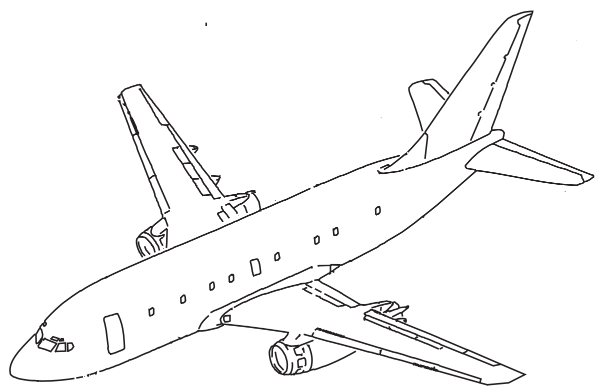
INTEGRATION OF GLOBAL POSITIONING SYSTEM USER EQUIPMENT INTO THE T-43 AIRCRAFT



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March 1, 1994

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1. INTRODUCTION

The purpose of this study is to determine the design options for integrating Global Positioning System (GPS) navigation equipment into the T-43 aircraft. The study was conducted as a team effort with participation from the GPS Joint Program Office (JPO), Oklahoma City Air Logistics Center (OC-ALC), and user representatives. The study will be delivered to the GPS JPO, the aircraft program manager at OC-ALC, and the using commands.

1.1 Objective

The objective of this study is to find the GPS implementation which best meets the mission requirements of the T-43 and can be implemented within the schedule and cost constraints of the Fiscal Year 95 (FY95) Presidential Budget Submittal (PBS). The result of this study is a specific recommendation for a GPS avionics architecture. The following components of that recommended architecture will be specified:

- Top level system design
- Line Replaceable Units (LRUs)
- Physical location of all new equipment
- Interface type (Aeronautical Radio Incorporation 429 (ARINC 429), Military Standard 1553 (MIL-STD-1553), analog, discrete, etc.)
- Functional interaction between GPS and other navigation sensors

The recommended GPS integration scheme was selected based upon its ability to satisfy user requirements, cost effectiveness, compliance with Federal Aviation Administration (FAA) certification requirements, and compliance with United States Air Force (USAF) GPS Integration Guidelines (GIG).

1.2 Physical Integration Environment

The following paragraphs describe the physical integration environment on the T-43.

1.2.1 Physical Description

The T-43 is the military variant of the Boeing 737-200 aircraft. It is powered by two Pratt & Whitney JT8D-9 turbofans. Overall length is 100 feet, and the wingspan is 93 feet. Two configurations are addressed in this study; 12 aircraft are configured as a navigation trainer and 2 aircraft (Serial numbers 72-0283 and 73-1149) are configured for executive transport.

1.2.2 Antenna Locations

The T-43 upper fuselage antenna and sextant mount locations are presented in Table 1 and Figure 1. All five sextant ports are closed out on the transport aircraft. The optimal GPS antenna location is the furthest forward sextant port. This location is feasible on the transport aircraft, but would require removal of the sextant equipment in the navigation trainer aircraft. In the case of the navigation trainer aircraft, the recommended GPS antenna location would be between the Identification Friend or Foe (IFF) and Tactical Air Navigation (TACAN) Number 1 antennas so that there is at least 1 meter separation between the GPS antenna and any other antenna. Sufficient room is available for a Fixed Reception Pattern Antenna (FRPA) and Antenna Electronics-4 (AE-4) or a similarly sized commercial GPS antenna and associated antenna electronics.

Table 1. *T-43 Upper Fuselage Antenna & Sextant Port Locations*

Antenna	Location	Comments
High Frequency (HF) (long wire)	Station (STA) 545	Extends to vertical stabilizer
Very High Frequency (VHF)	STA 630	73-1149 & 72-0283 only
Ultra High Frequency (UHF)	STA 490	Navigation Trainers only
Satellite Communication (SATCOM)	STA 363.5 to 400	72-0283 only
IFF	STA 305	
TACAN	STA 430	
TACAN	STA 500B+9	
TACAN	STA 580	
TACAN	STA 727A+10	
Sextant Mount	STA 353.0	
Sextant Mount	STA 513.75	
Sextant Mount	STA 605.5	
Sextant Mount	STA 718.0	
Sextant Mount	STA 852.75	

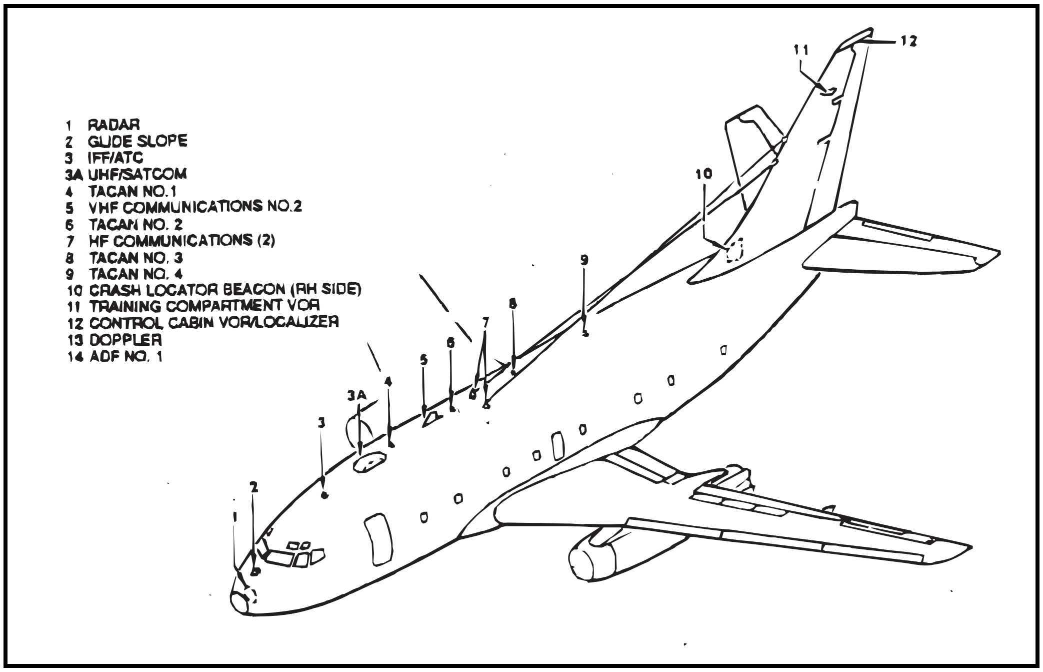


Figure 1. *Antenna Locations*

1.2.3 Avionics Racks Availability

The avionics rack configuration is shown in Figure 2. Electronics racks E-1, E-2, and E-3 are located in the lower forward lobe, forward of the Forward Cargo Door (stations 440-490) on all T-43 aircraft. Sufficient space is available for GPS equipment on these racks on all aircraft, making these areas the logical choice for locating new equipment.

On the navigation trainers and 73-1149, additional space is available on the E-4 electronics rack. On 72-0283, however, a communications console takes the place of the E-4 rack.

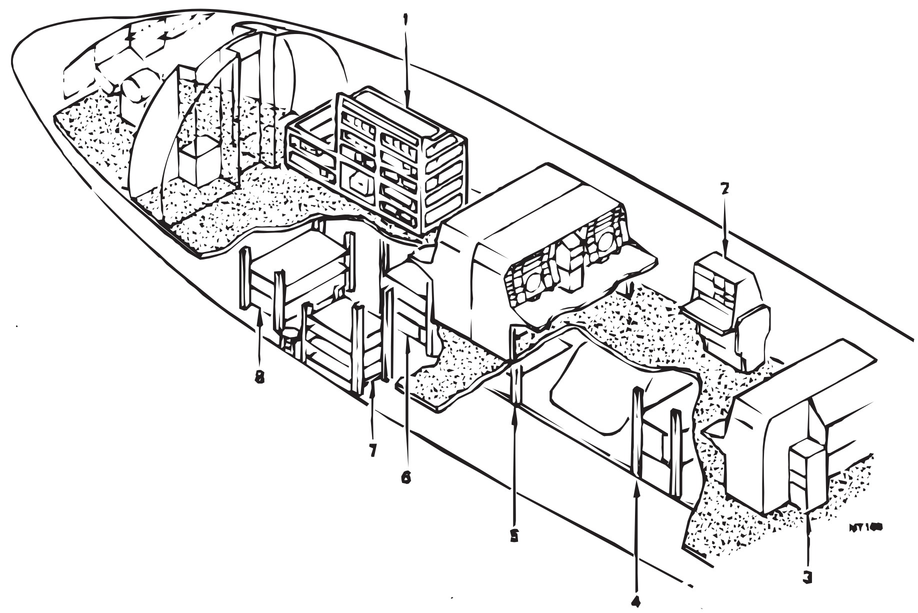


Figure 2. *Avionics Racks Locations*

1.2.4 Cockpit Space Availability

Cockpit space is very limited. Additional space can be made available by moving or removing existing radio control units. Cockpit space availability is discussed further in Chapter 4.

1.3 Baseline Avionics Configuration

The following paragraphs describe the current avionics on the T-43. A block diagram of the T-43 avionics configuration is shown in Figures 3 and 4.

