To the Graduate Council:

I am submitting herewith a thesis written by Michael Roy Barker entitled "The Increased Costs of Restricting the Procurement of New Capability in Aircraft Modernisation". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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The Increased Costs of Restricting the Procurement of New Capability in Aircraft Modernisation

A Thesis
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Degree
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Michael Roy Barker
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Abstract

As an element of the Government of Canada, the Canadian Forces are constrained by many financial and administrative regulations intended to ensure that public funds are expended judiciously. When these regulations restrict the acquisition of an improved capability, they may force program managers to accept a less capable product than could be obtained were only a simple cap on the total program cost imposed.

The CP-140 Aurora Navigation and Flight Instruments Modernisation Project is studied, highlighting specific areas where restrictions upon which capabilities could be improved or added, rather than simply how much money could be spent, resulted in program delays and a less capable final product. Lessons about the problems associated with the acceptance of unsolicited capabilities in the contract proposal, the necessity of applying up-to-date standards when designing for the installation of modern equipment, and the difficulties with the retention and forced integration of old equipment with new, are identified and discussed. Suggestions are made which will allow future aircraft modernisation programs to avoid some of the problems encountered by the Navigation and Flight Instruments Modernisation Project.

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List Of Abbreviations

ACAS	airborne collision avoidance system
ADC	air data computer
AFDS	autopilot flight director system
AIMP	Aurora Incremental Modernisation Project
AMS	avionics management system
ARINC	Aeronautical Radio Incorporated
AUP	Avionics Upgrade Program
CDU	control display unit
CP	Capital Procurement
DCP	display control panel
DLS	data loader system
DME	distance measuring equipment
DND	Department of National Defence
EFDI	electronic flight director indicator
EFDS	electronic flight display system
EGI	embedded Global Positioning System-inertial navigation system
EHSI	electronic horizontal situation indicator
GPDC	general purpose digital computer
GPS	Global Positioning System
IFF	identification friend or foe
MIL-STD	military standard

NAVCOM	navigator/communicator
NFIMP	Navigation and Flight Instruments Modernisation Project
NP	National Procurement
TACNAV	tactical navigator
TA/RA/VSI	traffic advisory/resolution advisory/vertical speed indicator
RAAWS	radar altimeter - altitude warning system
SIL	systems integration laboratory
TACAN	tactical air navigation radio set
US	United States
VNAV	vertical navigation

1. Introduction

The Navigation and Flight Instruments Modernisation Project (NFIMP) was intended to be a low-risk, first major step in the CP-140 Aurora Incremental Modernisation Project (AIMP). The technical and performance goals of the NFIMP were modest, in line with the allocated funding and aggressive, complex schedule of the AIMP. The prime contractor, experienced with similar modifications in civil aircraft and military helicopters, had proposed a modification largely composed of proven components and software written in-house by an experienced staff.

Despite this promising foundation and the hard work of everyone involved in the program, it fell years behind schedule and was forced to halt prototype flight testing when the accumulated problems made progressing any further impossible. Flight testing is expected to recommence in late April 2005 after a ten-month pause for design changes to be engineered and embodied.

Although the successes and shortcomings of the NFIMP were being monitored with the intention of applying best practices and lessons learned to subsequent stages of the overall AIMP, program managers and personnel at all levels were constrained by the bureaucracy and administrative controls of the Government of Canada and the Department of National Defence (DND). Although these regulations were intended to ensure that taxpayer dollars were spent in a prudent and responsible manner, they collectively robbed decision makers and managers of some flexibility. In the case of the NFIMP, this loss of flexibility and decreased opportunity for innovation resulted in the DND receiving less operational capability than it would otherwise have been able to obtain. The net effect was the Canadian Taxpayer not getting the best value for their money.

Most aspects of the NFIMP were funded under the National Procurement (NP) Program as obsolescence management activities using funds specifically allocated for the routine maintenance of the CP-140 fleet. The NP program prohibited any non-incidental increase in capability. The remaining aspects of the NFIMP were Capital Procurement (CP) Program initiatives intended to provide a new capability across all DND aircraft fleets. This created two separate "accounts" for the program, but dollars could not cross between the NP and CP portions of the whole.

Specifically, prohibiting program managers from acquiring new or improved capability with the portion of project funds that came from the NP ultimately resulted in a less capable final product, much later than originally scheduled, than had a simple cap on total program cost been enforced.

Three broad lessons learned through the process of preparing for and flight testing the NFIMP prototype will be discussed within the context of how limited flexibility in how new or improved capability could be funded reduced the value obtained by the taxpayer. Each supports the declaration above and cites particular characteristics of the NFIMP design where the prototype exhibited unsatisfactory performance or unexploited potential:

1. The DND was unable to provide funding for unsolicited capability offered by the contractor in their bid. Thus, the contractor was liable for any additional costs, making these features high-risk areas if additional engineering was required. The DND contract simply accepted the capabilities as proposed without additional specifications or requirements because there was no mandate to include them in the modification.

2. The DND had a restricted ability to take advantage of the capabilities inherent in modern avionics, even where there would be a marginal increase in cost for a significant improvement in capability. This resulted in new shortcomings in the final modification that did not exist in the original aircraft.

3. Retaining a significant amount of legacy equipment in the modification forced the integration of modern and 25 year old avionics. This proved to be far more difficult, and thus costly, than forecast, possibly costing more than simply replacing the legacy equipment with a modern equivalent where practical.

After discussing the background of the program, these problem areas will be examined and recommendations will be made to avoid similar problems in future programs.

Constraints

It is exceptionally difficult to assign financial costs to many aspects of military projects. The fundamental absence of profit as a motive in any military activity means that more esoteric measurands, such as overall operational capability or a lack thereof, constitute the metrics against which success or failure of any endeavour may be measured. As such, any attempt to assign a financial cost to any delays or capability limitations in the NFIMP is beyond the scope of this effort.

Background

The CP-140 Aurora was Canada's long-range maritime patrol aircraft, used for surface and sub-surface surveillance and a submarine attack role. Eighteen aircraft were acquired in 1980. By 2000, the aircraft had become the Canadian Forces' only strategic surface surveillance platform.

Structural modifications to the airframe were anticipated to extend the estimated life expectancy of the basic airframe beyond 2015, thus allowing at least a decade of continued operations. Various cockpit, navigation and mission systems had reached an advanced stage of obsolescence, whereby "the ability of the Aurora to survive and operate effectively beside our Allies [had] eroded significantly since its introduction to service 20 years ago" (Project Charter,2000). The objectives of the AIMP were to "address equipment supportability issues and to provide the Aurora fleet with a modernised operational capability that [would] permit it to survive and operate alongside our allies" (Project Charter, 2000). The AIMP had to succeed for the DND to continue to operate the Aurora fleet.

The AIMP was sub-divided into four groups for ease of management. Contained in the second of these groups was the NFIMP, intended to address reliability and obsolescence problems in the aircraft's navigation and flight instrument avionics.

Navigation and Flight Instruments Modernisation Project

The NFIMP was the second major phase in the overall AIMP. Its objectives were to:

1. Replace the current inertial navigation system with an embedded Global Positioning System-inertial navigation system (EGI), including control display units (CDU) capable of controlling navigation and communication parameters.

2. Replace the flight director indicator and horizontal situation indicator with new electronic flight instruments.

3. Replace the autopilot with digital components.

4. Replace the radar altimeter.

5. Integrate an aircraft collision avoidance system (ACAS).

6. Reduce the repair and overhaul costs of the aforementioned equipment (Statement of Work for NFIMP, 2001).

CP-140 Aurora Aircraft

The CP-140 Aurora was described in its aircraft operating instructions manual as:

> … a multi-mission reconnaissance and antisubmarine warfare aircraft manufactured by the Lockheed-California Company. Its design incorporated selected features of both the P-3C Orion and the S-3A Viking. The Aurora was powered by four Allison T56-A-14 LFE turboprop engines with Hamilton Standard 54H60-77 hydromatic propellers, and was an effective surveillance platform for both low and high altitude missions, capable of ranges over 4000 nautical miles and speeds up to 405 knots indicated airspeed. The aircraft was certified for instrument flight rules flight and to operate in Minimum Navigation Performance

Specification/Canadian Minimum Navigation Performance Specification airspace.

The normal crew consisted of two pilots, one flight engineer, a tactical navigator (TACNAV), a navigator/communicator (NAVCOM), two acoustic sensor operators and three non-acoustic sensor operators. The tactical crew compartment was designed to give the TACNAV a view of the NAVCOM, acoustic sensor operators' and non-acoustic sensor operators' stations thereby optimizing mission coordination (CP-140 Aurora/CP-140A Arcturus Basic Aircraft Systems, 2002).

Figure 1 shows the exterior layout of the aircraft. Figure 2 shows the general interior layout of the aircraft.

NFIMP Equipment

The AIMP Master Implementation Plan directed that "[t]he AIMP acquisition process will emphasise the competitive selection of non-developmental items/off-the-shelf solutions…" (Master Implementation Plan, 2001). The NFIMP modification followed this direction in that the upgrade was an integrated suite of "off-the-shelf" hardware, with custom software running in the four CDUs. Much of the equipment was available on the civil market,

