Establishing Qualification Zones in a Core System

A Pattern for Rapid Deployment of Capabilities to a Previously Qualified Core System

Air Force FACE™ TIM Paper by:

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Executive Summary

The Future Airborne Capability Environment (FACE) approach has improving the speed-to-field as one of its business objectives. This objective is also one of the primary goals of the Crew Mission Station (CMS) project and the Rapid Integration Framework it inspired (Edwards, Price, & Mooradian, September, 2018).

One area of schedule impact that can drastically affect speed-to-field is the qualification of an avionics system that supports the capability being deployed. The FACE™ Technical Standard is principally concerned with software capabilities, however software must be deployed on some hardware system and the addition of any software must be viewed as an impact to the system that supports that software.

CMS utilization of DO-297 (RTCA, Inc, November 2005) Integrated Modular Avionics (IMA) reduces qualification efforts through the definition of a Core System (IMA Platform) and separate Capabilities (IMA Applications) These capabilities, if procured from the FACE Registry or from another prior development, could already include qualification artifacts.

Ideally, deployment of a capability with no airworthiness concerns (DAL-E) should have no airworthiness activities for deployment. Similarly, a capability with a function assessed at DAL-D should be deployed without impact or retest of higher DAL capabilities. The development of a core system designed to accommodate new capabilities must factor in strategies for the deployment of new capabilities at appropriate DAL levels in order to support rapid deployment.

This paper explores three commonly used methods for separation of DAL concerns as they apply to platforms following the Rapid Integration Framework, such as CMS.

The Problem Space

The Crew Mission Station (CMS) project has been designed to provide a means for the rapid deployment of new capabilities in the shortest time frame possible. In order to enable that deployment, the CMS qualification plan must establish a means to qualify the installation and upgrade of CMS to the satisfaction of the airworthiness authority. This problem is common to other systems utilizing the Future Airborne Capability Environment (FACE) approach for effective rapid deployment of capabilities. Throughout this paper, CMS represents a platform within the Rapid Integration Framework and is representative of a use of the FACE™ Approach for reducing program schedule.

Airworthiness includes an analysis of the effects the failure of a capability has on safe function of an aircraft. These effects are analyzed as part of the safety of flight documentation for equipment used in flight and developed following process like DO-178C (RTCA, Inc, 2012). Subsystems are assigned a Design Assurance Level (DAL) based on the established criticality of failures of the system. In DO-178C, DAL is assigned a letter from A (most critical) to E (least critical, no airworthiness impact). Supporting artifacts for each level increase from DAL E, requiring almost no documentation, to DAL A, artifacts that have been known to burn half of the total development costs.

Systems must be designed, developed, and tested to the highest criticality of the most critical function within the system. Systems designed to a higher DAL require more rigor in design, development, and testing. These systems take more time to field than systems that have less impact or systems that have no impact on the airworthiness of the aircraft. If a system supports multiple functions, it must be designed to the highest criticality of those functions. This negatively impacts the time-to-field of systems that support higher DAL functions.

If a single subsystem contains critical and non-critical functions, the software supporting non-critical functions must be developed to the higher criticality. This results in undesirable effort being spent qualifying functions of little airworthiness impact.

To reduce this undesirable effort, a system can group functions into partitions. In a partition, all functions are assessed at the highest DAL of any function in the partition. Grouping functions of similar DAL into partitions can eliminate this undesirable effort.

For this to work, the system must clearly establish the effects one partition can have on another and quantify the probabilities that a failure will have an adverse effect on the other partition. This is easy to do when functions are separated into different processors and do not share computing resources. In this case, the interfaces between the partitions are clearly established in design and the effects of possible ill-behaving communication can be easily scoped and managed across the interface.

When the software partitions share resources (processors, memory, disk space, etc.), the effects are harder to establish. The ability to partition software is one of the principal aspects of ARINC-653 (RTCA, Inc, 2010). Partitioning multicore processors is the subject of the CAST-32 paper (FAA Certification Authorities Software Team, 2016) and an area of extensive research over the past several years.

