Enclosure

(Ref. Technical Letter F063-L08-066)

MITRE

Center for Advanced
Aviation System Development

Terrain and Airspace Basemap Digitization

Prepared for

Dirección General de Aeronáutica Civil
Secretaría de Comunicaciones y Transportes

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1.0 Introduction

As part of MITRE's support to Mexico's Dirección General de Aeronáutica Civil (DGAC), MITRE has developed computerized terrain and airspace basemaps for the Texcoco Airport site. The basemaps also include relevant information on Toluca Airport and its surroundings. They will be used by MITRE to conduct aeronautical analyses, such as the siting of new runways, evaluations of instrument approach and departure procedures, and examinations of airspace and noise exposure.

The intent of this document is to provide the DGAC with information on the overall development of the basemaps, which constitutes the main task for the period May-July with an agreed-upon completion date of July/August 2008. A large multi-disciplinary team of experts in several fields has continuously worked on the development of the basemaps since May.

Construction of the basemaps is a very labor-intensive, but essential effort. A properly created basemap enables better control, usage and manipulation of data, more efficient and accurate analyses, and provides extensive visualization capabilities.

This document is structured as follows:

- Background
- Software and specialized computer tools
- Key data
- Methodology
- Sample images of key elements of the basemaps
- Closing remarks

2.0 Background

The basemaps provide a three-dimensional (3D) work environment within which MITRE can analyze a wide variety of important aeronautical matters, such as obstacle limitation surfaces and instrument approach and departure procedures. Additionally, the complexities of airspace analyses, procedure development, runway siting, and the sheer amount of data that must be considered necessitate the need for complete and comprehensive basemaps. Therefore, MITRE invests a great deal of time and effort in creating basemaps in order to appropriately conduct its aeronautical analyses.

Advantages of creating basemaps include, for example:

- Improved data control and management
- Maximum use of data formats (e.g., digital terrain data, images, etc.)
- Fast and efficient incorporation of new data
- Improved accuracy and flexibility
- Extensive visualization capabilities

3.0 Software and Specialized Computer Tools

MITRE makes use of a number of software and computerized tools to create its basemaps. These applications and tools are also used by MITRE to conduct many of its aeronautical analyses and to present results in a visually meaningful manner. For the Texcoco project, MITRE created two separate basemaps for use with software applications and tools that are best suited for MITRE's specific analytical purposes: AutoCAD[1] (a computer aided design platform), and MITRE's Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) tool.

The AutoCAD basemap will primarily be used for runway siting, instrument procedure development, the examination of noise exposure and other types of airport siting related tasks. The TARGETS basemap will mainly be used for the development of advanced satellite-based navigation instrument procedures, as well as for the examination of potential airspace issues. These software applications complement each other in many ways and allow for the efficient transfer and use of data.

AutoCAD is an extremely capable and powerful 3D software application and it works with other programs which utilize its capabilities. For example, MITRE uses a program called PDToolKit to develop and evaluate instrument procedures and conduct obstacle assessments. PDToolKit provides a suite of instrument procedure design tools that reside within the AutoCAD environment making full use of AutoCAD's geospatial, drawing, and 3D capabilities. Working in tandem, AutoCAD and PDToolKit allow MITRE engineers to create a 3D environment that contains all relevant aeronautical and obstacle information in order to examine and evaluate various aeronautical factors. Figure 1 shows the AutoCAD work environment being used with PDToolKit to accurately and efficiently draw a portion of an Instrument Landing System (ILS) approach procedure.

TARGETS was developed by MITRE on behalf of the United States (U.S.) Federal Aviation Administration (FAA) to study advanced Area Navigation (RNAV) concepts, such as instrument procedures based on Required Navigation Performance (RNP). These types of procedures are

[1] MITRE currently uses AutoCAD 3D Map 2008

ideal for environments where conventional procedures may not be possible due to terrain and/or airspace complications. Much like the AutoCAD basemap, the TARGETS basemap contains relevant aeronautical and obstacle information required to design and evaluate instrument procedures and examine airspace constraints.

TARGETS also has many other additional capabilities that make it ideal for developing RNP instrument approach procedures and for studying airspace issues. For example, TARGETS can be used to ensure that RNP procedures meet appropriate criteria. It can also be used to evaluate the flyability of proposed RNAV arrival and departure procedures to determine if the procedures being designed are within aircraft performance capabilities. Additionally, TARGETS has the ability to read radar track data (in the appropriate format) which can then be used to generate traffic simulations. See Figure 2. The radar track data can be modified to test and evaluate various operational scenarios to determine optimum interaction between various traffic flows to or from a single airport or between multiple airports. See Appendix A for additional information on TARGETS.

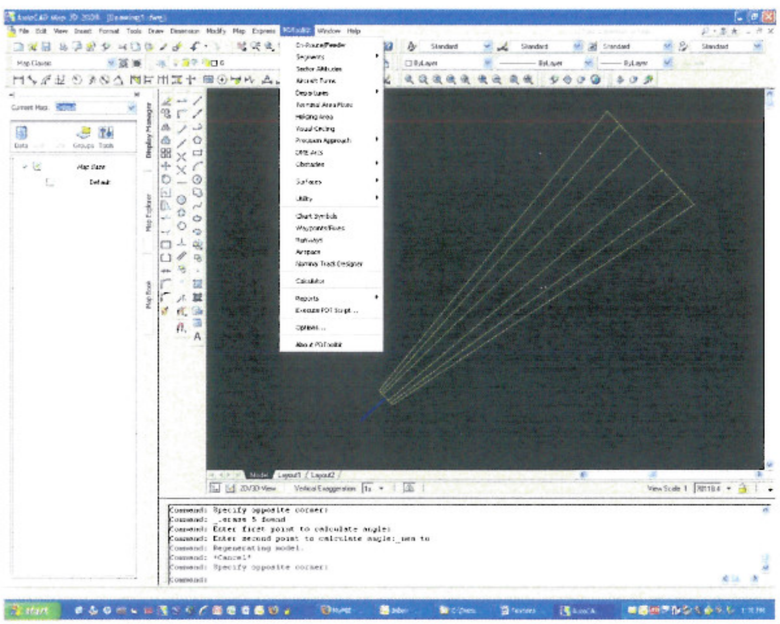

Figure 1. AutoCAD Work Environment Showing Use of PDToolKit to Draw the Final Segment of an ILS Approach