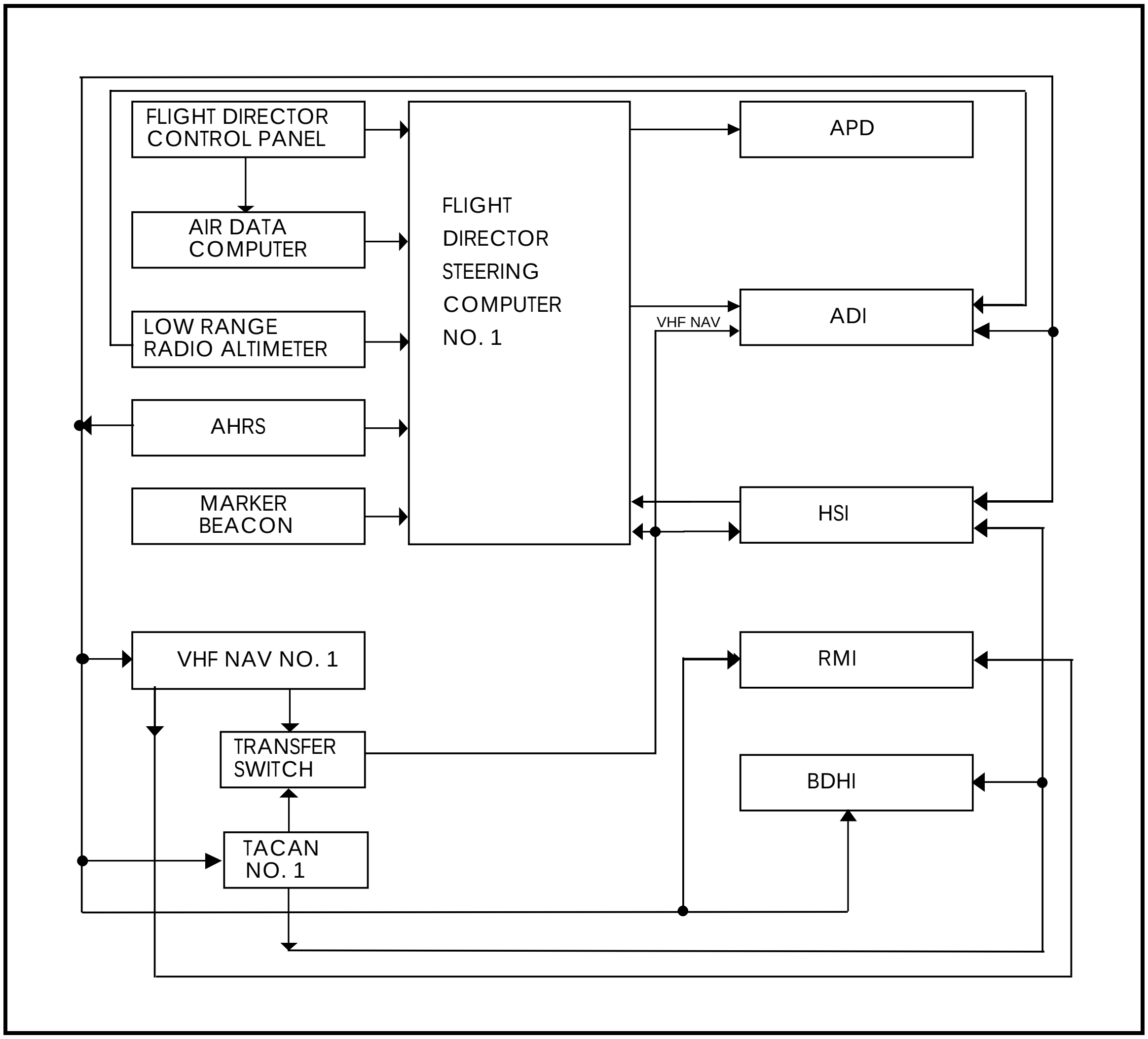


Figure 3. *Pilot's Flight Instruments*

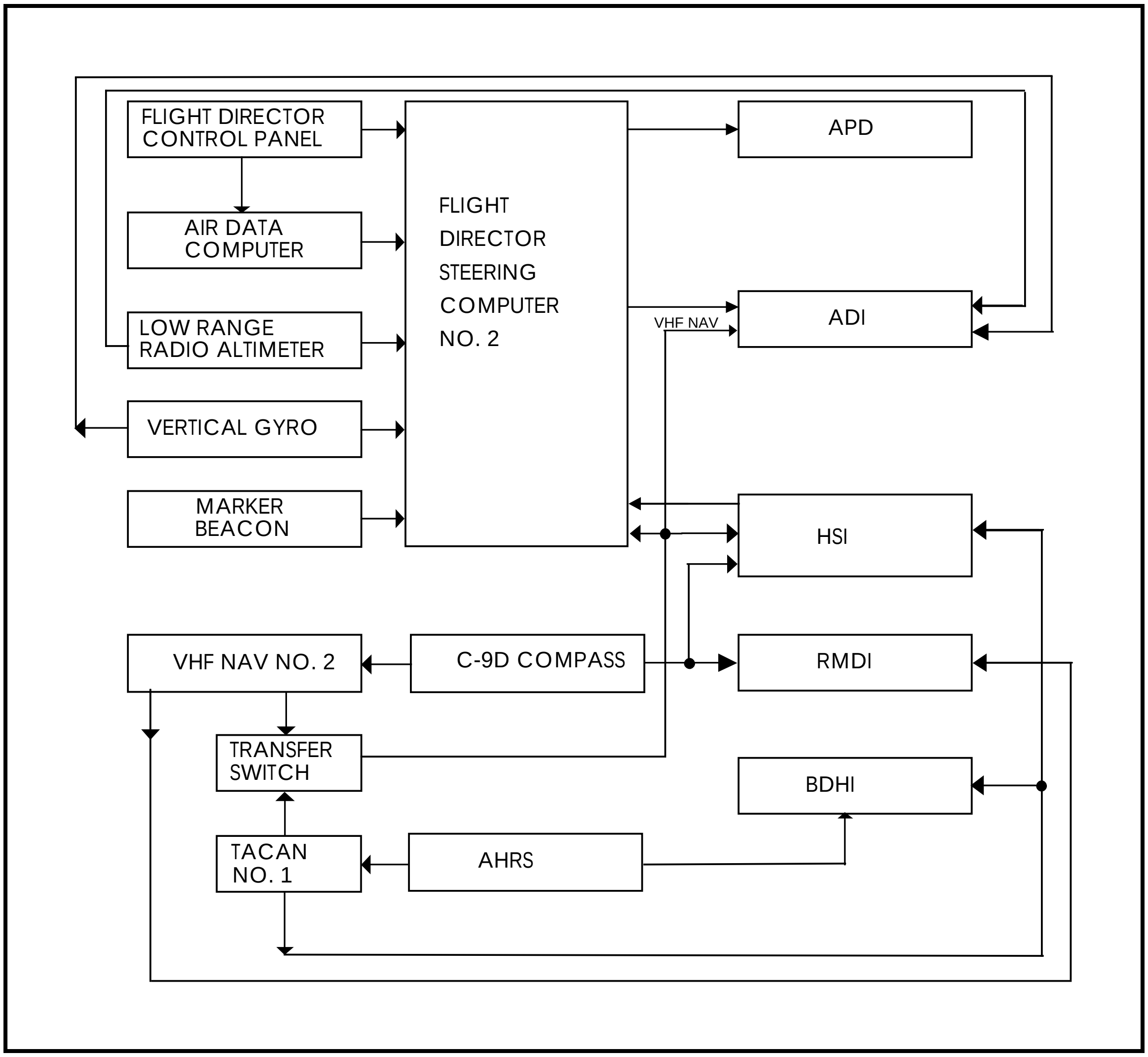


Figure 4. *Copilot's Flight Instruments*

1.3.1 Primary Flight Instruments

The Lear-Seigler AF/A24G-1A Attitude Heading Reference System (AHRS) provides attitude and heading reference to the pilot's Attitude Director Indicator (ADI) and Horizontal Situation Indicator (HSI). The copilot's ADI and HSI receive attitude references from a vertical gyro (Honeywell/Sperry M158/M159/M353) and the C-9D compass. Both pilots have FD-108 Flight Directors. Only the Very High Frequency Omnidirectional Range (VOR) and TACAN navigation data are currently displayed on the pilot's and copilot's flight instruments. Either VOR or TACAN can be selected using the transfer switch.

1.3.2 Central Air Data Computer

The Honeywell HG 180U-205 Central Air Data Computer (CADC) provides altitude information to the student consoles, the pressurization system and autopilot. The CADC provides an altitude pitch signal to the pilot's and copilot's flight directors when the altitude hold function is selected. The IFF altitude source is switch selectable from either altitude computer.

1.3.3 TACAN

The T-43 currently is equipped with a Gould ARN-84 TACAN which is being replaced with a BF Goodrich ARN-154 TACAN as a form, fit and functional replacement. Included in the TACAN upgrade is a 97RBA Range Bearing Adapter. The 97RBA translates the digital outputs of the TACAN into analog outputs for older cockpit instruments meeting the ARINC 521D requirements for Radio Magnetic Indicators (RMIs), Bearing Distance Heading Indicators (BDMIs) and HSIs such as those found in the T-43. The 97RBA also has two ARINC 429 input ports which can be used to receive limited inputs from a GPS receiver for displaying GPS navigation data on existing cockpit instruments. However, this adapter is currently only capable of presenting horizontal information. It does not provide the required enunciations for GPS and is not adequate for complete integration of GPS.

1.3.4 LTN-72 Inertial Navigation System (INS)

The Litton LTN-72 INS is a self-contained navigation system for commercial aircraft that is independent of any ground-based aids. It contains three gyros and three accelerometers mounted on a gimbaled platform. The AETC navigation trainer aircraft are equipped with a single LTN-72 which is controlled via a CDU located at the master training station. The transport aircraft are configured with two LTN-72's controlled from the cockpit. The ANG trainer aircraft also have two LTN-72s. Currently there is no electronic interface between the LTN-72 and the autopilot or flight instruments. However, all T-43's will be modified (under a different modification) to be able to use the LTN-72 as an alternate source of attitude and heading reference for the pilot's ADI and HSI. Although much interest has been expressed in replacing the LTN-72 with a newer INS, this study will not consider replacing the LTN-72 as part of the GPS integration. The designs considered in this study will not preclude replacing the LTN-72, but the GPS integration design will strongly influence the choice of a future INS.

1.3.5 VOR/Localizer

The Collins 51RV-2B provides bearing for radio navigation using VOR radial or Instrument Landing System (ILS) localizer beam. The VOR/Localizer works on line-of-sight and has a maximum effective range of up to 200 nmi for VOR and 45 nmi for ILS localizer. The output of the VOR/Localizer is sent to the flight instruments via the transfer switch.

1.3.6 Weather Radar

The two transport aircraft (72-0283 and 73-1149) are equipped with a Honeywell Primus-90 color weather radar. GPS data is required to be sent to the Primus-90 to provide a moving map display. Color weather radar is being considered for the trainer aircraft. The navigation trainer aircraft are currently equipped with Texas Instruments APQ-122 search radars used in navigator training. The APQ-122 is not impacted by any proposed GPS integration design.

2. REQUIREMENTS

2.1 Operational Requirements

Ten of the T-43 aircraft are owned by Air Education and Training Command (AETC) and are primarily operated out of Randolph Air Force Base (AFB). Two are owned by the Air National Guard (ANG) operating out of Buckley AFB. The T-43 is used to train navigator candidates and each aircraft is outfitted with 12 student training stations.

Generally, there are three mission profiles flown in support of navigator training: high level, low level, and over-water. Each mission typically lasts 4 - 5 hours and consists of an outbound and return leg. An aircrew for the typical training mission consists of a pilot, copilot, 6 instructors and 12 students.

Air Combat Command (ACC) and United States Air Forces Europe (USAFE) each have one aircraft for transporting personnel from point to point worldwide. Although these transport aircraft operate outside of combat zones, they may operate in the vicinity of jamming and spoofing threats. The ACC aircraft supports the United States Southern Command Commander In Chief and flies mainly in the North and South American continents. The USAFE aircraft is flown throughout Europe, including former Eastern Block countries. The mission profiles include enroute and over-water navigation, and approach and landing at both commercial and military runways.

2.1.1 Crew Support

The crew support requirements are listed below:

Validated Waypoint Database
Horizontal Position Accuracy: 0.3 nautical miles (nmi) Circular Error Probable (CEP)
Velocity Range: 0-999 nautical miles per hour (knots)
Time-to-First-Fix: 5 minutes maximum cold oscillator
GPS Reacquisition: Less than 10 seconds for a single satellite loss of less than 15 seconds
TACAN Emulation
Vertical Navigation

2.1.2 Enroute Navigation

The avionics system is required to perform enroute navigation in the National Airspace System (NAS) and the International Civil Aviation Organization (ICAO) using GPS as the primary external reference. T-43 enroute navigation when using GPS as the primary external sensor must be transparent to Air Traffic Control System (ATCS) ground controllers and other aircraft flying in the enroute structure. To meet the enroute navigation requirement, the T-43 GPS avionics system must be at least TSO C-129 Class A2 or Class B4 compliant.

The following requirements for the avionics system can be derived from the requirement for enroute navigation.

2.1.2.1 Validated Waypoint Database

The avionics system must use a validated waypoint database containing all existing nav-aids, named intersections, and all IFR flight routes. The pilot must be able to use GPS to navigate to/from the points in that database along or offset from the routes in the database without information from other radio nav-aids.

2.1.2.2 TO-TO, TO-FROM, DIRECT-TO Navigation

The avionics system must be capable of TO-TO, TO-FROM, and DIRECT-TO navigation as defined in the USAF GIG.

2.1.2.3 Phase of Flight Annunciation

The avionics system must be capable of annunciating the phase of flight as defined in the USAF GIG.

2.1.2.4 Fly-over and Fly-by Waypoints

The avionics system must be capable of handling both "fly-over" and "fly-by" waypoints.

2.1.2.5 Vertical Steering

The avionics system must be capable of displaying vertical steering on the ADI for descents. When vertical navigation is selected, the GPS avionics system (with pilot consent) should also be capable of coupling with the autopilot to provide a smooth descent to a specified altitude.

2.1.2.6 ETE to Waypoints

The avionics system must be capable of providing continuously updated Estimated Time Enroute (ETE) to the next waypoint or to any other selected waypoint.

2.1.2.7 CDI Scaling

The avionics system should have growth provisions which will allow it to automatically transition from en route scaling on the CDI to terminal scaling on the CDI.

2.1.3 Oceanic Enroute Navigation

The avionics system is required to perform oceanic enroute navigation using GPS as the primary external reference. T-43 oceanic enroute navigation which uses GPS as the primary external sensor must be transparent to other aircraft flying in the oceanic enroute structure.

2.1.4 Terminal Area Navigation

The avionics system shall be able to navigate in Category B airspace (previously called terminal control areas or TCAs) using GPS as the primary external reference. T-43 terminal area navigation shall be transparent to ATCS ground controllers and other aircraft flying in the terminal area. To meet this requirement, the T-43 GPS avionics system must be either TSO C-129 Class B4 or Class A2 compliant or better for operations in civil terminal areas and must be GIG compliant for operations at military airfields. In particular, TACAN emulation as defined in the USAF GIG must be available for terminal operations at military airfields.

2.1.4.1 Standard Instrument Departures (SIDs) and Standard Terminal Arrivals (STARs)

The avionics system must be capable of autoflying SIDs and STARs. To do this the avionics system should be capable of flying the following leg types as defined in ARINC 424:

Course from fix to altitude	Course from fix to manual termination
Course to intercept	Course from fix to along track distance
Course from fix to DME distance	Course to radial
Course to fix	Course to altitude
Course to DME distance	Heading to Radial
Heading to DME distance	Heading to manual termination
Heading to intercept	Direct to fix
Track to fix	Procedure Turn
DME arc	Initial fix

The avionics system must accept both user-defined SIDs and STARs and validated database SIDs and STARs.

2.1.5 Non-Precision Approach

The avionics system is required to perform non-precision approach using GPS as the primary external reference. To perform GPS non-precision approaches, the T-43 GPS avionics system must be either TSO C-129 Class B1 or Class A1 compliant for approaches at civil airports, and it must be GIG compliant for approaches at military airfields.

2.1.5.1 TACAN Emulation

The avionics system must perform TACAN emulation as defined in the USAF GIG.

2.1.5.2 GPS Receiver Requirements

The GPS receiver or GPS avionics system must provide the following:

Receiver Autonomous Integrity Monitoring (RAIM)
Continuous tracking of 6 or more satellites (derived from RAIM requirement)

2.1.6 Precision Approach

The avionics system is required to be capable of performing precision approaches. Because the FAA has not defined the requirements for precision approach, this requirement may not be met with any system currently available. However, the characteristics that will be needed in the display system, the GPS avionics system and GPS receiver to support precision approach are well understood. As the designs in this study are rated, those systems which provide the characteristics needed for GPS based precision approach (Receiver Autonomous Integrity Monitoring (RAIM), All-in-View, Differential GPS (DGPS), etc.) will be rated higher than those which do not incorporate these features.

2.1.6.1 Vertical Steering

The GPS avionics system must be capable of providing vertical steering based on GPS sensor outputs.

2.1.6.2 GPS Receiver Requirements

The GPS receiver or GPS avionics system must provide the following:

Receiver Autonomous Integrity Monitoring (RAIM)
Continuous tracking of 6 or more satellites (RAIM requirement])
Carrier Phase Tracking
Special Category I (SCAT I) Differential GPS input
Growth provisions for GPS Integrity Channel (GIC)
Growth provisions for Wide Area Differential GPS from Communication Satellites

2.1.7 Unkeyed Operation

AETC and ANG units operating the T-43 as a navigator trainer do not have the facilities needed to store and handle cryptographic equipment required for GPS Precise Positioning Service (PPS) operation and do not have a combat or combat support mission. Therefore, the GPS integration must be able to meet the FAA navigation accuracy requirements using GPS Standard Positioning Service (SPS).

2.1.8 GPS at Navigation Trainer Stations

A GPS receiver which is controlled from the training compartment is required for the navigation trainer aircraft. The GPS navigation data is required at the 12 student training stations.

2.1.9 Transport Requirements

The ACC and USAFE aircraft may fly in the vicinity of jamming and spoofing threats, therefore these aircraft require a PPS receiver with Selective Availability (S/A) and Anti-Spoofing (A-S) capability.

2.1.10 Redundancy

The GPS navigation system shall have, to the maximum extent practical, the same level of redundancy as the VHF radio navigation system to support approach and landing. This requires redundant sets of GPS navigation equipment.

2.2 Programmatic Requirements

2.2.1 Number of Aircraft

The T-43 fleet consists of 12 navigation trainer aircraft and two executive transport aircraft. This size fleet limits options for either hardware or software development. A common GPS integration into the various T-43 configurations is required to minimize logistics costs and reduce schedule impacts. These aircraft are not scheduled to be phased out in the foreseeable future.

2.2.2 Cost/Schedule

The FY95 PBS currently allows $8.3 million for the acquisition and installation of GPS user equipment on the T-43. The schedule calls for procurement of assets in 1995, with installation to begin in 1997 and be completed by 2000.

2.2.3 Certification

The GIG requires that the T-43 operate transparently in the NAS. Therefore, the GPS integration must at a minimum retain its FAA certification under Technical Standing Order (TSO) 115A. However, we recommend that the GPS integration be TSO C129 Class A1 or B1 certified. TSO C-129 Class A1 or B1 certification will allow the T-43 to perform GPS overlay approaches in the NAS.

Prior to the final elimination of TACAN, VOR and ILS, an avionics system which meets the FAA definition for GPS Required Navigation Performance (RNP) in NAS for all phases of flight will have to be incorporated into the T-43. The 1992 Federal Radionavigation Plan (FRP) calls for TACAN to be decommissioned by 2000, and for VOR/ILS to be decommissioned "when no longer needed."

