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Air Transport Avionics Cost Estimation Related to Future Communication Transitions: Coordination Draft

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Abstract

This paper classifies the air transport aircraft fleet into separate classes of aircraft with similar communication architectures. Using this classification, likely avionics equipment changes and costs for aircraft upgrades to VDL-Mode-2, VDL-Mode-3 voice, and VDL-Mode-3 voice and data capabilities are identified. Additionally 8.33 kHz double sideband amplitude modulation (DSB-AM) capabilities and likely transition are considered and cost estimates provided. Assumptions, based on industry information, are used to provide prices for equipment, upgrades, installation services and materials to provide communication upgrades to both existing and forward fit aircraft. This analysis addresses only the airborne equipment associated with upgrading to the above mentioned technologies.

Costs and equipage estimates made in this paper will be validated with vendors, airlines and service providers to result in a consistent cost estimation for the FAA.

The equipage and cost information is assembled in an MS Excel workbook for easy updating and analysis and is part of this report.

KEYWORDS: Air Transport Aircraft, Avionics, VHF Communication Radios, Avionics Costs, NEXCOM, VDL-Mode 2, VDL-Mode 3, VHF Data Radio, Data Link, Avionics Transitions, 8.33 kHz. DSB-AM.

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1.1. Introduction

Making acceptable decisions on implementing new technology requires accurate and timely information on costs. In making the Next Generation Communication (NEXCOM) decisions for timing and benefits, the costs of implementing such a system should be adequately understood. Many factors go into determining the costs of systems and this paper identifies several factors involving the installation of the NEXCOM avionics in older classic aircraft as well as newer technology aircraft.

These factors include current pricing, market trends on volume discounts, sparing requirements, aircraft architecture, installation and avionics upgrade paths. This paper is unique in that it takes a bottoms-up approach to determining the costs based on assumptions that can be validated and/or modified as better information is obtained.

To identify costs to upgrade the aircraft the transition paths must be defined. Since there are several different transition paths to a final communication capability, many different transition paths were considered. There are 65 different transition paths considered in this analysis over the different classes of aircraft types. These transitions also include considerations for 8.33 kHz. functionality This may sound daunting for the reader, but the grouping of the transitions by aircraft class makes this easier to understand and evaluate.

1.2. Purpose:

To provide baseline numbers to coordinate with stakeholders; FAA, airlines, service providers, and airframe manufacturers. The objective is to arrive at a “best” FAA indication of the costs. These upgrade costs are important in understanding airline modernization timelines.

1.3. Approach

This paper presents a spreadsheet approach to identifying avionics costs. When used in conjunction with a separate model that considers current fleet growth rates, aircraft mixes, and overall timing of upgrade capabilities, total costs and costs attributable to NEXCOM can be produced. This model is covered in a separate working note. The paper is organized with a flow that carries the reader from the assumptions about the aircraft architectures to defining the configurations of the aircraft to determining the equipage needs per aircraft transition to pricing the individual transition configurations.

Costs and equipage estimates made in this paper will be validated with vendors, airlines and service providers to provide a consistent cost estimation for the FAA. Revisions to this initial paper are likely as a result.

This paper includes an MS Excel spreadsheet that summarizes the assumptions, equipage, equipment costs and total aircraft costs per transition.

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2. Assumptions and Definitions

The fundamental assumptions and definitions used in the analysis are defined in this section. Understanding this information will provide the background for evaluating the results of the avionics costs rolled up for each aircraft class/transition combination.

2.1. Global

There are several assumptions that apply across the entire analysis. These affect the overall costs or computation of the costs.

1. The analysis in this paper is used as a baseline for costs that are included in another effort that is not reported here. That other effort will be referenced as the *Total NEXCOM Costs Model* within this paper.
2. Certification costs for individual transitions are estimated in this analysis, but **not** included in the separate Total NEXCOM Costs Model that uses this analysis.

It was relatively easy to assign certification costs to each of the transitions in the costs estimation. However, it is not easy to include them in the rollup of costs for *the Total NEXCOM Costs Model*. Certification costs result from two different means: retrofit of existing aircraft, or the acquisition of new aircraft. Assigning costs to the transitions is easy to do, however, assigning certification costs across an entire fleet is more difficult.

The cost of certification for new aircraft is generally included as part of the option decisions made by an airline for specific equipment. For new aircraft, it can be different for the same equipment on different aircraft types. Not knowing the specifics means it is more difficult to know how to assign the costs.

The certification costs for retrofitting an existing aircraft can be handled by the airline in different ways. Existing aircraft are certified through a Supplemental Type Certificate (STC) process. These STCs apply to all aircraft of a specific aircraft type and, therefore, the cost of the STC can be borne over several aircraft. Until the specific number of aircraft are identified within an airline, it is difficult to assign a cost of certifying the installation for that airline.

3. Two upgrades are necessary for the VHF Data Radios (VDRs) to provide VHF Data Link Mode-3 Voice and Data (VDL-M3vd) capability.

This assumption considers the transition of the voice capabilities that can happen earlier than data link capabilities within VDL-M3. In addition, due to the market pressures and the airlines desire to upgrade to the NEXCOM data link at different times, the manufacturer will offer separate upgrade kits.

4. Any avionics transition beyond VHF Data Link Mode-2 (VDL-M2) is attributable to NEXCOM costs.

Airlines will accept VDL-M2 for improved AOC performance, and this transition prepares the aircraft to accept NEXCOM upgrades more readily. However, it was decided that VDL-M2 costs should not be attributable to the cost of NEXCOM.

5. 8.33 kHz capabilities are treated with a subset of transition states that may include upgrades that provide 8.33 kHz capabilities without growth to VDL-M3.

2.2. Classifying Aircraft Types

To simplify determination of avionics costs, the air transport aircraft examined were grouped into four classes based on avionics architecture and date of introduction to service. Aircraft currently in service (1999) were classed as Classic, FMS/E/CAS, or, integrated. Aircraft introduced after 1999 were classed as Forward Fit (New) without regard to actual aviation architecture.

2.2.1. Classic Aircraft

The Classic aircraft typically do not have digital interfaces or electronic displays, but rely on instrumentation with electromechanical designs. They are certainly capable of providing the pilot with the required information to fly the aircraft, however, the systems are difficult to upgrade economically. For this analysis, Classic air transport aircraft are represented by the following aircraft models grouped by manufacturer:

Airbus:	A300
Boeing:	727-200; 737-100; 737-200; 737-200A; 737-300; 747-100; 747-200; 747-200F DC10-10; DC10-30; DC10-30F; DC10-40; DC9-10; DC9-30; DC9-40; DC9-41; DC9-50; MD80; MD83; MD88
Lockheed:	L1011-50; L1011-100; L1011-200; L1011-250; L1011-500

All of these aircraft were originally delivered with ARINC 566a VHF communication radios, which are referred to as “analog” radios. Tuning of these radios is achieved with up to 21 wires run in parallel that provide the tuning to the radio by grounding or floating each tuning line. None of the manufacturers of these radios offers an upgrade to the new VHF Data Radio (VDR) (VHF Data Radio [ARINC 750]) functionality required for VDL-M2 or above. To achieve VLD-M2 or greater capabilities on the classic aircraft will require the replacement of all of the communication radios currently installed on the classic aircraft.

For the top ten airlines, all but one currently uses data link in their operations. Of the Data Link Management Units (DLMs) installed, virtually all of them will also have to be replaced to accommodate the new data link protocols. The new Communications Management Units (CMUs) have the ability to support VDL-M2 through VDL-M3vd. Therefore, all classic aircraft will require a new CMU.

For the classic aircraft to use the VDL-M2 or above capabilities, a new Data Link Control Display Unit (DL CDU) will also need to be installed. The units currently installed on the classic aircraft to support Aircraft Communications Address and Reporting System (ACARS) data link cannot be upgraded to interface with the new CMU or will not support the software certification requirements of the ATC data link communication.

Installation of the NEXCOM avionics and related systems is likely to take longer than similar installations on aircraft with digital bus architectures. This is because the new VDRs, CMUs, DL CDUs and Radio Control Panels (RCPs) only support digital busses and, therefore, that wiring will need to be pulled to facilitate the installation. Also, the new units require new equipment trays to be installed and the old ones removed, which will lengthen the installation process.

In summary, to provide NEXCOM capabilities, classic aircraft will require:

1. All current VHF communication radios to be replaced with VDRs.
2. The Data Link Management (DLM) to be replaced with a CMU.
3. A new DL CDU for all.
4. Installation effort, which will have the highest cost for the classic aircraft.

2.2.2. FMS/EFIS Aircraft

The Flight Management System/Electronic Flight Instrument System (FMS/EFIS) aircraft are characterized by the use of ARINC 429 digital interfaces interconnecting much of the systems on the aircraft. These aircraft are generally equipped with electronic flight displays of either Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD) technologies. Most of the aircraft delivered today fit into the FMS/EFIS class of aircraft. In addition, many of the longer range aircraft will also have some form of an FMS which includes a Multi-function Control Display Unit (MCDU) for accessing the FMS, data link and other systems requiring a pilot input/output interface.