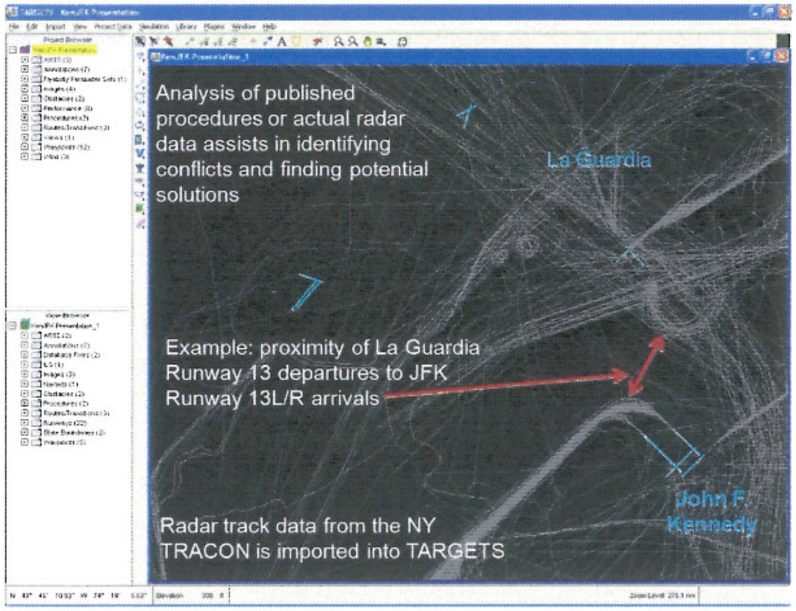

Figure 2. MITRE's TARGETS Tool Showing a Radar Track Data Example

4.0 Key Data

Current, accurate and comprehensive data are essential to any project. MITRE utilizes data obtained from a number of sources. While much of the data used for this project comes in electronic format, there is still a substantial amount that has to be entered manually. The following provides an overview of the data MITRE used in the development of the basemaps.

- **Mexican Aeronautical Information Publication (AIP)**: Mexico's AIP provides a wealth of information on runway dimensions, navigational aids, the airway structure, Special Use Airspace (SUA), instrument procedures, etc.

- **Shuttle Radar Topography Mission (SRTM) Digital Terrain Elevation Data (DTED)**: SRTM DTED is a uniform matrix of elevation values indexed to specific points on the ground and is MITRE's primary source of digital terrain data. The horizontal datum used is the World Geodetic System 1984 (WGS 84) and the vertical datum used is Mean Sea Level (MSL), as determined by the WGS 84 Earth Gravitational Model (EGM 96) geoid. SRTM DTED can be manipulated a number of ways for analytical and presentation purposes. It is important to note that SRTM DTED are terrain postings based on a fixed grid system and, therefore, it is possible that a higher elevation point between postings may not be accounted for. To compensate for this issue, terrain points (spots and peaks) obtained from topographic maps are used to identify spots and peaks that may not be included in the SRTM DTED.

- **Topographic Maps**: As mentioned in MITRE's Master Data Request document sent to the DGAC on 6 June 2008 (see Enclosure 3 to Technical Letter F063-L08-040), MITRE took the initiative, in the interest of time, to contact several map providers in Mexico and the U.S. and ordered numerous topographic maps. These maps were used to examine and identify spots and peaks to supplement the SRTM DTED.

MITRE has also requested from the DGAC a photogrammetric survey of the Texcoco area, as well as an additional survey of terrain and other obstacles (e.g., trees, buildings, towers, etc.) surrounding the site (see Enclosure 4 to Technical Letter F063-L08-040). It is however requested that no new collection is performed without previous coordination with MITRE. These data and other appropriate DGAC-provided information will be incorporated into the basemaps as they are received and reviewed by MITRE.

5.0 Methodology

The general basemap development process is described below. It is important to mention that this is not an all-inclusive description. Only some of the most important parts of the overall basemap development process are highlighted.

The development of a basemap is a very tedious and time-consuming effort that requires a systematic process to ensure that a complete and comprehensive basemap is created. The basemaps were developed by a large team of MITRE engineers over several months. During the creation of the basemaps, the MITRE team conducted numerous interdependent tasks, many of which occurred simultaneously.

Many members of the MITRE team involved in the development of the basemaps will also be conducting the actual aeronautical analyses. As a result, key MITRE engineers are now extremely familiar with the terrain and airspace environment surrounding the Texcoco Airport site and Toluca Airport, as well as the location of other surrounding airports such as Puebla and Cuernavaca.

5.1 Basemap Development Process

Prior to beginning any project the basemap has to be "setup" or prepared for the introduction of data. This includes assigning a coordinate system and establishing the units of measurement that the basemap will use. For example, the AutoCAD basemap coordinate system is based on the Universal Transverse Mercator (UTM)/WGS 84 datum. The unit of measurement is meters. The TARGETS basemap uses basically the same coordinate system. As a result, data can be easily transferred between the two basemaps.

The next step is to determine the extent of the basemap work environment that needs to be considered for the basemaps. This is an important step that requires careful planning and input from a number of specialists to ensure that the basemap work environment is large enough to be used for runway siting, procedure design, airspace, noise and other key tasks. Of course, the size of the basemap work environment dictates the amount of data that must be considered. All of this work requires close coordination and oversight in order to complete the basemaps in an efficient, accurate, and timely manner.

An important consideration for the Texcoco Airport site is the development of independent approaches to three parallel runways. The examination of independent approaches requires large amounts of airspace and obstacles to be assessed. Therefore, the extent of the basemaps work environment needed to encompass enough area to allow for the appropriate evaluation of independent approaches to three parallel runways, as well as other supporting tasks such as airspace and noise.

