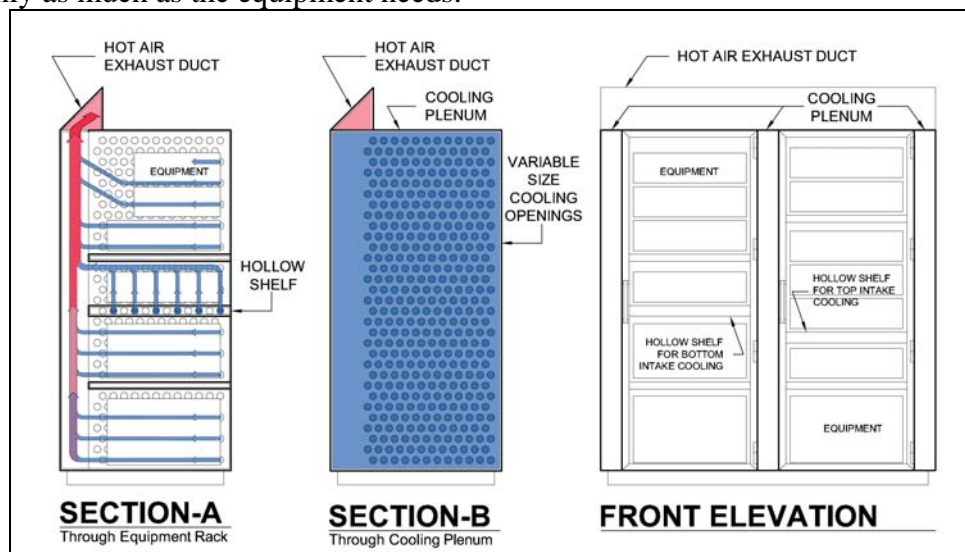


Figure 7. Modular Rack Cooling

The benefits of the proposed cooling supply architecture are as follows. The use of the plenum allows the existing aircraft cold air supply to interface effectively at the top, bottom or rear of the plenum. This helps to reduce the rerouting effort of any existing aircraft cooling ductwork. The architecture also has the benefit of being scalable in two ways. First, cooling comes with each rack, so as racks are added, the cooling scales proportionally. Second, as boxes are added or subtracted

to a rack, the matrix of variable size openings allows cooling to be scaled up or down without redesigning the rack structure. Finally, there is the use of rack zones, which can be moved to optimize the use of cooling without additional fabrication of rack structure.

Hot equipment air must be exhausted overboard or re-cooled before being introduced back into the main cold air supply duct. Most equipment is rear exhaust, and heated air has a lower density causing it to naturally rise to the top of the rack. Because of this, the ideal location for most hot air exhaust systems is the top and rear of the rack. The proposed exhaust method is to attach triangular shaped duct to the top, rear of the rack as shown in Figure 7. The duct is triangular in shape to accommodate the curvature of a round fuselage, and would have openings along the bottom of the duct to draw air out of the top of the rack. It should be pointed out that unlike traditional systems where the ducting is separate from the rack, the exhaust ducting should come as an integral part of the rack. The benefit is that as racks are added, the exhaust ducting is scaled proportionally.

There is a trend of increasing heat loads and heat densities. In some cases, the magnitude and density of heat loads has surpassed the ability of the more common forced air cooling systems described above. The demand is on the rise for liquid cooling systems to address increases in heat density (Liebert Corporation 2006, 8). The plenum design, described above, allows a means to convert the interior of the plenum into a liquid distribution space. Similar to air, a main liquid line coming from the aircraft cooling source can interface at the plenum wall. The plenum would no longer serve as an air duct, but as space for distributing and controlling liquid to boxes within the rack. This conversion could be scaled on a rack by rack basis as cooling demand increases. The benefit is that the architecture will accommodate the functional change of adding liquid cooling, but retain the same form and fit used for modular racks.

Example Application of an Agile Installation Architecture

Let us look at the proposed architecture in an example application. Assume a customer has just requested a new Intelligence Surveillance Reconnaissance (ISR) mission system to be installed. The customer has several aircraft which will be arriving from the field in the near future, and has designated the program QRC. It is also understood that several of the aircraft will receive future variants of the system, but there is no definition yet. The general mission system capability requirements are defined, but some of the details of the box interfaces are unknown.