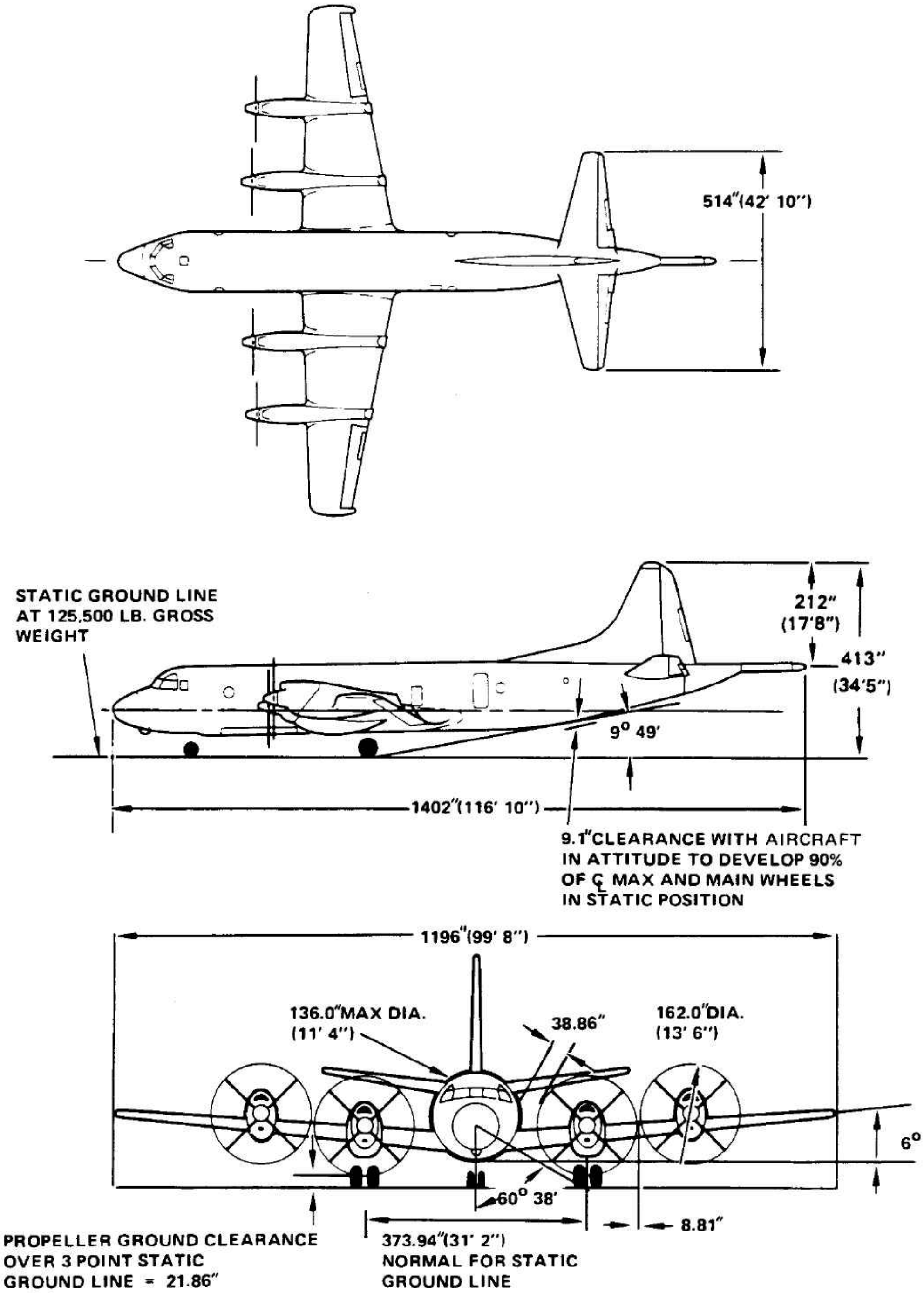

Figure 1: CP-140 Exterior Arrangement

Taken from CP-140 Aurora/CP-140A Arcturus Basic Aircraft Systems, 2002.

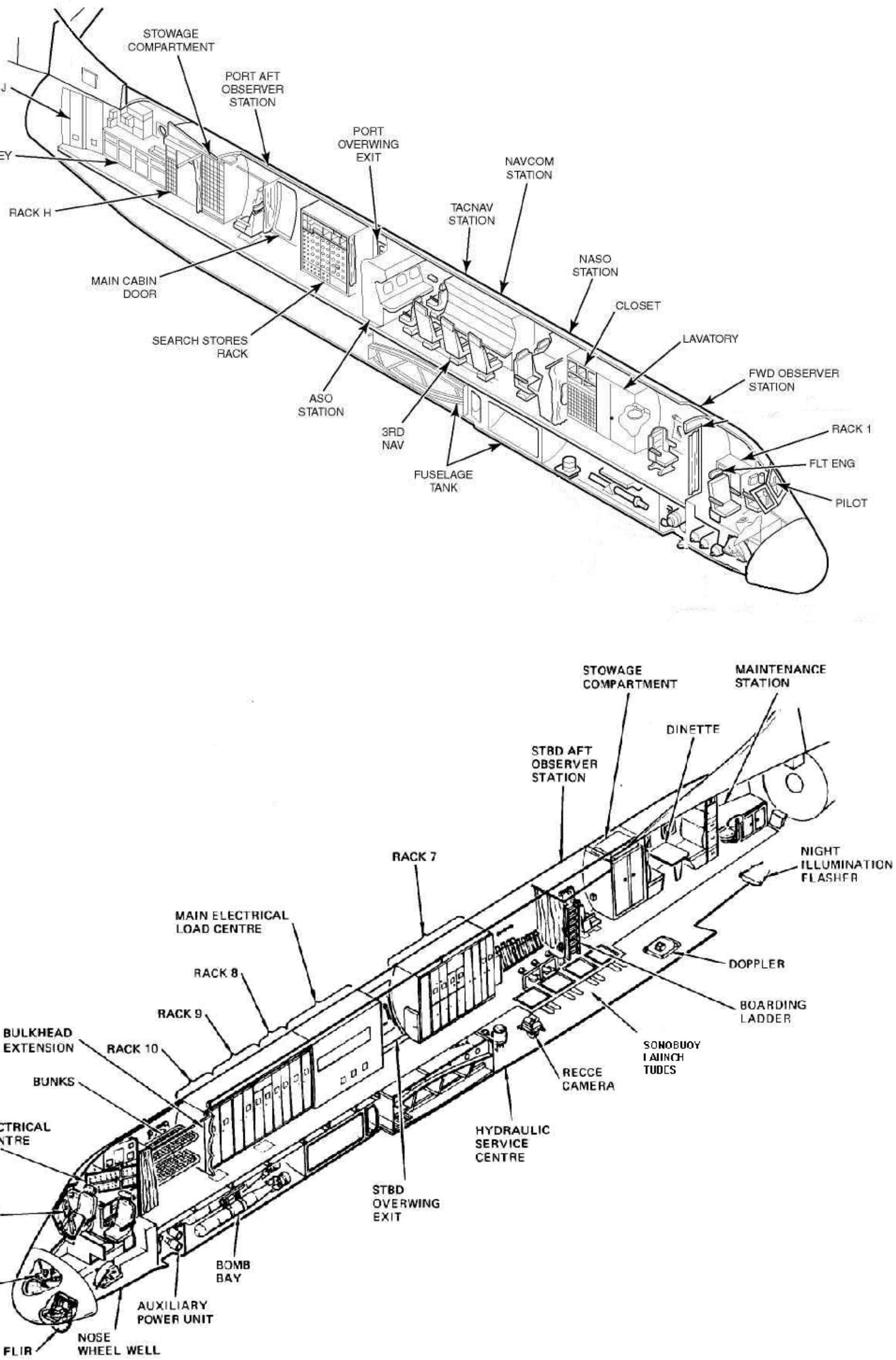

Figure 2: CP-140 Interior Arrangement

Taken from CP-140 Aurora/CP-140A Arcturus Basic Aircraft Systems, 2002.

although some systems contained military-specific items. Individual systems are briefly discussed below with increased detail, a system architecture diagram and cockpit layout contained in the appendix.

EGI. Two identical EGIs were the primary attitude and navigation sources for the system. Each was composed of a laser-ring-gyroscope inertial navigation system integrated with a military code capable Global Position System (GPS). The EGIs were receiver autonomous integrity monitoring capable, and had been installed in large numbers by the United States (US) Air Force.

Avionics Management System. The avionics management system (AMS) formed the heart of the NFIMP modification. The AMS consisted of four Military Standard (MIL-STD)-1553B networked CDUs, installed at the left and right pilot, TACNAV and NAVCOM stations. The CDU managed and controlled most of the new systems, communicated with the legacy mission computer and displayed flight, navigation, and systems information graphically. The CDU hardware was a derivative of other military CDUs, running all new software. The AMS software was capable of flight planning, providing departure, en route and approach guidance and sending steering commands to the AFDS.

Electronic Flight Display System. New electronic flight director indicators (EFDI) and electronic horizontal situation indicators (EHSI) were installed at the left and right pilots' station as form-fit replacements for the original electromechanical displays. An EHSI was installed at the NAVCOM station. Each station had its own Display Control Panel (DCP) for managing its displays. The displays were commercially available 10 centimetre active matrix liquid crystal, and were completely interchangeable. The combination of the displays and DCPs was called the electronic flight display system (EFDS).

Autopilot Flight Director System. The new autopilot flight director system (AFDS) provided the full functionality of the old autopilot including heading and attitude hold, control wheel steering, altitude hold, and heading select, plus new approach modes, coupled navigation, altitude select and airspeed hold modes. The AFDS also incorporated a full range of flight director functions. It had been specifically designed to act as a replacement for the existing P-3 autopilot, and had been fielded by the Royal Australian Air Force, Royal New Zealand Air Force and US Customs Service in their P-3s. Part of this modification was a pair of commercially available air data computers (ADC) used to provide digital air data to the AFDS.

ACAS. A new military enhanced ACAS was installed, along with a new identification friend or foe (IFF) transponder. The ACAS information was displayed on a new, traffic advisory/resolution advisory/vertical speed indicator (TA/RA/VSI) display at each pilot's station. The TA/RA/VSI indicator was a form-fit replacement for the original vertical speed indicator. This system had been successfully installed on the Canadian CC-130 Hercules aircraft fleet without the enhanced capability enabled.

Radar Altimeters. A pair of low-probability of intercept radar altimeters replaced those already installed in the CP-140. The radar altimeters had been installed previously on US Navy P-3s, however only as a single system rather than as a pair.

Procurement Strategy

The AIMP was divided into 23 sub-projects, each with its own approval process and financial arrangements. These sub-projects were then clustered into capability groups. The NFIMP was the second capability group, composed of two sub-projects, one of which was made up of two sub-sub-projects. Although more complex to manage, a major reason this approach was used for the AIMP was to allow funding to be approved in smaller increments. This had the collateral benefit of reducing the apparent financial footprint of the overall AIMP. The two major fiscal mechanisms used to pay for the AIMP were the NP, and CP programs.

The NP program was the mechanism through which the DND maintained existing equipment and capability. Its stated purpose is below:

> The National Procurement Program … [was] allocated for the centrally managed acquisition of material and services (excluding

> realty assets) required to support equipment, services and systems in the DND inventory. … *projects shall not create a new or improved capability* [italics added] (VCDS National Procurement Prioritization Process, 2004).

The DND acquired new or improved capabilities through the CP program. The CP program differed from the NP program in that:

> …these projects must be for the acquisition of:
>
> 1. New equipment/systems (assets);
> 2. For life extension (beyond one year); and,
> 3. Capability enhancement of existing assets. (VCDS Vote 5 - Capital Program, 2004)

Each piece of equipment within NFIMP was acquired via one of the two programs or a combination of both. Expenditures to acquire improved capability were only allowed where that capability had been identified as part of the CP portion of the program. In the case of NP funded systems, improved or additional capability could only be acquired incidentally, where a modern system had inherently better performance than the legacy equipment it was replacing, or where the contractor offered the capability at no additional cost.

In a parallel effort to limit the cost of the NFIMP, and to reduce the crown's risk in the program overall, the NFIMP modification was a fixed-price contract.

Although this sort of fiscal security added a premium to the initial contract price, it was attractive in the way it limited the likelihood of large cost over-runs which could jeopardize later stages of the AIMP.

2. Execution

The bulk of the AIMP funding came from the NP program. Specific capabilities such as the GPS capability of the EGIs and the ACAS had been funded through national programs designed to deploy new capabilities across all DND fleets. These systems were the only two of the entire NFIMP funded through the CP.