In order for CMS or any other platform under the Rapid Integration Framework to live up to the goal of "shortest time frame possible," the qualification strategy must have an established means to separate low DAL capabilities from higher DAL functions. If CMS is to support capabilities of multiple DALs, CMS should have a partitioning strategy in order to avoid undesirable effort in qualification.

Qualification Zones

The easiest way to look at the problem is to separate the combined system into zones with barriers between them. If CMS is connected to the avionics system, CMS becomes part of the avionics network. The qualification of the CMS install must include some proof that software installed on CMS cannot adversely affect the avionics systems to which it is connected.

A barrier must be defined between rapidly deployed CMS capabilities and the avionics. Interfaces that cross the barrier must be understood well enough to prove that any software installed on CMS cannot adversely affect the avionics. In the simplest case, we establish an Avionics Zone and a CMS Capability Zone with a defined interface barrier between them.

The installation of the CMS Core System on the aircraft can establish this barrier through its qualification efforts; new capabilities added to CMS would not require any qualification under the following conditions:

1) There is no function provided by the new capability that impacts safety of flight, and

2) The hardware/software supporting the barrier is unaffected by the addition.

A hard barrier, supported entirely by hardware and firmware, can eliminate the need for qualification of any software. Barriers enabled by software should provide the same benefit if the qualification of the barrier provides similar assurances.

The barrier can also be viewed as a kind of firewall. Industry has used subsystems to provide a regulated bridge between avionics and a lower DAL zone for years. CMS including either a hardware bridge or a software bridge within a partitioned system is a logical extension of these concepts.

This technique involves definition of the supported interfaces as part of the installation of the CMS System onto the aircraft, with a plan to install new capabilities without affecting the qualification of the installation.

Many of CMS Capabilities will have no safety of flight impacts and would be qualified to DAL-E as long as CMS has a zone for DAL-E software. DAL-E requires no software development artifacts for qualification. If the CMS System is partitioned to support the addition of these capabilities without impact to the CMS System qualification, it can provide the fastest path through the qualification process.

A Unidirectional Hardware/Firmware Barrier

This approach is easy to define in the initial instances of CMS. A single system component within the CMS system provides a clear barrier established by its hardware and firmware. Using this pattern, qualification of the CMS system amounts to a simple design document and an analysis that the CMS system cannot affect the avionics if the I/O Converter meets its requirements. The purchase of a previously qualified I/O Converter, along with its airworthiness artifacts, completes the airworthiness effort. Once CMS is installed, new software can be added to the system without further qualification effort. This new software can use the existing information from the avionics or install equipment on the CMS side of the I/O Converter barrier for additional capabilities. This solution satisfies the airworthiness of any software capabilities used on the CMS, provided those capabilities are not in support of the safe operation of the aircraft.

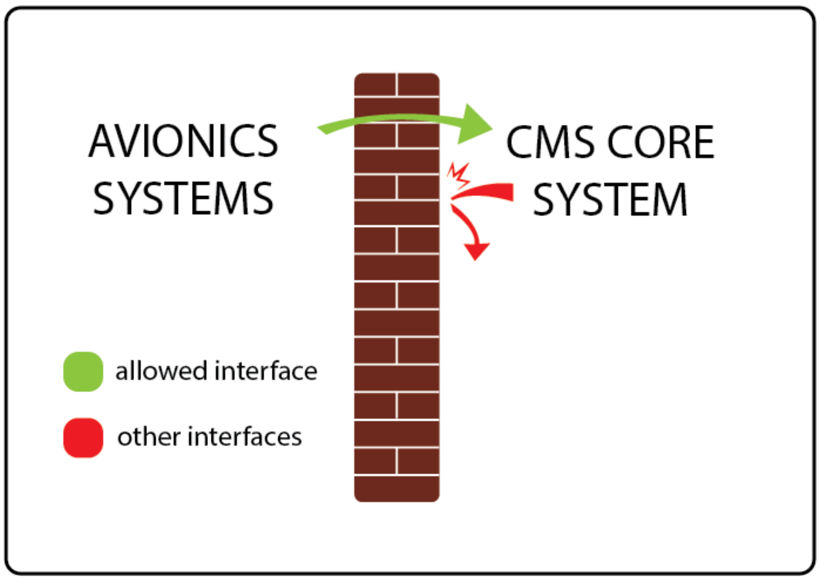

Figure 1 - Unidirectional Zone Separation

First Generation CMS

CMS provides situational awareness via an interactive display to the crew chief and passengers in the main cabin. All current CMS capabilities are for use by the crew chief; the use of these capabilities have no impact to the safety of flight of the aircraft.