As traditional navigation aids such as VOR-DME are decommissioned, the current avionics system of the T-43 will become less viable. For the T-43 to remain functionally viable, it is important that it be either GIG compliant, or meet the requirements of TSO C129 Class A1 or B1. The GIG defines the system architecture requirements for integrating a military encrypted precision code (P/Y code) GPS receiver which will allow it to operate transparently in the NAS. Refer to Radio Technical Commission for Aeronautics (RTCA) document DO-208 and FAA TSO C-129 for a complete list of TSO C-129 requirements. Table 2 summarizes the requirements of TSO C129.

TABLE 2. *TSO C-129 Classification Summary*

TSO C-129	**Stand Alone GPS System**		**Remote GPS Sensor Interfaced to a Multi-Sensor Navigation System**							
Classification	A1	A2	B1	B2	B3	B4	C1	C2	C3	C4
Approved for Enroute	√	√	√	√	√	√	√	√	√	√
Approved for Terminal	√	√	√	√	√	√	√	√	√	√
Approved for Approach	√		√		√		√		√	
Integrity through RAIM in GPS Receiver	√	√	√	√			√	√		
Integrity through comparison with other sensors					√	√			√	√
Special HSI deviation required (± 5 nmi Enroute, ± 1 nmi Terminal, ± 0.3 nmi Approach)	√	√	√	√	√	√				
Standard HSI deviation with Flight Director commands (Part 121 aircraft only)							√	√	√	√

3. TOP LEVEL SURVEY

This chapter describes the top-level design options which were considered for GPS integration into the T-43 avionics and mission systems. The designs are rated using a weighted scoring system. The weight for each of the evaluation factors in Table 3 was determined based on the T-43 requirements. Each design was then rated against each of the evaluation factors to construct the final evaluation matrix listed in Table 4. Under this methodology the advantages and disadvantages of each design are determined as well as its relative worth as compared to each of the other design candidates.

Table 3. *Design Rating Matrix*

RATING: FACTOR:	1	2	3	4	5
PRIMARY MISSION REQUIREMENTS WEIGHT 16.0	The resulting avionics system will meet 60-69% of the aircraft's primary mission requirements.	The resulting avionics system will meet 70-79% of the aircraft's primary mission requirements.	The resulting avionics system will meet 80-89% of the aircraft's primary mission requirements.	The resulting avionics system will meet 90-99% of the aircraft's primary mission requirements.	The resulting avionics system will meet 100% of the aircraft's primary mission requirements.
INERTIAL NAVIGATION SYSTEM WEIGHT 15.0	An INS may be added or replaced to the avionics system with moderate to high difficulty.	An INS may be added or replaced to the avionics system with only minor modifications.	The resulting avionics system has provisions for an INS which may be added without further modifications to the avionics system.	The resulting avionics system contains a medium accuracy (0.8 - 1 nmi/hr) INS which is fully integrated into the avionics system.	The resulting avionics system contains a high accuracy (< 0.8 nmi/hr) INS which is fully integrated into the avionics system.
UPGRADE TO GPS SOLE MEANS WEIGHT 14.0	The anticipated cost and risk to upgrade to GPS Sole Means is high.	The anticipated cost and risk to upgrade GPS to Sole Means is moderate-to-high.	The anticipated cost and risk of upgrade to GPS Sole Means is moderate.	The anticipated cost and risk to upgrade to GPS Sole Means is moderate-to-low.	The anticipated cost and risk of upgrade to GPS Sole Means is low.
TSO/GIG COMPLIANCE WEIGHT 13.0	The proposed design varies greatly from GIG or TSO C-129 requirements. Little or no compliance with the "intent" of the GIG/TSO can be achieved.	The proposed design can achieve the "intent" of the GIG or TSO C-129 only by extensive work arounds using aircrew actions and/or innovations.	The design complies with the majority of the GIG or TSO C-129 requirements. Work arounds are available to meet the remaining requirements with little impact on normal aircrew procedures.	The design complies with nearly all GIG or TSO C-129 requirements. Work arounds require little aircrew intervention.	The design meets or exceeds all GIG or TSO C-129 requirements.
PILOT VEHICLE INTERFACE WEIGHT 12.0	The proposed design provides a very poor avionics interface. The design could impact safety of flight.	The proposed design provides an awkward avionics interface. The design will inconvenience the aircrew.	The proposed design provides an adequate avionics interface.	The proposed design improves the aircrew's ability to interact with the avionics system.	The proposed design greatly improves the aircrew's ability to interact with the avionics system.

TECHNICAL RISK WEIGHT 8.0	Technical risk associated with the proposed design is very high.	Technical risk associated with the proposed design is high-to-moderate.	Technical risk associated with the proposed design is moderate.	Technical risk associated with the proposed design is moderate-to-low	Technical risk associated with the proposed design is low.
SCHEDULE IMPACT WEIGHT 7.0	The proposed design will require an additional year or more of dedicated schedule.	The proposed design will require an additional 9 months of dedicated schedule.	The proposed design will require an additional 6 months of dedicated schedule.	The proposed design will require an additional 3 months of dedicated schedule.	The proposed design will not impact the existing schedule.
RELIABILITY WEIGHT 7.0	< 3000 hr calculated MTBF for the GPS avionics system	3,000 - 4,000 hr calculated MTBF for the GPS avionics system.	4,000 - 5,000 hr calculated MTBF for the GPS avionics system.	5,000 - 6,000 hr calculated MTBF for the GPS avionics system.	> 6,000 hr calculated MTBF for the GPS avionics system.
COST WEIGHT 5.0	The proposed design is expected to cost much more than the FY95 PBS allocation.	The proposed design is expected to cost slightly more than the FY95 PBS allocation.	The proposed design is expected to cost no more than the FY95 PBS allocation.	The proposed design is expected to cost slightly less than the FY95 PBS allocation.	The proposed design is expected to cost much less than the FY95 PBS allocation.
RECEIVER WEIGHT 3.0	The GPS receiver utilized in this design is a coarse/aquisition (C/A) code commercial set.	-	The receiver utilized in this design is a non JPO receiver with Selective Availability (S/A) and Anti-Spoofing (A-S) capability.	-	The receiver utilized in this design is a JPO provided receiver with S/A and A-S capability.

The ratings for each design are based on the equipment specifications or latest information available. The performance and reliability figures are provided by the vendors and have not been verified by the Air Force. Detailed cost estimates for each design are presented in Appendix B.

3.1 Design 1 - Embedded GPS/Smart Control Display Unit (CDU)

3.1.1 Design 1 Description

Design 1 is illustrated in Figure 5. This design is based on an Embedded GPS/Smart CDU. The embedded GPS card is a 5-channel military P/Y code receiver which resides inside the Smart CDU. The Smart CDU receives data from the existing LTN-72 INS via an ARINC 575 data bus and integrates it with the GPS data using a Kalman filter to derive the navigation solution.

The flight instruments are driven by either the TACAN, VOR/ILS or the Smart CDU outputs depending on the transfer switch setting. The transfer switch is modified to handle the additional input from the Signal Data Converter (SDC), which converts the digital data from the Smart CDU into analog signals which can drive the flight instruments.

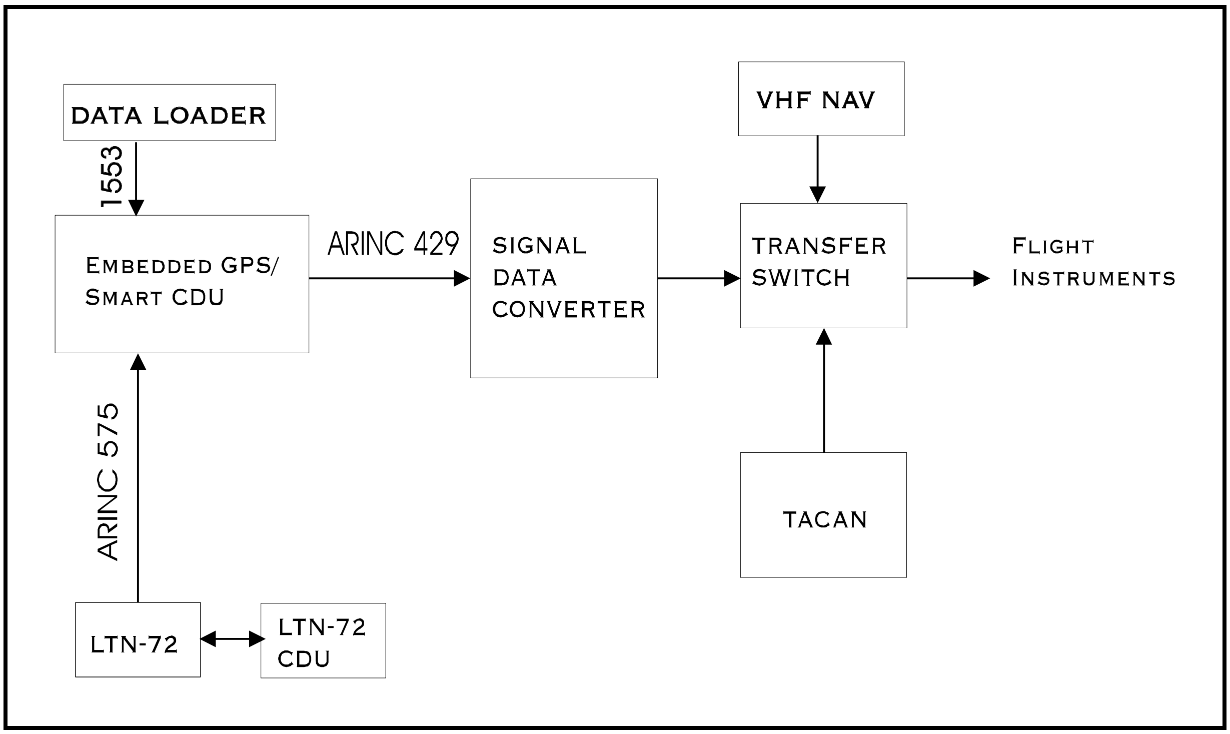


Figure 5. *Design 1 Block Diagram*

3.1.2 Design 1 Evaluation

Primary Mission Requirements: {4} This design does not meet landing approach accuracy requirements in SPS mode. Because of the lack of ionospheric modelling software, the embedded GPS receiver is about 25% less accurate than a commercial C/A code receiver when not keyed. With the addition of ionospheric modelling software, this design could potentially meet the required accuracy in SPS mode.

Inertial Navigation System: {4} This design integrates the existing LTN-72 INS (a medium accuracy INS) with the GPS avionics system.

Upgrade to GPS Sole Means: {2} We anticipate a moderate to high cost to upgrade this avionics package to a "GPS Sole External Reference" avionics package when/if required.

TSO/GIG Compliance: {4} The embedded GPS receiver is not TSOed and is not GIG compliant. However, the resulting avionics system would be largely GIG compliant due to the functionality of the Smart CDU.

Pilot Vehicle Interface: {4} The Smart CDU improves the pilot vehicle interface by providing flight planning, flight instrument interface, and communications controls.

Technical Risk: {3} The technical risk associated with this design is moderate because the embedded GPS receiver is still under development.

Schedule Impact: {4} The first production Embedded GPS/Smart CDUs are scheduled to be available mid-1995. Other aircraft will be ahead of the T-43 on the Embedded GPS/Smart CDU schedule. In addition, the Embedded GPS/Smart CDU is still under development, so a potential schedule risk exists.

Reliability: {4} Smart CDU: 5000 - 6000 hours estimated Mean Time Between Failures (MTBF), embedded GPS: 10,000 hours estimated MTBF, SDC: 9400 hours estimated MTBF.

Cost: {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and Smart CDUs could possibly be provided within the FY95 PBS.

Receiver: {3} The Embedded GPS receiver is a P/Y code receiver with S/A and A-S capability, but may or may not be a JPO-supplied receiver, so a waiver might be required.

3.2 Design 2 - MAGR/Smart CDU

3.2.1 Design 2 Description

Design 2 is illustrated in Figure 6. This design uses a Smart CDU which communicates with a MAGR over a MIL-STD-1553 data bus. The Smart CDU receives data from the existing LTN-72 INS via an ARINC 575 data bus and integrates it with the GPS data using a Kalman filter to derive the navigation solution.

The flight instruments are driven by either the TACAN, VOR/ILS or the Smart CDU outputs depending on the transfer switch setting. The transfer switch is modified to handle the additional input from the SDC, which converts the digital data from the Smart CDU into analog signals which can drive the flight instruments.

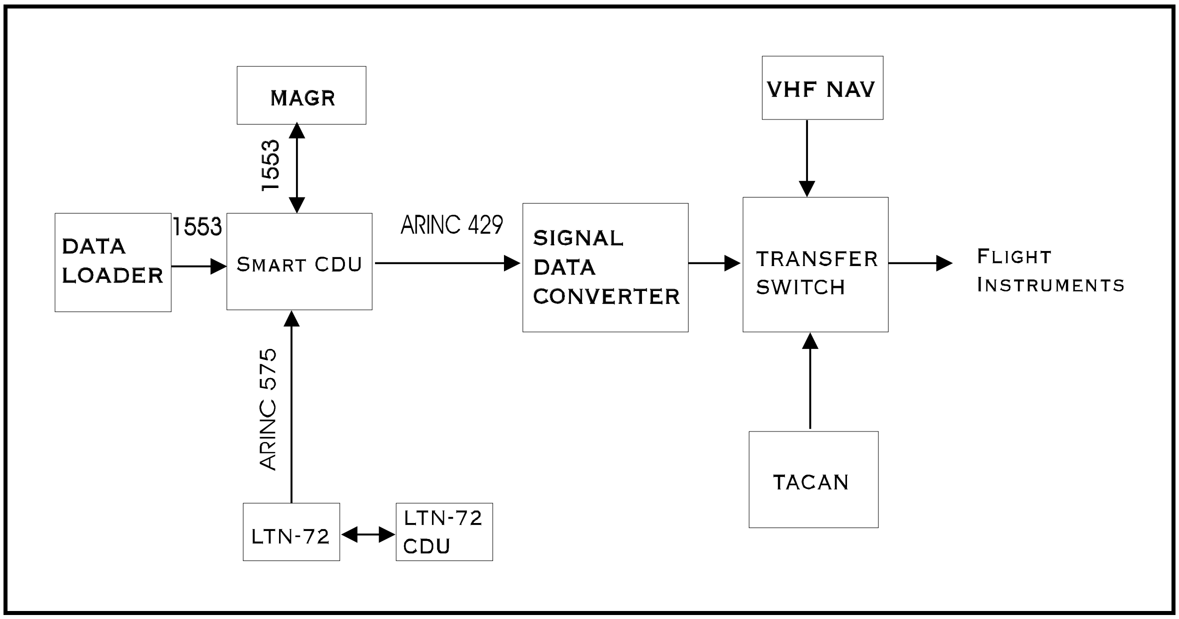


Figure 6. *Design 2 Block Diagram*

3.2.2 Design 2 Evaluation

Primary Mission Requirements: {4} This design does not meet landing approach accuracy requirements in SPS mode. Because of the lack of ionospheric modelling software, the MAGR is about 25% less accurate than a commercial C/A code receiver when not keyed. With the addition of ionospheric modelling software, this design could potentially meet the required accuracy in SPS mode.