For this study the specific air transport category aircraft types considered FMS/EFIS aircraft are the following, by manufacturer:

Airbus: A319; A320; A321; A330; A340

Boeing: 737-400; 737-500; 737-700; 737-800; 737-900; 747-400; 757-200; 767-200; 767-200ER; 767-300; 767-300ER; 767-400; 767-400ER; MD11; MD90

Fokker: F-100

To distinguish the FMS/EFIS classed aircraft with upgradeable communication radios from those without that capability, we defined a "digital" vs. "analog" identification. Many of the early FMS/EFIS aircraft were delivered with ARINC 716 radios, which are actually ARINC 429 bus radios, however, these are not upgradeable to ARINC 750 VDRs. In this analysis, these aircraft are identified as "analog" to distinguish them from the FMS/EFIS aircraft delivered with ARINC 750 upgradeable communication radios. For example, later in the analysis transitions of FMS/EFIS aircraft from "analog" to VDL-M2 (a-2) or analog to VDL-M3v (a-3v) will be identified. These are the FMS/EFIS aircraft with ARINC 716 communication radios being upgraded with VDRs (ARINC

750). Approximately 70% to 80 % of the FMS/EFIS fleet have the older ARINC 716 communication radios since upgradeable VDRs only became available in 1996.

In a similar way, the transitions of FMS/EFIS aircraft starting from "digital" status are considered upgradeable through the application of upgrade kits and do not require replacing the radios. For example, these would be identified by transitions from "digital" to VDL-M2 as (d-2) or from "digital" to VDL-M3v as (d-3v). More on the upgrade transitions later in this analysis.

As with the classic aircraft, the data link management unit on the FMS/EFIS aircraft will have to be replaced with a NEXCOM compatible CMU. Of the top 10 airlines, most FMS/EFIS aircraft are currently using ACARS data link. Almost all of those aircraft are equipped with ARINC 724B DLMs that are not upgradeable to an ARINC 758 CMU.

Many of the FMS/EFIS aircraft are equipped with an MCDU as part of an FMS system. This unit is assumed to be upgradeable to VDL-M3v or VDL-M3vd capability.

The FMS/EFIS aircraft assumptions are summarized below:

1. All "analog" transitions require replacing the VHF communication radios with ARINC 750 compatible radios.
2. All "digital" transitions assume the aircraft is equipped with upgradeable ARINC 750 VHF communication radios.
3. All aircraft will require new CMUs to replace current ACARS Data Link Management Units (DLMs).
4. The FMS MCDU is capable of upgrade to support NEXCOM.

2.2.3. Integrated Avionics Aircraft

Currently there is only one air transport aircraft design that fits into this category, the Boeing 777. The aircraft architecture is heavily hardware and software integrated with many functions, like data link, that are not the traditional line replaceable units (LRUs). Because the hardware and software are heavily integrated and the sole source aspect of this design, accurate cost information is not readily available in the marketplace. This analysis has assumed that the cost of upgrading to NEXCOM on the B-777 is similar to the upgrade costs of the digital FMS/EFIS aircraft. The costs could be higher or lower depending on the assumptions made vs. the actual costs to upgrade the integrated aircraft.

The B-777 does use VHF communication radios that are ARINC 750 compatible LRUs, so this element of the configuration can be priced easily. However, the data link capabilities are a combination of a hardware card and software that runs on the card. The specific costs to upgrade these systems could be different from the assumed costs on the classic or FMS/EFIS aircraft. This analysis assumes the costs of upgrading the B-777 to NEXCOM is identical to the FMS/EFIS aircraft. The model of the costs can be easily modified to account for the integrated aircraft costs if better information is made available.

2.2.4. Forward Fit Aircraft

Forward Fit aircraft are considered as those aircraft that enter fleets starting from the current time frame. This construct is used to distinguish from the FMS/EFIS aircraft that are "analog" with ARINC 716 VHF communication radios and already exist as part of an airlines fleet.

To identify the costs attributable to NEXCOM, the concept of a premium was defined. A premium is defined as the additional cost an airline would pay to purchase an aircraft that would be upgradeable to NEXCOM capabilities. In other words, the additional cost to the airline vs. what they would pay for an aircraft bought today. For example, suppose an airline is planning a purchase of some new aircraft. They can purchase them with the older analog radios and ACARS DLM, but his would not be a NEXCOM upgradeable configuration. However, the airline can select to purchase new upgradeable radios and a CMU that will support NEXCOM functionality in the future. Selecting these newer avionics will cost more compared to the cost of the original analog radios and an ACARS DLM. This difference in price is by the definition of premium and this additional cost is associated with NEXCOM in the cost rollup model. In this way we can capture the costs an airline would pay now to get future ease of upgrading to NEXCOM. The Equipage tab identifies the quantity of premiums needed

to achieve a particular end state for each transition. The value of the premiums is identified in the Total Dollars tab. The use of premiums is only considered in the Total NEXCOM Costs Model.

2.3. Transition States

These are the definitions of transitions priced in the analysis. Because the airlines could make multiple transitions along the way to VDL-M3vd several intermediate transitions are considered. For example, a transition from an analog equipped classic to VDL-M2 to VDL-M3v to VDL-M3vd (a-2-3v-3vd) is a likely possibility. The analysis defined in this paper identifies 58 different class of aircraft/transition combinations with an additional seven premium states identified. These are all identified in the worksheet tabs for equipage and total costs.

2.3.1. Transition to VDL-M2

Assumptions for this transition consider that adding VDL-M2 to the aircraft will require replacing one VHF communication radio with a VDR and will require a CMU. There are also requisite installation changes needed to complete the upgrade, such as additional install kits.

The transition is assumed to affect only one of the three VHF communication radios on the aircraft. The reason for this is that most of the airlines considered in this study are already using ACARS and this only affects one of the radios. VDL-M2 provides a considerable benefit to the airlines for the AOC communications as this configuration greatly improves the data throughput. The assumption of only installing one VHF communications radio with a VDR could result in assigning a higher cost to VDL-M3 than if all three VHF communication radios were installed during the transition to

VDL-M2. Some airlines may select to install all three radios as VDRs during the transition to Mode 2 in order to have common equipment so as to reduce maintenance costs. In this case, more of the costs would be assigned to Mode 2 and less to the upgrade of Mode 3.

2.3.2. Transition to VDL-M3 Voice Only

This transition requires considerable changes in the aircraft affecting the communication radio, the Radio Control Panel (RCP), and the DLM.

1. All three communication radios must be either replaced or upgraded unless upgrading from VDL-M2 (which only requires the remaining two radios to be replaced or upgraded)
2. Adds three new RCPs to support NEXCOM
3. Any current ACARS DLM replaced with a CMU
4. Upgrades of the equipment to support VDL-M3v

2.3.3. Transition to VDL-M3 Voice and Data

Depending on the prior state of the aircraft avionics, this can be a relatively simple upgrade or could be quite extensive. The following assumptions consider that the aircraft is equipped with upgradeable VDRs, a CMU, DL CDU and RCPs.

1. All VDRs need upgrades to support VDL-M3vd.
2. CMU needs to have VDL-M3vd upgrade.
3. RCP requires the VDL-M3vd upgrade.
4. The DL CDU will need the VDL-M3vd upgrade.

2.3.4. Transitions to 8.33 kHz

There are three primary 8.33 kHz. transition states considered in this study. These choices are the result of equipment available from manufacturers to satisfy the 8.33 kHz. requirements. Depending on the operators choice, 8.33 kHz capabilities can be achieved in three basic ways.

First, the current 760 channel communications transceivers installed on current aircraft may or may not be upgradeable to 8.33 kHz. If the current radios are upgradeable then a software/hardware upgrade kit can be installed to add the new 8.33 kHz. functionality, however, these upgraded radios will not support NEXCOM. [Table 1, Column Headed 833-U]

A second means of achieving 8.33 kHz. capabilities is to install new replacement radios with 8.33 kHz. capabilities. Again these radios will not support NEXCOM functionality. [Table 1, Column Headed 833-R]

The third method assumes the aircraft is already equipped with VDRs, then an 8.33 kHz. upgrade is available with the radio still capable of further upgrade to NEXCOM.

This third transition can also support a single thread VDL-Mode-2 data link capability. [Table 1, Column Headed 833-D]

This paper identifies three modifiers to the costing information for each class of aircraft and corresponding to the three 8.33 kHz. transition paths as defined above.

Table 1. 8.33 kHz Transition Column Heading Definitions

833-R	833-U	833-D
8.33 kHz capabilities achieved through a new replacement radio. This means the current DSB-AM radio is replaced with a new one. This transition provides a stand-alone cost figure for 8.33 kHz capabilities. No data link capability is provided.	8.33 kHz capabilities achieved through an upgrade to the existing DSB-AM radio. This transition provides a stand-alone cost figure for 8.33 kHz. capabilities. No data link capability is provided.	8.33 kHz is achieved by upgrading the existing VDRs (digital) on the aircraft. Costs associated with this upgrade would be added to the following column in the spreadsheet (either a-2 or d-2) to achieve an 8.33 kHz. and VDL-Mode 2 capability

Each of the aircraft classification sections in the spreadsheet contains costing information on the 8.33 kHz capabilities. There is also a column in the premiums area that identifies the incremental costs associated with the inclusion of 8.33 kHz. capabilities on the aircraft. This identifies the costs for 8.33 kHz. capabilities on a digital aircraft equipped with VDRs.