The restrictions against capability improvement contained in the NP policy had several consequences for the NFIMP, only some of which were apparent during the planning and engineering stages of the program. The first of these consequences was that the contractor was able to include unsolicited capability increases in their program proposal to improve its competitiveness, highlighting in their program proposal where they would exceed the established, validated and approved requirements laid out for the program. For example, in their technical proposal the contractor stated that the replacement AFDS "significantly exceed[ed]" the requirement to functionally replace the existing autopilot (BAE Systems Canada, 2000). This sort of proposal, once made by the contractor, could be accepted by DND and incorporated into the contract and program.

The second consequence was that the DND was unable to allocate any funds to obtain what were considered to be the standard capabilities of the day. Additional capabilities such as vertical navigation for the autopilot, a high degree of display integration, radio altimeter altitude hold and compliance with modern standards such as reduced vertical separation minimums were not approved. Even had the cost of a new capability been negligible within the scope of the entire AIMP or even the NFIMP, the DND could not specifically fund it.

Possibly the greatest consequence of the NP restrictions was not apparent until the flight test program was underway. Firm limitations on which equipment could be replaced or added to the system, driven by the NP restrictions, had encouraged the contractor to integrate new equipment with the legacy equipment remaining in the aircraft. In many cases this proved to be an difficult engineering exercise. When the modern digital equipment used the information provided by legacy analogue equipment, the results were often disappointing.

The inflexible restrictions on how program funds could be expended caused a number of problems for the entire program team. They resulted in a significant delay in the final product being released for operational use and considerable inefficiencies in the allocation of engineering resources. The overall price to DND of the restriction is difficult to quantify, because of the constraints discussed earlier. In almost any environment, the cost of the first 24 months of a 36 month program running approximately 100% over schedule would be considerable.

Unsolicited Capability

The contractor team drew upon their experience with a similar modification they had designed and installed in the US Customs Service P-3B fleet when designing for the NFIMP (BAE Systems Canada, 2000). Technical risk within the program was reduced by the extensive use of non-developmental equipment, with several components having been previously installed on other P-3 or military fleets. Although the CDU and its AMS software were developmental items, the hardware had a long pedigree of successful progenitors, and the contractor had extensive experience with military and commercial AMS software for them.

One aspect of the contractor's bid that enhanced its attractiveness to the DND was that it contained a number of unsolicited capabilities or capabilities that would exceed stated requirements. Much of this supplemental capability was inherent in modern avionics and was not expected to add significant complexity to the modification. Naturally, this supplemental capability was attractive to the DND, thus it was included in the contract when it was awarded.

Vertical Navigation

Vertical Navigation (VNAV) was a common feature in modern flight management systems when the NFIMP modification was designed. VNAV would be a new capability for the CP-140 fleet, potentially reducing workload throughout all non-tactical phases of flight. Despite its advantages, this capability had not been established as a requirement, thus there was no CP funding allocated. The contractor had implemented VNAV in some of its other products however, presumably to the satisfaction of its customers and certainly to that of regulators, and offered the capability as an enhancement to its technical proposal. It was included in the system specification as simply "[t]he navigation system should provide en route Vertical Navigation" (CP-140 NFIMP Navigation System Specification, 2003).

In Advisory Circular 20-129, the Federal Aviation Administration described VNAV equipment as:

> … provid(ing) vertical path guidance computed as deviation from a desired ascending or descending path to a specified altitude at a waypoint. Vertical guidance is generally provided as a linear deviation from the desired track defined by a line joining two waypoints with specified altitude or as a vertical angle from a specified waypoint. Such a system may be enhanced by inclusion of secondary inputs such as optimized climb or descent profiles, vertical acceleration and true airspeed. The desired vertical path may be pilot selectable or may be determined by the VNAV computer by computations based on the altitudes associated with successive waypoints. (Federal Aviation Administration, 1988).

A simple VNAV capability was embodied in the NFIMP modification by allowing the AMS to send altitude data to the AFDS. By comparing the current system altitude to the altitude on the TO waypoint in the active flight plan, the AFDS commanded a level off without control over the aircraft's power setting. When passing the TO waypoint, the system would annunciate "SEQUENCE WPT" on the EFDI, cycle to the next waypoint in the flight plan, and then steer toward it. This function was less complex than the VNAV functions available on more integrated cockpits, but a similar system had been successfully installed in the CC-130 Hercules Avionics Upgrade Program (AUP), also without aircraft power control.

One of the primary motivators for the automation of cockpit functions was that of workload reduction (Wiener & Nagel,1988). Allowing the aircraft to climb or descend itself to an assigned altitude would free the pilots to carry out other tasks or to devote more time to supervision of the flight as a whole, thus enhancing safety and effectiveness. Successfully implementing this functionality had proven a difficult task to avionics designers though. A 1999 study of the Aviation Safety Reporting System showed that 63% of "pilot-cockpit interaction issues" were with the VNAV functions (Vakil and Hansman in Sherry, et al, 2001). Although the VNAV capabilities of the NFIMP systems were much simpler than those ascribed to VNAV systems by the Federal Aviation Administration and those in the 1999 study, they proved equally prone to confusion.

In the NFIMP modification, the VNAV capability was controlled exclusively through the AMS software in the CDU, with vertical guidance information available on the EHSI and AFDS mode annunciations on the EFDI and AFDS control panel. Sherry et al (2002) identified two characteristics of a successful AMS interface; first, that it not force the pilot to reformulate tasks into alternate or sub-tasks the AMS does support; and second, that the actions required to command the tasks can be accessed using visual cues rather than memory and training. The NFIMP AMS software did not possess either of these characteristics.

Commanding a VNAV climb or descent required a modification to the waypoints in the active flight plan. First, the crew would need to decouple the AFDS from the AMS guidance and either fly the aircraft manually or engage an altitude or heading hold mode. Modifying the waypoint took 6 keystrokes to access the flight plan menus, disengage the active flight plan, select the appropriate waypoint, and then access the waypoint altitude attribute. The new target altitude could then be entered. The operator would need to move back up two levels of the menu structure, re-engage the flight plan and finally re-couple the AFDS to AMS guidance. The pilot would then need to adjust the aircraft power setting or attitude to start a climb or descent. If a change in power setting was to be used, the AFDS had to be set into an airspeed hold mode for it to command a pitch change.

When the AFDS detected that the aircraft was approaching the target altitude, it would begin to command a level off, and an "ALT SEL" indication on the AFDS control panel and EFDI would cycle to "ALT". As the primary cockpit altimeters functioned independently of the digital air data system, it was unlikely that the selected altitude would exactly match the final altitude shown on the pilot's altimeter, thus forcing the pilot to adjust the final level altitude. In any case, the pilot would be required to adjust his power setting if he wished to maintain his desired airspeed.

In the event that the target altitude was not captured before the AMS cycled to the next waypoint, the system would remain in the climb or descent the pilot originally set up without any specific annunciation. The "ALT SEL" indications on the AFDS control panel and EFDI would simply disappear, along with the vertical guidance on the EHSI. Without pilot intervention, the aircraft would either hit the ground or climb as high as it could.

When ground tested, the VNAV capability was found to be unacceptable for operational use (Systems Integration Laboratory Human Factors Evaluation, 2002). The user interface was not intuitive and required operators to know upon which menu page the various functions resided. The programming process was prone to error and had little capability to trap mistakes as they were entered. The poor cues it provided to pilots about system status and intentions made confusion in the cockpit likely, and caused great concerns about the overall safety of the VNAV capability for use. Advisory Circular 20-129 was also cited to provide additional support to the observations.

Having been proposed in the contractors bid submission, there were no specific requirements identified for the design or utility of the VNAV capability. Without a testable specification, based on established and approved operational requirements, the DND could only accept what the contractor provided as long as overriding airworthiness standards were met.

The addition of a dual-function altitude selector/alerter system was suggested to resolve this deficiency (Systems Integration Laboratory Human Factors Evaluation, 2002). This sort of device had been used on the similar CC-130 AUP modification, with full fleet implementation. Other options included significantly re-designing the AMS interface or enabling the system to provide an additional warning if a target altitude were missed. Program managers were unable to pay for an altitude selector because of the restriction against adding new capability, in the form of a vertical control for the autopilot, to the aircraft using NP funds.

Program management staff was hesitant to make changes to the system based on ground test alone. The test crew had limited training and exposure to the system in a lab environment, and were unable to provide a constructive solution to the problem based on their incomplete evaluation. The decision was made to wait until flight test results were available. Unfortunately, problems with the ADC-AFDS integration prevented meaningful flight test of the system before April 2005.

The test team had made several recommendations to improve the capability enough to allow it to be fielded. Key amongst them was the addition of an altitude selector/alerter. If the VNAV capability is found unacceptable when flight tested in spring 2005, it will be very late in the already delayed program schedule to make significant changes to the design. Considering that contractual acceptance of the prototype aircraft had been planned for mid-2003 (AIMP 5-Year Master Schedule, 2002), few schedule and cost effective options will remain to fix the problem. Even if there are NP funds remaining in the budget, the program will not be able to spend them on this new capability. The most likely outcome in the event of an unacceptable finding will be removal of the capability.

Removing the VNAV capability from the CDU would require further engineering effort. The total amount of time and money expended in producing, testing and subsequently removing the VNAV capability from the NFIMP modification would be difficult to capture. Whether VNAV is finally removed or not, the exercise had expended resources that could have been better put to use in other areas of the program.

By not writing requirements and specifications for the supplemental capabilities offered by the contractor, the DND had few courses of action available when the implementation did not match expectations or needs. As no funds could be expended to improve them, the contractor was not willing to modify them to the meet the DND's desires. Whenever a contractor offers supplemental capability, the DND must analyse the capability, and write specifications to ensure the final product will meet its needs.

Modern Capability Requires Modern Standards

The definition of what would constitute improved or new capability was necessarily open to interpretation. Acquisition professionals needed to be able to apply it to all the equipment the DND could buy. A conservative interpretation of this definition was applied to the NFIMP in an effort to control costs.

Although the motives were laudable, in assuming that what was acceptable on the legacy aircraft would continue to be acceptable on a modified aircraft program staff created a situation where the interaction between new and old systems combined to put additional demands on equipment and its operators.

Electronic Flight Display Size

The CP-140 NFIMP EFDS Functional and Performance Requirements Specification (2003)dictated that the new displays maintain the existing "T" configuration of the instrument panel. This specification was included to reduce re-training and cockpit modification costs. It also prohibited the contractor from suggesting a less conventional but perhaps more effective configuration, possibly similar to the large screen, side-by-side arrangement that had been selected for the US Customs Service P-3B modification. A secondary consequence was of reducing the likelihood of any of the remaining instruments being moved.

The EFDS System Specification also dictated that the displays would incorporate the functions of the legacy Navigation Advisory panel and Marker Beacon lights. The Navigation Advisory panel had served to let each pilot know the status of the various radio navigation aids and other navigation systems. Figure 3 is an illustration of the panel showing the range of annunciations it provided.