MITRE personnel collected relevant information from the Mexico AIP that will ultimately be of use not only for the analysis of the Texcoco Airport site, but also for the Toluca Airport work. Relevant aeronautical data within an approximate 150 km radius of the Texcoco Airport site were collected and examined. (81nm)

A large amount of relevant AIP information had to be appropriately formatted and then inserted into the basemaps. For example, WGS 84 latitude and longitude coordinate information had to be converted to the UTM coordinate system and formatted so that it could be inserted into the AutoCAD and TARGETS basemaps. SUAs and airways were also drawn in both basemaps for procedure design and airspace analysis. The entering of the AIP information into the basemaps was a laborious effort that required a great deal of diligence to ensure the data were accurate and properly formatted.

MITRE ordered and received over 70 geo-referenced 1:50,000 scale topographic maps and nine 1:250,000 scale topographic maps from INEGI that cover the entire work area and more. All of these maps provided valuable terrain information to supplement the SRTM DTED.

Using all the information mentioned above, MITRE identified and entered into the basemaps nearly 2600 spots and peaks. It is important to mention that some topographic maps contained discrepancies. This mainly involved irregularities pertaining to contour line elevation intervals. For conservative planning purposes, MITRE chose to use the higher of the two conflicting elevation intervals.

As a final step in this process, the MITRE basemap teams conducted an extensive joint peer review to ensure that the basemaps are accurate and complete.

6.0 Sample Images of Key Elements of the Basemaps

This section graphically illustrates some of the key data elements contained within the AutoCAD and TARGETS basemaps. Sample images from the basemaps are listed in Table 1, and are shown in Figures 3 through 7.

Table 1. Sample Basemap Images

Data Element	Basemap (AutoCAD or TARGETS)	Figure Number
Mexico City Basin Low Airway Structure	TARGETS	Figure 3
Mexico City Basin High Airway Structure	AutoCAD	Figure 4
Mexico City Basin SUAs (not all airspace is shown)	AutoCAD	Figure 5
Spots and Peaks Near Toluca Airport	AutoCAD	Figure 6
Contours Lines Generated from SRTM DTED	AutoCAD	Figure 7