2.3.4.1. Summary of Costs to Achieve 8.33 kHz Functionality

Equipping an aircraft with 8.33 kHz. capabilities can be achieved in several ways with different total costs. Depending on the classification of the aircraft being equipped and the radios already installed on the aircraft. Table 2 identifies a summary of the 8.33 kHz costs for each of the classes of aircraft. The last column indicates the total costs for an aircraft of that class equipped with VDL-Mode-2 capabilities including 8.33 kHz. See section 4.3 for an additional summary of the overall transition costs including transition state diagrams.

Table 2. Costs Summary for 8.33 kHz Functionality (per aircraft)

Aircraft Class	833-R	833-U	833 and VDL-Mode-2
Classic	$74.6K	$47.5K	$210.8K
FMS Analog	$74.6K	$47.5K	$174.5K
FMS Digital	N/A	N/A	$84.9K
Integrated Digital	N/A	N/A	$84.9K
Fwd Fit Analog	$74.6K	$47.5K	$174.5K
Fwd Fit Digital	N/A	N/A	$84.9K

2.4. Forward Fit (New) Aircraft Considerations

Transition states in new aircraft normally do not occur soon after delivery as the airlines normally have the aircraft configured as desired from the factory. This is not always the case if the airframe manufacturer is not offering a particular upgrade from the factory. In this case the airline would have the new equipment installed just after delivery but before entering service. This situation is considered an update at delivery since it occurs at initial aircraft acquisition. Any additional costs paid by the airlines are not considered in this analysis. However, for this analysis, it is assumed that once a new aircraft is delivered, it would not be upgraded until the next level of capability is available. The logic covering this situation is handled in the Total NEXCOM Costs Model (not a part of this paper), which uses the equipment costs identified in this analysis.

2.4.1. Delivered with VDL Capabilities

Forward Fit aircraft are assumed to be purchased with the capability to support NEXCOM. This is either:

1. An aircraft with three upgradeable VDRs installed.
2. VDL-M2 capable installation (three upgradeable VDRs with one upgraded to VDL-M2 capability).
3. VDL-M3v capable installation (all three VDRs upgraded to VDL-M3v capability).
4. VDL-M3vd capable installation.

Transitions to the next level of capability have a specific equipage requirement, which translates into a cost to make that transition. These are identified in the worksheet as Forward Fit aircraft with sixteen different transitions considered. These will be explained later in the analysis.

2.4.2. Premiums

For the Total NEXCOM Costs Model to accurately capture the costs related to NEXCOM, a means was needed that would allow identifying the costs of the NEXCOM capabilities. This method was a construct called a premium. A premium is any additional costs for NEXCOM functionality or services above what the airline would normally pay to achieve VHF communication capabilities on the aircraft. This allowed the analysis to separate out the extras the airline was paying to have NEXCOM features available through upgrades. The analysis identifies six different premiums related to different aircraft equipage capabilities.

2.5. Shortcut Nomenclature

To simplify the analysis, a shorthand nomenclature was defined to communicate the transitions defined. This greatly simplified the referencing of the transitions and allowed standardizing across aircraft classes.

States are identified by the shorthand that relates to the capability of the communication system as identified in Table 3 below:

Table 3. Communication State Shorthand Definitions

Shorthand	Meaning
2	VDL-M2 capability
3v	VDL-M3 voice only capability
3vd	VDL-M3 voice & data only capability
a	Analog aircraft configuration
d	Aircraft with upgradeable VDRs

To create a transition, the shorthand states are separated by a hyphen as shown in the following examples in Table 4.

Table 4. Examples of Transition Definitions

Transition	Meaning
a-2	Existing analog aircraft upgraded to VDL-M2 capability
a-2-3v	Existing analog aircraft upgraded to VDL-M2 then later upgraded to VDL-3 voice only
d-3v-3vd	Aircraft with VDRs upgraded to VDL-M3 voice only then later upgraded to VDL-M3 voice and data
2-3vd	New aircraft delivered with VDL-M2 then later upgraded to VDL-M3 voice and data

The usage of these definitions can be seen in the column headings on the Equipage and Total Dollars tabs in the workbook, which will be defined in more detail later.

2.6. Economic Considerations

The analysis includes several assumptions that relate to the cost of the avionics and services needed to provide the transitions for communication. Each of these assumptions can be easily changed in the analysis.

2.6.1. Pricing

Pricing was determined by considering several sources within the industry. They are to be considered guidelines, as prices tend to vary due to economic conditions within the industry and on particular aircraft configurations. Several vendors were contacted and asked to provide pricing for equipment configurations or upgrades. These included manufacturers of equipment and installation centers. In addition, price books are available on the Internet that indicate catalog prices for equipment. These are most helpful as guidelines. Finally, this author has worked for one of the air transport avionics manufacturers and can therefore provide some experience to the likely pricing for products. It is not important to get the exact price for a particular piece of equipment, because of the significant variety of aircraft configurations. However, it is useful to get the prices within an acceptable range so that in the aggregate the final totals are reasonable.

2.6.2. Discounts

To allow the analysis to consider the market trend in actual costs to the airlines, a discount to the manufacturers catalog pricing is included in the analysis. This is not necessarily accurate for all airlines, but volume discounting does occur as these avionics exist in a competitive environment. In this analysis, costs for equipment is 80% of manufacturers' list prices.

2.6.3. Avionics Sparing

Due to equipment reliability, airlines must consider the cost of spares. In some cases the airlines purchase spares directly, and in other cases, they may sign a maintenance contract with the avionics manufacturer or maintainer. Even with a maintenance agreement, the airline still "pays" for spares, which are bundled in the maintenance contract cost. Therefore, including some level of sparing is appropriate across the airlines. A sparing cost of 15 % is representative in this industry and is used in this analysis for the equipment only.

2.6.4. Labor

For this analysis shop labor rates for installations or upgrades is $70.00 per hour. This is the rate for the labor used to perform installation of equipment or to provide upgrades to specific avionics. This is based on installations occurring through outside organizations. The airlines may have a bit lower labor rate, but it may reflect only the incremental cost of the labor. This is a variable in the analysis and can easily be modified as necessary.

2.6.5. Installation Kits

Installation kits are the materials needed to complete an installation to the desired NEXCOM capability. The kit is dependent on the initial communication state of the aircraft and the desired communication capability of the aircraft. Examples of the contents of an installation kit are:

equipment trays	cabling ties
wiring or harnesses	connectors and pins
wiring jumpers	fasteners and other hardware

Generally the kits to upgrade the classic aircraft are the most expensive and the kits for the FMS/EFIS are less, with kits for the integrated aircraft being the least expensive.

3. Basic Aircraft Configuration Definitions

3.1. Basic Equipage per End Transition State

Table 5 identifies for each of the aircraft communication capability states, the avionics and upgrades required to achieve the stated functionality. The quantities of each avionics component are shown in the equipage tab of the workbook. They are derived based on all the assumptions defined earlier for the classes of aircraft and communication transitions.

Table 5. Basic Communication State Avionics Configurations

Transitions				
(VDL-M2)		(VDL-M3 Voice only)		(VDL-3 Voice and Data)
-2		**-V3**		**-3vd**
VDR Radio		VDR Radio		VDR Radio
VDR HS data upgd		VDR HS data upgd		VDR HS data upgd
VDR M2 upgd		VDR M2 upgd		VDR M2 upgd
		VDR M3 upgd		VDR M3 upgd
CMU		CMU		CMU
CMU SW M2		CMU SW M2		CMU SW M2
		CMU SW M3v		CMU SW M3v
				CMU SW M3 vd
DL CDU		DL CDU		DL CDU
		DL CDU SW M3v		DL CDU SW M3v
				DL CDU SW M3vd
		RCP M3v		RCP M3v
				RCP vd upgd

Basic transitions are listed as headings to the columns of Table 5 with the avionics or upgrade listed below each transition. Only the avionics and upgrades are indicated here.

A more detailed look at the transitions that are considered in this analysis involves partial equipage that does not fully prepare the aircraft for VDL-M3 upgrades. Specifically upgrading an analog aircraft with VDL-M2 only requires a single VDR, CMU and DL CDU plus associated upgrades to equipment and install kits. This means that two of the three communication radios are not VDRs when the upgrade is complete. When the decision to transition to VDL-M3 occurs, the other two radios must be replaced with VDRs.

On examining the worksheet tabs for equipment and total costs, this can be seen in any of the transitions that involve upgrading through VDL-M2 to VDL-M3 voice or data. In fact, to identify the transition equipage and costs, each transition is divided into sub-columns that show the equipage and costs sub-totaled respectively. The sub-column for the VDL-M2 (2) will show single equipment requirements and the next sub-column for VDL-M3v (3v) will show picking up the other two VDRs required to complete the three ship-set compliment of communication radios.

For example, see Figure 2 and Figure 3 at transition column [a-2-3v]. Two sub-columns define the equipage and costs respectively for that transition. Each of the transition sub-columns identifies the equipage and costs respectively for the VDL-M2 and VDL-M3 voice transition states. This construct is used in all of the multiple transitions considered in the analysis for all classes of aircraft.

4. Avionics Cost Workbook

4.1. Overview of the MS Excel Workbook

The avionics costs are computed with several worksheets contained in an MS Excel workbook. Separate tabs are used for each worksheet with several of the worksheets providing a summary of the workbook, the assumptions, definitions and a summary of the information contained on each tab. The two major tabs of the workbook are the Equipage and Total Cost tabs. These tabs respectively identify the equipment compliment that is to be priced along with the individual prices for each piece of equipment and the total costs of each communication transition, new aircraft or premium associated with the upgrades.