In addition to the Navigation Advisory Panel and the Marker Beacons, the

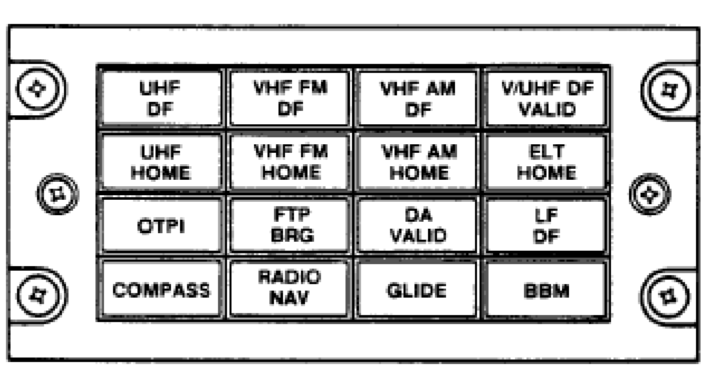

Figure 3: Legacy Navigation Advisory Panel

Taken from CP-140 Aurora/CP-140A Arcturus Basic Aircraft Systems, 2002.

EFDS was specified to display information provided by the EGIs, navigation waypoint information, operating limits, and system status (CP-140 NFIMP EFDS System Specification, 2003). The EFDS was also the only readily available location upon which to display AFDS and other important system messages. All of this information was in addition to the flight and navigation information already presented on the legacy flight director indicator and horizontal situation indicator. The display of multiple, important annunciations and indicators was constrained to a pair of displays with "a minimum Active Image Display area 10 centimetres high and 10 centimetres wide" (CP-140 NFIMP EFDS System Specification, 2003).

Although the new EFDS was not unavoidably constrained to the footprint of the legacy indicators, the size and layout specifications made identically sized replacements an obvious and cost-saving choice. In isolation, this would seem to be a reasonable set of specifications to use and it would certainly be in line with the "no new capability" direction. When one considers the volume of new information to be presented on the EFDS, questions about the suitability of 10 cm displays begin to surface.

Two years before the beginning of flight test, problems with clutter on the EHSI were identified. Specifically, too many data elements were being displayed on it (Systems Integration Laboratory Human Factors Evaluation, 2002). The recommendations at the time were to include a de-clutter function, reduce the size of some elements, eliminate other elements or use colour to improve the ease with which pilots could discern required information from the EHSI. Only the font size was decreased in an attempt to reduce clutter prior to flight testing.

The AFDS had significant capability beyond that of the legacy ASW-31 autopilot, installed in the 1970's. The ASW-31 was a simple autopilot capable of barometric altitude hold, heading select and hold via a moveable indicator on the horizontal situation indicator, and had an analogue yaw damper. The new AFDS was able to perform these three simple tasks, plus a relatively standard set of modern functions such as altitude select, airspeed hold and couple to radio navigation aids or steering commands from the AMS. This greatly increased level of automation in the cockpit made pilot awareness of the system's current state and goals much more important (Sarter & Woods, 1992). The control head for the new AFDS provided little information about the current modes of the system, and was positioned at the aft edge of the centre pedestal near the location of the legacy panel (see figure A-2), far outside of either pilot's primary or secondary field of view (General Aviation Manufacturers Association, 2000).

Without adding an additional autopilot status panel to the cockpit, arguably an increased capability, the only location available for status display was the EFDS. The design intent was to occupy the top lines of the EFDI with AFDS annunciations. Figure 4 shows the available display fields on the EFDI. Table 1 indicates in which field annunciations from the AFDS would appear.

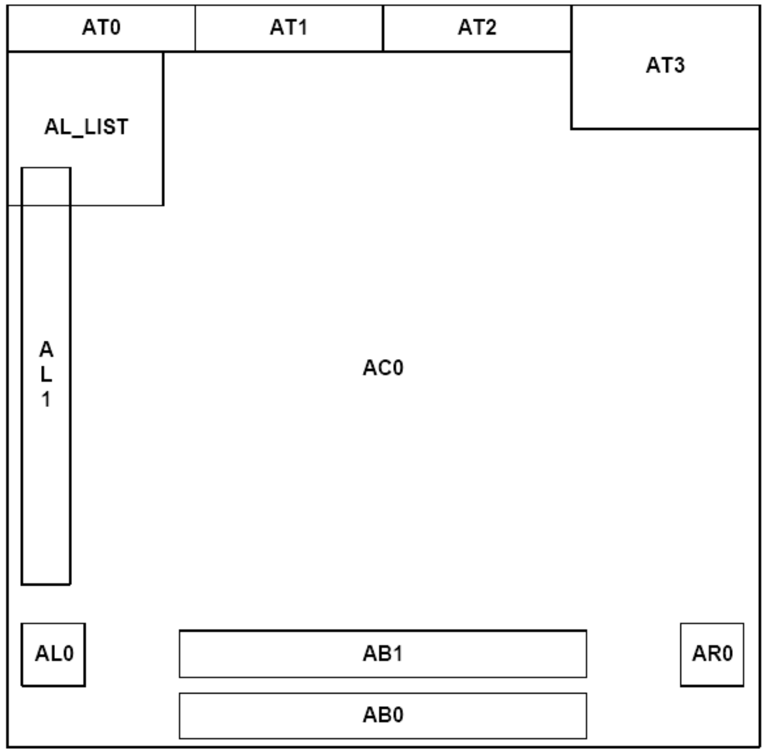

Figure 4: EFDI Display Fields

Taken from CMC Electronics Human Interface Specification, 2005

Table 1: AFDS Display Fields

Display Object	EFDI Field
AFDS Status	AT0
AFDS Roll Modes	AT1
AFDS Pitch Modes	AT2
AFDS Faults	AT3

The EFDI needed to display a great deal of information in a manner conducive to quick and accurate assimilation by the pilots. Figure 5 shows a sample co-pilot EFDI screen when the AFDS was in altitude hold mode, controlled by the pilot, with the flight director coupled to AMS steering commands.

The flight test crew identified numerous AFDS modal awareness problems when they became confused in flight or had to carefully analyse the status of the AFDS (Post Flight Report #10, 2004). Screen layouts from other aircraft with

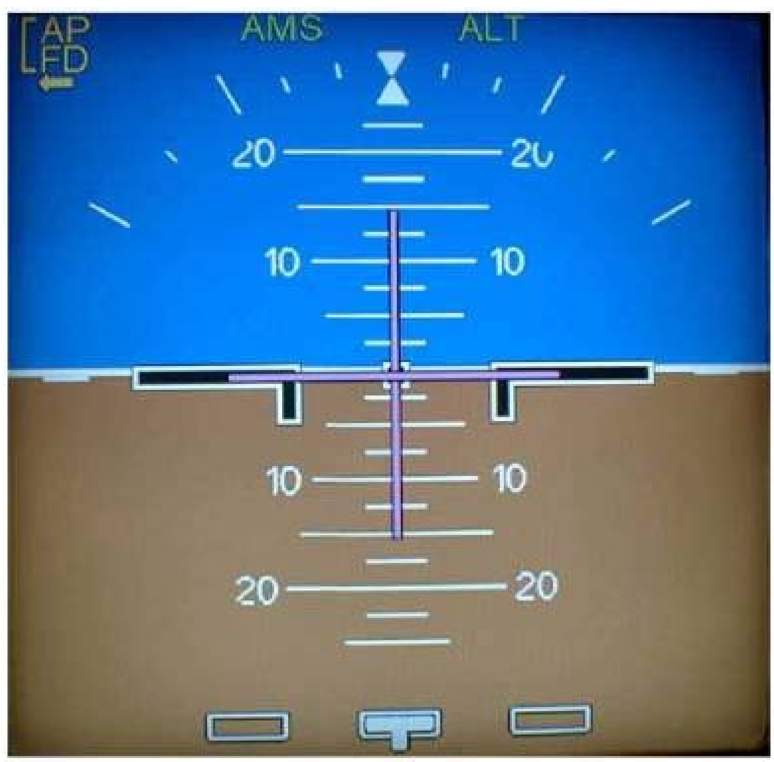

Figure 5: Sample EFDI Screen

Taken from CMC Electronics Human Interface Specification, 2005 similar and more capable autopilots were analysed, including the Airbus 320, CC-130 AUP, and C-130J, and modifications were suggested. During this process, it became clear to the team that a larger display or dedicated AFDS status display in the primary field of view would provide a better solution.

The primary mechanism through which the ASW-31 had communicated faults to the pilots was through flashing the red, radar altimeter - altitude warning system (RAAWS) flashers mounted on the left and right glare shields in the pilots' primary field of view, shown in the appendix. The RAAWS flashed when the aircraft descended below a selected altitude on the radar altimeter or when there had been an abnormal AFDS disconnection.

The ASW-31 had not been equipped with a dedicated audible alerter. It did however make an audible "click" when the magnetically held switches on the control panel were released as a mode was disengaged. Pilots used this incidental auditory indication to augment the flashing RAAWS lights to alert them when the autopilot was disengaged.

The heavy use of the EFDS for communicating information to the pilot, despite its display area being the same as the legacy displays, contributed to AFDS modal awareness deficiencies that confused a highly trained flight test crew. This was combined with the loss of an undocumented legacy annunciation, the disengagement "click" of the ASW-31, to make AFDS modal awareness a significant issue for the modification. Several iterations of display arrangements were designed, but no satisfactory solution had been identified by the end of April 2005.

Integration of Old and New Equipment

Wherever possible, old components were integrated with new components. They often remained as data sources for the new systems, or were activated by the new systems. The result was frequently disappointing when the output characteristics of the old equipment didn't meet the requirements of the new systems.

AFDS Integration

The AFDS had been previously installed in the P-3Ks of the Royal New Zealand Air Force, the P-3Bs of the Royal Australian Air Force and the P-3Bs of the US Customs Service. It had been designed to be a drop-in replacement for older P-3 autopilots and used a number of the same sensors and control actuators. An extensive development program had been carried out to ensure the system would work well within the basic P-3 envelope (Jackson, 2002), with satisfactory results. Although there was a great degree of commonality between those previous implementations and that for the CP-140 (CMC Electronics AFDS Equivalence, 2003), all three had different interfaces with the other aircraft systems. In the case of the Royal Australian Air Force and Royal New Zealand Air Force, analogue interfaces conveyed radio navigation aid information to the autopilot computer whereas the US Customs Service had digital radio navigation aid receivers. The NFIMP modification sent data to the AFDS from the original navigation aid receivers that had undergone an analogue-digital conversion inside the EFDS. All three implementations had digital ADCs, using the original pitot and static ports, providing air data to the AFDS. In the case of the NFIMP, the ADCs were commercially available and had been previously installed in helicopters (BAE Systems Canada, 2000). Despite the confidence of the entire program team in the AFDS itself, its data sources were an untried combination.

The integration of the AFDS proved to be one of the most problematic portions of the entire NFIMP. Like all systems, it had been tested as much as practical in the Systems Integration Laboratory (SIL) and on the ground prior to flight test. Lessons learned in previous installations had been incorporated into the software and other elements. Although a moderate number of envelope expansion test points had been programmed (CMC Electronics Flight Test Plan, 2004), the risk of errant gains or AFDS malfunction was thought to be low.