An engineering team determines they will need nine class B racks to fit the immediate needs, but plans for twelve racks to accommodate the upcoming undefined growth. Since racks have standardized interfaces, the engineering team divides into two groups. Group one begins researching the aircraft and designing the installation infrastructure. Group two lays out the zones of the intra-rack configuration while production crews immediately begin assembling the main rack structure from pre-stocked standardized parts,. With modularized rack architecture, modification activities occur in parallel.

Once the intra-rack design is complete, production finishes the assembly of the rack, which includes connecting the adjustable shelves to the main rack structure, adding the zone partitions, setting the adjustable cooling openings, connecting and programming the SSPCs, and mounting the boxes. The racks are now complete and delivered to the system integration lab (SIL) for testing. The SIL is constructed with the same class B rack mount interfaces that are being applied to the aircraft. By connecting up to the power, structure, and cooling interfaces, the rack is tested for form, fit, and function before the aircraft arrives.

When the aircraft arrives, production begins on the installation infrastructure to create the standardized rack interface. With the installation architecture complete, the racks are installed and

the power and cooling connected. Given that the racks were already tested in the SIL, problems normally found during aircraft ground and flight testing will likely be minimized. Since ground and flight testing are typically critical path tasks on the delivery schedule, reducing issues for these efforts makes improves quick reaction capability. Decoupling the rack design from the aircraft installation infrastructure maximizes aircraft availability and minimizes the down time during a mission system upgrade. Work can begin on the next variant of the mission system at any time. Even without the aircraft being present, the racks could be constructed and the mission equipment installed and tested.

In a QRC program, schedule is paramount. Based on the example above, Figure 8 illustrates the schedule advantages of an agile architecture over a more traditional architecture. By working the racks and aircraft modifications in parallel, schedule reductions of up to 30% appear possible. Even greater schedule benefits could be achieved on follow-on variants since the aircraft is already modified to accept plug and play modular racks.

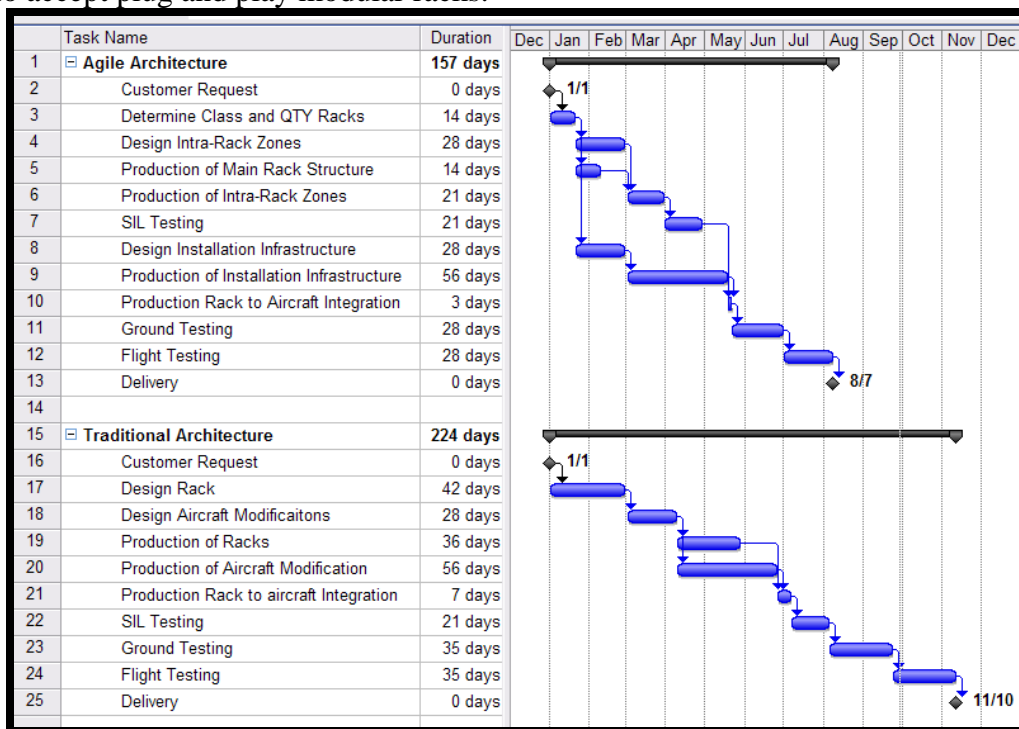


Figure 8. Agile vs Traditional Architecture Schedule Comparison

The cost is also affected by the architecture. The cost can be categorized into engineering labor, production labor, and material costs for comparing an agile architecture to a traditional architecture. An agile architecture has a one-time upfront cost to design a standardized class of racks. It is anticipated that this effort is roughly similar to the traditional architecture cost of building a new rack, so we will not include this element in the additional categories of cost explored.