4.2. Costs per Aircraft Transition

4.2.1. Individual Equipment and Upgrade Pricing Assumptions

Figure 1 is from the Equipage tab and indicates the base cost and final costs associated with each avionics equipment required.

The prices indicated with yellow shading are computed values based on the discount and sparing assumptions made for this analysis. The discount assumption only applies to the equipment and upgrade prices. The sparing assumption only applies to the equipment and **not** the upgrades.

Each base price is derived from a composite of catalog information, discussions with vendors or installation provider, and experience in the air transport market. It is easy to change these prices and the effects will ripple through each aircraft class/transition in the workbook. In this way, the sensitivity of changes in equipment pricing could be determined.

	Includes Equip. Discount and spares	Base Cost
Equipment	**$ Each**	
VDR Radio Incr	5520	6000
8.33 replacement Radio	11960	13000
8.33 radio upgrade	4324	4700
VDR Radio	22080	24000
8.33kHz upgrade	2000	2500
VDR HS data upgd	8800	11000
VDR M2 upgd	3600	4500
VDR M3 upgd	5200	6500
CMU	26680	29000
CMU SW M2	2000	2500
CMU SW M3v	2800	3500
CMU SW M3 vd	3600	4500
DL CDU	23000	25000
DL CDU SW M3v	2000	2500
DL CDU SW M3vd	2800	3500
RCP M3v or 833	6440	7000
RCP vd upgd	2000	2500
Install Kits	**$ Each**	
Equipment in Analog	5000	
Equipment in FMS, integ, FF	4000	
Equipment for digital ready	1000	
RCP kits	2000	
Installation	**Hrs**	
Hourly Rate =	$ 70.00	
VDR Install Analog	50	
VDR Install FMS	40	
CMU Install	40	
DL CDU Install	32	
RCP Install	32	
8.33 only radio install	32	
8.33 upgd radio install	8	
VDR Upgrade install	8	
CMU Upgrade Install	8	
DL CDU Upgrade Install	8	
RCP Upgrade install	8	
8.33 kHz upgd	4	

Figure 1. Pricing of Avionics and Services

The assumptions of the kit pricing are also defined here. Similarly, the prices of these items can be varied to determine sensitivities to overall aircraft transition pricing.

Finally, installation labor pricing and estimates of labor hours are also defined here. Changes in these definitions affect all of the installation labor charges that are computed in the workbook.

Each of the classes of aircraft (Classic FMS/EFIS, Integrated and New) has a pair of figures associated with each aircraft class. This is also true for the special class called premium.

The first figure of each pair of figures identifies, by column, the equipage required for each transition being considered in each aircraft class. A quantity is indicated in each row for the equipment that is needed to provide the capability indicated by the end-state of the transition. These quantities are then multiplied by the prices as indicated in Figure 1 to arrive at the respective price shown in the total costs tab for the aircraft class in question.

For each class of aircraft the second figure in each pair identifies the prices for a transition of the aircraft class as identified in that columns' shorthand notation. The bottom of each column is the total cost for equipping the aircraft class/transition to the transition as indicated.

The following pages contain sets of figures with the first figure of each set identifying the equipage definition, and the second identifying the total costs for each of the indicated transitions. Due to the size of these figures in the workbooks, each page contains a separate figure.

4.2.2. Integrated Aircraft Issues

Specific information on integrated aircraft upgrades and installation is difficult to obtain. As will be identified in the Future Studies section, further information is needed that better represents the pricing for transitions of this aircraft class. For this analysis, it is assumed that the costs to upgrade the FMS/EFIS and integrated aircraft are similar. Because the B-777 only represents about 5% of the aircraft fleet, making this assumption would not change the analysis significantly.

4.2.3. Classic Aircraft Equipage

Figure 2. Classic Aircraft Equipage in Units

	Classic														
Equipment	833-R	833-U	833-D	a-2	a-3v	a-2-3v		a-3vd	a-2-3vd		a-3v-3vd		a-2-3v-3vd		
VDR Radio Incr															
8.33 replacement Radio	3														
8.33 radio upgrade		3													
VDR Radio			2	1	3	1	2	3	1	2	3		1	2	
8.33kHz upgrade			3												
VDR HS data upgd				1	3	1	2	3	1	2	3		1	2	
VDR M2 upgd				1	3	1	2	3	1	2	3		1	2	
VDR M3 upgd					3		3	3		3	3			3	
CMU				1	1	1		1	1		1		1		
CMU SW M2				1	1	1		1	1		1		1		
CMU SW M3v					1		1	1		1	1			1	
CMU SW M3 vd										1		1			1
DL CDU				1	1	1		1	1		1		1		
DL CDU SW M3v					1		1	1		1	1			1	
DL CDU SW M3vd								1		1		1			1
RCP M3v or 833	3	3	3		3		3	3		3	3			3	
RCP vd upgd								1		3		3			3
Install Kits															
Equipment in Analog			2	3	5	3	2	5	3	2	5		3	2	
Equipment in FMS, integ, FF															
Equipment for digital ready															
RCP kits	3	3	3		3		3	3		3	3			3	
Installation															
Hourly Rate =															
VDR Install Analog			2	1	3	1	2	3	1	2	3		1	2	
VDR Install FMS															
CMU Install				1	1	1		1	1		1		1		
DL CDU Install				1	1	1		1	1		1		1		
RCP Install	3	3	3		3		3	3		3	3			3	
8.33 only radio install	3														
8.33 upgd radio install		3													
VDR Upgrade install				1	3	1	3	3	1	3	3		1	3	
CMU Upgrade Install				1	1	1	1	1	1	1	1	1	1	1	1
DL CDU Upgrade Install					1		1	1		1	1	1		1	1
RCP Upgrade install								1		3		3			3
8.33 kHz upgd		3	3												

4.2.4. Classic Aircraft Total Costs

Figure 3. Classic Aircraft Total Cost in $K by Transition

	Classic															
Equipment	833-R	833-U	833-D	a-2	a-3v	a-2-3v		a-3vd	a-2-3vd		a-3v-3vd		a-2-3v-3vd		
VDR Radio Incr																
8.33 replacement Radio	35.9															
8.33 radio upgrade		13.0														
VDR Radio			44.2	22.1	66.2	22.1	44.2	66.2	22.1	44.2	66.2		22.1	44.2	
8.33kHz upgrade			6.0												
VDR HS data				8.8	26.4	8.8	17.6	26.4	8.8	17.6	26.4		8.8	17.6	
VDR M2 upgd				3.6	10.8	3.6	7.2	10.8	3.6	7.2	10.8		3.6	7.2	
VDR M3 upgd					15.6		15.6	15.6		15.6	15.6			15.6	
CMU				26.7	26.7	26.7		26.7	26.7		26.7		26.7		
CMU SW M2				2.0	2.0	2.0		2.0	2.0		2.0		2.0		
CMU SW M3v					2.8		2.8	2.8		2.8	2.8			2.8	
CMU SW M3 vd										3.6		3.6			3.6
DL CDU				23.0	23.0	23.0		23.0	23.0		23.0		23.0		
DL CDU SW M3v					2.0		2.0	2.0		2.0	2.0			2.0	
DL CDU SW M3vd								2.8		2.8		2.8			2.8
RCP M3v or 833	19.3	19.3	19.3		19.3		19.3	19.3		19.3	19.3			19.3	
RCP vd upgd								2.0		6.0		6.0			6.0
Install Kits															
Equipment in Analog			10.0	15.0	25.0	15.0	10.0	25.0	15.0	10.0	25.0		15.0	10.0	
Equipment in FMS, integ, FF															
Equipment for digital ready															
RCP kits	6.0	6.0	6.0		6.0		6.0	6.0		6.0	6.0			6.0	
Installation															
VDR Install Analog			7.0	3.5	10.5	3.5	7.0	10.5	3.5	7.0	10.5		3.5	7.0	
VDR Install FMS															
CMU Install				2.8	2.8	2.8		2.8	2.8		2.8		2.8		
DL CDU Install				2.2	2.2	2.2		2.2	2.2		2.2		2.2		
RCP Install	6.7	6.7	6.7		6.7		6.7	6.7		6.7	6.7			6.7	
8.33 only radio install	6.7														
8.33 upgd radio install		1.7													
VDR Upgrade install				0.6	1.7	0.6	1.7	1.7	0.6	1.7	1.7		0.6	1.7	
CMU Upgrade Install				0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
DL CDU Upgrade Install					0.6		0.6	0.6		0.6	0.6	0.6		0.6	0.6
RCP Upgrade install								0.6		1.7		1.7			1.7
8.33 kHz upgd		0.8	0.8												
Sub Total per transition recur -->	74.6	47.5	100.0	110.8	250.9	110.8	141.2	256.3	110.8	155.3	250.9	15.2	110.8	141.2	15.2
Total per shipset -->	$74.6	$47.5	$100.0	$110.8	$250.9	$252.0		$256.3	$266.1		$266.1		$267.2		