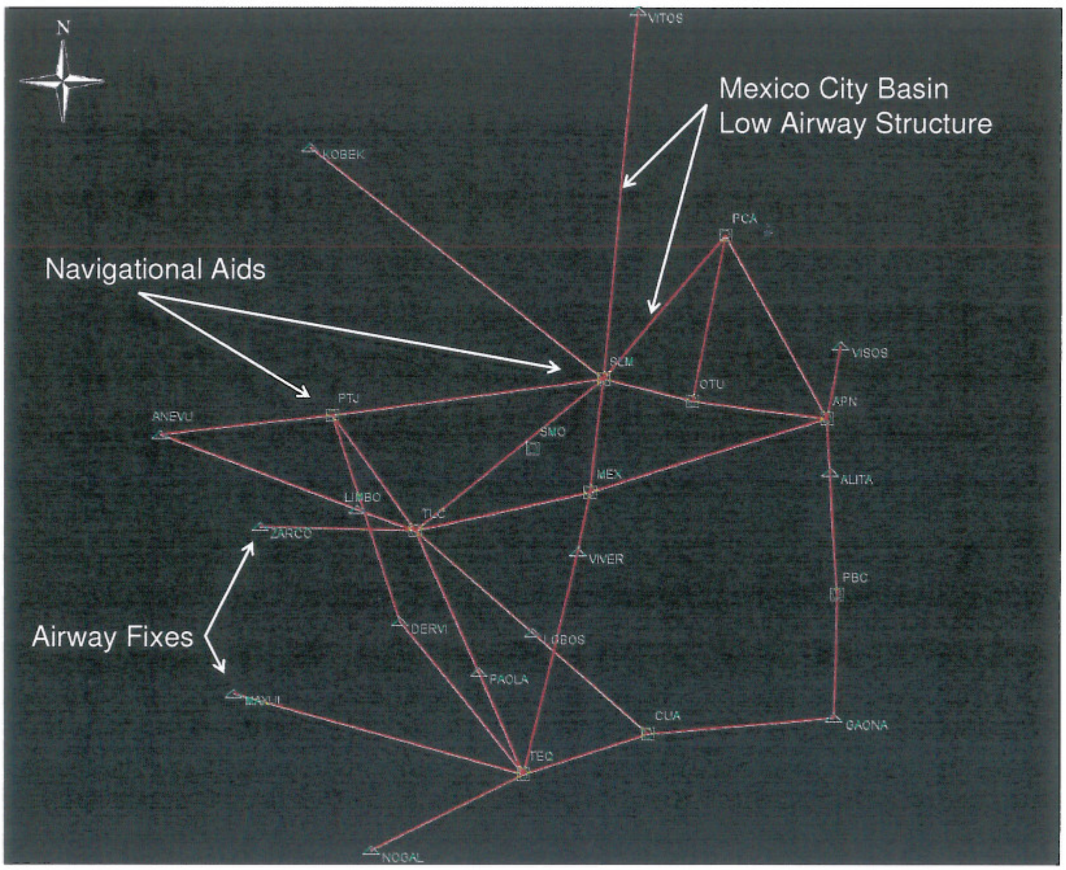

Figure 3. Mexico City Basin Low Airway Structure

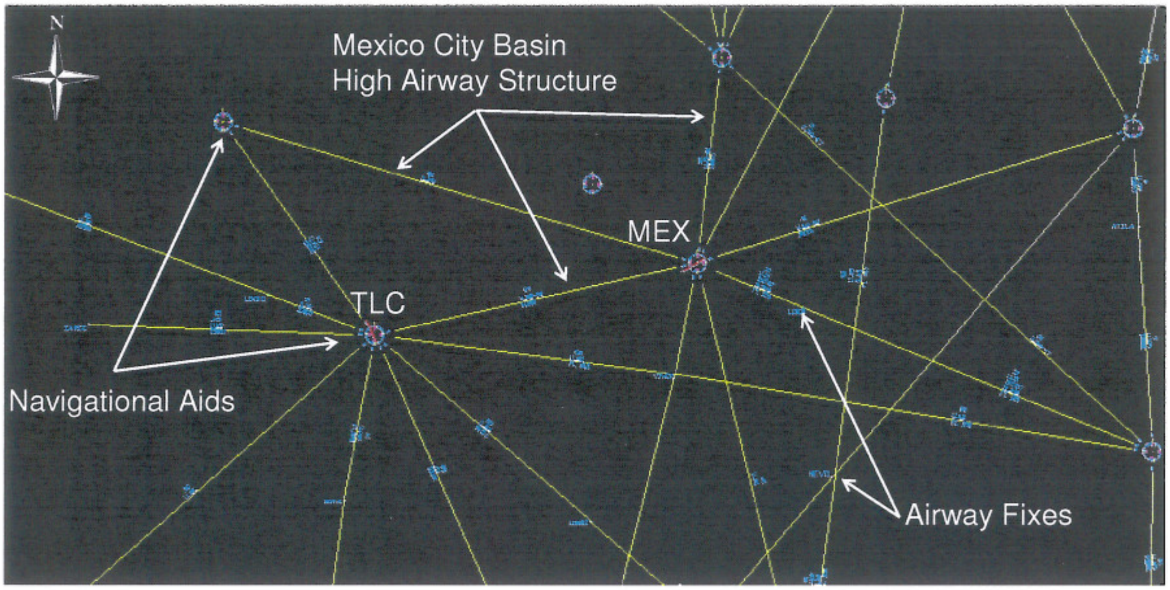

Figure 4. Mexico City Basin High Airway Structure

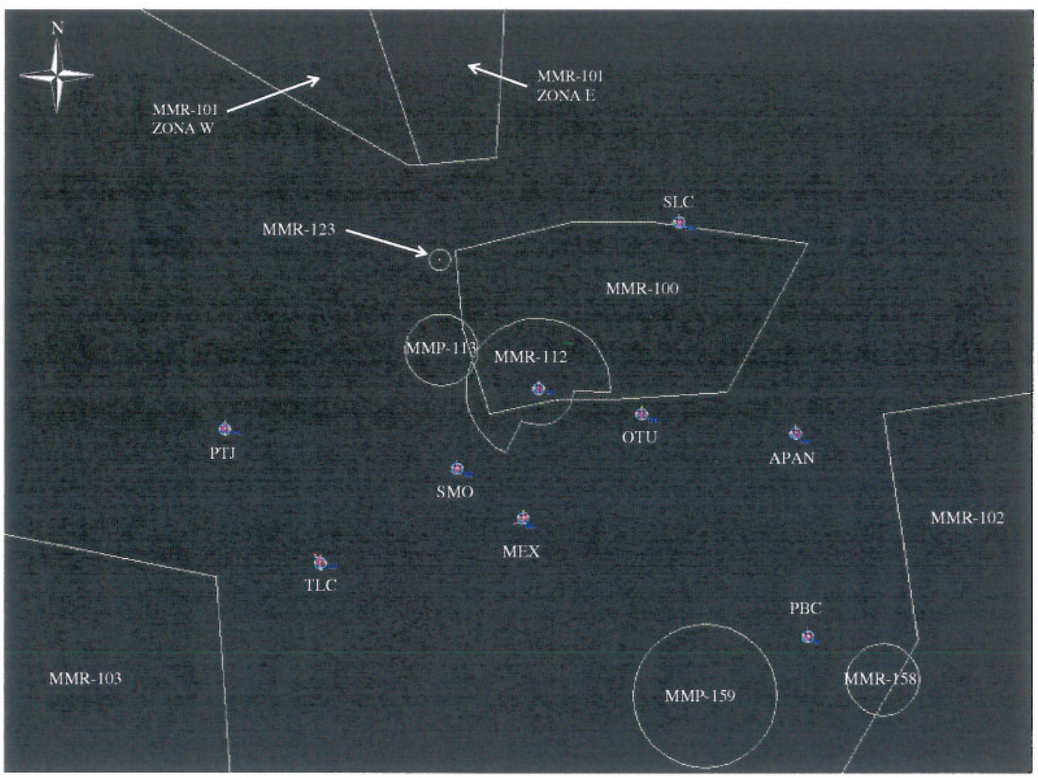

Figure 5. Mexico City Basin SUAs
(Not all SUAs are Shown)