Inertial Navigation System: {4} This design integrates the existing LTN-72 INS (a medium accuracy INS) with the GPS avionics system.

Upgrade to GPS Sole Means: {2} The MAGR is not currently "GPS Sole External Reference" capable. We anticipate a moderate-to-high cost to upgrade the MAGR to a "GPS Sole External Reference" receiver.

TSO/GIG Compliance: {4} The MAGR is not TSOed and is not GIG compliant. However, the resulting avionics system would be largely GIG compliant due to the functionality of the Smart CDU.

Pilot Vehicle Interface: {4} The Smart CDU improves the pilot vehicle interface by providing flight planning, flight instrument interface, and communications controls.

Technical Risk: {5} The techincal risk associated with this design is low because very similar designs have already been implemented in U.S. Navy aircraft.

Schedule Impact: {5} No schedule impact is expected because all components are currently in production.

Reliability: {3} MAGR has an estimated 5000 hour MTBF. Smart CDU: 5000-6000 hours estimated MTBF.

Cost: {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and Smart CDUs could possibly be provided within the FY95 PBS.

Receiver: {5} The MAGR is an approved JPO, P/Y code receiver. Its use does not require any waiver requests.

3.3 Design 3 - Receiver 3A (RCVR 3A)

3.2.1 Design 3 Description

Design 3 is illustrated in Figure 7. This design uses a RCVR 3A controlled by a standard GPS CDU. The LTN-72 provides aiding to the RCVR 3A through its ARINC 575 interface. A Kalman filter residing in the RCVR 3A provides a blended GPS/INS navigation solution.

The flight instruments are driven by either the TACAN, VOR/ILS or the RCVR 3A outputs depending on the transfer switch setting. The transfer switch is modified to handle the additional input from the SDC, which converts the digital data from the RCVR 3A into analog signals which can drive the flight instruments.

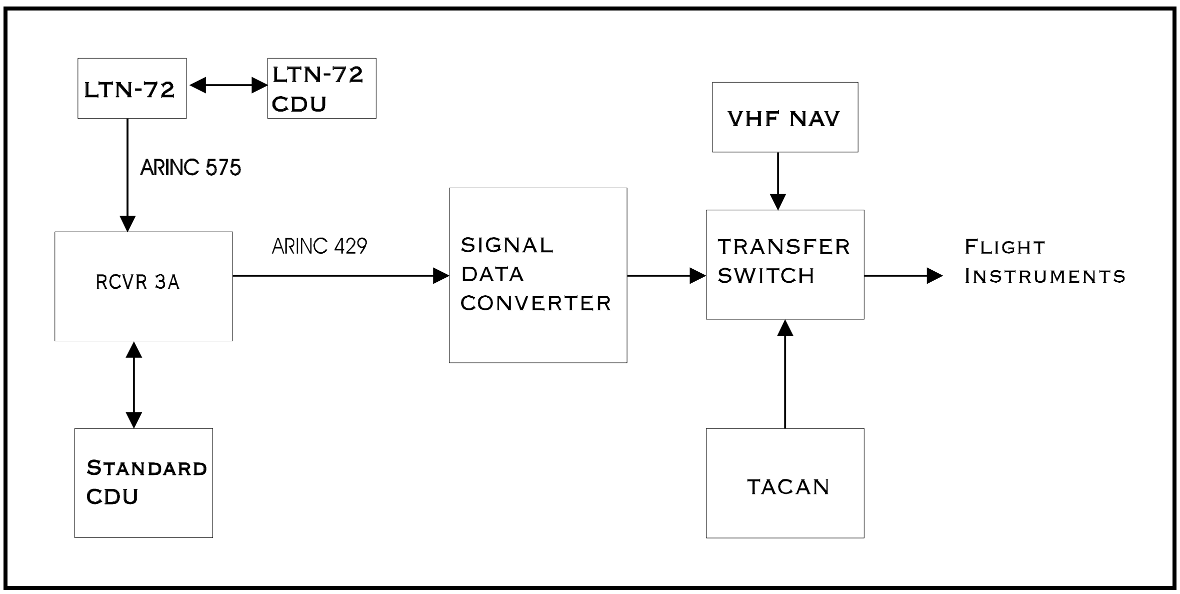


Figure 7. *Design 3 Block Diagram*

3.2.2 Design 3 Evaluation

Primary Mission Requirements: {3} This design does not meet the landing approach accuracy requirements in SPS mode. Because of the lack of ionospheric modelling software, the RCVR-3A is about 25% less accurate than a commercial C/A code receiver when not keyed. With the addition of ionospheric modelling software, this design could potentially meet the required accuracy in SPS mode.

A further limitation of this design is that the RCVR-3A is classified when keyed. Essentially, this design limits the T-43 cross country flights to military bases because if the T-43 lands at a civil airport, the receiver must be zeroized before the crew can leave the aircraft. Since the keys and the KYK-13 are both classified, it is unlikely that they would be available at a civil airport. This limits the T-43 to operating in SPS mode only from civil airports.

Inertial Navigation System: {4} This design integrates the existing LTN-72 INS (a medium accuracy INS) with the GPS avionics system.

Upgrade to GPS Sole Means: {2} The RCVR-3A is not currently "GPS Sole External Reference" capable. We anticipate a moderate-to-high cost to upgrade the RCVR-3A to a "GPS Sole External Reference" receiver.

TSO/GIG Compliance: {2} The RCVR-3A is not TSOed and is not GIG compliant. There is no navigation computer in this design to enhance the RCVR-3A capability.

Pilot Vehicle Interface: {3} The standard CDU interface is adequate.

Technical Risk: {5} This design consists entirely of off-the-shelf equipment and a very minor modification to the transfer switch.

Schedule Impact: {5} No schedule impact is anticipated for this design.

Reliability: {2} RCVR 3A's estimated 3000 hour MTBF limits the reliability of this design.

Cost: {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and Smart CDUs could possibly be provided within the FY95 PBS.

Receiver: {5} The RCVR-3A is an approved JPO, P/Y code receiver. Its use does not require any waiver requests.

3.4 Design 4 - Embedded GPS/INS (EGI)

3.4.1 Design 4 Description

Design 4 is illustrated in Figure 8. This design uses an EGI system being procured by Aeronautical Systems Center (ASC/SM). Since the contract has not been awarded, this design is rated based on the Systems Requirements Document for EGI dated 19 July 93. The EGI replaces the LTN-72 INS as well as providing GPS capability. The Embedded GPS card is a JPO-approved military P/Y code receiver which resides inside the INS. EGI is controlled by a Smart CDU programmed to interface with the EGI. The INS is a 0.8 nmi/hour ring laser gyro system.

Flight instruments are driven using the SDC and the transfer switch. The flight instruments are driven by either the TACAN, VOR/ILS or the EGI outputs depending on the transfer switch setting. The transfer switch is modified to handle the additional input from the EGI.

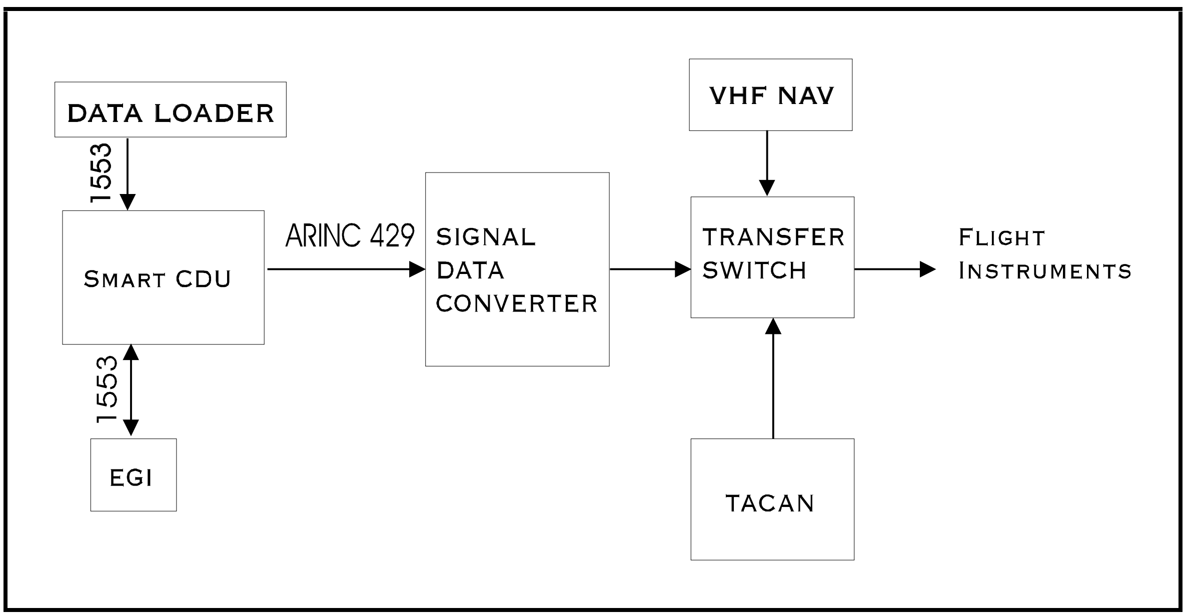


Figure 8. *Design 4 Block Diagram*

3.4.2 Design 4 Evaluation

<u>Primary Mission Requirements:</u> {4} This design does not meet the landing approach accuracy requirements in SPS mode. Because of the lack of ionospheric modelling software, the EGI is about 25% less accurate than a commercial C/A code receiver when not keyed. With the addition of ionospheric modelling software, this design could potentially meet the required accuracy in SPS mode.

Inertial Navigation System: {4} This design replaces the existing LTN-72 INS with a medium accuracy INS.

Upgrade to GPS Sole Means: {2} The EGI is not required to be "GPS Sole External Reference" capable. We anticipate a moderate-to-high cost to upgrade the EGI to a "GPS Sole External Reference" receiver.

TSO/GIG Compliance: {4} The EGI is is not required to be either GIG or TSO compliant by its System Requirements Document. However, the resulting avionics system would be largely GIG compliant due to the functionality of the Smart CDU.

Pilot Vehicle Interface: {4} The Smart CDU improves the pilot vehicle interface by providing flight planning, flight instrument interface, and communications controls.

Technical Risk: {2} The technical risk associated with the EGI is moderate to high because it is still in development. In addition to the EGI development, the interface to a CDU would have to be developed.

Schedule Impact: {2} The current EGI schedule calls for the first production units to be delivered in mid-1995. Since unique EGI to flight instrument interfaces would have to be developed, additional development time would be required. In addition, since the T-43is a trainer it would probably be one of the last aircraft to receive EGI.

Reliability: {3} EGI is required to have a 4000 hour MTBF, which is considerably better than the current LTN-72 MTBF.

Cost: {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and Smart CDUs could possibly be provided within the FY95 PBS.

Receiver: {5} The EGI will be an approved JPO, P/Y code receiver. Its use does not require any waiver requests.

3.5 Design 5 - MAGR/Commercial Flight Management System (FMS)

3.5.1 Design 5 Description

Design 5 is illustrated in Figure 9. Design 5 is based on a commercial FMS, which includes a navigation computer and CDU. The FMS receives data from the existing LTN-72 INS via an ARINC 575 data bus. An ARINC 429 interface card is added to the TACAN to interface with the FMS. The FMS also receives data from the VOR/ILS. The FMS integrates all of the sensor data using a Kalman filter to derive the "Best Computed Position" navigation solution. The FMS drives the flight instruments and autopilot directly using a digital to analog conversion card inside the FMS. The HSIs are replaced with ARINC 429 compatible HSIs such as the Bendix-King KPI 553A. The FMS is capable of driving the moving map display of a color weather radar via ARINC 429.

The MAGR provides Position, Velocity, Time (PVT) to the FMS via the Bus Control Interface Unit (BCIU) and provides full military P/Y code capability with minimal impact on the rest of the avionics. The BCIU is being developed for the C-21 by OC-ALC. The BCIU is designed to provide bi-directional data translation necessary to interface the ARINC 429 data bus to the MIL-STD-1553B data bus. The MAGR is controlled from a small control panel which consists of an on/off switch, key status lights and a KYK-13 fill port.

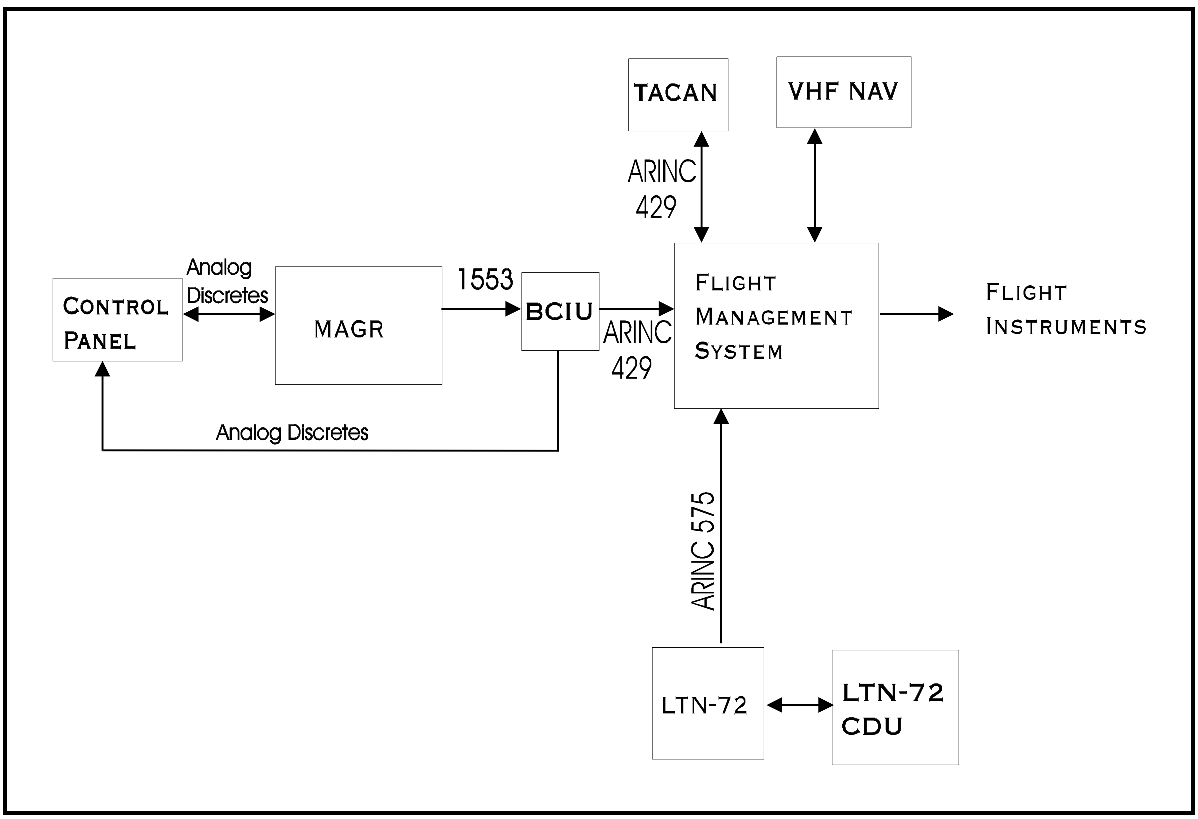


Figure 9. *Design 5 Block Diagram*

3.5.2 Design 5 Evaluation

Primary Mission Requirements: {4} This design does not meet the landing approach accuracy requirements in SPS mode. Because of the lack of ionospheric modelling software, the MAGR is about 25% less accurate than a commercial C/A code receiver when not keyed. With the addition of ionospheric modelling software, this design could potentially meet the required accuracy in SPS mode.