4.2.5. FMS/EFIS Equipage

Figure 4. FMS/EFIS Aircraft Equipage in Units

	FMS																											
Equipment	833-R	833-U	833-D	a 2	a 3v	a 2 3v		a 3vd	a 2 3vd		a 3v 3vd		a 2 3v 3vd			833-D	d 2	d 3v	d 2 3v		d 3vd	d 2 3vd		d 3v 3vd		d 2 3v 3vd		
VDR Radio Incr																												
8.33 replacement Radio	3																											
8.33 radio upgrade		3																										
VDR Radio			2	1	3	1	2	3	1	2	3		1	2														
8.33kHz upgrade			3													3												
VDR HS data upgd				1	3	1	2	3	1	2	3		1	2			1	3	1	2	3	1	2	3		1	2	
VDR M2 upgd				1	3	1	2	3	1	2	3		1	2			1	3	1	2	3	1	2	3		1	2	
VDR M3 upgd					3		3	3		3	3			3				3		3	3		3	3			3	
CMU				1	1	1		1	1		1		1				1	1	1		1	1		1		1		
CMU SW M2				1	1	1		1	1		1		1				1	1	1		1	1		1		1		
CMU SW M3v					1		1	1		1	1			1				1		1	1		1	1			1	
CMU SW M3 vd								1		1		1			1						1		1		1			1
DL CDU																												
DL CDU SW M3v					1		1	1		1	1			1				1		1	1		1	1			1	
DL CDU SW M3vd								1		1		1			1						1		1		1			1
RCP M3v or 833	3	3	3		3		3	3		3	3			3		3		3		3	3		3	3			3	
RCP vd upgd								3		3		3			3						3		3		3			3
Install Kits																												
Equipment in Analog																												
Equipment in FMS, integ, FF			2	2	4	2	2	4	2	2	4		2	2														
Equipment for digital ready																	1	1	1		1	1		1		1		
RCP kits	3	3	3		3		3	3		3	3			3		3		3		3	3		3	3			3	
Installation																												
Hourly Rate =																												
VDR Install Analog																												
VDR Install FMS			2	1	3	1	2	3	1	2	3		1	2														
CMU Install				1	1	1		1	1		1		1				1	1	1		1	1		1		1		
DL CDU Install																												
RCP Install	3	3	3		3		3	3		3	3			3		3		3		3	3		3	3			3	
8.33 only radio install	3																											
8.33 upgd radio install		3																										
VDR Upgrade install				1	3	1	3	3	1	3	3		1	3			1	3	1	3	3	1	3	3		1	3	
CMU Upgrade Install				1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
DL CDU Upgrade Install					1		1	1		1	1	1		1	1			1		1	1		1	1	1		1	1
RCP Upgrade install								3		3		3			3						3		3		3			3
8.33 kHz upgd		3	3													3												

4.2.6. FMS/EFIS Total Costs

Figure 5. FMS/EFIS Aircraft Total Cost in $K by Transition

	FMS																											
Equipment	833-A	833-U	833-D	a-2	a-3v	a-2-3v		a-3vd	a-2-3vd		a-3v-3vd		a-2-3v-3vd			833-D	d-2	d-3v	d-2-3v		d-3vd	d-2-3vd		d-3v-3vd		d-2-3v-3vd		
VDR Radio Incr																												
8.33 replacement Radio	36.9																											
8.33 radio upgrade		13.0																										
VDR Radio			44.2	22.1	66.2	22.1	44.2	66.2	22.1	44.2	66.2		22.1	44.2														
8.33kHz upgrade			6.0													6.0												
VDR HS data				8.8	26.4	8.8	17.6	26.4	8.8	17.6	26.4		8.8	17.6			8.8	26.4	8.8	17.6	26.4	8.8	17.6	26.4		8.8	17.6	
VDR MD upgd				3.6	10.8	3.6	7.2	10.8	3.6	7.2	10.8		3.6	7.2			3.6	10.8	3.6	7.2	10.8	3.6	7.2	10.8		3.6	7.2	
VDR MD upgd					15.6		15.6	15.6		15.6	15.6			15.6				15.6		15.6	15.6		15.6	15.6			15.6	
CMU				26.7	26.7	26.7		26.7	26.7		26.7		26.7				26.7	26.7	26.7		26.7	26.7		26.7		26.7		
CMU SW MD				2.0	2.0	2.0		2.0	2.0		2.0		2.0				2.0	2.0	2.0		2.0	2.0		2.0		2.0		
CMU SW MDv					2.8		2.8	2.8		2.8	2.8			2.8				2.8		2.8	2.8		2.8	2.8			2.8	
CMU SW MD vd								3.6		3.6		3.6			3.6						3.6		3.6		3.6			3.6
DL CDU																												
DL CDU SW MDv					2.0		2.0	2.0		2.0	2.0			2.0				2.0		2.0	2.0		2.0	2.0			2.0	
DL CDU SW MDvd								2.8		2.8		2.8			2.8						2.8		2.8		2.8			2.8
RCP MDv or 833	19.3	19.3	19.3		19.3		19.3	19.3		19.3	19.3			19.3		19.3		19.3		19.3	19.3		19.3	19.3			19.3	
RCP vd upgd								6.0		6.0		6.0			6.0						6.0		6.0		6.0			6.0
Install Kits																												
Equipment in Analog																												
Equipment in FMS, integ, FP			8.0	8.0	16.0	8.0	8.0	16.0	8.0	8.0	16.0		8.0	8.0														
Equipment for digital ready																	1.0	1.0	1.0		1.0	1.0		1.0		1.0		
RCP kits	6.0	6.0	6.0		6.0		6.0	6.0		6.0	6.0			6.0		6.0		6.0		6.0	6.0		6.0	6.0			6.0	
Installation																												
VDR Install Analog																												
VDR Install FMS			5.6	2.8	8.4	2.8	5.6	8.4	2.8	5.6	8.4		2.8	5.6														
CMU Install				2.8	2.8	2.8		2.8	2.8		2.8		2.8				2.8	2.8	2.8		2.8	2.8		2.8		2.8		
DL CDU Install																												
RCP Install	6.7	6.7	6.7		6.7		6.7	6.7		6.7	6.7			6.7		6.7		6.7		6.7	6.7		6.7	6.7			6.7	
8.33 only radio install	6.7																											
8.33 upgd radio install		1.7																										
VDR Upgrade install				0.6	1.7	0.6	1.7	1.7	0.6	1.7	1.7		0.6	1.7			0.6	1.7	0.6	1.7	1.7	0.6	1.7	1.7		0.6	1.7	
CMU Upgrade Install				0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
DL CDU Upgrade Install					0.6		0.6	0.6		0.6	0.6	0.6		0.6	0.6			0.6		0.6	0.6		0.6	0.6	0.6		0.6	0.6
RCP Upgrade install								1.7		1.7		1.7			1.7						1.7		1.7		1.7			1.7
8.33 kHz upgd		0.8	0.8													0.8												
Sub Total per transition recur -->	74.6	47.5	96.6	77.9	214.6	77.9	137.8	228.6	77.9	151.9	214.6	15.2	77.9	137.8	15.2	38.9	46.0	124.9	46.0	80.0	139.0	46.0	94.1	124.9	15.2	46.0	80.0	15.2
Total per shipset -->	$74.6	$47.5	$96.6	$77.9	$214.6		$215.7	$228.6		$229.8		$229.8			$230.9	$38.9	$46.0	$124.9		$126.0	$139.0		$140.1		$140.1			$141.2

4.2.7. Integrated Aircraft Equipage

Figure 6. Integrated Aircraft Equipage in Units

	Integrated												
Equipment	833-D	d-2	d-3v	d-2-3v		d-3vd	d-2-3vd		d-3v-3vd		d-2-3v-3vd		
VDR Radio Incr	[redacted]												
8.33 replacement Radio													
8.33 radio upgrade													
VDR Radio	2	[redacted]											
8.33kHz upgrade	3												
VDR HS data upgd		1	3	1	2	3	1	2	3		1	2	
VDR M2 upgd		1	3	1	2	3	1	2	3		1	2	
VDR M3 upgd			3		3	3		3	3			3	
CMU		1	1	1		1	1		1		1		
CMU SW M2		1	1	1		1	1		1		1		
CMU SW M3v			1		1	1		1	1			1	
CMU SW M3 vd						1		1		1			1
DL CDU													
DL CDU SW M3v			1		1	1		1	1			1	
DL CDU SW M3vd						1		1		1			1
RCP M3v or 833	3		3		3	3		3	3			3	
RCP vd upgd						3		3		3			3
Install Kits													
Equipment in Analog	[redacted]												
Equipment in FMS, integ, FF													
Equipment for digital ready	2	1	1	1		1	1		1		1		
RCP kits	3		3		3	3		3	3			3	
Installation													
Hourly Rate =													
VDR Install Analog	[redacted]												
VDR Install FMS	2												
CMU Install		1	1	1		1	1		1		1		
DL CDU Install													
RCP Install	3		3		3	3		3	3			3	
8.33 only radio install													
8.33 upgd radio install													
VDR Upgrade install		1	3	1	3	3	1	3	3		1	3	
CMU Upgrade Install		1	1	1	1	1	1	1	1	1	1	1	1
DL CDU Upgrade Install			1		1	1		1	1	1		1	1
RCP Upgrade install						3		3		3			3
8.33 kHz upgd	3												