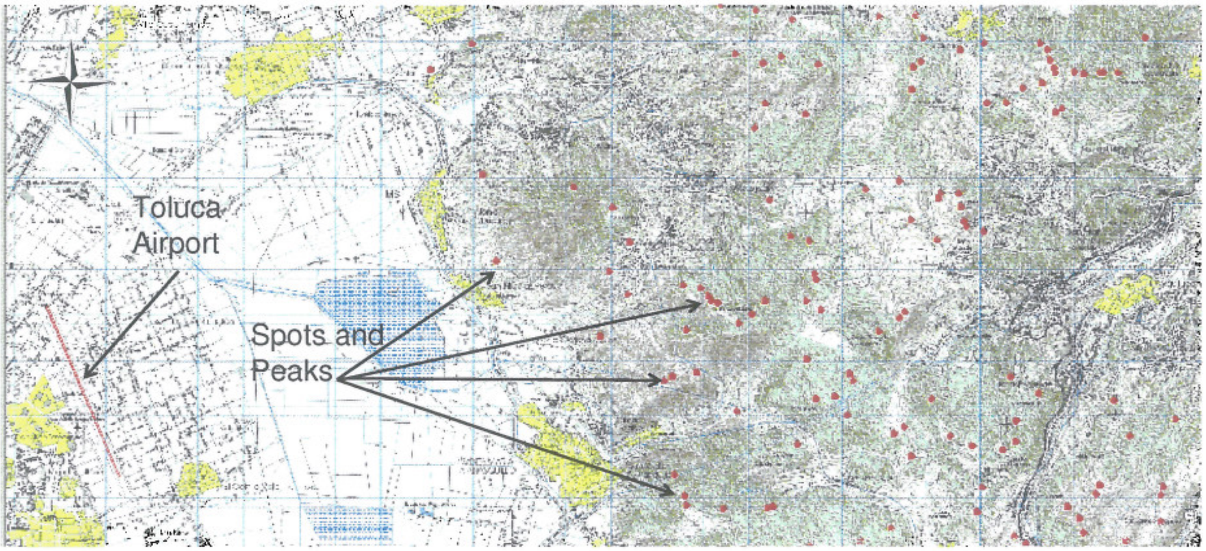

Figure 6. Spots and Peaks Near Toluca Airport

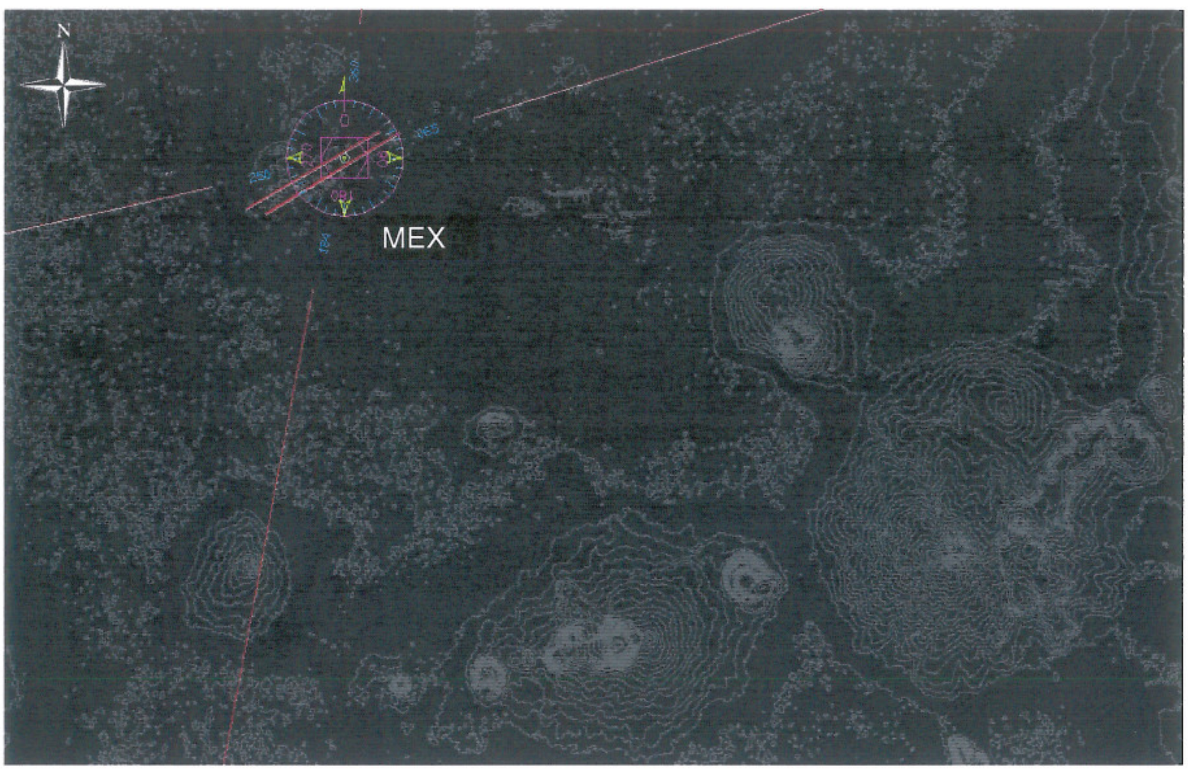

Figure 7. Contour Lines Generated from SRTM DTED

7.0 Closing Remarks

Construction of a basemap is an extensive and time-consuming process requiring careful planning and coordination. The basemaps not only serve as the repository for project data, but as the operational environment from which MITRE will conduct many of its aeronautical analyses. The Texcoco basemaps are essentially complete. The most important aeronautical information and terrain data have been entered, and the basemaps have also gone through an extensive MITRE-peer review process. As a result, MITRE can proceed to the next stage of the project.

The timely receipt of the survey data is extremely important to MITRE's aeronautical analyses. The survey data and other information to be provided by the DGAC will be incorporated into the basemap as soon as they are received.

Appendix A

Description of the MITRE-developed Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) Tool

The Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) tool offers a unique combination of capabilities for the design, analysis, and operational assessment of procedures and airspace. Developed by MITRE, the tool is used by the United States (U.S.) Federal Aviation Administration (FAA) in support of the implementation of Area Navigation (RNAV) and Required Navigation Performance (RNP) operations.

TARGETS incorporates data visualization capabilities with readily accessible design elements to enable procedure designers to rapidly and easily develop advanced procedures. The integrated capabilities of TARGETS enable quick assessment of alternative design concepts, leading to robust solutions that satisfy operational needs and comply with design constraints. TARGETS integrates with standard office applications, making it easy to prepare presentations or document procedure design. TARGETS data output is formatted to support operational, certification and charting needs.