Early AFDS flight tests were plagued by uncommanded disconnects whenever the pilot applied a small amount of positive or negative normal acceleration in a turn or wings level pull up or push over (Post Flight Report #5, 2004). All aircraft systems appeared to be serviceable, however the system could not be employed in any turn or moderately aggressive attitude change.

An analysis of fault code data recorded by the flight test instrumentation indicated a problem with one of the normal accelerometers that fed data into the AFDS. It was a legacy component, unaffected by the NFIMP modification. Ground checks of the accelerometer showed it to be within specifications and functioning normally. In an attempt to avoid delays to the flight test program, the accelerometer was ordered replaced as a troubleshooting step and the problem never reoccurred.

The aircraft had no autopilot malfunctions prior to induction into the NFIMP modification line, thus it is likely that the accelerometer was presenting adequate data for the legacy autopilot. That same component, which had ground checked serviceable, was now not up to the task. There would be no indication for front-line maintenance personnel to suspect it were a similar failure to occur in normal use, as the flight test instrumentation would not be available on production aircraft. The long-term impact of this new potential problem on the availability rate of the system was not known.

As the AFDS test program carried on, it became apparent to crews that the AFDS was not flying the aircraft in wings-level balanced flight (Post Flight Report #8, 2004). The aircraft appeared to be in a slight, steady-heading sideslip with the left wing down. Further analysis of flight data indicated a +/- 0.5° roll oscillation with a period of approximately 5.5 seconds (CMC Electronics Ground Test Report, 2005). Following inconclusive ground checks, a detailed analysis of the databus traffic recorded by the flight test instrumentation showed that the problem could lie in the hydraulic actuator systems in the empennage and wings of the aircraft that translated the AFDS commands into the hydraulic actions necessary to move the control surfaces.

Although the legacy systems were serviceable by established on-aircraft maintenance standards, they were not able to function properly when connected to the new AFDS. The contractor carried out an extensive series of ground tests using non-standard techniques, confirming that both the aileron and rudder hydraulic actuator systems required replacement (CMC Electronics Ground Test Report, 2005). The aileron and rudder hydraulic actuator systems had not yet been replaced by April 2005, so the correctness of the contractor's conclusions had not been verified.

The DND must now ascertain the impact of this finding. It may be required to order extra testing or the overhaul of all the aileron and rudder hydraulic actuator systems, at a significant cost. Additionally, maintenance manuals and technician training will require changes to include these newly discovered serviceability criteria. Although the new AFDS did not specifically require the modification of the remaining components of the flight control system, there will be at least a short-term cost to make equipment that meets current requirements compatible with the newly installed AFDS.

These two maintenance problems did not exist with the legacy autopilot system, but no cost neutral solution had been found to deal with them. Maintenance and engineering effort was expended during the flight test program to solve them, but both the long and short-term costs remained unknown.

There is significant technical and schedule risk whenever modern equipment is expected to function properly with older, legacy equipment. A careful analysis of these risks must be made, and allowances for the re-work of the legacy equipment must be made both in schedule and effort.

The altitude hold capability of the AFDS was gradually explored during the flight test program. One operationally important use for the altitude hold was while conducting low-level operations over the ocean. CP-140 crews routinely operated as low as 100 feet above the ocean's surface in all weather conditions (Statement of Operating Intent, 2000). The legacy autopilot had been used to maintain aircraft altitude during these manoeuvres. Operational techniques had been developed to ensure a safe descent from en route altitudes, allowing 60° bank turns to be performed just above the ocean's surface. It was essential that the new AFDS be capable of performing the same task.

At moderate altitudes, the AFDS showed itself to be sluggish in maintaining altitude (Post Flight Report #13, 2004). There were constant pitch oscillations while the AFDS was holding an assigned altitude. The aircraft would exceed the +/-50 foot altitude band that the system was specified to maintain (CP-140 NFIMP Automatic Flight Control System Specification, 2003). The AFDS would frequently not engage altitude hold mode when commanded, despite all the preconditions being met according to pilot indications. Performance was lacklustre and "undesirable" (Post Flight Report #13, 2004).

Despite this poor performance, the flight test team continued to try to use the AFDS in all its modes. A seemingly unrelated problem was found when attempting a coupled Instrument Landing System approach; the AFDS was unable to couple to the navigation aid. The system would immediately disconnect and provide an AFDS error message (Post Flight Report #5, 2004).

An analysis of the ADC data showed that the signal contained a great deal of apparently random noise. Although this noise had been observed in earlier analysis, it had not been considered significant as the magnitude of the noise was generally less than +/-20 feet. A two-minute sample of ADC data, recorded by flight test instrumentation during straight, level, unaccelerated flight is shown in Figure 6.

This noise was interpreted by the ADCs as large altitude rates. These high rates would cause failures of the various crosschecks between the ADC outputs, often causing the AFDS to disconnect. As many of the AFDS control outputs were scheduled according to airspeed, this noise was also causing poor

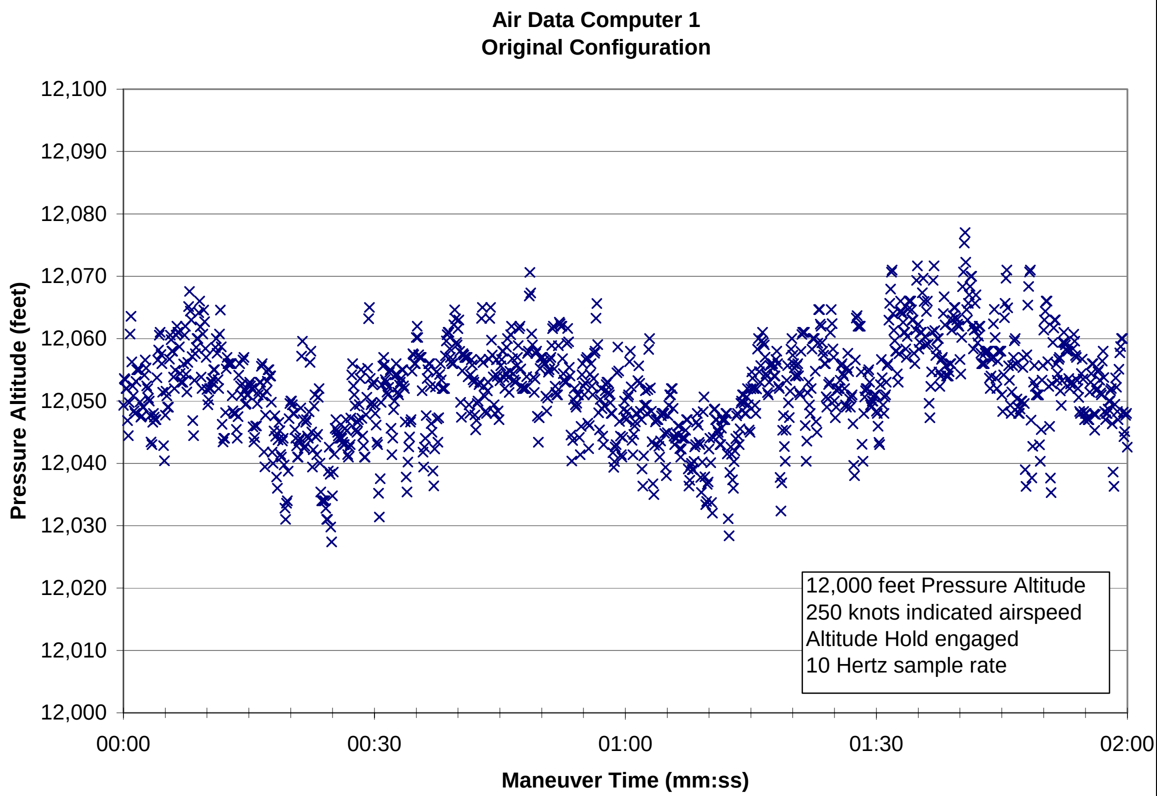

Figure 6: Air Data, Original Configuration

performance. Further analysis by the contractor showed the frequency of the noise to be at approximately the same frequency as the rotation of the propellers. Ground tests involving starting and shutting down of engines with pitot-static system ports blocked and unblocked confirmed that the airflow behind the propellers was causing the disturbance. The static ports were located behind the main cabin door, aft of the wing.

The new ADCs used the existing aircraft pitot-static system by tapping into the co-pilot's side. The pilot's side remained untouched. The high frequency noise had always been present in the system; it had simply not mattered to the legacy, analogue avionics. In the early 1990's, restrictors had been placed into the static system to resolve a problem with the aircraft oscillating unacceptably when in Altitude Hold (CP-140 Porpoising Problem Investigation, 1991). These had been removed during the NFIMP modification as a solution to that problem had been incorporated into the AFDS itself.

Ground tests showed that re-insertion of the restrictors would remove the high frequency components of the noise, and software in the ADCs could be modified to remove the lower frequency components of the noise. This combination of software filters and mechanical restrictors inserted into the system were intended to reduce the noise on the signal sufficiently to allow altitude capture and instrument landing system glideslope capture functions to proceed, without introducing other unsatisfactory characteristics. Flight tests later proved that the noise level had been sufficiently reduced.   Figure 7 presents air data recorded during a manoeuvre identical to that in Figure 6, after the ADC software had been changed and the restrictors re-inserted into the static lines in the positions defined during previous testing (CP-140 Porpoising Problem Investigation, 1991).

The re-introduction of the static restrictors in their original locations had resolved the noise problem, but there were an unacceptable number of uncommanded AFDS disconnects during subsequent flight testing when the aircraft was aggressively manoeuvred (Post Flight Report #22, 2005). Flight test