Inertial Navigation System: {4} This design integrates the existing LTN-72 INS (a medium accuracy INS) with the GPS avionics system.

Upgrade to GPS Sole Means: {2} We anticipate a moderate to high cost to upgrade this avionics package to a "GPS Sole External Reference" avionics package when/if required.

TSO/GIG Compliance: {4} The MAGR is not TSOed and is not GIG compliant. However, the resulting avionics system would be largely GIG compliant due to the functionality of the FMS.

Pilot Vehicle Interface: {5} The FMS greatly improves the pilot vehicle interface by providing full flight management and flight planning, flight instrument interface, autopilot coupling, and communications controls.

Technical Risk: {4} The technical risk associated with this design is low because it consists entirely of off-the-shelf items.

Schedule Impact: {5} No impact to the GPS integration schedule is anticipated.

Reliability: {3} MAGR has an estimated 5000 hour MTBF. The FMS MTBF is estimated to be 7000 hours.

Cost: {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and Smart CDUs could possibly be provided within the FY95 PBS.

Receiver: {5} The MAGR is an approved JPO, P/Y code receiver. Its use does not require any waiver requests.

3.6 Design 6 - MAGR, Commercial FMS, C/A Code Receiver

3.6.1 Design 6 Description

Design 6 is illustrated in Figure 9. Design 6 is based on a commercial flight management system (FMS), which includes a navigation computer and CDU. The GPS receiver is a commercial C/A code receiver which meets TSO C-129 Class A1 or B1 requirements, including RAIM. The FMS receives data from the existing LTN-72 INS via an ARINC 575 data bus. In the navigation trainer aircraft, the LTN-72 can continue to be controlled from the training compartment and be de-selected by the pilots if the LTN-72 is in error. An ARINC 429 interface card is added to the TACAN to interface with the FMS. The FMS also receives data from the VOR/ILS. The FMS integrates all of the sensor data using a Kalman filter to derive the "Best Computed Position" navigation solution. The FMS drives the flight instruments and autopilot directly using a digital to analog conversion card inside the FMS. The HSIs are replaced with ARINC 429 compatible HSIs such as the Bendix-King KPI 553A. The FMS is capable of driving the moving map display of a color weather radar via ARINC 429.

On the transport aircraft, the addition of a MAGR would provide full S/A and A-S capability when flying in the vicinity of jamming or spoofing threats, while the C/A code receiver would serve as a hot backup outside of the threat area. The MAGR is controlled from a small control panel which consists on a MAGR on/off switch, key status lights and a KYK panel. The GPS signals coming from the GPS antenna are split off to feed both receivers. The MAGR provides PVT to the FMS via the BCIU. The BCIU is being developed for the C-21 by OC-ALC. The BCIU is designed to provide bi-directional data translation necessary to interface the ARINC 429 data bus to the MIL-STD-1553B data bus.

The dual GPS design presented in Design 6 combines the strengths of the commercial C/A code receiver (SPS accuracy, RAIM, FAA certification, future GPS Sole Means) with the strengths of the military P/Y code receiver (S/A and A-S). This design is the only one which meets all the mission requirements of both the navigation trainer and transport aircraft using a common configuration. It also provides the additional benefit of redundant GPS receivers.

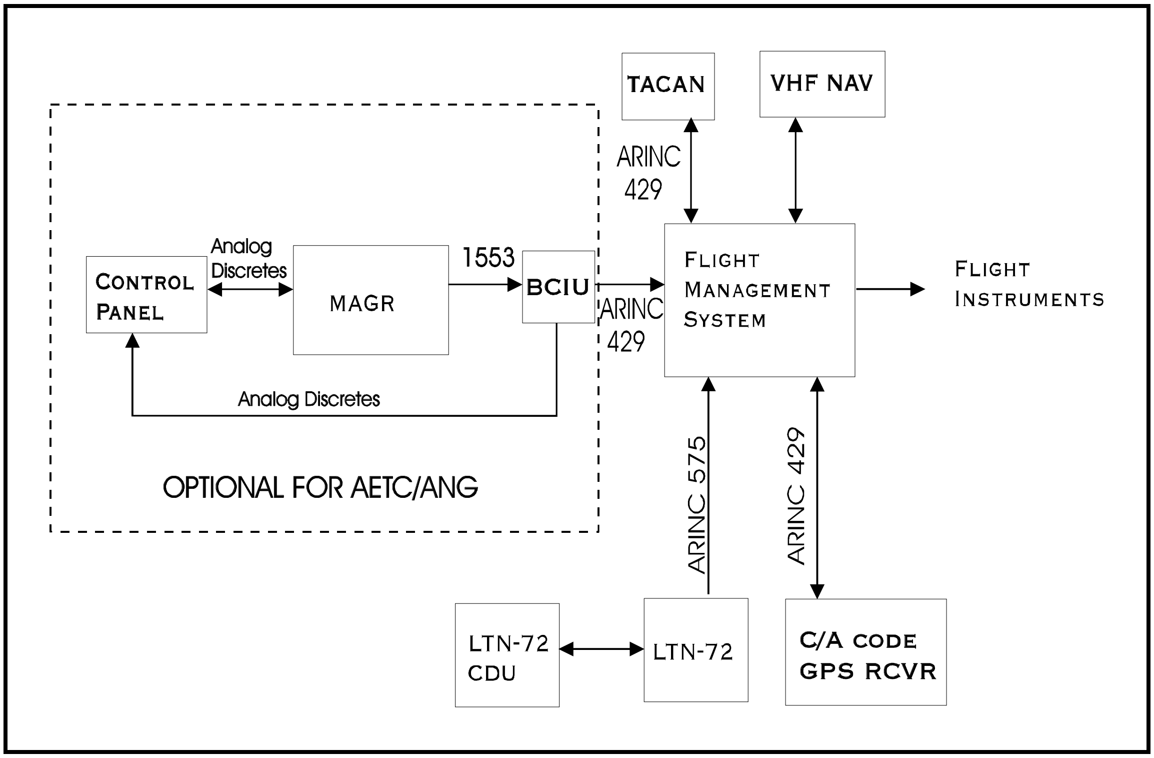


Figure 10. *Design 6 Block Diagram*

3.5.2 Design 6 Evaluation

Primary Mission Requirements: {5} This design meets all known mission requirements.

Inertial Navigation System: {4} This design integrates the existing LTN-72 INS (a medium accuracy INS) into the avionics system.

Upgrade to GPS Sole Means: {5} The C/A code receiver provides an easy upgrade path to meet future FAA requirements, therefore we anticipate a low cost to upgrade this avionics package to a "GPS Sole External Reference" avionics package when/if required.

TSO/GIG Compliance: {5} This design will be TSO C-129 Class A1/B1 certified.

Pilot Vehicle Interface: {5} The FMS greatly improves the pilot vehicle interface by providing full flight management and flight planning, flight instrument interface, autopilot coupling, and communications controls.

Technical Risk: {4} The technical risk associated with this design is moderate to low because it consists of off-the-shelf items (except the BCIU).

Schedule Impact: {5} No impact to the GPS integration schedule is anticipated.

<u>Reliability:</u> {4} This design features redundant GPS receivers. Commercial GPS receivers with 10,000 hour MTBF are available. The FMS MTBF is estimated to be 7000 hours.

<u>Cost:</u> {5} This design is expected to cost much less than the FY95 PBS allocation. Redundant GPS receivers and FMSs could possibly be provided within the FY95 PBS.

<u>Receiver:</u> {5} The MAGR is an approved JPO, P/Y code receiver. Its use does not require any waiver requests. However, a waiver is required if the MAGR is not used.

3.7 Design Assessment

Table 4 summarizes the outcome of the design evaluation process. Design 6 scored highest of the design options.

Table 4. *Design Evaluation Matrix*

Evaluation Factor	Wt	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Primary Mission Requirements	16	64	64	48	64	64	80
Inertial Navigation System	15	60	60	60	60	60	60
Upgrade to Sole External Reference	14	28	28	28	28	28	70
TSO/GIG Compliance	13	52	52	26	52	52	65
Pilot Vehicle Interface	12	48	48	36	48	60	60
Technical Risk	8	24	40	40	16	32	32
Schedule	7	28	35	35	14	35	35
Reliability	7	28	21	14	21	21	28
Cost	5	25	25	25	25	25	25
Receiver	3	9	15	15	15	15	15
SCORE		**366**	**388**	**327**	**343**	**392**	**470**

4. COMPONENT ANALYSIS AND PHYSICAL INTEGRATION

Based on the design rating criteria and weighting, Design 6 is the best solution. In this chapter, we will determine which FMS best fits the needs of the T-43 and discuss the physical integration. The Universal Navigation UNS-1B, UNS-1M, and Global Wulfsberg GNS-X flight management systems will be considered for selection.

4.1 Flight Management System Selection

4.1.1 UNS-1B

The UNS-1B consists of three components: a cockpit mounted Control Display Unit (CDU), a remotely mounted Navigation Computer Unit (NCU), and a data loader (mounted or portable).

The NCU has ARINC 429 (high and low speed), ARINC 561, ARINC 571 and RS422 digital output capability along with ARINC 429, ARINC 571, ARINC 575 and RS422 digital input capability. ARINC 407 three-wire synchro and separate two-wire analog outputs are also provided along with a complement of conventional valids and discretes for external system status. The long range and short range navigation inputs to the UNS-1B FMS are summarized below :

Five (5) long range navigation (LRN) ports exist in any of the following combinations :

- GPS - maximum of two
- INS - maximum of three
- Omega/VLF Sensor System (OSS) - maximum of two
- Loran C Sensor System (LCS) - maximum of one
- Radio Reference Sensor (RRS) - maximum of one
- Airborne Flight Information System (AFIS) - maximum of one

Three short range navigation ports exist in any of the following combinations :

- DME Distance Information - maximum of one
- VOR Bearing Information - maximum of one

The NCU provides intelligent mixing of navigational data from its multiple sensor inputs to provide the pilot with one Best Computed Position (BCP). The BCP is derived from an internal Kalman Filter which takes into account inputs from all the available sensors.

The UNS-1B FMS can support the following INSs (* UNS-1B can control):

- Delco Carousel IV and VI*
- Honeywell Laseref*/Lasernav
- Honeywell GPIRU*

- Litton LTN-72, 72RL
- Litton LTN-90*
- Litton LTN-92*
- Litton LTN-100*

The Control Display Unit has the following key specifications :

- Color display with 5 inch diagonal CRT
- Faceplate : Grey or Black
- Power : Input from the NCU
- Panel Lighting : 5 or 28 VDC
- RTCA Requirements : DO-160B Environmental Categories : A2D2/A/SKP/XXXXXXZAAZZ
- Size:
  - Height 6.375 in. (1.875 in. more than the UNS-1 CDU)
  - Width   5.75 in.
  - Depth   7.88 in.
- Weight : 7.8 lbs.

The NCU has the following key specifications :

- Power : 27.5 VDC Nominal; 55 Watts Maximum; 26 VAC 400 Hz, 1VA
- RTCA Requirements : DO-160C Environmental Categories : [A2E1]-BA(BMN)E2WXXXXXZZAZZVZKXX
- Operating Temperature : -55 deg C to +70 deg C
- Operating Altitude : 70,000 ft MSL Maximum
- Cooling : Convection
- TSO : C115A (presently), C129 Class B1 (June 1994)
- Size :
  - Height 7.64 in.
  - Width   2.24 in.
  - Depth   15.23 in.
- Weight : 7.8 lbs.

The data loader has the following key specifications :

- Panel mounted or portable
- Hard wired to NCU
- Uses 3.5 inch disks
- Uses bi-directional data
- Power: 27.5 VDC Nominal, 28 Watts Nominal
- Size:
  - Height: 2.25 in
  - Width: 5.75 in (panel width)

Length: 7.58 in

- Weight: 3.5 lbs

4.1.2 UNS-1M

The UNS-1M is a fully integrated navigation management system designed to provide the pilot with centralized control for the aircraft's navigation sensors. This unit consists of a flat panel liquid crystal display, alphanumeric and function keys, a C/A code GPS sensor and master computer, all housed in a single cockpit panel/pedestal Dzus mounted box.

The UNS-1M Nav Data Base (Jeppesen) is contained in a flash memory card which is inserted into the front of the CDU. The database is updated every 28 days. This database contains 80,000 waypoints and navaids.

The UNS-1M has ARINC 429 (high and low speed), ARINC 561 and ARINC 571 digital output capability along with ARINC 429 (high and low) digital input capability. The UNS-1M can use OMEGA/VLF, LORAN-C, GPS sensors (external), scanning DMEs, and inertial inputs. The internal GPS card inputs are always used as primary even if an external GPS receiver is connected to one of the 3 available LRN inputs. If an external GPS P/Y-Code receiver needs to be used as the primary, the pilot must manually disable the internal GPS card inputs via the CDU.