Some of the key features of TARGETS include:

- Integration of essential capabilities into a single desktop application, featuring multi-platform compatibility
- An interface utilizing a comprehensive Geographic Information System (GIS) to display information that expedites procedure development
- Capture of route/procedure design information in project files and distribution packages, for dissemination to dispersed stakeholders
- Automated evaluation of key procedure areas to ensure compliance with FAA, noise, and operational requirements
- Data export capabilities that include seamless exchange with standard office applications, auto-population of regulatory forms, electronic data exchange using web services, and flat files
- Java-based software with object-oriented design that runs on a variety of platforms, including most desktop PC systems
- Plug-in architecture, which provides user controlled modularity and extensibility

TARGETS Graphical User Interface

The TARGETS Graphical User Interface (GUI) contains a plan view where users can display videomaps and overlay navigational aids (NAVAIDs), fixes, routes, holding patterns, and other data from several readily available aviation databases. Users can also display a number of different images including geo-referenced aviation charts and satellite photographs (see Figure A-1). Data files containing historical aircraft tracks can be imported into TARGETS and overlaid on the plan view. The TARGETS tool also provides users the capability to create user-defined waypoints and Special Use Airspace (SUA) via a user-friendly point-and-click interface. Users can pan and zoom the plan view or re-center the view on airports, NAVAIDs, or waypoints. At any time, the view and its contents can be saved as an image file (e.g., JPEG).

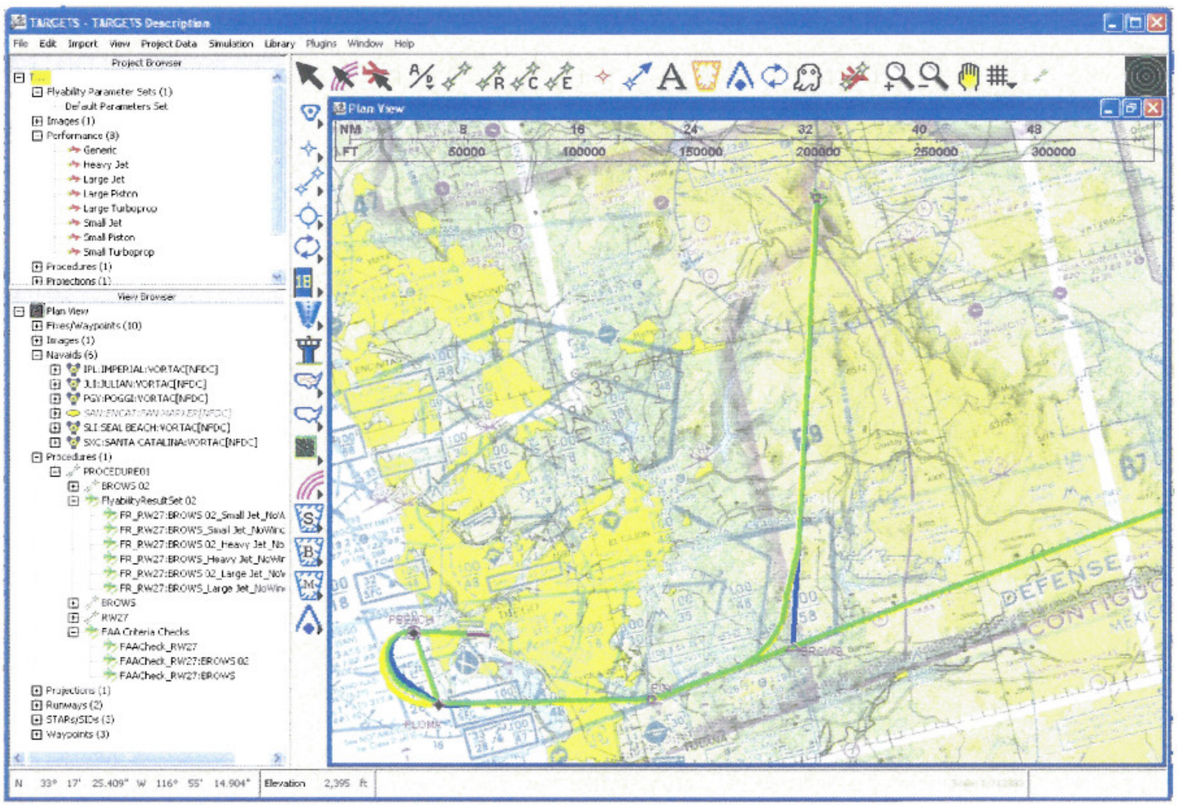

Figure A-1. A Typical TARGETS Screen Interface

Procedure Design

TARGETS provides stakeholders with an automated tool that allows them to work collaboratively to examine the many constraints that must be considered and evaluated during the development of a procedure. By providing a design tool that takes advantage of a vast array of data and design capabilities, a procedure designer can rapidly develop, evaluate, modify, and assess a procedure, thereby enabling a much quicker and higher quality design. TARGETS users follow a straightforward process to develop new arrival, departure, and approach procedures as follows:

Step 1 – Import supporting data

All of the needed reference and visualization data (i.e., airport information, runways, waypoints, obstructions, terrain, etc.) are imported into a project.

Step 2 – Build route, procedure, or approach

Using a graphical point-and-click interface, the user places waypoints that define the two-dimensional path including enroute transitions, common routes, and runway transitions, final approach segments, missed approach segment, etc.

Step 3 – Add speed and altitude constraint

After placing the waypoints the user can specify altitude and speed constraints as needed.

Step 4 – Assign leg types

The user can specify Aeronautical Radio Incorporated (ARINC) 424 leg types to assist the users with procedure design. TARGETS has internal rules that govern standardized RNAV route coding. TARGETS will verify that the leg type selected is valid and sequenced properly as defined in Supplement 16 to the ARINC Specification 424-18, *Navigation System Data Base*) [Reference 1].

Step 5 – Flyability assessment

After the procedure has been defined, a flyability assessment can be performed to determine the usability of the proposed procedure. The flyability assessment is done using a generic medium fidelity Flight Management System (FMS) model. The default flyability performance set used in the TARGETS evaluation is for heavy, large, and small jets as shown in Figures A-2 through A-4. The basis for the aircraft performance is the EUROCONTROL Base of Aircraft Data (BADA) [Reference 2] with some further performance enhancements made by MITRE. For more advance assessments users are able to enter specific aircraft performance parameters such as acceleration and deceleration rates, bank angles, and climb/descent gradients, aircraft weight, temperature, and specific wind speed and direction at various altitudes.