The demonstration and subsequent installations of CMS on a UH-60 aircraft utilized ARINC-429 as the interface to the other avionics systems. This type of interface only allows one-way communication. The lone possible impact this CMS can have on the avionics is if the CMS somehow disrupted the 429 communication. To prove that the addition of CMS to the aircraft cannot affect the aircraft systems, a CMS Core System simply needs to utilize a hardware device that can present a low enough probability of failure.

CMS currently employs Platform Specific Service Segment (PSSS) Device Services (DS) Units of Conformance (UoCs) that only provide the data from these devices, without sending data back. As long as this data is only needed by DAL-E capabilities, the PSSS UoCs can also exist in the DAL-E zone.

Establishing Qualification Zones in a Core System

This approach places all software of the CMS Core System into the DAL E zone. Deployment of new capabilities to this system requires no airworthiness activities. The use of multicore processors within the system are also outside of the bounds of the airworthiness activities, releasing the CMS airworthiness from the current concerns over interference patterns associated with multicore expressed in CAST-32A (FAA Certification Authorities Software Team, 2016).

Addition of New 429 Interfaces

New capabilities added to this system will not impact the airworthiness provided that those capabilities only rely on data from systems previously connected to the CMS core system. Connecting the Core System to more interfaces can expand the amount of data available for new capabilities. The definition of the equipment that the Core System is connected to should be analyzed to provide the greatest possible future flexibility. This supports common data that might be needed by future capabilities.

An implementation utilizing only ARINC 429 has some restrictions in available data. ARINC-429 inputs require a new connection for each device the CMS system receives data from. The Core System hardware specification should be designed for growth to support future connectivity.

Addition of MIL-STD-1553

Connection on a MIL-STD-1553 bus provides data from devices that are not on ARINC-429. It also provides a single connection that supports many devices, but 1553 is a two-way communication bus. In order to connect to 1553, the qualification of the CMS Core System must prove that the CMS Capabilities cannot adversely affect anything else on the 1553 bus.

In the initial use of MIL-STD-1553, the CMS I/O Converter was programmed to operate in a bus-monitor only manner on the 1553 bus. For 1553, the I/O Converter must prove its firmware cannot interfere with the communication. This firmware forms part of the barrier; airworthiness artifacts for it will be needed to qualify the interface.

Ethernet

A larger amount of data is available on the UH-60 LAN used by the cockpit systems. The CMS could attach to this LAN to receive this data. To access this LAN with a hardware/firmware separation, the CMS would need a switch programmed to only allow packets to be forwarded to the CMS equipment without allowing any communication to flow the other way.

Artifacts

With the barrier established as one-way through hardware/firmware solutions, the artifacts needed to prove the DAL-E zone are limited to the high-level design of the system, an analysis of the potential effects of the hardware/firmware on the interfaces, and the documentation needed to prove the reliability of the hardware/firmware barriers.

Establishing Two Way Communication

A system that utilizes two way communication over a separation of DAL boundary must establish the security of the data being returned to the higher DAL system in terms of its impacts to the higher DAL system. Each type of communication allowed must be assessed for such impacts and other types of communication must be blocked by the interface.