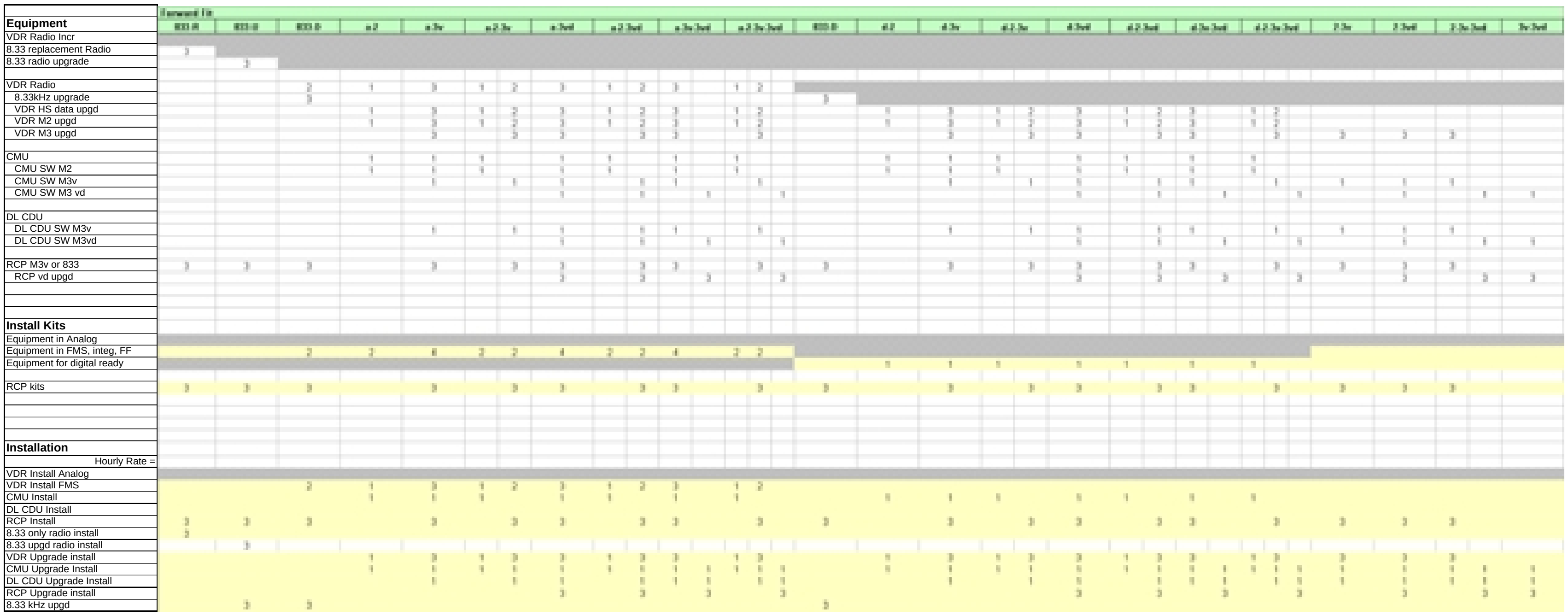
4.2.8. Integrated Aircraft Total Costs

Figure 7. Integrated Aircraft Total Cost in $K by Transition

	Integrated												
Equipment	833-D	d-2	d-3v	d-2-3v		d-3vd	d-2-3vd		d-3v-3vd		d-2-3v-3vd		
VDR Radio Incr													
8.33 replacement Radio													
8.33 radio upgrade													
VDR Radio													
8.33kHz upgrade	6.0												
VDR HS data		8.8	26.4	8.8	17.6	26.4	8.8	17.6	26.4		8.8	17.6	
VDR M2 upgd		3.6	10.8	3.6	7.2	10.8	3.6	7.2	10.8		3.6	7.2	
VDR M3 upgd			15.6		15.6	15.6		15.6	15.6			15.6	
CMU		26.7	26.7	26.7		26.7	26.7		26.7		26.7		
CMU SW M2		2.0	2.0	2.0		2.0	2.0		2.0		2.0		
CMU SW M3v			2.8		2.8	2.8		2.8	2.8			2.8	
CMU SW M3 vd						3.6		3.6		3.6			3.6
DL CDU													
DL CDU SW M3v			2.0		2.0	2.0		2.0	2.0			2.0	
DL CDU SW M3vd						2.8		2.8		2.8			2.8
RCP M3v or 833	19.3		19.3		19.3	19.3		19.3	19.3			19.3	
RCP vd upgd						6.0		6.0		6.0			6.0
Install Kits													
Equipment in Analog													
Equipment in FMS, integ, FF													
Equipment for digital ready		1.0	1.0	1.0		1.0	1.0		1.0		1.0		
RCP kits	6.0		6.0		6.0	6.0		6.0	6.0			6.0	
Installation													
VDR Install Analog													
VDR Install FMS													
CMU Install		2.8	2.8	2.8		2.8	2.8		2.8		2.8		
DL CDU Install													
RCP Install	6.7		6.7		6.7	6.7		6.7	6.7			6.7	
8.33 only radio install													
8.33 upgd radio install													
VDR Upgrade install		0.6	1.7	0.6	1.7	1.7	0.6	1.7	1.7		0.6	1.7	
CMU Upgrade Install		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
DL CDU Upgrade Install			0.6		0.6	0.6		0.6	0.6	0.6		0.6	0.6
RCP Upgrade install						1.7		1.7		1.7			1.7
8.33 kHz upgd	0.8												
Sub Total per transition recur -->	38.9	46.0	124.9	46.0	80.0	139.0	46.0	94.1	124.9	15.2	46.0	80.0	15.2
Total per shipset -->	$38.9	$46.0	$124.9	$126.0		$139.0	$140.1		$140.1		$141.2		

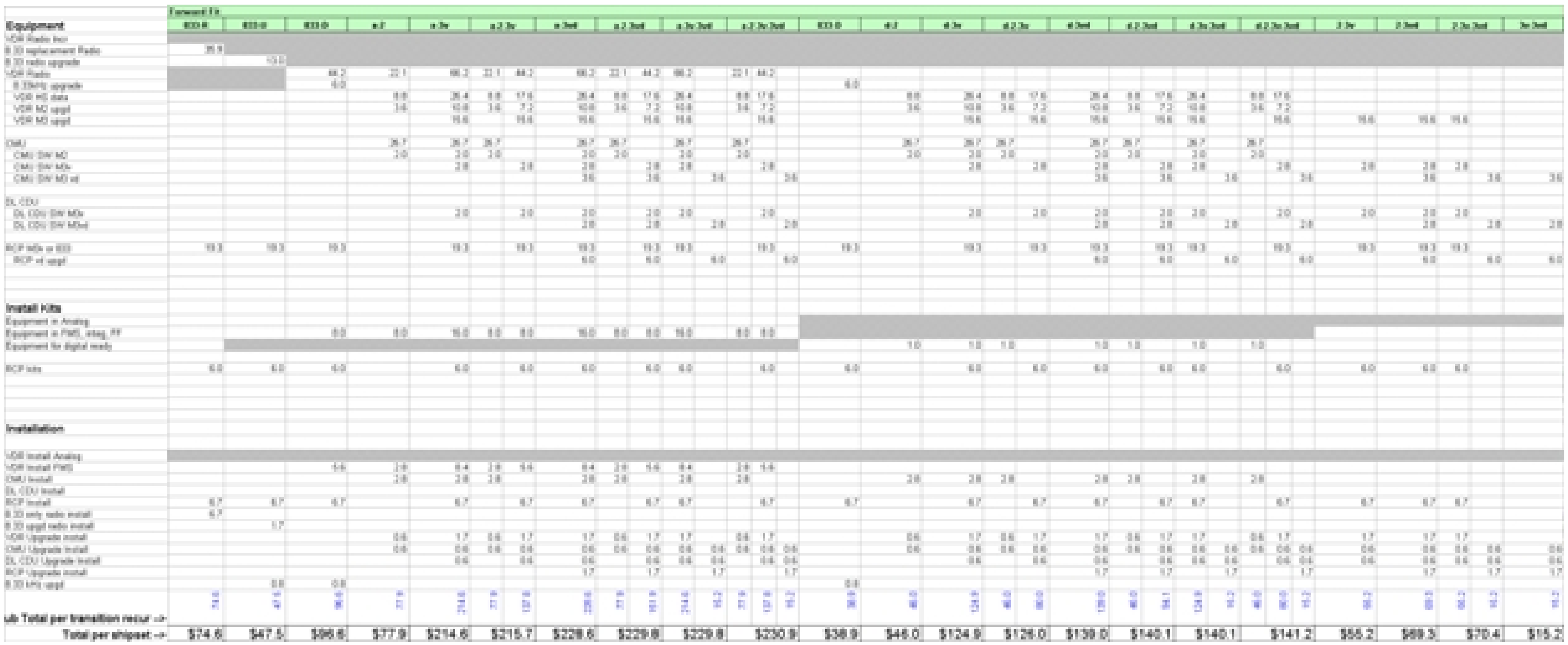
4.2.9. Forward Fit Delivery Aircraft

Figure 8. Forward Fit Delivery Aircraft Equipage in Units



4.2.10. Forward Fit Aircraft Total Costs

Figure 9. Forward Fit Aircraft Total Cost in $K per Transition



4.2.11. Premium Equipage

Figure 10. Premiums Equipage in Units

	Premimum						
Equipment	**833**	**DIG**	**VDL-2**	**VDL-2a**	**VDL-2d**	**VDL-3v**	**VDL-3vd**
VDR Radio Incr		3	3	1		3	3
8.33 replacement Radio							
8.33 radio upgrade							
VDR Radio							
8.33kHz upgrade	3						
VDR HS data upgd			3	1	1	3	3
VDR M2 upgd			3	1	1	3	3
VDR M3 upgd						3	3
CMU			1	1	1	1	1
CMU SW M2			1	1	1	1	1
CMU SW M3v						1	1
CMU SW M3 vd							1
DL CDU							
DL CDU SW M3v						1	1
DL CDU SW M3vd							1
RCP M3v or 833	3					3	3
RCP vd upgd							3
Install Kits							
Equipment in Analog							
Equipment in FMS, integ, FF							
Equipment for digital ready							
RCP kits							
Installation							
Hourly Rate =							
VDR Install Analog							
VDR Install FMS							
CMU Install							
DL CDU Install							
RCP Install							
8.33 only radio install							
8.33 upgd radio install							
VDR Upgrade install							
CMU Upgrade Install							
DL CDU Upgrade Install							
RCP Upgrade install							
8.33 kHz upgd	3						