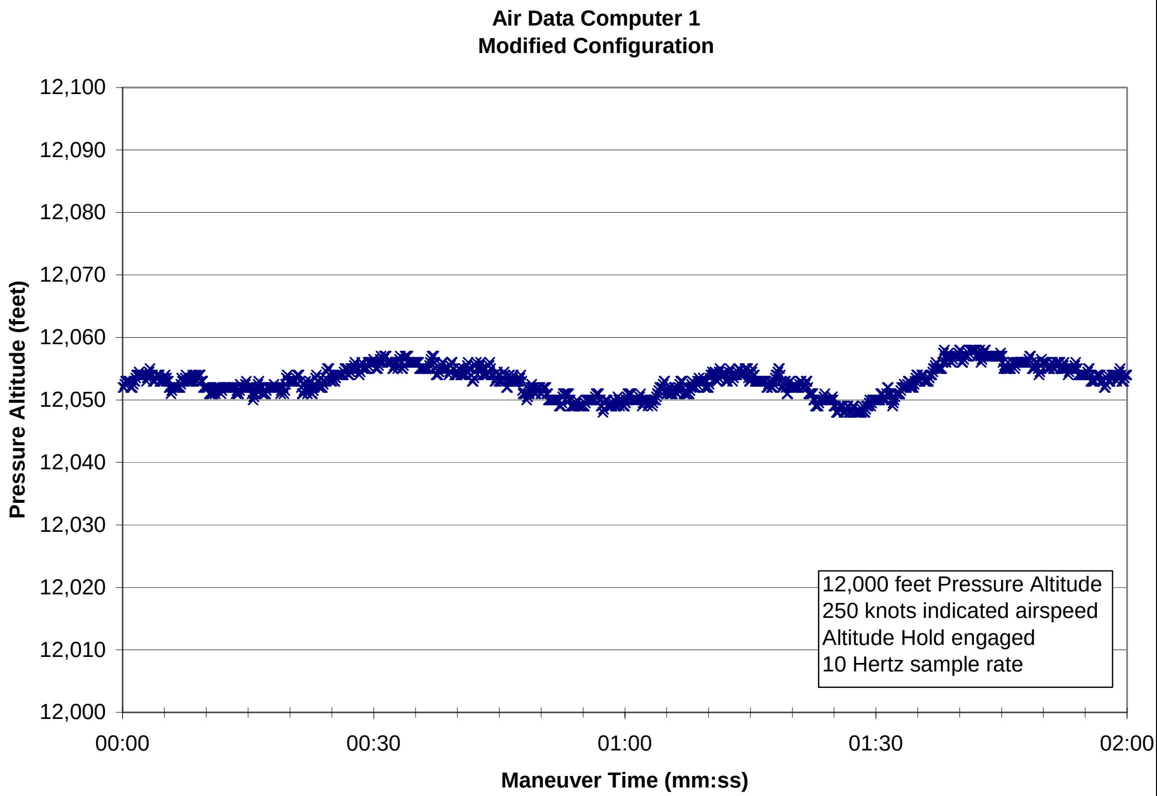

Figure 7: Air Data, Modified Configuration

data analysis showed a new differential between ADC 1 and ADC 2, manifested as a lag. Figure 8 shows a high speed, wings level pull-up manoeuvre where the different altitudes being reported by the two ADCs are shown. During this relatively steady manoeuvre, the altitude difference was up to 65 ft. In aggressive pull-ups or other rapid altitude changes, this difference would increase to approximately 200 feet.

The AFDS compared data from the two ADCs, disconnecting whenever an altitude difference of more than 100 feet was reported. This safety check was

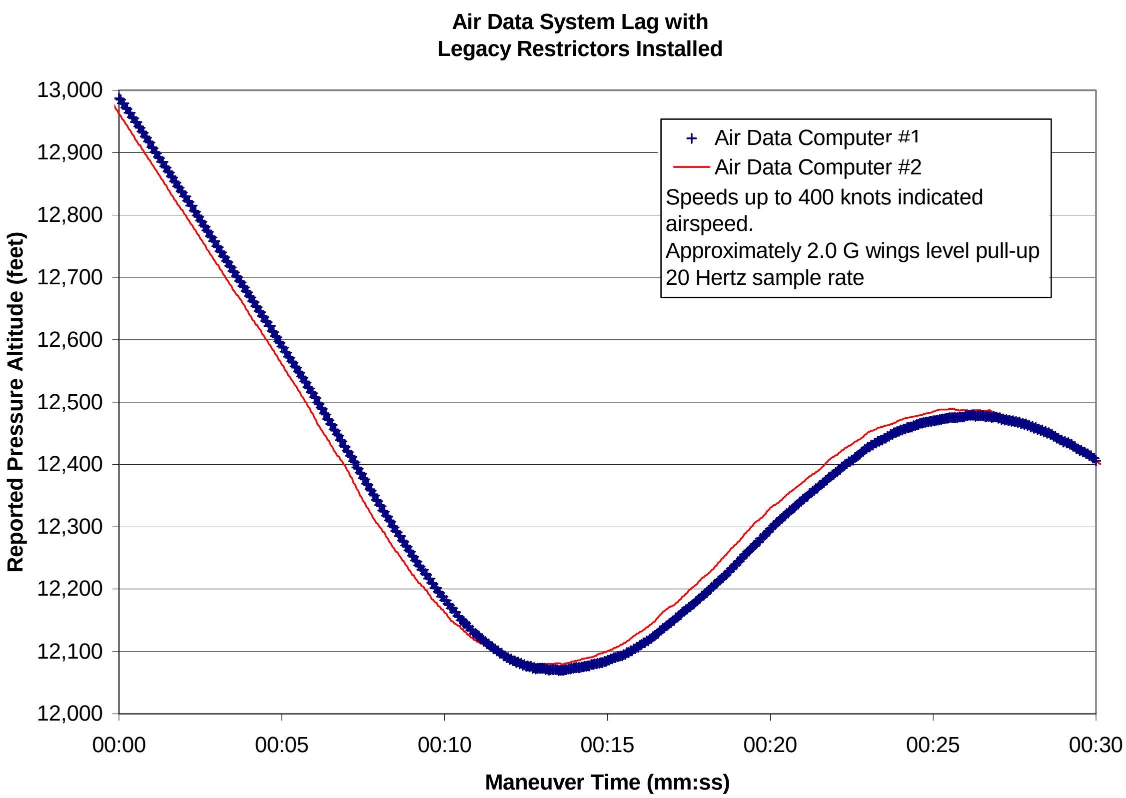

Figure 8: Air Data System Lag with Legacy Restrictors Installed

triggering the uncommanded disconnects. An examination of the different positions of the restrictors in the ADC 1 static line and the ADC 2 static line showed a volumetric imbalance between the two systems. There was a larger volume of air between ADC 2 and its restrictor that was responsible for the lag. The intended solution, balancing the volume of the two systems, had not been flight tested by the end of April 2005.

The static air pressure sensing system of the CP-140 had a proven track record, as did the ADC selected for the NFIMP modification. Changes to the static air system had been minimized in an attempt to reduce technical risk. Despite this mitigation, their unacceptable combined performance with the AFDS in actual flight conditions could not have been predicted by lab or static ground tests. These difficulties are typical of the sorts of problems one should expect and plan for when dealing with a complex interaction of new and old systems.

Display of Distance Measuring Equipment Range

One of the intended uses of the SIL was to "integrate and test the NFIMP systems" (BAE Systems Canada, 2000). Approximately one year before the beginning of flight testing, a problem was identified with the display of data from the legacy AN/ARN-504 tactical air navigation radio set (TACAN) on the EFDS in the SIL (NFIMP Problem Report Database, 2005). Specifically, line-of-sight range data from the distance measuring equipment (DME) was being misinterpreted by the EFDS, and subsequently presented to the pilot with ten miles added to the result. This new problem could easily confuse pilots using the DME for navigation tasks. Table 2 shows the actual and anticipated DME range displayed, based on SIL testing, when the range was increasing. Table 3 shows the actual and anticipated DME range displayed when the range was decreasing.

Despite having been found well before the beginning of the flight test program, the problem was not rectified at that stage. The contractor had queried members of the flight test team about the relative importance of the problem, who responded that the severity of the problem depended on the length of time the

Table 2: Actual Range Increasing and Expected DME Display

Actual Range Increasing (nautical miles)	Expected DME Display
9.8	9.8
9.9	9.9
10.0	19.9 briefly, then 10.0
10.1	10.1
10.2	10.2

Table 3: Actual Range Decreasing and Expected DME Display

Actual Range Decreasing (nautical miles)	Expected DME Display
10.2	10.2
10.1	10.1
10.0	10.0
9.9	19.9 briefly, then 9.9
9.8	9.8
9.7	9.7

erroneous data would be presented. A misleading distance, presented for only a second would possibly be acceptable, as other aircraft in the Canadian Forces fleet exhibited this shortcoming (CT-133 Silver Star Aircraft Operating Instructions, 2002). A longer presentation of incorrect range was unlikely to be accepted.

During flight test, the full extent of the problem became apparent (Post Flight Report #1, 2004). Rather than a brief presentation of false data, the DME would be wrong while the aircraft was in the last half nautical mile of any range decade. At a nominal cruise speed of 200 knots indicated airspeed at 10,000 feet, heading directly away or toward the ground station, the incorrect range would be displayed for approximately 10 seconds. When flying a tangential arc a fixed radius from a ground station, a frequent practice when instrument flying in bad weather, the display would be often jump back and forth between correct and incorrect ranges. The potential for confusion, or certainly at least annoyance, with this characteristic was significant. Table 4 shows the typical, actual DME range displayed when the distance was increasing. Table 5 shows the typical, actual DME range displayed when the distance was decreasing.

The DME data were encoded into a 3-wire synchro signal inside the TACAN, and sent to the display. Investigation by the contractor determined that the legacy electromechanical horizontal situation indicator DME display used a Geneva Gear, similar to the odometer in a car, to display DME data. Any ambiguity in the synchro signal was resolved by the display, as the mechanical pins in the gear prevented it from moving non-sequentially. When the synchro signal, including a small amount of ambiguity, was interpreted by the new EFDS, the ambiguity remained and was displayed to the pilots.

The TACAN installed in the prototype aircraft was confirmed as being serviceable and representative of the systems installed in the rest of the fleet. Analysis by the contractor determined that the ambiguity was an inherent characteristic of the TACAN that was compensated for within the legacy horizontal situation indicator DME display. No solution to this problem had been installed in the prototype aircraft by the end of April 2005.

Table 4: Actual Range Increasing and Actual Displayed DME

Actual Range Increasing (nautical miles)	Displayed DME
9.3	9.3
9.4	9.4
9.5	19.5
9.6	19.6
9.7	19.7
9.8	19.8
9.9	19.9
10.0	10.0
10.1	10.1
10.2	10.2

Table 5: Actual Range Decreasing and Actual Displayed DME

Actual Range Decreasing (nautical miles)	Displayed DME
10.2	10.2
10.1	10.1
10.0	10.0
9.9	19.9
9.8	19.8
9.7	19.7
9.6	19.6
9.5	19.5
9.4	9.4
9.3	9.3

The integration of old and new equipment in an aircraft can be a difficult engineering task. There will often be systems, such as with the air data system in the CP-140, where ground tests may not be able to uncover the problem early in a program. In other cases, the problem may be found early on, but the solution may prove troublesome to implement. Program managers must keep a reserve of resources to expend on these types of problems, often uncovered only near the end of their program schedule.

Suggestions for Future Programs

By restricting the acquisition of new capability with NP program funds, the DND ensured that the resources required for routine maintenance could be allocated without a great deal of oversight on how they were spent. Aircraft engineering officers were thus able to maintain the systems they were responsible for with a reasonable amount of independence. New capabilities were only acquired where there was an established, validated requirement, authorised at the appropriate headquarters level, rather than being haphazardly acquired through a maintenance process.

A critical part of any large program is a clear articulation of the aim and objectives. For military aircraft modernisation programs, a statement of the minimum capability level to be preserved or acquired is also essential. The results of this goal setting process must then become a prominent part of all decisions made regarding the allocation of resources.

When NP funds are used to as part of a large modernisation effort, as was the case with the NFIMP, program managers should be given an expanded mandate to bring both the systems and capabilities being modernised up to the current state of the art, in line with stated program goals. These new capabilities should not expand the role of the aircraft or enable it to perform significantly changed missions without specific authorisation through the normal requirements management process. Provided they don't, program managers should be given the flexibility to acquire all the up-to-date capability they can, in accordance with program goals, with the financial resources they've been given.