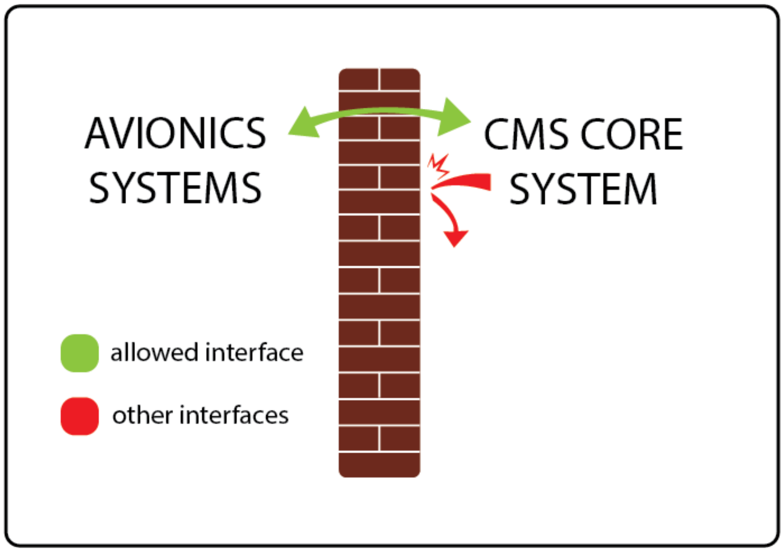

Figure 2 - Bidirectional Zone Separation

An easy example of this type of connection includes the CMS connection to the aircraft data loader. This data loader provides access to the mission planning data as well as the map files used by the cockpit displays. If CMS were allowed access to this device, the CMS system could utilize the same charts loaded for the cockpit maps as well as utilize other data provided by the mission planning station.

Access to this data loader would put the CMS Core System in contact with the avionics LAN. This is a bi-directional bus with an abundance of data related to the safety of flight for several systems. Any CMS connection to this bus must be proven to only interface with the avionics in ways specified and tested as part of the Core System. The allowed interfaces must be proven to have no impact.

In effect, this moves the handling of the Avionics side of the interface to form part of the barrier. The functions and all hardware and software supporting these functions are part of the barrier and should be separated from the rest of the CMS Core System and the future capabilities.

When accessing the data loader, the barrier device providing the interface between the CMS Capabilities and the avionics system must present an interface to the CMS Core System that will accept communications from CMS in a manner that effectively blocks all other communication. The software in the device must be developed to a DAL sufficient to mitigate any potential impacts that it might interfere with other communications on the avionics LAN.

Establishing Qualification Zones in a Core System

As mentioned above, there is a possibility of establishing a restriction on access to the Data Loader based on IP routing, but this would not cover a case where the writing of specific files is not allowed, while the writing of other files is allowed.

The software and hardware providing this function would need to show designs proving all communications (erroneous or malicious) from the remainder of the CMS system cannot cause errant behaviour beyond the allowed behaviour of the interface as defined by the design. The Data Loader function would have to be partitioned away from the capability software, and a dedicated Ethernet line would have to be provided between this partition and the Avionics LAN. Qualification artifacts for the Core System would include all artifacts necessary to allow this Data Loader Partition access to the LAN.

Partitioning interface functions within the CMS Core System could be easily accomplished by use of a Mission Computer with two LAN connections. This would leave the rest of the CMS Core Software running on the displays at a low DAL.

Other utility interfaces can be established in similar ways. Some other connections to data sources might require TCP request/response data to bring desired information into the CMS system. Utility functions can be established to request this data and provide it to the rest of the CMS.

In these cases, CMS access to utility equipment or avionics data can be envisioned before capabilities are developed. The CMS Core System can be qualified with access to these data items and functions, allowing rapid deployment for FACE UoCs that need them. If new capabilities are added with a need for additional interfaces, the addition of those interfaces would have to include partitioning of those interfaces.

In some cases, there is a desire to add a capability that accesses an interface specific to that capability's function. These interfaces might include the replacement of an existing system with a software function or the interface to a specific system that was not planned in the initial deployment of the CMS Core System. In these cases there may not be a way to reduce qualification efforts, but a partitioning scheme can be designed into CMS that isolates these functions from the potential DAL-E capabilities.

Artifacts

With a two-way barrier, artifacts will be needed to support the software restricting the interfaces. This can necessitate the establishment of qualification for some aspects of the Core System, including processing hardware, the operating system, and any transport mechanisms provided across the barrier. It is still possible to restrict the artifacts to the subset of software present in a single processor.