The UNS-1M can support the following INSs (* UNS-1M can control):

- Delco Carousel IV and VI*
- Honeywell Laseref*/Lasernav
- Honeywell GPIRU*
- Litton LTN-72, 72RL
- Litton LTN-90*
- Litton LTN-92*
- Litton LTN-100*

The UNS-1M has the following key specifications :

- Active Matrix LCD Flat Panel
- Faceplate : Grey or Black
- Power : 19 to 32 VDC, 27.5 VDC Nominal; 35 Watts maximum; 26 VAC 400 Hz
- Panel Lighting : 5 or 28 VDC
- RTCA Requirements : DO-160C Environmental Categories : [A1D1]-BA(BMN)XXXXXXZZAZZVZA3E3XX
- TSO : C115A; C129 Class C4 (presently), C129 Class A1 (September 1994)
- Size:
    - Height 4.5 in.
    - Width 5.75 in.
    - Depth 9.5 in.
- Weight : Approximately 7.0 lbs.

4.1.3 GNS-X

The GNS-X consists of three components: a cockpit mounted Control Display Unit (CDU), a remotely mounted Nav Management Unit (NMU), and a data loader (mounted or portable).

The NMU has ARINC 429 (high and low speed), ARINC 561, ARINC 571 and RS-422 digital output capability along with ARINC 429, ARINC 571, ARINC 575 and RS-422 digital input capability. ARINC 407 three-wire synchro or four-wire analog outputs are also provided along with a complement of conventional valids and discretes for external system status. The long range and short range navigation inputs to the GNS-X FMS are summarized below :

Three (3) long range navigation (LRN) ports exist in any of the following combinations :

- GPS maximum of one
- INS maximum of one
- Omega/VLF Sensor System (OSS)
- Loran C Sensor System (LCS)
- Radio Reference Sensor (RRS)
- Airborne Flight Information System (AFIS)

Three short range navigation ports exist in any of the following combinations :

- DME Distance Information - maximum of one
- VOR Bearing Information - maximum of one

The NMU provides intelligent mixing of navigational data from its multiple sensor inputs to provide the pilot with one Best Computed Position (BCP). The BCP is derived from an internal Kalman Filter which takes into account inputs from all the available sensors.

The GNS-X FMS can support the following INSs (* GNS-X can control):

- Delco Carousel IV and VI
- Honeywell Laseref*/Lasernav
- Honeywell GPIRU*
- Litton LTN-72, 72RL
- Litton LTN-92
- Litton LTN-100*

The Control Display Unit has the following key specifications :

- Color display with 5 inch diagonal CRT
- Power : Input from the NMU
- Panel Lighting : 5 or 28 VDC
- RTCA Requirements : DO-160B Environmental Categories : A2D2/A/SKP/XXXXXXZAAZZ

- Size:

  Height 7.13 in.
  Width 5.75 in.
  Depth 9.17 in.
- Weight : 7.8 lbs.

The NMU has the following key specifications :

- Power : 28 VDC Nominal; 3.7 Amps Maximum; 26 VAC 400 Hz, 3.0 VA
- RTCA Requirements : DO-160C Environmental Categories : [A2E1]-BA(BMN)E2WXXXXZZAZZVZKXX
- Operating Temperature : -55 deg C to +70 deg C
- Operating Altitude : 70,000 ft MSL Maximum
- Cooling : Convection
- TSO : C115A (presently), C129 Class A1 (December 1994)
- Size :

  Height 7.50 in.
  Width 2.75 in.
  Depth 15.10 in.
- Weight : 8.75 lbs.

The data loader has the following key specifications :

- Panel mounted or portable
- Hard wired to NCU
- Uses 3.5 inch disks
- Uses bi-directional data
- Power: 28 VDC Nominal, 0.35 Amps Nominal
- Size:

  Height 2.50 in
  Width 5.00 in (panel width)
  Length 6.375 in
- Weight: 3.0 lbs

4.1.4 FMS Evaluation

Table 5 summarizes the FMS selection criteria.

Table 5. *FMS Selection Criteria*

Criteria	Score				
	1	2	3	4	5
TSO C-129 Status	Not capable of providing the data required for use in a TSO C-129 avionics system	Plans for demonstrating TSO C-129 compliant data, however required testing has not been completed	FAA verification of TSO C-129 A-1 or B-1 compliance is pending	The GPS receiver is currently used in a TSO C-129 B-1 certified avionics system.	The GPS receiver is embedded in a TSO C-129 A-1 certified avionics system
Program Memory	< 128K memory	128 - 256K	256 - 512 K	512K - 1 M	> 1 M
Digital Interfaces	No ARINC 429 or MIL STD 1553 < 5 discretes	ARINC 429 or MIL STD 1553 5 - 10 discretes	ARINC 429 or MIL STD 1553 10 - 15 discretes	ARINC 429 and MIL STD 1553 15 - 20 discretes	ARINC 429 and MIL STD 1553 > 20 discretes
Analog Interfaces	SDC required	Optional analog interface can be added at little or no cost	Standard analog flight instrument interface. No servo outputs, no Autopilot Outputs	Standard analog flight instrument and autopilot outputs, no servo outputs	Existing analog interface to flight instruments with autopilot and servo outputs.
Flight Planning	No off aircraft flight planning. Manual entry of waypoints in cockpit only.	Off aircraft and on aircraft flight planning for "user defined" waypoints, no special handling of "validated" waypionts.	Off aircraft and on aircraft flight planning. User defined and validated waypoints available.	Off aircraft and on aircraft flight planning. User defined and validated waypoints available. Validated SIDS and STARS available for each runway by name.	Off aircraft and on aircraft flight planning. User defined waypoints, SIDS, and STARS available. Validated waypoints, routes, and intersections, available. Validated SIDS and STARS available for each runway by name.
GPS Approaches	No GPS based approaches supported		Supports GPS based RNAV approaches		Supports GPS based RNAV and Overlay Approaches. Provides "glideslope" like vertical steering during GPS approaches. Displays will support precision approach without further modification

Kalman Filter	No Kalman filter	Kalman Filter used, but nav solution is weighted toward existing radio-navigation aids.	Kalman Filter used, nav solution is heavily weighted toward GPS, other sensors limited to existing radio-navigation aids, no INS capability. Does not weight P/Y position higher than C/A.	INS used but not modeled, recognizes P/Y code vs C/A (GPS weight based on EHE)	Full INS model, recognizes, P/Y code vs C/A
# of Long-Range Nav Ports Available	< 2	2 - 3	3 - 4	5	> 5
Data Loader	No Data Loader available.	Standard data loader cartridge holds less than 1 Mb. Planner for user defined waypoints only, Not AFMSS compatible	Standard data loader cartridge holds between 1 and 2 Mb. Planner for validated waypoints and user defined waypoints. AFMSS compatible.	Standard data loader cartridge holds between 2 and 4Mb. Planner for validated waypoints and user defined waypoints. AFMSS and Jeppesen compatible.	Standard data loader cartridge holds more than 4Mb. Planner for validated waypoints and user defined waypoints. AFMSS and Jeppesen compatible.
Frequency Management	No frequency management		Minimal frequency management capability, limited to a single vendor radio type.		Robust frequency management, capable of controlling radios from all major manufacturers.
GPS Mechanization	The FMS does not support GPS navigation	The FMS supports navigation from a single GPS receiver		The FMS supports navigation from two different GPS receivers (GPS-1 or GPS-2)	The FMS supports navigation inputs from GPS-1, GPS-2, or GPINS (embedded GPS/INS)
Standard Mission Support Software	No applicable software standard on unit	Integrates INS or LTN-72 but does not control either	Integrates both GPS and LTN-72, but does not control either.	Integrates both GPS and LTN-72 and controls either GPS or LTN-72 (not both)	Integrates and controls both GPS and LTN-72.
Power Requirements	> 75 W	50 - 75 W	40 - 49 W	35 - 39 W	< 35 W
Pilot-Vehicle Interface	Multi-character keys, < 5 lines, NVG/Mono	Multi-character keys, rotary, 5-7 lines, <22 char/line NVG/Mono	Single-character keys, soft keys, 8 lines, 22 char/line NVG/Mono	Single-character keys, soft keys, 8 lines, 22-24 char/line NVG/Mono	Single-character keys, soft keys, 8 lines, >24 char/line NVG/Mono
Risk	No previous GPS integrations	Previous GPS integrations	Previous GPS/INS integrations or 737 integrations	Previous GPS integrations with LTN-72 and 737 integrations	Previous MAGR integrations with LTN-72 and 737 integrations
Cost	> $100 K	$ 80 K - $ 100 K	$ 60 K - $ 80 K	$ 40 K - $ 60 K	< $ 40 K

Table 6 summarizes the outcome of the FMS evaluation. The UNS-1B is the most capable of the three FMSs, however, the evaluation did not consider the requirement for redundancy in the GPS navigation system. When this requirement is considered, cost becomes a more important factor in choosing the FMS. The UNS-1B lists at $43,000 per unit and the GNS-X lists at $61,400 per unit. The UNS-1M, which includes an embedded GPS receiver, provides the most capability per dollar with a list price of $20,000 per unit.

Table 6. *FMS Evaluation Matrix*

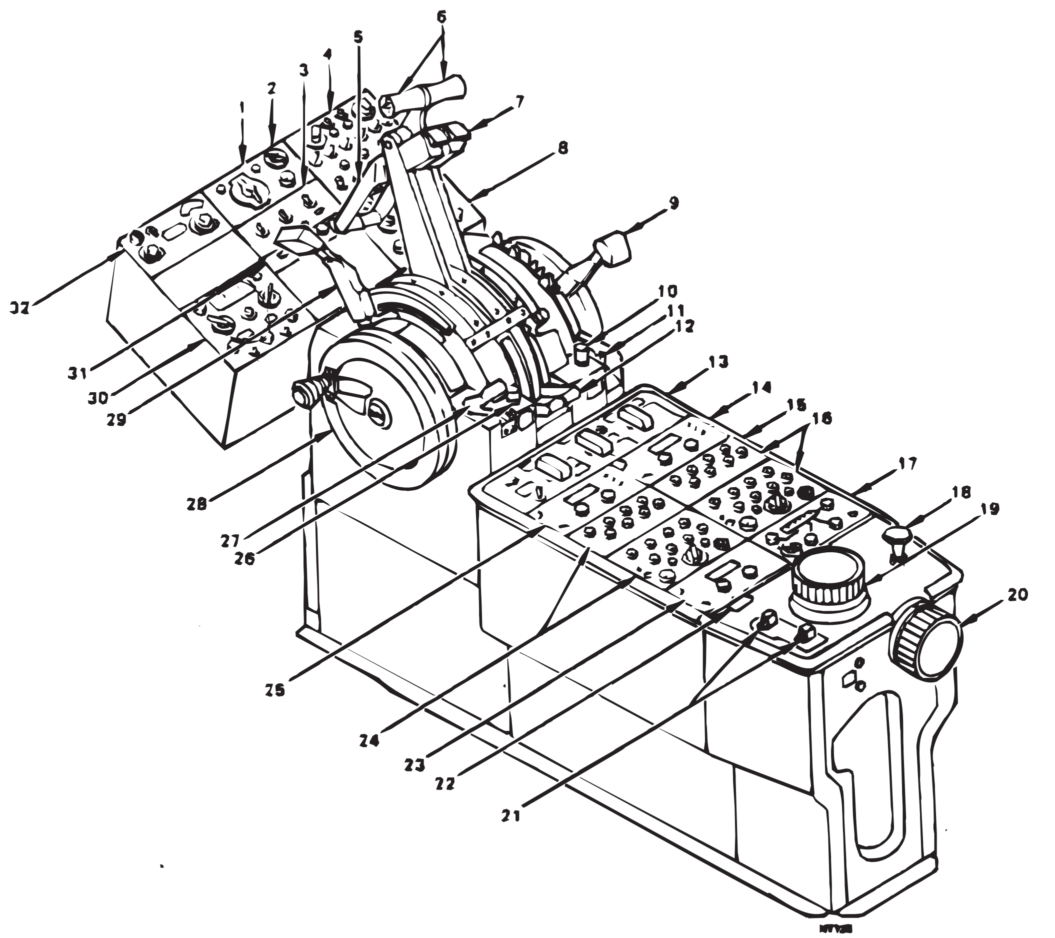
Criteria	UNS-1B	UNS-1M	GNS-X
TSO C-129 Status	3	3	3
Program Memory	4	3	4
Digital Interfaces	3	3	3
Analog Interfaces	4	4	4
Flight Planning	5	1	5
GPS Approaches	5	5	5
Kalman Filter	4	4	4
# of Long-Range Nav Ports Available	5	2	2
Data Loader	3	4	4
Frequency Management	3	3	5
GPS Mechanization	5	5	2
Standard Mission Support Software	4	4	4
Power Requirements	2	4	1
Pilot-Vehicle Interface	5	3	5
Risk	3	3	3
Cost	4	5	3
Total	**62**	**56**	**57**

4.2 Physical Integration

4.2.1 Space Availability and Allocation

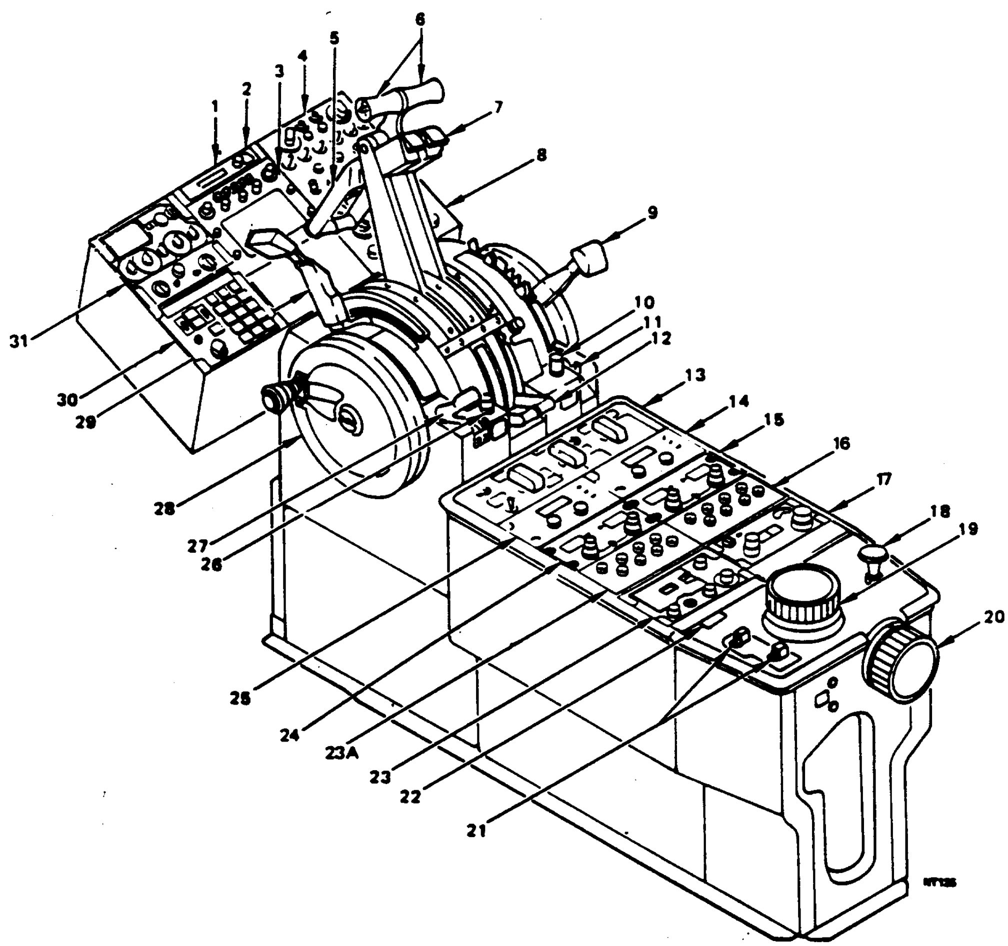
The UNS-1M is a single LRU that contains the navigation computer, control display unit and GPS receiver, so only cockpit space is needed for the trainer aircraft. The best location for the UNS-1M is the control stand between the pilot and copilot, just behind the fire control panel as shown in Figures 11 and 12. The VHF nav and comm radio controls would be moved to accomodate the dual UNS-1Ms or these radios would be controlled by the UNS-1Ms.