Managers must be ready to embrace current technology, ideas and standards when considering new equipment. In doing so, they must be equally prepared to make up for the loss of some of the qualities inherent in the equipment being replaced. In the case of the NFIMP, the loss of stabilising characteristics of the electromechanical displays and the audible disengagement of autopilot modes had left the updated aircraft with deficiencies. When considering which equipment to replace or retain, managers should avoid closely integrating old and new systems, but they must also be prepared to compensate for the collateral decreases to crew awareness, system stability or overall airworthiness when old equipment is removed.

When considering unsolicited capability offered in contractor proposals, managers must develop detailed requirements for those capabilities, similar to those developed at the outset of the program. Detailed requirements and specifications will ensure that any additional capability will benefit operational flight crews and that engineering effort will not be wasted on marginal improvements or half-efforts.

Given the problems routinely uncovered in flight test despite significant amounts of lab and ground testing, a financial and schedule reserve must be planned to allow issues uncovered during flight testing to be addressed. Without this reserve, programs will be forced to make unpalatable decisions, likely sacrificing performance or capability, to resolve problems discovered late in their schedule.

3. Conclusion

The NFIMP modification was intended to update the 25-year old cockpit of the CP-140 through a combination of system replacements and additions. Strict regulations governing the allocation of funds to either the acquisition of new capability or the maintenance of existing capability resulted in a delayed deployment of the final product with a diminished operational utility compared to the likely product had a simple cap on total expenditures been enforced.

In submitting a competitive bid for the program, the contractor offered a significant number of capabilities beyond the minimum called for in the NFIMP System Specifications. Although unable to specifically authorize additional expenditures on these extra capabilities, the DND accepted their proposal, including all the promised extra capabilities. No detailed requirements or specifications were developed for the extra capabilities.

As the program schedule incurred numerous delays caused by development and integration problems, it became apparent that continued effort on these features, deemed non-essential in the earliest stages of program planning from a military point of view, would further extend the schedule unless additional resources could be brought to bear on the problems. By eliminating the extra capability from the final product or reducing it to insignificant utility, the

DND effectively wasted the effort previously expended on its integration or development.

Where the extra capability was highly desirable for inclusion in the modification, as in the case of VNAV, the DND was unable to authorize the expenditure of additional funds to specifically address those shortcomings. Instead, overall program schedule was sacrificed to allow technical problems to be solved with the resources at hand, further delaying the final product.

Without firm, testable requirements and specifications for the extra capabilities, the DND was left with few mechanisms through which to ensure the final implementation of the extra capability possessed any particular characteristics. In the end, it was up to the contractor to determine the final state of any of the extra capability.

In the process of replacing obsolescent equipment, the DND had an opportunity to take advantage of current industry standards in avionics. Technically simple options were available that would have decreased the workload for crews and increased the overall capability of the NFIMP modification. These included items such as larger EFDS screens, AFDS annunciators and altitude selector-alerters. The restriction against increasing capability with NP program funds prevented such equipment from being included in the modification.

By not taking advantage of widely available modern equipment and options that were standard in other systems, even within the DND aircraft fleet, the NFIMP modification introduced new shortcomings in the overall system. Essentially, by incorporating that additional capability which was unavoidable or included as "exceeding requirements" in the contractor's proposal without looking to the impact on the whole, the modification created an integrated system that had new deficiencies from a flight safety or operational effectiveness point of view.

These new deficiencies required additional effort on the part of the contractor and the flight test team to rectify. In some cases, the most obvious and lowest technical risk solution could not be entertained because of the additional capability it would add. The administrative effort required to justify the capability was not made. In some cases, the test team recommended the removal of some of the new capability to ensure that the remaining systems could be operated safely.

One element of the overall effort to reduce program cost was the retention of the maximum amount of legacy equipment; the corollary was that the replacement of equipment that was not yet obsolescent could not be justified. This resulted in the maintenance of legacy pitot-static instruments in the cockpit, and all radio navigation receivers in the aircraft.

The contractor was responsible to integrate their new equipment with that remaining in the aircraft. Problems were encountered when the outputs of analogue equipment were to be used by the new digital system. Similarly, the wide tolerances and inherent stabilizing characteristics of analogue, legacy equipment were incompatible with the digital computations performed by some of the modern equipment. These incompatibilities caused a significant amount of engineering effort to be expended, with accompanying schedule delays.

Had the option existed to simply replace the legacy equipment with modern equipment with an equivalent function, a cost/benefit analysis could have been conducted. Considering the marginal acquisition cost of such standard equipment and the likely reduction in follow-on maintenance costs, the savings in engineering effort and schedule delay could have made a convincing case for updates.

Future modernisation programs should have their NP and CP resources combined and program managers given the authority to allocate funds as required to achieve program objectives. This will enhance their ability to maximize the benefits of the program.

Embracing the full range and capability of modern technology will free managers from the limitations of the systems they are replacing, and will help to minimise the shortcomings of the remaining equipment. It may also reduce the number of integration problems that may not be discovered until late in the program.

Despite increased fiscal flexibility and the maximisation of new technology, problems will always be encountered during flight testing, late in the program schedule. A meaningful reserve should be allocated to deal with these problems, thus avoiding a trade-off between capability and schedule or costs.

Although it is difficult to assign a dollar cost to the schedule delays and the engineering effort expended by government personnel, it is not difficult to argue that the cost of a program being 100% over schedule, with a significant reduction in final capability, was considerable.

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Appendix

Adapted from Flight Test Plan and Procedures for the Canadian Forces CP-140 Aurora Navigation and Flight Instruments Modernisation Project (CMC Electronics, 2004).

<u>Overall Modification</u>

The NFIMP system provided the pilot, co-pilot, TACNAV and NAVCOM with new avionics to maintain and improve current aircraft capabilities and provide for future growth.

The NFIMP upgrade introduced Aeronautical Radio Incorporated (ARINC) and MIL-STD-1553B databuses as replacements for the existing analogue system. Dual EGIs provided attitude and position data which were fed using standard ARINC 429 serial links to the flight displays and navigation data to the CDUs on the MIL-STD-1553B avionics databus. The CDUs were the bus bontrollers for the avionics data bus. The CDUs also communicated as receiver-transmitters with the CP-140 mission computer, the general purpose digital computer (GPDC), via the MIL-STD-1553B mission databus. Legacy avionics, such as very high frequency omni range, instrument landing system, TACAN, low frequency beacon receivers and compass were integrated into the flight displays using their existing interface formats (synchros or deviations). When required, the EFDS converted this analogue information into an ARINC 429 digital format for use by other NFIMP systems.

Under failure conditions, the system had graceful degradation characteristics, with redundancy and reversion modes.

AMS

The AMS provided the core NFI avionics/mission system integration element. The AMS comprised four identical CDUs and a data loader system (DLS). Two CDUs resided in the cockpit center pedestal, the third at the NAVCOM station, and the fourth at the TACNAV station. The DLS was installed at the NAVCOM station.

The CMA-2082D CDU was an intelligent multiprocessor system that incorporated a 10-centimetre by 10-centimetre flat panel active matrix liquid crystal display and associated multifunction key panel. Each CDU provided the capability to implement all control, display and processing for navigation, communications and mission system management. Functionally, the CDUs provided the multifunction operator interface for control of the EGIs, IFF, ACAS and RAAWS, as well as navigation source selection, civil area navigation, tactical navigation, database upload/download and editing, the setup and control of flight plans and tactical patterns, and the display of sensor, navigation and status information.

The CDUs provided area, vertical and tactical navigation outputs to the EFDS and AFDS based on the selected navigation source and the active flight plan. As well, the CDUs interacted with the GPDC, to provide navigation solution data and exchange tactical flight data from it.

The DLS provided a medium, which could upload user-specified mission data into the AMS via a Personal Computer Memory Card International Association solid-state data transfer medium. Likewise, the DLS provided a download capability for mission-related and maintenance data. The data loader was also used to load CDU software and the monthly-produced civilian navigation database required for worldwide, airways navigation.

EGI

Two EGIs replaced the legacy LN-33 inertial navigation systems and provided a GPS capability, as well as two GPS antennas and a cryptographic load panel. They also replaced the rate-of-turn gyroscopes, and provided the data for the electronic turn/slip inclinometers. The EGI cryptographic load port provided a load capability for classified GPS cryptographic keys from standard KYK-13 cryptographic loading devices.

EFDS

An EFDS replaced the existing electro-mechanical primary flight instruments. It included one EFDI, one EHSI and one DCP installed in each of the pilot and co-pilot instrument panels. There was also one EHSI and one DCP installed at the NAVCOM station. The EFDI and EHSI displayed basic EGI attitude/heading, flight director bars, lateral and vertical deviations, autopilot modes, area/tactical navigation information, radio navigation aids bearing pointers and selected warnings.

The DCP permitted selection of navigation course source, attitude and heading source, and bearing pointers source at each crew station. The EFDS also incorporated Map, and Plan modes. This allowed the display of nearby airports, navigation aids and waypoints based on data provided from the CDU navigation database.

The EFDS received standby attitude and compass heading inputs as backup when the selected EGI data were unavailable. The EFDS provided heading outputs to the Weather Reconnaissance System, and attitude to the Radar, in accordance with crew selections as per current aircraft operation.

AFDS

The AFDS replaced the existing ASW-31 autopilot/flight director system. The upgrade included two solid-state rate gyroscope assemblies, an autopilot/flight director computer and a control panel, which provided for combined autopilot and flight director selections. The autopilot/flight director computer interfaced with the existing actuators, accelerometers, trim indicator, control wheel switches/sensors, RAAWS warning flashers, and hydraulic power switch. AFDS status and mode annunciations were provided on both the autopilot control panel and the EFDS.

The new AFDS provided the full suite of autopilot functions including heading and attitude hold, control wheel steering, altitude hold, heading select, approach modes, and coupled navigation. In addition, the AFDS provided altitude select and airspeed hold modes. The AFDS also incorporated a full range of flight director functions. All flight director modes could be driven from either Pilot or co-pilot settings, and could be coupled to the autopilot for lateral and vertical steering.

ADC

Two ADCs were installed to replace the existing AFDS barometric controllers, the true airspeed computer and the flight data recorder transducer. These units were not used to provide information to the primary flight displays. Primary altitude and airspeed display to the pilot and co-pilot was accomplished with the existing legacy instruments. The ADCs interfaced with the existing dual-output temperature sensor, and static and pitot pressure inputs, to provide ARINC-429 air data for use by the AFDS and CDU. Barometric corrections for the ADCs could be entered on any of the CDUs. The CDUs accepted data from the ADC and routed true airspeed and outside air temperature to the GPDC via the mission data bus, altitude and airspeed to the IFF and outside air temperature to the flight data recorder via the avionics data bus. The ADC transmitted data directly to the flight data recorder for altitude recordings. The ADCs were also used by the CDU as the altitude sensor for the VNAV guidance.