The TARGETS flyability assessment analyzes the ability of aircraft to comply with the procedure speed and altitude constraints. Also, the flyability assessment determines if the distance between waypoints is adequate enough for the aircraft to complete the turn, stabilize the aircraft and stay on the route. Lastly, the TARGETS flyability assessment provides an expected ground track and vertical profile of aircraft flying the procedure. Figure A-5 shows the graphic flyability results of the default small, large, and heavy jets.

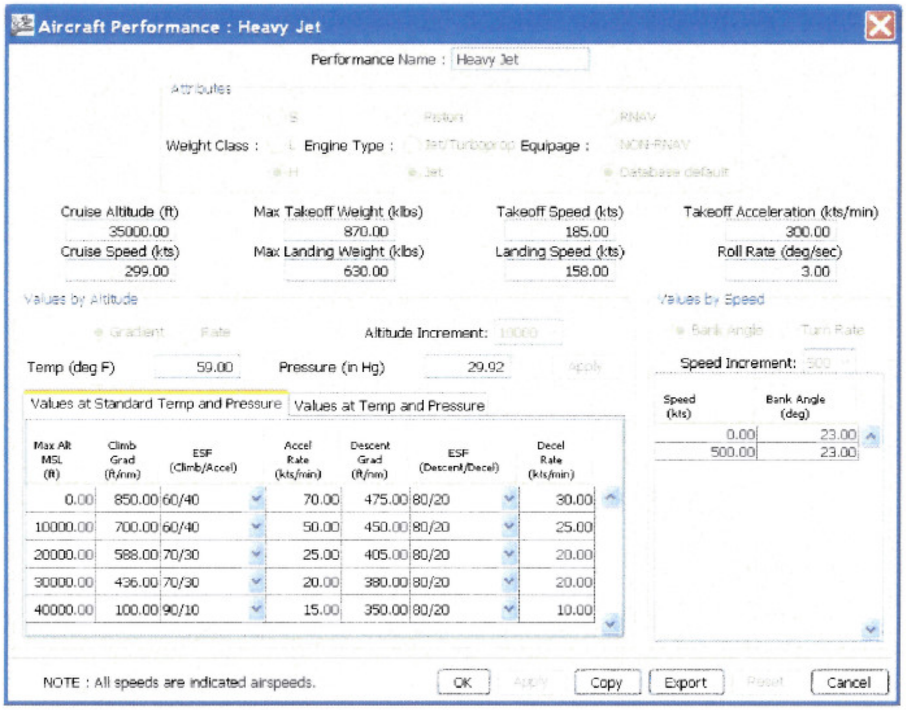

Figure A-2. A TARGETS Performance Profile for a Heavy Jet

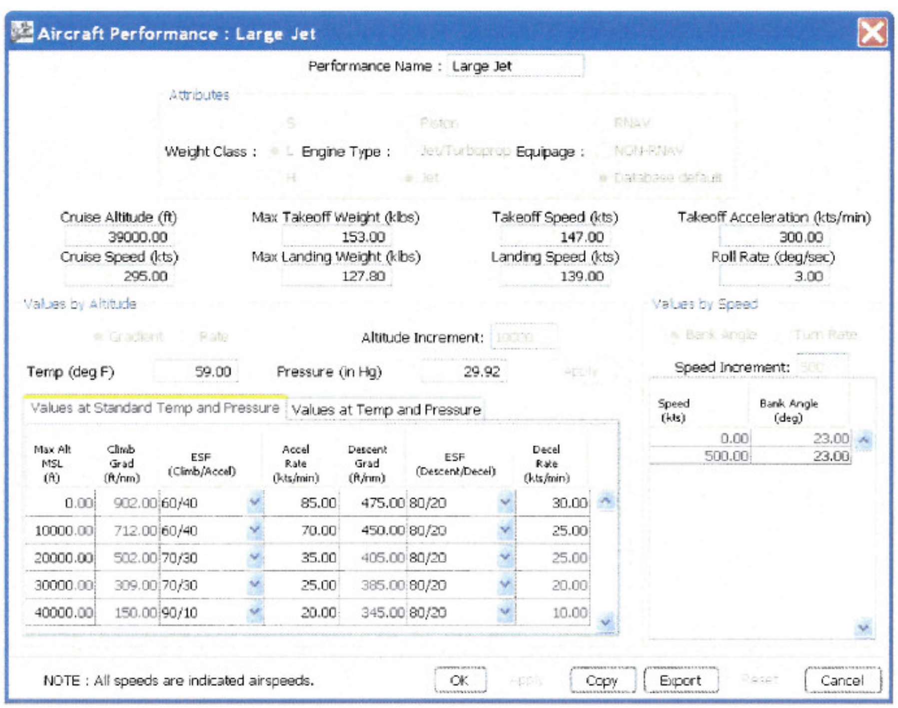

Figure A-3. A TARGETS Performance Profile for a Large Jet

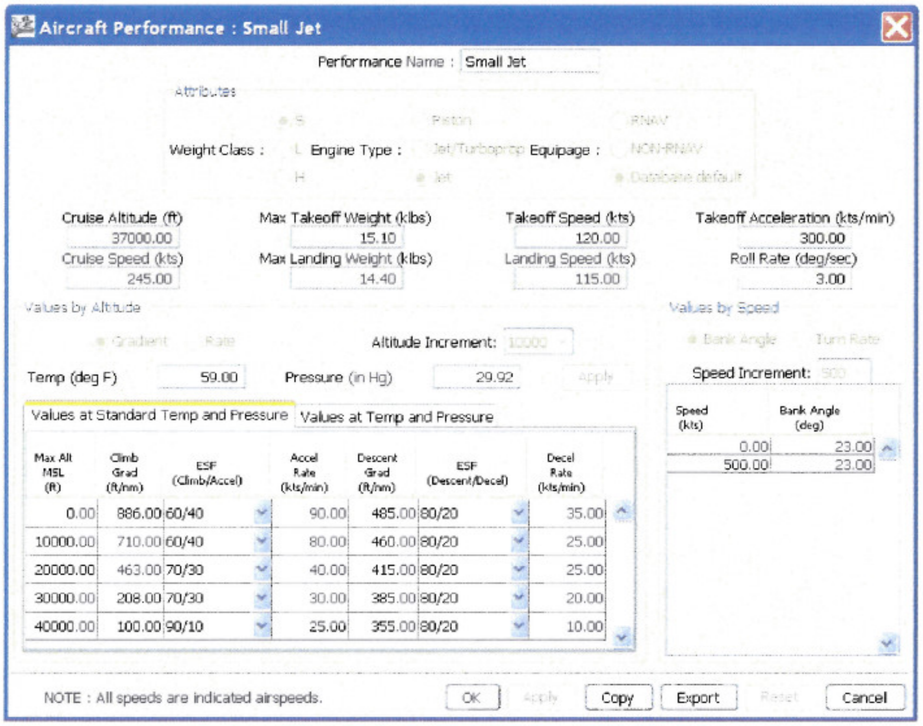

Figure A-4. A TARGETS Performance Profile for a Small Jet

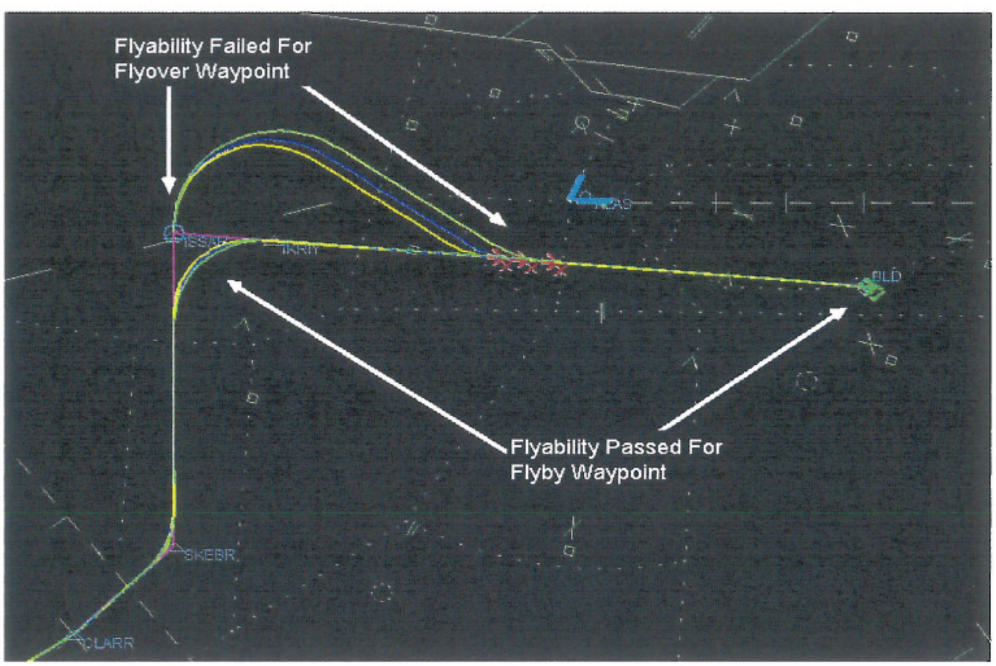

Figure A-5. A Typical TARGETS Flyability Results Graphic

Data Exchange

Once the procedure has been designed and assessed, TARGETS users are able to share the procedure data in either a Comma-Separated file or an Adobe Portable Document (PDF) distribution package. An example of the Comma-Separated output file is shown in Figure A-6.

WP	Distance	Leg Type	Turn Type	Latitude	Degrees	Minutes	Seconds	Longitude	Degrees	Minutes	Seconds	Altitude	Speed	True Course	Magnetic Course	Turn Angle
RW27:DER				N	32	44	13.62	W	117	12	15.66					
PBEACH	3.79	DF	FO	N	32	45	16.37	W	117	16	35.09			285.99	272.99	110.66
PLOMA	5.38	DF	FB	N	32	39	54	W	117	16	4			175.34	162.34	72.8
PGY	14.99	TF	FB	N	32	36	37.22	W	116	58	44.68			102.54	89.54	19.29
BROWS	10.67	TF	FB	N	32	37	52.02	W	116	46	11.71			83.25	70.25	
BROWS	0	IF		N	32	37	52.02	W	116	46	11.71					
JLI	31.89	TF	FB	N	33	8	25.65	W	116	35	9.36			16.9	2.9	