The pilot's digital DME Slave Indicator can be located just to the left of the pilot's HSI, under the RMI and the copilot's can be located just to the left of the HSI, under the RMDI. On the transport aircraft, the MAGR and BCIU can be located on Electronics racks E-1, E-2, or E-3.



1 FORWARD ELECTRONIC PANEL
2 TACAN CONTROL PANEL
3 UHF & IFF ANTENNA SWITCHING/ALTITUDE REPORTING
4 IFF/ATC TRANSPONDER CONTROL PANEL
5 REVERSE THRUST LEVERS
6 THROTTLES
7 GO AROUND SWITCHES
8 NO. 2 UHF RADIO CONTROL PANEL
9 FLAP LEVER
10 STABILIZER TRIM LIGHT
11 STABILIZER TRIM CUTOUT SWITCHES
12 START LEVERS
13 FIRE CONTROL PANEL
14 NO. 2 VHF NAV RADIO CONTROL PANEL
15 AFT ELECTRONIC PANEL
16 COPILOT'S INTERPHONE PANEL
17 HF RADIO CONTROL PANEL
18 STABILIZER BRAKE RELEASE
19 RUDDER TRIM WHEEL
20 AILERON TRIM WHEEL
21 CONTROL STAND LIGHTING SWITCHES
22 CONTROL CABIN DOOR LOCK SWITCH/LIGHT
23 VHF COMM RADIO CONTROL PANEL
24 PILOT'S INTERPHONE PANEL
25 NO. 1 VHF NAV RADIO CONTROL PANEL
26 PARKING BRAKE LIGHT
27 PARKING BRAKE LEVER
28 STABILIZER TRIM WHEEL
29 SPEED BRAKE LEVER
30 NO. 1 UHF RADIO CONTROL PANEL
31 CABIN PRESS BARO SET PANEL
32 ADF CONTROL PANEL

Figure 11. *Trainer Aircraft Control Stand*



1 FORWARD ELECTRONIC PANEL
2 CABIN PRESS BARO SET PANEL
3 WEATHER RADAR PANEL
4 IFF/ATC TRANSPONDER CONTROL PANEL
5 REVERSE THRUST LEVERS
6 THROTTLES
7 GO AROUND SWITCHES
8 NO. 2 INS CDU
9 FLAP LEVER
10 STABILIZER TRIM LIGHT
11 STABILIZER TRIM CUTOUT SWITCHES
12 START LEVERS
13 FIRE CONTROL PANEL
14 NO. 2 VHF NAV RADIO CONTROL PANEL
15 NO. 2 VHF COMM RADIO CONTROL PANEL
16 COPILOT'S INTERPHONE PANEL
17 ADF CONTROL PANEL
18 STABILIZER BRAKE RELEASE
19 RUDDER TRIM WHEEL
20 AILERON TRIM WHEEL
21 CONTROL STAND LIGHTING SWITCHES
22 CONTROL CABIN DOOR LOCK SWITCH/LIGHT
23 TACAN CONTROL PANEL
23A PILOT'S INTERPHONE PANEL
24 NO. 1 VHF COMM RADIO CONTROL PANEL
25 NO. 1 VHF NAV RADIO CONTROL PANEL
26 PARKING BRAKE LIGHT
27 PARKING BRAKE LEVER
28 STABILIZER TRIM WHEEL
29 SPEED BRAKE LEVER
30 NO. 1 INS CDU
31 UHF CONTROL PANEL

Figure 12. *Transport Aircraft Control Stand*

5. RECOMMENDATIONS

Design 6 combines the strengths of the commercial C/A code receiver (SPS accuracy, RAIM, FAA certification, future GPS Sole Means) with the strengths of the military P/Y code receiver (S/A and A-S). This design meets all the mission requirements of both the navigation trainer and transport aircraft using a common configuration. However, we recommend putting MAGR on only the transport aircraft, since P/Y code capability is not required on the trainer aircraft. This will require a waiver from the Assistant Secretary of Defense for Command, Control, Communication and Intelligence for the use of SPS or non-standard GPS UE.

The need for redundancy in the GPS navigation system makes cost an important factor in deciding how best to meet the T-43 mission requirements. The Universal Navigation UNS-1M flight management system, which includes an embedded GPS receiver, provides the most capability per dollar with a list price of $20,000 per unit. If redundancy is a hard requirement, we recommend the UNS-1M or its follow-on.

No clear guidance has been issued by either the FAA or DOD on the requirements for redundancy in the navigation system after the traditional navigation aids are eliminated. If redundancy in the GPS navigation system is not a requirement or if the LTN-72 provides sufficient redundancy, we recommend the Universal Navigation UNS-1B or its follow-on. By the time the T-43 begins procuring GPS equipment, there may be several options for P/Y code GPS receiver cards as well as C/A code receivers, which are certified to TSO C-129 Class A1 and compatible with the UNS-1B.

We recommend that a qualified test organization perform rigorous testing of the UNS-1M embedded GPS receiver as well as the MAGR/BCIU/UNS-1M system to ensure that performance requirements are met.

APPENDIX A. REFERENCES

The following documents contain technical information which is relevant when integrating GPS on USAF aircraft.

A.1 Applicable Documents

These documents contain specific interface definitions for GPS user equipment. The information in these documents is directly applicable to the candidate integrations of GPS into the T-43.

a. ICD-GPS-059, Revision C *GPS User Equipment Interface Control Document for Mil-Std 1553 Multiplex Bus Interface*, 21 Sep 1993

b. ICD-GPS-073 *GPS User Equipment Interface Control Document for Digital Flight Instruments ARINC 429 Interface*, 12 July 1990

c. ICD-GPS-070 *GPS User Equipment Interface Control Document for Arinc Type Inertial Navigation Systems*, 11 April 1990

d. MIL-STD-1553B *Aircraft Internal Time Division Command/Response Multiplex Data Bus*, 21 September 1988

f. *USAF Aircraft GPS Integration Guidelines (GIG)*, 5 August 1993

g. *Technical Description UNS-1M Navigation Management System, Revision No 1*, 10 August 1993

h. *Systems Requirement Document for an Embedded Global Positioning System (GPS) Receiver in an Inertial Navigation System (INS) EGI*, ASC/SMEV, Wright-Patterson AFB, OH, 19 July 1993

i. *Operations and Maintenance Manual, Satellite Signals Navigation Set AN/PSN-11*, TO 31R4-2PSN11-1, Rockwell International Corporation, 1 September 1993

j. *Systems Integration Cost Analysis Model II (SICAM II) Users Guide*, TR-9238-017-03, August 1993

A.2 Reference Documents

The following documents contain general policy information which was used in evaluating the potential designs included in this study.

a. *CJCS Master Navigation Plan of 11 Sep 1992*

b. *1992 Federal Radio Navigation Plan*

c. *Approval of Area Navigation Systems for Use in the U.S. National Airspace System (DOT/FAA Advisory Circular 90-45A)*

d. *Minimum Operational Performance Standards for Airborne Navigation Equipment Using Multi-Sensor Inputs (RTCA/DO-187)*

e. *U.S. Standard Terminal Instrument Procedures (AFM 55-9, OPNAV Inst 3722.16C, TM 95-226, or CG 318 Chng 12)*

f. *Airworthiness Approval of Multi-Sensor Navigation Systems for Use in the U.S. National Airspace System (NAS) (FAA Advisory Circular 20-130A)*

g. *Airworthiness Approval of Vertical Navigation (VNAV) Systems for Use in the U.S. National Airspace System (NAS) (FAA Advisory Circular 20-129)*

h. RTCA/DO-178B December 1992

i. RTCA/DO-208 July 1991

j. *ARINC Specification 424-9 Navigation System Data Base*

k. FAA Technical Standard Order (TSO) C129 12 December 1992

l. DoD GPS Security Policy August 1992

APPENDIX B. COST ESTIMATE

B.1 Introduction

This appendix provides a rough order of magnitude cost estimate for incorporation of GPS user equipment on the T-43 aircraft. Costs for each of the design options are presented to assess the relative cost of each design.

The costs are estimated for the six avionics configurations documented in Chapter 3 of the study. We used the System Integration Cost Analysis Model (SICAM) version 2.2, which was developed by Management Consulting and Research, Inc. for the JPO, to develop the estimates. The cost risk factor is approximately 25% of cost for all costs in the study.

B.2 Assumptions

We are assuming a single set of GPS equipment per aircraft. The requirement for redundancy in the GPS navigation system would double the estimated recurring costs. Included are estimates for spares which are estimated at 10% of the Group B hardware cost estimates. Design 5 assumes the commercial FMS is the UNS-1B. Design 6 assumes the commercial FMS is the UNS-1M and optional MAGRs (and associated LRUs) for the two transport aircraft only. Table B-1 lists the hardware prices used for this estimate. Designs 5 and 6 assume the ARINC 429 HSI is the Bendix-King KPI 553A. Contractor labor rate of $79.83 per hour is assumed for the time frame of the modification work.

Table B-1. *Hardware Pricing Used For This Estimate*

LRU	UNIT PRICE
FRPA	1,000
AE-4	3,300
Standard CDU	10,000
MAGR	22,000
RCVR-3A	36,300
Data Loader	11,000
Smart CDU	25,000
Smart CDU w/Embedded GPS	30,000
Signal Data Converter (SDC)	20,500
EGI	110,000
FMS (UNS-1B)	43,000
FMS w/Embedded GPS (UNS-1M)	20,000
C/A Code Receiver	17,000
BCIU	12,000
HSI	10,300

We are assuming no software development required. We are also assuming all equipment is off-the-shelf, therefore no tooling costs are assumed. For Design 4, we are assuming that EGI control software is already developed. For Designs 5 and 6, we are assuming that all BCIU software is already developed for the C-21. For Design 4, we are assuming the cost of missionization is included in the $110,000 price of the EGI.

The flight testing program is assumed to consist of 50 total hours of flight at a cost of $6000 per hour. In addition, test support consisting of data reduction and analysis at a cost of $1500 per hour of flight.

B.3 Work Breakdown Structure (WBS)

The WBS refers to a listing of all of the separately costed elements involved in the GPS integration. However, not all cost elements are included. The areas not addressed include: warranties, program management, and support equipment.

B.3.1 Non-Recurring Cost Elements

Non-recurring costs are those which are not dependent on how many aircraft are modified and only occur one time. Non-recurring costs are broken down in the following elements: Engineering, Software, Prototype, Test, Trial Installation, Tooling, Kit Proofing, and Data.

B.3.1.1 Engineering

Engineering includes the effort and costs expended in the study, analysis, design, development, evaluation and redesign of hardware to install the Group B equipment on the aircraft. This includes the preparation of specification, parts lists, wiring diagrams, technical coordination between engineering and manufacturing, supplier coordination between engineering and manufacturing, supplier coordination, test planning and scheduling, analysis of test results, and data reduction. Engineering also includes the determination and specification of requirements for reliability, maintainability, and quality control.

B.3.1.2 Software

Software costs include the effort and costs expended in the design, development, test, and evaluation of all computer code used (both new and modified) to interface the Group B equipment being installed with the existing aircraft systems.

B.3.1.3 Prototype

A prototype is primarily a hand-built original or model of a final product that is subject to full service test. The only differences between the operational prototype model and the production model will be those identified as a result of testing.

B.3.1.4 Test

The test costs include engineering and manufacturing support activities to provide component, subsystem, and system verification by simulated or real operational use of portions or total end items to determine the acceptability of designs and requirements.

B.3.1.5 Trial Installation

This is the cost of the first attempt at locating units of equipment in place, ready for operation, and connecting the necessary services such as electricity, cooling, data interface, and others.

B.3.1.6 Tooling

This includes the costs for all jigs, dies, fixtures, molds, patterns, special gauges, other equipment and manufacturing aids, and replacements thereof, acquired or manufactured for use in the performance of a contract. These tools are of such specialized nature that, without substantial modification or alteration, their use is limited to the particular effort for which they were developed.

B.3.1.7 Kit Proofing

This includes all costs for the verification of the first production kit based on the specifications determined from the hand-built prototype. This first complete kit must show proof that it meets all requirements in order to continue the manufacturing process for the remaining quantity of kits.

B.3.1.8 Data

This includes all costs for the graphic and written information, whether technical or non-technical. Data may be in the form of drawings, documents, time-compliance technical orders (TCTOs), technical orders (TOs), reports, letters, machine printouts, brochures, and other applicable forms not specifically mentioned. Data is usually controlled by the contract data requirments list (CDRL) attached to the contract.

B.3.2 Recurring Cost Elements

Recurring costs are those which are dependent on how many aircraft are modified. Recurring costs are broken down in the following elements: Group A Kit Theoretical First Unit Cost, Installation Manhours, and Group B LRU Average Unit Cost.

B.3.2.1 Group A Kit

These costs are associated with manufacturing the Group A Kit. The Group A Kit includes all brackets, cables, wiring harnesses, connectors, and structural items required to install the Group B equipment. The Group A Kit first unit cost is calculated assuming a 95% learning curve on the historical production of Group A kits.