Engineering labor for an agile architecture is anticipated to be less for the first installation. The reduction in engineering cost is the result of the main rack dimensions, stress analysis, and interfaces already being pre-defined by the class of rack. The engineering labor is reduced to arranging intra-rack zones rather than designing entire racks from scratch. For follow-on variants of the mission system, the engineering effort is reduced even further to a subset of the intra-rack zone arranging that was accomplished during the first installation.

Production costs for the first installation of an agile architecture are anticipated to be equal or less costly than a traditional architecture. Since modular racks use many common parts and may be used on multiple aircraft types, there is a possibility for economy of scale in the manufacturing process that traditional racks don't have. Standardizing racks lowers the tooling setup costs, decreases learning curves, and allows time for process improvement. Since racks are modular and capable of being tested in the shop prior to aircraft integration, errors can be found earlier in the process and therefore reduce the number of more costly downstream errors found during ground and flight testing. For follow-on variants of the mission system, production costs are greatly reduced since the effort to rearrange equipment should not require any extensive rack fabrication.

Material cost for the first installation is anticipated to be roughly equal for low quantities, but may have opportunities for lower cost due to economies of scale. For follow-on variants of the mission system, material costs could be minimal since the racks would simply be re-arranged rather than requiring new materials.

Manifesting Agile Principles

This section summarizes the manifestation of agile principles in the proposed architecture and the benefits they provide.

Self Contained Units. Racks are self contained units that can be inserted or removed efficiently without affecting adjacent equipment or racks. The proposed rack system provides a more holistic system view that includes wiring and cooling as part of the rack unit. Racks can be pre-built and tested in the shop without an aircraft present. This reduces the testing, trouble shooting, and rework that would need to be accomplished while the aircraft is down for maintenance, thereby maximizing aircraft availability to the customer.

Plug Compatibility. Standardized rack interfaces allow rack modules to be removed and re-connected on multiple platforms, and allow parallel work to be performed simultaneously on both the aircraft and the racks.

Facilitated Re-use. Minimal standards facilitate reuse of boxes and racks by streamlining the assembly and disassembly of rack configurations and racked equipments, and readily moving racked equipment between SIL and aircraft installations.

Flat Interaction. Rack structure, cooling, and power is provided in parallel allowing racks to interface the aircraft resources directly rather than through a sequential dependence. This allows a failure or removal of one rack without affecting another rack's operation.

Deferred Commitment. Since rack cooling can be adjusted, power trip points can be programmed, and mounting can be easily re-arranged, equipment installation decisions can be deferred until maximum box definition is available.

Distributed Control and Information. Power and cooling control is localized within each rack rather than centrally controlled, minimizing wire runs, wiring effort, ducts, and ducting effort.

Self Organization. Self organization is not manifested in the agile architecture currently proposed. Future opportunities might exist, for instance, in dynamic load balancing in response to cooling anomalies.

Evolving Standards. Rack interface standards can evolve to incorporate new interfaces like liquid cooling, with timely anticipatory evolution a designated and continuous job responsibility of process management.

Redundancy and Diversity. Differences in box sizes and cooling-channel locations are accommodated with a limited variety of standardized rack-assembly modules, which can be configured to structurally accommodate multiple boxes of both similar and different sizes; and to

accommodate multiple boxes of both similar and different cooling entry and exhaust points.

Elastic Capacity. Racks can be inserted and removed as needed, and the mounting space, power available, and cooling available will scale proportionally. Internal to the racks, the cooling can be adjusted to match the head load, and circuit protection trip points can be programmed to accommodate a range of power requirements.