Fully Partitioning a Rapid Integration Platform

Both of the prior examples are valid solutions for a Rapid Integration Platform that primarily provides DAL E capabilities. There are cases when an implementation of the Rapid Integration Framework (or another implementation of the FACE Approach) might need to display information from multiple capabilities of differing DALs. Once the display of mixed DAL comes into play, the separation of DAL is embedded into many of the Core Capabilities of the RIF. There is a need to establish a zone for DAL-E capabilities, into which software can be deployed without impact to the configuration of the higher DAL systems or the established barrier.

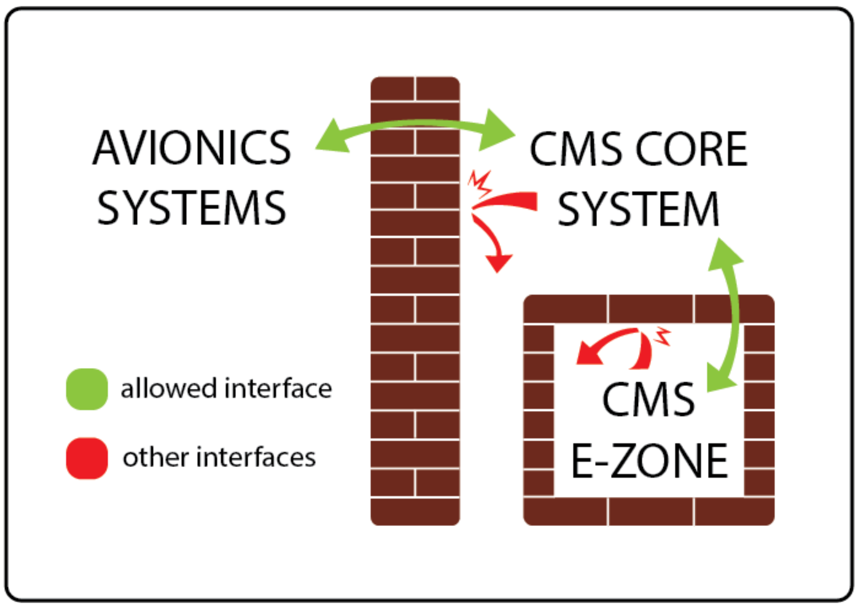

Figure 3 - CMS with an Established DAL-E Zone

There are capabilities that CMS might support that provision an airworthiness function. The possibility of supporting multiple DAL levels has always been in the design of CMS. As the CMS development progressed, some concerns were identified about the partitioning and its capability to establish and still allow rapid deployment of capabilities after the initial qualification of the Core System.

The establishment of multiple zones within the definition of the CMS Core System can support varying future capabilities. To continue allowing rapid deployment of DAL-E capabilities, a DAL E zone must be established within the core processing of the CMS. Interfaces in and out of this zone must be documented and established as part of an integration of all capabilities with a DAL of A-D. An effective implementation should allow for multiple DAL-E capability combinations to be deployed within the DAL-E zone without affecting the original qualification of the zone container. This can be carried forward as the support of multiple DAL-E software deployments between the higher DAL deployments that would require a longer development cycle.

Establishing Qualification Zones in a Core System

Nested Paritioning Zones

If multiple DAL A-D levels are needed, they could be established in a series of nested integration events, each supporting multiple iterations of the next. If a RIF implementation needed to support DAL B capabilities, the integration of those capabilities could support a DAL-C zone. The integration of the DAL-C zone could be developed to support DAL-D zones and so on. The configuration of the container for each zone can be established and tested as part of the qualification of the containing layer.