B.3.2.2 Installation Manhours

This represents the average cost to install the Group A equipment into the host aircraft. This cost is calculated by multiplying the estimated average installation hours by the weighted average wage rate for a maintenance technician at a contractor facility.

B.4 Cost Summary

Table B-2 summarizes the Group B hardware costs on a per aircraft basis.

Table B-2. *Group B Hardware Cost Estimate ($K per aircraft)*

LRU	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	DESIGN 5	DESIGN 6
CDU/FMS	25.0	25.0	10.0	25.0	43.0	20.0
GPS Receiver	5.0	22.0	36.3	110.0	22.0	0
Antenna Electronics	3.3	3.3	3.3	3.3	0	0
GPS Antenna	1.0	1.0	1.0	1.0	0	0
Data Loader	11.0	11.0	11.0	11.0	0	0
SDC	20.5	20.5	20.5	20.5	n/a	n/a
BCIU	n/a	n/a	n/a	n/a	12.0	12.0
HSI	n/a	n/a	n/a	n/a	20.6	20.6
Optional MAGR	n/a	n/a	n/a	n/a	n/a	22.0
Miscellaneous	n/a	n/a	n/a	n/a	1.2	1.2
TOTAL	65.8	82.8	82.1	170.8	98.8	75.8

Table B-3 summarizes the Group B hardware costs on a total program, assuming 14 aircraft.

Table B-3. *Group B Hardware Cost Estimate ($K)*

LRU	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	DESIGN 5	DESIGN 6
CDU/FMS	350.0	350.0	140.0	350.0	602.0	280.0
GPS Receiver	70.0	308.0	508.2	1540.0	308.0	0
AE-4	46.2	46.2	46.2	46.2	0	0
FRPA	14.0	14.0	14.0	14.0	0	0
Data Loader	154.0	154.0	154.0	154.0	0	0
SDC	287.0	287.0	287.0	287.0	n/a	n/a
BCIU	n/a	n/a	n/a	n/a	168.0	24.0
HSI	n/a	n/a	n/a	n/a	288.4	288.4
Optional MAGR (2)	n/a	n/a	n/a	n/a	n/a	44.0
Miscellaneous	n/a	n/a	n/a	n/a	16.8	2.4
TOTAL	921.2	1159.2	1149.4	2391.2	1383.2	638.8

Table B-4 summarizes the anticipated total cost for the entire GPS integration program.

Table B-4. *Program Cost Estimate ($K)*

COST ELEMENT	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	DESIGN 5	DESIGN 6
NON-RECURRING						
Engineering	118.1	118.1	118.1	118.1	234.0	253.3
Software	0	0	0	0	0	0
Prototype	30.7	33.5	30.8	31.8	19.7	22.5
Test	432.5	432.5	432.5	432.5	432.5	432.5
Trial Installation	16.8	21.9	16.8	21.9	47.5	52.6
Tooling	0	0	0	0	0	0
Kitproof	9.4	11.3	9.4	11.3	11.3	13.2
Data	47.0	53.1	47.0	52.0	132.1	150.1
RECURRING						
Group A Kit	32.5	34.3	32.5	36.1	34.3	36.1
Install Manhours	318.8	322.9	318.8	327.1	322.9	327.1
Group B Hardware	921.2	1159.2	1149.4	2391.2	1383.2	638.8
Spares	92.1	115.9	114.9	239.1	138.3	63.9
TOTAL	2019.1	2302.7	2270.2	3661.1	2755.8	1990.1

APPENDIX C. NAVIGATION TRAINING STATION DESIGN

The navigation trainer aircraft are each configured with 12 student training stations for navigator training. This appendix outlines top-level options for adding GPS to the training compartment. A GPS receiver which is controlled in the training compartment is required to fulfill this mission. The GPS navigation data must be available to the 12 student training stations on the navigation trainer aircraft. As shown in Figure 13, space is available to the right of the radar scope at each station for mounting GPS equipment.

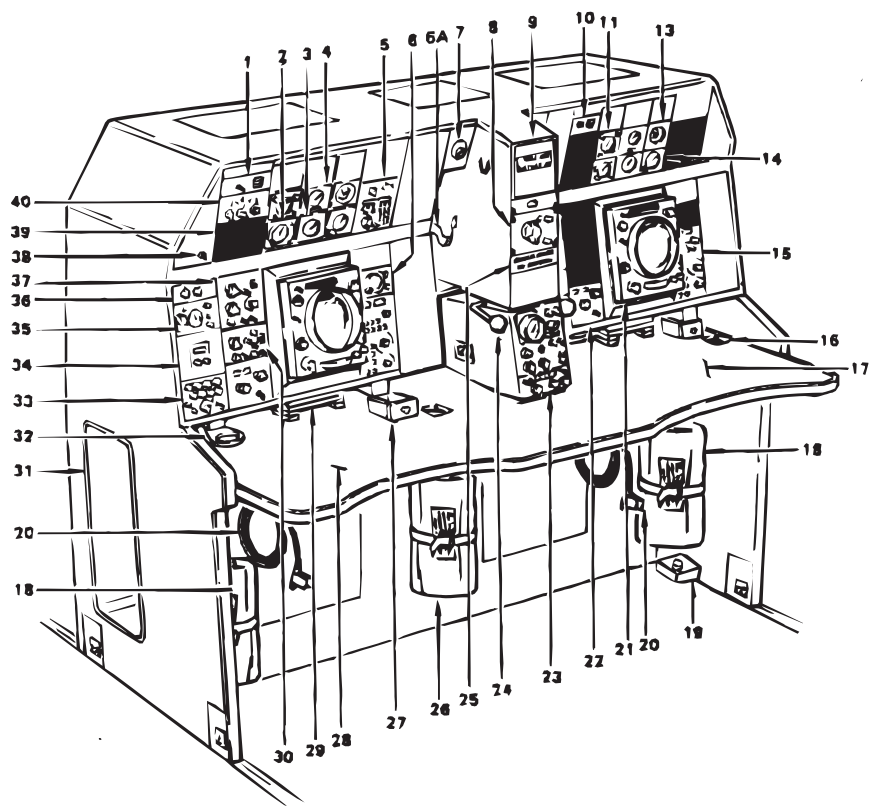


Figure 13. *Navigation Training Station*

C.1 Option 1: Precision Lightweight GPS Rececciver (PLGR)

This option proposes placing an AN/PSN-11 PLGR at each training console. PLGR is a five-channel L1 P/Y code military GPS receiver, which features selective availability/antispoofing (SA/A-S) and antijam capability. The receiver contains a PPS-SM module which allows it to be handled as unclassified when keyed. It has a four-line, liquid crystal display with integral backlighting that is Night Vision Goggle (NVG) compatible. PLGR can store up to 99 user-defined waypoints and one user-defined route consisting of ten waypoints. It can display horizontal and vertical distance, as well as angular measurements, to waypoints. The PLGR costs approximately $1200 per unit.

PLGR mounting kits are available to securely attach the PLGR units to the aircraft. PLGR will run on a 5W DC power source (9 - 32 volts), so it can be connected to 24 volt aircraft power. GPS signals can be fed into PLGR from a sextant port or externally mounted GPS antenna. Splitter amplifiers could be used to split off the GPS signal from a single antenna to numerous receivers. This would be a very simple modification to the aircraft, which could probably be done by local maintenance personnel.

C.2 Option 2: Commercial GPS Receiver

Another potential option is to place a commercial panel-mounted GPS receiver at each training console. Many very capable commercial GPS receivers are out on the market today which perform most of the functions of an entire flight management system at a very affordable price. GPS signals can be fed into the receiver from a sextant port or externally mounted GPS antenna. Splitter amplifiers could be used to split off the GPS signal from a single antenna to numerous receivers. This also would be a very simple modification to the aircraft, which could probably be done by local maintenance personnel. We would be willing to provide a market survey if AETC wishes to explore this option further.

C.3 Option 3: MAGR

This option would use one MAGR controlled at the master training station. The MAGR would feed GPS data to either repeater terminals or personal computers at each station. This option would be the most expensive option and probably provide the least amount of training value because the MAGR is controlled only at the master training station.

C.4 Personal Computer Terminals

If funding is available, each training station could be equipped with a personal computer (PC) which is fed data from a GPS receiver and the Air Data Computer. The PC can be programmed to simulate any desired navigation system or cockpit instrument based on the real-time data. The interface between the PC and the GPS receiver would be different depending on which receiver is chosen.

PLGR supports RS-232 or RS-422 interfaces, which allows GPS data to easily be fed to a PC or other instrumentation. Most commercial GPS receivers also support RS-232 or RS-422 interfaces. The MAGR primarily supports the MIL-STD-1553 interface, but also provides an RS-422 interface. Both the RS-422 and MIL-STD-1553 interfaces would require an additional interface card in the PC, while most PCs come equipped with RS-232 serial ports built in.

APPENDIX D. ACRONYMS

The following acronyms are commonly used in avionics and GPS integration:

Acronym	Definition
ACC	Air Combat Command
ADC	Air Data Computer
ADI	Attitude Director Indicator
AE-1	Antenna Electronics for CRPA GPS antenna
AE-4	Antenna Electronics for FRPA GPS antenna
AETC	Air Education and Training Command
AHRS	Attitude Heading Reference System
AFB	Air Force Base
AFPRO	Air Force Plant Representative
AFS	Air Force Station
AFSPACECOM	Air Force Space Command
AP CPLD	Auto Pilot Coupled Switch
ARINC 429	Aeronautical Radio Incorporation 429 Digital Interface
ASC	Aeronautical Systems Center (Wright-Patterson AFB, OH)
ATCS	Air Traffic Control System
BAA	Bilateral Airworthiness Agreement
Baro	Barometer
BC	Bus Controller
BDHI	Bearing Distance Heading Indicator
BIT	Built In Test
C/A Code	Coarse/Acquisition Code
CADC	Central Air Data Computer
CARP	Computed Air Release Point
CDI	Course Deviation Indicator
CDNU	Control Display Navigation Unit
CDU	Control Display Unit
CI	Course Indicator
CIGTF	Central Inertial Guidance Test Facility
CINC	Commander-In-Chief
CJCS	Chairman, Joint Chiefs of Staff
CLS	Contractor Logistics Support
CRPA	Controlled Radiation Pattern Antenna
CRT	Cathode Ray Tube
CSK	Course Set Knob
CW	Continuous Wave

DAC	Digital-to-Analog Converter
DGPS	Differential GPS
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
DOD	Department of Defense
DOT	Department of Transportation
DSN	Defense Switching Network
DT&E	Development Test and Evaluation
EEPROM	Electrically Erasable Programmable Read-Only Memory
EFIS	Electronic Flight Instrument System
EHE	Expected Horizontal Error
EHSI	Electronic Horizontal Situation Indicator
EMCON	Emission Controlled
ETE	Estimated Time Enroute
EUROCAE	European Organization for Civil Aviation Electronics
FAA	Federal Aviation Administration
fC	foot candle
FDI	Flight Director Indicator
FMECA	Failure Mode Effects and Criticality Analysis
FOM	Figure of Merit
FRP	Federal Radionavigation Plan
FRPA	Fixed Radiation Pattern Antenna
FTE	Flight Technical Error
FY	Fiscal Year
GFE	Government Furnished Equipment
GIG	Air Force GPS Integration Guidelines
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPSAS	GPS Avionic System
GPSIM	Global Positioning System Integration Module
GS	Glide Slope
HSI	Horizontal Situation Indicator
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IFC	Instrument Flight Center
IFF	Identification Friend or Foe
IFR	Instrument Flight Rules

ILS	Instrument Landing System
IMS	Integrity Monitoring System
INS	Inertial Navigation System
IOT&E	Initial Operational Test and Evaluation
JPO	GPS Joint Program Office
KT	Knot (Nautical Mile per Hour)
KYK-13	Cryptographic Key Loader for GPS Receiver
LED	Light Emitting Diode
LRU	Line Replaceable Unit
MAGR	Miniaturized Airborne GPS Receiver
MAJCOM	Major Command
MAR	Minimum Avionics Requirement
MASPS	Minimum Aviation System Performance Standard
MB	Megabyte
MCS	Master Control Station
MHz	Megahertz
MIL-STD-1553B	Military Standard 1553 Multiplex Bus
MLS	Microwave Landing System
MODE SEL	Mode Select
MSL	Mean Sea Level
MTBF	Mean Time Between Failures
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCA	National Command Authority
NCU	Navigation Computer Unit
NDB	Non-Directional Beacon
nmi	Nautical Miles
NSE	Navigation System Error
NVG	Night Vision Goggle
OC-ALC	Oklahoma City Air Logistics Center
PBS	Presidential Budget Submittal
P-code	Precision Code
PDOP	Position Dilution of Precision
PMD	Program Management Directive
PPS	Precise Positioning Service
PVI	Pilot-Vehicle Interface
PVT	Position, Velocity, Time
P/Y code	Encrypted P-code

QOT&E	Qualification Operational Test and Evaluation
QT&E	Qualification Test and Evaluation
R&M	Reliability and Maintainability
RAM	Random Access Memory
RAIM	Receiver Autonomous Integrity Monitor
RCVR	Receiver
RCVR 3A	Rockwell-Collins Receiver 3A
RDF	Radio Direction Finder
RF	Radio Frequency
RMDI	
RMI	Radio Magnetic Indicator
RMS	Root Mean Square
RNAV	Area Navigation
RNP	Required Navigation Performance
RT	Remote Terminal
RTCA	Radio Technical Commission for Aeronautics
SDC	Signal Data Converter
SEP	Spherical Error Probable
SIDs	Standard Instrument Departures
SMC	Space and Missile Center
SNU	Standard Navigation Unit
SPO	System Program Office
SPS	Standard Positioning Service
SRAM	Static Random Access Memory
STARs	Standard Terminal Arrivals
TACAN	Tactical Air Navigation
TBD	To Be Determined
TCA	Terminal Control Area
TERPs	Terminal Instrument Procedures
TSO	Technical Standing Order
TSPI	Time Space Position Information
UE	GPS User Equipment
UHF	Ultra High Frequency
UNS	Universal Navigation Systems
UPT	Undergraduate Pilot Training
USAF	United States Air Force
USAFE	United States Air Forces - Europe
UV-EPROM	Ultraviolet Erasable Programmable Read-Only Memory
UVPROM	Ultraviolet Programmable Read-Only Memory

VAC	Volts AC
V/STOL	Vertical/SHort Takeoff and Landing
VDC	Volts Direct Current
VDI	Vertical Deviation Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
VORTAC	VOR with TACAN
WGS	World Geodetic Survey
WYPT, WPT	Waypoint
Y-code	Encrypted P-code

APPENDIX E. POINTS OF CONTACT

We would like to express its appreciation to following individuals who contributed to this study:

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