4.2.12. Premium Total Costs

Figure 11. Premiums Total $K per Transition

	Premimum						
Equipment	833	DIG	VDL-2	VDL-2a	VDL-2d	VDL-3v	VDL-3vd
VDR Radio Incr		16.6	16.6	5.5		16.6	16.6
8.33 replacement Radio							
8.33 radio upgrade							
VDR Radio							
8.33kHz upgrade	6.0						
VDR HS data			26.4	8.8	8.8	26.4	26.4
VDR M2 upgd			10.8	3.6	3.6	10.8	10.8
VDR M3 upgd						15.6	15.6
CMU			26.7	26.7	26.7	26.7	26.7
CMU SW M2			2.0	2.0	2.0	2.0	2.0
CMU SW M3v						2.8	2.8
CMU SW M3 vd							3.6
DL CDU							
DL CDU SW M3v						2.0	2.0
DL CDU SW M3vd							2.8
RCP M3v or 833	19.3					19.3	19.3
RCP vd upgd							6.0
Install Kits							
Equipment in Analog	[redacted]						
Equipment in FMS, integ, FF	[redacted]						
Equipment for digital ready	[redacted]						
	[redacted]						
RCP kits	[redacted]						
	[redacted]						
	[redacted]						
	[redacted]						
	[redacted]						
Installation	[redacted]						
	[redacted]						
VDR Install Analog	[redacted]						
VDR Install FMS	[redacted]						
CMU Install	[redacted]						
DL CDU Install	[redacted]						
RCP Install	[redacted]						
8.33 only radio install	[redacted]						
8.33 upgd radio install	[redacted]						
VDR Upgrade install	[redacted]						
CMU Upgrade Install	[redacted]						
DL CDU Upgrade Install	[redacted]						
RCP Upgrade install	[redacted]						
8.33 kHz upgd	[redacted]						
Sub Total per transition recur -->	25.3	16.6	82.4	46.6	41.1	122.2	134.6
Total per shipset -->	$25.3	$16.6	$82.4	$46.6	$41.1	$122.2	$134.6

4.3. Summary of Transition Costs

A top-level look at important transition costs is presented in Table 6. Not including the costs of certification, the costs range from $49K to a high of over $250K. The retrofit of the analog aircraft is, as expected, the highest cost to upgrade. The integrated aircraft upgrade costs need further data and should be considered not as indicative of the actual upgrade costs.

Table 6. Summary of Basic Transition Costs per Aircraft ($K)

Transition	Classic	FMS/EFIS	Integrated	Fwd Flt
a-2	$110.8	$77.9	-	$77.9
a-3v	$250.9	$214.6	-	$214.6
a-3vd	$256.3	$228.6	-	$228.6
d-2	-	$46.0	$46.0	$46.0
d-3v	-	$124.9	$124.9	$124.9
d-3vd	-	$139.0	$139.0	$139.0

Premium costs are the additional costs attributable to equipment and services that are beyond what the airline would pay for current day communication systems. These premiums are identified in Table 7. This construct is used in the Total NEXCOM Costs Model to assign costs to NEXCOM. Premiums are not used in this analysis, but are used later to identify the costs associated with NEXCOM.

Table 7. Premium Costs per Aircraft Configuration ($K)

Configuration	Premium
Digital	$16.6
VDL-M2	$82.4
VDL-M2 Analog	$46.6
VDL-M2 Digital	$41.1
VDL-M3v	$122.2
VDL-M3vd	$134.6

The costs, per aircraft, attributable to 8.33 kHz are identified in Table 8. There are four basic configurations that are priced for each class of aircraft.

The “-R” configuration is for 8.33 kHz. configuration achieved by purchasing replacement radios for the original radios on the aircraft. This is required for any aircraft that has DSB-AM radios that are not upgradeable to 8.33 kHz. capability and the airline does not want to purchase new VDRs. This would normally occur on analog aircraft.

For the "-U" configuration, this identifies those aircraft that contain DSB-AM radios that can be upgraded to 8.33 kHz. capability through an upgrade process. These radios could be on either analog or digital aircraft.

Finally the "-D" configuration indicates the cost to provide 8.33 kHz. capabilities on aircraft through the use of upgradeable VDRs.

Table 8. 8.33 kHz. Upgrade Costs Summary per Aircraft ($K)

Transition	Classic	FMS/EFIS	Integrated	Fwd Flt
Analog 833-R	$74.6	$74.6	-	$74.6
Analog 833-U	$47.5	$47.5	-	$47.5
Analog 833-D	$100.0	$96.6	-	$96.6
Digital 833-D	-	$38.9	$38.9	$38.9

Many of the key transitions are illustrated in the following state diagrams (Figures 12 and 12) that show transitions from the initial aircraft configuration to states consisting of 8.33 kHz.; VDL-Mode 2 and VDL-Mode 3 voice; and VDL-Mode 3 voice and data.