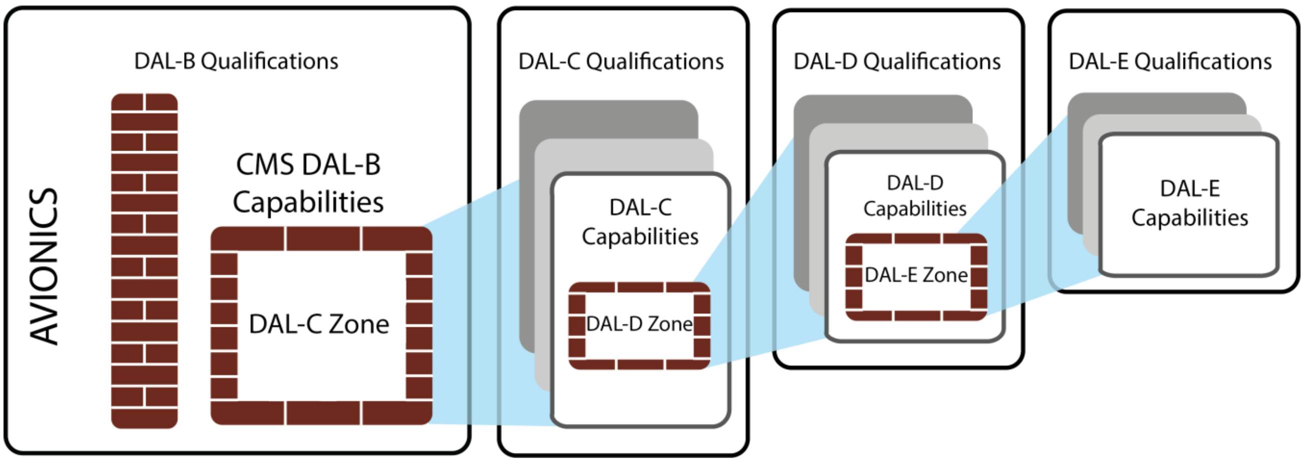

Figure 4 - CMS with Multiple DAL Zones

Paritioning Interfaces

The partition zones and interfaces have to be established. The deployment of CMS with pre-arranged partitioning should establish what interfaces are allowed in each zone. The simplest partitioning scheme might be to only allow rapid deployment of UoCs in the Portable Capability Segment (PCS). In this case the Transport Services Segment (TSS) would have to be qualified to the highest DAL of the CMS Core System and the individual UoCs would only interface through it.

This scheme would restrict UoCs that utilize new hardware functions for non-critical functions, such as the receipt of off-board video and the control of the radio that receives it. If interfaces to additional Ethernet devices is allowed, the partitioning will likely include the addition of PSSS Device Services UoCs.

Some of the CMS demonstrations have included radio tuning of new equipment with functions not critical to the aircraft. Additional I/O Capability, such as spare Serial Ports, could also be allocated to DAL-E partitions in the expectation that experimental functions or new equipment might take advantage of such ports.

Partitioning Configuration of the Core Capabilities

Another aspect of partitioning pre-qualification, is the configuration of the core capabilities in the CMS. CMS includes several configurable components that support new capabilities. The Operating System, TSS, graphic services, and Menu System all represent highly configurable capabilities with configuration files that might be modified when new capabilities are installed.

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Qualification of Parameter Data Items

Ideally, configuration items affecting the CMS System Installation qualification are not changed when new capabilities are added. According to DO-178C (RTCA, Inc, 2012), these Parameter Data Items (PDIs) would require some level of testing in their final configuration against the newly composed system. This qualification would have to be performed at the highest criticality level of the affected system.

Each of the Core System capabilities should be examined for ways to either pre-configure for new capabilities, or separate their configurations to those that support each level of DAL, while preventing the next DAL configurations from affecting the higher criticality configurations.

An example of this problem is the CMS Menu System. If menu options are configured for accessing DAL C capabilities, the addition of DAL E Capabilities should not be able to prevent access to the DAL C capabilities. The integration of the DAL C capabilities should provide for a lower DAL configuration that cannot override the DAL C Configuration. Qualification of the DAL C configuration would prove that the lower DAL configurations cannot block the higher DAL access. Thus the lower DAL development would not have to provide any artifacts to support the higher DAL.

There are techniques that can be used to perform qualification of systems if these interfaces change. An assessment can be made on the program schedule impacts for retesting the higher DAL configurations against the development of this more robust implementation.

TSS Routing

Configuration of the TSS could allow access to any data connection provided throughout the TSS. The configuration of the TSS when the partitions are established should institute rules that cannot be broken by the TSS configuration of a new capability.

Example: The subscriber of Publisher/Subscriber topic T assumes all publishers on T are qualified to DAL-C. The configuration of the TSS during qualification of the partitioning must establish that new capabilities cannot publish on topic T. If it is not possible to prove this by design and implementation, the barrier is not rigid enough to provide the separation.