BROWS	0	IF		N	32	37	52.02	W	116	46	11.71					
IPL	64.26	TF	FB	N	32	44	55.91	W	115	30	30.88			83.36	69.36	

Figure A-6. TARGETS Procedure Comma-Separated Output File

Traffic Simulation

In addition to route definition and assessment functions, the TARGETS tool contains a traffic simulation capability. Having the appropriate data, users can quickly and easily define traffic scenarios which can include traffic flying RNAV routes, aircraft departing from specified runways, aircraft flying vectors, and aircraft that follow selected Automated Radar Terminal System tracks. For each aircraft in the scenario, users can specify aircraft identification, aircraft type/performance, RNAV equipage, controller identification, data block offset direction, and other information. "Control Lines" can be drawn on the screen that will trigger certain automatic actions such as vectors or joining an RNAV route when aircraft cross them. When scenarios are run, aircraft appear in the plan view. Scenarios can be run in real time or fast time. Aircraft in the scenario can be vectored, given speed or altitude instructions, or cleared to an RNAV route via keyboard entries.

Hardware/Software Architecture

The TARGETS tool is written entirely in the Java programming language. The GUI is written using "Swing" software components. The internal database is InstantDB, a Java database. Development and testing are done using both Linux and Windows 2000/XP platforms on Intel-based hardware. The object-oriented design of the TARGETS software makes adding functions and features easy.

List of References

1. Aeronautical Radio Incorporated (ARINC) Specification 424-18, Navigation Systems Database.

2. EUROCONTROL, *Base of Aircraft Data (BADA).*