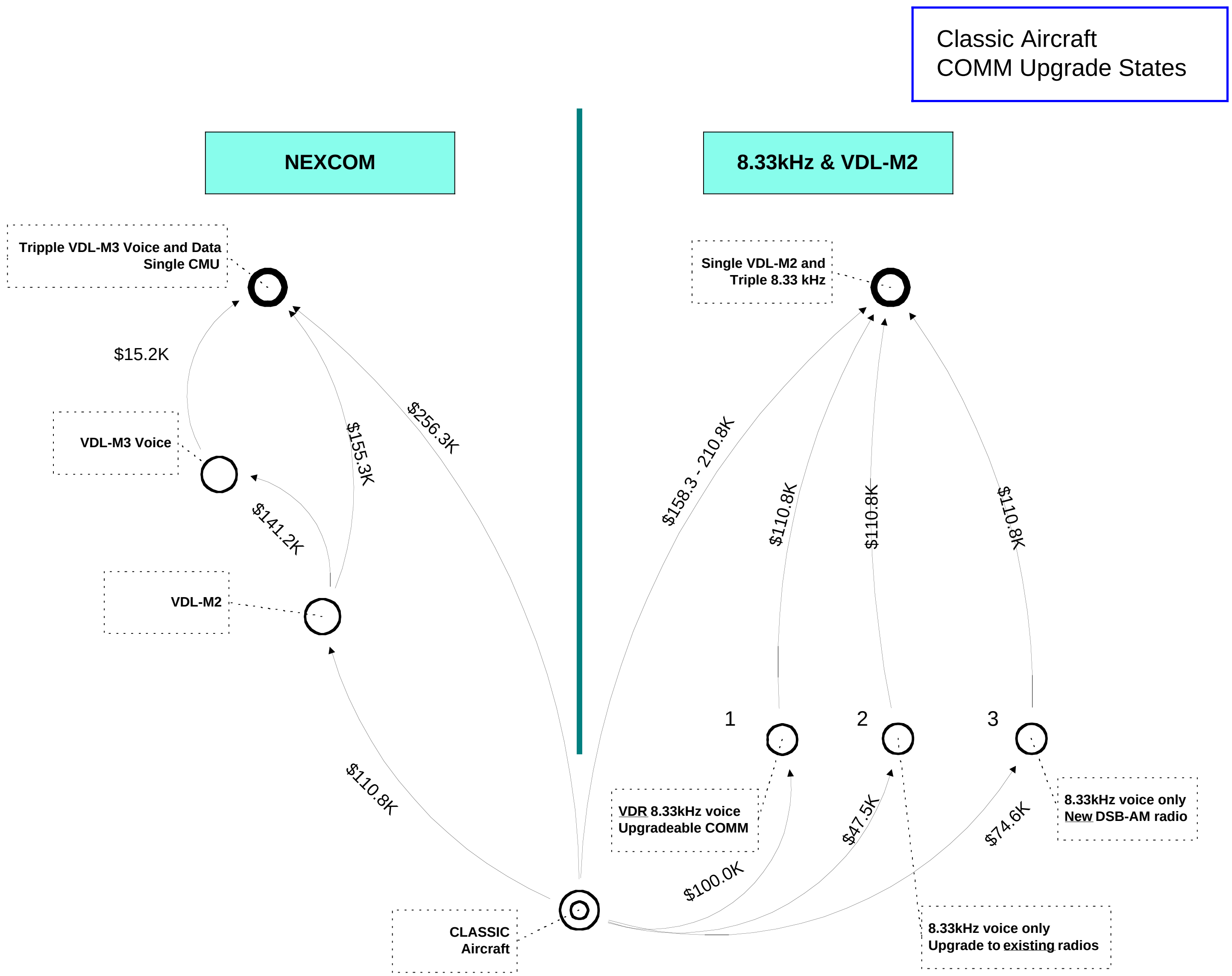


Figure 12. Classic Aircraft Upgrade Cost by Transition State

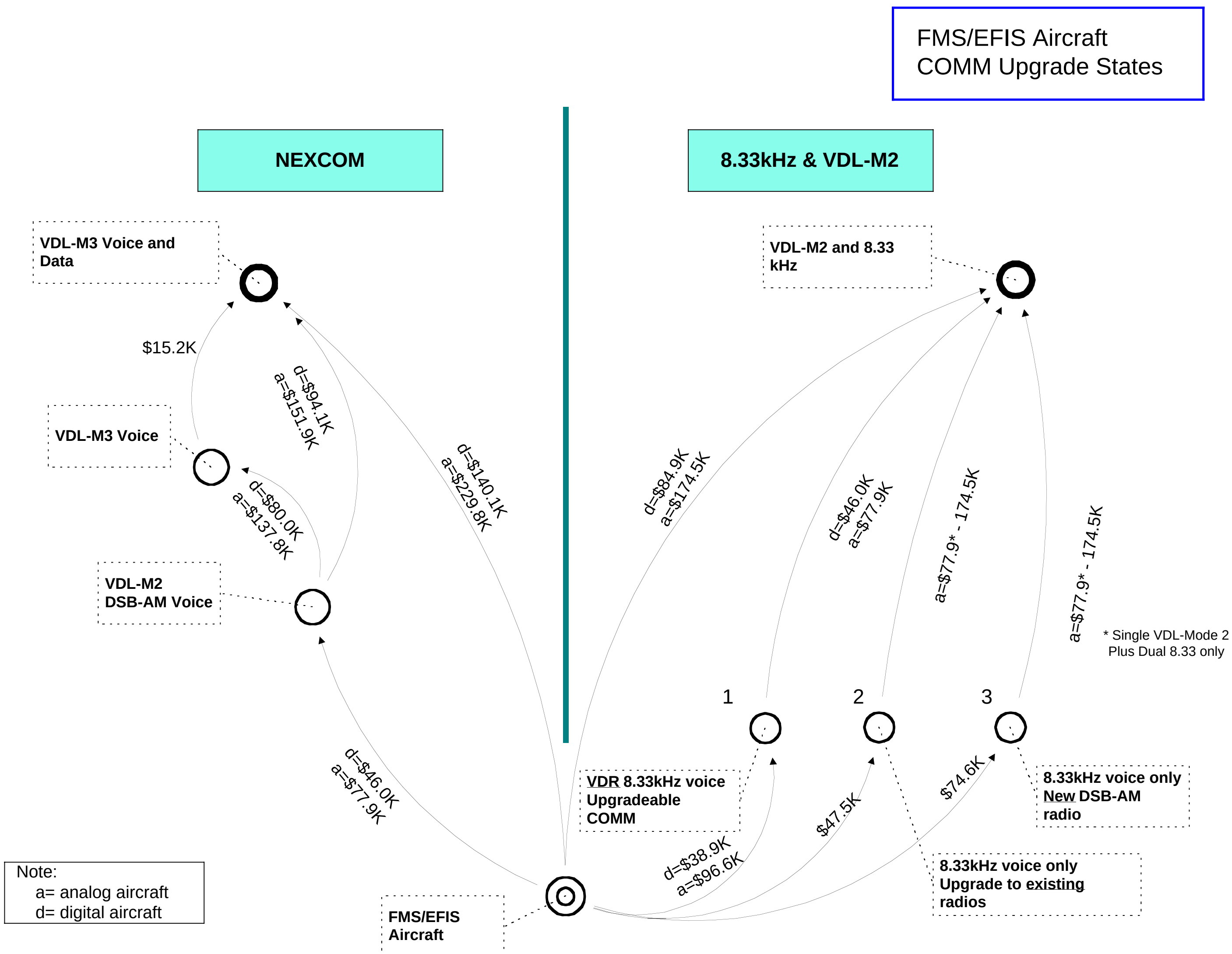


Figure 13. FMS/EFIS Aircraft Upgrade Cost by Transition State

In each of the figures above transitions that end in 8.33 kHz and VDL-Mode 2 or NEXCOM voice and data are considered. These states include the capability for expanded voice and data capabilities. The state diagrams make the summary tables a bit easier to visualize and indicate the likely candidates for final configurations. These values are found in the Totals tab in the spreadsheet presented in Figure 3 through Figure 9.

Figure 12 identifies the likely Classic aircraft upgrade paths and the related costs. On the 8.33 kHz. side of the chart at the bottom are three initial transitions to 8.33 kHz. capabilities. Moving from left to right these transitions are respectively:

1. the upgrade of VDRs that already exist on the aircraft to 8.33 kHz capabilities. VDRs are radios that can be readily upgraded to NEXCOM or advanced high-speed data link capabilities
2. the upgrading of existing ARINC 716 radios to allow 8.33 kHz. capabilities. These upgraded radios, however, cannot be further upgraded to NEXCOM
3. finally to achieve 8.33 kHz. capabilities some aircraft with current communication radios cannot be upgraded to 8.33 kHz. These radios must be replaced. An airline can choose to purchase radios that only add an 8.33 kHz. capability. This transition represents the cost to provide that functionality.

In transition 2 and 3 above if high speed communication capabilities required for VDL-Mode 2 and NEXCOM is required, the airline must replace the communication radios with VDRs that will support these capabilities. These transitions to 8.33 kHz. result in additional expense if the ultimate goal is NEXCOM functionality and should be considered carefully in airline fleet equipage planning. This can be seen when comparing the NEXCOM and 8.33 kHz. sides of Figure 12 and the total transition costs.

It should be pointed out that the transitions represented by 2 and 3 above only provide for VDR capabilities on one of the three radios on the aircraft. The costs of transitions 2 and 3 are throw away if later NEXCOM is desired. Therefore, the total cost is either the cost of transition 2 or 3 plus the cost of transition 1 plus the cost to the final transition for 8.33 kHz. with VDL-Mode 2 at the top of the right side of Figure 12. Remember transitions 2 and 3 cannot support NEXCOM functionality.

On the left side of Figure 12 for the Classic aircraft are the transitions to NEXCOM functionality. These are easy to follow as only intermediate states for VDL-Mode 2 and VDL-Mode 3 voice are available. These transitions all require VDRs and therefore can also support 8.33 kHz. if desired with very minimal additional cost.

For the FMS/EFIS aircraft transitions, a similar method to the Classic aircraft transitions is identified in Figure 13. The only significant difference is that the FMS/EFIS aircraft can exist in either an analog or digital configuration. This results in two costs identified depending on whether the aircraft is initially analog or digital (see the “a” or “d” identification before the cost value in Figure 13 transitions).

This concludes the discussions on costs of future communication avionics costs. As the FAA continues to plan for communication improvements this paper has identified some of the likely costs to users related to the currently planned communication technologies. These costs will assist in calibrating the benefits gained with these technologies and can also assist in investment analysis and justification.

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5. Suggested Further Study

One refinement that would improve overall pricing for the integrated aircraft class transitions is determining more accurate prices for equipment, upgrades and installation. Much of the information on the integrated class aircraft systems must come from Boeing, as the aircraft architecture includes imbedded software as well as LRUs that will need modification. Pricing for the LRUs can be readily determined however the pricing for the integrated systems needs to be validated with Boeing.

Further work on other costs related to NEXCOM should also be developed. This analysis does not consider the operational costs of NEXCOM, such as training and other operational aspects.

The detailed aircraft architecture changes needed to host NEXCOM must also be determined. There are industry organizations, such as the Airline Electronic Engineering committee (AEEC), that are looking at these changes in concert with the airlines, equipment manufacturers, service providers, and airframe manufacturers. Once those details are understood, this analysis should be modified to account for those changes.

Another tactic would be to transition this information to a relational database such as MS Access. This would be a more efficient approach, if further analysis and comparisons are to be made, and it would make the cost data more readily available.

Finally this paper is intended to be a detailed starting point for further discussion and to develop a consistent representation of communication avionics costs. Further discussions with vendors, airlines, service providers and within the FAA should produce an industry acceptable estimate of these costs that can be used for further investment analysis and justification.

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6. Glossary

ACARS	Aircraft Communications Addressing and Reporting System
AEEC	Airline Electronic Engineering Committee
CMU	Communications Management Units
CRT	Cathode Ray Tube
DL CDU	Data Link Control Display Unit
DLM	Data Link Management
DSB-AM	Double Sideband Amplitude Modulation
EFIS	Electronic Flight Instrument System
FMS	Flight Management System
FMS/EFIS	Pertains to aircraft with electronic flight instrument displays and incorporating an FMS
LCD	Liquid crystal display
LRU	Line Replaceable Unit
MCDU	Multi-function Control Display Unit
NEXCOM	Next Generation Communications (Digital Radios)
RCP	Radio Control Panel
STC	Supplemental Type Certificate
VDL-M2	VHF Data Link Mode 2
VDL-M3vd	VHF Data Link Mode 3 Voice and Data
VDR	VHF Data Radio
VHF	Very High Frequency
8.33 kHz	Double Sideband AM Radios with 8.33 kHz Channel Spacing