In order to avoid additional qualification of the CMS Integration of a new capability, the TSS configuration for future capabilities must be blocked from allowing the connection to topic T by previously established (and unmodified) TSS configurations provided as part of the partitioning qualification.

Once again, the effort to design this robust configuration scheme should be weighed against the increased cost of modifying artifacts related to the higher DAL. If the goal is rapid deployment of DAL E capabilities, these efforts should be included in the system design.

Partitioning Graphic Services

The Rapid Integration Framework and the FACE Technical Standard recommend using ARINC 661 as a means to provide window management between separate UoCs providing graphical interfaces. ARINC 661 has an inherent ability to provide partitioning between DAL. Within the ARINC-661 CDS, similar concerns must be addressed on a configuration hierarchy exist. The CDS Connector Reference Table, the Super Layer, and other functions within the CDS must either pre-configure capability functions (possibly through the use of test applications that stand-in for future capabilities) or support a multi-level means of configuration where the higher DAL configuration can be extended, but not modified, by additional lower DAL capabilities.

Establishing Qualification Zones in a Core System

The OSS and ARINC-653

If CMS is to support multiple DAL levels within a single processor, CMS will need to adopt the FACE Safety Profile and utilize a software partitioning scheme following ARINC-653 (RTCA, Inc, 2010). The configuration of the ARINC-653 partitions should be established for future capabilities in order to reduce or eliminate possible changes when new capabilities are added. The use of test applications to take the place of future capabilities can solve some of these problems.

Regression Testing

If the configurations of the OSS, TSS, CDS or other core capabilities cannot reach the ideals presented above, then the qualification of the system can include a defined regression test of the impacts of PDI changes. The effects of some of these PDIs can be quite extensive, such as the time partitioning of capabilities in relationship to each other when processing data. Regression tests should be developed to cover all potential effects of the changed PDIs. Measures should be taken to reduce the efforts of these regression tests for projects installing capabilities.

If PDIs were developed as part of the qualification of a partitioning zone, and were not changed, these regression tests should rely on prior testing of parameter boundaries and be designed to prove non-interference by the new additions to prevent the need for exhaustive testing.

Artifacts

With partitioning established within the CMS processors, the CMS qualification artifacts should be developed to include documentation of the integration of CMS with the capabilities used at aircraft installation. This would be a subset of capabilities and would not necessarily include functions in the DAL-E zone. This level of artifact will survive changes to DAL-E capabilities without altering the qualification artifacts.

The plan for software qualification and other plans should include what level of regression testing might be needed should the installation of capabilities cause a change.

Conclusion

A Rapid Integration Platform such as CMS can be developed to support the rapid deployment of new UoCs, provided that the Core System accounts for the interfaces used by those UoCs and was qualified to provide those interfaces. While this may seem like an impossible task, it is fairly easy to bound the nature of potential system capabilities that would primarily support Situation Awareness.

When functions are added that need new interfaces, the impact of these new interfaces creates additional airworthiness impacts in any system. A CMS or other system following the FACE approach can use these partitioning zone techniques to reduce airworthiness concerns.

There are core capabilities that support these multiple DAL interfaces, and the configuration of these capabilities needs special attention in order to properly establish the interface boundaries and avoid a need to requalify a configuration.

Regression testing may alleviate some of the complexity of a configurable core system supporting pre-defined partitions, but these tests can be eliminated if the qualification zone can be firmly established, qualified, and un-altered by subsequent capability deployments within that zone.

A Rapid Integration Platform can utilize a straightforward hardware/firmware separation using Commercial off-the-shelf (COTS) equipment if it is developed to support only DAL E capabilities and those capabilities do not need to send any data back to the other side of the interface barrier.

If the capabilities need to communicate back across the barrier, a separate device or partition can be developed with software to provide the bridge to the avionics system. This will increase the level of development and related airworthiness artifacts, but in a limited and manageable way.

If a Rapid Integration Platform must support capabilities of multiple DALs, care must be taken in the development of the Core System components to provide partitioning such that the deployment of new capabilities affects only the configuration of the Core System, and that the modifications to the Core System configuration files can be limited such that configuration for higher DAL is not affected.

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About the Author

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