Conclusions

In a QRC environment, the market need is for quick integration and deployment of the latest technology. A key metric for measuring success on a QRC program is time-to-change. An aircraft installation architecture that has the flexibility to rapidly adjust to changing power, weight, heat load, and space allocations during modification has significant advantages to meet this need. To accomplish this, a three-level architecture consisting of zone modules, rack modules, and an installation infrastructure is proposed. This three-level approach reduces the number of interfaces, isolates changes to the lowest level, and prevents time consuming collateral changes to adjacent equipment. By standardizing and reducing the number of interfaces, the design consists of self-contained modules, which allows concurrent design and production, often before an aircraft arrives, reducing schedule as a result.

Though clear advantages can be seen in the proposed agile architecture, they have to be weighed against potential disadvantages. A modular rack may weigh more since the weight is driven by designing to the max potential weight of the rack class rather than the actual equipment installed. Also, modular racks may not be beneficial in small or odd shaped compartments of the aircraft such as tail cones, baggage compartments, or nose cones. These areas are typically unique to each aircraft type and may require a custom class of rack. The proposed methods described in this paper suggest some ways agility could be implemented to improve QRC programs, and are intended to display architectural concept and potential benefits worthy of further exploration. This article outlined an approach unlikely to be accomplished in one step, as customer agreement and unification across multiple company work disciplines are required. To mitigate this transition, the concepts can be implemented in incremental steps as part of a long term agile upgrade. By integrating smaller steps into new bid proposals, the expectation is that small successes will lead to an accelerated demand for more.

References

- AcuTemp (2009). Acutemp RKN product data sheet.
http://www.acutemp-rkn.com/pdf/CSafe_ProductSheet_FINAL_72309.pdf (accessed Aug 31, 2009)
- Abercrombie, Henry E. 2007. DCGS-A - Lessons Learned Developing the Army's Premier Intelligence, Surveillance and Reconnaissance (ISR) Platform. PB70-07-02 Army Acquisition Logistics and Technology AL&T April-June 2007 Putting Better Technology Into Soldiers' Hands Faster. http://asc.army.mil/altmag/default_previous.cfm?issueYear=2007&issueMonth=2_AprMayJun
- Blair, Edward T. DCGS-A. 2007. Creating the Army's Intelligence, Surveillance and Reconnaissance (ISR) Net-Centric Enterprise System. PB70-07-02 Army Acquisition Logistics and Technology AL&T April-June 2007 Putting Better Technology Into Soldiers' Hands Faster. http://asc.army.mil/altmag/default_previous.cfm?issueYear=2007&issueMonth=2_AprMayJun
- Dove, Rick. 2001. Response Ability: *The Language, Structure, and Culture of the Agile*

- Enterprise*. New York: John Wiley and Sons Inc.
- F-35, Joint Strike Fighter Program Office. 2009. Program Overview .
<http://www.jsf.mil/program/> . (accessed August 26, 2009).
- Hagenuk Marinekommunikation. 2009. Modular Rack System MRS 5000. Component data sheet.
http://www.hmk.atlas-elektronik.com/fileadmin/Objekte/Hagenuk_HMK_/pdf-downloads/DbI_JUL2009/MRS_5000.pdf. (Accessed September 3, 2009)
- Liebert Corporation. 2006. Blade Servers and Beyond: Adaptive Cooling for the Next Generation of IT Systems. A white Paper from Experts in Business-Critical Continuity.
<http://www.liebert.com/common/ViewDocument.aspx?id=98> . (accessed September 1, 2009)
- Miller, Rich. 2009. *Plug-n-Play Data Centers, Built to Order*.
<http://www.datacenterknowledge.com/archives/2009/05/04/plug-n-play-data-centers-built-to-order/>. (accessed October 3, 2009)
- Moir, Ian, Allan Seabridge, 2008. Aircraft Systems mechanical, electrical, and avionics subsystem integration Third Edition. West Sussex, England. John Wiley & Sons Ltd.
- Sun Microsystems. 2009. Containerized Data Centers Lower Capital and Operating Costs. New Options with Sun Microsystems and Active Power Containerized Datacenter Solutions White Paper February 2009. <http://www.sun.com/products/sunmd/s20/index.jsp> (accessed August 15, 2009).
- U.S. Air force. 2007. Electronic Warfare (EW) Operations. Air Force Instruction 10-706, 30 November. <http://www.e-publishing.af.mil/?txtSearchWord=10-706&rdoFormPub=rdoPub>

Biography

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