RAAWS

A redundant RAAWS was installed to replace the legacy AN/APN-511 RAAWS. Each RAAWS was a stand-alone unit, including a height indicator equivalent to the indicator currently used on the CP140A, a new transceiver sensor, two antennas for each transceiver (total of 4 installed for the dual system) and interfaces to the legacy cockpit flasher and intercom system. This system provided the same functionality as the legacy CP-140 RAAWS. The new system provided a low-probability-of-intercept capability and full performance up to 35,000 feet. Although, the height indicator only displayed altitude to 5,000 feet, the CDU could display the full altitude range. The radar altimeter interfaced with the CDU, which in turn provided the data to the mission computer. The CDU also used these data to inhibit VNAV guidance below 1000 ft above ground level.

The radar altimeter provided data to the ACAS to inhibit descent RA's when the aircraft was at low altitudes. The radar altimeter did not support coupled vertical steering (AMS or AFDS).

ACAS

The ACAS included an ACAS processor, two TA/RA/VSI displays (one at each of the pilot positions), and two (top and bottom) directional antennas. The displays served two purposes – to indicate Traffic Advisories and Resolution Advisories, as well as indicate vertical speed, replacing the existing vertical speed indicators. The ACAS processor used the interrogation replies received from other transponder-equipped aircraft in the vicinity to determine their position and potential to cause collision. As the potential to cause a conflict increased, the processor used the transponder data of the intruder aircraft to predict the time to, and the separation at, the intruder's closest point of approach. Had the ACAS predicted that certain safe boundaries might be violated, it would issue a Traffic Advisory to alert the crew that closing traffic was in the vicinity. If the intruder continued to close, the ACAS would issue a Resolution Advisory to obtain or maintain safe vertical separation between own aircraft and the intruder. The Resolution Advisory provided both a visual and audio commands to the crew that would resolve the conflict if acted upon in a timely fashion. The unit included an "Enhanced" mode with increased range and rendezvous features.

AN/APX-100 Mode S IFF

AN/APX-100 Mode S IFF transponder with embedded Mode 4 replaced the legacy AN/APX-77 transponder set and KIT-1A. The IFF system included the legacy IFF antennas and an AN/APX-100 transponder. The transponder was capable of receiving and decoding interrogation challenges for the selective identification feature Modes 1, 2, 3/A, C, and Mode 4 (or National cryptography), as well as Mode S Level 2. It also featured an ACAS capability and an embedded Mode 4 cryptographic module. The integrated Mode 4 module eliminated the need for an external KIT-1C cryptographic computer. The IFF was fully integrated with the ACAS (described above). The MIL-STD-1553B interface allowed the

CDU to provide the primary control interface to the IFF. Switches were installed in the cockpit centre pedestal to provide Mode 4 code hold, emergency IFF, and Mode 3 identification functions.

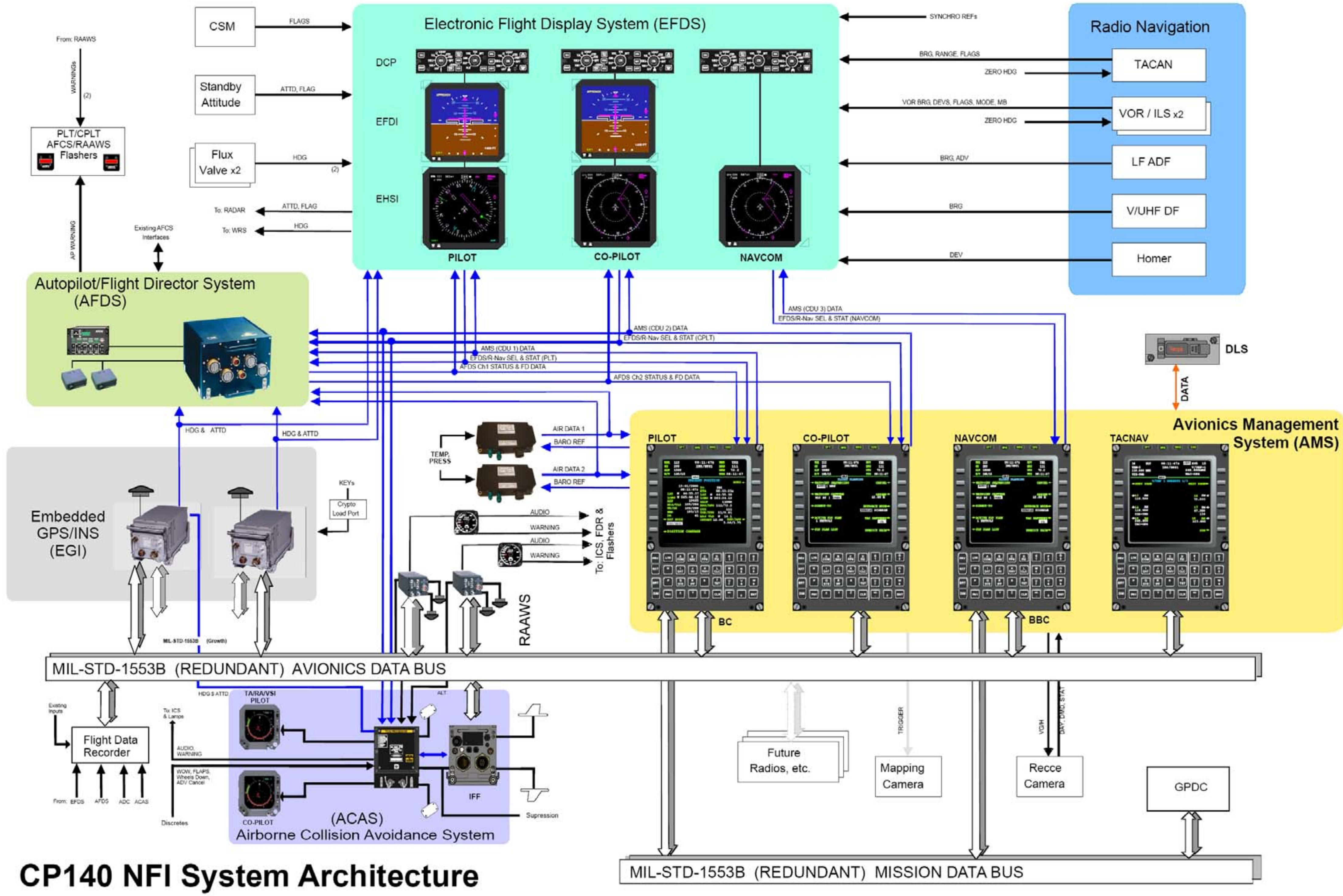

Figure A - 1: System Architecture

Taken from CMC Electronics Flight Test Plan, 2004.

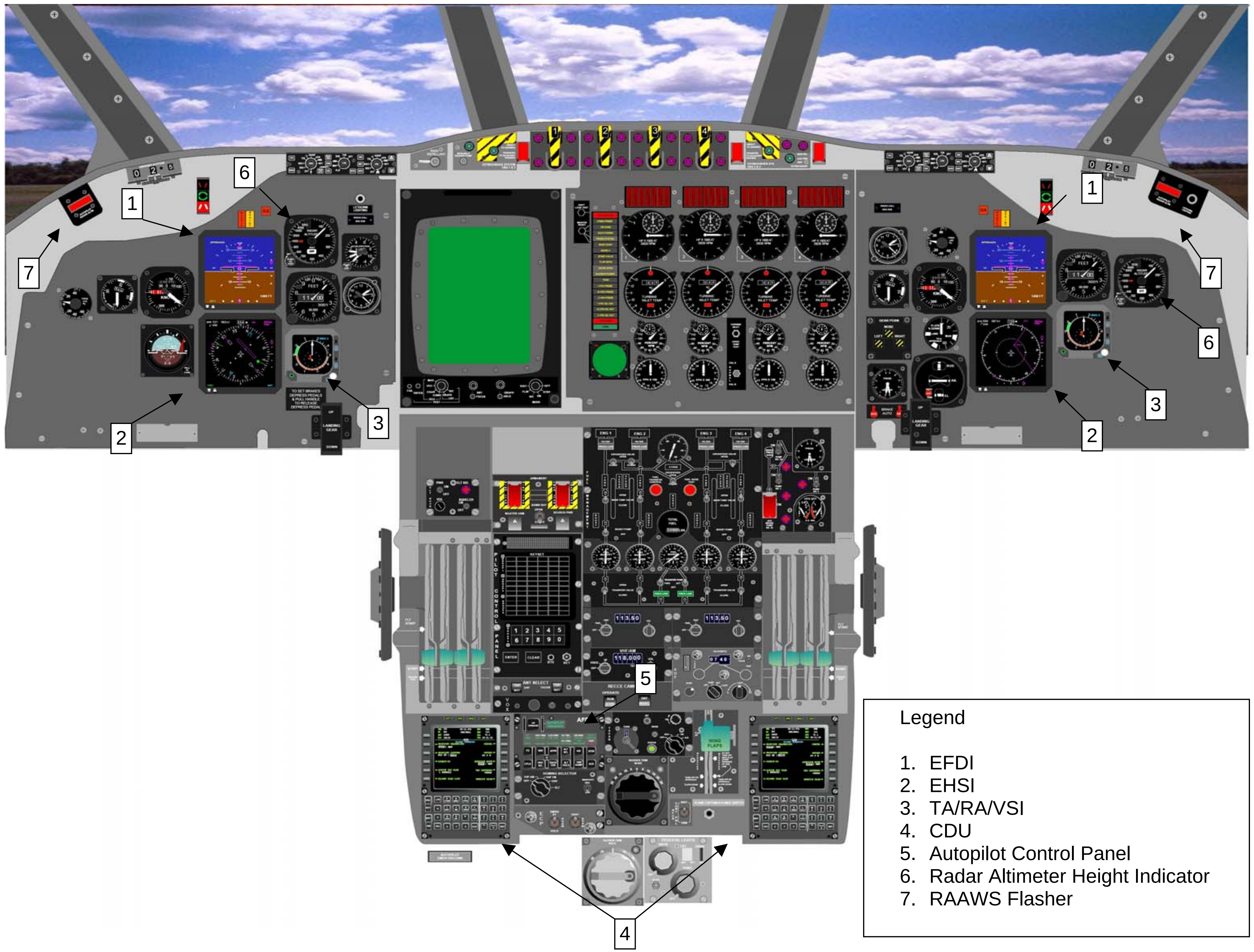

Figure A - 2: NFIMP Equipment Cockpit Layout
Taken from CMC Electronics Flight Test Plan, 2004.

Vita

Michael Roy Barker was born in Sydney, Nova Scotia, Canada, on 04 July 1973. He joined the Canadian Forces as an Aerospace Engineer in June, 1991 and went to the Royal Military College of Canada in Kingston, Ontario where he received a Bachelor's of Engineering (Mechanical) in 1995. In 2002 he graduated from the United States Air Force Test Pilot School as a Flight Test Engineer before going to work at the Aerospace Engineering Test Establishment in Cold Lake, Alberta in the Multi-Engine Evaluation Flight.

He is currently the Department of National Defence Test Team Lead for the Navigation and Flight Instruments Modernisation Project Combined Test Force.